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EARTH SYSTEM MONITOR

U.S. Integrated Ocean Observing System

Data and communications infrastructure

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Congress has directed the U.S. marine environmental science communities to come together to plan, design, and implement a sustained Integrated Ocean Observing System (IOOS). The IOOS is envisioned as a network of observational, data management, and analyses systems that rapidly and systematically acquires and disseminates marine data and data products describing the past present and future states of the oceans. Existing and planned observing system elements will be integrated into a sustained ocean observing system that addresses both research and operational needs in the following areas:

- detecting and forecasting oceanic components of climate variability;
- facilitating safe and efficient marine operations;
- ensuring national security;
- managing resources for sustainable use;
- preserving and restoring healthy marine ecosystems;
- mitigating natural hazards;
- ensuring public health.

The OceanUS Office, which is responsible for planning and coordinating the development of IOOS, was established in 2000 under the auspices of the interagency National Oceanographic Partnership Program (NOPP). The IOOS is the U.S. contribution to the Global Ocean Observing System (GOOS). Planning for GOOS, an initiative of the Intergovernmental Oceanographic Commission, began in the early 1990's. GOOS is also a

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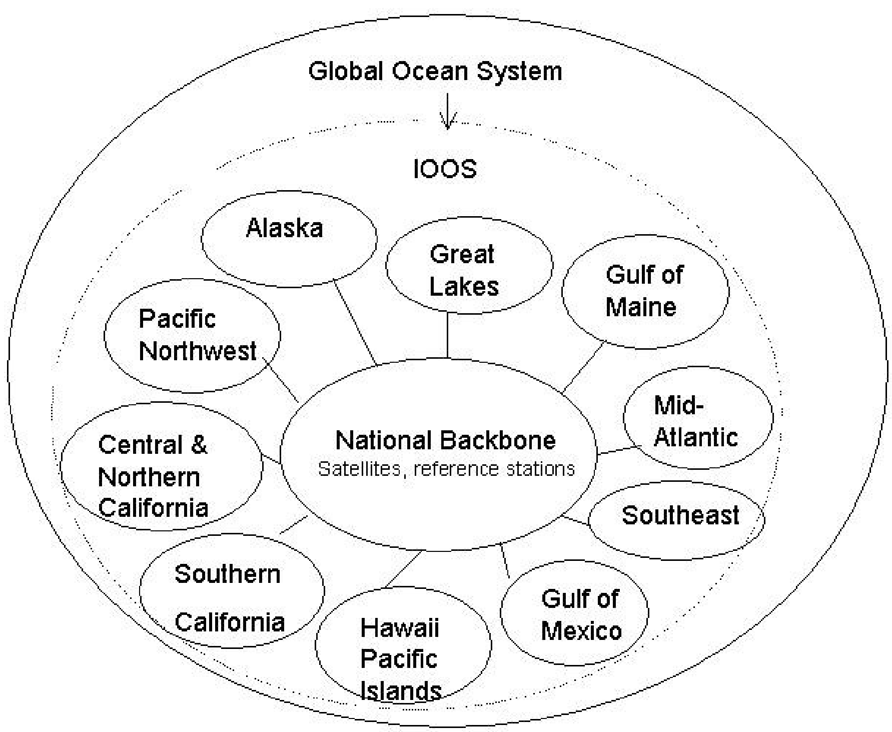

▲ **Figure 1.** The U.S. Integrated Ocean Observing System

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component of the Integrated Global Observing Strategy developed through a partnership of international agencies concerned with global environmental issues.

IOOS is developing as two closely coordinated components — global and coastal — that encompass the broad range of scales required to assess, detect, and predict the impacts of global climate change, weather, and human activities on the marine environment (Figure 1). The global component consists of an international partnership to improve forecasts and assessments of weather, climate, ocean state, and boundary conditions for regional observing systems, in support of GOOS. The coastal component blends national observations in the Exclusive Economic Zone (EEZ) with measurement networks that are managed regionally to improve assessments and predictions of the effects of weather, climate, and human activities on the state of the coastal ocean, its ecosystems and living resources, and the nation's economy. The coastal component encompasses the nation's EEZ, Great Lakes, and estuaries. Detailed information on the planning and implementation of the global and coastal components of IOOS can be found in the proceedings of the 2002 OceanUS Workshop (OceanUS, 2002); Parts I and II of the IOOS Implementation Plan (OceanUS, 2003a; OceanUS, 2003b); recent editions of the MTS Journal and Oceanography devoted to ocean observing systems (MTS, 2003; Oceanography, 2003), and the proceedings of the 2003 Regional Summit (OceanUS, 2003c).

IOOS is composed of three subsystems: the Observing Subsystem (collection of environmental measurements and their transmission from platforms); the Data Management and Communications Subsystem (DMAC - discovery and delivery of data within IOOS and interoperability with other relevant observing systems); and the Modeling and Analysis Subsystem (evaluation and prediction of the state of the marine environment). A coherent strategy for integrating marine data streams across disciplines, organizations, time scales, and geographic locations is central to the success of IOOS. The DMAC Subsystem is the primary integrating element of IOOS. It provides the linkages among IOOS components and partner organizations, as well as to systems in other disciplines (i.e., terrestrial and atmospheric), and to international marine data management systems.

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Data management & communications

In the spring of 2002, the OceanUS Office appointed the Data Management and Communications Steering Committee (DMAC-SC) to develop a detailed, phased implementation plan for this IOOS subsystem. The DMAC Plan (Hankin and DMAC-SC, 2003) consists of three main parts: Part I provides an overview of the system requirements, the unique challenges it presents, and the plan for addressing them; Part II presents the detailed implementation plan leading to an Initial Operational Capability for the DMAC subsystem within five years; and Part III, the Appendices, provides in-depth discussion of key technical topics.

IOOS Data Flow

IOOS observations originate at international, national, and regional observing systems (Figure 2, *page 5*). The raw measurements from these systems are transferred by various mechanisms (e.g., mail, telephone, radio and satellite transmission, microwave, and the Internet) to centers where primary data assembly and (typically) quality control occurs. Generally some form of primary data assembly is required before IOOS data can be utilized. This processing may involve, for example, hand entry of data from log sheets, or real-time conversion of instrument voltages to physical units.

