


Annual Report

The State of the Ocean and the Ocean Observing System For Climate







Fiscal Year 2004


Office of Climate Observation
Office of Global Programs
National Oceanic and Atmospheric Administration

ANNUAL REPORT ON THE STATE OF THE OCEAN AND THE OCEAN OBSERVING SYSTEM FOR CLIMATE

FY 2004

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ANNUAL REPORT ON THE STATE OF THE OCEAN AND THE OCEAN OBSERVING SYSTEM FOR CLIMATE

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Foreword

The Office of Climate Observation is pleased to present the 2004 *Annual Report on the State of the Ocean and Ocean Observing System for Climate*. This effort is intended to be primarily an internal management tool but it is hoped that the *Annual Report* may develop over the next few years into an authoritative public record of the progress of the global observing system and its effectiveness in documenting the ocean's contribution to climate variability and change.

Many people have contributed to this report either directly or indirectly, including scientists, researchers, teachers, post-docs, and students at laboratories, universities, and oceanographic and atmospheric centers and institutions. The officers, crew, and volunteers on board vessels where the fieldwork occurred played a major role as well. This document is a collaborative effort produced by a team of individuals focused on learning more about the influences of our oceans on climate.

The plan for the global ocean observing system has been developed and we have taken great strides as a community to fulfill the long-term goals set forth internationally to achieve this effort. We are proud to be part of the NOAA community that has worked closely with partners from more than 60 nations to bring the global observing system this far.

During FY 2004 the ocean observing system for climate was advanced by 3% (from 45% to 48% complete) and plans are in the works to reach 53% completion by the end of FY 2005. In addition to the scientific activities completed by the project managers and researchers in FY 2004 (as outlined in Chapter 3), their accomplishments in the service arena were equally impressive. Principal investigators and project leaders served the scientific community through more than 127 appointments to science and implementation panels, science teams, advisory boards, as committee members, officers, and steering committee members. Our observationalists presented at or attended 183 conferences and workshops. On 15 occasions scientists contributed their time and talent through outreach during press/media interviews, public lectures, and school visits.

The Office of Climate Observation sincerely believes that the accomplishments outlined within this document will help the global community understand more clearly the role of the oceans in our climate across Earth. We look forward to the future as we unravel the mystery of our oceans together. It is with great pleasure that we present this work.

Mike Johnson
Director, Office of Climate Observation
March 2005

ANNUAL REPORT ON THE STATE OF THE OCEAN AND THE OCEAN OBSERVING SYSTEM FOR CLIMATE

Executive Summary

This Annual Report is a compilation of articles, progress reports, and references focused on the current state of the ocean and the status of the ocean observing system for climate in fiscal year (FY) 2004. The report synthesizes observations integrated with models and scientific expertise to provide products to decision makers, the science community, and the public. This reporting framework establishes a formal mechanism for implementing a "user-driven" observing system and for reporting on the system's performance in meeting the requirements of operational forecast centers, international research programs, and major scientific assessments. Stakeholders are invited and encouraged to provide formal recommendations for system improvement and evolution.

Chapter 1 provides an introductory overview of the ocean and its role in climate with an explanation of the ocean's physical parameters that contribute to Earth's changing climate. Ocean-atmosphere interactions are addressed along with the impacts of climate change on sea ice extent and sea level. Connections are made between ocean observations and economic and societal impacts.

Chapter 2 includes a series of summaries focused on ocean climate from FY 2004 placed in historical context, reasons why it is increasingly important to monitor climate variables, accompanying climate applications, and how the observing system needs to be enhanced to improve ocean analysis and product development. Chapter 2 focuses on the products linked with the observing system, specifically sea level, ocean carbon, sea surface temperature, surface currents, air-sea exchanges of heat, momentum, and fresh water, heat content variations, and sea ice.

Chapter 3 focuses on the observing system and provides a compilation of all FY 2004 progress reports and work plans written by the project managers. These projects are focused on the mission of the Office of Climate Observation, namely, documenting long-term trends in sea level change, ocean carbon sources and sinks, the ocean's storage and global transport of heat and fresh water, and the ocean-atmosphere exchange of heat and fresh water, along with accompanying parameters.

Chapter 4 contains selected abstracts from refereed publications, and a bibliography of science articles and publications written by the scientific community during FY 2004 treating the global observation of ocean heat, carbon, fresh water, and sea level change.

*The State of the Ocean in 2004**

Global Sea Level Rise—L. Miller and B. C. Douglas
Satellite altimeter observations since 1993 show global sea level has risen almost steadily at a rate of 2.8 ±0.4 mm yr^{-1} (Fig. 1). This trend is significantly higher than the 20^{th} century rate of 1.8 ±0.3 mm yr^{-1} determined from tide gauge observations made over the past 50 to 100 years (Douglas 1997; Peltier 2001; Miller and Douglas 2004; Church et al. 2004; Holgate and Woodworth 2004; White et al. 2005). However, it is unclear whether the increased rate observed

by satellite altimeters reflects a long-term change with respect to the historical rate, or some manifestation of inter-decadal variability.

A map of the altimeter-measured trends (Fig. 2) shows that all of the ocean basins experienced rising sea levels over the past decade, but large regional variations are also evident. The tropical western Pacific and Southern Oceans exhibited large positive trends (>10 mm yr^{-1}), while the Northern Pacific was distinctly negative. The geographical pattern of trends was roughly similar to that observed in the change in upper ocean heat content as determined from *in situ* hydrographic measurements (Cabanes et al. 2001) suggesting that, at least on decadal time scales, regional sea level trends have been largely controlled by thermal processes. Mean warming of the upper 750 m of the water column in all ocean basins can account for 1.6 ±0.2 mm yr^{-1} of global sea level change between 1993 and 2003 (Willis et al. 2004). This contrasts sharply with the average 20th century contribution to sea level rise from thermal expansion, estimated to be about 0.5 mm yr^{-1} (Antonov et al. 2002). The remaining portion of the total trend for the past decade, roughly 1.2 mm yr^{-1}, was likely due to the melting of grounded ice on Greenland and/or Antarctica and, to a lesser extent, from mountain glaciers, which is a result consistent with the average 20th century mass contribution to sea level rise estimated by Miller and Douglas (2004).

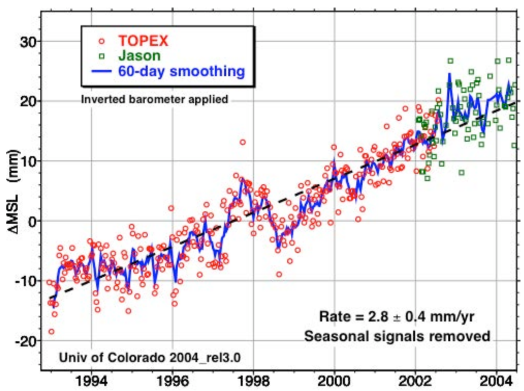


Figure 1. Global mean sea level variations determined using altimeter measurements from the TOPEX (1993-2002) and Jason-1 (since 2002) satellites. (Source: http://sealevel.colorado.edu; Leuliette et al. 2004).

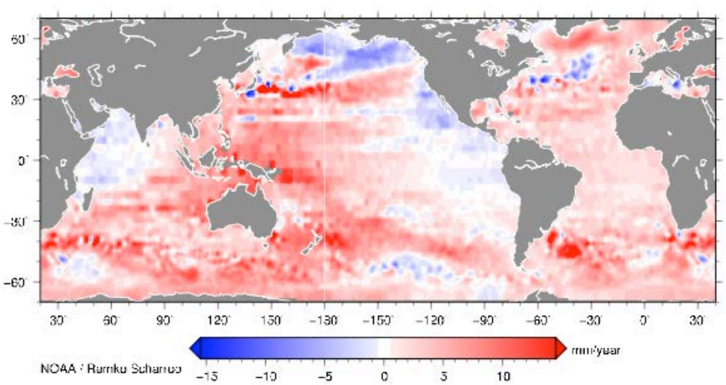


Figure 2. Sea level trends over the period 1993-2004 determined from TOPEX and Jason-1 satellite altimeter observations. The global mean of this map gives the 2.8 mm yr^{-1} value shown in Fig. 1.

Sea Surface Temperatures—R. W. Reynolds

Sea surface temperature (SST) variability during 2004 was examined using the weekly optimum interpolation (OI) analysis of Reynolds et al. (2002). This analysis combines in situ SST data (i.e., ship and buoy data) with satellite SST retrievals from the infrared (IR) channels of the Advanced Very High Resolution Radiometer (AVHRR). To clearly demonstrate the overall changes between 2004 and other years, a time series of the mean monthly OI SST anomaly from

75°S to 75°N was constructed for the entire period of record (Fig. 3). The general change over this period has been a slow warming with several large fluctuations of 1-3 years. The climatological base period used is 1971-2000 (Xue et al. 2003), so the overall warming tends to favor positive over negative anomalies toward the end of the record. Fluctuations of 1-3 years are usually due to the warm and cold SST anomalies in the tropical Pacific associated with strong El Niño and large La Niña events, respectively. Impacts from these events often influence the tropical Indian SST anomalies and may influence the tropical Atlantic SST anomalies, but the "phase" of the SST relationship appears to have varied. For example, the El Niño event of 1982-83 occurred along with cold tropical Atlantic SST anomalies, while the El Niño event of 1997-98 occurred along with warm tropical Atlantic SST anomalies. However, the SST anomaly curve was relatively flat from 2001 through 2004, which suggests that overall warming trends were small over this period and that no large El Niño or La Niña events occurred during this time.

The mean and standard deviation of the weekly anomaly for 2004 is shown in Figure 4. The mean anomalies in the upper panel show positive SST anomalies in the central Pacific, the North Atlantic and to a weaker extent, the tropical Indian Ocean and the western Indian Ocean near 35°S. The standard deviation of the anomaly (Fig. 4, lower panel) shows the strongest variability between roughly 30°N and 70°N, and in the eastern tropical Pacific. In addition, there was more modest variability along the equator in the eastern Pacific, and between 30°S and 50°S east of South America, and both east and west of the Cape of Good Hope near the southern tip of Africa.

The most important signal observed in 2004 associated with extra-tropical SST variability, which also occurred in 2003, was between the 60°N to 70°N latitude band. These positive SST anomalies between August and October were the oceanic response to large and warm summer and fall air masses, and their associated positive land surface air temperatures anomalies found along this same latitude band.

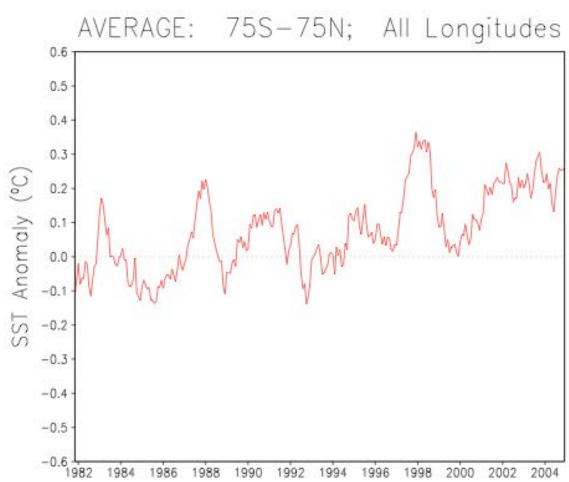


Figure 3. Time series of average monthly sea-surface temperature (SST) anomalies between 75°S and 75°N for the period November 1981 through December 2004. The anomalies were computed relative to a 1971-2000 base period.

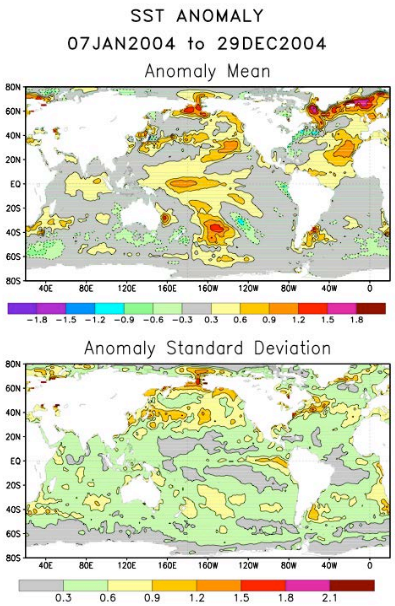


Figure 4. Weekly SST anomalies for the period 7 January 2004 through 29 December 2004: top) mean, and bottom) standard deviation. The anomalies were computed relative to a 1971-2000 base period. The contour interval used is 0.3°C, and the 0°C contour is not shown.

Ocean Heat and Fresh Water Content and Transports—L. Talley

Operational products of subsurface temperature and salinity fields are produced for the Atlantic basin, and the subsurface temperature field only for the North Pacific basin. Water temperature changes in the upper ocean had important regional variations in 2004, with warming in the subtropics and highest polar latitudes, and cooling at sub-polar latitudes in the northern hemisphere (both in the North Pacific and North Atlantic). Global ocean heat content calculated from combined data sets increased monotonically from 1993 to 2003 (Fig. 5), and since 1999 in the tropics.

Freshening of upper ocean waters around the high latitude North Atlantic has been reported over the past several decades (Dickson et al. 2003; Curry et al. 2003). The observed salinity decreases persisted into 2004 (not shown), along with continued thinning of Arctic sea ice. Freshening of surface and intermediate water north of the Antarctic Circumpolar Current, and increased salinity in surface waters south of the current over the past decade have also been observed.

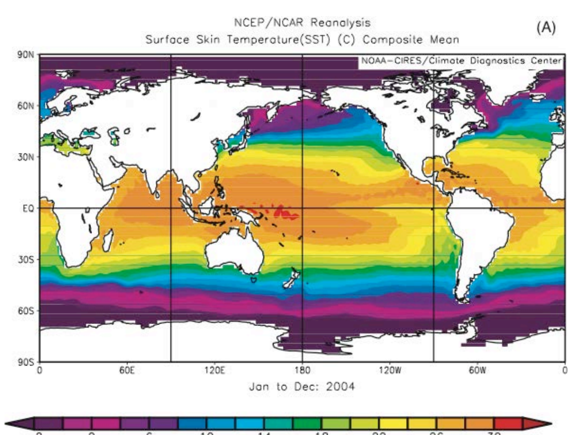


Figure 5. Total oceanic heat content (in J x 10^{22}) integrated over the tropics (green line) and the globe (red line). The figure was adapted from Willis et al. (2004).

Evolution of the 2004 El Niño—M. J. McPhaden

A weak El Niño developed in the second half of 2004 in the equatorial Pacific Ocean. Anomalous warming of the ocean mixed-layer and surface conditions was, for the most part, centered near the International Date Line, with near normal SSTs in the equatorial cold-tongue of the eastern Pacific and along the west coast of South America. SST anomalies in the Niño 3.4 index region (5°N-5°S, 120°-170°W) were approximately 0.8°C above average from August to December 2004. The Southern Oscillation Index (SOI) was consistently negative during the latter half of 2004 (-0.6 average index value during August-December), which is indicative of the warm phase of the El Niño/Southern Oscillation (ENSO). The near-equatorial trade winds were unusually weak west of the date line, associated with the elevated central and western Pacific SSTs and negative SOI values. In contrast, the trade winds in the eastern Pacific were near- to above-normal throughout much of 2004.

The 2004 El Niño event was unusual in that it followed the moderate amplitude 2002-03 El Niño by only one year (McPhaden 2004). Factors contributing to the development of the 2004 El Niño so quickly after the termination of the previous event are not fully understood. However, it is noteworthy that the 2002-03 El Niño was followed by an extended period of excess warm water volume (i.e., heat content) in the equatorial zone, which was atypical of conditions following most previous El Niños. It is likely that the presence of weak, positive heat content anomalies following the 2002-03 El Niño generated large-scale conditions favorable for the recurrence of another warm event earlier than would otherwise have been expected. Episodic westerly wind forcing (i.e., westerly wind bursts) in the boreal spring and summer of 2004 (Fig. 6) may have served as the stimulus for the development of the observed warm anomalies by displacing the western Pacific warm pool towards the east (e.g., Kessler et al. 1995).

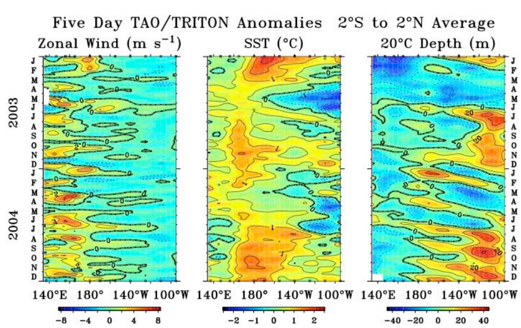


Figure 6. Five-day average anomalies of zonal wind, SST, and 20°C depth (which corresponds to the depth of the thermocline) relative to the mean seasonal cycle. The data were averaged over the 2°N–2°S region, and based on TAO/TRITON moored time series data. Tick marks on the horizontal axis indicate those longitudes sampled at the start (top) and end (bottom) of record.

Global Ocean Carbon Cycle: Inventories, Sources and Sinks—R. A. Feely and R. Wanninkhof

As a result of the measurements during the global CO_2 survey in the 1990s, and current improved methods of quantifying the anthropogenic CO_2 signal above the large natural background, the first measurement-based inventory of anthropogenic CO_2 in the ocean is now available (Fig. 7).

Anthropogenic CO_2 is unevenly distributed throughout the oceans, and the highest vertically integrated concentrations are found in the North Atlantic. The Southern Ocean south of 50ºS has very low vertically integrated anthropogenic CO_2 concentrations. Approximately 60% of the total oceanic anthropogenic CO_2 inventory is stored in the Southern Hemisphere oceans, roughly in proportion to the larger ocean area of this hemisphere. Approximately 30% of the anthropogenic CO_2 is found shallower than 200 m and nearly 50% above 400 m depth. The global average depth of the 5 µmol kg^{-1} contour is approximately 1000 m. Therefore, the majority of the anthropogenic CO_2 in the ocean is confined to the thermocline region.

From cruises in the North Pacific, the difference between the Repeat Hydrography measurements in 2004 and those from the World Ocean Circulation Experiment (WOCE) in 1994 quantitatively document changes of natural and anthropogenic CO_2 over the past decade. Significant increases in dissolved inorganic carbon (DIC) of up to 35 µmol kg^{-1} were observed in surface waters and in intermediate depths ranging from 200-1000 m. The increases are due to uptake of anthropogenic CO_2, changes in the strength of ventilation and biological processes, and the influence of eddies in the region. On average, mixed layer DIC increases of 1.5 ± 0.2 µmol kg^{-1} yr^{-1} were observed in the sub-tropical waters of the North Pacific over the past decade, indicating that the oceanic uptake of CO_2 in this part of the global oceans has been faster than the rate of growth of CO_2 in the atmosphere.

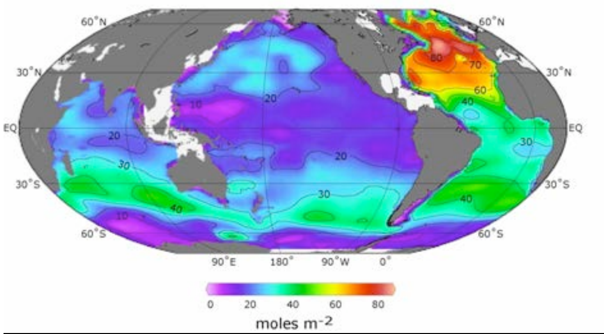


Figure 7. Column inventory of anthropogenic CO_2 in the ocean. High inventories are associated with deep water formation in the North Atlantic, and intermediate inventories with mode water formation between 30°-50°S. Total inventory of shaded regions is 106±17 Pg C (Sabine et al. 2004b).

Surface Current Observations—P. Niiler and N. Maximenko

The "*Global Drifter Program*" produces instrumental data records of the near surface velocity of the global oceans (Niiler 2001), which are maintained at NOAA's Atlantic Oceanographic and Meteorological Laboratory (AOML) for all drifters (8049 as of July 2004).

The western tropical Pacific circulation injects significant surface water from the Philippine Sea to the South China Sea through the Luzon Strait (Centurioni et al. 2004) during the October-December periods of the northeast monsoon. Drifters have observed significant inter-annual changes of the patterns of this inflow. A comparison of the 2003 and 2004 drifter tracks during this monsoon period (Fig. 8) shows that the inflow in 2004 was much broader to the west, and stronger than observed in 2003. These changes were consistent with the altimeter observations of the differences of the sea level patterns in the Philippine Sea and the South China Sea.

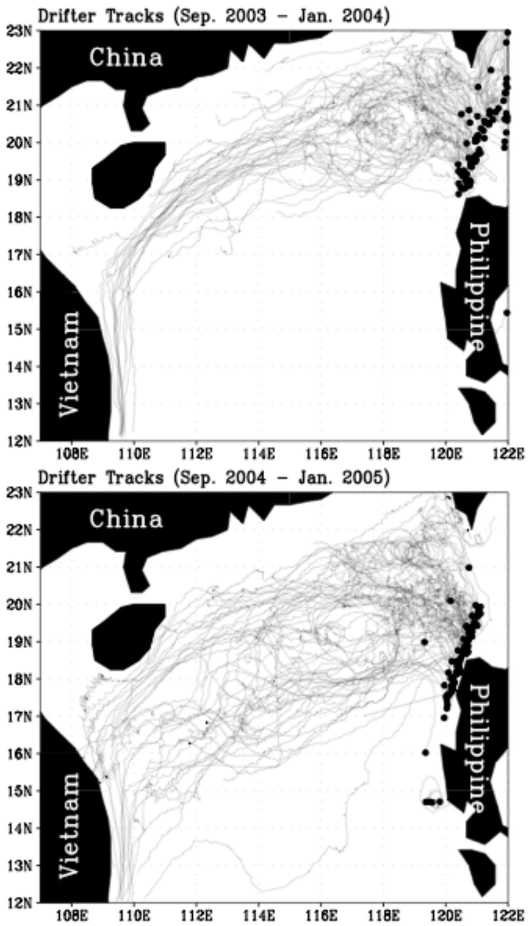


Figure 8. September-January tracks of Argos drifters that were released in the vicinity of the Luzon Strait in 2003-2004 (upper panel; 77 drifters – processed data) and in 2004-2005 (lower panel; 85 drifters – raw data). Note that significant interannual differences occurred in the north- south extent of the westward circulation in the South China Sea.

Sea Ice Extent and Thickness—I. G. Rigor and J. Richter–Menge

The annual average extent of Arctic sea ice has decreased by 8% over the past 30 years, and these decreases were larger (15–20%) during summer (ACIA 2004). The decline of Arctic Ocean sea ice has been attributed to the warmer air temperatures observed in the basin (e.g., Rigor et al. 2000; Jones et al. 1999), which may have thinned and decreased the extent of sea ice (ACIA 2004). However, there is also some evidence that changes in the circulation of sea ice on the Arctic Ocean driven by changes in winds over the Northern Hemisphere are important in explaining the recent minima in summer sea ice extent.

The last three summers have exhibited record low sea ice extent on the Arctic Ocean. The summer of 2002 set the record minimum for the Northern Hemisphere, while the summer of 2004 (Fig. 9; NSIDC 2004) had reduced sea ice over the Arctic Ocean than in 2002, but more sea ice was observed in the Canadian Archipelago and in the Laptev Sea. The age and thickness of sea ice explains more than half of the variance of the observed summer sea ice extent. The younger and thinner state of most of the sea ice on the Arctic Ocean persisted through 2004 (NSIDC 2004).

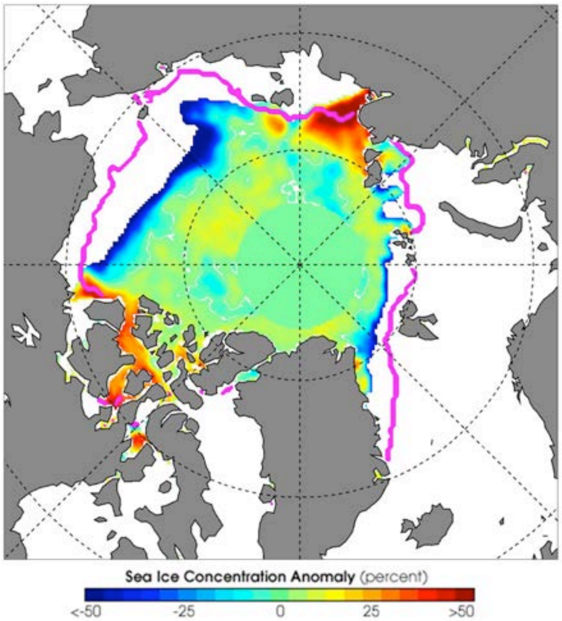


Figure 9. Sea ice concentration anomalies in September 2004 over the Arctic basin. The 2004 anomalies were estimated as the difference in sea ice concentration in 2004 with respect to the 1979–2000 base period. The pink line indicates the 1979-2000 median September ice edge. Anomalies are not calculated north of the circle centered over the pole (shown as light green) where satellite coverage prior to 1988 is unavailable. (Source: the National Snow and Ice Data Center, University of Colorado, Boulder; http://nsidc.org/news/press/20041004_decline.html).

The State of the Global Ocean Observing System for Climate in 2004 – **M. Johnson**

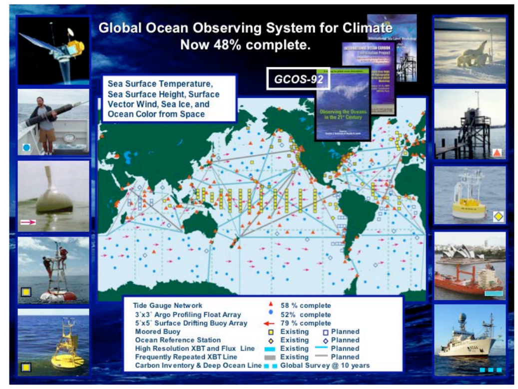
The observing system being put in place to meet climate requirements also supports global weather prediction, marine services, military applications, global and coastal ocean prediction, marine hazard warning systems (e.g., tsunami warning), and marine environmental monitoring, among other things. Many non-climate users also depend on the baseline composite system that is nominally referred to as the global ocean observing system for climate.

NOAA's Climate Observation Program provides a major part of the global component of the U.S. Integrated Ocean Observing System (IOOS) and the ocean baseline of the Global Earth Observation System of Systems (GEOSS). The global ocean observing system for climate is composed of moored and drifting buoys, Argo profiling floats, tide gauge stations, trans-oceanic ship lines, data and assimilation subsystems, and continuous satellite missions. The Climate Observation Program focuses on advancing the in situ networks and associated data and modeling components. The goal of the Program is to build and sustain a global observing system that will respond to the long-term observational requirements of the operational forecast centers, international research programs, and major scientific assessments.

The overarching priority is to achieve global coverage. In 2004 incremental advances were accomplished across all of the observing system networks. The system advanced from 45% complete in FY 2003 to 48% complete in FY 2004 (Fig. 10).

NOAA's contributions to implementation of the global ocean observing system are managed by 19 distributed centers of expertise at the NOAA Labs, Centers, Joint Institutes, universities and with business partners. These include AOML, PMEL, ETL, JIMAR (University of Hawaii), JIMO (Scripps Institution of Oceanography), CICOR (Woods Hole Oceanographic Institution), JISAO (University of Washington), CIMAS (University of Miami), CICAR (Columbia University), NCDC, NODC, CO-OPS, AMC, PMC, NDBC, NCEP, FSU (Florida State University), and SAI (Service Argos Inc.). The "System" is centrally managed at the Office of Climate Observation (OCO), a project office within the NOAA Climate Program Office.

Figure 10. A schematic of the global ocean observing system representing 48% completion. The ten small icons surrounding the map represent the array of instruments and platforms enabling monitoring of our global ocean.



International and interagency partnerships are central to the NOAA climate observing system implementation strategy. All of NOAA's contributions to global observation are managed in cooperation internationally with the Joint WMO/IOC Technical Commission for Oceanography and Marine Meteorology (JCOMM), and nationally with the U.S. Integrated Ocean Observing System (IOOS). NSF has initiated their Ocean Observatories Initiative (OOI), which will potentially provide significant infrastructure in support of ocean climate observation, beginning in FY 2006. Commencement of an ongoing NSF-NOAA cooperative project for CLIVAR-carbon ocean surveys has proved to be an interagency-international-interdisciplinary success. ONR maintains a GODAE data server at Monterey that needs to be sustained after the experiment period (2003-2007) as permanent international infrastructure. NOAA ships and the UNOLS fleet provide ship support for ocean operations and NASA's development of remote sensing techniques is vital.

The observing system delivers "up front" information to the forecast centers, research programs, and assessments. In 2004, the first *Annual Report on the State of the Ocean and the Ocean Observing System for Climate* for fiscal year 2003 was produced as a demonstration project; it proved highly successful; the project will be continued documenting the state of the ocean and reporting on observing system progress annually. The annual reports include sections targeted for three audiences: 1) decision-makers and non-scientist, 2) scientists, 3) observing system managers.

The second Annual System Review was conducted April 13-15 in Silver Spring, Maryland. This meeting brought together project managers to discuss system-wide issues and engage in program strategic planning. It also provided the annually scheduled forum for observing system users to provide feedback and discuss their requirements and recommendations for system evolution with the project managers. Review of the NDBC and PMEL plan for transition of TAO operations from PMEL to NDBC was a major topic of discussion during the 2004 Annual Review. The issue of the gap in delivery of ocean analyses as an end product of ocean observations was also a major part of the strategic discussions. The Climate Observation Program in FY 2005 will begin a program of ocean analysis work to ensure that this gap gets filled.

In cooperation with the international GCOS program office in Geneva, the OCO developed a special web page in support of the GCOS *Implementation Plan for the Global Observing System for Climate in Support of the UNFCC*C (GCOS-92). The OCO web page, www.oco.noaa.gov/page_status_reports_global.jsp, provides up-to date global maps and summary statistics from JCOMMOPS and other observing system partners contributing to international implementation of GCOS-92.

A demonstration project was initiated at OCO in cooperation with the GOOS Program Office at UNESCO and JCOMMOPS in Toulouse, to routinely report on progress of the observing system and contributions by countries. A consolidated report is now available on the OCO web site, accessible via the international portal at www.jcommops.org/network_status, which lists the 64 countries and the European Union that maintain elements of the composite ocean observing system and the number of platforms and expendables contributed by each country. This report allows tracking of progress toward international implementation of the ocean system specified in GCOS-92.

***** References cited in the *State of the Ocean in 2004* section of this Executive Summary can be found at the end of each expanded article in Chapter 2 of this Annual Report.

CHAPTER 1

THE ROLE OF THE OCEAN IN CLIMATE

Kevin E. Trenberth, Ph.D.
National Center for Atmospheric Research[1]

1. Introduction

The oceans cover about 71% of the Earth's surface and contain 97% of the Earth's water. Through their fluid motions, their high heat capacity, and their ecosystems, the oceans play a central role in shaping the Earth's climate and its variability. Changes in sea level have major impacts on coastal regions. Accordingly, it is vital to monitor and understand changes in the oceans and their effects on climate, and improve the verisimilitude of model ocean simulations. Much of the following is adapted from Trenberth (2001).

The most important characteristic of the oceans is that they are wet and, while obvious, this is sometimes overlooked. Water vapor, evaporated from the ocean surface, provides latent heat energy to the atmosphere during the precipitation process. In units of 10^3 km^3 per year, evaporation E over the oceans (436) exceeds precipitation P (399), leaving a net of 37 units of moisture transported onto land as water vapor. On average, this flow must be balanced by a return flow over and beneath the ground through river and stream flows, and subsurface ground water flow. The average precipitation rate over the oceans exceeds that over land by 72% (allowing for the differences in areas), and precipitation exceeds evapotranspiration over land by this same amount (37) (Dai and Trenberth 2002). This flow into the oceans occurs mainly in river mouths and is a substantial factor in the salinity of the oceans, thus affecting ocean density and currents. A simple calculation of the volume of the oceans of about 1330×10^6 km^3 and the through-flow fluxes of E and P implies an average residence time of water in the ocean of over 3,000 years.

Changes in phase of water, from ice to liquid to water vapor, affect the storage of heat. However, even ignoring these complexities, many facets of the climate can be deduced simply by considering the heat capacity of the different components of the climate system. The total heat capacity considers the mass involved as well as its capacity for holding heat, as measured by the specific heat of each substance.

The atmosphere does not have much capability to store heat. The heat capacity of the global atmosphere corresponds to that of only a 3.5 m layer of the ocean. However, the depth of ocean actively involved in climate is much greater than that. The specific heat of dry land is roughly a factor of 4.5 less than that of sea water (for moist land the factor is probably closer to 2). Moreover, heat penetration into land is limited by the low thermal conductivity of the land surface; as a result only the top two meters or so of the land typically play an active role in heat storage and release (e.g., as the depth for most of the variations over annual time scales). Accordingly, land plays a much smaller role than the ocean in the storage of heat and in providing a memory for the climate system. Major ice sheets, like those over Antarctica and Greenland, have a large mass but, like land, the penetration of heat occurs primarily through conduction so that the mass experiencing temperature changes from year to year is small. Hence, ice sheets and glaciers do not play a strong role in heat capacity, while sea ice is important where it forms.

[1] The National Center for Atmospheric Research is sponsored by the National Science Foundation.

The seasonal variations in heating penetrate into the ocean through a combination of radiation, convective overturning (in which cooled surface waters sink while warmer more buoyant waters below rise) and mechanical stirring by winds. These processes mix heat through the mixed layer, which, on average, involves about the upper 90 m of ocean. The thermal inertia of a 90 m layer can add a delay of about 6 years to the temperature response to an instantaneous change (this time corresponds to an exponential time constant in which there is a 63% response toward a new equilibrium value following an abrupt change). As a result, actual changes in climate tend to be gradual. With its mean depth of about 3800 m, the total ocean would add a delay of 230 years to the response if rapidly mixed. However, mixing is not a rapid process for most of the ocean so that in reality the response depends on the rate of ventilation of water between the well-mixed upper layers of the ocean and the deeper, more isolated layers that are separated by the thermocline (the ocean layer exhibiting a strong vertical temperature gradient). The rate of such mixing is not well established and varies greatly geographically. An overall estimate of the delay in surface temperature response caused by the oceans is 10–100 years. The slowest response should be in high latitudes where deep mixing and convection occur, and the fastest response is expected in the tropics. Consequently, the oceans are a great moderating effect on climate changes.

Wind blowing on the sea surface drives the large-scale ocean circulation in its upper layers. The oceans move heat around through convection and advection (in which the heat is carried by the currents, whether small-scale short-lived eddies or large-scale currents). Hence ocean currents carry heat and salt along with the fresh water around the globe. The oceans therefore store heat, absorbed at the surface, for varying durations and release it in different places; thereby ameliorating temperature changes over nearby land and contributing substantially to variability of climate on many time scales.

The ocean thermohaline circulation (THC), which is the circulation driven by changes in sea water density arising from temperature (thermal) and salt (haline) effects, allows water from the surface to be carried into the deep ocean, where it is isolated from atmospheric influence and hence it may sequester heat for periods of a thousand years or more. The oceans also absorb carbon dioxide and other gases and exchange them with the atmosphere in ways that change with ocean circulation and climate change. In addition, it is likely that marine biotic responses to climate change will result in subsequent changes that may have further ramifications, for instance by changing ocean color and penetration of sunlight into the ocean.

2. An example: The annual cycle

In the subtropics, the oceans typically take up in excess of 100 W m^{-2} in the winter months and give it to the atmosphere in summer mostly in the form of evaporation of moisture. This cools the ocean while eventually warming the atmosphere when released as latent heat in precipitation (Trenberth and Stepaniak 2003). In mid-latitudes, air coming off the ocean is warmer than the land in winter and cooler in summer, giving rise to refreshing sea breezes and moderating temperatures. Regions influenced by the ocean in this way are referred to as having maritime climates.

An example of the role of the oceans in moderating temperature variations is the contrast in the mean annual cycle of surface temperature between the northern hemisphere (NH) (60.7% water) and southern hemisphere (SH) (80.9% water). The amplitude of the 12-month cycle between 40 and 60° latitude ranges from <3°C in the SH to about 12°C in the NH. Similarly, in mid-latitudes from 22.5–67.5° latitude, the average lag in temperature response relative to peak solar radiation is 32.9 days in the NH versus 43.5 days in the SH (Trenberth 1983), reflecting the differences in thermal inertia.

3. The oceans and sea ice

Sea ice is an active component of the climate system and varies greatly in areal extent with the seasons, but only at higher latitudes. In the Arctic where sea ice is confined by the surrounding continents, mean sea ice thickness is 3–4m thick and multi-year ice can be present. Around Antarctica the sea ice is unimpeded and spreads out extensively, but as a result the mean thickness is typically 1–2 m. Sea ice caps the ocean and interferes with ocean-atmosphere exchanges of heat, moisture, and other gases. Melting sea ice freshens the ocean and diminishes the density. However, its greatest impact is through changes in albedo of the surface, the much darker ocean surface absorbs more solar radiation, further warms the ocean and leads to the ice-albedo positive feedback that amplifies initial perturbations. Diminished sea ice also increases moisture fluxes into the atmosphere, which may increase fog and low cloud, adding further complexity to the net albedo change. Ocean currents transport sea ice, which is also subject to stresses from surface wind.

4. Coupled ocean-atmosphere interactions

Understanding the climate system becomes more complex as the components interact. El Niño events are a striking example of a phenomenon that would not occur without interactions between the atmosphere and ocean. El Niño events involve a warming of the surface waters of the tropical Pacific. Ocean warming takes place from the International Dateline to the west coast of South America and results in changes in the local and regional ecology. Historically, El Niño events have occurred about every 3–7 years and alternated with the opposite phases of below average temperatures in the tropical Pacific, dubbed La Niña. In the atmosphere, a pattern of change called the Southern Oscillation is closely linked with these ocean changes, so that scientists refer to the total phenomenon as ENSO. Then El Niño is the warm phase of ENSO and La Niña is the cold phase.

The strong sea surface temperature (SST) gradient from the warm pool in the western tropical Pacific to the cold tongue in the eastern equatorial Pacific is maintained by the westward-flowing trade winds, which drive the surface ocean currents and determine the pattern of upwelling of cold nutrient-rich waters in the east. Because of the Earth’s rotation, easterly winds along the equator deflect currents to the right in the NH and to the left in the SH and thus away from the equator, creating upwelling along the equator. Low sea level pressures are set up over the warmer waters while higher pressures occur over the cooler regions in the tropics and subtropics. The moisture-laden winds tend to blow toward low pressure so that the air converges, resulting in organized patterns of heavy rainfall and a large-scale overturning along the equator called the Walker Circulation. Because convection and thunderstorms preferentially occur over warmer waters, the pattern of SSTs determines the distribution of rainfall in the tropics, and this in turn determines the atmospheric heating patterns through the release of latent heat. The heating drives the large-scale monsoonal-type circulations in the tropics, and consequently determines the winds. If the Pacific trade winds relax, the ocean currents and upwelling change, causing temperatures to increase in the east, which decreases the surface pressure and temperature gradients along the equator, and so reduces the winds further. This positive feedback leads to the El Niño warming persisting for a year or so, but the ocean changes also sow the seeds of the event’s demise. The changes in the ocean currents and internal waves in the ocean lead to a progression of colder waters from the west that may terminate the El Niño and lead to the cold phase La Niña in the tropical Pacific. The El Niño develops as a coupled ocean–atmosphere phenomenon and, because the amount of warm water in the tropics is redistributed, depleted and restored during an ENSO cycle, a major part of the onset and evolution of the events is determined by the history of what has occurred one to two years previously. This means that the future evolution is potentially predictable for several seasons in advance.

5. Sea level

Another major role of oceans in climate that has major impacts on multi-decadal time-scales is sea level rise. Climate models estimate that there is a current radiative imbalance at the top-of-the-atmosphere of about 0.5 to 1 W m^{-2} (Hansen et al. 2002) owing to increases of greenhouse gases, notably carbon dioxide, in the atmosphere. This has increased from a very small imbalance only 40 years ago. Where is this heat going? Some heat melts glaciers and ice, contributing to sea level rise (Levitus et al. 2001). Recently a number of studies have highlighted changes in salinity. Changes in the freshwater balance of the Atlantic Ocean over the past four decades have been revealed by Dickson et al. (2002) and Curry et al. (2003). They find a freshening in the North Atlantic and also south of 25°S, while salinity has increased in the tropics and subtropics, especially in the upper 500 m. The implication is that there have been substantial increases in moisture transport by the atmosphere from the subtropics to higher latitudes, perhaps in association with changes in atmospheric circulation, such as the North Atlantic Oscillation (NAO). If this is the main process of importance then it has small effects on global mean sea level as fresh water is redistributed. However, Antonov et al. (2002) suggest that there is a secular decrease in overall ocean salinity, raising questions about the role of melting glaciers in sea level rise. Wadhams and Munk (2004) suggested that the 20^{th} century eustatic rise (from added mass) is 0.6 mm/yr.

However, the main candidate for a heat sink is the oceans, leading to thermal expansion and sea level rise. Levitus et al. (2000) estimated that the heat content of the oceans increased on average by about 0.3 W m^{-2} over the past few decades, but in a somewhat irregular fashion. Sea level has risen throughout the twentieth century by 1.5±0.5 mm/year (IPCC 2001) but the rate appears to have accelerated in the 1990s when accurate global measurements of sea level from TOPEX/Poseiden and Jason altimetry are available (Church et al. 2004). Nevertheless, controversy remains about longer-term sea level rise (Munk 2003) and there is evidence of bias in the historical sea level station network (Cabanes et al. 2001).

Recent estimates of sea level rise are 3.1 mm/year for 1993-2002, of which 0.3 mm/year is from isostatic rebound, and with the suggestion that most of this is thermosteric (i.e., from thermal expansion) (Cabanes et al. 2001; Cazenave and Nerem 2004). However, they suggest that there is strong observational evidence for a significant eustatic contribution of order 1 mm/yr during this period. That is to say that melting of glaciers and ice sheets has added mass to the oceans at this rate (see e.g., Meier and Byurgerov 2002). Estimates of other contributions (e.g., Cazenave et al. 2000) find that increased storage of water on land in reservoirs and dams accounts for –1.0±0.2 mm/yr, irrigation accounts for another –0.56±0.06 mm/yr but these are compensated for by ground water mining, urbanization, and deforestation effects so that the net sum of land effects is –0.9±0.5 mm/yr. Other small contributions also exist but there has been a reasonable accounting for the observed changes. In this case, the steric contribution from thermal expansion is based mostly on the analysis of the historical record of Levitus et al. (2000, 2001). Yet that record is based on sub-surface ocean measurements which are inadequate in many areas; for instance little or no sampling over many parts of the southern oceans to even determine the mean, let alone the variations with time. Moreover, other recent estimates for the past decade place only 1.6 mm/year of the total sea level rise as being the thermosteric contribution, corresponding to

0.86±0.2 W m^{-2} into the ocean (Willis et al. 2005), or in terms of energy about 0.6 W m^{-2} globally. Clearly this is one area where sampling by ARGO floats will have an enormous positive impact. Future sea level rise, and whether or not the rate is increasing are vital issues for climate change and impacts on small island states and coastal regions.

6. Why are we observing the ocean?

The above describes the critical role of the oceans in climate. Oceans take up heat in the summer half year and release it in winter, playing a major role in moderating climate. The oceans play a crucial role in ENSO. However, the enormous heat capacity of the oceans means that the oceans also play a key role on decadal and longer timescales. The exact role of the oceans in the North Atlantic Oscillation is being explored. Variations in the ocean affect ecosystems, including fisheries, which are of direct importance for food and the economy. It is therefore important to track the changes in ocean heat storage, as well as the uptake and release of heat in the oceans through the surface fluxes. Salinity effects on ocean density are also important but have been poorly measured, although ARGO profiles will help enormously. It is essential to be able to attribute changes in ocean heat content and the mass of the ocean to causes (such as changing atmospheric composition), perhaps using models. Climate models suggest that the THC could slow down as global warming progresses, resulting in counter-intuitive regional cooling in the North Atlantic region on multi-decadal time-scales.

It is vital to establish a baseline of the current state of the ocean as a reference for future assessments. Monitoring of the top 500 m of the tropical Pacific Ocean has been established because of ENSO. It is an excellent start. The World Ocean Circulation Experiment (WOCE) has paved the way. Increasing attention will be devoted to measurements of the biogeochemistry of the oceans and especially the carbon cycle, and possible feedbacks on carbon dioxide levels in the atmosphere. Relationships of physical ocean changes to ecosystems and fish stocks will enable improved fishery management. Observing technologies are evolving, and plans are already underway for an initial ocean observing system, but it has yet to be fully implemented. The observing system must evolve in ways that protects the integrity and continuity of the climate record. Such a system must be linked to comprehensive analysis capabilities of not only the ocean, but also the atmosphere, sea ice, radiation, precipitation, and other ingredients in the climate system. From time to time it is expected that reanalyses of the past ocean and climate record will be desirable as improvements are made in models and data assimilation systems. Tracking the performance of the observing system to ensure that it is meeting needs is another necessary component (Trenberth et al. 2002). With such information, good models will be enabled to make skilful predictions of climate on timescales ranging from weeks, to interannual (ENSO), to decades. However, good ocean observations are also essential for developing better models.

Ongoing assessments are therefore required of the continually changing state of the ocean, as well as our ability to observe it and assess what is going on. It is therefore appropriate for NOAA to carry out an annual assessment of both the state of the ocean and the state of the observing system, examine how well needs are being met, and find timely remedies for inadequacies. It is also vital to ensure that the observations are analyzed, and products generated to begin to address the issues outlined above. This synthesis phase is important for scientists, but it is essential to justify the ongoing costs of the observing system to taxpayers. Indeed, the increased knowledge and benefits in improved decision making will surely greatly exceed the costs.

References

Antonov, J. I., S. Levitus, and T. P. Boyer, 2002: Steric sea level variations during 1957-1994: Importance of salinity. *J. Geophys. Res.*, **107** (C12), 8013, doi:10.1029/2001JC000964.

Cabanes, C., A. Cazenave, and C. Le Provost, 2001: Sea level rise during past 40 years determined from satellite and in situ observations. *Science*, **294**, 840-842.

Cazanave, A., and R. S. Nerem, 2004: Present-day sea level change: observations and causes. *Rev. Geophysics*, **42**, 3, RG3001, doi:10.1029/2003RG000139.

Cazenave A., F. Remy, K. Dominh and H. Douville, 2000: Global ocean mass variation, continental hydrology and the mass balance of the Antarctica ice sheet at the seasonal time scale, *Geophys. Res. Lett.*, **27**, 3755-3758.

Church, J. A., N. J. White, R. Coleman, K. Lambeck, and J. X. Mitrovica, 2004: Estimates of the regional distribution of sea level rise over the 1950-2000 period. *J. Climate*, **17**, 2609-2625.

Curry, R., B. Dickson, and I. Yashayaev, 2003: A change in the freshwater balance of the Atlantic Ocean over the past four decades. *Nature*, **426**, 826-829.

Dickson B., I. Yashayaev, J. Meincke, B. Turrell, S. Dye and J. Holtfort, 2002: Rapid freshening of the deep North Atlantic Ocean over the past four decades. *Nature*, **416**, 832-837.

Dai, A., and K. E. Trenberth, 2002: Estimates of freshwater discharge from continents: Latitudinal and seasonal variations. *J. Hydrometeor*., **3**, 660–687.

Hansen, J., Mki. Sato, L. Nazarenko, R. Ruedy, A. Lacis, D. Koch, I. Tegen, T. Hall, D. Shindell, B. Santer, P. Stone, T. Novakov, L. Thomason, R. Wang, Y. Wang, D. Jacob, S. Hollandsworth, L. Bishop, J. Logan, A. Thompson, R. Stolarski, J. Lean, R. Willson, S. Levitus, J. Antonov, N. Rayner, D. Parker, and J. Christy 2002. Climate forcings in Goddard Institute for Space Studies SI2000 simulations. *J. Geophys. Res*. **107**, no. D18, 4347, doi:10.1029/2001JD001143.

IPCC (Intergovernmental Panel on Climate Change), 2001: *Climate Change 2001. The scientific basis*. Eds. J. T. Houghton, et al. Cambridge University Press, Cambridge, U.K. 881pp.

Levitus, S., J. I. Antonov, T. P Boyer, and C. Stephens, 2000: Warming of the world ocean. *Science*, **287**, 2225-2229.

Levitus, S., J. I. Antonov, J. Wang, T. L. Delworth, K. W. Dixon, and A. J. Broccoli, 2001: Anthropogenic warming of the Earth's climate system. *Science*, **292**, 267–270.

Meier, M. F., and M. B. Byurgerov, 2002: How Alaska affects the world. *Science*, **297**, 350-351.

Munk, W., 2003: Ocean freshening, sea level rising. *Science*, **300**, 2041-2043.

Trenberth, K. E., 1983: What are the seasons? *Bull. Amer. Meteor. Soc.*, **64**, 1276–1282.

Trenberth, K. E., 2001: Earth System Processes. *Encyclopedia of Global Environmental Change*. T. Munn (Ed. in Chief). Vol. 1. The Earth System: Physical and Chemical Dimensions of Global Environmental Change. M. C. MacCracken and J. S. Perry (Eds) John & Sons Ltd. 13–30.

Trenberth, K. E., T. R. Karl and T. W. Spence, 2002: The need for a systems approach to climate observations. *Bull. Amer. Meteor. Soc*., **83**, 1593–1602.

Trenberth, K. E., and D. P. Stepaniak, 2003: Seamless poleward atmospheric energy transports and implications for the Hadley circulation. *J. Climate*, **16**, 3705–3721.

Wadhams, P, and W. Munk, 2004: Ocean freshening, sea level rising, sea ice melting. *Geophys. Res. Lett.*, **31**, L11311, doi:10.1029/2004GL020039.

Willis, J., D. Roemmich, and B. Cornuelle, 2005: Interannual variability in upper ocean heat content, temperature and thermosteric expansion on global scales. *J Geophys. Res.*, **109**, C12036, doi:10.1029/2003JC002260.

CHAPTER 2

THE STATE OF THE OCEAN

This chapter includes an overview of the current state of knowledge about ocean climate in FY 2004, placed in historical context. Expert scientists who monitor, observe, and analyze the ocean products described in this chapter (e.g., sea level, ocean carbon, SST) have produced concise summaries describing why it is important to monitor these variables. Climate applications are presented along with an explanation of how the observing system needs to be enhanced to improve ocean analysis and reduce present uncertainties. This chapter focuses primarily on decision makers and non-scientists interested in, and concerned about, ocean research.

The short articles presented in this chapter describe the products listed in Table 2.1 and are the result of ocean projects funded, in whole or in part, by NOAA's Office of Climate Observation.

Table 2.1. Products

2.1 Global sea level rise to identify changes resulting from climate variability – *Laury Miller and Bruce Douglas*

2.2 Sea surface temperature to identify significant patterns of climate variability – *Richard Reynolds*

2.3 Ocean heat and fresh water content and transports to identify where anomalies enter the ocean, how they move and are transformed, and where they re-emerge to interact with the atmosphere. Identify the essential aspects of thermohaline circulation and the subsurface expressions of the patterns of climate variability – *Lynne Talley*

2.4 Evolution of the 2004 El Niño and heat content variations – *Michael McPhaden*

2.5 Global ocean carbon cycle: inventories, sources and sinks – *Richard Feely and Rik Wanninkhof*

2.6 Surface current observations to identify significant patterns of climate variability – *Peter Niiler and Nikolai Maximenko*

2.7 Air-sea exchange of heat, fresh water, momentum to identify changes in forcing functions driving ocean conditions and atmospheric conditions – *Robert Weller*

2.8 Sea ice extent and thickness – *Ignatius Rigor and Jackie Richter-Menge*

2.1 GLOBAL SEA LEVEL RISE

by Laury Miller[1], Bruce C. Douglas[2]

[1]Laboratory for Satellite Altimetry, NOAA/Lab for Satellite Altimetry, Silver Spring, MD
[2]Florida International University/Lab for Coastal Research, Miami, FL

Satellite altimeter observations since 1993 show global sea level rising almost steadily at rate of 2.8 +/-0.4 mm/year (Fig. 1). This trend is significantly higher than the 20th century rate of 1.8 +/-0.3 mm/year determined from tide gauge observations made over the past 50 to 100 years (Douglas 1997; Peltier 2001; Miller and Douglas 2004; Church et al. 2004; Holgate and Woodworth 2004; White et al. 2005). However, it is unclear whether the increased rate observed by satellite altimeters reflects a long-term change with respect to the historical rate or some manifestation of decadal variability.

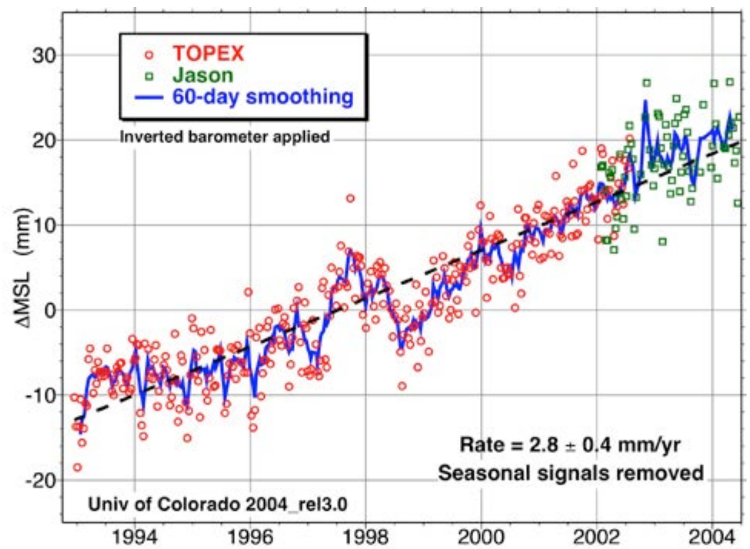


Figure 1. Global mean sea level variations determined from TOPEX and Jason-1 satellite altimeter observations.

A map of the altimeter-measured trends (Fig. 2) shows that all of the ocean basins experienced rising levels over the past decade, but large regional variations are also evident. The tropical western Pacific and Southern Oceans exhibit high positive trends (>10 mm/year), while the Northern Pacific is distinctly negative. The geographical pattern of trends is roughly similar to that observed in upper ocean heat content change as determined from *in-situ* hydrographic measurements (Cabanes et al. 2001) suggesting that, at least on decadal time scales, regional sea level trends are largely controlled by thermal processes. Global mean warming of the upper 750 m of the water column can account for 1.6 +/-0.2 mm/yr of global sea level change between 1993 and 2003 (Willis et al. 2004). This contrasts sharply with the average 20th century contribution to sea level rise from thermal expansion, estimated to be about 0.5 mm/yr (Antonov et al. 2002). The remaining portion of the total trend for the past decade, roughly 1.2 mm/year, is likely to have come from the melting of grounded ice on Greenland and/or Antarctica and, to a lesser extent, from mountain glaciers, a result consistent with the average 20th century mass contribution to sea level rise estimated by Miller and Douglas (2004). The true significance of the recent increased thermosteric contribution to sea level rise can only be determined by continuing altimetric and *in-situ* (e.g., ARGO) observations.

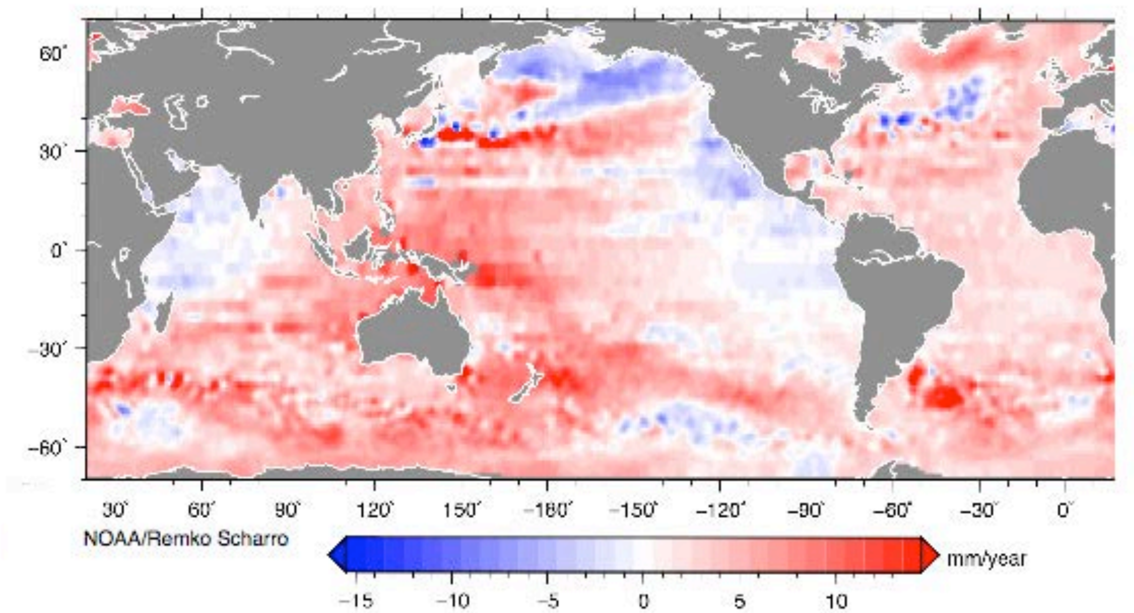


Figure 2. Sea level trends over 1993-2004 determined from TOPEX *and* Jason-1 satellite altimeter observations. The global mean of this map gives the 2.8 mm/yr value shown in Fig. 1.

References

Antonov, J.I., S. Levitus, and T.P. Boyer, 2002: Steric sea level variations during 1957-1994: Importance of salinity, *J. Geophys. Res.*, **107**, C12, 8103, doi:10.1029/2001JC000964.

Cabanes, C., A. Cazenave, and C. LeProvost, 2001: Sea level rise during the past 40 years determined from satellite and in-situ observations, *Science*, **294**, 840-842.

Church, J.A., N.J. White, R. Coleman, K. Lambeck, and J.X. Mitrovica, 2004: Estimates of the regional distribution of sea level rise over the 1950-2000 period, *J. Climate*, **17**, 2609-2624.

Douglas, B.C., 1997: Global sea rise: A redetermination, *Surveys in Geophys.*, **18**, 279-292.

Holgate, S.J., and P.L. Woodworth, 2004: Evidence for enhanced coastal sea level rise during the 1990's, *Geophys. Res. Lett.*, **31**, doi:10.1029/2004GL019626.

Miller, L., and B.C. Douglas, 2004: Mass and volume contributions to 20th-century global sea level rise, *Nature*, **428**, 406-409.

Peltier, W.R., 2001: Global glacial isostatic adjustment and modern instrumental records of relative sea level history, in *Sea Level Rise, History and Consequences*, edited by B.C. Douglas, M.S. Kearney, and S.P. Leatherman, 65-95, Academic, San Diego, Calif.

White, N.J., J.A. Church, and J.M. Gregory, 2005: Coastal and global averaged sea level rise for 1950 to 2000, *Geophys. Res. Lett.*, **32**, L01601.

Willis, J.K., D. Roemmich, and B. Cornuelle, 2004: Interannual variability in upper ocean heat content, temperature, and thermosteric expansion on global scales, *J. Geophys. Res.*, **109,** C12036.

2.2 SEA SURFACE TEMPERATURES IN 2004

by Richard W. Reynolds, National Climatic Data Center, Asheville, North Carolina

The purpose of this section is to discuss sea surface temperatures for 2004. This will include comparisons to other years, primarily 2000-2003. The analysis used is the weekly optimum interpolation (OI) analyses of Reynolds et al. (2002). The analysis uses ship and buoy in situ SST data as well as satellite SST retrievals from the infrared (IR) Advanced Very High Resolution Radiometer (AVHRR). The AVHRR was first available in November 1981, so the analysis begins in that month. The results will be shown as anomalies which are the defined as differences from a 1971-2002 climatological base period using methods described by Xue et al. (2003). Anomalies are used to best separate climate signals from the annual mean and seasonal cycle. In many of the figures which follow, monthly fields are used. The monthly fields are derived by interpolating the weekly fields to the day of the month and then averaging the daily values in the appropriate month. This was done to smooth the results so that the climate signal can more easily be extracted from the weekly variability.

To best demonstrate the overall changes between 2004 and other years, time series of the average monthly OI SST anomaly from 75ºS to 75ºN is shown for the entire period of record (Fig. 1).

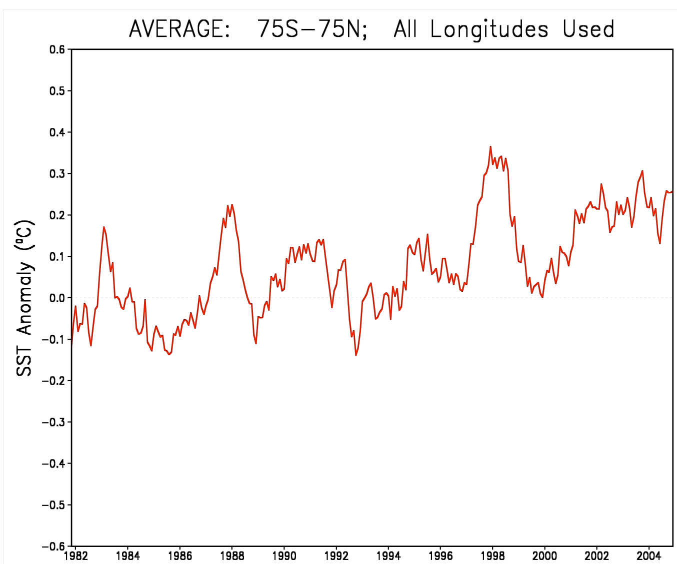


Figure 1. Time series of average monthly SST anomalies between 75**º**S and 75**º**N for the period November 1981 through December 2004. The anomalies are computed relative to a 1971-2000 base period.

The general change over this period is a slow warming with some large fluctuations of 1 to 3 years. Please recall that the climatological base period is 1971-2000 so the overall warming tends to favor positive over negative anomalies toward the end of the record. The 1 to 3 year fluctuations are usually due to the warm and cold SST anomalies in the tropical Pacific due to large El Niño and large La Niña events, respectively. The impacts of these events often influence the tropical Indian SST anomalies and may influence the tropical Atlantic SST anomalies. For example, the El Niño event of 1982-83 occurred along with cold tropical Atlantic SST anomalies while the El Niño event of 1997-98 occurred along with warm tropical Atlantic SST anomalies. However, the SST anomaly curve is relatively flat from 2001 through 2004. This suggests overall warming trends were small over this period and that no large El Niño or La Niña events occurred.

To now focus on the changes during 2004, the mean and standard deviation of the weekly anomaly for 2004 is shown in Figure 2. The mean anomalies in the upper panel show warm anomalies in the Central Pacific, the North Atlantic and to a weaker extent, the tropical Indian Ocean and the western Indian Ocean near 35ºS. The standard deviation of the anomaly in the lower panel shows the strongest variability between roughly 30ºN and 70ºN and in the eastern

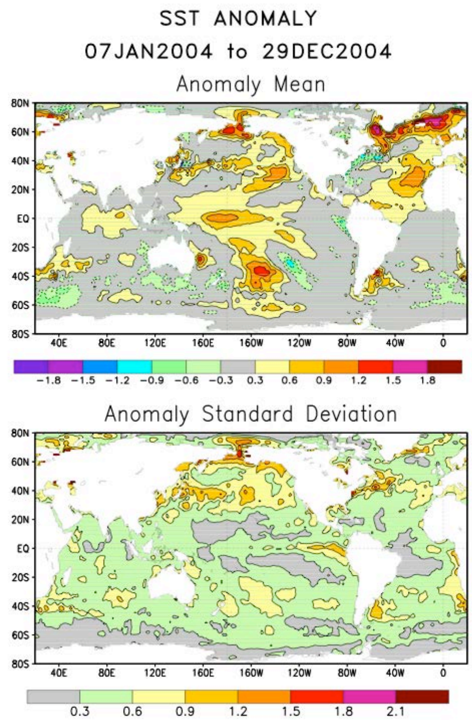


Figure 2. Mean and standard deviation of weekly SST anomalies for the period 7 January 2004 through 29 December 2004. The anomalies are computed relative to a 1971-2000 base period. The contour interval is 0.3°C; the 0 contour is not shown.

Tropical Pacific. In addition, there is more modest variability along the equator in the eastern Pacific and between 30ºS and 50ºS east of South America and both east and west of the Cape of Good Hope. To determine the similarity between 2003 and 2004, the 2003 weekly mean and standard deviation is shown in Figure 3. The figures show that the 2003 and 2004 standard deviations (lower panels) are very similar. The anomaly patterns (upper panels) are also similar with important differences in the eastern Pacific near 40ºN and in the South Atlantic especially near 20ºS.

It would be useful to also consider climate indices. However, the North Atlantic Oscillation, the Arctic Oscillation, the Pacific North American Pattern and the Antarctica Oscillation are expressed in terms of sea level pressure and these patterns are not confined to oceanic regions (see "teleconnections" on
http://www.cpc.ncep.noaa.gov/products/precip/CWlink/MJO/climwx.shtml
and http://www.ncdc.noaa.gov/oa/climate/research/teleconnect/teleconnect.html).

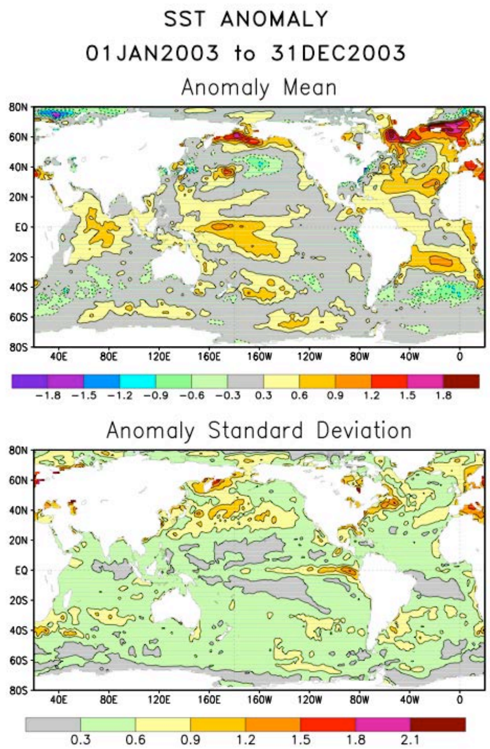


Figure 3. Mean and standard deviation of weekly SST anomalies for the period 1 January 2003 through 31 December 2003. The anomalies are computed relative to a 1971-2000 base period. The contour interval is 0.3°C; the 0 contour is not shown.

Thus, SSTs alone cannot define these indices. The relationship between sea level pressure and SST is better defined for El Niño and La Niña events. However, that will be discussed elsewhere in this report. The Pacific Decadal Oscillation (PDO) is defined in terms of SST (see http://tao.atmos.washington.edu/pdo/ and Mantua, et al, 1997). The PDO needs to be measured on annual and longer scales. A plot of the annual PDO for 1982 through 2004 (not shown) is noisy with a PDO value for 2004 is 0.11 which too close to zero to be significant.

To investigate the variations in 2004, the zonal monthly anomalies are examined for two longitude bands with large anomalies as suggested by Figure 2. The first zonal band is for the central Pacific (160ºE to 120ºW) and is shown in Figure 4 for 2000-2004. The region with the highest variability occurs along 60°N. There the anomalies are near normal from January 2000 until June 2002. For almost all of the remaining period (July 2002 through December 2004) the anomalies are above normal with especially strong anomalies for two periods of about 5 months each which are centered on July 2003 and July 2004. (Please note that the region of high variability near 65ºN, Bering Strait, is due to the limited ocean area for the average.) The other

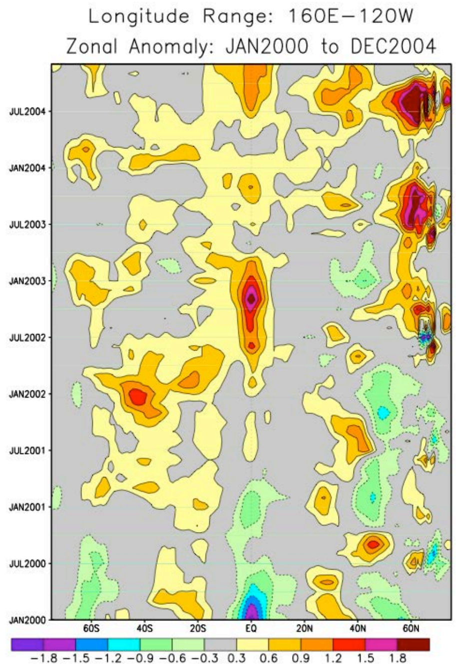


Figure 4. Zonal mean SST anomalies averaged between 160ºE and 120ºW (the Central Pacific) for the period January 2000 through December 2004. The anomalies are computed relative to a 1971-2000 base period. The contour interval is 0.3ºC; the 0 contour is not shown.

region with high variability occurs along the equator where the end of a La Niña event is evident in early 2000. This event is followed by an El Niño event in 2002-2003 and the beginning of a new El Niño event in the second half of 2004. The large positive anomaly (Fig. 2) centered near 40ºS and 160ºW is not strongly evident here even though it persisted through both 2003 and 2004. This was because it was often offset by nearby negative anomalies along the same latitude (Fig. 2).

The second zonal band is for the Atlantic (80ºW- 0º) for 2000-2004 (Fig. 5). Here the band of highest variability is centered on about 60ºN. It tends be above normal for the entire period with a tendency of peak warming during August through September. The size of these peaks becomes largest in 2003 and 2004 closely matching the variability found in the North Pacific along this same latitude band. The remaining features are less coherent. The warm anomaly in 2004 near 20ºN and 20ºW (Fig. 2) was primarily for the second half of 2004 and is suggested by the Fig. 5. However, it appears weaker because the zonal average is for the entire Atlantic while the anomaly is confined to the eastern half of the Atlantic.

The most important extra tropical SST variability for 2004 occurs in both 2003 and 2004 along 60ºN and with larger values between August and October. This is shown in Fig. 6 by the time series of the average weekly OI SST anomaly from 50ºN to 70ºN for 2003 and 2004. These summer and fall warm SST anomalies are the oceanic response to large summer and fall warm land surface air temperatures anomalies found along this same latitude band (see http://www.ncdc.noaa.gov/oa/climate/research/monitoring.html).

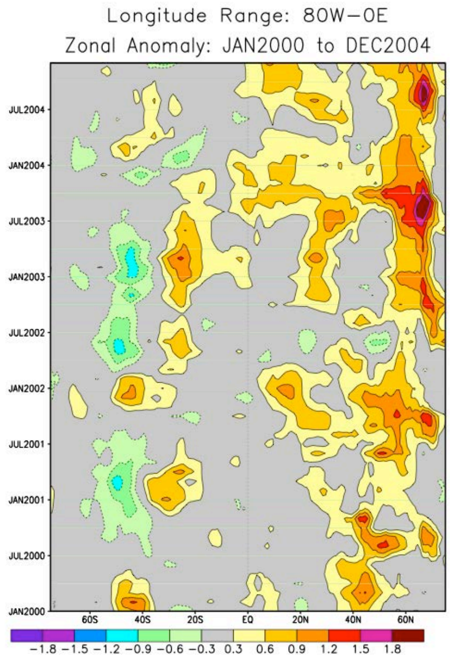


Figure 5. Zonal mean SST anomalies averaged between 80ºW and 0º (the Atlantic) for the period January 2000 through December 2004. The anomalies are computed relative to a 1971-2000 base period. The contour interval is 0.3ºC; the 0 contour is not shown.

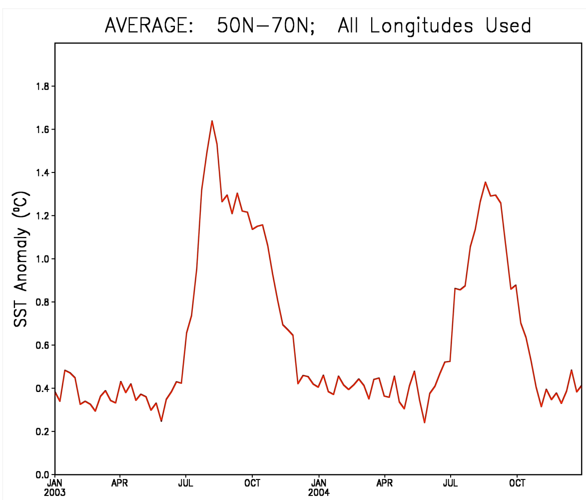


Figure 6. Time series of average weekly SST anomalies between 50ºN and 70ºN for the period 1 January 2003 through 29 December 2004. The anomalies are computed relative to a 1971-2000 base period.

References

Mantua, N.J. and S.R. Hare, Y. Zhang, J.M. Wallace, and R.C. Francis, 1997: A Pacific interdecadal climate oscillation with impacts on salmon production. *Bull. Am. Meteorol. Soc.*, **78**, 1069-1079.

Reynolds, R. W., N. A. Rayner, T. M. Smith, D. C. Stokes and W. Wang, 2002: An improved in situ and satellite SST analysis for climate. *J. Climate*, **15**, 1609-1625.

Xue, Y., T. M. Smith, and R.W. Reynolds, 2003: A new SST Climatology for the 1971-2000 Base Period and Interdecadal Changes of 30-Year SST Normal. *J. Climate*, **16**, 1601-1612.

2.3 OCEAN HEAT AND FRESH WATER CONTENT AND TRANSPORTS

by Lynne Talley, Scripps Institution of Oceanography, La Jolla, California

2.3.1 Introduction

Heat and freshwater transport changes as well as changes in local air-sea exchange are recorded in variations in ocean temperature and salinity distributions. Highlighted results are given in section 2.3.2.

Global fields and anomalies of SST for 2004 are shown in Section 2.3.3. No global surface salinity products are available for 2004, although the data sets that could be used to produce them are accruing.

Section 2.3.4 summarizes changes in the upper ocean through 2004, including variations in the tropical Atlantic and Indian Oceans, and Pacific Decadal Oscillation and North Atlantic Oscillation variations in the Pacific and Atlantic.

Section 2.3.5 describes temperature, salinity and transport variations in waters affected by the global overturning circulation. Variations in deep and bottom waters formed in the Antarctic are also described. In section 2.3.6, a new analysis of heat content change from 1993 to 2003 is reviewed.

2.3.2 Some highlights

(1) Sea surface temperature in 2004 was higher than the long-term mean (1968-1996) over most of the globe, with the greatest increases in the Arctic. Alternating cooling and warming regions occupy the far southern hemisphere. Temperature increases in most of the oceans are less than 0.5°C, but are much greater in the polar latitudes (> 4°C). A large cooled patch south of Africa also had relatively large departures from the mean (more than 2°C colder than the mean).

(2) Heat content calculated from combined data sets increased monotonically from 1993 to 2003.

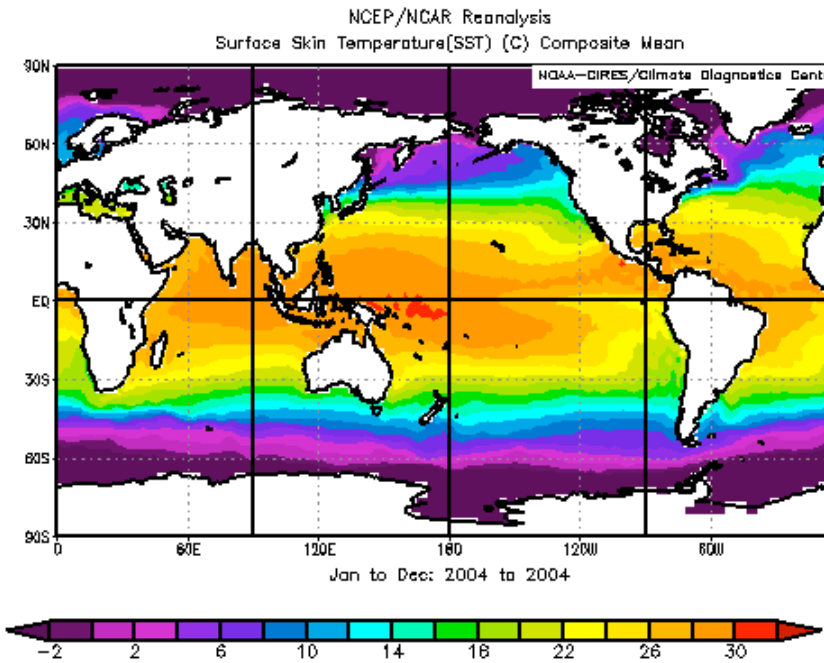
(3) Freshening in the high latitude North Atlantic continued into 2004.

2.3.3 Global upper ocean temperature and salinity

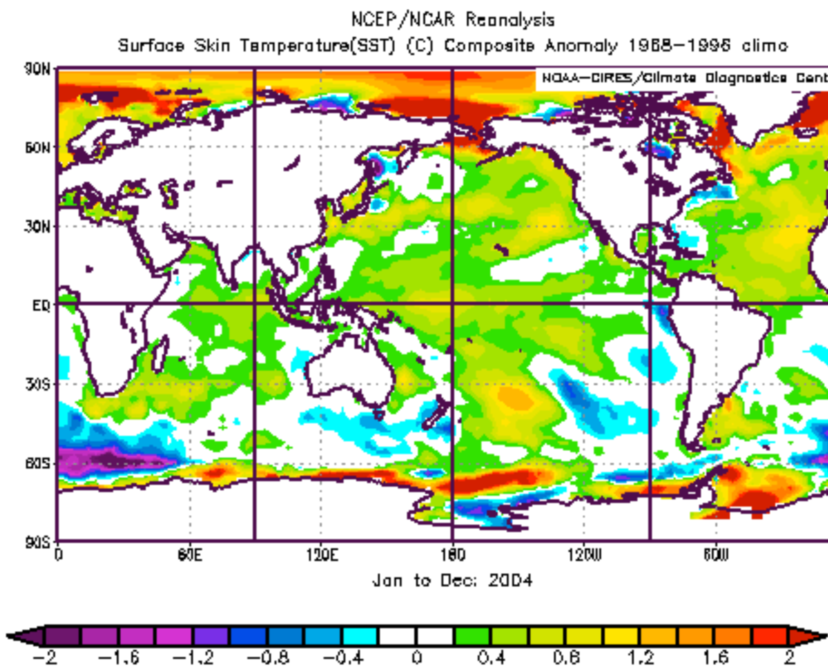
Annual mean and monthly anomalies of sea surface temperatures for 2004 are shown in Figure 1 (NCEP/NCAR reanalysis). Sea surface salinity analyses are much more difficult to find; the EU's Coriolis project produces maps for the Atlantic based on profiling ARGO data, but there is no global product. The U.K. Met Office global Forecasting Ocean Assimilation Model (FOAM) also produces surface salinity maps, but access is no longer available without charge.

Surface temperature is higher than the long-term mean (1968-1996) over most of the northern hemisphere and tropics. In most ocean basins, the excess is less than 0.5°C. The greatest extremes are found at polar latitudes. In the Arctic, the temperature is more than 4°C higher than the mean along the northern coast of Alaska and eastern Siberia, and around Greenland eastward to Svalbard and Russia. Major regions of cooler temperatures are restricted to the southern hemisphere, with the largest cooled region in a large patch of the Antarctic south of Africa. Alternating patches of warmed and cooled water are found around Antarctica, with warming in the Weddell Sea, along Queen Adelie Land, and in the northern Ross Sea. Within the southern hemisphere ocean basins, all three oceans show cooling in the east and warming in the west, which is consistent with an increase in strength of the subtropical gyres.

Global maps of upper ocean heat content and subsurface temperature anomalies for 2004 are apparently not publicly available. (Products from JEDAC that were used for the State of the Ocean 2003 report were discontinued in 2004.) New global heat content maps (Willis et al. 2004) showing decadal trends are presented in section 2.3.7.



(a)



(b)

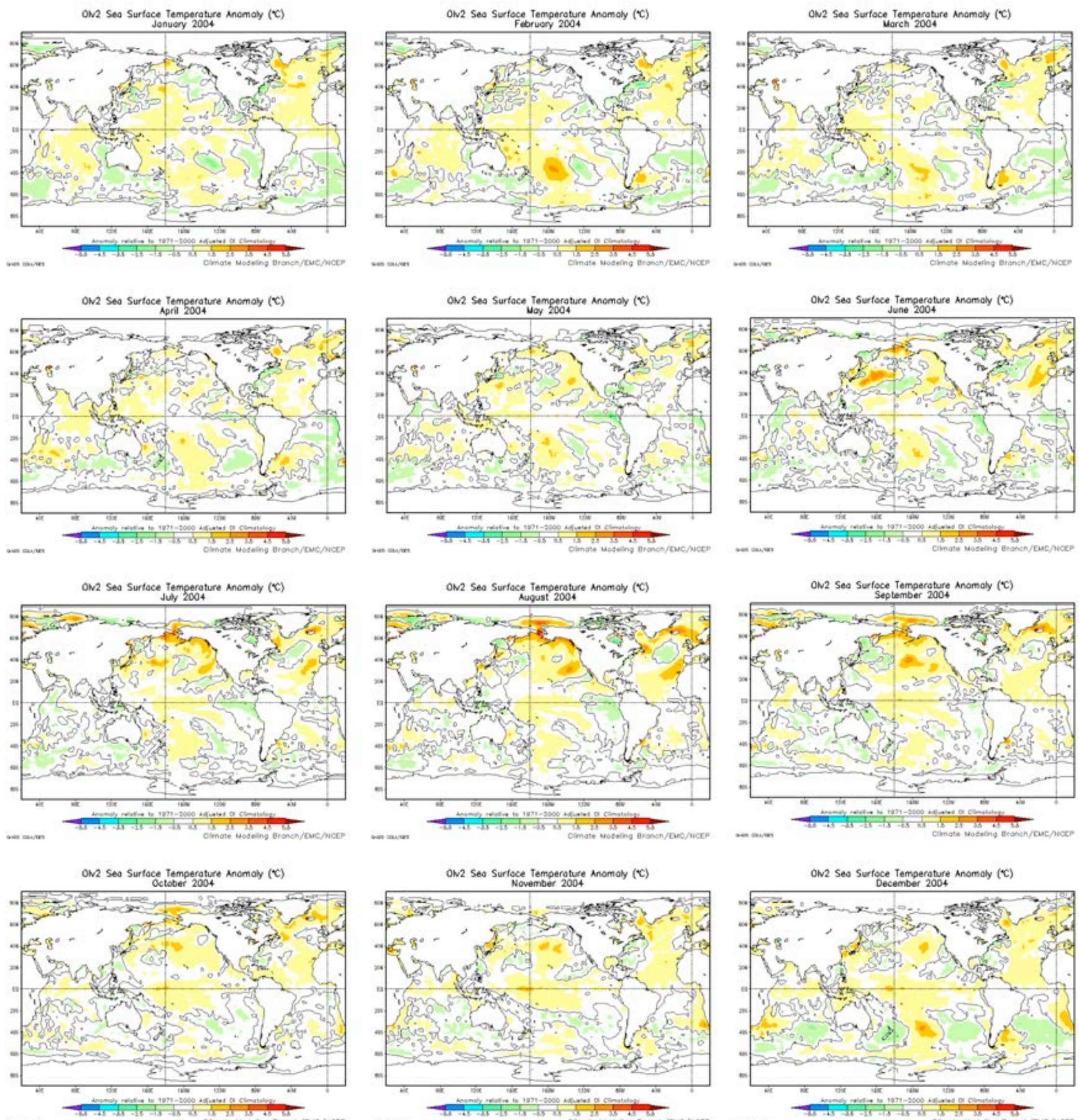


Figure 1. (a) Annual mean sea surface temperature and (b) anomaly from the 1968-2000 mean, for 2004 (NCEP/NCAR reanalysis). (http://www.cdc.noaa.gov/Composites/) (c) Monthly SST anomalies for 2004 from the 1971-2000 mean (Reynolds et al. 2002) (http://www.emc.ncep.noaa.gov/research/cmb/sst_analysis/)

Subsurface temperature is monitored through the XBT program (since the 1970s) and more recently from the ARGO profiling float program, with underwent rapid expansion in 2004 (Fig. 2). All non ice-covered basins are now instrumented with ARGO floats, although many regions are still undersampled. Implementation grew to the 50% level in late 2004. Operational products of subsurface temperature and salinity fields are being produced for the Atlantic (examples of salinity maps in Fig. 3), and of subsurface temperature for the North Pacific (examples in Fig. 5). Anomaly maps are apparently not yet available.

No operational global maps of surface or upper ocean salinity anomalies for 2004 are available. Salinity maps for the Atlantic Ocean are now being produced by the European Union's Coriolis project (Fig. 3) using ARGO data, but this is a fledgling effort as of now, covering neither the globe nor including salinity anomalies.

Because salinity impacts decadal and longer climate variability, and because of the use of salinity as a signature of such climate variability, it is imperative that regular salinity products be compiled and made publicly available as soon as possible. To be most useful, both the observed and anomaly fields should be shown. A fast turnaround taxes the ability to calibrate salinity observations in near real-time, and so products with some lag time would clearly be desirable.

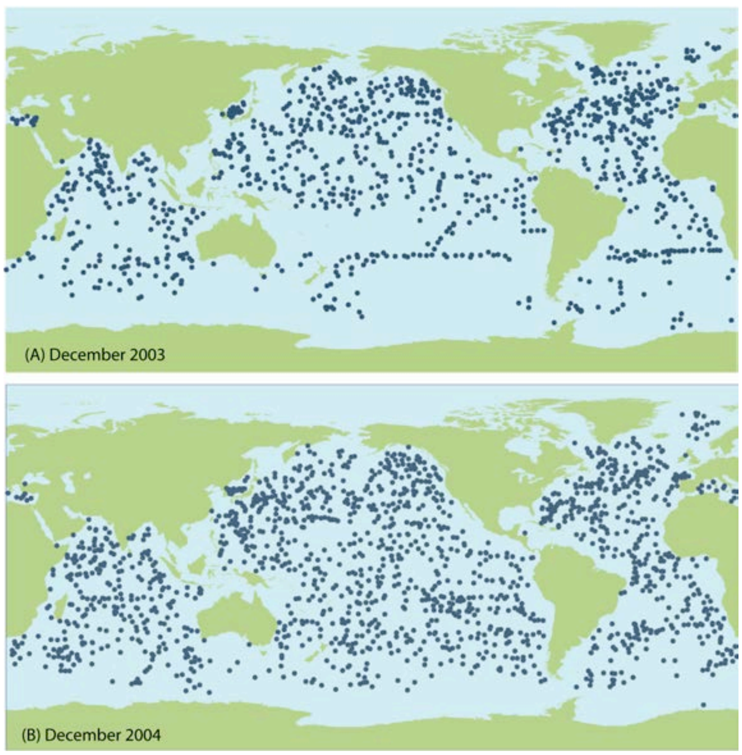


Figure 2. ARGO floats in December 2003 and December 2004 (http://www.jcommops.org).

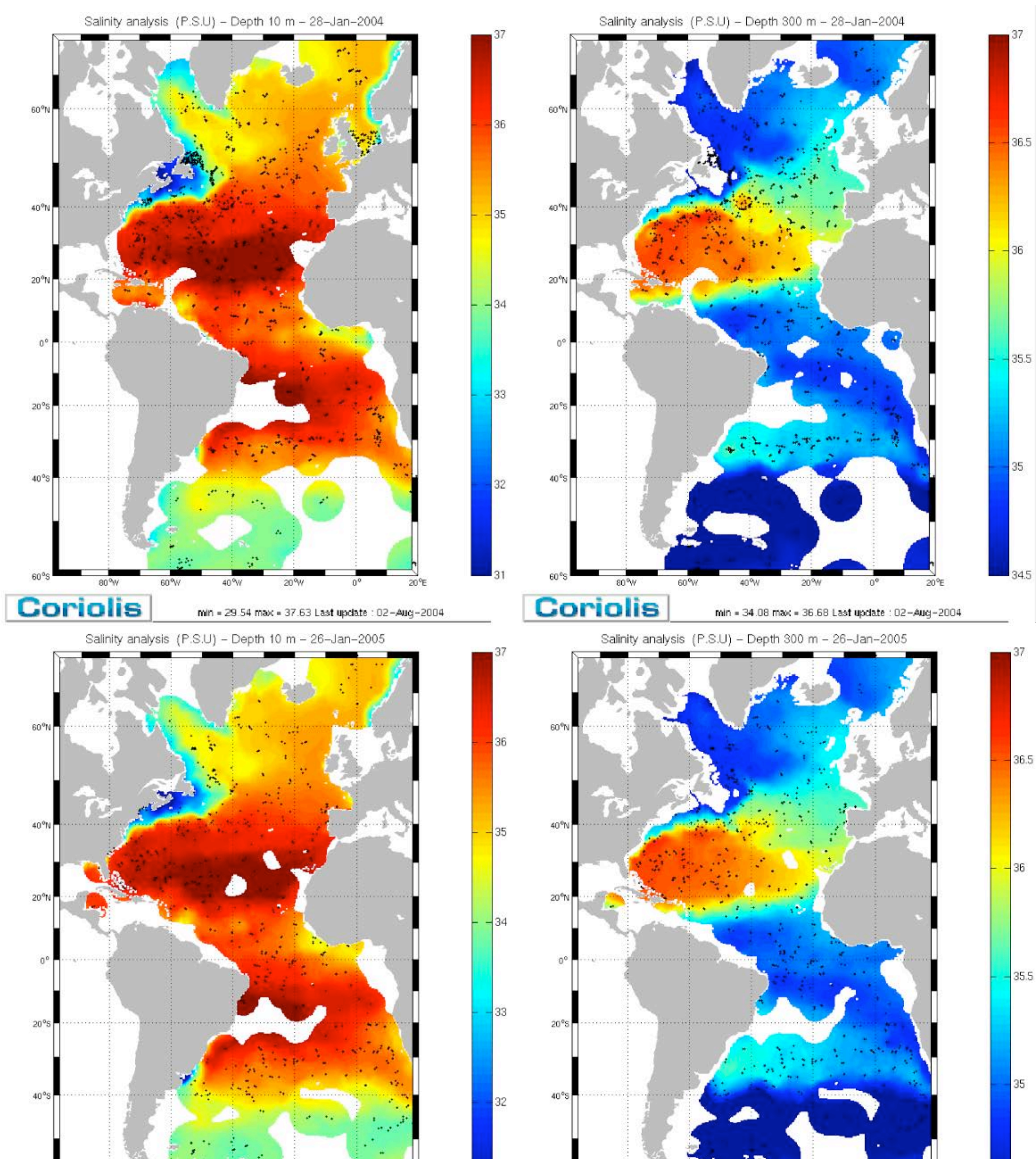


Figure 3. Salinity at 10m and 300 m in late January 2004 and January 2005, based on ARGO float data, from the Coriolis operational oceanography (http://www.coriolis.eu.org/coriolis/cdc/atlantic_area.htm). Maps are available at other depths, as are temperature maps.

2.3.4 Basin-scale upper ocean variations

Upper ocean variations in temperature, salinity and circulation are strongly associated with the natural modes of variability, variously identified as El Nino Southern Oscillation (ENSO), the Pacific Decadal Oscillation (PDO) (section 2.3.4.1), the tropical Atlantic dipole, the Indian dipole (both in 2.3.4.2), the Southern Annular Mode (SAM) (including the Antarctic Circumpolar Wave or Antarctic Dipole Mode) (2.3.4.3), and the North Atlantic Oscillation (NAO) and Arctic Oscillation (AO) (or Northern Annular Mode) (2.3.4.4). The ocean response in 2004 to the modes is reviewed in this section.

2.3.4.1. Upper ocean property variations in the mid-latitude Pacific and mid-latitude southern hemisphere

The extratropical Pacific and subtropical regions of the southern hemisphere respond to several identified climate modes. The Pacific Decadal Oscillation (PDO) (Fig. 4) (Zhang et al. 1997; Mantua et al. 1997) is a realization of the dominant Pacific mode, although recently it has been suggested that it is a combination of ENSO and the PNA mode (Aleutian Low strength) (Schneider and Cornuelle 2004). The PDO is meridionally symmetric about the equator. When the index is high, the tropical Pacific is warm and the high latitude Pacific is cold, and vice versa. A high PDO index is also associated with high pressure in the tropical Pacific and low pressure in the higher latitudes (deep Aleutian low). The PDO spatial pattern is similar to that of ENSO, but without the very large peak in amplitude in the tropics. The PDO thus modulates the strength of ENSO; when the PDO index is high, ENSO is especially pronounced. Boundary regions bordering continents are especially impacted by PDO-variations in the ocean, with impacts on marine-based economics (fisheries) and coastal climate. When the PDO index is high, circulation in the Gulf of Alaska is stronger and less subpolar water enters the California Current. The Oyashio is also strong during high PDO.

The PDO was high in 2004, continuing from mid-2002. This followed a short period of low PDO (1998-2002), preceded by a prolonged period of high PDO, which began in 1976. Because of the relatively long duration in any particular phase and because of the widespread ecological impacts of the PDO, much attention has been focused on identifying "regime shifts" such as that in 1976 as they happen, although a true shift can only be defined several (5 to 10) years after the fact.

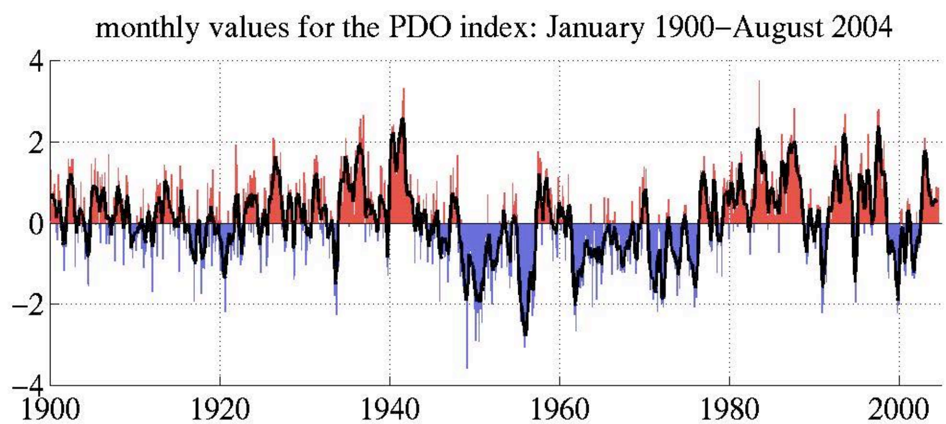


Figure 4. Pacific Decadal Oscillation index (http://tao.atmos.washington.edu/pdo/).

SST anomalies in 2004 (Fig. 1) generally showed the warm PDO phase, with warm eastern tropical waters and colder mid-latitude centers. The pattern also matches that of ENSO; the year 2004 continued a weak ENSO. The ENSO changes are apparent in the sample North Pacific temperature maps constructed from ARGO and XBT data (Fig. 5), with warmer equatorial waters at the end of 2004 and an eastward shift of the warmest water at 100 m to the central Pacific.

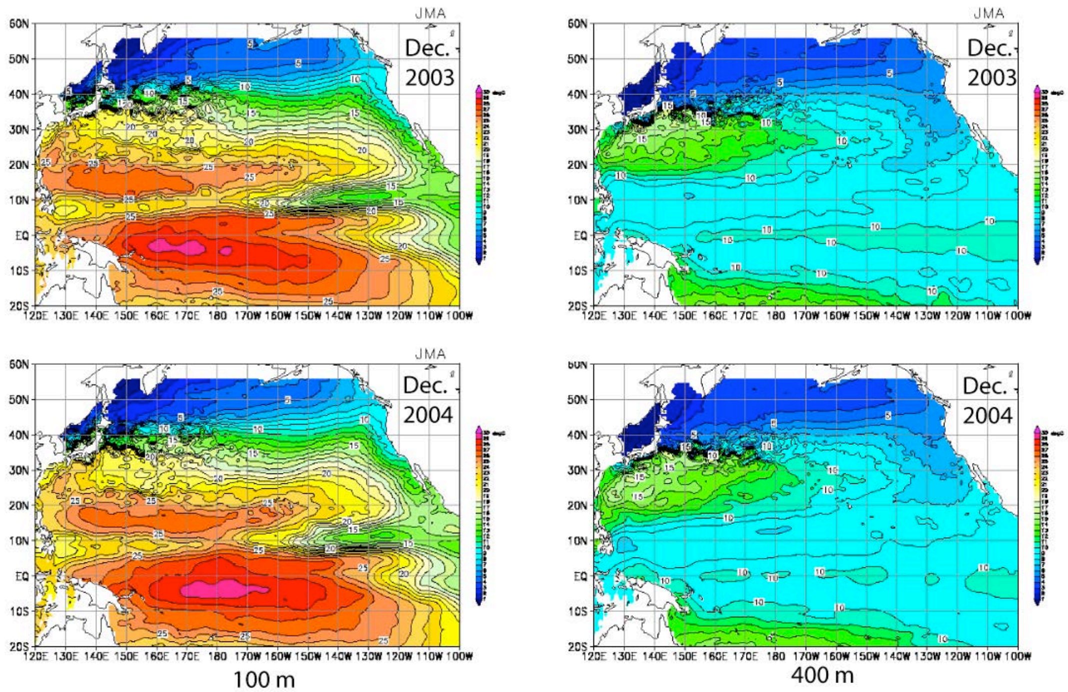
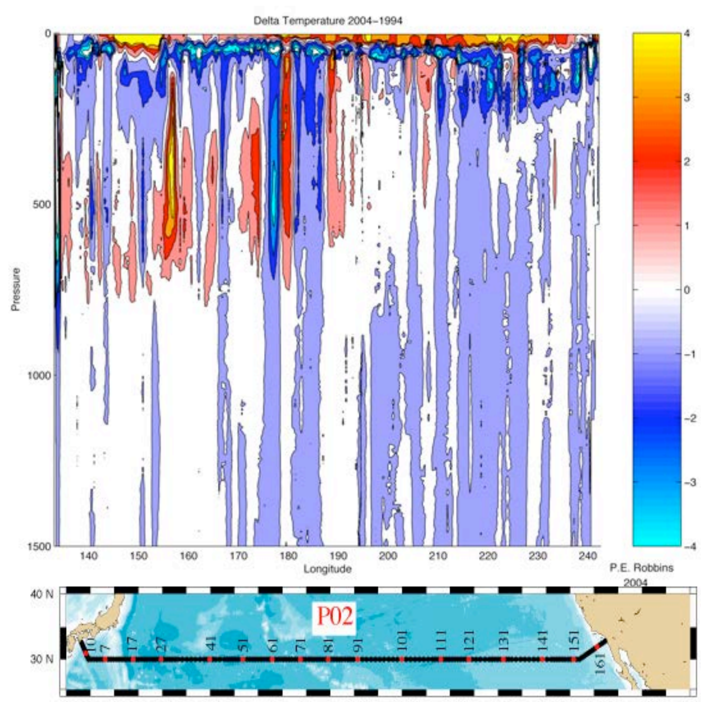


Figure 5. Examples of monthly sub-surface temperature analysis (available from surface down to 400 m), for December 2003 and December 2004, at 100 and 400 m, from the Japan Meteorological Agency, incorporating ARGO and XBT data (http://argo.kishou.go.jp/index.html).

A detailed repeated hydrographic section from east to west across the mid-latitude North Pacific occupied in summer 2004, as part of the U.S. Repeat Hydrography program for CLIVAR/CO, showed warming through the subtropical gyre, down into the thermocline (Robbins, personal communication) (Fig. 6).



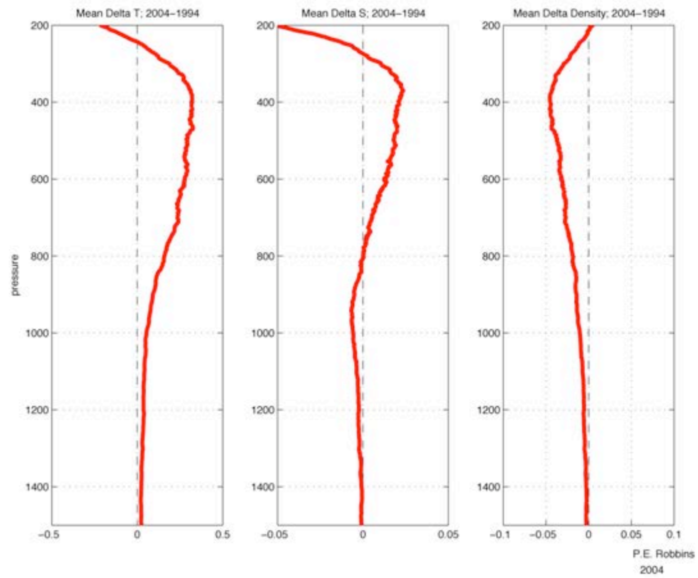


Figure 6. (a) Temperature change, (b) station locations, and (c) integrated temperature, salinity and potential density change, for hydrographic section occupied in 2004 minus another in 1994. (Robbins, personal communication).

2.3.4.2. Tropical Atlantic and Indian Oceans

The tropical regions of the Atlantic and Indian Ocean are influenced by upper ocean variations that might be separate from ENSO, although lagged ENSO response is also apparent. The tropical Atlantic experiences variability that has been described in terms of either a cross-equatorial dipole or as nearly independent modes north and south of the equator. There is no regularly produced index of a dipole or gradient mode. The Climate Diagnostics Center and Climate Diagnostics Bulletin (CDB) report separate Tropical North Atlantic (TNA) and Tropical South Atlantic (TSA) mode indices (Fig. 7).

The North and tropical Atlantic and the tropical Indian Ocean were anomalously warm throughout 2004 relative to a 1968-1996 mean (Fig. 1). The Atlantic warmth is reflected in continuing positive values of the TNA through 2004 (Fig. 6).

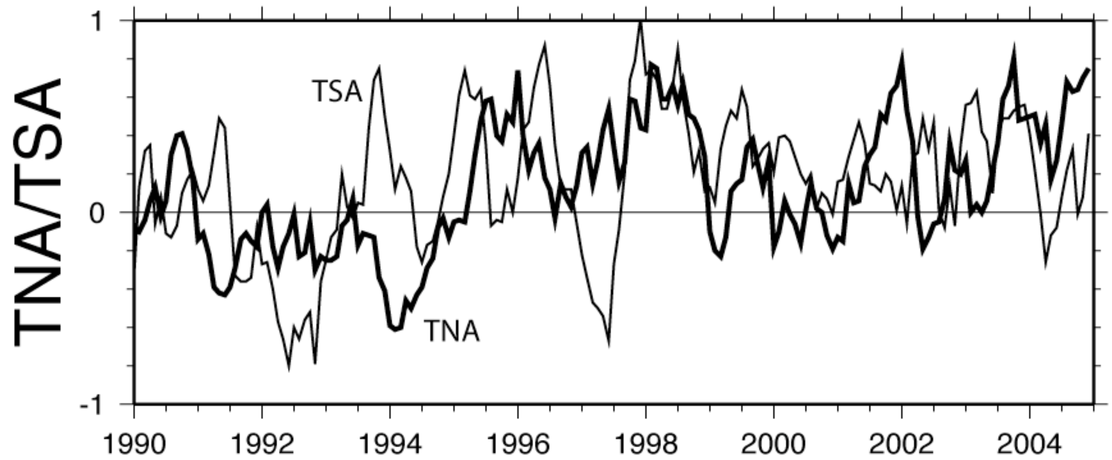
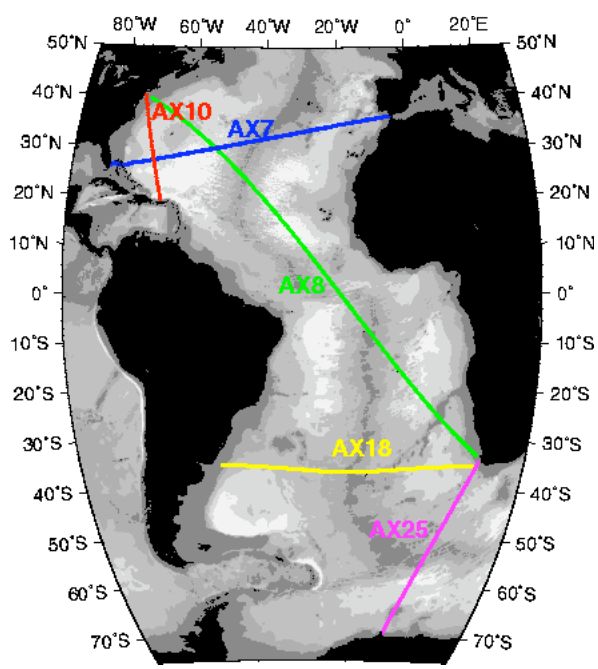


Figure 7. (a) Tropical North Atlantic (TNA - heavy) and Tropical South Atlantic (TSA - light) indices, including 2004. From the NOAA Climate Diagnostics Center (http://www.cdc.noaa.gov/ClimateIndices/Analysis/).

High density XBT sections are occupied across all oceans approximately seasonally, with profiling to more than 800 m depth and close station spacing to produce the highest quality volume transport estimates. As years of data accumulate, it will be possible to track interannual and then decadal variations in upper ocean temperature structure using these data. The Atlantic high density network maintained by NOAA is shown in Figure 8, with a sample section from line AX8.



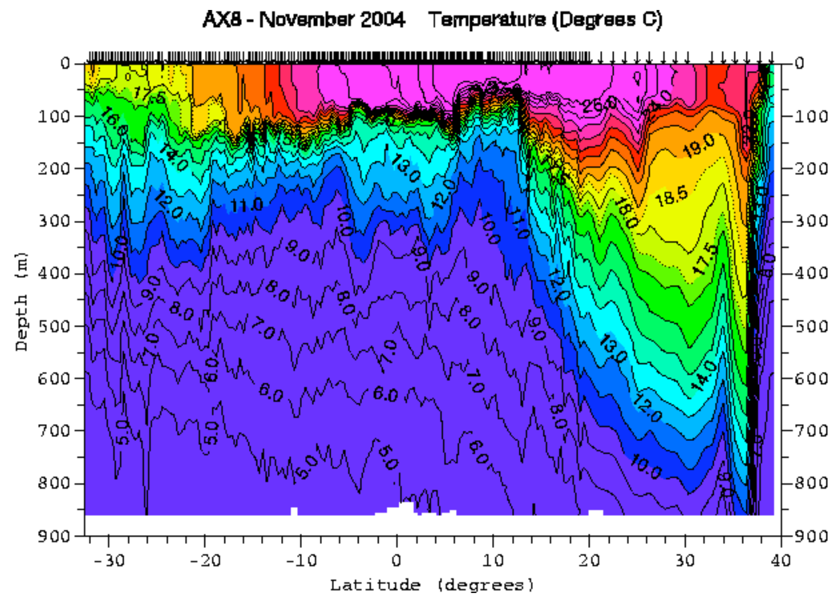


Figure 8. (a) High density XBT network maintained by NOAA AOML, with sections 4 times per year. (b) Sample section along AX8 (November 2004).
(http://www.aoml.noaa.gov/phod/hdenxbt/)

Indian Ocean variability has been described in terms of a dipole mode (Saji et al. 1999) (Fig. 9), although Indian variability is also heavily influenced by ENSO.

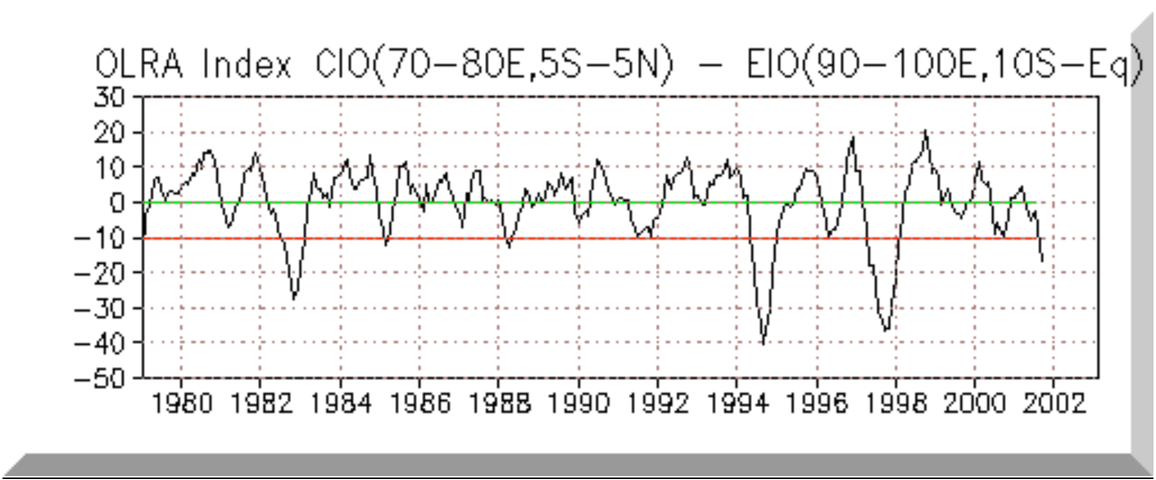
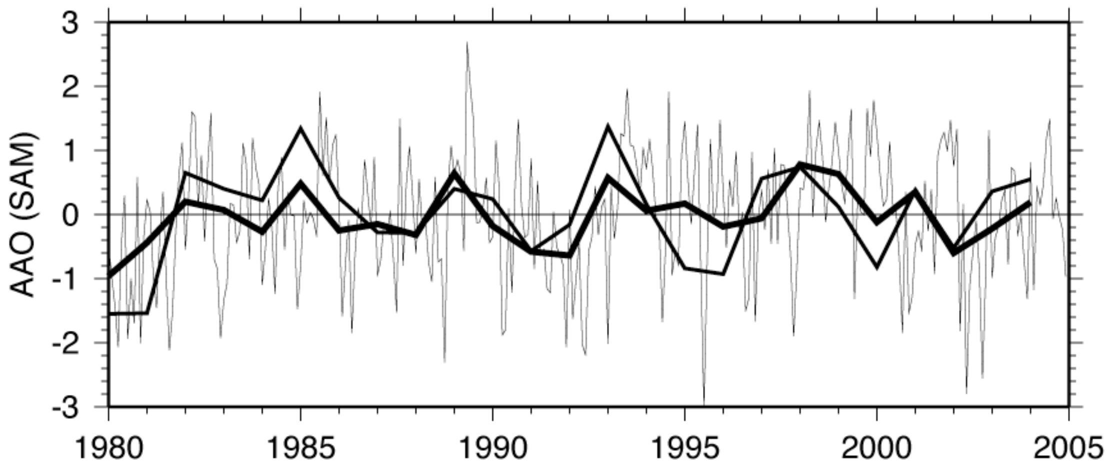
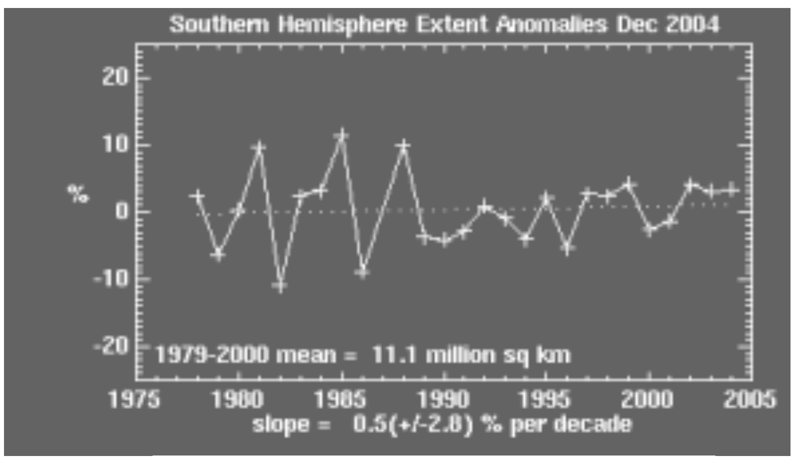


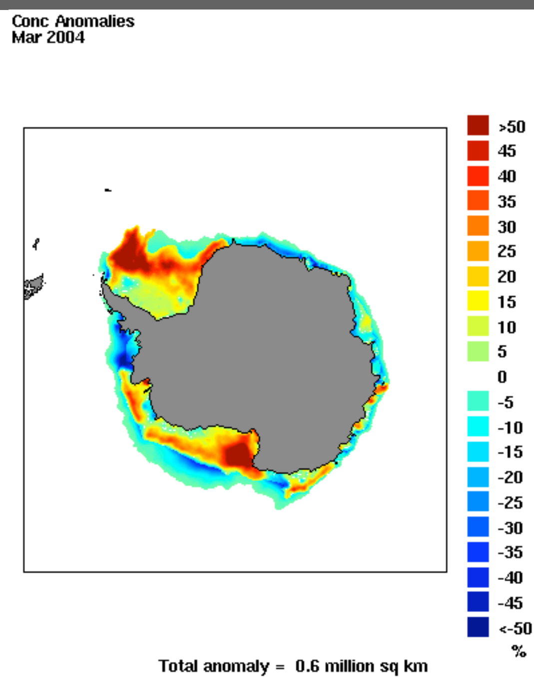
Figure 9. Indian Dipole Index, based on OLR (Saji et al. 1999)
(http://www.jamstec.go.jp/frsgc/research/d1/iod/dmi.html).

2.3.4.3. Southern Hemisphere Annular Mode

The Southern Hemisphere Annular Mode (SAM) or Antarctic Oscillation (AAO) is the major decadal mode of climate variation in the southern ocean (Thompson and Wallace 2001). When the SAM index is high, the westerly winds are shifted to the south and are stronger; that is, the polar vortex is spun up. The associated Antarctic temperature changes are a colder interior of the continent and warmer region in the Antarctic Peninsula and ocean in the area of the Subantarctic Front. The AAO is tracked by the Climate Prediction Center (Fig. 10).


AAO (SAM)
3
2
1
0
-1
-2
-3
1980
1985
1990
1995
2000
2005


Southern Hemisphere Extent Anomalies Dec 2004
%
20
10
0
-10
-20
1979-2000 mean = 11.1 million sq km
1975
1980
1985
1990
1995
2000
2005
slope = 0.5(+/-2.8) % per decade


Conc Anomalies
Mar 2004
>50
45
40
35
30
25
20
15
10
5
0
-5
-10
-15
-20
-25
-30
-35
-40
-45
<-50
%
Total anomaly = 0.6 million sq km

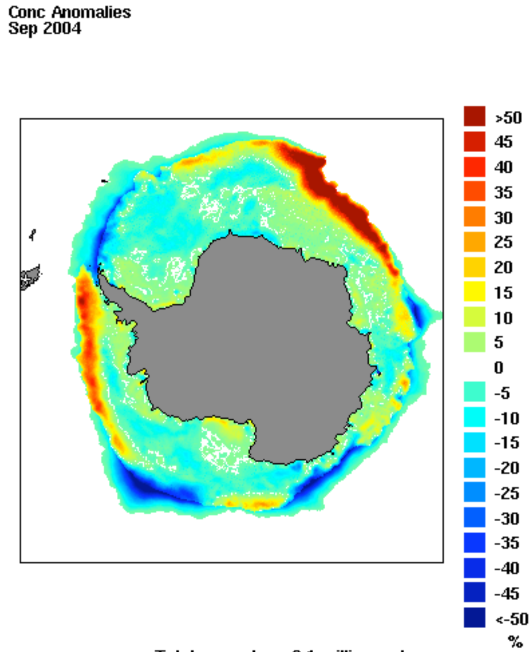


Figure 10. (a) AAO index based on monthly values from the Climate Prediction Center (thick: annual average; medium: JAS average; thin: monthly); (b) Sea ice index (http://nsidc.org/data/seaice_index/) (Fetterer and Knowles 2002, updated 2004); (c) and (d) Ice concentration anomaly in March and September 2004 (http://nsidc.org/data/seaice_index/archives/).

In 2004, the annual average AAO (SAM) was rising. The monthly SST maps (Fig. 1) do not show a simple polar vortex response, instead showing a version of the wavenumber 2 pattern that usually dominates. In the mean in 2004, this pattern included a cold region south of Africa, and a weak cold region in the eastern Ross Sea. Warm patches appeared in the western Ross Sea and Weddell Sea.

In winter (September) 2004, sea ice (Fig. 10d) matched the SST pattern, with increasing sea ice concentration in the cold region south of Africa, and in the eastern South Pacific. The total sea ice cover (Fig. 10b) continued a long-term but very noisy upward trend around Antarctica.

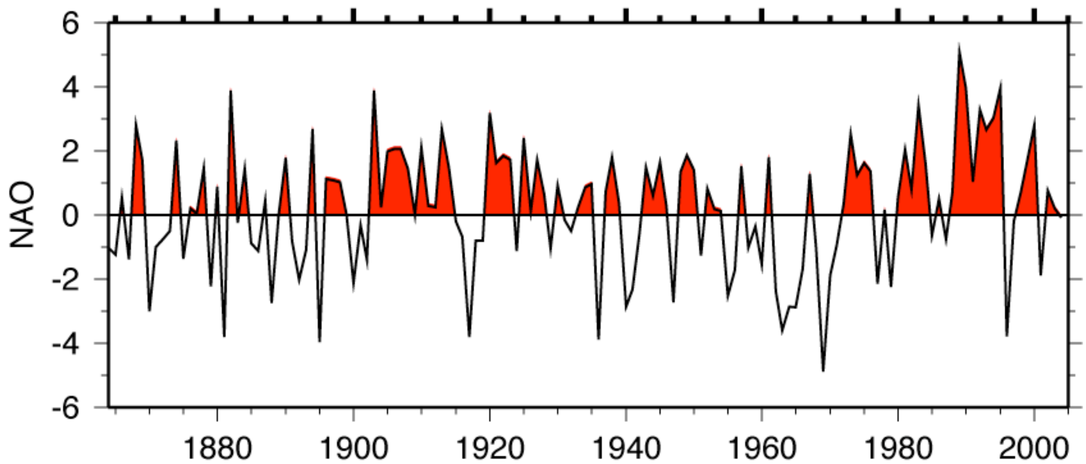
2.3.4.4. North Atlantic Oscillation

The northern North Atlantic (subpolar region and adjacent Nordic Seas, including the Greenland, Iceland and Norwegian Seas) receives special attention because of its role in global overturning circulation and proximity of the affected surface currents to western Europe and the eastern U.S. The overturning culminating in deep and intermediate water formation in the Nordic and Labrador Seas is sometimes called the ocean "conveyor", and is global in extent.

A particular scenario that has received attention is the possibility of freshening of the surface layer of the northern North Atlantic, as a result of ice melt and/or changed precipitation patterns. Such freshening is clearly being observed (section 2.3.5 below). Historically and in models, a freshened surface layer reduces or stops the convection that connects the surface to the intermediate layers in the Greenland and Labrador Seas. Freshwater from the Arctic impacts the Greenland Sea through the East Greenland Current, and impacts the Labrador Sea through Davis Strait.

Northern North Atlantic climate variability is strongly associated with the North Atlantic Oscillation (NAO) and its parent climate pattern, the Arctic Oscillation (AO) or Northern Annular Mode (NAM), which have quasi-decadal time scales. The NAO index measures the meridional atmospheric pressure gradient driving the westerlies. When the NAO index is high, the westerlies are in a northern position and strengthened, and vice versa.

The NAO index in 2004 continued to be close to neutral based on several available products (Fig. 11).



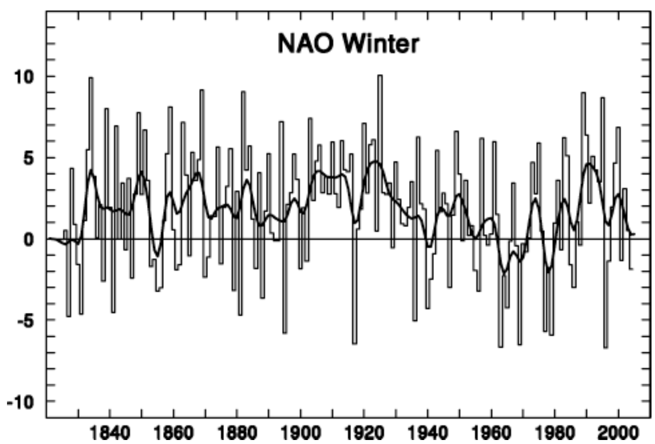


Figure 11. NAO index. (a) Winter Lisbon-Reykjavik SLP difference: values from http://www.cgd.ucar.edu/~jhurrell/nao.stat.winter.html
(b) Gibraltar-Reykjavik pressure difference: image from http://www.cru.uea.ac.uk/cru/climon/data/nao/ (Climate Monitor Online 2005).

Temperature anomalies along the zonal subtropical section crossing the North Atlantic at 24°N show an approximately 20-year signal (Fig. 12).

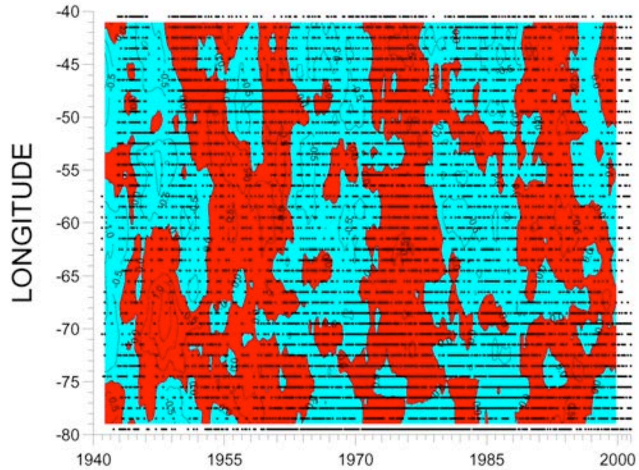


Figure 12. Surface temperature variations from BT and continuing XBT observations along 24°N showing an approximately decadal signal. Annual cycle and long-term trend were removed, and the data were filtered with a 3-year running mean (Baringer/AOML, personal communication).

2.3.5 Global overturning circulation

Deep overturn is affected by surface properties, particularly salinity and the presence and strength of a near-surface halocline. It is also affected by the overall stratification, hence properties, especially salinity, in and below the thermocline. A strong halocline supports surface cooling even to freezing without deep convection, whereas a weak halocline can permit deep overturn. Surface layer salinity is a function of regional precipitation and runoff and export of freshwater from winter ice-covered regions. Changes in freshwater content and sea ice extent thus have impacts on the thermohaline circulation, and are reviewed here.

The two sites that dominate thermohaline circulation of the global ocean are the deep and intermediate water formation sites in the northern North Atlantic, and at sites distributed around Antarctica. The waters from these two regions fill the global ocean, mixing with each other and with overlying thermocline waters. Upwelling occurs in many regions; this component of the thermohaline circulation is not yet well understood, but most likely involves a large amount of upwelling in the tropics and in the southern ocean. The North Pacific participates only weakly in thermohaline circulation because it is relatively fresh compared with the North Atlantic and Antarctic, and is not reviewed herein, although a section could be added on the North Pacific in future reports.

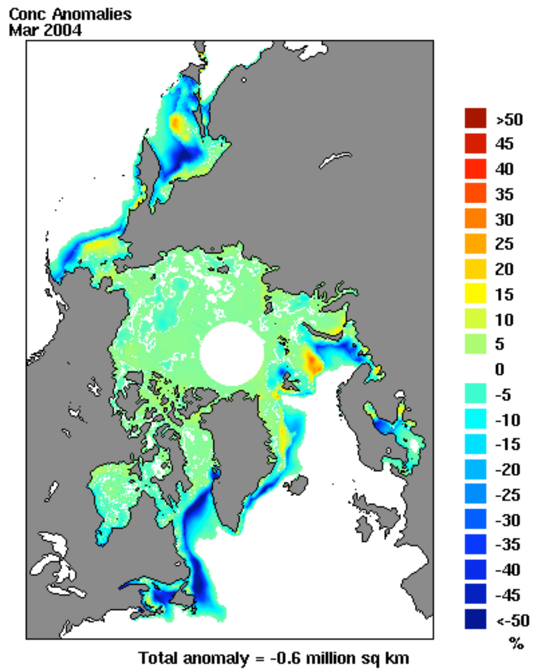
Major changes in thermohaline circulation are associated with glacial-interglacial changes in climate, with paleoclimate observations showing a weakening of the North Atlantic overturning and shift to shallower densities during the glacial periods. Variations in North Atlantic overturning are implicated in models of climate change, especially recent concepts of abrupt climate change (e.g., Alley et al. 2003). Southern Ocean overturning changes are the other end of the variability - models of thermohaline circulation variations often show alternating strength of overturn in the North Atlantic and Southern Ocean, with the implication that the present climate state is of strong North Atlantic overturn and relatively weak Southern Ocean overturn.

Change in thermohaline circulation result from changes in the temperature - salinity distribution and less importantly from changes in air-sea flux. A saltier basin provides the greater and denser overturn. Changes in the circulation are a response to a buildup over many years, although the actual change is predicted to be quite sudden at some phases of the climate cycle.

2.3.5.1 North Atlantic overturn

The components of North Atlantic Deep Water sink from the surface at convection sites in the Nordic Seas, the Labrador Sea and the Mediterranean Sea. Within the North Atlantic and tropical Atlantic, these three source waters are readily distinguishable. Variations in their properties could be well defined by the completed ARGO network. Future summaries will draw effectively from this source (e.g., Figs. 2 and 3). Current projects that regularly produce subsurface temperature maps do not include the deepest surfaces needed to characterize these water mass changes.

The source water for the sinking in the northern North Atlantic is upper ocean water that enters the North Atlantic from the southern hemisphere and from the Arctic. The Arctic source includes a fresh surface layer associated with continental runoff and the sea ice cycle. Major melting of Arctic sea ice was reported in 2002 and continued in 2003 (Figure 13). These fresh waters are exported to the North Atlantic in the East Greenland Current and through Davis Strait into the Labrador Sea. Freshening of upper ocean waters around the northern North Atlantic has been reported over the past several decades (Dickson et al. 2002, 2004; Curry et al. 2004) (Fig. 16). If continued, the freshening could initiate a weakening of the North Atlantic overturn.



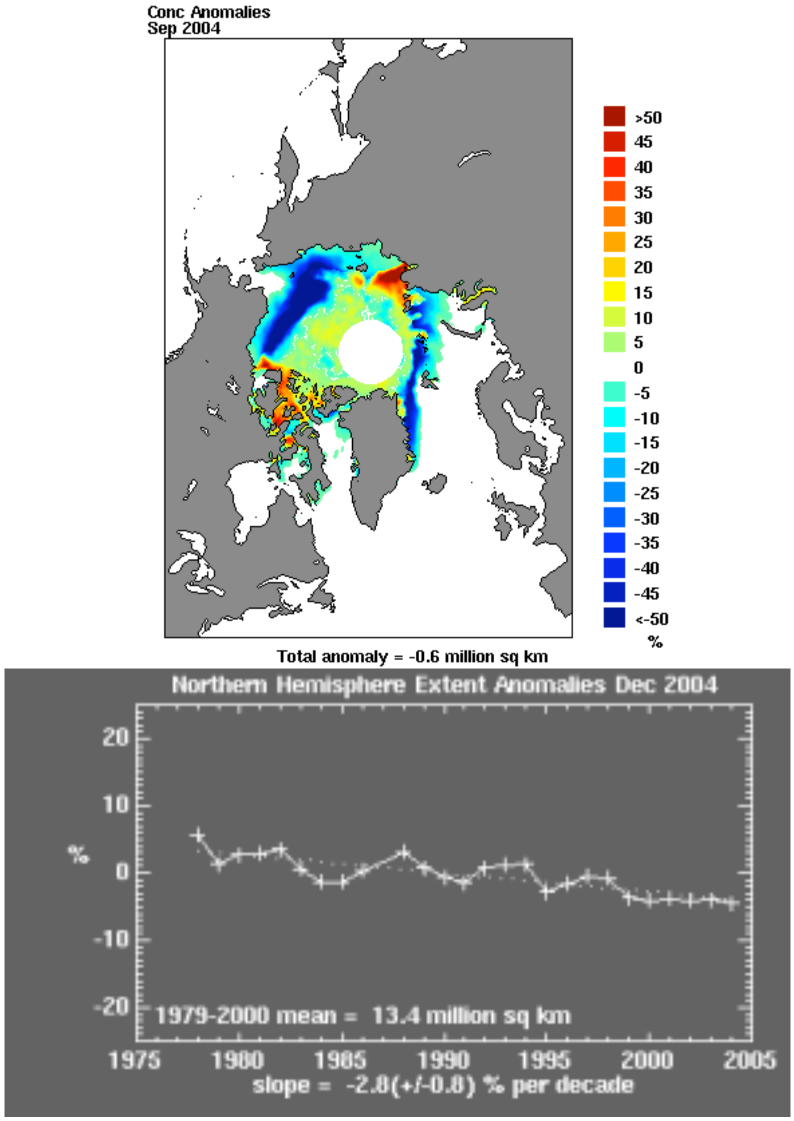


Figure 13. Arctic sea ice: concentration in (a) March 2004 and (b) September 2004. (http://nsidc.org/data/seaice_index/archives/) and (c) Multi-year time series of extent. (http://nsidc.org/data/seaice_index/).

A time series of salinity in the central Labrador Sea shows major freshening of the Labrador Sea Water (very thick near-surface layer) in the mid-1990s associated with vigorous deep convection brought on by high NAO (Fig. 14), continuing in a weaker way to the present. Time series of salinity from various locations around the northern North Atlantic shown by Dickson et al. (2002, 2003) show first the broad spatial scale of freshening. The important freshening trends emerge only with several decades of data and multi-year averaging.

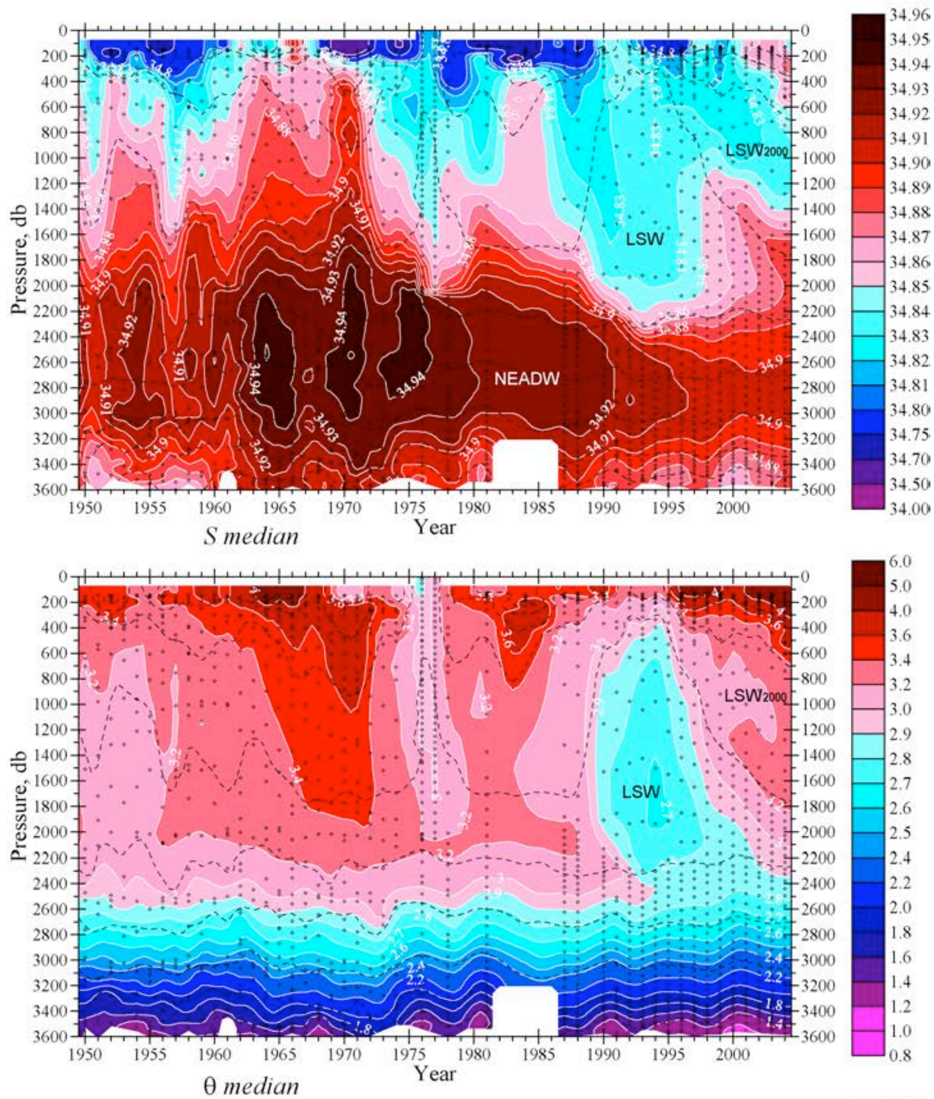


Figure 14. Time series of (a) salinity and (b) potential temperature in the central Labrador Sea. (Yashayaev, personal communication).

The Deep Western Boundary Current (DWBC) in the subtropical North Atlantic carries the various component of the new North Atlantic Deep Water southward. As noted above, these include waters from the Labrador Sea at about 1500-2000 meters and from the Nordic Seas below this. Ongoing observations of the DWBC (Molinari et al. 1998; Baringer personal communication) have shown the arrival of the extreme form of Labrador Sea Water that was formed in the1990s in the Labrador Sea. As of 2002, continuing into 2003, freshening of the whole repeated section crossing the DWBC was apparent.

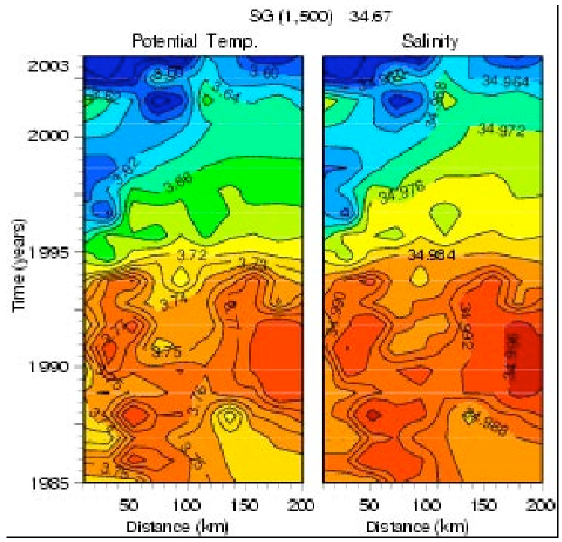


Figure 15. Hydrographic observations crossing the Deep Western Boundary Current east of Abaco at 26.5°N. Shown here are potential temperature and salinity at potential density σ_1= 34.67 (depth ~ 1500-1700 meters), showing the arrival of cold, fresh Labrador Sea Water after 1995 (from M. Baringer, NOAA/AOML).

Overall, the Atlantic has been becoming fresher and colder at high latitudes and more saline and warmer in subtropical latitudes (Curry et al. 2004) (Fig. 16). This suggests an increase in the strength of the hydrological cycle. The high latitude freshening could impact dense water formation adversely.

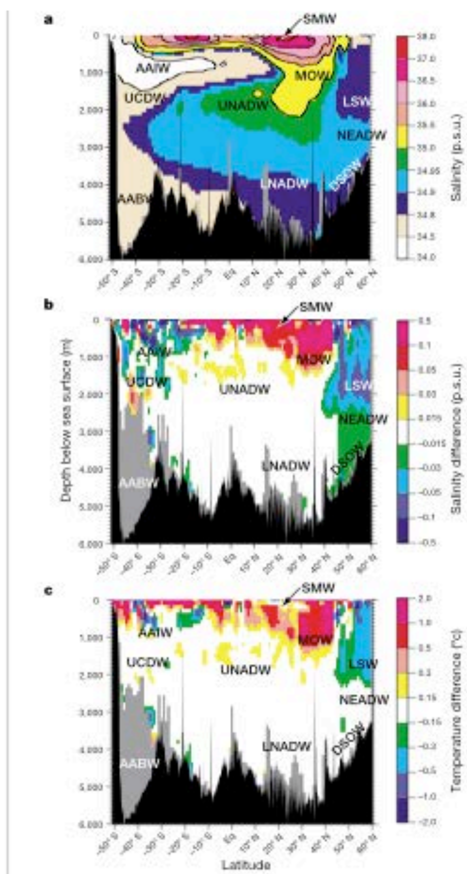


Figure 16. Changes in salinity and temperature of the major water masses in the Atlantic Ocean, along a section from south to north (Curry et al. 2004).

2.3.5.2. Southern Ocean overturn

Bottom waters are formed around Antarctica through brine rejection in polynyas near the coast. Deep waters are formed by deep convection in the Weddell and Ross Seas. The global overturning circulation also has an important upward limb in the Circumpolar Current system located north of the winter ice edge northward through the Subantarctic Front, where deep waters, formed in the North Atlantic and modified in the deep Indian and deep Pacific Oceans, upwell.

Sea ice extent around Antarctica in 2004 was illustrated in section 2.3.4.3 and in Figure 10. The densest waters in the world are formed in polynyas in the coastal regions of Antarctica, over the continental shelves. With increasing sea ice production, as has been occurring in the Antarctic over the past several decades (noisy increase seen in Fig. 10), denser shelf waters and hence denser bottom waters can be formed. With a decrease in summer ice melt (or smaller contrast between winter and summer ice extent), the freshwater surface layer inhibiting surface mixing would weaken, which also increases density and production of dense waters. Thus the changing sea ice conditions around Antarctica would appear to favor an increase in dense water production and density.

Variations in upper ocean temperature and salinity in the Australian sector of the Southern Ocean (Aoki et al. submitted) (Fig. 17) bear out this potential for increased dense water production. The surface waters in the south are becoming more saline while those at subtropical latitudes are becoming fresher. The increased salinity in the south could allow higher density convection.

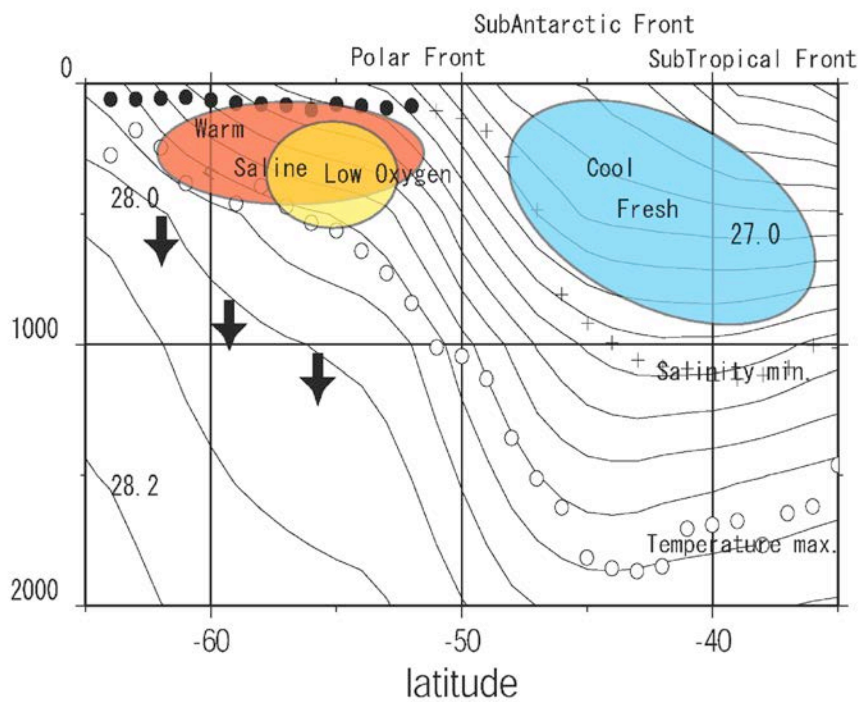
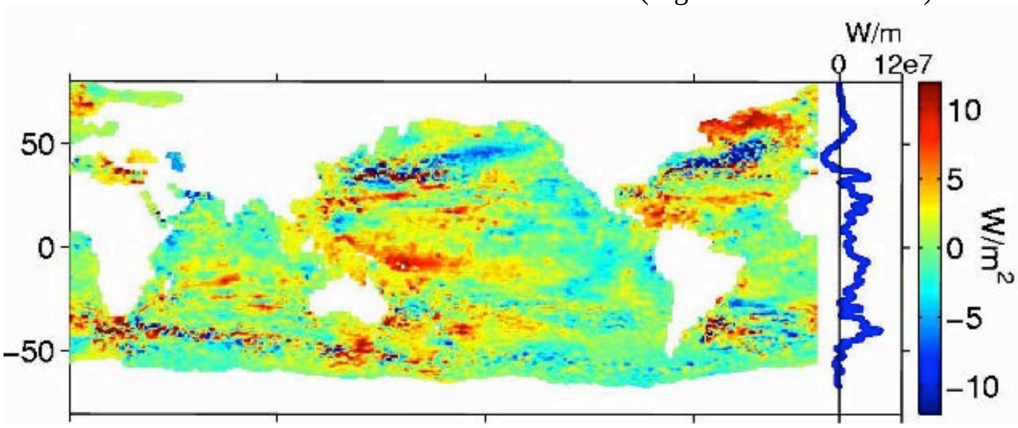


Figure 17. A summary of the meridional water mass changes from south of the ACC to mid-latitudes, between 30E and 160E (Aoki et al. 2005).

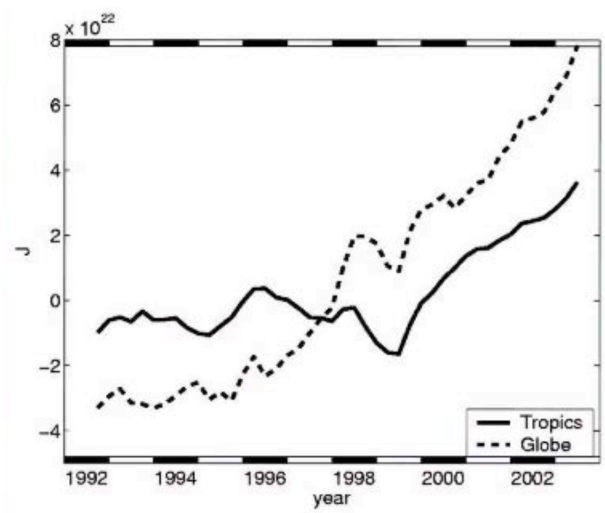
2.3.6. Heat and freshwater transport variations based on *in situ* data

Ocean heat and freshwater transports are calculated from either their air-sea fluxes or directly from in situ ocean observations of temperature, salinity and velocity. Annual global and full water column data sets of *in situ* properties, with requisite velocity analysis, are not possible.

Willis et al. (2004) have pioneered a mapping of ocean heat content from a combination of in situ measurements (ARGO and XBT profiles), altimetric sea surface height, and data assimilation. Using data through mid-2003, they show that the global heat content of the ocean has been rising since 1993 (onset of altimetry observations) (Fig. 18). Their analysis excludes the Arctic and southern ocean, and so the actual rise is likely larger, given the much larger SST increases observed in the Arctic than in the mid-latitude oceans (Fig. 1 and section 2.3.3).



(a)



(b)

Figure 18. Ocean heat content: (a) mapped changes from 1993 to 2003 in terms of surface heat flux (W/m^2), and (b) total heat content (Joules) integrated over the globe (Willis et al. 2004).

References

Aoki S., N.L. Bindoff, and J.A. Church: Interdecadal Water-mass changes in the Southern Ocean between 30E and 160E. *Geophys. Res. Lett.*, to be submitted.

Curry R., B. Dickson, and I. Yashayaev, 2004: A change in the freshwater balance of the Atlantic Ocean over the past four decades. *Nature*, **426**, 826-829.

Dickson, R. R., R. Curry and I. Yashayaev, 2003: Recent changes in the North Atlantic. *Phil. Trans. Roy. Soc*., London A, 10.1098/rsta.2003. **1237**, 18 pp.

Fetterer, F. and K. Knowles. 2002, updated 2004: Sea Ice Index. Boulder, CO: National Snow and Ice Data Center. Digital media.

Mantua, N.J., S. R. Hare, Y. Zhang, J. M. Wallace and R. C. Francis, 1997: A Pacific interdecadal climate oscillation with impacts on salmon production. *Bull. Amer. Meteor. Soc.,* **78**, 1069-1079.

Reynolds, R. W., N. A. Rayner, T. M. Smith, D. C. Stokes and W. Wang, 2002: An improved in situ and satellite SST analysis for climate. *J. Climate*, **15**, 1609-1625.

Saji, N. H., N. Goswami, P. N. Vinayachandran and T. Yamagata, 1999: A dipole mode in the tropical Indian Ocean. *Nature*, **401**, 360-363.

Smith, T. M. and R. W. Reynolds, 2003: Extended Reconstruction of Global Sea Surface Temperatures Based on COADS Data (1854-1997). *J. Climate*, **16**, 1495-1510.

Thompson, DWJ, and JM Wallace, 2000: Annular modes in the extratropical circulation.
Part I: Month-to-month variability. *J. Climate,* **13**, 1000-1016.

Willey, D. A., R. A. Fine, R. E. Sonnerup, J. L. Bullister, W. M Smethie and M. J. Warner, 2004. Global oceanic chlorofluorocarbon inventory. *Geophys. Res. Lett.,* **31**, L01303, doi:10.1029/2003GL018816.

Willis, J. K., D. Roemmich and B. Cornuelle, 2004: Interannual variability in upper ocean heat content, temperature, and thermosteric expansion on global scales. *J. Geophys. Res.*, **109**, C12036, doi:10.1029/2003JC002260.

Wunsch, C. 2002: What is the thermohaline circulation? *Science*, **298**, 1179-1181.

Zhang, Y., J.M. Wallace, D.S. Battisti, 1997: ENSO-like interdecadal variability: 1900-93. *J. Climate*, **10**, 1004-1020.

2.4 EVOLUTION OF THE 2004 EL NIÑO

by Michael J. McPhaden, Pacific Marine Environmental Laboratory, Seattle, Washington

A weak El Niño developed in the second half of 2004 in the equatorial Pacific. Anomalous warming was for the most part centered around the international date line, with near normal temperatures in the equatorial cold tongue of the eastern Pacific and along the west coast of South America. SST anomalies in the NINO3.4 index region (5°N-5°S, 120°-170°W) were approximately 0.8°C on average from August to December 2004. The Southern Oscillation Index (SOI), which is the normalized surface air pressure difference between Darwin, Australia and Tahiti, French Polynesia, was consistently negative during the latter half of 2004 (-0.6 on average for August-December) indicative of warm phase El Niño/Southern Oscilllation (ENSO) conditions. The trade winds were unusually weak west of the date line associated with the elevated central and western Pacific SSTs and negative SOI values. Conversely, trade winds in the eastern Pacific were near to or even slightly stronger than normal throughout much of 2004.

The 2004 El Niño was characterized by significant month-to-month variability, much of which was associated with the atmospheric Madden-Julian Oscillation (MJO). Individual MJO events were initiated by convective flare-ups over the Indian Ocean and subsequently propagated eastward into the western Pacific. The westerly phase of the MJO was linked to 2-3 week long westerly wind bursts in the western Pacific, which forced eastward propagating downwelling intraseasonal equatorial Kelvin waves (Fig. 1). These waves deepened the thermocline in the eastern Pacific by 20-30 m, but apparently had little impact on eastern Pacific SSTs.

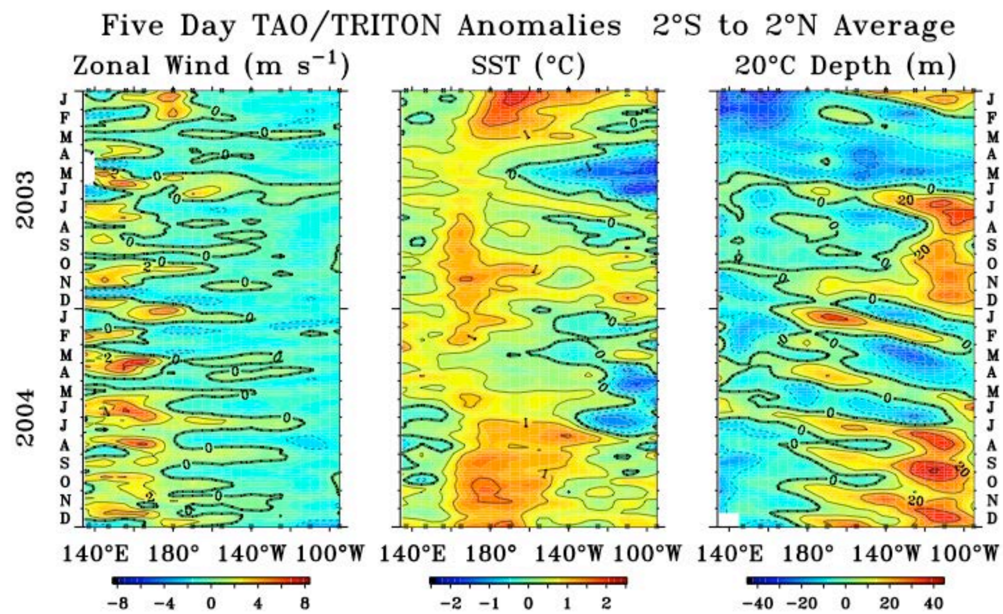


Figure 1. Five-day average anomalies of zonal wind, SST, and 20°C depth (an index for the depth of the thermocline) relative to the mean seasonal cycle averaged 2°N–2°S based on TAO/TRITON moored time series data. Ticks on the horizontal axis indicate longitudes sampled at the start (top) and end (bottom) of record.

Intraseasonal variability in convection was also pronounced in the western Pacific, but persistent anomalous atmospheric convection failed to develop over the elevated SSTs near the date line during the latter half of 2004. Thus, the ocean and the atmosphere did not appear to be as strongly coupled as in previous El Niño events. Lack of persistent anomalous deep convection in the western and central Pacific limited the impact of the El Niño on the global atmospheric circulation and teleconnections to higher latitudes in 2004. Likewise, the failure of persistent El Niño-related warm SST anomalies to develop in the eastern equatorial Pacific and along the west coasts of the Americas limited the effects of this El Niño on marine ecosystems and commercial fisheries in those regions.

