CHAPTER 4

Decadal to Centennial Climate Research

Climate varies on all time and space scales. Decadal to centennial (Dec-Cen) climate research is aimed at understanding climatic variability at longer than ENSO time scales, and regional to global spatial scales. Among the research topics focused on this area of climate research are: long-term ocean-atmosphere interactions, process studies linking climate variability on decadal-to-century time scales to shorter-term climate variations, including internal versus external mechanisms, and predictability studies of climate prediction at long-range lead times. The NOAA Strategic Plan identifies the goal of the NOAA Dec-Cen program as being able to "provide science-based advice to policy makers by detecting and assessing decadal-to-centennial changes in the global environment."

The Climate Diagnostics Center contributes to the NOAA Dec-Cen program by conducting studies to understand the role of the oceans in global change through research into the role of the oceans in forcing atmospheric variability at long time scales. CDC scientists are involved in efforts to model atmosphere-ocean interaction at Dec-Cen time scales and in the development of large-scale observational data sets. Both efforts advance understanding of critical climate processes and linkages and help to ensure the quality of the long-term observational records of climate, such as the Comprehensive Ocean-Atmosphere Data Set (COADS).

The Climate Diagnostics Center also evaluates climate model-based predictions of global climate changes to improve impact-assessment efforts regarding global climate changes, to reduce uncertainty in future climate scenarios (e.g., through improved regional details of future climates), and to assist in evaluation of the socioeconomic impacts arising from long-term climate variability and change, by helping to define vulnerability and adaptation strategies to future climate.

4.1 Understanding the role of the ocean in climate variations at decadal-to-century time scales

4.1.1 Climate variation as a function of elevation

Recent studies have documented widespread retreat of alpine glaciers and melting of tropical ice cap margins. These observations are important because they underscore the unusual nature of the general warming of the climate system that has been recorded in recent decades. A study has been conducted which compares temperature changes in the tropics, based on instrumental records for the past 3-4 decades, to the results of a modeling study where the model atmosphere was forced by the observed global pattern of sea surface temperature (SST) in a 19-yr simulation. The analysis focused on the time evolution of the height of the freezing-level surface (FLS, the height of the 0 °C isotherm) in the model in comparison with the evolution of this critical level in radiosonde measurements taken during a similar time interval. The analysis strongly indicates that the recent observed changes in freezing-level heights are related to a long-term increase of SST in the tropics and the resulting enhancement of the tropical hydrologic cycle (see **Fig. 4.1**). These findings are thus consistent with other recent studies of the effects of low-frequency changes in tropical SST and the resulting modulation of the tropical hydrologic cycle on large-scale climatic variations. Although hydrologic cycle changes in the tropics are likely to impact high-elevation hydrologic and ecological balances worldwide, tropical environments may be particularly sensitive to changes in tropical SST and accompanying changes in humidity, because these changes may be largest and most systematic there.

4.1.2 Low frequency changes in ENSO and its impact on U.S. precipitation

CDC researchers were among the early contributors to improving scientific understanding of the El Niño/Southern Oscillation (ENSO) phenomenon. Important studies were published on characteristic regional and hemispheric scale climatic responses to ENSO. Pioneering steps were also taken to improve our understanding of the long-term behavior of the ENSO phenomenon (see Diaz and Kiladis, 1995 for a comprehensive review). Studies of precipitation variability on ENSO, decadal and longer time scales have been com-

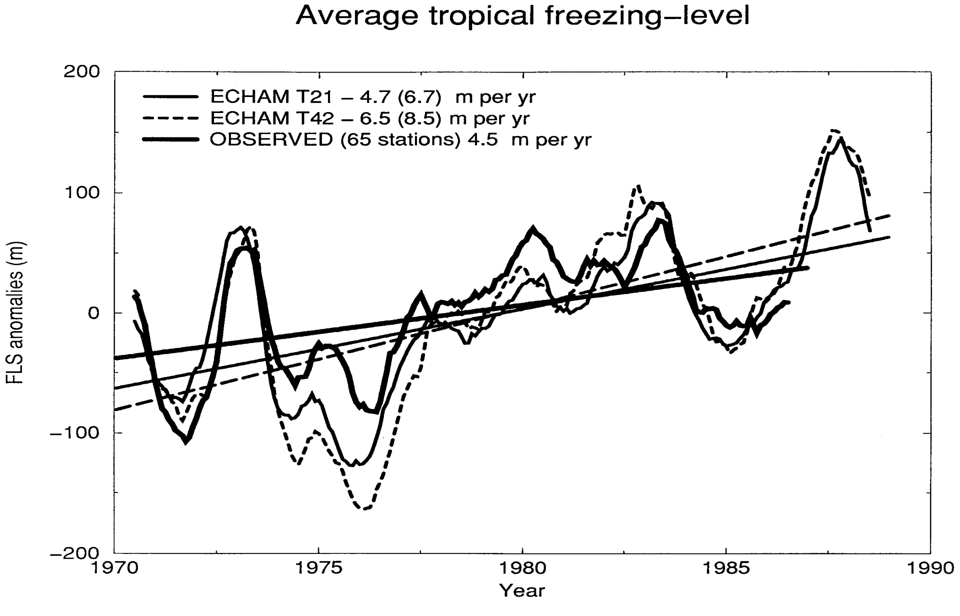
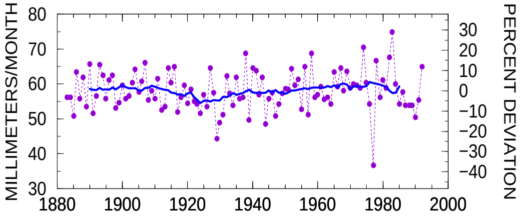