The DMAC subsystem "begins" with the output from the primary data assembly centers. At the entry points to

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News briefs

New International Geophysical Year, IGY-2

The 50th anniversary of the International Geophysical Year (IGY) and of the World Data Centers (WDC) will occur in 2007. A resolution supporting IGY-2 was approved by the U.S. House and the Senate. The resolution states that the President should submit to Congress, by March 15, 2004, a report detailing the steps taken in carrying out the possible activities and organizational structures for IGY-2 in 2007-2008. The Directors of the National Academy of Sciences and the National Science Foundation and the Administrator of the National Aeronautics and Space Administration are tasked with preparing the report. The National Geophysical Data Center and the WDCs play an important role in IGY-2, as it is defined by the IGY-2 task team.

For NESDIS, the most significant element of IGY-2 is the electronic Geophysical Year and the creation of "virtual observatories." The electronic Geophysical Year (eGY) is intended to promote improved access to all geophysical data whether they reside in data centers, in laboratories, or on a scientist's web site. "Virtual Observatories" will improve the use of geophysical data by 1) organizing all available sources of data for a specific region and 2) merging these comprehensive data sources with data assimilation models and physical models to compute the best description of the environment for a given location and time. "Virtual Observatories" are needed by satellite operators to determine and mitigate the causes of operational anomalies and by the transportation industry to determine precise locations using GPS systems.

GOES space environment monitor supports Mars Mission

The Odyssey Spacecraft in orbit around Mars carries instrumentation to evaluate the radiation environment in the vicinity of Mars, to plan the design of future manned spacecraft and missions to the planet. The Martian Radiation Environment Experiment (MARIE) is a particle spectrometer that measures radiation (20-450 MeV) from solar energetic particle events and galactic cosmic rays. The ANSER Corporation is using the GOES energetic particle archives to provide a second point of reference for the MARIE data and to validate the results.

NOAA progresses toward parallel CORS-West facility

Representatives from NOAA Satellites and Information, NOAA Oceans, and NOAA Research, including the Space Environment Center (SEC) and Forecast Systems Lab (FSL) met with an audience of over 50 state and local government, industry, and university constituents on February 25 to celebrate progress toward the establishment of a Continuously Operating Reference Station (CORS)-Global Positioning System (GPS) parallel data facility in Boulder, Colorado. Talks focused on the CORS-West facility and the geo-location, meteorological, and space weather products created from CORS-GPS data.

The National Geodetic Survey (NOS/NGS) and National Geophysical Data Center (NESDIS/NGDC) are working together to establish a parallel facility that is geographically separate from the primary CORS facility in Silver Spring, MD. CORS-West would actively collect, process, distribute, and archive CORS data, providing uninterrupted services to users and ensuring the collection and access to these important data.

The value of CORS data to users was estimated (May 2002) at $72 million per year. This annual value has more than doubled every year since the inception of the CORS program in 1994. The parallel facility in Boulder, CO, ensures continued collection and access to these data in the event the primary facility in Silver Spring is down.

With the expanded use of CORS data in near real-time weather and space weather products, the Boulder facility provides faster access, a level of redundancy, and improved services - both to NOAA Research and to the surveying and geodetic community. This effort involves three NOAA line offices, plus the Space Environment Center which will soon become part of the National Weather Service, a fourth line office.

NOAA Multibeam III meeting

The Third NOAA Multibeam Sonar / Ocean Mapping Workshop was held at the National Geophysical Data Center in March 2004. Significant exchanges of data content requirements, processing streams, and product requirements were made between the various NOAA communities using multibeam systems: Coast Survey, Sanctuaries, Fisheries, Research, and Ocean Exploration. Of particular emphasis for this conference was an extended discussion of Fisheries' need for volumetric mapping of the water column for fish inventory analysis, a three-dimensional (rather than the traditional two-dimensional) use of multibeam mapping systems. Agreement was reached on the initial steps toward coordinating the generation of metadata and the cooperative planning of collection efforts. The critical concept developed was that ocean mapping needs to be managed NOAA-wide, as it represents a primary activity for all those offices involved with the "O" in NOAA. The three-day meeting included 15 presentations, two breakout sessions, a tour of the Forecast Systems Laboratories, "Science on a Sphere," and a tour of NGDC.

Climatography of the United States No. 20, 1971-2000 period

The Climatography of the United States No. 20 (CLIM20), Monthly Station Climate Summaries for the 1971-2000 period of record have been completed and will be available online in March 2004 (*http://www.nndc.noaa.gov/cgi-bin/climatenormals/climatenormals.pl?directive=prod_select*). The new CLIM 20 updates and expands the previous version, last published in 1985 and covering the period 1951-1980. The types of statistics include means, medians, extremes, mean number of days exceeding threshold values, and probabilities from monthly precipitation and freeze data. There is also a table for each station with heating, cooling, and growing degree days for various temperature bases.

The summaries can be ordered by individual station, state, or subscription through the National Oceanic and Atmospheric Administration's National Climatic Data Center Online Store. A CLIM20 CD-ROM product will be available by early summer 2004.

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the DMAC Subsystem, data share a common Data Communications Infrastructure - standards and protocols which support:

- IOOS-wide descriptions of data sets (via metadata);
- the ability to search for and find data sets of interest (data discovery);
- the ability to access data in an interoperable manner from client applications (data transport);
- the ability to review the data through common Web browsers (online browse).

The DMAC Subsystem also includes Archive Centers which, in the mature IOOS, will utilize the Data Communications Infrastructure for the receipt and distribution of data. The DMAC Subsystem "ends" with the delivery of data and data products in usable form to users who wish to have access to these data and data products, or to organizations and applications that produce value-added information products for end users. These information products include text forecasts, maps of ocean variables and coastal features, materials for educational curricula, and time series showing trends useful for resource managers.

DMAC subsystem - data communications infrastructure

The Data Discovery capability of the DMAC Subsystem depends on the existence of accurate and timely metadata accompanying all IOOS data sets. The DMAC Plan specifies that all IOOS metadata records must be compliant with the Federal Geographic Data Committee (FGDC) metadata standards. Metadata creation is typically the responsibility of the data providers.The DMAC Plan calls for tools and training to be made available to assist data providers with this task. The establishment of a community-based core metadata working group is recommended to develop an FGDC profile that addresses those elements that are shared in common by all DMAC metadata. The Plan also calls for additional working groups to address more specialized, discipline-specific needs. The working groups will decide which metadata standards to adopt, and how they need be extended to address conflicts in terminology. Tools and techniques for translation among different metadata standards are also discussed in the Plan.