The 2004 El Niño was unusual in that it followed the moderate amplitude 2002-03 El Niño (McPhaden 2004) by only one year. This rapid sequencing of El Niños is analogous to what transpired in the early 1990s when the moderate amplitude 1991-92 El Niño was followed by a weak warm event in 1993. Factors contributing to the development of the 2004 El Niño so soon after the termination of the previous event are not fully understood. However, it is noteworthy that the 2002-03 El Niño was followed by an extended period of excess warm water volume (or equivalently heat content) in the equatorial zone, which is atypical of conditions following most El Niños (Fig. 2). According to the recharge oscillator theory for ENSO (Jin 1997), El Niño is supposed to purge the tropical Pacific of excess heat leaving a deficit that must be replenished before the next El Niño can occur. The presence of weak positive heat content anomalies following the 2002-03 El Niño created large-scale conditions favorable the recurrence of another warm event earlier than would otherwise have been expected. Episodic westerly wind forcing in boreal spring and summer 2004 (Fig. 1) may have served as the stimulus for the development of anomalous warming by displacing the western Pacific warm pool towards the east (Kessler et al. 1995).

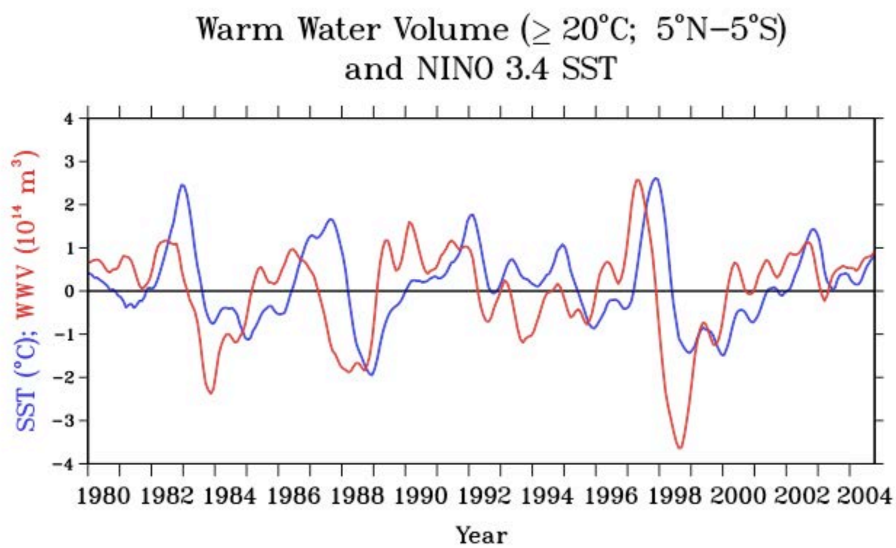


Figure 2. Monthly anomalies of warm water volume (5°N–5°S, 80°W–120°E above the 20°C isotherm) and NINO3.4 SST (5°N–5°S, 120°W–170°W) from January 1980 to December 2004. Warm water volume is based on a blended analysis of TAO/TRITON moored time series data and ship-of-opportunity expendable bathythermograph (XBT) data. Time series have been smoothed with a 5-month running mean filter for display.

Another unusual feature of the 2004 El Niño was the concentration of warm equatorial SST anomalies near the date line. A similar pattern was evident during the 2002-03 El Niño (see for example the start of the SST anomaly time series in Figure 1). In contrast, for most previous El Niños, eastern Pacific SST anomalies were much more pronounced. It is unclear what factors were responsible for this SST anomaly pattern. One possibility is that the Pacific has gone through a decadal regime shift in the late 1990s towards stronger trades and colder cold tongue SSTs (McPhaden and Zhang 2004). Such a decadal change in background state could favor weaker cold tongue SSTs during El Niño, but other processes may be at work as well.

Statistical and dynamical ENSO forecast models suggest that El Niño conditions will persist through the boreal spring of 2005 (http://iri.ldeo.columbia.edu/pred/). Afterwards, the models indicate a general tendency for continued warm SST anomalies with only slightly diminished amplitudes. However, forecasts through the "spring predictability barrier" are generally less reliable than those made up to and including the spring season, so there is greater uncertainty in El Niño forecasts for mid-2005 and beyond.

References

Jin, F.F., 1997: An equatorial recharge paradigm for ENSO. Part I: Conceptual model. *J. Atmos. Sci.*, **54**, 811-829.

Kessler, W.S., M.J. McPhaden, and K.M. Weickmann, 1995: Forcing of intraseasonal Kelvin Waves in the equatorial Pacific. *J. Geophys. Res.*, **100**, 10,613-10,631.

McPhaden, M.J., 2004: Evolution of the 2002-03 El Niño. *Bull. Am. Meteorol. Soc.*, **85**, 677-695.

McPhaden, M.J. and D. Zhang, 2004: Pacific Ocean circulation rebounds. *Geophys. Res. Lett.*, **31**, L18301, doi:10.1029/2004GL020727.

2.5 THE GLOBAL OCEAN CARBON CYCLE: INVENTORIES, SOURCES AND SINKS

by Richard Feely[1] and Rik Wanninkhof[2]

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Abstract
The ocean plays a major role in the global carbon cycle as it is a vast reservoir of carbon, naturally exchanges carbon with the atmosphere, and consequently takes up a substantial portion of anthropogenic carbon from the atmosphere. In response to the need for an integrated investigation of the carbon cycle in the oceans, the CLIVAR/CO_2 Repeat Hydrography and NOAA Underway pCO_2 Measurements Programs were established to document the trends in carbon uptake and transport in the global oceans. The CLIVAR/CO_2 Repeat Hydrography Program consists of a systematic re-occupation of select hydrographic sections to quantify global changes in storage and transport of heat, fresh water, carbon dioxide (CO_2), chlorofluorocarbon tracers and related parameters. Three North Atlantic cruises in 2003 marked the beginning of the US effort by reoccupying selected hydrographic sections on decadal time-scales. Early results from these cruises showed significant changes in oxygen and carbon dioxide and several other measurable parameters since the last global survey in the 1990s. The increases of DIC in the Subtropical Mode waters (STMW) are greater than expected from invasion of anthropogenic CO_2 from the atmosphere and may be the result of decadal changes in the local circulation in the North Atlantic.

2.5.1 The Global Carbon Cycle: Inventories, Sources and Sinks

The global utilization of fossil fuels for energy by mankind is rapidly changing the trace gas composition of the Earth's atmosphere, causing the greenhouse warming from excess CO_2 along with other trace gas species such as water vapor, chlorofluorocarbons (CFCs), methane, and nitrous oxide. These anthropogenic "greenhouse gases" play a critical role in controlling the earth's climate because they increase the infrared opacity of the atmosphere, causing the planetary surface to warm. Carbon dioxide is one of the major greenhouse gases, contributing about 60% of the total change in radiative forcing due to human perturbations. The release of CO_2 from fossil fuels and deforestation processes contributes approximately 6.3 ± 0.4 Pg C per year (Sabine et al. 2004a) to the atmosphere. Of this amount, approximately 3 Pg C of this so-called "anthropogenic CO_2" accumulates in the atmosphere and causes the atmospheric CO_2 levels to increase. The remaining 4 Pg C is sequestered by the terrestrial biosphere and global oceans. Where and how these two major sink regions vary in their uptake of CO_2 from year to year is the subject of much scientific research (Houghton et al. 2001).

The ocean plays a major role in the global carbon cycle as it is a vast reservoir of carbon, naturally exchanges carbon with the atmosphere, and consequently takes up a substantial portion of anthropogenic carbon from the atmosphere. Current estimates of anthropogenic CO_2 uptake by the oceans in the 1990s are about 1.9 ± 0.7 Pg C yr^{-1} (Figure 1; Sabine et al. 2004a). Future decisions on regulating emissions of greenhouse gases should be based on more accurate models of CO_2 sources and sinks that have been adequately tested against a well-designed system of measurements. The construction of a believable present-day carbon budget is essential for the reliable prediction of atmospheric CO_2 and global temperatures from available emission scenarios.

Our current understanding of the fate of the anthropogenic CO_2 released to the atmosphere is based on models; atmospheric observations of CO_2, carbon isotopes and small decreases in

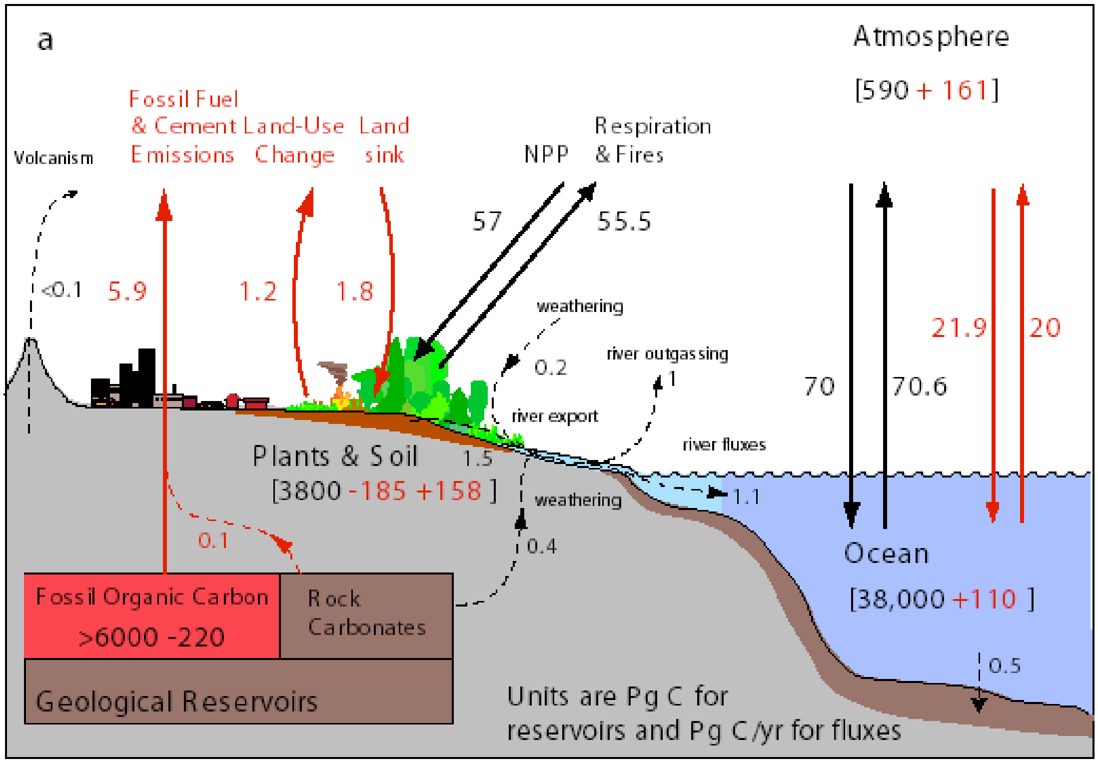

Figure 1. Cartoon of fluxes (arrows) and inventories (number in boxes) of the labile components of the global carbon system for the 1980ties. The red arrows are the perturbation fluxes resulting from emissions of anthropogenic CO_2 (Sabine et al. 2004a).

oxygen levels; terrestrial measurement of biomass inventories and primary productivity; and oceanic measurements of CO_2 inventories and fluxes between air and ocean. Less than a decade ago there were significant discrepancies between estimates leading to the popular notion of the "missing carbon sink" there now is a broad agreement that the "missing sink" is uptake by the terrestrial ecosystems based on disparate methods as summarized in Table 1. As the table indicates, our level of confidence in different observations ranges from a general good knowledge of the annual changes in some reservoirs, to highly uncertain estimates in others. Annual releases due to fossil fuel burning and cement production, and annual atmospheric CO_2 increases are the most constrained. Decadal changes in the ocean carbon inventory have recently been established with reasonable confidence. Changes in the terrestrial biosphere have been more difficult to pinpoint. From a variety of observations we now have a reasonable estimate of the partitioning of the fossil fuel carbon between reservoirs over the last two centuries with roughly 50% ending up in the ocean. The terrestrial systems released CO_2 over this same period. Over the last two decades, however, the terrestrial systems appear to have taken up CO_2 but the magnitude, cause, and particularly the longevity of this sink remains in great doubt. Significant efforts, such as those proposed in the North American Carbon Plan (NACP), are underway to directly determine CO_2 sources and sinks in the terrestrial system. However, in the foreseeable future the best approach for constraining the net terrestrial flux will be from the difference between atmospheric and oceanic observations and model calculations.

Table 1. Global inventory of anthropogenic CO_2 for the past 200 and 20 years

CO_2 Sources	1800-1994 [Pg C][a]		1980-1999 [Pg C][g]
Constrained sources and sinks			
(1) Emissions from fossil fuel and cement production	244 [(b)]	± 20	117±5
(2) Storage in the atmosphere	-165 [(c)]	± 4	-65±1
(3) Uptake and storage in the ocean	-118 [(d)]	± 19	-37±8
Inferred net terrestrial balance			
(4) Net terrestrial balance = [-(1)-(2)-(3)]	39	± 28	-15±9
Terrestrial balance			
(5) Emissions from land use change	100 to180[(e)]		24±12
(6) Terrestrial biosphere sink = [-(1)-(2)-(3)]-(5)	-61 to -141		-39±18

(From Sabine et al. 2004a)

The need for an integrated investigation of the carbon cycle has been well articulated in the US Carbon Cycle Science Plan (Sarmiento and Wofsy 1999). Through efforts of the Interagency Carbon Working Group and the Scientific Advisory Committee, science and implementation plans have been developed for subcomponents of the program including the NACP Science Plan, the NACP Implementation Strategy, the Ocean Carbon and Climate Change Implementation Strategy, and the Large Scale Carbon Observing Plan (LSCOP) (Bender et al. 2002). The LSCOP plan in particular focuses on the implementation and justification for sustained ocean observations. All of the plans address the central tenets of the Carbon Cycle Science Plan, which focuses on the "excess carbon", that is the carbon produced by fossil fuel burning and other activities of mankind releasing CO_2 such as land use change:

- Where has the excess carbon gone to over the last two centuries?
- Where will the excess carbon go to in the future?
- What processes are involved in sequestration of the excess carbon?
- Can the future sinks be managed and increased?

Because of the sensitivity of the global economy to terrestrial and oceanic ecosystems, and regional climate, the issue of carbon accounting transgresses the usual stakeholders of scientific information. Like emissions of pollutants, carbon emissions now have an economic value. A number $40 per metric ton carbon sequestered is often used in estimates. Improved constraints on the carbon sources and sinks can now be directly translated into a currency equivalent. For instance the global uptake of carbon by the ocean of about 1.6 Pg C yr^{-1} (Table 2) translates into a $64 billion service to the global economy. As shown in Table 2, the uncertainty in the ocean sink is significant translating into an uncertainty in the value of this commodity. Knowledge of the future sink strength of the ocean is thus a critical from scientific and economic perspective.

Table 2

Summary of estimated global CO_2 fluxes using different gas transfer velocities but the same ΔpCO_2 climatology

Parameterization	Uptake (Pg C/yr)
Wanninkhof, 1992	-1.6
Wanninkhof&McGillis, 1999	-1.9
Nightingale, 2000	-1.2
Liss and Merlivat, 1983	-1.0

All these values were obtained using the ΔpCO_2 climatology of Takahashi et al. 2002 and 41-year climatological 6-hour winds from the NCAR/NCEP reanalysis project. The divergence of values illustrates that besides determining seasonal ΔpCO_2 fields the gas transfer velocity needs to be better constrained.

The Sustained Ocean Component of the Carbon Cycle Science Plan The oceanic carbon-observing program addresses two important subcomponents of the determination of the fate of the excess CO_2 in the ocean:

- Determining oceanic carbon inventories and attributing the cause of the variations in inventories over time
- Quantifying the air-sea CO_2 fluxes and creating of seasonal flux maps

Ocean inventories

As a result of the measurements during the global CO_2 survey in the 1990s and improved methods of quantifying the anthropogenic CO_2 signal above the large natural background, we now have the first measurement based inventory of anthropogenic CO_2 in the ocean (Fig. 2). The excess CO_2 has been gridded at 1 degree spacing and 33 levels so it can be compared directly with model outputs. Anthropogenic CO_2 is unevenly distributed throughout the oceans. The highest vertically integrated concentrations are found in the North Atlantic, leading this ocean basin to store 23% of the global oceanic anthropogenic CO_2, despite covering only 15% of the global ocean area. The Southern Ocean south of 50ºS has very low vertically integrated anthropogenic CO_2 concentrations, containing only 9% of the global inventory. Approximately 60% of the total oceanic anthropogenic CO_2 inventory is stored in the Southern Hemisphere oceans, roughly in proportion to the larger ocean area of this hemisphere. Characteristic cross sections for the Atlantic, Indian and Pacific basins are shown in Figure 3. The distribution closely follows the known ventilation pathways of the ocean with deep penetration in the North Atlantic and storage of much of the carbon in the mid-latitude convergence zones. The total uptake over the past 200 years shown in Table 1 validates the model estimates. The total inventory is similar to models but the regional inventory is quite different suggesting that most of the models do not adequately capture the processes responsible for uptake at regional scales.

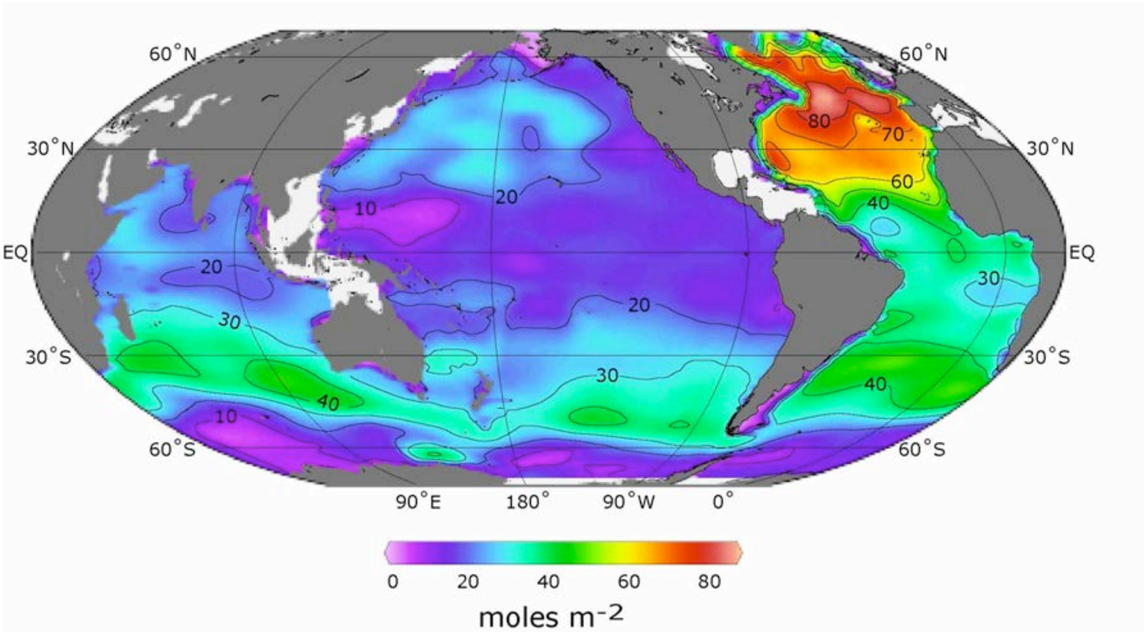

Figure 2. Column inventory of anthropogenic CO_2 in the ocean. High inventories are associated with Deep Water formation in the North Atlantic and Intermediate and Mode Water formation between 30°-50°S. Total inventory of shaded regions is 106±17 Pg C (after Sabine et al. 2004b).

Approximately 30% of the anthropogenic CO_2 is found shallower than 200 m and nearly 50% above 400 m depth (Fig. 3). The global average depth of the 5µmol kg^{-1} contour is approximately 1000 m. The majority of the anthropogenic CO_2 in the ocean is, therefore, confined to the thermocline, i.e., the region of the upper ocean, where temperature changes rapidly with depth. The deepest penetrations are associated with convergence zones at temperate latitudes where water that has recently been in contact with the atmosphere can be transported into the ocean interior. Low vertical penetration is generally observed in regions of upwelling, such as the Equatorial Pacific, where intermediate depth waters, low in anthropogenic CO_2, are transported toward the surface.

Decadal inventory changes

The measurement based total inventory of anthropogenic carbon in the ocean is a critical constraint for models and for our understanding of the role of the ocean in the sequestration of excess carbon. However, information on shorter timescales is essential to determine any feedbacks of oceanic carbon sequestration due to climate change, and to determine the role of natural variability on the oceanic carbon system. Therefore the COSP has started, in collaboration with NSF and NASA, a CLIVAR/CO_2 Repeat Hydrography Program. The main objective of the repeat hydrography component of the sustained ocean observing system for climate is to document long-term trends in carbon storage and transport in the global oceans. This program will provide composite global ocean observing system large-scale observations that include: 1) detailed basin-wide observations of CO_2, hydrography, and tracer measurements; and 2) data delivery and management. This repeat hydrography program will provide the critical and timely information needed for climate research and assessments, as well as long-term, climate quality, and global data sets.

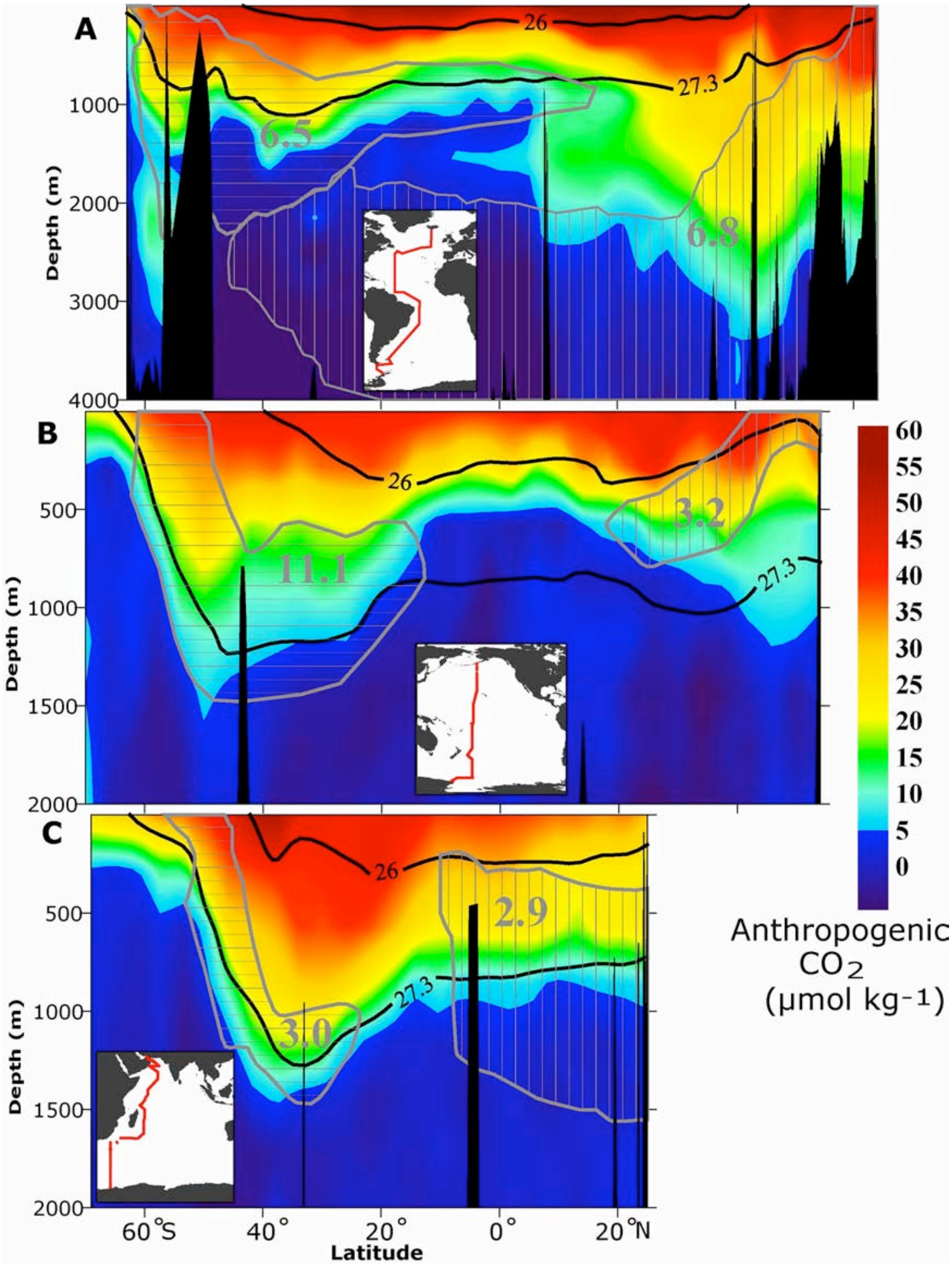

Figure 3. Representative sections of anthropogenic CO_2 (μmol kg^{-1}) from the Atlantic (a), Pacific (b) and Indian (c) oceans. Grey hatched regions and numbers indicate amount of anthropogenic carbon stored (Pg C) in the intermediate water masses The two heavy lines on each section give the characteristic potential density contours for the near surface water and intermediate water. Much of the penetration of anthropogenic carbon into the ocean follow isopycnal surfaces. From Sabine et al. 2004b.

The first three cruises of the Repeat Hydrography Program in 2003 marked the beginning of a large effort to document long-term trends in carbon storage and transport in the global oceans by reoccupying selected hydrographic sections on decadal time-scales. Early results from this work showed significant changes in oxygen and carbon dioxide and several other measurable parameters since the last global survey in the 1990s.

The initial highlights are that the ventilation pattern/circulation in the North Atlantic thermocline has changed based on a significant change in oxygen content. Also, we have been able to unambiguously determine an increase in total carbon content in the upper ocean over 6 to 10 years suggesting that uptake of anthropogenic CO_2 continues unabated and that we can detect anthropogenic carbon increase in the ocean on decadal timescales (Fig. 4). The data indicate significant increases of DIC in the shallow waters masses over the depth range of 100-1200m between the last occupation of these stations during the WOCE era (1993) and the 2003 occupation. For example, in the 0-1400m depth range, DIC increases on the order of 2-25 µmol kg^{-1} were observed over the 10 year period between the two cruises. In contrast, the DIC at depths >1500m showed very little change.

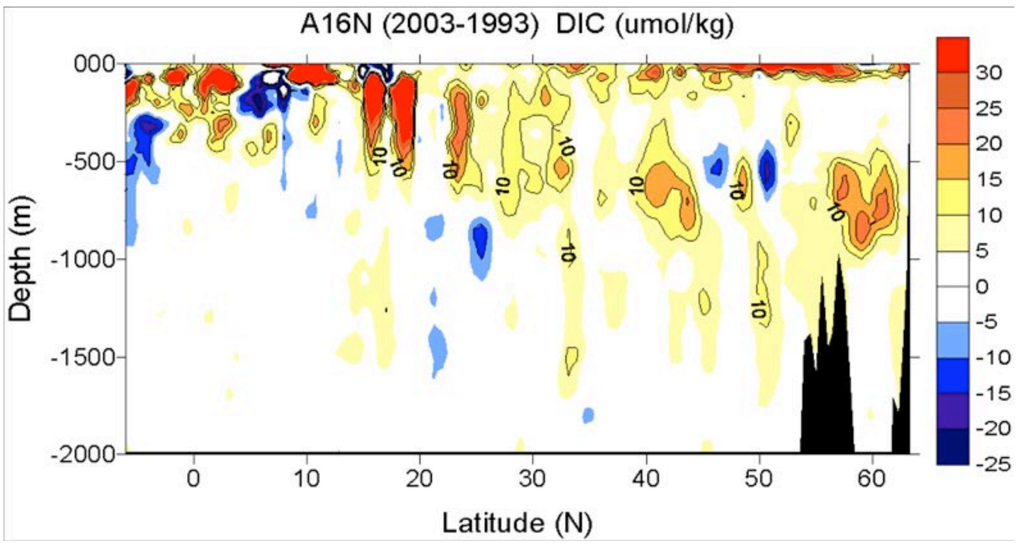

Figure 4. Difference of the dissolved inorganic carbon (DIC in µmol/kg) between 2003 and 1993 as a function of latitude and depth along the A16N cruise track in the North Atlantic.

Similar increases in DIC and AOU were also observed between 100-1200m for the A22/A20 cruises in the western North Atlantic. The increases of DIC in the Subtropical Mode waters (STMW) are greater than expected from invasion of anthropogenic CO_2 from the atmosphere and may be the result of decadal changes in the local circulation in the North Atlantic, and/or changes in new production and remineralization of organic matter along the flow path. As we continue to process the physical and biogeochemical data from these cruises, we should be able to attribute the large-scale changes in the carbon content of the Atlantic Ocean.

2.5.2 Atmosphere-Ocean CO_2 Fluxes

Changes in carbon inventory are the most robust means of assessing sources and sinks but for the oceans these methods are limited to changes over decadal timescales. On average the total dissolved inorganic carbon content (DIC) of the surface ocean increases by about 1.2 µmol kg^{-1}

per year or about 0.05 % over the background. While the accuracy of DIC measurements is about 2 µmol kg^{-1} making detection of the anthropogenic signal in principle possible on shorter time scales, the surface ocean DIC changes by 20 to 50 µmol kg^{-1} seasonally masking changes less than 5 to 10 µmol kg^{-1}.

To assess changes in exchanges between reservoirs on sub-decadal timescale we have to determine the fluxes. The fluxes can be determined from measuring the partial pressure differences of CO_2 between surface ocean and lower atmosphere, Δ pCO_2, and a quantity referred to as the gas transfer velocity that is related to physical forcing and often parameterized with wind speed. Thus, if ΔpCO_2 fields can be determined and used in combination with wind fields, regional fluxes can be obtained.

Creation of flux maps

This approach has been applied successfully using a global climatology of ΔpCO_2 painstakingly developed based on 40-years of ΔpCO_2 data from many investigators (Takahashi et al. 2002). Uptakes based on this climatology range from 1 to 1.9 Pg C yr^{-1} depending on the relationship between gas exchange velocity and wind speed (Table 2). This approach will be used to quantify regional fluxes on seasonal timescale. The implementation will require a significant increase in ΔpCO_2 observations, development of methods to interpolate ΔpCO_2 in time and space, and improvement of algorithms to quantify the gas transfer from wind or other relevant parameters, such as surface roughness, that can be directly observed from remote sensing.

Following a recommendation in the LSCOP plan a surface ocean flux observing system is being put in place with autonomous instrumentation on volunteer observing ships VOS, research ships, and buoys. The LSCOP plan lays out an observing strategy based on scaling analysis that involves sampling of the ocean roughly at 10 degree spacing and monthly intervals. By coordinating efforts with international and national partners this goal will be attainable in the next decade for the North Atlantic, North Pacific and Equatorial Pacific, particularly if we develop methods to increase time and space scales of observation through use of remotely sensed observations. The scheme of implementing such a system utilizing in situ and remotely sensed data is outlined in Figure 5.

Determining and attributing changes in ΔpCO_2

The approach of utilizing remote sensing, algorithms of ΔpCO_2 and gas exchange with remotely sensed products has been utilized in test beds in the Equatorial Pacific and Caribbean Sea (Figures 6 and 7). For the Equatorial Pacific work the algorithms are used in a retrospective fashion to determine the large variations in air-sea flux due to the ENSO cycle.

Limited time series records of surface water pCO_2 levels have shown that for much of the ocean the surface water pCO_2 rises roughly at the same rate as the atmospheric increase implying that the global air-sea flux remains the same. However, changes in the rate of increase are a sensitive indicator of changes in the uptake of the ocean and perturbations in the biogeochemical cycles. Using a historical database of ΔpCO_2 for the Equatorial Pacific Takahashi et al. (2003) determined significantly slower increases in the 80-ties than in the 90-ties that were attributed to a climatic re-organization in the North and Equatorial Pacific referred to as the Pacific Decadal Oscillation (PDO).

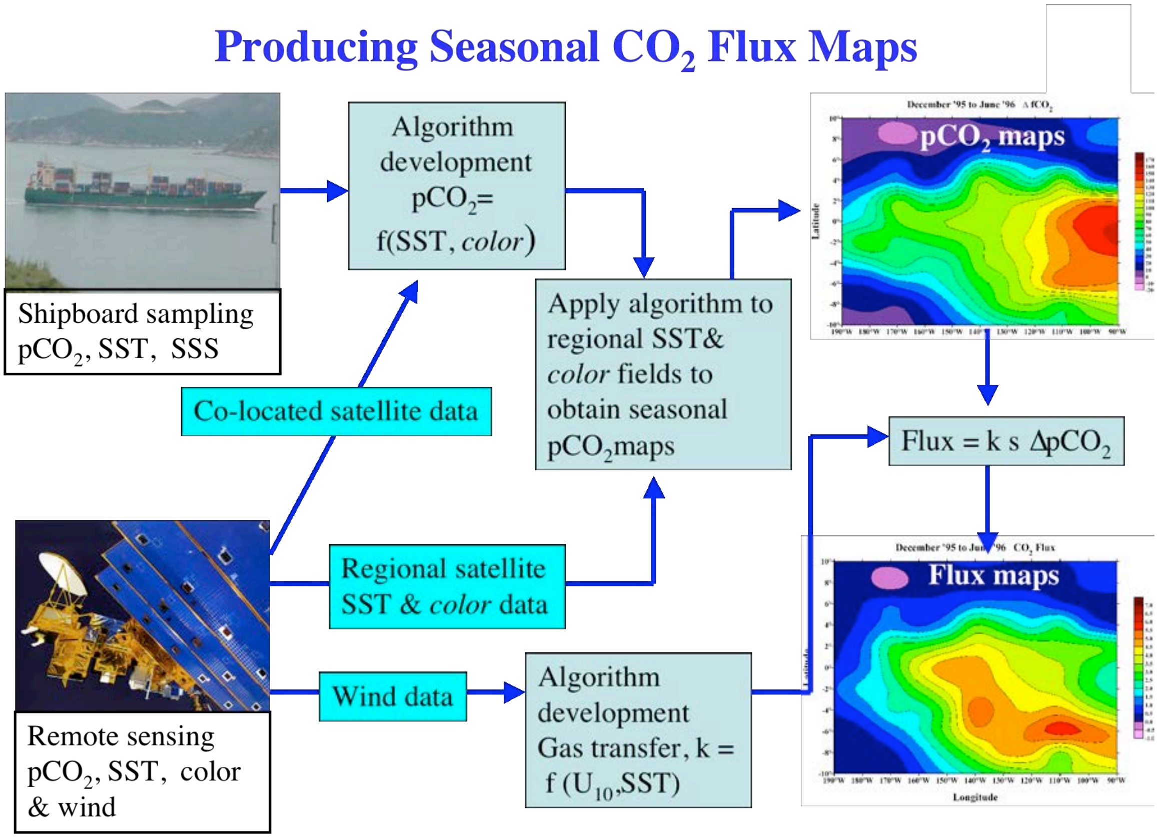

Figure 5. Flow diagram of data and procedures to produce pCO_2 flux maps.

Future plans and milestones

The observational efforts to detect changes in water column inventories and to attribute the causes, and the development of regional CO_2 flux maps are part of well documented and justified integrated carbon plans. The CLIVAR/CO_2 Repeat Hydrography Program has a series of cruises planned for the next decade that will yield sequential basin wide inventory changes for the Atlantic, Pacific, Southern and Indian oceans. The cruise sequence is listed in Table 3. NOAA/COSP has the lead on the cruises for A16S, A16N, P16N, P18 and I8. NOAA participants will perform DIC and pCO_2 measurements on all cruises. Operational Milestones are provided in Table 4.

Table 3. Sequence of CLIVAR/CO_2 Repeat Hydrography cruises in the oceans.

Schedule of US CLIVAR/CO2 Repeat Hydrography Lines (as of 10/04)					
Dates	**Cruise**	**Days**	**Ports**	**Year**	**Contact/Chief Scientist**
					Overall Coordinator: Jim Swift, SIO
6/19/03-7/10/03	A16N, leg 1	22	Reykjavik-Madeira	1	Bullister, NOAA/PMEL
7/15/03-8/11/03	A16N, leg 2	28	Madeira - Natal, Brazil	1	Bullister, NOAA/PMEL
9/15/03-10/13/03	A20	29	WHOI - Port Of Spain	1	Toole, WHOI
10/16/03-11/07/03	A22	21	Port Of Spain - WHOI	1	Joyce, WHOI
6/13/04-7/23/04	P2, leg 1	41	Yokohama-Honolulu	2	Robbins, SIO
7/26/04-8/26/04	P2, leg 2	32	Honolulu - San Diego	2	Swift, SIO
1/11/05-2/24-05	A16S	45	Punta Arenas-Fortaleza	3	Wanninkhof/Doney; NOAA/AOML/WHOI
1/8/05-2/18/05	P16S	40	Tahiti-Wellington	3	Sloyan/Swift, WHOI/SIO
2006	P16N	57	Tahiti-Alaska	4	Feely/Sabine, NOAA/PMEL
austral summer 07	S4P/P16S	25.5	Wellington-Perth	5	
austral summer 07		25.5	Wellington-Perth	5	
2008	P18	32	Punta Arenas-Easter Island	6	
2008		35	Easter Island- San Diego	6	
2008	I6S	42	Cape Town	6	
2009	I7N	47	Port Louis/Muscat	7	future planning
2009	I8S	38	Perth- Perth	7	future planning
2009	I9N	34	Perth- Calcutta	7	future planning
2010	I5	43	Perth - Durban	8	future planning
2010	A13.5	62	Abidjan-Cape Town	8	future planning
2011	A5	30	Tenerife-Miami	9	future planning
2011	A21/S04A	42	Punta Arenas-Cape Town	9	future planning
2012	A10	29	Rio de Janeiro-Cape Town	10	future planning
2012	A20/A22	29	Woods Hole-Port of Spain-Woods Hole	10	future planning

Years 1-6 are funded.

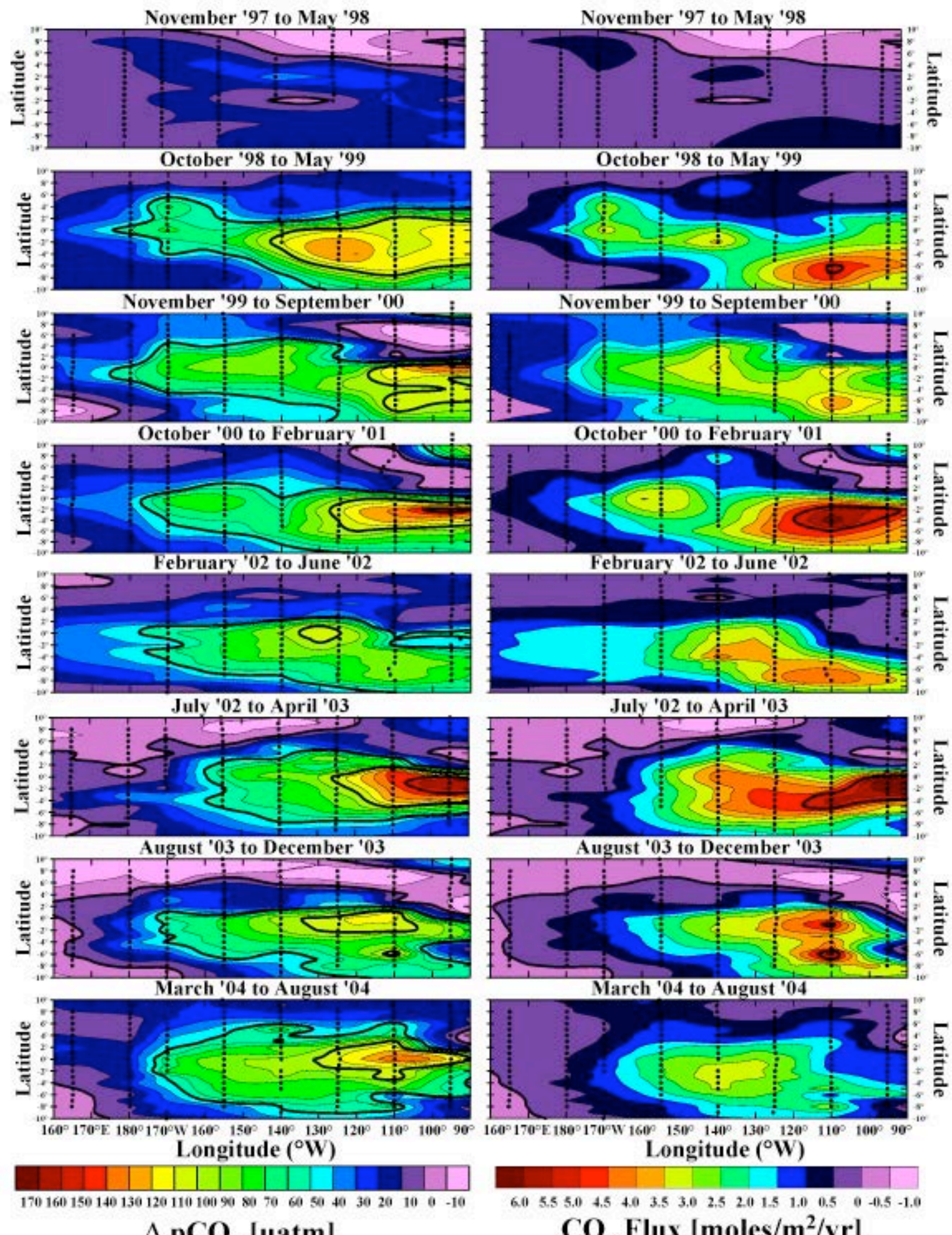

Figure 6. Time Series of ΔpCO_2 (left) and CO_2 fluxes in moles m^{-2} yr^{-1} in the equatorial Pacific from November 1997 thru August 2004. Low CO_2 fluxes are observed during both the strong 1997-98 El Nino and the weak 2002-3 event (Feely et al., in preparation).

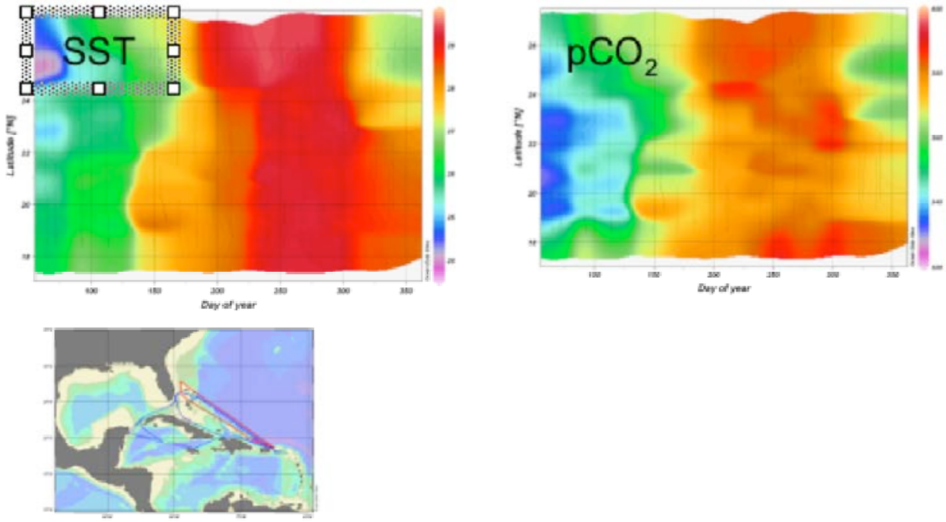

Figure 7. Production of pCO_2 maps in the Caribbean. Empirical algorithms are being developed with parameters that are measured at higher density/frequency (e.g. through remote sensing.). The close correspondence of temperature (left panel) trends and pCO_2 (right panel) along the cruise track (bottom) facilitates robust algorithms to extrapolate the pCO_2 to regional scales (Olsen et al. 2004).

Table 4. Operational milestones of the CLIVAR/CO_2 Repeat Hydrography Program

Summer 2003	Organize and complete the A16N cruise in the North Atlantic and provide leadership (chief scientist), CTD, oxygen, nutrient, total carbon and pCO_2 analysis.
Winter 2003/2004	Provide final CO_2, oxygen, CTD data to the repeat hydrography data center at Scripps.
Summer 2004	Analyze total inorganic carbon on the P2 cruise.
Winter 2004/2005	Provide final total CO_2 data to the repeat hydrography data center at Scripps.
Winter 2004/2005	Organize and complete the A16N cruise in the North Atlantic and provide leadership (chief scientist), CTD, Oxygen, nutrient, total carbon and pCO_2 analysis.
Winter 2004/2005	Analyze total inorganic carbon on the P16S cruise.
Spring 2006	Organize and complete the P16N cruise in the Pacific and provide leadership (chief scientist), CTD, Oxygen, nutrient, total carbon and pCO_2 analysis.

The COSP CO_2 flux map effort focuses on the ΔpCO_2 observations needed to create the seasonal maps. The implementation schedule is presented in Table 5 with the italicized text that will be proposed in FY 05. The effort is starting to incorporate time series on moorings that are critical to determine the higher frequency (< 1-month) temporal variability. Particularly in the coastal oceans and Equatorial Pacific large changes can occur on weekly timescales. The exact balance and number of fixed pCO_2 observing sites vs. ship based (moving) observing platform has not been firmly established. Analysis of the results of the initial surface pCO_2 observing system will be used to optimize spacing, frequency, and mix of observing methods. Optimizing the observing system requires inclusion of measurements of biogeochemical and physical parameters that influence pCO_2 as well in order to investigate extrapolation routines. The added benefit will be that these parameters yield mechanistic information that can be used in prognostic models and interpolation schemes utilizing satellite data. An to end-to end iterative effort starting from observations to interpretation and analysis feeding into improved observing system design and assessing the state of the ocean carbon cycle is critical at this point and attainable within national and international frameworks.

Table 5. Operational milestones pCO_2 project

Fall 2003	Complete installation of pCO_2 system on Skogafoss (Iceland-Norfolk) line AX2
Spring 2004	Complete installation of pCO_2 system and TSG system on Columbus Waikato (Long Beach -New Zealand) line PX13
Summer 2004	Complete installation of pCO_2 system on Oleander (Bermuda-Norfolk)
Winter 2004/2005	Complete standardized data reduction and quality control scheme for all ships Start submitted data to LDEO on routine basis for contextual QC.
Spring 2005	Complete installation of pCO_2 system on Sealand Express (Iceland-Norfolk)
Fall 2005	Complete installation of pCO_2 system on 24N line (Miami-Gibraltar)
Winter 2005/2006	*Install system on VOS ship in North Pacific*
Spring 2006	*Install system on NOAA survey ships in Gulf of Mexico (Gunther) and Bering Sea (Rainer)*

Data for all projects will be distributed to the community at large through a Live Access Server within two years after collecting the data.

National and International linkages

The COSP carbon program is an integral part of national and international programs in carbon cycle research. NOAA's contribution is unique as it is the only program that has the sustained observational effort necessary to constrain sources and sinks and provide input for prognostic models to predict future trends. The international connection for the repeat hydrography effort is through WCRP/CLIVAR and the IGBP/IMBER programs. The former is focused on the physical aspects of climate variability while the latter is geared to the ecological and biogeochemical components. The flux map effort is connected to the SOLAS effort theme 3: Air-Sea Flux of CO_2 and Other Long-Lived Radiatively-Active Gases. International coordination for both aspects of CO_2 COSP will occur through the International Ocean Carbon Co-ordination Project (IOCCP). International ties between the ocean carbon programs and the atmospheric, terrestrial, and human dimension carbon cycle research are provided through the IGBP/WCRP/IHDP Global Carbon Project (GCP).

At a national level the CO_2 COSP effort is part of the US Carbon Cycle Science Plan. Its critical role in the overall US ocean science effort is outlined in the multi-agency implementation plan, the Ocean Carbon and Climate Change plan (Doney 2004). Information about the programs linked to, or a part of, COSP-CO_2 can be found in Table 6.

Table 6. Web sites of the CO_2/COSP program and program partners:

Data sites for pCO_2 data from ships:	
AOML	http://www.aoml.noaa.gov/ocd/gcc
PMEL	http://www.pmel.noaa.gov/uwpco2/
LDEO	http://www.ldeo.columbia.edu/res/pi/CO2/
Program sites	
CLIVAR:	Climate Variability and Predictability: www.clivar.org
SOLAS:	Surface-Ocean Lower Atmosphere Study: www.uea.ac.uk/env/solas/
IOCCP:	International Ocean Carbon Coordination Project www.ioc.unesco.org/ioccp
IGBP:	International Geosphere-Biosphere Project: www.igbp.kva.se/cgi-bin/php/frameset.php
IMBER:	Integrated Marine Biogeochemistry and Ecosystem Research http://www.igbp.kva.se/cgibin/php/
WCRP:	World Climate Research Program: www.wmo.ch/web/wcrp/wcrp-home.html
GCP:	Global Carbon Project: http://www.globalcarbonproject.org/

References

Bender, M., S. Doney, R.A. Feely, I.Y. Fung, N. Gruber, D.E. Harrison, R. Keeling, J.K. Moore, J. Sarmiento, E. Sarachik, B. Stephens, T. Takahashi, P.P. Tans, and R. Wanninkhof, 2002: A large Scale Carbon Observing plan: In Situ Oceans and Atmosphere (LSCOP), pp. 201, Nat. Tech.Info. Services, Springfield.

Doney, S., 2004: The Ocean Carbon and Climate Change Report, UCAR, Boulder.

Feely, R.A., J. Boutin, C. E. Cosca, Y. Dandonneau, J. Etcheto, H. Y. Inoue, M.Ishii, C. Le Quere, D. Mackey, M. McPhaden, N. Metzl, A. Poisson, and R. Wanninkhof., 2002: Seasonal and interannual variability of CO_2 in the Equatorial Pacific. *Deep Sea Res. II*, **49**, 2443-2469.

Feely, RA., C.L. Sabine, T. Ono, A. Murata, R. Key, C. Winn. M. Lamb, and D. Greeley, 2004: CLIVAR/CO_2 Repeat Hydrography Program: Initial carbon results from the North Pacific Ocean. *Eos Transactions, AGU,* **85**(47), *Fall Meeting Supplement OS24B-02*.

Houghton, J.T., Y. Ding, D.J. Griggs, M. Noguer, P.J.v.d. Linden, and D. Xiaosu, Climate Change 2001: The Scientific Basis: Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), pp. 944, Cambridge University Press, Cambridge, England.

Sabine, C.L., M. Heimann, P. Artaxo, D. Bakker, C.-T.A. Chen, C.B. Field, N. Gruber, C. LeQuéré, R.G. Prinn, J.E. Richey, P.R. Lankao, J. Sathaye, and R. Valentini, 2004a: Chapter 2, Current status and past trends of the global carbon cycle. In SCOPE 62, *The Global Carbon Cycle: Integrating Humans, Climate, and the Natural World*, C.B. Field and M.R. Raupach, Eds., Island Press, Washington D.C., 17–44.

Sabine, C.L., R.A. Feely, N. Gruber, R.M. Key, K. Lee, J.L. Bullister, R. Wanninkhof, C.S. Wong, D.W.R. Wallace, B. Tilbrook, F.J. Millero, T.-H. Peng, A. Kozyr, T. Ono, and A.F. Rios, 2004b: The oceanic sink for anthropogenic CO_2. *Science*, **305**, 367–371.

Sarmiento, J.L., and S.C. Wofsy, 1999: A U. S. carbon cycle plan, pp. 69, UCAR, Boulder.

Takahashi, T., S.G. Sutherland, C. Sweeney, A.P. Poisson, N. Metzl, B. Tilbrook, N.R. Bates, R. Wanninkhof, R.A. Feely, C.L. Sabine, J. Olafsson, and Y. Nojjiri, 2002: Global sea-air CO_2 flux based on climatological surface ocean pCO_2, and seasonal biological and temperature effects, *Deep-Sea Res. II*, **49**, 1601-1622, 2002.

Takahashi, T., S.C. Sutherland, R.A. Feely, and C.E. Cosca., 2003: Decadal variation of surface water pCO_2 in the Western and Central Equatorial Pacific. *Science*, **302**, 852-856.

2.6 SURFACE CURRENT OBSERVATIONS FOR CLIMATE RESEARCH

by Peter Niiler[1] and Nikolai Maximenko[2]

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[2]International Pacific Research Center, Honolulu, Hawaii

Background

A principal scientific objective of the "*Global Drifter Program*" of the NOAA Ocean Climate Observing System is to produce instrumental data records of the near surface velocity of the global oceans (Niiler 2001). The velocity is derived from observing the motion of Argos satellite located drifting buoys that are drogued to 15m depth. Velocity is computed from the six hourly displacements of drifters and these observations are corrected for "slip" of the drogue through water due to forces of wind (and waves) on the surface float and the tether that connects the float to the drogue (Pazan and Niiler 2001). The *Global Drifter Data* Center at the Atlantic Oceanographic and Meteorological Laboratory of NOAA produces and maintains data files from all drifters (8049 up to July 2004) and a *Bibliography* of the research papers which have used these data for understanding ocean circulation physics:
(http://www.aoml.noaa.gov/phod/dac/drifter_bibliography.html).

From 1992 to 2002 enough drifter velocity data was accumulated that a 10-year time-mean circulation could be computed for about 80% of the surface of the globe. These time mean circulation data, together with wind and satellite altimeter observations, were used to compute the absolute sea level map of the world oceans for the 2003 Climate Observation Report (Niiler et al. 2003). This sea level distribution, or surface dynamic topography, has been assimilated in a number of Ocean General Circulation Models (OGCMs) for climate studies. For the 2004 Report we compute and discuss the seasonal mean and El Niño and La Niña anomaly circulation patterns for the tropical Pacific. These circulation data are being used to verify the ocean surface current patterns of the OGCMs, which are employed in the prediction of ENSO.

Tropical Pacific Seasonal Currents

Modern drifter observations in the ocean current systems of the tropical Pacific began in 1978 (Hansen and Paul 1984). Since 1988, an array of over 200 drifters has been maintained within 20 degrees latitude of the equator. The objective was to measure the basin scale seasonal currents so the circulation anomalies during El Niño and La Niña could be determined. On Figure 1a the mean of the 15m depth velocity is computed from the ensemble of 6 hourly observations within 2x5 degree boxes. All the major known current systems of the tropical Pacific are displayed with an accuracy and degree of certainty that has not been possible from any other data source (Niiler et al. 2004).

As an aid to sailing mariners, geographers have named the east-west components of the surface currents on Figure 1a, from south to north, as: the South Equatorial Current, the North Equatorial Countercurrent and the North Equatorial Current. Just as important for climate studies, however, are the north-south components, whose strength and patterns were not known before drifter velocity observations. These poleward flows are driven directly by the Trade Winds (Ralph and Niiler 1999) and they are warmed by solar heating as they move away from the cold, up welled zone on the equator. They then give back their thermal energy to the atmosphere in the center of the Trades. This pattern of heat transfer can be seen by noting on Figure 1a the angle the currents make with the SST distribution that underlies the circulation vectors. If the vector points toward warm water the water parcels absorb heat from the atmosphere, toward cold water if the water parcels give up heat to the atmosphere.

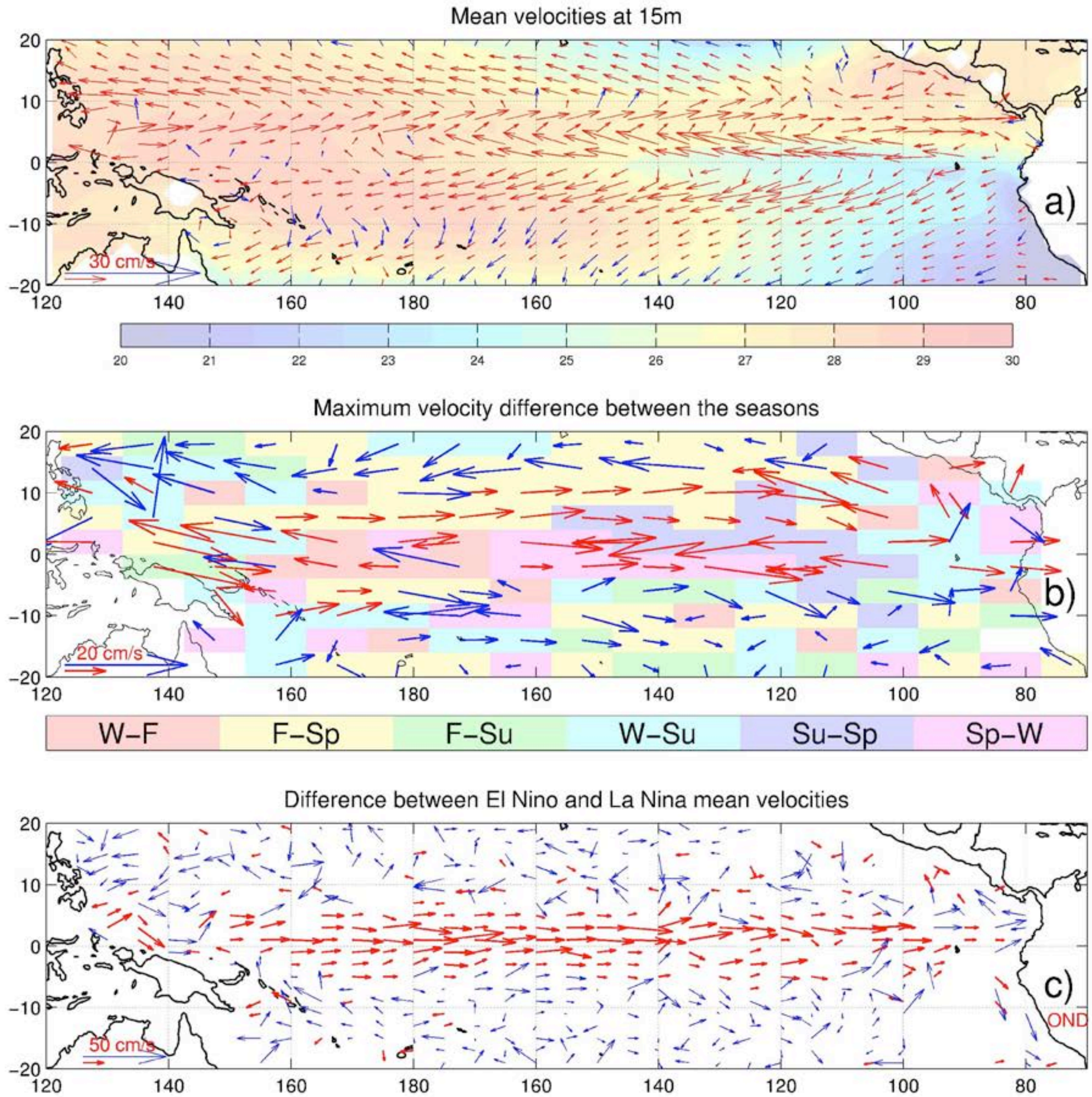

Figure 1. *(a)* Mean current velocities at 15 m depth derived from Lagrangian drifters (vectors) overlaid on mean COADS SST (colors). *(b)* Pairs of boreal seasons (colors), between which the velocity demonstrate the largest differences (vectors). *(c)* Velocity differences between the October-December averages over three El Niño (1991, 1997 and 2002) and three La Niña (1988, 1995 and 1999) events. Vectors that are smaller than 5, 15 and 20 cm/s, correspondingly, are shown on panels *(a)*, *(b)* and *(c)* in blue color.

The summary of the seasonal changes on Figure 1b display that the largest changes are zonally oriented. These occur in the South Equatorial Current between January-March (W) and April-June (Sp) periods and North Equatorial Countercurrent between April-June (Sp) and October-December (F) periods. A more complete description and the dynamical causes for these seasonal changes have not been fully complete, but could be in light of these robust data sets. Changes of zonal currents in the tropics are related most strongly to the wind stress curl changes. A central CLIVAR modeling objective is to understand the seasonal changes of ocean circulation and these data are vital to a verification of this modeling activity.

The El Niño – La Niña Anomalies

The seasons of October-December (F) 1991, 1997 and 2002 characterize the mature El Niño seasons and in 1988, 1995 and 1999 mature La Niña seasons occur during the same months. The largest differences of the ensemble averages of the October-December seasonal velocities for the mature El Niño and mature La Niña years on Figure 1c occur across the entire 5 degree latitude band of the equator. These equatorial La Niña current can be are over 100 cm/sec more to the west than El Niño currents. These changes can be caused directly by reversal or collapse of the Southeast Trade Winds (Ralph et al. 1997) in the western Pacific or equatorial Kelvin waves that are a result of these wind changes. Kelvin waves travel eastward over the entire extent of the equatorial basin so current changes can be remotely forces as well. These anomalous zonal currents are thought to cause anomalous movements of warm water across the equatorial basin (Picaut et al. 2001). Locally these velocity changes were observed with equatorial moorings (Wang and McPhaden 2000), but broad latitude and longitude extent of the changes of equatorial circulation due to the Pacific ENSO were not known before basin scale drifter velocity observations became available.

Future of Circulation Observations

Observations of the movement of drogued drifters will continue within the *Global Drifter Program*. By June 2005 the global array of drifters will be increased to, and maintained for the foreseeable future at, 1250 elements. Together with satellite altimeter and wind observations, these drifter data will continue to provide valuable data sets for the study of the changing circulation patterns of the global near surface circulation.

References

Hansen, D. V., and Paul C. A., 1984: Genesis and effects of long waves in the equatorial Pacific. *J. Geophys. Res.*, **89**, 10431–10440.

Niiler, P., 2001: The World Ocean Surface Circulation. Chapter 4.1 in "*Ocean Circulation and Climate- Observing and Modeling the Global Ocean*", *Ed*. by J. Church, G. Siedler and J. Gould, Academic Press, London. 715pp.

Niiler, P.P., N.A. Maximenko, and J.C. McWilliams, 2003: Dynamically balanced absolute sea level of the global ocean derived from near-surface velocity observations. *Geophys. Res. Lett.,* **30** (22), 2164, doi:10.1029/2003GL018628.

Niiler, P., D.-K. Lee and J.E. Moisan, 2004: "The mechanisms of El Nino SST evolution in the tropical Pacific". *J. Mar. Res*., **62**(6): 741-760.

Picaut, J.M., C. Loulalen, C. Menkes, T. Delcroix, M.J. McPhaden, 1996: "Mechanism of the zonal displacements of the Pacific Warm Pool: Implications for ENSO". *Science,* **274**: 1486-1489.

Pazan, S.E., P.P. Niiler, 2001: "Recovery of near-surface velocity from undrogued drifters". *J. Oc. Atm. Tech.,* **18**(3): 476-489.

Ralph, E.A., K.N. Bi and P.P. Niiler, 1997: "A Lagrangian description of the western equatorial Pacific response to the wind burst of December 1992: heat advection in the warm pool." *J. Climate,* **10**(7): 1706-1721.

Ralph, E.A., P.P. Niiler, 1999: "Wind driven currents in the tropical Pacific". *J. Phys. Oceanogr.,* **29**(9): 2121-2129.

Wang, W. and M.J. McPhaden, 2000: “The surface-layer heat balance in the equatorial Pacific Ocean. Part II: Interannual variability”, *J. Phys. Oceanogr*., **30**(11): 2989-3008.

2.7 AIR-SEA EXCHANGE OF HEAT, FRESH WATER, MOMENTUM

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Abstract

Exchanges of heat, freshwater, and momentum between the ocean and the atmosphere play a key role in determining the climate of the earth and its variability. Our present knowledge of these fluxes is poor, which is evident when high quality time series observations of these air-sea fluxes from a surface mooring are compared against climatological values and against fluxes from models (Fig. 1). The NOAA Climate Observation Program is addressing the need for accurate observations of the exchange of heat, freshwater, and momentum between the ocean and atmosphere by working toward a global array of such high quality surface moorings, known as Ocean Reference Stations. These moorings, together with Volunteer Observing Ships (VOS), will provide the data critical to developing improved maps of the air-sea fluxes; a pilot project has produced improved maps in the Atlantic (Fig. 2). In 2004 progress was made when a third Ocean Reference Station was deployed and work to produce global maps of fluxes began.

The ocean has a distinct role in governing the variability of the earth's atmosphere, land, and ocean. It carries heat poleward from the equatorial regions where the sun shines most strongly. It releases heat and moisture into the lower atmosphere to drive weather patterns, storms and hurricanes, and longer period climate variability that includes the El Niño-Southern Oscillation. The ocean, which covers 70% of the earth, can store 1100 times more heat than the atmosphere due to the larger heat capacity and density of water. The upper 2.5 m of the ocean, when warmed 1°C, thus stores an amount of heat that would raise the entire column of air above it 1°C as well. As a consequence, an anomalously warm region of the ocean has the potential of releasing considerable energy to the atmosphere above and thus driving the weather on short time scales and, if the release of heat persists, altering climate. Energy to drive the atmosphere is also transferred from the ocean by evaporation, and the ocean's role as a source of moisture is critical to understanding weather and climate as well as the global cycle of freshwater. The ocean stores 97% of the earth's water and plays a major role in the global cycle of freshwater that heavily impacts agriculture and human activities; 86% of the evaporation and 78% of the precipitation occur over the ocean. The third exchange between the ocean and atmosphere of interest is that of momentum, the transfer of which determines how the surface winds drive the ocean currents and how the ocean surface provides drag to the atmosphere. The shallow, wind-driven ocean currents are of particular interest because of their role in transporting the surface waters that are warmed and cooled by exchanges with the atmosphere.

One goal of the NOAA Climate Observation Program is to collect long, accurate time series of the air-sea exchanges of heat, freshwater, and momentum at key locations around the world's ocean, aiming toward 16 such sites by 2006 and building to 51 of these sites, known as ocean reference stations. A second goal is to use these accurate observations together with surface meteorological and air-sea flux observations from Volunteer Observing Ships (VOS) to produce daily maps of the air-sea fluxes over the global ocean.

What are the reasons for these goals? First, these maps will show where and how much heat and freshwater are exchanged between the ocean and atmosphere, show how the winds drive the surface currents, and thus quantify the exchanges between the ocean and atmosphere that play important roles in weather, climate, and the global water cycle. With this information we would be able to document the impact on climate of anomalous heat and freshwater loss to the atmosphere by a region of the ocean and to search for the connections across the globe between rainfall and temperature anomalies on land and where and how much heat and freshwater was released from the ocean. At present, due to sparse observations and large uncertainties in the present estimates of the air-sea exchanges, we cannot (across time scales that range from hurricanes to decadal) determine across the globe whether or not anomalous ocean conditions cause or result from anomalous atmospheric conditions. We look to new, accurate flux maps with good temporal and spatial resolution to show where and when change in the ocean leads or lags change in the atmosphere and leads to climate variability on land; this information is key to improved prediction of climate variability.

Second, the flux maps will provide the surface forcing for numerical ocean models used to investigate oceanic variability and the ocean's role in climate; such models are now forced using climatological surface fluxes or other fields of fluxes that have large uncertainties, which in turn add uncertainty to the results of the ocean modeling. The ocean, as pointed out above, has a large ability to store heat. It also has a three-dimensional circulation that is much slower than that of the atmosphere, with the deep waters being exposed to the atmosphere only every 100 years or so. Accurate surface forcing is needed as we look to improve the ability of these ocean models to properly simulate the mixing, overturning, and decadal and longer term transport, storage, and release back to the atmosphere of heat and freshwater.

Third, atmospheric models are now forced at the sea surface with sea surface temperature fields and use their own parameterizations to develop surface fluxes of heat, fresh water, and momentum. By comparison with data from the ocean reference stations that are being deployed by the NOAA Climate Observation Program, the air-sea fluxes in these atmospheric models are found often to have large differences from the actual fluxes. This needs to be addressed because many ocean modelers use the atmospheric model flux fields as their surface forcing and also because the role of the ocean in weather and climate variability in these atmospheric models and in climate models that use the same or similar code may not be well represented. Moreover, accurate fields of the surface exchanges are required for evaluation of the ability of coupled ocean-atmosphere climate models, such as those used in IPCC (Intergovernmental Panel on Climate Change) predictions of future climate change, to simulate present day climate. Such evaluations are necessary if we are to have confidence in the future climate change scenarios predicted by these models.

Fourth, surface flux fields are widely used in observational studies by the oceanographic research community studying large scale ocean circulation and its impact on climate, in synthesis with sub-surface measurements, to determine the transports of water and heat across basin scale ocean sections. In particular, the fields of momentum flux are required to determine the wind-driven or Ekman component of the ocean transport, and the fields of heat, fresh water, and momentum flux are needed to provide surface forcing conditions for analyses of hydrographic (ocean temperature and salinity) data which use inverse techniques to estimate the transports of water with different, characteristic temperatures and salinities.

Finally, the accurate time series from the ocean reference stations serve several key functions: 1) provide accurate long time series of known accuracy at key locations which are of high value as records of variability and change in the coupling of the ocean and atmosphere, 2) help to calibrate and validate remote sensing, 3) provide the ability to examine the realism of the air-sea fluxes in numerical weather and climate models, 4) provide accurate records of the surface forcing to be used in studies of oceanic response to and interaction with the atmosphere, and 5) provide critical points across the ocean basins to use as standards and anchor sites to develop the global air-sea flux fields through the synthesis of data from the diverse sources needed to achieve daily, global fields.

The context for this element of the Climate Observation Program can be illustrated by Figure 1, which compares time series of air-sea fluxes from a surface mooring of the type being deployed at the Ocean Reference Stations. Monthly means of wind stress (momentum flux) and net heat flux from two state of the art numerical weather models, one from the National Center for Environmental Prediction (NCEP) and one from the European Centre for Medium Range Weather Forecasts (ECMWF) are plotted against the monthly means from the buoy and monthly means from flux fields developed at Southampton Oceanography Centre (SOC) from VOS observations. Note not only how large the differences in net heat flux are between the NCEP and ECMWF monthly means and those of the buoy but also that the NCEP heat fluxes have the wrong sign during June and July. Indeed the ECMWF model indicates through the year about 50 W m^{-2} less heat into the ocean than observed, and the NCEP has a negative bias of about 100 W m^{-2}. Errors of this size have been seen at other sites. Yet, recent ongoing efforts to understand the dynamics of the upper ocean and the ocean's role in climate, such as the World Ocean

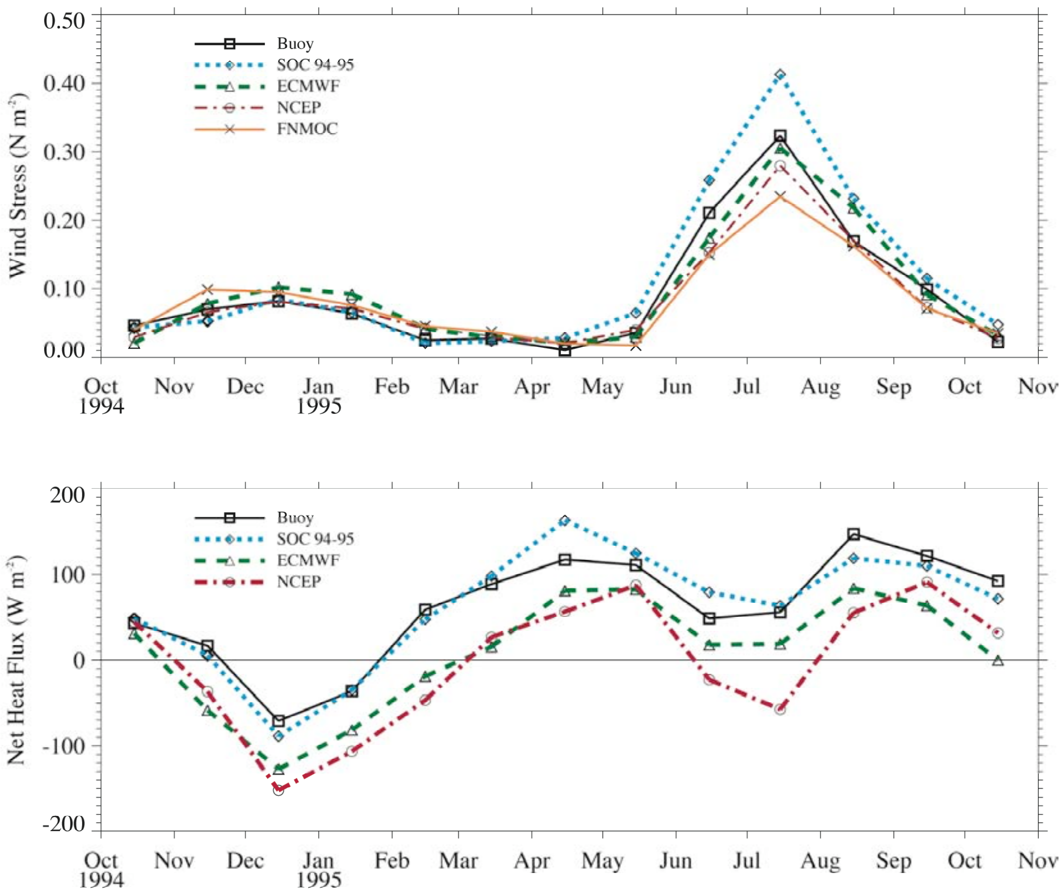

Figure 1. Monthly mean wind stress (momentum exchange) (upper) and net heat flux (positive into the ocean) at a mooring deployed in the northern Arabian Sea for one year.

Circulation Experiment (WOCE), the Tropical Ocean-Global Atmosphere Program (TOGA), and the Climate Variability (CLIVAR) Program have identified the need for monthly mean net heat flux estimates to be available with accuracy of better than 10 W m^{-2}. Consistent accuracy targets for precipitation and wind stress are 0.01 mm hr^{-1} and .01 N m^{-2}, respectively. These lead to target accuracies for sea and air temperature of 0.1°C, for wind speed of better than 5%, for relative humidity of better than 3%, for incoming shortwave of better than 10 W m^{-2}, and for incoming longwave of better than 5 W m^{-2}. Some of the errors cancel, and these target accuracies typically allow the 10 W m^{-2} goal in the net heat flux to be met at present. A more challenging objective for the future of this effort motivated by the desire to better understand long term climate change would be to resolve mean values of the net heat flux well enough to be able to sense shifts in the surface radiation budget associated with changes in greenhouse gases and aerosols, thus requiring the reduction of errors in the net heat flux to approximately 4 W m^{-2}.

This element of the Climate Observation Program is in its initial phase. The goals are to deploy and maintain the Ocean Reference Stations and, using these time series as the critical accurate reference observations, to produce global maps of the air-sea fluxes of heat, freshwater, and momentum. The challenge is a significant one, requiring cruises to deploy and maintain each Ocean Reference Station once per year, requiring dedicated on the land and at sea calibration efforts to obtain the sought after accuracies in these unattended surface moorings, and also requiring well-instrumented VOS that cross the ocean basins to obtain essential complementary information about the spatial variability in the surface meteorological and air-sea fluxes and in the differences between these observed fields and the model and remotely-sensed fields used to synthesize global maps.

At present, one Ocean Reference Station is operating under the stratus clouds off the coast of northern Chile (20°S, 85°W), one in the tropical western North Atlantic (15°N, 51°W), and one north of Hawaii (23°N, 158°W). Near term plans are to complement the sensors on four existing TAO-TRITON sites in the equatorial Pacific to qualify them as Ocean Reference Stations. A pilot project has been conducted, using past buoy, model, and satellite data, to test and develop the methodology of producing air-sea fluxes fields on basin scales. Figure 2 shows a comparison of the long-term (1988 to 1997) mean sum of the latent and sensible heat flux components from a new flux product developed by L. Yu at Woods Hole Oceanographic Institution (WHOI) with the SOC climatology and mean fields from ECMWF and NCEP. The WHOI product produced by data assimilation methodology compared the best against the buoy data available from this period. This pilot project affirmed the approach being taken, and Yu is now developing global flux fields.

As yet, the observations made under this component are sparse. The data are withheld and not used in preparation of model fields by the operational weather and climate modeling centers. This is done so that the Ocean Reference Station time series can serve as an independent assessment of model performance and thus to stimulate the ongoing dialog that will motivate improvements to these models. The sparse Ocean Reference Stations are building evidence of biases and errors in the models at the few sites now occupied. A milestone for the project will be when the deployed buoys cover many of the critical weather and climate regimes of the global ocean and thus can be used to identify and fix problems in these models common to all sites as well as to identify issues unique to specific regimes.

With sufficient funding and with new observatory technology to be developed under the Ocean Observatory Initiative of the National Science Foundation, the deployment of the planned numbers of Ocean Reference Stations is entirely feasible. Each site will require a regular, once per year commitment of ship time and of on land and at sea calibration. Significant milestones will be achieved when the Ocean Reference Stations in each basin provide time series from the meteorological and air-sea regimes characteristic of those basins. When that is accomplished, the time series from these moorings will provide compelling evidence to drive the process of partnering with the atmospheric modeling community to improve the realism of those models and to produce basin scale flux fields of the desired accuracy.

Linkage to the climate and weather modeling communities is being actively pursued, as are ties to research programs seeking long time series. In part this is done through dialog with the NSF Observatory Initiative. It is also done through the Partnership for Ocean Global Observations (POGO), through participation in planning for the Global Earth Observing System, and through participation in the World Climate Research Program Working Group on Surface Fluxes (WGSF). The WGSF especially supports the ties between the Ocean Reference Stations and the international climate and weather modeling efforts and the development of improved accuracies in surface meteorological and air-sea flux measurements. The addition of attitude (pitch, roll, heave, and mean tilts) measurements and of turbulent flux capabilities to the Ocean Reference Stations are identified as next steps to be taken that would determine the comparability of the radiation observations from the buoys with the land based observations of the Surface Radiation Network and would improve flux accuracies in the low and high wind speeds where the bulk formulae methods have remaining uncertainties.

These time series sites should be accompanied by accurate measurements from the ships that deploy and recover the mooring to provide in-the-field calibration of the moored time series. They should also be accompanied by improved measurements from selected VOS to obtain direct observations of the spatial variability of the surface meteorological and air-sea flux fields. Practical considerations require the implementation of a hierarchy of VOS observations systems. The state of the art instrumentation of two to three long cross-basin ship lines (with preference for the high resolution XBTs lines) in each ocean basin will provide estimates of high absolute accuracy. A few hundred ships recruited under the VOSClim program will have improved instrumentation and sufficient documentation to allow any measurement biases to be quantified and corrected through comparison with the Ocean Reference Stations. The majority of the international VOS fleet (some six thousand ships) will continue to provide basic observations over large areas of the world oceans which must be verified against the higher quality observations from the specially chosen ships and buoys. These observing efforts should be accompanied by quality control efforts, by close interaction with the atmospheric modeling centers and those working up remotely-sensed fields at the ocean surface, and by production of global fields of the air-sea exchanges of heat, freshwater, and momentum that are made available to the research and operational communities.

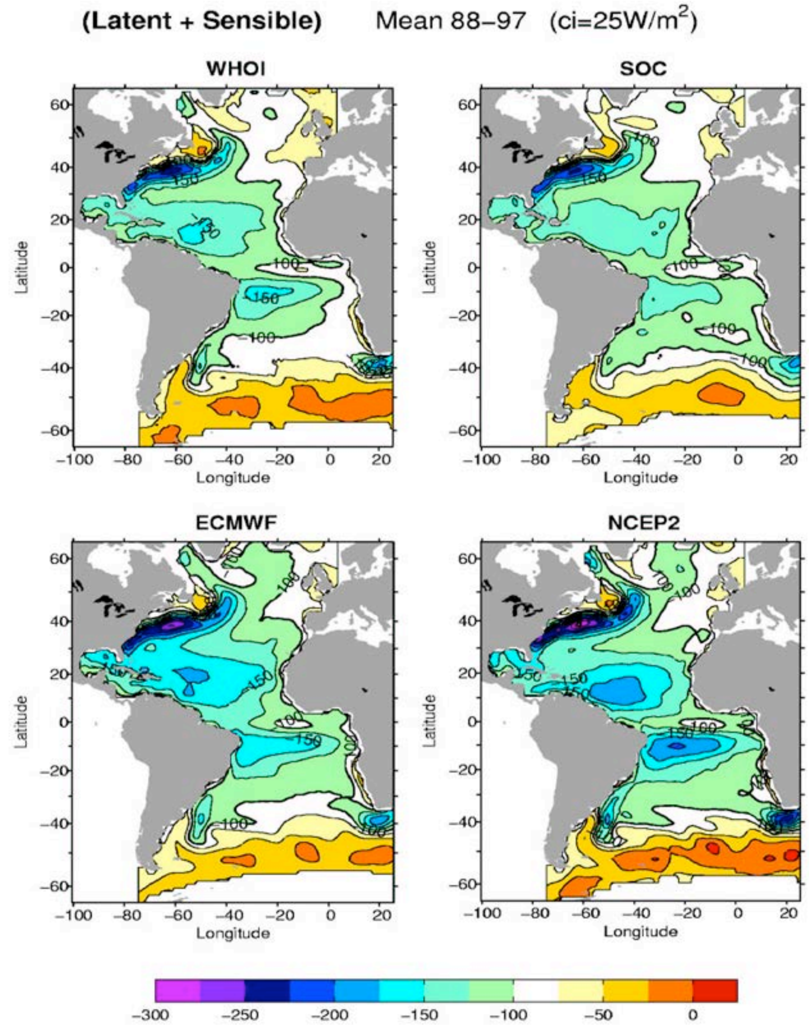

Figure 2. Four maps of the long-term (1988-1997) sum of latent and sensible heat flux components in the Atlantic basin. WHOI was produced by L. Yu at WHOI and validated against buoy data. SOC is a climatological product based on VOS data; ECMWF and NCEP2 are analyses based on those numerical weather prediction models.

Acknowledgement

This section on air-sea exchange of heat, fresh water and momentum was written with input from Drs. Peter Taylor and Simon Josey of the Southampton Oceanography Centre, UK, Dr. Chris Fairall of the NOAA Environmental Technology Laboratory, Boulder, Colorado, and Dr. Frank Bradley of the Commonwealth Scientific and Industrial Research Organization (CSIRO), Canberra, Australia.

2.8 SEA ICE EXTENT AND THICKNESS

by Ignatius Rigor[1] and Jackie Richter-Menge[2]

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Abstract
Although the extent of sea ice is limited to the higher latitudes of the Arctic (Fig. 3) and Antarctic, and covers only 7% of the global oceans, sea ice has a profound affect on the climate of the mid-latitudes in which we live. Sea ice affects many aspects of the global climate system through its role in maintaining global temperatures at levels which make life on earth sustainable and by its effect on the global thermohaline circulation which transports heat around the earth.

The extent and thickness of sea ice on the global ocean has been decreasing dramatically during the last few decades, and the last three summers have exhibited record low sea ice extent on the Arctic Ocean. The summer of 2002 set the record minimum for the Northern Hemisphere, while the summer of 2004 (Fig. 6) was very close to this record. The precipitous decline of sea ice has been attributed to the long-term effects of changes in wind, which have blown most of the older, thicker sea ice out of the Arctic Ocean, and warmer temperatures melting sea ice. These changes have been associated with the increases in greenhouse gases in the atmosphere.

Introduction
Understanding the state of sea ice on the global ocean is important since changes in sea ice may foreshadow changes in global climate and affect the global climate system.

The Arctic has been argued to be a harbinger of global climate change since global climate models predict that when the concentrations of CO_2 in the atmosphere doubles the Arctic would warm by more than 5°C, compared to a warming of 2°C for subpolar regions (Manabe et al. 1991), thus the increases in global temperature can be detected in the Arctic sooner than in lower latitudes. This enhanced warming of the Arctic was attributed to the ice-albedo feedback, a process in which an anomalous decrease in sea ice would increase the exposed area of the darker ocean, increasing the amount of sun light absorbed, thus warming the ocean, melting more sea ice, and amplifying the initial perturbations.

Although the extent of sea ice is limited to the higher latitudes of the Arctic and Antarctic, and covers only 7% of the global oceans, sea ice has a profound affect on the climate of the mid-latitudes in which we live. Sea ice affects many aspects of the global climate system through its role in maintaining global temperatures at levels, which make life on earth sustainable and by its effect on the global thermohaline circulation which transports heat around the earth (Aagaard and Carmack 1994).

Figure 1 shows some of the connections between the Arctic and the global climate system. Excess heat from the sun absorbed at lower latitudes is transported poleward by the atmosphere and ocean where it is radiated back out to space. Sea ice has a higher albedo (reflectivity) than the darker ocean (Fig. 2), and hence its presence reduces the amount of sunlight absorbed by the sea ice covered ocean, thus allowing the earth cool more efficiently. However, sea ice also insulates

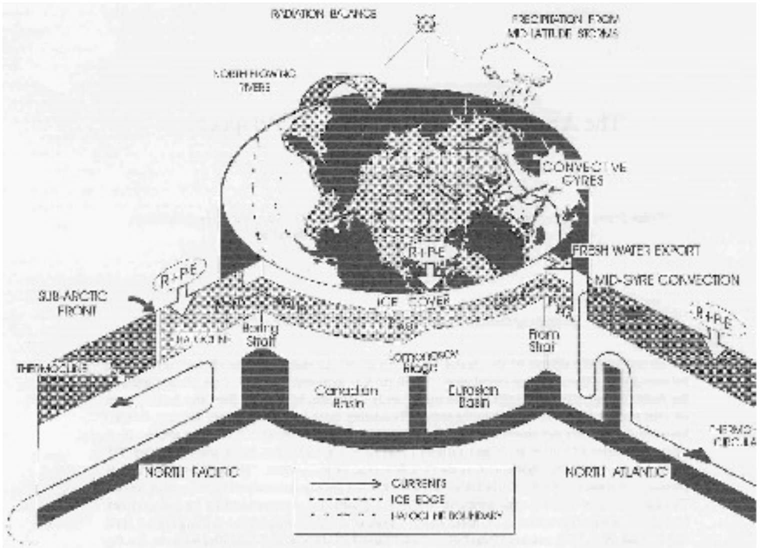

Figure 1. Schematic of Arctic connections to global climate. In the horizontal place, the extent of sea ice in winter is shown by the shaded region and the mean surface circulation by arrows. Sections of the North Pacific and the North Atlantic extend through Bering and Fram straits, respectively. The subarctic front separates the salt-stratified upper waters of the arctic and the subarctic oceans from the temperature-stratified upper waters of the subtropical oceans. The components of the freshwater balance include runoff (R), precipitation (P), evaporation (E), storage in the upper North Pacific (F_{NP}), and Arctic Ocean (F_{AO}), and the North Atlantic (F_{NA}), and the horizontal freshwater fluxes (Q_{in} and Q_{out}). Shaded ovals indicate the present sites of convection in the Greenland and Iceland seas (from Aagaard and Carmack 1994).

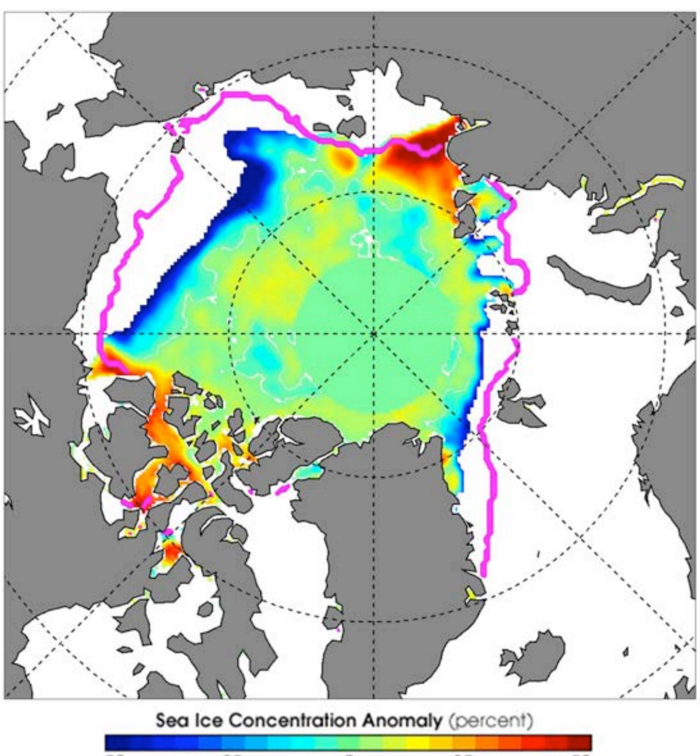

Figure 2. The record minimum sea ice extent in the Northern Hemisphere in September 2002. Image provided by National Aeronautic and Space Administration, http://www.nasa.gov.

the colder atmosphere from the warmer ocean thus reducing the amount of heat lost to space. These opposing processes underscore the complexity of the Arctic and global climate system.

Sea ice affects the global thermohaline circulation through its effect on the salt and fresh water budget of the global ocean (Aagaard and Carmack 1994). As sea ice grows, salt is expelled from the sea ice into the ocean. Since sea ice primarily grows on the Arctic Ocean, it expels most of its salt in this area. The fresher sea ice is then transported towards Fram Strait and the convective regions in the Greenland and Labrador seas (North Atlantic, Figs. 1–3). The melting ice provides a source of fresh water, which is less dense than sea water and may hinder the formation of deep water, thereby slowing the global thermohaline circulation, thus reducing the amount of heat transported by the ocean from the tropics to the higher latitudes (Aagaard and Carmack 1994; Kwok and Rothrock 1999; Belkin 2004).

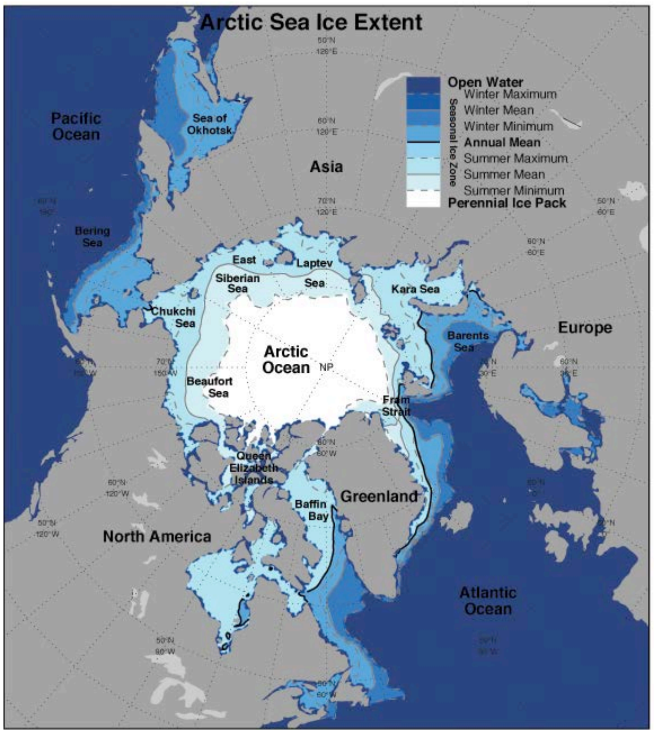

Figure 3. Climatological mean sea ice extent and geography of the Arctic. The extent of sea ice varies by season and from year to year. The seasonal mean sea ice extent lines define the boundary within which sea ice has been observed during at least half the seasons on record (1901 – 2002), the seasonal minimum lines define the boundary within which sea ice has been observed during all seasons, and seasonal maximum lines define the boundary within which sea ice has been observed at least once (Rigor 2004).

Sea ice also has a direct and significant impact on wildlife and people. Many species and cultures depend on the sea ice for habitat and subsistence. The lack of sea ice in an area along the coast may expose the coast line to ocean waves which may threaten low lying coastal towns and accelerate the rate of erosion (Lynch et al. 2003). And from a global economic viewpoint, the lack of sea ice during summer makes the Arctic more accessible for navigation; these shipping routes are as much as 60% shorter from Europe to Asia and the west coast of America, compared to the tradition routes through the Suez and Panama canals (ACIA 2004).

Climatology of Sea Ice

The state of sea ice in the global climate system can be summarized by its areal extent and thickness, which vary with the seasons and from year-to-year. For the Arctic, the extent of sea ice can readily be estimated from the observational records from 1901 to 1999, compiled by Walsh (1978, updated) and from passive microwave satellite data, which are available from 1979 to the present (Comiso 1995, updated). The average extent of sea ice estimated from these data varies from 7.5 x 10^6 km^2 during the summer minimum in September (Fig. 3), when sea ice in the Arctic is typically only found in the interior of the Arctic Ocean and in the Greenland Sea, to 15.5 x 10^6 km^2 during the winter maximum in March when ice in the Arctic extends south to cover the Sea of Okhotsk, the northern reaches of the Bering Sea, Baffin Bay, the Labrador Sea and a part of the North Atlantic.

For the Antarctic, long-term records of sea ice extent are limited to the satellite data. Sea ice extent ranges from 3.8 x 10^6 km^2 during the Southern Hemisphere summer minimum in March to 19 x 10^6 km^2 during the winter maximum in September (Comiso 2003). In contrast to the Arctic, most of the sea ice in the Antarctic grows during winter and does not persist from year-to-year.

In comparison to observations of sea ice extent, long-term records of sea ice thickness are limited in space and time to data collected by occasional submarine cruises under the sea ice and field studies on the sea ice, by ice profiling sonars which are moored to the sea floor, and by buoys drifting with the sea ice. However, using satellite altimeter data, which are available from 1993–2001, Laxon et al. (2003) were able to estimate the climatology of Arctic sea ice thickness. They show that the sea ice typically ranges from 1–5 m in thickness, depending on the region, season and year. The ice is thickest along the Canadian Archipelago where sea ice tends to raft against the coast, and thinnest north of Siberia and Alaska where the ice tends to drift away from the coast.

In the Antarctic, Wadhams (1994) reported that sea ice in the Antarctic is typically less 0.6 m, and large ridges of sea ice are rare. The thinnest sea ice is typically found on the periphery of the sea ice pack, which are at warmer latitudes, while the thickest sea adjacent to the continent where the sea ice is sporadically compressed against the coast (Hass 2003). Since Antarctic sea ice is much thinner than in the Arctic, this limits the reliability of satellite altimeters for estimating sea ice thickness over the Southern Ocean.

Variations in Sea Ice

The state of the Arctic sea ice pack is determined by the effects of the atmosphere and ocean upon the sea ice on various time scales. As the sea ice drifts over the Arctic Ocean, its motion is driven primarily by the surface winds, which account for 70% of the day-to-day variance (Thorndike and Colony 1982). On time scales of days to weeks, wind stresses from storms (Shy and Walsh 1996) produce ridges, which thicken sea ice, and areas of open water, which quickly freeze up during winter. Together, these changes act to increase the overall volume of sea ice within a specified area. Ridging tends to occur preferentially during storms, when the wind stress is strong enough to produce large deformations in the sea ice. The number of storms that any given parcel of ice has experienced is cumulative, and hence the amount of ridged ice tends to increase with the age of the ice. The thicker, ridged ice provides stronger insulation for the atmosphere, but a significant amount of heat is still lost to the atmosphere through the cracks in which new sea ice may grow. During spring and summer, the presence of open water allows more solar energy to be absorbed and stored in the ocean mixed layer, thereby prolonging the melt season, and further increasing the annually integrated absorption of solar radiation.

Many of the changes in Arctic climate and sea ice on all time scales have been attributed to the Arctic Oscillation (AO, Thompson and Wallace 1998), which has been identified as the primary mode of variability of Northern Hemisphere atmospheric circulation. Over the Arctic Ocean, the AO explains more than 54% of the variance in sea level pressure during winter, and 36% during winter and thus many of the changes in Arctic climate such as the increases in surface air temperature and the decreases in sea ice extent and thickness are highly correlated with variations in the AO through the advection of heat and redistribution of sea ice by the wind (Rigor et al. 2002).

Dramatic changes in Arctic sea ice have been documented during the last few decades. Sea ice thickness has decreased by over 40% when the submarine ice profiling sonar records from the 1993–1997 are compared to the records from 1958–1976 (Rothrock et al. 1999). The annual average extent of sea ice has decreased by 8% per decade, and these decreases are larger during summer, 15–20% per decade over the past 30 years (ACIA 2004). Taken together, these studies imply a precipitous decline in total volume of sea ice on the Arctic Ocean. The decline of Arctic sea ice has been attributed to the warmer air temperatures that have been observed (e.g., Rigor et al. 2000, and Jones et al. 1999), which may have thinned and decreased the area of sea ice (ACIA 2004), but there is also some evidence that changes in the circulation of sea ice on the Arctic Ocean driven by changes in winds over the Northern Hemisphere are also important in explaining the recent minima in summer sea ice extent. In contrast, the trends in Antarctic sea ice extent from 1979 to 2000 are insignificant (Comiso 2003).

The last three summers have exhibited record low sea ice extent on the Arctic Ocean. The summer of 2002 set the record minimum for the Northern Hemisphere, while the summer of 2004 was close to the record and had less sea ice over the Arctic Ocean than in 2002, but more sea ice was observed in the Canadian Archipelago and in the Laptev Sea. In Figure 4 we show the trends in summer Arctic sea ice concentration from 1979–2002 (Rigor and Wallace 2004). The strongest trends are observed north of Alaska, and are typically associated with winds coming from southeast, which carry warm continental air onto the Arctic Ocean, and also blow the sea ice away from the coast towards the northwest (e.g., Drobot and Maslanik 2003). However, during the summer of 2002, the air was actually colder over this area, and the winds came from the northwest, which tended to blow the sea ice towards the Alaskan coast and yet a record minimum in sea ice extent was observed.

To explain this apparent discrepancy between the atmospheric forcing and sea ice extent during the summer of 2002, Rigor and Wallace (2004) hypothesized that there may have been a change in the character of the sea ice drifting towards the Alaskan coast. Given the paucity of observations of sea ice thickness, they used the drift of buoys to estimate the age of sea ice as a proxy for sea ice thickness (sea ice thickens with age). In this study, they showed that the area covered by older, thicker sea ice decreased dramatically in the early 1990’s with the step to high Arctic Oscillation conditions. The winds during this period blew most of the older, thicker sea ice out of the Arctic Ocean, and new, thinner sea ice grew in its place. Then during the recent years, this younger, thinner sea ice was observed to drift towards the Alaska coast, where the extensive decrease in sea ice extent was observed during the summer of 2002 and 2003, even though temperatures were locally colder than normal. Rigor and Wallace (2004) argue that the sea ice recirculating towards the Alaskan coast is simply not thick enough to survive the summer. The

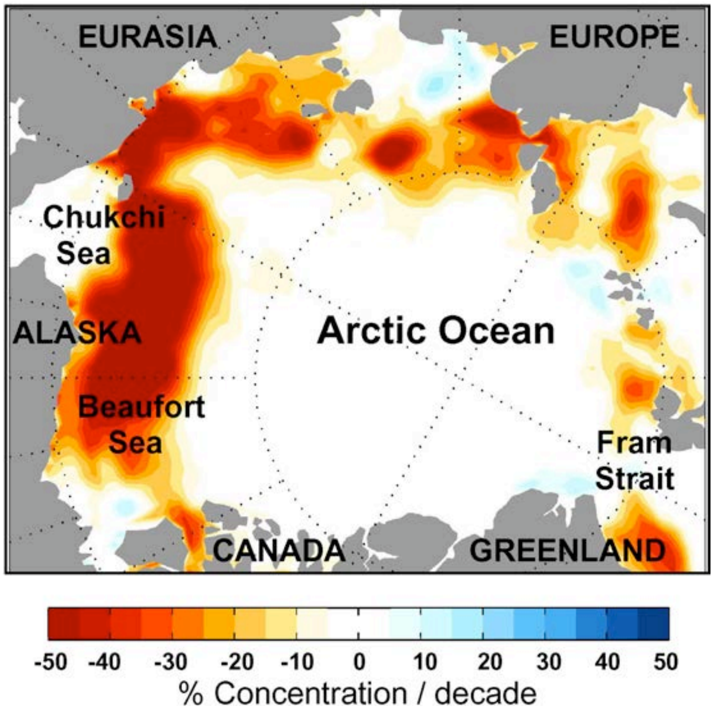

Figure 4. Trends in September sea ice concentration from 1979–2002. Adapted from Rigor and Wallace (2004).

age and thickness of sea ice explains more than half of the variance of summer sea ice extent. The younger, thinner state of most of the sea ice on the Arctic Ocean persists through today.

Rigor and Wallace (2004) show that the recent minima in Arctic sea ice extent may be attributed more to a change in atmospheric circulation sweeping most of the older, thicker sea ice out of the Arctic Ocean, rather than warmer temperatures melting sea ice. However, this does not imply that the decline of Arctic sea ice is not related to the increase in greenhouse gases, since the changes in atmospheric circulation have been attributed to the AO, and there is a growing amount of evidence that greenhouse warming favors high AO conditions.

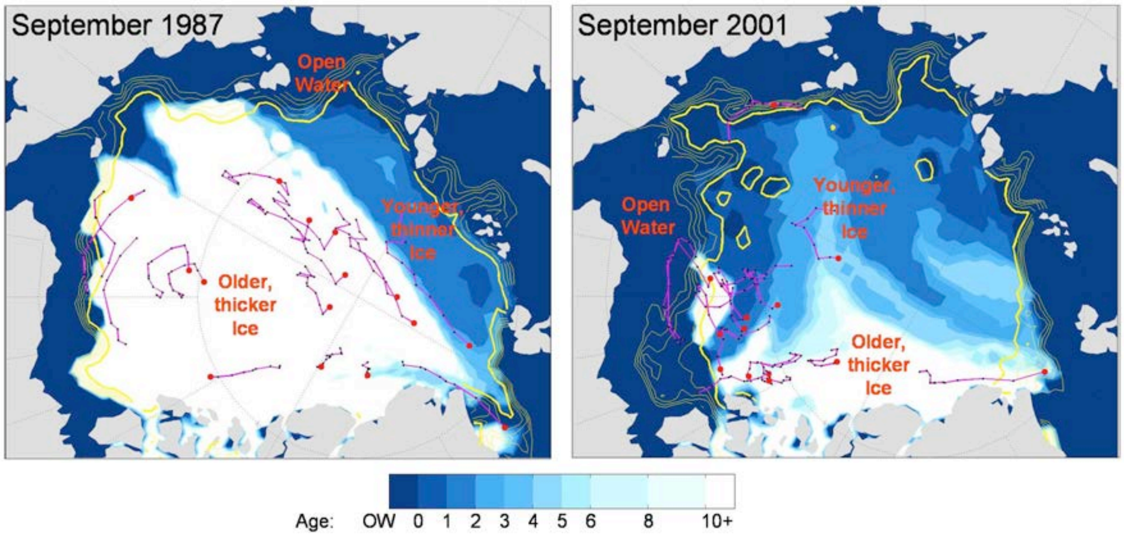

Figure 5. Estimated age of sea ice on the Arctic Ocean in 1987 & 2001. Adapted from Rigor and Wallace (2004).

References

Aagaard, K. and E. C. Carmack, 1994: The Arctic Ocean and climate: A perspective. The Polar Oceans and Their Role in Shaping the Global Environment: The Nansen Centennial Volume, O.M. Johannessen, R. D. Muench, and J. E. Overland, Eds., Amer. Geophys. Union, pp. 5 – 20.

ACIA, 2004: *Impacts of a Warming Arctic: Arctic Climate Impacts Assessment*. Cambridge University Press, 139 pp.

Belkin, I. M., 2004: Propagation of the "Great Salinity Anomaly" of the 1990s around the northern North Atlantic. *Geophys. Res*. *Lett*., **31**.

Comiso, J.C., 1995: SSM/I ice concentrations using the Bootstrap algorithm. NASA Report 1380.

Comiso, J., 2003: Large-scale Characteristics and Variability of the Global Sea Ice Cover. Sea Ice, An Introduction to its Physics, Chemistry, Biology, and Geology, D. N. Thomas & G. S. Dieckmann Eds., Blackwell.

Drobot S.D., and J.A. Maslanik, 2003: Interannual variability in summer Beaufort Sea ice conditions: Relationship to winter and summer surface and atmospheric variability. *J. Geophys. Res*., **108(C7),** 3233, doi: 10.1029/2002JC001537.

Haas, C., 2003: Dynamics versus Thermodynamics: The Sea Ice Thickness Distribution. Sea Ice, An Introduction to its Physics, Chemistry, Biology, and Geology, D. N. Thomas & G. S. Dieckmann Eds., Blackwell.

Jones, P.D., M. New, D.E. Parker, S. Martin, and I.G. Rigor, 1999: Surface air temperature and its changes over the past 150 years. *Rev. Geophys*. **37(C2)**, 173-200.

Kwok, R., and D. A. Rothrock, 1999: Variability of Fram Strait ice flux and North Atlantic oscillation. *J. Geophys, Res.*, **104(C3)**, 5177 – 5189.

Laxon, S., N. Peacock & D. Smith, 2003: High interannual variability of sea ice thickness in the Arctic region. *Nature*, **425**, 947 – 950.

Lynch, A.H., E.N. Cassano, J.J. Cassano, L.R. Lestak, 2003: Case studies of high wind events in Barrow, Alaska: climatological context and development processes. *Mon. Wea. Rev*., **131**, 719-732.

Manabe, S., R. J. Stouffer, M. J. Spellman, and K. Bryan, 1991: Transient response of a coupled ocean-atmosphere model to gradual changes of atmospheric CO_2, I. Annual mean response. *J. Climate,* **4**, 785-818.

Rigor, I.G., R.L. Colony, and S. Martin, 2000: Variations in Surface Air Temperature in the Arctic from 1979-1997. *J. Climate*, **13**, no. 5, pp. 896 - 914.

Rigor, I.G. and J.M. Wallace, 2004: Variations in the Age of Sea Ice and Summer Sea Ice Extent. *Geophys. Res. Lett.*, **31**, doi:10.1029/2004GL019492.

Rigor, I.G., J.M. Wallace, R.L. Colony. 2002: Response of sea ice to the Arctic Oscillation. *J. Climate,* **15**, *18*, 2648 – 2663.

Rigor, I.G., Interdecadal Variations in Arctic Sea Ice, *Ph. D. Dissertation,* Univ. of Washington, Seattle, pp. 100, 2004.

Rothrock, D.A., Y. Yu, and G.A. Maykut, 1999: Thinning of Arctic sea ice. *Geophys. Res. Lett., 26*, 3469–3472.

Shy T.L., and J.M. Walsh, 1996: North Pole ice thickness and association with ice motion history. *Geophys. Res. Lett.* **23**, 2975–2978.

Thompson, D. W. J., and J. M. Wallace, 1998: The Arctic Oscillation signature in the wintertime geopotential height and temperature fields. *Geophys. Res. Lett.*, **25(9)**, 1297–1300.

Thorndike, A. S., and R. Colony, 1982: Sea ice motion in response to geostrophic winds. *J. Geophys. Res*., **87(C8)**, 5845–5852.

Wadhams, P., 1994: Sea ice thickness changes and their relation to climate. The Polar Oceans and Their Role in Shaping the Global Environment: The Nansen Centennial Volume, O.M. Johannessen, R. D. Muench, and J. E. Overland, Eds., Amer. Geophys. Union, pp. 337–362.

Walsh, J.E., 1978: A data set on Northern Hemisphere sea ice extent. World Data Center-A for Glaciology (Snow and Ice), "Glaciological Data, Report GD-2", part 1, pp. 49–51.

CHAPTER 3

THE STATE OF THE OBSERVING SYSTEM

Project Summaries, FY 2004 Progress, FY 2005 Plans

This chapter is comprised of FY 2004 progress reports followed by FY 2005 plans submitted by scientists funded by NOAA's Climate Observation Program. A request for annual progress reports was issued in late August 2004 (see Appendix D). Excerpts from the submitted reports are presented here summarizing efforts focused on enhancement of the global ocean observing system for climate.

The chapter begins with a report describing the Office of Climate Observation's Climate Observation Program, the primary sponsor of the documented projects, followed by a table of OCO-funded projects and their accompanying web sites. The reports that follow are in alphabetical order based on the Principal Investigator's last name.

PROGRAM OVERVIEW
FY 2004 PROGRESS

Office of Climate Observation, Climate Observation Program

by Mike Johnson, Office of Climate Observation, Silver Spring, MD

Introduction

This report provides an annual progress report and work plan for NOAA's Climate Observation Program. The program was initiated by the Office of Global Programs (OGP) with Climate and Global Change (C&GC) funding in 1998. Since then the program has grown to include funding accounted for within five separate budget lines. This report presents the composite Program as managed through the Office of Climate Observation (OCO).

Program Description

Goal and Objectives:
The goal of the program is to build and sustain a global climate observing system that will respond to the long term observational requirements of the operational forecast centers, international research programs, and major scientific assessments. The Climate Observation Program focuses on building the ocean component. The program objectives are to:

- document long term trends in sea level change;
- document ocean carbon sources and sinks;
- document the ocean's storage and global transport of heat and fresh water;
- document ocean-atmosphere exchange of heat and fresh water.

Specific issues, requirements, and customer need motivating the program:
The ocean is the memory of the climate system and is second only to the sun in effecting variability in the seasons and long-term climate change. In order for NOAA to fulfill its climate mission, the global ocean must be observed. At present, the Climate Observation Program is

arguably the world leader in supporting implementation of the *in situ* elements of the global ocean climate observing system.

The Climate Goal via the Climate Observation Program provides the major part of NOAA's contribution to the global component of the U.S. Integrated Ocean Observing System (IOOS). The observing system being put in place for climate requirements also supports global weather prediction, marine services, military applications, global and coastal ocean prediction, marine hazard warning systems (e.g., tsunami warning), and marine environmental monitoring, among other things. Many non-climate users also depend on the baseline composite system that is nominally referred to as the global ocean climate observing system.

The ocean climate observing system needs to have the capability to deliver continuous instrumental records and analyses accurately documenting:

- Sea level to identify changes resulting from climate variability.
- Ocean carbon content every ten years and the air-sea exchange seasonally.
- Sea surface temperature and surface currents to identify significant patterns of climate variability.
- Sea surface pressure and air-sea exchanges of heat, momentum, and fresh water to identity changes in forcing function driving ocean conditions and atmospheric conditions.
- Ocean heat and fresh water content and transports to: 1) identify changes in the global water cycle; 2) identify changed in thermohaline circulation and monitor for indications of possible abrupt climate change; and 3) identify where anomalies enter the ocean, how they move and are transformed, and where they re-emerge to interact with the atmosphere.
- Sea ice thickness and concentrations.

Present ocean observations are not adequate to deliver these products with confidence. The fundamental deficiency is lack of global coverage by the *in situ* networks. Present international efforts constitute only about 48% of what is needed in the ice-free oceans and 11% in the Arctic. The *Second Report on the Adequacy of the Global Observing System for Climate in Support of the UNFCCC* concludes that "the ocean networks lack global coverage and commitment to sustained operations…Without urgent action to address these findings, the Parties will lack the information necessary to effectively plan for and manage their response to climate change." The *Strategic Plan for the U.S. Climate Change Science Program* calls for "complete global coverage of the oceans with moored, drifting, and ship-based networks."

The 2003 Earth Observation Summit raised to the highest levels of governments the awareness of the need for a global observation system. The climate question is high on the political agendas of many nations and can be answered authoritatively only by sustained earth observation. The Earth Observation Summit reaffirmed NOAA's leadership and commitment to fulfilling the need for global coverage and the Climate Observation Program is NOAA's management tool for implementing the ocean component.

In response to the Second Adequacy Report, international GCOS produce the *Implementation Plan for the Global Observing System for Climate in support of the UNFCCC* (GCOS-92). GCOS-92 was published in October 2004. It has been endorsed by the UNFCCC; and it is expected to be endorsed by the Earth Observation Summit III in Brussels, in February 2005. In particular:

1. The UNFCCC, Decision CP.10, "Encourages Parties to strengthen their efforts to address the priorities identified in the [GCOS] implementation plan, and to implement the priority elements …"

2. The draft *Global Earth Observation System of Systems (GEOSS) 10-Year Implementation Plan*, 6-year targets include: "Support implementation of actions called for in GCOS-92."

OCO's *Program Plan for Building a Sustained Ocean Observing System for Climate* is in complete accord with GCOS-92 and provides the framework for NOAA contributions to the international effort. In particular 21 of the specific actions listed in the GCOS-92 ocean chapter (pages 56-84) are being acted upon by the Climate Observation Program in cooperation with the implementation panels of the Joint WMO/IOC Technical Commission for Oceanography and Marine Meteorology (JCOMM), the International Ocean Carbon Coordination Project (IOCCP), and the Climate Variability and Predictability (CLIVAR) Program. These specific GCOS-92 actions now provide an excellent roadmap to guide observing system work over the next five years. GCOS-92 is accessible via link from the OCO web site: www.oco.noaa.gov -- click on "Reports & Products."

Partnerships:
The Climate Observation Program is managed as an inter-LO, interagency, and international effort. The Climate Goal, through the Climate Observation Program, provides the backbone of the Global Component of NOAA's Integrated Ocean Observing System (IOOS) project. The work of 19 distributed centers of expertise and 151 people is supported through the Program. Presently most NOAA contributions to the global system are being implemented by the OAR laboratories, joint institutes, universities and business partners. NOS, NMFS, and NWS maintain observational infrastructure for ecosystems, transportation, marine services and coastal forecasting that do or have potential to contribute to climate observation. NOS sea level measurements in particular provide one of the best and longest climate records existent. NESDIS data centers are essential. NMAO ship operations are necessary for supporting ocean work. NESDIS and NPOESS continuous satellite missions are needed to provide the remote sensing that complements the *in situ* measurements.

International and interagency partnerships are central to the Climate Observation Program implementation strategy. All of the Program's contributions to global observation are managed in cooperation internationally with the Joint WMO/IOC Technical Commission for Oceanography and Marine Meteorology (JCOMM), and nationally with the U.S. Integrated Ocean Observing System (IOOS). NSF has initiated their Ocean Observatories Initiative (OOI), which will potentially provide significant infrastructure in support of ocean climate observation, beginning in FY 2006. The ongoing NSF-NOAA cooperative project for CLIVAR-carbon ocean surveys has proved to be an interagency-international-interdisciplinary success. ONR maintains a GODAE data server at Monterey that needs to be sustained after the experiment period (2003-2007) as permanent international infrastructure. The UNOLS fleet provides ship support for ocean operations. NASA's development of remote sensing techniques is key.

Focus of the Program:

- Extending the *in situ* networks to achieve global coverage – moored and drifting buoys, profiling floats, tide gauges stations, and repeated ship lines. The networks are illustrated in Figure 1.
- Building associated data and assimilation subsystems.
- Building observing system management and product delivery infrastructure.

Linkage to NOAA strategic goals:

- NOAA's Mission Goal 2 – "Understand climate variability and change to enhance society's ability to plan and respond."

- NOAA Strategy – Monitor and Observe: "We will invest in high-quality, long-term climate observations and will encourage other national and international investments to provide a comprehensive observing system in support of climate assessments and forecasts."

Intended program outcomes and performance measures:

- Outcome -- A sustained global system of complementary *in situ*, satellite, data, and modeling subsystems adequate to accurately document the state of the ocean and force climate models.
- Performance Measures:
    - Reduce the error in global measurement of sea surface temperature.
    - Reduce the error in global measurement of sea level change
    - Reduce the error in global measurement of ocean carbon sources and sinks
    - Reduce the error in global measurement of ocean heat content and transport

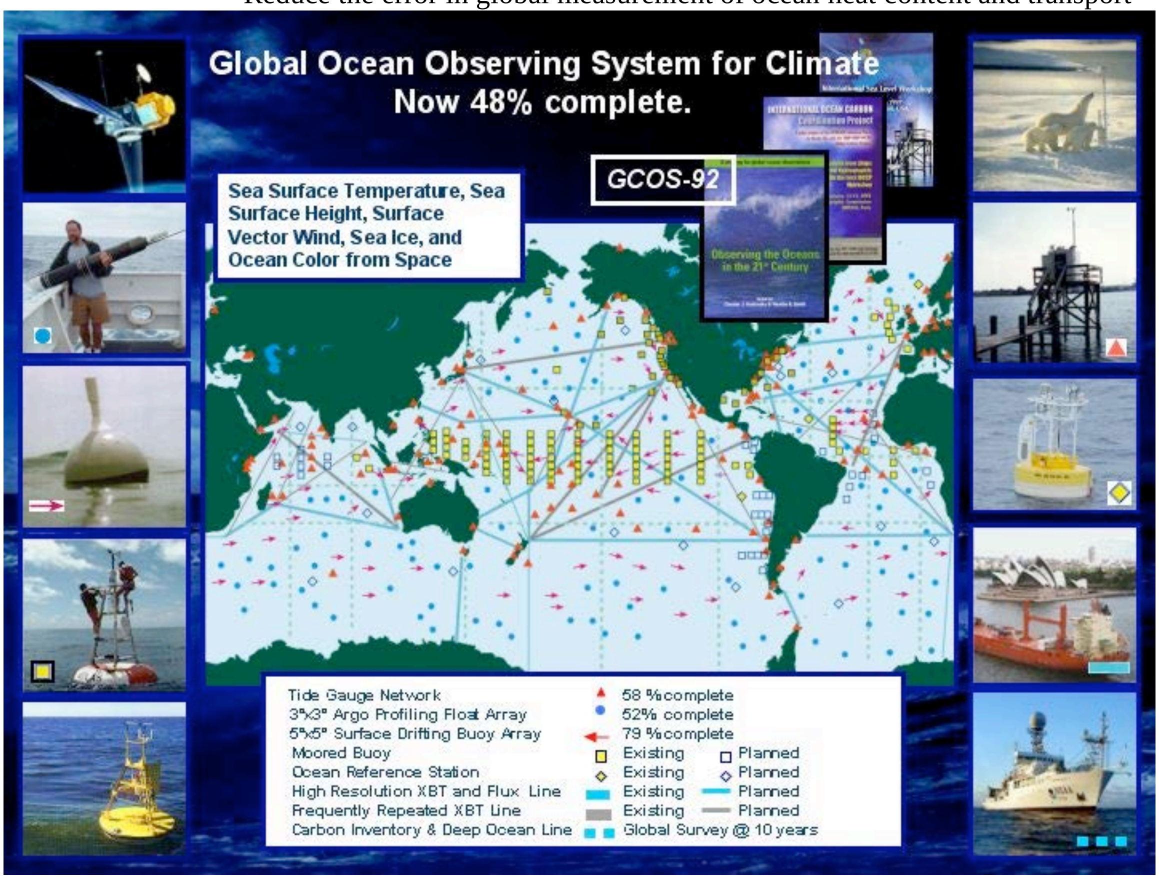

Figure 1

Schedule and milestones: "FY 2006 Current Program" contained in the Climate Goal Program Plan.

Year	2003	2004	2005	2006	2007	2008	2009	2010
System % complete:	45	48	53	55	63	65	68	73

Communications plan for providing information to decision makers (government and non-government):

The observing system delivers the "up front" information to the forecast centers, research programs, and assessments. In the past, the program has depended largely on these partner

Climate Program Components to develop and deliver information products that are user-friendly for management and policy decisions. During FY 2003, however, the need was identified for the program to begin addressing the development of climate data records and analyses as first order products in addition to depending on the forecast, research, and assessment partners for climate product delivery. In 2004, the OCO produced the first *Annual Report on the State of the Ocean and the Ocean Observing System for Climate*. This first report for the fiscal year 2003 was a demonstration project; it proved highly successful; the project will be continued documenting the state of the ocean and reporting on observing system progress annually. The annual reports include sections targeted for three audiences: 1) decision-makers and non-scientist, 2) scientists, 3) observing system managers.

How implementation is being accomplished:
The "Networks" are managed by 19 distributed centers of expertise at the NOAA Labs, Centers, Joint Institutes, universities and business partners. The "System" is centrally managed at the Office of Climate Observation (OCO), a project office within the NOAA Climate Program Office.

Where it is being done (lab, university, joint institute):
AOML, PMEL, ETL, JIMAR (University of Hawaii), JIMO (Scripps Institution of Oceanography), CICOR (Woods Hole Oceanographic Institution), JISAO (University of Washington), CIMAS (University of Miami), CICAR (Columbia University), NCDC, NODC, CO-OPS, AMC, PMC, NDBC, NCEP, FSU (Florida State University), SAI (Service Argos Inc.) and OCO.

By whom (detail on number and type of personnel involved):
- 45 Federal FTEs
- 103 non-Federal FTEs
- 2 Contract FTEs and 1 Federal seconded FTE at international coordination offices

Customers, NOAA and non-NOAA, served:
- Operational forecast centers (e.g., NCEP, ECMWF, BoM, JMA)
- International research programs (e.g., CLIVAR, GEWEX, ASOF)
- Major scientific assessments – national and international (e.g., IPCC)

Potential benefits:
The Nations of the world will have the quantitative information necessary to: 1) forecast and assess climate variability and change, and 2) effectively plan for and manage their response to climate change.

FY 2004 Accomplishments:
Incremental advances were accomplished across all of the networks. These advancements are documented in the individual progress reports that follow. The ocean system overall advanced from 45% complete in FY 2003 to 48% complete in FY 2004.

The new Office of Climate Observation (OCO) was officially opened at 1100 Wayne Avenue, Silver Spring, on April 14, 2004. Seven personnel were assigned to the OCO, six in Silver Spring and one detailed to the IOC at UNESCO in Paris to serve on the JCOMM secretariat. The OCO staff consists of three Federal employees, one IPA scientist, two contracted technical experts, and one program management intern detailed to the OCO from JAMSTEC. The OCO management plan provides for development of system-wide services to:

- Monitor the status of the globally distributed networks; report system statistics and metrics routinely and on demand.
- Evaluate the effectiveness of the system; recommend improvements.
- Advance the multi-year Program Plan; evolve the *in situ* networks through directed funding;
- Focus intra-agency, interagency, and international coordination.
- Organize external review and user feedback.
- Produce annual reports on the state of the ocean and the adequacy of the observing system for climate.

The second Annual System Review was conducted April 13-15 in Silver Spring. This meeting brought together project managers to discuss system-wide issues and engage in program strategic planning. It also provided the annually scheduled forum for observing system users to provide feedback and discuss their requirements and recommendations for system evolution with the project managers. Review of the NDBC and PMEL plan for transition of TAO operations from PMEL to NDBC was a major topic of discussion during the 2004 Annual Review. The issue of the gap in delivery of ocean analyses as an end product of ocean observations was also a major part of the strategic discussions. The Climate Observation Program in FY 2005 will begin a program of ocean analysis work to ensure that this gap gets filled.

During the Annual System Review, the OCO sponsored an external review of the NDBC/PMEL TAO Transition Planning. The review panel consisted of the Climate Observing System Council (COSC) members plus invited experts including international partners from JAMSTEC and the IOC. As a result of the review the Transition Plan was modified to address recommendations of the panel and then a second quick turn around review of the modified plan was conducted by the COSC in September before the plan was presented to NOAA management for approval.

In cooperation with the international GCOS program office in Geneva, the OCO developed a special web page in support of the GCOS *Implementation Plan for the Global Observing System for Climate in Support of the UNFCCC* (GCOS-92). The OCO web page, www.oco.noaa.gov/page_status_reports_global.jsp, provides up-to date global maps and summary statistics from JCOMMOPS and other observing system partners contributing to international implementation of GCOS-92.

A demonstration project was initiated at OCO in cooperation with the GOOS Program Office at UNESCO and JCOMMOPS in Toulouse, to routinely report on progress of the observing system and contributions by countries. A consolidated report is now available on the OCO web site, accessible via the international portal at www.jcommops.org/network_status, which lists the 64 countries and the European Union that maintain elements of the composite ocean observing system and the number platforms and expendables contributed by each country. It is the intent of the OCO to develop a routine to update this report quarterly. This report allows tracking of progress toward international implementation of the ocean system specified in GCOS-92.

Table 3.1. This table provides names of PIs (in alphabetical order), the title of their funded projects, and websites linked with their projects.

Office of Climate Observation – 2004 Funded Projects		
Principal Investigator/ Co-Principal Investigator(s)	**i. ii. Title of Project**	**Project Website**
Baringer, Molly Goni, Gustavo Garzoli, Silvia	Atlantic High Density XBT Lines	http://www.aoml.noaa.gov/phod/hdenxbt/
Baringer, Molly Johns, Elizabeth Meinen, Christopher Garzoli, Silvia	Western Boundary Time Series in the Atlantic Ocean	http://www.aoml.noaa.gov/phod/floridacurrent/
Bernard, Landry	The Tropical Atmosphere Ocean (TAO) Array	http://www.pmel.noaa.gov/tao/
Cook, Steven Molinari, Robert	ENSO Observing System, XBT component	http://seas.amverseas.noaa.gov/seas/goosplots.html Associated projects: http://ww.jcommops.org http://seas.amverseas.noaa.gov/seas http://www-hrx.ucsd.edu http://www.cmdl.noaa.gov http://www://sahfos.org http://www.aoml.noaa.gov/phod/benchmarks/index.html
Consortium on the Ocean's Role in Climate (CORC)		
Cayan, Daniel	1. CORC: Surface Fluxes and Analysis	Data distributed by: ftp://tenaya.ucsd.edu/pub
Cornuelle, Bruce Stammer, Detlef Miller, Art	2. CORC: Four-Dimensional Variational (4DVAR) Data Assimilation in the Tropical Pacific	
Davis, Russ	3. CORC: Underwater Gliders for Monitoring Ocean Climate	www.Spray.UCSD.edu
Niiler, Pearn	4. CORC: Drifter Observations	
Roemmich, Dean	5. CORC: High Resolution XBT/XCTD (HRX) Transects	http://www-hrx.ucsd.edu
Rudnick, Daniel	6. CORC: Development of an Underway CTD	
Schmitt, Ray	7. CORC: Lagrangian Salinity Profiling: Evaluation of Sensor Performance	

Weller, Robert Bahr, Frank Hosom, David	8. CORC: Observations of Air-Sea Fluxes and the Surface of the Ocean	http://uop.whoi.edu/vos/ http://frodo.whoi.edu ftp.whoi.edu/pub/users/fbahr/VOS
Cronin, Meghan Meinig, Christian Sabine, Christopher	Flux Mooring for the North Pacific's Western Boundary Current: Kuroshio Extension Observatory (KEO)	http://www.pmel.noaa.gov/keo
Fairall, Chris	High Resolution Climate Data from Research and Volunteer Observing Ships	http://www.etl.noaa.gov/et6/air-sea/
Feely, Richard Wanninkhof, Rik Sabine, Chris Johnson, Gregory Baringer, Molly Bullister, John Mordy, Calvin Zhang, Jia-Zhong	Global Repeat Hydrographic/CO_2/Tracer Surveys in Support of CLIVAR and Global Carbon Cycle Objectives: Carbon Inventories and Fluxes	
Garzoli, Silvia Molinari, Robert	Surface Drifter Program	www.aoml.noaa.gov/phod/dac/ http://www.aoml.noaa.gov/phod/trinanes/java.html
Gill, Stephen Zervas, Chris	National Water Level Program Support Towards Building a Sustained Ocean Observing System for Climate	http://tidesandcurrents.noaa.gov http://www.co-ops.nos.noaa.gov/sltrends/sltrends.shtml
Hankin, Steve Feely, Dick Kozyr, Alex Peng, Tsung-Hung	An End-to-End Data Management System for Ocean pCO_2 Measurements	http://cdiac3.ornl.gov/underway/servlets/dataset http://mercury.ornl.gov/ocean/ http://www.ferret.noaa.gov/Ferret/LAS/CDIAC_LAS/
Harrison, Ed	Observing System Research Studies	
Kermond, John	Teachers at Sea	www.tas.noaa.gov
Kern, Kevin Hankin, Steve	Progress Report for the Observing System Monitoring Center (OSMC)	http://osmc.noaa.gov/OSMC/
McPhaden, Michael	An Indian Ocean Moored Buoy Array for Climate	ftp://ftp.marine.csiro.au/pub/meyers/Implementation%20Plan/
McPhaden, Michael	Pilot Research Moored Array in the Tropical Atlantic (PIRATA)	http://www.pmel.noaa.gov/pirata/ http://www.pmel.noaa.gov/tao/
Merrifield, Mark	The University of Hawaii Sea Level Center	http://uhslc.soest.hawaii.edu
Miller, Laury	Satellite Altimetry	http://ibis.grdl.noaa.gov/SAT/
Niiler, Peter	The Global Drifter Program	
O'Brien, James Smith, Shawn Bourassa, Mark	Climate Variability in Ocean Surface Turbulent Fluxes	http://www.coaps.fsu.edu/RVSMDC/SAC http://www.coaps.fsu.edu/RVSMDC/SAC/index.shtml

O'Brien, James Smith, Shawn Bourassa, Mark	U.S. Research Vessel Surface Meteorology Data Assembly Center	http://www.coaps.fsu.edu/RVSMDC/
Reynolds, Richard	*In situ* and Satellite Sea Surface Temperature (SST) Analyses	http://www.emc.ncep.noaa.gov/research/cmb/sst_analysis/
Richter-Menge, Jackie	Monitoring Ice Thickness in the Western Arctic Ocean	http://www.crrel.usace.army.mil/sid/IMB/
Rigor, Ignatius	Monitoring Eurasian Basin of the Arctic Ocean	http://iabp.apl.washington.edu/
Sabine, Chris Chavez, Francisco	High-Resolution Ocean and Atmosphere pCO_2 Time-Series Measurements	http://www.pmel.noaa.gov/co2/moorings/
Wanninkhof, Rik Feely, Richard Bates, Nicholas Millero, Frank Takahashi, Taro Cook, Steven	Document Ocean Carbon Sources and Sinks: Initial Steps Towards a Global Surface Water pCO_2 Observing System; Underway CO_2 Measurements on the NOAA ships Ka'imimoana and Ronald H. Brown and RVIB Palmer and Explorer of the Seas	http://www.aoml.noaa.gov/ocd/gcc http://www.pmel.noaa.gov/co2/uwpco2/ http://www.ldeo.columbia.edu/res/pi/CO2/
Weller, Robert Plueddemann, Albert	Ocean Reference Stations and Northwest Tropical Atlantic Station for Flux Measurement (NTAS)	WHOI: https://www.whoi.edu UOP Group: http://uop.whoi.edu Stratus Project: http://uop.whoi.edu/stratus NTAS Project: http://uop.whoi.edu/ntas WHOTS Project: http://uop.whoi.edu/hawaii
Weller, Robert Bahr, Frank Hosom, David	Implementation of One High Density XBT Line with TSG and IMET Instrumentation in the Tropical Atlantic (Atlantic VOS)	http://frodo.whoi.edu http://uop.whoi.edu/vos/

3.1a. Atlantic High Density XBT Lines

by Molly Baringer, Gustavo Goni and Silvia Garzoli

PROJECT SUMMARY

This program is designed to measure the upper ocean thermal structure in key regions of the Atlantic Ocean (Figure 1). The seasonal to interannual variability in upper ocean heat content and transport is monitored to understand how the ocean responds to changes in atmospheric and oceanic conditions and how the ocean response may feedback to the important climate fluctuations such as the NAO. This increased understanding is crucial to improving climate prediction models. Within this context, five XBT lines have been chosen to monitor properties in the upper layers of the Atlantic Ocean. The continuation of AX07 and AX10 and the implementation of AX08 and AX18 were recommended at the Meeting of the Ocean Observing System for Climate held in St. Raphael in 1999.

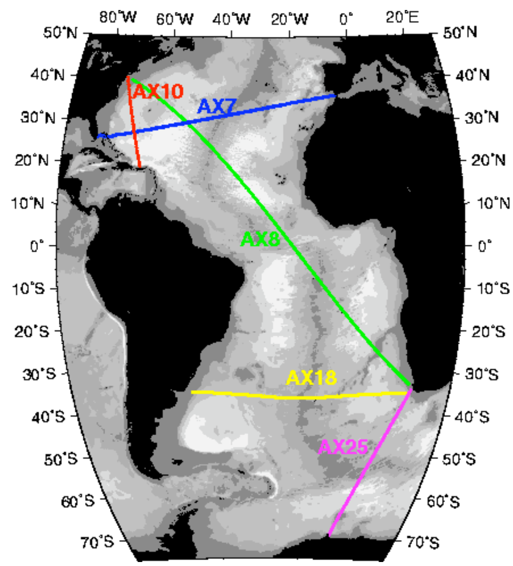

Figure 1. Location of high density XBT lines AX07, AX08, AX10, AX18, and AX25.

The high-density line AX07 is located nominally along 30°N extending from the Straits of Gibraltar in the eastern Atlantic to the east coast of the United States at Miami, Florida. This latitude is ideal for monitoring heat flux variability in the Atlantic because it lies near the center of the subtropical gyre, which has been shown to be the latitude of the maximum poleward heat flux in the Atlantic Ocean.

The high-density line AX10 is located between the New York City and Puerto Rico. This line closes off the United States eastern seaboard, where subtropical temperature anomalies could have the greatest interaction with the atmosphere. This line was chosen to monitor the location of the Gulf Stream and its link to the NAO.

The high-density line AX08, part of the Tropical Atlantic Observing System, crosses the tropical Atlantic in a NW-SE direction between North America and South Africa. Historical data along AX08 and other historical temperature observations in the tropics exhibit decadal and multidecadal signals. It has been hypothesized that this large time scale signal may cause atmospheric variability. Given the importance of the tropical Atlantic in climate variability, and the scarcity of observations in this region, data obtained from the measurements along this line are key to improve our understanding of the ocean and ability of climate forecast. Temperature profiles obtained from this line will help to monitor the main zonal currents and undercurrents in the tropical Atlantic and to investigate their spatial and temporal variability.

The high-density XBT line AX18, which runs between Cape Town and South America (Montevideo, Uruguay, or Buenos Aires, Argentina) is geared towards improving the current climate observing system in the South Atlantic, a region of poor data coverage. The main objective of this line is to monitor the meridional mass and heat transport in the upper 800 m across 30S. Given the importance of the South Atlantic and the scarcity of observations in this region, data obtained from the measurements along this line will be used to investigate the role of the South Atlantic in improving climate forecasts.

The AX25 line was implemented to measure changes in the variability in the upper layer interocean exchanges between South Africa and Antarctica on seasonal and interannual time scales. In addition, by exploiting the relationship between upper ocean temperature and dynamic height, XBTs can be used to infer velocities even in the Southern Ocean where salinity changes are important. In this way XBT sections can be used to measure changes in oceanic heat transport.

The global atmospheric and oceanic data from Ships of Opportunity (SOOP) have been the foundation for understanding long-term changes in marine climate. This program is a direct component of the NOAA's Program Plan for building a sustained Ocean Observing System for Climate and directly addresses one of its *milestones:*

- Occupy 41 volunteer observing ship (VOS) lines for high accuracy upper ocean and surface meteorological observations, by 2007 (Figure 2).

Figure 2. NOAA's Global Observing System for Climate.

The Global Ocean Observing System (GOOS) Center and its integral components, the Global Drifter Program (GDP) and Voluntary Observing Ship (VOS) XBT Program are both participating members of JCOMM and JCOMMOPS. The VOS XBT program is represented annually at the WMO/IOC Ship Observations Team (SOT) meeting. AOML presently Chair the Ship of Opportunity Implementation Panel (SOOPIP).

Responsible institutions:
NOAA/AOML is solely responsible for managing all aspects of this project. International partners collaborate in maintaining these lines: The Hydrographic Naval Office (SHN) of Argentina, the University of Cape Town, and the South African Weather Service are currently collaborating with this program.

Project web site:
http://www.aoml.noaa.gov/phod/hdenxbt/

Interagency and international partnerships:
Several agencies are currently collaborating with this project. The Argentine Hydrographic Office (SHN) provides the personnel to deploy the XBTs in AX18. The South African Meteorological Service is our contact in Cape Town and Durban to store the equipment in between transects and to provide ship riders.

Relation to the Ten Climate Monitoring Principles:
High-density line AX07 and AX10 have been maintained since 1994 and 1996, respectively, providing a homogeneous data set for almost a decade. Sustained observations from these and the other two high-density lines are required to have observations with adequate spatial and temporal resolution for climate studies. High-density observations in AX08, AX18, and AX25 provide data in poorly surveyed regions. Data are of easy access, interpretation and visualization. AOML has the facilities, personnel and infrastructure to maintain a stable, long-term commitment to these observations.

FY 2004 PROGRESS

Instrument/platform acquisitions for FY2004 and locations where XBTs were deployed:

Line	Number XBTs launched
AX07	1173(1)
AX08	1189(2)
AX10	425
AX18	725(3)
AX25	188

(1) Includes 143 XBTs deployed during September 2003, which were not included in last year's report. (2) Includes an estimate number of 300 XBTs from a recently finished transect that has not been processed yet. (3) Includes an estimate number of 180 XBTs from an underway transect.

The exact locations of XBT deployments are shown on the web page corresponding to each line (Figure 3).

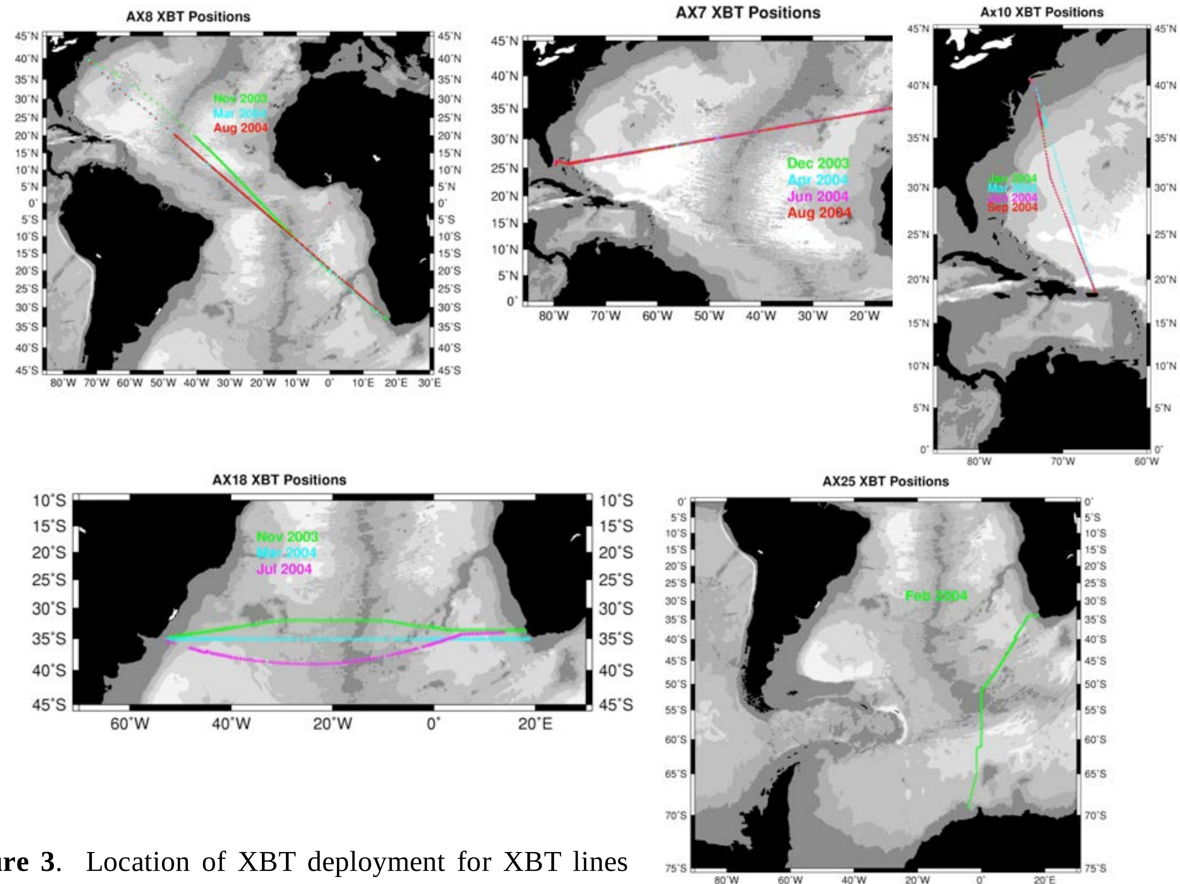

Figure 3. Location of XBT deployment for XBT lines AX07, AX08, AX10, AX18 and AX25

Data:
The temperature profiles specifications include depths from 0 to 750 m., although sometimes temperatures can be recorded as deep as 800 m. Data are stored on the computer system on the ships on which we have installed Shipboard Environmental data Acquisition (SEAS) Systems. The real-time data are transmitted via Standard C and are distributed on the GTS and the delayed mode or full resolution data are stored at the National Oceanographic Data Center (NODC). Data are also kept at AOML and provided through a web page approximately two weeks after each transect is finished.

Project Costs:
Please refer to the Proposed Budgets for information on anticipated and unanticipated project costs.

Ships of Opportunity:
These transects are occupied by *ships of opportunity.* The AX07, AX08, AX10, AX18, and AX25 transects last, in average, approximately 10, 17, 3, 11, and 15 days. We also provide information to them on how the data obtained from these high density cruises are used to improve weather and climate forecast.

The search for ships of opportunity remains an issue as ships constantly change routes. A major effort is required to contact Shipping Lines that cover the transects. The coordination necessary among multiple groups using ship facilities is handled by high-density personnel.

Research Highlights:
High density XBT data allows us to compute statistical information about the independent spatial scales that is necessary for data assimilation and mapping. Below is an example (Figure 4) of the decorrelation length scale determined along AX07 indicating that the spatial scales are depth dependent.

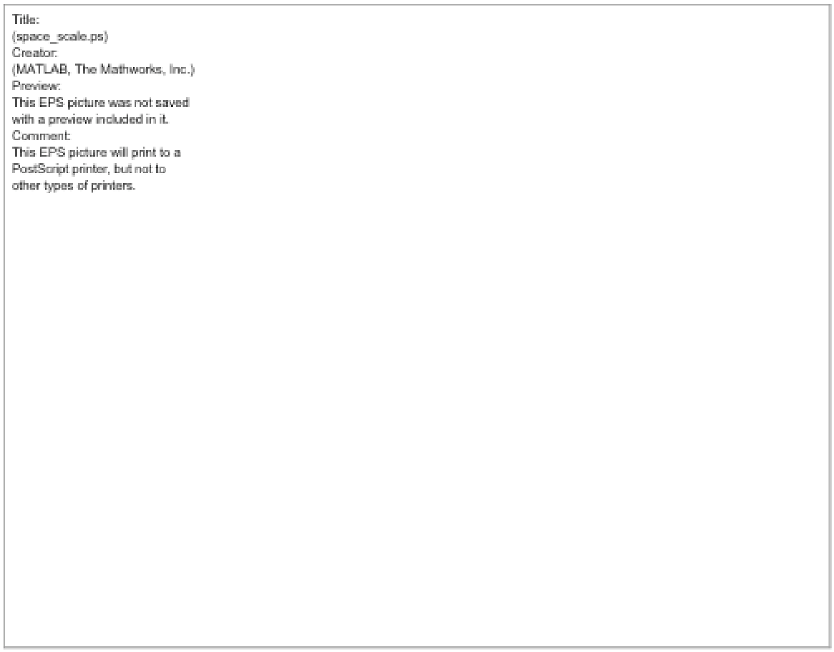

Figure 4. Decorrelation length scale (in km) as a function of depth for AX07. The solid line is the mean and the dotted line is the standard deviation.

The long time series available along some of the high density XBT lines allows us to examine decadal trends in subsurface (and surface) temperature anomalies. Below we show an example from AX10 of the temperature anomalies at 150 meters smoothed using a three-year running mean (Figure 5).

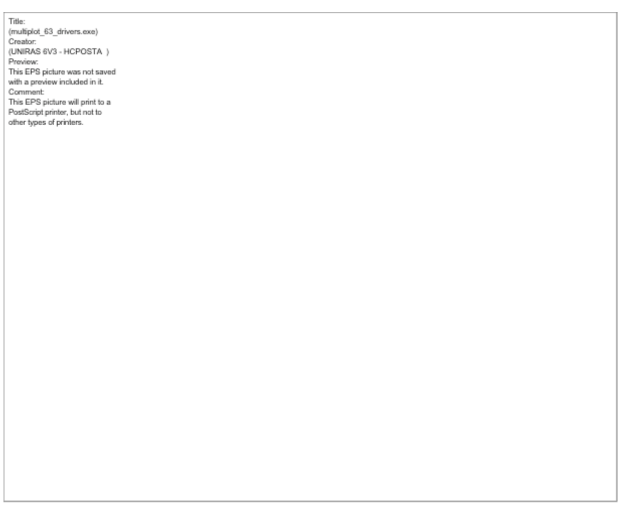

Figure 5. Sea surface temperature anomalies along AX10 showing a long time (decadal) signal.

Temperature sections from the AX08 transect are used to investigate the location, geostrophic transport and their variability of the main zonal upper ocean currents in the tropical Atlantic (Table 1).

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with a preview included in it.
Comment:
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PostScript printer, but not to
other types of printers.

Table 1. Upper ocean currents in the tropical Atlantic during the first three AX08 transects.

Data from the AX18 transect is currently being used to estimate the transport of the major western boundary currents (Brazil and Agulhas) and of rings shed by these current systems (Figure 6). These values are being compared with altimeter-based estimates.

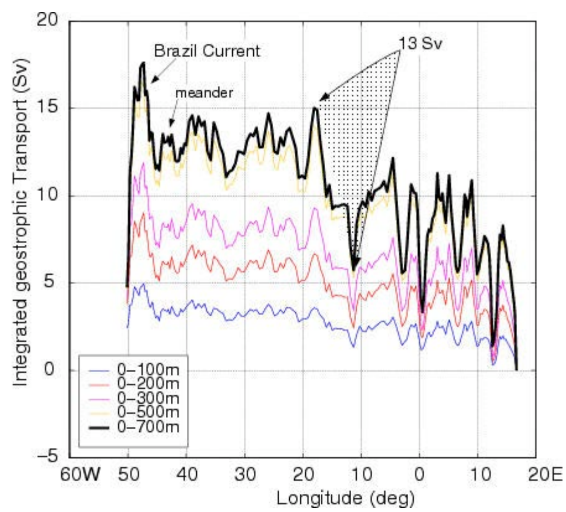


Figure 6. (a) The integrated water mass transport from west to east is computed for the July 2002 AX18 transect. The contribution from 5 layers from the surface to 100, 200, 300, 500, and 700 m relative to a zero flow at 800 m are shown.

3.2a. Western Boundary Time Series in the Atlantic Ocean

Project Managers: Molly Baringer and Silvia Garzoli
Scientists Involved: Molly Baringer, Christopher Meinen, Silvia Garzoli, and Elizabeth Johns

PROJECT SUMMARY

This program is included in one of the eleven components of the NOAA Global Ocean Observing System: Ocean reference stations. This project consists of two components to monitor the western boundary currents in the subtropical Atlantic: *Task 1:* Florida Current transport measurements using a submarine telephone cable plus calibration cruises, *Task 2:* Deep Western Boundary Current transport and property measurements using dedicated research ship time and moored instruments.

Scientific Rationale:

In the subtropical North Atlantic, the meridional overturning circulation consists primarily of two western boundary components: the northward flowing Gulf Stream and the southward flowing Deep Western Boundary Current. The Gulf Stream is the strong surface intensified flow along the east coast of the United States that brings warm waters of tropical origin northward along the eastern seaboard of the United States. The Gulf Stream also brings with it carbon, nutrients and tropical fish. It supplies warm waters along the coast that impact a multitude of important climate phenomena including hurricane intensification, winter storm formation and moderate European weather. The Gulf Stream includes the bulk of what we call the upper limb of the thermohaline circulation in the subtropical Atlantic, in addition to a strong wind-driven flow. As the Gulf Stream flows northward, it loses heat to the atmosphere until eventually in the subpolar North Atlantic some of it becomes cold enough to sink to the bottom of the ocean. This cold deep water then returns southward along the continental slope of the eastern United States as the Deep Western Boundary Current, continuing the circuit of the overturning circulation.

Off the coast of Florida, the Gulf Stream is referred to as the Florida Current and is fortuitously confined within the limited geographic channel between Florida and the Bahamas Islands, thus making a long-term observing system cost effective and sustainable. Similarly, the Deep Western Boundary Current is located within several hundred miles to the east of the Abaco Island, Grand Bahamas. The convenient geometry of the Bahamas Island chain thus allows an effective choke point for establishing a long term monitoring program of this deep limb of the overturning circulation.

Task 1: Transport of the Florida Current

This project maintains NOAA's well-established and climatically significant Florida Current volume transport time series. Over 20 years of daily mean voltage-derived transports have been obtained for the Florida Current using out-of-service and in-use cables spanning the Straits of Florida. The cable voltages can be converted to physically meaningful transport estimates, i.e. intensity of the flow, using electromagnetic induction theory and data from calibration sections. These transport measurements contain decadal changes on the order of 10-25% of the long-term mean transport and these decadal changes track the North Atlantic Oscillation Index. The strong correlation of Florida Current transport variability with the North Atlantic Oscillation by extension indicates a correlation with the large-scale sea-surface temperature patterns associated with the North Atlantic Oscillation. This suggests connections to tropical Atlantic variability on climatically significant time scales, and links with the numerous socially significant weather and climate phenomena that are thought to be related through large scale ocean-atmosphere patterns in the Atlantic, including decadal and interdecadal variations in fisheries, rainfall, and hurricane activity.

Funding provides for continuous collection of cable voltages (every minute) and automated processing of simple geomagnetic corrections. In addition to the cable measurements, quarterly calibration cruises are required for this project's success. These measurements complement a related project that measures the upper ocean thermal structure in the Atlantic through high-density VOS XBT observations. Funding provides for four two-day small charter boat calibration cruises on the R/V F. G. WALTON SMITH each year.

Task 2: Deep Western Boundary Current Time Series

Over the past 20 years a variety of snapshot sections and time series moorings have been placed along the continental slope east of Abaco Island, Grand Bahamas, in order to monitor variability of the transport carried by the Deep Western Boundary Current. The Abaco time series began in August 1984 when the NOAA Subtropical Atlantic Climate Studies Program extended its Straits of Florida program to include measurements of western boundary current transports and water mass properties east of Abaco Island, Grand Bahamas. Since 1986, over 20 hydrographic sections have been completed east of Abaco, most including direct velocity observations, and salinity and oxygen bottle samples. Many sections have also included carbon, chloroflourocarbon, and other tracers.

The repeated hydrographic and tracer sampling at Abaco has established a high-temporal-resolution record of water mass properties in the Deep Western Boundary Current at 26ºN. Events such as the intense convection period in the Labrador Sea and the renewal of classical Labrador Sea Water in the 1980's are clearly reflected in the cooling and freshening of the Deep Western Boundary Current waters off Abaco, and the arrival of a strong chlorofluorocarbon pulse approximately 10 years later. This data set is unique in that it is not just a single time series site but a transport section, of which very few are available in the ocean that approach a decade in length.