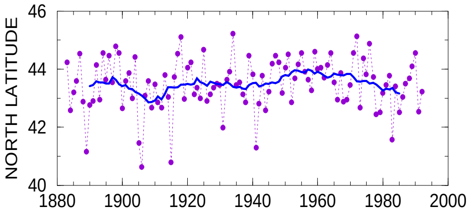
Fig. 4.1. Anomaly time series of the average height (in meters) of the 0 ˚C surface (the freezing-level surface, or FLS) in the tropics (1970-88), derived from two sets of GCM simulations at T21 and T42 spectral resolutions (light solid and dashed curves, respectively), and compared with observations (dark solid curve). The observed curve is based on a network of 65 radiosonde stations in the tropics and on the period 1970-86. Linear trends of 4.7 and 6.5 m per year for FLS height in the T21 and T42 simulations, respectively, may be compared with a linear trend of 4.5 m per year in the observations. Figure taken from Diaz and Graham (1996).

pleted. These studies focus on the interaction among climatic variations occurring on different time scales. We continue to explore the question of whether climatic variability at the longer time scales is simply a telescoped version of the variability on the shorter time scales. Another question that is being addressed is whether variations in the total amount of precipitation integrated over the full spatial domain of the North American Cordillera represent spatial redistribution of the precipitation, or net increases and decreases in the total amount.

Total precipitation along the west coast of North America, from 25˚N to 55˚N, varies by about 10 mm from one winter to the next, representing fluctuations of about 10% of the long-term area average (**Fig. 4.2**). Superimposed on this domain-average variability are considerable year-to-year fluctuations of precipitation concentrations from north to south that affect the distribution of precipitation but not the overall amount. An important component of precipitation variability in the region is characterized by regional north-south contrasts that appear at time scales from interannual to interdecadal.

Analysis of 100 years of station precipitation records in western North America was done in terms of spatial empirical orthogonal functions (EOFs) and spatial moments (domain average, central latitude, and latitudinal spread) of zonally averaged precipitation anomalies along the westernmost parts of North America (**Fig. 4.2**). These indices were correlated with global sea-level pressure (SLP) and sea-surface temperature (SST) series, on ENSO-band (3-7 yr) and decadal (>7 yr) time scales. Zonal EOFs of the ENSO and decadal filtered versions of the zonal precipitation series are remarkably similar. At both time scales, two leading EOFs describe a north-south seesaw of precipitation pivoting near 40˚N and variations in precipitation near that pivot point, respectively. The positive phase of the seesaw patterns (wet south and dry north) is promoted by ENSO-like atmospheric circulations and SST patterns. The pivot-point pattern has stronger correlations to more local Northern Hemisphere circulations. The central latitude and latitudinal spread of precipitation distributions are strongly influenced by precipitation


a. Domain Average Precipitation, 25N − 55N


b. Central Precipitation Latitude

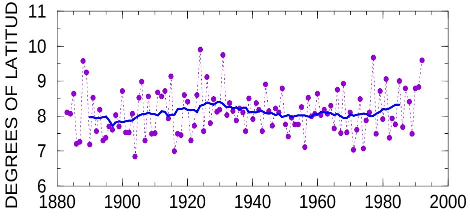

c. Latitudinal spread

Fig. 4.2 Domain average precipitation (top graph), central precipitation latitude (middle panel), and latitudinal spread (bottom panel) of western North America precipitation (1880-1994). Heavy curves are 15-yr moving averages. Taken from Dettinger, Cayan, Diaz, and Meko (1997).

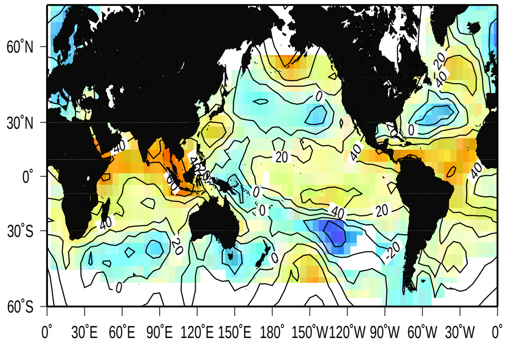
variations in the southern parts of western North America and are closely related to EOF-1 (whereas EOF-2 is related more to domain average). Central latitude of precipitation moves south (north) with tropical warming (cooling), on both ENSO and decadal time scales and also is strongly related to Western Pacific SLP conditions on decadal scales. The north-south contrasts are characteristic of a broad range of frequencies, including $(15\ \mathrm{yr})^{-1}$, $(5.5\ \mathrm{yr})^{-1}$, and $(4.2\ \mathrm{yr})^{-1}$, with most spectral peaks coherent with the Southern Oscillation Index.