A fundamental concept for DMAC is the "Web Services", which support the ability to connect independent data management systems. In the DMAC Plan, the term Web Services is used to refer to reusable software components based on the eXtensible Markup Language (XML) that provide a standardized way for computer systems to request data and data processing from one another. These services use Hypertext Transfer Protocol (HTTP), the ubiquitous communications protocol of the World Wide Web (Web). They are accessed through the familiar URIs (Universal Resource Identifiers) that begin with "http://". DMAC will define uniform means to access diverse data and metadata management systems through the use of Web Services.

Data Discovery will be achieved through searches of IOOS FGDC metadata records using both commercial Web search engines such as *Google* and *Yahoo* and more specialized geospatial searches. DMAC metadata searches will allow users to formulate queries through Web portals (Web sites), and will also support machine-to-machine searches using Web Services interfaces. More advanced data discovery methods such as the Semantic Web (*http://www.w3.org/2001/sw*) will be evaluated for use by DMAC and incorporated as they mature.

As described earlier, IOOS data will be accessible through DMAC Data Transport standards and protocols, subsequent to primary data assembly (Figure 1). The OPeNDAP [Open source Project for a Network Data Access Protocol; this is a non-profit corporation formed to develop and maintain the middleware formerly known as the Distributed Ocean Data System (DODS); see *http://www.unidata.ucar.edu/packages/dods*] data access protocol is the most widely tested and accepted system for distributed data access within the marine sciences. OPeNDAP, which has been in use since 1995, underlies the National Virtual Ocean Data System (NVODS); NVODS was created with support from a Broad Agency Announcement (BAA) issued by the National Oceanographic Partnership Program in 2000. OPeNDAP employs a discipline neutral approach to the encapsulation of data for transport (data structures or vocabulary are not tied to a single field of study). This feature of OPeNDAP is very important for IOOS because of the wide variety of data types and users it encompasses. The DMAC-SC has designated OPeNDAP as an initial operational component for transport of gridded data, and a pilot component for delivery of non-gridded data.

"Operational" is the designation used in IOOS for activities and systems in the fourth, most mature stage of development; earlier stages are research, pilot, and pre-operational; see the IOOS Implementation Plan Part I. "Pilot" is the designation used in IOOS for activities and systems in the second stage of development leading to the operational level.

All data in the mature DMAC subsystem must be delivered with consistent syntactic and semantic data models (or families of data models) to achieve the desired level of interoperability. Syntactic refers to the atomic data types in a data set (ie., ASCII, binary, real, etc.), the data structures, dimensions of the data arrays, etc; semantic refers to the meaning of variables (ie., T represents ocean tempera ture), special value flags (ie., -1 means missing data, 0 means land data, etc), units, etc. The DMAC Plan calls for community-based working groups to be convened to develop comprehensive data models. The semantic data model must harmonize with existing models in other data communities, especially those models used by geographic information systems (GIS) and climate modeling. It must standardize controlled vocabularies, including the encoding of ocean biological and taxonomic data such as those used by the Ocean Biogeographic Information System (OBIS); OBIS is a globally distributed network of systematic, ecological, and environmental data systems (*http://iobis.org*). It must also describe a diverse range of

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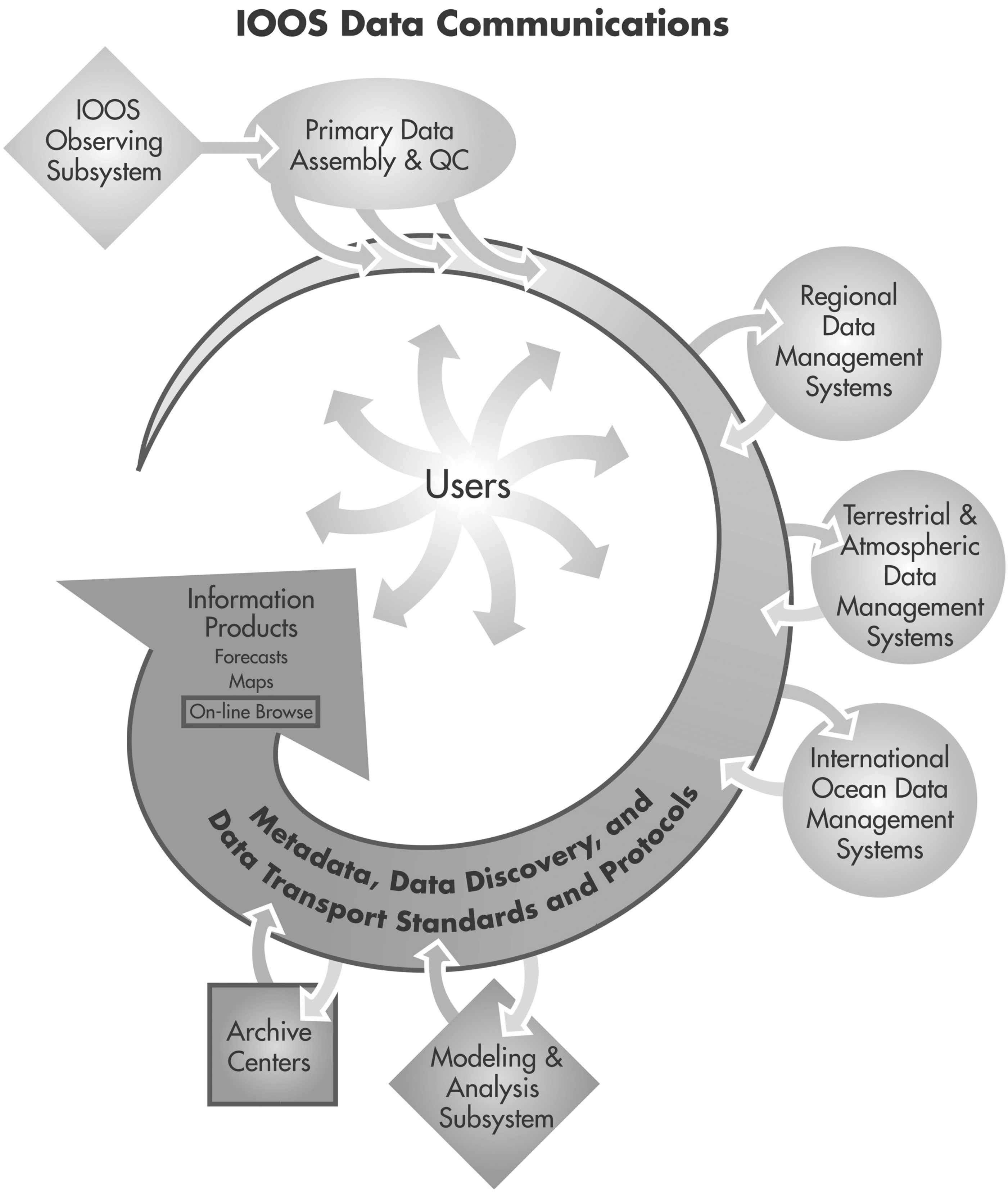