This task includes annual cruises across the DWBC to measure the water mass properties and transports and seeks to develop a cost effective method for long-term continuous monitoring of this flow. In a previous test project, from October 1995 to June 1997 three Inverted Echo Sounders (IES) were deployed adjacent to the sites of current meter moorings deployed by scientists from RSMAS/UM (Johns et al. 2004). The objective of the IES deployments was to study the possibility of establishing a low cost monitoring system to replace the current meter moorings and to extrapolate the hydrographic data over the spans between cruises. Analysis of the data (Meinen et al. 2004), demonstrated that through a combination of IES, pressure gauges and hydrographic data, the DWBC transport and the Antilles Current can be accurately monitored. Based on these results, 3 PIES (PIES: IESs additionally equipped with bottom pressure gauges) funded by OCO (one also equipped with a current meter, a C-PIES) were deployed along the Abaco line. These instruments are designed so that the data can be collected via acoustic telemetry from a passing ship without recovering the instruments. It is expected that the data will be collected every 6 to 12 months, depending on the number of cruises. In addition to the PIES funded by OCO, 2 additional instruments (one IES and 1 PIES) were deployed. These instruments do not have the acoustic telemetry capability; funding permitting the instruments may be upgraded in the future. This project is part of an interagency and international partnership, RAPID/MOCHA, and over the next four years the combination of RAPID/MOCHA along with the NOAA funded WBTS project will allow us to visit our new moorings sites twice each year.

These continued time series observations at Abaco are seen as serving three main purposes for climate variability studies:

- Monitoring of the DWBC for water mass and transport signatures related to changes in the strengths and regions of high latitude water mass formation in the North Atlantic for the ultimate purpose of assessing rapid climate change.
- Serving as a western boundary endpoint of an international subtropical meridional overturning circulation (MOC)/heat flux monitoring system designed to measure the interior dynamic height difference across the entire Atlantic basin and its associated baroclinic heat transport.
- Monitoring the intensity of the Antilles Current as an index (together with the Florida Current) of interannual variability in the strength of the subtropical gyre.

How this project addresses NOAA's Program Plan for *Building a Sustained Ocean Observing System for Climate*:

The program plan for "Building a Sustained Ocean Observing System for Climate" includes the objectives of:

1) Documenting the heat uptake, transport, and release by the ocean; and
2) Documenting the air-sea exchange of water and the ocean's overturning circulation.

This project is one component of the "Ocean Reference Station" at approximately 26ºN in the Atlantic Ocean that specifically addresses these goals by providing long-term measures of two components of the global thermohaline (overturning) circulation. Long-term monitoring of key choke points, such as the boundary currents along the continents including the Gulf Stream and the Deep Western Boundary Current, will provide a measurement of the primary routes of ocean heat, and mass transport and hence include the bulk of the Meridional Overturning Circulation.

How this project is managed in cooperation with the international implementation panels, in particular the JCOMM panels:

This program is managed under the AOML Global Ocean Observing System (GOOS) Center, created in cooperation with national and international steering committees to provide an administrative umbrella that coordinates several operational oceanographic data collection networks. As part of GOOS, this program falls within the Observations Program Area of the Joint Technical Commission for Oceanography and Marine Meteorology (JCOMM) where the AOML GOOS center is a participant.

Responsible institutions for all aspects of project:

NOAA/AOML is responsible for this project.

Project web site URL and pertinent web sites for your project and associated projects:

http://www.aoml.noaa.gov/phod/floridacurrent/

Interagency and international partnerships:

This project provides the cornerstone observations required for a national and international pilot program to develop an observing system to monitor the intensity and heat transport of the overturning circulation at 26ºN in the Atlantic. NOAA provides the essential Florida Current component of the monitoring system, direct hydrographic observations of the DWBC and its history since 1984 east of Abaco Island, Grand Bahamas, repeated high density lines at a nearby latitude, plus ship time that doubles the temporal sampling for both programs. Partners in this project include the National Science Foundation sponsored Meridional Overturning, Circulation and Heat transport Array (MOCHA) proposal to the University of Miami, the United Kingdom's National Environmental Research Council (NERC) sponsored Rapid Climate Change Program proposal to the University of Southampton (England) and the Woods Hole Oceanographic Institution.

Project management and the Ten Climate Monitoring Principles:
This program is managed in accordance with the Ten Climate Monitoring Principles (Program Plan, Mike Johnson 2003). This time series contains several gaps in the continuous record due to logistical requirements, funding shortfalls and, more recently, to instrument failure. To assure an adequate climate record, parallel testing and parallel measurements would be required to assure continuity of the time series without gaps. ‘Data quality and continuity’, principle 4 of the ten climate monitoring principles, and ‘data and metadata access’, principle 10, have suffered as a direct result. We request additional funds in “*Budget Justification*” to address these deficiencies and assure a better research quality time series.

FY 2004 PROGRESS

Instrument/platform acquisitions for fiscal year and where equipment was deployed:

Task 1: Continuous transport of the Florida Current

Recording instruments are located at Eight Mile Rock, Grand Bahamas Island. At Eight Mile Rock and in West Palm Beach, Florida, electrode equipment is in place, securing a stable reference voltage (i.e. grounds) at either end of the submerged telephone cable owned by AT&T. The monitored cable can be seen in Figure 1, stretching across the Florida Straits. Data acquisition has continued without incident until August 31, 2004 when Hurricane Frances and then Hurricane Jeanne substantially damaged infrastructure to the Bahamas including telephone service and electricity. The building with the recording equipment lost its roof and the equipment appears to have been shorted out by excess water. As a result of this dramatic occurrence, some data are likely to be unrecoverable. An upcoming trip to the Bahamas will ascertain the extent of the damage. This FY has seen considerable progress in quality control of the calibration section data and the cable transport data including de-tiding cable transports and section data and preliminary analysis of geomagnetic signal removal. Cable voltages are recorded every

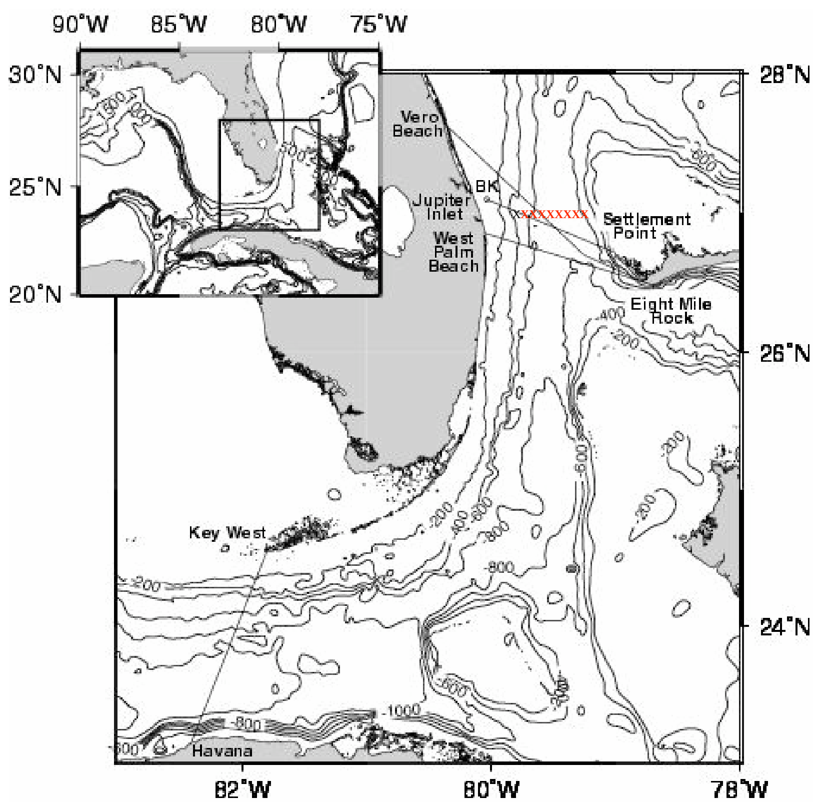


Figure 1: Location of submarine telephone cables (solid black) and nine stations (red) occupied during calibration cruises.

minute, hourly averaged and post processed to form daily transport estimate. The Table 1 below shows the number of hourly averaged voltage measurements.

FY 2004	FY 2003	FY 2002
7632 Hours 87% Return	7755 Hours 89% Return	6264 Hours 72% Return[1]

Table 1: Data return from continuous cable voltages (% Return based on the maximum number of hours possible in one year: e.g. 8760 for non-leap years and 8784 for leap years like 2004).

Planned Cruise	FY 2004	FY 2003	FY 2002
1	9-Dec-2003	- clearance problems	- weather problems
2	16-Dec-2003	- clearance problems	Dec 14, 2001
3	9-Jan-2004	- equipment problems	Mar 12, 2002
4	13-Jan-2004 – GPS failure on two stations	18-Mar-03	Mar 18, 2002
5	7-May-2004	June 7, 2003 – dropsonde failure	June 3, 2002
6	24-May-2004	- no dropsonde	June 6, 2002
7	Jun 7, 2004	- no dropsonde	Aug 23, 2002 – dropsonde lost
8	Jun 11, 2004	- no dropsonde	
9	Aug 24, 2004		
10	1-Sep-2004 - GPS antenna failure		
	80% successful[2]	13% successful[3]	63% successful

Table 2: Cruise dates for 1-day small boat calibration cruises using dropsonde instrument.

Small charter boat calibration trips

A total of ten 1-day surveys were conducted using a dropsonde profiler. Typically eight cruises are scheduled per year, but additional cruises were carried out this year due to scheduling and equipment problems from last FY. Measurements are taken at nine stations (shown in Figure 1) and include vertically averaged horizontal velocity, surface velocity and expendable temperature probes (XBTs). The cruise dates are shown in Table 2.

New equipment was purchased by AOML base funds this FY to build a new dropsonde after the loss of the previous dropsonde on August 23, 2002. The new purchases included a self-recording conductivity, temperature depth (CTD) recorder, GPS, radio transmitter, glass pressure housing, batteries and antennae.

[1] Note old recording system failed in FY 2002.
[2] Two additional cruises were planned for FY04 due to dropsonde failures in FY03.
[3] Sections missing due to: dropsonde failure (4) and clearance problems (2).

Full Water Column calibration cruises:
Four 2-day cruises on RV Walton Smith were conducted. All cruises include nine stations with full water column CTD, lowered ADCP, and continuous shipboard ADCP. The station locations are the same as those shown in Figure 1. Table 3 below includes the cruise dates and number of water samples taken for oxygen concentration (O_2) and salinity (S).

New equipment acquired this FY included the fabrication of a small CTD frame.

FY 2004		FY 2003	
Date	Water Samples	Date	Water Samples
Jan 8-9, 2003	55 O2, 46 S	Nov 20, 2002	43 O2, 44 S
May 6-7, 2004	47 O2, 43 S	Mar 22, 2003	59 O2, 49 S
July 4-5, 2004	56 O2, 46 S	July 16, 2003	56 O2, 46 S
Aug 27-28, 2004	55 O2, 42 S	Oct 2-3, 2003	57 O2, 43 S
100% of Planned Cruises		100% of Planned Cruises	

Table 3: Cruise dates for 2-day calibration cruises on the RV Walton Smith.

Task 2: Deep Western Boundary Current time series
A full water column cruise of CTD, Lowered ADCP on the NOAA Ship RONALD H. BROWN (one per year scheduled) was conducted within the Florida Straits and east of Abaco Island, Bahamas. At each station, a package consisting of a Seabird Electronics Model 9/11+ CTD O_2 system, RDI Lowered Acoustic Doppler Current Profilers, and 24 ten-liter Niskin bottles, was lowered to the bottom. This provided profiles of velocity, pressure, salinity (conductivity), temperature, and dissolved oxygen concentration. Water samples were collected at various depths and analyzed for salinity and oxygen concentration to aid with CTD calibration.

The hydrographic cruise this year took place on the NOAA Ship RONALD H. BROWN from September 21 to October 3, 2004. A total of 41 stations were occupied at the locations shown in Figure 2. Table 4 lists the cruise dates and bottle samples taken compared to previous years. Five inverted echo sounders (IES) were deployed as shown in Figure 2 including: one IES, three IES with pressure sensors (PIES) and one IES with pressure sensor and bottom current meter (C-PIES). A new shipping container (10 feet by 10 feet by 8 feet) was acquired to aid in equipment storage and delivery to the ship.

FY	Date	Stations	Bottle Samples	Comments
2004	Sep, 2004	42	634 O2, 629 S	5 IES mooring deployments
2003	Feb, 2003	54	844 O2, 843 S	3 IES Mooring recoveries, Short Seabeam in Florida Straits
2002	June 2002	57	924 O2, 924 S	Extended Seabeam survey east of Abaco Island, SF6 samples.
2001	2001	33	607 O2, 659 S	4 IES mooring deployments

Table 4: Cruise dates and water samples taken for Large Vessel full water column surveys of the Deep Western Boundary Current.

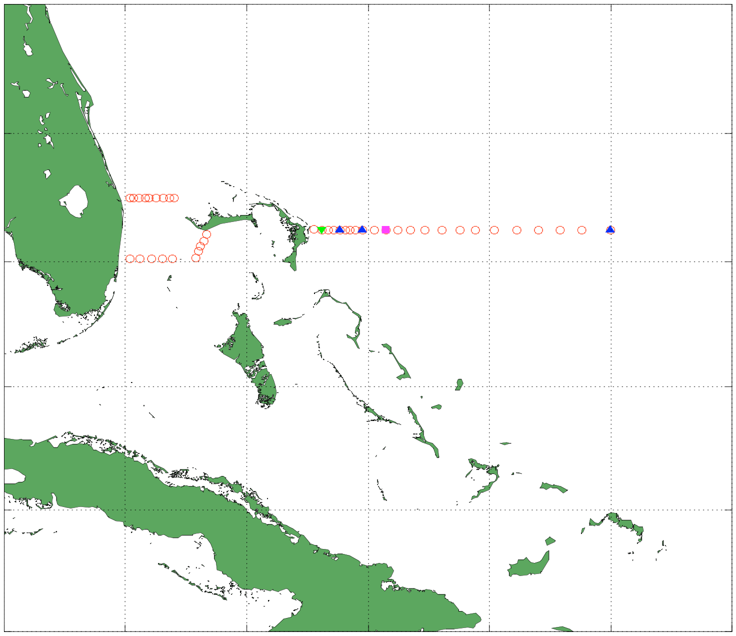


Figure 2: Locations of full water column hydrographic stations sampled on the NOAA Ship Ronald H. Brown cruise in FY 2004. Red circles denote CTD sites. Blue and green triangles denote PIES and IES moorings respectively, while the pink square denotes a C-PIES mooring.

Where data are stored, data distribution, availability and access to data:
All data are stored at AOML and are available upon request. Cable data are collected and stored on a computer in the Bahamas and downloaded daily to AOML. Preliminary cable data are available via web interface upon request and will be more freely available once the new calibration system is operational. CTD data will be distributed to NODC and the WOCE hydrographic program office when final calibration is complete.

How data are currently being used and shared:
Small boat calibration data are processed to supply a total transport of the Florida Current and are used to check the cable voltage measurements. Water bottle sample data are used to calibrate CTD data, to compute property fluxes within the Deep Western Boundary Current and Florida Current. Water properties of the Deep Western Boundary Current are used to infer time scales of deep-water renewal and monitor the intensity of the thermohaline circulation. All data are stored at AOML and are freely available upon request.

Task 1, Continuous cable voltage recording: Unanticipated costs included substantial processing time to quality control the voltage data to produce transport numbers. See "*Budget Justification*" for further details. Recent equipment damage may result in additional unanticipated costs.
Task 1, Calibration cruises: Additional unanticipated and unfunded costs included the loss of the dropsonde equipment in 2003 that required a replacement, purchased by AOML. We have been borrowing the University of Miami's CTD package, frame, rosette and bottles because our large frame is too big for the RV Walton Smith. This year we began the process of building our own small CTD frame.
Task II, DWBC Time Series: No additional costs incurred.

Problems encountered:

Task 1, Continuous cable voltage recording: Problems include only the recent loss of electricity and phone service in the Bahamas after the passage of Hurricanes Frances and Jeanne. The equipment may have been damaged when the building lost its roof. An upcoming visit will ascertain the extent of the damage and determine what repairs are necessary.

Task 1, Calibration cruises: Problems included the failure of the new dropsonde to accurately record GPS positions in August. We suspect this was due to a new antenna design and the increasing sea-state due to the approach of Hurricane Frances.

Task II, DWBC Time Series: Hurricane Jeanne cut short several stations within the Florida Strait and along the eastern most end of the DWBC section. The NOAA Ship Ronald H. Brown delayed departure from Charleston for 34 hours due to engineering and staffing issues that resulted in fewer Sea Days than requested assigned to the project.

Logical considerations (e.g., ship time utilized):

- Clearances to do technical work in the Bahamas to the recording equipment are necessary and very difficult to obtain.
- Blanket clearances are necessary to work on calibration cruises due to the short lead-time for scheduling the cruises.
- Bahamian clearances for the large ship Deep Western Boundary Current cruises are also necessary.
- This work would not be possible without the considerable help of BattelCo, the Bahamian telephone company, for the use of their facilities to store our equipment, install phone lines and to instrument their telephone submerged cable.
- Ship days required:

Ship	Seadays per trip	Trips per year	Total Seadays (including weather days)
NOAA Ship Ronald H. Brown	14	1	16
RV Walton Smith	2	4	10
Charter Fishing Boat	1	8	10

Research highlights:

<u>Task 1: Continuous transport of the Florida Current</u>

Voltage estimates recorded from the submarine cable were corrected for geomagnetic variations due to the changing ionosphere and then adjusted using the transfer function that relates voltages to total flow through the Florida Straits (Larsen, 1992). Preliminary estimates of the flow are shown in Figure 3 and are available on the project web site. Several features of note appear to be related to the failure of the reference electrode at Eight Mile Rock, Grand Bahamas. Data gaps in the record will remain until personnel become available to recover the data.

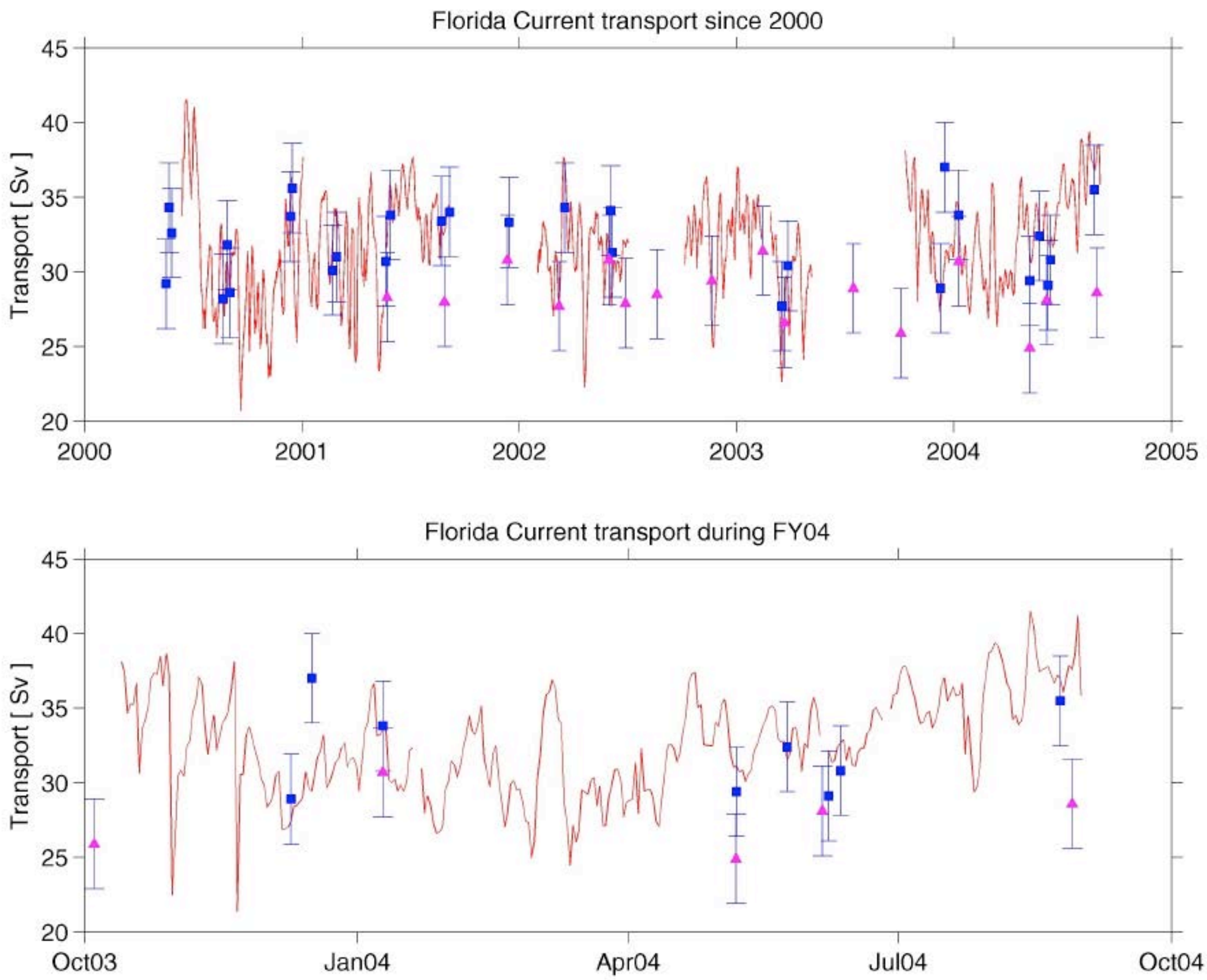
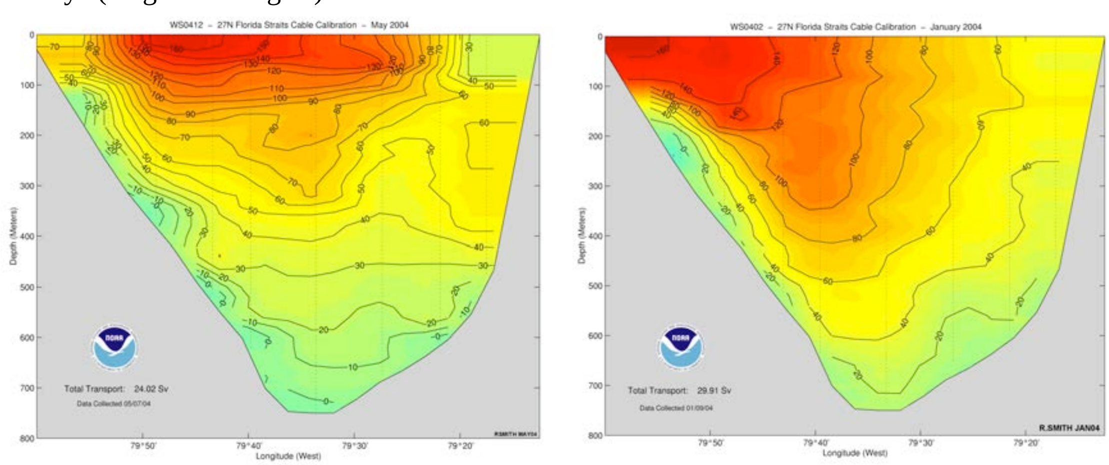


Figure 3: Daily estimates of Florida Current transport determined by voltages induced on a submarine telephone cable. Transports are given in Sv (1 Sv = 10^6 m^3 s^{-1}). Symbols with error bars represent calibration cruises from: small charter boats (blue squares) and full water column surveys (magenta triangles).



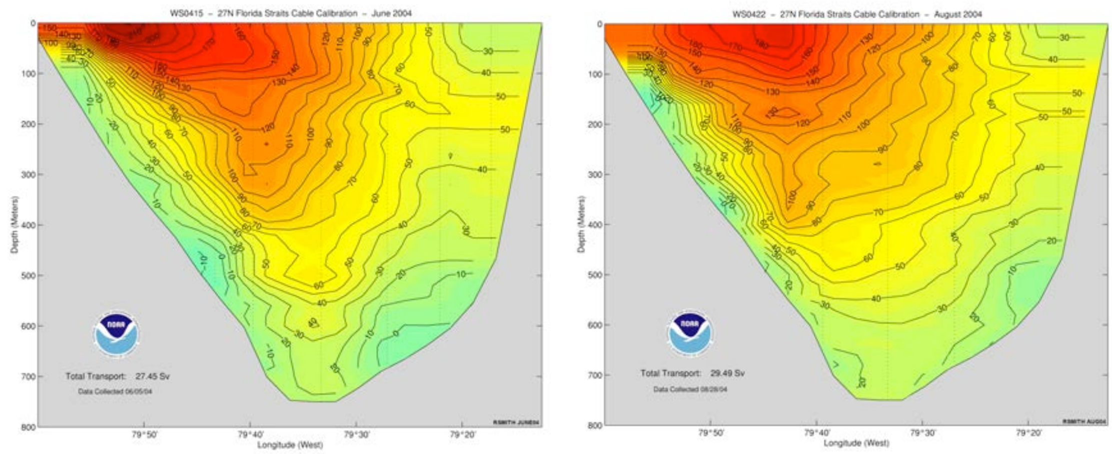


Figure 4: Full water column calibration cruises show the complex vertical structure of the Florida Current.

Task 1: Florida Current calibration cruises

Calibration cruises show transports of the Florida current varying from 26.9 to 30.8 Sv. Note that, the current is not always monotonically northward. A subsurface southward flow between 150 to 500 meters deep along the western side of the Strait can be seen in several of the full water column sections.

Task 2: Deep Western Boundary Current Time Series

Full water column Deep Western Boundary Current CTD/LADCP sections show the arrival of newly formed Labrador Sea water in the center of the subtropical gyre (T<3.7ºC, S < 34.98) beginning in late 1994 (Figure 5). Since its first arrival, the Labrador Sea Water is seen to become progressively colder and fresher and its influence is felt further and further offshore.

In preparation for the inverted echo sounder deployments in FY 2004, a preliminary test of the use of PIES for measuring the variability of the Deep Western Boundary Current and the Antilles Current utilizing three inverted echo sounder records (IES) and two bottom pressure records (BPR) from 1996-1997 was completed. Comparisons are shown between transports estimates derived from the IES and BPR (Figure 6) showing excellent agreement with the more expensive and traditional current meter moorings (Meinen *et al*. 2004).

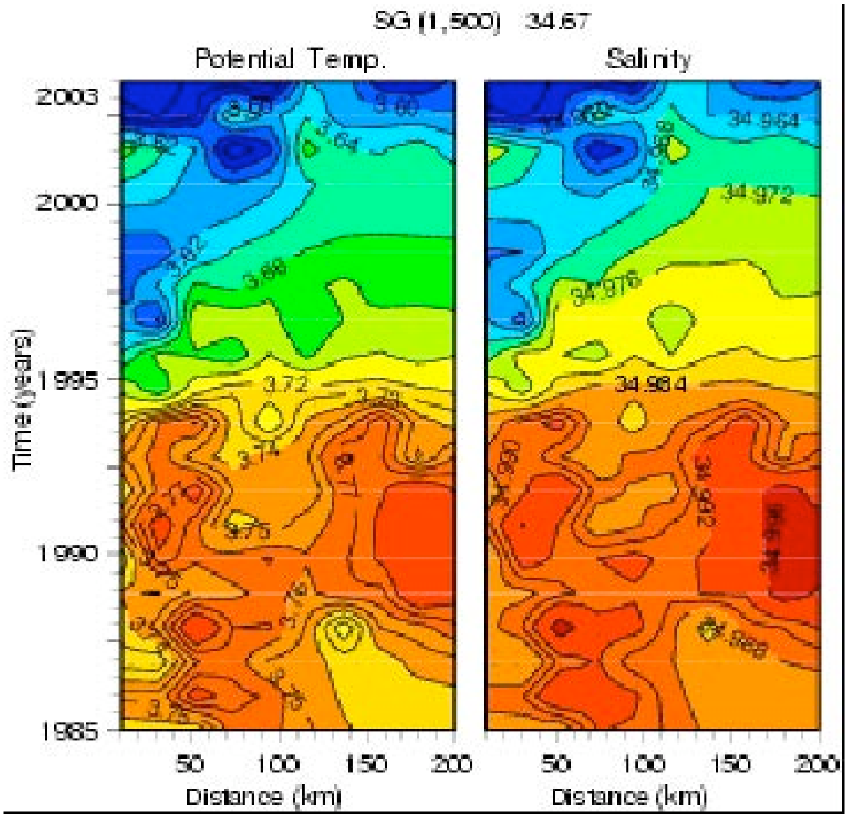


Figure 5: Potential temperature and salinity time series within the Deep Western Boundary Current off Abaco Island, Grand Bahama on the density surface representative of the Labrador Sea Water ($_{1.5}$ = 34.67, approximately 1700 meters). The time series shows the arrival of cold, fresh Labrador Sea Water in late 1994, which steadily extends offshore through the 2003 cruise.

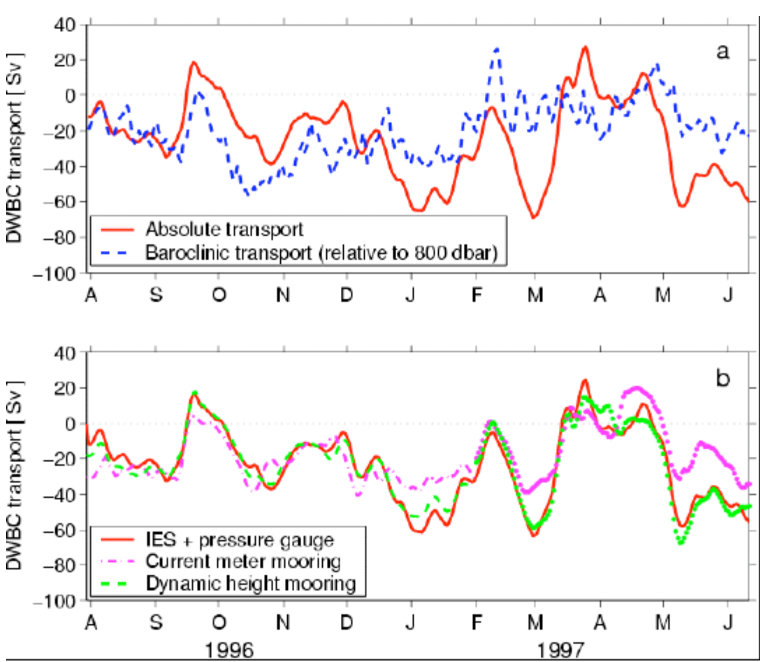


Figure 6: Transport of the Deep Western Boundary Current offshore of Abaco Island. a) Baroclinic transport, relative to an assumed level of no motion at 800 dbar, and absolute transport integrated between 800 dbar and 4800 dbar and between mooring sites B and D. b) Absolute transport from the IES combined with the bottom pressure measurements compared to absolute transport integrated from the observations of the coincident current meter line. Because the current meter data were only available at 1200 dbar and below, the transports in this panel are integrated only over 1200-4800 dbar. Also shown is the transport determined by calculation dynamic heights from the temperature sensors

moored alongside the current meters, utilizing the same bottom pressure sensors for the barotropic reference as were used with the IES data. Current meter and dynamic height mooring estimates are dotted after February 1997 because the mooring at site B lost its top portion at that time. Units are in Sverdrups (1 Sv = 10^6 m^3 s^{-1}).

3.3a. The Tropical Atmosphere Ocean (TAO) Array

by Landry J. Bernard, III and Daniel J. Laurent

PROJECT SUMMARY

This continuation proposal requests funds to maintain the Tropical Atmosphere Ocean (TAO) array as part of NOAA's effort to "Build a Sustained Ocean Observing System for Climate". TAO is the U.S. contribution to the TAO/TRITON array, a network of moored buoys spanning the tropical Pacific Ocean maintained in partnership with the Japan Marine Science and Technology Center (JAMSTEC). TAO/TRITON supports NOAA's strategic plan goal to "Understand Climate Variability and Change to Enhance Society's Ability to Plan and Respond." It also underpins Climate Variability and Predictability (CLIVAR) research efforts on El Niño/Southern Oscillation (ENSO). Management of the array is consistent with the "Ten Climate Monitoring Principles". Program oversight at the international level is through the CLIVAR/JCOMM Tropical Moored Buoy Implementation Panel (TIP). A web site containing comprehensive information on both programs can be found at http://www.pmel.noaa.gov/tao/.

<u>FY 2004 PROGRESS</u>

TAO/TRITON Array

Background:

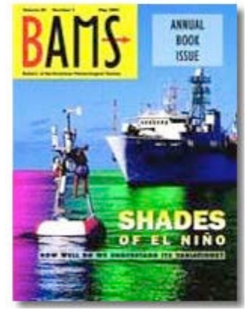
FY 2004 was the fourth full year of the combined TAO/TRITON array and the partnership with JAMSTEC is working well. NOAA maintains the portion of the array between 95°W and 165°E, while JAMSTEC maintains sites between 156°E to 138°W. JAMSTEC added three moorings along 130°E for its own purposes in FY 2002, though these moorings complement those of the TAO/TRITON array proper. Basic measurements from ATLAS and TRITON buoys are transmitted on the GTS and are merged into a unified data set available on the World Wide Web at PMEL (http://www.pmel.noaa.gov/tao/) and a mirror site in Japan (http://www.jamstec.go.jp/jamstec/TRITON).

TAO Project Highlights:

At present, TAO/TRITON data indicate the development of weak El Niño conditions in the tropical Pacific. Forecast models, many of which depend heavily on TAO/TRITON data for initialization, suggest that warming will continue into early 2005. As a consequence, weather patterns in the US and elsewhere around the world are likely to be affected as El Niño-related atmospheric teleconnections emanate from the tropical Pacific to affect the general circulation of the atmosphere. Pacific marine ecosystems and commercial fisheries may likewise be affected.

In December 2003, the TAO Project Office was awarded the 2003 Grace Hopper Government Technology Award ("Gracie Award") for "Leadership in the innovative application of information technology that contributes to the advancement of scientific knowledge and its application." The Grace Hopper Government Technology Leadership Awards are sponsored by Government Executive magazine and selected by a panel comprised of leading experts on the federal government's use of technology, drawn from government, prominent federal contractors and the academic community.

The TAO Project was highlighted on the cover of the May issue of the *Bulletin of the American Meteorological Society*. The cover story, authored by the Project Director, highlighted how far we have come, and how far we have yet to go, in our ability to understand and predict El Niño. The importance of sustained observations in the tropical Pacific was a central theme of the article.



Fieldwork:
PMEL is responsible for maintaining 55 ATLAS sites at and east of 165°E. At four of these sites (165°E, 170°W, 140°W, 110°W along the equator) current meters are attached to the ATLAS mooring lines and a nearby subsurface ADCP mooring is deployed. An ADCP mooring is maintained by JAMSTEC at 0°, 147°E. During the past year, the TAO Project deployed 63 ATLAS moorings and 4 subsurface ADCP current meter moorings in the tropical Pacific. The number of ATLAS deployments exceeds the number of ATLAS sites in the array because of mooring system failures or losses during the year, because some sites (like the equatorial current meter mooring sites at 110°W and 140°W) are turned around regularly on a 6-month rather than 12-month schedule and because cruise schedules are such that some moorings are deployed for slightly shorter than their 12-month design lifetime. There was also one ATLAS deployment for engineering development purposes included in these totals. For comparison, in FY 2003, 71 ATLAS (including 3 for EPIC) and 5 subsurface current meter moorings were deployed in the TAO array.

Ship Time and Sea Time:
In FY 2004, 264 days at sea were required to support the TAO portion of the TAO/TRITON array (221 days on the Ka'imimoana and 43 on the Ron Brown) a total of 688 PMEL person days at sea (number of people times days at sea) in support of TAO field work were required during FY 2003. For comparison, 267 days at sea (232 days on the Ka'imimoana and 35 on the Ron Brown) and a total of 658 PMEL person days at sea in support of TAO fieldwork were required during FY 2003. The increase in person days in FY 2004 was due mainly to PMEL sending the TAO Field Operations Manager to interact with NDBC personnel performing DART work from a TAO cruise.

Real-time Data Return:
Percentage real time data return for primary TAO variables integrated over all 55 sites for FY 2004 was as follows:

	AIRT	SST	T(Z)	WIND	RH	ALL
FY 2004	88	88	89	76	89	88
FY 2003	90	88	85	75	88	85

Real time data return for the entire TAO/TRITON array (including JAMSTEC TRITON moorings) was 86% for primary variables. Data return from the most recently recovered PMEL ADCPs in FY 2004 was effectively 100% at the four equatorial sites. For comparison, ATLAS data return from FY 2003 is shown in the above table. The returns for surface sensors are comparable, with relatively insignificant changes of ≤2%. Subsurface temperature data returns improved significantly (4%) in FY 2004, due to improvements in inductive telemetry hardware.

Subsurface temperature data comprise more than 70% of primary data, thus the increase in their data return resulted in a significant (3%) increase in overall data return.

After mooring recovery, data recorded on board the buoy are available and may augment data not available in real time. For this reason, combined delayed mode and real time data return for primary TAO sensors in FY 2003 was 92%, representing an increase over real time alone of 7%. Not all internally recorded data have been recovered yet for FY 2004. However, a partial accounting indicates an increase to the database of about 3% so far, for an overall data return of 91%. This number may further increase once a full accounting is possible.

Wind data return is lower than that for other sensors due to two factors. First, the sensor's placement at the top of the mooring exposes it to increased vandalism potential. Secondly, the wind sensors have a higher failure rate compared to other instruments. The failure is mainly in the vane circuitry and has been isolated to a single component. Consultation with the manufacturer has suggested that the grounding the sensor may improve reliability. Redesign and testing of the ATLAS wind system to provide grounding was completed in FY 2003 and all new mooring deployments in FY 2004 will have ground wind sensors.

In addition to primary ATLAS variables, additional measurements were made as part of research efforts supported by other programs. These measurements include ocean velocities, rain rate, salinity, shortwave and longwave radiation, and barometric pressure. These data are distributed via TAO web pages. TRITON sites also measure rain rate, shortwave radiation, and ocean velocity (at 10 m).

Shipboard Measurements:
CTD casts, and underway ADCP and thermosalinograph measurements, are conducted from mooring servicing cruises on the Ka'imimoana and Ron Brown. These data are an integral part of the TAO Project, providing in situ calibration checks on mooring sensor performance. They also provide hydrographic and current field information that helps to put the moored time series measurements into a broad scale hydrodynamic context. The data are a valuable resource for climate model development and climate analyses, and are frequently used together with moored times series data in scientific publications.

A total of 400 CTD casts (338 on the Ka'imimoana and 62 on the Ron Brown) were made on TAO cruises in FY 2004, which was a small increase over FY 2003 (383, with 338 from the Ka'imimoana and 45 from the Ron Brown). The shipboard ADCP data are forwarded to, processed, archived, and distributed by Eric Firing and colleagues at the University of Hawaii. Underway sea surface salinity measurements are processed at PMEL, then forwarded regularly to the IRD laboratory in Noumea for distribution (by CD-ROM) with other sea surface salinity data (http://www.ird.nc/ECOP/siteecopuk/cadres.htm).

Problems with the shipboard ADCP data quality from the NOAA Ship Ka'imimoana identified by Eric Firing and colleagues in FY 2003 were addressed by the installation of a new 75 kHz RDI Ocean Surveyor ADCP and a POS/MV attitude sensor in FY 2004. Initial analysis of the data by the University of Hawaii indicates that the new system is working well and data quality has improved.

Engineering Tests:
There was one ATLAS deployment for engineering development purposes at 5°N, 140°W in September 2003. This mooring was deployed to test two types of sonic anemometers for possible replacement of the RM Young propeller and vane assembly, namely the Handar WS425

Ultrasonic and the Gill model Windsonic. The system also included a KVH C100 compass, as a possible replacement for an older model KVH which has been problematic on some ATLAS systems. The field test also includes a standard wind RM Young wind sensor for comparison. Preliminary results were encouraging and were reported at the OCO Annual System Review and the 2nd High-Resolution Marine Meteorology (HRMM) Workshop, both in April 2004 in Silver Spring, MD. The mooring was recovered in May 2004 and analysis of high temporal resolution data from the system is planned. Sonic anemometers and new compasses require significantly more power than the present ATLAS system. Inclusion of these sensors into a 3^{rd} generation ATLAS system may include increased battery packs, conversion from alkaline to lithium batteries, and/or reduction in sampling frequency or duration.

Another engineering effort to improve wind data return was to ground the existing R.M. Young anemometers. This required new connectors, modification of the ATLAS system mast, internal wiring and top section cable. Several modified systems were deployed in FY 2004 including reinstrumentation of the test mooring at 5ºN, 140ºW and deployment of a second test mooring at 2ºN, 140ºW. Wind data from the test systems were comparable to that from the non-grounded systems, and no vane circuitry failures (as noted in 2.5 above) occurred. Based on these results, the decision to ground all systems deployed in FY 2005 was made.

The Project participated with the University of Washington and Aeromet, Inc., to compare several precipitation gauges on Kwajalein Atoll. The experiment, which began in July 2003 and continued through December 2003, compared the sensor used on TAO and PIRATA moorings (R.M. Young model 50203-34, modified for use with the ATLAS system) with other gauges (Tipping bucket, Hasse, Disdrometer). Results of the intercomparison were presented at the Eighth International Conference on Precipitation in Vancouver B.C. in August 2004, by Dr. Sandra Yuter of the University of Washington. The conclusions included the fact that all sensors yielded similar results when daily accumulations were greater than or equal to 10mm.

PMEL is also testing a modified TAO rain gauge designed to decrease spiking found in the present version gauge. Preliminary results indicate that the modifications have improved the sensor performance. Testing and analysis of modified systems will continue in FY 2005.

We investigated the feasibility of measuring a high vertical resolution current profile in the upper 50m from an ATLAS mooring. Initial results indicate that the presence of fish around a surface mooring will significantly bias the data. While disappointing, this result will factor significantly into plans for other research investigations such as PUMP. Use of high vertical resolution current profilers from other mooring systems may still be considered.

Guest Investigator Research Projects Using TAO Moorings and TAO Cruises:
One of the primary missions of the TAO/TRITON array is to provide real-time data for improved detection, understanding, and prediction of El Niño and La Niña. The primary function of the NOAA Ship Ka'imimoana is to service buoys of the TAO/TRITON array. However, the TAO Project Office actively promotes use of the Ka'imimoana and, when it is used for TAO cruises, the Ron Brown for other meritorious scientific investigations that are of relevance to NOAA's mission. These projects are developed, funded, and lead by investigators from NOAA laboratories, other national research laboratories, and academia. Two categories of ancillary projects are described which are (a) ongoing and (b) one-time. An ongoing project is either planned or has been onboard already for more than one year. A list of PIs, their institutions and project titles are itemized below. The name of the ship from which the work is done (KA or BROWN) is indicated in parentheses.

a. Ongoing ancillary projects on TAO cruises for FY 2004:

Project, Principal Investigator, Institution (Ship)

Underway CO_2, Richard Feely, NOAA/PMEL (KA and BROWN)

Turbulent flux measurements and wind profiler, Chris Fairall and Jeff Hare, NOAA/ETL (BROWN)

Atmospheric monitoring, balloon radiosonde profiles, Nick Bond, NOAA/PMEL (BROWN)

Barnacle Project, Cynthia Venn, Bloomsburg University (KA and BROWN)

Carbon cycle, Michael Bender, Princeton University (BROWN)

Dissolved Inorganic Carbon (DIC) Analysis, Andrew Dickson, Scripps Institution of Oceanography (KA)

Argo float deployments, Greg Johnson, PMEL (KA)

Global Drifter Program, Robert Molinari, NOAA/AOML (KA and BROWN)

Iron limitation, Mike Behrenfeld, NASA/Goddard (BROWN)

CO_2 moorings, Chris Sabine, NOAA/PMEL (KA)

Bio-optical measurement and nutrient analysis, Francisco Chavez, MBARI (KA)

Haruphone mooring recoveries/deployments, Robert Dziak, NOAA/PMEL (BROWN)

Tsunami/DART mooring recovery deployment at 8.5°S, 140°W, NOAA/NDBC (KA)

Bigeye mooring deployments, Rusty Brainard, NOAA/NMFS (KA)

Acoustic rain gauges on ATLAS moorings, Jeff Nystuen, University of Washington (KA and BROWN)

Atmospheric radiation, Mike Reynolds, Brookhaven National Laboratory (BROWN)

Underway ADCP, Eric Firing, University of Hawaii (KA and BROWN)

Underway pO_2/pN_2- Gas Tension device and O_2 probe, Craig McNeil, Univ. of Rhode Island (BROWN)

Underway CIRIMS skin temperature device, Andy Jessup, UW/APL (BROWN)

O_2, N_2, Ar, CO_2 underway sampling, Jan Kaiser, Princeton University, (KA)

Underway DMS sampling, Tim Bates, PMEL, (BROWN)

Nitrate and O_2 isotope analysis, Patrick Rafter, Scripps Institution of Oceanography (KA)

b. One-time ancillary projects on TAO cruises for FY 2004:

Underway DMS sampling, Barry Huebert, University of Hawaii, (BROWN)

Membrane Inlet Mass Spectometry, Blake Sturtevant, Princeton University, (KA)

Spondylus buoy recovery, Jorge Cardenas, INOCAR, (KA)

TAO Project Web Pages:

The TAO Project continues to update the content and functionality of its web site (http://www.pmel.noaa.gov/tao/). This site provides easy access to TAO/TRITON and PIRATA data sets, as well as updated technical information on buoy systems, sensor accuracies, sampling characteristics, and graphical displays. For FY 2004, TAO web pages received a total of 21,016,647 hits, about the same as in FY 2003 (22,136,074). Also during FY 2004, a total of 11,591 separate user requests delivered 153,502 TAO data files. These numbers are up 16% and 44%, respectively from the year before.

We had hoped to begin inclusion of TRITON salinities, radiation, rainfall, and currents to the TAO/TRITON web pages in FY 2004, but the development of a new TRITON Data Management System at JAMSTEC, which is necessary for the TAO/TRITON web page enhancement, is behind schedule.

Operational Use of TAO/TRITON:

TAO/TRITON data are distributed to operational centers such as NCEP via the GTS. These data are used routinely in climate forecasting and analyses. The data are also used for weather and severe tropical Pacific storm forecasting. A weekly ftp transfer is routinely made to the NCEP coupled modeling project so as to ensure maximum ocean data availability for coupled model ENSO forecasts. TAO data placed on the GTS include spot hourly values of wind speed and direction, air temperature, relative humidity, barometric pressure, and sea surface temperature. Daily averaged subsurface temperature data are also transmitted on the GTS. The TAO Project Office has been working with Service Argos to include ATLAS salinity data on the GTS. Progress has been made towards this end, with modifications to the GTS subsystem completed and presently being tested.

Vandalism:
Vandalism continues to plague portions of the TAO/TRITON arrays. Data and equipment return are generally lower in regions of high tuna catch in the eastern and western equatorial Pacific. In addition to partial mooring hardware and instrumentation losses, 4 complete moorings systems were confirmed lost in the Pacific due to the effects of vandalism and another 2 moorings are suspected to be lost, but not yet confirmed. For comparison, 7 mooring systems were lost in FY 2003.

Efforts to combat vandalism continue, though it is not clear they are making much impact. These efforts include distribution of information brochures to national fishing agencies, fishing boats in ports of call, and industry representatives, and have contributed to international efforts to decrease vandalism through the DBCP. We may replace the attractive RM Young wind sensor with a less conspicuous sonic anemometer if tests of the latter prove encouraging and funding for system upgrades become available.

FY 2004 TAO Transition Accomplishments:
The revised Transition Plan for the operation and maintenance for the Tropical Atmosphere Ocean (TAO) buoy array was provided to the Office of Global Programs March 2004. The TAO Transition is being conducted in accordance with the high level guidance provided in the NOAA Executive Council (NEC) approved plan. The revised plan, the result of tasking received in November 2003 from the Climate Program Manager, details the management of the tasks, cost, and schedule for the TAO transition, establishes the foundation for sustained operation and technology refresh after the transition and describes further cooperation between PMEL and NDBC.

The TAO Transition Plan of March 2004 was briefed to the NOAA Observing System Council (NOSC) in March 2004, at the NOAA Climate Observation Program Annual System Review on April 14, 2004, and to the Climate Observing System Council (COSC) in April 2004.

Based on comments received from the NOSC and COSC reviews and the PA&E review of the TAO Transition Plan of March 2004, the plan was rewritten and submitted to the Office of Global Programs on August 31, 2004. This revised plan was briefed to the NOAA Deputy Administrator on September 15, 2004. The TAO Transition Plan of August 31, 2004, is now being executed.

3.4a. ENSO Observing System, XBT component, Task 1-Operations

by Steven K. Cook and Robert L. Molinari

PROJECT SUMMARY

General overview of the project, including brief scientific rationale:

The primary objective of the AOML XBT component of the ENSO Observing System is to provide oceanographic data needed to initialize the operational seasonal-to-interannual (SI) climate forecasts prepared by NCEP. Specifically, AOML manages a global XBT network that provides subsurface temperature data. The subsurface data are used in the initialization of the SI forecast models and have been shown to be necessary requirements for successful predictions. Global coverage is now required as the forecast models now not only simulate Pacific conditions but global conditions to improve prediction skill. Secondary objectives of this project are to use the resulting data to increase our understanding of the dynamics of SI variability, to perform model validation studies and to quality control delayed mode data to climate research standards. Thus, this project addresses both operational and scientific goals of NOAA's program for building a sustained ocean observing system for climate.

Statement about how your project addresses NOAA's Program Plan for "Building a Sustained Ocean Observing System for Climate":

This project provides critical data for initializing SI forecasts. The data resulting from this project will also address objectives 3 and 4 (i.e., the heat content and air-sea flux elements) of the OCO Program Plan.

Statement about how your project is managed in cooperation with international implementation panels, in particular the JCOMM panels:

The Voluntary Observing Ship (VOS) XBT Program is a participating member of JCOMM and JCOMMOPS. The VOS XBT program is represented annually at the WMO/IOC Ship Observations Team (SOT) meeting and Steven Cook presently is Chair of the Ship of Opportunity Implementation Panel (SOOPIP), a JCOMMOPS subcommittee. Participation on these international panels provides an important mechanism for integrating and coordinating with other national or regional programs which, in the long run, improves our national climate mission by making more efficient and effective use of available resources.

Responsible institutions for all aspects of the project:

The VOS XBT program is a component of the GOOS Center located within the Physical Oceanography Division of AOML and manages NOAA's Voluntary Observing Ship (VOS) XBT Program. The VOS XBT Program utilizes the National Weather Service Global Telecommunications System (NWSGTS) gateway for the real-time distribution of data and the National Oceanographic Data Center (NODC) for the archival of delayed mode data.

Project web site URL and pertinent web sites for your project and associated projects:

http://seas.amverseas.noaa.gov/seas/goosplots.html

Associated projects:

http://www.jcommops.org
http://www,cmdl.noaa.gov,http
http://seas.amverseas.noaa.gov/seas
http://www://sahfos.org
http://www-hrx.ucsd.edu
http://www.aoml.noaa.gov/phod/benchmarks/index.html

Interagency and international partnerships:
The GOOS Center has close cooperative working arrangements across all NOAA Line Offices (NWS, NESDIS, NOS, NMFS and OMAO), the U.S. Navy and Coast Guard, several major national (SIO, WHOI, RSMAS, URI, UW and SCMI) and international (BSH, CSIRO, BOM, SABOM, JAMSTEC, IFREMER, IRD-Brest and IRD-Noumea) oceanographic and meteorological institutions as well as private contractors. The program also provides XBT's to international partners for deployment on lines of mutual interest. The partners provide all the ship greeting and data transmission functions, which reduces considerably the logistical load on the GOOS Center and in many instances provides data in regions that otherwise would not be accessible to us.

Statement that your project is managed in accordance with the Ten Climate Monitoring Principles:
This program is managed in accordance with the Ten Climate Monitoring Principles.

FY 2004 PROGRESS

Instrument/platform acquisitions for the fiscal year and where equipment was deployed:
Funding at $260.8 K and a price of $32.00 per probe purchases 8150 probes. XBT's are deployed along selected transects in the Pacific, Atlantic and Indian Oceans. In addition, 6140 probes were supplied to international partners primarily for deployment in the western tropical Pacific and tropical Atlantic Oceans.

Number of AOML deployments by calendar year – compare to the previous year:
2003 – 11,907
2004 – estimate, 14,000

Percentage of data return for fiscal year:
The ratio of XBT's deployed to real time data transmitted is essentially 100% except for profiles from High Density transects. Not every High Density XBT collected is transmitted in real time primarily due to time limitations while sampling, but all delayed mode data not transmitted in real time are still inserted onto the GTS within 30 days of the completion of each cruise. Probe failure remains consistently between 2% and 5% with expected higher failure rates in the higher latitudes during the hemispheric winters.

Measurements taken, where data are stored, data distribution, availability and access:
XBT data provide subsurface temperature data to a depth of approximately 800 meters along 30 selected transects in all three-ocean basins. Data are stored on the computer system on the ships on which we have installed Shipboard Environmental data Acquisition (SEAS) Systems. The real-time data are transmitted via Inmarsat Std. C. Automatic quality control tests are applied to the data and those profiles that pass are distributed on the GTS. An operator reviews those profiles that fail the automatic quality control procedures. The operator decides whether or not to send the data to the GTS. Full resolution data are stored on disks and obtained by ship greeters when the VOS return to port. The data are forwarded to AOML, placed in established formats and then sent to the National Oceanographic Data Center (NODC). Additionally, all Atlantic XBT data are scientifically quality controlled at AOML as NOAA's contribution to the GTSPP. These data are stored at the Atlantic Data Assembly Center located at AOML and returned to NODC after review.

How data are currently being used and shared:
XBT data are used in real time for ENSO monitoring and prediction and the initialization of climate models at centers for environmental prediction and in delayed mode for research concerning seasonal to decadal climate studies of the upper ocean thermal layer. There are no restrictions on sharing this information as it is distributed in real time on the GTS.

Where the data are archived:
All XBT data are archived at the NODC and a subset of all Atlantic XBT data are archived at the DAC located at AOML.

Problems encountered:
Volatile shipping industry requires considerable time and travel resources to continually recruit and re-outfit vessels for participation in the VOS. This volatility is particularly troublesome in the Indian Ocean, where we have not been able to maintain a portion of the low-density network.
Late funding has precipitated an increase of air shipping vs. ground shipping to deliver on time XBTs to those participating Research and Voluntary Observing Ships that had pre-set and therefore inflexible time schedules.

Research highlights:
Research using XBT data during the last fiscal year was primarily directed at decadal signals in the northwestern subtropical Atlantic. Molinari (2004), in press, generated a fifty-year times series of Gulf Stream transport and position from an XBT line between N.Y. and Puerto Rico. Decadal signals of these properties were in phase with the North Atlantic Oscillation and a recirculation gyre observed south of the Gulf Stream. The XBT data also indicate that the extension and retraction of the Gulf Stream are in phase with SST signals that propagate along the Gulf Stream. Analysis in the paper demonstrates that Argo float data can capture upper ocean temperature features previously observed in XBT representations of these features. Continued interactions with international scientists have demonstrated the importance of continued XBT sampling in the tropical Atlantic. Specifically, AOML scientists are involved in planning of the African Monsoon Multidisciplinary Analysis project. The objectives of AMMA are to study the West African monsoon and its associated offshore features (i.e., the atmospheric waves that can generate tropical storms and hurricanes).

3.5a. CORC: Surface Fluxes and Analysis

by Dan Cayan

PROJECT SUMMARY

Dan Cayan's CORC effort is 1) to produce sea-air heat, moisture, and momentum fluxes, estimated from marine weather reports using bulk formulae, and 2) assess the usefulness of those flux estimates in representing variability on seasonal to multi-year time scales.

The primary source of long (several decade) records of air-sea fluxes is from human-observer ship weather reports via bulk formulae. Traditionally, monthly turbulent and radiative flux components have been estimated using aggregates of bulk formulae calculations over all observations collected each month. To assess diurnal variability and to avoid errors from visual sky cover, wind observations taken after dark, we are recalculating the short wave flux and the other flux components using only daytime observations. This daytime-based flux dataset begins in 1950 and is updated through 2002. Because other investigators will prefer to apply their own menu of bulk formulae, we are saving the individual weather variables required to calculate each flux component.

Observations of the heat, moisture and momentum fluxes are needed to understand and predict how the atmosphere drives the ocean, and how the variability that is contained in the ocean may influence the atmosphere. Because this variability operates on a range of time scales from synoptic periods to decades, it is important for the Ocean Observing System to include an envelope of observations from marine weather reports in order to understand longer period variability using diagnostic analyses and model experiments.

This Project is managed locally by Dan Cayan at SIO. This effort is broadly guided by monitoring principles 4 (evaluation of quality and homogeneity) and 10 (a data management system--in order to process and distribute these datasets).

Data are distributed from an FTP server ftp://tenaya.ucsd.edu/pub.

FY 2004 PROGRESS

We have produced a preliminary version of bulk formulae surface heat flux (short wave, long wave, latent and sensible components) estimates using only daytime, and only nighttime (for long wave, latent and sensible components) observations. These daytime and nighttime flux dataset covers 1950 through 2002. Because other investigators will prefer to apply their own menu of bulk formulae, we are saving the individual weather variables required to calculate each flux component.

As an area of interest to CORC, we have processed the individual marine reports from the COADS set over the eastern North Pacific region (165W-105W, 15N-35N) during the 1950-2002 period. This region contains about 240,000 daytime reports for each month during the 53-year period. There are more observations during daytime than nighttime, ranging from about 30,000 more observations during winter months and 80,000 more observations during summer months.

There are substantial differences between daytime and nighttime properties. Not surprisingly, northeast Pacific average air temperature (T_{air}) and sea surface temperature (SST) are warmer in daytime than nighttime. However, somewhat surprisingly, the amplitude of the day-night difference in SST is not much smaller than for T_{air}. A common measure of stability at the air/sea interface, ($SST-T_{air}$), is used in bulk formulae to regulate turbulent fluxes of heat, momentum and moisture. Interestingly, nighttime ($SST-T_{air}$) in the NE Pacific varies relatively little between winter and summer, with average values ranging between about 1.5 in late winter to 1.0 in summer. $SST-T_{air}$ is less in daytime than in the nighttime for each month and over most of the ocean basin, as determined from a separate analysis of the global $SST-T_{air}$ distribution. Also, in contrast to the nighttime case, daytime ($SST-T_{air}$) has more seasonal variation, from 1.0 in winter to -0.06 in early summer.

There are other daytime vs. nighttime differences that could introduce possible biases in the fluxes if all observations are included in the monthly flux estimates. For example, daytime-only cloud cover is greater than is night-time only in most months, by about .4 oktas or about 5%, over most of the global ocean, including the stratocumulus-dominated northern oceans (Figure 1). It is suspected that this may result from observer bias—nighttime observers report less cloudiness because they can't see the sky well enough. The shortwave flux from daytime-only observations is lower than that calculated from nighttime-only. Differences of the shortwave flux calculated from daytime-only vs. that from nighttime-only observations are typically –10 to –40 Watt/m^2. Also, daytime wind speeds tend to be higher by about 0.4m/s or about 5% (Figure 2). This tends to introduce a commensurate increase in the loss of heat that would be calculated from daytime-only vs nighttime-only observations. Together, greater observed daytime cloud cover and higher daytime wind speeds tend to decrease the shortwave heating and increase the latent and sensible heat losses calculated by daytime-only observations—i.e., a tendency for lower net heat flux.

This suggests that the seasonal cycle of turbulent fluxes may be more strongly controlled by daytime than nighttime processes. Implications for the surface fluxes of using the daytime subset appear to be: lower net (into ocean) shortwave fluxes, greater latent and especially sensible flux heat losses from the ocean. Work is underway to compute bulk formulae fluxes from the daytime and nighttime data, and to compute anomalies and evaluate the variability within this dataset.

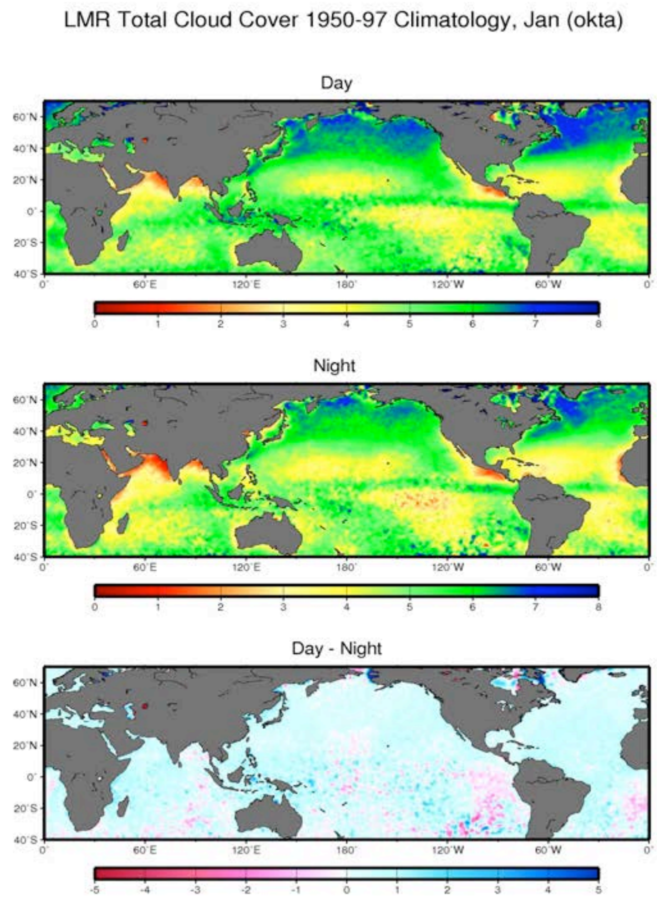


Figure 1. Cloud cover (oktas) from coads individual weather reports aggregated into monthly mean (1950-1997) for January. Daytime (top), nighttime (bottom) and daytime-nighttime difference (bottom).

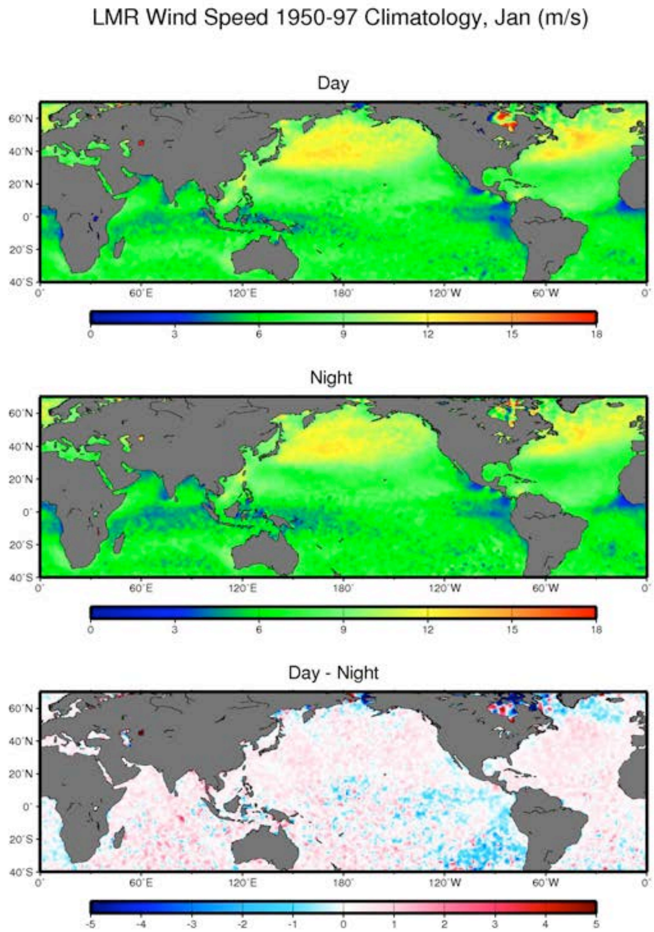


Figure 2. Wind speed (m/s) from COADS individual weather reports aggregated into monthly mean (1950-1997) for January. Daytime (top), nighttime (bottom) and daytime-nighttime difference (bottom).

3.6a. CORC: Four-Dimensional Variational (4DVAR) Data Assimilation in the Tropical Pacific

by Bruce Cornuelle, Detlef Stammer and Art Miller

PROJECT SUMMARY

The observational dataset of the tropical Pacific Ocean is both sparse and inhomogeneous, and one of the major challenges of data management is to combine the various data types into a coherent and useful picture of the ocean state, both physical and biological. The goal of this effort is to use the MIT general circulation model (MITgcm) and its adjoint (the ECCO assimilation system) to dynamically merge the Consortium for the Ocean's Role in Climate (CORC) observations, along with most other observations of the tropical Pacific: TAO, satellite sea surface height (SSH) and sea surface temperature (SST), surface drifters, and XBT, CTD and ARGO profiles. This will allow us to assess the capabilities of the MITgcm and its adjoint, determine optimal resolution, and explore the physical balances of the tropical Pacific. We also aim at producing optimized forcing fields, which are consistent with the model momentum, mass, salt, and heat budgets. Such a dynamically consistent framework will provide a unique tool to understand the variability of the tropical Pacific in greater detail than has been possible before. The optimized model states and forcing fields can be indeed used to explore mid-latitude influences on the tropics, examine ENSO variability through the years, and explore oceanic limitations on predictability of El Nino-Southern Oscillation (ENSO) events.

This project addresses section 6.12.3, subtask 3, of NOAA's Program Plan for building a sustained ocean observing system for climate: Four dimensional data assimilation including GODAE.

The project is managed as part of the Consortium for the Ocean's Role in Climate, serving the observational programs in CORC, which are reporting separately (e.g., High-Resolution XBT sections).

SIO is the primary responsible institution. Detlef Stammer is now at the University of Hamburg, and his involvement has declined. MIT is critical for the support of the MITgcm and the ECCO assimilation system, but is not supported as part of this project.

Project web site is http://ecco-group.org.

The project is managed in accordance with the Ten Climate Monitoring Principles, particularly principle 10.

FY 2004 PROGRESS

The data acquisition efforts are being reported separately, we focus here on progress in the data assimilation. Over the course of the earlier years of the project, a $1/3^{o}\times1/3^{o}$ model of the tropical Pacific was configured and run using a variety of initial conditions and forcing sets, including forcing and initial conditions from the global $1^{o}\times1^{o}$ assimilation by the ECCO project, headed by Detlef Stammer. The inner model has been run first in forward mode, for validation with data and sensitivity studies in preparation for assimilation experiments. The comparisons to observations, which have been evaluated for several different 9-year integrations (01/1992-12/2000), show promising agreement between the model outputs and the observations (Figure 1-2), and we have concluded that the model is sufficiently capable to be used for data assimilation.

In the current year, forcing fields, initial and boundary conditions were adjusted to bring the model into more consistency with TOPEX sea surface height (SSH), Reynolds sea surface temperature (SST), and Levitus temperature (T) and salinity (S) profiles over 1-year durations, for 1998 and 1999. The assimilations have required several innovations to make them work, including novel methods for adjusting the open boundary conditions and for removing extreme sensitivity from the adjoint of the model (see Problems Encountered below). The assimilation system is now working routinely. Several runs were first performed to find the best initial guess for the control parameters, revealing that the mean of the ECCO forcing corrections provide the lowest cost function value. After 30 iterations, the assimilation has improved the overall model fit to the data by more than 55% (Fig. 3). This is significant since the assimilation starts from an already optimized initial guess. This was also true for all the individual observations cost terms, which show a continuous decrease in the Model/data misfit (Fig. 4). The adjustments to the NCEP forcing fields produced by the assimilation are reasonable (Fig. 5). Moreover, early results suggest that the forcing adjustments are not strongly sensitive to the starting guess.

Problems Encountered:

The transition of the assimilation system from the 1-degree ECCO global model to the 1/3 degree tropical Pacific was not straightforward and two major difficulties were encountered. The first difficulty was due to the instabilities and nonlinearities of the higher resolution tropical Pacific model, which significantly limit the length of the model predictability, and therefore greatly increase the difficulty of the assimilation over long periods. This is a common problem with 4DVAR methods when applied to strongly nonlinear models and is related to the inability of the tangent linear model to provide good approximation to nonlinear perturbations. One major reason is that the linearized physical processes may not represent the major feedback loops between the nonlinear processes, leading to a projected exponential growth of initial perturbations with time without any saturation. Such unbounded sensitivities imply very small optimization steps, preventing any significant decrease in the total cost function. To damp the growth of sensitivities in our adjoint run, larger viscosity and diffusivity parameters were used in the model backward run. This enabled us to stabilize the adjoint model over the one-year assimilation period and therefore to successfully carry out the assimilation over this period.

The other major difficulty was related to the very strong sensitivity of the cost function, more precisely of the SSH term, to the velocities at the open boundaries. Indeed, a small variation in the barotropic component of the normal velocities at the open boundaries may produce a huge variation in the model SSH. To deal with these high sensitivities, a novel decomposition (based on the Quasi-Geostrophic model formulation) of the normal velocities at the open boundaries into barotropic and baroclinic components was introduced which allow us to specify different weights for each component in the optimization.

Biological model:

The latest MPI version of ROMS has been ported to the COMPAS cluster and the physical solution compares well with runs on other machines. ROMS is being used to develop the biological code that will be used with the MITGCM physical code. We currently have results from a simple, single tracer model simulating nitrogen-based nutrients with a uniform, light level mediated, loss term. We are currently improving this model by adding a phytoplankton component and have made runs for skill assessment. We have started to incorporate the single tracer biological code into the MITGCM code and plan to make comparison runs shortly. It is our current goal to continue enhancing the biological code on ROMS and port each enhancement to the MITGCM for comparison while moving on to the next enhancement on ROMS.

3.7a. CORC: Underwater Gliders for Monitoring Ocean Climate

by Russ E. Davis

PROJECT SUMMARY

Temperature, salinity and velocity are the fundamental variables for ocean climate observations. They are directly connected to the large-scale processes that shape climate variability and determine the storage and transports of heat and freshwater that defines climate change in the atmosphere and ocean.

The Argo array of profiling floats is now providing global coverage of subsurface temperature and salinity while a few of the TAO Array moorings provide sustained observations of velocity. Boundary currents are largely overlooked in today's observing system because of the difficulty of monitoring these narrow flows that often have significant transports. While Argo floats sample these currents, their density is much too low (typical spacing of 300 km) to resolve them, or even to determine their overall transports. It is not cost effective to significantly increase float density in these limited regions because floats remain in them only for short times; moorings are expensive and are impractical in strong and deep boundary currents like the Kuroshio or Gulf Stream.

The CORC underwater glider project aims to develop a cost-effective method to monitor temperature, salinity and velocity in specified regions where the small scales of the climate field demand a higher local density of observations than is feasible with floats. Gliders are buoyancy-driven vehicles, much like Argo floats, that use wings to glide forward while cycling up and down. The glider used for this effort is 'Spray' which was developed at SIO, initially under ONR funding. Our objectives are (1) to improve both sensor and platform performance in real-world circumstances, (2) evaluate the utility of the data gathered by these slow-moving platforms, and (3) begin monitoring regions where higher resolution observations are needed.

The objectives of the *Program Plan for Building a Sustained Ocean Observing System for Climate* to which gliders potential contribute are: document ocean carbon sources and sinks; document the ocean's storage and global transport of heat and fresh water; and document the air-sea exchange of heat and water and the ocean's overturning circulation. These are the same objectives to which Argo contributes. The plan identifies gliders as augmenting Argo with observations focused in selected regions, like boundary currents and deep-water formation sites, where higher observational density is needed. This project intends to first improve glider technology so that it can be effective in long-term observations and second to implement some sustained research observations so that readiness for operational monitoring can be evaluated.

At this developmental stage there are no national or international coordinating bodies for glider observations nor are gliders ready for inclusion in the Argo program. The project is managed at SIO and the investigator is an active participant in the Argo program, which glider development is meant to augment. SIO also has ONR and NSF projects that use gliders. The ONR project uses gliders to gather enough data in limited coastal regions to make possible synoptic-scale ocean predictions using data- assimilating models. The NSF project in collaboration with Breck Owens of WHOI is exploring glider observations of the Gulf Stream observations. The first transect from Massachusetts to Bermuda is under way as this is written. The CORC effort focuses on expanding the suite of glider sensors by implementing Acoustic Doppler current profiling, improving the long-term reliability and resistance to bio-fouling of sensors, and establishing regular sustained observations of the California Current on climate time and space scales to evaluate the utility of glider observations.

The sustained observations are being implemented in the Southern California Bight, which has been surveyed quarterly for over 50 years by the CalCOFI program. The glider observations cannot replace these ongoing surveys, which are based on collecting plankton, larvae and egg samples along with physical observations. The existence of a long and ongoing CalCOFI program will, however, simplify our commitment to the Ten Climate Monitoring Principles. Evaluation of the impact (hopefully synergistic) on CalCOFI will be key to establishing glider utility, documenting performance of unattended sensors and data homogeneity. Hopefully comparison of new and old systems will motivate eventual transition of this research system to operations. The data and metadata will be freely available through the Southern California Coastal Observing System web site soon to be established. Spray data from this program can now be examined at www.Spray.UCSD.edu.

FY 2004 PROGRESS

Early work in this program, which began in FY2001, showed that there were significant problems with Spray reliability. In one of our first sections off the California coast, a glider was lost after gliding about 250 km offshore. Figure 1 shows the track from this operation along with the measured ocean currents averaged from the surface to 500 m. Figure 2 shows the density section calculated from temperature and salinity reported through satellite in real time.

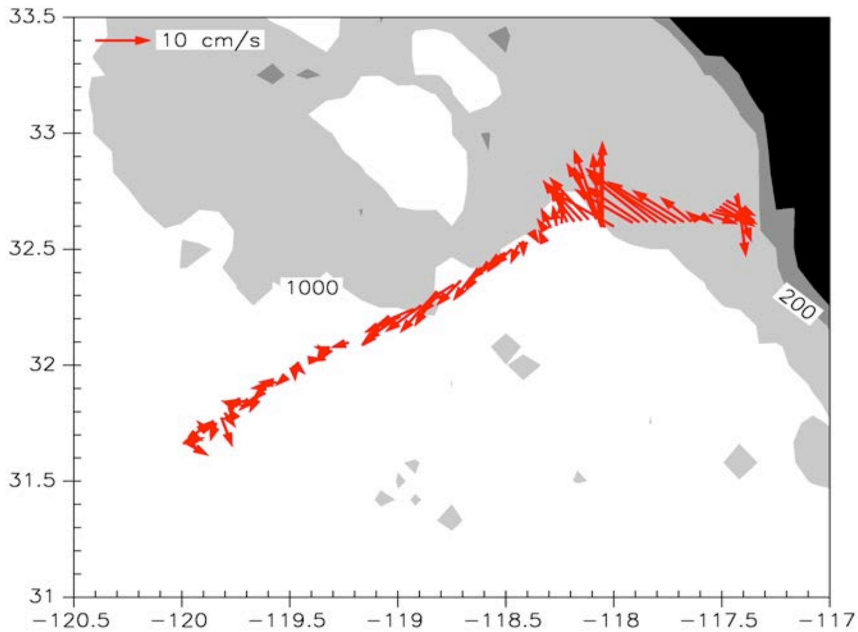


Figure 1. Trajectory of an early Spray glider section off San Diego. Vectors are average current between the surface and 500 dbar. The northwestward flow evident 50 km offshore may be a manifestation of the California Undercurrent or the Southern California Bight Eddy, a recurrent feature of the California Current.

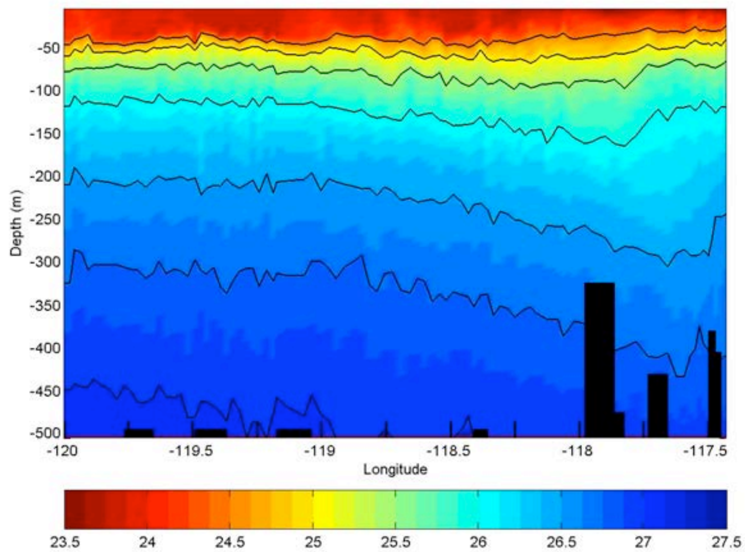


Figure 2. Potential-density section along the track depicted in Figure 1. The isopycnal slope between 118° and 119°W is consistent with the poleward flow seen directly. Such northwestward flow is common but not consistent element in the region. The inshore equatorward flow seen in velocity and density is not well known.

Failure of this early float precipitated a thorough design review of the systems most likely to have been involved: communication, buoyancy control, high-pressure integrity and the control mechanism for gliding. A number of modifications to these systems were designed and implemented in FY 2002. Following implementation of upgrades, a sequence of increasingly long local field tests was begun early in FY 2002. On the third test, the vehicle was lost because it was run over by a surface vessel, destroying its antennae but not sinking it. This initiated a second design review and the decision to switch to Iridium communication, to employ redundant communication/GPS antennas, and to install a backup Argos system

The ONR sponsored, August 2003, Autonomous Ocean Sampling Network II (AOSN-II) field experiment in Monterey Bay provided an attractive opportunity to prove out the various improvements introduced to Spray. Two NOAA-sponsored Sprays and three purchased with ONR funds were deployed along a 100 km stretch of coast spanning Monterey Bay. They were directed to run back and forth on offshore lines of approximately 80 km length. Figure 3 shows the trajectories and average velocities to 400 m from the five vehicles during a 10-day period early in the experiment. Gliders profiled temperature and salinity, generally to 400 m but occasionally to 750 m, and measured the vertically averaged water velocity as the difference between the measured motion through the water and distance made good. All five vehicles functioned perfectly for periods of 35-42 days before normal recoveries, showing a substantial duration advantage over Slocum gliders participating in the same exercise.

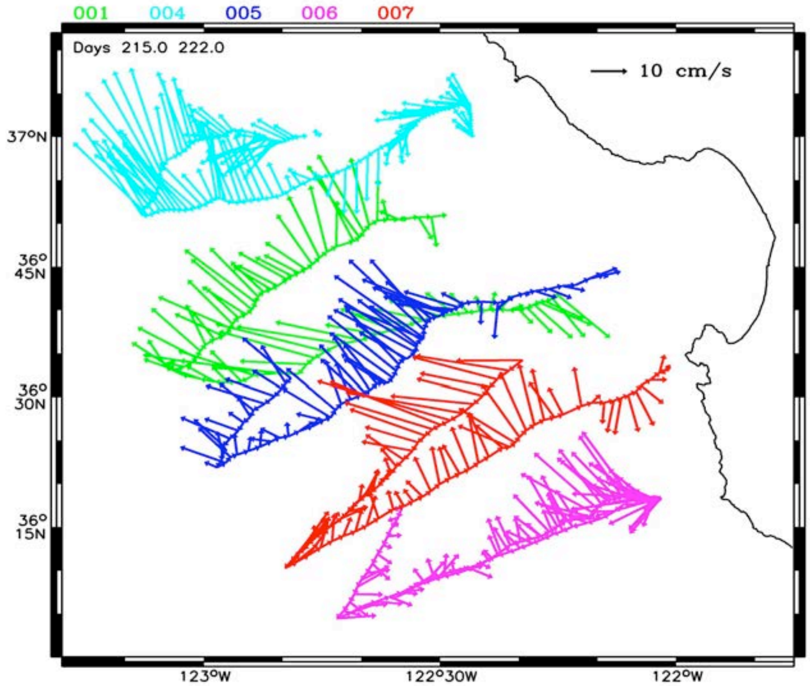


Figure 3. Velocity from five Spray gliders during 2-12 August 2003 while operating off Monterey Bay, CA. The solid line along arrow bases is the vehicle trajectory. Arrows represent average water velocity from the surface to 400 m. A strong California Undercurrent produces flow to the northwest at over 25 cm/s. Temperature and salinity profiles were measured on each dive-and-ascend cycle. Sampling extended over 42 days without interruption.

FY04 activity has focused on designing, implementing and testing new sensors and improved systems to rectify weaknesses exposed in the Monterey Bay operations:
(1) The PME conductivity sensor, which was unduly affected by bio-fouling in Monterey Bay, was replaced by a Sea Bird CTD similar to that used on most Argo floats. Unlike the Seaglider and Slocum gliders, we use the CTD's pump to optimize dynamic response, to improve corrections for dynamic response, and to provide a pumped water system that is protected from bio-fouling by poisons and can be used by optical sensors. (2) A Sontek 3-beam 500 kHz ADP was installed to directly measure vertical shear that can be combined with measured depth-average velocity to determine the full velocity profile. (3) A secondary hydraulic pump was introduced to avoid vapor lock of the primary buoyancy pump caused by air bubbles in the hydraulic system, a problem noted on one Monterey Bay dive.

In an NSF-sponsored collaboration with Breck Owens of WHOI, we have begun testing the ability of Spray to monitor climate signals in the Gulf Stream using periodic Spray transects from Cape Cod to Bermuda. Because the Stream is so much faster than the gliders, these will not be transects in the usual sense but rather should be regarded as sampling the changes across the strong western boundary current. Figures 4 shows the highly distorted path of Spray on the first crossing of the Gulf Stream along with the surface to 1000 m average current (this glider does not have an ADP). Because the glider forward velocity is much less than current velocities, the path was temporarily reversed to northward motion by a deep meander in the Stream. Figure 5 shows the temperature and salinity variations across the Gulf Stream – even though the path is highly distorted the glider is always headed across the current as deduced from SST maps and the velocity encountered. The critical question in this project is whether data collected in this manner are adequate to document climate-relevant changes in the Stream.

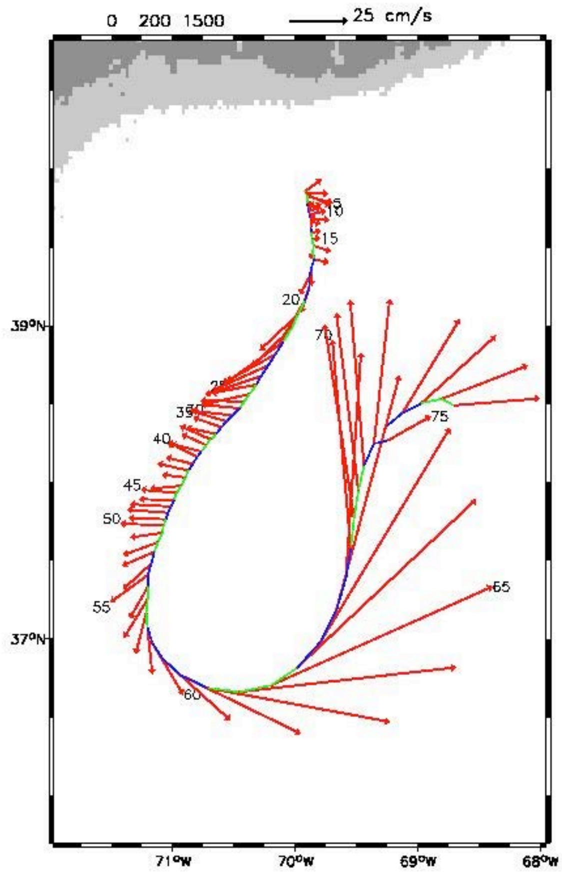


Figure 4. A Spray crossing the Gulf Stream. The blue-green line is the path of a Spray as it tries to cross the Gulf Stream and is caught in a deep meander. The red arrows (scale is at the top) are the depth-averaged current (from the surface to 1000 m) of the Gulf Stream. Shading at the top is bathymetry of Massachusetts with gray-scale breaks at 0, 200 and 1500 m depth. At all points along the path the glider is steered to be moving across the Gulf Stream.

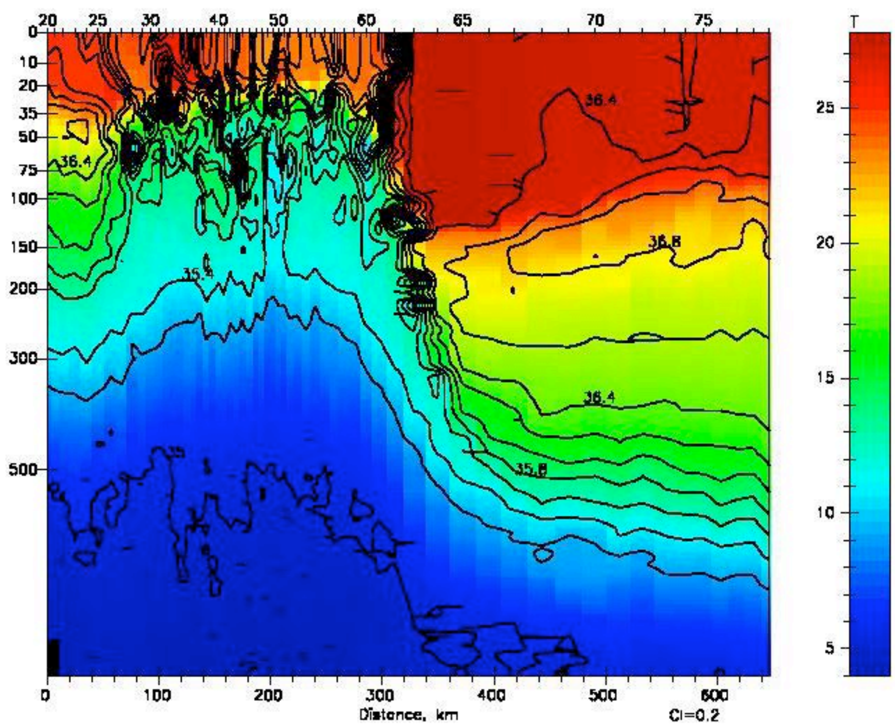


Figure 5. Sections of temperature (color shading) and salinity (line contours with interval of 0.2 psu) crossing the Gulf Stream. Depth scale is not linear. Horizontal scale is actual geographical movement in kilometers. "Stations" shown at the top are closely spaced when the glider is slowed by the current. The glider is steered across the instantaneous current at all times, regardless of the heading that is produced.

Performance Details. During FY04 we upgraded one previously constructed Spray with a Sea Bird SBE 41CP CTD and pumped water system and upgraded a second glider with a previously purchased Sontek 3-bean Acoustic Doppler current Profiler (ADP). We also began construction of 3 new gliders that will be put into service in FY05.

We tested the new ADP in two one-day field tests within 20 miles of SIO and tested the SBE CTD in three similar one-day tests. The data recovery from these missions was 100% but the records were short and the tracks chosen for logistic convenience, not scientific value. CTDs and optical backscatter sensors were carried on all these tests. To date Spray gliders have completed 38 missions spanning 294 days and completed 3018 profile cycles with the loss of one early vehicle for unknown reasons and severe damage to another in a collision with a surface vessel.

The data from all missions is stored at SIO on multiple media. Most missions were designed for engineering and are not of great scientific value. However, the data from the mission described in Figures 1 and 2, from the joint NOAA-ONR effort in AOSN-II, and from the initial crossing of the Gulf Stream are available at www.Spray.UCSD.edu.

Scientific Progress:

Scientific focus this year has been on three areas. Much work was done extracting descriptions of regional and basin-scale ocean circulation from profiling float deployments begun up to 14 years ago. Studies include descriptions of the subtropical North Atlantic subduction zone, enhanced carbon sequestration as the result of the Southern Ocean iron fertilization experiment, and the intermediate-depth circulation of (a) the Indian and South Pacific (based in part on CORC observations), (b) the South Atlantic (based largely on CORC observations), and (c) the subpolar North Atlantic:

3.8a. CORC: Drifter Observations and Analyses

by Pearn P. Niiler

PROJECT SUMMARY

a) Drifter Acquisitions and Enhanced Deployments in the Tropical Pacific:
This year SVP drifters were ordered from Technocean, Inc. (50) and Clearwater, Inc. (50). These were shipped to AOML and were deployed in the tropical Pacific between 20°N and 20°S, with 40 CORC and 60 ONR drifters being deployed into the region of the Luzon Strait to measure the seasonal inflow from the western tropical Pacific into the South China Sea (Fig. 1: Centurioni et al. 2003).

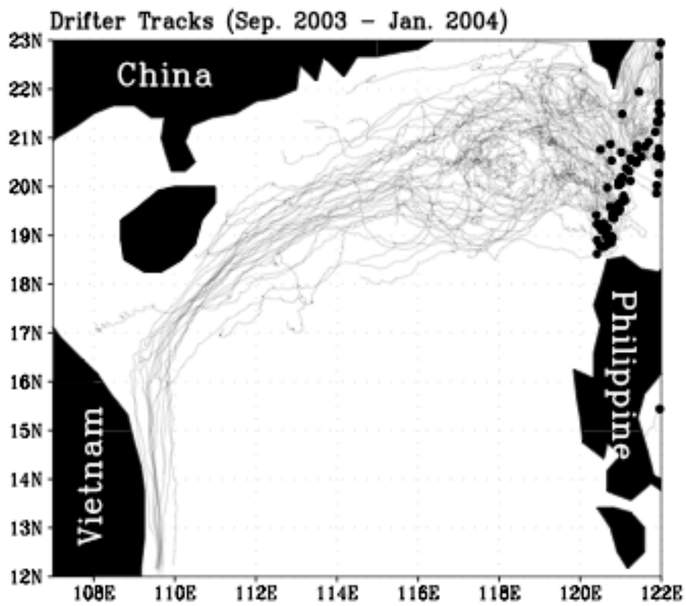


Figure 1. The SVP drifter tracks from the September 2003-January 2004 deployments into the Luzon Strait.

b) Attachment of MICROCAT Salinity Sensor to the SVP Drifter:
In the period 2000-2004, Sea Bird SEACATs were attached to 28 SVP drifter surface floats. These were deployed into the East China Sea in the August-September periods of each year to follow the Yangtze River out-flow during the Southwest Monsoon floods (Fig. 2). The technical objective of this development was to facilitate the SVP network as platforms for SSS observations that are stable to 0.02 psu for more than 300 days. NASA plans to call for the use of the North Pacific and Tropical Atlantic SVP drifter arrays for calibration and validation of the AQUARIUS SSS satellite that is to be deployed in late 2007. Further testing of the SEACATS, with and without pumped sensors will be done into the eastern North Atlantic in 2005 with the cooperation of the French Meteorological Service buoy tenders for deployments and recoveries.

SALINITY DRIFTER TRACKS

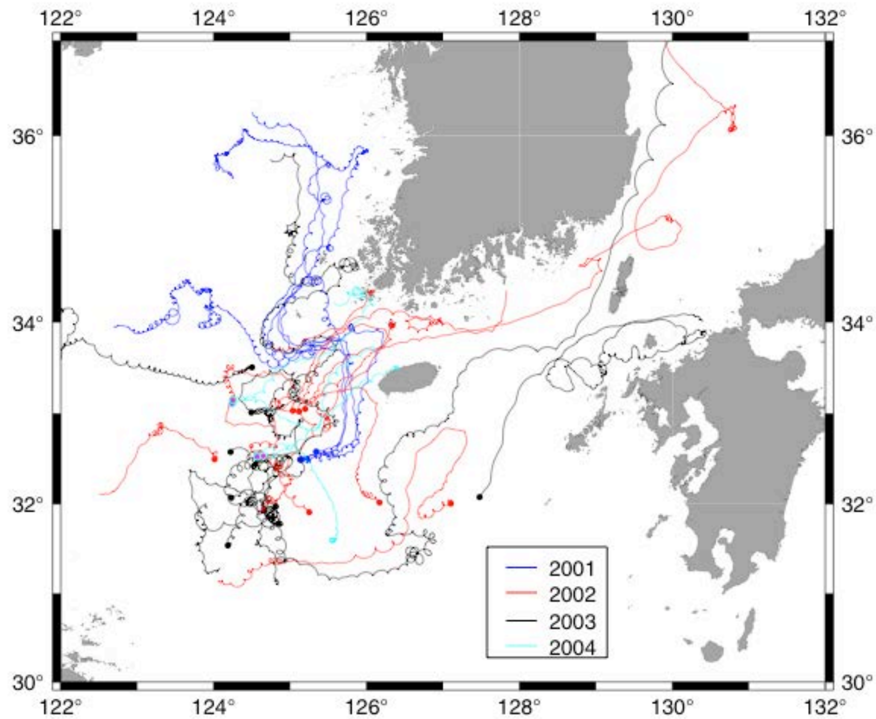


Figure 2. Drifter tracks from 2000-2004 (each year is different color) in the East China Sea with attached MICROCATs for SSS observations.

c) *Analysis of Southern Ocean CORC Observations*

In the period 1994-2000, CORC drifter observations were taken in the Southern Ocean. In partnership with members of the WMO operational meteorological services, these provided the impetus for deployment of a permanent array of about 200 SVP-B ("B" is for barometer) drifters south of 35°S. Analyses of these data have provided high spatial resolution maps of the Aghulas Current system along the east coast of South Africa and its seaward extension (Pazen and Niiler, 2003). Apparent in the Aghulas Extension are seven semi-permanent meanders. A theoretical explanation for these meanders can be found in the theory of steady, eastward flowing meandering jets (e.g., Robinson and Niiler 1967), as shown in Figure 3.

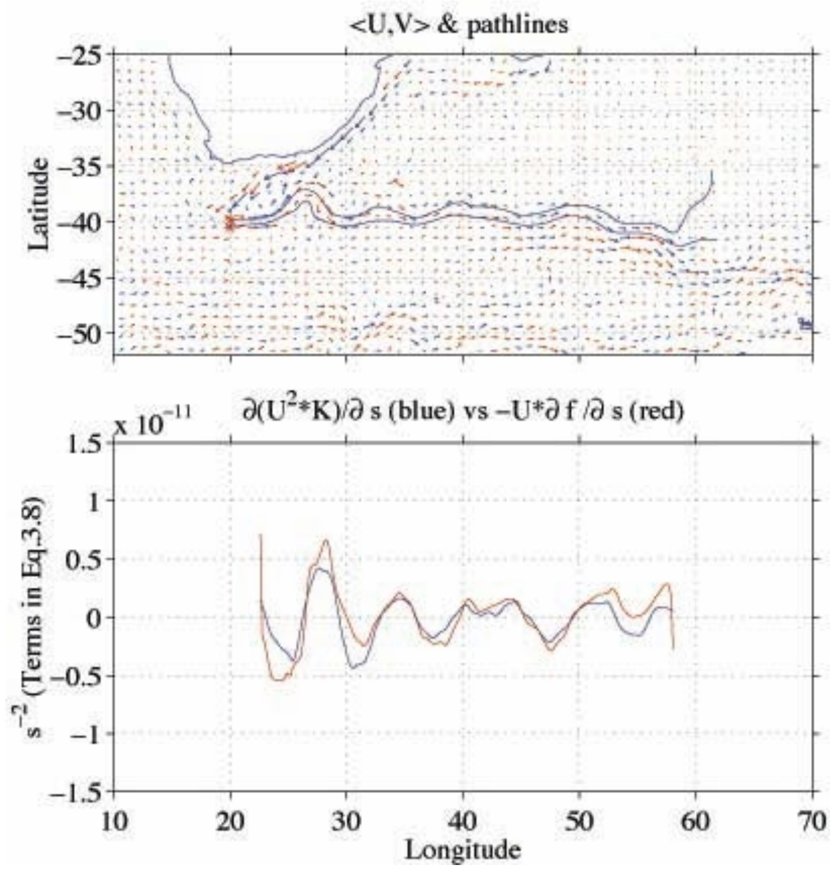


Figure 3. (a) Semi-permanent meanders in the surface current of the Aghulas Extension. The velocity data are an ensemble average of observations from 1978 to 2003 on 1/2 degree resolution, with arrows blue when a northward component of velocity is present.

(b) The time mean surface vorticity balance in the path-wise coordinate system along the time mean path very near the velocity maximum. The advection of relative vorticity (red line) is balanced by the advection of planetary vorticity (blue line) indicating that near the velocity maximum eddies are inefficient in providing for a vorticity transport convergence (courtesy of Dr. Pepe Ocheo 2004).

3.9a. CORC: High Resolution XBT/XCTD (HRX) Transects

by Dean Roemmich, Bruce Cornuelle, and J. Sprintall

PROJECT SUMMARY

Overview: Eddy-resolving boundary-to-boundary temperature (XBT) transects are collected on a quarterly basis along selected routes in the Pacific and Indian Oceans, as shown in Fig 1. Objectives are to measure annual and interannual fluctuations of temperature, salinity, and large-scale ocean circulation, including the variability of mass, heat and freshwater transports. These large-scale transports constitute the ocean's dynamic contribution to the climate system. The HRX sampling mode captures important elements of time variability in ocean circulation, transport, and property distributions that are missing from one-time hydrographic sections and from broad-scale XBT sampling. Since its beginnings in 1986, the HRX Network has resulted in a considerable body of original research, including studies of water mass properties and variability, ocean general circulation, heat transport variability, and equatorial dynamics.

HRX transects are usually carried out by a technician or scientist on board a commercial vessel, and consist of 0-800 m XBT temperature profiles at spatial intervals of 30-50 km in the ocean interior and 10-20 km in boundary regions. A number of additional activities are carried out by the ship riders, including:

- Sparse sampling with XCTDs to resolve large-scale T/S variability.
- Testing of the new 2000-m research quality T-12 XBT.
- Occasional deployment of Argo floats.
- Technical support for VOS IMET installations (R. Weller, PI).

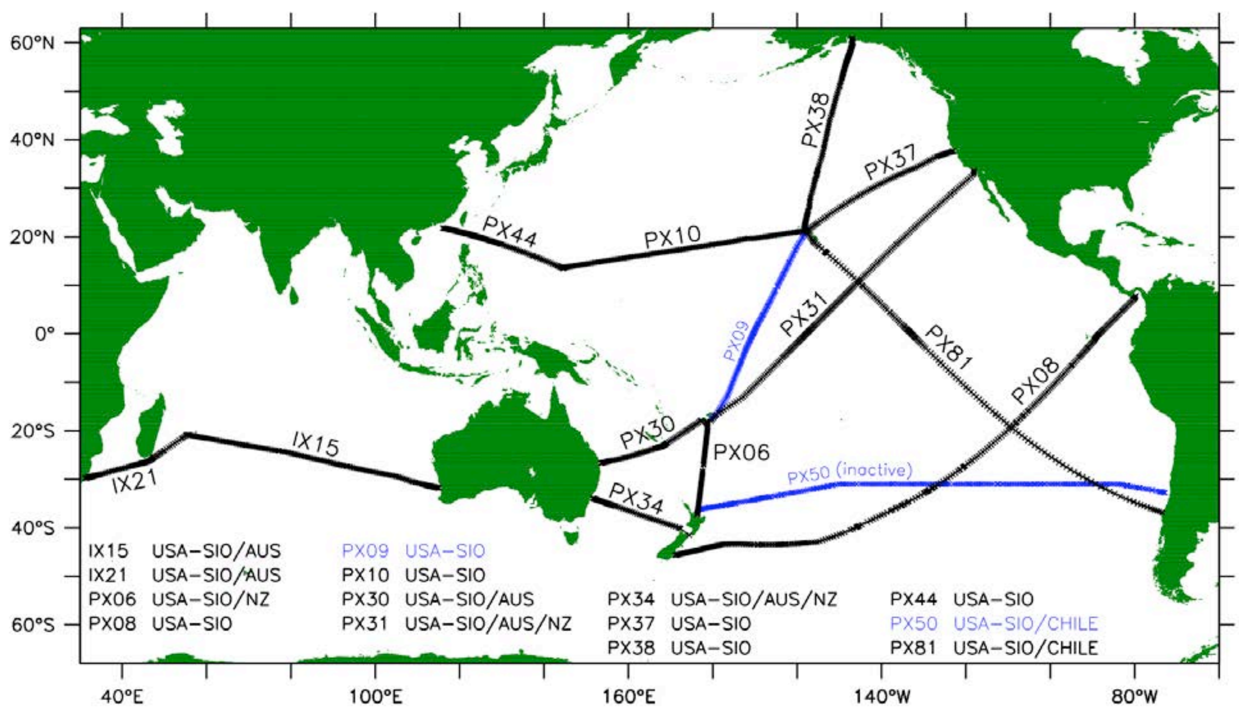


Figure 1: SIO HRX transects in the Pacific and Indian Ocean. PX30 and PX34 are carried out on an equal collaborative basis with CSIRO.

Role in the NOAA Program Plan for *Building a Sustained Ocean Observing System for Climate*: The HRX Network is a named element in the Program Plan *(Sect 6.4.*). It directly addresses the Plan's objectives *(3) Document heat uptake, transport, and release by the ocean;* and *(4) Document the air-sea exchange of water and the ocean's overturning circulation.* In addition, it indirectly addresses objective *(1) Document long-term trends in sea level change*, by helping to understand the subsurface causes of steric sea level change.

Management: We participate in the Ship of Opportunity Implementation Panel (SOOPIP) under the JCOMMOPS Ship Observations Team (SOT). Overall priorities for the HRX networks were established by the Upper Ocean Thermal Review at the Bureau of Meteorology, Melbourne in August 1999, and are applied in managing the program.

Web site: All transects are displayed as temperature contour plots at http://www-hrx.ucsd.edu, and data are available for download from that site. Although HRX data are archived at NODC, they are not made available by NODC in the form of single-cruise transects. Since HRX data have high value as transects, the HRX web site referenced above provides them in that form.

Partnerships: The HRX program is a multinational collaboration involving scientists from the USA, Australia, Japan, Chile and New Zealand. The global HRX network began with a single transect, carried out by D. Roemmich and B. Cornuelle between New Zealand and Fiji in 1986. It was subsequently expanded to the ocean-spanning array shown in Figure 1, with an equivalent Atlantic HRX network carried out by NOAA/AOML with other international partners. Collaboration with the NOAA GOOS Center at AOML results in HRX data being transmitted in near real-time to the GTS as part of the NOAA SEAS system.

Climate Monitoring Principles: The HRX Program is managed in accordance with the Ten Climate Monitoring Principles.

FY2004 PROGRESS

The status and progress on HRX XBT transects in the Pacific and Indian Oceans in the last year is described below, with track locations shown in Figure 1. The report includes lines presently supported by NOAA and also lines proposed for NOAA support in the coming year. These lines are presently supported by an expiring NSF grant.

A summary of successfully completed transects for all lines during FY2004 is given in Table 1. The table also lists the starting year of HRX sampling along each line, and for comparison the number of successfully completed transects during the previous 5-year period. A "transect completion score" is calculated from the ratio of completed transects (up to 4 per year for each line) to nominal transects (4 per year). For FY04 the completion score is 45/48 = 94%, slightly less than for the previous 5-year period, 192/200 = 96%.

It also continues to be the case that ships carrying ship-riders produce better sampled transects (fewer and smaller gaps) and a higher percentage of good drops (mostly due to stern-launching rather than bridge-launching). In the SIO HRX program about 95% of probes produce good data.

Line	Year started	FY04 transects	Previous 5 years
PX37/10/44	1991	4/4/4	20/20/20
PX06/09 or PX06/31	1986/1987	4/3	19/19
PX81	1997	3	20
PX50 or PX08	1993	4	18[2]

PX38	1993	3	17
PX30[1]	1991	5	18
PX34[1]	1991	4	21
IX15/21	1994[3]	4/4	Note 3

Notes- 1: Collaborative with CSIRO Marine Research.
2: Shipping along PX50 was discontinued in April 2003 and is still dormant.
3: Shipping along IX15/21 was discontinued in 1995, resumed some years later.

Transects presently supported by NOAA

South Pacific line - (PX50) New Zealand-Chile, (PX08) New Zealand-Panama: Commercial shipping was discontinued on the direct route between Australia/New Zealand and South America (PX50) in mid-2003. The nearest alternate route is Auckland-to-Panama (PX08). We began HRX sampling along PX08 in January 2004. Four transects have been carried out aboard *PONL Mairangi*, in January, March, May, and September 2004. Our plan is to continue HRX sampling along PX08 unless shipping is resumed along PX50.

East Pacific line (PX81) Hawaii-Chile:
Three transects were carried out, on *NYK Nacre* in October 2003, and on *NYK Forestal Diamante* in May and August 2004. Shipping on the line is bulk cargo carriers trading between Japan and Chile. Individual ships do not remain in service for long, and the Hawaii port call for bunker fuel has been temporarily discontinued. Therefore, our ship-riders rode from Japan to Chile (PX25) in this year's cruises. We're evaluating the possibility of crew sampling along this line.

South Indian line (IX15/21) Fremantle-Mauritius-Durban:
Four transects on this newly implemented line were carried out aboard *MSC Federica* in December 2003, and March, July, and September 2004. Local logistical support is provided by CSIRO Marine Research. The ship sometimes follows a direct route from Fremantle to Durban (IX02) without advance notice.

Southern Ocean lines (AX22) Drake Passage, (IX28) Hobart-Dumont D'Urville:
We provide only technical/logistical assistance for AX22 (J. Sprintall, PI), which is sampled on a year round basis on the *R/V LM Gould*. IX28 is carried out by CSIRO Marine Research; we provide a small fraction of probes. During austral summer 2003-2004, six transects along IX28 were carried out aboard *L'Astrolabe*.

Transects proposed for NOAA support under Add Task 1 (presently NSF).

North Pacific line (PX37/10/44), San Francisco-Honolulu-Guam-Hong Kong:
Four transects were carried out aboard *Horizon Enterprise* in October 2003, and in January, May, and August 2004. The Enterprise is the longest serving ship in the HRX network, having been used along PX37/10/44 since its inception as an HRX line in 1991.

Northeast Pacific line (PX38), Honolulu-Alaska:
Three transects were carried out, one aboard *R/V Kilo Moana* in October 2003, and two aboard *Marine Columbia* in January and May 2004. There continues to be shipping along this route (mostly oil tankers), but the absence of scheduled repeating transits makes sampling somewhat problematic.

Central Pacific line (PX06/09) New Zealand-Fiji-Honolulu (or Los Angeles):
Four transects were carried out, beginning with the *Columbus Florida* in November 2003. That ship was taken offline, with no remaining ships along NZ-Fiji-Honolulu. Sampling was resumed

along NZ-Fiji-Los Angeles (PX06/30), which has been an alternate route over past years of our program, with transects aboard *Direct Tui* in April, July and August. The August XBT sampling was terminated in Fiji due to technical problems, and *Direct Tui* was subsequently taken offline. The next transect is planned for November using another *ANZDL* vessel.

Southwest Pacific lines (PX30) Fiji – Brisbane and PX34 (Wellington – Sydney):
These lines are carried out collaboratively with CSIRO. We provide most of the XBT probes while CSIRO provides most of the PX30 ship riders and the local logistical support. Sampling along PX34 is by the ship's crew. Five transects were carried out along PX30 aboard the *Forum Samoa*, in October 2003 and in January, March, June, and September 2004. Four cruises were carried out along PX34 aboard *ANL Progress* and *MSC New Plymouth*, in October 2003 and January, May and September 2004.

Other activities related to observations:

XCTD deployments: XCTD probes are deployed to measure large-scale variability in the T/S relation, with typically 12 – 18 probes used on a basin-spanning transect. Use of XCTDs is being slowly phased out as more regions become well populated with Argo floats. 134 XCTDs were deployed in FY2004.

T-12 XBT testing: We've carried out partially successful tests of the Sippican MK-12 XBT probe (2000 m, 20 kt, research quality), and are waiting on the manufacturer for additional probes.

VOS IMET systems: We provide logistical assistance to the WHOI IMET group for installation and maintenance of VOS IMET systems. There are presently two systems operating in the Pacific, on the *Horizon Enterprise* and the *Columbus Florida*.

Argo float deployment: HRX vessels are used for float deployment whenever floats are available for these lines. We provide logistical assistance and carry out the deployments.

MK21/autolauncher integration: Major software development work is nearly completed to convert the XBT autolauncher system from MS-DOS/Sippican MK-12 data acquisition to Windows/Sippican MK-21. This conversion is being done collaboratively with NOAA/AOML in order to produce fully compatible systems. We already collaborate with NOAA/AOML to provide real-time (GTS) transmission of data from HRX transects, and for shared use of equipment on joint use vessels.

Data distribution, availability, access and archive:
There are three pathways for HRX data distribution.

- GTS. All XBT profiles are immediately transmitted to the GTS using the NOAA SEAS system, except on vessels that do not have the necessary hardware (presently PX38, PX30). This is the primary conduit for use by operational centers and other near real-time users.
- Internet. Our web site (http://www-hrx.ucsd.edu) provides downloadable data in the form of 1 ASCII file per HRX transect, with 10-m vertical averaging. All data are stored and backed up at SIO. Requests for 2-m vertical resolution files, and for data too recent to have completed final QC, are handled on an individual basis.
- Data are passed to NODC to be archived and distributed. NODC/GTSPP is the primary data source.

Major research users of Pacific and Indian HRX data, in addition to SIO, include scientists at CSIRO Marine Research (Australia), NIWA (New Zealand), and Tohoku University (Japan).

Problems encountered:

- The most serious problem facing the HRX Network is the present "instability" of international shipping, somewhat exacerbated by increased global security measures. By "instability", we mean that the average time spent by a vessel trading on a particular route has decreased markedly in the past decade. Ships and even routes now come and go, where they used to remain in place for many years. Along well-traveled routes, this is merely an inconvenience and expense, requiring laborious changes from ship-to-ship. Along lightly traveled routes, especially PX50 and PX81, it is a serious problem that threatens the viability of sampling along those lines. Increased security measures add to the difficulty by making it more likely that any particular vessel or owner will decline to carry scientific ship riders, thus further narrowing the list of prospective vessels.
- Conversion of auto-launcher software to SEAS compatibility operating under Windows/Sippican-MK21 has been slow and time-consuming (involving both SEAS and SIO personnel). As the changeover is not yet completed, we are still operating the autolauncher under MS-DOS/Sippican-MK12. MK12 data acquisition cards are no longer available or supported by Sippican, and are prone to frequent failure. During the past year this resulted in one transect being terminated (PX06/31). It is expected that this issue will be solved in the next 6 months with completion of the conversion

Research highlights:

HRX data are being incorporated in regional, basin-wide, and global analyses, as well as being used for comparison with data assimilation modeling results, such as ECCO.

- **Combining XBT and altimetric height data.** Willis et al. (2003) developed a new technique for combining XBT and satellite datasets, and applied it regionally in the southwestern Pacific. This was followed by a study of global interannual heat storage (Willis et al. 2004).
- **Regional to basin-wide studies of circulation and heat budgets** using HRX datasets are being carried out in the northeast Pacific (Douglass et al. (2004)), the southwest Pacific (Roemmich et al. 2004), and Drake Passage (Sprintall and Adams 2004).
- **Dynamical studies.** Willis (2004) used a quasi-geostrophic data assimilation model to study the structure and dynamics of propagating eddies in the North Pacific (following on Roemmich and Gilson, *Journal of Physical Oceanography* 2001). Work on this topic is ongoing.
- An especially noteworthy paper is the global analysis of ocean heat content and sea level variability, 1993 – 2003, by Willis et al. (2004).

3.10a. CORC: Development of an Underway CTD

by Daniel L. Rudnick

PROJECT SUMMARY

The development of the Underway Conductivity Temperature Depth instrument (UCTD) is motivated by the desire for inexpensive profiles of salinity from underway vessels, including volunteer observing ships (VOS) and research vessels. While expendable CTDs (XCTDs) do provide the needed salinity profiles at present, their cost limits how many can economically be used. The temperature-salinity (T-S) relationship is most variable in the mixed layer and seasonal thermocline where the ocean is in direct contact with the atmosphere. Deeper, climatological T-S relationships combined with XBTs are sufficient for observing the hydrographic structure that enters into momentum, heat and salt budgets. Thus, the design goal for UCTD was to obtain profiles deeper than 100 m at 20 knots (typical of a VOS). This goal has been surpassed, as we are able to profile to over 150 m at 20 knots, and to over 400 m at 10 knots.

The UCTD operates under the same principle as an XCTD. By spooling tether line both from the probe and a winch aboard ship, the velocity of the line through the water is zero, line drag is negligible and the probe can get arbitrarily deep. The challenge is to recover the probe, because the line velocity will then equal the ship speed, and line drag may become large. This has proven possible using a Spectra line commercially available for fishing. A number of advantages accrue because the UCTD is recovered rather than expendable. First, the cost per profile decreases as the probe is reused. Second, because the probe is recovered, sensors can be calibrated post-deployment, improving the quality of the observations. Third, the UCTD carries a pressure sensor so depth is measured more accurately than by the drop-rate equation typical for an expendable.

All of the components of the UCTD system have been designed, built, and used successfully. A description of the components follows. The probe has a four-electrode conductivity sensor, a thermistor, and a pressure sensor. Data from the sensors are logged at a frequency of 10 Hz by a Persistor microprocessor to solid-state memory. Between UCTD casts, data are downloaded to a laptop computer via a serial connection, the probe's battery is recharged, and the probe is initialized for the next cast. Deck gear consists of a davit, a winch, and a mechanism to rewind line onto the tail. The davit has a 4'x4' footprint, and can pivot and extend. The winch is a Penn International fishing reel equipped with a DC motor for fast recovery. The rewinding mechanism is driven by a variable speed motor, while level winding is accomplished with an adjustable pitch, reversing unit available commercially.

The UCTD operation is carried out easily and safely on an underway vessel, making no demands on vessel operators other than space on an aft quarter to put the equipment. The UCTD is deployed by dropping over the stern while letting the winch free spool (Fig. 1). As the fall rate is approximately 5 m/s, a 400-m profile takes 80 s. Assuming the ship is steaming at a speed of 5 m/s (10 knots), 400 m of line is pulled off the winch. The total of 800 m of line deployed at the conclusion of a profile takes roughly 15 min to recover with our current winch design. Recovery of the probe is accomplished by adjusting drag on the reel to be strong enough to pull in the probe but too weak to break the line, a simple matter as the probe weighs 10 lb, while the line breaks at over 300 lb. The probe is then pulled snug against a foam block attached over the line at the davit. Rewinding the tail and downloading data take about 10 minutes so that consecutive profiles can be done as rapidly as every 30 min.

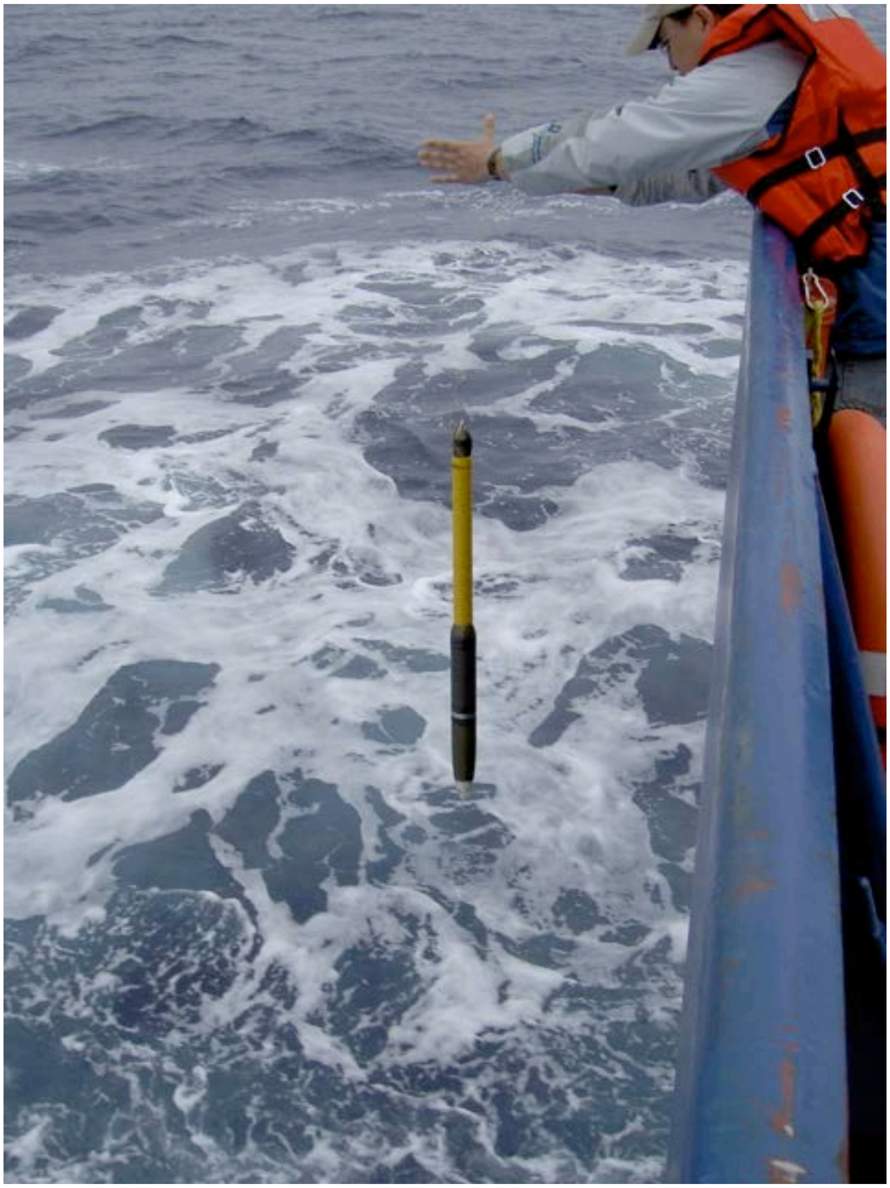


Figure 1. The UCTD falling into the water on deployment. The yellow on the tail is 400 m of Spectra line. Conductivity and temperature sensors are protected in the white nosepiece.

The UCTD directly contributes to the *Program Plan for Building a Sustained Ocean Observing System for Climate* by addressing the need for observations of upper-ocean salinity and temperature. These observations are needed to quantify the heat transport of the ocean, and air/sea interactions central to climate. The UCTD will fit naturally into the Ships of Opportunity Program (SOOP), and will increase the productivity of NOAA research vessels by providing the capability to make more underway observations.

As the UCTD has only this year begun to be operational, data are not yet being managed in cooperation with relevant international panels. As UCTD sees greater use, its data will be managed as are other temperature and salinity profiles in the ocean observing system.

UCTD was used on two cruises this year as part of the ONR-sponsored North Pacific Acoustics Laboratory (NPAL). Cooperating institutions included Woods Hole Oceanographic Institution and University of Washington.

UCTD is a new system with potential for improving the upper-ocean salinity database of the ocean observing system. UCTD is thus at step 1 of the 10 Climate Monitoring Principles: assessment prior to implementation. Should UCTD prove valuable, it will address point 7 by improving observations of relatively poorly observed upper-ocean salinity.

FY 2004 PROGRESS

The major accomplishment of the past year was the first operational use of the UCTD. We participated on an ONR-sponsored cruise whose purpose was to examine the effects of internal waves and density compensating thermohaline variability (sometimes called spice) on long-range acoustic propagation. The cruise resulted in over 160 successful UCTD casts (Fig. 2). The primary goal of the cruise was to deploy four acoustic moorings on a 1000-km path in the central North Pacific subtropical gyre. UCTD was used while the ship steamed at 10-13 knots between moorings. The resulting hydrographic section had a resolution of 10 km horizontally and 5 m vertically. The section clearly showed the effects of thermohaline variability on sound speed.

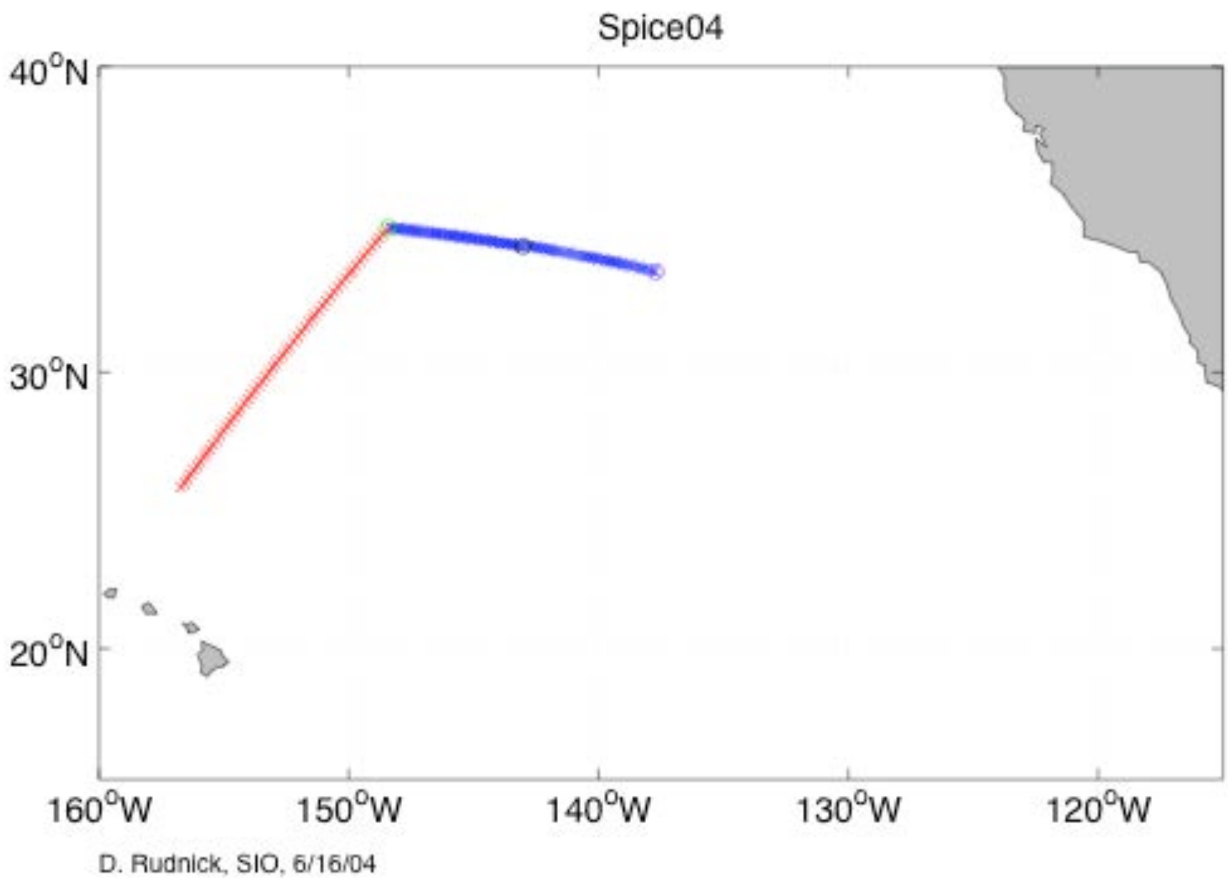


Figure 2. Locations of UCTD casts (x) and acoustic moorings (o) from the May-June NPAL cruise. The section marked by the blue crosses is shown below.

The section was done from east to west (Fig. 3). The changing depth of the profiles was directly related to ship speed. During the first quarter of the section ship speed was 11-12 knots, the second quarter 12-13 knots, and the second half 10 knots. Over the second half of the section the casts were mostly greater than 400 m, with the deepest ones greater than 430 m.

The summer mixed-layer depth of 20 m is evident in the figures as is the 100-150 m depth of the remnant winter mixed layer. Temperature-salinity features can be seen covering the depth of the winter mixed layer. Sound speed variability (changes as large as about 6 m/s over a horizontal distance of 10 km), and the resulting effects on acoustic propagation were the motivation for this experiment. The salinity minimum near the base of the winter mixed layer is a distinctive feature of this region.

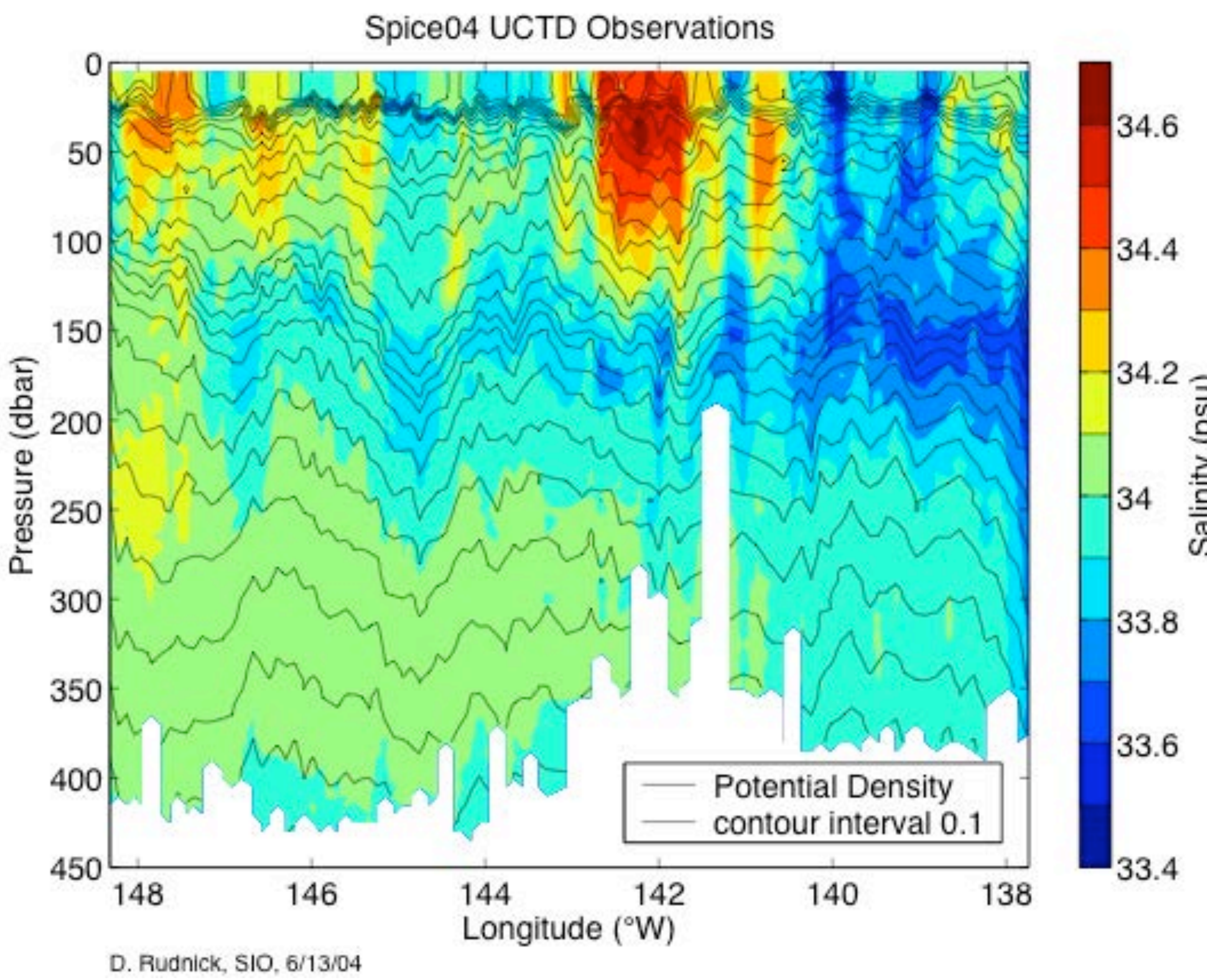


Figure 3. UCTD section of salinity (color image) and potential density (black contours) along the blue path in Figure 1.

UCTD was used again as part of NPAL during a cruise September-October 2004. Over 170 casts were completed during the first use of UCTD by operators other than the developers. This cruise marks an important step toward general use by the oceanographic community.

Data from the NPAL exercise are currently being processed to ensure accurate temperature and salinity. They will be archived at SIO and shared with interested scientists, especially others involved with NPAL. A major issue is the stability of the conductivity sensor.

3.11a. CORC: Lagrangian Salinity Profiling: Evaluation of Sensor Performance

by Raymond W. Schmitt

PROJECT SUMMARY

Principle investigator Schmitt has long been concerned with the challenge of assessing the strength of the hydrologic cycle over the ocean (Schmitt et al. 1989; Schmitt 1995). One important indicator of the water cycle is the salinity structure of the upper ocean (Schmitt and Montgomery 2000). This project focuses on instrumentation used to measure salinity on autonomous vehicles.

A basic need in *Building a Sustained Ocean Observing System for Climate* is reliable measurement technology and we are here focused on the quality of oceanic salinity instrumentation. Under CORC sponsorship we have advanced automated salinity measurement technology by working with Falmouth Scientific, Inc. (FSI) to improve their conductivity cell performance and assist in development of their “Excell” Float CTD. This work has helped to address problems with present instrumentation and provide diversified technology sources for salinity measurements within the ARGO float program. Early versions of the Excell were tested extensively for electronic performance and tuned to have proper dynamic response. Later models are performing much better than initial versions. Several FSI-equipped SOLO floats were deployed in the eastern tropical Pacific last year as part of the CORC/ARGO array.

Considerable effort has also gone into studies of the dynamic response of the sensors. Dynamic response is always a concern with salinity measurements from moving sensors, as temperature and conductivity cells inevitably have different response times, with different speed dependencies. This leads to an error in the calculated salinity which can be significant in strong thermoclines, and leads to subtle errors elsewhere. Salinity spiking and density inversions from SeaBird CTD equipped floats in ARGO has been a noticeable problem in some areas (G. Johnson, personal communication). Salinity spikes can be avoided if the dynamic response characteristics of temperature and conductivity cells are understood and adjusted for prior to calculation of salinity. This is an especially important issue for profiling floats as transmission of raw data is impractical and data reduction must be done on-board.

As this project seeks to improve the instrumentation at the basis of the growing climate monitoring system it certainly adheres to the philosophy of the 10 climate monitoring principles.

FY 2004 PROGRESS

In order to address the dynamic response problem we have constructed a special double-diffusive interface tank capable of long-term maintenance of a very sharp temperature/salinity step (Schmitt et al. 2004). Traversing the CTD through the interface reveals the sensor mismatches and allows development of an appropriate filter to optimize the accuracy of the salinity calculations. This has been done for the Excell float CTD. Figure 1 shows the dynamic response tank we are using for these tests. A new speed control mechanism was recently installed for tests of the SeaBird pumped CTD.

Research Highlights. Dynamic response testing of the SeaBird has recently been completed and a rather complex response function revealed. Figure 2 shows average scaled conductivity and temperature data from 11 such trials. Eleven plunge tests were averaged to account for the random timing between the slow Sea-Bird sample rate and the passage through the interface. Issues that can be identified in this type of plot are: 1. the relative placement of the temperature and conductivity probes, 2. the time constant of the temperature probe, and 3. the thermal mass of the conductivity cell. In addition, there appear to be electronic drift issues that complicate the development of a suitable correction algorithm. A correction algorithm for implementation on board the float is under development.

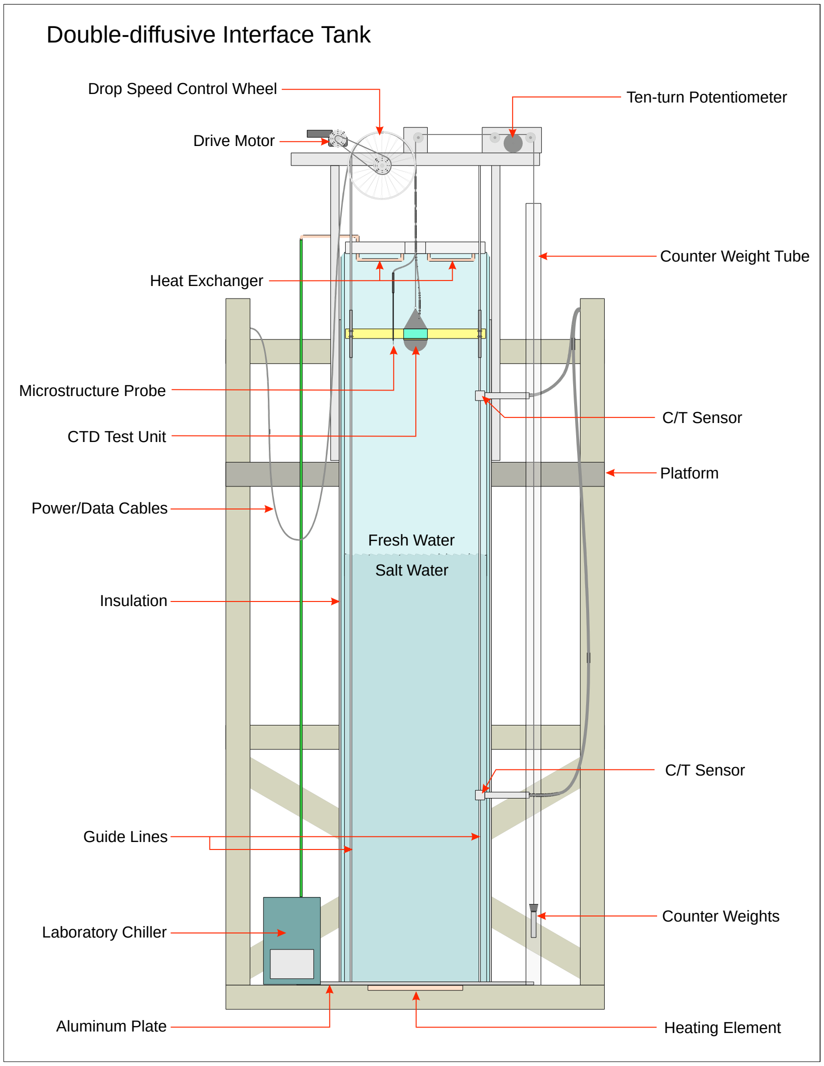


Figure 1. The double diffusive dynamic response tank used for tests of float CTDs. The 3 ft diameter pipe is 15 ft deep with a aluminum plate bottom. A heating element drives convection in the lower salty water and a heat exchanger cools the top of the upper fresh water. A computer controlled winch lowers the instruments through the sharp interface at a set speed. Sensors monitor the temperature and salinity of the mixed layers.

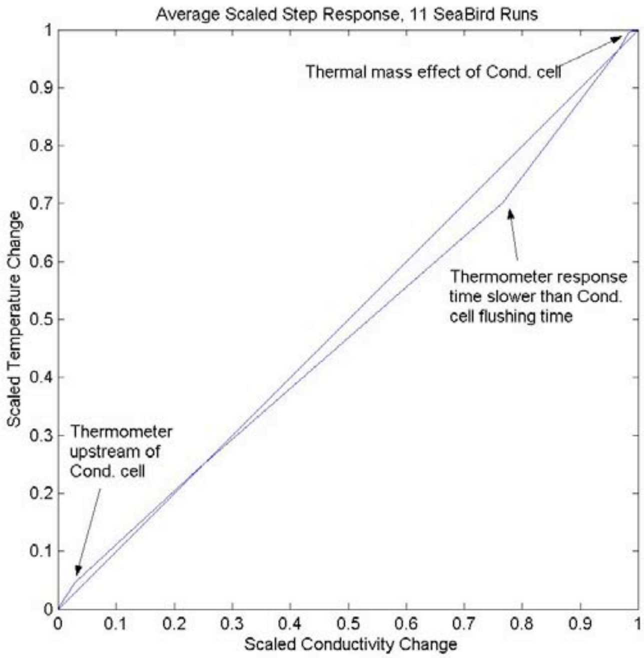


Figure 2. The average scaled step response from 11 plunges of the Sea-Bird float CTD through the double diffusive interface. The fall speed was 10 cm/sec and only data from the moving portion of the plunge were used. The instrument starts in the cold-fresh upper layer (0,0) and traverses to warm fresh (1,1). The deviation of the data from a straight line is indicative of lag and response time issues as shown.

3.12a. CORC: Observations of Air-Sea Fluxes and the Surface of the Ocean

by Robert A. Weller, Frank Bahr, and David S. Hosom

PROJECT SUMMARY

Central to present efforts to improve the predictability of climate is the need to understand the physics of how the atmosphere and ocean exchange heat, freshwater, and momentum and, in turn, to accurately represent that understanding in the models to be used to make predictions. At present, over much of the globe, our quantitative maps of these air-sea exchanges, derived either from ship reports, numerical model analyses or satellites, have errors that are large compared to the size of climatically significant signals. Observations made using the IMET technology on the Volunteer Observing Ships on long routes that span the ocean basins are essential to providing the accurate, in-situ observations needed to:

1) identify errors in existing climatological, model-based, and remotely-sensed surface meteorological and air-sea flux fields,
2) to provide the motivation for improvements to existing parameterizations and algorithms,
3) to provide the data needed to correct existing climatologies, and
4) to validate new model codes and remote sensing methods.

AutoIMET was developed by the Woods Hole Oceanographic Institution to meet the need for improved marine weather and climate forecasting. It is a wireless, climate quality, high time resolution system for making systematic upper ocean and atmospheric measurements. This interfaces to the NOAA SEAS 2000 (Shipboard Environmental (Data) Acquisition System) that automatically receives meteorological data (from the AutoIMET) and sends in automated one hour satellite reports via Inmarsat C. This system will document heat uptake, transport, and release by the ocean as well as the air-sea exchange of water and the ocean's overturning circulation.

Note that descriptions, technical information and data from the several VOS being serviced are posted on the site: http://uop.whoi.edu/vos/. Data (plots) are available for all ship sets.

Data (numbers) are available via anonymous ftp for the last data set only: ftp.whoi.edu/pub/users/fbahr/VOS. If data from previous times are desired please contact Frank Bahr at: fbahr@whoi.edu.

There is a link to the site: http://frodo.whoi.edu where there is detailed information on the AutoIMET and ASIMET modules. Instrument design questions can be addressed to Dave Hosom at: dhosom@whoi.edu.

Ship selection and interface to the NOAA SEAS system is via AOML. There is ongoing cooperation with Scripps via the CORCIII program on ship scheduling as well as Southampton Oceanography Centre (SOC) of Southampton UK on Computer Flow Dynamics (CFD) for evaluation of the flow turbulence around the ship and its effect on the sensor placement. Some logistic support is provided by the Southern California Marine Institute on ship turnarounds. There is ongoing cooperation with the Atlantic Marine Ocean and Atmosphere Laboratory (AOML) in Miami on the Atlantic VOS program. There is also ongoing cooperation with many sensor manufacturers and the VOS people at the German Weather Service (Deutscher Wetter Dienst) in Hamburg Germany.

This project is managed in accordance with the Ten Climate Monitoring Principles.

FY 2004 PROGRESS

The CORCIII program supports two ships in the Pacific and had the following activities:

Horizon Enterprise

Columbus Florida

This is for the period 1 October 2003 through 30 September 2004 on a program to improve the surface meteorological and sea surface temperature observations made by U.S.VOS as described by WHOI Proposal Serial No. PO10731.01. The actual accomplishments at this point in time match the goals and objectives of the proposal. During this period we continued to build the program to attempt to improve the observations made by the U.S. Volunteer Observing Ship (VOS) fleet and to collaborate with VOS Expendable Bathythermograph (XBT) investigators on testing and evaluating data from modules developed during the program.

December 2003. ASIMET modules were removed and an AutoIMET system installed on the Horizon Enterprise in Oakland CA.

December 2003. The AutoIMET system was turned around on the Columbus Florida in Long Beach, CA. The system that was removed had sustained serious sea damage in that the wind sensor was rearranged at the top of the bow mast and the HullCom (acoustic modem for SST) was flooded.

The HullCom was repackaged in an o-ring sealed titanium housing for re-installation. This packaging is the standard for use on ocean buoys using IMET. One set of ASIMET modules was converted to the AutoIMET configuration. Note that with the 3 new and 3 conversions all 6 systems are in the AutoIMET configuration to support 4 ships.

February 2004. Computer problem serviced in Hawaii on the Horizon Enterprise.

March 2004. The power system on the Columbus Florida was converted from batteries to an all a.c. system. Note that the power unit was located near the SST and the HullCom was removed. The ship officers were very supportive and provided bulkhead stuffing tubes and power interface.

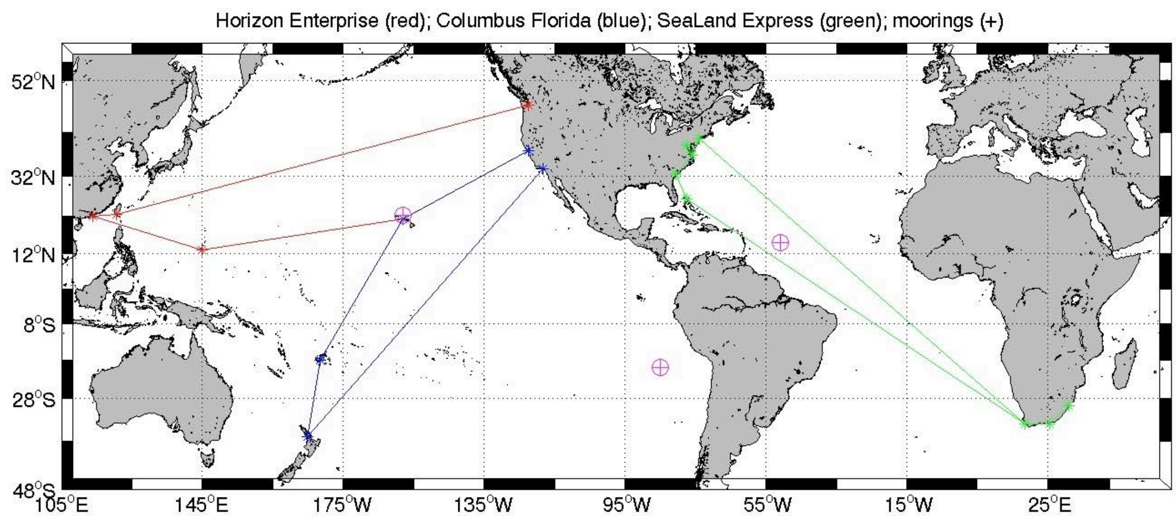
April 2004. Annual Office of Climate Observation (OCO) Workshop and the 2nd High-Resolution Marine Meteorology (HRMM) Workshop in Silver Spring, MD.

April 2004. Turnaround of AutoIMET on the Horizon Enterprise in Oakland, CA.

May 2004. Turnaround of AutoIMET system on the Columbus Florida in Long Beach, CA.

Sept 2004. Turnaround of AutoIMET on the Horizon Enterprise in Oakland, CA. The ship has provided a bulkhead fitting that will permit the SST to operate on a.c. power and remove the batteries and acoustic modem (HullCom). This improves reliability, gives SST every 6 minutes to SEAS, and reduces the cost of operation (no batteries).

ROUTE MAP



Note the Ocean Monitoring Stations (circle with cross) being operated by WHOI.

The CFD (Computer Flow Dynamics) work continues at Southampton Oceanography Centre on the feasibility of CFD on generic VOS.

3.13a. Flux Mooring for the North Pacific's Western Boundary Current: Kuroshio Extension Observatory (KEO)

by Meghan F. Cronin, Christian Meinig, and Christopher L. Sabine

PROJECT SUMMARY

Overview:

As a NOAA contribution to the global network of ocean time series reference stations, an air-sea flux buoy was deployed in the Kuroshio recirculation gyre at 144.5°E, 32.3°N in June 2004. During this first deployment (June 2004-June 2005), the buoy is monitoring air-sea heat, moisture, and momentum fluxes, and surface and subsurface temperature and salinity. In June 2005, we plan to include a pCO_2 sensor to monitor carbon flux (see Sabine Add-Task). The site is within the NSF-funded Kuroshio Extension System Study (KESS) domain and KESS has provided ship time, equipment and personnel for mooring operations. In addition, KESS will provide important oceanic data for understanding processes affecting the heat content and strength of the recirculation. Collaborations with Japanese PIs have begun and a partnership for developing and maintaining the KEO array appears to have broad support.

Scientific Rationale:

As with other western boundary currents, the North Pacific's western boundary current has some of the largest air-sea fluxes found in the entire basin. It is one of the largest sinks of carbon in the North Pacific, has the characteristic maxima lobes of latent, sensible, and net surface heat loss, and is co-located with the Pacific storm track. As the northward flowing Kuroshio current leaves the Japanese coast, it carries warm water at nearly 140 million cubic meters per second (i.e. 140 Sv) eastward into the North Pacific, where it is termed the Kuroshio Extension (KE). Wind-driven Sverdrup transport accounts for about a third of this transport; the other ~90 Sv is due to a tight recirculation gyre whose size varies on seasonal-decadal time scales (Fig. 1). As cold dry air comes in contact with the warm KE and recirculation water, heat and moisture are extracted from the surface, resulting in deep atmospheric convection and rainfall (Fig. 2). This heat and moisture are then carried poleward and eastward by the Jet Stream's storm track. In late-winter, surface water in the KE recirculation region is subducted into the permanent thermocline to form *Subtropical Mode Water*. As mode water is formed, carbon is sequestered. Large dust clouds blowing eastward off Asia are visible in satellite images and can be traced all the way across the Pacific basin. Asian dust is rich in iron and other nutrients. At present we have no in situ information on how the carbon cycle's biological pump is affected by the passage of these clouds.

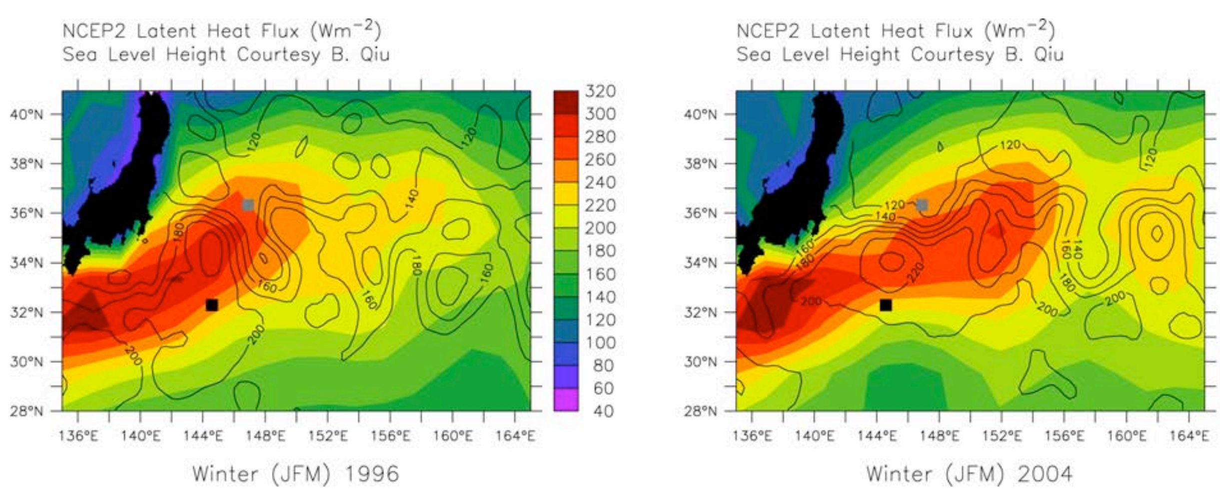


Figure 1. Wintertime (January-March) latent heat flux and sea level height in the Kuroshio Extension region during 1996 (left) and 2004 (right). The KEO site is indicated by a black square. Sea level height contours can be interpreted as surface geostrophic streamlines of flow. The KEO-2 site is indicated by a gray square.

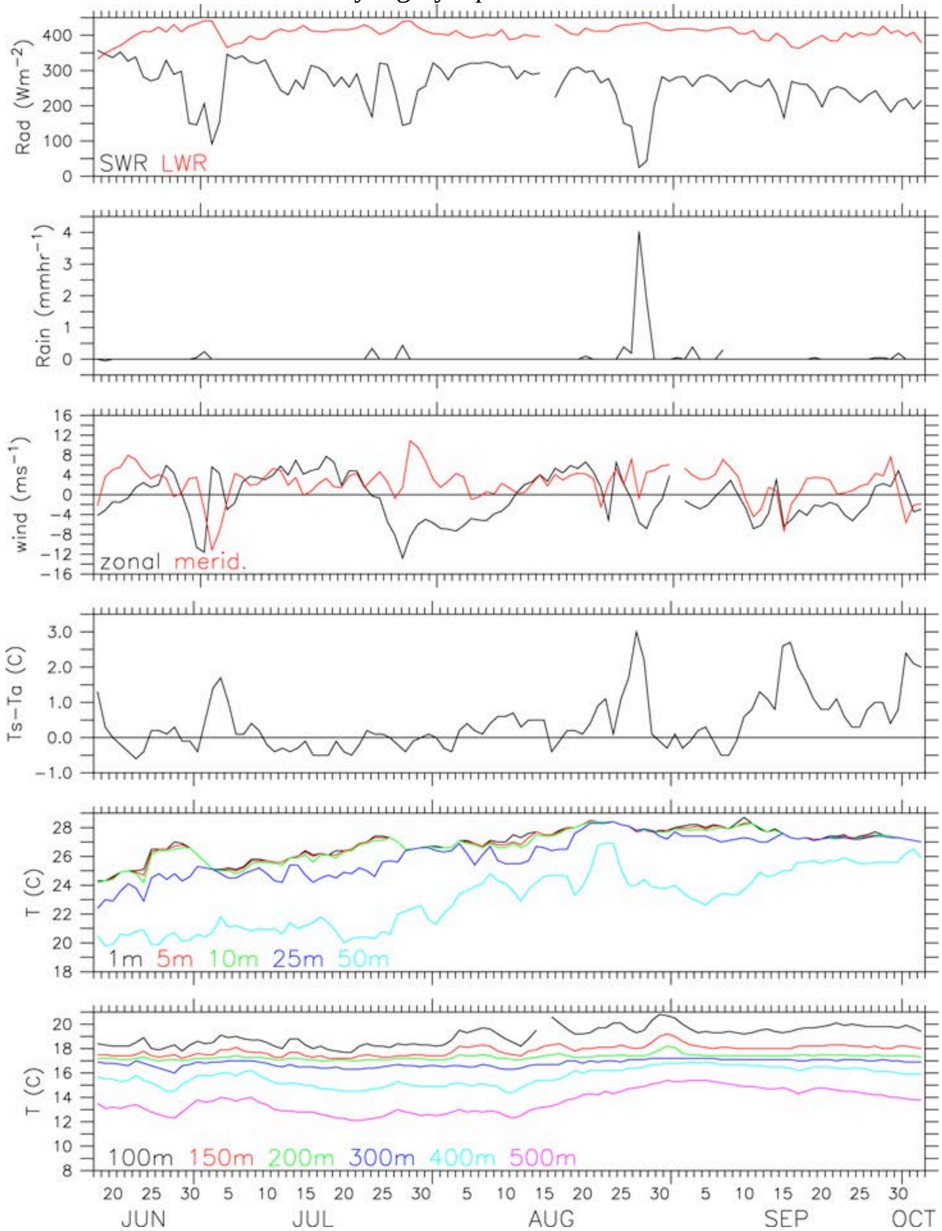


Figure 2. KEO telemetered daily-averaged data during 2004.