The similarity of EOFs of zonal precipitation across time scales indicates that the north-south precipitation patterns, (i) are frequency-independent like white noise--that is, they do not fall distinctly into one or the other of these broad frequency bands, (ii) share similar climatic driving forces and spatial patterns in the precipitation field of western North America, or (iii) are some combination of (i) and (ii). Correlation patterns of the corresponding ENSO and decadal PC series with global SLP and SST fields are broadly similar, though they also exhibit some distinct differences. On both ENSO and decadal scales, the positive phase of the first EOF pattern (wet south and dry north) is promoted by warm SSTs in the tropical Pacific and Indian Oceans. EOF-2 has stronger correlations to the Northern Hemisphere circulations and is less global than EOF-1. The ENSO band north-south differences (EOF-1) appear to be most sensitive to fluctuations in storm tracks over southern North America, whereas decadal differences are associated more with the overall circulation setting, and particularly to the strength and position of the subtropical jet across the North Pacific. Zonal precipitation EOF-1 contributes about 30% of variability in both ENSO and decadal bands, and amounts to a redistribution of zonal precipitation with little change in overall amount. EOF-2 contributes another 20% of variability, and directly affects the overall amount of precipitation. Thus, north-south precipitation variations in western North America constitute a complex mix of redistribution and overall variation of the amounts of precipitation. On ENSO time scales, the pattern and amount are anti-correlated, whereas, on decadal time scales, the two are largely independent.

Do the north-south precipitation patterns reflect changes or re-distributions of the overall amount of precipitation delivered to the cordillera of western North America? We find that, in general, total winter precipitation varies only by about 10% from year to year and that total precipitation has been remarkably stationary during the last 115 years (and, based on tree-ring pattern correlations, perhaps much longer). Given the strong climatological contrasts in precipitation from the wet northern areas to the dry southern areas, even the overall distribution of precipitation from north to south--as measured by central latitude and latitudinal spread--has varied relatively little from year to year and over the course of the last 115 years and longer. However, in particular years, such as 1977 and 1983, much larger excursions in amount and distribution of precipitation have occurred. Climate conditions during these years may provide the best insights into the character of large-scale climate changes.

Do the different precipitation time scales reflect different processes and teleconnections? EOF analyses showed that the dominant spatial patterns of precipitation in western North America are similar almost regardless of the time scale considered, from 2-20 years. Despite these spatial similarities, several frequency bands are important across much of the study area and display phase differences from band to band to form a complex tapestry. The complex phase relations suggest that there may be subtle differences in the precipitation processes when finer frequency distinctions are considered than were used here. The climatic conditions (SLPs and SSTs) that force the spatial patterns also show many similarities from ENSO to decadal time scales (**Fig. 4.3**), although ENSO patterns seem to be more closely associated with particular local circulation conditions, whereas decadal patterns tend to reflect conditions from farther afield. Both ENSO and decadal patterns reflect tropical variations, although the decadal patterns are almost as sensitive to the long-term condition of the Western Pacific jet. Thus, time-scale differences among the precipitation processes remain elusive. Important tropical-extratropical connections appear to underlie both the ENSO and decadal patterns, but with possible differences in emphasis from one time scale to the next.

The strong similarities in climate conditions associated with the ENSO and decadal precipitation variations, however, allow the possibility that the decadal variations are largely accumulations of the ENSO-scale variations and processes.


a. CORRELATIONS, ENSO ZONAL PPT EOF 1 VS GRIDDED SSTS

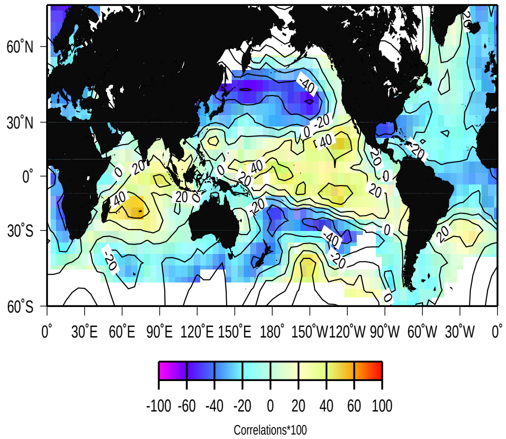

b. CORRELATIONS, DECADAL ZONAL PPT EOF 1 VS GRIDDED SSTS

Fig. 4.3. Correlations (x100) between ENSO-filtered SST and ENSO-scale zonal precipitation PCs for western North America (top panel) and between decadal-filtered SST and decadal-scale zonal precipitation PCs (lower panel).

Regional patterns and zonal averages of precipitation-sensitive tree-ring series are being used to corroborate these patterns and to extend them into the past and appear to share much long- and short-term information with the instrumentally based zonal precipitation EOFs and moments. Some corroboration of these precipitation patterns, and their extension into the past, was obtained using selected precipitation-sensitive tree-ring series. Comparisons of the long- and short-term variations of (limited) zonal averages of the tree-ring series with precipitation patterns during the same periods indicate much shared information. The temporal correlations of tree rings to the precipitation principal components (PCs) and spatial moments yielded moderate correlations, which can be used with year-to-year tree-ring variations to capture about 50% of the variance of the precipitation PCs and moments. The relatively close correspondence between tree-ring variation patterns and large-scale precipitation patterns suggests avenues for further extending the history of precipitation patterns (and perhaps their climatic forcings) into the pre-instrumental past. In addition, the present results suggest that the temporal and spatial structure of western North American winter precipitation has been relatively stable for several hundred years.

4.1.3 Ocean-atmosphere interactions

Over the past three years several studies conducted by CDC scientists have focused on midlatitude atmosphere-ocean interaction and interactions between the surface and deeper layers in the ocean. As the ocean evolves much more slowly than the atmosphere, a better understanding of these interactions may lead to improved seasonal and longer forecasts of the climate system.