▲ **Figure 2.** Data flow in the U.S. Integrated Ocean Observing System (IOOS). Elements that are outlined in darker gray are classified as components of DMAC.

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data structures, including spectral and finite element models, arbitrary curvilinear coordinate systems, and multi-level hierarchies of *in situ* measurements. Users of the mature DMAC Subsystem will find that software applications which they use for scientific analyses and product generation are adapted to work directly with DMAC Web Services. Access to distributed IOOS data will be transparent.

A basic browsing and visualization capability that extends across all data in the DMAC Subsystem will be required for effective management. Standard web browsers will provide uniform access to geo- and time-referenced graphics. Users will reach the On-line Browse functionality through DMAC Data Discovery, which can then use DMAC Data Transport protocols to access specific subsets of data. The principle users of the Online Browse will initially be marine data specialists who have responsibilities for managing elements of IOOS, however, the capabilities will doubtless be useful to many other user groups. An NVODS rendering and visualization tool, the Live Access Server (LAS), has proven to be effective in the delivery of Online Browse capabilities across a broad range of marine data types; *http://www.ferret.noaa.gov/LAS*. The LAS has been designated as an initial pre-operational component of Online Browse by the DMAC-SC; "pre-operational" is the designation used in IOOS for activities and systems in the third stage of development leading to the operational level. Other emerging technologies such as Open GIS may be integrated into the Online Browse and Data Transport solutions as they mature.

DMAC Subsystem - data archive and access

A DMAC Archive working group will be convened early in the implementation of the DMAC Subsystem. This group will establish guidelines which must be adhered to by all IOOS Archive Centers. The working group will inventory existing archives and anticipated data streams to ensure that all data deemed appropriate for archival have designated Archive Centers. They will also participate in the development of DMAC metadata standards to ensure that elements essential for data stewardship are included. Key features of the Archive Centers are as follows:

- Data will be accessible online to the greatest extent possible, at no cost to users. Data from offline sources will similarly be available at not more than the cost of providing service.
- Data and metadata will be made available using DMAC Data Trans port protocols, metadata standards, and Data Discovery interfaces.
- Data and metadata migration plans will be developed to accommodate evolution of media and systems, and ensure long-term preservation of irreplaceable data. All relevant IOOS data policies and Federal regulations will be followed.

Next steps

Planning and concept development for the IOOS are well underway. Implementation plans are being formulated and budget initiatives are moving forward. The ocean community is working with the OceanUS Office to establish regional associations which will oversee coastal observing system development on a regional scale. A National Federation of Regional Associations is being established to enhance cooperation among regions and provide a unified national interface for these efforts. The global component of IOOS is more advanced than the coastal component, but further expansion is needed in the global arena as well to meet IOOS goals.

The DMAC Plan provides a roadmap for implementation of a data communications infrastructure that will meet the needs of the marine environmental observing community. The information technology required to meet most of the DMAC requirements, while challenging, can be developed from existing capabilities through relatively straightforward software engineering. The major challenge facing DMAC is one of coordination and cooperation among the IOOS partners and user communities. DMAC will only succeed if barriers to participation are minimized, and participants realize that adopting DMAC data and metadata standards, communication protocols, software, and policies is to their advantage. A strong outreach program is critical to foster continued coordination, cooperation, and support for IOOS within the regional, national, and international marine environmental observing communities.

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The Northern Hemisphere annular mode in the ocean

Boundary currents and heat transportation

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Strong western boundary currents in the Northern Hemisphere oceans transport heat from the warm tropical regions to the midlatitudes, where much of the heat is fluxed to the atmosphere as the warm currents encounter cooler air masses. Some of this heat continues on into the subpolar gyre to warm the high-latitude regions and some heat is stored in a region of recirculating currents with deep wintertime mixed layers.

Observations of sea surface height (SSH) anomalies from the TOPEX/POSEIDON radar altimeter since 1992 suggest that there are large interannual-to-decadal variations in the structure of these current systems (Qiu, 2000; Vivier et al., 2002; Dong and Kelly, 2004). In Figure 1 the SSH anomaly has been combined with an estimate of the mean SSH to illustrate the nature of the circulation changes. Large-scale anomalies occur just to the south of the current core (the closely spaced SSH contours); maps of SSH show similar changes in the Atlantic and in the Pacific, with an expanded region of high SSH in 1993 (not shown) and 1999, and a contracted region of high SSH in 1996. Changes in SSH correspond to changes in heat content, because a warming water column expands, increasing SSH.