The KEO site is at 144.5°E, 32.3°N on the southern side of the Kuroshio Extension in its recirculation gyre. The Partnership for the Observation of the Global Oceans (POGO) has recommended the Kuroshio Extension as a site for an Ocean Sustained Interdisciplinary Timeseries Environmental Observatory (OceanSITES). With surface currents of almost 3 knots (~150 cm/s), a typically rough sea state, and lying in the Jet Stream's storm track, the KE is an extremely difficult region to observe. Ships have been the traditional platform for observing air-sea interaction in western boundary currents. However research cruises typically last no more than a month or two, and measurements from research ships and vessels of opportunity are biased towards good weather. To survive the strong currents, the surface mooring must be carefully engineered to have extremely low drag. Mooring design analyses have been performed by engineers at PMEL (co-PI Meinig is PMEL lead engineer) and vetted with scientists and engineers at WHOI and JAMSTEC. The mooring is slack-line with a scope of 1.4, and has minimal subsurface instrumentation during the first year. To minimize the risk involved in this project, the first year deployment is relatively modest and highly leveraged. Furthermore, the mooring is carrying a load-cell and telemetering engineering data, as well as the physical data. Although historically the KE has meandered over the site location, the KE appears to have entered a quasi-stable straight path, with axis north of the site (Fig. 1). Although we are confident that the buoy will survive the winter, in the event that the buoy sinks, we will have the engineering data to understand the tolerance limits of the mooring. Western boundary flux mooring will undoubtedly require ongoing engineering. We are eagerly awaiting wintertime when air-sea interactions intensify.

Addressing NOAA's Program Plan:
The KEO buoy is a contribution to the network of Ocean Reference Stations in a key region for air-sea interaction and therefore directly addresses the sixth element of the Program Plan for Building a Sustained Ocean Observing System for Climate (Ocean Reference Stations). With a Carbon Flux sensor this project would directly address the eighth element "Ocean Carbon".

Management in Cooperation with International Panels:
The KEO site has been endorsed by the International Time Series Science Team (co-chaired by R. Weller), which reports to the Ocean Observations Panel for Climate (OOPC). The two primary international ocean carbon research programs are the Integrated Marine Biogeochemistry and Ecosystem Research (IMBER) and the Surface Ocean Lower Atmosphere (SOLAS) programs. Both groups strongly recommend carbon time-series measurements and are very supportive of NOAA's efforts to develop a global pCO_2 mooring network. The KEO mooring is an important part of that effort. Time-series carbon measurements are also a key element of the United States research programs like the Ocean Carbon and Climate Change Program (OCCC).

Responsible Institution:
NOAA Pacific Marine Environmental Laboratory is the responsible institution for this project.

Websites:
KEO website: http://www.pmel.noaa.gov/keo/

Partnerships:
The KEO project has several strong partners. The KEO buoy is an element of the OceanSITES network of reference sites and therefore is partners with other buoy programs in the network (e.g., stratus, NTAS, HOT, TAO/TRITON,…). TAO and the NSF-funded Kuroshio Extension System Study (KESS) are particularly close working partners. The buoy was originally purchased under the now-complete NOAA OGP funded TAO-Eastern Pacific Investigation of Climate (EPIC) project. Professional staff supported by the KEO project are drawn from the pool of professional staff that participate in the TAO program. Located within the KESS array and within 10 km of N. Hogg's subsurface profiler mooring, the KEO buoy is contributing scientifically to the KESS experiment. KESS in turn has provided ship time, technicians and equipment for mooring operations. After the final KESS recovery cruise in June 2006, it is hoped that ship time will be provided through JAMSTEC. Partnership with JAMSTEC during FY04 resulted in a science meeting at JAMSTEC, "KESS and Beyond" co-organized by Drs. Cronin and Ichikawa. Subsequently, Prof. Kubota has asked Cronin to collaborate on a project titled "KESS-flux" and

Drs. Ichikawa, Konda, and Tanimoto have a proposal pending in which PMEL would be contracted to deploy a buoy, much like KEO, across the jet from the KEO site, either upstream or downstream. This partnership is a step towards our goal of having an array of buoys that would monitor the patterns of atmosphere and ocean exchanges in this dynamic region. During FY05, we hope to add a pCO_2 flux sensor to the suite of sensors. With this the carbon measurement, the KEO project would become a partner to NOAA's Global Carbon Cycle Program. This partnership is represented by co-PI Sabine.

Monitoring Principles:
The project is managed in accordance with the Ten Climate Monitoring Principles.

FY2004 PROGRESS

KEO buoy:
FY2004 was the first year of the KEO project. During FY2004, a buoy from the now-complete TAO-EPIC project, was retrofit into a more robust platform. The mooring was redesigned to be a slack-line mooring with 1.4 scope and 500 m of fairing. A load cell and GPS transmitter were purchased to monitor the tensions and location of the buoy. To survive winter storms, the standard RM Young vane and propeller wind sensor was replaced with a sonic anemometer. The full suite of meteorological measurements on the first-deployment of the KEO buoy includes: wind speed and direction, air temperature, relative humidity, rainfall, and solar and longwave radiation. Surface and subsurface measurements include sea surface temperature and salinity at 1 m, subsurface temperature at 11 depths down to 500 m, subsurface salinity at 8 depths down to 400 m, and pressure at 100 m, 300 m, and 500 m.

The KEO buoy was shipped to Yokohama, Japan and deployed from the KESS mooring cruise aboard the R/V Thompson with N. Hogg (WHOI) as Chief Scientist in June 2004. The mooring operation was led by PMEL mooring technician S. Kunze and aided by 3 WHOI mooring technicians, as well as other KESS and ship personnel. M. Cronin helped stage the buoy in Yokohama prior to deployment, but did not go on the cruise. During staging, M. Cronin and H. Ichikawa held a "KESS and Beyond" science meeting at JAMSTEC that drew together KESS scientists and climate scientists from throughout Japan.

In addition to the "KESS and Beyond" meeting, there have been several informal meetings with Japanese investigators at the CLIVAR2004 conference in Baltimore, MD, and at the AMS air-sea interaction conference in Portland ME. These discussions have culminated in a JAMSTEC proposal submitted in late September 2004 by Drs. Ichikawa, Konda, and Tanimoto to deploy a PMEL KEO buoy in the KE in fall 2005. This effort represents a clear intention by JAMSTEC to form a partnership with PMEL to build a Kuroshio Extension Observing array. Ultimately the success of the KEO project will depend upon the formation of such a partnership and thus this JAMSTEC proposal represents a major step forward for the KEO project.

Data Management:
Daily-averages of nearly all data (surface and subsurface) are telemetered to PMEL and made available in near-real time from: http://www.pmel.noaa.gov/keo/data.html
Because the KEO array is at this time an array of one buoy, the data are being withheld from the Global Telecommunications System (GTS) so that they can be used as an independent validation in comparisons with satellite and numerical weather prediction (NWP) fields. This decision will be reviewed periodically. High-resolution surface and subsurface data will be made publicly available through the KEO website within 6 months of recovery.

KEO data has had an excellent data return, with greater than 99% data return for the surface meteorological measurements. Due to transmission failure from the 75 m module and several random transmission drop-outs, the overall data return for KEO telemetered data is 93%. When data are recovered from internal memory, the overall data return may increase.

Research Highlights:
Within days of the deployment, remnants of super typhoon Dianmu passed over the buoy and can be seen in the KEO data (Fig. 2). Likewise, the eastern edge of typhoon Megi passed over the KEO site in late August, resulting in nearly 10 cm of rainfall in one 24-hour period and a 24-hour average solar radiation value of 25 Wm^{-2}. Large air-sea temperature differences can also be seen in the data. Heat fluxes associated with cold-air outbreaks can contribute to explosive cyclogenesis, yet are often poorly modeled and can contribute to systematic biases in seasonal and climatological NWP flux estimates. For this reason, researchers at ECMWF (Beljaars 2004, personal communication) and elsewhere are very interested in tracking cold-air outbreaks in the KEO data. Although it is early for detailed analyses, already KEO data are being used to compute air-sea heat fluxes for comparisons with the J-OFURO satellite derived flux products (Kubota 2004, personal communications). Kubota has a proposal submitted to Japan's Ministry of Education, Culture, Sports, and Technology to collaborate with Cronin on "KESS-fluxes". As can be seen in Fig. 1, the Kuroshio Extension appears to have entered into a stable path-state. During 2003 and 2004 no large meanders were observed (Qiu 2004, personal communication). The KEO site is well placed for investigating the role of the recirculation gyre heat content and air-sea heat exchanges in maintaining the quasi-stable path.

3.14a. High Resolution Climate Data From Research and Volunteer Observing Ships

by C. W. Fairall

PROJECT SUMMARY

This project involves the measurement of direct high-resolution air-sea fluxes on two cruises per year and the development of a roving standard flux measuring system to be deployed on a series of NOAA and UNOLS research vessels to promote the improvement of climate-quality data from those platforms. An adjunct task is maintenance and operation of the C-band scanning Doppler radar and the stabilized wind profiling radar on the NOAA ship *Ronald H. Brown*. Because buoys and most ships and satellites rely on bulk methods to estimate fluxes, another aspect of this project is the use of direct measurements to improve the NOAA/COARE bulk flux algorithm. One cruise is the annual TAO buoy tending cruise to 95° and 110°W on the *Ronald Brown*, which occurs every fall. The second cruise, which also occurs in the fall, is the annual excursion to turn around the Stratus climate buoy at 20°S, 85°W. A full suite of direct, inertial-dissipation, and bulk turbulent fluxes are measured along with IR and solar radiative fluxes, precipitation, and associated bulk meteorological properties. This effort represents a partial transition of research from the OGP CLIVAR PACS program to operations under the Climate Observation Program (COP).

The project development is the result of a recent NOAA-sponsored workshop on high-resolution marine measurements (Smith et al. 2003, *Report and Recommendations from the Workshop on High-Resolution Marine Meteorology*, COAPS Report 03-01, Florida State University, pp 38) which identified three important issues with the planned NOAA air-sea observation system: 1) the need for a data quality assurance program to firmly establish that the observations meet the accuracy requirements, 2) the need for observations at high time resolution (about 1 minute), and 3) the need to more efficiently utilize research vessels, including realizing their potential for the highest quality data and their potential to provide more direct and comprehensive observations. For seasonal time scales, the net air-sea flux (sum of 5 flux components) must be constrained within 10 Wm^{-2}. Buoys and VOS systems are required to operate virtually unattended for months, so considerations of practical issues (e.g., power availability, instrument ruggedness, or safe access) are balanced against inherent sensor accuracy and optimal sensor placement. As discussed above, an important function of the in situ measurements is to provide validation data to improve NWP and satellite flux fields. Here, high time resolution and more direct observations are invaluable for interpreting surface flux measurements and diagnosing the source of disagreements; such information can be provided by suitably equipped research vessels (R/V). Thus, the accuracy of buoy and VOS observations must be improved and supplemented with high-quality, high time resolution measurements from the US R/V fleet (which is presently underutilized). The necessity for both high time resolution and high accuracy places extreme demands on measurements because some sources of error (such as the effect of ship flow distortion on wind speed) tend to average out over a large sample. To accomplish this task will require a careful intercomparison program to provide traceability of buoy, VOS, and RV accuracy to a set of standards.

This project directly addresses the need for accurate measures of air-sea exchange (Sections 5.2 to 5.4, *Program Plan for Building a Sustained Ocean Observing System for Climate*). The project is a joint effort by ETL and Dr. Robert Weller of the Woods Hole Oceanographic Institution (WHOI). NOAA COP funds the ETL component and Dr. Weller is seeking NSF funds for the WHOI component. The ETL Air-Sea Interaction Group website can be found at:

http://www.etl.noaa.gov/et6/air-sea/. ETL also cooperates with Dr. Andy Jessup (APL University of Washington) on radiative sea surface temperature measurements, Dr. Frank Bradley (CSIRO, Canberra Australia) on precipitation, Drs. M. Cronin and N. Bond (PMEL) on buoy-ship intercomparisons and climate variability analysis, and Dr. Mike Reynolds (DOE BNL) on radiative fluxes. A new website is under construction for this project (High Resolution Climate Observations). The website is planned to contain a handbook on best practices for flux measurements plus a database of high-resolution flux data. This work will be closely monitored by the new WCRP Working Group on Surface Fluxes (WGSF), which is chaired by C. Fairall. This will give the project high visibility in the CLIVAR, GEWEX, and SOLAS programs. This project will be managed in cooperation with JCOMM (and other) panels as per instructions of Mike Johnson.

FY2004 PROGRESS

For the *Ronald Brown* C-band and wind profiler radar project, hardware upgrades and routine maintenance was performed on the wind profiler prior to the NOAA New England Air Quality Study (NEAQS) conducted off New Hampshire and Maine in July and August 2004. The wind profiler performed well during the cruises and was constantly monitored to evaluate boundary layer wind speed and direction. The C-band radar was also used on this project. While the ship was in Portsmouth, NH, Engineer David Lefcourt of SIGMET, Inc., spent two days upgrading the C-band radar software and improving the functionality of the new LINUX computers that were purchased last year. The software licenses and maintenance were also continued with SIGMET. The C-band radar and wind profiler are also operated during the TAO tender cruise in fall 2004.

ETL completed two research cruises as planned: the annual TAO tender cruise to 95° and 110°W longitude in the equatorial Pacific on board the R/V *Ronald H. Brown* and the joint ETL/WHOI cruise to the climate reference buoy (25°S, 80°W) on board the R/V *Roger Revelle*. Three significant research accomplishments are highlighted here. The joint ETL/WHOI cruise in the fall 2003 signified the first time that air-sea fluxes, cloud remote sensing, and aerosol properties were all measured simultaneously from a ship in the subtropical stratus cloud region. These unique observations showed strong correlations between cloud properties, aerosols, and the air-sea flux forcing of the ocean energy budget. A paper on this has already been accepted for publication (Kollias et al. 2004). A second major accomplishment is the application of parameterizations developed from the ETL TAO tender ship-based observations to an analysis of data from the enhanced monitoring system on the TAO buoys on 95°W (joint with Meghan Cronin of PMEL and Bob Weller of WHOI). This has allowed us to compare the buoy-observed annual cycle of the effects of clouds on the surface energy budget with estimates from satellites, NCEP and ECMWF reanalysis products. This analysis has identified several regions/seasons where the operational products have significant errors and shown that the reason for the errors is incorrect model cloud type (e.g., the model has tropical convective clouds where it should have stratocumulus clouds). A publication on this has also been submitted (Cronin et al., 2004). The third accomplishment involves ongoing work on improving the NOAA/COARE flux algorithm through direct measurements of air-sea gas transfer. The use of trace gases allows us to dig into internal details of the algorithm associated with the partition of oceanic versus atmospheric transport processes. We completed a comparison of the algorithm with data from the NOAA Carbon Cycle program's GASEX-01 field program (see Hare et al., 2004). Also, in 2003 we hosted a piggyback project from the University of Hawaii on the *Ronald Brown*'s fall TAO tender cruise. This resulted in the first ever direct measurements of DMS flux from a ship. This technological breakthrough adds a second (along with CO_2) biologically coupled gas transfer process to our capabilities (see Huebert et al. 2004).

3.15a. Global Repeat Hydrographic/Co_2/Tracer Surveys In Support Of CLIVAR And Global Carbon Cycle Objectives: Carbon Inventories And Fluxes

by Project Managers: Richard A. Feely and Rik Wanninkhof
Co-Principal Investigators: Christopher Sabine, Gregory Johnson, Molly Baringer, John Bullister, Calvin W. Mordy, Jia-Zhong Zhang

PROJECT SUMMARY

General Overview:

The Repeat Hydrography CO_2/tracer Program is a systematic and global re-occupation of select hydrographic sections to quantify changes in storage and transport of heat, fresh water, carbon dioxide (CO_2), chlorofluorocarbon tracers and related parameters. It builds upon earlier programs (e.g., World Ocean Circulation Experiment (WOCE)/Joint Global Ocean Flux Survey (JGOFS) during the 1990s) that have provided full depth data sets against which to measure future changes, and have shown where atmospheric constituents are getting into the oceans. The Repeat Hydrography CO_2/tracer Program (Fig. 1; Table 1) will reveal much about internal pathways and changing patterns that will impact the carbon sinks on decadal time scales. It is designed to assess changes in the ocean's biogeochemical cycle in response to natural and/or man-induced activity. Global warming-induced changes in the ocean's transport of heat and freshwater, which could affect the circulation by decreasing or shutting down the thermohaline overturning, can be followed through long-term measurements. Below the 2000 m depth of the Argo array, Repeat Hydrography is the only global measurements program capable of observing these long-term trends in the ocean. The program will also provide data for the Argo sensor calibration (e.g., www.argo.ucsd.edu), and support for continuing model development that will lead to improved forecasting skill for oceans and global climate.

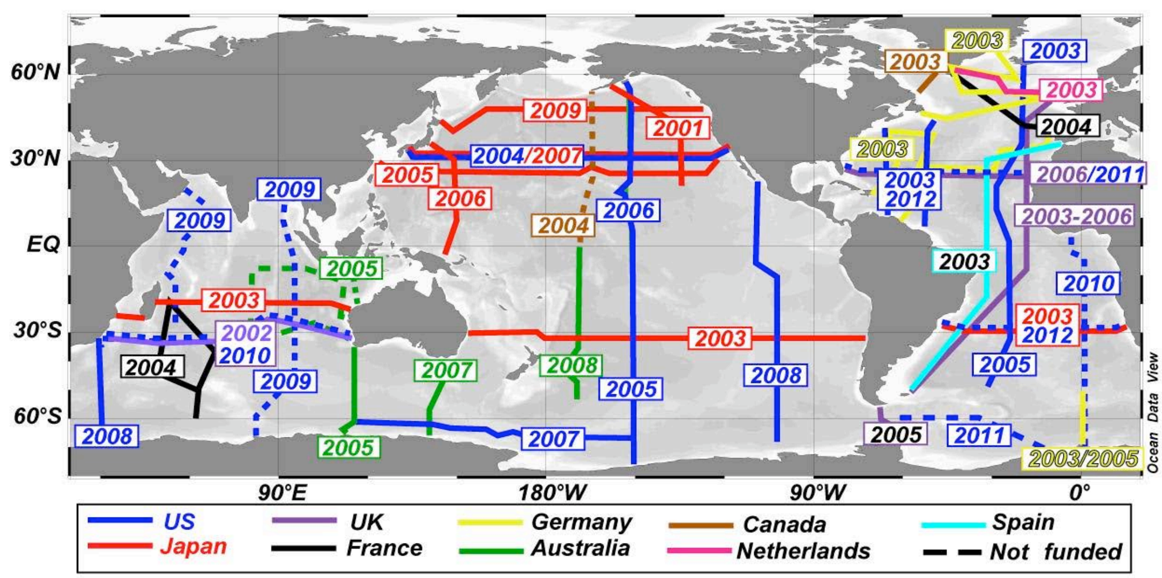


Figure 1. Global map of planned Repeat Hydrography CO_2/tracer Program hydrographic sections with carbon system measurements. Solid lines indicate funded lines. Dashed lines indicate planned lines that are not fully funded at this time. The U.S. A16S and P16S cruises in the South Atlantic and South Pacific, respectively, are designated with solid blue lines for calendar year 2005.

By integrating the scientific needs of the carbon and hydrography/tracer communities, major synergies and cost savings have been achieved. The philosophy is that in addition to efficiency, a coordinated approach will produce scientific advances that exceed those of having individual carbon and hydrographic/tracer programs. These advances will contribute to the following overlapping scientific objectives: 1) data for model calibration and validation; 2) carbon inventory and transport estimates; 3) heat and freshwater storage and flux studies; 4) deep and shallow water mass and ventilation studies; and 5) calibration of autonomous sensors.

Table 1. Sequence of Repeat Hydrography CO_2/tracer cruises in the oceans for the decade starting in June of 2003.

Schedule of US CO_2/CLIVAR Repeat Hydrography Lines (as of 10/04)

Dates	Cruise	Days	Ports	Year	Contact/Chief Scientist
					Overall Coordinator: Jim Swift, SIO
6/19/03-7/10/03	A16N, leg 1	22	Reykjavik-Madeira	1	Bullister, NOAA/PMEL
7/15/03-8/11/03	A16N, leg 2	28	Madeira - Natal, Brazil	1	Bullister, NOAA/PMEL
9/15/03-10/13/03	A20	29	WHOI - Port Of Spain	1	Toole, WHOI
10/16/03-11/07/03	A22	21	Port Of Spain - WHOI	1	Joyce, WHOI
6/13/04-7/23/04	P2, leg 1	41	Yokohama-Honolulu	2	Robbins, SIO
7/26/04-8/26/04	P2, leg 2	32	Honolulu - San Diego	2	Swift, SIO
1/11/05-2/24-05	A16S	45	Punta Arenas-Fortaleza	3	Wanninkhof/Doney; NOAA/AOML/WHOI
1/8/05-2/18/05	P16S	40	Tahiti-Wellington	3	Sloyan/Swift, WHOI/SIO
2006	P16N	57	Tahiti-Alaska	4	Feely/Sabine, NOAA/PMEL
austral summer 07	S4P/P16S	25.5	Wellington-Perth	5	
austral summer 07		25.5	Wellington-Perth	5	
2008	P18	32	Punta Arenas-Easter Island	6	
2008		35	Easter Island- San Diego	6	
2008	I6S	42	Cape Town	6	
2009	I7N	47	Port Louis/Muscat	7	future planning
2009	I8S	38	Perth- Perth	7	future planning
2009	I9N	34	Perth- Calcutta	7	future planning
2010	I5	43	Perth - Durban	8	future planning
2010	A13.5	62	Abidjan-Cape Town	8	future planning
2011	A5	30	Tenerife-Miami	9	future planning
2011	A21/S04A	42	Punta Arenas-Cape Town	9	future planning
2012	A10	29	Rio de Janeiro-Cape Town	10	future planning
2012	A20/A22	29	Woods Hole-Port of Spain-Woods Hole	10	future planning

Years 1-6 are funded.

National Linkages:

The Repeat Hydrography CO_2/tracer Program is being implemented to maintain decadal time-scale sampling of ocean transports and inventories of climatically significant parameters in support of Objective 8 (Ocean Carbon Monitoring Network) of the Program Plan for Building a Sustained Observing Network for Climate. The sequence and timing for the sections (Fig. 1) takes into consideration the program objectives, providing global coverage, and anticipated resources. Also considered is the timing of national and international programs, including the focus of CLIVAR on the Atlantic in the early years of the program; the Ocean Carbon and Climate Change Program (OCCC) that emphasizes constraining the carbon uptake in the Northern Hemisphere oceans, in part, in support of the North American Carbon Program (NACP); and the international Integrated Marine Biogeochemistry and Ecosystem Research (IMBER) program. In addition, the proposed sections are selected so that there is roughly a decade between them and the WOCE/JGOFS occupation.

The scientific objectives are important both for the CLIVAR and the OCCC programs, and for operational activities such as Global Ocean Observing System (GOOS) and Global Climate Observing System (GCOS). In mid-2001 the US scientific steering committees of CLIVAR (www.clivar.org) and the Carbon Cycle Science Program, (CCSP; www.carboncyclescience.gov) programs proposed the creation of a joint working group to make recommendations on a national program of observations to be integrated with international plans. Several community outreach programs and efforts have been implemented to provide information about the program, such as a web site with interactive forum (http://ushydro.ucsd.edu/index.html), articles in EOS (Sabine and Hood 2002) and the JGOFS newsletter, as well as AGU and Ocean Science meeting forums. The Repeat HydrographyCO_2/tracer Program addresses the need, as discussed by the First International Conference on Global Observations for Climate (St. Raphael, France; October 1999), that one component of a global observing system for the physical climate/CO_2 system should include periodic observations of hydrographic variables, CO_2 system parameters and other tracers throughout the water column (Smith and Koblinsky 2000; Fine et al. 2001). The large-scale observation component of the OCCC has also defined a need for systematic observations of the invasion of anthropogenic carbon in the ocean superimposed on a variable natural background (Doney et al. 2004; Fig. 1).

The CCSP has identified the critical need for the federal government to begin delivering regular reports documenting the present state of the climate system components. Through this program plan NOAA will develop the infrastructure necessary to build, with national and international partners, the ocean component of a global climate observing system and to deliver regular reports on the ocean's contribution to the state of the climate and on the state of the observing system. The goal of this plan is to build and sustain the ocean component of a global climate observing system that will respond to the long-term observational requirements of the operational forecast centers, international research programs, and major scientific assessments.

Relationship to NOAA's Program Plan for Building a Sustained Ocean Observing System for Climate: (Objective 8: Ocean Carbon Monitoring Network)
The ocean is the memory of the climate system and is second only to the sun in effecting variability in the seasons and long-term climate change. It is estimated that the ocean stores 1000 times more heat than the atmosphere, and 50 times more carbon. Additionally, the key to possible abrupt climate change may lie in deep ocean circulation. Accordingly, the main objective of the repeat hydrography component of the sustained ocean observing system for climate is to document long-term trends in carbon storage and transport in the global oceans. This program will provide a composite global ocean observing system large-scale observations that includes: 1) detailed basin-wide observations of CO_2, hydrography, and tracer measurements; and 2) data delivery and management. This end-to-end ocean system will provide the critical "up-front" information needed for climate research and assessments, as well as long-term, climate quality, global data sets. At the same time, the data management system will provide the necessary data to serve the needs of the other federal agencies in accomplishing their missions.

International Linkages:
Recognizing the need to develop an international framework for carbon research, various working groups of programs like the International Geosphere-Biosphere Programme (IGBP), the World Climate Research Programme (WCRP), the International Human Dimensions Programme (IHDP), the Intergovernmental Oceanographic Commission (IOC), and the Scientific Committee on Oceanic Research (SCOR) have worked together to develop research strategies for global carbon cycle studies. Based on the recommendations coming from these programs, NOAA and NSF have co-sponsored the Repeat Hydrography CO_2/tracers Program, with program direction coming from the Repeat Hydrography Oversight Committee (Richard Feely and Lynne Talley, co-chairs; http://ushydro.ucsd.edu/index.html). Many other nations are also sponsoring similar carbon studies that are comparable in focus and have been designed to be complimentary to our program (http://www.clivar.org/carbon_hydro/index.htm). Consequently, there is an immediate need for global-scale coordination of these carbon observations and research efforts to achieve the goal of a global synthesis. There is also an urgent need to critically assess the overall network of planned observations to ensure that the results, when combined, will meet the requirements of the research community. Because of these issues, the IOC-SCOR Ocean CO_2 Panel (http://www.ioc.unesco.org/iocweb/co2panel/) and the Global Carbon Project (GCP; http://www.globalcarbonproject.org/) have initiated the International Ocean Carbon Coordination Project (IOCCP; http://www.ioc.unesco.org/ioccp/) to: (1) gather information about on-going and planned ocean carbon research and observation activities, (2) identify gaps and duplications in ocean carbon observations, (3) produce recommendations that optimize resources for international ocean carbon research and the potential scientific benefits of a coordinated observation strategy, and (4) promote the integration of ocean carbon research with appropriate atmospheric and terrestrial carbon activities. It is through the workings of the IOCCP and international CLIVAR that international coordination of data management, data synthesis and scientific interpretation of the global repeat sections results will be implemented. In addition, the Repeat Hydrography CO_2/tracer Program is being managed in accordance with the COSP Ten Climate Monitoring Principals.

FY 2004 PROGRESS

A16N Cruise in the North Atlantic

The Repeat Hydrography CO_2/tracers Program started with the FY03 reoccupation of WOCE Section A16N (a meridional section from Iceland to 6°S nominally along 20°W in the eastern Basin of the N. Atlantic) on the NOAA Ship *Ronald H. Brown* (Table 1; Fig. 1). The cruise ran from Iceland southward past the equator and repeated an oceanographic section occupied in 1988, and again in 1993, looking for possible changes in the physics, chemistry and biology of the ocean in this region. All of the major goals of this expedition were met.

NOAA took the lead on measuring core hydrographic parameters (CTD/O_2, salinity, dissolved oxygen, CO_2 and nutrients) for that cruise. Participating scientists from PMEL, AOML and 13 other scientific institutions made a wide variety of atmospheric and oceanic measurements. Atmospheric (CO_2, chlorofluorocarbons, aerosols) and near surface seawater (temperature, salinity, pCO_2, fluorescence, ADCP) measurements were made while underway along the cruise track. Six ALACE profiling floats were deployed along the section, along with 3 newly developed 'Carbon Explorer' profiling floats designed to measure particulate inorganic carbon (PIC). Full water column CTD/rosette casts were made at 150 stations, with 5000 discrete seawater samples collected using a specially designed 36-position, 12-liter rosette package. In addition to the CTD, the rosette frame held a lowered ADCP, transmissometer and particulate inorganic carbon sensor.

Seawater samples were analyzed on board ship for salinity, dissolved oxygen, nutrients, Total CO_2 (DIC), Total Alkalinity (TA), pCO_2, pH, chlorofluorocarbons (CFCs), HCFCs, iron and aluminum and alkyl nitrate. Water samples were collected for shore-based analyses of helium, tritium, dissolved organic carbon, particulate organic and inorganic carbon, ^{13}C and ^{14}C. As the samples were analyzed on board, the data were collected and compiled by the data manager, allowing near real-time examination and comparison of the data sets as they were generated. The A16N CTD and bottle set is publicly accessible on line at: http://whpo.ucsd.edu/data/co2clivar/atlantic/a16/a16n_2003/index.htm. The cruise is designated as A16N_2003a with Expocodes: 33RO200306_01 and 33RO200306_02. Final calibration and processing of the cruise data set is nearly finished and we anticipate completing this process by the end of FY-2004.

During FY04 much effort was devoted to data reduction and quality control of the data. In the quality control procedure each data point was assigned a WOCE quality control flag based on intensive checks of the validity of the data. The data reduction of DIC, pCO_2 discrete, TA, pH, inorganic nutrients and oxygen is detailed in a data report that will be published by CDIAC (Peltola et al. 2004) with a synopses provided below. The quality control was performed in a systematic fashion starting with careful checks of each parameter scrutinizing analyzer performance, duplicate values, notebook entries during the cruise, and screening for outliers in profile plots. Then, contextual quality control procedures were followed by looking at internal consistency of inorganic carbon parameters, and utilizing multi-linear regressions between DIC, TA, and pCO_2 with theta, dissolved oxygen, salinity and nutrients. The difference between the calculated and measured value was calculated and if it exceeded three times the standard deviation of the average difference (ranging from 1500 to 2200 data points depending on the carbon parameter), each parameter used in the algorithm was checked closely. If deemed appropriate a flag indicating a questionable point (QC=3) was added.

What follows are the details on quality control for each parameter checked by our group and the group of Dr. Frank Millero of the U. of Miami, RSMAS, who was funded by NSF to perform TA and pH measurements.

DIC: For the cruise we relied on liquid Certified Reference Materials (CRMs) for calibration of our two coulometers. Precision of analyses was determined by taking duplicate samples at three depths (surface, 1000 m and bottom) at nearly all the casts. The duplicate analyses were performed at different times during the runs, with different coulometer solutions, and between the two instruments. No systematic biases were discerned and the average difference of the samples was 1.0 µmol kg^{-1} for surface values; 1.2-µmol kg^{-1} for duplicate samples at 1000 m and 1.4-µmol kg^{-1} for duplicate samples near the bottom. Figure 2 shows a graph of the difference of all duplicates taken on A16N_2003a. This precision meets our stated goals to quantitatively determine changes natural and anthropogenic over decadal timescales that will be on the order of 10-µmol kg^{-1} in surface water. DIC is the primary carbon parameter needed to determine the anthropogenic uptake of CO_2. Based on the high quality work of the analysts and successful performance of instruments we will attain our goals. We are in the process of quantifying changes compared to the NOAA NAtl-93 cruise. Deep-water value comparisons that are an indication of biases between the cruises are shown in Figure 3. No systematic biases are apparent.

pCO_2(20) discrete: Measurement of discrete pCO_2 at a constant temperature of 20°C is a unique skill of personnel at the NOAA laboratories. The measurement offers the ability to overdetermine the inorganic carbon system thereby making it possible to independently verify the integrity of carbon system parameters. On the NOAA led cruises we measure pH as well thereby making it possible to assess biases in carbonate dissociation constants. This "redundancy" of measurements to cross check quality of data is of critical importance to insure the integrity for climate quality data. pCO_2(discrete) is also very sensitive to changes in inorganic carbon and alkalinity in the ocean making it a good indicator to change. The measurement is challenging requiring an equilibration between water and an isolated headspace. In particular issues with water vapor interference and corrections to perturbation have affected the accuracy that is determined through comparison with CO_2 in air gas standards. For the A16N cruise we changed data reduction routines and how we deal with water vapor correction. This has increased the precision of our measurements that is estimated at 2 µatm or 0.3 % (Fig. 4) but there appears a bias in the deep-water pCO_2 values compared to data in 1993 and 1998. We think it is unlikely that the differences observed are real but to date have not been able to attribute the bias to a particular dataset (Fig. 5).

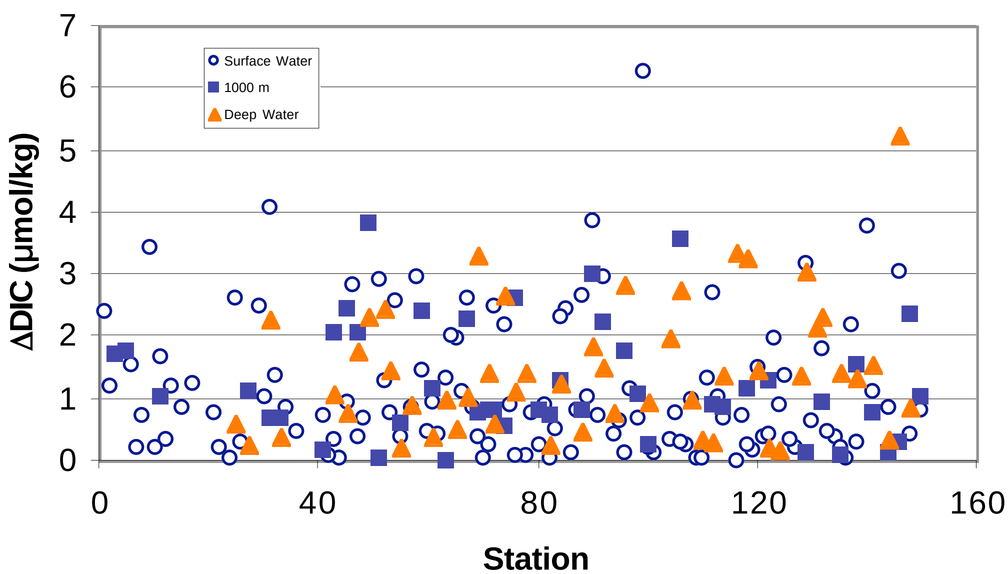


Figure 2. Duplicate DIC values versus station. Open circles are duplicates at the surface; solid squares are duplicates at 1000-m; and triangles are duplicates from near bottom. No systematic differences with depth were observed.

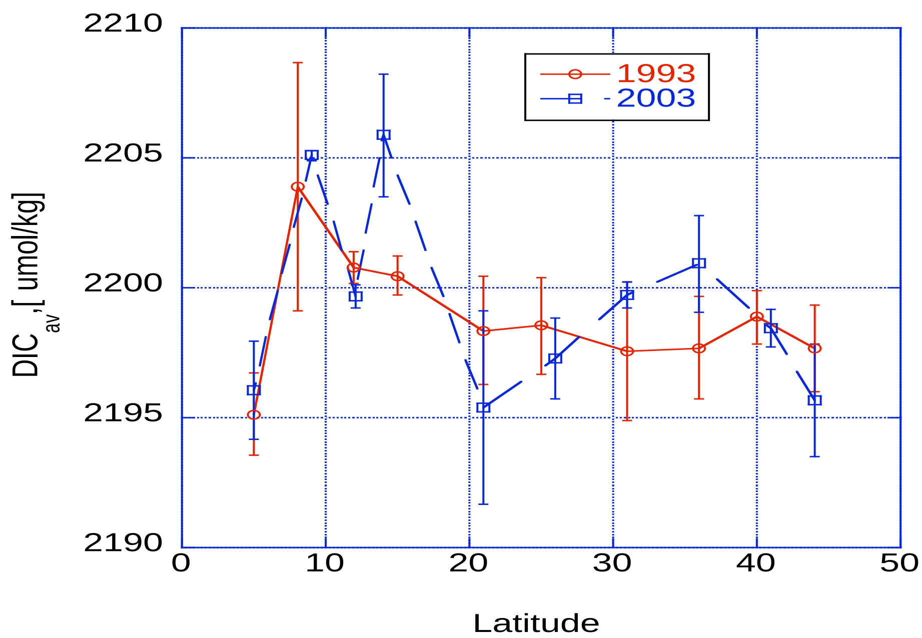


Figure 3. Comparison of deep-water values for DIC between 1993 (red line with open circles) and 2003 (blue line with open squares). The average of two to five bottom water samples at roughly five-degree spacing were compared. No systematic offset is observed with agreement better than 2 µmol kg^{-1}.

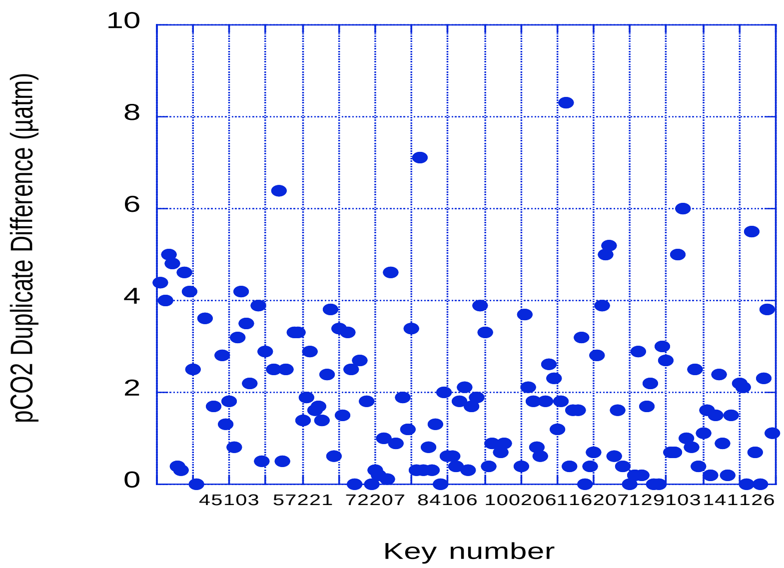


Figure 4. Differences of duplicate pCO_2 samples taken during the A16N-2003a cruise.

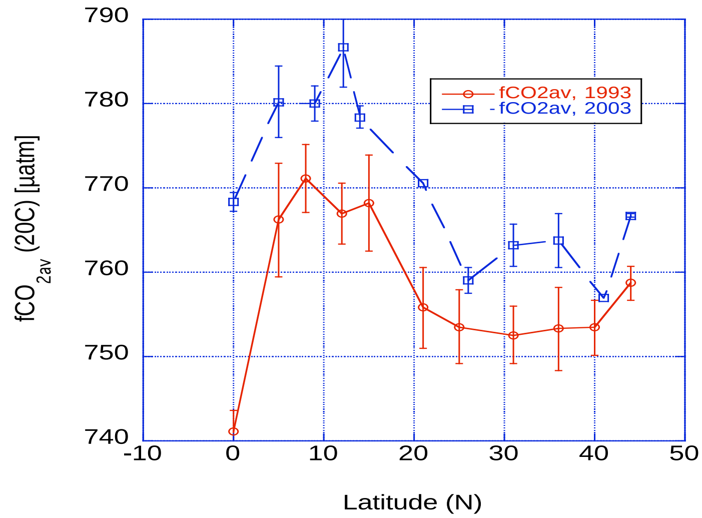


Figure 5. Comparison of deep-water values for discrete $pCO_2(20)$ between 1993 (red line with open circles) and 2003 (blue line with open squares). The average of two to five bottom water samples at roughly five-degree spacing were compared. A systematic offset of about 10 µatm is apparent.

TA and pH: These samples were analyzed by the group of Prof. Millero funded through NSF with details presented in Peltola et al. (2004). Joint quality control procedures of all carbon parameters were undertaken which benefited all parameters. Comparisons with values in 1993 are shown in Figure 6. A comparison of internal consistency of measured TA values and those calculated from DIC and $pCO_2(20)$ are shown in Figure 7. The figure suggests that the TA, $pCO_2(20)$ and DIC values are internally consistent.

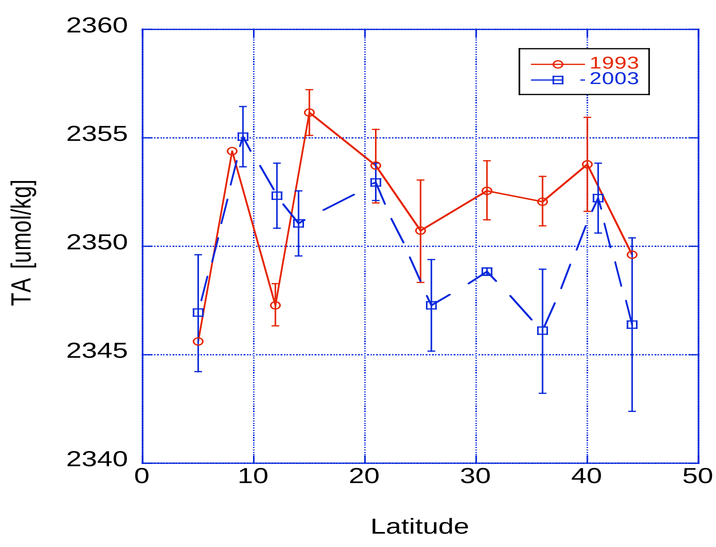


Figure 6. Comparison of deep-water values for TA between 1993 (red line with open circles) and (blue line with open squares). The average of two to five bottom water samples at roughly five-degree spacing were compared. There appears a small systematic offset of about 2-µmol kg^{-1} for several of the stations.

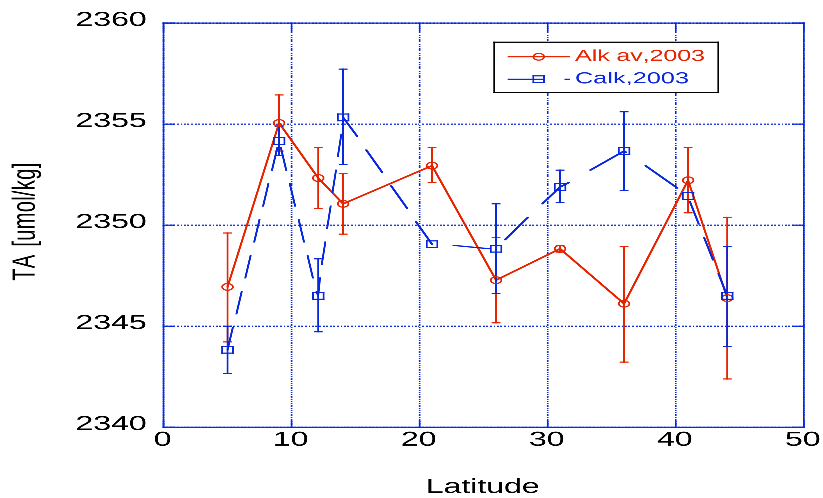


Figure 7. Comparison of deep-water values for measured TA for 2003 (red line with open circles) and calculated TA from $pCO_2(20)$ and DIC (blue line with open squares). Two to five bottom water samples at roughly five-degree spacing were compared. There is no clear offset between values.

Dissolved Oxygen: A total of ~5000 samples were taken on A16N, which included samples from each Niskin bottle. Precision based on 20 replicates taken at the first station is 0.1%. On the whole, dissolved oxygen analyses were problematic during the cruise. Lack of attention to detail compromised the quality. In particular the oxygen equipment had been used on cruises preceding A16N and problems with the instrument, in particular the pipettes to dispense standard, and sample bottle breakage and replacement was not relayed to the analysts on A16N. Sample bottle volumes must be known as the titration is performed on the whole sample right in the bottle. Following the cruise, all bottle volumes were re-determined and pipettes were recalibrated after which the data reduction was performed from scratch. The data were subsequently quality controlled by the cruise Chief Scientist J. Bullister by checking profiles and comparing with oxygen data from the Oceanus 202 cruise and the NOAA/OACES NATl -93 cruise that occupied the same transect in 1988 and 1993, respectively. Following post-cruise processing, agreement between deep-water values on the A16N and Oceanus 202 cruises is ± 2-µmol kg^{-1}.

Nutrients: Nutrient samples were taken from all Niskin bottles. Samples were analyzed for nitrate, nitrite, phosphate and silicate on an auto-analyzer. Data are of excellent quality. Precision based on duplicate samples taken from the bottom Niskin bottle is 0.08-µmol kg^{-1} (≈ 0.2 %) for nitrate, 0.01-µmol kg^{-1} (≈ 0.3 %) for phosphate, and 0.1-µmol kg^{-1} (≈ 0.1 %) for silicate.

A detailed analysis and interpretation of these cruise data should greatly improve our understanding of key ocean processes in this region and how they may be changing on decadal timescales. The results will be presented at a special session of the 2004 Fall AGU meeting and significant findings will be published in the scientific literature. Some key initial findings from the A16N cruise are that between the 2003 section and earlier occupations, significant changes in water mass properties, including temperature, salinity and dissolved oxygen, were observed in subpolar mode waters and Labrador Sea water. The changes in apparent oxygen utilization (AOU) observed may be due to changes in the strength of ventilation processes in the region during the decade prior to the 2003 occupation compared to the years prior to the earlier samplings, as well as to possible changes in biological production, and organic matter export and remineralization rates. Regions in the water column with large increases in apparent oxygen utilization (AOU) tended to have relatively large increases in pCFC derived apparent ages, indicating that the AOU changes may be driven in part by a slowdown in the strength of the ventilation processes. Simple numerical model simulations are being used to estimate the contribution of steady-state mixing processes to the temporal trends in pCFC derived apparent age fields observed in this region. NOAA was responsible for the DIC measurements on the FY04 Repeat Hydrography CO_2/tracer Program cruises. During FY04 post-cruise instrument calibrations for A16N were performed, bottle salinity, nutrient and carbon data were finalized, as were CTD temperature and salinity data. Corrections of bottle oxygen data have just been completed, and final CTD oxygen calibrations are just getting started, which will allow a final check of the bottle oxygen data. The CFC group worked on final data quality control for the CFC data collected on the A16N cruise, and J. Bullister coordinated final data quality evaluation of the other parameters measured during the cruise. Initial analysis of the first results from the Repeat Hydrography Program has begun. Some of these results were presented at the First International CLIVAR Science Conference and also will be presented at a special session of the Fall 2004 AGU meeting.

A20/A22 Cruises in the North Atlantic:
The A20/A22 cruises commenced in mid-September 2003 aboard the *R/V Knorr* from Woods Hole, MA and were completed in November. The first leg (A20) was along 52°W and ended in Trinidad; the second leg (A22) was along 66°W and ended back in Woods Hole (Table 1). Scientists from NOAA were responsible for DIC measurements. During the two cruises 150 stations were occupied and >3200water samples were collected for analysis of DIC. The quality of the measurements was considered excellent based on results of the analyses of the CRMs (Figure 8). In addition to DIC, samples also were analyzed on board ship for salinity, dissolved oxygen, nutrients, TA, and CFCs. Water samples were collected for shore-based analyses of helium, tritium, dissolved organic carbon, ^{13}C and ^{14}C. As the samples were analyzed on board, the data were collected and compiled by the data manager, allowing near real-time examination and comparison of the data sets as they are generated.

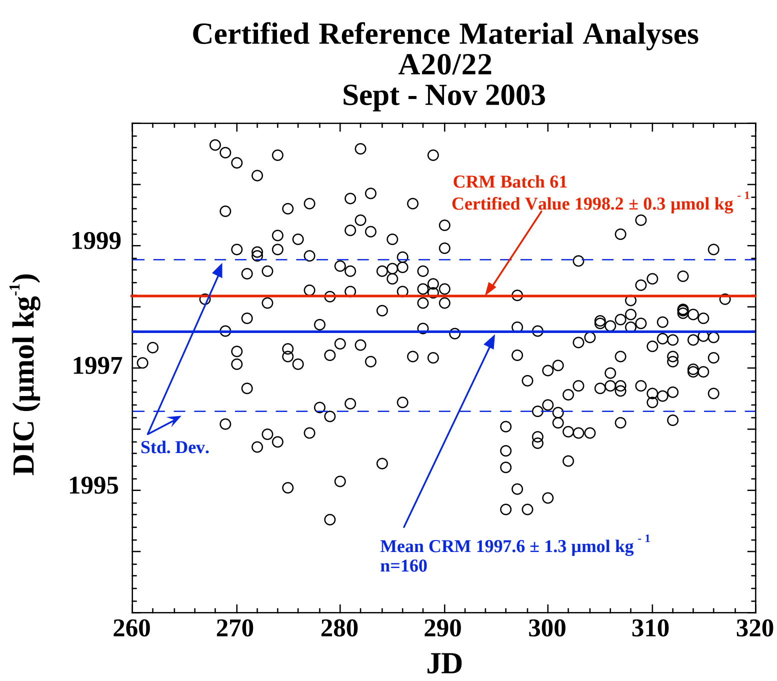


Figure 8. Results of CRM analyses during A20/22 in the Atlantic between Sept – Nov 2003.

The DIC results from the A20 cruise (Figure 9a) along 52°W can be compared to previous cruise results from the 1997 occupation (Figure 9b). The difference plot (Figure 9c) indicates significant increases of DIC in the shallow waters masses over the depth range of 100-600 m between the last occupation of these stations during the WOCE era (1997) and the 2003 occupation. For example, along the 200-600 m depth range, DIC increases on the order of 2-20 $\mu mol\ kg^{-1}$ were observed over the six year period between the two cruises (Figure 9c). In contrast, the DIC at depths >1000 m showed very little change (Figure 9c). These increases of DIC in the Subtropical Mode waters (STMW) may be the result of decadal changes in the local circulation, invasion of anthropogenic CO_2 into the interior North Atlantic, and/or changes in new production and remineralization of organic matter along the flow path. As we continue to process the physical and biogeochemical data from these cruises, we should be able to determine the large-scale changes in the carbon content of the Atlantic Ocean.

The DIC results from the A22 cruise (Fig. 10a) along 66°W can be compared to previous cruise results from the 1997 occupation (Fig. 10b). The difference plot (Fig. 10c) indicates similar increases of DIC in the Subtropical Mode (STMW) further to the west. The DIC increases are highest between 20 and 25°N in the western North Atlantic.

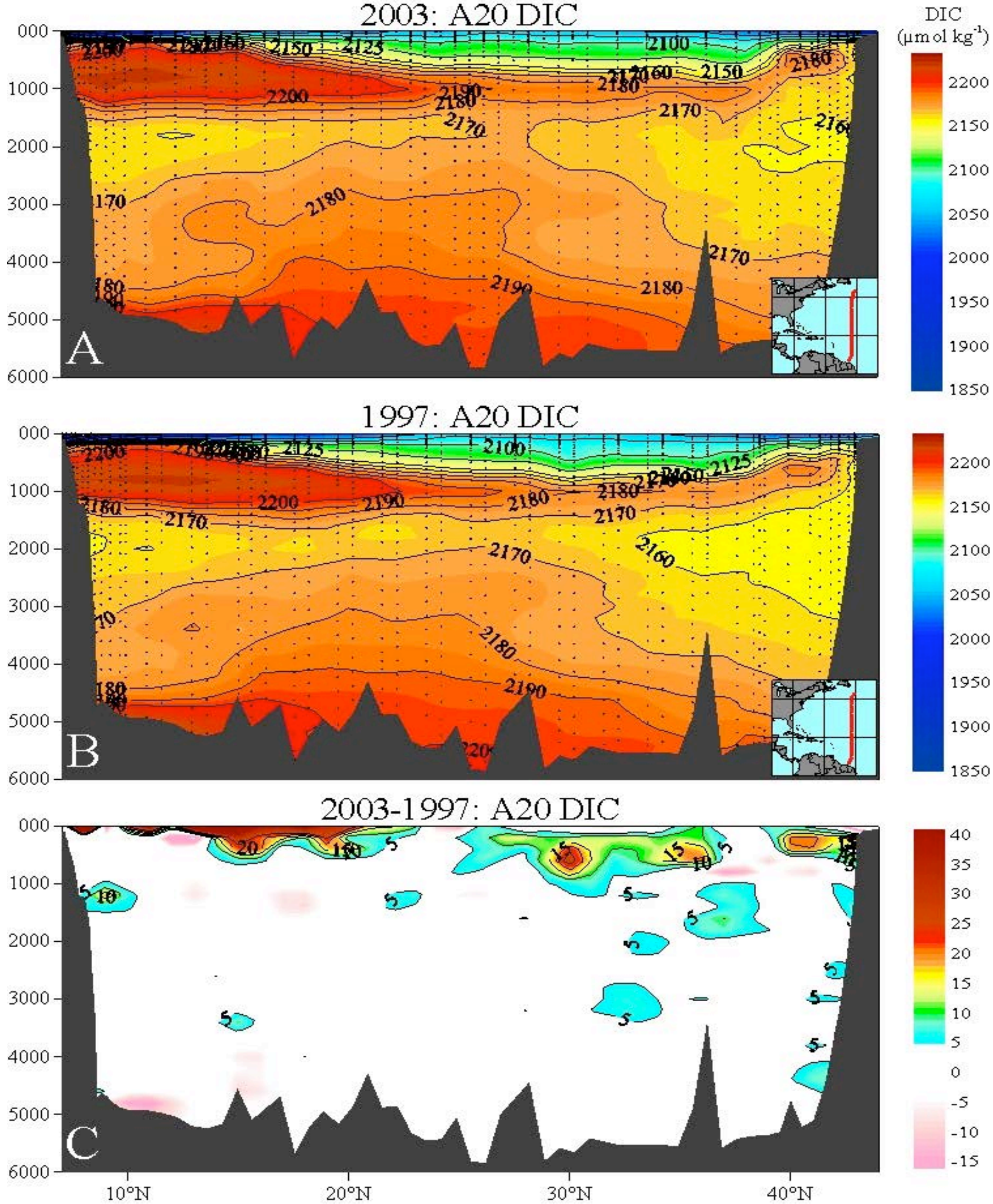


Figure 9. Distribution of DIC (μmol kg^{-1}) along 52°W in the western North Atlantic during the 2003 reoccupation (9a), the 1997 occupation (9b), and the difference 2003 – 1997 (9c).

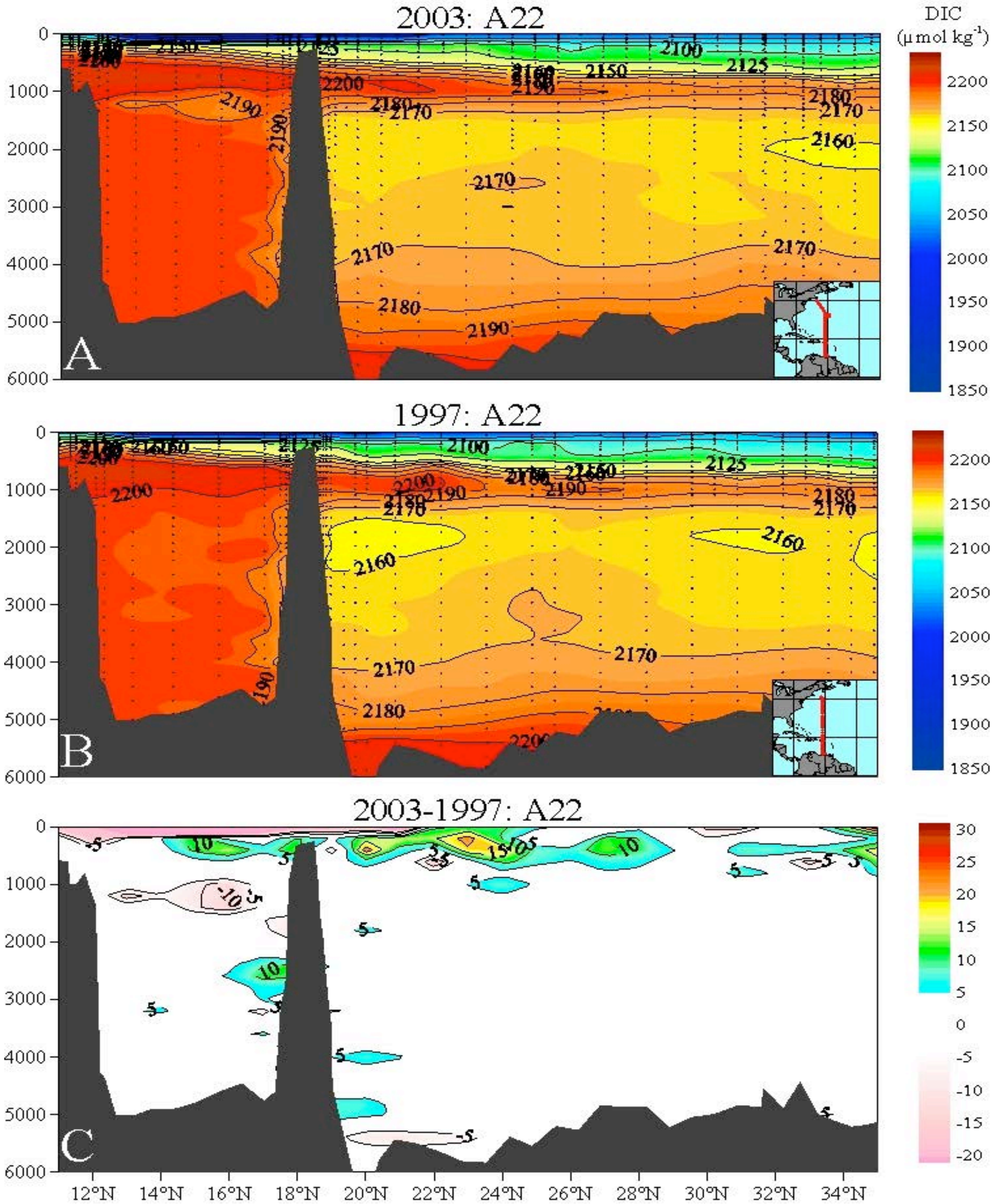


Figure 10. Distribution of DIC (μmol kg^{-1}) along 66°W in the western North Atlantic during the 2003 reoccupation (10a), the 1997 occupation (10b), and the difference 2003 – 1997 (10c).

P2 Cruise in the North Pacific:
The P2 cruise commenced in June aboard the *R/V Melville* from Yokohama, Japan with Leg 1 ending in Honolulu. Tightly spaced stations were taken angling southeast across the Kuroshio Current, and then an easterly transect was begun along 30°N/135°W. Two typhoons caused delays early in the leg, and as a consequence, station spacing was increased slightly. Leg 2 started from Honolulu and continued stations along 30°N ending in San Diego. Seawater samples were analyzed on board ship for salinity, dissolved oxygen, nutrients, DIC, TA, and CFCs. Water samples were collected for shore-based analyses of helium, tritium, dissolved organic carbon, ^{13}C and ^{14}C. During the cruise 190 stations were occupied and ≈ 6,000 water samples were collected for analysis of all these parameters. As with the previous Repeat Hydrography cruises, the real time data analyzed aboard were collected and compiled by the data manager and will be submitted to the CLIVAR and Carbon Hydrographic Data Office (CCHDO; http://cchdo.ucsd.edu/) and CDIAC. Preliminary evaluation of the shipboard data indicates that they are of high quality and should meet or exceed WOCE guidelines.

NOAA was responsible for the DIC measurements on P2. The full water column was analyzed for DIC on even stations, and generally the upper 1200m analyzed on alternate stations. Results of analyses of CRMs indicate that the data quality is excellent (Fig. 11). The accuracy and precision of the analyses is

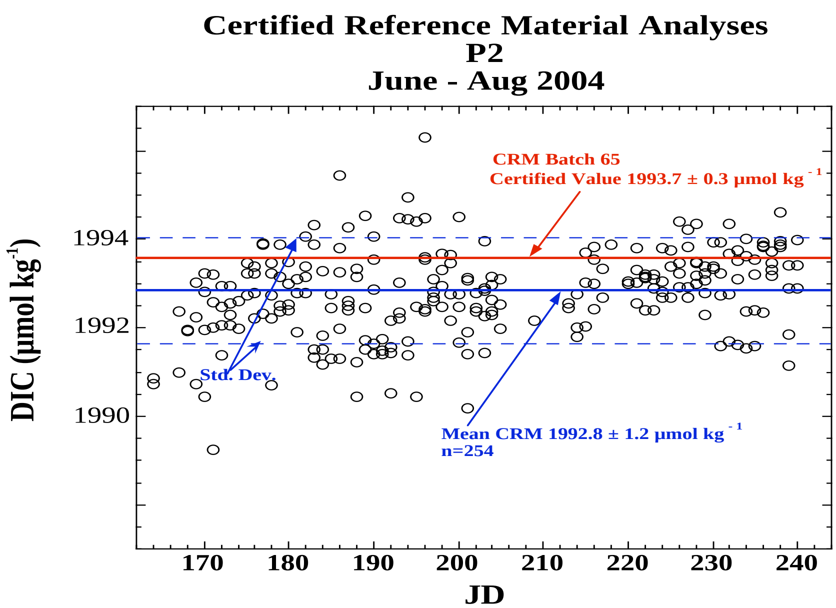


Figure 11. Results of CRM analyses on P2 cruise in the N. Pacific during June – Aug 2004.

Well within the maximum error of ±2 µmol kg^{-1} needed to quantitatively determine changes of natural and anthropogenic CO_2 over decadal timescales. Difference plots for the 2004 Repeat Hydrography – the 1994 WOCE cruises are shown in Figs. 12 and 13 for salinity and temperature, respectively. Significant differences are observed in surface waters and in intermediate depths ranging from 200-1000 m. The differences may be due to changes in the strength of ventilation processes in the region during the decade prior to the 2004 occupation compared to the years prior to the earlier samplings or to possible changes due the presence of eddies. Figs. 14 and 15 show the corresponding distributions and difference plots for AOU and DIC. The AOU maxima and minima correspond very closely with the DIC maxima and minima, suggesting that similar physical and/or biogeochemical processes are controlling the distributions of both parameters. While these results indicate that the quality of the overall data sets are quite good, they also suggest that local mesoscale processes are important and must be determined before the long-term trends can be isolated from the data sets.

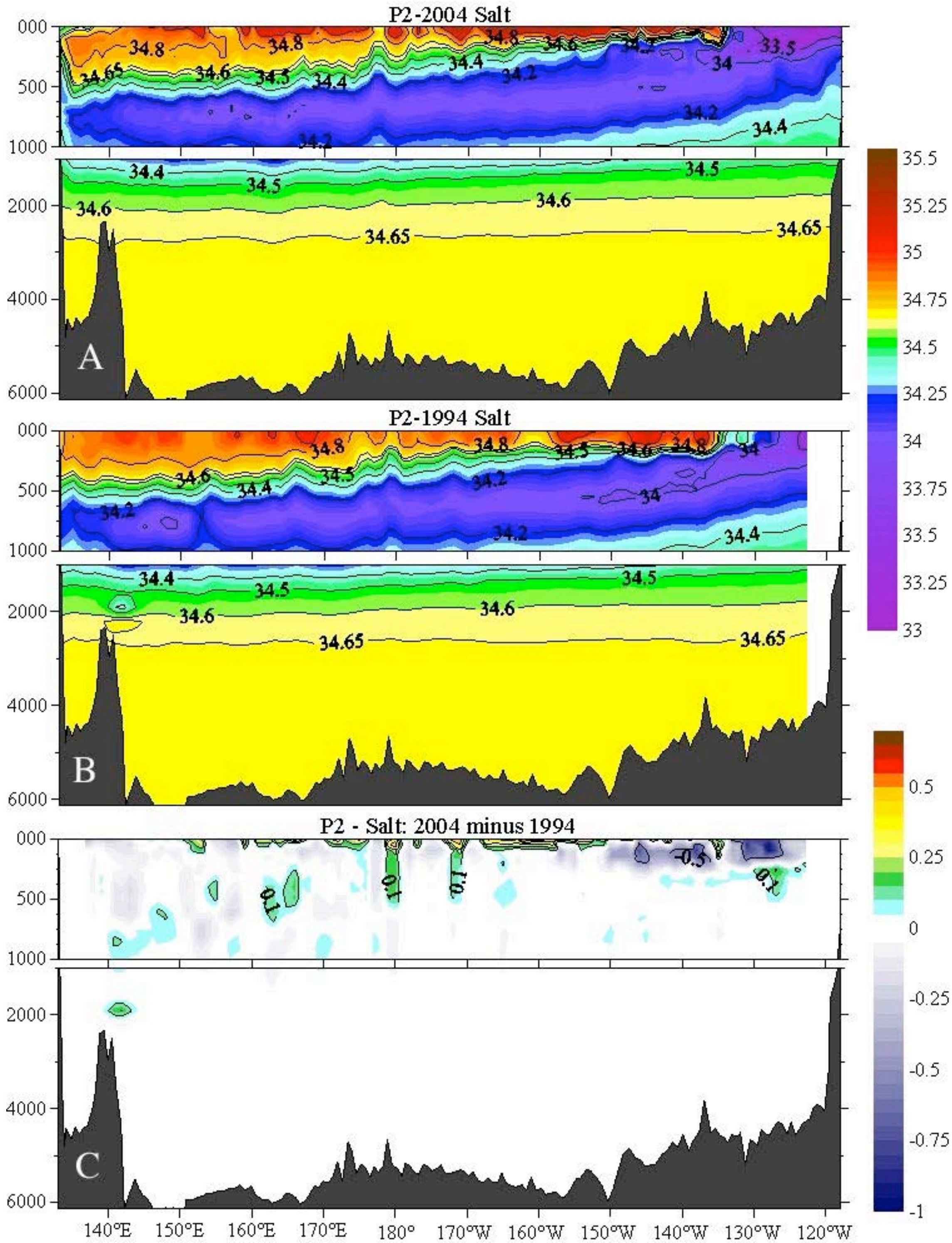


Figure 12. The difference plots for both salinity and temperature results from the P2 cruise.

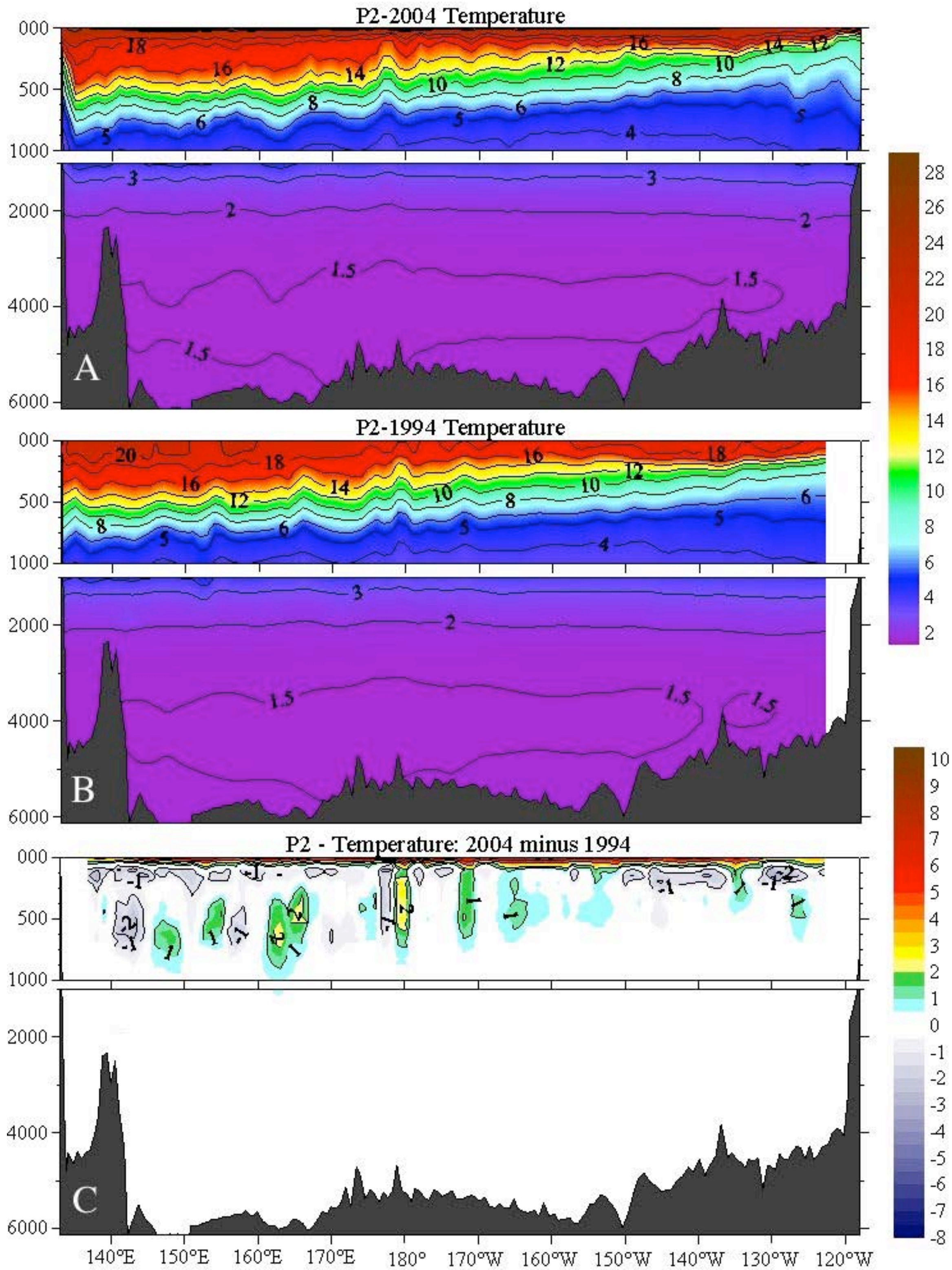


Figure 13. Distribution of temperature (°C) along 30°N in the North Pacific during the 2004 reoccupation (13a), the 1994 occupation (13b), and the difference 2004 – 1994 (13c).

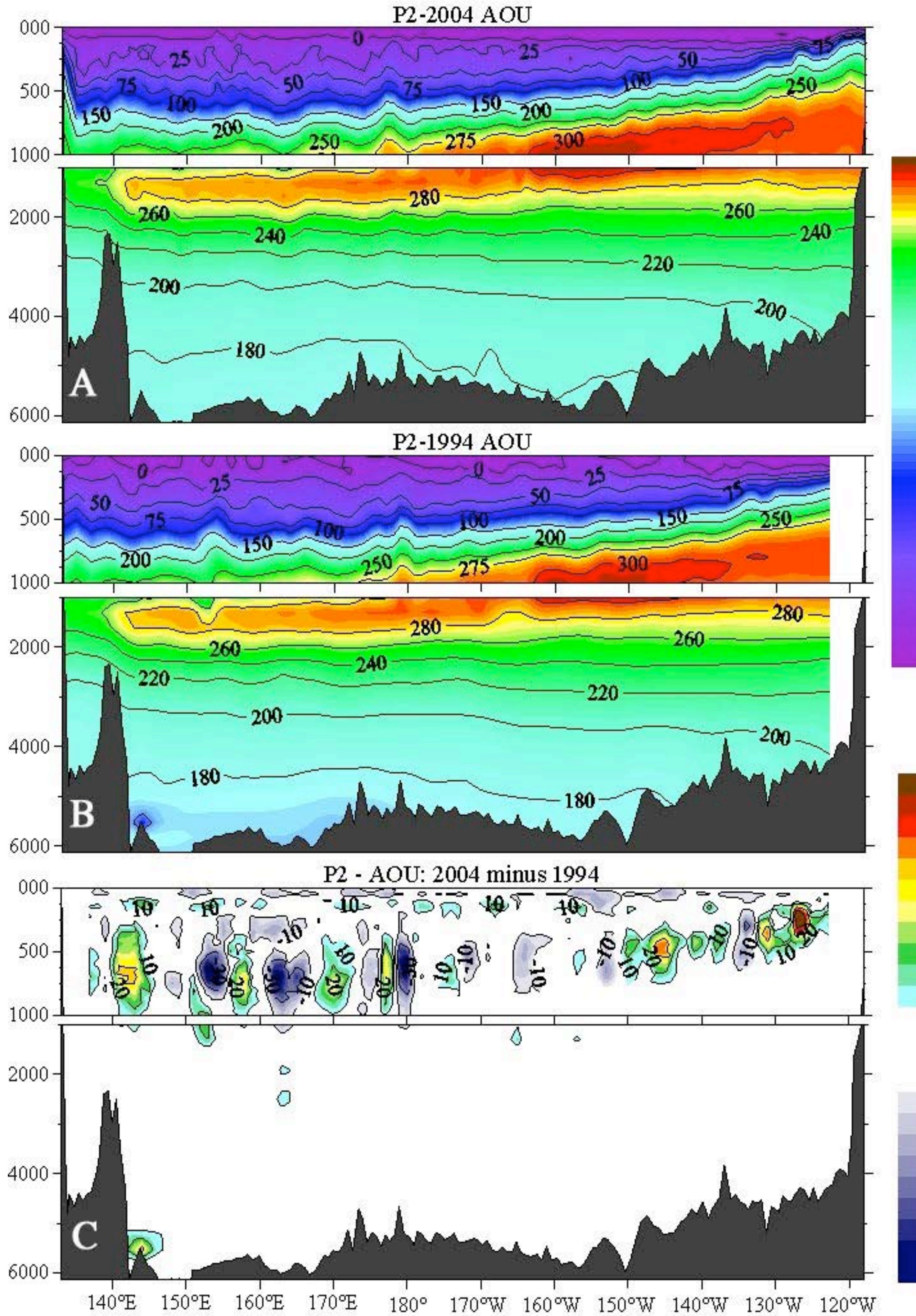


Figure 14. Distribution of AOU (μmol kg^{-1}) along 30°N in the North Pacific during the 2004 reoccupation (14a), the 1994 occupation (14b), and the difference 2004 – 1994 (14c).

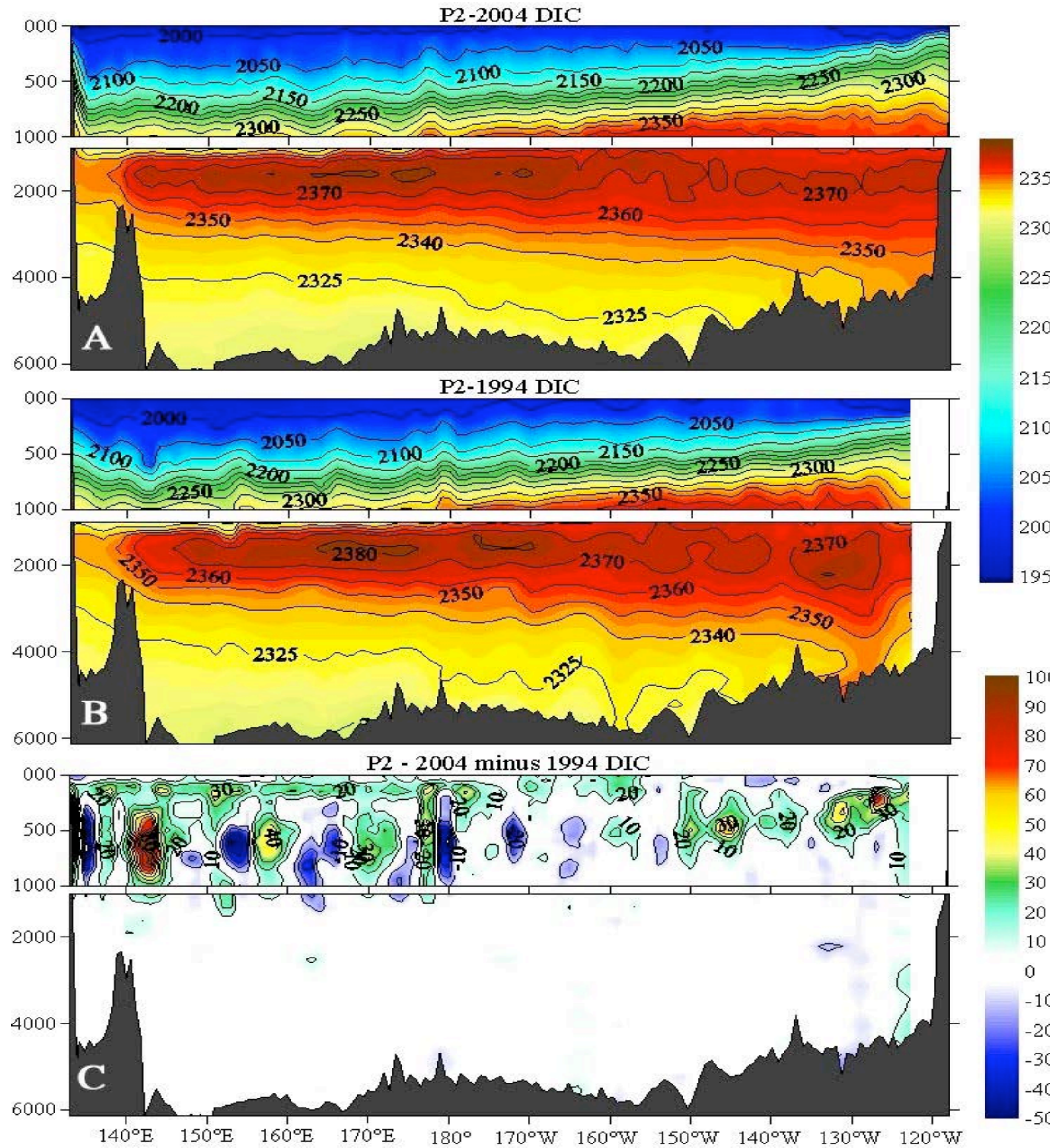


Figure 15. Distribution of DIC (μmol kg^{-1}) along 30°N in the North Pacific during the 2004 reoccupation (15a), the 1994 occupation (15b), and the difference 2004 – 1994 (15c).

A16S Cruise in the South Atlantic:
In FY04, preparations for the FY05 repeat of A16S (a meridional section from 60°S to 4°S nominally along 25°W in the western basin of the South Atlantic) on the NOAA Ship *Ronald H. Brown* have begun. Scientific supplies (salinity bottles, a laptop computer, cable terminations, a CTD oxygen sensor, a bottle frame cover, a nutrient detector, o-rings, etc.) have been purchased. In addition CTDs, frames, pylons, water sampling bottles, nutrient detectors and the like have been assembled, checked, maintained, and prepared for shipping. Nutrient analysis software has been upgraded.

P16S Cruise in the South Pacific:
Preparations for the reoccupation of P16S (a meridional section from 20°S to 67°S along 150°W) have begun for the January-February 2005 period. NOAA is responsible for DIC and underway pCO_2 measurements on P16S, and will send two analysts to participate on the cruise.

PMEL Tracer Efforts in FY2004:
The PMEL CFC Tracer group did not have fieldwork scheduled in FY 2004 as part of Global Repeat Hydrography CO_2/tracer Program. To help maintain support for CFC personnel (F. Menzia -JISAO and D. Wisegarver) during this period, F. Menzia participated on Repeat Hydrography Program sections A22 and P2 as a CFC analyst, supported by the UM/RSMAS group. D. Wisegarver participated on section P2 as a DIC analyst, supported by the PMEL Carbon group. Menzia and Wisegarver also assisted with the development of instruments with the Carbon and Hydrographic groups at PMEL during this period.

During FY 2004, the PMEL CFC group blended and calibrated gas-phase CFC standards for CFC-11, CFC-12, CFC-113 and carbon tetrachloride in high-pressure gas cylinders. These cylinders were initially analyzed at PMEL for uniformity and were monitored for possible concentration drift. These standards have been distributed to the US groups participating in the Repeat Hydrography Program Addition cylinders were prepared for distribution to international groups participating in the Repeat Hydrography Program. We anticipate that this set of cylinders will provide a reliable CFC standard reference material for the upcoming decade.

Data from the Repeat Hydrography Program are located at the CLIVAR and Carbon Hydrographic Data Office (http://cchdo.ucsd.edu/) as well as at CDIAC, where they are freely and publicly accessible. These data are being used widely in scientific studies on variability in ocean ventilation (including impacts on ocean heat, salt, oxygen, nutrients and carbon). Data from A16N were first presented in posters given at the 1st International CLIVAR Science Conference, June 2004, Baltimore, Maryland. More detailed presentations, including results from additional Repeat Hydrogaphy cruises will be given at the AGU Fall Meeting, December 2004, San Francisco, California as part of the special session entitled "Decadal Variations in Ocean Interior Circulation and Biogeochemistry: First Results From the CLIVAR/CO_2 Repeat Hydrography Program."

3.16a. Surface Drifter Program

by Silvia L. Garzoli and Robert L. Molinari

PROJECT SUMMARY

This program combines the previous AOML drifter component of the ENSO observing system (Molinari and Cook PIs, now "Operations") and the Tropical and sub-tropical Atlantic Surface Drifters Array (Garzoli, PI, now "Atlantic drifters"). Participants in the combined program are Bob Molinari, Silvia L. Garzoli, Steve Cook, Rick Lumpkin, Mayra Pazos, Craig Engler and Jessica Redman.

General overview of the project, including brief scientific rationale:

Operations

The primary objective of the former AOML drifter component of the ENSO Observing System is to provide oceanographic data needed to initialize the operational seasonal-to-interannual (SI) climate forecasts prepared by NCEP. Specifically, AOML manages a global drifting buoy network that provides sea-surface temperature (SST), surface current and air pressure data needed to (a) calibrate SST observations from satellite; (b) initialize SI forecast models; and (c) provide nowcasts of the structure of global surface currents. Global drifter coverage is required as the forecast models now not only simulate Pacific conditions but global conditions to improve prediction skill. Secondary objectives of this project are to use the resulting data to increase our understanding of the dynamics of SI variability, and to perform model validation studies. Thus, this project addresses both operational and scientific goals of NOAA's program for building a sustained ocean observing system for climate.

b. Atlantic Drifters

The main objectives of this program, a joint effort between SIO and the AOML that started in 1997, is to deploy and maintain an array of SVP drifting buoys in the tropical Atlantic, within 20 degrees of latitude of the equator for the purpose of filling up the gaps to accurately observe the basin-wide scale tropical current and SST fields on time scales of the inter-annual variations of tropical Atlantic SST. In FY03, a new component of this program started to partially solve the problem of data scarcity in the subtropical south Atlantic (20°S to 40°S).

Large-scale SST distributions drive the response of the climate in the tropical Atlantic sector, and over land areas as distant as the southern and eastern Unites States. In spite of its importance, no dynamical model has successfully predicted tropical Atlantic SST one-to-several seasons in advance. The current generation of coupled ocean-atmospheric models cannot reproduce, much less predict, the SST in the tropics. A recent comparison of 23 GCM results (Davey et al. 2002) concentrated on simulated fields from the tropical oceans (i.e. SST, zonal wind stress and upper layer depth averaged temperature). In the Atlantic Ocean, discrepancies between the model and observed mean states were dramatic. Specifically, in the equatorial Atlantic, the simulated meridional temperature gradient was wrong, with cold temperatures in the west and warm temperature in the east (Figure 4, Davey et al. 2002[1]). Furthermore, the variability of the sub-tropical Atlantic and its interaction with the tropics is far from being understood. This is primarily due to the paucity of data that for years has been mainly collected in the major commercial lanes. Products of SST are considerably deficient in the center of the south Atlantic basin and between 20°S to 40°S. A recent paper (Kushnir et al. 2003[2]) demonstrated that the variability of the inter-tropical converge zone (ITCZ) is highly sensitive to changes in SST gradients within the broader tropical Atlantic region, particularly in the meridional direction south of the tropics and during the boreal spring. To better understand this variability, it is necessary to improve the SST products in the South Atlantic. The development and future success of such models will depend on understanding the processes driving SST changes and providing products based on observations that models can attempt to simulate.

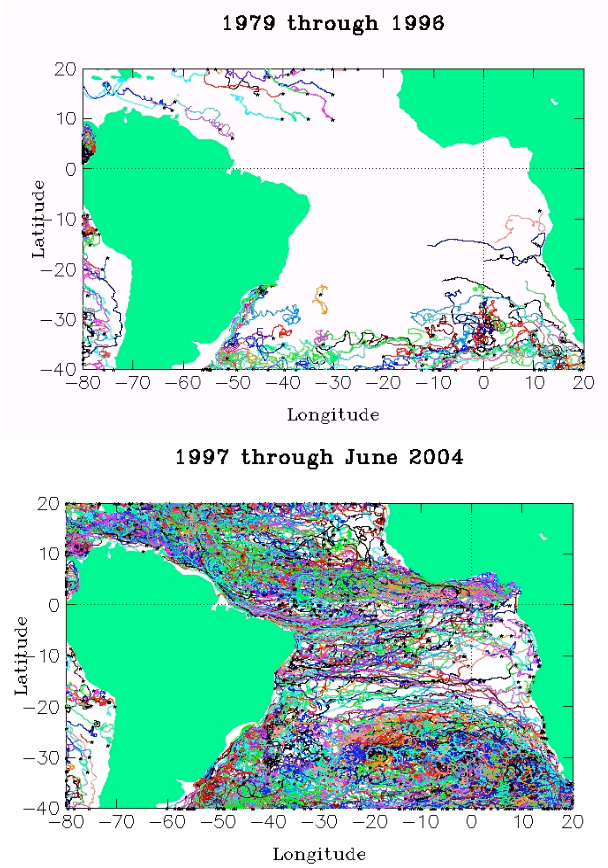


Figure 1: Evolution of the tropical Atlantic surface drifters array. Left: trajectories of drifters deployed in or entering the region from 1979 through 1997 (18 years); Right: trajectories of drifters deployed in or entering the region, funded under the Atlantic drifters (20°N - 40°S) from 1997 through June 2004 (7.5 years).

Statement about how your project addresses NOAA's Program Plan for Building a Sustained Ocean Observing System for Climate:

This project provides critical data for initializing seasonal to interannual forecasts. In addition, this program is a direct component of NOAA's Program Plan for building a *Sustained Observing System for Climate.* The first milestone for in-situ networks in this plan is to "Deploy an array of 1250 drifting buoys for sea surface temperature, pressure and current measurement by 2004".

Statement about how your project is managed in cooperation with the international implementation panels, in particular the JCOMM panels:

The GOOS Center and its integral component, the Global Drifter Program (GDP) is a participating member of JCOMM and JCOMMOPS. Both the GDP and GDP – Data Assembly Center (DAC) are represented annually at the WMO/IOC Data Buoy Cooperation Panel (DBCP) and Joint Tariff Agreement (JTA) meetings. Participation on these international panels provides an important mechanism for integrating and coordinating with other national or regional programs which, in the long run, improves our national climate mission by making more efficient and effective use of available resources.

Responsible institutions for all aspects of project:
The GOOS Center located within the Physical Oceanography Division at AOML manages and operates the Global Drifter Program (GDP). The GDP is closely aligned with the Scripps Institution of Oceanography, SIO, for the procurement of Drifting Buoys. The GDP utilizes the National Weather Service Global Telecommunications System (NWSGTS) gateway for the real-time distribution of data and the National Oceanographic Data Center (NODC) and Marine Environmental Data Services (MEDS) for the archival of delayed mode data. The data are placed on GTS for operational use by Service Argos. AOML, under the direction of Mayra Pazos, quality controls and processes these data to quarter - day intervals and on six-month intervals sends to Marine Environmental Data Service (MEDS)/Canada for international distribution.

Project web site URL and pertinent web sites for your project and associated projects:
The program web site is maintained and updated by Mayra Pazos, DAC manager.
http://www.aoml.noaa.gov/phod/dac/

- Associated projects links
  - http://www.jcommops.org
  - http://www-hrx.ucsd.edu
  - http://www.cmdl.noaa.gov
  - http://www://sahfos.org
  - http://www.aoml.noaa.gov/phod/benchmarks/index.html
  - http://www.aoml.noaa.gov/phod/enso/index.html
  - http://www.aoml.noaa.gov/phod/taos/index.html

Interagency and international partnerships:
Drifters are launched using the AOML/GOOS infrastructure of NOAA interagency and international partners. Specifically, participation on the Data Buoy Cooperation Panel (DBCP) increases deployment opportunities.

Statement that your project is managed in accordance with the Ten Climate Monitoring Principles:
This program is managed in accordance with the Ten Climate Monitoring Principles (Program Plan, Mike Johnson 2003).

FY 2004 PROGRESS

Instrument/platform acquisitions for fiscal year and where equipment was deployed:
Operations: All Drifters for the Global Drifter Center are purchased by SIO. Drifting Buoys are deployed globally, in all four oceans (Pacific, Atlantic, Indian and Southern).
Atlantic drifters: Drifters for the Atlantic program are purchased by AOML. During FY04, a 100 buoys were deployed within the tropical Atlantic (30°N – 20°S), and 41 SVP buoys (9 upgraded with barometers) were deployed in the subtropical south Atlantic (20°S- 40°S).

Number of deployments – compare to the previous year:
The number of operations deployments (except for the Atlantic) increased from 222 in FY03 to 509 in FY04.
The number of deployments in the tropical Atlantic increased from 79 in FY03 to 100 in FY04.
The number of deployments in the subtropical south Atlantic was increased by 41 in FY04.

Percentage data return for fiscal year and 'lifetime' statistics – compare to the previous year:

<u>The following statistics are for the global array, and includes the Atlantic drifters</u>*:* On average on any given day we are receiving in real-time six (6) Sea Surface Temperature (SST) observations per Drifting Buoy deployed. As the total global array approaches 800 Drifters we are receiving about 5000 SST observations per day.

Between 1998 and 2004:

- Transmitter lifetime[1] improved from 330 to 440 days
- SST sensor lifetime[1] improved dramatically, from 85 to >700 days
- Drogue lifetime[1] improved dramatically, from 90 to >550 days
- Deployments have increased every year while failure upon deployment has steadily decreased (12% in 1998, 5% in 2000, 3% in the last fiscal year)

[1] – median lifetime (half-life) for years 1998—2000 and 2001—2003, for all drifters that were not picked up or run aground. Drifters which stopped transmitting before SST sensor failed were not counted in SST sensor lifetime calculations, so this lifetime must be considered the half-time of the sensor, not of SST observations.

Measurements taken, where data are stored, data distribution, availability and access to data:

Observations collected include*:* Position data, sea surface temperature (SST), some sea surface barometric pressure, some wind speed and direction. Data are stored at the GOOS Center in the Global Drifter Program's Data Assembly Center (DAC). Real time data are transmitted via Argos transmitters and distributed via the Global Telecommunications System (GTS) by Service Argos and available to everyone. The delayed mode and scientifically quality controlled data are available via access to web, ftp or personal communication with the DAC within two months of collection and a copy of the data are archived at the Marine Environmental Data System (MEDS).

How data are currently being used and shared:

Drifter data are used in circulation research among several national and international oceanographic institutions. SST data are used among several national and international centers for environmental prediction (i.e. NCSP, US Navy, European Community Center for weather forecast, British and French Meteorological Offices, etc.), for ENSO monitoring and prediction and to initialize climate models. There are no restrictions on sharing this information as it is distributed in real time on the GTS.

Where the data are archived:

Drifter data are archived at the GOOS Global Drifter Program Data Assembly Center (DAC) and at the Marine Environmental Data Service (MEDS) in Canada.

Anticipated and unanticipated project costs:

Drifter costs are declining because of improved design changes but shipping costs have increased due to late funding which required the use of air shipping rather than the less expensive ground shipping.

Problems encountered:

Three main problems arose:

1. Due to delays in disbursement of funds (funds arrived to AOML in late May), we were unable to buy and deploy a few of the drifters that were funded for FY04. These drifters will be deployed during FY05.

2. Due to war related issues, the US Navy stopped coordinating air deployments. As a consequence, all deployments are made now from ships. This limits our capability to seed regions not visited by ships (VOS or research vessels).

3. Drogue on-off status is determined from the submergence or tether strain sensor. For an increasing number of drifters, these data are extremely noisy, ambiguous or faulty such that drogue status is uncertain. We have been communicating with manufacturers to resolve this issue.

Logical considerations (e.g., ship time utilized):
The program is based on deploying the drifters through VOS and R/V available in the region. This limits our capability of filling up gaps not transited by either of these vessel types.

Research highlights:
Atlantic Drifters: The tropical Atlantic surface drifting buoy observations were used to determine time-mean near-surface currents and their seasonal variations. As a consequence of the considerable increase in data coverage due to this program and a new analysis technique developed for the data (Lumpkin and Garraffo 2004), the major pathways of near-surface currents are now resolved at unprecedented detail (Fig. 2). An analysis of the currents' seasonal variations (Lumpkin and Garzoli 2004) reveals how northern and southern hemisphere fluctuations are "communicated" via the equatorial gyre route. Ongoing extensions of this study, also heavily dependent upon the drifter observations, are examining the distribution and possible rectification of mesoscale variability and are providing estimates of the role of lateral heat advection in modulating/controlling observed SST variations.

A monthly climatology of near-surface currents and SST, derived from the drifter observations using the methodology of Lumpkin and Garraffo (2004), has been made available by the Drifting Buoy Data Assembly Center (www.aoml.noaa.gov/phod/dac/).

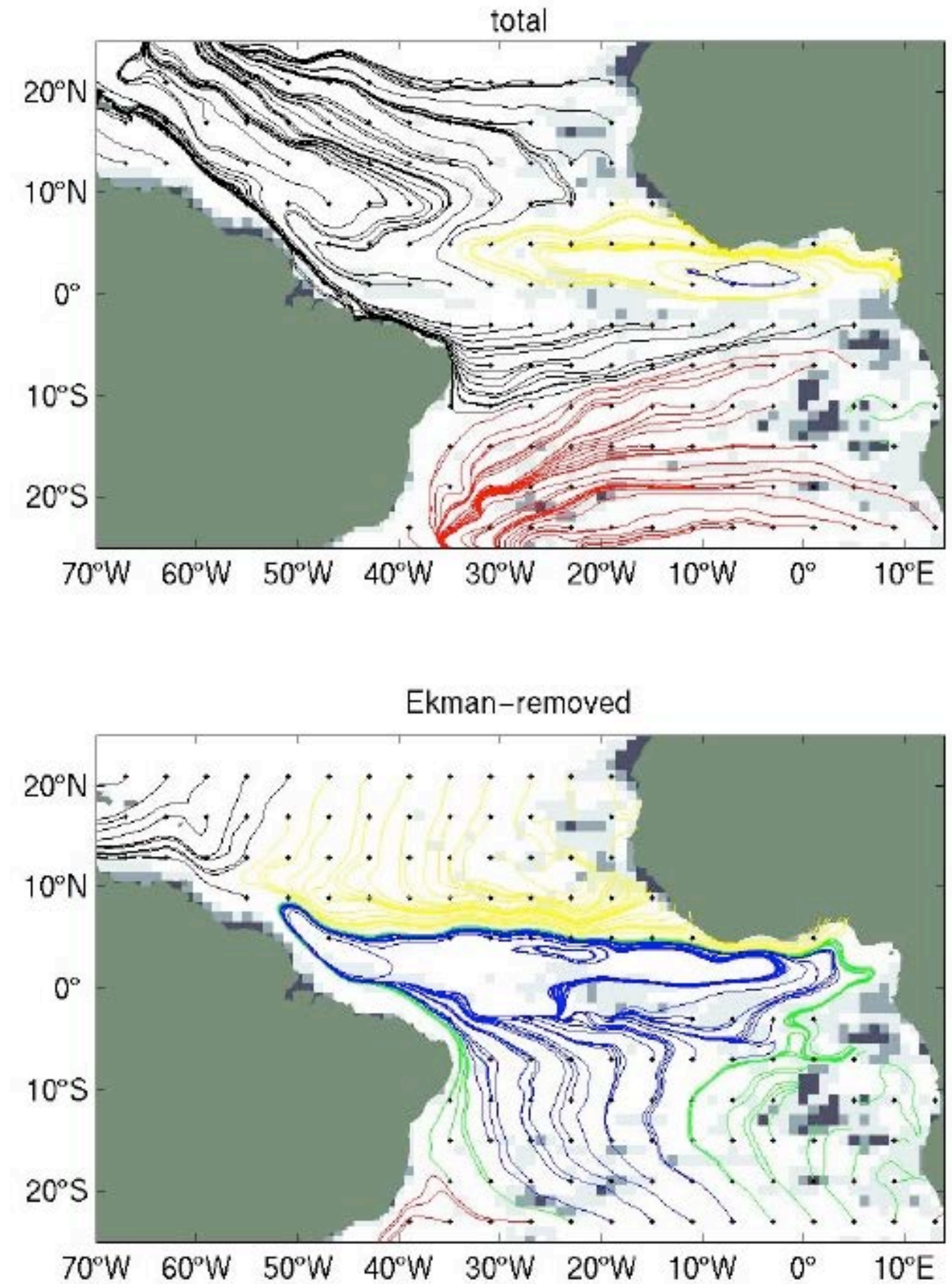


Figure 2: Pathways of advection from time-mean currents derived from surface drifter observations and visualized by integrating the currents from "release points" (black dots; see Lumpkin and Garzoli 2004 for more details). Top: advection by total currents, including the wind-driven Ekman flow. Bottom: advection by the Ekman-removed flow.

3.17a. National Water Level Program Support Towards Building A Sustained Ocean Observing System For Climate

by Stephen K. Gill and Chris Zervas

PROJECT SUMMARY

The purpose of this document is to provide a proposal for a program plan for sea level observations that could be implemented by the NOS Center for Operation Oceanographic Products and Services (CO-OPS) over the next several years in support of the NOAA Office of Global Programs Climate Observation Program. Three distinct tasks have been identified for which the NOAA National Ocean Service (NOS) Center for Operational Oceanographic Products and Services (CO-OPS) would provide support:

1) develop and implement a routine annual sea level analysis reporting capability that meets the requirements of the Climate Observation Program

2) upgrade the operation of selected National Water Level Observation Network Stations to ensure continuous operation and connection to geodetic reference frames

3) operate and maintain water level measurement systems on Platform Harvest in support of calibration of the TOPEX/Poseidon and Jason 1 satellite altimeter missions.

The fundamental URL's are:
http://tidesandcurrents.noaa.gov for access to all programs, raw and verified data products, standards and procedures, and data analysis reports and special reports.
http://www.co-ops.nos.noaa.gov/sltrends/sltrends.shtml for access to the latest NWLON sea level trends and monthly mean sea level anomalies.

The 10 Climate Operating Monitoring Principles are very much the same as used for the NOAA National Water Level Program (NWLP) for which the National Water Level Observation Network (NWLON) is a long-term continuous operational oceanographic network that's strives to meet NOAA's mission needs for tides and water levels. The NWLP is an end-to-end program that is planned, managed, and operated to provide products that meet user-driven needs. The program also consists of technology development, continuous quality control, data base management, and operational readiness and fully open web site for data delivery.

These data and related sea level products are made available over the web site for use by PSMSL, UHSLC, and the WOCE communities.

Project Task Descriptions

Task One - Routine Sea Level Analysis Reports

A Climate Observation Program Workshop was hosted by the NOAA Office of Global Programs (OGP) on May 13 - 15, 2003. The objectives of the workshop were to:

1. Initiate an Annual Program Review
2. Design a framework for regular reports on the ocean's contribution to the state of the climate and on the state of the observing system.
3. Design a framework for implementing Expert Teams to continually evaluate the skill and effectiveness of ocean products and of the observing system.

There are 18 NOAA National Water Level Observation Network (NWLON) stations identified in the International Sea Level Workshop Report (1997) as being part of the core global subset for long-term trends. The Climate Observation Program Plan calls these climate "reference stations" and includes the following performance measures for the reference stations:

1. Routinely deliver an annual report of the variations in relative annual mean sea level for the entire length of the instrumental record.
2. Routinely deliver an annual report of the monthly mean sea level trend for the past 100 years with 95% confidence interval.

The 18 NWLON stations are (in alphabetical order):

Name:	Series Length (years):
Atlantic City	90
Bermuda	59
Boston	80
Charleston	80
Crescent City	68
Fernandina Beach	104
Guam	53
Hampton Roads	74
Honolulu	96
Ketchikan	82
Key West	88
Kwajalein	55
Neah Bay	67
New York City	144
Pensacola	78
Portland	89
San Diego	95
San Francisco	150

The Climate Observation Program will be producing a second annual report on the state of the ocean and the state of the observing system for climate. It is proposed that CO-OPS produce an annual report on these reference stations that would be one section of that larger report. Over the next 3 years it is required that the report include all 62 global reference stations. The current CO-OPS report on sea level (Zervas 2001) is being used as a starting template for an annual report.

Task Two – Upgrade Ocean Island Station Operations

There are several coastal and island NWLON stations critical to the Global Climate Observing System. The operation and maintenance of the ocean island stations of the National Water Level Observation Network (NWLON) has been increasingly more difficult over time due to the slow abandonment of the island facilities at which the stations reside. Finding routine flights and flights which are cost effective are becoming increasingly difficult, yet these stations require high standards of annual maintenance to ensure the integrity of their long term data sets. Annual maintenance is even more important, in light of the fact that corrective maintenance is logistically very difficult and expensive.

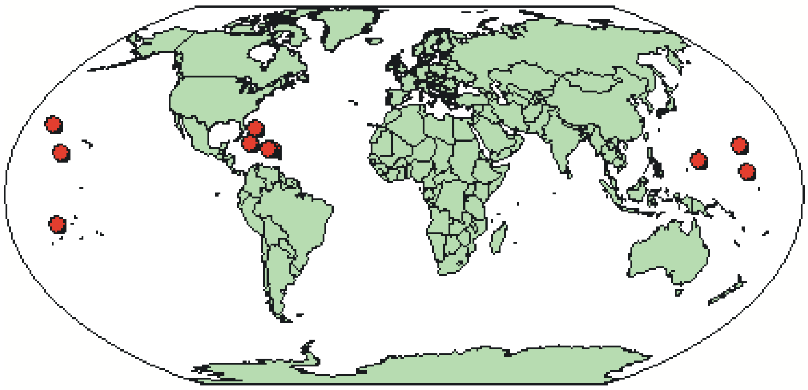


Figure 1. Ocean Island NWLON Station Map.

Although operation of all of the stations is important, it is proposed that Ocean Island stations begin to be upgraded first with this funding to ensure their continuous operation (program funding and budget initiatives will be used for operation of the coastal stations). These targeted funds will be used for travel costs and for upgrade to backup systems. The upgrades will include high accuracy acoustic or paroscientific pressure sensors and redundant Data Collection Platforms (DCP's) with equal capability to the existing primary systems. The station operations will also be enhanced with GPS connections to geodetic systems followed by installation of CORS at selected sites. The following is a list of the ocean island NWLON stations (not including Hawaii) that should be considered in this category as priority for upgrade.

Station	CORS Operating
Guam	Yes
Kwajalein	Yes
Pago Pago	Yes
Wake	No
Midway	No
Adak	No
Bermuda	Yes
San Juan. PR	Yes
Magueyes Island, PR	No
Charlotte Amalie, VI	No
St Croix, VI	Yes

Task Three - Satellite Altimeter Mission Support

Support for the TOPEX/Poseidon satellite altimeter mission began with installation of an acoustic system and a digibub system on Platform Harvest in 1983 (see Fig. 2). Using reimbursable funding under MOA with JPL/Caltech, systems operations include provision of water level measurements relative to the satellite altimeter closure analysis reference frame for calibration monitoring (see B. Hanes et al, Special Issue of Marine Geodesy, 2003 "The Harvest Experiment: Monitoring Jason-1 and TOPEX-Poseidon from a California Offshore Platform".

Figure 2. Platform Harvest Calibration Site at which NOAA tide gauges are located.

CO-OPS special support has included a vertical survey on the Platform necessary to relate the water level sensor reference zeros (near the bottom catwalk) to the GPS reference zero (located up top at the helipad on the Platform. Continuous data are required to monitor effects of waves on the water level measurements and to ensure provision of data during the times of altimeter overflights every ten days. The original acoustic system was replaced by a digibub pressure system prior to the Jason-1 altimeter launch.

Platform Harvest tide gauge operations will continue with the operation of two digibub pressure systems collecting continuous water level data streams surveyed into the Platform and Satellite Orbit Reference frames. Funds will cover travel and routine an emergency maintenance and water level and ancillary sensor calibrations.

<u>FY 2004 PROGRESS</u>

Task One:

CO-OPS began the development efforts for an annual report that includes the 18 NWLON stations listed above. A tailored version of the graphics and analyses from the existing CO-OPS sea level report (Zervas, 2001) has been completed that includes the three fundamental types of analyses where data series allow. The following figures illustrate the types of analyses proposed using Honolulu as an example.

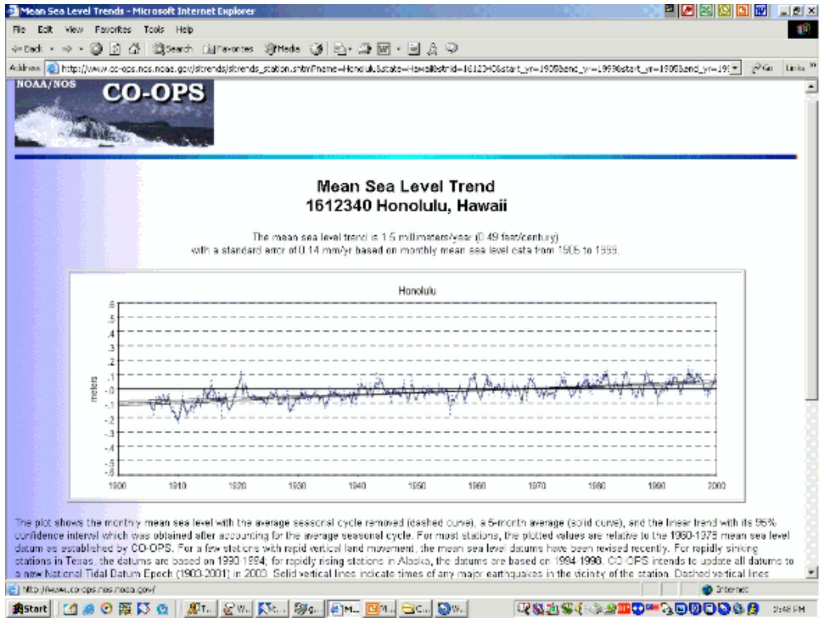


Figure 3. Sea level Trends Analyses would be updated annually.

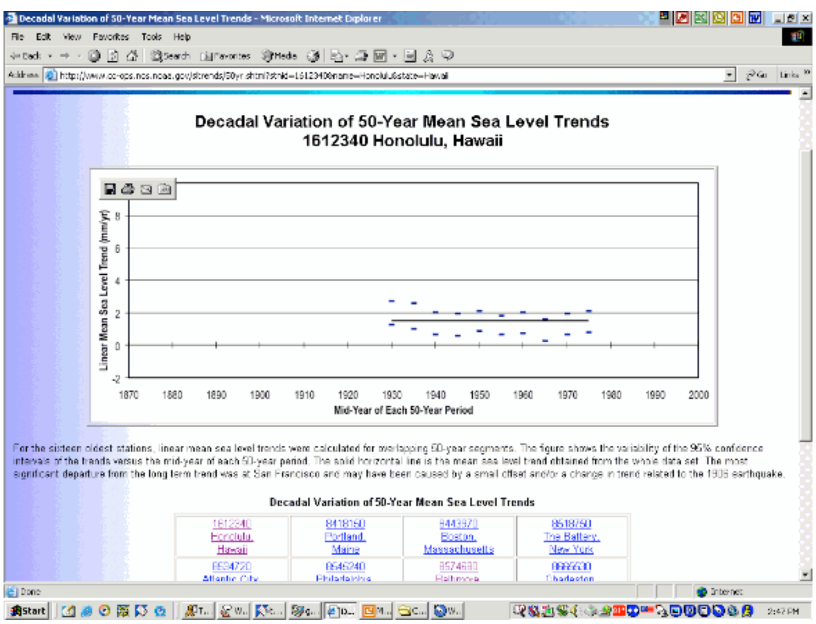


Figure 4. Long-term Variation in Trends would be routinely updated.

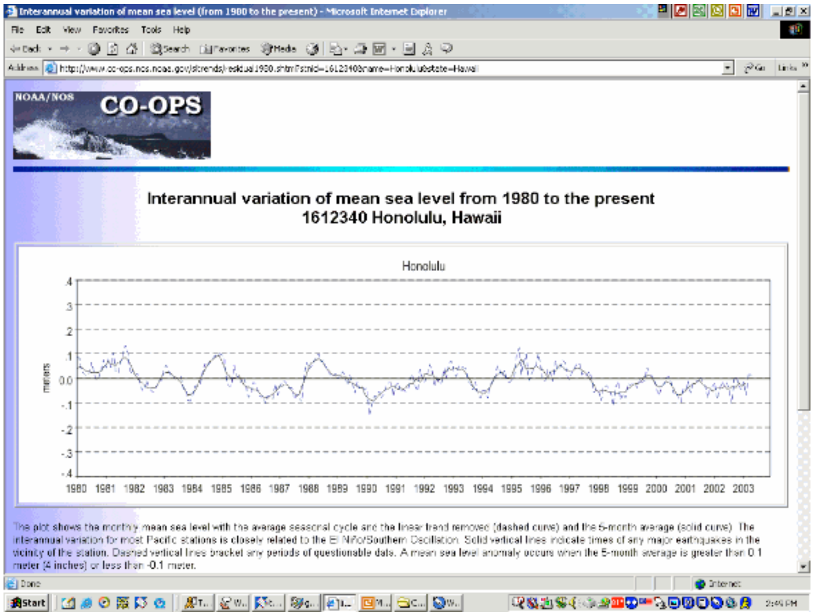


Figure 5. The Monthly Mean Sea Level variations would be updated annually.

Task Two:

Maintenance of the ocean island NWLON stations continued using FY'04 CO-OPS resource levels. Major corrective maintenance required at Guam did not take place due to Typhoon damage and backup systems were not upgraded due to lack of year-end funds. However this points to the need to have appropriate resource levels to recover from events for reference stations in general and the need to keep the records from experiencing large gaps.

Task Three:

Operation and maintenance of the station continued under MOA with Caltech/JPL. This MOA expired at the end of FY '04. Coordination of activities continues with JPL. One of the pressure systems requires repair to bring it back online, however continuous data have been maintained. JPL has arranged for underwater maintenance of the bubbler pressure system orifices.

3.18a. An End-to-end Data Management System for Ocean pCO_2 Measurements

by Steve C. Hankin, lead PI, Richard Feely, Alex Kozyr, Tsung-Hung Peng

PROJECT SUMMARY

Reliable and efficient data management within the NOAA Global Carbon Cycle Program will require standards and infrastructure to: upload/ingest new data; quality control data sets; provide users with timely access to data; and ensure its long-term archival. The October 2001 Carbon Data Management Plan, a product of the carbon data management workshop held at PMEL (Feely and Sabine 2002), articulates a community consensus on the need for a systematic approach to ocean CO_2 data management. The ultimate objective of the plan is to provide the oceanographic community with easy access to high-quality near real-time CO_2 and related physical, chemical and biological data sets. The plan outlines the need for new standards regarding analytical measurement techniques, data formats, metadata content, quality control and assessment procedures. The plan recognizes that the data management system must build upon existing capabilities and must be compatible with the emerging standards for integrated ocean data management within the U.S. It identifies the Carbon Dioxide Information Analysis Center (CDIAC) as a regional quality control and data management facility and the Live Access Server from PMEL as a sound software foundation for the system. It also recommends the creation of a CO_2 Science Team and a Data Management Group to guide the creation of standards and the evolution of the data management system.

This report "An End-to-end Data Management System for Ocean pCO_2 Measurements", is a road map for the implementation of that data management plan as an end-to-end data management system, and a process for governance of that system under the CO_2 Science Team. The vision of the data system is of five integrated components coordinated through a suite of data standards and procedures. The components are i) local QA/QC and the initial collation of shipboard data; ii) regional QC and assembly of data and metadata; iii) operational data base management; iv) the Web-based data and metadata access subsystem; and v) permanent archival. The partners in the development of this solution are NOAA/PMEL, CDIAC and NOAA/AOML.

The Carbon Data Management (CDM) system that is under development through this proposal is an essential component of NOAA's Program for *Building a Sustained Ocean Observing System for Climate.* The CDM approach will utilize the standards and protocols advocated by the emerging Data Management and Communications (DMAC) subsystem of the US IOOS. As such the CDM will be fully compatible with the data and assimilation systems that will deliver routine ocean analyses through the international Global Ocean Data Assimilation Experiment (GODAE). It will be similarly integrated with the international ocean data frameworks, the Observing System Monitoring Center (OSMC), the US GODAE Server and its climate data-serving partner the Asia Pacific Data Research Center (APDRC) through the National Virtual Ocean Data System (NVODS).

The data management principles that are integrated into the CDM system design are in accordance with the Ten Climate Monitoring Principles requires:

- The need for data management systems that facilitate access, use, and interpretation of data and products;
- A fully integrated approach that embraces both data and metadata management including details and history of local conditions, instruments, operating procedures, data processing algorithms, and other factors pertinent to interpreting data;
- Continual assessment of the quality and homogeneity of data; and

- Flexible access to data through multiple protocols and formats making it readily usable in the creation of environmental and climate-monitoring products and assessments.

Work on the CDM system began only in March of 2004, so many of its capabilities are not yet available for access through a stable Web site. The initial URLs for the CDM are

- http://cdiac3.ornl.gov/underway/servlets/dataset
  -- initial carbon data access via LAS
- http://mercury.ornl.gov/ocean/
  -- initial carbon metadata access via Mercury
- http://www.ferret.noaa.gov/Ferret/LAS/CDIAC_LAS/
  -- database design discussion and documentation

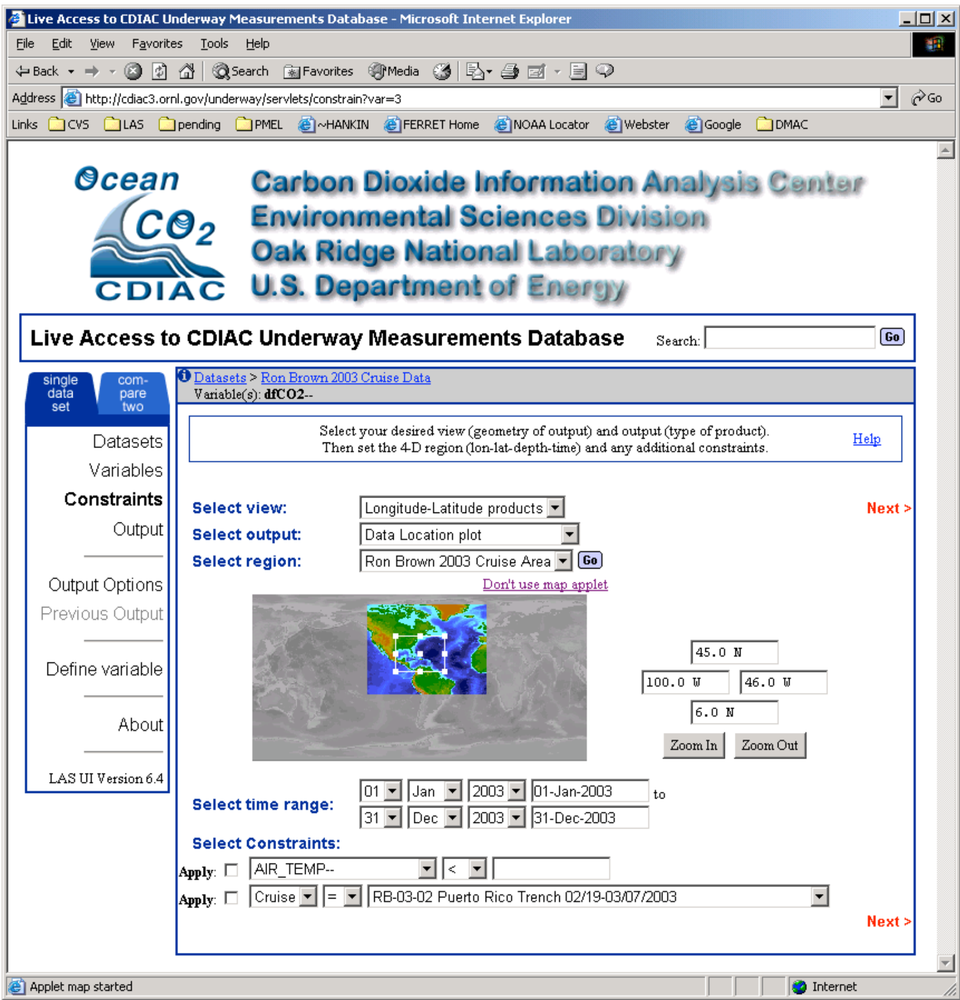


Figure 1. Underway CDM user interface.

FY 2004 PROGRESS

Since the start of work on the CDM system began in March of 2004 the following milestones have been achieved:

PMEL Accomplishments:

1. A new software developer Yonghua Wei, with a high level of expertise in database design, was recruited for the PMEL CDM development team;
2. PMEL designed an initial relational database management system (RDBMS) schema that will accommodate the data storage and access requirements for underway data generated by the carbon community. This work is documented at the URL previously given in the Project Summary;
3. Scripts were written to ingest ASCII-formatted cruise data files from CDIAC into the RDBMS;
4. Underway data from CDIAC (the Ron Brown 2003 cruises) was used to populate an initial version of the database. An initial Live Access Server (LAS) was configured with one year's worth of Ron Brown cruise data;
5. PMEL created a synthetic database representative of the size of the mature CDM system to test performance and operations. Tests with over 500 MBytes of synthetic data indicate that the current database schema will efficiently subset data based upon realistic time and space constraints.
6. Jon Callahan of PMEL traveled to CDIAC to install the new underway database and configure an underway LAS.

Examples of the user interface design and initial output products are shown in Figures 1 and 2.

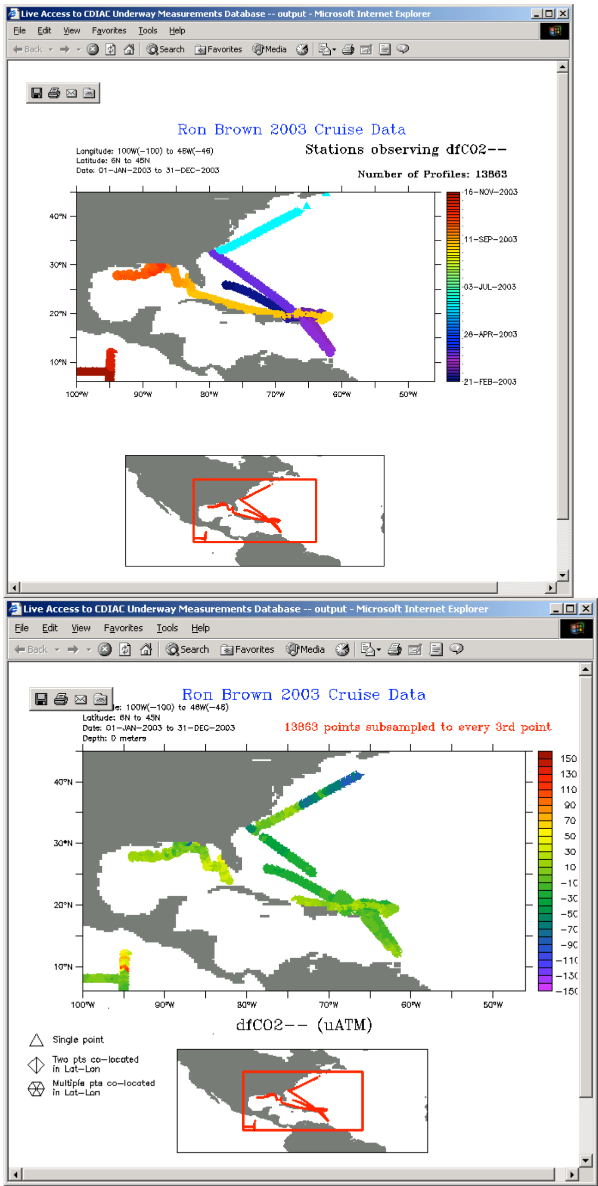


Figure 2. Prototype plots obtained from LAS to visualize (left) the available data within a specified time-space region and (right) the measured values

CDIAC Accomplishments:

1. CDIAC has been developing a web page for VOS data management work with links to the data. The web page is under construction at this time, however it is linked from the CDIAC Ocean home page at: http://cdiac.ornl.gov/oceans/home.html as "VOS Project Data". The VOS web page will include a map with past and future (planned) cruises on Volunteer Observation Ships. These clickable maps will link to the data files for each cruise/VOS route.

2. CDIAC established a prototype system to search for ocean metadata and retrieve associated underway and ASCII bottle data utilizing the Mercury system. The link to CDIAC Ocean Data Mercury: http://mercury.ornl.gov/ocean/. Mercury incorporates a number of important features:

- Implements a dynamic, distributed approach to scientific data and metadata management;
- Puts control in the hands of data providers (carbon science investigators);
- Has a very "light touch" (i.e., is inexpensive to implement);
- Is implemented using Internet standards, including XML;
- Supports international metadata standards, including FGDC;
- Is compatible with Internet search engines; and
- Is based on COTS software, including Blue Angel Technologies' MetaStar® products and Hummingbird's Fulcrum SearchServer®.

3. With help of Jon Callahan and Yonghua Wei of PMEL CDIAC opened the first Live Access Server for underway carbon data at: http://cdiac3.ornl.gov/underway/servlets/dataset. The Underway LAS is open for public access with the Ron Brown 2003 Cruises Data as an example. The data management utilizes the content standard that was established during the Workshop on Ocean Surface pCO_2, Data Integration and Database Development. Tsukuba International Congress Center, January 14-17 2004 (http://ioc.unesco.org/ioccp/Tsukuba2004Results.htm).

4. Alex Kozyr of CDIAC delivered above accomplishments at the VOS Underway Data Science Team meeting at the University of Miami on October 6, 2004.

AOML Accomplishments:

As outlined in the proposal AOML has focused on instituting uniform data reporting formats and quality control procedures. At a meeting at Lamont Doherty Earth Observatory in September 2003 agreement was reached on a data format and content standard that will be used for all NOAA underway pCO_2 ship data. This format with slight modification and appropriate, uniform metadata content was adopted as the recommended protocol for the International Ocean Carbon Coordination Project (IOCCP) in Tsukuba, Japan, January 2004.

Our current data are processed in this format with the parameters listed in Table 1. The parameter list is comprehensive in the sense that an outside investigator can recalculate the pCO_2 and perform screening based on meteorological conditions, and ship's speed and location. Quality control flags are included for the water and air pCO_2 measurements. The data that have undergone "local" quality control is posted on our web site, http://www.aoml.noaa.gov/ocd/gcc, generally within one to six-months after receiving the data from the ships.

Table 1. Parameters to be included in surface water pCO_2 files as recommended by the IOCCP and adopted by the NOAA VOS group.

GROUP/SHIP	xCO2A_PPM
CRUISE_DESIGNATION	PRES_EQUIL_hPa
JD_GMT	PRES_SEALEVEL_hPa
DATE_DDMMYYYY	EqTEMP_C
TIME_HH:MM:SS	SST(TSG)_C
LAT_DEC_DEGREE	SAL(TSG)_PERMIL
LONG_DEC_DEGREE	WATER_FLOW_L/MIN
xCO2W_PPM	GAS_FLOW_IR_ML/MIN
TEMP_IR_C	fCO2A_uATM

PRES_IR_hPa	QC_FLAG_AIR
SHIP_HEADING_TRUE_DEGREE	dfCO2_uATM
SHIP_SPEED_KNOT	FLUORO_uG/L
WIND_DIR_REL_DEGREE	WIND_SPEED_TRUE_M/S
WIND_SPEED_REL_M/S	WIND_DIR_TRUE_DEGREE
fCO2W@SST_uATM	AIR_TEMP_C
QC_FLAG_WATER	

As part of this project we are also reformatting our historical data and providing the metadata in the agreed-upon format. Data from the NOAA ship MALCOLM BALDRIGE starting 1991 through 1995 has recently been posted on the website listed above. The 2003 data sets from NOAA ship BROWN were imported successfully into the LAS system developed in this project – a validating test for the new data formats.

3.19a. Observing System Research Studies

by D. E. Harrison

PROJECT SUMMARY

This project supports the design and development of the global ocean observing system for climate through a variety of data analysis and modeling studies, intended to expand our knowledge about what we know and what we cannot know from the observing system as deployed and the historical data set that has been produced over the decades. It also supports the evolution of the observing system through evaluation of alternative observing strategies and evaluation of the differences between available ocean analysis products (taken as one measure of the uncertainty in the analysis products). Finally it supports the Office of Climate Observation and NOAA's observing strategy through the PI's activities as Chair of the Ocean Observation Panel for Climate (co-sponsored by the GOOS, GCOS and WCRP) and other sustained ocean observing leadership activities.

Initial focus has been on SST variability since it is agreed to be the most important variable for climate impacts. Work with other variables will be expanded in the coming year as described below.

FY 2004 PROGRESS

Overall, the work of the group provided a variety of scientific and social impact justifications for continuing the deployment of the planned global climate observing system, and continued to define the space and time scales of observations needed for specific phenomena that must be accurately observed.

The Indian Ocean remained a focus of activity, because NOAA plans to extend the tropical mooring array into this ocean in FY05. Indian continental rainfall and its dependence on SST anomalies is one of the primary societal impacts, as almost one billion people depend on the Southwest monsoon's rainfall. The Vecchi and Harrison paper is the first, to our knowledge, to establish a firm connection between Indian SST anomalies and Indian continental rainfall. What made this discovery possible was recognizing that All-India Rainfall (AIR), the most widely used measure of Indian rainfall, is the sum of two non-correlated regional rainfalls. When correlations are sought between SST and the two different regions, relationships exist even though there are not significant correlations between AIR and Indian SST.

This result provides one path to link ocean observations and process studies to a major societal impact. The equatorial waveguide is not the region that should get priority, unlike the tropical Pacific. The strongest relationship is between western Indian rainfall and SST variability in the Arabian Sea in the months preceding the onset of the SW monsoon. Whether there is predictability for these Arabian Sea anomalies needs to be explored further.

Unpublished work on Indian Ocean SST is well advanced as this is written. Subtropical SST anomalies have been linked to eastern African rainfall anomalies, but the mechanisms responsible for these anomalies (and, hence, their predictability) remains controversial. One of the major instances of this connection occurred in the 97-98 El Nino; it remains to be seen if the connection is primarily an El Nino connection or if other processes may be at work. Exploring these questions will be part of Chiodi's Ph.D. thesis work. Chiodi has already discovered a new mode of summer subseasonal southern hemisphere SST anomalies, which are not well resolved in the Reynolds/Smith SST analysis. Work will continue in the characterization of these anomalies, the challenges posed to the observing system to resolve them properly and to understand the processes responsible for them (in order to explore their predictability).

The TRMM TMI SST data set, based on microwave SST retrievals has been essential in the Indian Ocean work, because it permits observation of SST anomalies under many types of cloudy conditions. SST is not observable by IR techniques under these conditions. The work of this project thus makes a strong case for the importance of continuing access to TRMM quality microwave SST information as a component of the global ocean observing system.

Work on equatorial Pacific SST variability also continued during FY04. Previous work into the relationships between westerly wind events (WWE), the Madden-Julian Oscillation (MJO) and waveguide SST warming has been updated. The relationships that were found previously, but which were of marginal statistical significance are now clearly statistically significant. They establish that WWEs are no more likely to occur during an MJO than they are when an MJO is not present, that waveguide warming follows the passage of an MJO only when a WWE occurs during the MJO but that WWEs, if they occur during an MJO, are more likely to occur during the convective phase of the MJO. Together with the earlier published work that establishes a dynamical connection between WWEs and waveguide warming, this work strongly suggests that observing and predictive attention should be given to WWEs and not to the MJO, if El Nino prediction is the objective. High time resolution observations are essential to proper characterization of WWEs; the TAO/Triton moorings remain key to this capability.

Predicting the termination of El Nino events is another objective of NOAA’s seasonal to interannual prediction efforts. Via a series of ocean numerical model studies, the processes responsible for the termination of the 1997-98 and 2002-03 El Nino events have been identified. In each case the mechanism appears to be that proposed by Harrison and Vecchi (1999), in which the coupled interaction between the seasonal meridional cycle of solar insolation and near-equatorial SST anomalies, and the zonal wind anomalies associated with the resulting SST anomalies near the Dateline, is key. Delayed oscillator processes are not necessary to account for the observed oceanic behavior. The state of cold tongue zonal winds at the height of the El Nino determines whether the oceanic response to the zonal wind anomalies will lead to termination of the El Nino in early spring (as happened in 2002-03), or if the El Nino will continue into late spring (as happened in 1997-98 and 1982-83). Again, accurate near-equatorial wind and SST knowledge, such as is obtained from the TAO/Triton array, is key to successful prediction.

Work has also continued in the use of TAO/Triton data to test existing models of the equatorial Pacific. It has been found that the Gent/Cane intermediate model cannot be reconciled with the observations, when used with the limited vertical resolution that has been adopted so far in model studies using this formulation. The mooring data have been essential to this study, providing an important result for the relevance of intermediate coupled models for study of El Nino predictability and processes.

The importance of high latitude information for US seasonal weather anomaly forecasting has been given a new twist by our discovery that the weather anomalies, particularly over the eastern half of the US during an El Nino winter depend on the sign of the Arctic Oscillation (AO). Further we have found that there is a reasonable statistical basis for Winter AO forecasting, given knowledge of autumn AO conditions. We have communicated this result at national meetings and to L. Uccelini. Accurate knowledge of the AO thus appears key to improved US winter weather forecasts. It may be that improved knowledge of MSLP over the Arctic will lead to improved understanding of the AO and improved means for its seasonal prediction.

The MJO is useful for forecasting certain U.S. West Coast weather anomalies, as we have shown in two publications. One addresses winter flooding events in the Pacific Northwest and the other major winter warm episodes in Alaska. For these applications, improved ability to forecast the MJO is needed. Present thinking seems to be that improved information about air-sea interaction in the Indian Ocean is needed for better understanding of the predictability of MJO events. Thus expansion of the ocean observing system into the Indian Ocean is called for.

A new project, undertaken with Mark Carson (graduate student at University of Washington) is examination of the subsurface temperature trends in the World Ocean Data Set prepared at NODC. Because recent work with this data set and sea level gauge data suggested that interpolation of the ocean data could lead to incorrect inferences about subsurface heat changes, we have taken a different approach. We identify the one-degree grid boxes with the best data distribution over the post-WWII period and evaluate the temperature trend over each box. No interpolation in space or time is done; neither is any ocean climatology removed from the temperature observations. The primary uncertainty source in our approach is inhomogeneity of the observing technology (MBTs to T4 XBTs to T7 XBTs); we have not determined yet if NODC has made corrections for known fall-rate differences between T4 and T7 probes. Taking the observations as given from NODC, we find that the 50year trends at 100m, 300m and 500m vary considerably from basin to basin and from one gyre to another. In some regions there is cooling; in others there is warming. There is no tendency to basin scale warming in each ocean, as has been suggested in studies using an interpolated version of the data set. Additional work needs to be done, but the present results strongly suggest that the existing ocean subsurface data set is not adequate for the determination of subsurface multi-decadal basin averaged trends. This clearly indicates the importance of global deployment and maintenance of the Argo profiling float array, if ocean subsurface trends are to be known accurately in future decades.

3.20a. Teachers at Sea

by John Kermond

PROJECT SUMMARY

The NOAA Teacher at Sea (TAS) program started in 1990, is managed part-time from Seattle, WA, and more than three hundred teachers participated between 1990 and 2004.

The Aerosol Characterization Experiment –Asia (ACE-Asia) in 2001 saw the introduction of a new TAS category – a sponsored teacher. The NOAA Office of Global Programs (OGP) pioneered this new program with support from program managers within the office.

Consistent support for teachers at sea has come from the Office of Climate Observation (OCO). Either alone or in partnership with other OGP programs, as well as with the National Science Foundation, OCO has provided funding for teachers (both national and international) to participate in programs such as the Tropical Atmosphere Ocean Array (TAO), the Eastern Pacific Investigation of Climate (EPIC), the South American Low Level Jet Experiment (SALLJEX), Climate Variability (CLIVAR), the North American Monsoon Experiment (NAME), and STRATUS cruises.

Supported teachers have brought a new dimension of education and outreach to NOAA. Their daily logs, lesson plans, email responses, digital pictures, and live web broadcasts have brought both the fundamental and the cutting-edge science of the agency to global audiences. This has contributed mightily to the NOAA-wide goal of enhanced literacy in both oceanic and atmospheric matters.

With TAS program management now full-time and centrally coordinated, the program is going from strength to strength – something not un-noticed by lawmakers on Capitol Hill, in Washington, D.C. Representative Vern Ehlers (R-MI) remarked in regard to the TAS program "I do not know what you spend on this program, but you really should triple it – and I will help you find the money".

Even the modest financial support for the TAS program has brought with it some remarkable technological breakthroughs. Live web broadcasting from NOAA ships; the move from indoor broadcasting to outside on the decks (and with it live ship operations); the captioning of the broadcasts for the hearing impaired; broadcasting in foreign languages (both Japanese and Spanish); and from both the northern and southern hemispheres. The supported TAS program has seen teachers in Chile, Bolivia, Japan, South Korea, the Galapagos Islands, Nuku Hiva in the French Marquesas, Mexico, and as far north as Alaska and as far south as Punta Arenas at the tip of South America.

Teachers and their classes have adopted TAO buoys; they have adopted drifting buoys (a new program element started in December of 2004 and sponsored by the Office of Climate Observation); and in March of 2005 the first children's book will be published based on a cruise supported by OCO. Written by TAS Mary Cook and former TAS Diane Stanitski, this book will be given to teachers at the National Science Teachers Association (NSTA) annual meeting in Dallas, TX.

Information on the TAS program can be found at www.tas.noaa.gov, and also at www.ogp.noaa.gov.

3.21a. Progress Report For the Observing System Monitoring Center (OSMC)

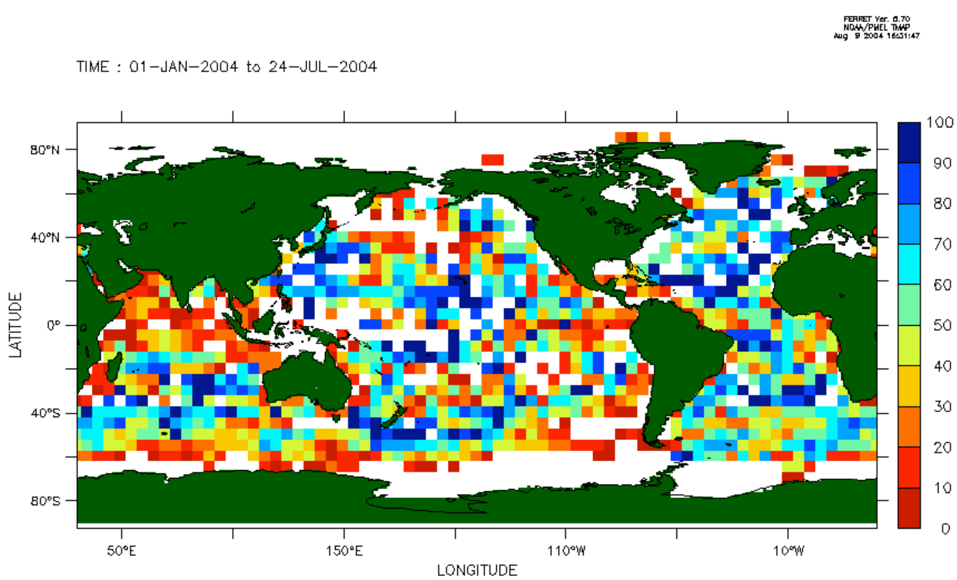
by Kevin J. Kern and Steven Hankin

PROJECT SUMMARY

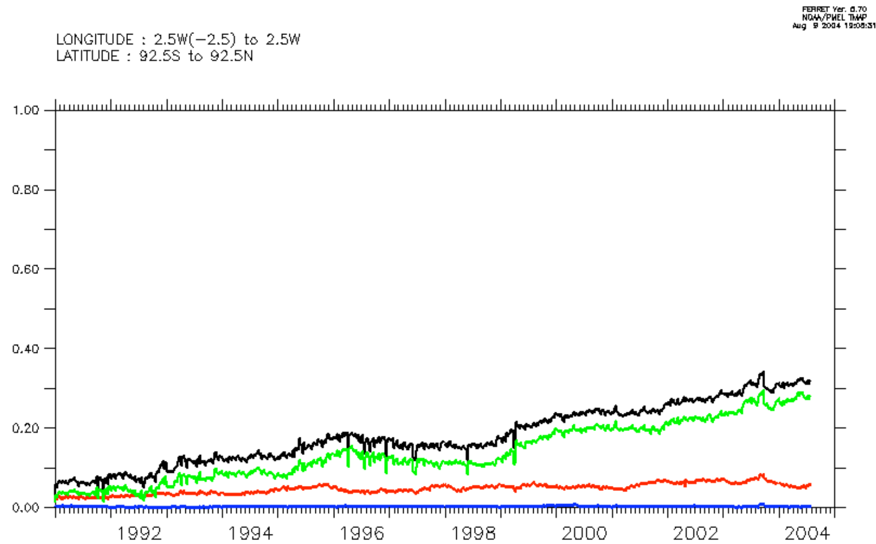
The Observing System Monitoring Center (OSMC) system is an information gathering, decision support, and display system for the National Oceanic and Atmospheric Administration's (NOAA) Office of Climate Observations (OCO) located in Silver Spring, MD. The OSMC system displays current and historical status of globally distributed meteorological and oceanographic data collection systems. The OSMC system provides data visualization tools to identify the coverage of any given collection of platforms and parameters. These visualization tools are available via the internet and can be used to present information from OSMC to other NOAA centers, national partners, and international partners. The OSMC system can be accessed through the use of a conventional web browser (i.e. MS Internet Explorer). The system can be accessed by following the links from the OCO Web page (www.oco.noaa.gov) or accessed directly at the following URL: http://osmc.noaa.gov/OSMC/.

The OSMC project is a joint development effort between the National Data Buoy Center (NDBC) located at Stennis Space Center in Mississippi and the Pacific Marine Environmental Laboratory (PMEL) located in Seattle Washington. Funding is provided by OCO under the direction of Mr. Mike Johnson. The project is aligned to take advantage of the strengths of each organization. NDBC (an operational organization) is responsible for the data, while PMEL (a scientific organization) is responsible for the user interface/graphics/analysis tools. PMEL has taken advantage of their existing tools Live Access Server (LAS), and Ferret (a data visualization and analysis tool) in the development and support of OSMC. NDBC has leveraged its investment in Oracle to support the OSMC database.

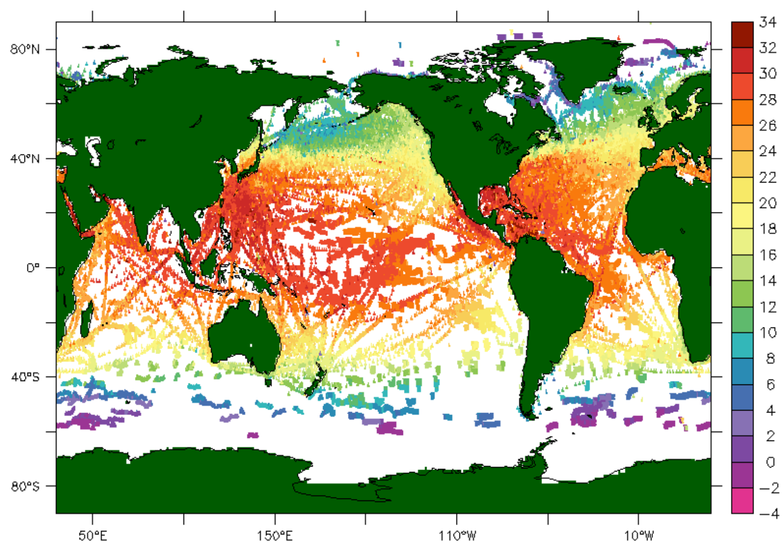
The following provides sample displays from the current OSMC system.



Percent of Weeks with 25 Accuracy Weighted sst obs in 5x5 Box 2004



Fraction of 5x5 Ocean Boxes with 25 Weekly Accuracy Weighted sst obs



All SST Observations jul 2004

FY 2004 PROGRESS

The following progress was made on OSMC during fiscal year 2004.

- Continued the development and updating of project documentation. The documentation includes: Architecture Design Document, Data Management Software Requirements Specification, Database Design Document, and the User Interface Specification.
- Installed the hardware/software to support OSMC at NDBC in time to support the OCO Climate Workshop held in April 2004. This included configuring the web server, installing the LAS software, installing Ferret software and installing the OSMC Executive Interface software. In addition, network devices controlled by NDBC and NASA had to be updated to allow the flow of OSMC traffic through the network.
- Continued updating the gridded observation tables and the (pre-created) high performance graphics available through the Executive User Interface on a monthly basis.
- Made improvements to the user interface of the OSMC software and to the output products of OSMC like the smooth filled contoured plots, displaying each plot in a separate browser window, displaying the "information" page in a separate window, etc.
- Created prototypes of new animations using ship tracks, drifter tracks and moored buoys.
- Created a "mockup" GIS-style User Interface for OCO to be reviewed and solicit comments. Supported a meeting between OCO, PMEL, and NDBC to discuss User Interface design options.
- Creating a linkage that grants PMEL developers direct access to the OSMC database in Oracle at NDBC. This linkage is key to efficient, parallel, collaborative software development between PMEL and NDBC.
- Developed and presented an OSMC overview poster at the Climate Observation Program Review and the Technical Science Workshop. Also created a kiosk-style PowerPoint slide presentation of the poster contents for presentation on the OSMC display screens. Presented a live demonstration and discussion of the system at the OCO Open House. A sample of the poster is included in Appendix A.
- Developed the initial OSMC Oracle database. Defined the schema, loaded initial lookup/verification tables with data extracted from other systems, and began processing the GODAE T-files on a daily basis starting 1 June 2004. The database is being populated at a rate of over 20K new entries each day – updated daily. The entity relationship diagram for the database is shown in Appendix C.
- Developed programs to update the NetCDF files accessed by the Executive User Interface with the data that is written to the Oracle database during the daily updates.
- Supported various OCO meetings including the Climate Observation Program Review and the Technical Science Workshop in April, the Etienne Charpentier meeting in January, and other technical/design meetings. NDBC and PMEL also conduct a technical exchange conference call weekly to discuss the OSMC project.
- Updated OSMC to use the latest version of LAS v6.2.
- Working with OCO to support the Adopt-A-Drifter program.
- Paper on OSMC submitted to and accepted by the American Meteorological Society. Presented an OSMC poster at the AMS meeting in January 2004 in Seattle.

Appendix A – OSMC Poster

THE OBSERVING SYSTEM MONITORING CENTER:
A TOOL FOR THE MONITORING AND EVALUATION OF THE GLOBAL OCEAN OBSERVING SYSTEM

Steve Hankin[1], Kevin O'Brien[2]

Landry Bernard[3], Don Conlee[3], Kevin Kern[3]

[1] NOAA/Pacific Marine Environmental Lab [2] University of Washington/JISAO

[3] NOAA/National Data Buoy Center

OSMC Background

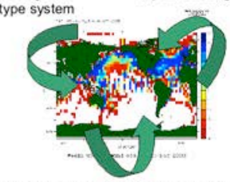
- There is a clear need for a system that provides a full view of the global ocean climate observing system
- The intent of the OSMC is to create a decision support tool for NOAA that shows the gaps and overlaps in the observing system
  - Accessed via Internet
  - Displayed on large-panels in OSMC briefing room

- A useful tool for users throughout the ocean community
  - Assessment of data for assimilation into models
  - Improve understanding of data product limitations
- Initial Operational Capability in late 2004
- Full Operational Capability in late 2005

Software Development Approach

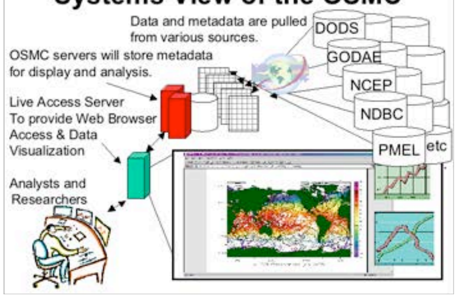
Pacific Marine Environmental Laboratory (PMEL) in Seattle, Washington develops prototype system

NOAA Office of Global Programs (OGP) in Silver Spring, Maryland requests changes & features



National Data Buoy Center (NDBC)at Stennis Space Center, Mississippi hosts OSMC servers and performs metadata management

Systems View of the OSMC

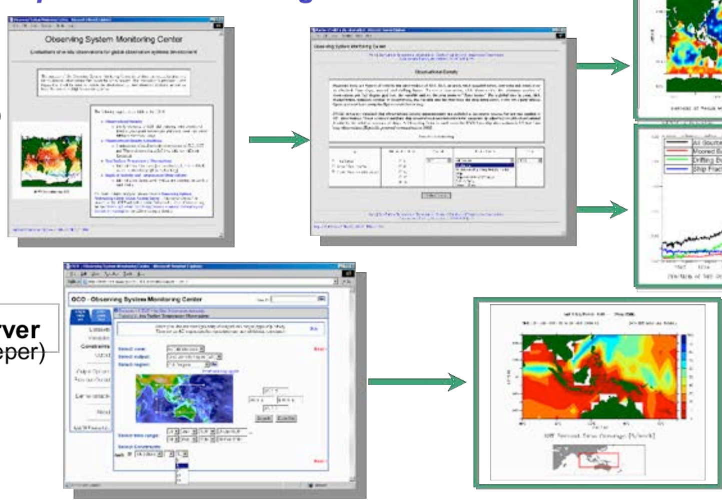


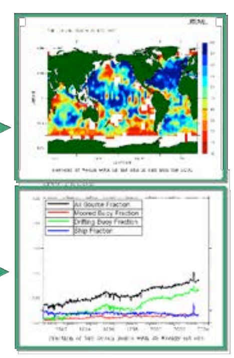
Current OSMC Capabilities

Available from ***http://www.oco.noaa.gov***

"Executive" User Interface (standard products)

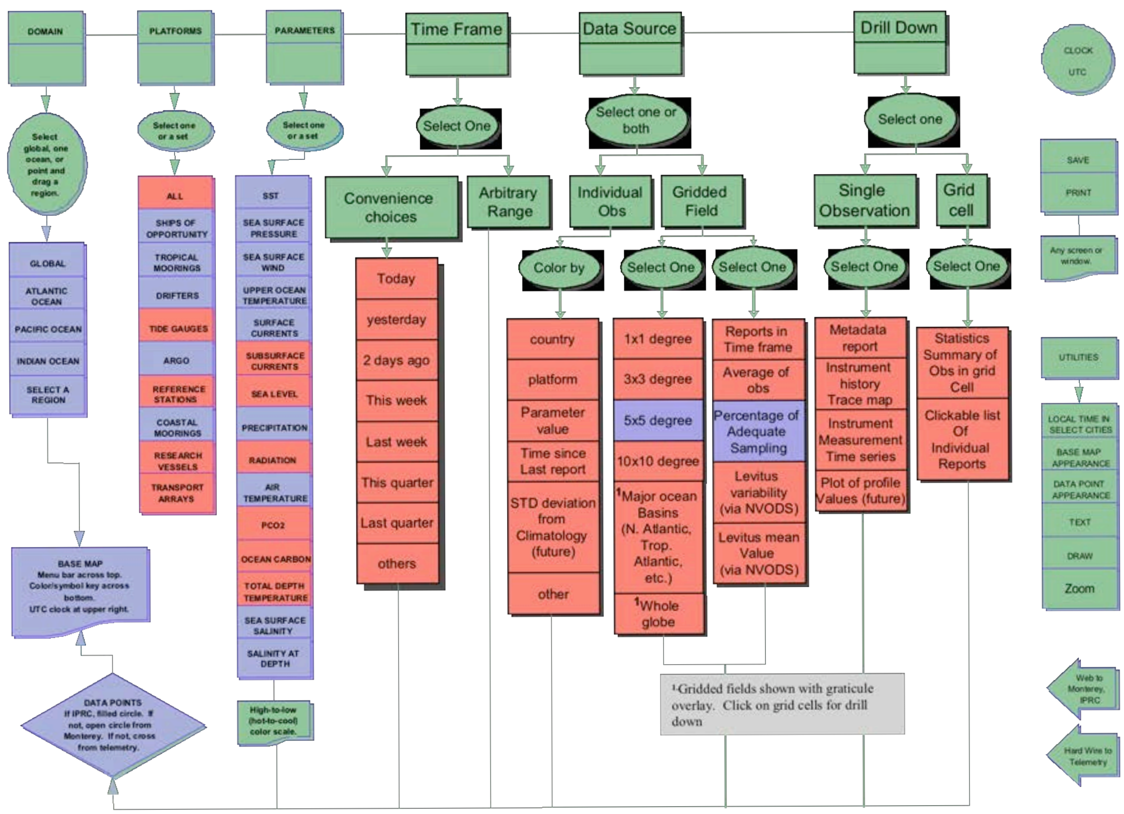
Live Access Server (a probe to look deeper)





Appendix B – OSMC Revised Bubble

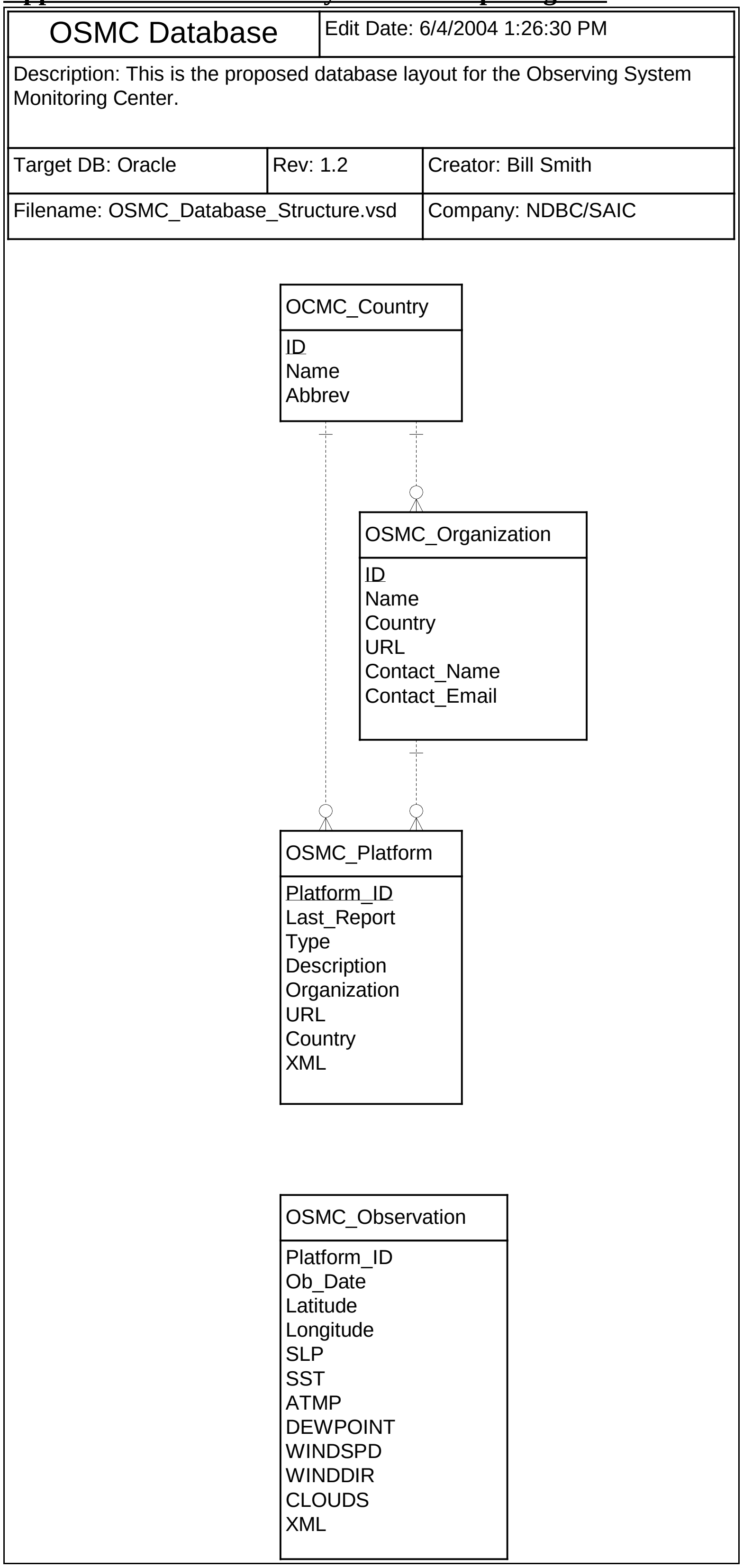
Observing System Monitoring Center



KEY: Blue = Completed Red = FY05 Work Green = System Navigation

Note: Data accumulation will occur over time. Currently the database has data from 1 June 2004, however, it will be back filled to 1 January 2004

Appendix C – OSMC Entity Relationship Diagram



3.22a. An Indian Ocean Moored Buoy Array For Climate

by M.J. McPhaden

PROJECT SUMMARY

This continuation proposal requests funds to maintain 3 mooring sites in the equatorial Indian Ocean as part of a fledgling Indian Ocean moored buoy array. This work is a contribution to NOAA's effort to “Build a Sustained Ocean Observing System for Climate” and supports NOAA’s strategic plan goal to "Understand Climate Variability and Change to Enhance Society's Ability to Plan and Respond." The array is part of a multi-national effort within the context of the Climate Variability and Predictability (CLIVAR) research program to improve our understanding of the Australian-Asian monsoon and its far field impacts. Management of this array is consistent with the "Ten Climate Monitoring Principles". Program oversight at the international level is through the CLIVAR/GOOS Indian Ocean Panel (IOP) and the CLIVAR/JCOMM Tropical Moored Buoy Implementation Panel (TIP). A web site for data display and access is under construction. An Add Task to expand this fledgling array to 6 sites is appended to this proposal.