Namias and Born [*J. Geophys Res.*, **75**, 5952(1970); *J. Geophys. Res.*, **79**, 797(1974)] noted a tendency for midlatitude SST anomalies to recur from one winter to the next without persisting through the intervening summer. They hypothesized that temperature anomalies that form over the relatively deep ocean mixed layer in winter could remain intact in the summer seasonal thermocline, and then reappear at the surface when the mixed layer again deepened via entrainment in the following fall and winter. We examined this “re-emergence mechanism” using both subsurface temperature data and mixed layer model simulations at Weather Stations in the North Atlantic and North Pacific Oceans (see Alexander and Deser 1995; Alexander and Penland 1996). At locations away from strong currents lead-lag correlations showed that temperature anomalies beneath the mixed layer in summer are associated with the temperature anomalies in the mixed layer in the previous winter/spring and following fall/winter but are unrelated or weakly opposed to those in the summer seasonal thermocline.

Ocean modeling experiments confirmed that entrainment plays an important role in the ocean heat budget by regulating the mixed layer depth in addition to controlling the heat flux through the base of the mixed layer. A key process in the re-emergence mechanism is the mean entrainment of the anomalous difference in temperature between the water within and below the mixed layer which strongly influences the surface layer heat budget in early fall.

Recently, temperature fields obtained from the NCEP ocean data assimilation system have been used to examine the extent to which the re-emergence mechanism occurs over the North Pacific basin. The time series of the leading pattern of variability in the summer seasonal thermocline (65-85 m during August-September) is strongly correlated with SSTs over the central and eastern north Pacific during the previous winter and following fall but not during the concurrent summer months. To confirm these results lead-lag correlations were computed using temperature anomalies over a region in the central North Pacific where the re-emergence signal appeared to be strong (**Fig. 4.4**). The correlations suggest that temperature anomalies created in late winter descend into the seasonal thermocline by July and return to the surface in the following November.

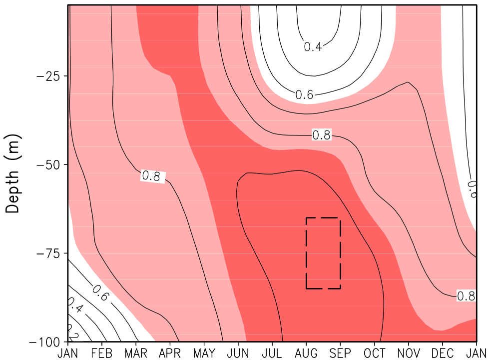


Fig. 4.4. Lead-lag correlations for the region 146˚W-158˚W, 36˚N-44˚N computed in reference to the temperature time series at 65-85 m during August-September (dashed box). Contour interval is 0.1. Light (dark) shading indicates correlations in excess of 0.65 (0.85).

The role of midlatitude air-sea interaction on climate variability has also been examined by comparing simulations in which an atmospheric GCM is coupled to a mixed layer ocean model in the North Atlantic to a control simulation where climatological SSTs are specified in the North Atlantic. The dominant pattern of the anomalous air temperature, which is similar in the two runs, decays much more slowly in the coupled run. The enhanced persistence of this pattern is tied to two processes: reduced thermal damping and the re-emergence of SST anomalies. There is a reduction in the damping of air temperature anomalies in the coupled run as the ocean can adjust to the overlying atmosphere which reduces the negative surface air-sea feedback. The re-emergence mechanism which occurs in the northwest Atlantic, in agreement with observations, is the dominant process which enhances the interannual persistence of SST anomalies in the model. Furthermore, the SST anomalies in the coupled model appear to influence atmospheric circulation patterns downstream over Europe.

These observational and modeling studies suggest that the re-emergence mechanism is an important climate signal over portions of the North Atlantic and Pacific oceans. In addition, thermal anomalies stored within the upper ocean may return to the surface and influence the atmospheric circulation in subsequent seasons.

We have also been actively studying the decade-long climate shift that began in late 1976 over the North Pacific. From approximately 1977 to 1988, particularly during the winter-half of the year, the atmospheric circulation over the North Pacific was characterized by a deeper than normal Aleutian Low pressure system, accompanied by stronger than normal westerly winds across the central North Pacific and enhanced southerly flow along the west coast of North America. Sea surface temperatures during this time period were below normal in the central North Pacific and above normal along the California coast northward to the Gulf of Alaska. The climate change also affected marine biological activity, including phytoplankton biomass in the central North Pacific and salmon catch in Alaska.

While the atmospheric and surface oceanic aspects of the decade-long Pacific climate anomaly are well documented, little is known about the changes beneath the ocean surface. A more complete description of the observed vertical structure of the oceanic thermal changes may shed light on the mechanisms which produced the climate change, as well as provide important verification for ocean modeling experiments. For example, can one see thermal anomalies propagate downward from the ocean surface? How deep do the thermal anomalies penetrate? Are they confined to the upper mixed layer, or do they extend into the permanent thermocline? Does the Kuroshio Current System exhibit any changes? We examine these issues using a recently expanded compilation of upper ocean temperature profiles (see Deser, Alexander, and Timlin 1996).