Dominant modes of heat content

Because the SSH time series (10 years) is too short to give a reliable estimate of the dominant modes of heat content variability, we compute the empirical orthogonal functions (EOFs) of heat content from the Joint Environmental Data Analysis Center (JEDAC) for 1955-2001. The fraction of variance

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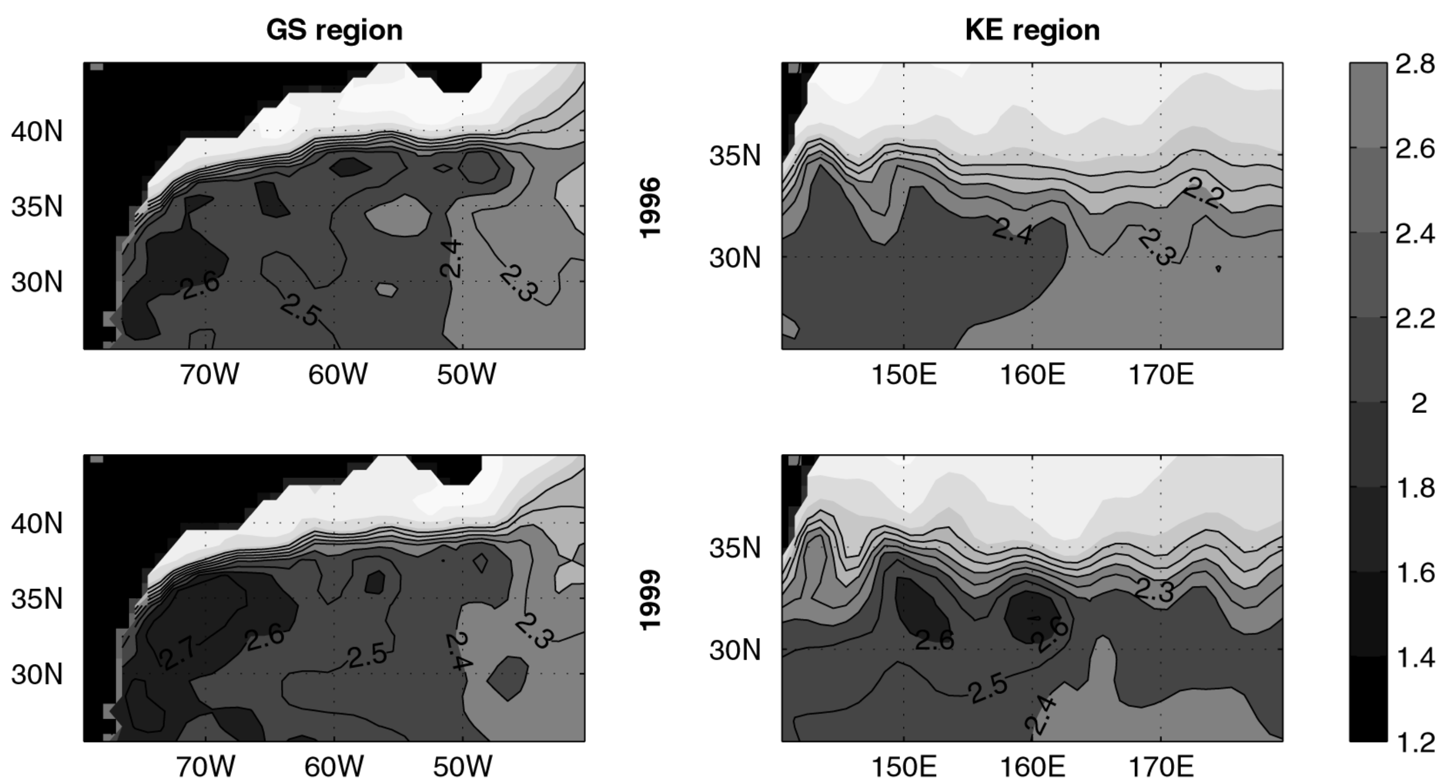

▲ **Figure 1.** Sea surface height maps from the TOPEX/POSEIDON altimeter. At the left is the Gulf Stream region in the North Atlantic, and at right is the Kuroshio Extension region in the North Pacific, for years (top) 1996 and (bottom) 1999. Units are in meters. More positive SSH indicates more heat stored in the ocean.

Northern hemisphere, *from page 7*

in the first two modes is 26% and 16% respectively, and both are significant at the 95% level (Kelly and Dong, *in press*). The first mode of heat content (Figure 2a) shows maxima in the extension regions of the western boundary currents, with coherent variations between the North Atlantic and the North Pacific. Variability in the second mode (not shown) is primarily in the Pacific Ocean. The heat content time series reveal similarities with climate indices: the first mode of heat content (Figure 2b) resembles the Arctic Oscillation (AO) Index (Thompson and Wallace, 1998), whereas the second mode of heat content resembles the Pacific Decadal Oscillation (PDO, Hare and Mantua, 2000).

An EOF analysis of SSH from the altimeter of 1992-2002 gives modes (not shown) that resemble those of the JEDAC heat content, but with the first and second mode order reversed. The reversal of the mode order suggests that the Pacific mode variance was larger during the 1990s than was typical for the longer period. The SSH mode time series also resemble these same climate indices, with the coherent mode (EOF 2) resembling the AO.

Northern Annular Mode in the ocean

The Northern hemisphere Annular Mode (NAM, Wallace and Thompson, 2000), describes zonally coherent fluctuations in sea level pressure (SLP). The AO Index is the principal component (time series) of the SLP mode. A positive AO corresponds to anomalously strong westerlies throughout the northern hemisphere.

Coherent variations of heat content are correlated (r = 0.49, significant at 95%), with AO leading the heat content by 13 months, which suggests that the heat content anomalies are caused by changes in the strength of the midlatitude westerly winds. The simplest explanation, that stronger winds cause larger air-sea fluxes and therefore a loss of ocean heat, can be ruled out by the sign of the correlation (Figure 2). Strong westerlies correspond to high heat content.

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The upper ocean heat budget

To understand the causes of observed fluctuations in ocean heat content and SSH, parallel studies of the upper ocean heat budget were conducted for the western North Pacific and North Atlantic (Vivier *et al.*, 2002; Dong and Kelly, 2004). A simple upper ocean layer model was forced by surface heat fluxes, winds, and currents to predict temperature for the regions shown in Figure 1. Geostrophic velocity was specified from altimeter data and Ekman velocity was estimated from wind stress. The North Atlantic and the North Pacific heat budgets both showed that advection is the dominant term responsible for the interannual changes in upper ocean heat content; net surface heat fluxes are nearly as large as the advection term, but not consistently correlated with the tendency of heat content. The contribution of geostrophic currents to advection is substantially larger than that by the Ekman component (Qiu, 2000; Dong and Kelly, 2004).

Based on these heat budget studies, we argue that the observed changes in heat content reflect changes in heat transport caused by changes in ocean circulation, not by air-sea fluxes. Therefore, the correlation with strong westerlies likely reflects a strengthening of ocean circulation that in turn causes an increase in advection.