Background:

The US Climate Change Science Program has identified the critical need for the federal government to begin delivering regular reports documenting the present state of the climate system. As stated in the *US Climate Change Research Initiative* (CCRI, 2002), long-term monitoring systems are the foundation for research, modeling, and informed decisions. Yet an observing system capable of accurately documenting the full range of climate variability and change does not presently exist, especially for the oceans.

Much of the natural variability observed in the climate system originates in the tropics where heat from the sun enters the ocean. This heat is exported to higher latitudes on long time scales to moderate the Earth’s mean climate. On shorter interannual to decadal time scales, ocean feedbacks to the atmosphere influence patterns of global weather variability through teleconnections such as those associated with El Niño and the Southern Oscillation (ENSO). The advanced understanding of the role of the tropics in forcing mid-latitude weather and climate was learned primarily through the observations of the tropical moored buoy array (TAO/TRITON) in the Pacific. A similar pilot array in the Atlantic basin (PIRATA) now offers the potential of even better understanding, improved forecasts, and improved ability to discern the causes of longer term changes in the oceans and their remote impacts over the US. The addition of an Indian Ocean array will complete the moored component of a tropical ocean observing system.

The Indian Ocean influences the dynamics of the Indian and Asian monsoons. It also remotely affects the climate over the US and North America via monsoon-ENSO interactions and via atmospheric intraseasonal oscillations which are spawned over the Indian Ocean. The Indian Ocean is much less well sampled than either of the other two tropical basins however, resulting in serious limitations in the ability to predict seasonal-to-interannual climate variability. Thus, international planning efforts assign a high priority to establishing a comprehensive *in situ* observing system in the Indian Ocean as part of the Global Ocean Observing System (GOOS), the Global Climate Observing System (GCOS), and the World Climate Research Program’s Climate Variability and Predictability (CLIVAR). As in the two other tropical basins, a broad scale Indian Ocean moored buoy array will form the cornerstone of systematic *in situ* ocean measurement efforts designed to improve description, understanding, and prediction of large ocean-atmosphere interactions and their influence on regional and global climate.

The goal of this effort is to develop a moored buoy array in the tropical Indian Ocean in concert with other observing system components such as the Argo floats, surface drifters, SOOP measurements, times series reference stations, tide gauges, and satellite remote sensing. Coordination at the international level is through the newly formed CLIVAR/GOOS Indian Ocean Panel and the CLIVAR/JCOMM Tropical Moored Buoy Implementation Panel. In addition to providing data for understanding and forecasting physical climate variations, moorings of the array can provide platforms for supporting instrumentation to measure carbon dioxide and other parameters essential for understanding the global carbon balance, biogeochemical cycles, and marine ecosystem dynamics. Thus, the array will support the development of improved climate analysis and prediction products of use to NOAA managers, policy makers, and the general public.

FY 2004 PROGRESS

The first meeting of the CLIVAR/GOOS IOP was held in Pune, India, in February 2004. The PI of this proposal is a member of the IOP and lead the effort to develop a draft plan for an Indian Ocean moored buoy array. The proposed array includes 36 surface moorings, 9 of which would have full air-sea flux measurement capability, and 5 subsurface ADCP moorings (Fig. 1). Two of the surface moorings sites and one of the ADCP sites have already been occupied by JAMSTEC along 90°-95°E. A full discussion of the scientific rationale for the array, as well as other elements of a proposed Indian Ocean observing system for climate, can be found in the IOP strategy document at ftp://ftp.marine.csiro.au/pub/meyers/Implementation%20Plan/.

During the meeting the PI identified an opportunity for early initial deployments from a cruise planned for September 2004 on the Indian *RV Sagar Kanya*. He then wrote a proposal with scientists from India's National Institute of Oceanography (NIO) to seek 5 days of ship time for the deployment of 3 ATLAS moorings along 80.5ºE at 1.5ºN, 0º, and 1.5ºS, and a subsurface ADCP mooring near the equatorial site. While awaiting official approval of the ship time request, the TAO Project began procuring equipment, assembling moorings and planning logistics in March 2004. The necessary mooring equipment was mostly purchased with FY 2004 funds provided by the Office of Climate Observation. However, we took advantage of equipment left over from the recently completed EPIC program in the eastern Pacific to increase available inventory. This augmentation proved to be very advantageous, as it allowed us to send a spare system as described below.

We were notified of tentative cruise dates and ports in mid-June, and made shipping and travel arrangements based on this information. In mid-July we received formal notification that the ship time request was approved, along with a start date of October 4. The shipment of mooring equipment left Seattle shortly thereafter, to arrive in India a month before the cruise, which was presumably sufficient time to clear Indian Customs.

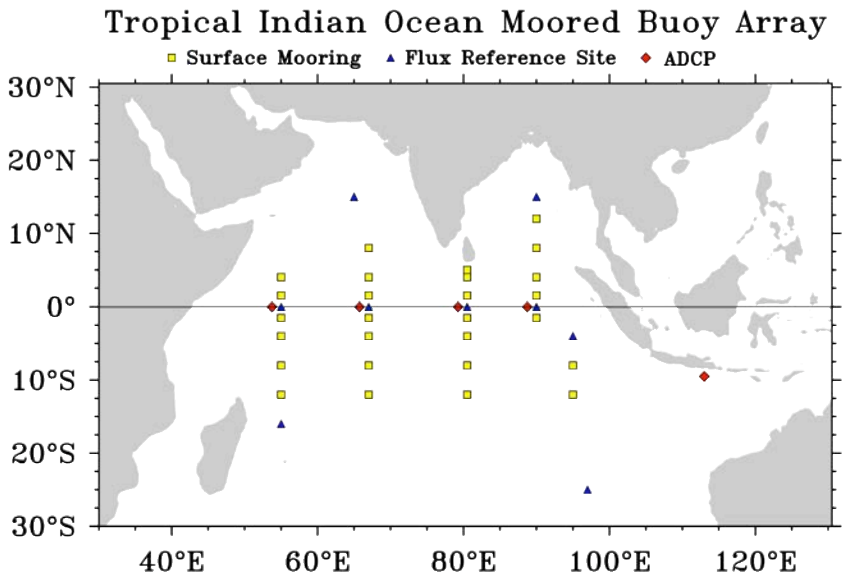


Figure 1. Proposed Indian Ocean Mooring Array.

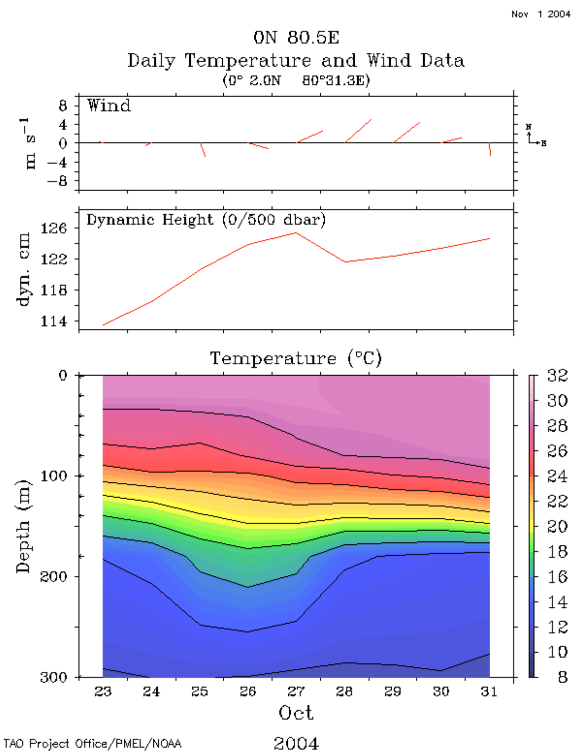
In September we were notified that the cruise ports had been changed, which lead to significant increases in our shipping and travel costs. Customs clearance was delayed for nearly 30 days because problems with the Indian shipping agent and their subcontractor in the new port, resulting in significant additional charges. Finally, in October after PMEL cruise participants had arrived in India, the cruise dates and departure port were again changed, leading to yet more shipping and travel costs. The lesson to be learned from this narrative is that planning and logistics with our Indian colleagues can be highly variable, costly and time consuming. Nonetheless, all equipment arrived in time and the cruise commenced on 11 October 2004.

As of the date of this report (November 1) 3 ATLAS moorings and the subsurface ADCP mooring have been deployed. The ATLAS moorings measure winds, air temperature, relative humidity, precipitation, shortwave radiation, sea surface temperature and salinity, subsurface temperature at 11 depths in the upper 500 m, subsurface salinity at 4 depths in the upper 100 m, ocean pressure at 2 depths, and mixed layer velocity at 10 m depth. The equatorial site is enhanced with additional subsurface temperature, salinity, velocity measurements, plus longwave radiation and barometric pressure to make it compatible with the OceanSITES time series reference station sampling requirements (http://www.oceansites.org). Because of concerns about elevated drag on the moorings due to strong Wyrtki Jets along the equator, the central mooring includes a newly designed load cell with Iridium telemetry.

We prepared and shipped a fourth ATLAS system as a spare in case any problems developed with the 3 primary systems. It was not necessary to use any of the components from this system though and NIO indicated that they did not have space available for storage after the cruise. Rather than ship the mooring back to Seattle, we requested and have received approval to deploy it later on the cruise at 0°, 90ºE. This mooring has the same measurement suite as those as 1.5°N and 1.5°S and will be situated nearby the JAMSTEC ADCP mooring at 0°, 90°E in accordance with the array design in Figure 1.

Real-time data from the ATLAS moorings deployed so far indicate that all systems are working well. Figure 2 shows an example of the initial data from 0°, 80.5°E.

October is a time of transition between the Southwest Monsoon and the Northeast Monsoon when strong westerlies develop along the equator. These westerlies drive an intense eastward current—the Wyrtki jet—in the surface layer. These features are evident in just the first week's worth of data. Also, one can see that as the winds intensified, the thermocline rapidly deepened at the equator, consistent with the notion of local Ekman convergence and downwelling.



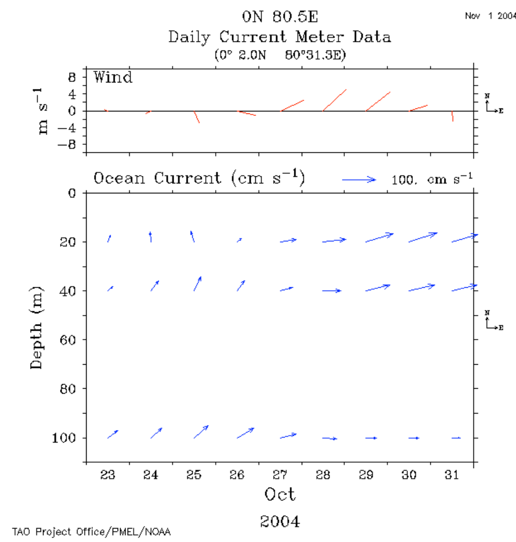


Figure 2. Initial real-time wind, temperature and velocity data from the ATLAS mooring deployed at 0°, 80.5°E. Note the transition winds and Wyrtki jet in the upper 100m.

In FY 2004 we proposed to develop a 7-element pilot scale ATLAS array over FY 2005-2007 according to the following schedule:

End of FY 2005--3 moorings in the water
End of FY 2006--5 moorings in the water
End of FY 2007--7 moorings in the water

Thanks to the early opportunity provided by this cruise, careful planning, and efficient execution of mooring operations on the cruise itself, we will have 4 ATLAS and 1 ADCP mooring in the water early in FY 2005. Our progress thus far puts us well ahead of our scheduled plans.

3.23a. Pilot Research Moored Array in the Tropical Atlantic (PIRATA)

by M.J. McPhaden

PROJECT SUMMARY

This continuation proposal requests funds to maintain the Pilot Research Moored Array in the Tropical Atlantic (PIRATA) as part of NOAA's effort to "Build a Sustained Ocean Observing System for Climate". PIRATA is a joint effort between the U.S. (NOAA/PMEL), France (Institut de Recherche Scientifique pour le Développement en Coopération [IRD] and Meteo-France), and Brazil (Instituto Nacional de Pesquisas Espaciais [INPE] which is the Brazilian space agency and Diretoria de Hidrografia e Navegacao [DHN] which is the naval hydrographic service). PIRATA supports NOAA's strategic plan goal to "Understand Climate Variability and Change to Enhance Society's Ability to Plan and Respond." It also underpins Climate Variability and Predictability (CLIVAR) research efforts on tropical Atlantic climate variability. Management of PIRATA is consistent with the "Ten Climate Monitoring Principles". Program oversight at the international level is through the PIRATA Scientific Steering Group and the CLIVAR/JCOMM Tropical Moored Buoy Implementation Panel (TIP). A web site containing comprehensive information on the program can be found at http://www.pmel.noaa.gov/pirata/

FY 2004 PROGRESS

Background:

During FY 2004, the PIRATA array was maintained in a 10-mooring configuration as agreed upon for the consolidation phase of the program (2001-2005). Political unrest in the Ivory Coast in the past three years has required shifting of ports-of-call and revision of logistical arrangements for French cruises out of West Africa. The program has proceeded up to the present however without any major interruptions in service.

France and Brazil provide ship time and support for equipment shipments as part of a tri-lateral agreement to maintain the array. PMEL is charged with providing equipment, technical support for moorings and instrumentation, and support for data processing, dissemination, and display. France also provides some technician support.

As in the Pacific TAO array, PIRATA primary variables include winds, air temperature and relative humidity, SST, subsurface ocean temperature and pressure. By design however, PIRATA also includes salinity at the surface and at 3 depths in the upper 120 m, shortwave radiation, and rainfall. Shipboard CTD and ADCP data collection and processing are the responsibility of France and Brazil. PIRATA data are available from the PIRATA web site (http://www.pmel.noaa.gov/pirata/) and the TAO web site (http://www.pmel.noaa.gov/tao/). There are also mirror sites in France and Brazil.

Ship Time and Sea Time:

Ten new ATLAS moorings were deployed on 2 cruises in FY 2004. A total of 39 sea days (21 on the French R/V Atalante and 18 on the Brazilian R/V Antares) were required to service the array. PMEL personnel spent 18 person-days at sea on these cruises, significantly less than in past years. This was mainly because French mooring and electronic technicians are sufficiently familiar with the ATLAS system to deploy and recover moorings without PMEL participation. In addition, PMEL participation on the Brazilian cruise was limited to one technician, with a French technician also aboard. PMEL covered the travel costs of the French technician on the Brazilian cruise.

The Brazilian cruise was only 18 days in duration, but it was split into two legs with six days in port between legs. This cruise schedule significantly increased the travel costs of the PMEL and technician, and caused the French technician to participate in only the first leg.

Data Return:
Real-time data return was 79% overall for FY 2004, 11% higher than for FY 2003. The increased data return was in main due to an improvement in subsurface telemetry hardware. Nevertheless PIRATA data return remains lower than Pacific data return for TAO/TRITON of 86%. The difference between the two basins relates to the greater susceptibility of the smaller PIRATA array to fishing vandalism and to a less frequent servicing schedule (one per year vs. twice per year for much of the Pacific). While no PIRATA moorings were lost in FY 2004, two are presently not transmitting and presumed lost.

Real-time PIRATA data return by variable for FY 2004 (and for comparison, FY 2003) is shown below.

	AIRT	SST	T(Z)	WIND	RH	Rain	SWR	SAL	ALL
FY 2004	92	78	81	68	86	64	84	75	79
FY 2003	83	72	66	73	87	65	84	60	68

PIRATA Web-based Data Distribution:
The TAO Project continues to update the content and functionality of its web site (http://www.pmel.noaa.gov/tao/). This site provides easy access to TAO/TRITON and PIRATA data sets, as well as updated technical information on buoy systems, sensor accuracies, sampling characteristics, and graphical displays. For FY 2004, a total of 2,839 separate user requests delivered 13,559 PIRATA data files. These numbers are up 46% and 8%, respectively from the year before.

Operational Use of PIRATA Data:
PIRATA data are distributed via the GTS to centers such as NCEP, ECMWF, and Meteo-France where they are used for operational weather, climate, and ocean forecasting and analyses. PIRATA data placed on the GTS include spot hourly values of wind speed and direction, air temperature, relative humidity, and sea surface temperature. Daily averaged subsurface temperature data are also transmitted on the GTS. Daily ftp transfers are made from PMEL to the CORIOLIS operational oceanography program in France. The MERCATOR program in France makes use of the CORIOLIS database to generate operational ocean model based data assimilation products. PIRATA data are also available on the GODAE server in Monterrey, California.

The TAO Project Office has been working with Service Argos to include ATLAS salinity data on the GTS. Progress has been made towards this end, with modifications to the GTS subsystem completed and presently being tested.

Vandalism:
Vandalism continues to plague portions of the PIRATA array. Data and equipment return are generally lower in regions of high tuna catch in the Gulf of Guinea, where data return for FY 2004 was about 50% and both moorings in the region are presently not transmitting. Four of the 5 eastern most PIRATA moorings showed evidence of interaction with fishermen (fishing line, missing or damaged sensors, damaged buoys) when recovered in FY 2004.

Efforts to combat vandalism continue, though it is not clear they are making much impact. These efforts include distribution of information brochures to national fishing agencies, fishing boats in ports of call, and industry representatives, and have contributed to international efforts to decrease vandalism through the DBCP. The attractive RM Young wind sensor may be replaced with a less conspicuous sonic anemometer if tests of the latter prove encouraging and funding for system upgrades become available.

TAO Transition Plan:
In a memo dated 13 August 2002, the Deputy Directors for OAR and the National Weather Service

instructed the directors of PMEL and NDBC to develop a plan for transferring PMEL operations to NDBC. The memo was in response to the Administrator of NOAA's endorsement of a recommendation by the NOAA Program Review Team that TAO mooring operations be consolidated with those at NDBC. After several iterations, the Deputy Administrator of NOAA formally approved a TAO transition plan in September 2004.

The NOAA Climate Observing System Council (COSC) reviewed a preliminary version of this plan in which TAO and PIRATA were both proposed for transfer to NDBC. The COSC observed that transfer of PIRATA was premature and recommended against it at this time. That recommendation was incorporated into the final plan. The issue of PIRATA transfer will be reconsidered once a decision is made towards the end of the consolidation phase to continue the program as a permanent component of the Atlantic climate observing system. It is expected that that decision will be made this year.

3.24a. The University of Hawaii Sea Level Center

by Mark Merrifield

PROJECT SUMMARY

The University of Hawaii Sea Level Center (UHSLC) collects, processes, and distributes tide gauge information from around the world in support of various climate research activities. The measurements are used for the evaluation of numerical models (e.g., those in operation at NCEP), joint analyses with satellite altimeter datasets, the calibration of altimeter data, the production of oceanographic products through the WMO/IOC JCOMM Sea Level Program in the Pacific (SLP-Pac) program, and research on interannual to decadal climate fluctuations. Also, in support of satellite altimeter calibration and validation and for absolute sea level rise monitoring, the UHSLC and the Pacific GPS Facility maintain co-located GPS systems at select tide gauge stations (GPS@TG). Over the years the UHSLC has participated in various national and international programs including NORPAX, TOGA and WOCE, and currently is a designated CLIVAR data assembly center and an IOC GLOSS data archive center. Data collected by the UHSLC are managed to meet both the requirements of GLOSS and NCDC's ten climate monitoring principles. The UHSLC distributes in situ sea level directly from its dedicated web site, http://uhslc.soest.hawaii.edu, through a dedicated OPeNDAP server, PMEL's CDP, the NOPP sponsored NVODS project, and the NOSA geospatial and geospatial metadata databases being developed at NGDC. We also are providing in-situ sea level data to the GODAE program. The center also collaborates with NODC to maintain the Joint Archive for Sea Level (JASL), which is a quality assured database of hourly sea level from selected stations from around the world, and continues to work with PMEL on data distribution formats and methods.

The primary UHSLC operations are administered under the Joint Institute for Marine and Atmospheric Research co-operative agreement, and funded by the Office of Global Programs. GPS@TG projects are supported by OGP in the Atlantic Ocean, and by NASA for stations in the Pacific and Indian Oceans. We are working with other groups associated with the global observing system to provide syntheses of various datasets and to compile and distribute associated products.

<u>FY 2004 PROGRESS</u>

Tide Gauge Operations:

The UHSLC operates 39 tide gauge stations in the global sea level network, with 4 in the Global Climate Observing System (GCOS) Category 1 list and 27 in the Category 2 list. In the past fiscal year we serviced 13 sites, installed 3 new stations, and serviced 16 sites remotely. Station maintenance during FY2004 included on-site service trips to Diego Garcia, Settlement Point, Kanton, Baltra, Santa Cruz, Palau, Pohnpei, Manzanillo, Valparaiso, Easter, Male, Gan, Hanimaadhoo. New stations were installed at Christmas Island, Colombo, Sri Lanka and Salvador, Brazil. Stations that developed problems that our technicians were able to solve remotely during FY2004 included Point La Rue, Port Louis, Hululue, Azores, Lamu, Easter, Salalah, Settlement Point, Baltra, Saipan, Tern Island, Rikitea, Penhryn, Yap, Ushuaia, Manzanillo, and Diego Garcia. We are upgrading key network sites to acoustic or radar sensors in place of the older float gauges, and an on-site data storage device has also been in development as a back-up system when satellite transmissions fail. The historical data return for the UHSLC network is 93.8%, the current year's return is 95.3%, and the previous years return 96.8%.

The UHSLC is providing technical support to the ODINAFRICA project, which will oversee the installment of 10-20 new tide gauges in Africa. The center is working with the Survey of India (SOI) on a plan to install satellite transmitting gauges at selected Indian GLOSS and GCOS sites, and to produce a quality assured database of hourly sea level from selected Indian stations. A MOU between NOAA and BAKOSURTANAL in Indonesia has been drafted for the purpose of upgrading the Indonesian tide gauge network. The UHSLC will help install up to 6 new gauges in the region, and contribute ongoing technical and scientific support for the operation of the network.

We have completed 7 GPS installations to date, and we are continuing to explore opportunities for further expansion in this area. We are negotiating with the Azores about a possible installation. The center is also in contact with the National Tidal Centre (NTC) in Australia concerning their South Pacific gauges, and with agencies in Brazil.

Dataset Holdings:
The Joint Archive for Sea Level (data latency: 1-2 years) is a collaborative arrangement between NODC, the World Data Center-A for Oceanography, and the UHSLC. Beginning in the fall of 2000, the JASL was supported by NOAA's NCDDC. The JASL produces a quality assured database of hourly sea level from stations around the world. In the past year, the UHSLC increased its JASL holdings to 10,007 station-years, including 5617 station-years at 202 GLOSS sites. Of the 101 GLOSS stations that are presently operating on islands, 93 are available through the JASL. The 2003 submission of the JASL data to the World Data Center-A for Oceanography included 120 series that contained measurements through the year 2002. We are also working with IPRC to ensure that the JASL delayed mode observations are available through the APDRC servers.

The UHSLC maintains a fast delivery database (data latency: 1 month) in support of various national and international programs (e.g., GODAE, CLIVAR, GLOSS, GCOS). To ensure active participation and coordination with the international community, the database has been designated by the IOC as a component of the GLOSS program. The fast delivery data are used extensively by the altimeter community for ongoing assessment and calibration of satellite altimeter datasets. In particular, fast delivery data are used for monitoring the latest JASON altimeter and for the tie between JASON, TOPEX/Poseidon, ERS, and GEOSAT satellites. The fast delivery sea level dataset now includes 141 stations 113 of which are located at GLOSS sites, of which 44 are located at GCOS 1 sites, and 43 at GCOS 2 sites. The historical return for the fast delivery dataset is 94.0%, the current year’s return is 94.8%, and the previous year’s return 95.5%.

We are working with the GODAE steering committee to ensure that tide gauge information in real-time is available through the UHSLC. Approximately 70 stations currently are available on this time frame with plans for ongoing expansion. When operational, we will distribute this product through our web site, and make it available in a netCDF format via an OPeNDAP (formerly DODS) server.

As part of the JCOMM SLP-Pac, the UHSLC operates a Specialized Oceanographic Center that produces sea surface topography maps (monthly) and diagnostic time series (quarterly) for the Pacific Ocean. This activity is a continuation of one of the earliest examples of operational oceanography. The UHSLC presently distributes these products through the Internet and by mail to users. The net result is that approximately five weeks after the end of a month, hundreds of users throughout the world receive an analysis of the state of the Pacific Ocean sea surface topography for that month. The analysis includes comparisons of tide gauge and altimeter sea surface elevations that are available through the UHSLC web site.

The UHSLC distributes in situ sea level and associated products directly from dedicated web and anomalous ftp sites. Both have been designed such that the response is very fast. The code has been kept very simple and focused on the tasks that the users will want. Whether the user has access via a dial-up modem, cable, or DSL the access speed is kept high by using small, compressed, pre-generated images sent from a central server. This allows users worldwide to conveniently acquire the center’s holdings. The center produced cdroms that mirror the UHSLC web site. These cds are distributed with the JASL annual data report, shared with all data originators, and sent to other users upon request. Over 100 were distributed again last year.

Research Highlights:

Interannual and decadal changes and sea level rise have been our primary research focus areas during FY2004. A manuscript describing decadal oscillations in sea level in the eastern Pacific is in press at the Journal of Physical Oceanography. We have described how the long sea level record collected at the Honolulu tide gauge is connected to Pacific North America (PNA) related fluctuations in winds and surface pressure.

We are continuing our study, in collaboration with the NTC, of a case history of sea level data collection at the Funafuti atoll in Tuvalu. The UHSLC maintained a station at Funafuti for nearly 20 years. The data are now being extended forward by the NTC. This paper will document how a consistent high quality time series that is useful for climate studies is collected and managed.

The island of Hawaii experienced one of the highest sea level events on record during the latter part of 2003. Flooding of low-lying coastal areas and enhanced beach erosion throughout the State were attributed to this event. A paper describing the role that mesoscale eddies play in these events is in review at Geophysical Research Letters. Similar extreme event analyses are planned for other island regions.

A study of island sinking rates along the Hawaiian island chain formed the basis for a student Masters thesis and an article submitted that is currently in review at Geophysical Research Letters. Differences in sea level rise rates recorded at Hilo and Honolulu have long been attributed to variable subsidence rates associated with volcanic activity. Continuous GPS measurements indicate that the rates are more similar between the islands. We find that recent sea level rate differences are due in part to steric variations associated with large-scale wind patterns. We are extending this analysis to consider differential GPS rates at tide gauges throughout the Pacific.

Estimates of coastal sea level rise in the Southern California region are being made in conjunction with Ben Brooks at the Pacific GPS Facility. SAR images are used to estimate vertical ground motion along the entire coastal strip. Tide gauge and GPS information are then incorporated to give a full description of relative sea level variability along the coastline.

We are collaborating with Philip Woodworth of the Proudman Oceanographic Laboratory and Gary Mitchum of the University of South Florida on an annual report describing sea level variability for the previous year (similar to the climate assessments made each year in the Bulletin of American Meteorological Society). The first set of products is under development, including updates on sea level trends, extreme events, and large-scale variations.

Our research effort has advanced our understanding the GPS ground motion datasets at each of our sites, with the goal of providing absolute sea level trends at all GPS@TG stations. We are working with Mike Bevis of Ohio State University to establish a global reference frame in which to analyze the GPS vertical data. In conjunction with the GPS analysis, we are making a thorough evaluation of all benchmark survey datasets at UHSLC sites. This work could be accelerated with more resources (see add task 2).

The JASL and CLIVAR/GLOSS datasets were added to the NOSA geospatial and geospatial metadata databases being developed at NGDC. These databases are expected to play an important role in the NOAA Enterprise GIS efforts. This arrangement allows the UHSLC datasets to be accessed along with other NOAA supported climate products through the NOSA web site. The center continues to work with the ncBrowse and Climate Data Portal projects. The center's goal is to integrate all of our datasets and products into these systems. We have continued to integrate the UHSLC datasets and products into the NVODS LAS.

Figure 1. Tide gauge data collected by the UHSLC with data latency (time from observation to distribution) indicated in color.

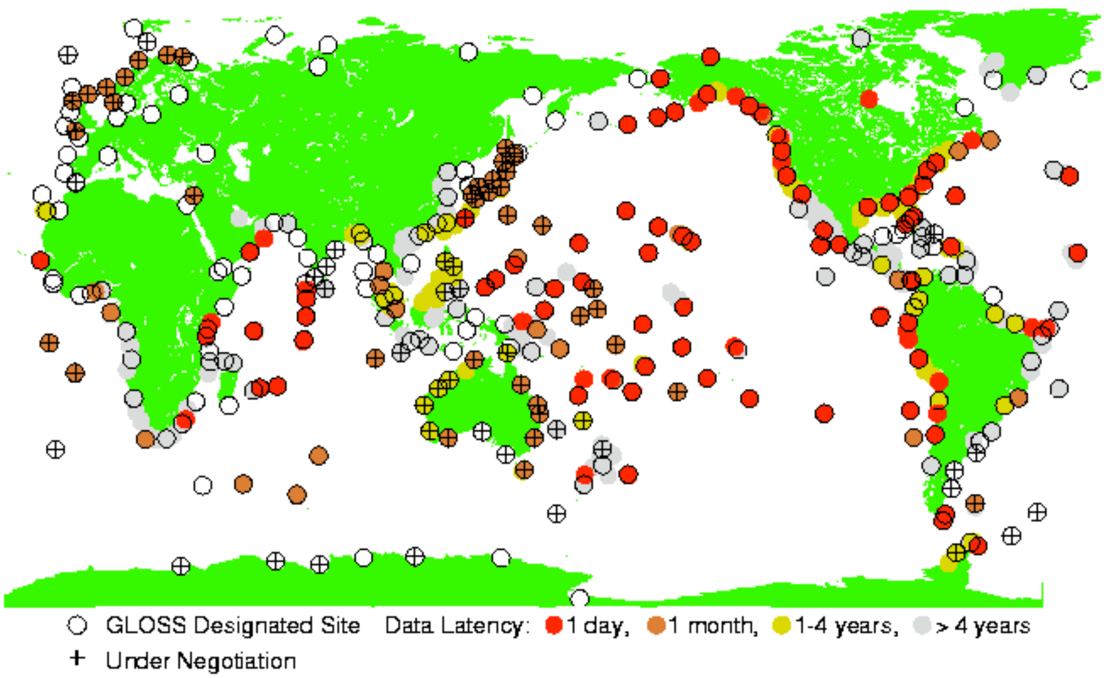
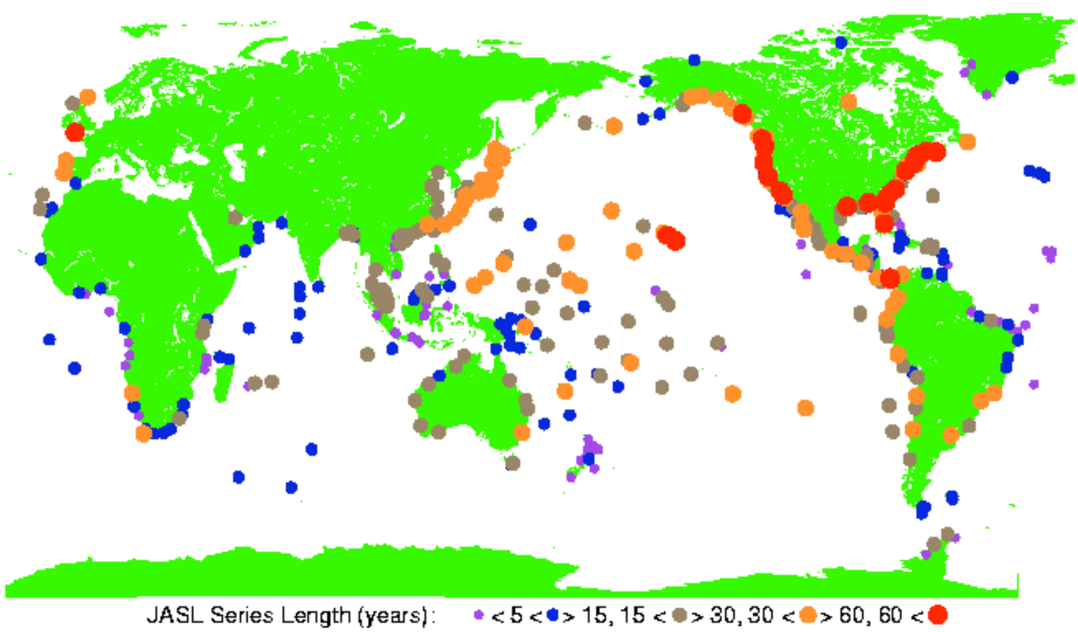


Figure 2. Sea level time series record lengths in the Joint Archive for Sea Level (JASL).



3.25a. Satellite Altimetry

Laury Miller

PROJECT SUMMARY

Satellite altimetry is a unique type of ocean remote sensing observation because it provides much more than a surface measurement. Spatial and temporal variations in sea surface height are driven by temperature and salinity changes throughout the water column. The NOAA Laboratory for Satellite Altimetry (LSA) has been involved in every satellite altimeter mission: Geos-3, Seasat, Geosat, ERS-1, Topex/Poseidon (T/P), ERS-2, Geosat Follow-On (GFO), Jason-1, and Envisat. Many of these have been research programs or operational demonstrations. However, since the mid-1990s it has been possible to produce quick-look, altimeter-generated analyses of sea surface height with sufficient accuracy and resolution to have operational utility. This capability is largely due to advanced satellite orbit determination techniques based on systems like the Global Positioning System. As a result, NOAA now incorporates satellite altimetry in a number of its operational products. For example, near-real time sea surface height analyses are assimilated into NCEP ocean models used to forecast El Niño, hurricane intensification, and coastal circulation. Over longer time scales, altimetry is being used to observe the North Atlantic Oscillation and monitor global sea level rise.

Because of the value of altimetry to NOAA and the U.S. Navy, a commitment has been made to fly altimeters operationally as part of the National Polar-Orbiting Operational Satellite System (NPOESS) beginning in 2013. In the meantime, NOAA must continue to leverage its resources to take advantage of existing satellite altimeter missions, and prepare to assume responsibility for the Jason-2 ground system beginning in 2008.

This project contributes to the NOAA goals (1) Understand climate variability, and (2) Serve society's needs for weather and water information. It provides the satellite altimeter "research-to-operations" component of NOAA's Program Plan for Building a Sustained Ocean Observing System for Climate.

LSA maintains connections with many agencies, institutions, and programs. LSA staff members serve on NASA's Ocean Surface Topography Science Team, the Envisat altimeter advisory group, and science teams for CryoSat, and IceSat. See http://ibis.grdl.noaa.gov/SAT/.

FY 2004 PROGRESS

Four altimeters were operating during 2004: GFO, T/P, Envisat, and Jason-1. Most of the Climate Observations altimeter funds were used to support GFO, which is a NOAA-Navy collaboration.

(a) GFO

Geosat Follow-On (GFO) has been operational since 2000. During 2004, LSA provided partial funding for the precise orbit determination effort and also supports a calibration/validation team at Ohio State University. LSA worked closely with the Navy, NASA, universities, and project contractors to prepare and distribute the final, research-quality Geophysical Data Records (GDRs). Thus far, LSA has produced 4 years of GDRs and distributed the data to users on DVD (http://ibis.grdl.noaa.gov/SAT/gfo/). GDR production and distribution will continue routinely for the life of the GFO mission. It is estimated that the satellite will operate until at least 2006. In addition to the research data sets, GFO is a source of near-real time sea surface height that is used by the Navy and NOAA for ocean and atmosphere operations. As an example, the National Hurricane Center uses all available altimetry to compute "hurricane heat potential" maps as an aid to forecasting storm intensification, and GFO contributes significantly to the analysis.

(b) Geosat

The Geosat mission (1985-89) provided the first long time-series of altimetry measurements and allows us to extend multi-mission altimetry back 7 years prior to T/P. LSA has completed a data recovery project for the Geodetic Mission data (GM, 1985-86) and needs to secure funding to recover the remaining Exact Repeat Mission data. This requires a data forensics firm equipped to transfer the original Sensor Data Records (SDRs) from aging 9-track tapes to modern media. The cost is estimated to be in the $100-200K range. The GM data are particularly useful for geophysical applications such as predicted bathymetry. By merging the SDRs with the original altimeter waveforms (obtained from a separate archive at NASA Goddard) we have been able to significantly improve the along track spatial resolution. Refinements in the re-tracking of the waveforms will ultimately provide a much sharper picture of the small-scale seafloor structure and marine gravity field. To further improve the Geosat data, a new orbit will be computed that leverages the tuned gravity model of GFO, which flies in the same 17-day repeat orbit as Geosat. Global sea-level rise studies will benefit from the extra 7 years of data from an improved Geosat time-series.

(c) T/P and Jason-1

The 10-year archive of T/P sea level analyses was kept up to date on the LSA web site, together with the Pacific island tide gauge comparisons that have become the standard for monitoring the health and accuracy of the T/P observations. Jason-1 has now replaced T/P as the high-precision satellite altimeter, and NCEP is receiving analyses operationally for applications such as El Nino monitoring and coastal current forecasting.

The LSA is supporting a study by a student of Dr Steve Nerem, University of Colorado, to improve estimates of Global Sea Level Rise (GSLR) over the past 50 years using a combination of satellite altimeter and tide gauge observations. The work involves applying regional spatial patterns of sea level rise determined from 13 years of T/P and Jason-1 altimeter data to longer but more sparsely sampled tide gauge records. As part of the collaborative aspect of this project, the student, Tom Jakob, spent last summer working with Laury Miller at the LSA.

(d) Jason-2

LSA spent a significant amount of time planning for NOAA’s new role in Jason-2. Jason-2 will be a 4-agency partnership with contributions from NOAA, NASA, CNES, and EUMETSAT. A new Jason-2 initiative for FY06 was approved by DOC in August 2004. This would provide $1.6 M to allow NESDIS to assume responsibility for command/control from Suitland, downlinks at Wallops and Fairbanks, operational processing and distribution, and archive.

(e) Global Sea Level Rise

The rate of 20th century Global Sea Level Rise (GSLR) and its causes are the subjects of intense controversy. Most in-situ measurements from tide gauges made over the past 50 to 100 give a rate of about 2 mm/year, while indirect estimates based on the two processes responsible for sea level rise, namely mass and volume change, fall far below this figure. Estimates of the volume increase due to ocean warming produce a rate of about 0.5 mm/year and the rise due to mass increase, primarily from the melting of continental ice, is thought to be even smaller. To further complicate matters, estimates of GSLR based on measurements made by T/P, Jason-1 and four other satellite altimeter missions over the past decade indicate a rate of about 3 mm/year. In a recent paper, Miller and Douglas (*Nature*, 2004) resolved some of this controversy by demonstrating that tide gauge estimates of GSLR are not biased high, as some have suggested due to coastal warming, and that the rate due to mass increase is actually 2 to 3 times greater than the rate due to volume increase. In short, they found that 2 mm/year is a reasonable figure for the 20th century rate of GSLR. The question of how this result relates to satellite altimeter estimates of the past decade is topic of a joint research project with Dr. Steve Nerem, University of Colorado, (see section c.)

3.26a. The Global Drifter Program:
Global Drifter Measurements of Surface Velocity, SST and Atmospheric Pressure
by Peter Niiler

PROJECT SUMMARY

Rationale: The principal scientific questions of the role of the ocean in climate change are how well can we describe or model the ocean circulation today and how well can these descriptions or models predict the evolution of future climates. Drifters provide the instrumental data sets for describing ocean surface circulation and SST evolution and these data are used for testing climate models. Atmospheric pressure is assimilated into weather prediction models and is used by operational meteorological agencies to discern severe weather conditions over the oceans.

Objectives of the Global Drifter Program:

The "Global Drifter Program" (*GDP*) is the principal international component of the *"Global Surface Drifting Buoy Array"*. It is a scientific Project of the DBCP of WMO/IOC. It is a near-operational ocean-observing network of drifters that, through the ARGOS satellite system, returns data on ocean near-surface currents, SST and atmospheric pressure (and winds and salinity) and provides a data processing system for scientific utilization of these data. In addition to *GDP*, drifters are deployed by operational oceanographic and meteorological agencies, whose data are utilized by *GDP*. In turn, *GDP* data are made available on GTS to operational users. Barometers, wind-sensors and salinity sensors can be and are added to SVP drifters. The international protocols for these data exchanges and sensor additions are worked out each year by DBCP.

The scientific objectives of the *GDP*, and its operational partners, are to:

1) Provide to GTS an operational, near-real time data stream of SST, sea level pressure (and surface velocity).
2) Observe the mixed layer velocity on a global basis with 0.5° resolution and produce new charts on the seasonal and interannual changing circulation of the world ocean (Fig. 1).
3) Develop and introduce into the drifter construction technological advances in sensors, electronics, power, methods of assembly and deployment packaging.
4) Provide enhanced research quality data sets of ocean circulation that include drifter data from individual research programs, historical data from instruments different from the Surface Velocity Program (SVP) Lagrangian Drifter and the corrected data sets for wind-produced slip of drifter velocity.
GDP:

- Provides to the coupled ocean-atmosphere climate modelers gridded, global data sets of SST and near surface circulation and dynamic topography and for assimilation and the verification of the parametrized processes, such as wind-driven Ekman currents.
- Provides the Lagrangian data sets for the computation of single particle diffusivity, dispersal of ocean pollutants, the enhancement of models of fisheries recruitment and improvement of air-sea rescue.
- Obtains high-resolution coverage of ocean variability and time mean circulation in support of ENSO prediction model verification in the tropical Oceans and supports short-term research projects that require enhanced upper ocean velocity observations.

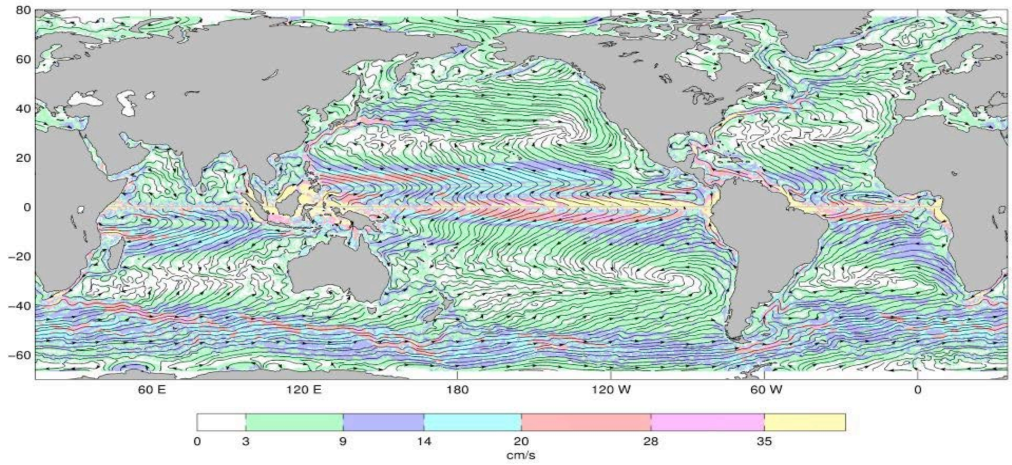


Figure 1. The streamlines of 1992-2003 15m-depth drifter derived currents at 0.5º resolution (Courtesy of N. Maximenko, U. of Hawaii, IPRC, 2004). This figure reflects the mean near surface circulation of the global ocean.

Required Drifter Observations and Status of Global Array:
GDP began in 1988 as a TOGA research program. WOCE made contributions in the period 1991-1993. Between 1992 and 2003, an array of 600 SVP drifters was maintained in the global ocean with contributions of resources from a variety of operational and individual research programs. Since October 2003 the array has consisted of over 900 drifters. Full implementation for SST observations will be completed by June 2005.

The 'required' global drifter array size is based on the need to maintain 1250 platforms that return instrumental observations of daily average SST (+/- 0.1^0C) over the global ocean at the 5º resolution, or the spatial scale of the error covariance function of satellite SST sensors. Surface pressure sensors are also supported by regional meteorological agencies based on local needs.

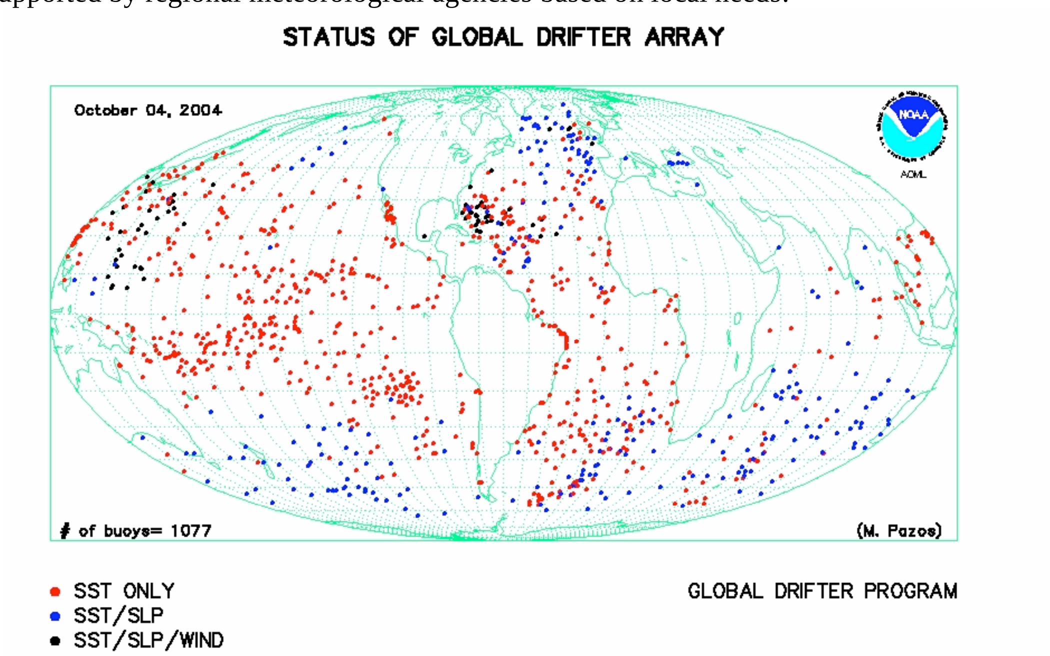


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Figure 2. The Global Drifter Program array on October 4, 2004.

The actual number of drifters in the array will be larger than 1250 because the required uniform spatial distribution will be difficult to maintain in the complex ocean surface circulation and many drifters go ashore in remote locations. On October 4, 2004 1077 of the 1250 'required drifters are reporting to GTS and the AOML *Drifter Data Center* (Figure 2). NOAA Climate Observation Program, together with cooperation of ONR, has funded sufficient numbers of SVP drifters (940) in FY'04, and with the expected contributions of drifters (200-300) from other sources, the array will be fully deployed by June 2005. In 2005 will begin more directed efforts to adjust the array spatial density.

Management:
GDP reports every year to the DBCP, for advances in technology in the Technical Sessions and in deployment plans and organization in the Plenary Sessions. *GDP* is largely a NOAA funded program and is managed according to the *"Ten Climate Monitoring Principles"* established by JCOMM. In these tasks, there is close coordination between the following entities:

• US manufacturers in private industry (*Technocean, Inc*. of Cape Coral, FL*; Clearwater, Inc*. of Watertown, MA*; Pacific Gyre, Inc.* of Carlsbad, CA*)* who build the SVP drifters according to closely monitored specifications. Internationally a total of 6 private firms and 3 research laboratories build SVP drifters.

• Atlantic Oceanographic and Meteorological Laboratory (AOML) who carries out the deployments at sea, processes the data and archives these at MEDS, Canada, maintains the META file on the description of each drifter deployed, and the upgrades the *GDP* website,

• Joint Institute of Marine Observations at the Scripps Institution of Oceanography (JIMO/SIO) who supervises the US industry, acquires the NOAA funded drifters, upgrades the technology, develops sensors and enhanced data sets and maintains liaison with individual research programs that deploy SVP drifters. Periodically, drifter construction manuals are upgraded and are posted on the DBCP website.

The requirements of the international science bodies from the drifter array are to provide instrumental observations of SST. In the research community 99% of reviewed scientific research papers use drifter velocity observations: (viz. list of publications at:
http://www.aoml.noaa.gov/phod/dac/drifter_bibliography.html)
Nearly all research program contributions to the drifter array have been justified on the basis of upper ocean velocity observations.

FY 2004 PROGRESS
Funding of the FY'04 Global Drifter Program, and the ancillary CORC and ONR sponsored activities at JIMO/SIO, occurred in the last week of September 2004. Since then the following activities have taken place, jointly with CORC funding:

1. *Drifter Acquisitions and Technology: In summary, 967 drifters and 8 temperature chain wind drifters were ordered and 60% will be delivered in time for deployment before June 2005.*

a) A total of 550 SVP-Mini drifters were ordered from Clearwater Instruments, Inc and Technocean, Inc. These will be delivered to AOML for deployment. Component parts for an additional 210 SVP-Mini drifters were ordered (jointly with ONR funds) from Clearwater Instruments, Inc and Pacific Gyre, Inc. These component parts will be sent to Busan National University for assembly and deployment in to the western Pacific in support of CORC and ONR joint sponsored activities.
b) A total of 125 SVP-B drifters were ordered from Technocean, Inc. and Pacific Gyre, Inc. These will be deployed under the direction of AOML in the North Pacific (50) and the Southern Ocean (75).

c) A total of 12 Minimet wind-drifters were ordered from Pacific Gyre, Inc. These will be configured for air-deployment into the Atlantic hurricane(s?) during the 2005 season.
d) Components for a total of 20 SVP-Sea Surface Salinity (SSS) drifters were ordered from Seabird, Inc. and Pacific Gyre, Inc. These will be assembled at SIO; 12 will be sent for deployment into the North Atlantic by MeteoFrance in March 2005 and they will make a best effort will for recovery and recalibration over the following 12 month period; 8 will be sent for deployment into the East China Sea to study the effects of the construction of the Great Yangtze River Dam.

3.27a. Climate Variability in Ocean Surface Turbulent Fluxes

by James J. O'Brien, Mark A. Bourassa, and Shawn R. Smith

PROJECT SUMMARY

Ocean surface turbulent fluxes will be examined for climate-related variability. Typically SSTs, winds, and pressures are examined in such studies. The observed changes in winds (speed and direction) and SSTs alter turbulent surface fluxes, which have a far-reaching influence on regional climatologies. It is expected that surface turbulent fluxes (stress, sensible heat, and latent heat) are more directly linked to climate-related changes than winds and pressures. Similar approaches will be applied to two overlapping periods. We are objectively deriving a high quality set of monthly surface fluxes (and related fields), covering 1950 to 2005, for the global oceans north of ~30°S to examine variability on a wide range of spatial and temporal scales (seasonal to decadal). Similar daily fields (including surface radiative fluxes) are under development from July 22, 1999 through 2005, with greater spatial resolution. Our goal is to produce the most accurate flux fields available.

Reanalysis surface fields have large biases and systematic errors in comparison to surface truth (Cotton et al. 1999, Renfrew et al. 2000, Smith et al. 2001). The physics of the boundary layer are not well modeled in NWP reanalyses, resulting in poor surface fields. The errors are sufficiently large to bias climate-related studies (Cotton et al. 1999, Smith et al. 2001); therefore, in-situ (ship and buoy) observations are being objectively combined to create a better turbulent-flux product. Comparing subjectively-derived, in-situ based, Equatorial Pacific surface wind products (the FSU winds) to the NCEP/NCAR Reanalysis clearly verified the above mentioned shortcomings (Putman et al. 2000). However, the FSU wind fields are excellent matches to satellite ocean surface vector wind fields (Pegion et al. 2000), thereby confirming the accuracy of the in-situ based products. The surface flux fields developed though this study can be used to help validate flux fields created with couple ocean-atmospheric models (after the removal of the above short comings). The techniques developed in this study will also be of use for programs such as GODAE and SEAFLUX (which require the assimilation of data from multiple platforms), as well as energy budget studies based on WOCE and GOOS observations. The flux analysis methods will also be of interest to the newly formed WCRP working group on surface fluxes.

An objective analysis technique (Bourassa et al. 2004) has been developed to produce fields of surface turbulent fluxes (momentum, latent heat, and sensible heat fluxes) and the fields used to create the fluxes (vector wind, scalar wind, near-surface air temperature and humidity, SST, and pressure). This approach treats the various types of observations (volunteer observing ships, moored buoys, drifting buoys, different satellites) as independent, and objectively determines weights for each type of observation. The weights for each type of observation are objectively determined.

The flux project at FSU targets the data assimilation milestones within the Program Plan. Our assimilation efforts combine ocean surface data from multiple Ocean Observing System networks (e.g., VOS, moored and drifting buoys, and satellites). One set of performance measures targeted in the Program Plan is the air-sea exchange of heat, momentum, and fresh water. When products are combined with ocean models (either at FSU or other institutes), performance measures relating to surface circulation and ocean transports can be addressed. The FSU flux project also focuses on the task of evaluating operational assimilation systems (e.g., NCEP and ECMWF reanalyses) and continues to provide timely data products that are used for a wide range of ENSO forecast systems.

All development of the objective flux system and operational production of the FSU winds and fluxes are the responsibility of COAPS. Our satellite partners include Gary Wick (NOAA-ETL; satellite SST), Frank Wentz and Deborah Smith (Remote Sensing Systems; scatterometer winds, passive microwave scalar winds, passive microwave SST), and Bill Rossow and Yuanchong Zhang (NASA; radiative fluxes). We maintain a long-term collaboration with Dr. Jacques Servain (IRD, France) who focuses on data and products for the tropical Atlantic Ocean. We also continue to collaborate with U. S. and international partners in the CLIVAR program, SEAFLUX, and GODAE to provide the wind and flux products needed to achieve these projects goals. All the FSU wind (and eventually flux) products are freely available at: http://www.coaps.fsu.edu/RVSMDC/SAC/.

The FSU flux project began managing its operation in accordance with many of the Ten Climate Monitoring Principles long before they were spelled out by the NRC. We continue to fully document and provide free access to all of the FSU wind and flux products. The FSU Pacific and Indian Ocean winds have been continuously produced and distributed since the mid-1970s, and a historical retrospective containing past procedures and methods in now published (Smith et al. 2004). We endeavor to maintain a consistent product over many years and are careful to include parallel testing whenever possible before changing analysis methods. When a former product is discontinued, we provide a comparative assessment of the new and old products to aid the users transition (e.g., Bourassa et al. 2004). Finally, we continually evolve our data access and distribution system to take advantage of new distribution formats (e.g., netCDF) and access technology (e.g., LAS, DODS). This evolution will continue in the future to achieve the goals of new data management programs (e.g., Ocean.US IOOS-DMAC).

FY 2004 PROGRESS

In-situ surface wind and flux products

The objective method (Bourassa et al. 2004) continues to be applied to create two-degree tropical Pacific Ocean wind (pseudo-stress) fields based on in-situ data input. Quick-look two-degree gridded pseudo-stress fields are produced at the beginning of each month using the previous month's GTS-transmitted data, and a research product for the preceding year is produced each summer using delayed-mode GTS data from NCDC. In addition, COAPS continues to produce one-degree pseudo-stress fields for the tropical Indian Ocean using the method of Legler et al. (1989). A switch to produce Indian Ocean fields with the Bourassa et al. (2004) method was delayed due to the complicated nature of developing a new one-degree objective system (see below). Both two-degree fields for the Pacific Ocean and one-degree fields for the Indian Ocean FSU winds are available at http://www.coaps.fsu.edu/RVSMDC/SAC/index.shtml. Objective Pacific winds (known as the FSU2) are available for 1978-2003 (research) and Jan. - Sept. 2004 (quick-looks). Indian Ocean winds are available for 1970-2003 (research) and Jan. - Sept. 2004 (quick-looks).

The 2°x2° FSU2 and the subjective FSU product for the Equatorial Pacific Ocean have been compared to monthly averages of scatterometer (NSCAT and QSCAT) pseudostress analyzed on the same grid as the FSU2 winds. The scatterometer observations are gridded with the same objective technique used herein, except that the satellite uncertainty estimates consider observational error and representativeness, there is no manual quality control of the scatterometer data, and the length scale for spatial smoothing is approximately one tenth of the scale for in situ data. The scatterometer observation density is sufficient to produce much finer spatial resolution for monthly time scales: scatterometer winds are the best available standard of comparison. The comparison times are Oct. 1996 through June 1997 for NSCAT, and Aug. 1999 through Dec. 2003 for QSCAT. The comparison to scatterometer data includes mean differences (biases) as well as standard deviations, which are more indicative of seemingly random differences.

The comparisons of mean differences (Fig. 1) between the scatterometer and FSU wind products have similar spatial patterns, however, the differences between the scatterometer and subjective FSU pseudostress are much greater than for the objective (FSU2) pseudostress. The clearest pattern occurs in the meridional wind comparisons and is related to an underestimation of the FSU products' convergence about the ITCZ. The zonal differences are partially due to the scatterometer measuring current relative winds while the in situ winds are earth relative. The magnitude and direction of speed biases (Fig. 1, top) near the equator are consistent with the South Equatorial Current (SEC; Kelly et al. 2001). The biases near the SEC are also partially due to the broad spatial smoothing used to create the background field for the FSU2. The speed biases to the North of the North Equatorial Counter Current (7° or 8°N) are greater than the observed and modeled currents. This region has very sparse coverage, and the information that propagates into this region is a relatively poor match to local conditions. For a strong majority of locations, the magnitude of the bias in stress components is <0.006 Nm^{-2}.

Greater differences between the subjective and objective FSU winds are seen in standard deviations of differences with scatterometer winds (Fig. 2). These standard deviations are much greater in the comparisons with the subjective FSU winds. The subjective FSU product has local maximums around the ITCZ and the SPCZ. The subjective products shortcomings related to the SPCZ are likely due to the use of 10° longitudinal bins in the hand analysis. The FSU2 also has remarkably improved accuracy in the western Pacific Ocean. Presumably the good quality of the FSU2 winds extends as far back as there are adequate in situ observations. Degradation in quality with time can be examined in future studies if in situ data from the scatterometer time period can be sub-sampled to simulate coverage during earlier times.

Development of a high quality 1°x1° in situ based product (which was requested by users of our products) has proven to be much more complicated than expected. We have overcome or are near overcoming these problems:

1) Differences between the uncertainty of moored and drifting buoy winds,
2) For finer spatial/temporal resolution products, sampling-related differences in observing systems are more apparent,
3) Near coastal features must be much more finely resolved,
4) For the Pacific basin, working with 1°x1° binned data results in too much data to be manually quality controlled.

The first three problems were particularly evident near coastlines, in archipelagos, and near TAO buoys. These problems have been resolved through five modifications to our approach. For example we now treat moored and drifting buoys as separate types of platforms. Our solution to the fourth problem (based on quality assurance techniques developed in our quality control of research ship data) is undergoing testing. This approach is expected to save a great deal to time, particularly for flux products.

<u>Satellite surface wind and flux products</u>

Development of our satellite-based products continues. We can now produce fields on an arbitrarily fine spatial resolution. We take advantage of this utility when examining fine structure, usually within observational swaths. Currently, we are using such fields to examine the transition of tropical cyclones to extratropical cyclones. We have also nearly completed work on the uncertainty of the wind fields. For global gridded fields the uncertainty is dominated by sampling issues. It is only for fine spatial resolution, high temporal resolution fields within swaths that the observational uncertainty dominates the uncertainty in the gridded output.

Currently available products are:

- Daily average pseudostress fields:
  http://www.coaps.fsu.edu/scatterometry/Qscat/gcv_glob_L2B_1x1.html
- Monthly global 1x1 fields:
  http://www.coaps.fsu.edu/scatterometry/Qscat/gcv_glob_L2B_1x1_mon.html
- 12-hourly fields for the Gulf of Mexico
  http://www.coaps.fsu.edu/scatterometry/Qscat/gcv_glob_L2B_hlfxhlf_GofM.html
- Monthly global 0.5x0.5 pseudostress fields
  http://www.coaps.fsu.edu/scatterometry/Qscat/gcv_glob_L2B_hlfxhlf.html

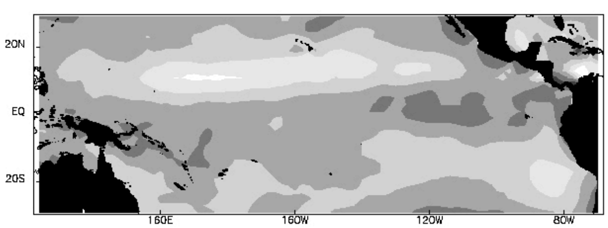
We have used our gridded surface winds to examine the propagation of the Madden-Julian Oscillation (MJO). The MJO causes very important variability in the tropics, and is usually identified by its signal in outgoing long wave radiation and in cloud cover. We have shown that there is a very strong signal in the surface winds (Arguez et al. 2004).

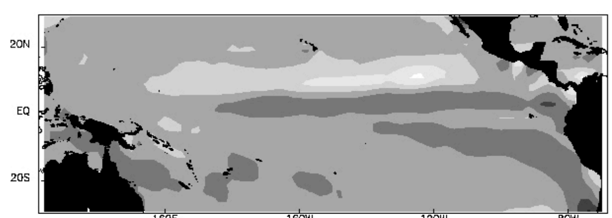
The gridded satellite wind fields have been used to examine variability in the southern ITCZ (SITCZ) in the eastern Pacific Ocean. The results show that our gridded fields are capturing the expected variability on scales of approximately 5 days. Averaging on a monthly scale, such as is necessary with the in situ data alone, hides the vast majority of this variability as the existence of the SITCZ. The advection of divergence from the north is caused by several considerations: large scale increase in southward winds associated with gap flow, and spatial changes in vertical mixing associated with changes of atmospheric stability on these spatial scales (Jones 2004).

We are now coupling scatterometer wind observations with various NWP fields to construct forcing fields for our Gulf of Mexico ocean model. This atmospheric forcing is coupled with ocean model through surface turbulent fluxes calculated with an updated version (Bourassa 2004a,b) of the Bourassa-Vincent-Wood flux model (Bourassa et al. 1999). The new water-wave related physics considered in this model results in more accurate surface turbulent fluxes for wind speeds from 2 to 30 ms^{-1}.

We have solved a problem related to temporally inconsistent data used for sea surface temperature (SST) and air temperature. For example, weekly Reynolds SSTs combined with NWP air temperatures. In too many cases this combination resulted in a net transfer of atmospheric water vapor to the ocean. We have solved this problem by changing the form of moisture used in the objective method from specific humidity to relative humidity. This approach has removed the possibility of super-saturation of the atmosphere near the ocean surface, resulting in much more realistic moisture fluxes.
Prototype SST fields are currently being constructed from microwave SST products. Traditionally, SST fields are either constructed for a week, or based only on pre-dawn observations. These options avoid complications due to the diurnal cycle. We are considering a new approach that would consider the diurnal cycle and would utilize all the observations. This approach should result in more accurate fields and allow for a much finer resolution of the diurnal cycle.

As noted earlier, the FSU2 winds are being freely distributed via the web. The data are also available via anonymous ftp (ftp coaps.fsu.edu/pub/wind) and the DODS (http://www.coaps.fsu.edu/RVSMDC/html/dods.shtml). We are currently working to install a LAS. The operational Pacific FSU2 pseudostress fields continue to be used by U. S. government agencies (e.g., NCEP, NOAA/AOML, NASA/JPL) and universities (e.g., Columbia University, New York University, University of California – Los Angeles, University of California – San Diego, University of Maine, University of Hawaii, and FSU). International users include ECMWF, the Royal Netherlands Meteorological Institute, CSIRO (Australia), the National Institute Of Oceanography in India, and the Shanghai Typhoon Institute. The quick-look Pacific fields are also reproduced on a monthly basis in the Climate Diagnostics Bulletin distributed by NOAA. At present, the FSU winds are periodically provided to NCAR for archival by their Data Support Section.





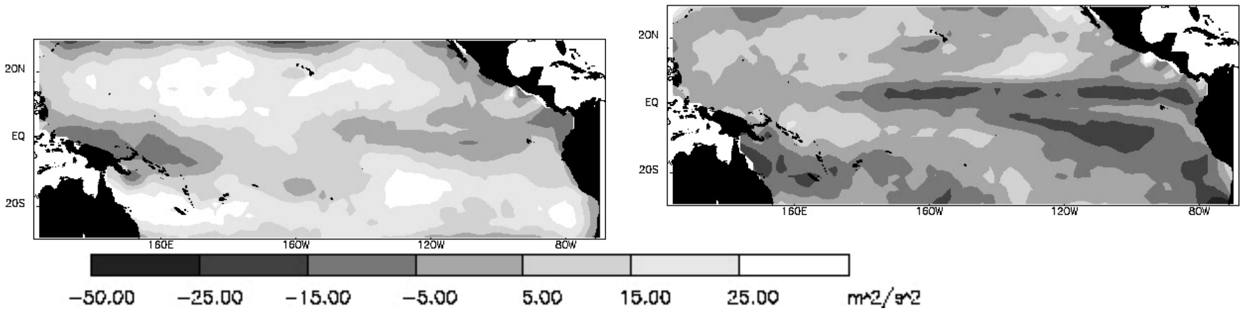


Fig. 1. Mean monthly differences of FSU and scatterometer pseudostress components (FSU minus scatterometer), where zonal pseudostress is on the top row and meridional pseudostress is on the bottom row. The new objective FSU winds (left) are much more similar to the scatterometer winds than the old subjective FSU winds (right). The Meridional differences indicate that neither the subjective or objective FSU winds capture the strong Meridional convergence about the ITCZ. The patterns in the zonal winds are related to the currents. Scatterometer winds are current relative, whereas the FSU winds are earth relative.

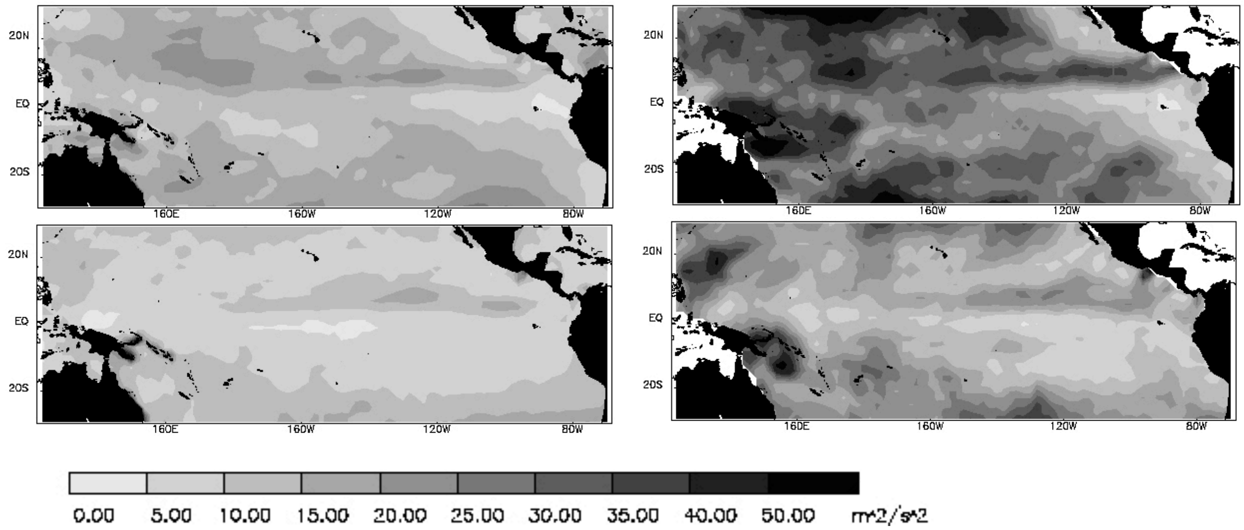
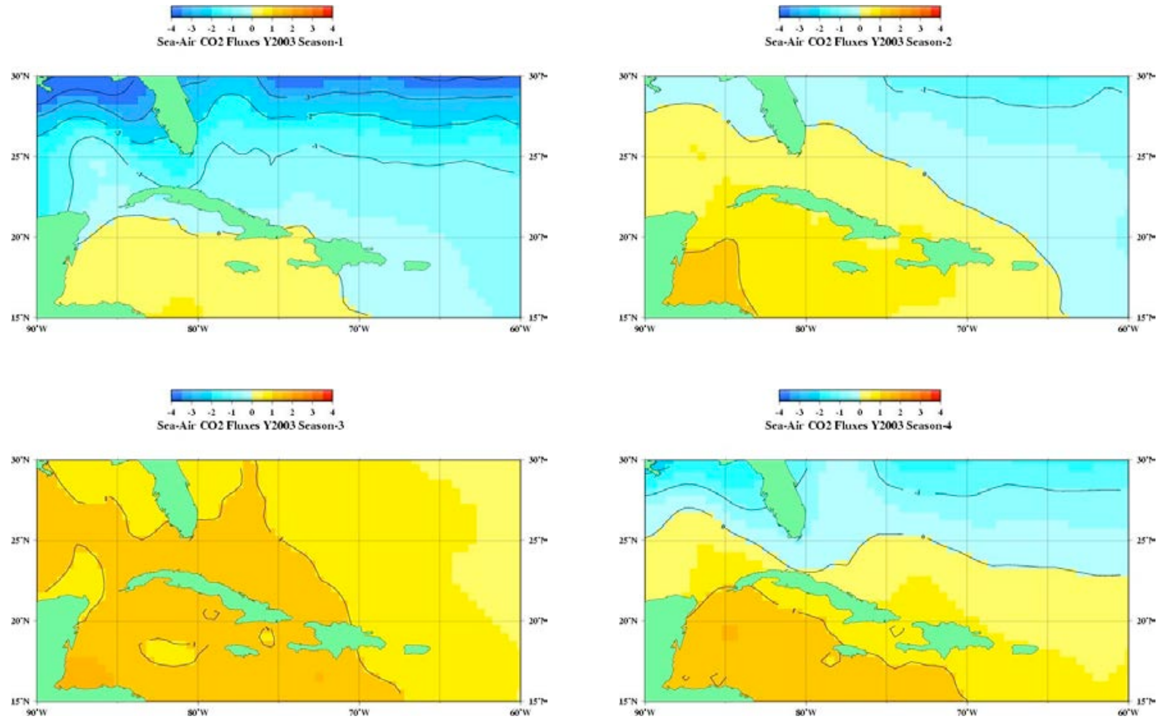


Fig. 2. Standard deviations of monthly differences of FSU and scatterometer pseudostress components, where zonal pseudostress is on the top row and meridional pseudostress is on the bottom row. The new objective FSU winds (left) are much more similar to the scatterometer winds than the old subjective FSU winds (right). The meridional standard deviations have a local maximum about the ITCZ and in the area of the SPCZ. The VOS observation pattern is easily identifiable in the subjective FSU winds.

Document Ocean Carbon Sources and Sinks



Seasonal flux maps for the Caribbean Sea for 2003 based on observations of the Explorer of the Seas and algorithms using remotely sensed SST.

3.28a. U.S. Research Vessel Surface Meteorology Data Assembly Center

by James J. O'Brien, Mark A. Bourassa, and Shawn R. Smith

PROJECT SUMMARY

Accurate estimates of turbulent air-sea fluxes over the global oceans are necessary for ocean modeling, climate modeling, and are a key component of the Climate Observation Program. The Research Vessel Surface Meteorology Data Center (RVSMDC) continues to evaluate the accuracy of turbulent fluxes from in-situ observations, satellite observations, and globally gridded flux fields (e.g., FSU fluxes, national meteorological center reanalyses). These activities specifically target performance measures related to sea surface temperature, sea-level pressure, and air-sea exchanges of heat, momentum, and fresh water as outlined in the Program Plan.

The unique component of the RVSMDC activities is the source of in-situ data: quality-evaluated, automated meteorological observations collected by research vessels (R/Vs). Through an expansion of funding from the NOAA Office of Climate Observation (OCO) to COAPS, the RVSMDC is seeking to obtain marine meteorological data on a routine basis for all U.S. sponsored R/Vs. During the development and pilot project phase of the expansion, the RVSMDC continues to augment its R/V data holdings with observations from the NOAA vessels *Ronald Brown* and *Ka'Imimoana*, as well as observations collected internationally on CLIVAR hydrographic cruises. Initial evaluation of IMET (Hosom 1995) equipped VOS vessels are also underway.

Production of quality-evaluated R/V meteorological observations and turbulent fluxes provides an important data source for validation of the analyses (sea surface pressure, winds, precipitation, sea temperature, and air-sea fluxes) desired by the Climate Observation Program. Benefits of our R/V flux evaluations include uncertainty estimates that will allow future improvements of global flux fields. Future inclusion of vessels operating in polar regions will allow evaluation of fluxes under extreme environmental conditions. R/V observations are too sparse in space-time to validate monthly products, such as an objective version of the FSU winds (Bourassa et al. 2003); however, the R/V observations can be used to validate satellite observations, which can then be used to validate the monthly products. Directly or indirectly, R/V data are an excellent source of comparison data for surface reanalyses (e. g., Smith et al. 2001).

All R/V observations are currently evaluated using an improved automated and visual quality processing system. Through the OCO supported Shipboard Automated Meteorological and Oceanographic (SAMOS) initiative (formerly the HRMM initiative), the RVSMDC is designing a more sophisticated automated quality processing system. The framework for the new system has been established and development of databases and computer tools is underway. Through the SAMOS initiative we have expanded and will continue our interaction with R/V operators, and anticipate improvements in the accuracy of all SAMOS data. Free distribution of our quality evaluated R/V data (http://www.coaps.fsu.edu/RVSMDC/) continues to benefit U. S. and international scientists. Expanding access to quality-evaluated R/V meteorological data is a primary mission of our data center and this activity addresses the Milestones for Dedicated Ship Time and Data and Assimilation Subsystems outlined in the Program Plan.

All activities of the RVSMDC are the responsibility of personnel at COAPS. To complete the activities, we directly coordinate data receipt from the ship technicians, vessel operators, and international data archives. Collaboration continues with Robert Weller, David Hosom, and Frank Bahr at the Woods Hole Oceanographic Institute in regards to the VOS IMET program. During FY 2004, we extended our collaboration with members of several JCOMM panels through the SAMOS initiative, specifically through the 2nd Workshop on High-Resolution Marine Meteorology (Smith 2004a, b). We are building further partnerships with the WMO VOSClim program, the WCRP Working Group on Surface Fluxes

(Smith is a member), the IODE GOSUD project, both the U. S. and international CLIVAR program, GOOS, IOOPC, and the Ocean.US IOOS-DMAC.

RVSMDC activities are managed in accordance to the Ten Climate Monitoring Principles outlined by the NRC. Since our inception with WOCE and TOGA-COARE, the COAPS R/V data center has emphasized the importance of metadata to fully document our data sets. We have a clear focus on data quality and have applied a number of innovative quality assurance (QA) techniques for R/V data. Since the end of WOCE, the data center has been a strong advocate for continued data stewardship for R/V meteorological observations. We continue to call for additional resources to be applied to the remote regions of the oceans (e.g., Southern Oceans), where R/Vs can serve as a vital component of an ocean observing system. From the outset of the SAMOS initiative, the RVSMDC has sought input from scientists, technicians, data and archival experts, and policy makers to ensure that the design and implementation future RVSMDC data quality and distribution practices meet a broad range of user needs. Finally, we continue to provide free and open access to all R/V data, metadata, and documentation at the COAPS surface meteorology data center.

FY 2004 PROGRESS

SAMOS Initiative:

The SAMOS initiative focuses on improving the quality of and access to surface marine meteorological and oceanographic data collected *in-situ* by automated instrumentation on ships. As part of this effort, the NOAA OCO hosted the *2nd High-Resolution Marine Meteorology (HRMM) Workshop* in Silver Spring, Maryland on 15 and 16 April 2004 (Smith 2004a, b). The purpose of the second workshop was to discuss implementation of the recommendations from the *Workshop on High-Resolution Marine Meteorology* held in Tallahassee, FL on 3-5 March 2003 (for details see http://www.coaps.fsu.edu/RVSMDC/marine_workshop/Workshop.html).

Throughout the past year, members of the RVSMDC have been actively promoting the SAMOS initiative and both U.S. and international meetings. We have coordinated efforts by other SAMOS panelist to introduce the SAMOS initiative to the Scientific Committee and Antarctic Research, JCOMM, CLIVAR, and the IODE GOSUD project. Feedback from the scientific and technical community has been supportive and constructive as the RVSMDC begins development of a data collection and distribution system for SAMOS observations.

The expanded OCO funding specifically allows the RVSMDC to coordinate the collection, QA, distribution, and future archival of SAMOS data collected on U. S. research and merchant vessels. The RVSMDC will collaborate with WHOI and SIO to design a ship-to-shore-to-user data pathway,which will support data transmission from each ship to the DAC on a daily basis. A “quick-look” version of the SAMOS data will be available within a few days of receipt at the DAC. The quick-look data will undergo common formatting and automated quality control. Visual inspection and further scientific quality control will result in a “research” quality SAMOS product. The RVSMDC will provide distribution services for the quality-controlled data in formats that meet user needs and will ensure that the original and quality controlled data are submitted to several national data archives.

The RVSMDC activities related to the SAMOS initiative are still in the early stages. The initial design for a ship-to-shore-to-user data pathway is complete. Several steps of this pathway will involve working with our pilot project partners at WHOI and SIO and a team of programmers at the RVSMDC is beginning development of necessary processing codes and display tools.

Another key component of the SAMOS initiative is the development of a metadata profile for each ship providing SAMOS data. A draft SAMOS metadata standard has been developed and is being reviewed by members of the scientific and technical community. A related task includes the development of a SAMOS metadata database at the RVSMDC. The database is being designed and will provide community access to SAMOS metadata. The database will also play a key role in augmenting SAMOS data with important metadata. Additional databases will track the files from arrival to archival and will provide for data quality statistics.

Data quality and distribution:
The enhanced QA system was applied to historical data from the *Ronald Brown* (Jan. 2002 – May 2004, *Revelle* (May – Sept. 2003), *Melville* (May – July 2003), *Meteor* (June 2003 – May 2004), and *Polarstern* (May 2003 – June 2004)[Fig. 1]. Data for the *Ronald Brown* (the only NOAA vessel examined) covered portions of the Pacific and Atlantic oceans. The observations from the *Revelle*, *Melville*, *Meteor*, and *Polarstern* were collected and evaluated as part of our satellite validation efforts. Data from all the vessels are sampled at one-minute intervals and typically include the ship's position, speed, course, and heading along with standard meteorological parameters (e.g., ship- and earth-relative winds, air and sea temperature, atmospheric pressure, humidity, and shortwave and longwave radiation).

Data QA for the *Ronald Brown* continued to reveal significant problems with these data, primarily from the wind sensors (Fig. 2). For the period Jan 2002 – November 2003 an average of 5 - 10% of the wind observations were flagged as suspect. Other parameters tended to have fewer suspect values. Further analysis leads the RVSMDC to suspect that many of the flagged data result from distortion of the airflow over the vessel and inadequate sensor ventilation. Recently, the meteorological sensors have been moved from the old IMET mast on the bow to the bow jackstaff. Analysis of future data will reveal whether or not this move will improve data quality.

The RVSMDC continues to evaluate systematic errors in R/V meteorological data by creating innovative display tools to identify problems related to the direction of air-flow over the vessel. In 2004, the RVSMDC completed a detailed examination of the stack exhaust impact on temperature and moisture data collected on the *Meteor* (Rolph and Smith 2004a). Through this short report we identify ship-relative winds angles from which the stack exhaust will adversely impact the temperature and humidity data. The report goes on to make specific recommendations to resolve this problem. To date we are attempting to make appropriate contacts in Germany so that this report can be properly reviewed. The RVSMDC notes that problems of this nature are not unique to the *Meteor* and we anticipate making future recommendations for sensor relocations on other vessels.

Recently, we have had problems with the postal service delivering data disks sent from the *Ronald Brown*. These data are somehow being lost in route to COAPS. To alleviate this problem, I have requested that the technician on the *Ronald Brown* send his next shipment using certified or somehow tracked mail service. After 2001, we also lost our data connection to the *Ka'Imimoana*. Conversations with PMEL indicated that our data requests had been lost during a period of poor retention of technicians on the *Ka'Imimoana*. Some historical data from the *Ka'Imimoana* for 2002-2004 have been provided by PMEL and are now beginning QC. The problems with the current data delivery protocol (i.e., the technician burning data disks and mailing them to the RVSMDC) provide clear examples of the need for a reliable, fully automated transfer of the underway meteorological data from the vessel to the RVSMDC. Hopefully the new SAMOS data protocol will ensure reliable data delivery.

While tracking down the *Ka'Imimoana* observations it became evident that a need for standardization of data logging for COAPS and NODC exists. Currently the *Ronald Brown* and *Ka'Imimoana* record meteorological data for both COAPS and NODC; however, the parameters and sampling intervals differ. Since the RVSMDC plans to provide quality-processed data to NODC, the logical first step would be for both organizations to receive the same raw data from each vessel. A dialog between NODC and COAPS to coordinate the NOAA scientific computer system data logging is planned (S. Rutz, personal communication, 2004).

We anticipate receiving data from one or two VOS-IMET vessels by the end of 2004. In addition, we periodically receive data from CLIVAR sponsored hydrographic cruises (see http://www.coaps.fsu.edu/RVSMDC/CLIVAR/). Over the next year we will process U.S. CLIVAR data under the current RVSMDC funding; however, we are still seeking resources to process international CLIVAR data.

The value-added data and quality control reports (Rolph and Smith 2004b, c, d) are available from our center at http://www.coaps.fsu.edu/RVSMDC/. The report for the *Polarstern* (Rolph and Smith 2004e) has been provided to the Germans and we are awaiting their approval before distributing these data online. Shipboard data are also available via ftp://wocemet.fsu.edu/pub/woce/rv or pub/rvsmdc/rv and our DODS server (http://www.coaps.fsu.edu/RVSMDC/html/dods.shtml). We are committed to an open data sharing policy so data access is not restricted. Through supplemental funding through NOAA/ESDIM, a majority of the RVSMDC holdings are being subsampled for inclusion in the International Comprehensive Ocean Atmosphere Data Set (I-COADS). We have also opened communication with NODC to ensure the archival of post-WOCE quality-evaluated data.

Data applications:
Quality evaluation continues to show problems with the wind observations from the *Ronald Brown*. In late 2003, the *Ronald Brown* was operating in the Gulf of Mexico and this provided an opportunity to compare the SCS meteorological data from the *Ronald Brown* to observations from the National Data Buoy Center (NDBC) Gulf moorings. The *Ronald Brown* IMET data, with and without QC flags considered, were compared to NDBC Gulf of Mexico buoy data for the periods in which the vessel was within 75 km of any buoy. *Ronald Brown* IMET 1-minute shipboard data was averaged in the same manner as the NDBC buoy data. For example, the 12 UTC wind observation consists of 1142 - 1150 UTC data, vector averaged for the 'continuous winds' and were recorded in 10-minute intervals. The time stamp for the shipboard data averages were assigned the corresponding NDBC time stamp, converted to COAPS time. In addition to the winds, 10-min averages of atmospheric pressure, air temperature, sea temperature, and specific humidity were created; however these ship values were only matched to the nearest hourly NDBC observation (as only hourly NDBC data was available). When QC flags were considered, averages were required to have at least 6 of the 8 possible data values composing the 10-minute average to have 'good' flags otherwise the average was considered missing. Also, in the statistics, if the shipboard average was missing, the corresponding value for the buoy was changed to missing and not used. Atmospheric data were height adjusted to 10 m. The sea temperatures remain at different depths as is apparent in the statistical results. Plots were created for each buoy and variable as well as plots combining all of the ship and buoy data (e.g., Fig. 3). The data were also plotted according to the distance between the vessel and buoy.

When comparing the Ron Brown and buoy data without considering QC flags, the preliminary results demonstrate that, as a whole, the winds were less correlated than the variables of state. The wind speed correlation between the ship and buoys ranged from 17.5 - 74.8% for individual buoys with enough data to calculate a correlation and is 72.8% for all data. The direction data had correlations ranging from 48 - 86.7% per buoy and was 84.9% when all of the data was combined. The meteorological data was much better with pressure correlations ranging from 76.8 - 98.9% (99.1% cumulative) resulting in little uncertainty in the data. The air temperature data were also highly correlated with values from 88.6 - 92.8% (96.2% total). Again there was little variation in the air temperature data as described by RMS of only 0.737 ˚C for all of the data. The sea temperature data was also highly correlated (91.5%) and there were only small variations in the values, hence a small RMS (.677 ˚C). Given a small RMS and the high correlation, a large degree of confidence can be placed in the sea temperature data. The specific humidity data had a high correlation (94.9%), with low RMS and uncertainties in the means, again resulting in a large amount of confidence in the humidity data.

Differences in the statistics between the Ron Brown and NDBC buoys occurred when the comparison was limited to ‘good’ ship data (those with A, I, G, or Z flags). The correlation of the wind data, direction and speed, were typically greater when the quality control flags were not considered; however, the overall RMS for wind speed dropped from 2.0 to 1.7 ms^{-1} when only ‘good’ values were compared. The pressure correlation was higher or the same when the flags were taken into account. The air temperature correlation was the same or slightly lower, with a maximum difference of less than 1% between data sets. The sea temperature correlations are very similar between the two data sets. For specific humidity, the maximum correlation difference is 6.4% between the 'good' flagged data and all of the data for buoy 42040. When all of the data is combined (Fig. 3), the only variables to have less than a 90% correlation were the winds with the speed (72.8% and 61.7% respectively) for all of the data and the 'good' data and the direction having 84.9% and 74.8% respectively. Overall, the buoy comparisons suggest that applying QA to the Ronald Brown data can improve the usefulness of the observations; however, some fundamental changes in either instrument location or observing practices is needed to significantly improve the data quality.

R/V observations also have played a key role in estimating the natural variability of surface vector winds. Quantification of this natural variability was use to estimate the extent to which such variability contributes to uncertainty in satellite (scatterometer) observations of surface vector winds. These estimates were applied to current designs, and found to be consistent with error estimates that distinguished between observational errors and differences due to inexact spatial/temporal co-location (Bourassa et al. 2003). Furthermore, the same data were used to estimate the influence of natural variability on accuracy of scatterometers that are early in the planning stage. Considering these aspects prior to building the satellite represents a first for NASA. In simple terms, we are able to provide the NASA engineers with realistic estimates of small-scale variability in the variables that they are planning to measure. These R/V observations clearly demonstrated that problems quite reasonably feared by several members of the Science Working Group would not be serious for any of the designs being considered, for most conditions.

A similar approach is being used to estimate how much vector winds change (on a various spatial scales) in association with rain. Rain modifies the signal received by scatterometers in several ways (Weissman et al. 2002, 2003). Efforts are underway to remove rain-related errors from scatterometer winds. The results of this study will indicate how much wind speed change on the spatial scales that scatterometers used to retrieve vector winds. This information has become critical for determining what types of data can be used as a proxy for truth.

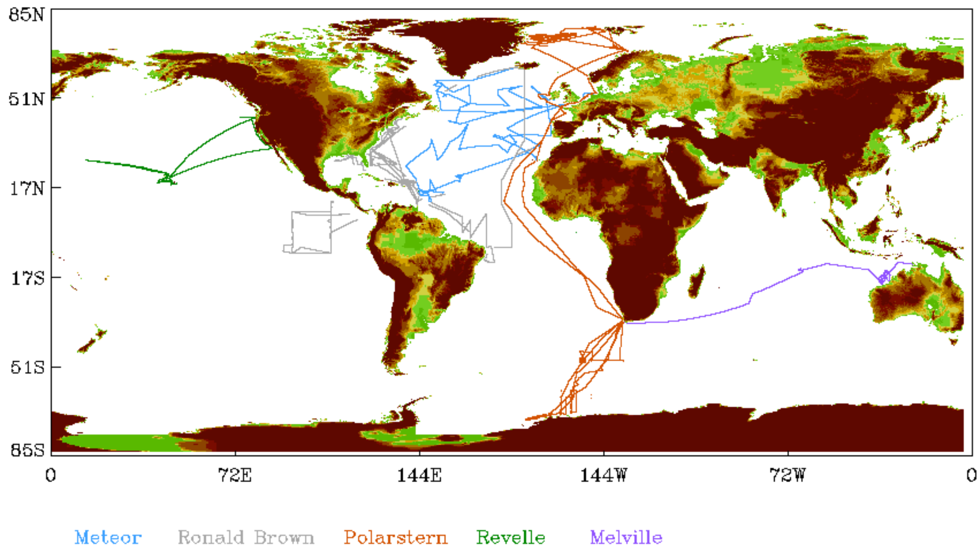


Fig. 1: Ship tracks for research vessel data passing quality evaluation at the RVSMDC between October 2003 and September 2004. Data dates are: *Ronald Brown* (Jan. 2002 – May 2004, *Revelle* (May – Sept. 2003), *Melville* (May – July 2003), *Meteor* (June 2003 – May 2004), and *Polarstern* (May 2003 – June 2004). All data were sampled at 1-minute intervals by automated instrument systems.

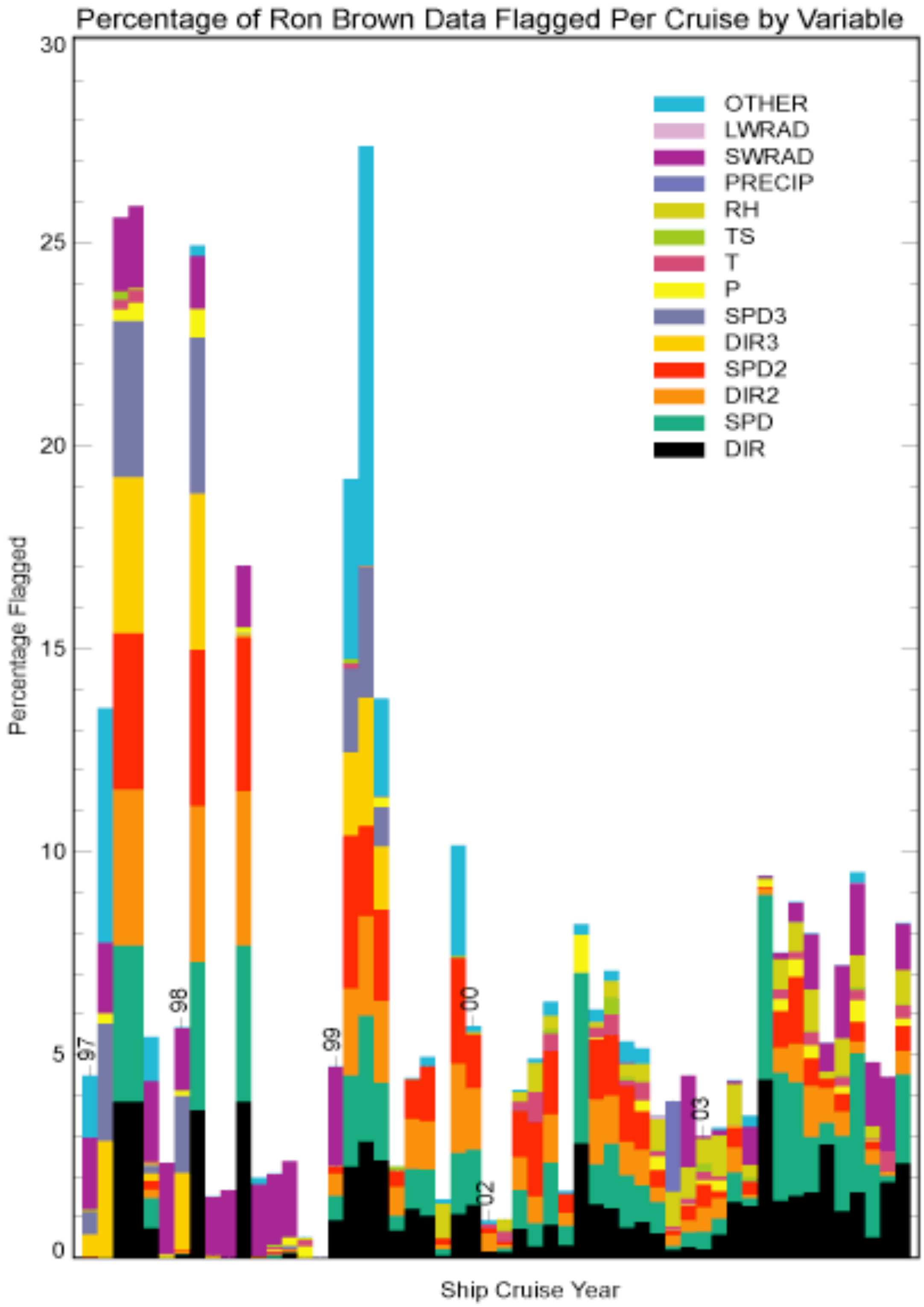


Fig. 2: The total percent of data flagged per cruise on the Ronald Brown. Bars are color coded by measured parameter according to the legend. The length of the color is proportional to the number of flags each of the variables contribute to the total amount of data flagged per cruise.

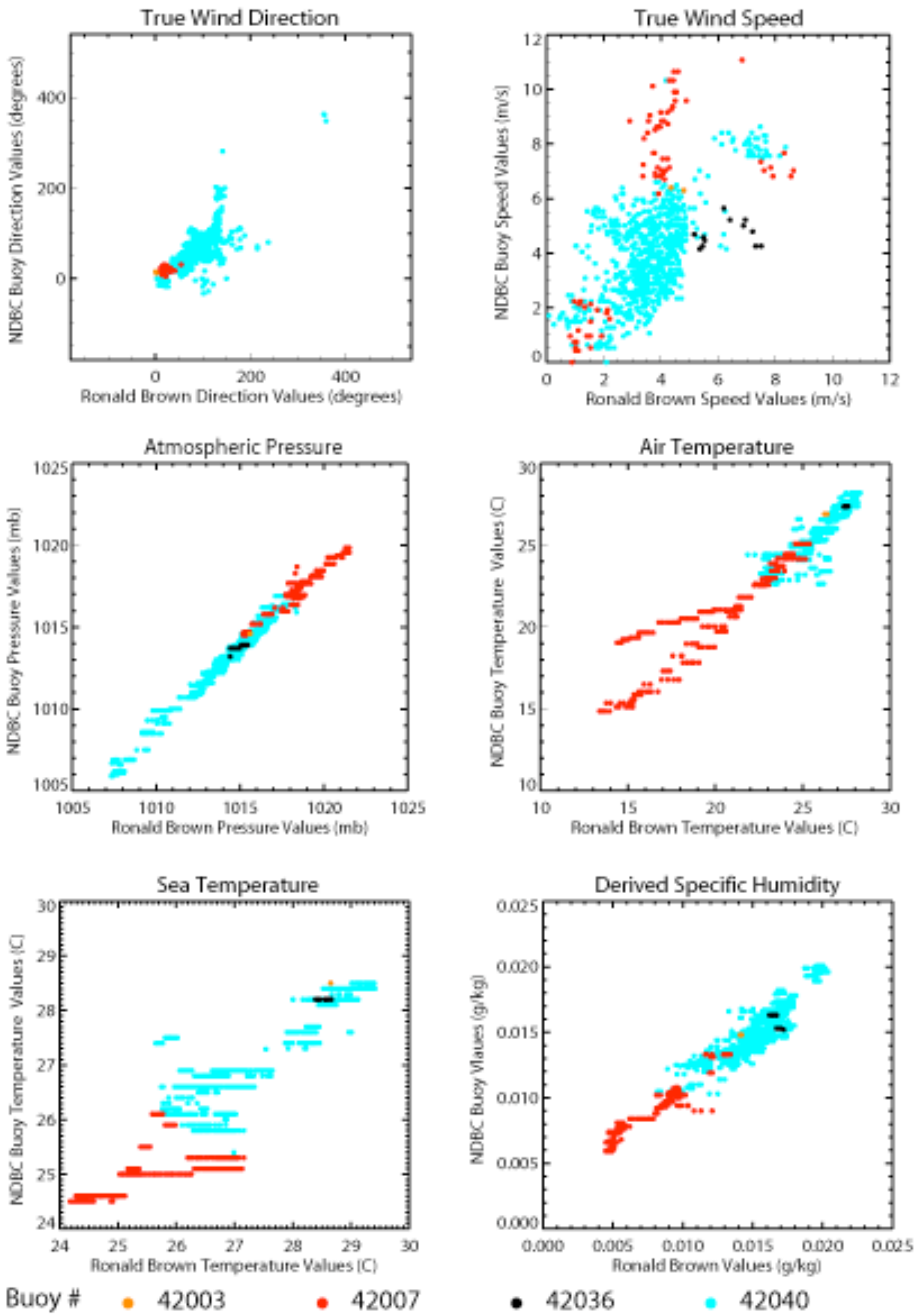


Fig. 3: Scatter plots of height adjusted meteorological data from the Ronald Brown versus four NDBC buoys. All values represent 10-minute averages (see text). The buoys are color coded according to the legend.

THE CENTER FOR OCEAN-ATMOSPHERIC PREDICTION STUDIES
THE FLORIDA STATE UNIVERSITY

Focusing on Improving Automated Meteorological Observations from Ships

The High-Resolution Marine Meteorology (HRMM) community is working to improve the quality of, and access to, surface marine meteorological and oceanographic data collected in situ by automated instrumentation on ships and moored platforms. The purpose of the Second High-Resolution Marine Meteorology Workshop, hosted by the National Oceanic and Atmospheric Administration (NOAA) Office of Climate Observation (OCO), last April, was to discuss implementation of the recommendations from the Workshop on High-Resolution Marine Meteorology held in Tallahassee, Florida on 3-5 March 2003 (for details, see http://www.coaps.fsu.edu/RVSMDC/marine_workshop/Workshop.html).

Shipboard automated meteorological and oceanographic systems (SAMOSs) are an essential component of a sustained ocean observing system. SAMOSs provide platform navigation, surface meteorology, and near-surface ocean data that are ideal benchmarks for new satellite sensors (e.g., WindSat, future National Polar-orbiting Operational Environmental Satellite System (NPOESS) sensors) and global ocean-atmosphere models. SAMOS sampling is adequate to provide accurate estimates of the variability on scales (from subdiurnal) needed for satellite calibration and validation. Sampling rates also are ideal for estimating turbulent air-sea heat, momentum, and moisture fluxes that are critical for climate research and can be used to help understand sources of bias and uncertainty in global model flux fields. SAMOS observations from oceanographic research vessels (R/Vs) are of particular importance since these vessels frequently operate in areas far outside the normal merchant shipping lanes.

The workshop panel recommended that the HRMM community focus first on improving access to SAMOS data collected by U.S. R/Vs and follow that with improving access to data from SAMOSs deployed on merchant ships and international R/Vs operating in the polar oceans. Close collaboration with established mooring programs is anticipated to improve SAMOS metadata, sensor calibration, and data accuracy. The panel identified a list of navigation, meteorology, and near surface ocean parameters required to meet the science objectives outlined at the first workshop. In addition, the panel outlined an effort to create a set of guidelines for metadata to be provided routinely to SAMOS operators.

The panel also intends to petition the University-National Oceanographic Laboratory System (UNOLS) council and other cooperating ship programs to agree to a new data policy whereby access to underway meteorology and thermosalinograph data would be free and open by default, and the data would be exempt from the current practice of a 2-year proprietary hold by chief scientists. A chief scientist would have to specifically request any hold on these data. Free and open access will allow SAMOS observations to become part of a sustained ocean observing system, making these data readily available for use by the climate research, modeling, and remote sensing communities.

The panel plans to seek international participation through the World Meteorological Organization (WMO) Volunteer Observing Ship Climate (VOSClim) program, World Climate Research Program (WCRP) working group on surface fluxes, the WCRP Climate Variability and Predictability (CLIVAR) hydrographic program, and the International Ocean Carbon Coordination Project (IOCCP). Finally, the panel agreed that periodic HRMM workshops provide an important forum for the exchange of ideas and methods. Future workshops will include additional input from data users and developers of new SAMOS technology.

The panel, chaired by Shawn R. Smith, included representatives from the scientific and operational marine observational communities. Participants represented six NOAA facilities (Environmental Technology Laboratory (ETL), Office of Oceanic and Atmospheric Research, National Climatic Data

Center, National Oceanographic Data Center, National Weather Service/National Centers for Environmental Prediction, and Pacific Marine Environmental Laboratory), the Brookhaven National Laboratory, and the U.S. Coast Guard (USCG). The university community was represented by the Woods Hole Oceanographic Institution (WHOI), the Scripps Institution of Oceanography (SIO), the University of Miami, Columbia University, and Florida State University. International representatives were present from the Commonwealth Scientific and Industrial Research Organization (CSIRO) (Australia), the Joint WMO-Intergovernmental Oceanographic Commission's Technical Commission for Oceanography and Marine Meteorology, WCRP, and the Global Ocean Observing System (GOOS). Program managers from NOAA OCO and the National Science Foundation were also present.

Progress and New Initiatives:
The HRMM community is focusing on improving access to quality-controlled SAMOS data for scientific and operational users, improving the accuracy of SAMOS measurements, and providing training for data collectors and improved metadata to users. The HRMM community has (1) established a data assembly center (DAC) for SAMOS observations from U.S.-sponsored R/Vs and VOS, (2) begun developing a roving surface flux standard instrument suite for onboard instrument comparison, (3) outlined a "Handbook on Meteorological Measurements at Sea." (4) initiated communication with vessel operators (e.g., NOAA, UNOLS, USCG), and (5) solicited support and input from the U.S. and international marine and climate science communities. Several pilot projects were outlined by the second HRMM panel that will be initiated in 2004-2005.

The DAC was established specifically to coordinate the collection, quality control, distribution, and future archival of SAMOS data. The DAC, funded at the Florida State University (FSU) in 2004, will collaborate with WHOI and SIO to design a ship-to-shore-to-user data pathway for U.S. research vessel SAMOS data. In the past, the data flowed from ship to shore only in a delayed mode with a 3-month to 2-year lag between collection and availability to the user community. The new vision will support data transmission from each ship to the DAC on a daily basis. A "quick-look" version of the SAMOS data will be available within a few days of receipt at the DAC. The quick-look data will have undergone common formatting and automated quality control. Visual inspection and further scientific quality control will result in a "research"-quality SAMOS product. The DAC will provide distribution services for the quality-controlled data in formats that meet user needs and will ensure that the original and quality-controlled data are submitted to several national data archives.

Several improvements to the accuracy of SAMOS data are being investigated. Instrumentation developers at NOAA ETL and WHOI are designing a two-part roving standard instrument suite that will be used for onboard validation and comparison with a research vessel's permanent SAMOS. The first component of the roving standard will be a state-of-the-art turbulent flux instrument suite that will be installed to provide the best possible measure of air-sea fluxes and surface meteorology. A second set of traditional marine weather instruments will be located near the R/V's SAMOS instruments to provide side-by-side comparison with the permanent shipboard sensors. A trained technician will travel with the roving standard and work with the R/V's technician (over the course of several weeks at sea) to identify discrepancies between the roving and standard and the R/V SAMOS measurements. A pilot project to compare the state-of-the-art flux sensors and an R/V SAMOS is planned for 2005.

Another initiative to improve data accuracy will provide for computational fluid dynamics (CFD) modeling of the airflow around vessels. Research at the Southampton Oceanography Centre, WHOI, and other institutions revealed that modeled airflow can be used to determine optimal sensor locations. CFD results also can be used to adjust meteorological measurements to remove biases caused by the airflow around various ship structures. Discussions are under way to complete CFD modeling on new R/Vs during their design phase.

The focus of the training activities lies in the production of a handbook or guide to best procedures and practices for meteorological measurements at sea. This was first proposed by the WCRP/Scientific Committee on Oceanic Research Working Group on Air-Sea Fluxes and adopted at the first HRMM Workshop at FSU in 2003. The handbook is aimed at the seagoing research community and ships' technical staff. Topics will include information on preferred sensor location, calibration, in situ comparisons, documentation, metadata, bulk flux methodology, and measurement error. Plans are for a dynamic handbook that will be available online. Users will be able to download relevant computer code, specifications, and technical information whether on land or at sea.

Future Activities:
At the second HRMM workshop, the panel decided to focus initially on U.S. research vessel SAMOS data. Clearly there is an opportunity to expand this initiative to the international marine community. The panel specifically noted the importance of vessels operating in the polar oceans and identified polar R/Vs as the first international vessels to integrate into the network of routine SAMOS measurements. The polar oceans play a key role in global ocean-atmosphere circulations, and R/Vs provide platforms of opportunity to observe these regions. The panel discussed participation in the upcoming International Polar Year as a possible way to initiate inclusion of polar SAMOS observations into the network.

International collaboration is expected to continue and be expanded in the future. The goal of establishing a sustained global ocean observing system will involve contributions from many nations. The international fleet of R/Vs and SAMOS-equipped VOS will be a key component of that observing system, providing data for air-sea flux estimates and benchmark observations for global data assimilations and new satellite sensors. The HRMM community intends to expand its collaboration with ongoing international climate programs (e.g., CLIVAR, GOOS).

Improving the availability, accuracy, and quality of SAMOS measurements will require a wide range of technical and scientific expertise. For example, there is a need to develop more robust sensors for severe ocean environments, to expand broadband communication between ships and shore, and to provide education on best practices for SAMOS. User input also is critical to ensure that the HRMM community provides products that are useful to modelers, oceanographers, and meteorologists. User input has already resulted in improved data quality, and the panel expects this process will continue. The HRMM community encourages members of the AGU to provide input toward the development of a sustained network of SAMOSs on research vessels and VOS.

The Second High-Resolution Marine Meteorology Workshop was held at NOAA’s Office of Climate Observation on 15-16 April 2004, in Silver Spring, Maryland.

3.29a. *In Situ* and Satellite Sea Surface Temperature (SST) Analyses

by Richard W. Reynolds

PROJECT SUMMARY

The purpose of this project is to focus on improvements to the climate-scale SST analyses produced at NOAA as described by Reynolds and Smith (1994) and Reynolds et al. (2002). This effort is designed to support the development of an ocean climate observing system. The analysis is done by optimum interpolation (OI) with a separate step to correct any large-scale satellite biases relative to the in situ data. The analysis uses infrared (IR) satellite data from the Advanced Very High Resolution Radiometer (AVHRR) and in situ data from ships and buoys. In this proposal we discuss our progress and our plans to improve these analyses. The improvements include the development of better bias corrections, the use of new SST data sets and the development of better error statistics. We also present a discussion of an objective method to determine where addition buoy data are needed for improved climate SST.

One of the important goals of the Sustained Ocean Observing System for Climate is to improve the SST accuracy over the global ocean. For this purpose we evaluated the adequacy of the recent in situ network. Because of the high coverage of satellite data, in situ data used in the analysis tends to be overwhelmed by satellite data. Thus, the most important role of the in situ data in the analysis is to correct large-scale satellite biases. Simulations with different buoy densities showed the need for at least two buoys on a 10^o spatial grid. Using this criterion, regions were identified where additional buoys are needed, and a metric was designed to measure the adequacy of the present observing system.

The present version of the OI uses infrared (IR) satellite data from the Advanced Very High Resolution Radiometer (AVHRR) instrument. A study was completed which showed a clear advantage if satellite SST retrievals from Tropical Rainfall Measuring Mission (TRMM) Microwave Imager (TMI) were used in the OI analysis. We are presently involved in modifying the code to do this and to reevaluate the OI error statistics.

Richard W. Reynolds is the chair of the SST and sea ice working group which is shared by two GCOS panels: the Ocean Observation Panel of Climate and the Atmosphere Observation Panel of Climate. This proposed work is part of the work of the working group. The working group membership is a broad group of interested national and international scientists. All work presented here follows the Ten Climate Monitoring Principles.

The funds requested for this proposal support work at NCDC. However additional funds at the International Research Institute (IRI) are requested in the added tasks section to support an evaluation of SST analyses using atmospheric models. In addition, the National Center for Environmental Prediction (NCEP) runs the OI analysis operationally at no cost to this project. Information on the analyses and the analyzed fields themselves can be found at: http://www.emc.ncep.noaa.gov/research/cmb/sst_analysis/.

FY 2004 PROGRESS

During FY2004, we have made significant progress in two main areas.

1. Design of an in situ SST network to improve the SST analysis

To design an effective and efficient in situ network, we first determined a maximum acceptable error. Following Needler et al. (1999) we specify that the monthly SST error must be less than or equal to 0.5^oC on a 5^o spatial grid. This error must include random, sampling and bias errors. The random and sampling error can be determined directly from the OI or from an optimum average (OA) procedure. We found that the sampling and random errors using in situ and AVHRR data were always less than 0.3^oC on a monthly 5^o grid. These errors were low because of the high density and full coverage of satellite data. The regions with the largest errors were cloud-covered regions where IR data are limited. The use of global microwave satellite data, which can retrieve SSTs in cloud-covered regions, would further reduce the errors.

Biases occur with all satellite data due to instrument and algorithm problems. For AVHRR typical biases are 0.2 to 0.5ºC. However, AVHRR biases have reached between 2 to 3ºC over the tropical oceans following the 1982 volcanic eruptions of El Chichón and the 1991 eruptions of Mt. Pinatubo. Unfortunately, it is not possible to predict when biases of this size will occur. Thus, it is necessary to have an in situ network that will ensure a final product with acceptable bias errors.

To examine the impact of in situ data on satellite bias correction, the OI was computed with simulated biased satellite data and simulated unbiased buoy data. The maximum satellite bias error was selected to be 2ºC as a worse case. This will be defined as the "potential satellite bias error." Thus, the potential satellite bias error would be 2ºC if there were no in situ data to correct the bias.

The data density of the present in situ network was evaluated to determine where more buoys are needed. These buoys could be either moored or drifting. However, because of the high cost of moored buoys they will be assumed to be drifters. To evaluate this requirement using actual observations, it is necessary to determine how to combine ship and buoy data in the results. Because ship observations are noisier (random error of 1.3°C, Reynolds and Smith 1994) than buoy observations (random error of 0.5°C), roughly 7 ship observations are required to have the same accuracy of one buoy observation. Therefore, an equivalent buoy density is defined as: $n_b + n_s/7$, where n_b and n_s are the number of buoys and number of ships in a 10º box, respectively.

The equivalent buoy density was defined for each month, and then averaged seasonally to indicate where additional buoys need to be deployed. An example is shown in Figure 1 for July - September 2004. Boxes poleward of 60°N and 60ºS were not shown along with boxes with less than 50% ocean by area, as well as boxes in Hudson Bay and the Mediterranean Sea. The figure shows a clear need for additional buoys in the middle latitude Southern Hemisphere oceans. Please note that this figure is completely defined by the in situ data distribution of ships and buoy.

A measure of the performance of the in situ observational system for SST can be calculated from these results. This is done using the potential satellite bias error as a function of equivalent buoy density. The individual potential satellite bias error values can then be averaged spatially. This is described in detail in Zhang et al. (2004) which accompanies this report. The results of this study have already had an influence on future buoy deployments. The NOAA Atlantic Oceanographic and Meteorological Laboratory (AOML) is using figures like Figure 1 to guide surface drifting buoy deployments.

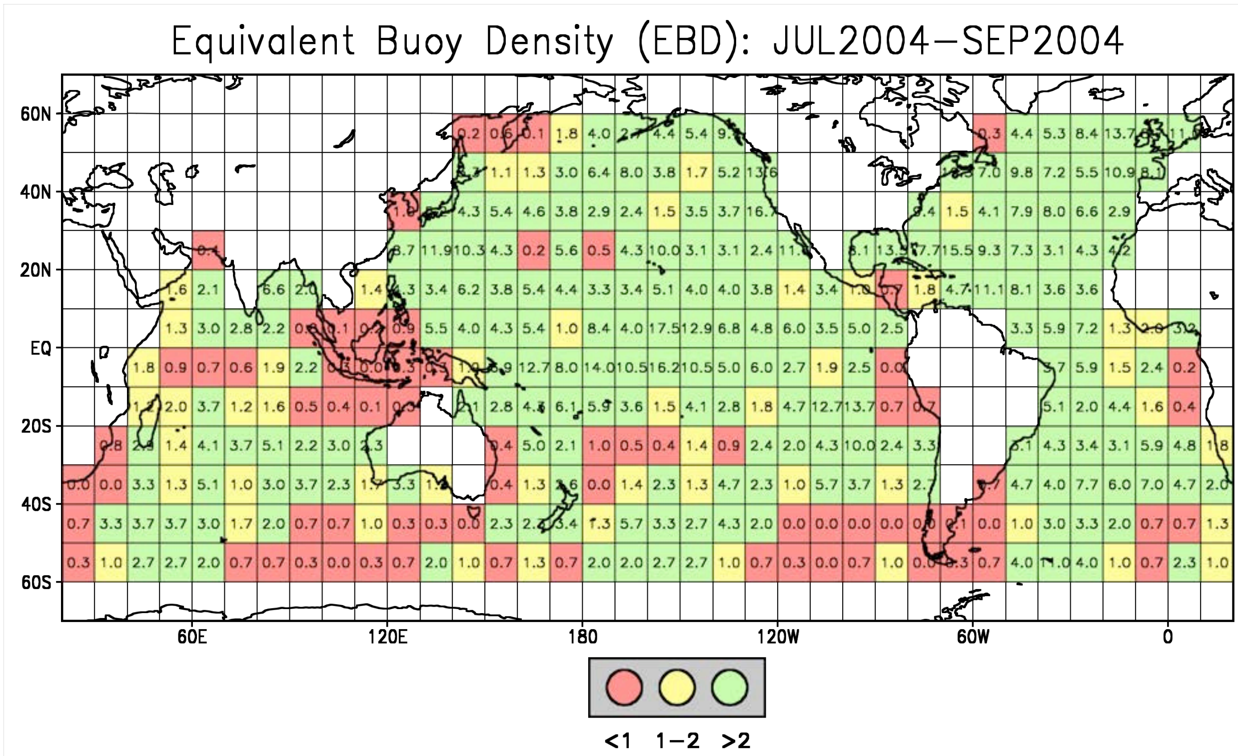


Figure 1. Seasonally (July – September 2004) averaged monthly equivalent buoy density (EBD) on a 10° grid. EBD includes contributions from both buoys and ships, accounting for their typical random errors. Green shading indicates where *EBD*≥2 and no more buoys are needed. Red shading indicates critical regions where *EBD*<1 and two more buoys are needed. Yellow shading indicates 1≤*EBD*<2 and one more buoys is needed.

2. Improve the SST analysis by improving the analysis method and the use of additional data

The present version of the OI uses infrared (IR) satellite data from the Advanced Very High Resolution Radiometer (AVHRR) instrument. A study was completed and is now published (Reynolds et al. 2004) to evaluate the impact of satellite SST retrievals from Tropical Rainfall Measuring Mission (TRMM) Microwave Imager (TMI) on the OI analysis. The results of the intercomparisons showed that both AVHRR and TMI data have biases that must be corrected for climate studies. The addition of TMI data clearly improved the OI analysis accuracy without bias correction, but was less significant when bias correction was used. However, there are areas of the ocean with limited in situ data and restricted AVHRR coverage due to cloud cover, and the use of both TMI and AVHRR should improve the accuracy of the analysis in those areas. It is planned to recompute the OI analysis for the entire time period using additional satellite data.

The OI code has been modified to use multiple satellite products. In addition, the spatial error covariances have been recomputed. We did the correlation scales by fitting a Gaussian function to satellite data as we did in Reynolds and Smith (1994). However, there were two important differences. The first was to determine the scales using periods without large satellite biases. The second was to reduce the weights at points far from the data point of interest. Both methods will significantly reduce the spatial scales which will increase the spatial detail.

NCEP presently runs the operational version, which has not been changed since 2002. To make these changes operational it will be necessary to get the entire OI analysis procedure operational at NCDC. A programmer (Chunying Liu) has been hired to get the OI code running at NCDC so that this can be done. At this time we are getting the codes to run with operational data available at NCDC.

3.30a. Monitoring Ice Thickness in the Western Arctic Ocean

by Jackie Richter-Menge, and co-investigators/collaborators
H. Melling, J. Overland, R. Lindsay, J. Zhang, and D. Perovich

PROJECT SUMMARY

Rationale:

Recent studies indicate that the sea ice cover is undergoing significant climate-induced changes, affecting both its extent and thickness. For instance, satellite-derived estimates of maximum ice extent suggest a net reduction between 1978 and 1996, at an average rate of –3% per decade (Parkinson et al. 1999). A recent report by Comiso (2002) indicates an even more rapid reduction in the perennial sea ice cover, of –9% per decade. Data on the ice thickness, derived from submarine-based upward looking sonar, also suggest a net thinning of the sea ice cover since 1958 (Rothrock et al. 1999; Wadhams and Davis 2000; Tucker et al. 2001). It is important that we continue and expand efforts to monitor these changes to (a) improve the fundamental understanding of the role of the sea ice cover in the global climate system and its influence on the Arctic ecosystem and (b) take advantage of the sensitivity of the sea ice cover as an early indicator of the magnitude and impact of climate change.

The extent of the sea ice cover is effectively monitored from satellite platforms using passive microwave imagery. Monitoring changes in the ice thickness is more problematic. As with ice extent, the ideal platform for monitoring ice thickness is a satellite because it provides a full-basin perspective. Until recently, no technique had been adequately developed to obtain reliable satellite-based measurements of ice thickness. Exciting new results, reported by Laxon et al. (2003), suggest a possible breakthrough in the use of satellite altimeter measurements of ice freeboard to determine the mean ice thickness field and it variability. As this and other satellite-based technologies develop, we must also find ways to make more effective use of ice thickness measurements collected from other platforms, including submarines, aircraft, seafloor moorings, and drifting buoys. While these measurement platforms have spatial limitations, they can play a central role in the validation and calibration of satellite-based instruments. Further, their capacity to collect data at higher temporal resolutions can provide information necessary to understand and attribute observed changes in the ice thickness.

Brief statement of objectives:

The primary objective of this proposal and the related proposal “Monitoring the Eurasian Basin of the Arctic Ocean” is to establish and maintain a large-scale sea ice thickness observing system. The establishment of two distinct elements recognizes the different logistical challenges in the western and eastern sectors of the Arctic region. This work focuses specifically on measurements within the western sector of the Arctic. This sector of the Arctic is currently more accessible and, therefore, makes it feasible to conduct a program involving instrumentation that must be maintained after deployment. Within the western sector of the Arctic, we propose to initiate an array of moored ice profiling sonar (IPS) (Melling and Riedel 1996) and drifting ice mass balance buoys (IMB) (Perovich and Elder 2001).

The IMB buoys are equipped with thermistor strings, which extend through the thickness of the ice cover, and acoustic sensors monitoring the position of the top and bottom surfaces of the ice. These instruments provide a time series of snow accumulation and ablation, ice mass balance, internal ice temperature fields, and temporally-averaged estimates of ocean heat flux. Together, these data not only provide a record of changes in the ice thickness, but equally important they provide the information necessary to understand the source of these changes. This is critical to extending the result from these individual sites to other regions of the Arctic. The IMB buoys are also equipped to measure position, sea level pressure (SLP), and surface air temperature (SAT). The drift pattern of the buoys provides information on the circulation pattern of the sea ice cover. Data on SLP and SAT are designed to be compatible with similar data collected from the more basic drifting buoys deployed under the International Arctic Buoy Program (IABP, http://iabp.apl.washington.edu/). The moored upward looking sonar measure ice draft and velocity as the ice drifts overhead, providing a measure of the ice thickness distribution at a specific location within the Arctic Basin.

Instrumentation within the large-scale observing network will be located to complement existing measurement sites and activities and to take advantage of historical data records. Specifically, we look to augment the data currently being collected at the North Pole Environmental Observatory (NPEO, http://psc.apl.washington.edu/northpole/), by the IABP, and from SCICEX cruises. Specific site locations will be determined using models of ice motion, which incorporate recorded observations. Data from the observation sites will be combined with data from other sources to produce annual reports on the state of the sea ice cover, including both its extent and thickness. A contextual setting for current data will be established by summarizing earlier observations in the Western Arctic of sea ice mass balance over an annual cycle, which begins in 1957. We will also investigate the availability of data in the Russian literature, which is likely to cover the Eastern Arctic.

This ice thickness observing network is a component of NOAA's Arctic Climate Observing System (ACOS), which is a contribution to the NOAA Climate Observations and Analysis Program. The ACOS is coordinated out of NOAA's Arctic Research Office.

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Modeling. A sea ice dynamics model (Zhang et al. 2003) was used to help determine the best location for establishing the mooring site CH01 (see item 3 below). The model is designed to assimilate ice velocity and ice extent data and was used to generate simulations of ice thickness distributions that cover the period from 1948 to 2002. With regard to the site CH01, the model was applied with the objective of optimizing the location of instrumentation to monitor changes in the mean annual thickness of the sea ice cover in the basin. During 2004, we used this same model to investigate how to best monitor temporal changes in the spatial patterns of the ice thickness. This was done using a linear regression analysis to determine the points that maximize the explained variance for the most important principle components (PC), generated from an empirical orthogonal function (EOF) analysis. Preliminary results are presented in Figure 1. Figure 1a shows the spatial pattern of total variance explained by a single point, which produces a maximum of 37% in the Eastern Siberian Sea. Figure 1b shows the spatial pattern of the additional variance explained by a second point, assuming that ice thickness measurements continue to be made at the North Pole Environmental Observatory (NPEO). In this case, the maximum additional explained variance is 19% in the northeastern portion of the Beaufort Sea; however it is apparent that many locations in the Beaufort and Chukchi Seas do nearly as well. Figure 1c shows the spatial pattern of the additional variance explained by a third point, assuming the continued measurement of ice thickness at the NPEO and CH01. The maximum point is in the East Siberian Sea, adding 15% to the explained variance. This analysis suggests that, collectively, data from these three sites produce results that explain 66% of the total variance in temporal changes in the spatial patterns of ice thickness. A paper on these results in near completion, and will be submitted to Journal of Physical Oceanography for peer review in 2005.

1. *Equipment Fabrication*: Completed the fabrication of second mooring, equipped with an ice profiling sonar (IPS), acoustic Doppler current profiler and release system. Fabricated 6 ice mass balance (IMB) buoys. One of the IBM was fabricated for deployment in support of this specific project. The other 5 were fabricated for deployment in support of the companion project, "Monitoring the Eurasian Basin of the Arctic Ocean".
2. *Maintenance of Ice Profiling Sonar Site CH01, on the Chukchi Plateau.* The mooring site, deployed on 19 August 2003 and designated site CH01, was successfully recovered on 19 September 2004. The site was re-established on the same day with the successful deployment of a second mooring, also

equipped with an IPS. The CH01 site is located on the Chukchi Plateau at 75°06.0' N, 168° 00.0' W (Figure 2). Site maintenance in 2004 was conducted by the *USCG Healy*.

3. *Ice Mass Balance Buoy Deployment*. A drifting buoy, equipped to measure and attribute changes in the thickness of the ice cover, was deployed from the *CCGS Louis St. Laurent* 19 August 2004. The buoy was installed at 76°10.02' N, 141°10.32' W. In collaboration with the Arctic Group at the Woods Hole Oceanographic Institute, this IMB was collocated with a newly developed ice-tethered profiler (ITP). The ITP, developed with funding from the National Science Foundation, is designed to measure ocean temperature and salinity (http://www.whoi.edu/itp/). Combined, the IMB and ITP provide a more comprehensive data set on the evolving characteristics of the ice-ocean environment. The deployment location of this buoy (IMB 7413) and the IMBs launched as part of the companion project "Monitoring the Eurasian Basin of the Arctic Ocean", is shown in Figure 2.

4. *Ice Mass Balance Buoy Recovery*. A drifting IMB deployed in August 2003 in the Beaufort Sea as part of this program, was recovered on 24 August 2004. The recovery took place during the same cruise described in item 4 above. The recovered buoy was operational from 31 August 2003 until 28 July 2004. The drift track of this buoy is shown in Figure 3. Recovery of the buoy revealed that the buoy had stopped operating because it tipped over in a melt pond, causing the satellite transmission antenna to be under water. This buoy will be returned to CRREL and prepared for redeployment.

5. *Data Collection and Analysis*. The processing and quality control of the data collected from the drifting buoys is being done in coordination with the companion NOAA/SEARCH project "Monitoring the Eurasian Basin of the Arctic Ocean". These data are being archived at the World Data Center for Glaciology.

   We have completed the analysis of the data from the IMB buoy deployed in the Beaufort Sea in August 2003 and recovered this fall (see item 5) over its period of operation (Fig. 4). The data from this buoy serve to illustrate the advantages of the buoy design which permit us to monitor and attribute changes in the thickness of the ice cover. Specifically, we can observe whether the change in the thickness of the ice cover was the result of atmospheric or oceanic forcing. In this case, the data show the offset in surface and bottom melting that is typically observed. When the buoy was installed, surface melting was at its peak for the season and, in fact, snow had begun to accumulate. While surface melting had ended, bottom melting was still under way. When bottom melting came to an end, in mid-October, the ice thickness had been reduced by another 25 cm. By the beginning of November, almost 25 cm of snow had accumulated on the top of the ice and the ice had cooled enough to begin bottom growth. Bottom growth continued until mid-may, increasing the ice thickness by 135 cm, from 60 cm to 200 cm. In early June, both the snow cover and bottom surface of the ice cover began to melt. Rapid melting of the snow and ice surface occurred in mid-June. A notable increase in the rate of melting at the bottom surface began in early July. When the IMB buoy stopped operating on 28 July, 25 cm of ice had been lost on the top surface of the ice and 50 cm was lost at the bottom surface. At this point in time, the ice had experienced a net gain of approximately 60 cm in thickness.

   With the successful recovers of data from the instruments at the mooring site CH01, we will analyze and document the annual cycle of ice thickness at this location during fiscal year 2005.

6. *Webpage Development*. We have begun the construction of a webpage, designed to present the data in near real time, http://www.crrel.usace.army.mil/sid/IMB/. The webpage has links to related products, including IABP (http://iabp.apl.washington.edu/) and Arctic Theme page (http://www.arctic.noaa.gov/). The webpage also includes general background information, serving as a tool for educational outreach.

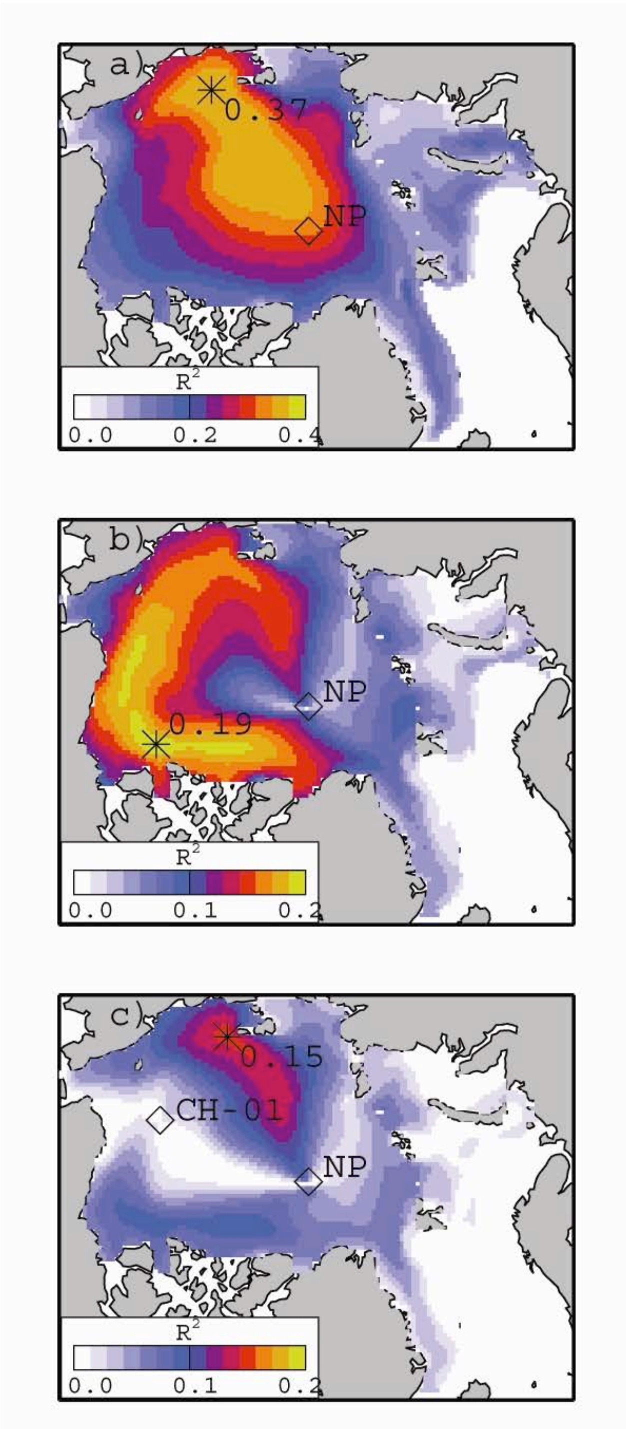

Figure 1. Preliminary results indicating the optimum location of instrumentation to monitor temporal variability in the mean ice thickness of the Arctic sea ice cover; (a) assumes a single instrumentation location, (b) assumes 2 locations, one being the existing NPOE and (c) assumes 3 locations, one being the NPOE and the other being the existing CH01 mooring site. These results are produced by applying linear regression analysis to sea ice dynamics model simulations of the ice thickness distribution.

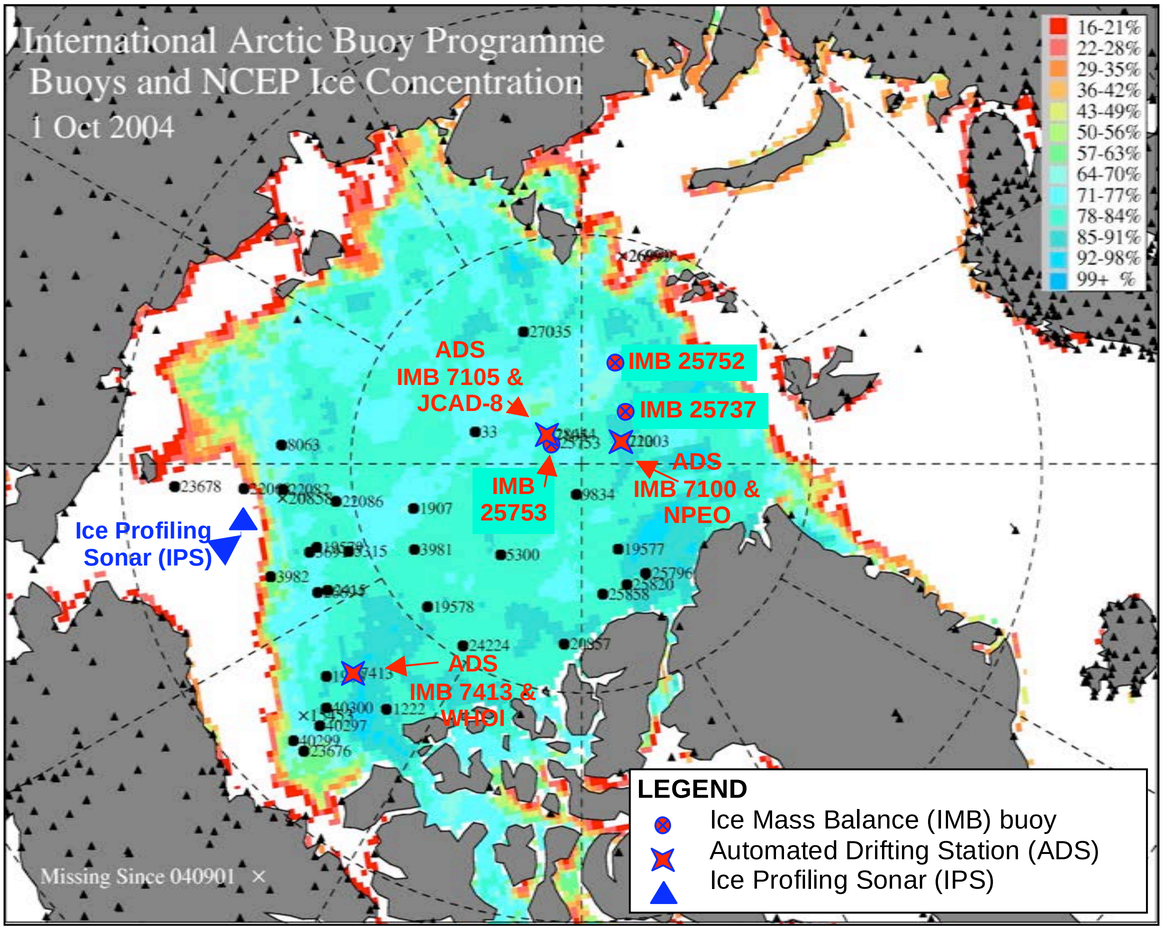

Figure 2. Current locations of Ice Mass Balance (IMB) buoys. The locations of "solo" IMB buoys are marked by red dots, while IMB buoys deployed in Automated Drifting Station (ADS) are marked by red stars. The positions of other IABP buoys (black dots) and the Ice Profiling Sonar (IPS, blue triangle) are also shown. The sea ice concentration data were obtained from the National Center for Environmental Prediction.

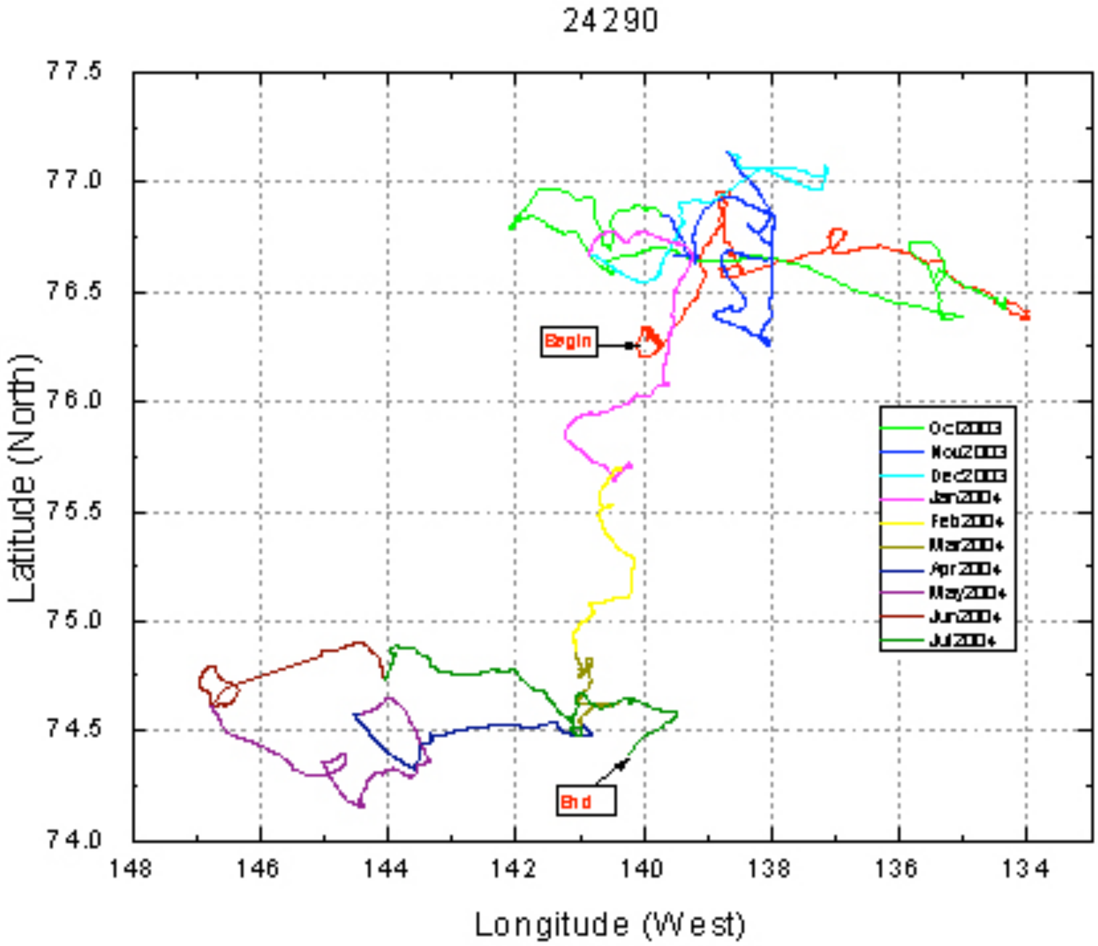

Figure 3. Drift track of IMB 24290, deployed 31 August 2003 in the Beaufort Sea. This IMB was operational until 28 July 2004 and was recovered on 24 August 2004.

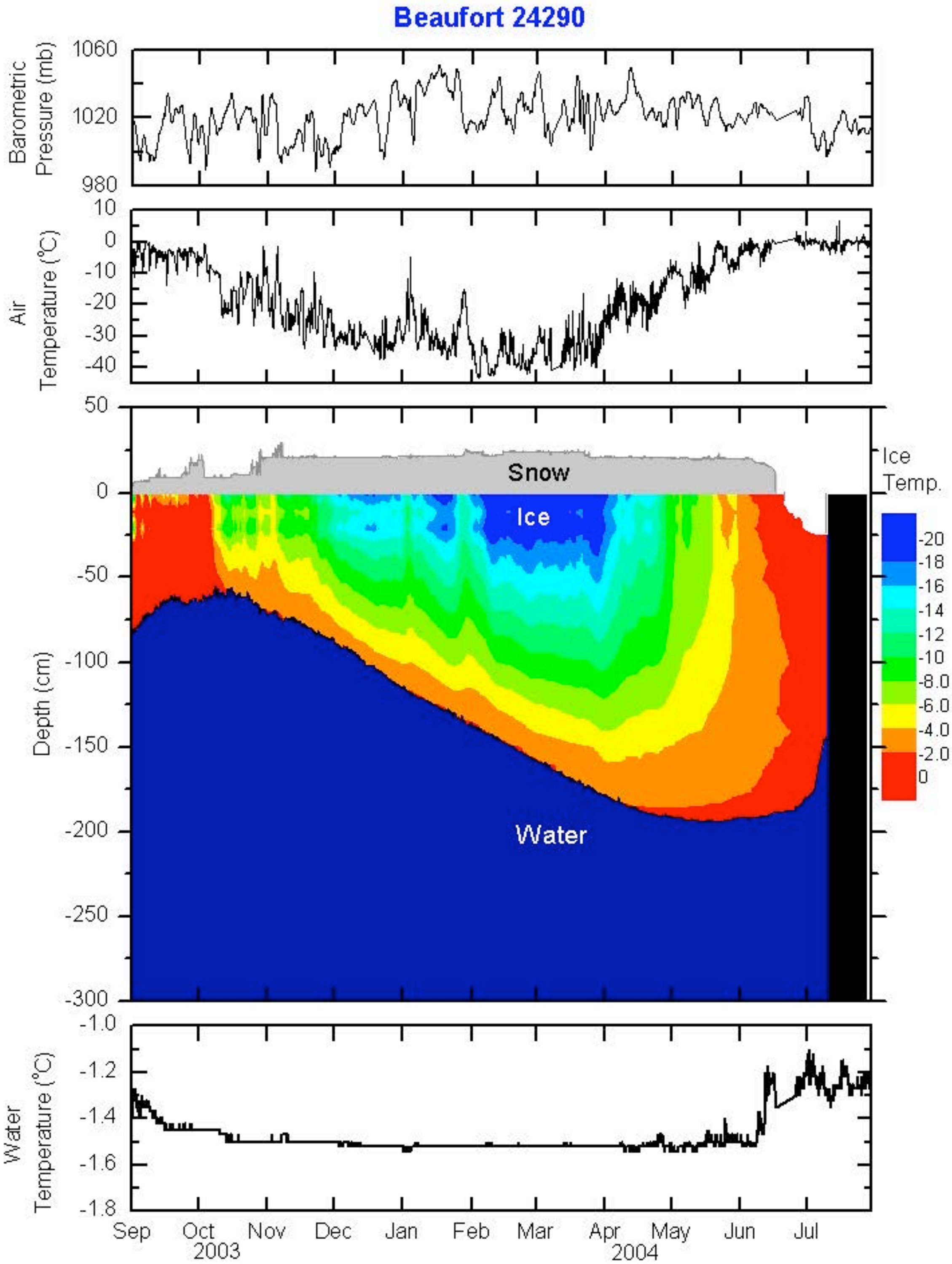

Figure 4. Data collected from IMB 24290, deployed in the Beaufort Sea and operational from 31 August 2003 to 28 July 2004.

3.31a. Monitoring Eurasian Basin of the Arctic Ocean

by Ignatius G. Rigor

PROJECT SUMMARY

Co-Investigators and Collaborators: Andy Heiberg, University of Washington; Magda Hanna, National Ice Center (NIC); Igor Dmitrenko, International Arctic Research Center (IARC); Takashi Kikuchi, Japan Agency for Marine-Earth Science and Technology (JAMSTEC); Igor Polyakov, IARC; and Sergey Priamikov, Arctic and Arctic Research Institute (AARI), St. Petersburg, Russia, and other Participants of the International Arctic Buoy Programme (IABP, http://iabp.apl.washington.edu/). This project is coordinated with the NOAA/SEARCH project Monitoring Ice Mass Balance in the Western Arctic Ocean, managed by J. A. Richter-Menge at the Cold Regions Research and Engineering Laboratory.

Rationale:

Dramatic changes in Arctic climate have been noted during the past two decades. Observations from the International Arctic Buoy Programme (IABP) have played a significant role in the detection of this change. For example, using IABP data, Walsh et al. (1996) showed that sea level pressure (SLP) has decreased; Rigor et al. (2000) showed that surface air temperature (SAT) has increased; and in concert, the circulation of sea ice and the ocean have changed so as to flow less clockwise (Steele and Boyd 1998; Kwok 2000; and Rigor et al. 2002). In addition to studies of Arctic climate and climate change, observations from the IABP are also used to validate satellites, for forcing, validation and assimilation into numerical climate models, and for forecasting weather and ice conditions.

Monitoring the Eurasian Basin is important since this is the center of many of the changes in Arctic climate. For example, the decrease in SLP noted by Walsh et al. (1996), the warming in SAT noted by Rigor et al. (2000), and the thinning of Arctic sea ice noted by Rothrock et al. (1999) are most significant in this area. One could ask, did the increase in SAT act to thin sea ice, or did the thinner sea ice allow more heat to flow from the ocean to warm the atmosphere? It has been hypothesized that the dynamic thinning of sea ice driven by the changes in atmospheric circulation causes the increasing trends in SAT (e.g., Rigor et al. 2002).

Brief Statement Of Objective:

We propose to deploy enhanced buoys in the Eurasian Basin of the Arctic Ocean (Fig. 1), which will monitor the mass balance of sea ice to verify this hypothesis, and complement the observations collected by the IABP. Establishing a record of climate-induced changes in the thickness of the sea ice cover is essential to understanding the role of the sea ice cover in the global climate system and to the application of the sea ice cover as an early indicator of global climate change. As explained in the recent report on the Study of Environmental Arctic Change (SEARCH) Workshop on Large-Scale Atmosphere/Cryosphere Observations (Overland et al. 2002), buoys within the IABP network can play an important role in monitoring changes in ice mass balance by enhancing their measurement system.

The observational array of the IABP is maintained by the 20 Institutions from 10 different countries (http://iabp.apl.washington.edu/Participants.htm), supports the World Climate Research Programme (WCRP), the World Meteorological Organization (WMO) World Weather Watch (WWW) Programme. The IABP is an Action Group of the Joint WMO-IOC Technical Commission for Oceanography and Marine Meteorology (JCOMM).

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1. Ice Mass Balance Buoy Deployments (Fig. 2)
    1.1. Oden Deployment – September 2004

Collaborated with the Swedish Meteorological and Hydrological Institute (SMHI) to deploy 1 Ice Mass Balance buoy (Buoy # 25753) during their Arctic Coring Expedition.

1.2. North Pole Environmental Observatory (NPEO, http://psc.apl.washington.edu/northpole/) Deploymenbts – April 2004

Collaborated with the PSC North Pole Environmental Observatory (NPEO) project to deploy 4 Ice Mass Balance buoys (Buoy #s: 7100, 7105, 25752, and 25753). Two of these buoys were deployed in Automated Drifting Stations (ADS) collocated with an ocean buoy from JAMSTEC (Buoy # JCAD-8), and with a suite of buoys at the NPEO.

1.3. IOS/JAMSTEC/WHOI CCG Deployment – September 2003 and 2004

Collaborated with the Institute of Ocean Sciences researchers to deploy 3 Ice Mass Balance buoys north of the Beaufort Sea from the CCGS Louis St. Laurent in September 2003 and 2004. These buoys were collocated in ADS' with ocean buoys from JAMSTEC and the Woods Hole Oceanographic Institute (WHOI).

1.4. IARC/AARI NABOS Deployment – September 2003

Collaborated with the International Arctic Research Center (IARC) Nansen and Amundsen Basins Observational Systems (NABOS) researchers to deploy a CRREL Ice Mass Balance buoy north of the Laptev Sea (80.1N 146.1E) from the Kapitan Dranitsin in September 2003. This buoy was deployed in a 300km array with meteorological buoys of the IABP.

2. Data Collection and Analysis

We have begun processing and quality control of the data collected from the Ice Mass Balance buoys. For operational use, these data are available in near real-time through the Global Telecommunications System. For research, the data from the Ice Mass Balance buoys are included in the databases of the IABP, which are analyzed at the PSC, and are available through the IABP web server (http://iabp.apl.washington.edu/). The data are also archived at the World Data Center for Glaciology.

Data from the IABP have been used in over 450 publications. Please see http://iabp.apl.washington.edu/Citations/ for list citations through 2003.