The vertical structure of the thermal anomalies in the Central North Pacific shows a series of cold pulses, beginning in the fall of 1976 and continuing until late 1988, that appear to originate at the surface and descend with time into the main thermocline (**Fig. 4.5**). The interdecadal climate change, while evident at the surface, is most prominent below ~150 m where interannual variations are small. The spatial pattern of the interdecadal thermal change vary with depth (**Fig. 4.6**). At 100 m, within the winter mixed layer, the thermal anomalies are centered east of ~180˚. At 400 m, within the permanent thermocline, the thermal anomalies are westward-intensified,

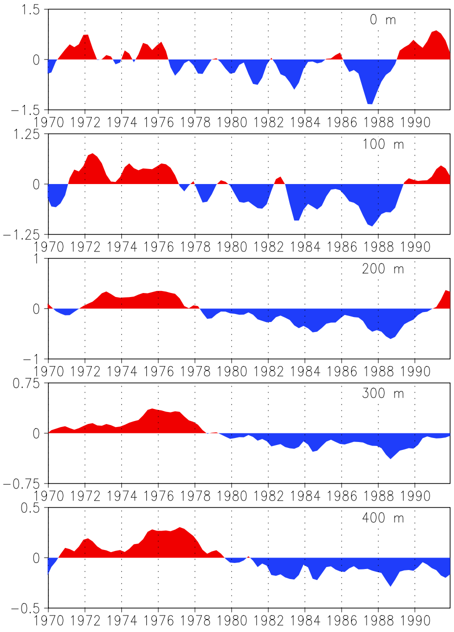


Fig. 4.5. Seasonal temperature anomalies (˚C) in the central North Pacific Region (44˚N-28˚N, 178˚W-46˚W) at selected depths. Note that the scale for the temperature anomalies is different for each depth.

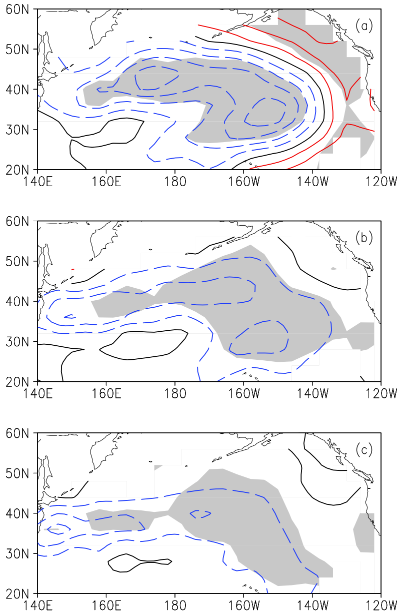


Fig. 4.6. Temperature difference between (a) 1978-89 and 1971-76 at 100 m, (b) 1979-90 and 1972-77 at 250 m and (c) 1980-91 and 1972-78 at 400 m. Contour interval is 0.25 ˚C. Negative contours are dashed. Shading denotes SST differences that are significant at the 95% level.

indicative of gyre-scale circulation changes. Indeed, it can be shown that the intensification and southward expansion of the westerly winds over the North Pacific during the 1980's relative to the 1970's resulted in similar changes in the eastward transport of the Kuroshio Current Extension, in line with Sverdrup theory.

The temperature anomalies for three consecutive 5-year periods (1977-81, 1982-86 and 1987-91) were chosen to span the duration of the interdecadal cooling in the central North Pacific. In the early stage of cooling, the largest negative temperature anomalies (less than -0.3 ˚C) are found in the upper 150 m between ~30˚N and 40˚N (**Fig. 4.7**). These anomalies move southward and downward over the next 10 years, becoming detached from the surface by the last pentad. It can be shown that the thermal anomalies follow the path of the mean wind-driven circulation according to the theory of the ventilated thermocline, in which water parcels are advected by the mean currents along surfaces of constant density. The fate of the thermal anomalies beyond 1991 is currently being investigated.

4.2 Ensuring a long-term climate record

CDC pioneered the development of the Comprehensive Ocean-Atmosphere Data Set (COADS) - an international resource for historical weather observations over the world oceans. Global surface marine data for 1854-1995 have been assembled, quality controlled, and made widely available to the international research community in easily used products. This is the result of a U.S. multi-agency cooperative project which began in 1981.

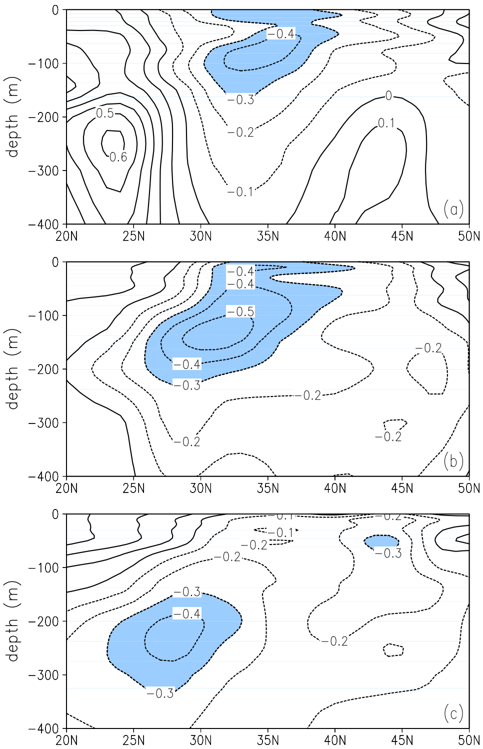


Fig. 4.7. Annual temperature anomalies as a function of depth and latitude for the longitude band 170˚W-145˚W for (a) 1977-81, (b) 1982-86, and (c) 1987-91. Negative anomalies are dashed. Anomalies less than -0.3 ˚C are shaded.

4.2.1 *The Comprehensive Ocean-Atmosphere Data Set (COADS)*

Ship observations are our only major source of long-term climate data for the global oceans before the advent of automated platforms such as buoys and satellite measurements. Satellite data now provide more complete coverage (spatially and temporally), but ship and other in-situ observations remain crucial as ground-truth baseline information and to provide a longer, historical climate perspective. The Climate Diagnostics Center and its predecessor units, dating to its establishment as a programmatic unit in the ERL Director's Office in 1981, has been continuously involved in the development of this global data set in support of the U.S. and international climate research communities.