The heat content anomalies south of the western boundary currents are caused by changes in the upper ocean thermal structure, in waters that are part of the upper ocean mixed layer only in winter. Positive anomalies of heat content (and SSH) are negatively correlated with the thickness of the 18-degree layer (subtropical mode water) in the Gulf Stream region, based on a 50-yr record (Kwon, 2003; Dong, 2004). A similar relationship between the mode water layer thickness and fluctuations in the Kuroshio Extension has been found by Yasuda and Hanawa (1997). The negative correlation means that subtropical mode water contributes a heat content deficit to the upper ocean.

Heat flux anomalies forced by heat content

During periods of high heat content in the western boundary currents, fluxes of heat from the ocean to the atmosphere are also anomalously large. To estimate the effect of the coherent heat content anomalies (Figure 2a) on air-sea fluxes, we regress the NCEP/NCAR net surface fluxes onto the first mode of heat content (Figure 2b). The regression coefficients (Figure 3) are negative with maximum amplitudes in the western boundary current extension regions, consistent with regions of high heat content forcing anomalous fluxes of heat from the ocean. The magnitude of these flux anomalies is as large as 15-25 watts per square meter, approxmately 20% of the annual mean oceanic heat loss in these regions.

The association of larger oceanic heat losses with increased ocean heat con itent, caused by advection, suggests that the ocean may be forcing changes in the atmosphere in the vicinity of the western boundary currents on interannual-to-decadal time scales. The idea that the western boundary currents force an atmospheric response has been raised by numerous authors, particularly in regard to changing the wintertime "storm tracks" (Rodwell *et al.*, 1999; Nakamura et al., 1997; Joyce *et al.*, 2000).

Conclusions

A surprising fraction (26%) of the variations in midlatitude heat content are coherent between the North Atlantic and the North Pacific and correlated with the Northern hemisphere Annular Mode (NAM) or Arctic Oscillation (AO). These coherent variations have their largest amplitudes in the extension regions of the northern hemisphere midlatitude western boundary currents, the Gulf Stream and the Kuroshio Extension. Although it is tempting to attribute the ocean heat content variations to changes in the surface fluxes

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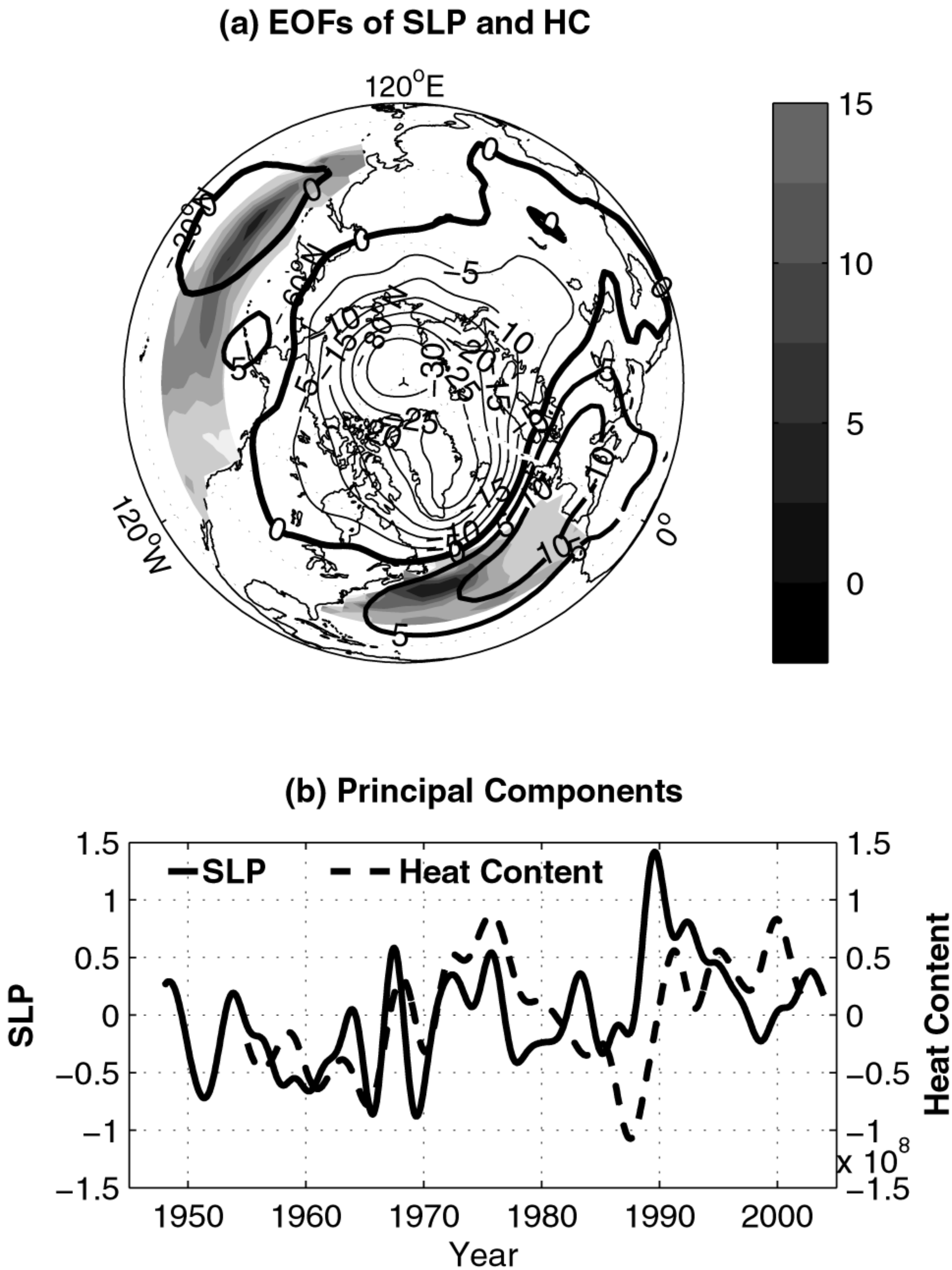
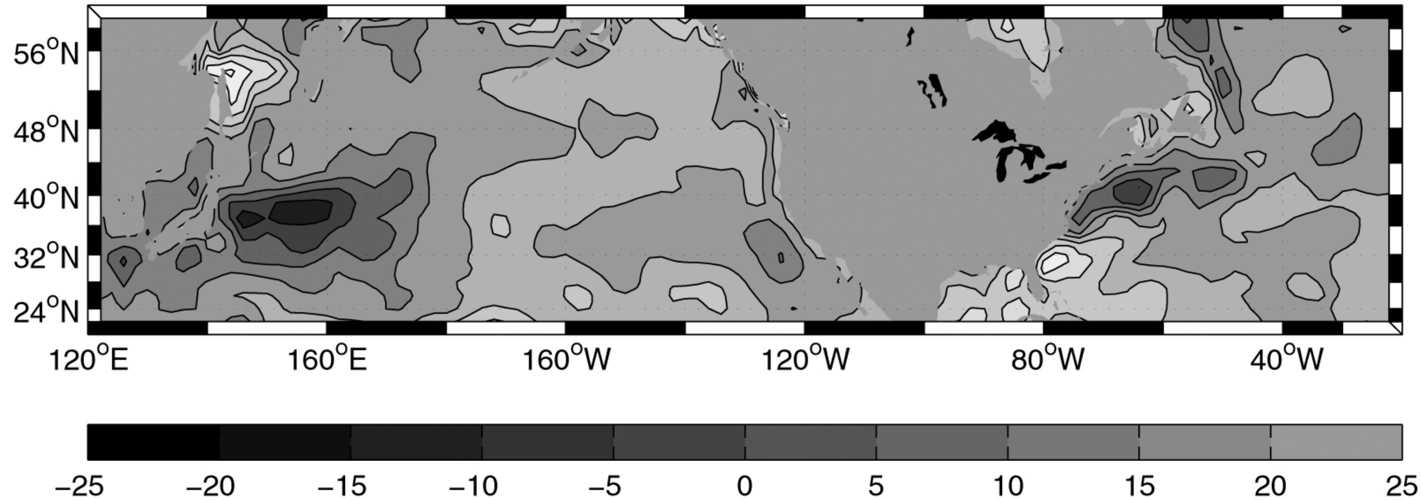