Figures

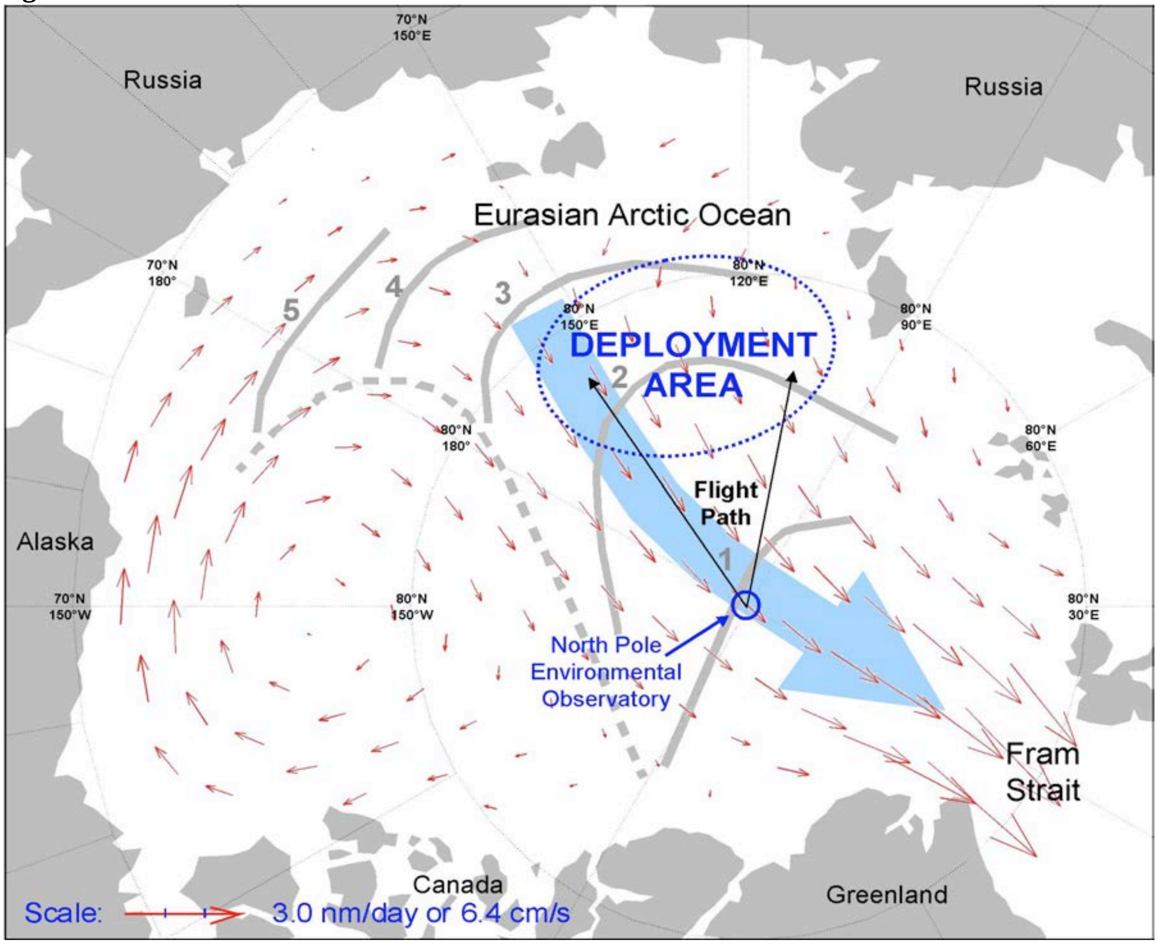


Figure 1. This map shows the area of the Eurasian Arctic Ocean where we plan to deploy enhanced buoys from the North Pole Environmental Observatory. This map also shows the mean field of ice motion analyzed from buoy data (red arrows); the residence time of sea ice (gray lines, these contours show the number of years that ice along each line would take to drift across the Arctic Ocean and exit through Fram Strait); the boundary between ice that will exit Fram Strait or recirculate in the Beaufort Gyre (dashed gray line); and the Transpolar Drift Stream (thick blue arrow).

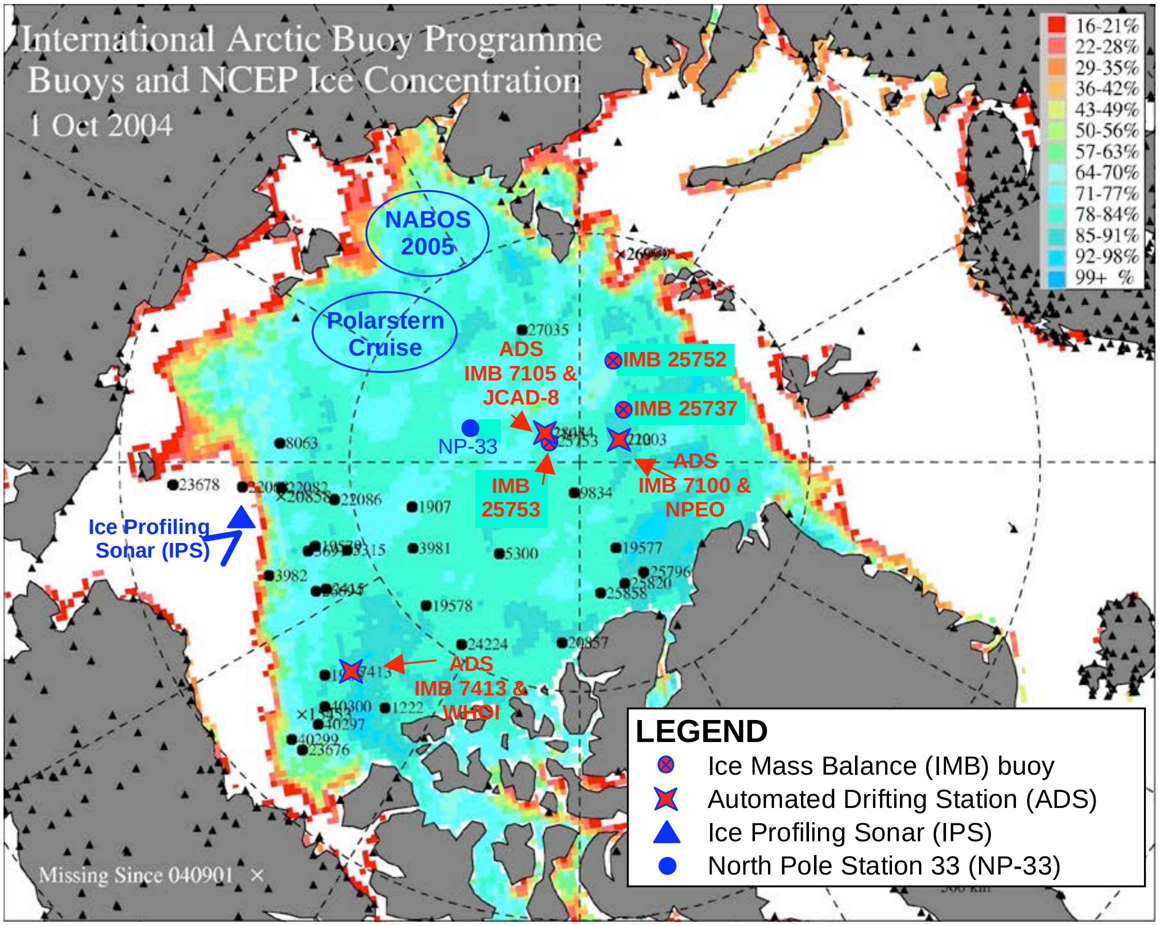


Figure 2. Current locations of Ice Mass Balance (IMB) buoys. The locations of "solo" IMB buoys are marked by red dots, while IMB buoys deployed in Automated Drifting Station (ADS) are marked by red stars. The planned deployment areas of IMB buoys from the NABOS and Polarstern cruises during the summer of 2005 are shown by blue ovals. The positions of other IABP buoys (black dots) and the Ice Profiling Sonar (IPS, blue triangle) are also shown. The sea ice concentration data were obtained from the National Center for Environmental Prediction.

3.32a. High-Resolution Ocean And Atmosphere PCO$_2$ Time-Series Measurements

by Christopher Sabine

PROJECT SUMMARY

General Overview

The fossil fuel carbon sources and the growth of atmospheric CO_2 are reasonably well known based on economic reconstructions and atmospheric monitoring (Prentice et al. 2001). A number of complementary, albeit indirect, means have been proposed for partitioning the long-term net carbon sink between ocean and land reservoirs, producing generally similar results for the global net ocean uptake of ~2 Pg C yr^{-1}. These include global ^{13}C budgets for CO_2 (Quay et al. 1992; Tans et al. 1993; Heimann and Maier Reimer 1996; Quay et al. 2003), data based estimates of anthropogenic CO_2 inventories in the ocean (Gruber et al. 1996, Sabine et al. 1999, Sabine et al. 2002, Sabine et al. 2004), ocean forward and inverse models (Sarmiento et al. 2001; Gloor et al. 2003), and combined use of atmospheric oxygen and CO_2 records (Keeling and Shertz 1992, Keeling et al. 1996). Given the significant uncertainties that are associated with each of these indirect methods, it is imperative to document the time evolution of surface ocean CO_2 concentrations over time.

The regional air-sea flux patterns are less well known, with significant disagreement among atmospheric inversions, ocean surface pCO_2 flux estimates and ocean numerical models (Takahashi et al. 2002; Gurney et al. 2002). The limited number of long-term ocean time series stations show significant biogeochemical variability from sub-diurnal to decadal timescales. Changes in large-scale ocean-atmosphere patterns such as El Niño/Southern Oscillation (ENSO), the Pacific Decadal Oscillation (PDO), and the North Atlantic Oscillation (NAO) appear to drive much of the inter-annual variability, and this variability is expressed on regional (several hundred-to-thousands of kilometers) rather than basin-to-global scales. Large inter-annual variability in the partial pressure of surface water CO_2 (pCO_2) and CO_2 fluxes in the Equatorial Pacific are well documented (e.g., Feely et al. 2002). The general magnitude and mechanisms of mid-latitude variability signals are less clear (LeQuere et al. 2000; 2003), but significant year to year variability is evident in the subtropical Bermuda Atlantic Time-Series Station (BATS) and Hawaii Ocean Time-Series (HOT). Large annual and interannual variation in pCO_2 is also observed in sub-polar regions, but is very poorly characterized due to a lack of data.

The slower, decadal time-scale ocean responses (e.g., changes in nutrient stocks and community structure) are not as well characterized as the interannual response, though there is tantalizing evidence for large-scale biogeochemical regime shifts (or perhaps secular trends) (Karl 1999) and changes in nutrient distributions (Emerson et al. 2001). Distinguishing a human-induced, climate-change signal from natural decadal variability on this time-scale is often singularly difficult, particularly given the relatively short duration of most oceanographic data records. But model projections suggest that anthropogenic impacts are accelerating and may become more evident in the near future.

A wide variety of mechanisms have been identified that could conceivably alter ocean carbon uptake, but in many cases even the sign of the biogeochemical response, let alone the quantitative magnitude, is uncertain (Denman et al. 1996; Doney and Sarmiento 1999). Potential effects include:

- decreased calcification from lower pH and CO_3^{-2} ion concentrations resulting from anthropogenic CO_2 uptake (Kleypas et al. 1999; Riesebell et al. 2000, Feely et al. 2004);
- decreased vertical nutrient supply and in some regions enhanced, effective-surface-layer light supply leading to often opposing regional changes in primary productivity (Bopp et al. 2001);
- alterations in the spatial patterns and community composition of marine biomes due to changes in stratification (Boyd and Doney 2002);

- modifications in dust deposition and iron fertilization affecting the high nitrate-low chlorophyll (HNLC) regions such as the Southern Ocean and possibly subtropical nitrogen fixation;
- decoupling of carbon and macronutrient cycling because of shifts in the elemental stochiometry of surface export and differential subsurface remineralization.

Accounting for such hypotheses in future climate projections is presently problematic given our current understanding and modeling tools (Doney 1999; Falkowski et al. 2000).

Time-series records are key to characterizing the natural variability and secular trends in the ocean carbon cycle and for determining the physical and biological mechanisms controlling the system. Year-to-year variations in physics (e.g., upwelling, winter mixing, lateral advection), bulk biological production, and ecological shifts (e.g., community structure) can drive significant changes in surface pCO_2 (and thus air-sea flux) and surface nutrient fields. The biological and chemical responses to natural perturbations (e.g., ENSO, dust deposition events) are particularly important with regard to evaluating potential climate responses and for evaluating the prognostic models used in future climate projections.

Ship-based time-series measurements are impractical for routinely measuring variability over intervals from a week to a month; they cannot be made during storms or high-sea conditions, and they are too expensive for remote locations. Instrumental advances over the past 15 years have led to autonomous moorings capable of sampling properties of chemical, biological, and physical interest with resolution as good as a minute and a duty cycle of a year or more (e.g., Chavez et al. 1999; Dickey 2003). This work has provided a growing body of evidence that episodic phenomena are extremely important causes of variability in CO_2 and related biogeochemical properties and processes. Time-series moorings are essential for documenting the temporal evolution of the ocean carbon system. These moorings, particularly when co-located with shipboard time-series programs, are also invaluable for developing and testing new chemical and biological techniques and autonomous sensors as well as serving as focal points for process studies.

Since December 1996, the Monterey Bay Aquarium Research Institute (MBARI) has maintained bio-optical and chemical instrumentation on two moorings in the Equatorial Pacific in collaboration with NOAA/PMEL, with support from the NOAA/OACES (then NOAA/OGP's Global Carbon Cycle program) and NASA/SIMBIOS programs. In 2002 NOAA's Global Carbon Cycle (GCC) program funded a proposal to begin transferring the pCO_2 system technology developed at MBARI to PMEL with the idea that PMEL would begin developing a pCO_2 mooring network. While MBARI maintained its original two systems at 0°, 155°W and 2°S, 170°W, PMEL built and deployed two new systems at 0°, 125°W and 0°, 140°W. In 2003, PMEL was funded by the GCC to also deploy a system at the Hawaii Ocean Time-series site, bringing the total number of systems to five. In 2004, the moored CO_2 program was picked up by the Office of Climate Observations as part of the ocean observing system for climate. The moored pCO_2 network is still in its infancy, but hopes to expand into a global network of surface ocean and atmospheric CO_2 observations that will make a substantial contribution to the production of CO_2 flux maps for the global oceans. The long-term goal is to populate the network of OCEAN Sustained Interdisciplinary Timeseries Environment observation System (OceanSITES; http://www.oceansites.org/OceanSITES/) so that CO_2 fluxes will become a standard part of the global flux mooring network. This effort has been endorsed by the OceanSITES science team. Additional information about the moored pCO_2 program can be found at: http://www.pmel.noaa.gov/co2/moorings/.

Relationship to NOAA's Program Plan for Building a Sustained Ocean Observing System for Climate: The moored pCO_2 program directly addresses key element 8) Ocean Carbon Monitoring Network, as outlined in the Program Plan, but also provides a value added component to elements 4) Tropical Moored Buoy Network and 6) Ocean Reference Stations. Within the Ocean Carbon Monitoring Network element, there are three major related components: repeat hydrographic sections, underway surface pCO_2 measurements, and moored pCO_2 measurements. Each component addresses a different timescale of variability. The moored pCO_2 program is designed to assess the short-term variability that cannot be accomplished with shipboard measurements. Obtaining long-term records of these high-resolution measurements allows a full integration of the short-term variability into the longer-term records obtained from the other elements of the CO_2 program. In particular, the moored pCO_2 data will directly contribute to the production of regional CO_2 flux maps and is being examined as a component of a new breed of data assimilation models that include estimates of carbon distributions and fluxes.

National and International Linkages:
Recognizing the need to develop an international framework for carbon research, various working groups of programs like the International Geosphere-Biosphere Programme (IGBP), the World Climate Research Programme (WCRP), the International Human Dimensions Programme (IHDP), the Intergovernmental Oceanographic Commission (IOC), and the Scientific Committee on Oceanic Research (SCOR) have worked together to develop research strategies for global carbon cycle studies. The two primary international ocean carbon research programs are the Integrated Marine Biogeochemistry and Ecosystem Research (IMBER) and the Surface Ocean Lower Atmosphere (SOLAS) programs. Both programs strongly recommend carbon time-series measurements. These programs are very supportive of NOAA's efforts to develop a global pCO_2 mooring network and a number of international colleagues have expressed interest in working with us to include carbon measurements on their moorings. Because ocean carbon is relevant to so many international programs, IOC, SCOR and the Global Carbon Project (GCP) have co-sponsored the International Ocean Carbon Coordination Project. The goals of the project are to gather information about on-going and planned ocean carbon research and observation activities, to identify gaps and duplications in ocean carbon observations, to produce recommendations that optimize resources for international ocean carbon observations and the potential scientific benefits of a coordinated observation program, and to promote the integration of ocean carbon observations with appropriate atmospheric and/or terrestrial carbon activities. In addition to providing direct links to the international research programs, our involvement in the IOCCP provides a link to the global observing programs such as GOOS, OOPC, GCOS, and JCOMM.

The primary large-scale ocean carbon program within the United States is the Ocean Carbon and Climate Change Program (OCCC). Carbon time-series measurements play a key role in the OCCC plan. The emphasis during the first part of OCCC Phase 1 is on maintaining existing open ocean Northern Hemisphere subtropical and equatorial stations and establishing new sites or augmenting ongoing time-series in the sub-polar North Atlantic or North Pacific Oceans as the groundwork for follow-on process studies. Pilot Southern Ocean time-series will be established toward the middle/end of OCCC Phase 1 as a prelude to a major Southern Ocean process study during Phase 2. The NOAA moored pCO_2 network is a critical component for meeting these national plans. In addition, the moored pCO_2 program is being coordinated with the overall NOAA and national carbon strategies through the Carbon Cycle Steering Team and is governed by the COSP Ten Climate Monitoring Principals.

FY 2004 PROGRESS

Background:
Since December 1996, MBARI has collaborated with PMEL to maintain pCO_2 sensors that were developed by MBARI on two TAO moorings in the equatorial Pacific at 155°W, 0° and 170°W, 2°S. During 2003, PMEL engineers worked with the MBARI group to take a similar MBARI designed pCO_2 system for a drifting buoy and modified it to work as a buoy based system. One major modification was the addition of a NOAA/CMDL certified standard gas that would allow the system to recalibrate autonomously. Four TAO buoys were also modified to house the new systems. The new buoy and pCO_2 systems were designed to allow any single component of the system to be easily exchanged, even on a deployed buoy if necessary. These new systems and buoys, which are built and maintained by PMEL, were deployed in September 2003 at 125°W, 0° and 140°W, 0°. In 2004, this program was officially transferred to the Office of Climate Observations (OCO). Also in 2004, a proposal to place a moored pCO_2 system on the new MOSEAN mooring to be deployed north of Honolulu at the Hawaii Ocean

Time-series site was funded by the OCO bringing the total number of system locations to five (Figure 1).

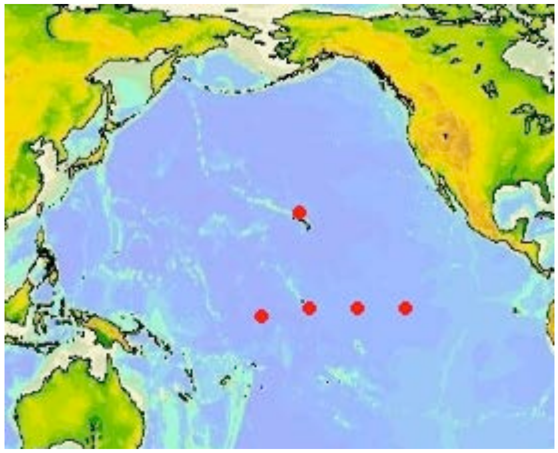


Figure 1. Map of moored pCO_2 systems currently deployed at part of this program.

This report summarizes the FY04 work from all of these programs.

Instrument/Platform Acquisitions and Number of Deployments:
Three new pCO_2 systems were built at PMEL during the year. Two systems were used to replace the recovered systems at 140°W, 0° and 125°W, 0°. The other system was built for the MOSEAN buoy. Systems at all four equatorial sites were replaced at least once during the year. The deployment at HOT was the only new deployment location for the year.

- 155°W, 0° - MBARI OASIS system swap in October 2003, internally recording instrument deployed in June 2004
- 170°W, 2°S – recovery and re-deployment of MBARI OASIS system in October 2003 and July 2004
- 125°W, 0° - recovery and re-deployment of PMEL pCO_2 system in May and battery and antenna replacement September 2004.
- 140°W, 0° - recovery and re-deployment of PMEL pCO_2 systems in May and Sep 2004.
- 158°W, 22.5°N – A PMEL pCO_2 system was deployed in MOSEAN Buoy at HOT in August 2004.

Problems and Improvements:
Vandalism has been a problem for the MBARI systems at 155°W and 170°W. The system deployed at 170°W in June 2003 was lost when the tower was ripped off the buoy. The MBARI system deployed at 155°W in October 2003 was also lost when the tower was removed. There was a time card problem at 170°W during the October 2003 deployment. This problem prevented the transmission of data back via satellite, but the data were still stored in the internal memory of the system and are being recovered now. Due to a shortage of systems resulting from the two tower losses, the MBARI system deployed at 155°W in June 2004 was only internally recording and did not have an Argos transmitter. The system at 170°W deployed in June 2004 stopped working after 6 weeks. With the latest revisit it was discovered that the battery cables had been severed and the batteries were dead.

FY04 was the first full field season for the PMEL pCO_2 moored systems. With each deployment and recovery, lessons were learned and improvements were made to the system. One difficulty that was experienced was the ability to verify the proper operation and accuracy of the moored pCO_2 systems before deployment. To resolve this problem, we designed a simple flow through container for the pCO_2 systems on the deck of the NOAA ship *Ka'imimoana* that is flushed with the same water being fed to the underway pCO_2 system being maintained by our group on this ship. The moored systems can then be turned on at the start of the cruise and compared with the underway data until they are set up in the buoy. Figure 2 provides an example comparison of the shipboard underway system and the moored system prior to deployment at 140°W. These data have shown that the moored systems are in good agreement with the underway data.

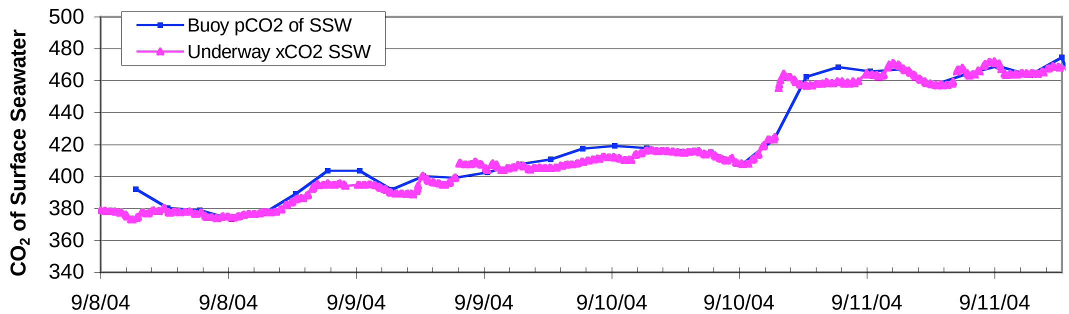


Figure 2. Underway (pink triangles) and moored (blue squares) pCO_2 system data recorded aboard the NOAA Ship *Ka'imimoana* along 140°W. Note that the moored pCO_2 system was mounted in a container on the deck of the ship with water from the underway system flowing through.

The software was also upgraded this year so that data collected immediately after the buoy deployment can be compared with the underway system to verify the proper functioning of the system and system accuracy. During the first few hours of deployment, the system collects data at faster intervals than its normal sample mode of every three hours. The shipboard operator can then call the buoy via satellite shortly after deployment to download the initial data collected to verify that everything is working properly before leaving the site (Fig. 3).

During the first deployments on the equator at 125°W and 140°W in 2003, the calibration gas regulators were not able to maintain a steady gas flow over the entire deployment period and the systems ran out of standard gas resulting in the loss of some data. Several changes were made to prevent this from happening in the future. First, fixed flow restrictors were installed into the regulators. Unlike the standard adjustable gas regulators, the flow restrictors are not susceptible to the buoy vibrations. We also modified the software to detect when the standard gas runs out so it knows to not attempt another recalibration of the instrument. Finally, the data stream was modified to collect the raw data from the detector in addition to the pCO_2 values based on the internal instrument calibrations. In the event that there is any problem with bad calibrations, the raw detector values can be used to recalculate final pCO_2 values using independently determined calibration factors.

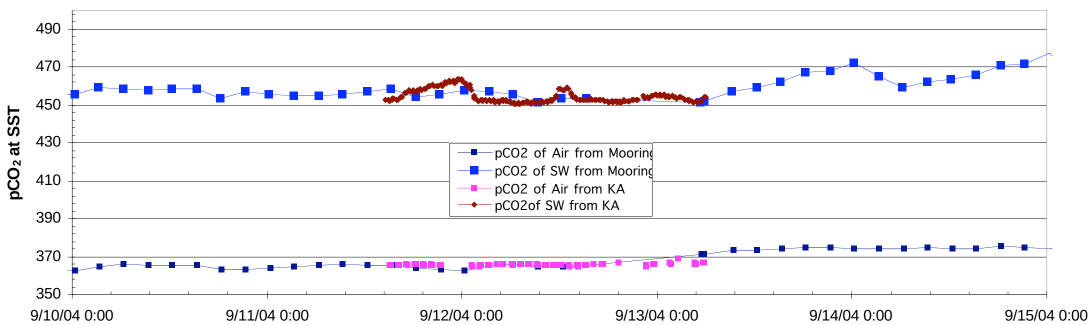


Figure 3. plot of moored pCO_2 values in surface seawater (large blue squares) and marine air (small purple squares) collected from the TAO buoy at 140°W, 0° and underway pCO_2 values (air=pink squares; water=brown triangles) while the ship was within 1° of the mooring. The moored pCO_2 system was serviced late in the day on 9/12/04. Note the continuity of the data before and after servicing.

Several mechanical obstacles were also overcome. In response to a recurrent valve leakage problem, the manufacture agreed to alter their design. The iridium modem was upgraded to a more robust model. The antennas were recently discovered to have a design flaw which causes cracks and allows saltwater to enter antenna. A redesign is being negotiated with the manufacturer. The equilibrators were initially made of low grade copper. After the first deployment, about 8 months, the bottom of copper legs partially eroded away. New equilibrators were built using a 70-30 copper-nickel alloy and were deployed in September 2004.

A problem was also encountered with the first MOSEAN deployment this year. As the Woods Hole Buoy Team was deploying the mooring, it flipped upside down and remained in this position for about an hour as the rest of the buoy cable and instrumentation was deployed. Once the full system was deployed, the weight of the cable and instrumentation righted the mooring, but our system had already run through at least three sampling cycles with the air intake approximately 1.5 meters underwater. Once upright, the pCO_2 was still operating and communicating, but it became immediately apparent that something in the pCO_2 system was not right. The suspected cause of malfunction was that the system had drawn water in through the air intake. This system will be replaced in November 2004 and we are exploring options for preventing this failure in the future.

Measurements and Data:
The MBARI systems measure the air-sea difference in pCO_2 at 3-hour intervals and had approximately a 50% return for FY04. At 155°W the data for the first half of the fiscal year were lost when the tower was removed. The data from the second half were only recorded internally and are in the process of being retrieved now. The data from 170°W in the first half of the year were recorded internally despite the fact that the satellite transmissions malfunctioned, but the data from the second half of the year were lost when

the battery cable was severed. MBARI is currently processing the data that was recovered from these two sites.

The PMEL moored pCO_2 system collects CO_2 and O_2 data from the marine boundary air and surface seawater. The systems are programmed to run every three hours and transmit a summary file each day. For the past year, 99% of the summary files were received from systems on the equator at 125°W and 140°W. Because the systems ran out of standard gas prematurely on the first deployment, some of the data were not properly calibrated but otherwise the systems mechanically functioned properly throughout the deployment. Since the second deployment in May of 2004, the data return for the systems at 125°W and 140°W has been 100% with no serious mechanical failures. See Figure 4 for representative data from 125°W and 140°W.

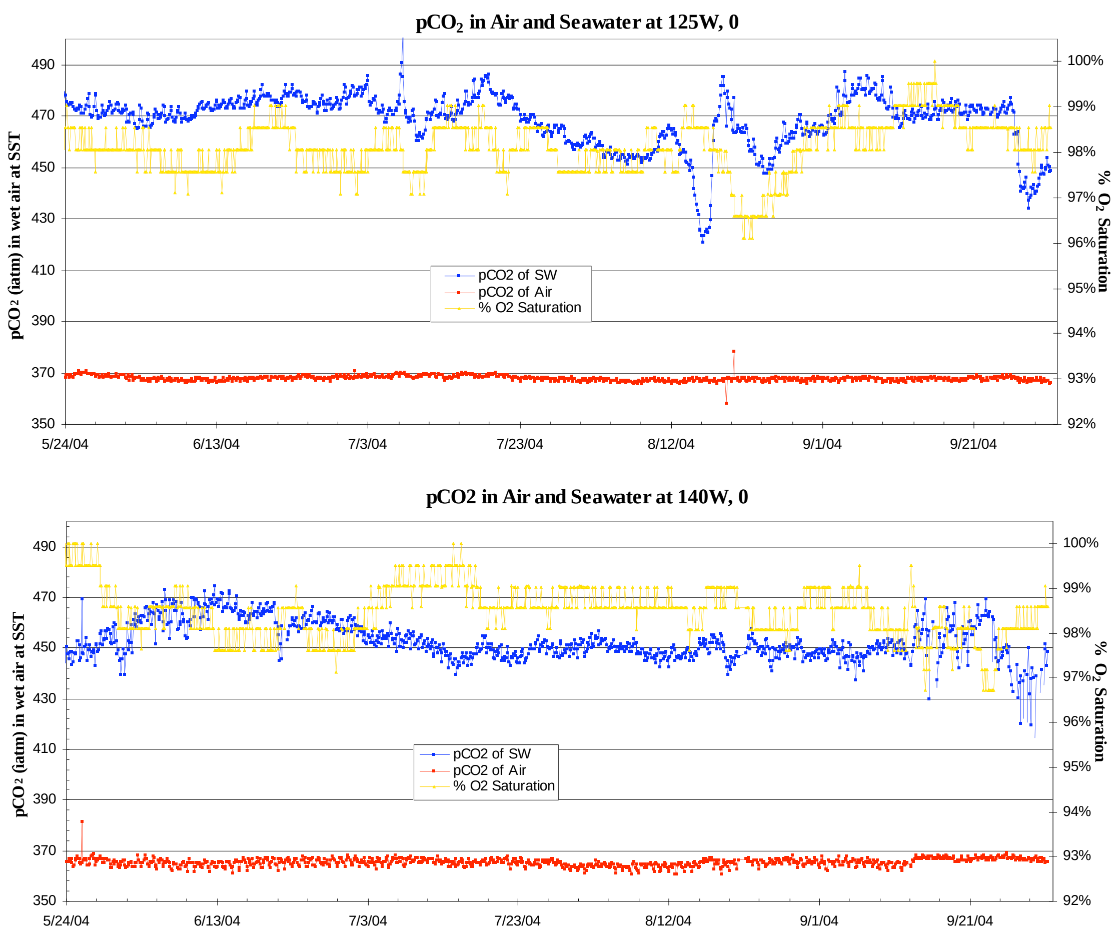


Figure 4. Surface seawater (blue) and marine air (red) pCO_2 values at 125°W, 0° (top) and 140°W, 0° (bottom) collected from the latest deployments of the systems. Gold values are the percent saturation of oxygen in surface water.

In addition to the moored pCO_2 data collected as part of this project, MBARI has been collecting nutrient and chlorophyll measurements on the TAO cruises. One person participates on each cruise and analyzes samples from the shipboard uncontaminated seawater supply and from CTD casts performed in-between buoy maintenance. These data have proven to be very helpful at interpreting the buoy based measurements and ultimately trying to examine the mechanisms controlling the observed variability in pCO_2.

Currently all the PMEL summary files are processed and graphed on a website that is updated daily [http://www.pmel.noaa.gov/co2/moorings/eq_pco2/eq_pco2.htm]. The data are currently stored at PMEL and are available from Christopher Sabine at PMEL. The MBARI data are available from Francisco Chavez at MBARI. Plans are now being put in place to archive the final calibrated data at the Carbon Dioxide Information Analysis Center (CDIAC) and the National Oceanographic Data Center (NODC) on a yearly basis.

Logistical Considerations:
The pCO_2 systems are mounted in buoys that are deployed from a ship. Currently all of our deployments are in conjunction with another project that is covering the buoy deployment and maintenance costs and has already allocated ship time. The pCO_2 systems are typically sent out on a cruise and are set up and deployed by a member of the scientific party as an ancillary task. This arrangement requires about 4 hours for setup and then approximately 10 additional man hours during the cruise. With our current configuration, the deployments do require a brief buoy visit with small boat to adjust the equilibrator to the correct depth. The nutrient and chlorophyll measurements require a person to be aboard each cruise to process samples.

3.33a. *Document Ocean Carbon Sources and Sinks:* Initial Steps Towards a Global Surface Water pCO_2 Observing System, and Underway CO_2 measurements on the NOAA ships *Ka'imimoana* and *Ron Brown* and RVIB *Palmer* and *Explorer of the Seas*

by Rik Wanninkhof, Richard A. Feely
with Nicholas R. Bates, Frank Millero, Taro Takahashi, and Steven Cook

PROJECT SUMMARY

Understanding the global carbon cycle and the determination of the regional sources and sinks of carbon are of critical importance to international policy decision making, as well as for forecasting long term climate trends. Projections of long-term global climate change are closely linked to assumptions about feedback effects between the atmosphere, the land, and the ocean. To understand how carbon is cycled through the global climate system, ocean measurements are of utmost importance. In this effort NOAA is outfitting research and commercial vessels with automated carbon dioxide sampling equipment to analyze the seasonal variability in carbon exchange between the ocean and atmosphere. This task is coordinated at the national level with the U.S. Global Carbon Cycle Science program and its subcommittee on Ocean Carbon and Climate Change (OCCC). To date it has benefited from the International Ocean Carbon Coordination Project (IOCCP) for international coordination exercises. The IOCCP is a joint endeavor of the SCOR/IOC CO_2 panel and the IGBP-IHDP-WCRP Global Carbon Project. Formal ocean basin ties are now being formed in the Atlantic through a Memorandum of Understanding with the European Union project Carbo-Oceans. Pacific collaboration is established through the PICES working group 13.

Documenting carbon sources and sinks relies critically on other efforts undertaken by the Climate Observations and Services Program, COSP including implementation of the ship lines, and moored and drifting arrays. The surface water pCO_2 programs support climate services by providing knowledge and quantification of climate forcing of the radiatively important gas, carbon dioxide. The near-term focus is on completion of the Northern Hemisphere ocean carbon observing system to assist in determining carbon dioxide sources and sinks over the coterminous United States in partnership with the atmospheric CO_2 observing system.

Two separate proposals have been joined into the underway pCO_2 observing program on volunteer observing ships (VOS) and research ships. It is a partnership of AOML, AOML/GOOS, PMEL, LDEO of Columbia University, RSMAS of the University of Miami, and the Bermuda Biological Station for Research (BBSR). Data from the project is being served from three websites that are linked and accessible from each.
1. http://www.aoml.noaa.gov/ocd/gcc
2. http://www.pmel.noaa.gov/co2/uwpco2/
3. http://www.ldeo.columbia.edu/res/pi/CO2/
All work follows established principles of monitoring climate forcing gases and biogeochemical cycles.

FY 2004 PROGRESS

Acquisitions, deployments and data return:

The pCO_2 observations from research ships and VOS have been performed on a routine basis on:

- NOAA ship *Ka'imimoana*: 8 cruises servicing the TAO mooring in the Equatorial Pacific
- NOAA ship *Ron Brown*: 15 cruises in Atlantic and Eastern Equatorial Pacific
- RVIB *Palmer*: 8 cruises in the Southern Ocean and Arctic, including a trans Pacific transit, between May 2003 and July 2004
- Royal Caribbean cruise line *Explorer of the Seas*: 48 cruises in the Caribbean Seas
- *Skogafoss* between Iceland and Boston (since December 2003)
- *Brown* (3 cruises since March 2004)

The cruise schedule of the research ships was similar to the previous year. The tracks for which data are posted for calendar year 2003 are shown in Figure 1. Data return from the ship was over 90%; the minimal data loss that did occur was due to instrument malfunction. Accurate records of malfunction are being kept such that we can get a better appreciation when systems need to be refurbished and to improve weak links. Although the systems are fully automated, all systems except that of the *Skogafoss* have a person on board for periodic checks. The *Skogafoss* operations have been problematic because of intermittent failures of the pumped waste water system that automatically shuts the system down to avoid flooding of the bilges.

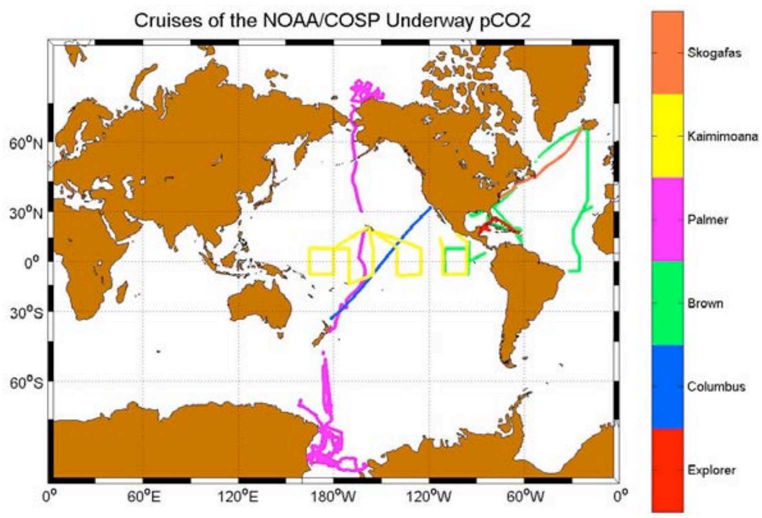


Figure 1. Lines occupied by the ships. The *Skogafoss* and *Columbus Waikato* tracks are monthly repeat occupations. The *Explorer of the Seas* are weekly occupations. The other tracks are one-time occupations during calendar year 2003.

A major component of the VOS pCO_2 work revolved around designing, building and testing the second generation of underway pCO_2 systems for ships of opportunity. A contractor at the University of Bergen built twelve systems with extensive input from the NOAA/COSP sponsored partners. Four of the systems are being purchased by the participants of this project. The others are going to groups throughout the world. The systems were intercompared against each other in Bergen in September 2004 with agreement between systems being better than 0.5 ppm; well within our performance standard of 1 ppm. Through close interaction of VOS group members with the builder, Craig Neill, we greatly facilitated the production and improvement of these systems. System parts were purchased by the VOS group members and credited towards instrument costs. The first generation systems that we currently have installed on VOS will be retrofitted to be fully compatible with the new systems.

In addition to our long-term underway pCO_2 measurements on the *Ka'imimoana*, we have successfully installed a new underway pCO_2 system on the *Columbus Waikato* this year for transits between the west coast of the United States, New Zealand, and Australia (Fig. 2). This research is done in collaboration with Drs. Paul Quay of the University of Washington and Bronte Tilbrook of the CSIRO in Hobart, Australia. In addition to supporting our underway pCO_2 measurements, they are also collecting samples for carbon isotope measurements (Quay) and DIC and nutrients (Tilbrook). For this reason, we have combined resources to place ship riders on each of the cruises. They maintain the underway systems and collect the discrete samples.

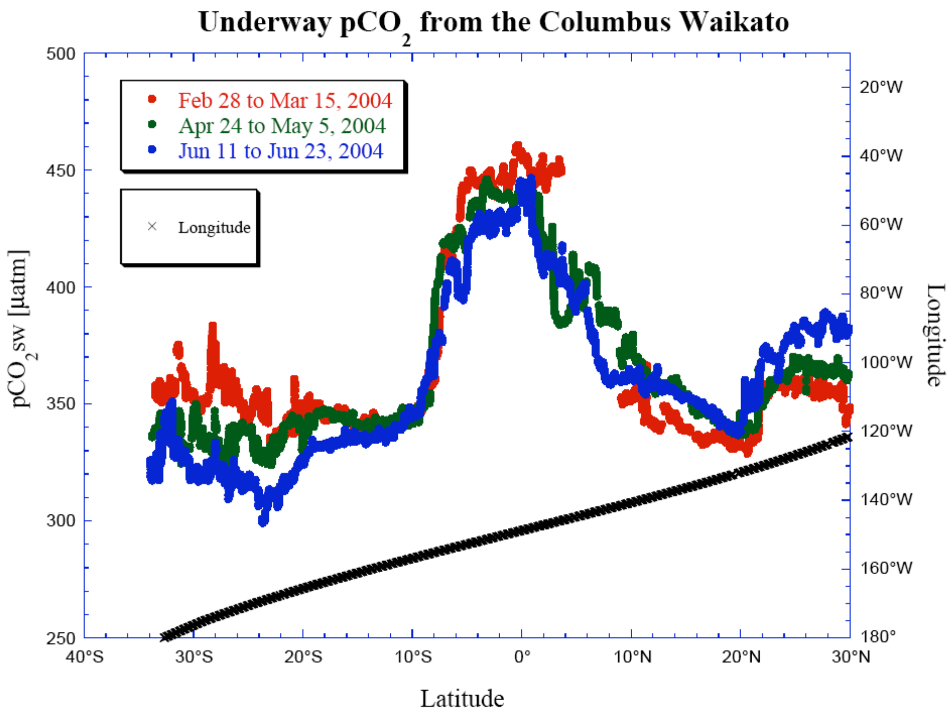


Figure 2. Surface water pCO_2 measurements from the first three transects of the *Columbus Waikato* across the Pacific Ocean from Long Beach CA to New Zealand.

The efforts of the NOAA VOS pCO_2 group thus have met the important monitoring principle of uniform instrumentation with a quantifiable accuracy. The first units were delivered in the summer of 2003, within a year of receipt of program funding. In FY04 two VOS ships were outfitted (the *Skogafoss* and the *Columbus Waikato*). The installation of the MV *Oleander* began at the end of the performance period.

NSF operates the RV *Gould* for the long-term study of ecological and biogeochemical changes in the Drake Passage and Antarctic Peninsula areas. Surface water pCO_2 has been measured by Colm Sweeney under a NSF funding in order to document the seasonal and interannual variability. These field data have been quality-controlled and processed at LDEO as a part of the VOS/NOAA program. Approximately 154,000 pCO_2 measurements have been finalized as described in the Progress Report Section for LDEO (Appendix 1, attached at the end of this report).

Data management and dissemination:
An important part of the VOS effort is to disseminate quality controlled data to the community at large in an expedient fashion. The LDEO group, in close interaction with the data acquisition groups, oversees shipboard quality control so that the quality of data is monitored as closely as possible to real time. This close coupling of the data acquisition with data processing/evaluation and interpretation will guarantee high quality field observation data. The LDEO group also coordinates submission of the collated data to the underway pCO_2 data center for community access. They participate in data interpretation with the data acquisition groups. This will facilitate discussions about data quality and insure that the observationalists will be engaged deeply in the interpretation processes.

Data obtained from the research ships are currently served from the institution responsible for the measurement. Although this component was not explicitly listed in the LDEO data management effort for the VOS proposal, the data from the research ships are currently being ingested by the LDEO group for their first annual release.

Data will be released to the internationally sanctioned data centers, NODC and CDIAC. CDIAC has just implemented a Live Access Server (LAS) for the data with funding from a companion effort. The LAS at http://cdiac3.ornl.gov/underway/servlets/dataset will be populated in the coming year. Investigators, and the oceanographic community use the data extensively. These data is also used for national and international assessments such as the IPCC.

Good progress has been made to post the pCO_2 data on the web sites. A listing of current updates is provided below. A major change has been the formatting. Based on a meeting in Japan sponsored by IOCCP in January 2004, an international standard of data formatting was adapted for this program. AOML and PMEL have reformatted most of their data to this format.

Latest updates (as of September 2004):

http://www.aoml.noaa.gov/ocd/gcc

Brown:	November 2003
Explorer:	August 2004
Skogafoss:	None

http://www.pmel.noaa.gov/co2/uwpco2/

Ka'imimoana:	August 2004
Columbus Waikato:	August 2004

http://www.ldeo.columbia.edu/res/pi/CO2/

Palmer	July 2004

In several instances, several years of data have been posted over the last year.

Problems:

The major problems encountered were late receipt of funds from NOAA, in particular for our academic colleagues, which slowed down the work schedule. Access to ships has been difficult at times, which has slowed installation, particularly for the MV *Oleander*. In this instance, installation of the pCO_2 system on the MV *Oleander* in the port of Newark became very problematic. At the request of the owners and captain, installation has shifted to Hamilton, Bermuda. Routine data downloads from the *Skogafoss* have sometimes not occurred in port because personnel of the GOOS/SEAS group, who are partners in this effort, were not available. Part of the problems is associated with lack of personnel resources which were requested as an "Add task" in FY-04 but were not funded. In FY-05 we have included the needed personnel in the budgeted request.

Systems on the ships have worked very well, except for the *Skogafoss*. The *Skogafoss* is the only ship without a person on board for periodic checks. The *Skogafoss* operations have been problematic because of intermittent failures of the pumped waste water system that automatically shuts the system down to avoid flooding of the bilges. Never-the-less data has been obtained on about half the transects (Fig. 3). On the *Oleander*, the equilibrator will free drain into a waste reservoir, which in turn will be drained by a new pump back into the seawater line downstream of the tap off to the pCO_2 system. A new equilibrator was placed on the *Explorer of the Seas.* We have determined that a ship rider is required to attend the underway system on the *Columbus Waikato* because of the difficulties associated with the language differences between the scientists and the crew. We found that by working with scientists from the University of Washington, CSIRO in Hobart and the University of Southern California we can accomplish that task, provided we continue our subcontract with the University of Southern California.

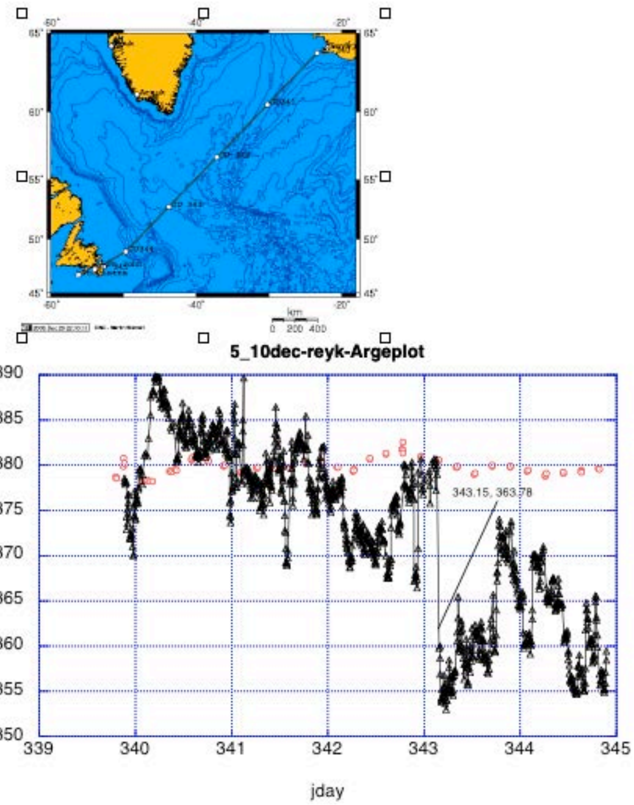


Figure 3. pCO_2 data from the *Skogafoss* from December 5-10, 2003. The top panel shows the cruise track with open circles demarking each day. The bottom panel shows the mole fraction of CO_2 (XCO_2) in air (red circles) and water (black line).

Project costs:
Anticipated- Anticipated data costs include data reduction, dissemination, interpretation, and data archiving. Anticipated instrument costs include design, purchase, installation and maintenance.
Unanticipated- Unanticipated costs included higher maintenance costs, instrument development costs, and personnel costs to repair and maintain systems.
Logistical considerations- Work on the research ships proceeded as planned. The *Brown* was used for the several coastal cruises in the NE Atlantic that will provide important baseline considerations for the anticipated coastal carbon program.

Although the RVIB *Palmer* has been operating primarily in the Southern Oceans, she was assigned to operate in the Arctic waters during 2003. Thus, the *Palmer* sailed from the Southern Ocean to the Arctic Sea across the equatorial Pacific and Bering Sea, and returned to the Southern Ocean. This has given us a tremendous pCO_2 data set: two N-S trans-Pacific profiles in a single year at no extra cost to the CO_2 project. This demonstrates that extensive observations can be made over the global oceans at virtually no extra cost.

Research highlights;

1. The NOAA Ocean and Atmosphere Research laboratories in collaboration with Joint Institute partners and other academic investigators sponsored through OAR/OGP have been on the forefront of field investigations on how gases exchange between the ocean and atmosphere. One of the goals is to investigate the patterns of sequestration of carbon dioxide. On average the ocean takes about 1/3 of the carbon dioxide produced by fossil fuel burning but with significant regional, seasonal, and interannual variability. As part of this project two large multidisciplinary field studies were performed in 1998 and 2001 in the north Atlantic and Equatorial Pacific on NOAA ship *Ronald Brown*. In 2004 the

results of these studies and that of other investigations of air-sea gas transfer were compiled in a special section of the Journal of Geophysical Research. Four major papers of importance from this volume are included in the reference section.

The papers describe the physical, chemical and biological conditions that affect the air sea exchange of CO_2 in the equatorial Pacific Ocean. The research provided new parameterizations of the air-sea exchange of CO_2 in the equatorial Pacific and new estimates of CO_2 flux for the region based on these parameterizations. The combined effects of uncertainties in the gas transfer velocity and wind fields lead to average difference of 27% between the lowest and highest estimates of the CO_2 flux from the region. Although the gas exchange wind speed expressions varied greatly, the calculated fluxes were very similar because of both the narrow wind speed range encountered and the converging relationships near the mean observed wind speed of 6 m/s. The most recent CO_2 data suggests that a weak ENSO event is beginning in the Eastern Pacific (Fig. 4).

2. The pCO_2 measurements performed over the last two decades in the Equatorial Pacific, primarily by the investigators in this proposal, have shown a large shift in pCO_2 levels and CO_2 fluxes. The pCO_2 levels in the 80-ties increased more slowly than in the 90-ties with the change in trend occurring at the beginning of the 90-ties. This timing corresponds with a change in the Pacific Decadal Oscillation (PDO). It reinforces the hypothesis that natural climate reorganizations have a major effect on air-sea CO_2 fluxes. While studies by our group have clearly shown the large effect of the ENSO on the fluxes, including the last few months (Fig. 4), this is the first time the effect of the longer time scale oscillations on the oceanic carbon system have been demonstrated. Our latest results are utilized to document the decadal changes in the CO_2 fluxes from this important region.

3. It is widely recognized that robust methods to interpolate CO_2 measurements in time and space are needed to produce CO_2 flux maps from measurements along a line. Publications by Cosca et al. (2003) and Feely et al. (2004) for the Equatorial Pacific and Olsen et al. (2003) for the Caribbean Seas show how temperature can be utilized to produce regional flux maps. The algorithms are area specific but show a robust predictive capacity and provide a way to utilize remote sensing to produce flux maps with high spatial and temporal resolution. The data used to create the algorithms were obtained on the ships funded under this effort.

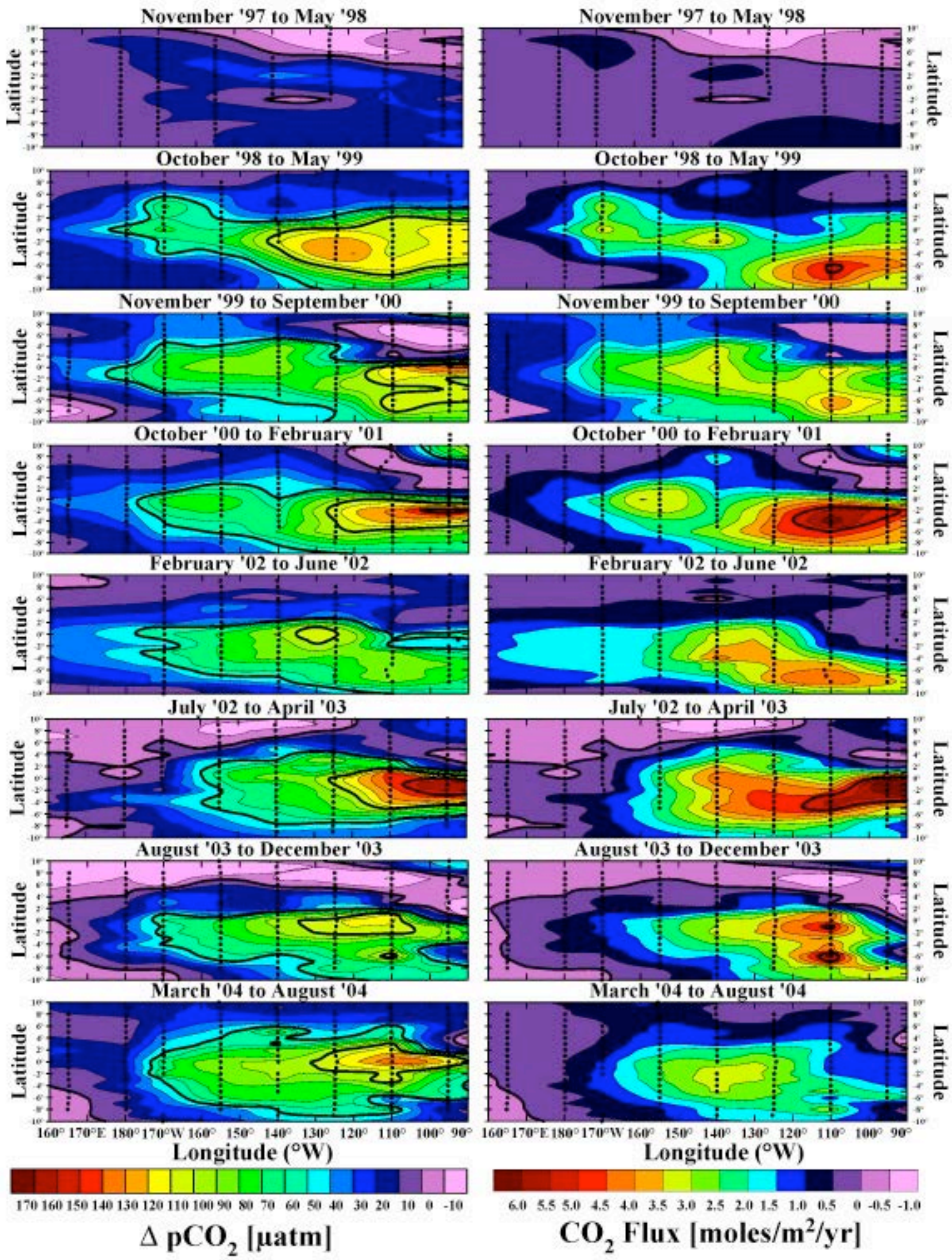


Figure 4. Time series of pCO_2 distributions (µatm) and CO_2 flux (mol/m^2/yr) between November 1997 and August 2004. Low CO_2 fluxes are observed during both the strong 1997-98 El Nino and the weak 2002-3 event.

The algorithms are area specific but show a robust predictive capacity and utilize remote sensing data to produce flux maps with high spatial and temporal resolution. The data used to create the algorithms were obtained on the ships funded under this effort. The efforts were continued with the Caribbean data from the *Sealand Express*. The algorithm developed for 2003 was very similar to the 2002 algorithm developed by Olsen et al. (2003) with an average offset of 1.5 µatm (that fortuitously is similar to the expected oceanic increase). Weekly flux maps were produced from this algorithm to estimate the regional flux in the area. The weekly flux maps are presented on: http://www.aoml.noaa.gov/ocd/gcc/salinity/explorer.html.

4. The decadal trends of surface water pCO_2 in 23 areas (about 5° x 5° on the average) in the tropical and North Pacific Ocean have been investigated by Takahashi using the observations made since the 1970's. In 19 areas that are located in the open North Pacific, the surface water pCO_2 values have been increasing at a rate similar to the mean atmospheric CO_2 increase of about 1.5 ppm/yr. Although surface waters are out of equilibrium with atmospheric CO_2 because of the seasonal swing of SST, biological production and deep-water upwelling, the ocean surface waters appear to take up CO_2 from the air keeping up with the atmospheric CO_2 increase. In contrast, in four areas located near and within the Bering and Okhotsk Seas, the surface water pCO_2 have been decreasing with time, in spite of the fact that surface water temperatures have been increasing. This may be attributed to an increase in photosynthesis in the high latitude northern North Pacific, that have been reported by Gregg et al. (2003) on the basis of remote-sensed ocean colors.

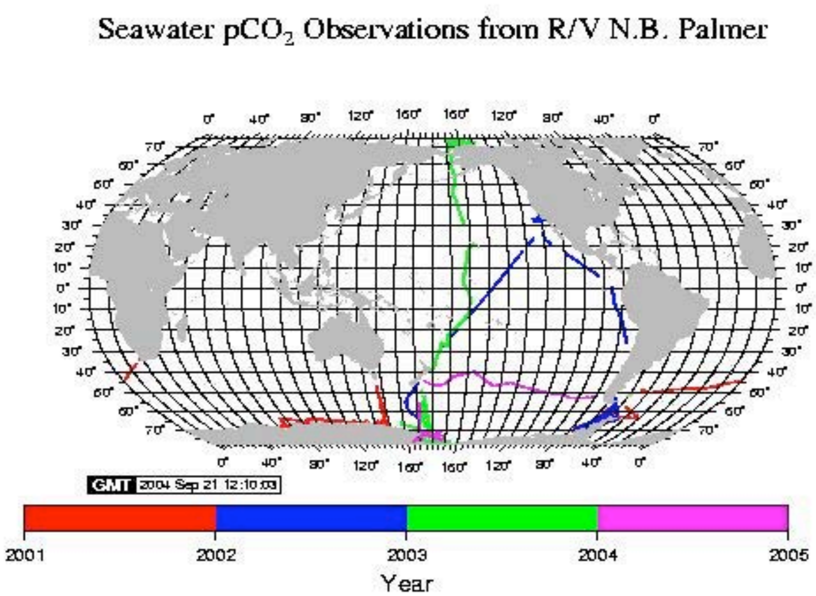


Figure A1 – Locations of the surface water pCO_2 measurements obtained aboard the RVIB Palmer in 2001 – 2004.

Seawater pCO_2 Observations from R/V L.M. Gould

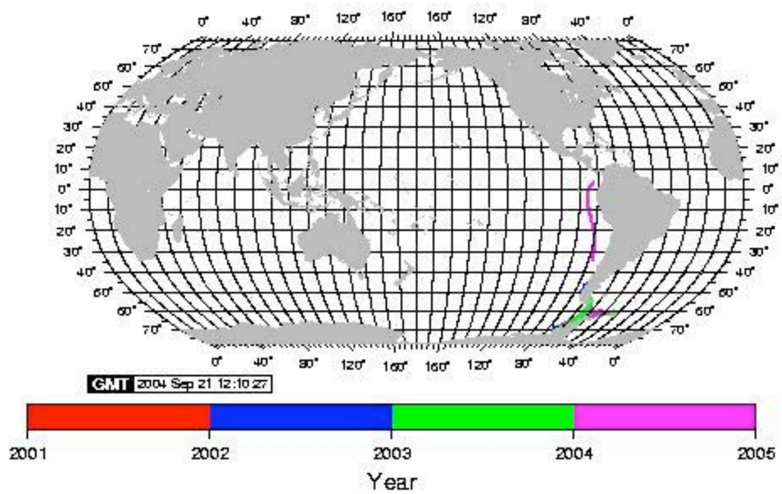


Figure A 2 – Locations of the surface water pCO_2 measurements obtained aboard the RV Gould in 2001 – 2004. The measurement program has been supported by NSF, and the data were obtained under the direction of Colm Sweeney. The data were processed under the VOS program.

3.34a. Ocean Reference Stations and Northwest Tropical Atlantic Station for Flux Measurement (NTAS)

Robert A. Weller and Albert J. Plueddemann

PROJECT SUMMARY

Overview:

The goal of this project is to maintain long-term surface moorings, known as Ocean Reference Stations (ORS), as part of the integrated ocean observing system. The scientific rational for these stations is to collect long time series of accurate observations of surface meteorology, air-sea fluxes, and upper ocean variability in regions of key interest to climate studies and to use those data to quantify air-sea exchanges of heat, freshwater, and momentum, to describe upper ocean variability and describe the local response to atmospheric forcing, to motivate and guide improvement to atmospheric, oceanic, and coupled models, to calibrate and guide improvement to remote sensing products and capabilities, and to provide an anchor point for the development of new, basin scale fields of the air-sea fluxes. Model, satellite, and climatological fields of surface meteorology and air-sea fluxes have large errors; high quality, in-situ time series are the essential data needed to improve our understanding of atmosphere-ocean coupling and to build more accurate global fields of air-sea fluxes.

Under this effort three sites are being maintained: the site at 20°S, 85°W under the stratus cloud deck off northern Chile (Stratus), the Northwest Tropical Atlantic Station (NTAS) at 15°N, 51°W, and a site north of Hawaii near the Hawaii Ocean Timeseries (HOT) site. The Hawaii WHOI reference station was established this year in cooperation with Dr. Roger Lukas of the University of Hawaii (funded by NSF) and is denoted WHOI-HOTS or WHOTS. After several years of support for mooring deployment and annual servicing under NOAA OGP, the Stratus and NTAS sites have transitioned to long-term Ocean Reference Stations. The Hawaii station is being done in collaboration with investigators that have made shipboard and moored observations in the HOTS region in recent years. In the management of the **Ocean Reference Stations** project, four tasks have been identified. First, there is the engineering, oversight, and data management (**Task I**), second, maintenance of the Stratus site (**Task II**), third, maintenance of the NTAS site (**Task III**), which is now covered under a grant to Plueddemann, but will in FY2005 shift to support as one of the operational ORS, and fourth, establishment of the Hawaii ORS (**Task IV)**. Progress on each of the Tasks is reported in more detail below. Note that we also report on the **Northwest Tropical Atlantic Station for Flux Measurement (NTAS)** project here in order to be responsive to the request for evolution toward a single report for an element of the observing system.

Addressing NOAA's Program Plan:

This program directly addresses the sixth element of the Program Plan for Building a Sustained Ocean Observing System for Climate – Ocean Reference Stations. It works in synergy with many of the other elements (Global Surface Drifting Buoy Network, Global Ships of Opportunity, Argo Profiling Float Array, Satellites for Sea Surface Temperature, Sea Surface Height, and Surface Vector Winds) by providing high temporal resolution at fixed points to complement the Lagrangian or spatial sampling of the other elements. It is also an important element of assimilation efforts, as surface fluxes can be diagnosed from the ocean and provide a means to assess the models being used for assimilation.

Management in Cooperation with International Panels:

The Ocean Reference Stations project is managed in cooperation with the International Time Series Science Team (co-chaired by R. Weller), a joint planning effort that involves the climate, carbon, and other disciplinary communities interested in long time series and that reports to the Ocean Observations Panel for Climate (OOPC) and to the Partnership for Ocean Global Observations (POGO, an international consortium of directors of oceanographic institutions). The link to JCOMM observations is through the OOPC. The ORS project, and more generally the International Time Series Science Team, because of its importance to and emphasis on air-sea fluxes, has also reported to the WCRP Working Group on Numerical Experimentation (WGNE) to develop explicit links to the weather and climate modeling centers. An outcome of this is the SURFA project, where time series we collect are provided to Peter Gleckler at PCMDI for inclusion in the AMIP (Atmospheric Model Intercomparison Project). We are now participating in a new WCRP/CLIVAR oversight group on air-sea fluxes formed recently with Chris Fairall as the Chair. We have participated in planning for CLIVAR, for the Carbon Cycle Science Plan implementation, and for SOLAS, working to see that the Ocean Reference Sites develop to serve the needs of the research programs.

Responsible Institution:
The Woods Hole Oceanographic Institution is the responsible institution for all aspects of this project.

Websites:

WHOI's website:	http://www.whoi.edu
UOP Group's site:	http://uop.whoi.edu
Stratus Project site:	http://uop.whoi.edu/stratus
NTAS Project site:	http://uop.whoi.edu/ntas
WHOTS Project site:	http://uop.whoi.edu/hawaii

Partnerships:
Planning and implementation of the ORS includes a number of partnerships. The Hawaii site was equipped with ocean instrumentation through a National Science Foundation grant to Roger Lukas of the University of Hawaii. The Stratus site was chosen in collaboration with the Chilean Navy Hydrographic and Oceanographic Service (SHOA), and trips to the Stratus site have involved Chilean (SHOA, the University of Concepcion, and the University of Chile, Santiago) and Ecuadorian (Navy oceanographic office, INOCAR) participation. The Stratus site provided the focal point for the stratus component of the multi-agency cooperative EPIC 2001 field program and is included as a focal point for a CLIVAR VOCALS (VAMOS Ocean Cloud Atmosphere Land Study) process study in 2006 or 2007. The NTAS site may similarly provide a focal point for a field study (RICO) of tropical convection and clouds now under discussion by Chris Bretherton and Bjorn Stevens. Surface meteorological and air-sea flux data from our sites are made available to various national/international centers (NCEP in the U.S., ECMWF in Europe). There is strong synergy between our program and the National Science Foundation program on Ocean Observatories, and the NSF effort is looked to as the means to develop observatory hardware capable of extending the ORS to higher latitude sites of high scientific and operational climate interest.

Monitoring Principles:
The project is managed in accordance with the Ten Climate Monitoring Principals.

Task I Engineering, oversight and data:
FY2004 PROGRESS
Design of a new buoy for use at the Ocean Reference Stations was completed in FY2003, and the first complete buoy system was deployed in 2004. These new buoys replace the 15-20 year old hulls presently used which are degrading (corrosion of the welded aluminum) and are expensive to ship as they do not fit inside a sea container like the new hulls. Six new buoy hulls were slated for construction. The first of the new buoy hulls, tower tops, and cabling systems was utilized for the WHOTS project, deployed in August 2004. This represents an increase in the number of stations being supported from two last year to three this year. Preparation of the second system has been completed; it will be deployed at the Stratus site in December 2004. The third buoy system is presently being outfitted for deployment at the NTAS site in March 2005. The remaining three hulls have been constructed, and one of them is nearing completion as a ready-for-sea system. These systems will be completed and deployed as a part of the next annual servicing cycles for WHOTS, Stratus, and NTAS, respectively. Four new meteorological sensor systems to be used to support the three sites have been acquired. Two complete systems were integrated with the

new tower tops, tested, and deployed at the WHOTS site. The other two systems are being integrated into a sensor pool that will support Stratus, NTAS and WHOTS. Data acquisition and processing for all three sites continues on schedule.

Acquisitions: Six new buoy hulls have been fabricated and four new meteorological sensor systems were acquired. These assets are being used for Tasks II (Stratus), III (NTAS), and IV (WHOTS).

Data storage, Distribution, Access, Archiving: The oversight task coordinates the common data tasks for the three sites. Oceanographic (velocity, temperature, salinity) and surface meteorological data (wind speed and direction, air and sea surface temperature, rain, incoming shortwave and longwave, relative humidity, and barometric pressure) are processed and stored on disks attached to our workstations. Telemetered data are made available via an FTP server and a website with download capability. This website is in the process of being upgraded and re-organized. We also maintain a public access archive of Upper Ocean Processes Group data from mooring deployments.

Anticipated and unanticipated project costs: Deployment of the WHOTS Ocean Reference Station (WHOTS) in August 2004 represented a two-year acceleration relative to our initial proposal and budget for deployment in summer 2006. The additional cost of this work was handled through a Project Acceleration or “Add Task” to the FY2004 ORS budget in the amount of $376,700.

Problems: None significant.

Note that Deployments, Data Return, Measurements, Data Sharing, Logistical Considerations, Research Highlights, Publications, Conferences, Meetings, and Outreach are described under the individual Tasks II, III, and IV below.

Task II Stratus Site:

Stratus FY 2004 PROGRESS

The stratus surface mooring was deployed first under the previous grant (under the Pan American Climate Studies) in October 2000. It was recovered and redeployed from the NOAA Ship *Ronald H. Brown* in October 2001. This mooring was recovered using the *RV Melville* (Puerto Caldera, Costa Rica to Arica, Chile) in October 2002 and a new mooring deployed at the same site. In 2003, the mooring was recovered and redeployed by *RV Revelle*, sailing from Manta, Ecuador on November 10, 2003 and arriving in Arica, Chile on November 26, 2003. During that cruise we assisted the Ecuadorian Navy (INOCAR) with one of their surface moorings and also supported NOAA (PMEL and NDBC) technicians training Chilean Navy (SHOA) staff in deploying a DART (tsunami detection) buoy purchased by Chile from PMEL. At the Stratus site in-situ comparisons of the ship’s and both buoys’ meteorological sensors were carried out. During the deployments, hourly-averaged surface meteorology was available from the buoy in near real time via Service ARGOS and a WHOI ftp site. Data exchanges were made with ECMWF, NCEP and others to examine numerical weather prediction model performance and examine air-sea fluxes under the stratus clouds. The telemetered meteorological data are also available via the website maintained for this site (http://uop.whoi.edu/stratus). Internally recorded 1-minute meteorological data as well as the oceanographic data, which are only internally recorded, were downloaded from the recovered instrumentation. Data recovery was good (estimated to be 90%), post-calibrations are being done, and data files have been shared with colleagues. Preliminary cruise reports were filed with the State Department soon after the cruise; final documentation that goes to foreign observers and the State Department includes copies of the underway data and a final cruise report. Telemetry from the buoy presently deployed indicates that it is on station and both meteorological systems are functioning well.

Work this year included down-cruising hardware and instruments recovered in November 2003, doing post-calibrations, data processing, writing cruise and data reports, preparing the mooring and instrumentation for the next deployment, scheduled for December 2004 on board the NOAA ship *Ronald H. Brown*, starting in Arica, Chile and ending in Valparaiso, Chile, coordinating that cruise, and assembling, using, and making available a composite 3-year data set. Work on this task is on schedule.

Acquisitions: We did not acquire instruments. On our cruise on *RV Roger Revelle,* we deployed 45 surface drifters and 9 Argo floats (Fig II-1) to bolster sampling in the southeastern Pacific. On the *Ronald H. Brown* we will again do surface drifter and Argo float deployments.

Deployments: The Stratus site is visited once per year, in October through December, as required by battery and calibration life. The surface mooring there is recovered and a new mooring deployed. This year we will again service a DART mooring for the Chilean Navy (SHOA).

Measurements: On the buoy: air temperature, sea surface temperature, relative humidity, incoming shortwave and longwave radiation, wind speed and direction, rain rate, and barometric pressure. On the mooring line: concentrated in the upper 300m, temperature, salinity, and velocity. During the deployment, high data rate (up to 1 sample per minute) data are stored in each instrument. Hourly-averaged surface meteorology is telemetered via Service ARGOS; the telemetered data are stored at WHOI on a workstation. The telemetered data are available on the website (http://uop.whoi.edu/stratus) in near real time; it is also set up to be FTP'd to collaborators and those who request it. The internally recorded data goes through processing, has calibration information applied, and is subject to preliminary analyses before being made publicly available on our website. In the interim, preliminary versions are made available upon request.

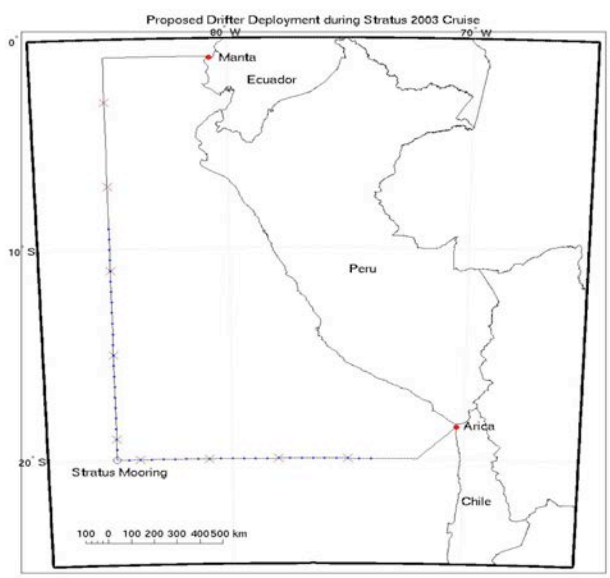


Figure II-1. Cruise track of RV Revelle in November 2003 during cruise to service the Stratus site. Forty-five surface drifters and nine Argo floats were deployed.

Data use and sharing: Hourly surface meteorological data are archived at WHOI, arriving within hours of when it was observed. These data are exchanged in near real time with ECMWF and NCEP; they in turn provide operational data at the grid point nearest the model. It is also shared with the Chilean Navy (SHOA). The same data are shared with CLIVAR investigators, especially modelers interested in the Stratus region, with VAMOS investigators in the U.S. and in South America. It is also sent to Peter Glecker at PCMDI for use in the SURFA project. These meteorological data are used to access the realism of operational atmospheric models in the stratus region. Once per minute, as well as hourly, surface meteorological time series are provided to the EPIC and VEPIC investigator communities (including Sandra Yuter, Chris Bretherton, Meghan Cronin). The surface meteorological data have been made available to the satellite community (including radiation – Langley, winds – Remote Sensing Systems and JPL, SST – Dick Reynolds, all variables – the SEAFLUX project). The oceanographic data are being used by Weller and a Postdoctoral Investigator at WHOI to investigate air-sea coupling and upper ocean variability under the stratus deck. In parallel it will be compared with ocean models (with Ragu Murtugudde, Univ. of Maryland).

Data archive: The initial archive is that maintained by the Upper Ocean Processes Group at WHOI, which maintains a public access server of their mooring data. We are working with the International Time Series Science Team to develop a number of sites that will maintain as many records of time series stations as can be collected to facilitate access to such data.

Costs: A great unknown continues to be the ports of call and length of the cruises to service the mooring; because of this labor costs for days at sea and shipping and agent's fees in foreign ports can exceed budgeted figures. We plan for roughly 16 days at sea. If we are assigned a longer cruise, the labor costs are beyond the budgeted amounts. Besides these costs we have been on track, with costs as laid out in the budget.

Problems: Availability of ship time continues to be a first order problem, as do the uncertainties of whether or not the ship costs will be covered by NOAA. Because of the high demand on Class 1 ships, we are often, as is the case this year, on a UNOLS vessel. There are difficulties of coordination between NOAA and UNOLS. There are also continuing issues about the UNOLS operators getting payment in a timely fashion. The performance of the RDI Acoustic Doppler Current Profilers deployed on this mooring has not been as expected. Range has been less than anticipated; additional Vector Measuring Current Meters (VMCMs) have been added to fill the gaps left by the RDI ADCP's short range. One of two units was returned to the manufacturer after failing to run for a full year; it was found to have excessive power consumption. In the last deployment we encountered problems for the first time with long-line fishing lines fouling some propeller current meters; we have deployed, and again will deploy in December 2004, additional single point acoustic current meters (Sontek and Aanderaa) to cope with this problem and assess the ability of these current meters to obtain data as good as that obtained by VMCMs.

Logistical considerations: We need to return every 12 months with about 2-4 weeks margin because of the lifetime of the batteries powering the instrumentation. Getting a Class 1 ship to the site every 12 months has become a major challenge,

We need 6 days on station with the ship at the mooring site. The work includes comprehensive comparison of ship and buoy meteorological sensors (Fig. II-2), which is critical to determining and demonstrating the accuracy of the moored sensors. The addition of air-sea flux studies at the Stratus site by Fairall (NOAA ETL) and others (such as cloud radar work by Yuter, Univ, of Washington) adds to the need, so that 10 days at site could be used. Every effort is made to work out of ports of call close to the site, but at times the ship opportunities that have been suggested have been as far as 20 steaming days away, which would cause a large increase in labor costs.

Figure II-2: The Stratus buoy with RV Melville in the background, taken during comparison of ship meteorological sensors (mounted on the tower on the bow) and buoy sensors.

Research highlights: The time series data from the buoy have provided the first accurate in-situ record of surface meteorology (Fig II-3) and air-sea fluxes (Fig II-4) under the stratus clouds, and there has been great interest in how the in-situ data compares to model and climatological data. Note that these figures provide documentation of significant biases in the reanalysis and climatological fields; the annual means are compared in Fig. II-5. Figure II-5 also points to greater year-to-year variability in the observations than in the model.

Another unique achievement of the Stratus mooring is the collection of the first record of upper ocean variability under the stratus clouds (Fig. II-6). Because these data have coincident surface forcing, work is underway to diagnose the local heat budget and assess the role of local air-sea interaction in maintaining the sea surface temperature under the stratus deck. Evidence of locally-wind driven flow to the southwest, off to the left of the wind, is apparent in the current

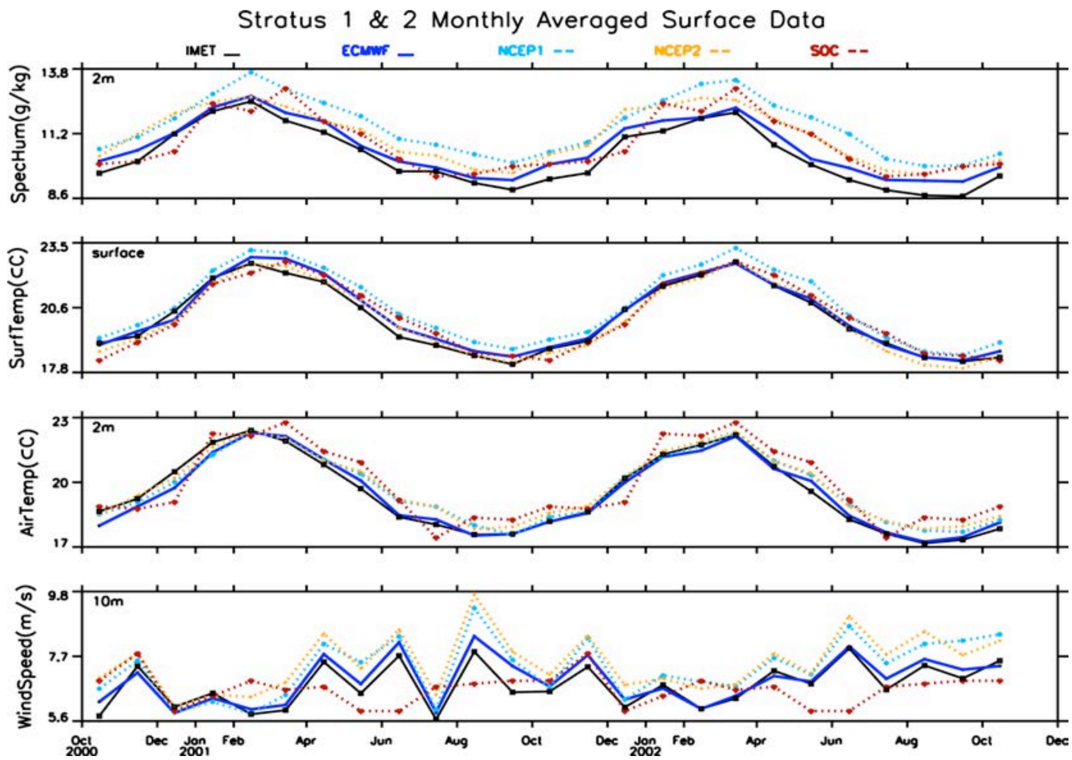


Figure II-3: Comparison of the first two years of stratus buoy meteorological data with atmospheric model reanalyses (ECMWF ERA-15, NCEP1, and NCEP2) and COADS climatologies.

Figure II-4 Comparison of the air-sea fluxes at the Stratus buoy for two years with reanalysis and climatological data as in Fig. II-2.

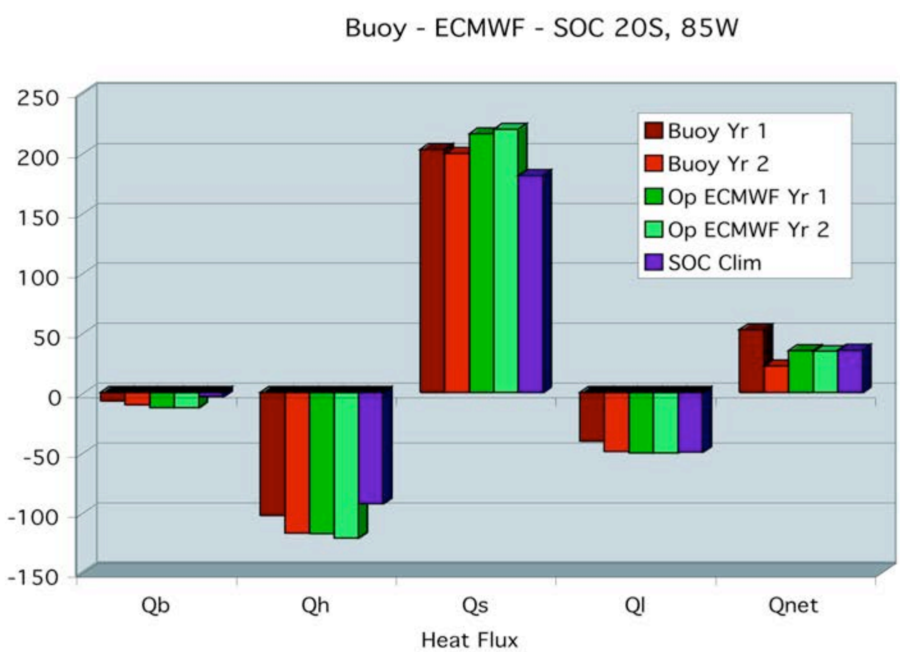


Figure II-5: Comparison of annual means of the heat flux components (sensible – Q_b, latent – Q_h, shortwave – Q_s, longwave – Q_l, and net heat – Q_{net}) for the first two years of data from the Stratus buoy with operational ECMWF model and SOC climatological heat fluxes.

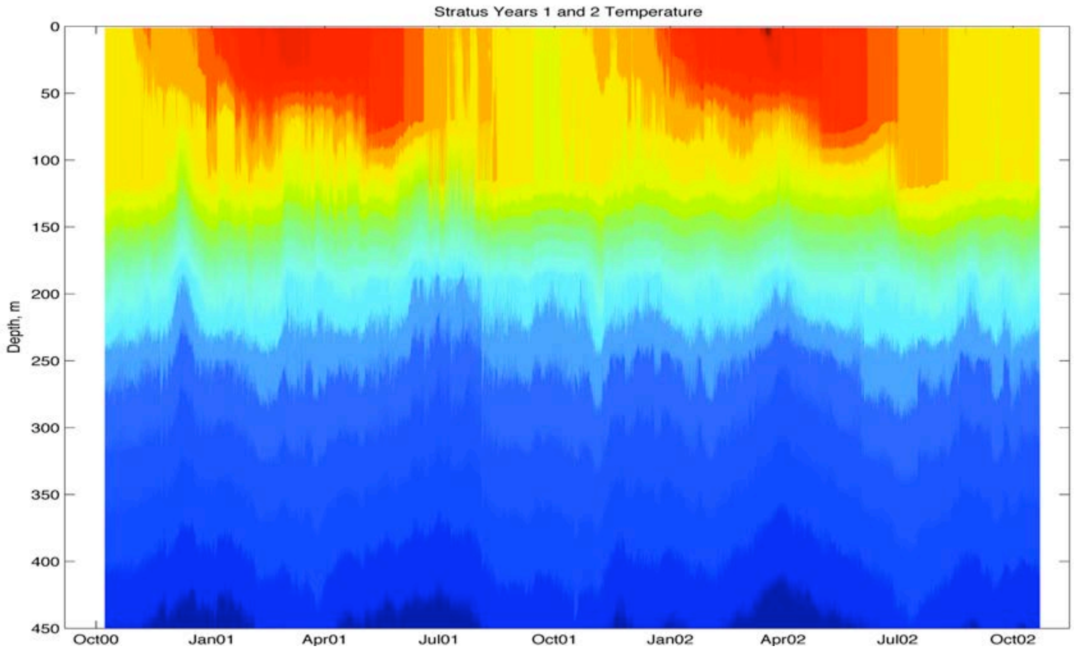


Figure II-6: Two years of temperature data from the upper 450 m at Stratus site.

meter data (Fig. II-7). Work is underway to quantify the extent to which this offshore flow carries cool water upwelled along the coast out under the stratus cloud deck. It has been found that local atmospheric heating of the ocean drives diurnal heating on low-wind days and a strong seasonal cycle, and also that another, non-one-dimensional process such as horizontal advection is needed to remove some of the heat from the atmosphere. We have just submitted a publication based on this work (Colbo and Weller, submitted – included in the Appendix.) The research community interested in stratus clouds, their impacts on radiation, and the processes that govern their formation have been very interested in the data. We have shared that data with the CLIVAR CPT (Climate Process Team) on cloud processes led by Chris Bretherton and participate in the steering team for that CPT. Our buoy data are being analyzed by several groups (Cronin at PMEL, Yuter, Bretherton, and Comstock at U. Washington, Nystuen at U. Washington Applied Physics Lab, and others) in the context of the EPIC program and the EPIC 2001 process study. Early results from EPIC 2001 are presented in Bretherton et al. (2004), which is included in the Appendix.

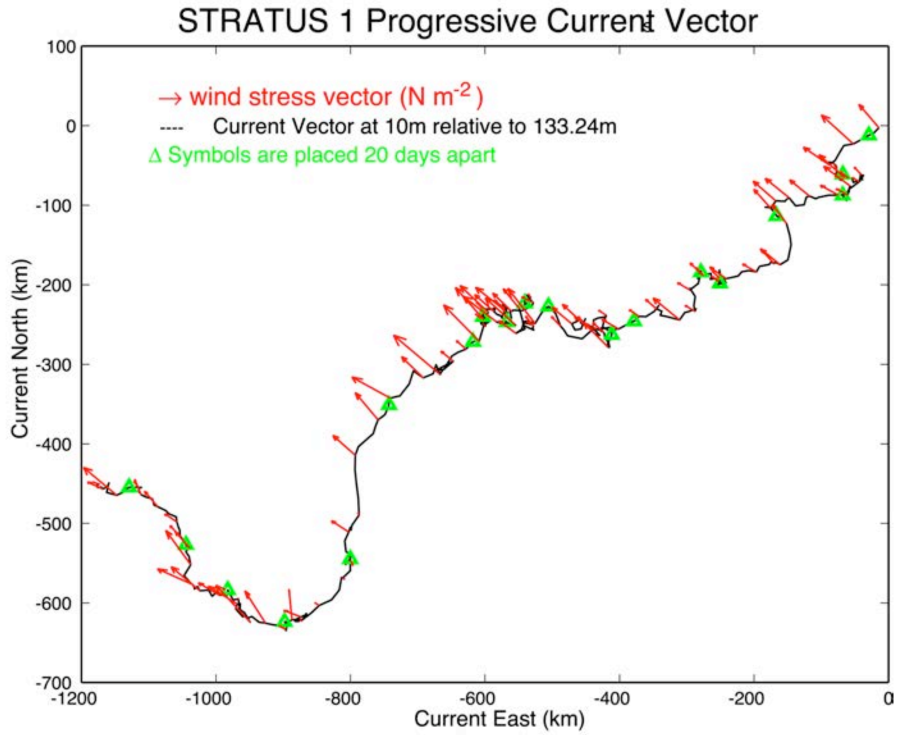


Figure II-7. The progressive vector diagram for the flow at 10 m relative to that at 133 m is plotted in black. Green triangles are spaced 20 days apart. Weekly-averaged wind stress vectors are shown as red arrows. The southeast Trades drive flow to the southwest in the upper ocean.

Task III NTAS Site:

The Ocean Reference Station grant will take over support for NTAS in 2005. At present NTAS is funded under its own grant, but managed by Al Plueddemann as an element of the Ocean Reference Station project. We thus include its report here.

The Northwest Tropical Atlantic Station (NTAS) project for air-sea flux measurement was conceived in order to investigate surface forcing and oceanographic response in a region of the tropical Atlantic with strong SST anomalies and the likelihood of significant local air-sea interaction on seasonal to decadal time scales. The strategy is to maintain a meteorological measurement station at approximately 15° N, 51° W through successive (annual) turn-arounds of a surface mooring (Fig. III-1). Redundant meteorological systems measure the variables necessary to compute air-sea fluxes of heat, moisture and momentum using bulk aerodynamic formulas.

NTAS has two primary science objectives. First, to determine the air-sea fluxes of heat, moisture and momentum in the northwest tropical Atlantic using high-quality, in-situ meteorological measurements from a moored buoy. Second, to compare the in-situ fluxes to those available from operational models and satellites, identify the flux components with the largest discrepancies, and investigate the reasons for the discrepancies. An ancillary objective is to compute the local (one-dimensional) oceanic budgets of heat and momentum and determine the degree to which these budgets are locally balanced.

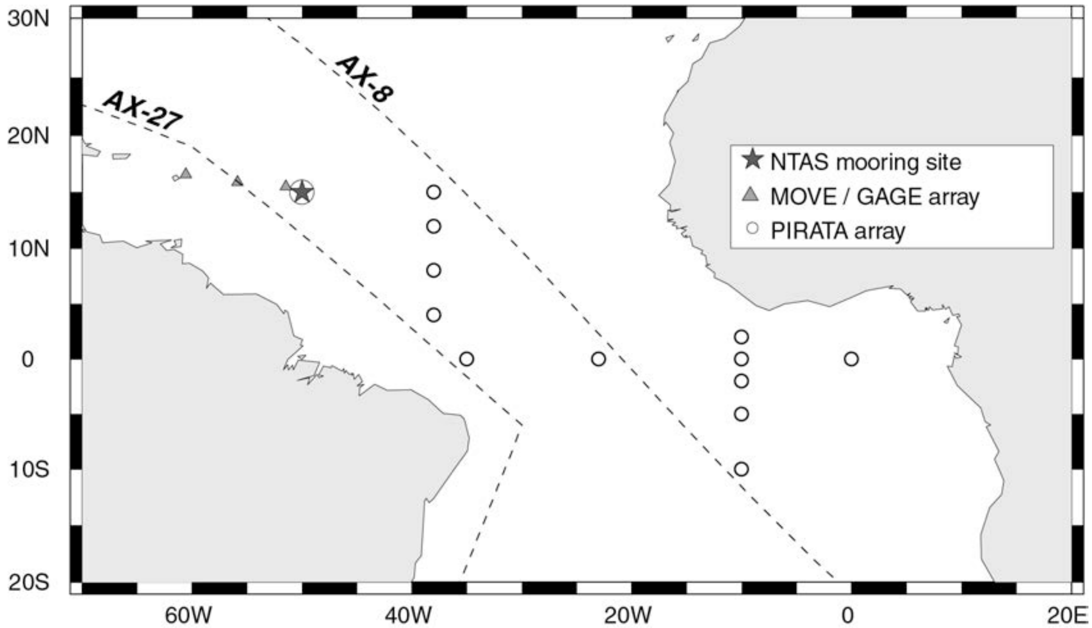


Figure III-1. Location of the NTAS site (circled star) relative to the GAGE/MOVE array (triangles) and the PIRATA array (circles). The approximate routes of XBT lines AX-8 and AX-27, along which surface flux observations are proposed, are shown as dashed lines.

This project addresses NOAA's Program Plan by maintaining an Ocean Reference Station providing high-quality surface meteorology and air-sea fluxes at a key site in the northwest tropical Atlantic. In conjunction with other elements of the Climate Observing System (e.g., volunteer observing ships) it is anticipated that the spatial scales over which the buoy data are applicable will be determined, leading to the development of improved surface flux fields for that region.

NTAS FY 2004 PROGRESS

Three Air-Sea Interaction Meteorology (ASIMET) systems were assembled and tested. Two systems, comprised of the best performing sensors, were mounted on a three-meter discus buoy in preparation for deployment. A mooring turn-around cruise was conducted on the NOAA Ship *Ronald H. Brown* in order to retrieve the existing mooring (NTAS-3, deployed 14° 50' N, 51° 01' W on 15 February 2003) and replace it with the new mooring (NTAS-4). The NTAS-3 mooring was recovered on 19 February 2004, and the NTAS-4 mooring was deployed at 14°44' N, 50°56' W on 21 February 2004. A 24-hour period immediately after deployment was dedicated to an intercomparison of the NTAS-4 ASIMET system and the shipboard meteorology. To ensure high-quality meteorological data, all NTAS-4 sensors were calibrated prior to deployment, and NTAS-3 sensors will be post-calibrated.

Data return from the ASIMET system on NTAS-3 was 100% for all sensors. NTAS-2 also had 100% data return. NTAS-1 had partial data return from AT, RH, SST and SSC sensors. However, the purposeful redundancy of the system meant that alternate sensors could be used in each case, and a complete record of NTAS-1 surface meteorology was obtained. The meteorological data are being used as the basis for air-sea flux computations using bulk formulas. Post-calibrated and quality controlled data from NTAS-1 and NTAS-2 are archived at WHOI and available on line from the UOP web site. Complete, but uncorrected data from NTAS-3, and 8 months of uncorrected data from NTAS-4 are also available on-line.

The project used 14 days of ship time on the *Ronald H. Brown* in FY2004. Logistical challenges and unanticipated project costs tend to revolve around ports, shipping and ship scheduling. For example, in 2002 the mooring service cruise was a very efficient 7-day round-trip out of Barbados, but we incurred substantial costs for port services and shipping relative to our budget, which was for a domestic port. For the 2003 cruise, shipping costs were reduced substantial because we were able to partially load and offload *Oceanus* in Woods Hole. However, the cruise duration (Barbados/Woods Hole rather than Barbados/Barbados) was many days longer than budgeted, and we effectively traded shipping costs for salary costs. In 2004 the situation was intermediate between the two. The cruise was on the *Ronald H. Brown* out of Charleston, SC, so the domestic shipping costs were in line with our budget. However, salaries for the cruise (Charleston/Barbados) and a return trip to Charleston to offload the ship were higher than budgeted.

NTAS Research highlights:

Figure III-2 shows the annual cycle at the NTAS site as depicted by selected meteorological variables averaged over 1 week on a 13-month time base. Spring (MAM) is characterized by SST increasing from its annual minimum and very low levels of precipitation. Summer (JJA) is characterized by steady northeast winds (towards 255°) at 6-8 m/s and continuing increases in SST. Episodic precipitation begins in late summer. Fall (SON) is characterized by reduced solar radiation, SST decreasing from its annual maximum, persistent precipitation, and variable winds. By mid winter (DFJ), solar radiation begins to increase, precipitation decreases, and winds become steadier. A distinct surface salinity minimum is observed in early winter of the first two years. Monthly averages show a clear tendency for strong precipitation to be associated with SST above 27°C, as is characteristic of the Inter-Tropical Convergence Zone.

A preliminary assessment of surface meteorology and fluxes for the NTAS site was made by comparing ASIMET data from the NTAS-1 buoy with numerical model products from ECMWF and NCEP. The ASIMET data were from the best performing sensors on the buoy, logged at 1 min intervals. The ECMWF data were from the surface meteorology and diagnostics variables of the operational forecast model for the grid point nearest the buoy (courtesy of Anton Beljaars). NCEP-1 fluxes were from the NCEP/NCAR Reanalysis-1 data set and the NCEP-2 fluxes were from the NCEP/DOE Reanalysis-2 data set. The SOC climatology is based on COADS ship reports from 1980-1993. The ASIMET (1 min) and ECMWF (1 hour) data were averaged over six hours to match the NCEP time base.

Initial comparisons of the NTAS 1 and 2 fluxes with gridded products (Fig. III-3) indicate a variety of issues for further investigation. The two-year mean net heat flux is significantly underestimated by the three models (mean differences are 4-5 times larger than the expected error of about 10 W/m^2 from the buoy data). For ECMWF and NCEP-1 this is due to overestimation of latent heat losses and underestimation of shortwave gains. NCEP-2 shows a dramatic improvement in shortwave flux relative to NCEP-1, but still has a large net heat flux error due to substantial overestimation of latent heat losses. As a result, the amplitude of the annual cycle and the timing of positive to negative heat flux transitions are poorly reproduced by the models. In addition, all three models indicate a negative two-year mean net heat flux, whereas the observed value is +40 W/m^2. Interestingly, the climatological net heat flux is a better match to the observations than any of the models.

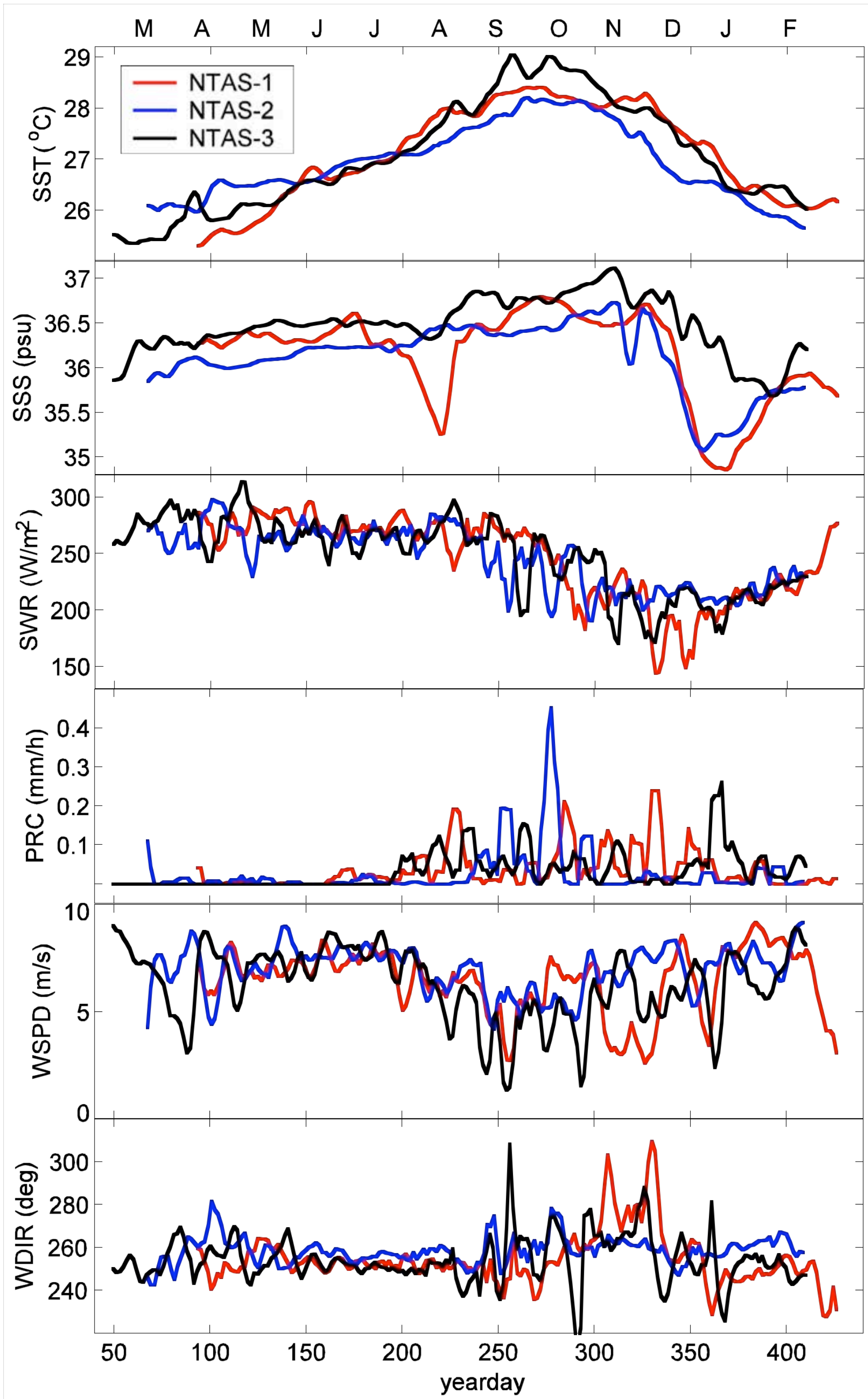


Figure III-2. The annual cycle of surface meteorology at the NTAS site as depicted by selected meteorological variables averaged over 1 week on a 13-month time base. Sea surface temperature (SST), sea surface salinity (SSS), downwelling shortwave radiation (SWR), precipitation rate (PRC), wind speed (WSPD) and wind direction (WDIR) are shown for deployments in 2001 (NTAS-1, red), 2002 (NTAS-2, blue) and 2003 (NTAS-3, black).

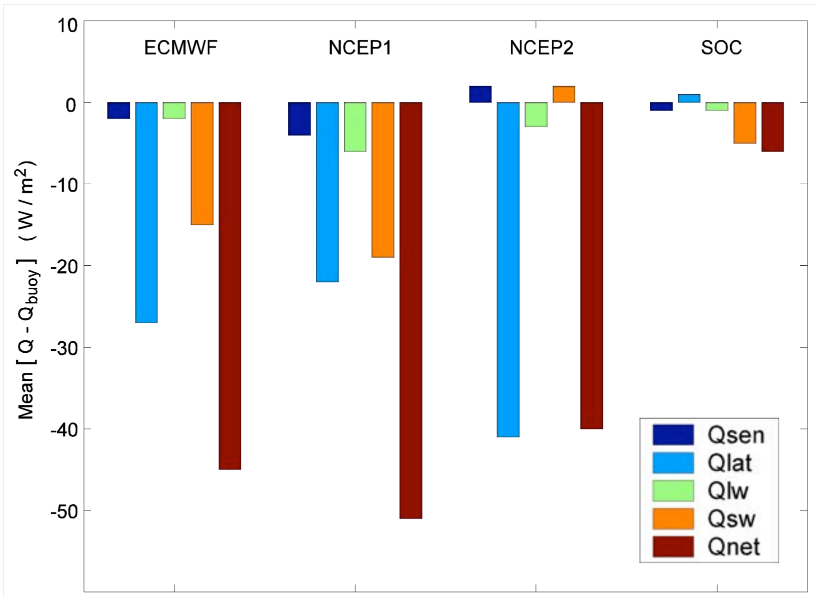


Figure III-3. Mean differences between heat flux components from gridded products and the NTAS buoy for a two-year period beginning in March 2001.

Task IV Hawaii Site:

This past year, with support from an add task put forward last year, we advanced the timetable for this element of the effort by two years. We had identified Hawaii as a third Ocean Reference Station site that would have high value to the integrated ocean observing system and also that could be maintained with tractable logistics and in cooperation with partners. These criteria were met, and we deployed a surface mooring equipped with two ASIMET meteorological systems at the HOT site, just north of Hawaii, in August 2004. The willing collaborators included Roger Lukas and colleagues at the University of Hawaii and Tom Dickey of the University of California, Santa Barbara. The logistics of cruises in and out of Hawaii were affordable and convenient, as some gear is now being staged there, reducing cost. Further, the heritage of prior observations at that site points to the value of an Ocean Reference Station there.

HAWAII FY2004 PROGRESS

Acquisition: None. Deployments, Data Return, Measurements, Data Storage, Data Use and Sharing, Data Archiving: The first deployment was successful and occurred in August 2004. Telemetered meteorological data is being made publicly available via the web. This data, plus that raw data to be recovered next year will be archived and made available.

Anticipated and Unanticipated Costs: Schedule has advanced two years, to deploy in the second year will require funds originally budgeted in the fourth year. These funds are listed below as an add task.

Problems and Logistical Considerations: Arranging for ship time each July is proving to be difficult; NOAA not having funds for the ship time continues to be a problem.

Implementation of One High Density XBT Line with TSG and IMET Instrumentation in the Tropical Atlantic

by Robert Weller

PROJECT SUMMARY

Central to present efforts to improve the predictability of climate is the need to understand the physics of how the atmosphere and ocean exchange heat, freshwater, and momentum and, in turn, to accurately represent that understanding in the models to be used to make predictions. At present, over much of the globe, our quantitative maps of these air-sea exchanges, derived either from ship reports, numerical model analyses or satellites, have errors that are large compared to the size of climatically significant signals. Observations made using the IMET technology on the Volunteer Observing Ships on long routes that span the ocean basins are essential to providing the accurate, in-situ observations needed to:

1) identify errors in existing climatological, model-based, and remotely-sensed surface meteorological and air-sea flux fields,
2) to provide the motivation for improvements to existing parameterizations and algorithms,
3) to provide the data needed to correct existing climatologies, and
4) to validate new model codes and remote sensing methods.

AutoIMET was developed by the Woods Hole Oceanographic Institution to meet the need for improved marine weather and climate forecasting. It is a wireless, climate quality, high time resolution system for making systematic upper ocean and atmospheric measurements. This interfaces to the NOAA SEAS 2000 (Shipboard Environmental (Data) Acquisition System) that automatically receives meteorological data (from the AutoIMET) and sends in automated one-hour satellite reports via Inmarsat C. This system will document heat uptake, transport, and release by the ocean as well as the air-sea exchange of water and the ocean's overturning circulation.

Note that descriptions, technical information and data from the several VOS being serviced are posted on the site: http://uop.whoi.edu/vos/. Data (plots) are available for all ship sets.

Data (numbers) are available via anonymous ftp for the last data set only:
ftp.whoi.edu/pub/users/fbahr/VOS. If data from previous times are desired please contact Frank Bahr at: fbahr@whoi.edu.

There is a link to the site: http://frodo.whoi.edu where there is detailed information on the AutoIMET and ASIMET modules. Instrument design questions can be addressed to Dave Hosom at: dhosom@whoi.edu.

Ship selection and interface to the NOAA SEAS system is via AOML. There is ongoing cooperation with Scripps via the CORCIII program as well as Southampton Oceanography Centre (SOC) of Southampton UK on Computer Flow Dynamics (CFD) for evaluation of the flow turbulence around the ship and its effect on the sensor placement. Some logistic support is provided by the Southern California Marine Institute on ship turnarounds. There is ongoing cooperation with the Atlantic Oceanographic and Meteorological Laboratory (AOML) in Miami on the Atlantic VOS program. There is also ongoing cooperation with many sensor manufacturers and the VOS people at the German Weather Service (Deutscher Wetter Dienst) in Hamburg Germany.

This project is managed in accordance with the Ten Climate Monitoring Principles.

FY 2004 PROGRESS

Ship selection for the Atlantic VOS was made late in 2003. AutoIMET systems were installed in June 2003 and December 2003 on the Pacific ships as part of a companion project.

SeaLand Express

- January 2004. A survey of the SeaLand Express was carried out by Frank Bahr in Newport News, VA in preparation for the AutoIMET system installation.

- March 2004. The AutoIMET system was installed on the SeaLand Express in Elizsabeth, NJ by Frank Bahr, Craig Marquette, Alan Gordon and Dave Hosom. The time in port was short and the weather was nasty. Steve Cook and Jim Farrington of NOAA helped with the AutoIMET installation and did the new NOAA SEAS 2000 installation on the bridge. The system was operating well with the exception of SST.

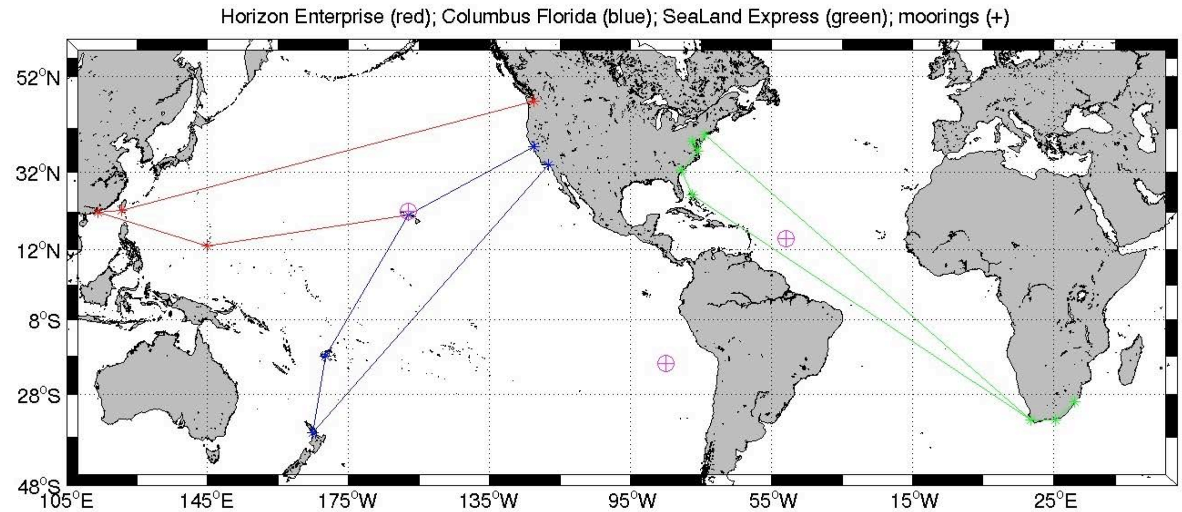
- May 2004. Frank Bahr visited the ship in Elizabeth, NJ to trouble shoot the SST system. The SST sensor (SeaBird 48) self records one-minute data but was not being transmitted via the HullCom (acoustic modem) to the logger on the bow mast. The “Local” and “Remote” HullCom units were re-located to try to get a better acoustic path. The system was still not working properly. The SST and HullCom units were removed from the ship and returned to WHOI. The units were tested and WHOI and found to be operating properly, pointing to the acoustic path as the problem. It is possible to re-locate the “Remote” HullCom so that the acoustic path is very short by using a 100-foot long cable between the “Remote” HullCom and the SBE48. This will be installed in June.

- June 2004. Frank Bahr and Laura Hutto reinstalled the SST and HullCom units on the SeaLand Express in Elizabeth NJ. There are reports of high wind “spikes” in the data, therefore a new WND module will be taken to the ship as well as a new IMET GPS to monitor “real wind” in post processing. The “real wind” currently is calculated in the NOAA SEAS 2000 system using the SEAS GPS data.

- August 2004. The wind sensor encoder failed and was replaced when the ship was in Baltimore, MD. Encoder failures seem to be due to overvoltage from the power supply coupled with ship power surges.

- October 2004. The system was turned around in Baltimore, MD. The data will be processed and be available on the web. The in port time was very short and the SST could not be serviced since there was welding in the hold that the SST is located in. A SST replacement is planned when the ship returns to Baltimore. The existing batteries should maintain SEAS data from the SST through December 2004 and the SST logger will continue until May 2005 even without battery changes.

ROUTE MAP



Note the Ocean Monitoring Stations (circle with cross) being operated by WHOI.

FY 2005 Plans

Office of Climate Observation, Climate Observation Program
by Mike Johnson

FY 2005 PLANS
The third Annual System Review will be held in Silver Spring, April 25-27. In addition the Office of Climate Observation (OCO) will host a meeting of the JCOMM Observations Coordination Group in conjunction with the System Review, April 28-29.

Advancements across all networks are planned in FY 2005 and are outlined in the individual reports that follow. The global ocean climate observing system will surpass the 50% completion milestone. Some significant highlights include:

- *Documenting long-term trends in sea level change*: Tide gauge stations, particularly in the Indian Ocean, will be upgraded for real-time reporting to contribute to the international tsunami warning system as well as to climate change monitoring. Transition from NASA to NOAA responsibility for the long-term support of the Harvest Platform altimeter calibration station will be completed.
- *Documenting the ocean's heat exchange with the atmosphere*: A significant observing system milestone will be achieved in September 2005. The Global Drifting Buoy array will reach its design capacity of 1250 drifters, thus becoming the first component of the Global Ocean Observing System to be completed. It has taken 10 years since the international community set out on the GOOS quest with the publication of the *Scientific Design for the Common Module of the Global Ocean Observing System and the Global Climate Observing System* by the Ocean Observing System Development Panel in 1995. A special celebration will be held during the second JCOMM Assembly in Halifax in September 2005 to commemorate this achievement and ceremonially deploy Global Drifter #1250. Expansion of the Tropical Moored Buoy network into the Indian Ocean will continue. Three sites were established in November 2004 by NOAA/PMEL in cooperation with Indian partners and two additional deployments are planned in 2005. In the Atlantic Ocean, PIRATA will be extended in cooperation with Brazil and France with two new moored buoy sites being established in the South West Expansion off the coast of North East Brazil.
- *Documenting the ocean's storage and global transport of heat*: The transition of the Indo-Pacific high-resolution XBT lines from NSF to NOAA long-term support will be completed. NOAA will thus become the sole agency of the United States supporting this sustained component of the international system. NSF will shift their funding to new CLIVAR research. In cooperation with the Brazilian navy, a new high resolution XBT line will be established to monitor meridional ocean transport across the western Atlantic.
- *Documenting carbon sources and sinks*: The global inventory of ocean carbon is needed at least once every 10 years. Systematic surveying of the ocean was initiated in partnership with NSF but the level of funding was only adequate for NOAA to complete its contribution to the global effort in at best 14 years. In FY 2005 NOAA will augment the project to bring the rate of survey up to the required 10-year cycle. Two new moored buoy sites will be established for long term ocean carbon monitoring, one in the Pacific and one in the Atlantic.
- *Data management*: A new tariff rate for data processing within the international Joint Tariff Agreement, which supports the Argos satellite data transmission/distribution system, will establish OCO as a preferential bulk user. OCO is the largest single government user of the Argos system in the world. The new agreement will transfer all primary and supplement costs to central management at OCO and will save an estimated 45% in data processing costs system wide. Global data base operations at the ocean data assembly center at NDBC will become

operational, thus combining Global Telecommunications System (GTS) and web based data sources into a single data base for near real time observing system monitoring.

- *Product delivery and observing system evaluation*: In 2005 OCO will begin a partnership with NCEP for routine delivery of ocean analysis products based on NCEP's operational Global Ocean Data Assimilation System (GODAS) output. A team of experts sponsored by OCO will begin routine evaluation of the model output products against observations with the goal of improving both the model outputs and observing system sampling strategies. The performance measure for reducing the error in global measurement of sea surface temperature that was developed in FY 2003 will serve as an example for developing three additional quantitative performance measures in FY 2005. Metrics will be developed for the Government Performance Review Assessment (GPRA) to quantitatively measure system progress in reducing errors in global measurement of sea level change, ocean carbon sources and sinks, and ocean heat storage and global transport.

Climate Observation Program
Budget ($K)
FY 04 Actual; FY 05 Planned

Network	System Total			Budget Line Accounts: C&GC		CCRI		COSP		CCRI CO2		ENSO/PACS		Other	
	FY 04	FY 05	Change	FY 04	FY 05	FY 04	FY 05	FY 04	FY 05	FY 04	FY 05	FY 04	FY 05	FY 04	FY 05
Tide Gauges	970	1345	375	0	275	320	921					650	0	0	149
Surface Drifting Buoys	2769	3406	637	627	386	1382	2324					760	696		
Ships of Opportunity	2487	2990	503	306	788	1184	885					530	1317	467	0
Tropical Moored Buoys	3625	4135	510	600	0	0	510	450	450			2575	3175		
Argo Floats	273	275	2	273	275										
Ocean Reference Stations	2819	3319	500	0	425	2282	2445					190	377	347	72
Arctic Ice Buoys	0	60	60											0	60
Ocean Carbon Networks	2875	3525	650	0	77	0	154	1616	1873	1259	1244	0	135	0	42
SURFRAD	210	0	-210	105	0									105	0
Rain Gauges	179	184	5	149	184									30	0
Dedicated Ships	523	80	-443	523	80										
Service Argos Data Processing	1525	1075	-450	235	125	626	825					664	0	0	125
Data & Assimilation	369	443	74	369	343	0	100								
Analysis & System Evaluation	658	1629	971	358	815	0	514	0	300			300	0		
Program Management	684	960	276	629	960	30	0					25	0		
Overhead	826	152	-674	826	152										
Total	20792	23578	2786	5000	4885	5824	8678	2066	2623	1259	1244	5694	5700	949	448

Table 1

3.1b. Atlantic High Density XBT Lines

by Molly Baringer, Gustavo Goni and Silvia Garzoli

FY 2005 PLANS

We plan to carry out four transects along AX07, AX10, AX08 and AX18, and a minimum of two transects along AX25.

Anticipated requirements to maintain the network at status quo

Augmented funding to cover increased costs of XBTs, now $32 per probe.

Logistics requirements:

Current levels of ship availability are needed.

New data collection methods:

We are currently testing a new 8-probe autolauncher and utilizing the new SEAS 2000 software for data collection.

Expected scientific results

We intend to identify the surface signal of each zonal current identified in the AX08 transects in the upper 750m by combining the XBT-derived temperature sections and the sea height anomaly fields from altimetry. We plan to continue the estimates of the meridional heat fluxes across 30°S (AX18) and 30°N (AX07) and combine these results with satellite observations to produce estimates when XBT observations are not available.

3.2b. Western Boundary Time Series in the Atlantic Ocean

Project Managers: Molly Baringer and Silvia Garzoli
Scientists Involved: Molly Baringer, Christopher Meinen, Silvia Garzoli, and Elizabeth Johns

FY 2005 PLANS

Task 1, Continuous transport of the Florida Current

- Continuous cable data recording will continue.
- 4 RV Walton Smith calibration cruises are planned. Tentative dates: Dec 04; Mar, Jun, Sep 05.
- Construction of 2 new dropsondes will be completed: 1 new one with self-recording CTD sensor for temp, salinity and pressure measurements; dropsonde with faulty antenna will be repaired.
- Approximately eight dropsonde cruises will be conducted: the cruises will be closely timed near the Walton Smith cruises and the AX7 high density XBT line.
- Web site will be enhanced once data quality stabilizes.
- Test/improve cable and section processing software.
- Study the disparity between LADCP and dropsonde transport estimates.

Task 2: Deep Western Boundary Current Time Series

- The NOAA Ship Ronald H. Brown will be used for the next Deep Western Boundary Current cruise, currently scheduled for summer/fall of 2005. Station locations close to those shown in Figure 2 will be sampled (including more complete sections at 26ºN and an Abaco section out to at least 70ºW). Should weather again become an issue, the first priority will be to the stations east of the Bahamas, second priority to the stations at 27ºN in the Florida Straits.
- The inverted echo sounders already deployed will be interrogated to telemeter their data to the ship. Through cooperation with the NSF funded MOCHA program, an additional hydrographic section will be occupied in April 2005. Additional data will be downloaded at that time, thus allowing us to process DWBC data in 6-month delayed intervals.
- Continue time series of water mass changes within the Deep Western Boundary Current.
- Compare section data across the Deep Western Boundary Current to the data from the moorings and begin construction of a transport time series.

Logistics requirements (e.g., shiptime)

Current levels of clearance and ship time are needed. The number of Sea Days requested should be maintained in spite of mechanical or logistical considerations that may affect the Ronald H. Brown schedule. Adequate resources must be made available to the Ronald H. Brown in order to assure that all scientific equipment is in proper working order to meet the science objectives.

New data collection methods

Add Task proposed to purchase backup recording equipment; instrument a second cable.

Expected scientific results

This proposal is funded to conduct fieldwork and data collection. Nevertheless, continued measurements of the western boundary currents will help scientists to:

- Monitor for abrupt climate change
- Understand natural climate variability
- Determine heat, fresh water and volume transports of two major components of the thermohaline circulation

3.3b. The Tropical Atmosphere Ocean (TAO) Array

by Landry J. Bernard, III and Daniel J. Laurent

FY 2005 PLANS
TAO/TRITON Array

Plans in FY 2005 call for maintaining 55 ATLAS mooring sites and 4 ADCP mooring sites between 95°W and 165°E. We anticipate that NOAA ship time requirements to maintain the TAO portion of the TAO/TRITON array in FY 2004 to be 278 days. Most of this ship time will be on the Ka'imimoana (236 days), with additional time provided by the Ron Brown (42 days).

We expect to get TAO salinity data on the GTS in early FY 2005. Service Argos has developed necessary algorithms, and the system is being tested. TRITON salinity data are already on the GTS.

We will continue to pursue engineering improvements to the array, specifically those that relate to improved compass accuracy, wind sensor reliability, and improved velocity measurements.

TAO Project staff will participate in the drafting of technical reports regarding measurement accuracy and sensor performance. The Project Director continues his analysis of TAO and related data sets, and his public service. Paul Freitag will continue his service as TAO representative to the DBCP and has already represented the Project at the October 2004 meeting of the DBCP in Chennai, India.

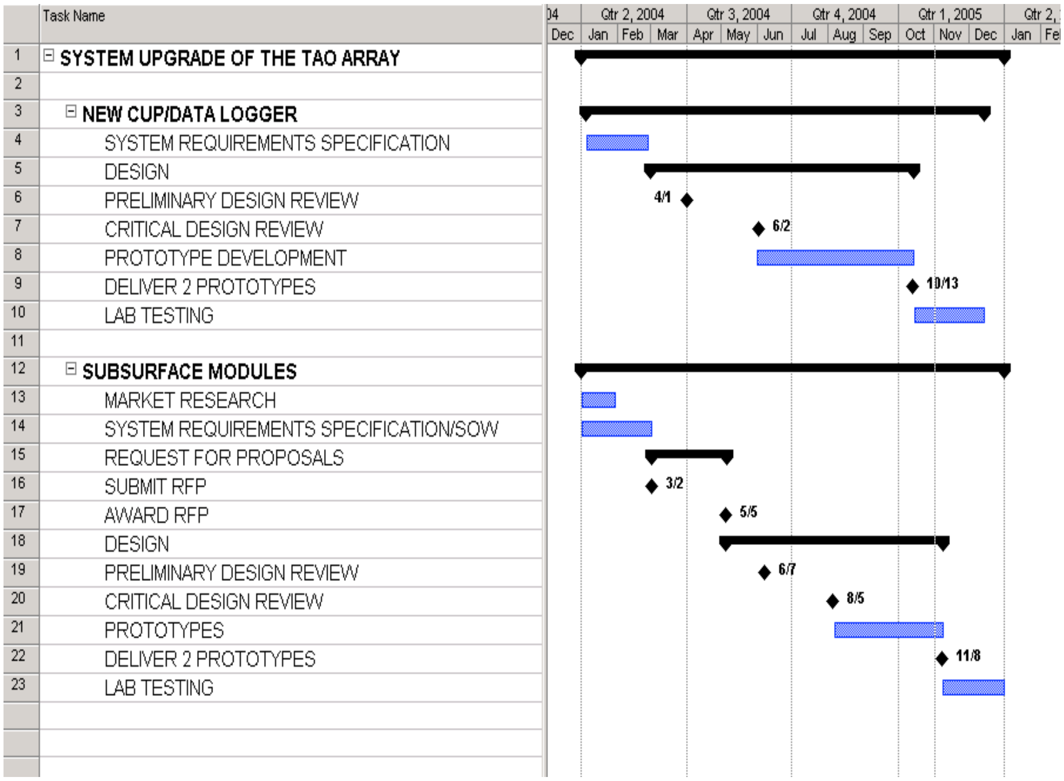
We will provide assistance to Oregon State University in their development of a new instrument to measure temperature gradient microstructure from a deep-water mooring. An initial test deployment from an ATLAS mooring is scheduled for the 4th quarter of FY 2005.

FY 05 TAO Transition Plans

a. Maintain the existing TAO array at current availability.
b. Establish the NDBC tropical mooring data assembly center (DAC) using NDBC’s Technical Services Contract and operate in parallel with current TAO Data Center at PMEL. DAC will provide Quality Assurance (QA/Quality Control (QC) of all data for both research and operational users, maintain TAO data base, maintain TAO data on web site, and distribute data via the NDBC web site, an IOOS DMAC standard distribution mechanism (i.e. OPeNDAP and GTS).
c. Prepare DAC Statement of Work (SOW) to design, integrate, test, and operate the NDBC DAC.
d. Establish liaison with JAMSTEC to document JAMSTEC requirements and integrate JAMSTEC’s data into NDBC DAC.
e. Establish NDBC/PMEL TAO Transition Team in Seattle.
f. Provide a Technology Refreshment Plan to the Climate Program for approval and replace any obsolete array components as available funding allows.
g. Ensure TAO array assets (i.e., buoys and ship resources) are available for research activities.
h. Provide next generation mooring proposal to Climate Program for approval.
i. Inventory TAO array and place under NDBC’s management.

Schedule

The following schedule starts when the proposal is awarded and the funds are available.


Task Name
Qtr 2, 2004
Qtr 3, 2004
Qtr 4, 2004
Qtr 1, 2005
Dec Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec Jan
1 SYSTEM UPGRADE OF THE TAO ARRAY
2
3 NEW CUP/DATA LOGGER
4 SYSTEM REQUIREMENTS SPECIFICATION
5 DESIGN
6 PRELIMINARY DESIGN REVIEW
7 CRITICAL DESIGN REVIEW
8 PROTOTYPE DEVELOPMENT
9 DELIVER 2 PROTOTYPES
10 LAB TESTING
11
12 SUBSURFACE MODULES
13 MARKET RESEARCH
14 SYSTEM REQUIREMENTS SPECIFICATION/SOW
15 REQUEST FOR PROPOSALS
16 SUBMIT RFP
17 AWARD RFP
18 DESIGN
19 PRELIMINARY DESIGN REVIEW
20 CRITICAL DESIGN REVIEW
21 PROTOTYPES
22 DELIVER 2 PROTOTYPES
23 LAB TESTING
4/1
6/2
10/13
3/2
5/5
6/7
8/5
11/8

3.4b. ENSO Observing System, XBT component, Task 1-Operations
by Steven K. Cook and Robert L. Molinari

FY 2005 PLANS

Anticipated requirements to maintain the network at status quo

The $32 cost per probe will continue through this fiscal year.

Expected scientific results

Further definition of the spatial patterns of important decadal signals in upper ocean thermal structure in all three-ocean basins, characterization of the decadal signals of these signals and nowcasts of the phase of these signals.

3.5b. CORC: Surface Fluxes and Analysis

by Dan Cayan

FY 2005 PLANS

1. Update estimates of heat flux (short wave, long wave, latent and sensible), moisture flux (evaporation), and momentum flux from COADS data through summer 2004 for individual observations and for monthly aggregates of daytime and nighttime periods.

2. Evaluate daytime vs nighttime differences of fluxes and key variables. Examine diurnal variability of fluxes and key variables to understand the daytime vs. nighttime differences. Focus on eastern North Pacific, but include whole Pacific and Atlantic as a basis for comparison.

3. Evaluate variability of the daytime and nighttime heat fluxes in connection with the changes in sea surface temperature and with available observational estimates of heat storage changes. Focus on eastern North Pacific, but include whole Pacific and Atlantic as a basis for comparison.

4. Distribute monthly flux data via FTP server with web site interface to describe dataset and bulk formuale employed. Requests for individual weather observations and associated flux estimates will be handled on an individual basis.

3.6b. CORC: Four-Dimensional Variational (4DVAR) Data Assimilation in the Tropical Pacific
by Bruce Cornuelle, Detlef Stammer and Art Miller

FY 2005 PLANS

After a detailed analysis of the different assimilation runs, we will examine the forecast skill of our assimilation system. The length of the assimilation period will be extended to several years and most of the CORC data will be also used in our assimilation system. The assimilation of profiles data is expected to reveal a crucial need of using smoothed error covariance matrices in the 4DVAR cost function. This last point will be carefully examined in our future work. We also aim at adjusting the mixing parameters by including them in the control vector in order to improve the quality of our analysis, particularly in the deep ocean. This work will produce a time-evolving ocean state estimate and an improved set of forcing and boundary conditions. These products will be analyzed to quantify forcing errors and to examine the detailed ocean structure and dynamical evolution through several ENSO cycles. The complete set of products (ocean state, forcings and boundary conditions) will be made available to the community for general scientific studies in tropical Pacific.

Figures

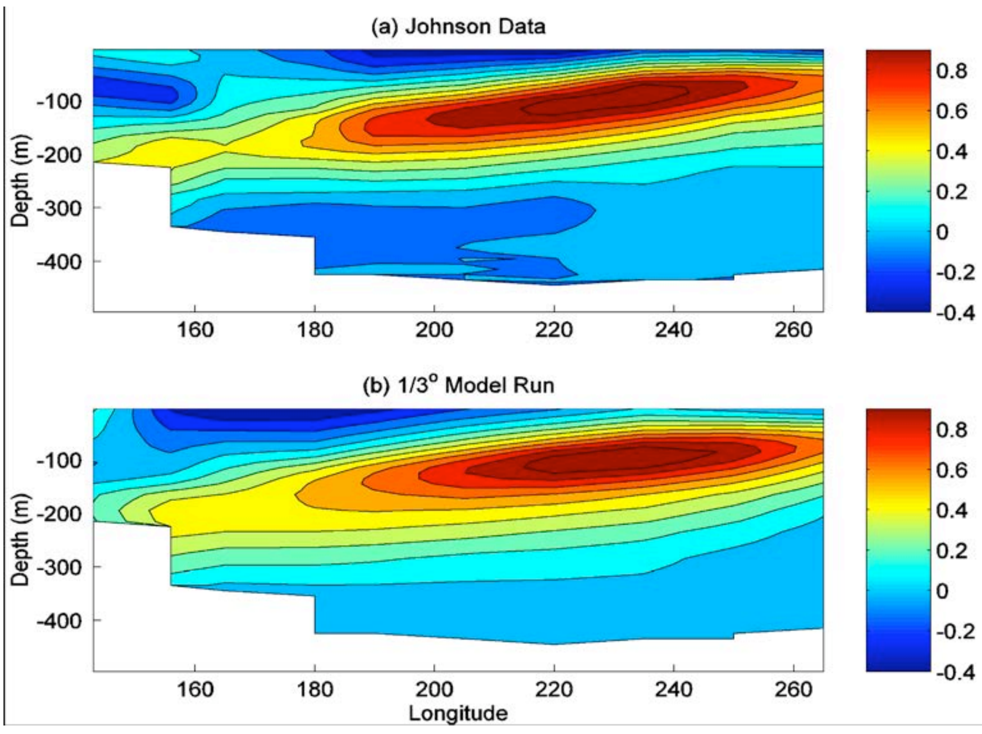


Figure 1. Mean Zonal Velocity on the equator from (a) Johnson data, and (b) 1/3° MITgcm free-run without assimilation.

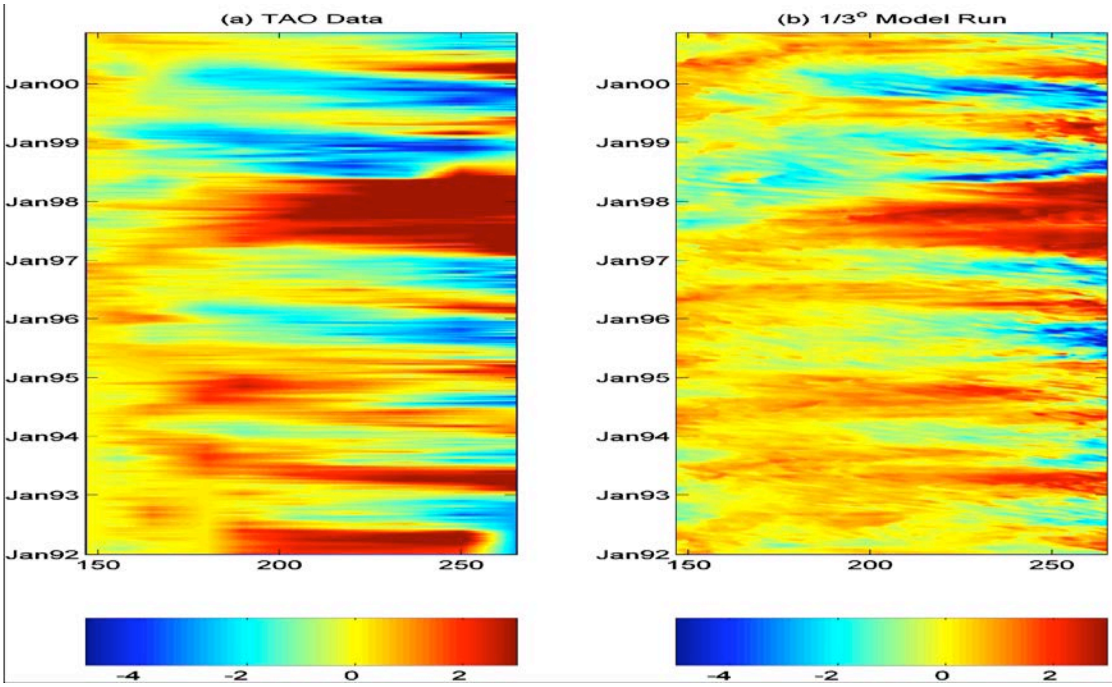


Figure 2. Sea surface temperature anomalies on the equator from (a) TAO data, and (b) 1/3^o MITgcm free-run without assimilation.

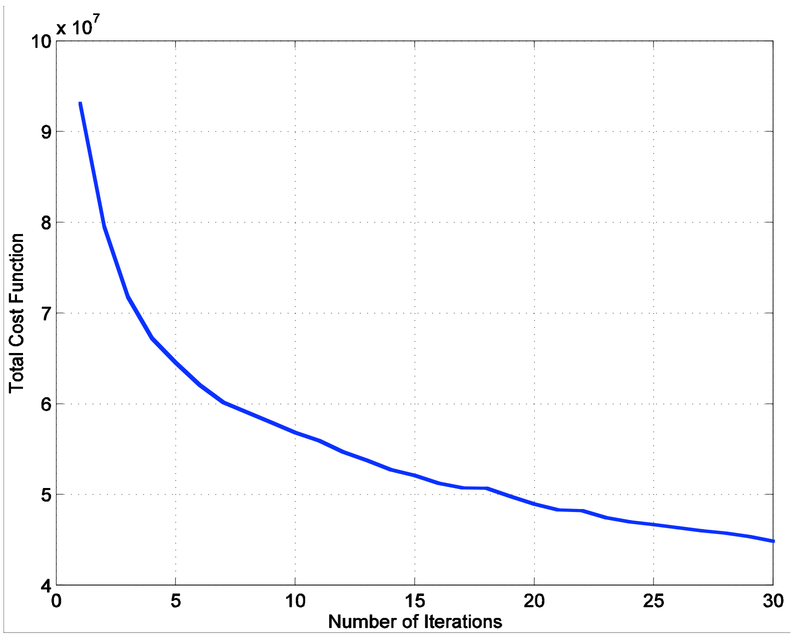


Figure 3. Evolution of the total cost function (over 1 year assimilation period) as function of the number of iterations.

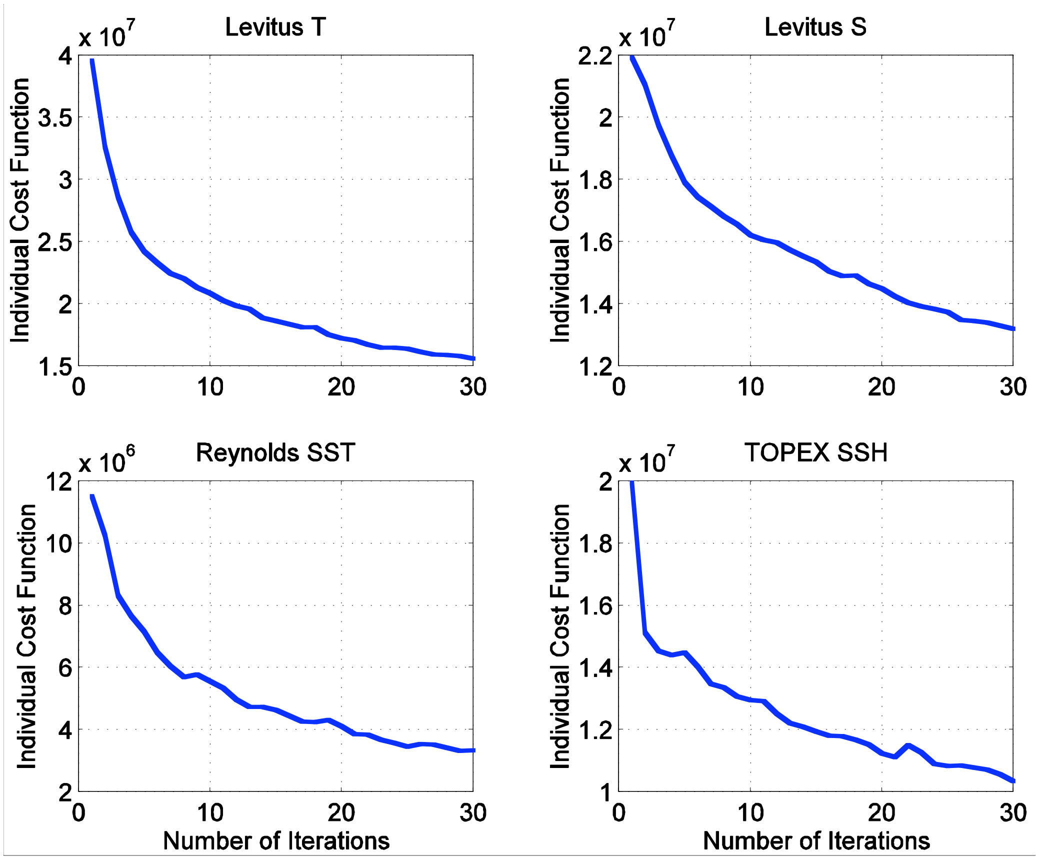


Figure 4. Evolution of the individual cost function observation terms (over 1 year assimilation period) as function of the number of iterations.

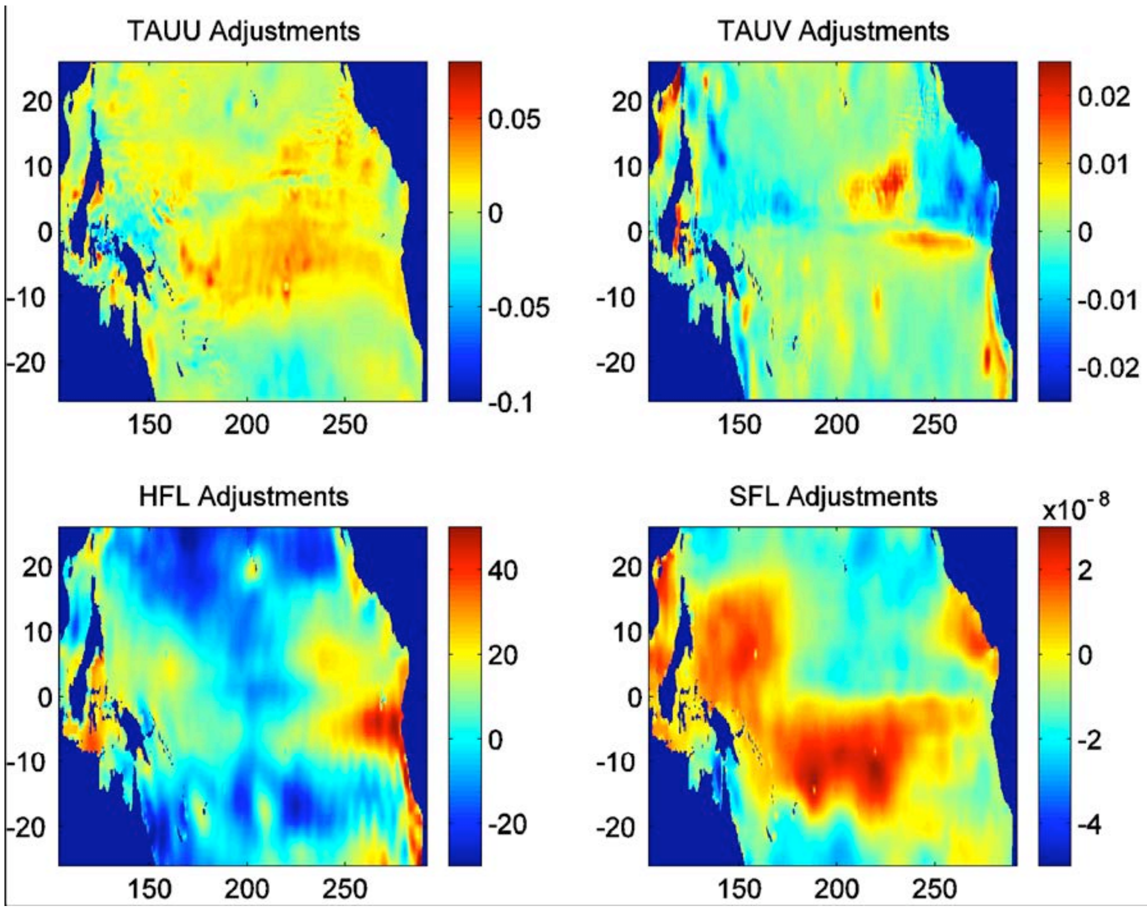


Figure 5. Mean adjustments to the NCEP forcing fields as estimated by the 4DVAR assimilation.

3.7b. CORC: Underwater Gliders for Monitoring Ocean Climate

by Russ E. Davis

FY2005 PLANS

Equipment Acquisition. To date we have completed 3 Spray gliders for this program and lost one through collision with a surface vessel. One remaining glider has been upgraded with an ADP and the other with a Sea Bird CTD. During FY05 we will complete 3 new Spray gliders now under construction and fit all with SBE CTDs and Sontek ADPs. We will also begin construction of the final 3 gliders to be built under this program.

Technical Development. The technical improvements introduced in FY04 need long-term testing for reliability and effectiveness. We will complete the final development on our list by installing optical sensors (chlorophyll-a florescence and optical backscatter) inside the pumped system where they can be protected from bio-fouling. This will require field testing for effectiveness and to verify accurate readings in the new circumstances.

Pilot Repeat Section in the California Current. The technical developments all require long-term field tests and we will use this as an opportunity to add to the climate record. One of the longest extant ocean climate time series is the CalCOFI program's 54 year sampling of the California Current System (CCS). This record clearly shows how climate variability, most notably connected to the ENSO and PDO cycles, influences the physical structure of the CCS and the structure and abundance of biological communities that live in it. NOAA Fisheries is in the process of proposing for FY 2007 a Pacific Coastal Ocean Observing System (PaCOOS) that will combine and coordinate stock assessment surveys, extended climate/ecological sampling of the CalCOFI type, and more modern methods to monitor the CCS along the entire west coast of the U.S.

Today's CalCOFI surveys are low resolution in time (quarterly) and space (71 km), better suited for providing many independent samples of biology than for characterizing the important mass, heat, nutrient and freshwater transports of the upwelling cell, the poleward California Undercurrent and the equatorward California Current. In the spirit of an Integrated Ocean Observing System (IOOS), we propose to begin higher density sampling roughly along CalCOFI Line 93 that tends 700 km southwestward from San Diego. Our hope is that the NOAA Fisheries PaCOOS effort and the new California Current LTER program, both aimed at characterizing the ecological response to climate variations, and the Climate Observing Program will find the resultant data valuable enough to continue. Indeed, it is our frustration that at this time the planning for ocean observations of climate variability and of ecological response to climate variability are proceeding without adequate coordination or an eye to the things that will impact most on both these programs.

3.8b. CORC: High Resolution XBT/XCTD (HRX) Transects

by Dean Roemmich, Bruce Cornuelle, and J. Sprintall

FY2005 PLANS

During FY2005 it is planned to collect 4 transects along each of the routes listed in Table 1: PX37/10/44 (San Francisco-Honolulu-Guam-Taiwan), PX38 (Honolulu-Alaska), PX81 (Honolulu-Chile), PX08 (New Zealand-Panama), PX06/30 (New Zealand-Fiji-Los Angeles), IX15/21 (Fremantle-Mauritius-Durban), PX30 (Fiji-Brisbane, collaborative with CSIRO) and PX34 (Wellington-Sydney, collaborative with CSIRO). Travel by ship riders to and from ports at end points of XBT transects is included in the budget, along with estimated cost of ship passage based on previous experience. On some transects under our management it is cost effective to hire ship riders from CSIRO, and the budget entry for CSIRO vessel services is for that purpose.

The lines will be sampled at the usual HRX resolution of 30 – 50 km in ocean interiors and 10 – 20 km in boundary and equatorial regions. This will require approximately 6,245 Sippican Deep Blue XBT probes. XCTD sampling will continue in areas that are inadequately sampled for T/S variability by Argo floats and experimental T-12 XBT probes will be deployed when they become available. We will continue to provide ancillary logistical assistance for the VOS IMET program and for Argo float deployments.

Overall management of the program is the responsibility of D. Roemmich, in consultation with Co-PIs B. Cornuelle and J. Sprintall. The PIs will set priorities for the program consistent with the recommendations of the 1999 Upper Ocean Thermal Review as well as other relevant international bodies (Ocean Observing Panel for Climate, CLIVAR Global Synthesis and Observations Panel) and the Ten Climate Monitoring Principles. Participation by D. Roemmich is at no cost.

The Operations Manager of the HRX Program is G. Pezzoli. He is responsible for scheduling of transects, for liaison with ships, ship owners and ship management, for training and scheduling of ship riders, and for logistical support of cruises including equipment and probes. He is occasionally a ship rider. The other full-time technical staff person is V. Cannon. She is responsible for frequent ship riding, for laboratory fabrication, preparation and testing of equipment, and to assist with ship rider training and with shipping. Other technical staff (D. Cutchin, B. Stanton, J. Afghan, and unnamed) are part-time ship riders. They are responsible for data collection activities not carried out by the full-time staff. Their time is budgeted in proportion to the number and length of cruises presently anticipated for FY2005. Pezzoli and Cannon will be responsible for conversion of the present autolauncher systems to the new Windows/MK21 hardware and software.

The Data Manager is L. Lehmann. She is responsible for data storage and access, for web site maintenance, and is the principle programmer for the SIO XBT Autolauncher System. She will complete the software development for Windows/MK21 operations. Along with J. Gilson, she provides scientific programming support. Data quality control is the responsibility of G. Pezzoli and ship riders, with final review by D. Roemmich.

3.9b. CORC: Development of an Underway CTD

by Daniel L. Rudnick

FY 2005 PLANS

The most important technical challenge for the coming year is to establish confidence in the UCTD conductivity sensor. To this end we plan a complete reevaluation of the sensor and associated electronics. Necessary changes to the system will be a priority of the coming year.

Expanding the user base of UCTD is a key goal. A cruise aboard the NOAA R/V Jordan is planned in collaboration with NOAA Fisheries scientist Valerie Andreassi. We plan to train NOAA personnel in UCTD operation so that they may assess whether the system meets their requirements.

Continued expansion of UCTD stocks is planned so that we may support additional cruises during the coming year. Several scientists and institutions have contacted us with interest in UCTD. Determining how best to address their needs is a considerable task for 2005.

3.10b. CORC: Lagrangian Salinity Profiling: Evaluation of Sensor Performance

by Raymond W. Schmitt

FY 2005 PLANS

We will continue to help improve salinity performance of profiling floats through laboratory testing and development of data processing algorithms.

3.11b. CORC: Observations of Air-Sea Fluxes and the Surface of the Ocean

by Robert A. Weller, Frank Bahr, and David S. Hosom

FY 2005 PLANS

Turnaround of the AutoIMET systems on all ships will be carried out every six months.

The original stand-alone ASIMET modules will all have been converted to the new Auto-IMET systems and these will have been installed on the three active ships, Horizon Enterprise, Columbus Florida, and Sealand Express. A fourth ship is scheduled to have a system installed in 2005 making a total of four VOS with Auto-IMET / NOAA SEAS systems that report via Inmarsat C in real time and store one minute data for retrieval every six months. This program is in an operational support mode for the current ships.

3.12b. Flux Mooring for the North Pacific's Western Boundary Current: Kuroshio Extension Observatory (KEO)

by Meghan F. Cronin, Christian Meinig, and Christopher L. Sabine

FY 2005 PLANS

KEO-1 operations

The KEO buoy was deployed in June 2004. Therefore in FY05, we will be carefully monitoring the buoy data. Having near-realtime data allows for accelerated scientific analyses of the data. During FY05 there is likely to be a science meeting on the Kuroshio Extension System Study. There has already been lively internet discussion about the role of the recirculation gyre in stabilizing the path of the Kuroshio Extension. In June 2005 on the KESS leg-1 cruise aboard the R/V Revelle, all sensors will be swapped with new sensors, and the buoy platform will be replaced with one containing the pCO_2 flux sensor. Cronin and one PMEL mooring technician will participate in this cruise. Cronin will be responsible for the carbon measurements.

3.13b. High Resolution Climate Data From Research and Volunteer Observing Ships

by C. W. Fairall

FY 2005 PLANS

The major effort in FY05 will be execution of the TAO and WHOI climate buoy cruises plus continued work on the *Ronald Brown* C-band radar. Approximately 40 days of air-sea flux data will be obtained on the TAO cruise and about 20 days of data on the WHOI cruise (Stratus04). A second component will be construction of the roving flux standard. Ship time for the flux standard development will be used in 'piggyback' mode for the existing projects. The new laser wave gauge was tested on NEAQS and will be deployed for the first time on TAO and Stratus04. Besides collecting the high-resolution flux data, we will be doing pilot study evaluation of a UNOLS ship (R/V *Revelle*) IMET system as part of our plans to upgrade the research vessel climate data. The ETL seagoing flux system will provide the roving standard. Construction will begin on the High Resolution Climate Observations website. The first task will be compiling material for the online handbook for flux observations. We also plan to update our ship database so that all cruises through 2003 are publicly available. Joint analysis projects with WHOI and PMEL will continue. We are also proposing to add a second task to connect this project to the Carbon Cycle program. This new task is to build a fast CO_2 system so we can set up a CO_2 flux reference site. This work would be done with the group from Southampton, UK. The site will be OWS "*Mike*" (66°N, 2°E), which is situated in a regime with some of the Earth's largest annually-averaged CO_2 fluxes (5 to 9 Tg C yr^{-1} per 4 ° x 5° area; Takahashi *et al.* 1997).

For the Ronald Brown radar systems project, the recent installation of the two new computers and software upgrades puts us in an excellent position for ongoing radar observations. Laser leveling of the antenna motion stabilization (INU) should be performed in port every few years; and will be scheduled. The Sigmet software licenses and maintenance will also need to be continued (this is k$9 per year). In the next year or so, we may need to install a completely new version of the software at significant expense.

Outreach efforts during the reporting period center on educational contacts through the University of Colorado CIRES Outreach program and the NOAA Teacher at Sea program. For the TAO cruise a link has been set up for twice-weekly exchanges with 10 middle school classes around the US. This project has been dubbed 'Ocean Interactions' and can be found at: http://cires.colorado.edu/~k12/interactions/. The WHOI climate buoy cruise will have two NOAA Teachers at Sea on board.

3.14b. Global Repeat Hydrographic/Co_2/Tracer Surveys In Support Of CLIVAR And Global Carbon Cycle Objectives: Carbon Inventories And Fluxes

by Project Managers: Richard A. Feely and Rik Wanninkhof
Co-Principal Investigators: Christopher Sabine, Gregory Johnson, Molly Baringer, John Bullister, Calvin W. Mordy, Jia-Zhong Zhang

FY 2005 PLANS

Anticipated Requirements to Maintain the Network at Status Quo:
The A16S and P16S cruises will be completed in January-March 2005 timeframe. The NOAA budget for FY05 covers costs required to finalize the data from the 2004 reoccupation of WOCE Section A20/22 and P2 cruises and to pay for outstanding costs for that section that were incurred in FY04.