It remains critical for global climate research within NOAA and throughout the world research community that important data sets such as COADS be extended as far back and as completely as possible. These data sets, in combination with detailed metadata (i.e., information about the data), will continue to be made readily available to support climate diagnostics and detection efforts, as well as climate change impact studies and related socioeconomic sustainability issues (e.g. the impacts of long-term sea level rise and polar ice decay on coastal environment and population). The importance of such historical data and related metadata is highlighted in the FY 1995 U.S. Global Change Research Program (USGRP) report, "Our Changing Planet," and through growing interest in international programs, such as the Global Climate Observing System (GCOS) and its ocean component the Global Ocean Observing System (GOOS), by governments and researchers throughout the world.

According to the United Nation's Intergovernmental Panel on Climate Change (IPCC), improving our predictive capabilities will require a better understanding of various climate processes, with oceanic influences of major importance. Improvement of Global GCMs is strongly dependent on high quality historical databases, which can be improved through better international exchange of climate data. These IPCC recommendations are an integral part of the COADS improvement and validation program. The USGCRP also sets as one of its major goals "developing worldwide data management and archiving systems and enhancing data accessibility" which has also been the long-term goal of the COADS project since its inception.

A wide variety of research has been carried out using COADS, ranging from projects focused on marine climate trends and oceanic forcing, to more far-ranging investigations like environmental correlations with Atlantic salmon catches, sea bird migration patterns, and coral growth rates. The full collection of marine boundary layer variables found in COADS often provides a complete systematically treated database for research. This has an important advantage over discordant collections from various independent sources as confirmed by the fact that over 400 copies of COADS products have been distributed worldwide, from NCAR, since the preliminary COADS Release 1 products became available in 1983. Furthermore, COADS has unrestricted public and private distribution and thus the data are redistributed even more widely.

Sea surface temperature is a crucial ocean surface variable. In modeling it provides coupling between the ocean and atmosphere and for observational studies it is used to monitor ocean surface conditions for climate anomalies, such as ENSO events. The most advanced SST analyses are created by blending real-time ship observations with satellite AVHRR data. COADS SST data, incorporating delayed-mode data collection and processing, are being used to enhance the coverage and quality of these SST analyses, and the improved SST analyses in turn are being provided, together with other basic COADS observations, for use in the National Centers for Environmental Prediction/NCAR Global Atmospheric Reanalysis Project.

4.2.2 Project background and accomplishments

The origins of an organized marine weather observing system can be traced back to Matthew F. Maury in the mid-1800s when as Superintendent of the U.S. Depot of Charts and Instruments he encouraged seamen to provide weather observations for development of a marine climatology to benefit navigation. This led to an international conference in 1853 in Brussels that produced some uniformity in codes and increased international cooperation. From these early beginnings the U.S. and other maritime nations developed programs to archive and digitize ship observations, whose international exchange was much later formalized and standardized under WMO Resolution 35.

In 1968, NOAA's National Climatic Data Center (NCDC) consolidated the 17 different marine data sets that it maintained in one relatively uniform database designated as Tape Data Family-11 (TDF-11). These data were quality controlled and used to produce the revised U.S. Navy Marine Climatic Atlases of the World. Then in January 1981, ERL and the Cooperative Institute for Research in Environmental Sciences (CIRES) planned with NCDC a project to produce an easily used, consolidated marine archive; NCAR soon joined in detailed planning and execution of this continuing project, which has produced COADS.

The consolidated TDF-11 data became the main core of data for 1854-1979 used to complete COADS Release 1 (Slutz et al., 1985; Woodruff et al., 1987). The TDF-11 data were augmented by ship data from a variety of other sources, including data since 1966 received via the Global Telecommunication System (GTS), and additional in-situ data (e.g., oceanographic and buoy data). In Release 1 processing the individual observations were “trimmed”, and 14 monthly statistics were calculated for 19 observed and derived variables, using 2˚ latitude x 2˚ longitude boxes. Trimming in COADS specifically refers to the process of flagging individual observations that exceed upper and lower quality control limits defined for each 2˚ box and month, and excluding them from the trimmed 2˚ monthly summaries. For Release 1, the trimming limits were set at the 3.5 standard deviation level using three climatological periods (1854-1909; 1910-49; 1950-79).

Inventories produced by Release 1 and the earlier projects strongly indicated the need for additional data coverage, for example during the World War I and II periods and the 19th Century. However, digitization and quality control by NCDC of the surviving U.S. Merchant Marine data encompassing the World War periods have proven to be expensive and time-consuming tasks. Therefore, international cooperation has been actively pursued to help fill additional gaps in the record (**Fig. 4.8**; Elms et al., 1993). For example, an agreement was reached in 1993 between NCDC and the Chinese National Oceanographic Data Center (CNODC) to digitize Maury's Collection of ship data extending back to the beginning of the 19th Century (digitization has been completed, and NCDC received final shipment in August 1996). Similarly, CDC was successful in making arrangements for the Arkeologisk Museum in Stavanger, Norway to start keying 600 19th Century Norwegian logbooks, and approximately 40% of the keyed data have been received for evaluation.

A workshop was held in Asheville, NC on 24 July 1995 to develop a strategy for implementing a merger between COADS and the UK Meteorological Office (UKMO) Main Marine Data Bank (MDB), as well as to discuss the historical digitization projects. The consensus of the workshop was to establish a continuing bilateral agreement between NOAA and the UKMO for marine data exchange, which came into effect on 16 September 1996. The COADS/MDB blend should also offer the opportunity for correction of significant problems in both data sets. For example, in “Dutch” (deck 193) data, which make up 12% of the pre-1970 COADS, sea level pressure was not translated from millimeters to millibars by NCDC because the conversion for gravity was not included; this fell outside the scope of the work at NCDC in 1968 that lead to creation of TDF-11.