▲ **Figures 2a,b.** Northern Hemisphere Annular Mode. At top (a) are the first EOF's of heat content (colors) and sea level pressure (contours), and below (b) are the time series of SLP (Arctic Oscillation Index, solid) and heat content (dashed). Heat content and SLP modes are negatively correlated with the AO leading heat content anomalies by 13 months.



▲ **Figure 3.** Relationship of net surface flux to heat content. Regression coefficients of net surface flux onto the first EOF of heat content (Figure 2b). Negative values indicate flux of heat from the ocean to the atmosphere associated with positive heat content anomalies.

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associated with changes in wind speed, the sign and phase of the correlations is inconsistent with a passive response of the ocean to air-sea heat fluxes.

Studies of the upper ocean heat budgets near western boundary current extensions have shown that the heat content variations are caused by ocean advection, rather than by surface fluxes. Much of the anomalous heat from advection is stored south of the boundary currents, in the subtropical mode waters. The source of the changes in ocean advection, which in turn cause most of the interannual changes in heat content, appears to be forcing by midlatitude winds.

Changes in ocean heat content have implications for the interannual-to-decadal scale climate variations through their contributions to air-sea fluxes: ocean heat content anomalies force fluxes, rather than the other way around, as in the ocean interior. The air-sea flux anomalies associated with changes in ocean heat content are of the order of 20% of the annual mean value. Although the geographical extent of these regions is small, they contribute most of the midlatitude air-sea fluxes.

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Upwelling on the central California coast

An introduction to the Sanctuary Integrated Monitoring Network

Josh Pederson, Sarah Smith, and
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Monterey Bay National Marine Sanctuary

The Monterey Bay (California) National Marine Sanctuary is an internationally recognized location for marine research, resource management, and policy. Over forty institutions and organizations in the greater Monterey Bay area are currently conducting research, which includes long-term monitoring programs that are essential to the further understanding and health of the marine ecosystem.

The Sanctuary Integrated Monitoring Network (SIMoN) serves as a focal point to integrate the existing monitoring programs and to identify gaps in information. SIMoN makes the monitoring data available to managers, decision makers, the research community, and the general public. More information on SIMoN can be found at the website: *http://www.mbnms-simon.org.*

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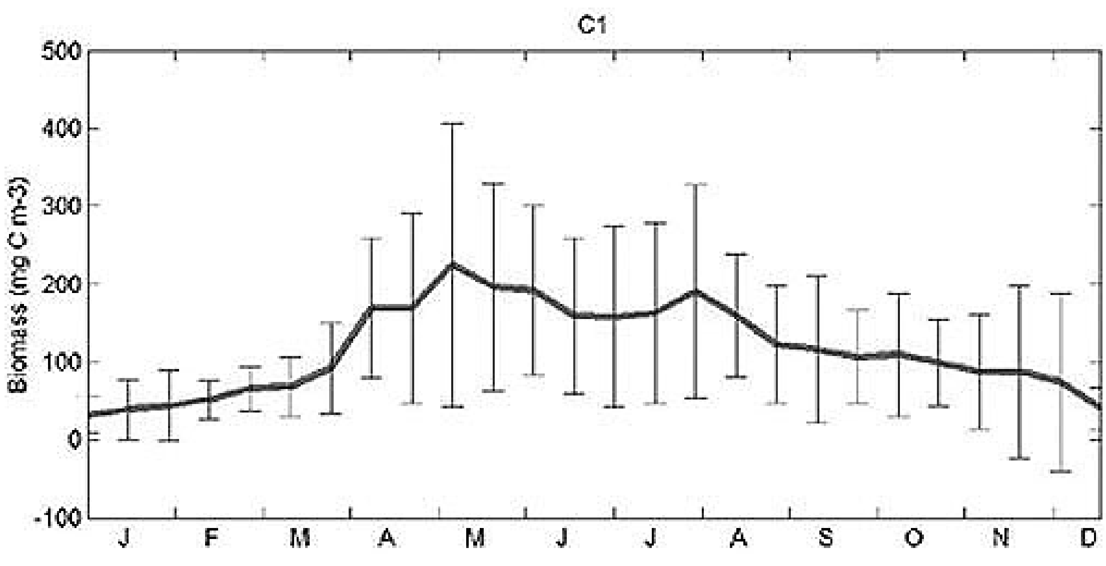
One of the major studies in the Sanctuary that SIMoN serves is that of the central coastal upwelling, which typically begins in March and ends around July. The effects of this seasonal occurrence can not only be seen in marine organisms such as phytoplankton, zooplankton (Figure 1), and the fish and marine mammals that feed upon them, but in the weather as well. The traditional foggy summers on the Central California coast are attributed to the physical interaction between the warm summer air and the newly upwelled cold ocean surface waters. As these waters cool the summer air, moisture collects and forms the coastal fog common to the Sanctuary.