Logistics Requirements (e.g., ship time):
We have been given 45 days of NOAA ship *Ronald H. Brown* ship time for the A16S cruise in the South Atlantic in 2005. We need to obtain new support for the FY 2006 cruise in the Pacific (P16N) as well as support for the underway pCO_2 measurements on the Repeat Hydrography cruises in the Pacific.

New Data Collection Methods:
New CTD oxygen sensors (SeaBird Electronics model 43) will be used on this cruise. With these two sensors, preliminary calibrations had typical standard deviations between sensors and water samples of 1 µmol kg^{-1} (0.5%). Also new (refined design) water sample bottles fabricated at PMEL for the 2003 A16N reoccupation worked very well, with effectively no evidence of leaking bottles.

Expected Scientific Results:
In FY05, NOAA will take the lead for core hydrographic measurements on the Repeat Hydrography Program reoccupation of A16S on the NOAA Ship *Ronald H. Brown*. The science leg for that cruise is presently scheduled for 45 days of ship time, departing from Punta Arenas, Chile, and arriving in Fortaleza, Brazil, with additional ship time for transit to and from these remote locations. NOAA will be in charge of CTD/O_2 data collection, calibration and processing, bottle salinity measurement, bottle oxygen and nutrient measurements, and underway pCO_2 and bottle carbon measurements. We anticipate occupying roughly 117 CTD stations along the line, with almost 4,000 water samples collected for analysis. The A16S section was last occupied in 1989. It is difficult to predict what differences in heat, freshwater, and biogeochemical parameters will be observed in the 16-year interval. Of course significant increases in carbon storage are expected, and heat storage seems likely to have increased in the interval as well. In many of the other ocean gyres reduction in oxygen within the subpolar thermocline has been observed, along with subpolar freshening and increases in subtropical saltiness. If these changes are also seen in the western Basin of the South Atlantic, it will suggest that the changes are of global extent, providing a modeling challenge.

The A16N, A20/22, A16S, P2 and P16S cruises will provide the necessary data required to assess changes in the Atlantic and Pacific Oceans of anthropogenic carbon and biogeochemical cycles in response to natural and/or man-induced activity. Global warming-induced changes in the ocean's transport of heat and freshwater, which could affect the circulation by decreasing or shutting down the thermohaline overturning, can be determined from the long-term observations derived from these cruises when combine with other results from the international community.

Travel is to embark on the cruise in Papeete, Tahiti and disembarking in Wellington, New Zealand. Shipping is for transport of equipment and PMEL CO_2 van to Papeete and return from Wellington. This budget covers the shipping of the PMEL CO_2 van and equipment. Three and a half months each of personnel time is allotted to complete the carbon data for A20/22 and P2. A key goal of the Repeat Hydrographic CO_2/tracers Program is the detection of changes in the global ocean and the investigation of their causes. In order maximize the utility of these data sets, careful data quality evaluation is required. This includes examination of the internal consistency of the data sets, comparison with complementary parameters collected on the expedition and comparison with existing and historical data using statistical methods. Drs Richard Feely and Chris Sabine are experienced in these techniques and will apply these methods to improve data quality evaluation for the repeat hydrography program. The methods developed should be of great value for the community in the future. Marilyn Roberts and Dave Wisegarver will process the data sets from the A20/A22 and P2 cruises and P16S data sets. Chris Sabine and Marilyn Roberts, or an alternate to be determined, will participate on the P16S cruise.

The AOML CO_2 Group will lead the A16S cruise in the South Atlantic scheduled for January/February 2005 as well as perform DIC and pCO_2 measurements. This includes planning and coordination efforts, with respect to shipping, personnel, and ship-science interaction. A web site to disseminate cruise information has been set up: www.aoml.noaa.gov/ocd/gcc/a16s. In accordance with our UNOLS repeat hydro counterparts we allocate funds for these efforts that includes 6-months of personnel time for organizational purposes, a CTD watch stander and travel for chief scientist's party.

AOML will perform the DIC and pCO_2 discrete measurements. The underway pCO_2 measurements will be done by AOML as well but this is covered under a different contract. Two qualified analysts will be sent to sea for DIC analysis and one for pCO_2 discrete analysis. To account for effort preparing and post cruise data reduction and work-up we use the formula multiplying the seadays by three for the shore based salary component. The personnel works on 12-hour shifts and appropriate overtime compensation is included. Travel is to embark on the cruise in Punta Arenas, Chile and disembarking in Fortaleza, Brazil. Shipping is for transport of equipment and CO_2 van and a storage van to Punta Arenas and return from Barbados. This budget covers the shipping of the AOML nutrient, O_2, and hydrography equipment and the equipment for alkalinity and pH measurements performed by the group of Prof. Millero from RSMAS. Two months of personnel time is allotted to complete the carbon, oxygen, and nutrient data report for A16N.

The AOML Hydrography budget includes ET support at AOML; 3 months for one ET attending the cruise, plus 1 month for instrument preparation/maintenance. Also, 1 month of technician support for instrument preparation, etc. Travel for one person to sea, and one person to the OCO annual review. Permanent equipment includes additional Niskin bottles for the 24-position 10-L rosette. (AOML’s supply includes only 50 bottles in stock 2-24 position frames, plus 1-12 position frame).

The NOAA hydrography budget is apportioned roughly 90% to operations, 5% to data management, and 5% to research and development. The program is primarily funded to collect, calibrate, and process hydrographic data, which is an operational function. The WOCE Hydrographic Program Office at SIO handles the bulk of data management for the hydrography program. However, interacting with them and NODC does require some part of our effort be put toward data management. In addition, we always have one eye out to upgrade our measurement techniques and improving efficiency by improving our calibration software, upgrading hardware, and the like. This means that a small portion of our effort is aimed towards research and development.

The CFC Tracer Group. The PMEL CFC group will send a CFC analyst to participate on the A16S cruise in FY 2005, sharing the analytical work with Dr. Mark Warner at the University of Washington. As outlined in the Repeat Hydro Program planning documentation, a goal of the joint CFC efforts on A16N and A16S is to ensure that analytical methods, data acquisition and processing techniques are compatible among the groups, and to enhance the development and transfer of improved methodology in the community. Dr. Warner will provide a CFC analytical system and the laboratory van to be used on

A16S. At present Dr, Warner does not have the capability for the analysis of carbon tetrachloride, so the PMEL group will provide this analytical system for the A16S cruise. Dr Warner will provide shipping costs for the analytical systems. Preliminary CFC and carbon tetrachloride concentrations will be calculated and made available during the cruise and the data set will be included in the data release at the end of the cruise. Final data processing will be done after the completion of the cruise, in accordance with the Global Repeat Hydrography/CO_2/Tracer Program data distribution policies.

J. Bullister will focus on the analysis, interpretation, and publication of results from this program. CFCs, together with other parameters collected as part of the repeat hydrography program, are key tracers for studying the rates and pathways of ocean ventilation processes. The CFC data will be of use in testing numerical models for circulation and transport. CFC data also provide information on the 'ages' of water and are essential in the calculation of anthropogenic CO_2 in the ocean based on the C* and other techniques. These data will be used in helping to estimate the vertical penetration of anthropogenic CO_2 and the flux of anthropogenic CO_2 in the ocean.

A key goal of the Repeat Hydrographic Program is the detection of changes in the global ocean and the investigation of their causes. In order to maximize the utility of these data, careful quality evaluation is required. This includes examination of the internal consistency of the data sets, comparison with complementary parameters collected on the expedition and comparison with existing and historical data using statistical methods. We have found, in comparing older data with new data, that statistical comparisons of CFCs with concurrently measured tracers (*e.g.*, T, S, O_2) can be useful in evaluating possible calibration and sampling biases in the CFC data sets. Dr. Rolf Sonnerup is experienced in these techniques and will assist in the development and testing of new methods to improve CFC data quality evaluation for the repeat hydrography program.

During FY 2005 we will upgrade our data acquisition systems. We plan to focus on improved methods for the simultaneous measurement of CFC-12, CFC-11, CFC-113 and carbon tetrachloride on the same analytical system. This should eliminate the need for multiple analytical systems and streamline the analysis and data processing.

3.15b. Surface Drifter Program

by Silvia L. Garzoli and Robert L. Molinari

FY 2005 PLANS

Anticipated requirements to maintain the network at status quo:

Globally deployments: over 700 Drifters will be deployed which will increase our shipping costs by about 50% or $25K for a total of $72K.

Logistics requirements (e.g., shiptime):

None

New data collection methods:

None

Planned deployments:

For FY05, plans are to deploy the following numbers of drifters:

- Tropical Atlantic (20ºS-20ºN): 175
- Extra-tropical Atlantic (20ºS-40ºS): 45
- Operations globally (less Atlantic): 480

Expected scientific results:

This proposal is funded to conduct the fieldwork and the data collection. Nevertheless, use of the data for scientific purposes by AOML scientist is expected. Science plans are as follows:

Atlantic component: (1) Analyses to map the distribution of eddy energy, examine Lagrangian spectra at time scales of mesoscale fluctuations, map and explain the distribution of Lagrangian length and time scales which characterize oceanic dispersion, and explore the role of eddy flux terms in the time-mean momentum budgets of the tropical Atlantic Ocean. (2) Characterize the near-surface circulation of the South Atlantic Ocean. Particular focus will be on the time-mean pathways of the boundary currents (Confluence of Brazil and Malvinas; the Agulhas/Benguela system) and the variations of the upper ocean exchanges associated with the meanders in the South Equatorial Current's bifurcation at the coast of Brazil.

3.16b. National Water Level Program Support Towards Building A Sustained Ocean Observing System For Climate

by Stephen K. Gill and Chris Zervas

FY 2005 PLANS

Task One:
CO-OPS will extend the compilation of the data and the reports from the 18 NWLON stations to include all 62 global reference stations assuming routine data availability each year. Efforts will concentrate on getting the data compiled in a timely fashion and generating routine reports established in the first year effort. Success will depend upon the ability to get timely data from all stations. These efforts will be coordinated with PSMSL, GLOSS and UHSLC programs.

Task Two:
Upgrades will be completed a two critical ocean island stations at Midway and at Guam. Upgrades will include installation of redundant sensors and DCP's and connection to geodetic datum using GPS. Efforts will be made to make connection between tidal benchmarks and existing CORS systems.

Task Three:
Operation and maintenance of Platform Harvest tide station will continue as required using OGP funding. The MOA with JPL/Caltech will expire. Coordination of Platform activities will continue to be coordinated with JPL scientists.

3.17b. An End-to-end Data Management System for Ocean pCO_2 Measurements
by Steve C. Hankin, lead PI, Richard Feely, Alex Kozyr, Tsung-Hung Peng

FY 2005 PLANS
The work that was begun in year one of this effort (FY05) was deemed to be highly successful by the CO_2 Science Team. Progress along the lines initiated in year 1 will be pursued as rapidly as possible in year 2 (FY05). These particular milestones are top priorities:

PMEL milestones:

- Improved visualizations through interactions with carbon scientists develop effective visualization products for (Lagrangian) underway data. Measured values may be represented by colors (as in figure 2) or in some cases by line plots mapped to the path of the ship. The output of ODV-formatted custom subsets will be explored and implemented if it is determined to be a capability that is useful to scientists.
- Detailed selection capability outputs will be enhanced so that individual cruises may be identified by name on plots that show many cruises and may be individually selected for inspection of metadata, single cruise visualization or subsetting.
- Data-metadata integration working jointly with CDIAC the creation of bi-directional linkages will be explored to unify the management of data and metadata into a single work environment. The goal is that a scientist should be able to "click" instantly to the metadata that is relevant to data being browsed; and "click" instantly to visualizations of data relevant to metadata that is being browsed.
- Solicit community feedback the initial underway data systems will be presented to carbon scientists and other science users through presentation at the CO_2 Science Team meetings, email announcements soliciting comments and face-to-face interviews requesting detailed assessment. All aspects of the design of the system will be reviewed based upon feedback and enhancements will be made accordingly.
- Database support for hydrographic profiles - the database design will be expanded to address carbon bottle data measurements. The initial design will be employed in a demonstration LAS in preparation for further development in the following year.
- Develop data ingestion scripts working cooperatively with CDIAC develop procedures and scripts to ingest legacy underway data formats into the CDM database.
- Operationalize the underway server working with CDIAC the contents of the underway database will be expanded and the server will be "operationalized" as a stable resource for the carbon science community.

CDIAC milestones:

- Complete the public web site for the VOS project including an operationalized LAS Web server for the underway carbon data;
- Add the VOS underway data into LAS as soon as they become available in QCed and publicly releasable form;
- Work with PMEL to review and improve the presentation of underway data through LAS;
- With the assistance of PMEL and Mercury groups CDIAC will explore mechanisms to link measured data on LAS with the metadata files in Mercury;
- Attend the VOS Science Team Meeting to present and discuss data management issues.

AOML milestones:

- Reaching community consensus on improved, automated data quality checking protocols for VOS pCO_2 underway data;

- Providing protocols for data reduction and quality control from VOS pCO_2 underway systems to expedite posting of uniform high quality data.;
- Achieving community consensus on appropriate formats and metadata standards for delivery of data to the regional QC site at CDIAC;

Participation in the development of regional QC procedures to be applied at CDIAC.

3.18b. Observing System Research Studies

by D. E. Harrison

FY 2005 PLANS

It is proposed to continue to investigate the space and time scales of significant climate anomalies, via examination of the historical data sets, comparison of operational and research analyses and numerical model studies when they can sharpen knowledge of the processes that cause the phenomena of interest and affect their predictability. It is proposed also to continue to promote, and to participate where appropriate and useful, efforts by others to carry out similar activities for the suite of climate variables that are priorities for the Office of Climate Observations. Finally, it is proposed to continue the national and international technical committee activities that support the design, evaluation and strategy for evolution of the global observing system for climate.

The relevance of particular phenomena is estimated by the degree to which land weather anomalies can be associated with them or the degree to which they must be resolved by the observing system and its analyses to improve climate forecasts, to provide warning about changes in the state of the ocean, or to avoid aliasing other climate-relevant phenomena. Studies on SST, SLP, surface wind, sea level and tropical Pacific subsurface temperature and salinity will be carried out, and preparatory work to make analyses of other variables available for future study. As has been done in previous SST studies, attention will be paid to the development of performance metrics for the observing system to be able to identify and resolve the relevant variability.

The southern hemisphere subseasonal SST studies carried out with Andy Chiodi will be submitted for publication. Further work will be done on the characteristics of subtropical Indian SST anomalies and their relationships with African rainfall anomalies. We believe that there is much to be learned from case studies; in this region there is good reason to expect the EOF and CEOF analysis approach may mislead about the real fundamental characteristics of the variability and, hence, the rainfall anomalies associated with the variability. Larkin and Harrison (2003) have shown how EOF analysis distorts the actual characteristics of El Nino and La Nina events, and we expect a similar result in these Indian Ocean studies. This work will help clarify the phenomena we need the observing system to study, thereby providing justification for continued observing system expansion into the southern hemisphere oceans.

The work on subsurface temperature trends also will be completed and prepared for publication. The fundamental need for sustained global observations, if we are to have accurate trend information (much less to characterize decadal variations), will be made very clear. The importance of Argo for global coverage and repeat XBT lines and time series for better information in selected locations, will be argued.

The tropical Pacific WWE/MJO/El Nino work will be prepared for publication. Hopefully it will be possible to get the TAO/Triton website data presentation to more accurately present the energetic time scales of near equatorial winds, as one response to the paper.

It is time to extend the activities of the project beyond SST variability; even though there is more work to be done on SST for climate progress toward implementing the global SST surface drifter array is well justified by the work that has been done to date.

Preliminary studies of global mean SLP analyses have revealed non-trivial differences between operational analyses, and they are large enough to introduce a non-trivial source of uncertainty in the sea surface height variability data from altimetric satellites. These differences will be characterized more fully and a paper on them will be prepared for publication. To begin with ECMWF and NCEP analyses will be used. If comparisons with other operational SLP analyses show substantially different characteristics, these also will be summarized. Accurate knowledge of SLP changes in the mean is important for atmospheric climate change studies and climate change projection model result evaluation.

Preliminary comparison of operational surface wind analyses has also been done and has revealed continuing very significant differences in the mean wind and in the wind variability. We have been expecting the analyses to begin to compare better, but there has been no dramatic improvement; it is time to put the numbers out and see if they can motivate improvements in operational analyses. The tropical moored buoys and time series reference site moorings will provide critical in situ results for these comparisons. The surface wind vectors from QuikScat also will also be included in the comparisons.

The historical data set of tide gauge records will be made available via a Live Access Server and an OpenDap data set will be constructed. These activities will greatly facilitate access to the tide gauge records; it is hoped that the GLOSS project will accept the task of updating the data set as new data are sent to GLOSS data sites. To the extent that high time resolution records are available, a separate data set of these records will be prepared to supplement the monthly mean GLOSS records.

Efforts to create an archive of operational surface fluxes at the US GODAE server will continue, under the auspices of the new WCRP surface flux working group. DOE is not going to make resources available for this activity at LANL, which is what the SURFA project had been counting on. Because knowledge of air sea flux uncertainties is critical for GODAE operational ocean analyses, GODAE has agreed to make the server available for this purpose.

A number of sea ice products are routinely produced. Nick Rayner at the Hadley Centre has carried out some preliminary comparisons and has found substantial differences in the deduced long-term trends. It is important to foster a thorough comparison of comparable sea ice products. Efforts will be made to engage Nick Rayner and others in the community to advance sea ice comparison work.

A variety of routinely produced regional and global ocean analyses (temperature, salinity, sea surface height and currents) are now available (through GODAE projects and other projects), but their relevance for climate purposes is unclear. Preliminary comparisons of North Atlantic analyses are being carried out by GODAE participants. A strategy for comparison of tropical Pacific analyses has been prepared but no group has undertaken the comparison work to date. It is proposed to try to advance the tropical Pacific analysis comparison project, involving as many of the routinely generated analyses as possible.

At present there is no accessible summary of what fields are routinely produced by groups and how they can be accessed for comparison with each other or with observations. Such a summary will be created as a sort of 'gap analysis' for ocean operational and climate-relevant products. The summary will identify those regions and variables that need enhanced analysis work, and will be made available to OOPC and JCOMM for recommendations about needed additional activities.

Much of the above will be carried out with the assistance of Steve Hankin's data access group at PMEL. Coordination activities will be handled via existing groups to the greatest extent feasible; only when it is not possible to make the needed fields available through existing efforts will we undertake OpenDap and LAS activities for these fields.

The PI also will continue to support the design, evaluation and evolution of the global observing system via his leadership activities in OOPC, US and International GODAE, US and International GOOS, GCOS and the WCRP. It is anticipated that these activities will take about 50% of the PI's time.

3.19b. Progress Report For the Observing System Monitoring Center (OSMC)
by Kevin J. Kern and Steven Hankin

FY 2005 PLANS

This FY2005 plan is based on the assumption that funding will be provided in FY2005 at the same level provided in FY2004. Additional details in regards to the budget are provided in Appendix A. During FY2005 the joint team of PMEL and NDBC will address the following OSMC tasks:

- Continue database and application development to fully support all requirements as identified in the updated OSMC Bubble Chart (see Appendix B).
- Complete the initial development of the GIS-style OSMC-LAS user interface as collaboration between PMEL, NDBC and OCO. Add drill-down capability (clickable maps) to retrieve metadata records, time series and statistical data summaries. Incorporate initial linkages to reference data sets that are available through the OPeNDAP networking (via the National Virtual Ocean Data System) into the OSMC design.
- Add functionality to support the OCO Adopt-A-Drifter program to provide educational opportunities for teachers to incorporate observing systems awareness into their curriculum.
- Incorporate data for the following platforms into the OSMC database: Tide Gauges, Reference Stations, and Transport Arrays, Research Vessels.
- Incorporate data for the following parameters into the OSMC database: PCO_2, Ocean Carbon, Total Depth Temperature (a temperature profile that covers the whole water column), and Sea Level.
- Backfill the database with historical data. (The initial goal is to start all data sources with data since 1 January 2004.)
- Develop a drill down capability within OSMC to get metadata and time series summaries about specific platforms and/or a specific instance of an observation.
- Improve metadata contained within the database for all platforms. An example of the metadata would be contact information (Name, E-Mail, phone, etc) related to the organization that owns the platform or payload and/or instrumentation information related to the platform. The specific metadata requirements will be defined as drill down functionality is developed and based on the needs of the OCC.
- Perform database analysis to determine growth and future requirements to support the OSMC over a five-year initial operations period.
- Resolve issues related to duplicate reporting of observations when updating the OSMC database.
- Assess the impacts of data correction/changes resulting from the QA/QC process of the data provider and how it will impact the integrity of the OSMC database.
- Continue to support OCO initiatives as resources permit for briefings, presentations, and ad-hoc requirements.
- Finalize software procedures to perform monthly (currently) updates of static images using NDBC OSMC database and NDBC systems.
- Continue to support up-to-date animations and pre-created graphics as needed that illustrate the evolution of the performance of the Observing System.

3.20b. An Indian Ocean Moored Buoy Array For Climate

by M.J. McPhaden

FY 2005 PLANS

In FY 2005, we will acquire sufficient equipment to replace the 3 ATLAS and 1 ADCP mooring along 80.5°E. Informal discussions with Indian colleagues indicate that enough sea days will be available on the *Sagar Kanya* in the September-November 2005 time frame for us to revisit these sites and 0°, 90°E for recovery and redeployment operations.

All data telemetered in real time from the moorings deployed in 2004 will be displayed and distributed by the TAO Project. Web page development will thus be a priority activity in FY 2004. In addition, the ATLAS mooring data will be placed on the GTS by Service Argos.

3.21b. Pilot Research Moored Array in the Tropical Atlantic (PIRATA)

by M.J. McPhaden

FY 2005 PLANS

Moorings at the 10 PIRATA sites will be recovered (if found) and new moorings deployed in FY 2005. Brazil has proposed a cruise in April 2005 to service the 5 westernmost sites. France has had some difficulty in identifying dedicated ship time, but has proposed a combination of a chartered vessel and piggybacking on another French cruise to maintain the 5 easternmost moorings. These cruises are scheduled for May and June 2005, about 15 or 16 months after the 2004 deployments. While ATLAS moorings are designed for nominal 12-month deployment duration, battery capacity and hardware integrity permit longer deployments. Delayed cruise schedules will impact data return though, especially in light of the fact that 2 moorings in the eastern Atlantic are not transmitting and may be lost.

PIRATA is nearing the end of a 5-year PIRATA consolidation phase. The future of PIRATA will be discussed at the PIRATA-10 meeting, to be held in Fortaleza, Brazil in December 2004. Proposals for enhancements and expansions of the array will also be discussed. The PI plans to attend this meeting.

3.22b. The University of Hawaii Sea Level Center

by Mark Merrifield

FY 2005 PLANS

We will continue the operation and maintenance of our tide gauge network. Planned station visits during FY2005 include Salalah, Masirah, Cape Verde, Dakar, Rodrigues, Port Louis, Point La Rue, Kapingamarangi, Yap, Saipan, Mombasa, Lamu, Zanzibar, Nauru, and French Frigate Shoals. As always, the stations visited may vary depending upon maintenance needs. French Frigate Shoals will require installing a new station when the sea wall is ready. The center will also continue to upgrade global network sites to acoustic and radar sensors in place of the older float gauges, and replace older DCPs with newer models capable of transmitting at higher baud rates. Many of the existing UHSLC installations are built on World War 2 era structures, and these structures are deteriorating. The UHSLC plans to either build new stations on newer structures or in remote areas we will begin building our own piers. We will deploy non-contact radar sensors where feasible. The UHSLC also plans to rebuild its spare part stockpile. This will enable us to respond quickly and efficiently to problems.

The UHSLC will continue as a partner in the ODINAFRICA project, which will oversee the installment of 10-20 new tide gauges in Africa. We will provide technical support to host countries seeking to reestablish dormant tide gauge stations in Sri Lanka, India, Argentina, and Indonesia, and coordinate with colleagues in Brazil to install a second satellite transmitting gauge and tie continuous GPS stations to the new tide gauge installation at Salvador. We could accelerate these installations with more resources (see add task 1).

The center is in the process of hiring a new technical staff person who will fully implement the real-time database in support of GODAE. We will continue to explore ways to expand the CLIVAR/GLOSS fast delivery and real-time data sets. Our ultimate goal is to provide the entire GCOS and ultimately the GLOSS tide gauge network in real or near-real time. The center will continue upgrading the data sets available on NOPP's NVODS LAS, and work with PMEL and the NODC to support the CDP, which enables researchers and others to access the products developed by the various elements of the Climate Observing System over the Internet without having to log on to multiple web sites. We will also continue working with IPRC to ensure that the JASL delayed mode observations are available through the APDRC servers. We expect that these efforts will provide the UHSLC datasets in common and easy to access formats for researchers and modeling centers.

The center will begin to upgrade the existing JASL metadata format into Federal Geographic Data Committee (FGDC) compliance. This will allow more thorough documentation, enhance computer searches, and facilitate data exchange.

Our research effort will include studies utilizing the GPS ground motion dataset at each of our tide gauges. Absolute sea level trends will be provided at all GPS@TG stations, and we will continue to work on defining secular and other relative sea level trends at in-situ stations, including trends of various maxima values. This work includes the calculation and correction for any local network trends identified by benchmark surveys, and the incorporation of SAR-based ground motion estimates.

We will submit a paper on the Tuvalu sea level rise analysis and an assessment of GPS vertical land motion rates in the Pacific. The center will continue collaborating with Philip Woodworth of the Proudman Oceanographic Laboratory and Gary Mitchum of the University of South Florida on an annual report describing sea level variability for the previous year.

3.23b. Satellite Altimetry

by Laury Miller

FY 2005 PLANS

All FY04 tasks will continue into FY05 and beyond, and level funding ($240K) should be sufficient to support them. Most of the support for LSA is derived from NESDIS base, but the increment from Climate Observation enables significant enhancement of altimeter data for climate applications and research. If the FY06 Jason-2 new initiative is ultimately approved by Congress, LSA would receive some new funds.

LSA is also involved in a collaboration with Dr. Gary Lagerloef (Earth Systems Research), Dr. Gary Mitchum (South Florida University), and several other partners, to operate a near-real time processing and data center which is providing maps of total surface current (geostrophic plus Ekman) in the tropical Pacific Ocean. This is being done by combining sea level from altimeters and wind vectors from scatterometers, using quick-look versions of both data types. These products are updated daily as part of a NESDIS operational activity, and results are distributed via a dedicated web site: http://www.oscar.noaa.gov/

3.24b. The Global Drifter Program

Global Drifter Measurements of Surface Velocity, SST and Atmospheric Pressure

by Peter Niiler

FY 2005 PLANS

Anticipated requirements to maintain the "Global Surface Drifting Buoys Array" at status quo:
With the current attrition rate of the global drifter array due to all causes (e.g., deployment failures, picked up, gone ashore, stopped working, etc.), the array needs effectively to be replaced every year. This conclusion is based on the observation that a global array of about 600-650 drifters was in the ocean during 1997-2002. During this time about 420 drifters per year were acquired by *GDP*, 100 drifters from individual research proposals and 120 drifters from the operational meteorological community, or a total of about 640 drifters each year were deployed.

To keep the status quo of US contribution of a 900-element drifter array in the ocean in 2006, GDP needs to acquire about 740 drifters in FY 2005. Additional 160 drifters come from ONR and CORC funded activities.

The continue to maintain the global SST/Velocity array of 1250, the required drifters can be acquired within the expected stable, or level, FY 04 funding of the NOAA climate observing system for FY 2005. Two add tasks are proposed:

Logistical Requirements:
Presently, most of the global drifter array is deployed from the "Volunteer Observing Ships" (VOS) and research vessels. Requirements from the NOAA Hurricane Center are also to deploy Minimet drifters in front of major hurricanes that threaten the US mainland. Continued air-deployments will be requested from C-130-J 53rd National Air Force Reserve "Hurricane Hunter Squadron", stationed at Keesler AFB, MS. In 2005, 20 air-deployment containers will be prepared at SIO which contain either Minimet wind drifters (12) or Minimet wind drifters with a thermistor-chain attachment (8). The request for the services of the 53rd will be made through Dr. Peter Black of the NOAA Hurricane Center. In September 2004, the 53rd successfully deployed 23 drifter containers in front of Hurricane "Frances".

Technical Developments and Data Enhancements:
In 2005, in cooperation with the CORC project, we will continue to pursue the construction and evaluation of SSS sensors. SeaBird Microcats attached to 12 SVP-B drifters will be deployed in the North Atlantic with the cooperation of the French Meteorological Service in the Bay of Biscay; they have offered to retrieve these for post-calibration during their regular cruises to service moored buoys west of France.

The CORC project will merge with the Global Drifter Program in FY 06. The objective in FY 06 will be to construct about 300 SVP-SSS drifters for the calibration and validation of the "Aquarius" SSS satellite that will be launched in 2007. The cost of the SVP-SSS drifter will be about $3400 in addition to the cost of a SVP-Mini drifter. About $1,100,000 will be sought from NOAA to fund the drifter component of the "Aquarius" cal-val program. NASA will fund the data analysis and interpretation.

Drifter velocity data enhancements will continue. We propose to continue the wind-slip corrections to the drifter velocity data set on a six-month basis and make requested gridded data available to the scientific community. Arrangements will be made to store these wind corrected data files at the AOML Global Data Center for submission to MEDS Canada, an activity that is now possible under the careful eye of Dr. Rick Lumpkin of AOML.

3.25b. Climate Variability in Ocean Surface Turbulent Fluxes

by James J. O'Brien, Mark A. Bourassa, and Shawn R. Smith

FY 2005 PLANS

- Test and implement new automated quality control of 1˚ input data
- Complete 1978-present 1° wind analyses for tropical Pacific, Indian, and Atlantic Oceans
- Evaluated methods for extending tropical Pacific and Indian Ocean fields prior to 1978
- Begin flux field production
- Calculate wind uncertainty fields for completed ocean basins
- Continue comparisons of FSU winds and fluxes to available products
- Complete development process for of satellite scalar winds
- Complete development process of micro-wave satellite SST
- Develop an objective technique for determining appropriate periods for temporal averaging of satellite data.

We anticipate analyzing gridded monthly flux fields for the Indian and Atlantic Oceans for spatial temporal patterns of variability. We will investigate the connection of known source of variability (e.g., NAO, ENSO, AO) to the variability in our gridded fields.

Our ocean model for the Gulf of Mexico will be forced with realistic fluxes (stresses, turbulent surface fluxes, and radiative fluxes for several purposes. One such purpose will be to test the energy budgets in the ocean model. Very preliminary tests are encouraging. If the testing is successful, we anticipate being able to examine the modeled heat fluxes for extreme wind speeds, a regime for which there are many interesting questions yet to be resolved. We will also be able to better examine the fate of fresh water input from rivers, as well as other process studies.

3.26b. U.S. Research Vessel Surface Meteorology Data Assembly Center

by James J. O'Brien, Mark A. Bourassa, and Shawn R. Smith

FY 2005 PLANS

- Continue liaison with UNOLS, USCG, NOAA, etc. to establish automated data transfers
- Evaluate and improve data ingest and quality control system based on FY 2004 experience
- Implement automated data transfer for up to 10 vessels
- Investigate four time per day data transfers if desired by user community
- Liaise with international community to lay groundwork for expansion to include international vessels.
- Compare R/V observations to global reanalysis products
- Continue comparison of R/V observations to independent marine platforms

The activities of the RVSMDC will be focused on the SAMOS initiative. Providing routine access to SAMOS observations will support NOAA's goal to "maintain sensor suites on a small core of vessels as the highest quality calibration points for validation of other system measurements" (NOAA 2003). The SAMOS observations will also provide a key part of network of high quality flux reference platforms that were recommended by the WCRP/SCOR Working Group on Air Sea Fluxes (WGASF 2000). Clearly once routine SAMOS data are available, their application for a wide range of validation studies is expected.

The RVSMDC will continue to focus on comparisons between the R/V SAMOS observations, global reanalyses, satellite measurements, and independent marine platforms (e.g., other ships and buoys). We anticipate that the SAMOS data will help quantify biases in the numerical products and inter-platform comparisons should help identify systematic sampling errors present on individual marine platforms.

3.27b. *In Situ* and Satellite Sea Surface Temperature (SST) Analyses

by Richard W. Reynolds

FY 2005 PLANS

During FY2005 we plan to get the OI analysis running at NCDC. This will allow improvements as described below to be implemented. Each improvement will be carefully tested before it is implemented into the operational version. Then the entire analysis from November 1981 (the beginning of multi-channel AVHRR retrievals) to present will be reprocessed. These changes will be then be passed on to NCEP who have agreed to update the operational version.

After the OI is operational at NCDC and tested, we plan to make changes to the OI code as listed below. After each step is complete, the entire analysis from November 1981 to present will be reprocessed and the analysis changes will be sent to NCEP.

a. Make improvements to the OI code.

The OI code has been modified to improved spatial error covariance. This modification will now be tested. Before the OI procedure is carried out, satellite biases are corrected relative to the in situ data. The scales for this correction will also be evaluated. In addition, the present error statistics computed in the OI include only sampling and random error and do not include bias errors. The error statistics will be reevaluated to also include bias errors in the final error estimates.

b. Add new sources of data to the OI and revaluate the improvements.

In Reynolds et al. (2004) we have already evaluated the use of microwave SST data from TMI. In the new version of the OI it is now possible to add additional sources of data. We plan to first focus on the microwave satellite SST products from TMI and Advanced Microwave Scanning Radiometer (AMSR). Then additional IR satellite products will be considered. We believe that the use of these data will produce an analysis with lower errors. After this stage is complete additional in situ data from oceanic profiles will be added. Preliminary testing has shown that these in situ data will have a minimal effect because they are so spares relative to surface marine data. However, these data need to be added to assure that no source of accurate SST data is neglected.

c. Modify the OI resolution.

After these two steps are completed, we will investigate the impact of improved temporal and spatial resolution. It is expected that these improvements will be modest (a daily analysis instead of weekly and a 0.5^{o} analysis instead of 1^{o}). However, improved resolution will be certainly be possible after December 1997 when both IR and microwave satellite SST data were available.

In addition to these improvements in the OI, we will also continue to monitor the in situ network to determine where new drifting buoy data are needed. This will include seasonal computations such as Figure 1 and computations of the average satellite potential bias error which is used as a metric to evaluate the in situ SST network. These results will be sent to both AOML and of course the OCO.

3.28b. Monitoring Ice Thickness in the Western Arctic Ocean

by Jackie Richter-Menge, and co-investigators/collaborators
H. Melling, J. Overland, R. Lindsay, J. Zhang, and D. Perovich

FY 2005 PLANS

1. Fabricate 4 IMBs (2 for this project and 2 for the companion project "Monitoring the Eurasian Basin of the Arctic Ocean")
2. Recovery and re-deployment of instruments at mooring site CH01.
3. Deployment of 2 IMB buoys in the Western Sector of the Arctic.
4. Collection, analysis and archiving of data from the mooring and buoys.
5. Completion of a webpage, which will present the data in a near real time format.
6. Presentation of results at national and international meetings.
7. Initiate plan to assimilate ice thickness data in sea ice dynamics models, used to forecast ice thickness distributions in the Arctic Basin.

3.29b. Monitoring Eurasian Basin of the Arctic Ocean

by Ignatius G. Rigor

FY 2005 PLANS

1. Ice Mass Balance buoy deployments
   1.1. Two buoys have been shipped to Kirkenes, Norway. These buoys will be deployed during the Nansen and Amundsen Basin Observing System (NABOS),
   1.2. http://www.frontier.iarc.uaf.edu/NABOS/index.php) 2005 cruise.
   1.3. One buoy has been shipped to Gothenburg, Sweden for the Swedish ice breaker Oden's 2005 Arctic Ocean transect from Bering Strait to the Greenland Sea. We plan to purchase additional buoys for this deployment opportunity if resources are available.
   1.4. Two or more buoys will be deployed by aircraft in collaboration with the NPEO in April 2005.
2. Data collection and analysis.
3. Presentations at national and international meetings.

3.30b. High-Resolution Ocean And Atmosphere PCO_2 Time-Series Measurements

by Christopher Sabine

FY 2005 PLANS

Anticipated Requirements to Maintain the Network at Status Quo:

The program currently maintains two different types of pCO_2 systems. The systems at 155°W, 0° and 170°W, 2°S have been in operation since 1997. These systems use an older dual path LiCor that is significantly more expensive than the LiCor 820 used in the systems built by PMEL. The standard MBARI systems also only provide a ΔpCO_2 measurement instead of individual air and water values. Over the past year, the LiCor 820 systems have proven themselves to be robust and accurate. Having the absolute measurements of water and air pCO_2 separately provides additional information for interpreting carbon flux variability. This together with the reduced cost of the new systems makes them a better choice for the development of the moored pCO_2 network. The MBARI pCO_2 systems, however, are integrated with a biooptical package that is funded by NASA. The NASA program has one final year of funding, therefore, we anticipate continuing with the historical systems at 155°W, 0° and 170°W, 2°S for one more year before converting to the PMEL systems. The MBARI budget reflects the continuation of these moorings for an additional year, including the need for two more 6-month recovery/deployment cycles.

The TAO buoys at 125°W, 0° and 140°W, 0° are scheduled to be replaced with new buoys in February/March of 2005. The pCO_2 systems at these locations will need to be replaced at this time. Replacement systems exist, but they have just recently returned from sea and will need to be refurbished and recalibrated. We expect that the refurbished systems will not need to be replaced for a year, but typically the ship makes a 6-month visit to the buoys to check on their status. Some minor maintenance may be required at that time.

The Hawaii mooring is recovered every 4 months, spends a week on shore being refitted, then is deployed again. The existing pCO_2 system will need to be replaced at the next recovery in November/December 2004. The first year budget for the HOT system only included money for one system, with plans for a second system to be built in FY05. Given the need for an early replacement of this system, we will use one of the refurbished systems from TAO for this deployment and build a new system to replace the shortfall for the spring TAO deployment. Two additional recovery/deployments are scheduled for FY05. The pCO_2 system is designed to operate for a year so we do not anticipate having to replace the system, but the system will be thoroughly evaluated with each recovery.

In addition to the mooring measurements, we have also been collecting nutrient and chlorophyll measurements on the TAO cruises. This work is an effort to evaluate the biological component of the pCO_2 variability we observe as part of both the mooring and the underway pCO_2 programs. Through this work we can better understand the new autonomous measurements that need to be developed for the moorings to evaluate the controls on the CO_2 fluxes. This work requires that a technician, supplied by MBARI, participate on each of the TAO cruises. In addition to taking care of the shipboard measurements, this technician will be primarily responsible for ensuring the proper deployment of the pCO_2 moorings.

New Data Collection:

The long-term vision for the moored pCO_2 array is to populate the OceanSite moorings with pCO_2 systems. The TAO OceanSite location at 170°W, however, is on the equator not at 2°S where our pCO_2 system is currently located. Logistical considerations associated with the TAO and MBARI systems prevented the preferred deployment at the equator when this site was first instrumented in 1997. Since the variability signals we are investigating are strongest at the equator, we will build and deploy a PMEL system at 170°W, 0° in FY05 to start establishing a time-series record in this critical location. This system will have a one year overlap with the historical system at 170°W, 2°S so we can investigate the correlations between the historical trends observed at 2°S and the future observations at the equator. After FY05 we anticipate ending the 2°S measurements unless compelling science is observed during the overlap period.

Logistics Requirements (e.g., ship time):
There are no additional ship-time requirements for this project at the current time because all of our systems are deployed on existing platforms. The ship-time required to maintain these platforms has already been justified and allocated for the core mooring programs. This program does require the presence of one additional participant on the TAO cruises to make the shipboard measurements and to install and activate the pCO_2 systems upon deployment. This person will be supplied by MBARI and is expected to assist in the mooring recovery/deployment when not occupied with duties related to this program. PMEL is also paying partial salary to a TAO technician, Patrick A'Hearn, to assist with the moored pCO_2 systems. One person is required to install and activate the pCO_2 system on the HOT mooring cruises. We have trained one of the technicians from the Hawaii Ocean Time-series Program to handle these duties in exchange for covering a portion of his salary. The actual time required to set up the pCO_2 system is minimal, so it is much more efficient to have someone already associated with the cruise to take on these additional duties.

Expected Scientific Results:
Over the past year, we have been evaluating the impact of tropical instability waves on the surface water pCO_2 in the equatorial Pacific. There appears to be a strong anti-correlation between sea surface temperature and surface pCO_2. Over the next year we anticipate quantifying this relationship and writing a manuscript describing the mechanisms controlling these short duration variations. There are also signs that we may be entering another El Niño year. We will be watching carefully to understand the timing of the CO_2 signal relative to the temperature anomalies associated with the El Niño. Although we do not yet have CO_2 sensors all the way across the Pacific, we will be able to use the four sites to evaluate the magnitude of the signal at different locations and how it propagates across the Pacific during its initiation. With the concurrent measurements off Hawaii we can start to examine the extra-tropical connections with the El Niño. In particular, we will be looking to understand the timing and mechanisms behind the connections to processes in the equatorial Pacific. The Hawaii system will also provide the first high-resolution pCO_2 time-series measurements over a full annual cycle at this JGOFS time-series station. Careful comparison against the Hawaii Ocean Time-series shipboard data will provide an assessment of any biases that may be present in the seasonal flux estimates calculated from the 15 years of monthly measurements of dissolved inorganic carbon and total alkalinity at this site.

3.31b. *Document Ocean Carbon Sources and Sinks:* Initial Steps Towards a Global Surface Water pCO_2 Observing System, and Underway CO_2 measurements on the NOAA ships *Ka'imimoana* and *Ron Brown* and RVIB *Palmer* and *Explorer of the Seas*

by Rik Wanninkhof, Richard A. Feely
with Nicholas R. Bates, Frank Millero, Taro Takahashi, and Steven Cook

FY 2005 PLANS

Requirements to maintain the network at status quo:
pCO_2 on research ships: the requested funding level can maintain status quo but focus will have to be on upgrading instrumentation that is beyond the useful lifespan. The added instrumentation cost will be recovered through reduced personnel cost currently expended on emergency repairs.

VOS: This effort is not yet fully operational and is behind schedule in outfitting as proposed because of late receipt of funds and longer lead times for instrument development and procurement. Scheduled outfitting can be completed with funds requested. See add task for requested augmentations.

Logistics requirements:
Research ships: The underway CO_2 efforts have been one of the first chemical measurements to run nearly unattended on the research ships. However, several of the ships have instrumentation for other projects. This has put a strain on space and ship resources since these measurements are not an integral part of the ship's projects and there are increasing pressures maintaining these efforts. More formal arrangements regarding sustained operations on research ships should be implemented onboard the *Brown* and *Ka'imimoana*.

VOS: Installation and maintenance of pCO_2 systems on VOS has proven to be a more substantial task than anticipated. There are a significant amount of uncertainties regarding interactions with ship's command, space availability, access to ship's etc that make the effort more time consuming and costly than originally anticipated. For example, in some cases ship riders are required to provide support for the instrumentation during the voyages. Despite this, ships have been found to carry our equipment on the proposed lines. For these efforts, auxiliary measurements (air flask measurements, XBT, fluorometry, plankton recorders, meteorology) are very beneficial for interpretation of results. In some cases this is becoming problematic because of overburdening the ships with projects.

The NOAA COSP underway pCO_2 program is the largest coordinated effort in the world. A major responsibility the group has taken on is to promote uniform instrumentation and data reduction and data dissemination protocols through informal and formal avenues. The formal mechanism has been through the IOCCP, Carbo-Oceans and PICES working group 13. We have been instrumental in developing the autonomous underway pCO_2 analyzer and finding a person to build them. This was done in collaboration with the University of Bergen. We are now seeking to find a commercial vendor to build the instruments and to find innovative means for product support.

New data collection methods:
The second generation of autonomous pCO_2 systems has been designed and built which, in time, will be capable of operating autonomously on VOS. The system has been designed such that data can be telemetered to shore and two-way communication allows instrument commands can be sent to the instruments on the ships. Systems on the research ships will be upgraded to this new system when funding allows.

Expected scientific results:

The work is in support of creating:

1. Seasonal CO_2 flux maps
2. Improving mechanistic understanding of the controls on pCO_2.
3. Increasing data coverage in regions with limited observations to improve the global pCO_2 climatology.

The mechanistic studies have a focus on providing input for modeling and empirical studies to improve methods of extrapolating/interpolating pCO_2 data in time and space. The papers presented in the reference section are testament to our progress in all three subject areas.

3.32b. Ocean Reference Stations and Northwest Tropical Atlantic Station for Flux Measurement (NTAS)

Robert A. Weller and Albert J. Plueddemann

FY 2005 PLANS

We plan to maintain the three ORS sites through a combination of instrument preparation and testing and mooring turnaround cruises during FY2005. Maintaining three sites will require a pool of hardware (buoy hulls) and instrumentation, ongoing maintenance of the buoys and meteorological and oceanographic instrumentation, fabrication of mooring components, ship time (detailed further under each task), labor for preparation and work at sea, calibrations support, ARGOS telemetry costs, work station and disk support, repair, and replacement, and support of data recovery from the instrumentation, processing, sharing. We are examining shifting from Service Argos to IRIDIUM for data telemetry. Science results are discussed under Task II and III below.

STRATUS FY 2005 PLANS

In December 2004 we will use the NOAA Ship *Ronald H. Brown* to recover and redeploy the Stratus mooring. On the same cruise we will deploy surface drifters and profiling Argo floats. We will also service tsunami moorings for PMEL/NDBC/Chilean Navy (SHOA), take air-sea flux (NOAA ETL) and aerosol (Texas A&M) observations, collect CTD profiles (for colleagues from the University of Concepcion, Concepcion, Chile), meteorological observations for colleagues from the University of Chile, Santiago, and other underway data.

Requirements, Logistics:

A cruise with 6 to 10 days on station at 20°S, 85°W with accompanying transit time.

New data collection methods:

None.

Expected scientific results:

We will have the third year of data processed and quality controlled, and telemetry of the fourth year of data coming in. We will begin to have an idea of the year-to-year variability in the forcing and response and its relation to ENSO variability. We will be providing data to the CLIVAR Climate Process Team working on cloud parameterizations and expect a better understanding of cloud forcing under the stratus to result. We will also be exchanging the ocean data with ocean modelers and examining the realism of ocean models at this site.

NTAS FY 2005 PLANS

Anticipated Requirements:

The NTAS project transitions to the ORS project in FY2005. The FY2005 budget, as outlined below, will be appropriate to maintain the NTAS Ocean Reference Station and sustain the NTAS project through 30 June 2005.

Logistics Requirements:

We will utilize 15 days of ship time on the NOAA Ship *Ronald H. Brown* for the mooring turnaround cruise originating in Bridgetown, Barbados and terminating in Charleston, SC. This cruise is presently scheduled for 9–23 March 2005. We plan to utilize NOAA dockside facilities in Charleston for unloading the scientific gear.

New data collection methods:

None.

Expected Scientific Results:
A publication is anticipated in FY2005 documenting the first 3 years of meteorological observations and bulk fluxes from the NTAS site. The in-situ fluxes will be compared to those available from operational models and satellites, the flux components with the largest discrepancies will be identified, and the reasons for the discrepancies will be investigated.

HAWAII FY 2005 PLANS:
We plan to recover and redeploy in July 2005. Ten days of ship time, on a Hawaii-to-Hawaii leg of a Class 1 ship are needed. The recovery and redeployment will sustain the establishment of a long time series moored perspective at the Hawaii site where a program of sampling from frequently repeated cruises has begun to build an understanding of the physical variability and of the interaction between physics, biology, and chemistry. It is expected that establishment of an Ocean Reference Station at this Hawaii location will accelerate progress toward understanding multidisciplinary science at the site, provide a key anchor site for developing air-sea flux fields in the Pacific, and provide a new regime in which to examine atmospheric, oceanic, and coupled model performance as well as the performance of remote sensing methods. Examination of the performance of models and remote sensing will lead to improvements in products and predictions.

3.33b. Implementation of One High Density XBT Line with TSG and IMET Instrumentation in the Tropical Atlantic

by Robert Weller

FY 2005 PLANS

Turnaround of the AutoIMET system will be carried out every six months.

The original stand-alone ASIMET modules will all have been converted to the new Auto-IMET systems and these will have been installed on the three active ships, Horizon Enterprise, Columbus Florida, and Sealand Express. A forth ship is scheduled to have a system installed in 2005 making a total of four VOS with Auto-IMET / NOAA SEAS systems that report via Inmarsat C in real time and store one minute data for retrieval every six months. This program is in an operational support mode for the current ships.

Rationale:

The nation is entering a new era of climate research and prediction requiring evaluation and integration of the climate data from VOS (Volunteer Observing Ships) that are now making high-resolution climate observations on a regular basis. Air-sea interaction plays a significant role in this problem and, as time scales increase from weeks, to intra-seasonal, to seasonal, the importance of air-sea interaction increases. The largest mode of short-term seasonal variability in the Earth's climate systems (El Nino) is an air-sea interaction phenomenon. The single most important process in air-sea interaction is the air-sea flux (in come sense, air-sea fluxes are air-sea interaction).

High-resolution climate data has been taken from VOS for several years now as part of an engineering effort to develop the instrumentation and logistical support required. This previous data as well as data being observed on three (soon to be four) VOS requires evaluation and analysis to insure that it is suitable for inclusion in the global climatology data base. This effort is beyond the effort now funded to make the observations and present "first-cut" integrated data on the web for general use.

Proposed Work:

Currently, the VOS program is funded to download the data from the instrumentation, do the time correlation and integration, and post the resulting data set to the web site, but not to do the data quality checking. This task will provide the additional processing and analysis required to:

1) Create a processed and checked, high quality data base of VOS meteorology and air-sea fluxes for public access,
2) Use the processed VOS AutoIMET data to examine how this data compares with surface meteorological and air-sea flux fields from numerical weather prediction (NWP) models and other flux data sets, including that being developed by Lisan Yu at WHOI,
3) Examine the space/time statistics of the VOS AutoIMET data and of the differences between these observations and other surface meteorological and air-sea flux fields,
4) Analyze the joint statistics of the variability at and differences between the AutoIMET data and the NTAS and WHOTS Ocean Reference Station ASIMET data, working toward the goal of understanding how the combination of high time resolution at a point and the space/time sampling along the ship tracks can best be used to further improve the Yu flux fields,
5) Work with Roemmich and Goni in the analysis of the combined AutoIMET and XBT (and other shipboard oceanographic observations) data to examine air-sea coupling and upper ocean transports by wind-driven and geostrophic flow.

CHAPTER 4

STATE OF THE SCIENCE

This final chapter contains selected abstracts and a bibliography of FY 2003 publications from scientific journals treating the global observation of ocean heat, carbon, fresh water, and sea level change. A select number of abstracts of particularly relevant scientific papers are presented first, chosen by the principal investigators (PI) of the science projects funded by NOAA's Office of Climate Observation. Website urls follow the bibliographic reference if the publication and expanded abstract can be found online.

4.1 Selected Abstracts

Bourassa, M. A., 2004: An Improved Seastate Dependency For Surface Stress Derived from In Situ and Remotely Sensed Winds. *Advances in Space Res.*, **33 (7)**, 1136-1142.
http://www.coaps.fsu.edu/~bourassa/pubs/Bourassa2004_stress_model.pdf

ABSTRACT
An improved model is developed for the dependency of surface turbulent stress on wave characteristics. Recent studies have used differences between satellite and in situ observations to gain insights into the physical processes that might be related to air-sea interaction. Both scatterometers and buoys provide very accurate measurements of wind speed. Differences between these measurements can be explained in terms of the different mechanisms to which the instruments respond. A physically-based flux model is developed herein. Prior results suggest that the stress parameterizations, converting neutral equivalent wind speed to stress, applied to in situ observations differ subtlety from those that should be used for scatterometer-derived winds. These differences are due to water waves modifying the surface stress. This model provides a physical explanation of the observed differences, and provides a model for calculating stresses from scatterometer winds. The model is validated with recent in situ observations gathered under severe conditions. The model explains more wave-related variability in surface stress than previous models.

Cai, W., M. J. McPhaden, and M. A. Collier, 2004: Multidecadal fluctuations in the relationship between equatorial Pacific heat content anomalies and ENSO amplitude. *Geophys. Res. Lett.*, **31**, L01201, doi:10.1029/2003GL018714.
http://www.agu.org/pubs/crossref/2004/2003GL018714.shtml

ABSTRACT
Observations over the past 20 years indicate that equatorial Pacific Ocean heat content variations associated with El Niño-Southern Oscillation (ENSO) cycles lead sea surface temperature (SST) anomalies in the equatorial cold tongue by about 7 months. However, an asymmetry exists in the relationship between SST and heat content: positive SST anomalies related to El Niño are stronger than negative SST anomalies related to La Niña for the same magnitude (but opposite sign) heat content anomaly. In this study, we analyze a multi-century simulation using the CSIRO Mark 3 coupled climate model to show that a similar asymmetry exists in some decades but not in others. This non-stationarity appears to be a consequence of modulations by a mode of multidecadal variability which affects the temperature of upwelled water and the efficiency with which upwelling generates SST anomalies.

Centurioni, L. R., P. P. Niiler, and D.-K. Lee, 2004: Observations of inflow of the Philippine Sea surface water into the South China Sea through the Luzon Strait. *J. Phys. Oceanogr.*, **34**, 113-121.
http://ams.allenpress.com/amsonline/?request=get-abstract&doi=10.1175%2F1520-0485(2004)034%3C0113:OOIOPS%3E2.0.CO%3B2

ABSTRACT
Velocity observations near the surface made with Argos satellite-tracked drifters between 1989 and 2002 provide evidence of seasonal currents entering the South China Sea from the Philippine Sea through the Luzon Strait. The drifters cross the strait and reach the interior of the South China Sea only between October and January, with ensemble mean speeds of 0.7 ± 0.4 m s–1 and daily mean westward speeds that can exceed 1.65 m s–1. The majority of the drifters that continued to reside in the South China Sea made the entry within a westward current system located at 20°N that crossed the prevailing northward Kuroshio path. In other seasons, the drifters looped across the strait within the Kuroshio and exited along the south coast of Taiwan. During one intrusion event, satellite altimeters indicated that, directly west of the strait, anticyclonic and cyclonic eddies resided, respectively, north and south of the entering drifter track. The surface currents measured by the crossing drifters were much larger than the Ekman currents that would be produced by an 8–10 m s–1 northeast monsoon, suggesting that a deeper westward current system, as seen in historical watermass analyses, was present.

Coale, K. H., K. S. Johnson, F. P. Chavez, K. O. Buesseler, R. T. Barber, M. A. Brzezinski, W. P. Cochlan, F. J. Millero, P. G. Falkowski, J. E. Bauer, R. H. Wanninkhof, R. M. Kudela, M. A. Altabet, B. E. Hales, T. Takahashi, M. R. Landry, R. R. Bidigare, Z. Chase, P. G. Strutton, G. E. Friederich, M. Y. Gorbunov, V. P. Lance, A. K. Hilting, M. R. Hiscock, M. Demerest, W. T. Hiscock, K. A. Sullivan, S. J. Tanner, R. M. Gordon, C. L. Hunter, V. A. Elrod, S. E. Fitzwater, S. Tozzi, M. Koblizek, A. E. Roberts, J. Herndon, D. Timothy, S. L. Brown, K. E. Selph, C. C. Sheridan, B. S. Twining, and Z.I. Johnson, 2004: Southern ocean iron enrichment experiment: carbon cycling in high-and low-Si waters. *Science,* **304** (5669), 408-414.
http://www.nicholas.duke.edu/news/dickbarber416.pdf

ABSTRACT
The availability of iron is known to exert a controlling influence on biological productivity in surface waters over large areas of the ocean and may have been an important factor in the variation of the concentration of atmospheric carbon dioxide over glacial cycles. The effect of iron in the Southern Ocean is particularly important because of its large area and abundant nitrate, yet iron-enhanced growth of phytoplankton may be differentially expressed between waters with high silicic acid in the south and low silicic acid in the north, where diatom growth may be limited by both silicic acid and iron. Two mesoscale experiments, designed to investigate the effects of iron enrichment in regions with high and low concentrations of silicic acid, were performed in the Southern Ocean. These experiments demonstrate iron's pivotal role in controlling carbon uptake and regulating atmospheric partial pressure of carbon dioxide.

Feely, R.A., C. L. Sabine, K. Lee, W. Berelson, J. Kleypas, V. J. Fabry, and F.J. Millero, 2004: Impact of anthropogenic CO_2 on the $CaCO_3$ system in the oceans. *Science*, **305 (5682)**, 362–366. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&list_uids=15256664&dopt=Abstract&holding=f1000

ABSTRACT
Rising atmospheric carbon dioxide (CO_2) concentrations over the past two centuries have led to greater CO_2 uptake by the oceans. This acidification process has changed the saturation state of the oceans with respect to calcium carbonate ($CaCO_3$) particles. Here we estimate the in situ $CaCO_3$ dissolution rates for the global oceans from total alkalinity and chlorofluorocarbon data, and we also discuss the future impacts of anthropogenic CO_2 on $CaCO_3$ shell-forming species. $CaCO_3$ dissolution rates, ranging from 0.003 to 1.2 micromoles per kilogram per year, are observed beginning near the aragonite saturation horizon. The total water column CaCO3 dissolution rate for the global oceans is approximately 0.5 +/- 0.2 petagrams of $CaCO_3$-C per year, which is approximately 45 to 65% of the export production of $CaCO_3$.

Firing, Y. L., M. A. Merrifield, T. A. Schroeder, and B. Qiu, 2004: Interdecadal Sea Level Fluctuations at Hawaii, *J. Phys. Oceanogr.*, **34**. 2514-2524. http://www.soest.hawaii.edu/oceanography/bo/FMSQ04.pdf

ABSTRACT
Over the past century, tide gauges in Hawaii have recorded interdecadal sea level variations that are coherent along the island chain. The generation of this signal and its relationship to other interdecadal variability are investigated, with a focus on the last decade. Hawaii sea level is correlated with sea surface height (SSH) over a significant portion of the North Pacific Ocean, and with the Pacific–North America (PNA) index, which represents teleconnections between tropical and midlatitude atmospheric variations. Similar variations extend well below the thermocline in World Ocean Atlas temperature. Comparison with NCEP reanalysis wind and pressure shows that high (low) sea level phases around Hawaii are associated with an increase (decrease) in the strength of the Aleutian low. The associated wind stress curl pattern is dynamically consistent with observed sea level anomalies, suggesting that sea level at Hawaii represents large-scale changes that are directly windforced in concert with the PNA. Atmospheric modulation, as opposed to Rossby wave propagation, may explain the linkage of Hawaii sea level to North American sea level and ENSO events. A wind-forced, baroclinic Rossby wave model replicates some aspects of the interdecadal SSH variations and their spatial structure but fails to predict them in detail near Hawaii. The accuracy of wind products in this region and over this time period may be a limiting factor. Variations in mixed layer temperature due to surface heat flux anomalies may also contribute to the interdecadal sea level signal at Hawaii.

Hare, J. E., C. W. Fairall, W. R. McGillis, B. Ward, and R. Wanninkhof, 2004: Evaluation of the NOAA/COARE air-sea gas transfer parameterization using GasEx data. *J. Geophys. Res.*, **109** (C8). http://cires.colorado.edu/science/projects/rp-hareJ01.html

INTRODUCTION
During the two recent GasEx field experiments, direct covariance measurements of air-sea carbon dioxide fluxes were obtained over the open ocean. Concurrently, the National Oceanic and Atmospheric Administration/Coupled-Ocean Atmospheric Response Experiment air-sea gas transfer parameterization was developed to predict gas transfer velocities from measurements of the bulk state of the sea surface and atmosphere. The model output is combined with measurements of the mean air and sea surface carbon dioxide fugacities to provide estimates of the air-sea CO2 flux, and the model is then tuned to the GasEx-1998 data set. Because of differences in the local environment and possibly because of

weaknesses in the model, some discrepancies are observed between the predicted fluxes from the GasEx-1998 and GasEx-2001 cases. To provide an estimate of the contribution to the air-sea flux of gas due to wave-breaking processes, the whitecap and bubble parameterizations are removed from the model output. These results show that moderate (approximately 15 ms1) wind speed breaking wave gas transfer processes account for a fourfold increase in the flux over the modeled interfacial processes.

Rudnick, D.L., R.E. Davis, C.C. Eriksen, D. Fratantoni, M.J. Perry, 2004. Undersea gliders for ocean research. *J. Marine Tech. Soc*., **38**(2), 73-84.
http://www-pord.ucsd.edu/~rdavis/publications/MTS_Glider.pdf

INTRODUCTION
Underwater gliders are autonomous vehicles that profile vertically by controlling buoyancy and move horizontally on wings. Gliders are reviewed, from their conception by Henry Stommel as an extension of autonomous profiling floats, through their development in three models, and including their first deployments singly and in numbers. The basics of glider function are discussed as implemented by University of Washington in Seaglider, Scripps Institution of Oceanography in Spray, and Webb Research in Slocum. Gliders sample in the archetypical modes of sections and of "virtual moorings." Preliminary results are presented from a recent demonstration project that used a network of gliders off Monterey. A wide range of sensors has already been deployed on gliders, with many under current development, and an even wider range of future possibilities. Glider networks appear to be one of the best approaches to achieving subsurface spatial resolution necessary for ocean research.

Smith, S. R., 2004: Focusing on improving automated meteorological observations from ships.
EOS, Trans Amer. Geophys. Union, **85**, 319.

INTRODUCTION
The shipboard automated meteorological and oceanographic system (SAMOS) initiative seeks to improve the accuracy, calibration, availability, and archiving of quality assured marine meteorological measurements collected using SAMOS on research vessels (R/Vs) and select volunteer observing ships (VOS). R/Vs are envisioned to be one component of a sustained ocean observing system that will be implemented over the next decade by U.S. and international partners (NOAA 2003). One goal of the ocean observing system is to provide better estimates of the heat, moisture, and momentum fluxes across the air-sea interface. The planners of the World Ocean Circulation Experiment (WOCE) recognized a need for an improved understanding of air-sea fluxes (Thompson et al. 2001) and a continued need was stated by the World Climate Research Program/Scientific Committee on Oceanic Research (WCRP/SCOR) Working Group on Air- Sea Fluxes (WGASF 2000). High quality, high accuracy fields of air-sea fluxes are necessary to achieve the scientific objectives of the Climate Variability and Predictability program (CLIVAR; WCRP 1995) and to support the activities of the Global Ocean Data Assimilation Experiment (GODAE). Over the ocean surface, these fields can be derived using in-situ and remotely sensed observations in combination with flux models and data assimilation systems. Regardless of the method used to derive the flux fields, there will be a need to benchmark the fields to some independent standard. Understanding the biases and uncertainties in global flux fields is necessary because poor quality fields can result in unrealistic ocean currents and heat transports when they are used to force an ocean model. The planners of a sustained ocean observing system look to future SAMOS installations as an excellent source of validation data for the flux fields (e.g., NOAA 2003, Smith et al. 2003).

Sabine, C.L., R.A. Feely, N. Gruber, R.M. Key, K. Lee, J.L. Bullister, R. Wanninkhof, C.S. Wong, D.W.R. Wallace, B. Tilbrook, F.J. Millero, T.-H. Peng, A. Kozyr, T. Ono, and A.F. Rios, 2004b: The oceanic sink for anthropogenic CO_2. *Science*, **305**, 367–371. http://www.ocean.washington.edu/courses/oc588/Sabine2004_CO2sink.pdf

ABSTRACT
Using inorganic carbon measurements from an international survey effort in the 1990s and a tracer-based separation technique, we estimate a global oceanic anthropogenic carbon dioxide (CO_2) sink for the period from 1800 to 1994 of 118 ± 19 petagrams of carbon. The oceanic sink accounts for 48% of the total fossil-fuel and cement-manufacturing emissions, implying that the terrestrial biosphere was a net source of CO_2 to the atmosphere of about 39 ± 28 petagrams of carbon for this period. The current fraction of total anthropogenic CO_2 emissions stored in the ocean appears to be about one-third of the long-term potential.

Lumpkin, R. and S. L. Garzoli, 2005: Near-surface Circulation in the Tropical Atlantic Ocean. *Deep-Sea Res*. I **52**(3),495-518, 10.1016/j.dsr.2004.09.001. http://www.aoml.noaa.gov/phod/dac/drifter_climatology.html

DESCRIPTION
Satellite-tracked SVP drifting buoys (Sybrandy and Niiler 1991; Niiler 2001) provide observations of near-surface circulation at unprecedented resolution. Since 1997, a joint SIO/AOML program has focused upon seeding the tropical Atlantic Ocean with these drifters as part of the Global Ocean Observing System. This effort has enormously increased the dataset of drifter observations in this region (Lumpkin and Garzoli 2005). A drifter is composed of a surface float, which includes a transmitter to relay data, a thermometer which reads temperature a few centimeters below the air/sea interface, and a submergence sensor used to detect when/if the drogue is lost. The surface float is tethered to a subsurface float which minimizes rectification of surface wave motion (Niiler et al. 1987; Niiler et al. 1995). This in turn is tethered to a holey sock drogue, centered at 15 m depth. The drifter follows the flow integrated over the drogue depth, although some slip with respect to this motion is associated with direct wind forcing (Niiler and Paduan 1995). This slip is greatly enhanced in drifters which have lost their drogues (Pazan and Niiler 2000). Drifter velocities are derived from finite differencing their raw position fixes. These velocities, and the concurrent SST measurements, are archived at AOML's Drifting Buoy Data Assembly Center where the data are quality controlled and interpolated to 1/4-day intervals (Hansen and Herman 1989; Hansen and Poulain 1996).

Miller, L., and B. C. Douglas, 2004: Mass and volume contributions to 20th century global sea level rise. *Nature*, **428**, 406-408. http://www.pol.ac.uk/ntslf/royalsociety2004.abstracts/douglas.doc

Both the rate and causes of 20th century global sea level rise (GSLR) are the subjects of intense controversy. Estimates from tide gauges range from about 1.0-2.0 mm/yr. In contrast, values based on the two processes that must be principally responsible for GSLR --mass increase (from mountain glaciers and the great high latitude ice masses) and volume increase (expansion due to ocean warming) – fall below this range. Either the gauge estimates are too high, or one (or both) of the component estimates is too low. Gauge estimates have long been controversial because of vertical land movements, especially due to glacial isostatic adjustment (GIA), and more recently the possibility that coastal tide gauges are subject to exaggerated rates of sea level rise because of localized ocean warming. Presented here are two approaches to a resolution of these problems. The first is heuristic, based on the limiting values of observed trends of 20th century relative sea level rise as a function of the distance from the center of the

ice loads at the last glacial maximum. This observational approach, which does not depend on a geophysical model of GIA, supports values of GSLR above 1.5 mm per year. The second approach involves an analysis of gauge and hydrographic (*in-situ* temperature and salinity) observations in the Pacific and Atlantic Oceans. It shows that gauge-measured sea level rates are in fact free from anomalous thermal effects. Thus sea level trends from tide gauges, which reflect both mass and volume change, are 2-3 times higher than hydrographic based rates which only reveal volume change. These results support those studies that put the 20th century rate in the higher end of the 1.0-2.0 mm/yr range, and provides the first clear evidence that mass increase plays a larger role than ocean warming in 20th century GSLR.

McPhaden, M. J., and D. Zhang, 2004: Pacific Ocean circulation rebounds. *Geophys. Res. Lett.*, **31**, L18301, doi:10.1029/2004GL020727.
http://www.agu.org/pubs/crossref/2004/2004GL020727.shtml

ABSTRACT
Recent observations indicate that the shallow meridional overturning circulation in the tropical Pacific Ocean has rebounded since 1998, following 25 years of significantly weaker flow. McPhaden and Zhang compared the 5-6 year average conditions before and after 1998 in the Pacific and report a recent increase in equatorward flow in the upper ocean linked to a change in the Pacific Decadal Oscillation. The circulation increase is also related to a strengthening of the trade winds, changes in the equatorial sea level, and the development of anomalously cool equatorial Pacific sea surface temperatures. The authors suggest that the changes may have affected the global climate and Pacific marine ecosystems. A pattern of stronger circulation was the norm prior to 1976-77, when weaker overturning flow began to dominate the Pacific. The researchers suggest that the abruptness of the circulation recovery in 1998 obscures presumed manmade warming trends indicated in the instrumental records from the tropical Pacific.

Reynolds, R. W, C. L. Gentemann, and F. Wentz, 2004: Impact of TRMM SSTs on a climate-scale SST analysis. *J. Climate*, **17**, 2938-2952.
http://ams.allenpress.com/amsonline/?request=get-abstract&doi=10.1175%2F1520-0442(2004)017%3C2938:IOTSOA%3E2.0.CO%3B2

ABSTRACT
Prior efforts have produced a sea surface temperature (SST) optimum interpolation (OI) analysis that is widely used, especially for climate purposes. The analysis uses in situ (ship and buoy) and infrared (IR) satellite data from the Advanced Very High Resolution Radiometer (AVHRR). Beginning in December 1997, "microwave" SSTs became available from the Tropical Rainfall Measuring Mission (TRMM) satellite Microwave Imager (TMI). Microwave SSTs have a significant coverage advantage over "IR" SSTs because microwave SSTs can be retrieved in cloud-covered regions while IR SSTs cannot. However, microwave SSTs are at a much lower spatial resolution than the IR SSTs.

In this study, the impact of SSTs derived from TMI was tested from the perspective of the OI analysis. Six different versions of the OI were produced weekly from 10 December 1997 to 1 January 2003 using different combinations of AVHRR and TMI data and including versions with and without a bias correction of the satellite data. To make the results more objective, 20% of the buoys were randomly selected and the SSTs from these buoys were withheld from the OI for independent verification. The results of the intercomparisons show that both AVHRR and TMI data have biases that must be corrected for climate studies. These biases change with time as physical properties of the atmosphere change and as satellite instruments and the orbits of the satellites, themselves, change. It is critical to monitor differences between satellite and other products to quickly diagnose any of these changes. For the OI analyses *with* bias correction, it is difficult using the withheld buoys to clearly demonstrate that there is a significant advantage in adding TMI data. The advantage of TMI data is clearly shown in the OI analyses *without* bias correction. Because IR and microwave satellite algorithms are affected by different sources of error, biases may tend to cancel when both TMI and AVHRR data are used in the OI. Bias corrections cannot be made in regions where there are no in situ data. In these regions, the results of the analyses without bias corrections apply. Because there are areas of the ocean with limited in situ data and restricted AVHRR coverage due to cloud cover, the use of both TMI and AVHRR should improve the accuracy of the analysis in these regions. In addition, the use of more than one satellite product is helpful in diagnosing problems in these products.

Rigor, I. G., and J. M. Wallace, 2004: Variations in the Age of Sea Ice and Summer Sea Ice Extent, Geophys. *Res. Lett.*, **v31**, doi:10.1029/2004GL019492.
http://iabp.apl.washington.edu/IceAge&Extent/

INTRODUCTION
Three of the past six summers have exhibited record low sea-ice extent on the Arctic Ocean. These minima may have been dynamically induced by changes in the surface winds. Based on results of a simple model that keeps track of the age of ice as it moves about on the Arctic Ocean, we show that the areal coverage of thick multi-year ice decreased precipitously during 1989–1990 when the Arctic Oscillation was in an extreme ‘‘high index’’ state, and has remained low since that time. Under these conditions, younger, thinner ice anomalies recirculate back to the Alaskan coast more quickly, decreasing the time that new ice has to ridge and thicken before returning for another melt season. During the 2002 and 2003 summers this anomalously younger, thinner ice was advected into Alaskan coastal waters where extensive melting was observed, even though temperatures were locally colder than normal. The age of sea-ice explains more than half of the variance in summer sea-ice extent.

Rudnick, D. L., R. E. Davis, C. C. Eriksen, D. Fratantoni, and M. J. Perry, 2004: Undersea gliders for ocean research. *J. Marine Tech. Soc.*, **38 (2)**, 73-84.
http://www-pord.ucsd.edu/~rdavis/publications/MTS_Glider.pdf

INTRODUCTION
Underwater gliders are autonomous vehicles that profile vertically by controlling buoyancy and move horizontally on wings. Gliders are reviewed, from their conception by Henry Stommel as an extension of autonomous profiling floats, through their development in three models, and including their first deployments singly and in numbers. The basics of glider function are discussed as implemented by University of Washington in Seaglider, Scripps Institution of Oceanography in Spray, and Webb Research in Slocum. Gliders sample in the archetypical modes of sections and of “virtual moorings.” Preliminary results are presented from a recent demonstration project that used a network of gliders off Monterey. A wide range of sensors has already been deployed on gliders, with many under current development, and an even wider range of future possibilities. Glider networks appear to be one of the best approaches to achieving subsurface spatial resolution necessary for ocean research. to the problem at hand; global distribution is appropriate for climate problems, while a study of, say, biophysical interactions in mesoscale eddies would require more focused deployments. A second advantage of small platforms is that they are readily portable to sample phenomena that may be intermittent and localized, such as mixing and upwelling events, and phytoplankton blooms. The scalability and portability of a fleet of autonomous platforms make them essential infrastructure for ocean research.

Takahashi, T., 2004: The fate of industrial carbon dioxide. *Science*, **305**, 352-354.
http://www.ocean.washington.edu/courses/oc588/Takahashi2004_FateCO2.pdf

INTRODUCTION

The atmospheric CO_2 concentration has increased from about 280 parts per million (ppm) in 1800—the beginning of the industrial age—to 380 ppm today (*1*). During this time, the observed annual rate of increase has been about 50% of that expected from the estimated industrial CO_2 emission rate into the atmosphere. This means that an amount of CO_2 equivalent to about one-half of the industrial CO_2 emitted each year has been missing, and thus Earth's atmosphere is receiving only one half the full impact of the anthropogenic CO_2 emissions. What process has been taking up the "missing carbon"? An answer to this question is fundamental not only for our understanding of the natural carbon cycle, but also for formulating a sound global CO_2 emission strategy. As reported on page 367 of this issue, Sabine *et al.* (*2*) used an extensive data set obtained for CO_2 concentration and other chemical properties during recent global oceanographic programs, together with a computational method developed by Gruber *et al*. (*3*), and provided a solid estimate for the total amount of CO_2 taken up by the global oceans from 1800 to 1994. Their results show that the oceans store a major proportion of the anthropogenic CO_2 and provide a better understanding of the carbon cycle.

Willey, D. A., R. A. Fine, R. E. Sonnerup, J. L. Bullister, W. M. Smethie, Jr., and M. J. Warner 2004: Global oceanic chlorofluorocarbon inventory. Geophys. Res. Lett., **31**, L01303, doi:10.1029/2003GL018816.
http://www.agu.org/journals/gl/gl0401/2003GL018816/

ABSTRACT

Chlorofluorocarbons (CFCs) dissolve in the oceans, but the total quantity and spatial distribution in the oceans was not previously known. The first estimate of the global oceanic CFC-11 uptake using field measurements is calculated from WOCE (World Ocean Circulation Experiment) CFC-11 concentrations. Here we find the total oceanic uptake of $5.5\ (\pm 1.2) \times 108$ moles was about 1% of total emissions through 1994. Eighty-two percent of the CFC-11 inventory is in the upper 1000 meters. The CFC inventory distribution implies that the dominant physical air-sea exchange of gases on decadal time scales occurs due to a combination of high gas solubility in cold high latitude waters and effectiveness of the wind-driven circulation. The global inventory provides a benchmark for models simulating climate change.

4.2 Bibliography of Science Articles and Reports Published by OCO-funded Scientists During FY 2004

A bibliography of all science publications published during FY 2004 is found below. Articles are separated into published articles and articles in press, books and book chapters, submitted articles, articles in preparation, reports and memos, proceedings, abstracts, encyclopedia entries, newsletters, and brochures and pamphlets.

Legend for projects affiliated with publications

A key is provided to show the affiliation between each published article and the science projects shown below (PI = Principal Investigator; co-PI = co-Principal Investigator; PM = Project Manager; PL = Project Leader; S = Scientists).

A. Atlantic High Density XBT Lines (PMs: Baringer, Goni, Garzoli)
B. Western Boundary Time Series in the Atlantic Ocean (PMs / S: Baringer, Garzoli / Johns, Meinen)
C. The Tropical Atmosphere Ocean (TAO) Array (PM: Bernard)
D. ENSO Observing System (PMs: Cook, Molinari)
E. Surface Fluxes and Analysis (PL: Cayan)
F. Four-Dimensional Variational (4DVAR) Data Assimilation in the Tropical Pacific (PLs: Cornuelle, Stammer, Miller)
G. Underwater Gliders for Monitoring Ocean Climate (PL: Davis)
H. Drifter Observations (PL: Niiler)
I. High Resolution XBT/XCTD (HRX) Transects (PL: Roemmich)
J. Development of an Underway CTD (PL: Rudnick)
K. Lagrangian Salinity Profiling: Evaluation of Sensor Performance (PL: Schmitt)
L. Observations of Air-Sea Fluxes and the Surface of the Ocean (PIs: Weller, Bahr, Hosom)
M. Flux Mooring for the North Pacific's Western Boundary Current: Kuroshio Extension Observatory (KEO) (PI / co-PIs: Cronin / Meinig, Sabine)
N. High Resolution Climate Data from Research and Volunteer Observing Ships (PM: Fairall)
O. Global Repeat Hydrographic/CO_2/Tracer Surveys in Support of CLIVAR and Global Carbon Cycle Objectives: Carbon Inventories and Fluxes (PMs / co-PIs: Feely, Wanninkhof / Sabine, Johnson, Baringer, Bullister, Mordy, Zhang)
P. Surface Drifter Program (PMs: Garzoli, Molinari)
Q. National Water Level Program Support Towards Building a Sustained Ocean Observing System for Climate (PMs: Gill, Zervas)
R. An End-to-End Data Management System for Ocean pCO_2 Measurements (PI / co-PIs: Hankin / Feely, Kozyr, Peng)
S. Observing System Research Studies (PI: Harrison)
T. Progress Reports for the Observing System Monitoring Center (OSMC) (PIs: Kern, Hankin)
U. An Indian Ocean Moored Buoy Array for Climate (PI: McPhaden)
V. Pilot Research Moored Array in the Tropical Atlantic (PIRATA) (PI: McPhaden)
W. The University of Hawaii Sea Level Center (PI: Merrifield)
X. Satellite Altimetry (PM: Miller)
Y. The Global Drifter Program (PI: Niiler)
Z. Climate Variability in Ocean Surface Turbulent Fluxes (PI / co-PIs: O'Brien / Smith, Bourassa)
AA. U.S. Research Vessel Surface Meteorology Data Assembly Center (PI / co-PIs: O'Brien / Smith, Bourassa)
BB. *In situ* and Satellite Sea Surface Temperature (SST) Analyses (PM: Reynolds)

CC. Monitoring Ice Thickness in the Western Arctic Ocean (PM: Richter-Menge)

DD. Monitoring Eurasian Basin of the Arctic Ocean (PM: Rigor)

EE. High-Resolution Ocean and Atmosphere pCO_2 Time-Series Measurements (PI / co-PI: Sabine / Chavez)

FF. Document Ocean Carbon Sources and Sinks: Initial Steps Towards a Global Surface Water pCO_2 Observing System Underway CO_2 Measurements on the NOAA ships Ka'imimoana and Ronald H. Brown and RVIB Palmer and Explorer of the Seas (PIs / co-PIs: Wanninkhof, Feely / Bates, Millero, Takahashi, Cook)

GG. Ocean Reference Stations and Northwest Tropical Atlantic Station for Flux Measurement (NTAS) (PMs: Weller, Plueddemann)

HH. Implementation of One High Density XBT Line with TSG and IMET Instrumentation in the Tropical Atlantic (Atlantic VOS) (PIs: Weller, Hosom)

Published Articles and Articles in Press

Auad, G., J. P. Kennett, and A. J. Miller, 2003: The North Pacific Intermediate Water response to a modern climate shift. *J. Geophys. Res.*, **108**, article no.3349. (F)

Bhat, G. S., G. A. Vecchi, and S. Gadgil, 2004: Sea surface temperature of the Bay of Bengal derived from TRMM microwave imager. *J. Atmos. Oceanic Technnol.*, **21 (8)**, 1283–1290. (S)

Bishop, J. K. B., T. J. Wood, R. E. Davis, and J. T. Sherman, 2004: Robotic observations of enhanced carbon biomass and export at 55oS during SOFEX. *Science*, **298**, 817-821. (G)

Bond, N. A., and G. A. Vecchi, 2003: The influence of the Madden-Julian Oscillation (MJO) on precipitation in Oregon and Washington. *Weather Forecast*, **18 (4)**, 600–613. (S)

Bourassa, M. A., 2004: An Improved Seastate Dependency For Surface Stress Derived from In Situ and Remotely Sensed Winds. *Advances in Space Res.*, **33 (7)**, 1136-1142. (Z)

Bourassa, M. A., D. M. Legler, J. J. O'Brien, and S. R. Smith, 2003: SeaWinds Validation with Research Vessels. *J. Geophys. Res.*, **108**, 3019, DOI 10.1029/2001JC001081. (AA)

Bretherton, C. S., T. Uttal, C. W. Fairall, S. Yuter, R. Weller, D. Baumgardner, K. Comstock, R. Wood, and G. Raga, 2004: The EPIC 2001 stratocumulus study. *Bull. Amer. Meteor. Soc.*, **85**, 967-977. (N), (GG)

Brunke, M. A., C W. Fairall, and X. Zeng, 2003: Which bulk aerodynamic algorithms are least problematic in computing ocean surface turbulent fluxes? *J. Clim.*, **16**, 619-635. (N)

Cai, W., M. J. McPhaden, and M. A. Collier, 2004: Multidecadal fluctuations in the relationship between equatorial Pacific heat content anomalies and ENSO amplitude. *Geophys. Res. Lett.*, **31**, L01201, doi:10.1029/2003GL018714. (C)

Centurioni, L. R., P. P. Niiler, and D.-K. Lee, 2004: Observations of inflow of the Philippine Sea surface water into the South China Sea through the Luzon Strait. *J. Phys. Oceanogr.*, **34**, 113-121. (H), (P)

Chavez, F. P., J. P. Ryan, S. Lluch-Cota, and M. Ñiquen, 2003: From anchovies to sardines and back- Multidecadal change in the Pacific Ocean. *Science*, **299**, 217-221. (Most highly cited paper in Geosciences in last quarter of 2003). (EE)

Coale, K. H., K. S. Johnson, F. P. Chavez, K. O. Buesseler, R. T. Barber, M. A. Brzezinski, W. P. Cochlan, F. J. Millero, P. G. Falkowski, J. E. Bauer, R. H. Wanninkhof, R. M. Kudela, M. A. Altabet, B. E. Hales, T. Takahashi, M. R. Landry, R. R. Bidigare, Z. Chase, P. G. Strutton, G. E. Friederich, M. Y. Gorbunov, V. P. Lance, A. K. Hilting, M. R. Hiscock, M. Demerest, W. T. Hiscock, K. A. Sullivan, S. J. Tanner, R. M. Gordon, C. L. Hunter, V. A. Elrod, S. E. Fitzwater, S. Tozzi, M. Koblizek, A. E. Roberts, J. Herndon, D. Timothy, S. L. Brown, K. E. Selph, C. C. Sheridan, B. S. Twining, and Z.I. Johnson, 2004: Southern ocean iron enrichment experiment: carbon cycling in high-and low-Si waters. *Science*, **304 (5669**, April 16, 2004**)**, 408-414. (FF)

Cosca, C. E., R. A. Feely, J. Boutin, J. Etcheto, M. J. McPhaden, F. P. Chavez, and P. G. Strutton, 2003: Seasonal and interannual CO_2 fluxes for the central and eastern equatorial Pacific Ocean as determined from fCO_2-SST relationships. *J. Geophys. Res.*, **108**, 3278, doi:10.1029/2000JC000677. (U), (EE), (FF)

Curry, J. A., A. Bentamy, M. A. Bourassa, D. Bourras, E. F. Bradley, M. Brunke, S. Castro, S. H. Chou, C. A. Clayson, W. J. Emery, L. Eymard, C. W. Fairall, M. Kubota, B. Lin, W. Perrie, R. A. Reeder, I. A. Renfrew, W. B. Rossow, J. Schulz, S. R. Smith, P. J. Webster, G. A. Wick, X. Zeng. 2004: SEAFLUX. *Bull. Amer. Meteor. Soc.*, **85**, 409-424. (N), (Z), (AA)

Davis, R. E., 2004: Intermediate-depth circulation of the Indian and South Pacific Oceans measured by autonomous floats. *J. Phys. Oceanogr.*, accepted. (G)

DeGrandpre, M. D., R. Wanninkhof, W. R. McGillis, and P. G. Strutton, 2004: A Lagrangian study of pCO_2 dynamics in the eastern equatorial Pacific Ocean. *J. Geophys. Res*, **109**, doi:10.1029/2003JC001960. (FF)

Delcroix, T., A. Dessier, Y. Gouriou, and M. J. McPhaden, 2004: Time and space scales for sea surface temperature in the tropical oceans. *Deep-Sea Res.*, in press. (C), (U)

DeSzoeke, S. P., C. S. Bretherton, N. A. Bond, M. F. Cronin, and B. Morley, 2004: The mean structure of the east Pacific atmospheric boundary layer from cold tongue to ITCZ characterized by EPIC 95W observations. *J. Atmos. Sci.*, in Press. (M)

Di Lorenzo, E., A. J. Miller, N. Schneider and J. C. McWilliams, 2004: The warming of the California Current: Dynamics, thermodynamics and ecosystem implications. *J. Phys. Oceanogr.*, in press. (F)

Dickey, T., G. Chang, D. Manov, N. Bates, R. Byrne, E. Kaltenbacher, F. Chavez, G. Friederich, R. Feely, C. Cosca, C. Moore, W. Strubhar, A. Derr, and R. Wanninkhof, 2003: New sensors monitor bio-optical/biogeochemical ocean changes. *Sea Tech.*, **44 (10)**, 17–22. (FF)

Fairall, C. W., E. F. Bradley, J. E. Hare, A. A. Grachev, and J. B. Edson, 2003: Bulk parameterization of air-sea fluxes: Updates and verification for the COARE algorithm. *J. Clim.*, **16**, 571-591. (N)

Feely, R.A., C. L. Sabine, K. Lee, W. Berelson, J. Kleypas, V. J. Fabry, and F.J. Millero, 2004: Impact of anthropogenic CO_2 on the $CaCO_3$ system in the oceans. *Science*, **305 (5682)**, 362–366. (O), (FF)

Feely, R. A., C. L. Sabine, R. Schlitzer, J. L. Bullister, S. Mecking, and D. Greeley, 2004: Oxygen utilization and organic carbon remineralization in the upper water column of the Pacific Ocean. *J. Oceanogr.*, **60 (1)**, 45–52. (O)

Feely, R. A., R. Wanninkhof, W.R. McGillis, M.-E. Carr, and C. E. Cosca, 2004: The effects of wind-speed and gas exchange parameterizations on the air-sea CO_2 fluxes in the Equatorial Pacific Ocean, *J. Geophys. Res.*, **109**, C08S03, doi:10.1029/2003JC001896. (FF)

Firing, Y. L., M. A. Merrifield, T. A. Schroeder, and B. Qiu, 2004: Interdecadal Sea Level Fluctuations at Hawaii, *J. Phys. Oceanogr.*, in press. (W)

Flatau, M. K., L. Talley, and P. P. Niiler, 2003: The North Atlantic Oscillation, surface current velocities and SST changes in the sub-polar North Atlantic. *J. Clim.*, 2355-2369. (H)

Foltz, G. R., and M. J. McPhaden, 2004: 30-70 day oscillations in the tropical Atlantic. *Geophys. Res. Lett.*, **31**, L15205, doi:10.1029/2004GL020023. (U)

Foltz, G. R., S. A. Grodsky, J. A. Carton, and M. J. McPhaden, 2003: Seasonal mixed layer heat budget of the tropical Atlantic Ocean. *J. Geophys. Res.*, **108 (C5)**, 3146, doi:10.1029/2002JC001584. (U), (Y)

Foltz, G. R., S. A. Grodsky, J. A. Carton, and M. J. McPhaden, 2004: Seasonal salt budget of the northwestern tropical Atlantic Ocean along 38°W. *J. Geophys. Res.*, **109 (C3)**, C03052, doi:10.1029/2003JC002111. (P), (U)

Fonseca C., G. Goni, W. Johns, and E. Campos, 2004: Investigation of the North Brazil Current retroflections and North Equatorial Countercurrent variability. *Geophys. Res. Lett.*, in press. (A)

Gloor, M., N. Gruber, J. L. Sarmiento, C. L. Sabine, R. A. Feely, and C. Rödenbeck, 2003: A first estimate of present and preindustrial air-sea CO_2 flux patterns based on ocean interior carbon measurements and models. *Geophys. Res. Lett.*, **30 (1)**, 1010, doi: 10.1029/2002GL015594. (O)

Goff, J. A. and W. H. F. Smith, 2003: A correspondence of altimetric gravity texture to abyssal hill morphology along the flanks of the Southeast Indian Ridge. *Geophys. Res. Lett.*, **30** (**24)**, 2269, doi:10.1029/2003GL018913. (X)

Goff, J. A., W. H. F. Smith, and K. M. Marks, 2004: The contributions of abyssal hill morphology and noise to altimetric gravity fabric. *Oceanogr.*, **17**, 24-37. (X)

Grachev, A. A., C. W. Fairall, J. E. Hare, and J. B. Edson, 2003: Wind stress vector over ocean waves. *J. Phys. Oceanogr.*, **33**, 2408-2429. (N)

Grodsky, S. A., J. A. Carton, and S. Nigam, 2003: Near surface westerly wind jet in the Atlantic ITCZ. *Geophys. Res. Lett.*, **30 (19)**, 2009, doi:10.1029/2003GL017867. (Y)

Hansell, D. A., H. W. Ducklow, A. M. Macdonald, and M. O. Baringer, 2004: Metabolic poise in the North Atlantic Ocean diagnosed from organic matter transports. *Limnology Oceanogr.*, **49 (4)**, 1084-1094. (B), (O)

Hare, J. E., C. W. Fairall, W. R. McGillis, B. Ward, and R. Wanninkhof, 2004: Evaluation of the NOAA/COARE air-sea gas transfer parameterization using GasEx data. *J. Geophys. Res.*, **109 (C8)**: Art. No. C08S. (N)

Hu, C., E. T. Montgomery, R. W. Schmitt, F. Muller-Karger, 2003: The Amazon and Orinoco River plumes in the tropical Atlantic and Caribbean Sea: Observation from space and S-PALACE floats. *Deep-Sea Res.*, in press. (K)

Johnson, G. C., P. J. Stabeno, and S. D. Riser, 2004: The Bering Slope Current System revisited. *J. Phys. Oceanogr.*, **34**, 384-398. (O)

Johnson, G. C., C. L. Sabine, K.E. McTaggart, and J.M. Hummon, 2004: Physical oceanographic conditions during GasEx 2001. *J. Geophys. Res.*, **109 (C8)**, C08S04, doi:10.1029/2002JC001718. (EE)

Kaplan, A., M. A. Cane, D. Chen, D. L. Witter, R. E. Cheney, 2004: Small-scale variability and model error in tropical Pacific sea level. *J. Geophys. Res.*, **107**, C02001, doi:10.1029/2002JC001743. (X)

Kollias, P., C. W. Fairall, P. Zuidema, J. Tomlinson, and G. A. Wick, 2004: Observations of marine stratocumulus in SE Pacific during the PACS 2003 Cruise. *Geophys. Res. Lett.*, to appear. (N)

Lee, K., S.-D. Choi, G.-H. Park, R. Wanninkhof, T.-H. Peng, R.M. Key, C.L. Sabine, R.A. Feely, J.L. Bullister, F.J. Millero, and A. Kozyr, 2003: An updated anthropogenic CO_2 inventory in the Atlantic Ocean. *Global Biogeochem. Cycles*, **17 (4)**, 1116, doi:10.1029/2003GB002067. (O)

Lumpkin, R., and S.L. Garzoli, 2004: Near-surface circulation in the Tropical Atlantic Ocean. *Deep-Sea Res. I*, in press. (P)

Macdonald, A. M., M. O. Baringer, R. Wanninkhof, K. Lee, and D.W.R. Wallace, 2003: A 1998-1992 comparison of inorganic carbon and its transport across 24.5°N in the Atlantic. *Deep-Sea Research, Part II*, **50 (22-26)**, 3041-3064. (B), (O)

Matsumoto, K., J. L. Sarmiento, R. M. Key, O. Aumont, J. L. Bullister, K. Caldeira, J.-M. Campin, S. C. Doney, H. Drange, J.-C. Dutay, M. Follows, Y. Gao, A. Gnanadesikan, N. Gruber, A. Ishida, F. Joos, K. Lindsay, E. Maier-Reimer, J. C. Marshall, R. J. Matear, P. Monfray, A. Mouchet, R. Najjar, G.-K. Plattner, R. Schlitzer, R. Slater, P. S. Swathi, I. J. Totterdell, M.-F. Weirig, Y. Yamanaka, A. Yool, and J. C. Orr , 2004: Evaluation of ocean carbon cycle models with data-based metrics. *Geophys. Res. Lett.*, **31**, L07303, doi:10.1029/2003GL018970. (O)

McGillis, W. R., J. B. Edson, C. J. Zappa, J. D. Ware, S. P. McKenna, E. A. Terray, J. E. Hare, C. W. Fairall, W. Drennan, M. Donelan, M. D. DeGrandpre, R. Wanninkhof, and R.A. Feely, 2004: Air-sea CO_2 exchange in the equatorial Pacific. *J. Geophys. Res.*, **109 (C8)**, C08S02, doi:10.1029/2003JC002256. (FF)

McGillis, W. R., W. E. Asher, R. Wanninkhof, A. T. Jessup, and R. A. Feely, 2004: Introduction to special section: Air-Sea Exchange. *J. Geophys. Res.*, **109 (C8)**, C08S01, doi:10.1029/2004JC002605. (FF)

McPhaden, M. J., and D. Zhang, 2004: Pacific Ocean circulation rebounds. *Geophys. Res. Lett.*, **31**, L18301, doi:10.1029/2004GL020727. (C), (U)

McPhaden, M. J., 2003: Tropical Pacific Ocean heat content variations and ENSO persistence barriers. *Geophys. Res. Lett.*, **30 (9)**, 1480, doi:10.1029/2003GL016872. (U)

McPhaden, M. J., 2004: Book review of "Our Affair with El Niño" by S. George Philander, Princeton University Press, 2004. *Nature*, **429**, 605–606. (C), (U)

McPhaden, M. J., 2004: Evolution of the 2002-03 El Niño. Bull. *Am. Meteor. Soc.*, **85**, 677–695. (C), (U)

Meinen, C. S., S. L. Garzoli, W. E. Johns, and M. O. Baringer, 2004: Transport variability of the Deep Western Boundary Current and the Antilles Current off Abaco Island, Bahamas. *Deep-Sea Research, Part I*, (in press). (B), (O)

Mestas-Nunez, A. M., and A. J. Miller, 2004: Interdecadal variability and climate change in the Eastern Tropical Pacific: A review. *Progress in Oceanogr.*, in press. (F)

Miller, A. J., F. Chai, S. Chiba, J. R. Moisan, and D. J. Neilson, 2004: Decadal-scale climate and ecosystem interactions in the North Pacific Ocean. *J. Oceanogr.*, **60**, 163-188. (F)

Miller, L., and B. C. Douglas, 2004: Mass and volume contributions to 20th century global sea level rise. *Nature*, **428**, 406-408. (X)

Miller, L., 2004: Satellite altimetry and the NOAA/NESDIS sea-surface height science team. *Backscatter*, 29-34. (X)

Molinari, R.L., 2004: Annual and decadal variability in the western Subtropical North Atlantic: Signal characteristics and sampling methodologies. *Progress in Oceanogr.* in press.(D)

Morey, S. L., M. A. Bourassa, X. Davis, J. J. O'Brien, and J. Zavala-Hidalgo, 2004: Remotely sensed winds for forcing ocean models. *J. Geophys. Res.*, accepted. (Z)

Niiler, P. P., N. A. Maximenko, and J. C. McWilliams, 2003: Dynamically balanced absolute sea level of the global ocean. *Geophys. Res. Lett.*, **30**, 22, 2164, doi:10.1029/2003GL018628. (H)

Niiler, P. P., W. Scuba, and D.-K. Lee, 2004: Performance of minimet wind drifters in hurricane Fabian. *The Sea Journal of Korean Society of Oceanography*. **9 (3)**. (H), (P), (Y)

Olsen, A., J. Triñanes, and R. Wanninkhof, 2004: Sea-air flux of CO_2 in the Caribbean Sea estimated using in situ and remote sensing data. *Remote Sensing of Environment*, **89**, 309–325. (FF)

Parker, D., E. Kent, S. Woodruff, D. Dehenauw, D. E. Harrison, T. Manabe, M. Meitus, V. Swail, and S. Worley, 2004: The Second JCOMM Workshop on Advances in Marine Climatology (CLIMAR-II). *WMO Bulletin*, **53 (2)**, 157-159. (S)

Pazan, S. E., and P.P. Niiler, 2004: New global drifter data set available. *EOS*, **85 (2)**, 17. (H)

Peng, T.-H., R. Wanninkhof, and R. A. Feely, 2003: Increase of anthropogenic CO_2 in the Pacific Ocean over the last two decades. *Deep-Sea Res. Pt. II*, **50**, 3065–3082. (O)

Petersen, W. A., R. Cifelli, D. J. Bocippio, S. A. Rutledge, and C. W. Fairall, 2003: Convection and easterly wave structure observed in the Eastern Pacific warm-pool during EPIC-2001. *J. Atmos. Sci.*, **60**, 1754-1773. (N)

Pfirman, S., W.F. Haxby, R. Colony, and I.G. Rigor, 2004: Variability in Arctic Sea Ice Drift. *Geophys. Res. Lett.*, **31**, doi:10.1029/2004GL020063. (DD)

Pyatt, H., B. A. Albrecht, C. W Fairall, Nick Bond, and P. Minnis, 2004: Evolution of marine atmospheric boundary layer structure across the Cold Tongue ITCZ Complex. *J. Geophys., Res.*, to appear. (N)

Rajeevan, M. and M. J. McPhaden, 2004: Tropical Pacific upper ocean heat content variations and Indian summer monsoon rainfall. *Geophys. Res. Lett.*, **31**, L18203, doi:10.1029/2004GL020631. (C), (U)

Raymond, D. J., S. K. Esbensen, M. Gregg, C. S. Bretherton, L. K. Shay, and T. Uttal, 2004: EPIC2001 and the coupled ocean-atmosphere system of the tropical East Pacific. *Bull. Am. Met. Soc.*, **85**, 1341-1354. (N)

Reynolds, R. W, C. L. Gentemann, and F. Wentz, 2004: Impact of TRMM SSTs on a climate-scale SST analysis. *J. Climate*, **17**, 2938-2952. (BB)

Reynolds, R. W., H.-M. Zhang, T. Smith, C. Gentemann, and F. Wentz, 2004: Impacts of in situ and additional satellite data on the accuracy of a sea surface temperature analysis for climate. *International J. Climate*, in press. (BB)

Richardson, 2004: Caribbean Current and eddies as observed by surface drifters. *Deep-Sea Res*., accepted. (P)

Rigor, I. G., and J. M. Wallace, 2004: Variations in the Age of Sea Ice and Summer Sea Ice Extent, Geophys. *Res. Lett*., **31**, doi:10.1029/2004GL019492. [Available at http://iabp.apl.washington.edu/IceAge&Extent/] (DD)

Roemmich, D., and W. J. Gould, 2003: The future of climate observations in the global ocean. *Sea Tech.*, **44 (8)**, 10-15. (I)

Roemmich, D., S. Riser, R.E. Davis, and Y. Desaubies, 2004: Autonomous profiling floats: workhorse for broad-scale ocean observations. *J. Mar. Tech*. **38 (2)**, 21-29. (G)

Rudnick, D.L., and R.E. Davis, 2003: Red Noise and Regime Shifts. *Deep-Sea Res. I*, **50**, 691-699. (G), (J)

Rudnick, D. L., R. E. Davis, C. C. Eriksen, D. Fratantoni, and M. J. Perry, 2004: Undersea gliders for ocean research. *J. Marine Tech. Soc.*, **38 (2)**, 73-84. (G), (J)

Sabine, C. L., R. A. Feely, G. C. Johnson, P. G. Strutton, M. F. Lamb, and K. E. McTaggart, 2004: A mixed layer carbon budget for the GasEx-2001 experiment. *J. Geophys. Res*., **109 (C8)**, C08S05, doi: 10.1029/2002JC001747. (EE), (FF)

Sabine, C. L., R. A. Feely, N. Gruber, R. M. Key, K. Lee, J. L. Bullister, R. Wanninkhof, C. S. Wong, D. W. R. Wallace, B. Tilbrook, F. J. Millero, T.-H. Peng, A. Kozyr, T. Ono, and A. F. Rios, 2004: The oceanic sink for anthropogenic CO_2. *Science*, **305 (5682)**, 367–371. (O)

Sabine, C. L., R. A. Feely, Y. W. Watanabe, and M. F. Lamb, 2004: Temporal evolution of the north Pacific CO_2 uptake rate. *J. Oceanogr.*, **60 (1)**, 5–15. (O), (EE)

Salo, S., N. Kachel, C. Mordy, J. Napp, and P. Stabeno, 2003: Horizontal and vertical scales of chlorophyll concentration. *EOS Transactions*, **84 (52)**, Ocean Sciences Meet. Suppl., OS32B-10. (O)

Scharroo, R., J. L. Lillibridge, W. H. F. Smith, and E. J. O. Schrama, 2004: Cross-Calibration and Long-Term Monitoring of the Microwave Radiometers of ERS, TOPEX, GFO, Jason, and Envisat. *Marine Geodesy*, **27**, 1&2, 279-298. (X)

Schmitt, R. W., R. C. Millard, J. M. Toole, and W. D. Wellwood, 2004: A double-diffusive interface tank for dynamic response studies. *J. Mar. Res.*, in press. (K)

Schott, F. A., J. P. McCreary Jr., and G. C. Johnson, 2004: Shallow overturning circulations of the tropical-subtropical oceans. In Earth Climate: The Ocean-Atmosphere Interaction, C. Wang, S.-P. Xie, and J. A. Carton, Eds., *American Geophysical Union Geophysical Monograph* **147**, 261-304. (O)

Serra, Y., and M. J. McPhaden, 2004: In situ observations of the diurnal variability in rainfall over the tropical Atlantic and Pacific Oceans. *J. Clim.*, **17**, 3496-3509. [(C), (U)]

Serra, Y. L., and M. J. McPhaden, 2003: Multiple time space comparisons of ATLAS buoy rain gauge measurements to TRMM satellite precipitation measurements. *J. Appl. Meteorol.*, **42** 1045–1059. [(U)]

Smith, S. R., 2004: Focusing on improving automated meteorological observations from ships. *EOS, Trans Amer. Geophys. Union*, **85**, 319. [(AA)]

Smith, S. R., J. Servain, D. M. Legler, J. N. Stricherz, M. A. Bourassa, and J. J. O'Brien, 2004: In situ based pseudo-wind stress products for the tropical oceans. *Bull. Amer. Meteor. Soc.*, **85**, 979-994. [(Z)]

Smith, T. M., and R. W. Reynolds, 2004: Improved Extended Reconstruction of SST (1854-1997). *J. Clim.*, **17**, 2466-2477. [(BB)]

Smith, T. M., and R. W. Reynolds, 2004: Reconstruction of Monthly Mean Oceanic Sea Level Pressure Based on COADS and Station Data (1854–1997). *J. Atmos. Ocean. Tech.*, **21**, 1272–1282. [(BB)]

Smith, T.M., and R.W. Reynolds, 2004: A global merged land and sea surface temperature reconstruction based on historical observations (1880-1997). *J. Clim.*, in press.[(BB)]

Smith, W. H. F, and D. T. Sandwell, 2004: Conventional bathymetry, bathymetry from space, and geodetic altimetry. *Oceanogr.*, **17**, 8-23. [(X)]

Smith, W. H. F., 2004: Introduction to this special issue on bathymetry from space. *Oceanogr.*, **17**, 6-7. [(X)]

Sprintall, J., 2003: Seasonal to interannual upper-ocean variability in the Drake Passage. *J. Mar. Res.*, **61**, 27-57. [(I)]

Steel, M. A., J. Morison, W. Ermold, I. G. Rigor, M. Ortmeyer, and K. Shimada, 204: The Circulation of Summer Pacific Halocline Water in the Arctic Ocean. *J. Geophys. Res.*, **v. 109**, c02027 doi:10.1029/2003JC002009. [(DD)]

Strutton, P. G., and F. P. Chavez, 2004: Biological heating in the equatorial Pacific: Observed variability and potential for real-time calculation. *J. Clim.*, **17**, 1097-1109. [(EE)]

Tai, C.-K., 2004: On the resolving power of a single exact-repeat altimetric satellite or a coordinated constellation of satellites. *J. Ocean Atmos. Tech. 21*, **5**, 810–818. [(X)]

Takahashi, T., 2004: The fate of industrial carbon dioxide. *Science*, **305**, 352-354. [(O)]

Takahashi, T., S.C. Sutherland, R.A. Feely, and C.E. Cosca, 2003: Decadal variation of surface water pCO_2 in the Western and Central Equatorial Pacific. *Science*, **302**, 852-856. [(FF)]

Vauclair, F., Y. DuPenhoat, and G. Reverdin, 2004: Heat and mass budgets of the warm upper layer of the Tropical Atlantic Ocean in 1979-99. *J. Phys. Oceanogr.*, **34**, 903-919. [(D)]

Vecchi, G. A., and D. E. Harrison, 2003: On the termination of the 2002-003 El Nino. *Geophys. Res. Lett.*, **30 (18)**. [(S)]

Vecchi, G. A., and N.A. Bond, 2004: The Madden-Julian Oscillation (MJO) and northern high latitude wintertime surface air temperatures. *Geophys. Res. Lett.*, **31 (4)**. (S)

Vecchi, G. A., S.-P. Xie, and A. Fischer, 2004: Ocean-atmosphere covariability in the western Arabian Sea. *J. Clim.*, **17 (6)**, 1213–1224. (S)

Wang, O., I. Fukumori, T. Lee, and G. C. Johnson, 2004: Eastern equatorial Pacific Ocean T-S variations with El Niño. *Geophys. Res. Lett.*, **31**, L04305, doi:10.1029/2003GL019087. (O)

Wanninkhof, R., K. F. Sullivan, and Z. Top, 2004: Air-Sea Gas Transfer in the Southern Ocean. *J. Geophys. Res.*, **109**, C08S19, doi:10.1029/982 2003JC001767. (FF)

Weissman, D. E., M. A. Bourassa, J. Tongue, and J. J. O'Brien, 2003: Calibrating the QuikSCAT/SeaWinds Radar for Measuring Rain Over Water. *IEEE Trans. Geosci. Remote Sens.*, **41**, 2814-2820. (AA)

Weller, R. A., P. W. Furey, M. A. Spall, and R. E. Davis, 2004: The large-scale context for oceanic subduction in the Northeast Atlantic. *Deep-Sea Res. I*, **51**, 665-699. (G)

White, W. B., D. R. Cayan, P. P. Niiler, J. Moisan, G. Lagerloef, F. Bonjean, and D. Legler, 2004: The seasonal cycle of diabatic heat storage over the Pacific Ocean. *Prog. Oceanogr.*, 14 pages (in review). (E)

Willey, D. A., R. A. Fine, R. E. Sonnerup, J. L. Bullister, W. M. Smethie, Jr., and M. J. Warner 2004: Global oceanic chlorofluorocarbon inventory. Geophys. Res. Lett., **31**, L01303, doi:10.1029/2003GL018816. (O)

Willis, J., D. Roemmich, and B. Cornuelle, 2004: Interannual variability in upper-ocean heat content, temperature and thermosteric expansion on global scales. *J. Geophys. Res.*, in press. (I)

Willis, J.K., D. Roemmich, and B. Cornuelle, 2003: Combining altimetric height with broadscale profile data to estimate steric height, heat storage, subsurface temperature, and sea-surface temperature variability. *J. Geophys. Res.*, **108 (C9)**, 3292, doi:10.1029/2002JC001755. (I)

Yaremchuk, M., and T. Qu, 2004: Seasonal variability of the large-scale currents near the coast of the Philippines. *J. Phys. Oceanogr.*, **34**, 844-855. (P)

Zeng, X., M. A. Brunke, M. Zhou, C. W. Fairall, N. A. Bond, and D. H. Lenschow, 2003: Marine atmospheric boundary layer height over the Eastern Pacific: Data analysis and model evaluation. *J. Clim.*, to appear. (N)

Zhang, D., M. J. McPhaden, and W. E. Johns, 2003: Observational evidence for flow between the subtropical and tropical Atlantic: The Atlantic subtropical cells. *J. Phys. Oceanogr.*, **33**, 1783–1797. (U)

Zhurbas, V., and I. S. Oh, 2004: Drifter-derived maps of lateral diffusivity in the Pacific and Atlantic Oceans in relation to surface circulation patterns. *J. Geophys. Res.*, **109**, C05015, doi:10.1029/2003JC002241. (P)

Books and Book Chapters

Chavez, F. P., J. T. Pennington, R. Michisaki, and J. P. Ryan, 2004: *The Monterey Bay Ocean Time-Series and Observatory (MOTO) Sheds Light on Multi-Decadal Basin-Scale Fluctuations of Anchovies and Sardines*. MBNMS Ecosystem Observations, 20-21. (EE)

Chavez, F.P., 2004: *Biological consequences of interannual to multidecadal variability*. Chapter 17 in Volume 13 of The Sea. A. Robinson and K. Brink (eds.), in press. (EE)

Sabine, C. L., M. Heimann, P. Artaxo, D. Bakker, C.-T.A. Chen, C.B. Field, N. Gruber, C. LeQuéré, R. G. Prinn, J. E. Richey, P. R. Lankao, J. Sathaye, and R. Valentini, 2004: *Chapter 2: Current status and past trends of the global carbon cycle. In SCOPE 62, The Global Carbon Cycle: Integrating Humans, Climate, and the Natural World, C.B. Field and M.R. Raupach (eds.)*. Island Press, Washington D.C., 17–44. (O), (EE)

Serreze, M. C., and I. G. Rigor, 2004: *Understanding Recent changes in the Arctic Sea Ice Cover, Glaciers and Earth's Changing Environment, ed. P. Knight*. Blackwell Publishing, Ltd, Oxford, in press. (DD)

Strutton, P. G., and F. P. Chavez, 2003: *Scales of Biological-Physical Coupling in the Equatorial Pacific. In, Handbook of Scaling Methods in Aquatic Ecology: Measurement, Analysis and Simulation*. CRC Press, LLC. (EE)

Submitted articles

Ansorge, I, S. Speich, J. Lutjeharms, G. Goni, C. de W. Rautenbach, P. Froneman, and S. Garzoli, 2004: Monitoring the oceanic flow between Africa and Antarctica: Report of the first GoodHope cruise. *South African J. Science*, submitted. (A)

Arguez, A., M. A. Bourassa, and J. J. O'Brien, 2004: Extraction of the MJO signal from QuikSCAT. *J. Atmos. Sci.*, submitted. (Z)

Bennett, A. F, B. S. Chua, H.-E. Ngodock, D. E. Harrison, M. J. McPhaden, 2004: Generalized inversion of the Tropical Atmosphere Ocean (TAO) data and the Gent-Cane model of the tropical Pacific. *J. Phys. Oceanogr.*, submitted. (S)

Bennett, A. F., B. S. Chua, H.-E. Ngodock, D. E. Harrison, and M. J. McPhaden, 2004: Testing the Gent–Cane model of the Tropical Pacific with generalized inversion of Tropical Atmosphere-Ocean (TAO) data. *J. Phys. Oceanogr.*, submitted. (C), (U)

Bond, N. A. and D. E. Harrison, 2004: U.S. Winter Weather Anomalies with El Nino and negative Arctic Oscillation: 2002-03 and before. *Weather and Forecasting*, submitted. (S)

Bourassa, M. A., 2004: Satellite-based observations of surface turbulent stress during severe weather, Atmosphere - Ocean Interactions, Vol 2., ed., W. Perrie. *Wessex Institute of Technology*. submitted. (Z)

Bourassa, M. A., R. Romero, S. R. Smith, and J. J. O'Brien, 2003: A new FSU winds and flux climatology. *J. Clim.*, submitted. (AA)

Bourassa, M. A., Rosario Romero, Shawn R. Smith, and James J. O'Brien, 2004: A new FSU winds Climatology. *J. Clim.*, submitted. (Z)

Caccamise, D. J., M. A. Merrifield, M. Bevis, J. Foster, Y. Firing, F. W. Taylor, and M. S. Schenwerk, 2004: Relative Sea and Land Level Changes in Hawaii. *Geophys. Res. Lett.*. submitted.(W)

Capotondi, A., M. A. Alexander, C. Deser, and M. J. McPhaden, 2004: Anatomy and Decadal Evolution of the Pacific Subtropical-Tropical Cells (STCs). *J. Clim.*, submitted. (C), (U)

Colbo, K, and R. A. Weller, 2004: The variability and heat budget of the upper ocean under the Chile-Peru stratus. *J. Geophys. Res.*. submitted. (GG)

Cronin, M. F., N. A. Bond, C. Fairall, and R. A. Weller, 2004: Surface cloud forcing in the east Pacific stratus deck/cold tongue/ITCZ complex. *J. Clim.,* submitted. (M)

Cronin, M. F., N. Bond, C. W. Fairall, and R. A. Weller, 2004: Surface cloud forcing in the Eastern Tropical Pacific. *J. Clim.*, submitted. (N)

Eicken, H., R. Gradinger, A. Graves, and I.G. Rigor, 2004: Sediment transport by sea ice in the Chukchi and Beaufort Seas: Increasing importance due to changing ice conditions? *Deep-Sea Res.*, submitted. (DD)

Fratantoni, D. M., and P. L. Richardson, 2004: The evolution and demise of North Brazil Current Rings. *J. Phys. Oceanogr.*, submitted. (P)

Grodsky, S., J. Carton, C. Provost, J. Servain, J. Lorenzzetti, and M. J. McPhaden, 2004: Tropical Instability Waves and the warming of the cold tongue of the tropical Atlantic. *J. Geophys. Res.*, submitted. (U)

Hare, J. E., C. W. Fairall, T. Uttal, D. Hazen, Meghan Cronin, Nicholas A. Bond, and Dana Veron, 2004: A seven-cruise sample of clouds, radiation, and surface forcing in the Equatorial Eastern Pacific. *J. Clim.*, submitted. (N)

Hare, J., C. Fairall, T. Uttal, D. Hazen, M. F. Cronin, N. A. Bond, and D. E. Veron, 2004: Cloud, radiation, and surface forcing in the equatorial eastern Pacific. *J. Clim.,* submitted. (M)

Huebert, B., B. Blomquist, J. E. Hare, C. W. Fairall, T. Bates, and J. Johnson, 2004: Measurements of the sea-air DMS flux and transfer velocity using eddy correlation. *Geophys. Res. Lett.*, submitted. (N)

Larkin, N. S. and D. E.Harrison, 2004: El Nino Definition and El Nino US Seasonal Weather Impacts. *J. Clim.*, submitted. (S)

Lavender, K. L., W. B. Owens, and R. E. Davis, 2003: The mid-depth circulation of the subpolar North Atlantic Ocean as measured by subsurface floats. *Deep-Sea Res. I*, submitted. (G)

Legeckis, R., C. W. Brown, F. Bonjean, and E. S. Johnson, 2004: The influence of Tropical Instability Waves on chlorophyll blooms in the wake of the Marquesas Islands during 1998 and on the currents observed during the drift of the Kon-Tiki in 1947. *Geophys. Res. Lettl,* submitted. (X)

Lumpkin, R. and Z. Garraffo, 2004: Evaluating the decomposition of tropical Atlantic drifter observations. *J. Atmos. Oceanic Tech.,* submitted. (P)

Marks, K. M. and W. H. F. Smith, 2004: Not all bathymetry grids are created equal. *Marine Geophys. Res*., GEBCO Special issue, submitted. (X)

McAdoo, D., C. Wagner, and S., Laxon, 2003: Improvements in Arctic Gravity and Geoid from CHAMP and GRACE: An Evaluation. *Proc. 2nd CHAMP Science Meeting*, submitted. (X)

Morey, S. L., M. A. Bourassa, D. Dukhovskoy, J. J. O'Brien, J. Zavala-Hidalgo, 2004: Modeling the Ocean Response to Air-Sea Fluxes During Energetic Episodic Atmospheric Events. *PECS 2004*, submitted. (Z)

Nuñez-Riboni, I. Boebel, M. Ollitrault, Y. You, P. Richardson and R. Davis, 2004: General circulation of the Antarctic Intermediate Water in the subtropical South Atlantic. *Deep-Sea Res. I*, submitted. (G)

Roemmich, D., J. Gilson, J. Willis, P. Sutton, and K. Ridgway, 2004: Closing the time-varying mass and heat budgets for large ocean areas: The Tasman Box. *J. Clim*., submitted. (I)

Tai, C.-K., 2004: On the aliasing of sea level sampled by a single exact-repeat altimetric satellite or a coordinated constellation of satellites, *J. Atmos. Oceanic Technol*., submitted. (X)

Tai, C.-K., and L.-L. Fu, 2004: 25-day period large-scale oscillations in the Argentine Basin revisited. *J Phys. Oceanogr*., submitted. (X)

Wick, G. A., J. C. Ohlmann, C. W. Fairall, and A. T. Jessup, 2004: Improved oceanic cool-skin corrections using a refined solar penetration model. *J. Phys. Oceanogr*., submitted. (N)

Zhang, H.-M., R. W. Reynolds, and T. M. Smith, 2004: Adequacy of In Situ Observing System in the Satellite Era for Climate SST Analysis. *J. Ocean. Atmos. Tech.*, submitted. (BB)

Articles in Preparation

Hoteit, I., B. Cornuelle, and D. Stammer, A variational data assimilation system with an Eddy-Permitting Model of the Tropical Pacific Ocean. In preparation. (F)

Thierry, V., I. Hoteit, B. Cornuelle, and D. Stammer, High resolution modeling for the Equatorial Pacific. Part II: Evolution and energetics of TIW during 96-00. In preparation. (F)

Reports and Memos

Bourassa, M. A., 2004: A Sea Surface Stress Parameterization Dependent on Directional Seastate. CAS/JSC Working Group on Numerical Experimentation, Research Activities in Atmospheric and Oceanic Modeling, World Meteorological Organization, ed. J. Côté, 2004 Edition, 4.07-4.08. [Available online at: http://www.cmc.ec.gc.ca/rpn/wgne/] (Z)

Doney, S.C., R. Anderson, J. Bishop, K. Caldeira, C. Carlson, M.-E. Car, R. Feely, M. Hood, C. Hopkinson, R. Jahnke, D. Karl, J. Kleypas, C. Lee, R. Letelier, C. McClain, C. Sabine, J. Sarmiento, B. Stephens, and R. Weller, 2004: Ocean Carbon and Climate Change (OCCC): An Implementation Strategy for U.S. Ocean Carbon Cycle Science, 108 pp., A report of the University Corporation for Atmospheric Research, Carbon Cycle Interagency Working Group, National Science Foundation, 108 pp.Wanninkhof, R. and F.J. Millero, Seakeepers network to study sea's role in absorbing greenhouse gases, *Showboats International*, 71. [(O), (EE), (FF)]

Feely, R.A., Y. Nojiri, A. Dickson, C.L. Sabine, M.F. Lamb, and T. Ono, 2003: CO_2 in the North Pacific Ocean, PICES Working Group 13 Final Report. PICES Scientific Report No. 24 2003, 49 pp. [(O)]

Hankin, S. and the DMAC Steering Committee, 2004: Data Management and Communications Plan for Research and Operational Integrated Ocean Observing System: 1. Interoperable Data Discovery, Access, and Archive, Ocean.US, Arlington, VA 292 pp. [(W)]

Hutto, L, R. Weller, J. Lord, J. Smith, J. Ryder, N. Galbraith, C. Fairall, S. Stalin, J. C. Andueza,a nd J. Tomlinson, 2004: Stratus Ocean Reference Station (20°S, 85°W) Mooring Recovery and Deployment Cruise, WHOI Tech Rep 2004-04, UOP Tech Rep 2004-01. [(GG)]

Hutto, L., R. A. Weller, J. Lord, J. Ryder, A. Stuart-Menteth, N. Galbraith, P. Bouchard, J. Maturana, O. Pizarro, and J. Letelier, 2003: Long-Term Evolution of the Coupled Boundary Layers (Stratus) Mooring Recovery and Deployment Cruise Report R/V Melville. Technical Report, WHOI-2003-02, UOP-2003-01. [(GG)]

Jones, B. 2004: Influence of Panamanian Wind Jets on the Southeast Inter-tropical Convergence Zone. M.S. Thesis, Dept. of Meteorology, The Florida State University, 36 pp. [Available online at: http://etd.lib.fsu.edu/theses/available/etd-07122004-140932/] [(Z)]

Johnson, M., 2003: Program plan for building a sustained ocean observing system for climate. NOAA Office of Global Programs, Silver Spring, MD. [(AA)]

Kilonsky B., and M. Merrifield, 2004: CLIVAR in situ sea level DAC, 1st CLIVAR Date Planning Meeting on Ocean Observations, SIO, San Diego, CA. [(W)]

Kilonsky B., and M. Merrifield, 2004: Some trends of relative sea level in the Pacific, 15th Symposium on Global Change and Climate Variations, AMS, Seattle, WA. [(W)]

Kilonsky B., and M. Merrifield, 2004: UHSLC data portal, 20th Conference on Interactive Information and Processing Systems (IIPS) for Meteorology, Oceanography, and Hydrology, AMS, Seattle, WA. [(W)]

Plimpton, P. E., H. P. Freitag, and M. J. McPhaden, 2004: Processing of subsurface ADCP data in the equatorial Pacific. NOAA Tech. Memo. OAR PMEL-125, Pacific Marine Environmental Laboratory, Seattle, WA. 41pp. [(C)]

Plueddemann, A. J., 2003. In-situ meteorology and air-sea fluxes in the Northwest Tropical Atlantic, NOAA Climate Observation Program Workshop Report, 13-15 May 2003, Silver Spring, MD. [(GG)]

Plueddemann, A. J., 2003: In-situ meteorology from the Northwest Tropical Atlantic Station, Proc. U.S. CLIVAR Atlantic Conf., Washington, DC, pp 9-13. [(GG)]

Plueddemann, A. J., W. M. Ostrom, N. R. Galbraith, J. C. Smith, J. R. Ryder, J. J. Holley and M. A. Walsh, 2003: The Northwest Tropical Atlantic Station (NTAS): NTAS-3 Mooring Turnaround Cruise Report, WHOI Tech. Rept. WHOI-2003-04, 69 pp. [GG]

Rolph, J. J., and S. R. Smith, 2004: Polarstern AWS data quality control report: May 2003 – June 2004. RVSMDC report 04-02, Center for Ocean-Atmospheric Prediction Studies, Florida State University, Tallahassee, Florida, 32306-2840, USA, 24 pp. [AA]

Rolph, J. J., and S. R. Smith, 2004: Recommendations for the elimination of the stack exhaust problem on the R/V Meteor. RVSMDC report 03-04, Center for Ocean-Atmospheric Prediction Studies, Florida State University, Tallahassee, Florida, 32306-2840, USA, 14 pp. [AA]

Rolph, J. J., and S. R. Smith, 2004: Ron Brown IMET data quality control report: August 2002-September 2003. RVSMDC report 03-05, Center for Ocean-Atmospheric Prediction Studies, Florida State University, Tallahassee, Florida, 32306-2840, USA, 13 pp. [AA]

Rolph, J. J., and S. R. Smith, 2004: Ron Brown IMET data quality control report: September – November 2003. RVSMDC report 04-01, Center for Ocean-Atmospheric Prediction Studies, Florida State University, Tallahassee, Florida, 32306-2840, USA, 10 pp. [AA]

Rolph, J. J., and S. R. Smith, 2004: Ron Brown IMET data quality control repot: 2002. RVSMDC report 03-03, Center for Ocean-Atmospheric Prediction Studies, Florida State University, Tallahassee, Florida, 32306-2840, USA, 10 pp. [AA]

Rudnick, D. L. and M. J. Perry, Eds., 2003: ALPS: Autonomous and Lagrangian Platforms and Sensors, Workshop Report. 64 pp. [J]

Smith, S. R., 2004: Report from the 2nd Workshop on High Resolution Marine Meteorology, COAPS Report 04-01, Center for Ocean-Atmospheric Prediction Studies, Florida State University, Tallahassee, Florida, 32306-2840, USA, 31 pp. [AA]

Smith, S. R., M. A. Bourassa, and R. Romero, 2003: Topical Pacific wind comparisons: objective FSU versus NCEP Reanalysis products. CAS/JSC Working Group on Numerical Experimentation, Research Activities in Atmospheric and Oceanic Modeling, World Meteorological Organization, ed. J. Côté, 2003 Edition, 2.25-2.26. [Available online at: http://www.cmc.ec.gc.ca/rpn/wgne/] [Z]

Soreide N., D. W. Denbo, J. E. Fabritz, B. Kilonsky, J. R. Osborne, L. C. Sun, and W. H. Zhu, 2003: Tools for accessing distributed collections of observed in situ data, 19th Conference on Interactive Information and Processing Systems (IIPS) for Meteorology, Oceanography, and Hydrology, AMS, Long Beach, CA. [W]

Yao, Q., and M. Baringer, 2003: Cable calibration cruises. [B]

Zavala-Hidalgo, J., P. Yu, S. L. Morey, M. A. Bourassa, and J. J. O'Brien, 2003: A new interpolation method for high frequency forcing fields. CAS/JSC Working Group on Numerical Experimentation, Research Activities in Atmospheric and Oceanic Modeling, World Meteorological Organization, ed. J. Côté, 2003 Edition, 3.21-3.22. [Available online at: http://www.cmc.ec.gc.ca/rpn/wgne/] [Z]

Proceedings and Preprints

Bourassa, M. A., 2003: Surface Observations in The Southern Ocean, Variability, and the Consequences on Fluxes. *US CLIVAR Southern Ocean working group workshop*, Nov., Tallahassee, FL. (AA)

Bourassa, M. A., 2004: Remote-sensing activities. *COAPS site review*, April 6, Tallahassee, FL. (AA)

Bourassa, M. A., and S. R. Smith, 2004: Applications for Fine Resolution Marine Observations. *2nd High Resolution Marine Meteorology Workshop*, April, Silver Springs, MD. (AA)

Bullister, J. L., N. Gruber, G. C. Johnson, M J. Warner, R A. Feely, R. Wanninkhof, C. Sabine, C. W. Mordy, and J.-Z. Zhang. 2004: Decadal changes along 20°W in the North Atlantic, *1st International CLIVAR Science Conference*, June 21-25, Baltimore, Maryland. (O)

Cunningham, S., J. Hirschi, J. Marotzke, W. Johns, M. Baringer, and H. Bryden, 2004: A Moored Array to Monitor the North Atlantic Thermohaline Circulation at 26°N, *CLIVAR North Atlantic Thermohaline Circulation Variability Workshop*, Sept 13-16, 2004, Kiel, Germany. (O)

Douglass, E., D. Roemmich, and D. Stammer, 2004: Interannual variability in the northeast Pacific Ocean, *CLIVAR Conference*, Baltimore, June 2004. (I)

Goni, G. M. Baringer, S. Garzoli, R. Molinari, C. Lumpkin, C. Schmid, and S. Cook, 2004: Sustained observations in the Atlantic ocean carried out by NOAA/AOML, *EGU Meeting*, Nice, France, April 2004. (A)

Johnson, G. C., and A. E. Wirts, 2004: Interannual upper ocean variability in the deep southeast Bering Sea, *51st Annual Eastern Pacific Ocean Conference (EPOC)*, 22-25 September, Vancouver Island, Canada. (O)

Johnson, G. C., P. J. Stabeno, and S. D. Riser, 2003: The Bering Slope Current System revisited, *First Argo Science Workshop*, November 12-14, Tokyo, Japan. (O)

Lyman, J. M., and G. C. Johnson, 2004: The Characteristics of Bering Sea Eddies, *51st Annual Eastern Pacific Ocean Conference (EPOC)*, 22-25 September, Vancouver Island, Canada. (O)

McAdoo, D. C., K. M. Marks, A. L. Ridout, and S. L. Farrell, 2004: Altimetric gravity and sea surface topography of the Artic Ocean: Comparisions with gravimetry, *IAG GGMS Proceedings*. (X)

Meinen, C. S., M. O. Baringer, A. H. Flosadottir, R. F. Garcia, L. Johns, R. H. Smith, and J. Larsen, 2004: Florida Current Transport, *SEA-COOS Spring 2004 Workshop*, May 17-18, Miami, FL. (B)

Meinen, C. S., S. L. Garzoli, W. E. Johns, and M. O. Baringer, 2004: Transport Variability of the Deep Western Boundary Current and the Antilles Current off Abaco Island, Bahamas, *2004 Ocean Sciences Meeting*, January 26-30, Portland, OR. (B)

Miller, L., and R. Scharroo, 2004: Global Sea Level Rise: A Decade of Multi-Satellite Altimeter Observations versus 100 Years of In-situ Observations, *AIAA Space 2004 Proceedings*. (X)

Shoosmith, D. R., M. O. Baringer, and W. E. Johns, 2004: Towards a Continuous Record of Florida Current Temperature Transport, *CLIVAR North Atlantic Thermohaline Circulation Variability Workshop*, Sept 13-16, 2004, Kiel Germany. (O)

Rolph, J. J., S.R. Smith, and M. A Bourassa, 2004: Quality of NOAA Vessel Underway Marine Meteorology. Abstracts from NOAA Office of Climate Observation Annual System Review, Silver Spring, MD, CDROM. [Available from NOAA, Office of Climate Observation, Silver Spring, MD]. [(AA)]

Garzoli, S. L., and M. Baringer, 2004: Meridional Heat Transport in the South Atlantic, *CLIVAR North Atlantic Thermohaline Circulation Variability Workshop*, Sept 13-16, 2004, Kiel Germany. [(A), (O)]

Smith, S. R., 2004: Automated Marine Weather Observations on Research Vessels as part of an Ocean Observing System. Preprints, *Symposium on Forecasting the Weather and Climate of the Atmosphere and Ocean*, Seattle, WA, Amer. Meteor. Soc., CDROM, in press. [(AA)]

Smith, S. R., and M. A. Bourassa, 2004: Automated weather system observations from research vessels for climate applications, *CLIVAR 2004*, Baltimore, MD, in press. [(Z), (AA)]

Smith, S. R., M. A. Bourassa, and J. J. O'Brien, 2003: Marine Meteorology Quality Control at the Florida State University, *First Workshop on the Quality Assurance of Real-Time Ocean Data (QARTOD)*, NDBC, Stennis, MS, in press. [(AA)]

Smith, S. R., M. A. Bourassa, J. J. O’Brien, and J. J. Rolph, 2004: Ocean Surface Data and Products from COAPS. *Office of Climate Observation Annual System Review*, April, Silver Springs, MD. [(Z)]

Smith, S. R., M. A. Bourassa, R. Romero, 2004: A comparison of FSU2, NCEPR1, and NCEPR2 winds in the tropical Pacific. Preprints, *20th Conference on Weather Analysis and Forecasting/16th Conference on Numerical Weather Prediction*, Seattle, WA, Amer. Meteor. Soc., CDROM, in press. [(Z)]

Sprintall, J. and A. Adams, 2004: Variability of mass and property fluxes in Drake Passage from XBT and altimeter measurements, *CLIVAR Conference*, Baltimore, June 2004. [(I)]

Stabeno, P. J., C. Ladd, C. W. Mordy, and M. E. Sullivan, 2004: Transport through the Aleutian Passes, *2004 Ocean Research Conference (ASLO-TOS) Honolulu*, Hawaii, February 15-20, 2004. [(O)]

Toole, J. M. and the participants in the 2003 North Atlantic Survey of the U. S. CLIVAR/ CO_2 Repeat Hydrography Program, 2004: Decadal- timescale evolution of the North Atlantic Ocean. *1st International CLIVAR Science Conference*, June 21-25, Baltimore, Maryland. [(O)]

Zavala_Hidalgo, M. A. Bourassa, S. L .Morey, J. J. O’Brien, and P. Yu, 2003: A new temporal interpolation method for high-frequency vector wind fields. *MTS/IEEE OCEANS2003*, Sept., San Diego, CA. [(Z)]

Zhang, J.-Z., and C. J. Fischer, 2004: Direct spectrophotometric determination of nitrate concentrations in seawater with resorcinol, *Meditereanan Conference of Chemistry of Aquatic Systems*, Reggio Calabria, Italy, September, 2004. [(O)]

Abstracts

Johnson, G. C., P. J. Stabeno, and S. D. Riser, 2003: The Bering Slope Current System revisited. *Eos Trans. AGU*, **84**(52), Ocean Sci. Meet. Suppl., Abstract OS12H-03. (O)

Kelly, K. A., S. Dickinson, and G. C. Johnson, 2003: Scatterometer winds at TAO buoys reveal time-varying surface currents for the tropical Pacific Ocean. *Eos Trans. AGU,*Ocean Sci. Meet. Suppl., **84**(52), Ocean Sci. Meet. Suppl., Abstract OS31J-05. (O)

Meinen, C. S, S. L. Garzoli, W. E. Johns, and M. O. Baringer, 2004: Transport Variability of the Deep Western Boundary Current and the Antilles Current off Abaco Island, Bahamas. *Eos Trans. AGU*, **84**(52), Ocean Sci. Meet. Suppl., Abstract OS21F-09, 2003. (O)

Schott, F. A., J. P. McCreary, and G. C. Johnson. 2003: Subtropical Cells. *Eos Trans. AGU*, Ocean Sci. Meet. Suppl., 84(52), Ocean Sci. Meet. Suppl., Abstract OS42L-01, invited. (O)

Smith, S. R., 2004: Recommendations from the 1st Workshop on High-Resolution Marine Meteorology. Abstracts from 2nd High-Resolution Marine Meteorology Workshop, Silver Spring, MD. [Available on line at http://www.coaps.fsu.edu/RVSMDC/marine_workshop2/]. (AA)

Smith, S. R., M. A. Bourassa, J. J. O'Brien, and J. J. Rolph, 2004: Ocean Surface Data and Products from COAPS. Abstracts from NOAA Office of Climate Observation Annual System Review, Silver Spring, MD, CDROM. [Available from NOAA, Office of Climate Observation, Silver Spring, MD]. (AA)

Smith, S. R., 2004: Automated Weather Observations from Ships and Buoys: A Future Resource for Climatologists. Abstracts from the Climate Prediction Applications Science Workshop, Tallahassee, FL, 21. (AA)

Smith, S. R., and R. Michael Reynolds, 2003: Recommendations from the Workshop on High-Resolution Marine Meteorology. Abstracts from CLIMAR-II, Second JCOMM Workshop on Advances in Marine Climatology, Brussels, Belgium, 10. (AA)

Encyclopedia Entry

Rigor, I.G., 2004: *Arctic Meteorological Stations, Encyclopedia of the Arctic*. Routledge, New York, in press. (DD)

Rigor, I.G., 2004: *Laptev Sea, Encyclopedia of the Arctic*. Routledge, New York, in press. (DD)

Rigor, I.G., 2004: *Sea Ice, Encyclopedia of the Arctic*. Routledge, New York, in press. (DD)

Newsletter

Harrison, D. E., A. Knap, T. Malone, 2004: Climate and the Marine Environment. World Climate News. 26, 3. (S)

Brochures and Pamphlets

Cooke, Compiled by, Ship rider's rules. (FF)

PMEL Global Carbon Cycle Program brochure. (O)

Wanninkhof , Compiled by - Introductory brochure of project for ship owners and command. (FF)

Posters

Plueddemann, A., 2004: Multi-year, in-situ surface fluxes in the northwest tropical Atlantic. *First International CLIVAR Science Conf.*, 21-25 June 2004, Baltimore, MD (poster). (GG)

Plueddemann, A. J. and R.A. Weller, 2004: Meteorology and air-sea fluxes from ocean reference stations. *NOAA Office of Climate Observation Workshop*, 12-14 April 2004, Silver Spring, MD (poster). (GG)

Plueddemann, A. J., 2003: In-situ meteorology and air-sea fluxes in the Northwest Tropical Atlantic. *NOAA Climate Observation Program Workshop*, Silver Spring, MD (poster). (GG)

Weller, R, A. Plueddemann, D. Hosom, R. Payne, J. Smith F. Bahr, and F. Bradley, 2003: The quality of surface meteorology from unattended buoys and volunteer observing ships. *CLIMAR-II Workshop on Advances in Marine Meteorology*, Brussels, Belgium, 17-22 November 2003 (poster). (GG)

Weller, R, A. Plueddemann, L. Yu and D. Hosom, 2003: Ocean Reference Stations. *ORION Workshop*, 4-8 January 2004, San Juan Puerto Rico (poster). (GG)

Weller, R, L. Yu, A. Plueddemann, D. Hosom, and S. Sathiyamoorthy, 2003: Synthesis of basin-scale air-sea flux fields. *CLIMAR-II Workshop on Advances in Marine Meteorology*, Brussels, Belgium, 17-22 November 2003 (poster). (GG)

Dissertation

Willis, J., 2004: Combining Satellite and In Situ data to Make Improved Estimates of Upper-Ocean Thermal Variability on Eddy to Global Scales. PhD dissertation, University of California San Diego. (I)

Series

Goni G., and P. Malanotte-Rizzoli (editors), 2003*: Interhemispheric Water Exchange in the Atlantic Ocean*, Elsevier Oceanographic Series, Vol. 68. (A)

Mayer, D. A., M. O. Baringer, and G. J. Goni, 2003: *Comparison of hydrographic and altimeter based estimates of sea level height variability in the Atlantic Ocean. Interhemispheric Water Exchange in the Atlantic Ocean, G. J. Goni and P. Malanotte-Rizzoli (eds.).* Elsevier Oceanography Series, 68 (ISBN 0444512675), 23-48. (A), (O)

Molinari, R. L., S. Bauer, D.Snowden, G. C. Johnson, B. Bourles, Y. Gouriou, and H.Mercier, 2003: *"A comparison of kinematic evidence for tropical cells in the Atlantic and Pacific oceans". In Interhemispheric Water Exchange in the Atlantic Ocean.* Elsevier Science Oceanographic Series 68, G. Goni and P. Malanotte-Rizzoli (Eds), pp 269-286. (Y)

APPENDIX A

FY 2004 Accounting and Preliminary FY 2005 Budget Planning (prior to final allocation)

Michael Johnson
Director, Office of Climate Observation

Climate Observation Program
Budget ($K)
FY 04 Actual; FY 05 Planned

Network	System Total			Budget Line Accounts: C&GC		CCRI		COSP		CCRI CO2		ENSO/PACS		Other	
	FY 04	FY 05	Change	FY 04	FY 05	FY 04	FY 05	FY 04	FY 05	FY 04	FY 05	FY 04	FY 05	FY 04	FY 05
Tide Gauges	970	1345	375	0	275	320	921					650	0	0	149
Surface Drifting Buoys	2769	3406	637	627	386	1382	2324					760	696		
Ships of Opportunity	2487	2990	503	306	788	1184	885					530	1317	467	0
Tropical Moored Buoys	3625	4135	510	600	0	0	510	450	450			2575	3175		
Argo Floats	273	275	2	273	275										
Ocean Reference Stations	2819	3319	500	0	425	2282	2445					190	377	347	72
Arctic Ice Buoys	0	60	60											0	60
Ocean Carbon Networks	2875	3525	650	0	77	0	154	1616	1873	1259	1244	0	135	0	42
SURFRAD	210	0	-210	105	0									105	0
Rain Gauges	179	184	5	149	184									30	0
Dedicated Ships	523	80	-443	523	80										
Service Argos Data Processing	1525	1075	-450	235	125	626	825					664	0	0	125
Data & Assimilation	369	443	74	369	343	0	100								
Analysis & System Evaluation	658	1629	971	358	815	0	514	0	300			300	0		
Program Management	684	960	276	629	960	30	0					25	0		
Overhead	826	152	-674	826	152										
Total	20792	23578	2786	5000	4885	5824	8678	2066	2623	1259	1244	5694	5700	949	448

APPENDIX B

Program Plan for Building a Sustained Ocean Observing System for Climate

Michael Johnson
Director, Office of Climate Observation

Program Plan
For
Building a Sustained Ocean Observing System for Climate

Updated: March 2005

Overall Summary

The Climate Change Science Program (CCSP) has identified the critical need for the federal government to begin delivering regular reports documenting the present state of the climate system components. Yet an observing system does not presently exist that is capable of accurately documenting climate variability and change in the Earth's oceans, atmosphere, cryosphere, and land surface. Through this program plan NOAA will develop the infrastructure necessary to build, with national and international partners, the ocean component of a global climate observing system and to deliver regular reports on the ocean's contribution to the state of the climate and on the adequacy of the observing system.

1.0 Base Program

1.1 Key activities currently carried out by NOAA for this strategy area: Over the past decade NOAA has worked with national and international partners to begin building a sustained global ocean system for climate, focusing first on the tropical Pacific, and expanding to the Atlantic and the Indian Oceans. It is now well understood that documenting and forecasting climate will require continuous measurements from space along with the instrumenting of the entire global ocean. The present international effort is about 51% of what will ultimately be needed for the global system. NOAA presently maintains approximately 60% of the *in situ* networks and 30% of the space components and is committed to the goal of providing at least 50% of the composite system over the long term.

The existing foundation is comprised of twelve complementary *in situ*, space based, data and assimilation subsystems: 1) Global Tide Gauge Network; 2) Global Surface Drifting Buoy Array; 3) Global Ships of Opportunity Network; 4) Tropical Moored Buoy Network; 5) Argo Profiling Float Array; 6) Ocean Reference Stations; 7) Coastal Moorings; 8) Ocean Carbon Monitoring Network; 9) Arctic observing System; 10) Dedicated Ship Operations; 11) Satellites for Sea Surface Temperature, Sea Surface Height, Surface Vector Winds, Sea Ice, and Ocean Color; 12) Data and Assimilation Systems and their products. The system design is illustrated in Figure 1. This is an international effort. NOAA's plan includes an additional element – System Management and Product Delivery – to focus program resources on answering the nation's highest priority policy- and economically-relevant questions.

The plan is being advanced via matrix management within the NOAA Climate Goal. Implementation of the in situ networks is through distributed centers of expertise at the NOAA Research laboratories, the National Ocean Service Center for Operational Oceanographic Products and Services, the National Data Buoy Center, and the university laboratories that have developed the instruments and techniques. The space components are centered in the NOAA Satellite and Information Service; the space components are being advanced via other NOAA program planning; they are noted here because of their central role in global observation but they are not detailed in this plan. The focal point for developing global ocean data assimilation capabilities will be the Geophysical Fluid Dynamics Laboratory in partnership with the National Centers for Environmental Prediction and university-based applied research centers. The system management functions are focused in the Office of Global Programs.

1.2 Matrix document showing key activities and current status: Illustrated in Figure 2 and detailed below in Section 6.

1.3 Current out-year performance measures based on current funding levels: The performance measures are given in Section 5. At current funding levels the out-year accomplishments will be frozen at the deliverables indicated for FY05.

1.4 Current budget for each of the major activities (FY 2005); based on the total ocean program baseline assessment.

Tide Gauge Network	$1.8 M
Drifting Buoy Array	$4.0 M
Tropical Moored Buoy Network	$4.8 M
Ships-of-Opportunity Network	$4.6 M
Argo Array of Profiling Floats	$10.4 M
Ocean Reference Stations	$3.7 M
Ocean Carbon Monitoring	$4.0 M
Integrated Arctic Observing System	$1.4 M
Dedicated Ship Time	$1.1 M
Data and Assimilation Subsystems	$3.9 M
Management and Product Delivery	$4.5 M
	$50.4 M

2.0 Statement of Need

The *Second Report on the Adequacy of the Global Observing System for Climate in Support of the UNFCCC* concludes “there has been progress and improvement in the implementation of global climate observing systems since the first report, especially in the use of satellite information and in the provision of some ocean observations. At the same time, the Report notes that the global terrestrial networks remain to be fully implemented; the ocean networks lack global coverage and commitment to sustained operations; and the atmospheric networks are not operating with the required global coverage and quality. The Report concludes, in agreement with the IPCC, that there remain serious deficiencies in the ability of the current global observing systems for climate to meet the observational needs of the UNFCCC. …Without urgent action to address these findings, the Parties will lack the information necessary to effectively plan for and manage their response to climate change.”

The Report goes on to note "new technology developed and proven by the ocean climate programs of the 1990s has allowed the ocean community to design and commence implementation of an initial ocean climate observing system that is well focused on the UNFCCC needs. The first priority is the full implementation of this system together with its associated data, analysis and product capabilities."

In response to the Adequacy Report, the international community has now published the GCOS Implementation Plan for the Global Observing System for Climate in support of the UNFCCC (GCOS-92), October 2004. This implementation plan details the actions needed to achieve global coverage by the ocean networks. The system put in place for climate will also support global weather prediction, global and coastal ocean prediction, marine hazard warning, marine environmental monitoring, and many other non-climate users.

This program plan is founded on the international design noted in GCOS-92; it is illustrated in Figure 1. Other requirement drivers include the CCSP Strategic Plan expressing need for "complete global coverage of the oceans with moored, drifting, and ship-based networks," and the OCEAN.US *Implementation of the Initial U.S. IOOS* specifying "the highest priority for the global component of the IOOS is sustained, global coverage." NOAA's contribution to global implementation is represented in the current program budget and the progress to date is illustrated in Figure 2. Implementation of this program plan will demonstrate to the world community that the United States is intent on taking immediate action to address the Report findings, is willing to play a leadership role in achieving global coverage of the ocean networks, and is committed to sustained operations.

2.1 Program Office requirements to be met: The NOAA Office of Global Programs is organized around four strategic objectives: 1) Development of an Earth System Model for climate change projections at GFDL; 2) Improvement of NWS operational seasonal to international climate forecasts; 3) Development of the in situ ocean component of the global climate observing system; and 4) Development of decision support tools. This plan describes the program for meeting the third objective.

2.2 Input from NOAA leadership related to this strategy: This program plan addresses NOAA's Strategic Plan, Climate Strategies, and the Annual Guidance Memorandum. In particular:

- Strategic Plan: Describe and understand the state of the climate system through integrated observations, analysis, and data stewardship.
- Climate Strategies: Improve the quality and quantity of climate observations, analysis, interpretation, and archiving by maintaining a consistent climate record and by improving our ability to determine why changes are taking place.
- Annual Guidance Memorandum: The Integrated Ocean Observing System (IOOS) must be developed as a major component of the U.S. contribution to the Global Earth Observation System of Systems (GEOSS).

2.3 External constituent input related to the strategy area: In 2001 the U.S. GOOS Steering Committee conducted a formal review of the 2001 version of this program plan.

The review panel included international representatives of the IOC, IGOS, CLIVAR, WOCE, OOPC, GODAE, and JCOMM as well as partner agencies within the United States – NASA and NAVOCEANO. The seven summary recommendations of the review are paraphrased below.

1. Strong overall support for the plan. U.S. GOOS urged NOAA to implement the plan with the following additional recommendations:
2. The need for a management plan – An effort of the proposed magnitude must be integrated, organized, and managed as a system in order to be effective. The management plan should define an orderly decision making process with management accountability that is understood by other agencies and by customers. A single NOAA point of responsibility and authority is very desirable. Sections 7.0–7.7 achieve this recommendation.
3. The need for a data and information management budget. Section 6.11 achieves this recommendation.
4. The need for improved ocean products – evaluation and delivery. Section 7.6 achieves this recommendation.
5. The need for transition to operations of precision altimetry. Section 6.10 achieves this recommendation.
6. The need for ocean carbon monitoring to be better defined. Section 6.8 achieves this recommendation.
7. The need to deal with dedicated ship time issues. Section 6.9 has been revised to achieve this recommendation.

2.4 Relevant Congressional input or guidance related to the strategy area: The FY03 Senate Committee on Appropriations Report "reaffirms its support for the establishment of an integrated, interagency ocean and coastal observing system … and requests the submission of a plan to implement such a system." The National Oceanographic Partnership Program's Ocean.US office is responding to this Congressional request on behalf of the contributing agencies. The climate system detailed below forms the nucleus of the global component of the U.S. Integrated Ocean Observing System.

2.5 Known impediments (legal, fiscal, policy) towards achieving performance targets and objectives: None.

3.0 Program Initiative

3.1 Overall strategy for addressing deficiencies outlined in the Statement of Need Section. The strategic approach underlying this program plan is as follows:

- Build the long-term ocean component of the observing system in the context of a comprehensive, multi-year, climate services initiative. Improved marine and coastal forecast services will be immediate byproducts.
- Set a 2000-2010 timeline for phased implementation.
- Establish accountability by defining specific objectives and performance measures.
- Define an "initial observing system design" that will accomplish the objectives and performance measures. Identify annual milestones to complete the initial

system over the ten-year time line. Emphasize that the initial design is our best guess at this time – it must be evolutionary as knowledge and technology advance.

- State the obvious – a global observing system cannot be built with existing budgets. Estimate the annual funding needed to achieve the identified milestones. Estimate that NOAA will implement about 50% of the global system.
- Work with national and international partners to achieve 100%.

Although NOAA's marine and coastal services and the mission services of the other agencies and nations will benefit from this plan, and are considered throughout, accomplishing NOAA's climate mission is the fundamental driver. The scientific foundations come from the Climate Variability and Predictability Program (CLIVAR), the Carbon Cycle Science Program, and the Global Water Cycle Program. It is not the intent of the plan to provide all of the observations needed by these programs but to provide a baseline observing system, to be sustained over the long term, that can be built upon where needed to answer specific questions. This baseline system looks for efficiencies to be gained by utilizing common platforms/sites/data infrastructure for several objectives in parallel, and seeks to foster a system approach to effective international organization of complementary in situ, satellite, data, and modeling components of climate observation.