Another major component of activities by CDC and NCDC, involving extensive cooperation and computer resources from NCAR, has been to extend and improve COADS, and its associated metadata, in phases. Following COADS Release 1, “interim” updates were completed on an annual basis to extend the period of record through 1991, until a full update for 1980-92, Release 1a, was completed in 1993 (Woodruff et al., 1993). Since

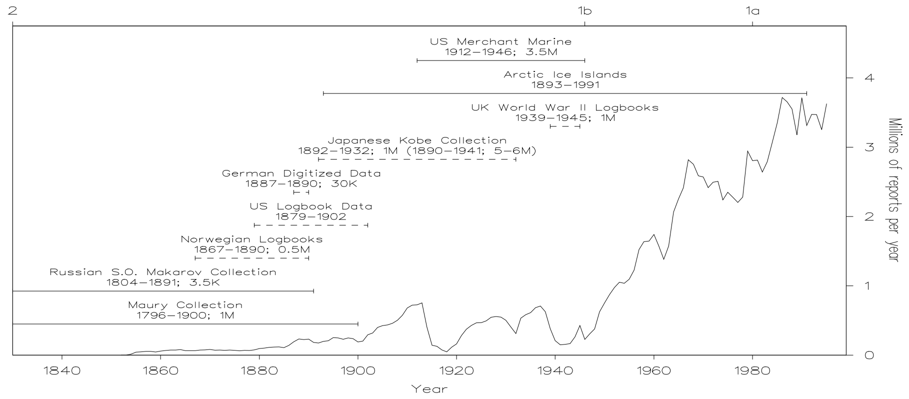


Fig. 4.8. Annual global marine reports after duplicate elimination (curve) for COADS Release 1 through 1949, continued by Release 1b through 1979, and by Release 1a through 1995. Horizontal lines span the time periods for data that have been collected and digitized (solid), or are partially digitized or proposed for future work (dashed), with the approximate numbers of reports shown in millions (M) or thousands (K). Labeled ticks along the upper horizontal axis mark the starting years for Releases 1a (1980), and 1b (~1946) and planned for Release 2 (1854, or earlier). Currently, only 1M reports from the Kobe Collection for 1892-1932 are planned for digitization, representing a subset from the 5-6M unkeyed reports (in parentheses).

then, the Release 1a data have been periodically updated, currently extending through 1995.

A variety of data additions were made for Release 1a, including replacement of many GTS ship reports by matching keyed logbook reports exchanged under WMO Resolution 35, because of typically higher quality and observational completeness. GTS measurements from drifting or moored buoys were also replaced by quality controlled data from Canada's Marine Environmental Data Service (MEDS), and from NOAA's Pacific Marine Environmental Laboratory (PMEL) and its National Data Buoy Center (NDBC). In addition, special fishing fleet data from the Inter-American Tropical Tuna Commission (IATTC) helped improve coverage in data-sparse regions of the equatorial Pacific Ocean.

As shown by, e.g., Wolter et al. (1989) and Wolter (1997), the 3.5 standard deviation trimming limits have proven overly restrictive for extreme climate anomalies such as the 1877-78 ENSO. It was for this reason that COADS Release 1a monthly statistics were produced in two versions. One version provides close compatibility with Release 1 data: the Release 1a “standard” statistics were restricted as nearly as possible to ship data, and trimmed using the Release 1 (1950-79) 3.5 standard deviation limits. In order to maximize coverage and provide a more accurate representation of extreme climate anomalies such as the 1982-83 ENSO, a second “enhanced” set of statistics included automated platform types in addition to ships, which was processed using the 1950-79 limits expanded to 4.5 standard deviations.

Release 1a data represent a crucial input to the NCEP/NCAR Global Atmospheric Reanalysis Project. In addition, we are providing Reanalysis with updated observations for earlier periods within the planned total scope of Reanalysis (starting approximately 1948), as part of COADS Release 1b processing. As of November 1996, we completed individual Release 1b observations for 1950-79; individual observations for the additional period 1948-49 will be completed at a later date if required by Reanalysis.

Similarly to Release 1a, a variety of important data additions were made for Release 1b. For example, Russia has provided its Marine Meteorological Data Set of ship data from the former Soviet Union extending back to 1888 (1980-90 data were used for Release 1a), and drifting Arctic “ice island” data back to 1950. Surface-level sea temperatures extracted from oceanographic profiles were added from the Levitus et al. [NOAA Tech. Report NESDIS 81, NOAA Atlas NESDIS 4, 1994]. World Ocean Atlas. Another important input for Release 1b was drifting buoy data gathered by MEDS for the FGGE period (1978-79), because FGGE drifting buoy data had to be omitted from Release 1 due to poorly documented data problems.

Data errors that were corrected or mitigated as part of Release 1b processing included addressing significant temperature biases in early GTS datastreams: an approximately +0.5 ˚C air temperature bias in 1966-69 data, and a -0.2 ˚C bias in air, sea surface, and dew point temperatures for 1973-April 1977. Moving backwards to the start of the Release 1b period the data mixture becomes largely ship data, but adverse trimming effects under the 3.5 standard deviation limits are still of concern, especially in view of new data corrections and data additions. Therefore, standard and enhanced sets of 2˚ monthly statistics, as defined for Release 1a processing, were also completed for 1950-79 as part of Release 1b.