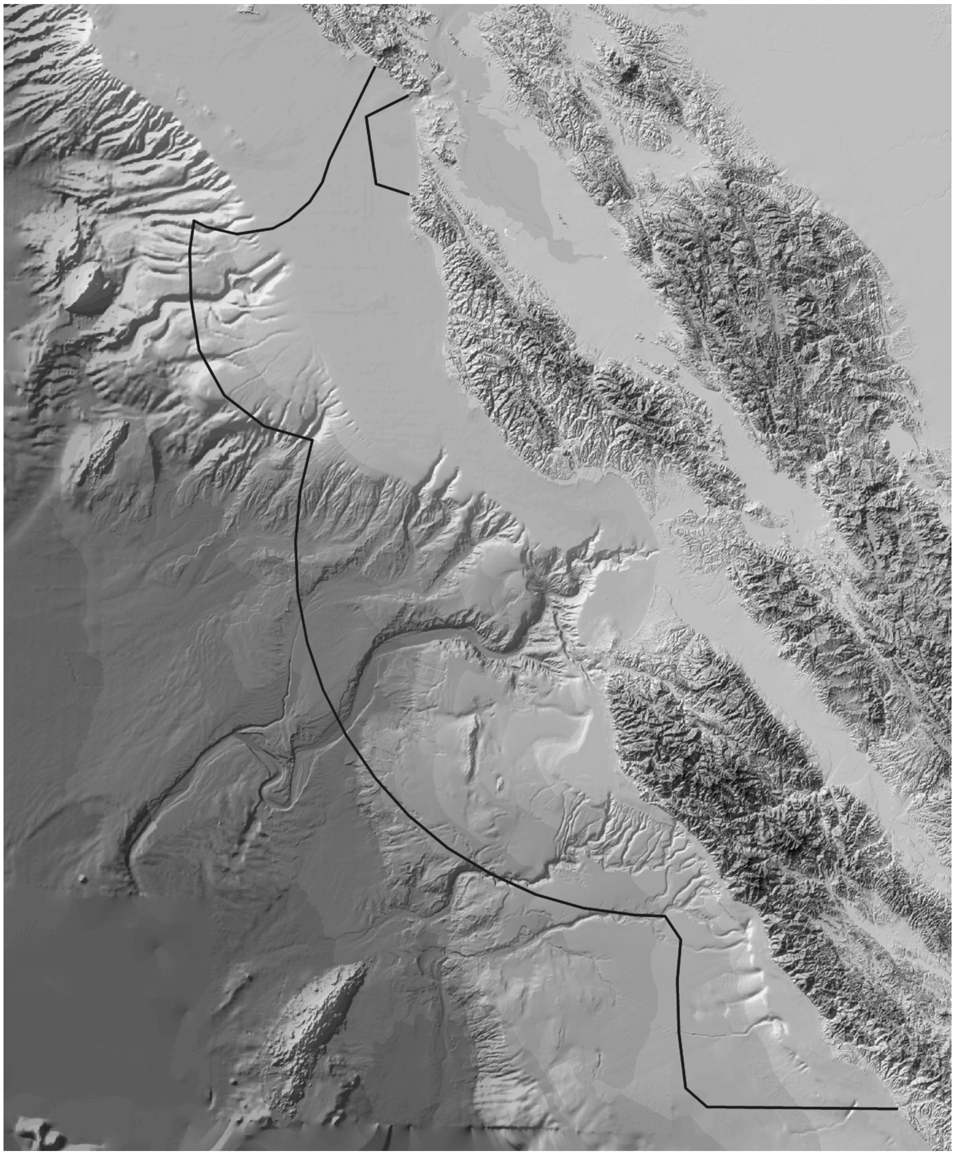
Scientists have developed instruments and technology to detect upwelling at the level of the primary producers. One instrument, the fluorometer, detects pigments, primarily chlorophyll, that phytoplankton use to perform photosynthesis. Chlorophyll measurements are used by oceanographers to determine the level of biological productivity throughout the food chain. Satellite imagery is used to detect pigmentation of the phytoplankton which reveals the quantity and distribution of phytoplankton over a given area of the ocean.

In the Monterey Bay National Marine Sanctuary (Figure 2, *page 12*) a variety of research groups are dedicated to collecting and analyzing information about the upwelling process. The UC Santa Cruz Center for Integrated Marine Technologies (CIMT) is collecting data on wind, primary productivity, krill, ocean temperature, seabirds, whales, and other components of the upwelling system. This data is analyzed and integrated to produce an enhanced understanding of the relationship between primary productivity and higher trophic level organisms such as fishes, marine mammals, and seabirds.

— continued on page 12



▲ **Figure 1.** Krill biomass increase during the typical upwelling period of 2001. Image: MBARI.



▲ **Figure 2.** Map of the Monterey Bay National Marine Sanctuary region; image from the SIMoN home page at *http://www.mbnms-simon.org*.

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The Monterey Bay Aquarium Research Institute (MBARI) also studies coastal upwelling in the Sanctuary. The Simulations of Coastal Ocean Physics and Ecosystems (SCOPE) project at MBARI assimilates data from satellites and ocean sensors to model the interconnected physical, chemical, and biological processes associated with upwelling. These models will help understand the distribution of marine mammals, seabirds, and fish during a period of upwelling, and will help resource management as well as direct future research projects and observational efforts.

With so many marine organisms utilizing the upwelling process for food and reproduction, it is important that Monterey Bay National Marine Sanctuary staff understand the dynamics of this annual process in order to effectively manage these interconnected resources during this time of the year. Fortunately, there are programs such as CIMT and SCOPE that are dedicated to enhancing the Sanctuary's knowledge of this incredible oceanic phenomenon. ■

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