Priorities for implementation are now in place based on the concept of extending the building blocks that have already been put in place, and on the international plan drafted by over 300 scientists from 26 nations that met in Saint Raphael, France, October 1999, at the OCEANOBS 99 Conference for design of *The Ocean Observing System for Climate*. This plan has now been codified in GCOS-92. NOAA will work to implement the specific actions called for in GCOS-92, particularly those actions assigned to the Joint WMO/IOC Technical Commission for Oceanography and Marine Meteorology (JCOMM). JCOMM is NOAA's principal intergovernmental linkage to international implementation.

3.1.1 NOAA context*:* This plan supports NOAA's strategic goal to monitor and observe: "NOAA will invest in needed climate quality observations and encourage other national and international investments to provide a comprehensive observing system in support of climate assessments and forecasts." The plan details how NOAA will achieve one element of that strategic goal – implementation of the sustained in situ ocean component of the climate observing system.

3.1.2 Interagency context: The observational objectives of NOAA's climate program and those of the CCSP are essentially identical and the ocean observing system architecture detailed below will be implemented by NOAA within the framework of, and as an element of, the CCSP. At the same time the observing system must be advanced in support of climate services, it must also be advanced in response to a national demand for the ocean agencies to coordinate implementation of an U.S. contribution to the global ocean observing system. It is recognized that an effective global ocean observing system can be achieved only through continuing interaction among all national (and international) partners. In this context, NOAA will provide a significant contribution to the global component of the Integrated Ocean Observing System. Implementation will be coordinated with the National Oceanographic Partnership Program agencies.

3.1.3 International context: The observational component of climate services has by far the greatest opportunity and necessity for international collaboration. A global observing system by definition crosses international boundaries and the potential exists for both benefits and responsibilities to be shared by many nations. The system described below is based on the international design of, and is an U.S. contribution to GCOS-92. The observing system projects that make up the climate component have been developed, and will continued to be evolved, organized and managed, in cooperation with the international implementation panels of the Joint IOC/WMO Technical Commission for Oceanography and Marine Meteorology (JCOMM), and with scientific guidance from the GCOS/GOOS/WCRP Ocean Observations Panel for Climate (OOPC).

3.2 Proposed out-year performance targets: See Sections 5.0-5.4.

3.3 Discussion of individual investments necessary to address shortfalls: Given in Sections 6.0-7.7.

3.4 Cost and schedule for each investment: Based on the Program Baseline assessment of the 100% requirement. Details given in Table 2. Summary:

	FY03	FY04	FY05	FY06	FY07	FY08	FY09	FY10
System annual operating cost ($ M)	35.2	40.7	50.4	53.6	76.0	101.3	120.8	141.5

4.0 Program Goal and Objectives

4.1 Goal

The goal of this plan is to build and sustain the ocean component of a global climate observing system that will respond to the long-term observational requirements of the operational forecast centers, international research programs, and major scientific assessments.

4.2 Objectives

The ocean is the memory of the climate system and is second only to the sun in effecting variability in the seasons and long-term climate change. It is estimated that the ocean stores 1000 times more heat than the atmosphere, and 50 times more carbon. Eighty-five percent of the precipitation that waters our Earth comes directly from the ocean. Changing sea level is one of the most immediate impacts of climate change. Additionally, the key to possible abrupt climate change may lie in deep ocean circulation.

Accordingly, the objectives of the sustained ocean observing system for climate are to:

1) Document long-term trends in sea level change;
2) Document ocean carbon sources and sinks;
3) Document the ocean's storage and global transport of heat and fresh water; and

4) Document the ocean-atmosphere exchange of heat and fresh water.

This implementation plan will provide a composite global ocean observing system of complementary networks that includes: 1) deployment and maintenance of observational platforms and sensors; 2) data delivery and management; and 3) routine delivery of ocean analyses. This end-to-end ocean system will provide the critical "up-front" information needed for climate forecasting, research, and assessments – continuous, long term, climate quality, global data sets and a suite of routinely delivered ocean analyses. At the same time, the system will provide real-time data to serve the needs of NOAA's marine and coastal forecast and warning missions and the needs of the other agencies in accomplishing their missions.

5.0 Performance Measures

In order to achieve the four objectives, the system must accurately measure: 1) sea level to identify changes resulting from climate variability; 2) ocean carbon content every ten years and the air-sea exchange seasonally; 3) sea surface temperature and surface circulation to identify significant patterns of climate variability; 4) sea surface pressure and air-sea exchanges of heat, momentum, and fresh water to identify changes in forcing functions driving ocean conditions and atmospheric conditions; 5) ocean heat and fresh water content and transports to identify where anomalies enter the ocean, how they move and are transformed, and where they re-emerge to interacting with the atmosphere; 6) identify the essential aspects of thermohaline circulation as well as the subsurface expressions of the patterns of climate variability; and 7) sea ice thickness and concentrations.

The sampling requirements for these parameters have been documented by international GOOS and GCOS. Table 1 lists the requirements as presented at the OCEANOBS 99 Conference in Saint-Raphael, France. It represents the best estimates of the international community at this time.

The Proceedings of OCEANOBS 99 and the final report from the conference, *Observing the Ocean in the 21st Century*, outline implementation strategies for achieving these sampling requirements. Additionally, for documenting sea level variability and change, the implementation strategy is further defined in the *International Sea Level Workshop Report*, 1998; and for documenting ocean carbon sources and sinks the implementation strategy is defined in the *Large Scale CO_2 Observing Plan: In Situ Oceans and Atmosphere (LSCOP)*, 2002. The latter plan is for the United States only at this time, but was developed by U.S. scientists working in collaboration with international partners. The international community met in Paris, January 2003, to advance international implementation of the ocean carbon monitoring system and the results have now been published in the International Ocean Carbon Coordination Project. The elements of the plans needed to achieve global coverage with an initial ocean observing system have now been summarized in GCOS-92. These foundation documents are available from the NOAA Office of Global Programs and are listed in Appendix A.

Based on the requirements in Table 1 and the implementation strategies defined in the foundation documents listed in Appendix A, the system's effectiveness in meeting the objectives will be gauged by the performance measure listed below. Detailed metrics are given for each objective in sections 5.1-5.4. Those detailed metrics will lead to a system that can be summarized in four overarching measures of success:

Performance Measure 1: Reduce the error in global measurement of sea surface temperature.

Metric: Potential satellite bias error (degrees Celsius):

2002	2003	2004	2005	2006	2007	2008	2009	2010
0.7 C	0.7 C	0.6 C	0.5 C	0.4 C	0.3 C	0.2 C	0.2 C	0.2 C

Performance Measure 2: Reduce the error in global measurement of sea level variability and change.

Metric: To be determined

Performance Measure 3: Reduce the error in global measurement of ocean carbon sources and sinks.

Metric: To be determined

Performance Measure 4: Reduce the error in global measurement of the ocean's storage and transport of heat and fresh water.

Metric: To be determined

5.1 Document long-term trends in sea level change.

Performance Measure 5: Complete the installation of real-time, remote reporting tide gauges and co-located permanent GPS receivers at the international GLOSS subset of 62 stations for Long Term Trends and subset of 30 stations for altimeter drift calibration.

Performance Measure 6: Establish the permanent infrastructure necessary to process and analyze the tide gauge and GPS data and deliver routine annual sea level change reports.

Metrics:

- For 170 climate reference stations worldwide, routinely deliver an annual report of the variations in relative annual mean sea level for the entire length of the instrumental record, and the monthly mean sea level trend for the past 100 years with 95% confidence interval.
- Routinely deliver an annual report of global absolute sea level change to an accuracy of 1 mm per year.

5.2 Document ocean carbon sources and sinks.

Performance Measure 7: Complete the Northern Hemisphere ocean observing system to assist in determining carbon dioxide sources and sinks over the coterminous United States in partnership with the atmospheric observing system.

Performance Measure 8: Complete the expansion of the global oceanic observing system to inventory global scale oceanic uptake of excess carbon dioxide in partnership with the atmospheric observing system.

Metrics:

- Report interhemispheric gradients of CO_2 constrained to 1 ppm on seasonal time scales.
- Improve measurements of North Atlantic and North Pacific Ocean basin carbon dioxide fluxes to within ±0.2 Pg/C per year.
- Reduce uncertainty on regional estimates of carbon sources and sinks on a global basis to ±50%.
- Report the change in ocean carbon inventory over the last decade constrained to 2 Pg/C per year.
- Provide publicly available, routine changes in inventory of carbon, heat, and salinity in the ocean basins on a decadal time frame to assess the effect of global change and feedbacks on the ocean

5.3 Document the ocean's storage and global transport of heat and fresh water.

Performance Measure 9: For the global ocean, complete the ocean observing system needed to measure the global variations in sea surface temperature, surface and 2000 m circulation, total heat content of the ocean, and the transport of heat across and between all ocean basins.

Performance Measure 10: Design, deploy, and implement instrument and analysis systems to provide long term integrated measures of the global thermohaline circulation and deliver yearly estimates of the state of the thermohaline circulation - intensity, properties, freshwater transport.

Metrics:

- At ocean reference stations, deliver routine annual analyses of variability in average temperature at 0-1000 m depth to 0.1°C, and seasonal average temperature change to 0.1°C per three months.
- Deliver analyses of the seasonal means of the surface and 2000 m ocean velocity fields on appropriate spatial resolutions that capture the major features of the overturning circulation for all the core climate variability regions (the global tropics, Pacific Decadal Oscillation, North Atlantic Oscillation, high latitude water mass formation regions both northern and southern hemispheres).
- Deliver analyses of monthly mean sea surface temperature anomaly at 500 km resolution to 0.2°C accuracy, average temperature at 0-1000 m depth to 0.5°C accuracy, and annual average temperature change to 0.5°C per year.
- For the sinking regions of the north Atlantic and southern hemisphere, deliver yearly estimates of the annual average temperature and salinity of the intermediate, deep, and bottom waters to 0.03°C and 0.03PSU.

- Across zonal sections in the Atlantic at 24°N, 47°N, and globally at 35°S, deliver estimates of the average annual meridional heat transport from surface to bottom at 0.3PWatt accuracy.

5.3 Document the ocean-atmosphere exchange of heat and fresh water.

Performance Measure 11: For the global tropical ocean belt, complete the upper ocean and surface meteorology observing system needed to measure the ocean-atmosphere exchange of heat.

Performance Measure 1: For the global ocean, complete the oceanographic, surface meteorology, and analysis system needed to measure variability in the ocean-atmosphere exchange of fresh water, i.e., precipitation and evaporation.

Metrics:

- For the global ocean, deliver analyses of weekly mean sea surface temperature at 500 km resolution to 0.2°C accuracy
- At ocean reference stations, deliver routine annual analyses of variability in ocean-atmosphere flux to 10 W/m^2.
- For the global ocean deliver weekly analysis of precipitation and evaporation at 500 km resolution to 5 cm per month accuracy.

6.0 Milestones

In order to achieve the Performance Measures, the integrated ocean observing system will be completed according to the following schedule. The schedule is based on the initial design and projections of adequate funding. The milestones will be updated annually to reflect evolution of the design as knowledge and technology advance, and to reflect the realities of funding availability.

	FY02	FY03	FY04	FY05	FY06	FY07	FY08	FY09	FY10
System % Complete:	40	45	48	53	55	66	77	88	100

Although individual network priorities are described below, they must all go forward together as a system. For example, the global Argo array of profiling floats is a primary tool for documenting ocean heat content; yet deployment of the floats in the far corners of the ocean cannot be achieved without the ships-of-opportunity and dedicated ship time elements; and the Argo array cannot do its work without global over-flight by continued precision altimeter space missions; while the measurements taken by all networks will be rendered effective only through the data and assimilation subsystems.

The following sections indicate network improvements that work toward building the observing system as a whole. The ocean observing system is a composite of complementary networks, each one contributing its unique strengths; most serve multiple purposes. One of the primary goals of NOAA’s Office of Climate Observation is to look for efficiencies to be gained by utilizing common platforms/sites/data infrastructure for several objectives in parallel. For these reasons it is difficult to assign the network components specifically to the climate service product lines on a one-to-one basis. In general, however, the network tasks described below will contribute to the deliverables as follows:

1) Document long-term trends in sea level change:
- Tide Gauge Network
- Satellites
- Data and Assimilation Subsystems

2) Document ocean carbon sources and sinks:
- Drifting Buoy Array
- Tropical Moored Buoy Network
- Ships of Opportunity
- Argo Array
- Ocean Reference Stations
- Ocean Carbon Measurements
- Coastal Moorings
- Dedicated Ship Time
- Data and Assimilation Subsystems

3) Document the ocean's storage and global transport of heat and fresh water:
- Tide Gauge Network
- Drifting Buoy Array
- Tropical Moored Buoy Network
- Ships of Opportunity
- Argo Array
- Ocean Reference Stations
- Coastal Moorings
- Arctic Observing System
- Dedicated Ship Time
- Satellites
- Data and Assimilation Subsystems

4) Document the ocean-atmosphere exchange of heat and fresh water:
- Drifting Buoy Array
- Tropical Moored Buoy Network
- Ships of Opportunity
- Argo Array
- Ocean Reference Stations
- Coastal Moorings
- Arctic Observing System
- Dedicated Ship Time
- Satellites
- Data and Assimilation Subsystems

Priorities and milestones for the individual networks follow. For each network the several priority tasks are listed in tabular form. The bottom lines of the tables give the representative milestones that are shown graphically in Figure 2; representative milestones are used to simplify the graphic depiction of the phased implementation plan illustrated by Figure 2. Relative emphases in completing the several components of the observing system will depend on the relative priorities assigned to the network tasks in the context of the overall requirements of climate services.

6.1 Tide Gauge Network: Tide gauges are necessary for accurately measuring long-term trends in sea level change and for calibration and validation of the measurements from satellite altimeters, which are assimilated into global climate models for predicting climate variability. Many tide stations need to be upgraded with modern technology. Permanent GPS receivers will be installed at a selected subset of stations, leading to a geocentrically located subset expansion from the present 43 GPS sites to 170 sites globally by 2010. These 170 climate reference stations will also be upgraded for real-time reporting, not only for climate monitoring, but also to support marine hazard warning (e.g., tsunami warning). In cooperation with international partners NOAA will maintain a global climate network of 199 tide gauges stations, including the subset noted above, for validation of satellite retrievals, validation of climate model results, and documentation of seasonal to centennial variability in the El Nino Southern Oscillation, Indian Ocean and Asian-Australian monsoons, tropical Atlantic variability, North Atlantic Oscillation, North Pacific variability, high latitude circulation, western boundary currents, and circulation through narrow straits and chokepoints. This task will contribute to climate services by providing the long term records needed to 1) document sea level change: 2) document heat uptake, transport, and release by the ocean (sea surface height contributes to the measurement of ocean heat content); and 3) documents the ocean's overturning circulation (gradients of sea surface height across straights and choke-points are used to calculate large-scale ocean currents).

	NOAA Contributions								International Goal
	FY03	FY04	FY05	FY06	FY07	FY08	FY09	FY10	
Operational stations	57	63	63	63	63	63	63	63	107
Research stations	6	0	0	0	0	0	0	0	0
Station upgrades	0	4	10	16	26	32	32	32	199
GPS installation	5	10	14	43	45	52	62	86	86
Real-time reporting	67	69	79	91	106	126	148	170	170
GPS data processing			X	X	X	X	X	X	X
Technology development				X	X	X	X	X	X
International GPS/DORIS	37	39	43	45	52	62	86	86	86

6.2 Drifting Buoy Array: Data sparse regions of the global ocean are a major source of uncertainty in the seasonal forecasts and are also a major uncertainty in the detection of long-term trends in global sea surface temperature, which in turn is an indicator of global change. Data gaps must be filled by surface drifting buoys to reduce these sources of error to acceptable limits. NOAA, together with international partners, will extend the global SST/velocity drifting buoy array to data sparse regions, increasing from 1050 to 1250 buoys by 2005, while adding wind, pressure, and precipitation measurement capabilities to serve short term forecasting as well as climate research, seasonal forecasting, and assessment of long term trends. This task will support climate services by providing measurements needed to 1) document heat uptake, transport, and release by the ocean; 2) document ocean carbon sources and sinks (sea surface temperature affects the rate of transfer of CO_2 between the ocean and atmosphere; 3) document the air-sea exchange of water and the ocean's overturning circulation, and 4) document sea level change by providing the sea surface atmospheric pressure measurements that are essential for calculating sea surface height from satellite altimeter measurements.

	NOAA Contributions								International Goal
	FY03	FY04	FY05	FY06	FY07	FY08	FY09	FY10	
Operational buoys	420	670	1040	1040	1040	1040	1040	1040	1250
Research buoys	200	200	0	0	0	0	0	0	0
Add met sensors	40	40	500	670	670	670	670	670	1250
Technology development			X	X	X	X	X	X	X
International array size	787	1050	1250	1250	1250	1250	1250	1250	1250

6.3 Tropical Moored Buoy Network: Most of the heat from the sun enters the ocean in the tropical/sub-tropical belt. The advanced understanding of the role of the tropics in forcing mid-latitude weather and climate was learned primarily through the observations of the tropical moored buoy array (TAO/TRITON) in the Pacific. A similar pilot array in the Atlantic basin (PIRATA) now offers the potential of even better understanding, improved forecasts, and improved ability to discern the causes of longer-term changes in the Oceans. In addition to monitoring the air-sea exchange of heat, the moored buoys provide platforms for supporting instrumentation to measure carbon dioxide and rainfall in the tropics. The global tropical moored buoy network will be expanded from 82 to 119 stations by 2010 and will ultimately span all three oceans - Pacific, Atlantic, and Indian Ocean. This task will support climate services by providing both ocean and atmospheric observations to 1) document heat uptake, transport, and release by the ocean; 2) document carbon sources and sinks; and 3) document the air-sea exchange of fresh water.

	NOAA Contributions								International Goal
	FY03	FY04	FY05	FY06	FY07	FY08	FY09	FY10	
Operational buoys	55	65	65	65	65	65	65	65	79
Research buoys	10	0	0	0	0	0	0	0	0
Indian Ocean expansion		3	6	15	15	15	15	33	33

Atlantic Ocean expansion			2	2	5	5	5	5	9
Add salinity sensors	10	10	60	65	65	65	65	65	99
Add flux capability to buoys			5	5	5	5	5	5	8
Technology development			X	X	X	X	X	X	X
International network size	79	79	82	84	90	100	115	115	115

6.4 Ships of Opportunity: The global atmospheric and oceanic data from Ships of Opportunity (SOOP) have been the foundation for understanding long-term changes in marine climate and are essential input to climate and weather forecast models. Improved instrument accuracy, automated reporting, and improved information about how the observations were taken will greatly enhance the quality of these data, reducing both systematic and random errors. NOAA will improve meteorological measurement capabilities on the global SOOP fleet for improved marine weather and climate forecasting in general, and will concentrate on a specific subset of high accuracy SOOP lines to be frequently repeated and sampled at high resolution for systematic upper ocean and atmospheric measurement. This climate-specific subset will build from 27 lines presently occupied to a designed global network of 51 lines by 2008 and will provide measurements of the upper ocean thermal structure, sea surface temperature and chemistry, and surface meteorology of high accuracy. Additionally, the SOOP fleet is the primary vehicle for deployment of the drifting arrays. This task will support climate services by providing ocean and atmosphere measurements needed to 1) document heat uptake, transport, and release by the ocean; and 2) document ocean carbon sources and sinks (carbon sampling instrumentation is detailed under a separate task below); and 3) document the air-sea exchange of water and the ocean's overturning circulation.

	NOAA Contributions								International Goal
	FY03	FY04	FY05	FY06	FY07	FY08	FY09	FY10	
Operational HRX lines	2	15	21	21	21	21	21	21	26
Research HRX lines	6	0	0	0	0	0	0	0	0
Frequently repeated lines	4	5	8	8	8	8	8	8	25
Add flux/salinity HRX	2	2	7	12	15	15	15	15	26
Auto-met package, VOSClim	0	0	40	100	200	200	200	200	200
Technology development				X	X	X	X	X	X
International lines	26	29	40	40	45	45	51	51	51

6.5 Argo array of profiling floats: The heat content of the upper 2000 meters of the world's oceans, and the transfer of that heat to and from the atmosphere, are variables central to the climate system. The Argo array of profiling floats is designed to provide essential broad-scale, basin-wide monitoring of the upper ocean heat content. Three thousand floats will be deployed worldwide by 2006. The U.S. contribution is approximately one-half of this international project. Glider technology will replace standard drifting Argo floats in the boundary currents and targeted deep circulation regions. This task will support climate services by providing measurements needed to 1) document heat uptake, transport, and release by the ocean; and 2) document the air-sea exchange of water and the ocean's overturning circulation.

	NOAA Contributions								International Goal
	FY03	FY04	FY05	FY06	FY07	FY08	FY09	FY10	
Operational Argo floats	320	1000	1500	1485	1485	1385	1385	1385	2800
Research Argo floats	15	0	0	0	0	0	0	0	0
Operational gliders	0	0	0	0	0	100	100	100	200
Research gliders	3	3	10	20	50	0	0	0	0
Technology development				X	X	X	X	X	X
International array size	1000	1500	2300	3000	3000	3000	3000	3000	3000

6.6 Ocean Reference Stations:

6.6.1 Subtask 1: NOAA, together with international partners, will implement a global network of ocean reference station moorings, expanding from the present six pilot stations to a permanent network of 21 (plus 8 within the tropical moored buoy network) by 2010. NSF's Ocean Observatories Initiative will provide a major piece of the infrastructure needed for this network, establishing high-capability re-locatable moored buoys in remote ocean locations. NOAA will maintain climate instrumentation aboard the NSF-supplied platforms.

6.6.2 Subtask 2: Monitoring the transport within the ocean is a central element of documenting the overturning circulation of fresh water and heat and carbon uptake and release; heat and carbon generally are released to the atmosphere in regions of the ocean far distant from where they enter. Long-term monitoring of key choke points, such as the Indonesian through-flow, and of boundary currents along the continents, such as the Gulf Stream, must be established to measure the primary routes of ocean heat, carbon, and fresh water transport.

6.6.3 Subtask 3: Monitoring thermohaline circulation is a central element of documenting the ocean's overturning circulation and a critical need for helping scientists understand the role of the ocean in abrupt climate change. It is essential that the ocean observing system maintain watch at a few control points at critical locations. Key monitoring sites have been identified by an international team of scientists for deployment of long-term subsurface moored arrays and repeated temperature, salinity, and chemical tracer surveys from research vessels. NOAA will focus with Canadian partners on monitoring the Labrador Sea and upstream locations in Davis Strait and the

Canadian Arctic Archipelago, while European partners will focus on the eastern north Atlantic. One exception to this is that NOAA will maintain the Greenland-Iceland-Norwegian (GIN) Seas times-series that was started in 1991. Additionally, to estimate the effect of Antarctic zone water on the global thermohaline circulation, NOAA will maintain time series moorings and repeat sections in the northwestern Weddell Sea, and will establish time series measurements in the Ross Sea. These locations are important to examine the variability of water mass transformation processes as they relate to climate variability in the Southern Ocean.

6.6.4 Summary: These three subtasks will support climate services by providing ocean and atmosphere measurements needed to 1) document heat uptake, transport, and release by the ocean; 2) document ocean carbon sources and sinks (carbon sampling instrumentation is detailed under a separate task below; and 3) document the air-sea exchange of water and the ocean's overturning circulation.

	NOAA Contributions								International Goal
	FY03	FY04	FY05	FY06	FY07	FY08	FY09	FY10	
Operational flux moorings	1	2	6	7	9	9	9	9	29
Research flux moorings 1	0	0	0	0	0	0	0	0	
Operational full depth stations	0	0	3	5	10	10	10	10	42
Research full depth stations	1	1	0	0	0	0	0	0	0
Operational transport stations	0	0	2	4	4	5	5	5	10
Research transport stations	2	0	0	0	0	0	0	0	0
Pacific Raingauge (PACRAIN)	0	28	28	28	28	28	28	28	28
Research rain gauge network	28	0	0	0	0	0	0	0	0
Operational GIN time series	0	1	1	1	1	1	1	1	1
Research GIN time series	1	0	0	0	0	0	0	0	0
Sinking regions, operational	0	2	2	4	4	4	4	4	5
Sinking regions, research	1	1	0	0	0	0	0	0	0
S. Hemisphere sections	0	0	0	2	3	3	3	3	3
Technology development				X	X	X	X	X	X
International flux array	6	7	10	14	16	29	29	29	29

6.7 Coastal Moorings: Improved near shore measurements from moored buoys are critical to coastal forecasting as well as to linking the deep ocean to regional impacts of climate variability. The boundary currents along continental coastlines are major movers of the ocean's heat and fresh water (e.g., the Gulf Stream). Furthermore, the coastal regions are critical to the study of the role of the ocean in the intensification of storms, which are key to the global atmospheric transport of heat, momentum and water, and are a significant impact of climate on society. Coastal arrays are maintained by many nations making this a "global" network of "coastal" stations. A climate subset of NOAA's existing network will be improved by augmenting and upgrading the instrument suite to provide measurements of the upper ocean as well as the sea surface and surface meteorology. Ten of these moorings will serve as platforms-of-opportunity for the addition of carbon sampling instrumentation. This task will support climate services by providing ocean and atmosphere measurements needed to 1) document heat uptake, transport, and release by the ocean; 2) document ocean carbon sources and sinks (carbon sampling instrumentation is detailed under a separate task below); and 3) document the air-sea exchange of water.

	NOAA Contributions								International Goal
	FY03	FY04	FY05	FY06	FY07	FY08	FY09	FY10	
Upgrade w/climate sensors	0	0	20	65	65	65	65	65	105
Technology development				X	X	X	X	X	X
International coastal network	0	0	20	85	95	105	105	105	105

6.8 Ocean Carbon: Understanding the global carbon cycle and the accurate measurement of the regional sources and sinks of carbon are of critical importance to international policy decision making as well as to forecasting long term trends in climate. Projections of long-term global climate change are closely linked to assumptions about feedback effects between the atmosphere, the land, and the ocean. To understand how carbon is cycled through the global climate system, ocean measurements are critical. NOAA will add autonomous carbon dioxide sampling to the moored arrays and the VOS fleet to analyze the seasonal variability in carbon exchange between the ocean and atmosphere, and in cooperation with NSF will implement a program of systematic global ocean surveys that will provide a complete carbon inventory once every ten years. This task is coordinated with the Global Carbon Cycle Science program, is dependent on implementation of the ship lines and moored and drifting arrays, and will support climate services by providing measurements to document ocean carbon sources and sinks.

	NOAA Contributions								International Goal
	FY03	FY04	FY05	FY06	FY07	FY08	FY09	FY10	
Inventory lines per decade	6	6	11	11	11	11	11	11	25
Time series moorings	2	2	4	6	6	6	6	6	12
Coastal flux moorings	0	0	0	11	11	11	11	11	29
Flux on ships of opportunity	4	7	12	12	12	12	12	12	21
Research flux on moorings	2	0	0	0	0	0	0	0	0
Trans rsch flux moorings to ops	0	2	2	2	2	2	2	2	2
Technology development			X	X	X	X	X	X	X
International flux array	14	17	28	38	48	62	62	62	62

6.9 Integrated Arctic Observing System: To understand the role of the Arctic on global environmental change, the amount of uncertainty in the causes and trajectories of global climate change needs to be reduced. Given the sensitivity of the Arctic environment to climate variability and change, it is in this region that early indications of the future progression of climate change are likely to be first detected.

Ocean Climate Observations in the Arctic Ocean and Northern High Latitude Seas – A program of sustained observations of this area is being conducted through dedicated and shared ship-based cruises and permanent oceanographic moorings, supplemented by acquisition and analysis of historical data sets. The long-term goal is to detect climate-driven physical and ecological change, especially due to changes in sea ice extent and duration, and in ocean density and circulation that together may lead to changes in ocean heat transport, productivity, and food web structure. International collaboration is essential for completing this program, especially with Russia and Canada. In FY2003, one new mooring was deployed in the Northern Bering Sea, a research cruise was conducted to the Chukchi Sea in collaboration with China, planning was initiated for a future Chukchi Sea cruise in collaboration with Russia, sea-glider deployments were initiated in the Labrador Sea, joint US-Canada observations were conducted in Barrow Strait, and efforts begun to discover, obtain and manage historical data sets.

Arctic Sea Ice Observations – Ice-tethered buoys and bottom-mounted moorings are deployed to monitor the drift of Arctic sea ice and to determine its thickness. The long-term goal is to provide an accurate record of changes in sea ice thickness that, together with satellite observations of sea ice extent, can provide an estimate of changes in sea ice volume. This information is critical for improvement of global climate models and development of a regional Arctic climate model. Several ice buoys and two ice thickness stations were deployed in summer 2004.

This task will support climate services by providing ocean and ice measurements needed to document heat uptake, transport, and release by the ocean.

	NOAA Contributions								International Goal
	FY03	FY04	FY05	FY06	FY07	FY08	FY09	FY10	
Arctic pathway moorings	0	0	1	2	4	6	8	8	12
Arctic Ocean moorings	0	0	1	2	4	6	7	7	8
ASOF gateway mooring sets	0.5	0.5	1	1	1	1	2	2	5
Automated drifting stations	0	0	1	2	2	2	2	3	3
Ice buoys	10	10	11	20	20	20	20	20	40
Hydrographic stations	0	0	1	4	6	8	9	10	16
Bering Sea moorings	1	1	1	2	4	6	6	6	6
Western boundary sections	0	0	1	1	1	1	1	1	1
Western boundary moorings	0	0	2	2	4	4	4	4	4
Ice buoys and moored stations	10	31	36	36	54	64	78	85	85

6.10 Dedicated Ship Time:

6.10.1 Subtask 1: Climate Ship time within the UNOLS research fleet for deployment of the moored and drifting arrays, and for deep ocean surveys is an essential component of this initiative. The deep ocean cannot be reached by SOOP and Argo; yet quantification of the carbon and heat content of the entire ocean column is needed to solve the climate equations. In addition to providing the survey and deployment platforms for the autonomous arrays, the research fleet will maintain sensor suites on a small core of vessels as the highest quality calibration points for validation of the other system measurements. Annual requirements for ship time are 54 days in addition to the Ka'imimoana for TAO/TRITON maintenance, 74 days for the carbon inventory, 34 days for PIRATA in addition to the French/Brazilian support (see Subtask 2), 47 days for ocean reference stations growing to 120 days, 60 days for deployment of the drifting arrays in remote regions, and 46 days for thermohaline circulation monitoring growing to 172 days.

6.10.2 Subtask 2: The PIRATA array has been maintained by French research vessels, once per year in the east, and the Brazilian navy once per year on the western side of the Atlantic. Two maintenance visits per year to each mooring are necessary to maintain adequate operational data flow, as has been demonstrated in the Pacific with the TAO/TRITON array. The PIRATA consortium (Brazil, France, U.S.A.) has proposed a plan to establish an international ship base in Natal, Brazil, and operate cooperatively a new ship dedicated to Atlantic climate operations. The consortium has proposed that NOAA and French partners cooperate to acquire a new ship, and build the capacity in Brazil to support long-term climate operations. The new ship would support Argo and drifter deployments as well as PIRATA maintenance. The U.S. homeport for the ship, and support base for north Atlantic operations, would be Charleston, SC; Natal would support operations in the tropical and south Atlantic. This is a new concept in international collaboration and capacity building. In 2003, NOAA began feasibility study together with French and Brazilian partners to identify the best long-term solution to this issue. In the mean time, NOAA will begin supplementing the once-per-year French and Brazilian maintenance cruises with a second maintenance cruise using UNOLS or other charter operations (see Subtask 1).

6.10.3 Summary: This task will support climate services by providing multi-use platforms for the ocean and atmosphere measurements needed to 1) document heat uptake, transport, and release by the ocean; 2) document ocean carbon sources and sinks; and 3) document the air-sea exchange of water and the ocean's overturning circulation.

Ship days at sea	NOAA Contributions							International Goal	
		FY03	FY04	FY05	FY06	FY07	FY08	FY09	FY10
Ka'imimoana		276	276	276	276	276	276	276	276	276
TAO/TRITON additional		54	54	54	54	54	54	54	54	90
PIRATA		0	0	34	34	34	34	34	34	124
Carbon survey		74	74	74	74	74	74	74	74	240
Coastal flux maps		0	0	0	36	40	40	40	40	240

Reference Stations	47	47	47	60	102	120	120	120	480
Deployment of drifting arrays	0	0	0	60	60	60	60	60	100
Thermohaline circulation	46	46	46	46	90	172	172	172	340
Arctic hydrographic sections	0	0	0	60	60	60	60	60	120
NOAA total	497	497	531	531	640	730	830	830	
International fleet	550	610	750	900	1200	1620	1620	1620	1620

6.11 Satellites:

The initial ocean observing system for climate depends on space based global measurements of 1) sea surface temperature, 2) sea surface height, 3) surface vector winds, and 4) ocean color. These satellite contributions are detailed in other NOAA program plans.

6.11.1 Sea surface temperature: Satellite measurements of sea surface temperature are included in NOAA's operational satellite program and the NPOESS program. Satellite data provide high-resolution sea surface temperature data. Both infrared and microwave satellite data are important. Microwave sea surface temperature data have a significant coverage advantage over infrared sea surface temperature data, because microwave data can be retrieved in cloud-covered regions while infrared cannot. However, microwave sea surface temperatures are at a much lower spatial resolution than infrared. In addition microwave sea surface temperatures cannot be obtained within roughly 50 km of land. A combination of both infrared and microwave data are needed because they have different coverage and error properties. Drifting buoy and other *in situ* data are critically important in providing calibration and validation in satellite data as well as providing bias correction of these data. Satellite biases can occur from orbit changes, satellite instrument changes and changes in physical assumptions on the physics of the atmosphere (e.g., through the addition of volcanic aerosols). Thus, drifting buoy and other *in situ* data are needed to correct for any of these changes.

6.11.2 Sea surface height: The value of spaced-based altimeter measurements of sea surface height has now been clearly demonstrated by the TOPEX/Poseidon and Jason missions. Changes in sea level during major El Nino events can now be discerned at high resolution and provide realistic model initializations for seasonal climate forecasting. The same data, when calibrated with island tide gauge observations, are also able to monitor the rate of global sea level change with an accuracy of 1 mm per year. The planned NPOESS altimeter will be adequate for shorter term forecasting, but the NPOESS altimeter will not fly in the same orbit as TOPEX/Poseidon and Jason; and for monitoring long-term sea level change, continuation of precision altimeter missions in the TOPEX/Poseidon/Jason orbit is necessary. Jason follow-on altimeter missions (Ocean Surface Topography Mission, OSTM) are necessary to continue the long-term sea level record. NASA and CNES have asked NOAA and EUMETSAT to transition the Jason-class altimeter from research to operations beginning with the OSTM. In FY2006, NOAA will assume primary U.S. responsibility for continuing this international effort. This task will contribute to climate services by providing the long term records needed to 1) document sea level change; 2) document heat uptake, transport, and release by the ocean;

and 3) document the ocean's overturning circulation (sea surface height contributes to the measurement of ocean heat and fresh water content and their transport).

6.11.3 Surface vector winds and ocean color: The best methods of sustaining satellite measurement of surface vector winds and ocean color are still a research and development question; over the next five years NOAA, NASA, and NPOESS will weigh the alternatives and determine the long term strategy for maintenance of these elements.

6.12 Data and Assimilation Subsystems:

6.12.1 Subtask 1 – Long Term Stewardship: The value of the observations does not end with their initial use in detecting and forecasting climate variability. The data must be retained and made available for retrospective analyses to understand long-term climate change, and for designing observing system operations and improvements. NOAA's long history and unique expertise in environmental data management will be applied to the ocean observing system. NOAA also will include the vast holdings of historical ocean observations within the context of the integrated environmental data access and archive system. Support will also be provided for a World Ocean Database to incorporate modern data into an integrated profile system.

6.12.2 Subtask 2 – Data Management and Communications: A robust and scalable data management infrastructure is essential to the vision of a sustained ocean observing system. NOAA's ocean climate data element will contribute a global component to the Data Management and Communications System (DMAC) of the U.S. Integrated Ocean Observing System (IOOS) that is being implemented by the National Oceanographic Partnership Program agencies. The DMAC plan integrates data transport, quality control, data assembly, limited product generation, metadata management, data archeology, data archival, data discovery, and administration functions. Uniform access to data will be addressed through the concept of "middleware" connectivity – a common set of standards and protocols that connects all data sources to data users. The middleware approach shields end users from many of the traditional barriers that have been associated with climate data access, including file formats, the distributed location of data, and the large size of some data sets. The preliminary design has been developed by the National Virtual Ocean Data System (NVODS) project.

The nature of IOOS requires the DMAC to be very highly distributed, supporting both large and small data providers at Federal, regional, state, municipal and academic levels. Data assembly centers will be built into the design to add fault-tolerance and increase ease of use. The GODAE server at Navy's Fleet Numerical Modeling Operations Center (FNMOC) in Monterey will provide robust, operational access to aggregated and quality-controlled real-time data streams and will be a primary assembly center for NOAA's real-time global measurements. Delayed-mode data sources will be distributed across many institutions including the Asia-Pacific Research Data Center (APDRC) (part of the International Pacific Research Center (IPRC) at the University of Hawaii) and the NOAA Data Centers. The APDRC will provide data assembly services for delayed-mode observations in a cooperative partnership with the GODAE Server.

The Data Management and Communications component of NOAA's ocean climate observing system must also deliver the information products needed by NOAA scientists and managers for decision support. The products must provide the information needed to monitor the month-by-month effectiveness of the observing system and to diagnose problems. The products should include intelligible scientific graphics and human-readable numeric tables that provide an overview of the integrated system, selectively merging the data from all relevant measurement streams. These information products will be a component of NOAA's contribution to IOOS.

6.12.3 Subtask 3 – Four dimensional data assimilation including GODAE: For climate forecasting, the combined fields from many different networks are used as initial conditions to begin the forecast. These combined fields, or analyses, are also used to document what the ocean and atmosphere are doing at present and what they did in the past, thus providing a record of the changing climate. By routinely comparing models and data, shortcomings in the observing system can be identified and both the models and forecasts can be improved. To utilize effectively the ocean observations, NOAA will expand the current ocean analyses (presently focused on the tropical Pacific) to the global domain and will develop and implement improved assimilation subsystems that can more effectively use the new data types that are being collected. The principal vehicle for developing this capability, involving both national and international communities and producing a variety of marine products in addition to the use of these observations in forecast systems, will be the Global Ocean Data Assimilation Experiment (GODAE). The global data and ocean product delivery will be operationalized as a contribution to, and continue as a follow-on to, GODAE through the interagency/international server infrastructure being implemented by GODAE for real-time at FNMOC and for delayed mode at the IPRC; NOAA will provide the primary U.S. support to sustain the IPRC server infrastructure over the long term (in cooperation with Japan). In addition to improving initializations for seasonal forecasting at NCEP, NOAA will implement sustained ocean data assimilation activities at GFDL to enable experimental decadal forecasts, provide ocean initial conditions for IPCC type scenarios, monitor ocean heat uptake, monitor the thermohaline circulation for abrupt changes, and develop a capability for monitoring changes in oceanic carbon sources and sinks.

6.12.4 Summary: This task will support climate services by providing the integrating data, synthesis, and analysis infrastructure for the ocean and atmosphere measurements, both *in situ* and space based, needed to: 1) document long-term trends in sea level change; 2) document heat uptake, transport, and release by the ocean; 3) document ocean carbon sources and sinks; and 3) document the air-sea exchange of water and the ocean's overturning circulation.

	NOAA Contributions								International Goal
	FY03	FY04	FY05	FY06	FY07	FY08	FY09	FY10	
Data set development	X	X	X	X	X	X	X	X	X
World Ocean Database				X	X	X	X	X	X
Standards and protocols			X	X	X	X	X	X	
Systems interoperability	X	X	X	X	X	X	X	X	X

Automated monitoring tools	X	X	X	X	X	X	X	X	X
IPRC server	X	X	X	X	X	X	X	X	X
GODAE pilot activities (JIMO)	X	X	X	X	X	X	X	X	X
Operationalize GODAE pilot		X	X	X	X	X	X	X	X
Global initialization for S-I	X	X	X	X	X	X	X	X	X
Experimental decadal forecast		X	X	X	X	X	X	X	X
Conditions for IPCC scenarios		X	X	X	X	X	X	X	X
Monitor ocean heat uptake		X	X	X	X	X	X	X	X
Monitor thermohaline circulation				X	X	X	X	X	X
Monitor carbon sources and sinks	X	X	X	X	X	X	X	X	X
Argos data processing – Drifting Buoy arrays	X	X	X	X	X	X	X	X	X
Argos data processing – Tropical Moored Buoy network	X	X	X	X	X	X	X	X	X
Argos data processing – Ocean Ref stations	X	X	X	X	X	X	X	X	X

7.0 Management Plan – System organization and product delivery

A global effort of the proposed magnitude must be integrated, organized, and managed as a system in order to be effective. Matrix management is NOAA's corporate business practice and standard protocol. This management plan will follow that protocol by capitalizing on the capabilities that presently exist across the agency while building toward the vision of a single composite system.

Implementation of the individual *in situ* networks will continue to be through distributed centers of expertise at the NOAA Research laboratories, the National Ocean Service Center for Operational Oceanographic Products and Services, the National Data Buoy Center, and the university laboratories that have developed the instruments and techniques. The space components and data management will be centered in the NOAA Satellite and Information Service. The focal point for developing global ocean data assimilation capabilities will be the Geophysical Fluid Dynamics Laboratory in partnership with the National Centers for Environmental Prediction and university-based applied research centers.

To weld the distributed efforts together into the single vision, NOAA has established a project Office of Climate Observation (OCO) under the auspices of the NOAA Climate Program. Organizationally the project office is located within the Office of Global Programs (OGP). OGP embodies a global perspective and is experienced in matrix management. One of OGP's four strategic objectives is "development of the *in situ* ocean component of the global climate observing system." Additionally, for the climate observing system institutional mechanisms must be put in place to ensure continuous and close involvement of the research community. Research, operations, and management are inseparable for climate observation and OGP will hard-wire that relationship.

The Director of OGP utilizing the OCO is charged with advancing NOAA's multi-year program plan for *Building a Sustained Ocean Observing System for Climate*. The OCO is a hybrid combining the functions of a traditional program office with the functions of a center for system monitoring, evaluation, integration, and action. The individual network managers will continue to monitor and evaluate the performance of their individual networks, while the OCO will build the capability to monitor and evaluate the performance of the system as a whole, and take action to evolve the *in situ* networks for overall effectiveness and efficiency in meeting climate observation objectives.

The OCO is the management focus for the distributed ocean network operations and, utilizing the NOAA Observing System Architecture, establishes and maintains operational linkages between the networks and NOAA's other *in situ* and satellite elements and the data and modeling activities that are essential components of climate observation. The office provides a central point of contact within NOAA for coordination with the other agencies and nations involved in observing system implementation. The office receives and acts on feedback from the observing system customers - the operational forecast centers, international research programs, and major scientific assessments - and acts on their observational requirements in accordance with the NOAA Requirements-Based Management Process.

7.1 Subtask 1 – System Monitoring: The OCO monitors the status of the globally distributed networks to anticipate gaps and overlaps in their combined capabilities. Real-time reports from all platforms are being centralized so that up-to-date status can be displayed at all times. The office is working to report system statistics and metrics, routinely and on demand.

7.2 Subtask 2 – Evaluation: An team of expert scientists both internal and external to NOAA is being established to continually evaluate the effectiveness of the networks in meeting the performance measures and the adequacy of the deliverables in meeting the system objectives. The team of experts will evaluate analysis/synthesis products, recommend product improvements, recommend where additional sampling is needed or redundancies are not needed, recommend better utilization of existing and new *in situ* and satellite data, and assess the impacts of proposed changes to the system.

7.3 Subtask 3 – Action: System monitoring and evaluation will be useless unless there is responsive action taken to build the system, fix problems, and improve sampling strategies. Decisions must be made to implement the best solutions to conflicting requirements (multiple partners and customers have differing missions and will inevitably have differing requirements), to re-deploy existing resources to best improve the system, to select the highest priorities for system extensions and funding of new ideas, and to agree on quid pro quo with interagency and international partners. The OCO is charged with advancing NOAA's multi-year program plan and with evolving the system for maximum effectiveness and efficiency along the way.

7.4 Subtask 4 – Intra-agency, Interagency, and International Coordination: National and international coordination is essential to success in building the global ocean observing system for climate. The OCO is charged with building the infrastructure necessary to organize NOAA's ocean observing efforts along three axes – 1) climate services, 2) the U.S. Integrated Ocean Observing System, and 3) international implementation.

1) For climate services the ocean observations must be available to be combined with data from the atmospheric networks, land surface networks, and cryosphere networks. The requirements from the three user communities – the forecast centers, research programs, and scientific assessments – must be received and synthesized into common requirements or prioritized if they do not resolve readily.

2) For the U.S. Integrated Ocean Observing System, NOAA's climate system will make a significant contribution to the global component where like data from the various platforms, *in situ* and space-based, must be combined to form complete fields (e.g., sea surface temperature from ships, drifting and moored buoys, and satellites). NOAA's efforts must be combined with the efforts of the other NOPP agencies into a seamless system.

3) For international implementation NOAA must work with the implementation panels of the Joint IOC/WMO Commission for Oceanography and Marine Meteorology (JCOMM) to ensure that consistent standards and formats are used by all participating nations so that data can be easily shared and that consistent quality can be expected from all platforms regardless of their national origin.

In addition to dedicated infrastructure needed for NOAA to operate an office for climate observation, dedicated infrastructure is also needed for operation of the interagency and intergovernmental planning and implementation coordination organizations. These interagency/international organizations rely on funding from the member agencies for their support. NOAA has historically provided a significant portion of the funding needed to maintain the existing international secretariats, science and implementation panels, and capacity building efforts of GOOS, GCOS, and the JCOMM. This funding support has been ad hock and in general from the research programs. As a central component of sustaining the long-term, operational global climate observing system, support for the national/international coordination/implementation infrastructure will be institutionalized via the OCO.

7.5 Subtask 5 – Annual Report on the Ocean's Role in Climate: The organizing framework to bring the multiple elements of the composite ocean observing system together is the routine delivery of an *Annual Report on the State of the Ocean and the Ocean Observing System for Climate*. The National Climate Change Science Program strategic plan has identified the critical need for regular reports documenting the present state of the climate system components. NOAA's Office of Climate Observation is leading the national effort to develop this reporting for the ocean component. The theme of the report is the CCSP overarching question for guiding climate observations and monitoring- "What is the current state of the climate, how does it compare with the past, and how can observations be improved to better initialize and validate models for prediction or long term projections?"

The annual report synthesizes satellite and *in situ* observations integrated with models and provides the products to decision makers, the science community, and the public. This reporting framework also establishes a formal mechanism for implementing a "user-driven" observing system and for reporting on the system's performance in meeting the requirements of the operational forecast centers, international research programs, and major scientific assessments. Stakeholders are invited to provide formal recommendations for system improvement and evolution as part of the annual report process.

The annual report contains four chapters:

1) This chapter describes The Role of the Ocean in Climate and includes a description of ENSO, SST, sea ice, and sea level, and the various demands on the system incorporating seasonal, interannual, decadal, and climate change time scales. This chapter sets the context for the report and outlines common themes, including the significance of the global ocean observing system and the demands on the system.

2) The second chapter documents the State of the Ocean. The target audience is decision makers and non-scientists. This chapter is written by the experts in the field and is an annually updated climatology of the ocean, placed in historical context, with discussion of the present uncertainties and with pointers to products of greater detail and climate applications.

3) The third chapter documents the State of the Observing System. The target audience is NOAA management. This chapter has two sections:

a) System Progress in meeting milestones is documented by the network managers for their projects and by the OCO for the system in total. Annual statistics and status are given.
b) Work plans for the next fiscal year include future efforts.

4) Chapter four recaps the State of the Science. The target audience is scientists. The final chapter of the report contains a bibliography of refereed publications from scientific journals treating the global observation of ocean heat, carbon, fresh water, and sea level change. Each year a selected number of abstracts of particularly relevant scientific papers are published with the report.

7.6 Subtask 6 – External Review: The execution of this plan will be subject to normal management review in accordance with NOAA's Requirements-Based Management Process. Additionally, for specific programmatic advice and guidance, the Climate Observing System Council (COSC) has been established to review the program's contribution to the international Global Climate Observing System and to recommend effective ways for the program to respond to the long-term observational needs of the operational forecast centers, international research programs, and major scientific assessments. The Council is comprised of members both internal and external to NOAA who individually offer their expert advice; the Council is not expected to develop consensus opinions. The term of membership is two years with a renewal option for two additional terms. The Council meets at least annually to:

- Advise the OCO on priorities for sustaining and enhancing components of the global climate observing system.
- Review the accomplishments and future plans of specific program activities.

- Recommend realignment of activities, or entirely new activities, within the program as appropriate to satisfy the evolving requirements for climate observation.
- Bring to the OCO a broad view on national and international climate research and operational activities and their implications.
- Provide coordinating linkages with national and international programs requiring and/or contributing to the implementation of the global climate observing system.
- Advise the OCO on the balance of activities within the program in the context of NOAA's overarching climate service requirements, of other national and international requirements, and of other national and international contributions to the global climate observing system.

7.7 System management and product delivery milestones:

	NOAA Contributions								International Goal
	FY03	FY04	FY05	FY06	FY07	FY08	FY09	FY10	
System Monitoring	X	X	X	X	X	X	X	X	X
System Evaluation:									
Seasonal forecasting		X	X	X	X	X	X		X
Decadal forecasting		X	X	X	X	X	X	X	X
Climate change				X	X	X	X	X	X
Sea level change		X	X	X	X	X	X	X	X
Carbon sources and sinks									X
Air-sea exchange,heat/water		X	X	X	X	X	X	X	X
Heat storage/thermohaline circulation		X	X	X	X	X	X	X	X
SST	X	X	X	X	X	X	X	X	X
Sea Ice		X	X	X	X	X	X	X	X
Interagency/International panels	X	X	X	X	X	X	X	X	
International capacity building				X	X	X	X	X	X
Transition SST eval res to ops	X	X	X	X	X	X	X	X	X
Mgmt – wkshps & science mtgs	X	X	X	X	X	X	X	X	
Mgmt – administration & finance		X	X	X	X	X	X	X	X
Mmgt ops funded from research	X	X	X	X	X	X	X	X	X
Annual Report		X	X	X	X	X	X	X	X
External review			X	X	X	X	X	X	

8.0 Education

The NOAA Office of Climate Observation sponsors three educational initiatives:

1) Teacher at Sea Program – OCO sponsors one or two teachers each year to participate in ocean research on board NOAA and other research vessels.

2) Adopt a Drifter Program – OCO established this program in December 2004 to enable K-16 teachers and their students to adopt a drifting buoy by partnering with an international school. They can follow their buoy's movement across the ocean by using an Adopt a Drifter Program website.

3) OCO is launching a student internship program to enrich students' understanding of and appreciation for NOAA and observing system science, and to provide additional support for OCO office projects.

A summary of the sampling requirements for the global ocean, based largely on OOSDP (1995), but with revisions as appropriate. These are a statement of the required measurement network characteristics, not the characteristics of the derived field. The field estimates must factor in geophysical noise and unsampled signal. Some projections (largely unverified) have been included for GODAE.

Sampling Requirements for the Global Ocean							
Code	**Application**	**Variable**	**Hor. Res.**	**Vert. Res.**	**Time Res.**	**#samples**	**Accuracy**
A	NWP, climate, mesoscale ocean	Remote SST	10 km	-	6 hours	1	0.1-0.3°C
B	Bias correction, trends	*In situ* SST	500 km	-	1 week	25	0.2-0.5°C
C	Climate variability	Sea surface salinity	200 km	-	10 day	1	0.1
D	Climate prediction and variability	Surface wind	2°	-	1-2 day	1-4	0.5-1 m/s in components
E	Mesoscale, coastal	Surface wind	50 km	-	1 day	1	1-2 m/s
F	Climate	Heat flux	2° x 5°	-	month	50	Net: 10 W/m^2
G	Climate	Precip.	2° x 5°	-	daily	Several	5 cm/month
H	Climate change trends	Sea level	30-50 gauges + GPS with altimetry, or several 100 gauges + GPS	-	monthly means		1 cm, giving 0.1 mm/yr accuracy trends over 1-2 decades
I	Climate variability	Sea level anomalies	100-200 km	-	10-30 days	~ 10	2 cm
J	Mesoscale variability	Sea level anomalies	25-50 km	-	2 days	1	2-4 cm
K	Climate, short-range prediction	sea ice extent, concentration	~ 30 km	-	1 day	1	10-30 km 2-5%
L	Climate, short-range prediction	sea ice velocity	~ 200 km	-	Daily	1	~ cm/s
M	Climate	sea ice volume, thickness	500 km	-	monthly	1	~ 30 cm
N	Climate	surface pCO_2	25-100 km	-	daily	1	0.2-0.3 µatm
O	ENSO prediction	T(z)	1.5° x 15°	15 m over 500 m	5 days	4	0.2°C
P	Climate variability	T(z)	1.5° x 5°	~ 5 vertical modes	1 month	1	0.2°C
Q	Mesoscale ocean	T(z)	50 km	~ 5 modes	10 days	1	0.2°C
R	Climate	S(z)	large-scale	~ 30 m	monthly	1	0.01
S	Climate, short-range prediction	U(surface)	600 km	-	month	1	2 cm/s
T	Climate model valid.	U(z)	a few places	30 m	monthly means	30	2 cm/s

Table 1. From *The Action Plan for GOOS/GCOS and Sustained Observation for CLIVAR* by Needler et al. -- *OCEANOBS 99*

Appendix A

Foundation Documents

Observing the Oceans in the 21st Century, edited by Chester J. Koblinsky and Neville R. Smith, 2001, GODAE Project Office, Bureau of Meteorology, Melbourne, Australia, ISBN 0642 70618 2.

OCEANOBS 99, proceedings of the International Conference on the Ocean Observing System for Climate, GCOS/GOOS/WCRP Ocean Observations Panel for Climate and the CLIVAR Upper Ocean Panel, Saint-Raphael, France, October 1999.

International Sea Level Workshop Report, GCOS/GOOS/WCRP Ocean Observations Panel for Climate and the CLIVAR Upper Ocean Panel, April 1998, GCOS #43, GOOS #55, ICPO #16.

A Large Scale CO_2 Observing Plan: In Situ Oceans and Atmosphere (LSCOP), a contribution to the implementation of the U.S. Carbon Cycle Science Plan by the *In situ* Large-Scale CO_2 Observations Working Group, April 2002.

Implementation Plan for the Global Observing System for Climate in support of the UNFCCC (GCOS-92), the Global Climate Observing System, October 2004, GCOS #92, WMO/TD #1219.

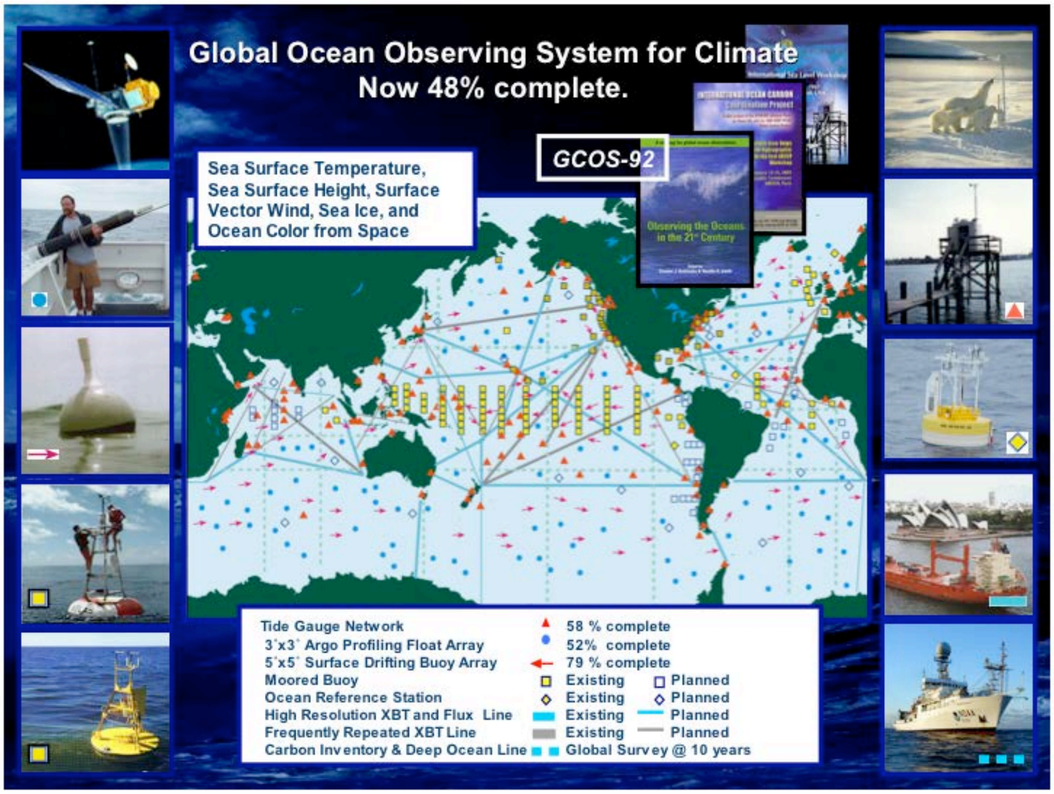


Figure 1

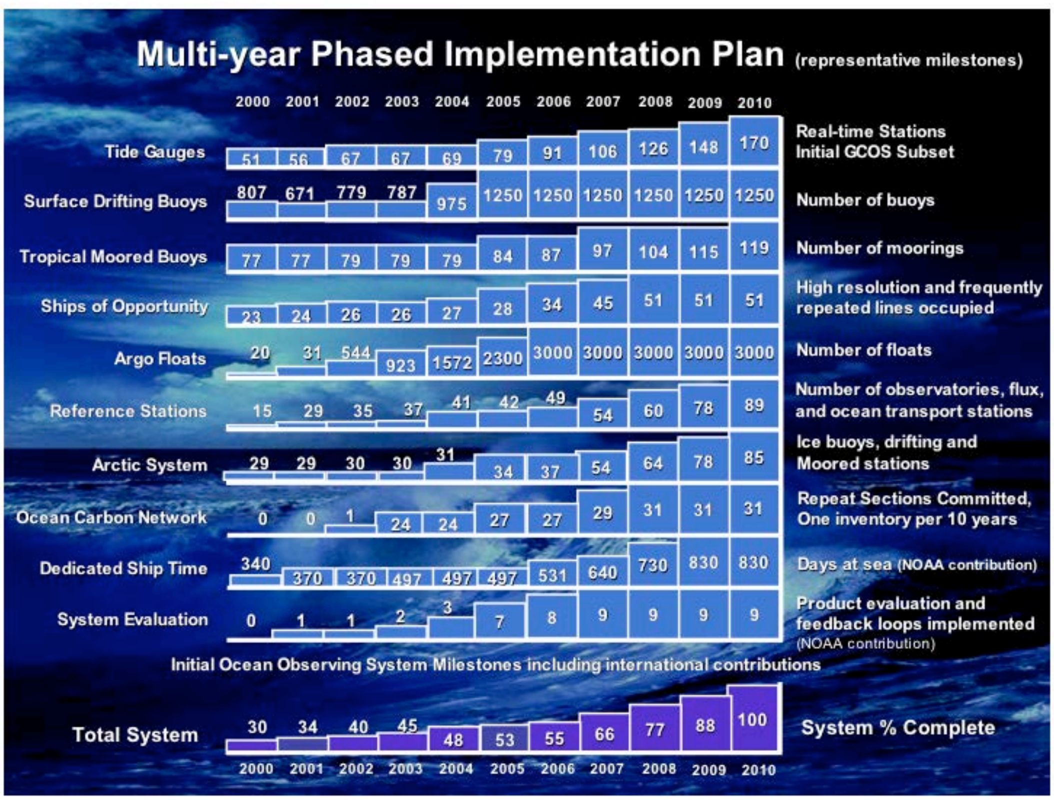


Figure 2

Table 2 Program Baseline Assessment

Climate Observation Program – Ocean Component ($ millions)									
				100% Requirement					Interntl
	FY04	FY05	FY 06	FY 07	FY 08	FY 09	FY 10	FY 11	Goal**
REQUIREMENT INPUT									
Capability A: Extend ocean network to achieve global coverage									
Capacity (Tide Gauge Network)									
Indo-Pacific network stations	39	39	39	39	39	39	39	39	39
Cost	0.7	0.8	0.8	0.8	0.9	0.9	0.9	0.9	
Station upgrades	4	10	16	26	32	32	32	32	199
Cost	0.1	0.3	0.3	0.3	0.3	0.4	0.4	0.4	
GPS stations	10	14	18	40	40	40	40	40	86
Cost	0.1	0.2	0.2	0.4	0.4	0.4	0.4	0.4	
GPS data processing		x	x	x	x	x	x	x	x
Cost	0	0.2	0.2	0.3	0.3	0.4	0.4	0.4	
Atlantic research network stations	0	0	0	0	0	0	0	0	0
Cost	0	0	0.0	0.0	0.0	0.0	0.0	0.0	
Transition Atlantic stations from research to ops	6	6	6	6	6	6	6	6	0
Cost	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.2	
Reference stations	18	18	18	18	18	18	18	18	62
Cost ($0.5 m) Commerce and Transportation		0.1	0.1	0.1	0.1	0.1	0.1	0.1	
Climate analysis		x	x	x	x	x	x	x	x
Cost	0	0.1	0.1	0.3	0.3	0.3	0.3	0.3	
Technology development			x	x	x	x	x	x	x
Cost	0	0	0.0	0.0	0.3	0.3	0.3	0.3	
Federal FTEs*	1	2	2	2	2	2	2	2	
Cost									
non-Federal FTEs*	6	7	7	7	7	7	7	7	
Cost									
Total	**1.0**	**1.8**	**1.8**	**2.4**	**2.8**	**3.0**	**3.0**	**3.0**	
% complete	**33**	**60**	**60**	**80**	**93**	**100**	**100**	**100**	
Capacity (Drifting Buoy Array)									
Global array operations buoys	670	840	840	840	840	840	840	840	1250
Cost	1.9	2.9	2.9	2.9	3.0	3.0	3.0	3.0	
Research buoys	200	0	0	0	0	0	0	0	0
Cost	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
Transition research contributions to operations	0	200	200	200	200	200	200	200	0
Cost	0	0.8	0.8	0.8	0.9	0.9	0.9	0.9	
Add met sensors/barometers	40	80	80	200	500	600	670	670	1250
Cost	0	0.2	0.2	0.5	1.0	2.0	2.8	2.8	
Technology development		x	x	x	x	x	x	x	x
Cost	0	0.1	0.1	0.4	0.4	0.4	0.4	0.4	
Federal FTEs	1	1	1	2	2	2	2	2	
Cost									
non-Federal FTEs	4	6	6	6	6	6	6	6	
Cost									
Total	**2.7**	**4.0**	**4.0**	**4.6**	**5.3**	**6.3**	**7.1**	**7.1**	
% complete	**38**	**56**	**56**	**65**	**75**	**89**	**100**	**100**	
Capacity (Tropical Moored Buoy Network)									
TAO/TRITON operations buoys	55	55	55	55	55	55	55	55	69
Cost	2.6	2.6	2.6	3.0	3.1	3.1	3.1	3.1	
Indian Ocean expansion	0	3	5	7	15	15	15	15	30
Cost	0.4	0.7	2.2	2.2	2.2	2.2	2.2	2.2	
PIRATA operations	10	10	10	10	10	10	10	10	10
Cost	0.6	0.6	0.6	0.7	0.7	0.7	0.7	0.7	
Atlantic Ocean expansions	0	0	4	4	6	9	9	9	9
Cost	0	0	0.6	0.6	1.0	1.0	1.0	1.0	
System upgrades	0	0	30	65	65	65	65	65	
Cost	0	0.5	0.5	0.5	0.5	0.5	0.5	0.5	
Add salinity sensors	10	10	55	65	65	65	65	65	99
Cost	0	0	0.3	0.3	0.3	0.4	0.4	0.4	
Add flux capability (as per Ocean Ref Station plan)	0	0	7	7	7	7	7	7	8
Cost	0.0	0	0.5	0.5	0.6	0.6	0.6	0.6	
Technology development			x	x	x	x	x	x	
Cost	0.0	0.0	0.3	0.3	0.3	0.3	0.3	0.3	
PMEL Operations	x	x	x	x	x	x	x	x	x
Cost	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	
Federal FTEs	14	14	14	14	14	14	14	14	
Cost									

Table 2 Program Baseline Assessment

Climate Observation Program – Ocean Component ($ millions)									
				100% Requirement					International Goal**
	FY 04	FY 05	FY 06	FY 07	FY 08	FY 09	FY 10	FY 11	
non-Federal FTEs	9	10	16	16	16	16	16	16	
Cost									
Total	**4.0**	**4.8**	**8.0**	**8.5**	**9.1**	**9.2**	**9.2**	**9.2**	
% complete	**43**	**52**	**87**	**92**	**99**	**100**	**100**	**100**	
Capacity (Ships of Opportunity Network)									
Ships-of-Opportunity operations (including 10,000 XBTs)	2	9	9	9	9	9	9	9	20
Cost	0.9	0.9	0.9	0.9	1.0	1.1	1.1	1.1	
Complete high resolution network	1	1	1	1	1	1	1	1	1
Cost	0.3	0.3	0.3	0.3	0.4	0.5	0.5	0.5	
Complete frequently repeated network	5	8	8	8	8	8	8	8	21
Cost	0	0.3	0.3	0.3	0.4	0.4	0.4	0.4	
HRX research lines & sensor R & D	0	0	0	0	0	0	0	0	0
Cost	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
Transition research lines to operations	6	6	6	6	6	6	6	6	0
Cost	1.1	1.1	1.1	1.1	1.2	1.2	1.4	1.4	
Transition NSF lines from research to operations	6	6	6	6	6	6	6	6	
Cost	0.2	0.5	0.5	0.5	0.5	0.5	0.5	0.5	
Add flux capability and salinity to high resolution network	2	7	12	15	15	15	15	15	21
Cost	0	0	0.0	0.5	1.0	2.5	4.7	4.7	
AOML ship and drifter operations	x	x	x	x	x	x	x	x	
Cost	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	
Add automated met package to 200 VOSClim ships (accounting in Local Forecasts and Warnings)	0	1	1	100	200	200	200	200	200
Cost	0.0	0.1	0.1	[1.6]	[1.6]	[1.6]	[1.6]	[1.6]	
Technology development				x	x	x	x	x	x
Cost	0	0	0.0	0.2	0.2	0.3	0.3	0.3	
Federal FTEs	2	2	2	2	2	2	2	2	
Cost									
non-Federal FTEs	6	7	7	8	8	8	8	8	
Cost									
Total	**3.9**	**4.6**	**4.6**	**5.2**	**6.1**	**7.9**	**10.3**	**10.3**	
% complete	**38**	**45**	**45**	**50**	**59**	**77**	**100**	**100**	
Capacity (Argo Array)									
Global operations of floats	750	1150	1485	1485	1385	1385	1385	1385	2800
Cost	10.1	10.1	10.1	10.1	10.1	10.1	10.1	10.1	
Research array of floats	0	0	0	0	0	0	0	0	0
Cost	0	0	0.0	0.0	0.0	0.0	0.0	0.0	
Glider development	3	10	20	50	100	100	100	100	200
Cost	0.3	0.3	0.3	1.0	2.0	4.0	5.0	5.0	
Technology development				x	x	x	x	x	x
Cost	0	0	0.0	0.3	0.3	0.3	0.3	0.3	
Federal FTEs	2	2	2	2	2	2	2	2	
Cost									
non-Federal FTEs	8	8	8	9	9	9	9	9	
Cost									
Total	**10.4**	**10.4**	**10.4**	**11.4**	**12.4**	**14.4**	**15.4**	**15.4**	
% complete	**68**	**68**	**68**	**74**	**81**	**94**	**100**	**100**	
Capacity (Ocean Reference Stations)									

Operational flux moorings	2	3	3	3	3	3	3	3	29
Cost	0.8	0.8	0.8	0.9	0.9	1.0	1.0	1.0	
Research flux moorings	0	0	0	0	0	0	0	0	0
Cost	0	0	0.0	0.0	0.0	0.0	0.0	0.0	
Transition research moorings to operations	1	1	1	1	1	1	1	1	0
Cost	0.8	0.8	0.8	0.8	0.9	0.9	0.9	0.9	
Climate sensors on NSF OOI stations	0	0	0	3	5	8	10	10	42
Cost	0	0	0.0	0.6	1.0	1.6	2.0	2.0	
Establish Transport monitoring network	0	1	1	2	3	5	6	6	10
Cost	0	0.4	0.4	0.8	1.2	2.0	2.5	2.5	
Research transport monitoring	0	0	0	0	0	0	0	0	0
Cost	0	0	0.0	0.0	0.0	0.0	0.0	0.0	
Transition research to operational transport monitoring	2	2	2	2	2	2	2	2	0
Cost	0.3	0.3	0.3	0.3	0.4	0.4	0.4	0.4	
Enhance flux data assembly center for ocean reference	x	x	x	x	x	x	x	x	x
Cost	0.3	0.3	0.3	0.4	0.4	0.4	0.5	0.5	
Establish reference fleet standard intercomparison	x	x	x	x	x	x	x	x	x
Cost	0.2	0.2	0.2	0.4	0.4	0.5	0.5	0.5	
Pacific Rain gauge network - PACRAIN	28	28	28	28	28	28	28	28	28
Cost	0.3	0.2	0.2	0.4	0.4	0.4	0.4	0.4	
Research rain gauge network	0	0	0	0	0	0	0	0	0
Cost	0	0	0.0	0.0	0.0	0.0	0.0	0.0	
Research Antarctic arrays (Weddell Sea)	0	0	0	0	0	0	0	0	0
Cost	0.1	0	0.0	0.0	0.0	0.0	0.0	0.0	
Transition research Antarctic arrays to operations	1	1	1	1	1	1	1	1	1
Cost	0	0.7	0.7	0.8	0.8	0.8	0.8	0.8	
Establish sinking region monitoring	0	0	0	1	2	3	4	4	5
Cost	0	0	0.0	0.7	1.4	2.4	2.4	2.4	
Southern hemisphere thermohaline monitoring sections	0	0	0	0	1	2	3	3	3
Cost	0	0	0.0	0.0	1.0	2.0	3.0	3.0	
Technology development						x	x	x	x
Cost	0	0	0.0	0.0	0.0	0.5	0.5	0.5	
Federal FTEs	1	1	1	2	2	2	2	2	
Cost									
non-Federal FTEs	9	10	10	15	21	27	32	32	
Cost									
Total	**2.8**	**3.7**	**3.7**	**6.1**	**8.8**	**12.9**	**14.9**	**14.9**	
% complete	**19**	**25**	**25**	**41**	**59**	**87**	**100**	**100**	
Capacity (Coastal Moorings): provided by Goal 3, Weather and Water, Local Forecasts and Warnings, National Data Buoy Center									
Upgrade climate subset with ocean sensors (65 stations)	0	0	0	65	65	65	65	65	105
Cost									
Technology development				x	x	x	x	x	x
Cost									
Federal FTEs									
Cost									
non-Federal FTEs									
Cost									
Total	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	
% complete									
Capacity (Ocean Carbon)									
Global inventory survey	6	11	11	11	11	11	11	11	25
Cost	1	1.5	1.5	1.7	2.0	3.0	3.3	3.3	
Time series moorings	3	4	4	5	6	7	8	8	12
Cost	0.1	0.4	0.4	0.8	1.5	1.5	2.0	2.0	
Coastal flux moorings	0	0	0	2	5	8	11	11	29
Cost	0	0	0.0	0.5	1.0	1.5	2.0	2.0	
Flux on ships of opportunity	7	7	7	8	8	12	12	12	21
Cost	1.3	1.3	1.3	1.5	1.5	1.8	2.1	2.1	
Research flux on moorings	0	0	0	0	0	0	0	0	0

Cost	0	0	0.0	0.0	0.0	0.0	0.0	0.0	
Transition research flux moorings to operations	2	2	2	2	2	2	2	2	0
Cost	0.3	0.3	0.3	0.3	0.4	0.4	0.4	0.4	
Satellite data, ocean color	0	0	0	0	0	0	0	0	x
Cost	0	0	0.0	0.0	0.0	0.0	0.0	0.0	
Data management	x	x	x	x	x	x	x	x	x
Cost	0.2	0.5	0.5	0.8	1.2	1.4	1.8	1.8	
Technology development				x	x	x	x	x	x
Cost	0	0	0.0	0.5	0.5	0.5	0.5	0.5	
Federal FTEs	6	6	6	7	8	8	8	8	
Cost									
non-Federal FTEs	2	6	6	10	14	20	26	26	
Cost									
Total	**2.9**	**4.0**	**4.0**	**6.1**	**8.1**	**10.1**	**12.1**	**12.1**	
% complete	**24**	**33**	**33**	**50**	**67**	**83**	**100**	**100**	
Capacity (Data and Assimilation Sub-Systems)									
Data set development (COSP NODC/NCDC 346K)					x	x	x	x	x
Cost	0.3	0.3	0.3	0.4	0.8	1.5	2.0	2.0	
World Ocean Database				x	x	x	x	x	x
Cost	0	0	0.0	0.3	0.6	0.8	1.1	1.1	
Standards and protocols			x	x	x	x	x	x	x
Cost	0	0	0.0	0.4	0.4	0.5	0.5	0.5	
Systems interoperabiity	x	x	x	x	x	x	x	x	x
Cost	0.1	0.5	0.5	0.5	0.5	0.6	0.6	0.6	
Transition research interoperability to operations									0
Cost	0	0	0.0	0.0	0.0	0.0	0.0	0.0	
Automated monitoring tools	x	x	x	x	x	x	x	x	x
Cost	0.3	0.5	0.5	0.5	0.5	0.6	0.6	0.6	
IPRC server (.5 IPRC, .2 global, .1 data interoperability									x
Cost	0	0	0.0	0.0	0.0	0.0	0.0	0.0	
GODAE pilot activities (JIMO)	x	x	x	x	x	x	x	x	x
Cost	0	0	0.0	0.0	0.0	0.0	0.0	0.0	
Operationalize GODAE pilot activities	x	x	x	x	x	x	x	x	x
Cost	0.3	0.3	0.3	2.3	2.3	2.3	2.3	2.3	
Global initialization for S-I forecasting (COSP)	x								x
Cost (0.5 to NCEP)	0.5	0	0.0	0.0	0.0	0.0	0.0	0.0	
Experimental decadal forecasting (COSP)	x								x
Cost (212 to GFDL)	0.2	0	0.0	0.0	0.0	0.0	0.0	0.0	
Altimetry (COSP 240 K)				x	x	x	x	x	x
Cost	0.2	0.2	0.2	0.4	0.4	0.8	1.0	1.0	
Monitor ocean heat uptake				x	x	x	x	x	x
Cost	0	0.7	0.7	0.9	0.9	1.1	1.3	1.3	
Monitor thermohaline circulation				x	x	x	x	x	x
Cost	0	0	0.0	0.2	0.2	0.4	0.6	0.6	
Monitor carbon sources and sinks		x	x	x	x	x	x	x	x
Cost	0	0.2	0.2	0.3	0.3	0.5	0.5	0.5	
Argos data processing - Drifting Buoy Arrays	x	x	x	x	x	x	x	x	x
Cost	0.6	1.0	1.0	1.0	1.0	1.1	1.1	1.1	
Argos data processing - Tropical Moored Buoy network	x	x	x	x	x	x	x	x	x
Cost	0.1	0.1	0.1	0.2	0.2	0.3	0.3	0.3	
Argos data processing - Ocean Reference Stations	x	x	x	x	x	x	x	x	x
Cost	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.2	
Federal FTEs	4	4	4	6	8	8	8	8	
Cost									
non-Federal FTEs	9	12	12	20	25	30	36	36	
Cost									
Total	**2.7**	**3.9**	**3.9**	**7.5**	**8.2**	**10.6**	**12.1**	**12.1**	
% complete	**22**	**32**	**32**	**62**	**68**	**88**	**100**	**100**	
Capacity (Management and Product Delivery)									
System monitoring	x	x	x	x	x	x	x	x	x
Cost	0.1	0.2	0.2	0.3	0.3	0.3	0.5	0.5	
System evaluation	x	x	x	x	x	x	x	x	x
Cost	0.3	0.4	0.4	0.5	0.5	0.5	0.5	0.5	

SST	x	x	x	x	x	x	x	x	x
Cost	0.1	0.1	0.1	0.2	0.2	0.4	0.5	0.5	
Sea level change		x	x	x	x	x	x	x	x
Cost	0	0.4	0.4	0.4	0.4	0.5	0.5	0.5	
Carbon sources and sinks									x
Cost	0	0.3	0.3	0.4	0.4	0.5	0.5	0.5	
Ocean storage, transport, heat and water		x	x	x	x	x	x	x	x
Cost	0	0.4	0.4	0.4	0.4	0.5	0.5	0.5	
Air-sea flux, heat, water	x	x	x	x	x	x	x	x	x
Cost	0.2	0.2	0.2	0.3	0.3	0.5	0.5	0.5	
Seasonal forecasting		x	x	x	x	x	x	x	x
Cost	0	0.1	0.1	0.2	0.2	0.2	0.5	0.5	
Decadal forecasting		x	x	x	x	x	x	x	x
Cost	0	0.2	0.2	0.2	0.3	0.4	0.5	0.5	
Climate change				x	x	x	x	x	x
Cost	0	0	0.0	0.2	0.2	0.4	0.5	0.5	
Transition SST evaluaton from research to operations									0
Cost	0	0	0.0	0.0	0.0	0.0	0.0	0.0	
Management -- workshops and science meetings	x	x	x	x	x	x	x	x	x
Cost	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.2	
Management -- administration and finance	x	x	x	x	x	x	x	x	x
Cost	0.3	0.4	0.4	0.5	0.5	0.5	0.5	0.5	
Improved Predictions PACS-GAPP (old PACS $)	x	x	x	x	x	x	x	x	x
Cost	1	1	1.0	1.0	1.0	1.0	1.0	1.0	
Annual Report	x	x	x	x	x	x	x	x	x
Cost	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.2	
International science and implemenation panels	x	x	x	x	x	x	x	x	x
Cost	0.3	0.4	0.4	0.9	1.0	1.0	1.0	1.0	
International panels, transition funding from research to ops									0
Cost	0	0	0.0	0.0	0.0	0.0	0.0	0.0	
Capacity building				x	x	x	x	x	x
Cost	0	0	0.0	0.3	0.3	0.5	1.0	1.0	
External review panel expenses				x	x	x	x	x	x
Cost	0	0	0.0	0.1	0.1	0.1	0.1	0.1	
Action -- system manager's contingency fund		x	x	x	x	x	x	x	x
Cost	0	0.2	0.2	0.3	0.4	0.5	0.5	0.5	
Federal FTEs	5	10	10	12	13	14	15	15	
Cost									
non-Federal FTEs	4	8	8	10	11	14	16	16	
Cost									
Total	**2.5**	**4.5**	**4.5**	**6.5**	**6.9**	**8.2**	**9.5**	**9.5**	
% complete	**26**	**47**	**47**	**68**	**73**	**86**	**100**	**100**	
Capacity (Dedicated Ship Time) days at sea									
Carbon and deep ocean surveys	70	70	70	70	70	70	70	70	240
Cost	[1.9]	[1.9]							
Coastal, Flux maps and deep ocean surveys	0	0	0	20	20	40	40	40	240
Cost	0	0	0.0	0.4	0.4	0.9	0.9	0.9	
Ka'imimoana	244	244	244	244	244	244	244	244	276
Cost	[5.2]	[5.2]	[5.2]	[5.2]	[5.2]	[5.2]	[5.2]	[5.2]	
TAO/TRITON	35	35	35	35	35	35	35	35	90
Cost	[1.4]	[1.4]				0.9	0.9	0.9	
PIRATA	0	34	34	34	34	34	34	34	124
Cost	0.1	0.6	0.6	0.6	0.6	0.6	0.6	0.6	
Reference Stations	47	47	47	47	57	57	57	57	480
Cost	[1.0]	[1.0]	0.0	0.0	0.6	1.3	1.3	1.3	
Deployment of drifting arrays	0	10	10	60	60	120	120	120	100
Cost	0.0	0.5	0.5	1.3	1.3	2.6	2.6	2.6	
Thermohaline Circulation Monitoring	26	26	26	90	90	170	170	170	340
Cost	0.0	0.0	0.0	0.0	1.0	2.0	4.4	4.4	
Process Research			56	230	230	230	230	230	
Cost									

Arctic Hydrographic Sections	0	0	0	60	60	60	60	60	120
Cost	0.0	0.0	0.0	1.3	1.3	1.3	1.3	1.3	
Federal FTEs (Ship time)	63	63	63	64	67	67	67	67	
Cost									
non-Federal FTEs				2	2	2	2	2	
Cost									
Total	**0.1**	**1.1**	**1.1**	**3.6**	**5.2**	**9.6**	**12.0**	**12.0**	
% complete	**1**	**9**	**9**	**30**	**44**	**80**	**100**	**100**	
Total ship days:	422	466	466	660	670	830	830	830	
Capacity (Integrated Arctic Ocean Observing System)									
Arctic Ocean pathway moorings	0	0	0	1	3	8	8	8	12
Cost	0	0	0.0	0.7	1.5	2.0	4.0	4.0	
Arctic Ice Mass and (in '07) Upper Ocean drifters	3	3	3	3	5	6	8	8	12
Cost	0.3	0.3	0.3	0.5	2.5	3.0	4.0	4.0	
Arctic Ocean gateway mooring sets (ASOF)	1	1	1	2	3	4	4	4	8
Cost	0.2	0.2	0.2	0.6	0.9	1.2	1.2	1.2	
Arctic Ocean automated drifting stations	0	0	0	1	2	3	3	3	3
Cost	0	0	0.0	0.8	1.6	2.4	2.4	2.4	
Ice buoys (IABP)	10	14	14	20	20	20	20	20	40
Cost	0.2	0.2	0.2	0.3	0.3	0.3	0.3	0.3	
Arctic Ocean hydrographic sections	0	0	0	1	2	4	6	6	12
Cost	0	0	0.0	1.0	2.0	4.0	6.0	6.0	
Bering Sea hydrographic sections	1	0	0	1	2	3	4	4	4
Cost	0.7	0	0.0	0.4	0.8	1.2	1.6	1.6	
Bering Sea biophysical moorings	1	1	1	1	4	4	6	6	6
Cost	0.3	0.3	0.3	0.3	0.6	0.6	0.9	0.9	
Deep western boundary current section	0	0	0	0	1	1	1	1	1
Cost	0	0	0.0	0.0	0.5	0.5	0.5	0.5	
Deep western boundary current moorings	0	0	0	0	3	4	4	4	4
Cost	0	0	0.0	0.0	0.4	0.5	0.5	0.5	
Retrospective data sets rescued/created	1	1	1	2	3	3	3	3	6
Cost	0.2	0.2	0.2	0.5	0.3	0.3	0.3	0.3	
Arctic Research Program Management									1
Cost	0.2	0.2	0.2	0.5	0.5	0.5	0.5	0.5	
Data analysis and assimilation									4
Cost	0	0	0	0.8	1.6	2.1	2.1	2.1	
Federal FTEs	1	1	1	2	2	2	2	2	
Cost									
non-Federal FTEs	12	12	12	20	28	36	41	41	
Cost									
Total	**2.1**	**1.4**	**1.4**	**6.4**	**13.5**	**18.6**	**24.3**	**24.3**	
% complete	**9**	**6**	**6**	**26**	**56**	**77**	**100**	**100**	
Capacity (Satellites)									
Real time data transmission									
Cost									
Sea surface temperature									
Cost									
Sea surface height									
Cost									
Surface vector wind									
Cost									
Total									
% complete									
Capacity (Facilities)									
Lab									
Cost									
Machine shop									
Cost									
Warehouse									
Cost									
Data assembly									
Cost									

Data archive									
Cost									
Office space for 75 shore-based FTEs									
Cost									
Operations center for system monitoring, evaluation, international coordination, and management		x	x	x	x	x	x	x	
Cost		0	0.0	0.0	6.0	0.0	0.0	0.0	
Total	**0.0**	**0.0**	**0.0**	**0.0**	**6.0**	**0.0**	**0.0**	**0.0**	
% complete									
Capacity (Aircraft)									
Arctic buoy deployment - flight hours	0	0	0	176	176	176	176	176	
Cost	0.0	0.0	0.0	0.2	0.2	0.2	0.2	0.2	
Total	**0.0**	**0.0**	**0.0**	**0.2**	**0.2**	**0.2**	**0.2**	**0.2**	
% complete									
Capacity (HR Support)									
Cost									
Total									
% complete									
Capacity (Institutional Overhead)									
Climate Office support	0.8	2.2	2.2	3.2	4.3	5.5	6.6	6.6	
OCO personnel & space	0.8	0.8	0.8	0.8	0.9	0.9	1.0	1.0	
AOML personnel,space	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	
PMEL personnel,space	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	
Other (get to 6.6 CLIVAR)	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
Subtotal	**5.6**	**6.2**	**6.2**	**7.2**	**8.4**	**9.6**	**10.8**	**10.8**	
GRAND TOTAL	**40.7**	**50.4**	**53.6**	**76.0**	**101.3**	**120.8**	**141.1**	**141.1**	
TOTAL Federal FTEs	**100**	**106**	**106**	**115**	**122**	**123**	**124**	**124**	
TOTAL non-Federal FTEs	**69**	**86**	**92**	**123**	**147**	**175**	**199**	**199**	
% complete - by dollars spent	29	36	38	54	72	86	100	100	
*All FTE costs are already included in displayed project costs									
**All spreadsheet figures represent the NOAA contribution toward the international goal shown in column N									

APPENDIX C

Professional Development and Community Service by Scientists Funded by The Office of Climate Observation

Professional Development and Community Service by Scientists funded by the Office of Climate Observation

Community Service (e.g., appointments to science and implementation panels)

Molly Baringer (NOAA/AOML)
AGU Ocean Science Secretary, 2002-present; Member NOAA/OAR ship time procurement procedure review panel; Associate Member IAPSO/SCOR Working Group 121 on Ocean Mixing.

Nicholas Bates (BBSR)
International Advisory Member of the European Carbo Ocean project.

Mark Bourassa (FSU)
NASA Ocean Vector Winds Science Team; NASA/OSU QuikSCAT mission; Next Vector Winds Mission Science Working Group; AMS Committee on Interaction of the Sea and Atmosphere.

John Bullister (NOAA/PMEL)
Served on WOCE Data Products committee.

Francisco Chavez (MBARI)
Member of NSF Geosciences Advisory committee (2003-2005); Member NSF Alan T. Waterman award committee (2003-2005); Member Advisory Board of the Instituto del Mar del Peru (IMARPE), the Peruvian fisheries and oceanography institute (2003-); Member Board of Directors of the Center for Integrated Marine Technologies (2002-); Member Board of Governors of Pacific Coastal Observing System (2003-); Member Science Team Global Ocean Timeseries (2002-); Member COCOA (Hyperspectral satellite coastal color imager) Science Team (2003-); Taught course on Coupled physical-biological and biogeochemical time series and advanced technologies at Universidad de Concepcion, Concepcion, Chile, January 20-24, 2003; Taught course on Coupled physical-biological and biogeochemical time series and advanced technologies at Instituto del Mar del Peru in Lima, Peru, January 27, 2003.

Steven K. Cook (NOAA/AOML)
WMO/IOC Ship Observations Team, Chairman – Ship of Opportunity Implementation Panel, Convener - Task Team on VOS Recruitment and Program Promotion; Task Team on VOS Automated Systems; Expert Group on Instrument Testing; WMO/IOC Data Buoy Cooperation Panel.

Bruce Cornuelle (SIO)
Serves on US GODAE SSC.

Meghan Cronin (NOAA/PMEL)
Co-organizer of "KESS and Beyond" science meeting at JAMSTEC, Yokohama, Japan, 5 June 2004; co-chair of U.S. CLIVAR PanAm panel; co-chair "Surface Fluxes" session at AMS 13th Conference on Interaction of the Sea and Atmosphere; co-organizer of NOAA PMEL colloquium series "Developing a North Pacific Observing System"; committee chair (advisor) for R. Wade, M.Sc. granted June 2004, University of Washington.

Yeun-Ho Chong Daneshzadeh (NOAA/AOML)
Global Temperature Salinity Profile Program committee.
Richard Feely (NOAA/PMEL)

Co-chair Repeat Hydrography CO_2/tracer Program Oversight Committee; Co-chair of NOAA Carbon Steering Committee; Member of International Ocean Carbon Coordination Project; Member of International Pacific CLIVAR Panel; Member of Carbon Cycle Science Program Science Steering Group; Team Member of the European CarboOcean; Member of PICES Working Group 17: Biogeochemical Data Integration and Synthesis; Member of U.S. SOLAS Steering Committee.

Silvia Garzoli (NOAA/AOML)
NOAA Experts Team to provide input to the interagency process developing a US Plan of Earth Observations; CLIVAR South Atlantic, Member of the Science Committee; GP Climate Goal 2 working group for Climate.

Gustavo Goni (NOAA/AOML)
NASA Ocean Surface Topography, Member of Science Team; NASA Panel Review for New Investigator Program in Earth Science.

Ed Harrison (NOAA/PMEL)
Chair, Ocean Observations Panel for Climate; Chair, OAR Climate Observing System Council; Co-Chair, US GODAE ST; US GOOS SC; Atmospheric Observation Panel for Climate; WCRP Working Group on Observations and Analysis; CLIVAR Global Synthesis and Observations Project; JCOMM Management Committee; Senior Fellow, JISAO; Senior Fellow, JIMAR.

Gregory Johnson (NOAA/PMEL)
Member, U.S. CLIVAR/CO_2 Repeat Hydrography Oversight Committee; Associate Editor, 2000, Journal of Physical Oceanography.

Michael McPhaden (NOAA/PMEL)
President of the Ocean Sciences Section of the American Geophysical Union (2 years); serves on the International CLIVAR Pacific; charter member of the new CLIVAR Global Synthesis and Observations Panel (GSOP) Panel and the CLIVAR GOOS Indian Ocean Panel (IOP); member of the JCOMM Observations Coordination Group; chairs the Tropical Moored Buoy Implementation Panel (TIP) which is an action group of the Data Buoy Cooperation Panel (DBCP); member of the OOPC/CLIVAR OceanSITES Working Group; member of the Bulletin of the American Meteorological Society editorial board.

Art Miller (SIO)
Member of U.S. CLIVAR Pacific Sector Implementation Panel; Member of U.S. GLOBEC Scientific Steering Committee.

Frank Millero (RSMAS/MAC)
Committees - Oversight Committee for the Repeat Hydrography Program (CLIVAR, CO_2/SCC) 2002-2004; Clair C. Patterson Award Committee, 2004; ACS Geochemistry Division Medal Committee, 2004; Sigma Xi, President-Elect, 2004-2006; AMLC Executive Board, 2004.

Mayra Pazos (NOAA/AOML)
WMO/IOC Data Buoy Cooperation Panel.

Ignatius Rigor (UW)
Coordinator of the International Arctic Buoy Programme (IABP); Member of National Aeronautics and Space Administration (NASA) Oceans and Ice Proposal Review Panel.

Dean Roemmich (SIO)
Serves on the U.S. CLIVAR Science Steering Committee, the international CLIVAR Global Synthesis and Observations Panel (GSOP), the JCOMM Observations Coordination Group, and the JCOMM Ship Observations Team's Ship of Opportunity Implementation Panel (SOOPIP).

Daniel Rudnick (SIO)
Co-chair of the CLIVAR Pacific Implementation Panel (PIP); Co-chair of the Autonomous and Lagrangian Platforms and Sensors (ALPS) workshop.

Christopher Sabine (NOAA/PMEL)
CARbon dioxide IN the Atlantic (CARINA); IGBP Integrated Global Carbon Observing (IGCO) theme team; US CLIVAR Southern Ocean panel; Member of International CLIVAR/CLIC Southern Ocean panel; Scientific Steering Committee member for IGBP/IHDP/WCRP Global Carbon Project; Working Group for the Implementation of the North American Carbon Program (NACP); Member of PICES Working Group 17: Biogeochemical Data Integration and Synthesis; Working Group for the Implementation of Ocean Carbon and Climate Change (OCCC) Program; Lead author for IPCC Special Report on carbon dioxide capture and storage.

Raymond Schmitt (WHOI)
Served on the Ocean Observing System Development Panel; served on CLIVAR International SSG; presently serves on the CLIVAR mixing process team; serves on the Editorial Board of Dynamics of Atmospheres and Oceans; recently served as a panel member for the NASA Oceans and Ice Review Panel, Aug. 30 – Sept 3, 2004.

Shawn Smith (FSU)
Ocean.US IOOS Expert Team on Archival and Access; WCRP Working Group on Surface Fluxes; Provide Pacific FSU wind fields each month for publication in the NOAA/CDC Climate Diagnostics Bulletin.

Taro Takahashi (LDEO)
Hosted a VOS/NOAA meeting held in September 2003 at the Lamont-Doherty Earth Observatory, NY; Participated in an advisory meeting on the NASA Suborbital Science Program, July 2004, held in Washington, D. C.

Rik Wanninkhof (NOAA/AOML)
NOAA carbon Steering Group; NOAA ocean CO_2 synthesis team; SOLAS implementation group 2 member; SOLAS implementation team 2, data liaison; SOLAS summer school organizing committee; Liege Colloquium Series on fluid dynamic: air-sea gas transfer- Science committee; Guest editor, special section JGR air-sea gas exchange; Opponent Ph.D. thesis of Abdirahman Oman, U. Bergen, Norway; Participant Cooperative Sensor Development Laboratory for Oceans of the University of South Florida; South Florida Meeting of CO_2 instrument development collaboration; Reviewer of the chemical oceanography program of the University of Concepcion, Chili; Partner in the European Union Carbon-Ocean Project.

Robert Weller (WHOI)
Provided preliminary design feasibility assessment of placing surface moorings in the Kuroshio Extension region to Meghan Cronin, PMEL; AGU, OS Section Executive Committee, Chair OS Section Awards Committee; Member, AGU-ALSO joint committee for Ocean Sciences meetings; Member, International CLIVAR SSG
Member, International CLIVAR Pacific Implementation Panel; Member CLIVAR VAMOS EPIC Science Team; Chair, CLIVAR VOCALS (VAMOS Ocean Cloud Atmosphere Land Study)

Science Team; Co-chair, U. S. CLIVAR Science Steering Committee; Member, UNESCO/IOC Ocean Observations Panel for Climate (OOPC); Member, UNESCO/WMO GOOS Capacity Building Panel; Member, NRC Environmental Satellite Data Utilization Committee, 2002-2004; Member, NRC Committee on Strategic Guidance to NSF Atmospheric Sciences Division, starting 2004

ORION (Ocean Research Interactive Observatories Network) Executive Steering Committee; NOAA: Climate Observing System Council, Climate Council

Co-chair, International Time Series Science Team; CCSP Interim Ocean Carbon Implementation Group, 2002-2004; Chair of the NOAA Joint Institute Directors, July 2003-July 2004; Member, NOAA Senior Research Council, starting July 2003.

List of conferences/workshops presented at/attended

Frank Bahr (WHOI)
Climate Observation Program Workshop in Silver Spring, MD – April 2004; data conference.

Molly Baringer (NOAA/AOML)
CLIVAR-North Atlantic Thermohaline Circulation Variability Workshop, Kiel, Germany, September 2004; AGU Program committee meeting, September 2004, Washington, D.C.; Invited talk, What is the potential of different types of observation systems for detecting/monitoring MOC changes?; OCO Annual Review, April 2004, Silver Spring, Maryland; Aquarius/SAC-D-SMOS-HYDROS Joint Science Workshop on Salinity and Soil Moisture Remote Sensing, April 2004, Miami, FL.

Nicholas Bates (BBSR)
Meetings: Invited talk at IOS, Victoria, BC (December 2003); Invited talks at Univ. Rhode Island (March 2004).

Mark Bourassa (FSU)
US CLIVAR Southern Ocean working group workshop; CLIVAR04; COAPS site review; 13th Conference on Interactions of the Sea and Atmosphere; 20th Conference on Weather Analysis and Forecasting/16th Conference on Numerical Weather Prediction; 26th Conference on Hurricanes and Tropical Meteorology; EGU 1st General Assembly
2nd High Resolution Marine Meteorology Workshop; IGARSS04; 2004 Joint Assembly.

John Bullister (NOAA/PMEL)
First International CLIVAR Science Conference: Decadal changes along 20°W in the North Atlantic.

Francisco Chavez (MBARI)
Represented Central California at a meeting to Establish a National Federation of Ocean Observing Systems, Washington, DC March 31-April 1, 2003; Represented the U.S. at the Tenth Session of the Joint IOC-WMO-CPPS Working Group on the Investigations of “El Niño” and Meeting for Establishing the GOOS Regional Alliance for the Southeast Pacific (GRASP); Presented Seminar “From anchovies to sardines and back-Multidecadal change in the Pacific Ocean” at Food and Agriculture Organization in Rome on September 17, 2003; Invited speaker at Chapman conference on “The Role of Diatom Production and Si Flux and Burial in the Regulation of Global Cycles”, Paroikia, Paros, Greece, 22-26 September 2003; “What limits diatom production in the High Nitrate Low Chlorophyll regions of the Pacific Ocean?”; Invited panelist at "Marine Biodiversity In the Past: The Known, Unknown, and Unknowable", Scripps, November 15-17; Keynote presentation at conference series Classroom Exploration of the Oceans, December 15-19, ”El Niño/La Niña”; Participant in ORION meeting and Moderator for Global Biogeochemical Cycles group in San Juan, Puerto Rico, January 4-8, 2004; Participant in Steering Committee meeting for OCEAN-SITES: A global network of timeseries stations, San Juan, Puerto Rico, January 5-9, 2004; Delivered plenary talk “A constant sea of change: The biological response to climate variability” at AGU Ocean Sciences. Portland, Oregon January 26, 2004; Steering Committee (with Hal Mooney, Margaret Palmer, William Schlesinger. Al Lucier) for Interagency Climate Change Science Plan Ecosystem Workshop, Washington, DC, February 22-24; Led the development of Science Committee for Central and Northern California Ocean Observing System (CeNCOOS); Participated in NSF Alan Waterman award committee meeting in Washington, DC, March 11, 2004; Delivered invited presentation “Biological consequences of interannual to multidecadal variability” at Scripps Spring Marine Biology Seminar Series, April

9, 2004; Participant in NASA's Ocean Color Research Team Meeting in Washington, D.C., 14-16 April 2004; Participant in NSF Geosciences Advisory committee meeting in Washington, DC, April 27-30, 2004; Participant as member of Board of Governors in Pacific Coastal Observing System (PaCOS) meeting, Scripps, May 17-18, 2004; Participant in North Pacific Carbon workshop in Seattle, WA on June 4-6. Delivered invited presentation on “Biogeochmical consequences on interannual to multidecadal climate variability”; Presented talk on “Autonomous measurements of carbon dioxide” at MBARI Day of Science and Technology; Traveled to Lima, Peru on July 2-8 to deliver autonomous systems for measurement of pCO_2 to Peruvian fisheries and oceanography institute; Participated in workshop on hyperspectral remote sensing of US coastal waters in NASA/JPL on September 15-16; Participant in International Council for Exploration of the Seas (ICES) meeting in Vigo, Spain and delivered invited talk “Evidence for Regime Shifts in the Pacific Ocean” on September 23; presented at Instituto de Investigaciones Marinas “De Peru a California y de regreso: mi facinacion con las areas de afloramiento” on September 22.

Steven K. Cook
High Resolution Marine Meteorology Workshop; NWS/Port Meteorological Officer Conference; OCO Annual review.

Bruce Cornuelle, Detlef Stammer, Art Miller (SIO)
Presentation at the ECCO meeting, MIT, Boston, August 2004; Poster at CLIVAR meeting, Baltimore, June 2004; Workshop on Climate Variability in the 20th Century ICTP, Trieste, Italy April 2004; Technical Workshop on Regional Modeling for the Southeastern Pacific CIIFEN, Guayaquil, Ecuador, June 2004; Presentation at 36th International Liège Colloquium on Ocean Dynamics, Liège, May 2004; Presentation at 1st EGU General Assembly, Nice, April 2004.

Meghan Cronin (NOAA/PMEL)
“KESS and Beyond” science meeting at JAMSTEC, Yokohama, Japan (co-organizer), 5 June 2004; AMS annual meeting, Seattle WA, 14 Jan 2004; Ocean Sciences meeting, Portland OR, 28-30 January 2004; U.S. CLIVAR PanAmerican Panel meeting, Baltimore, MD, 20-21 June 2004; CLIVAR2004 Conference, Baltimore, MD, 21-25 June 2004; AMS 13th conference on interactions of the Sea and Atmosphere, 9-10 Aug 2004.

Yeun-Ho Chong Daneshzadeh
GTSPP meeting, Southampton, England.

Craig Engler (NOAA/AOML)
ONR/MTS Buoy Workshop.

Chris Fairall (NOAA/ETL)
25th Session of the Joint Scientific Committee for the WCP, World Climate Research Program, Moscow, Russia, 1-6 March 2004; Presentation: The WCRP Working Group on Surface Fluxes; Seventh Annual Meeting of the WCRP/CLIVAR VAMOS Panel, NOAA-OGP, Guyaquil, Ecuador, 22-25, March, 2004; Office of Climate Observation Annual System Review, NOAA, Silver Spring MD, 13-15 April 2004; Poster presented: Cloud forcing of the surface energy budget of the ITCZ/Cold Tongue complex in the tropical Eastern Pacific; Second Workshop on High-Resolution Marine Meteorology, NOAA, Silver Spring, MD, 15-16 April, 2004; Paper presented: High-Resolution Climate Data from Research and Volunteer Observing Ships: A Strategic Intercalibration and Quality Assurance Program; Focus 2 Working Group for the International SOLAS Implementation Plan, Surface Ocean-Lower Atmosphere Study, IGBP, Montreal, Canada, 17-19 May, 2004; First International CLIVAR Scientific Conference, WCRP,

21-25 June, 2004; Posters given: 1) Cloud forcing of the surface energy budget of the ITCZ/Cold Tongue complex in the tropical Eastern Pacific, 2) Investigation of air-sea interaction and cloud processes in the EPIC stratocumulus region.

Richard Feely (NOAA/PMEL)
NOAA Carbon Steering Group Meeting, November 2003; AGU San Francisco and Town Hall Meeting of OAR Review Team, December 2003; IOCCP/PICES/NIES Workshop on Ocean Surface pCO_2, Data Integration and Database Development in Tsukuba, Japan, January 14-17, 2004; Center of Ocean Technology Meeting, St. Petersburg, FL, March 11-12, 2004; Office of Climate Observation Annual Review, Silver Spring, MD, April 13-15, 2004; Oceans in a High CO_2 World Meeting, Paris France, May 10-12, 2004; Ocean Dialogues, University of Washington, March 19, 2004; NOAA Carbon Science Team Meeting, Boulder, CO, May 25, 2005; North Pacific Carbon Cycle Workshop, Seattle, WA, June 2-4, 2004; AAAS/NOAA Press Conference, Washington DC, July 15, 2004; Mediterranean Conference on Chemistry of Aquatic Systems in Reggio Calabria, Italy, September 4-8, 2004. Testimony on impacts of Anthropogenic CO_2 in the Oceans before the Senate Commerce Committee, September 21, 2004.

Silvia Garzoli (NOAA/AOML)
OCO Annual review; CLIVAR-North Atlantic Thermohaline Circulation Variability Workshop, Kiel, Germany, September 2004.

Gustavo Goni (NOAA/AOML)
EGU 2005 Meeting, Nice, France, April 2004; Tropical Atlantic Workshop, Utrecht, The Netherlands, June 2004; IEEE's IGARSS Meeting, Anchorage, September 2004.

Ed Harrison (NOAA/PMEL)
JCOMM GLOSS-8, October 2003; US GOOS, SC November 2003; US GOOS work group December 2003; POGO-5 November 2003; NRC Climate Data Records, December 2003; GCOS 2AR IP, January 2004; GOOS COOP-6, January 2004; WCRP JSC25 Moscow, March 2004; GCOS SC, March 2004; JCOMM MAN-3, March 2004; OCO COSC, April 2004; AOPC, April 2004; GOOS SC, April 2004; JCOMM OceanOPS04, May 2004; US GOOS SC, May 2004; OOPC SOC, June 2004; CLIVAR SSG, June 2004; GCOS 2AR IP-Chairs, July 2004; Intl GODAE ST-9, July 2004; GCOS 2AR IP, August 2004; US IOOS Implementation, September 2004; US GODAE ST, September 2004; SCOR Coordination, September 2004; SCOR General Meeting, September 2004.

Dave Hosom (WHOI)
Climate Observation Program Workshop in Silver Spring, MD – April 2004; data conference.

Elizabeth Johns (NOAA/AOML)
SEACOOS meeting, Miami, FL, May 2004

Gregory Johnson (NOAA/PMEL)
Argo Data Management Meeting, November 2003, Monterey, California; First Argo Science Workshop, November 2003, Tokyo, Japan; 2004 Ocean Science Meeting, January 2004, Portland, Oregon; NOPP 2003 Excellence in Partnering Award for the Argo Program, February 2004, Washington DC; OCO Annual Review, April 2004, Silver Spring, Maryland; 2004 Eastern Pacific Ocean Conference, September 2004, Victoria, Canada.

Rick Lumpkin (NOAA/AOML)

ONR/MTS Buoy Workshop, Aquarius/SAC-D-SMOS-HYDROS Joint Science Workshop; OCO Annual Workshop; EGU First General Assembly, Nice, France, 25-30 April 2004 (presentation); DBCP meeting, October 16-19, Chennai, India: “Global Drifter Program”.

Nikolai Maximenko (UH)
GODAE International Workshop, St. Petersburg, FL, November 2004: “The dynamics of ocean surface circulation studied using altimeter, Lagrangian drifter and wind data”.

Michael McPhaden (NOAA/PMEL)
Participated in the Fall 2003 AGU meeting (San Francisco, December 2003) and Spring 2004 AGU meeting (Montreal, Canada, May 2004), the inaugural IOP meeting (Pune, India, February 2004); the NOAA Climate Observation Workshop (April 2004, Washington, DC); the High-Resolution Marine Meteorology meeting (April 2004, Washington, DC); and the CLIVAR SSG-13 meeting (Baltimore, MD, June 2004); Awarded Presidential Rank Award for Meritorious Federal Service; participated in the Change of Command Ceremony for the NOAA Ship Ka’imimoana (Honolulu, August 2004).

Christopher Meinen (NOAA/AOML)
SEACOOS meeting, Miami, FL, May 2004; 2004 Ocean Sciences Meeting, Portland, OR, January 2004.

Mark Merrifield and UHSLC personnel
IUGG, Sapporo, Japan, July 2003, paper on decadal sea level in the Pacific; GLOSS Group of Experts meeting, Paris, October 2003, presentation on importance of real-time data reporting; Annual American Meteorological Society Meeting, January 2004, presented two papers, one on data portals and another showing some sea level trends in the Pacific; 1st CLIVAR Planning Meeting on Ocean Observations, March 2004, presentations on in situ sea level observations and data management and distribution, and report on the UHSLC CLIVAR in situ sea level DAC; Federal Hazard Mitigation Partners in the Pacific Islands, Honolulu, March, co-chaired a working group on ocean observatories; Climate Observation Program Workshop, Silver Spring, April 2004, poster presented on activities of the UHSLC; India-US Climate Change Science Workshop, Delhi, July 2004, (UHSLC personnel); Served on the GOES working group, Seattle, August 2004 (UHSLC personnel); Pacific Data Management Meeting, September 2004, (UHSLC personnel), presented several papers on the state of sea level in the Pacific Ocean region; The UHSLC director was selected for a term as the GLOSS chair, and center personnel also serve on the GLOSS Scientific Steering Committee; UHSLC personnel serve on the National Oceanographic Partnership Program Ocean.US Applications and Products Expert Team (see Hankin et al., 2004 for a recent report on their activities).

Laury Miller (NOAA/NESDIS)
Oral/Poster Presentations (some with co-authors)
“Improved ERS and ENVISAT Precise Orbit Determination”, ENVISAT Symposium, Salzburg, Sept., 2004; Sea Ice Elevation from Laser Altimetry using ICESat/GLAS, Arctic Climate System Study (ACSYS) Final Science Conference, St. Petersburg, Russia, November, 2003; "The Correspondence of Altimetric Gravity Texture to Abyssal Hill Morphology", AGU Fall Mtg, 2003; “Improving Ocean Analyses and ENSO Forecasts at NOAA Using the Global Ocean Data Assimilation System and Altimetric Sea Level”, ENVISAT Symposium, Salzburg, Sept., 2004; “Rain and Ice Flagging of ENVISAT Altimeter and MWR Data”, ENVISAT Symposium, Salzburg, Sept., 2004; “Satellite Monitoring of Tropical Pacific Ocean Temperatures, Currents and Color During the 1998 El Nino”, Third GOES-R Users Conference, Broomfield, Colorado, May 2004; High Accuracy Gravimetric Geoid for Arctic Research (HAGGAR) From GRACE,

Airborne, and Surface Data, GRACE Science Team Mtg, Univ. of Texas Center for Space Research, October, 2003; "Arctic Ocean Geoids From GRACE and Surface Gravity Data: Comparisons With Altimetric Sea Surface Topography", Spring AGU, Montreal, Canada; "Capturing Large-Scale Change in the Arctic Ocean and Cryosphere", Union Session of the International Polar Year 2007-2008, Spring AGU, Montreal, Canada; "Altimetric gravity and sea surface topography of the Artic Ocean: Comparisons with gravimetry", IAG GGMS, Porto, Portugal, Sept., 2004; Mass and Volume Contributions to 20th Century Global Sea Level Rise, Jason Science Working Team Mtg, Arles, France, November 2003; "Mass and Steric Contributions to 20th Century Global Sea Level Rise", Celebration of UK Sea Level Science, Royal Society, London, Feb., 2004; "Global Sea Level Rise: The Past Decade Versus the Past Century", Joint meeting of the NOAA Science Advisory Board Climate & Global Change Working Group and Climate Monitoring Working Group, Duck Key, Florida, April 2004; "Mass and Volume Contributions to 20th Century Global Sea Level Rise", ESSIC Seminar Series, University of Maryland, April 2004; "Sea Level Observing System Issues", Office of Global Programs Annual Review, Silver Spring, Maryland, April 2004; Mass and Volume Contributions to 20th Century Global Sea Level Rise, NOAA Library Brown Bag Seminar, May 2004; "Global Sea Level Rise: The Past Decade vs. the Past 100 Years, COSPAR", Paris, July 2004; "Global Sea Level Rise: A Decade of Multi-Satellite Altimeter Observations versus 100 Years of In-situ Observations", AIAA Space 2004, San Diego, Sept. 2004; "Bathymetry from Space: Geophysics, Oceanography, and Climatology", ENVISAT Symposium, Salzburg, Sept. 2004; Cross-calibration and long-term monitoring of the microwave radiometers of ERS, TOPEX, GFO, Jason and Envisat, Jason Science Working Team Mtg, Arles, France, November 2003; "Multi-Satellite Altimetric Sea Level Change: 1992-2003 What Do We Know and What Not?", EGU04, Nice, France, April 2004; "Cross-calibration and Long-term Monitoring of the Radiometers of ERS-1, TOPEX/Poseidon, ERS-2, GFO, Jason-1 and Envisat", EGU04, Nice, France, April 2004; "Non-Parametric Sea-state Bias Models and Their Relevance to Sea Level Change Studies", ENVISAT Symposium, Salzburg, Sept. 2004; Correlating the textures of altimetric gravity and multibeam bathymetry, AGU Fall Mtg, 2003; "Bathymetry for Hydrodynamic Models: Not All Bathymetry Grids Are Created Equal, and Why It Matters to Modelers", NOAA Geophysical Fluid Dynamics Laboratory, Princeton, New Jersey, May 2004; "Bathymetry From Space: Geophysical Issues", Department of Geosciences, Princeton, New Jersey, May 2004.

Frank Millero (RSMAS/MAC)
Meetings – Lecture at University of South Florida, St. Petersburg, Fl, April 2004; SAML Meeting, Galveston, TX, May 12-14, 2004; M. González-Davila, J.M. Santana-Casiano and F.J. Millero, Oxidation of iron (II) nanomolar with H_2O_2 in seawater, 13th Annual V.M. Goldschmidt Conference, Copenhagen, Denmark, June 5-11, 2004, poster session; Gordon Research Conference, Bates College, Lewiston, Maine, June 20-25, 2004; AMLC Executive Board meeting/workshops, GRENADA, July 20-25, 2004; Invited lecturer, F.J. Millero, "The thermodynamics of carbonic acid in natural waters," Mediterranean Conference on Chemistry of Aquatic Systems in Honor of Frank J. Millero, Reggio Calabria, Italy, 4-8 September 2004; Elsevier Editor's Conference, Santa Fe, NM- October 29-31, 2004; Greensboro, NC, SLOAN Conference, November 3-5, 2004.

Robert Molinari (NOAA/AOML)
OCO Annual review.

Calvin Mordy (JISAO/UW)
EPOC, September 2003, Sydney, BC; NPCREP Workshop, September 2003, Seattle, WA; NEP GLOBEC, January 2004, Portland, OR; AGU Ocean Sciences, January 2004, Portland, OR;

Marine Science in Alaska 2004 Symposium, January 2004, Anchorage, AK; ASLO Conference, February 2004, Honolulu, HI; PICES, October 2004, Republic of Korea.

Peter Niiler (SIO)
Ocean Observations for Climate "Workshop", April 2004, Silver Spring, MD; Invited Faculty Lecture, UCLA Department of Atmospheric Sciences, October 27, 2004: "The observed surface circulation of the globe: New perspectives from drifters and satellite sensors".

James O'Brien (FSU)
COAPS site review.

Observing System Monitoring Center Team
American Meteorological Society meeting, January 2004, Seattle; OCO Annual System Review, April, Silver Spring, MD.

Al Plueddemann (WHOI)
ChalkEx PI Meeting, UNH, 16 October 2003; ONR Notheast Region Site Review, 20 November 2003; Roundtable Discussion on Ocean Exploration, U-Mass Dartmouth, 13 January 2004; NE-COSEE Telling Your Story Workshop, NE-COSEE, WHOI, 22 January 2004; AGU Ocean Sciences Meeting, 26-30 January 2004; NOAA Office of Climate Observations Workshop, 12-14 April 2004; SOLAS IMP-2 Workshop, 17-19 May 2004; ChalkEx PI Meeting, UNH, 27 May 2004; First International CLIVAR Science Conference, 21-24 June 2004; Ice Tethered Profiler Workshop, 28-30 June 2004;
AMS 16th Conf. on Boundary Layers and Turbulence, 9-13 August, 2004.

Richard Reynolds (NCDC)
Presentations:
Sea Surface Temperature (SST) Analyses for Climate and Their Errors, Presented at the Second Joint WMO-IOC Technical Commission for Oceanography and Marine Meteorology (JCOMM) Workshop on Advances in Marine Climatology, Brussels, Belgium, November 17-22, 2003; GCOS SST/Sea-Ice Working Group progress, Presented at the Ninth Ocean Observations Panel for Climate Meeting, Southampton Oceanographic Centre, Southampton, United Kingdom, 7-11 June 2004; In situ SST network with a focus on buoy requirements, Presented at the Climate Observation Annual System Review, Silver Spring, MD, April 13-15, 2004; Sea Surface Temperature Analyses for Climate, Presented at the Australia's Commonwealth Scientific and Industrial Research Organisation (CSIRO), Hobart Australia, July 19, 2004.

Jackie Richter-Menge (CRREL)
Presentations (some with co-authors):
An autonomous network measuring changes in the thickness of the Arctic sea ice cover, Eos Trans. AGU, Fall Meet. Suppl., Dec. 2004; Recent Progress Towards Establishing an Arctic Ocean Observing System - A NOAA Contribution to the Study of Environmental Arctic Change (SEARCH), Eos Trans. AGU, Fall Meet. Suppl., Dec. 2004; National Oceanic and Atmospheric Administration (NOAA) Arctic Climate Change Studies: A Contribution to IPY, Eos Trans. AGU, Fall Meet. Suppl., Dec. 2004; Recent Progress Towards Establishing an Arctic Ocean Observing System, Proc. Arctic Climate Impacts Assessment (ACIA) International Symposium on Climate Change in the Arctic, Reykjavik, Nov. 2004; The NOAA Arctic Climate Change Studies: A U.S. Contribution to Arctic Council Responses to the ACIA, Proc. Arctic Climate Impacts Assessment (ACIA) International Symposium on Climate Change in the Arctic, Reykjavik, Nov. 2004.

Ignatius Rigor (UW)
Presentations (some with co-authors):
Explaining the Recent Decreases in Sea Ice on the Arctic Ocean, Eos Trans. AGU, Fall Meet. Suppl., Dec. 2004; Recent Progress Towards Establishing an Arctic Ocean Observing System - A NOAA Contribution to the Study of Environmental Arctic Change (SEARCH), Eos Trans. AGU, Fall Meet. Suppl., Dec. 2004; National Oceanic and Atmospheric Administration (NOAA) Arctic Climate Change Studies: A Contribution to IPY, Eos Trans. AGU, Fall Meet. Suppl., Dec. 2004; The International Arctic Buoy Programme (IABP) – An International Polar Year Every Year, Eos Trans. AGU, Fall Meet. Suppl., Dec. 2004; An autonomous network measuring changes in the thickness of the Arctic sea ice cover, Eos Trans. AGU, Fall Meet. Suppl., Dec. 2004; Observed Changes at the Surface of the Arctic Ocean, Eos Trans. AGU, Fall Meet. Suppl., Dec. 2004; Recent Progress Towards Establishing an Arctic Ocean Observing System, Proc. Arctic Climate Impacts Assessment (ACIA) International Symposium on Climate Change in the Arctic, Reykjavik, Nov. 2004; Variations in Arctic Sea Ice, Proc. Arctic Climate Impacts Assessment (ACIA) International Symposium on Climate Change in the Arctic, Reykjavik, Nov. 2004; The NOAA Arctic Climate Change Studies: A U.S. Contribution to Arctic Council Responses to the ACIA, Proc. Arctic Climate Impacts Assessment (ACIA) International Symposium on Climate Change in the Arctic, Reykjavik, Nov. 2004; Variations in Arctic Sea Ice, Proc. ARCUS Workshop, Washington, D.C., May 2004; Recent Progress Towards Establishing an Arctic Ocean Observing System, Proc. NOAA Ocean Climate Observing System Review, Silver Spring, MD, Apr. 2004; Climate Observing System for Arctic Ocean, Proc. Marine Science in Alaska: 2004 Symposium, Anchorage, Jan. 2004; Variations in the Age of Sea Ice and Summer Sea Ice Extent, Lamont Mini-conference, Central Arctic: Battleground of Natural and Man-Made Climate Forcing, Lamont Doherty Earth Observatory of Columbia University, New York, Jan. 2004; Predicting the Extent of Sea Ice in the Arctic, Eos Trans. AGU, 84(46), Fall Meet. Suppl., Abstract OS11B-06, Dec. 2003; The International Arctic Buoy Programme (IABP), Proc. Eos Trans. AGU, 84(46), Fall Meet. Suppl., Abstract C41C-0987, Dec. 2003; Assessing, understanding, and conveying the state of the Arctic sea ice cover, Eos Trans. AGU, 84(46), Fall Meet. Suppl., Abstract C41C-0990, Dec. 2003; Recent Progress Towards Establishing an Arctic Ocean Observing System, Proc. NOAA Ocean Climate Observing System Review, Silver Spring, MD, Apr. 2004; Assessing, understanding, and conveying the state of the Arctic sea ice cover, Eos Trans. AGU, 84 (46), Fall Meet. Suppl., Abstract C41C-0990, Dec. 2003; The National Oceanic and Atmospheric Administration (NOAA) SEARCH Initiative, SEARCH Open Science Meeting, October 2003.

Daniel Rudnick (SIO)
Fall American Geophysical Union 2004 meeting.

Christopher Sabine (NOAA/PMEL)
IOCCP/PICES/NIES Workshop on Ocean Surface pCO_2, Data Integration and Database Development in Tsukuba, Japan, January 14-17, 2004 (co-organizer and working group 1 rapporteur); MOSEAN meeting, Honolulu, HI, February 21, 2004 (invited talk on PMEL moored pCO_2 system); Center of Ocean Technology meeting, St. Petersburg, FL, March 11-12, 2004 (invited talk on PMEL moored pCO_2 system); Office of Climate Observation Annual Review, Silver Spring, MD, April 13-15, 2004 (2 posters – Moored pCO_2 program; Carbon/CLIVAR repeat hydrography program); Oceans in a High CO_2 World Meeting, Paris France, May 10-12, 2004; NOAA Carbon Science Team Meeting, Boulder, CO, May 25, 2005; North Pacific Carbon Cycle Workshop, Seattle, WA, June 2-4, 2004 (meeting organizer); MOSEAN Mooring, Honolulu, HI, July 26-28, 2004 (Stacy Maenner and I made a presentation of Hawaii group about pCO_2 moorings and mounted the pCO_2 system in the MOSEAN mooring); Mediterranean Conference on Chemistry of Aquatic Systems in Reggio Calabria, Italy, September 4-8, 2004.

William Scuba (SIO)
DBCP meeting, October 16-19, Chennai, India: " Hurricane Drifter Deployment Results".

Raymond Schmitt (WHOI)
Salinity and Soil Moisture Remote Sensing Workshop, April 20-22, 2004, Miami, FL. Board of Atmospheric Sciences, National Academy of Sciences Summer Workshop, July 12-13, 2004, Woods Hole, MA.

Shawn Smith (FSU)
84th AMS Annual Meeting; 150th Anniversary of the Brussels Maritime Conference of 1853; CLIMAR-II, Second JCOMM Workshop on Advances in Marine Climatology
Climate Prediction Applications Science Workshop; 1st CLIVAR Data Planning Meeting on Ocean Observations; CLIVAR04; COAPS site review; 2nd High Resolution Marine Meteorology Workshop; Office of Climate Observation Annual System Review; 1st Workshop on the Quality Assurance of Real-Time Ocean Data.

Taro Takahashi (LDEO)
"Distribution and systematics of the pCO_2 in surface waters of the global ocean", a key note address delivered at the International Workshop on the Surface Water pCO_2" held in January, 2004, Tsukuba, Japan; "Decadal changes in the surface water pCO_2 in the tropical and North Pacific Ocean", an invited presentation at the "Workshop on the temporal change in the carbon chemistry of the North Pacific Ocean", held in June 2004, Seattle, WA.

Rik Wanninkhof (NOAA/AOML)
NOAA Carbon Steering Group Meeting, November 2003; AGU San Francisco and town hall meeting of OAR review team, December 2003; IOCCP pCO_2 methods workshop, Tsukuba, Japan, January 2004; COSP meeting, April 2004; NOAA Carbon Steering Group Meeting, May 2004; SOLAS Implementation Group 2 meeting, Montreal, May 2004; Oceans in a high CO_2 world meeting, Paris, May 2004; Caribbean: Media cruise Explorer of the Seas, Caribbean, June 2004; AAAS press conference, July 2004; SOLAS Implementation Group 2 writing team meeting, September 2004.

Robert Weller (WHOI)
Ocean Observations Panel for Climate (OOPC), Ottawa, Sept 2003; NRC Committee, Environmental Satellite Data Utilization, Sept 2003; PACS/EPIC PI workshop, NCAR, Sept 2003; DEOS Executive Committee, San Francisco, Oct 2003; NRC CCSP Committee, Irvine, Oct 2003; NOAA CIMMS site review, Norman, OK, Oct 2003; NRC Committee on Environmental Satellite Data Utilization, Irvine, Dec 2003; Fall AGU, OS Exec. Committee, San Francisco, Dec 2003; US CLIVAR SSC, Lamont Doherty, Dec 2003; ORION workshop, Puerto Rico, Jan 2004; International Time Series Science Team Meeting, Puerto Rico, Jan 2004; Interagency Working Group on Earth Observations, Dulles, VA, Jan 2004; Ocean Sciences Meeting, Portland OR, Jan 2004; NRC Committee, Environmental Satellite Data Utilization, Wash DC, Feb 2004; NOAA Senior Research Council, Silver Spring, MD, Feb 2004; NOAA Climate Council meeting, Airlie House, VA, March 2004; VAMOS (Variability of the American Monsoon Systems) Panel mtg, Guayaquil, Ecuador, March 2004; Climate Observation Program Workshop in Silver Spring, MD, April 2004; NOAA Joint Institutes Director and Administrators Meeting, Silver Spring, April 2004; ORION Executive Steering Committee, Wash DC, April 2004; CICOR Executive Board and Fellows meetings, WHOI, May 2004; ONR Non-Linear Internal Waves and Parameterization DRI meetings, Dulles, VA, May 2004; Meet with Adm. Jay Cohen, CNR, Wash DC, May 2004; Meet with Chet Koblinsky, NOAA OAR Climate team lead, May 2004; OOPC meeting,

Southampton Oceanography Centre, UK June 2004; Interagency Working Group on Earth Observations, Herndon, VA, June 2004; CLIVAR Conference, Baltimore, June 2004; International CLIVAR SSG, Baltimore, June 2004; ORION Executive Steering Committee, July 2004; Testimony at House hearing, Wash DC, July 2004; NRC Committee on Strategic Guidance for NSF ATM, Wash DC, August 2004.

Jia-Zhong Zhang (NOAA/AOML)
Mediterranean Conference of Chemistry of Aquatic Systems, September 2004, Reggio Calabria, Italy.

Outreach (e.g., education initiatives, press/media interviews, public lectures)

AOML
Data has been used for educational purposes at the University of Miami and at public schools across the nation.

Steven Cook (NOAA/AOML)
VOS Recruitment Presentations to: Bermuda Container Lines, Maersk Sea-Land Inc. SCMI.

Gustavo Goni (NOAA/AOML)
Mentor of high school student during Summer 2004; Article on Tropical Cyclone Heat Potential, The Miami Herald, January 25, 2004.

Elizabeth Johns (NOAA/AOML)
SEACOOS meeting, Miami, FL, May 2004.

Rick Lumpkin (NOAA/AOML)
Mentored an undergraduate student of City College of New York (CCNY) in a data analysis summer project, supported by NOAA funding separate from this project; made presentations for the general public in Miami, and for computer science undergraduates at CCNY.

Christopher Meinen (NOAA/AOML)
SEACOOS meeting, Miami, FL, May 2004.

Frank Millero (RSMAS/MAC)
Outreach – Sloan Conference Mentor, 2004.

Ignatius Rigor (UW)
Assisted with the development of graphics describing Arctic change in the National Geographic Article, Arctic Ice (2004); Gave a lecture on Arctic climate change and sea ice at the U.W. Program on Climate Change (PCC) Summer Institute, Leavenworth, WA, September 2004.

Raymond Schmitt (WHOI)
Interviewed this year on the Weather Channel, for the History Channel, and for numerous newspapers. Presented invited lecture on the oceans and climate at the Beckman Scholars Symposium, July 31 at National Academy of Sciences, Irvine, CA.

Robert Weller (WHOI)
We will have the NOAA Teacher-at-Sea program involved in our cruise in December 2004; Briefing on climate observation of Ocean Science Journalism Fellows, WHOI, September 2004.

APPENDIX D

Request for Annual Progress Report
and
Report Format

18 August 2004

Dear Climate Observationalists:

Thank you to all who participated in the Climate Observation Program's Annual System Review held from 13-15 April in Silver Spring, MD. The meeting provided continued direction for the development of the sustained global climate observing system. The illustrated poster sessions highlighted observing system progress and needs in addition to the science contributing to modeling and user efforts, thus complementing presentations by user groups and partners. In response to requests to focus more strongly on the science and accomplishments of the observing system we intend to hold a technical science workshop in conjunction with next year's Program Review. The 2005 Climate Observation Program Review and the Technical Science Workshop are tentatively scheduled for 26-28 April. Please place these dates on your 2005 calendar.

Following is a request for annual progress reports for FY 2004, work plans for FY 2005, and additional tasks. Note that this year proposals for additional tasks for ocean analysis will be accepted from the operational centers and other institutions as well as from existing projects. Please see the "Add Tasks" document for more detail. Your FY 2003 reports were outstanding and formed the bulk of Chapter 3 of the first *Annual Report on the State of the Ocean and the Ocean Observing System for Climate* (hereafter referred to as the *Annual State of the Ocean Report*). Your reports were also used to update the Program Plan for *Building a Sustained Ocean Observing System for Climate*. Both documents can be found on the Office of Climate Observation (OCO) web site at http://www.oco.noaa.gov/ under "Reports and Products" and "Program Plan", respectively. We appreciate your contributions to the *Annual State of the Ocean Report*.

Following last year's guidelines, your annual progress report should include: 1) a project summary, 2) FY 04 progress, 3) a FY 05 work plan, 4) a corresponding FY 05 budget, and 5) "Add Tasks". Attachment 1 is a slightly revised outline of the report format, including guidelines. The guidelines are intended to provide a somewhat standard look and feel across all the projects and to allow the Project Office to extract summary information and system-wide statistics to streamline preparation of the *Annual State of the Ocean Report*, provide information for other system reports, and to respond to questions from NOAA management.

Please remember that if your lab/center is implementing more than one project, we would appreciate receiving a single annual report for each network. The Project Office's *Annual State of the Ocean Report* will summarize progress by "network" (as per the JCOMM panels and per our Program Plan). If your lab/center works across several networks, please report these separately. For example, AOML's GOOS Center would file separate annual reports for the SOOP work and for the Global Drifter Program work. It may be difficult to break out personnel costs, etc., between projects if the same people work on more than one, but please provide your best estimate of the separation.

For FY 05, it is the intent of the Climate Observation Program to sustain existing projects at the FY 04 level of funding (depending on the appropriation/allocation process, of course). The budget sheet and cover sheet of your annual report should reflect the "base" budget level (i.e., FY 04 level) for FY 05 work.

Please remember that project managers should evolve their work within their "base" budget to achieve maximum effectiveness and efficiency as scientific understanding and technology advance. Any significant changes, however, must be accomplished in accordance with the Ten

Climate Monitoring Principles and in cooperation with the international implementation panels, in particular the JCOMM panels and the IOCCP. The Ten Principles are listed at the end of the Report Format/Guidelines document.

In addition to your base project Tasks, there is an opportunity to include "Add Tasks" with your report. The Add Tasks should outline incremental expansions and improvements that you would like to accomplish if additional funding becomes available. The Program's specific needs for FY 05 Add Tasks are detailed in the attached Add Tasks document. Please include a cost estimate for each Add Task. When/if new funding becomes available, the Project Office will review and evaluate the Add Task requests against Program priorities. For selected Add Tasks we will ask for a detailed budget sheet to document a supplement to your annual work plan. In most cases, the selected Add Tasks will then become part of the project's base funding for following years.

Budget planning values for FY 05 are included in the Add Tasks document. This plan was used to document NOAA's request for a FY 05 budget increase. You should use this as guidance in creating your Add Tasks. Of course, the Federal appropriation and NOAA allocations seldom equate to the budget planning. So, if possible, develop several modestly priced Add Tasks that could build the system incrementally according to actual funding availability. Please list your Add Tasks in your recommended priority order.

The FY 05 budget planning represented in the Add Tasks document was put in place two years ago and is, therefore, subject to modification. We continue to be serious about building an observing system that is responsive to our customers' requirements and are prepared to adjust course according to customer feedback. Therefore, we will constantly review user input and may modify planning and priorities as we move forward; the ratios of new funding applied to the networks may vary from the attached FY 05 plan. You should use it as guidance but should not be constrained by it.

Please submit your annual progress report and work plan by 15 October 2004 so that we can move money to you as soon as it becomes available in the fiscal year. It is also imperative that your reports be received on time because they will be used in developing a concise summary of the state of the ocean to be submitted for consideration in the *State of the Climate in 2004* Report completed by the NCDC for publication in a late spring 2005 issue of the *Bulletin of the American Meteorological Society* (BAMS). The deadline for the ocean contribution to this report is early 2005.

METHOD OF SUBMISSION

Your report should be submitted electronically by 15 October to climate.observation@noaa.gov.

Follow with hard copy to:
NOAA Office of Climate Observation
1100 Wayne Avenue, Suite 1202
Silver Spring, MD 20910
1-301-427-2089

Thank you for your continued dedication to building the sustained ocean observing system for climate.

Sincerely,
Diane Stanitski

PROGRESS REPORT AND WORK PLAN FORMAT / GUIDELINES

Overview

1. Cover Page
2. Project Summary
3. FY 2004 Progress
4. FY 2005 Plans
5. FY 2005 Budget
6. Add Tasks
7. Appendices

Please include the following information, where applicable, in your annual progress reports. Be as concise and comprehensive as possible and include the full name of all projects and acronyms used. Graphics are encouraged as a means to present your status and findings. Please provide a map(s) indicating locations instrumented or analyzed.

COVER PAGE

- Project title
- Report date – 15 October 2004
- Project Manager(s) – name, title, affiliation, address, phone, email for each
- Primary contact person for finance – name, phone, email
- Signature for person(s) responsible/accountable, e.g. Lab Director

PROJECT SUMMARY

- General overview of the project, including brief scientific rationale
- Statement about how your project addresses NOAA's Program Plan for *Building a Sustained Ocean Observing System for Climate*
- Statement about how your project is managed in cooperation with the international implementation panels, in particular the JCOMM panels
- Responsible institutions for all aspects of project
- Project web site URL and pertinent web sites for your project and associated projects
- Interagency and international partnerships
- Statement that your project is managed in accordance with the Ten Climate Monitoring Principles (see end of this document)

FY 2004 PROGRESS

- Instrument/platform acquisitions for fiscal year and where equipment was deployed (provide map)
- Number of deployments – compare to the previous year
- Percentage data return for fiscal year and 'lifetime' statistics – compare to the previous year
- Measurements taken, where data are stored, data distribution, availability and access to data
- How data are currently being used and shared
- Where the data are archived
- Problems encountered
- Logical considerations (e.g., ship time utilized)
- Research highlights
- Community service (e.g., appointments to science and implementation panels)
- List of conferences/workshops presented at/attended
- Outreach (e.g., press/media interviews, public lectures)

- A bibliography of all refereed publications, technical reports, and meeting proceedings related to your project published and in press during the last fiscal year, including references to papers using data accessed through your project. Please use the *Bulletin of the American Meteorological Society* as the style guide for your bibliographic entries. In addition, include the pdf or url where each complete article or report can be found online. Highlight one or two of your most important FY 04 refereed publications, and include the abstract for these papers in your report and a copy of each publication in its entirety in your Appendix. These particular publications will be highlighted in Chapter 4 of the Annual Report. In addition, send one paper copy of ALL publications, reports, etc. related to your project directly to the OCO with the hard copy of your report.

FY 2005 PLANS

Please include the following information, if applicable:

- Anticipated requirements to maintain the network at status quo
- New data collection methods
- Expected scientific results

FY 2005 BUDGET

- Show Program funding requirements
- Show non-Program support for the observing system (e.g., PI salary)
- Identify how much of your total budget goes toward: a) operations, b) data management, and c) R & D
- Identify how many FTEs the Program funding supports – a) Federal FTEs, and b) non-Federal FTEs.
- Identify how many FTEs dedicated to the project are not funded by the Program

ADD TASKS – see attachment for guidelines (1, 2, 3, 4)

- Rationale
- Proposed work
- Procurements needed
- Additional personnel needed
- **Cost estimate**

APPENDICES

- Copy of representative publication(s)
- List of Acronyms used in your report

THE 10 CLIMATE MONITORING PRINCIPLES

1. The impact of new systems or changes to existing systems should be assessed prior to implementation.
2. A suitable period of overlap for new and old observing systems is required.
3. The details and history of local conditions, instruments, operating procedures, data processing algorithms, and other factors pertinent to interpreting data (i.e., metadata) should be documented and treated with the same care as the data themselves.
4. The quality and homogeneity of data should be regularly assessed as a part of routine operations.
5. Consideration of the needs for environmental and climate-monitoring products and assessments, such IPCC assessments, should be integrated into national, regional, and global observing priorities.
6. Operation of historically uninterrupted stations and observing systems should be maintained.
7. High priority for additional observations should be focused on data-poor regions, poorly observed parameters, regions sensitive to change, and key measurements with inadequate temporal resolution.
8. Long-term requirements, including appropriate sampling frequencies, should be specified to network designers, operators, and instrument engineers at the outset of system design and implementation.
9. The conversion of research observing systems to long-term operations in a carefully planned manner should be promoted.
10. Data management systems that facilitate access, use, and interpretation of data and products should be included as essential elements of climate monitoring systems.

APPENDIX E

Contributors and Reviewers: Annual Report

Contributors and Reviewers

Chapter 1: The Role of the Ocean in Climate – *Kevin Trenberth, NCAR, Boulder, Colorado*

Chapter 2: The State of the Ocean
2.1 Global sea level rise – *Laury Miller and Bruce Douglas, NOAA/NESDIS, Silver Spring, Maryland*
2.2 Sea surface temperatures in 2004 – *Richard Reynolds, National Climatic Data Center, Asheville, North Carolina*
2.3 Ocean heat and fresh water content and transports – *Lynne Talley, Scripps Institution of Oceanography, California*
2.4 Evolution of the 2004 El Niño – *Michael McPhadean, Pacific Marine Environmental Laboratory, Seattle, Washington*
2.5 The global ocean carbon cycle: Inventories, sources and sinks – *Richard Feely, Pacific Marine Environmental Laboratory, Seattle, Washington; Rik Wanninkhof, Atlantic Oceanographic and Meteorological Laboratory, Miami, Florida*
2.6 Surface current observations – *Peter Niiler, Scripps Institution of Oceanography, California; Nikolai Maximenko, International Pacific Research Center, Honolulu, Hawaii*
2.7 Air-sea exchange of heat, fresh water, momentum – *Robert Weller, Woods Hole Oceanographic Institution, Woods Hole, Massachusetts*
2.8 Sea ice extent and thickness – *Ignatius Rigor, University of Washington; Jackie Richter-Menge, Cold Regions Research and Engineering Laboratory*

Chapter 3: The State of the Observing System
There were many contributors to each FY 2004 progress report and FY 2005 planning report; please refer to authors identified in Chapter 3 under report titles.

Chapter 4: The State of the Science
Contributions were made by the authors of each bibliographic reference.

Reviewers
Michael Johnson and Masahiko Kamei, both of the NOAA Office of Climate Observation, reviewed all or part of this report. Their contributions are much appreciated. David Levinson, of the National Climatic Data Center, served as co-editor of the State of the Ocean component of the Executive Summary.

This report was made possible through the outstanding contributions of those listed above and throughout this report. It has been a pleasure to work with such motivated and committed individuals. Their vision, dedication, and ingenuity will enable advancement and completion of the global ocean observing system for climate.

APPENDIX F

List of Acronyms

List of Acronyms

AAAS	American Association for the Advancement of Science
ABL	Atmospheric Boundary Layer
ADCP	Acoustic Doppler Current Profiler
AGU	American Geophysical Union
AMS	American Meteorological Society
AOML	Atlantic Oceanographic and Meteorological Laboratory
APDRC	Asia-Pacific Data Research Center
ARCs	Applied Research Centers
ARPEGE-CLIMAT	Climate Research Project on Small and Large Scales (France)
BAKOSURTANAL	National Coordinating Agency for Surveys and Mapping, Indonesia
BMRC	Bureau of Meteorology Research Centre (Australia)
BoM	Bureau of Meteorology (Australia)
BPR	Bottom Pressure Recorder
BSH	Bundesamt für Seeschifffahrt und Hydrographie (Federal Maritime and Hydrographic Agency) (Germany)
CARINA	CARbon dioxide IN the Atlantic
C&GC	Climate and Global Change
CCHCO	CLIVAR and Carbon Hydrographic Data Office
CCRI	Climate Change Research Initiative
CCSP	Climate Change Science Program
CDC	Climate Diagnostics Center
CDIAC	Carbon Dioxide Information Analysis Center
CDP	Climate Data Portal
CEOF	Complex Empirical Orthogonal Function
CFD	Computer Flow Dynamics
CGPS	Continuously Operated GPS
CICOR	Cooperative Institute for Climate and Ocean Research
CIMAS	Cooperative Institute for Marine and Atmospheric Studies
CIRES	Cooperative Institute for Research in Environmental Sciences
CLIPS	Climate Information and Prediction Services Project
CLIVAR	CLImate VARiability and Predictability
C-MAN	Coastal-Marine Automated Network
COLA	Center for Ocean, Land, and Atmosphere Studies
COAPS	Center for Ocean-Atmospheric Prediction Studies
COOP	Coastal Ocean Observations Panel (GOOS)
COP	Climate Observation Program
CORC	Consortium on the Ocean's Role in Climate
COSC	Climate Observing System Council
COSP	Climate Observations and Services
CLIVAR	Climate Variability and Predictability Program
CPC	Climate Prediction Center
CPRDB	Comprehensive Pacific Raining Database
CSIRO	Commonwealth Scientific and Industrial Research Organization
CTD	Conductivity, Temperature, Depth
DAC	Data Assembly Center
DART	Deep Ocean Assessment and Reporting of Tsunamis (Buoy)
DBCP	Data Buoy Cooperation Panel
DCP	Data Collection Platform
DCS	Data Collection System

DMC	Drought Monitoring Center
DODS	Distributed Ocean Data System
DOE	Department of Energy
DSL	Digital Subscriber Line
DWBC	Deep Western Boundary Current
ECCO	Estimating the Circulation and Climate of the Ocean
ECMWF	European Centre for Medium-Range Weather Forecasts
ENSO	El Niño-Southern Oscillation
EOF	Empirical Orthogonal Function
EPIC	Eastern Pacific Investigation of Climate
ERS	Earth Remote-sensing Satellite
ETL	Environmental Technology Laboratory
EVAC	Environmental Verification and Analysis Center
FAO	Food and Agriculture Organization (UN)
FGDC	Federal Geographic Data Committee
FRX	Frequently Repeated XBT
FSU-COAPS	Florida State University Center for Ocean-Atmosphere Prediction Studies
GAINS	GLOSS Development in the Atlantic and Indian Oceans
GCC	Global Carbon Cycle
GCOS	Global Climate Observing System
GCP	Global Carbon Project
GCTE	Global Change and Terrestrial Ecology Program
GCRMN	Global Coral Reef Monitoring Network
GDC	Global Drifter Center
GDP	Global Drifter Program
GEOSAT	Geodesy Satellite
GIS	Geographic Information System
GLOSS	Global Sea Level Observing System
GODAE	Global Ocean Data Assimilation Experiment
GOES	Geostationary Operational Environmental Satellite
GOOS	Global Ocean Observing System
GPCP	Global Precipitation Climatology Project
GPS	Global Positioning System
GPS@TG	Co-located GPS systems at tide gauge stations
GSOP	Global Synthesis and Observations Panel of CLIVAR
GTS	Global Telecommunications System
GTSPP	Global Temperature-Salinity Profile Program
HRX	High Resolution XBT
HURDAT	Atlantic Basin Hurricane Database
IAI	Inter-American Institute for Global Change Research
IOC	Intergovernmental Oceanographic Commission
IDOE	International Decade of Ocean Exploration
IES	Inverted Echo Sounder
IFREMER	Institut français de recherche pour l'exploitation de la mer (French Research Institute for Exploitation of the Sea) (France)
IGBP	International Geosphere-Biosphere Programme
IGCO	Integrated Global Carbon Observing team
IHO	International Hydrographic Organization
IMBER	Integrated Marine Biogeochemistry and Ecosystem Research
IMET	Improved METeorological Instrument
IOCCP	International Ocean Carbon Coordination Project

IOOS	Integrated Ocean Observing System
IOOS-DMAC	Integrated Ocean Observing System – Data Management and Communication
IPRC	International Pacific Research Center
IRD-Brest	L'Institut de recherché pour le developpement – Brest (France)
IRI	International Research Institute for Climate Prediction
ITCZ	Inter-Tropical Convergence Zone
IUGG	International Union of Geodesy and Geophysics
JAMSTEC	Japan Agency for Marine-Earth Science and Technology
JASL	Joint Archive for Sea Level
JCOMM	Joint WMO/IOC Technical Commission for Oceanography and Marine Meteorology
JGOFS	Joint Global Ocean Flux Survey
JIMAR	Joint Institute for Marine and Atmospheric Research, University of Hawaii
JIMO	Joint Institute for Marine Observations
JISAO	Joint Institute for the Study of the Atmosphere and Ocean
JMA	Japan Meteorological Agency
J-OFURO	Japanese Ocean Flux data sets with Use of Remote sensing Observations
JPL	Jet Propulsion Laboratory
JTA	Joint Tariff Agreement
KE	Kuroshio Extension
KEO	Kuroshio Extension Observatory
KESS	Kuroshio Extension System Study
LAS	Live Access Server
LLNL	Lawrence Livermore National Laboratory
MAN	Management Committee (JCOMM)
MEDS	Marine Environmental Data Services
MJO	Madden-Julian Oscillation
MOC	Meridional Overturning Circulation
MOCHA	Meridional Overturning, Circulation and Heat Transport Array
MOU	Memorandum of Understanding
NACP	North American Carbon Program
NAO	North Atlantic Oscillation
NASA	National Aeronautics and Space Administration
NCAR	National Center for Atmospheric Research
ncBrowse	Graphical netCDF File Browser
NDBC	National Data Buoy Center
NCDC	National Climatic Data Center
NCDDC	National Coastal Data Development Center
NCEP	National Centers for Environmental Prediction
NEAR-GOOS	North-East Asian Regional GOOS
NERC	National Environmental Research Council
NESDIS	National Environmental Satellite, Data, & Information Service
netCDF	network Common Data Form
NGO	Non-Governmental Organization
NIC	National Ice Center
NIH	National Institutes of Health
NIWA	National Institute of Water and Atmospheric Research (New Zealand)
NMFS	National Marine Fisheries Service
NMHS	National Meteorological and Hydrological Services
NMRI	Naval Medical Research Institute
NOAA	National Oceanic and Atmospheric Administration

NODC	National Oceanographic Data Center
NOPP	National Ocean Partnership Program
NORPAX	North Pacific Experiment
NOS	NOAA Ocean Service
NOSA	NOAA Observing System Architecture
NRC	National Research Council
NSCAT	NASA Scatterometer
NSF	National Science Foundation
NTC	National Tidal Centre, Australia
NWP	Numerical Weather Prediction
NWS	National Weather Service
NWS-PR	National Weather Service Pacific Region
NVODS	National Virtual Ocean Data System
MON	NWS Marine Observation Network
OCCC	Ocean Carbon and Climate Change Program
OceanSITES	Ocean Sustained Interdisciplinary Time series Environmental Observatory
OCO	Office of Climate Observation
ODINAFRICA	Ocean Data and Information Network for Africa
OGP	Office of Global Programs
OMAO	Office of Marine and Aviation Operations
OOPC	Ocean Observations Panel for Climate
OpeNDAP	Open Source Project for Network Data Access Protocol
PacificGOOS	Pacific Global Ocean Observing System
PACIS	Pan-American Climate Information System
PDO	Pacific Decadal Oscillation
PEAC	Pacific ENSO Applications Center
PHOD	Physical Oceanography Division
PIES	Pressure Gauge Equipped Inverted Echo Sounder
PMEL	Pacific Marine Environmental Laboratory
PNA	Pacific North America
PNNL	Pacific Northwest National Laboratory
POGO	Partnership for the Observation of the Global Oceans
QSCAT	Seawinds on QuikScat
RRP	ENSO Rapid Response Project
RSMAS	Rosenstiel School of Marine and Atmospheric Science
RVIB	Research Vessel / Ice Breaker
RVSMDC	Research Vessel Surface Meteorology Data Center
SAC	Special Analysis Center
SAR	Synthetic Aperture Radar
SCPP	Seasonal-to-Interannual Climate Prediction Program
SCMI	Southern California Marine Institute
SCOR	Scientific Committee for Ocean Research
SEACOOS	Southeast Atlantic Coastal Ocean Observing System
SEAFLUX	Ocean Surface Turbulent Flux Project
SEARCH	Study of Environmental Arctic Change
SEAS	Shipboard Environmental data Acquisition System
SEC	South Equatorial Current
SI	Seasonal-to-Interannual
SIO	Scripps Institution of Oceanography
SIO-ECPC	Scripps Institution of Oceanography-Experimental Climate Prediction Center
SLP	Sea Level Pressure

SLP-PAC	Sea Level Program in the Pacific
SOC	Southampton Oceanography Centre
SOI	Survey of India
SOLAS	Surface Ocean-Lower Atmosphere Study
SOOP	Ship-of-Opportunity Program
SOOPIP	Ship-of-Opportunity Implementation Panel
SOI	Southern Oscillation Index
SOT	Ship Observations Team
SPARCE	South Pacific Rainfall Climate Experiment
SPCZ	South Pacific Convergence Zone
SRDC	Surface Reference Data Center
SSG	Scientific Steering Group
SSP	Sea Surface Pressure
SST	Sea Surface Temperature
START	Global Change System for Analysis, Research, and Training
SURFRAD	Surface Radiation Budget Network
TAO	Tropical Atmosphere Ocean Array
TMI	TRMM Microwave Imager
TOGA	Tropical Oceans-Global Atmosphere Program
TOPEX	Ocean TOPography Experiment
TRMM	Tropical Rainfall Measurement Mission
UHSLC	University of Hawaii Sea Level Center
UNCED	United Nations Conference on Environment and Development
UNFCCC	United Nations Framework Convention on Climate Change
UOTC	Upper Ocean Thermal Center
URI	University of Rhode Island
USIABP	U.S. Interagency Arctic Buoy Program
USGCRP	U.S. Global Change Research Program
UW	University of Washington
VOS	Voluntary Observing Ships
WCRP	World Climate Research Program
WDC-A	World Data Center-A for Oceanography
WHO	World Health Organization
WHOI	Wood's Hole Oceanographic Institution
WMO	World Meteorological Organization
WOCE	World Ocean Circulation Experiment
WWE	Westerly Wind Event
WWW	The World Weather Watch of WMO
XBT	Expendable Bathythermograph
XCTD	Expendable Conductivity Temperature Depth