In support of NOAA's Pan-American Climate Studies (PACS) Program, a set of global monthly statistics at higher spatial resolution (1˚ latitude x 1˚ longitude) was created for 1960-93 (**Fig. 4.9**). Individual observations from Release 1a through 1993, plus from the last two decades of Release 1b (1960-79) were utilized as input data. An additional set of 1˚ summaries was created for the equatorial region from 10.5˚N to 10.5˚S, with the grid reoriented with respect to the global set so that a 1˚ box straddles the equator (0.5˚N - 0.5˚S), since most PACS research activities are focused on the tropics.

All of the PACS 1˚ summaries were calculated in standard and enhanced versions, as for Releases 1a and 1b. Statistics were calculated for the 19 regular COADS variables plus three additional fields that are new to COADS that make up a separate group file: the cube of the wind speed, W^3, as well as the zonal and meridional contributions to the latent heat flux, $U(Q_s - Q)$ and $V(Q_s - Q)$. In addition to statistics such as the 1˚ box mean, standard deviation, and number of observations, the PACS products include robust measures (the median, and 1st and 5th sextiles), and centroids of observations in time and space.

A large collection of electronic documentation for COADS (Releases 1a and 1b, and PACS products) is publicly accessible using the World Wide Web (http://www.cdc.noaa.gov/coads/) or anonymous ftp. Updates and improvements to the documentation continue, as one part of our preparations for Release 2 of COADS: an update of the entire period of record 1854 (or earlier) to date planned for completion around the year 2000.

Contributed by: *H. Diaz, M. Alexander, C. Deser, and R. Pulwarty.*

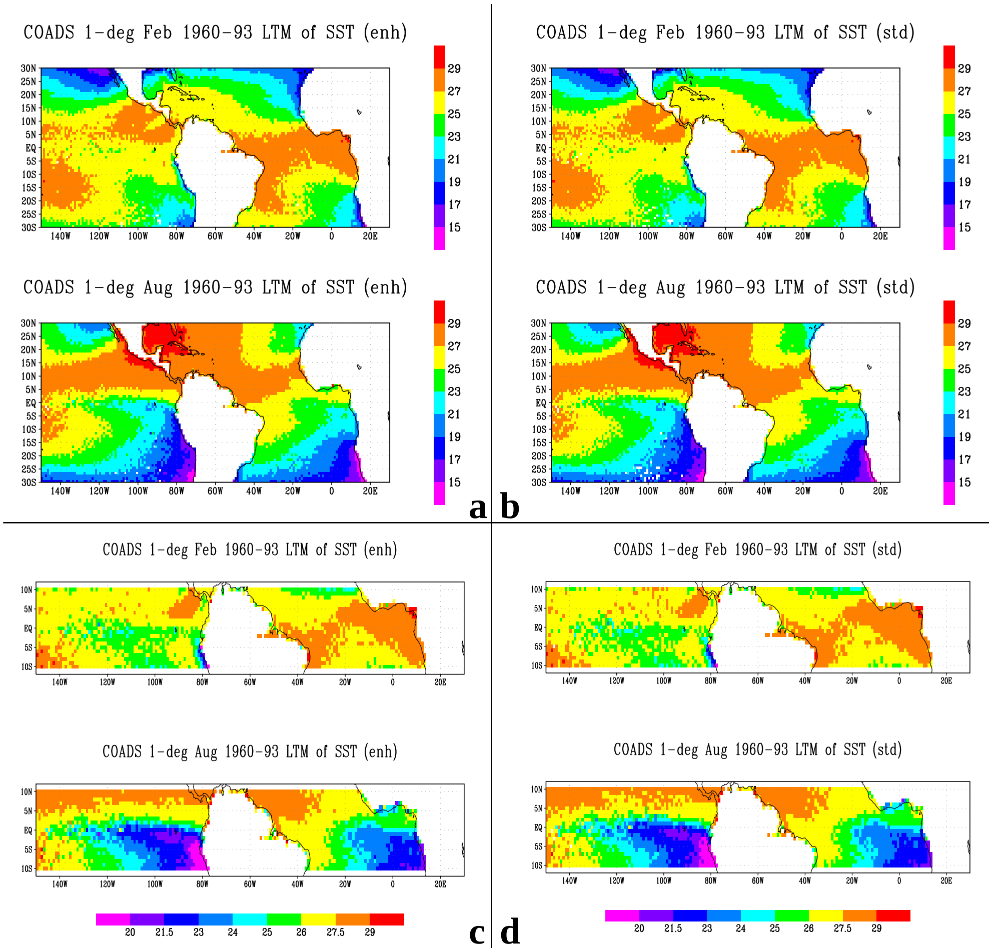


Fig. 4.9. Long-term (1960-93) mean sea surface temperature for February and August based on COADS 1˚ latitude x 1˚ longitude monthly summaries completed in support of NOAA's Pan-American Climate Studies (PACS) Program. The eight parts of this figure illustrate for two months the two spatial domains and the two statistics versions available: (a) Global enhanced (ships plus other platforms; 4.5 sigma trimming; shown here for the tropical Atlantic and Eastern Pacific); (b) Global standard (ships only; 3.5 sigma trimming; shown for tropical Atlantic and Eastern Pacific); (c) Equatorial enhanced (as in (a), but for a 21˚ latitude strip centered on the Equator); and (d) Equatorial standard (as in (b), for a 21˚ latitude strip centered on the Equator).

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