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EARTH SYSTEM MONITOR

Coral reef mapping: local partnerships in the Pacific support national effort

Geographic Information Systems help manage fragile coral reef ecosystem

A guide to NOAA's data and information services

INSIDE

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Coral reefs show us the benefit of partnerships: the plant life (algae) and the animal (coral) maintain a symbiotic union that supports their existence in the tropical, shallow, oceanic regimes of our planet. Partnerships are advantageous as well to diverse organizations with common goals of understanding, managing, and preserving these natural habitats. Across the Pacific, various agencies have come together to form the Marine Ecosystem Geographic Information System (GIS) working group (MEGIS). This group in turn is partnering with the U.S. Coral Reef Task Force (CRTF), an executive initiative to preserve coral reef ecosystems of the U.S. and U.S.-affiliated islands in the Caribbean and Pacific.

Within the CRTF, a Mapping and Information Synthesis Working Group (MISWG) has been formed with a similar goal of MEGIS—to develop data layers for a GIS of nearshore benthic habitats within tropical and subtropical zones as has recently been accomplished for the Florida Keys (NOAA, 1998). But considering the proportion of coral coverage in Hawaii and U.S. affiliated islands in the Pacific relative to the mainland U.S. and affiliations in the Caribbean (Figure 1), it is clear that the MEGIS significantly augments the MISWG.

The days of shuffling through paper atlas charts and tabular data are coming to an end, thanks in part to the technological convenience of modern GIS tools. The ability to have not only scientific observations and locations of historic surveys, but various maps such as management jurisdictions, cultural sites, and coastal population density, greatly enhance the value of GIS over traditional resources.

For example, the grounding of a tanker on a coral reef would signal the immediate response of the Natural Resource Damage Assessment (NRDA) teams. With a CD-ROM or online database loaded into a GIS, vast quantities of information could rapidly be disseminated to the ephemeral sampling teams and the multi-agency working groups. In addition, the historic maps of coral coverage would be essential as a baseline for the ensuing legalities of cost recovery.

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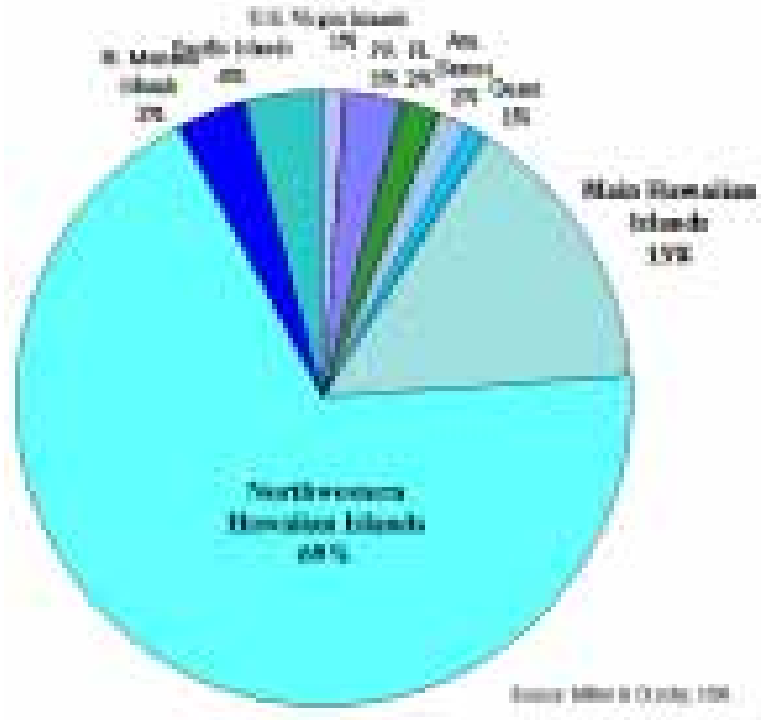

▲ **Figure 1.** Distribution of coral reef areas in the United States and affiliated islands. The Hawaiian islands comprise almost 85% of all coral reef area under U.S. jurisdiction. Source: Miller, S.L. and M.P. Crosby, 1998, "The extent and condition of U.S. coral reefs," in *NOAA State of the Coast Report*, Silver Spring, MD.

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Coral reef mapping, *from page 1*

Marine Ecosystem GIS Working Group

Coral reef and coastal interests in the Pacific overlap among many Federal, state, and county governmental offices, university laboratories, private consultants, non-governmental organizations (NGOs), commercial ventures, sports clubs, and the general public. The primary governmental bodies associated with management in the coastal area are summarized in Table 1 and the complex multi-jurisdictions are visually depicted by zone in Figure 2. Due to the greatly varying survey techniques and data storage formats, as well as the lack of readily available catalogs of information as to what is available at each office, it is difficult for policy makers and other stakeholders to easily integrate this information.

To address the issue of monitoring standards, the Hawaii Coral Reef Monitoring Workshop (Maragos, 1999) was held in June 1998, with over 100 participants from primarily Federal, state, and university offices. This workshop provided some initial discussion among data managers from the different affiliations. To address the needs for consolidated data products among the various agencies, the MEGIS was formed.

The MEGIS, spearheaded by Mr. Kevin Foster of the USFWS, held its first meeting in August 1998 to begin addressing how to best centralize and standardize the information as maintained by the multi-agency body. One of the obvious contemporary options was to strive to develop a common GIS database for Pacific marine ecosystems. The group subsequently has had additional meetings separately for resource managers and technical teams. The resource managers consist of biological experts whose main task is to prioritize potential data layers for the GIS. The resource managers also oversee data exchange among the agencies. It was unanimously agreed that free and open exchange take place. The technical

— *continued on page 4*

▲ **Table 1.** Governmental bodies involved in coastal area management.

Organization	Category	Acronym
Waste Water Management Division	County	WWMD
Bishop Museum of Natural Sciences	State	BMNS
Coastal Zone Management Program	State	CZM
Department of Agriculture	State	DOA
Clean Water Branch, Dept of Health	State	CWB,DOH
Division of Aquatic Resources, Division of Land and Natural Resources	State	DAR,DLNR
Department of Transportation	State	DOT
Hawaii Institure of Marine Biology, University of Hawaii	State	HIMB, UH
School of Ocean Earth Science and Technology, University of Hawaii	State	SOEST
Waikiki Aquarium	State	WA
Marine Laboratory, University of Guam	U.S.-Flag Is.	UOG
Guam Coastal Management Program	U.S.-Flag Is.	GCMP
Coastal Resource Management for Commonwealth of Northern Mariana Is.	U.S.-Flag. Is.	CRMS,CNMI
East-West Center	Federal	EWC
Dept of Commerce of American Samoa	Federal	ASDOC
Army Corps of Engineers	Federal/DoD	ACE
National Marine Fisheries Service	Federal/DoC	NMFS
National Oceanographic Data Center	Federal/DoC	NODC
National Ocean Service	Federal/DoD	NOS
US Fish and Wildlife Service	Federal/DoI	USFWS
US Geological Survey	Federal/DoI	USGS
US National Park Service	Federal/DoI	USNPS

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Tsunami research recognized in Scientific American

An article entitled "Tsunami–Predicting Destruction by Monster Waves" by Frank I. Gonzalez of NOAA's Pacific Marine Environmental Laboratory in Seattle appeared in the May 1999 issue of Scientific American. The article begins with an account of the Papua New Guinea tsunami of July 1998. Tsunami threats in general are discussed and makes the statement: "Historical patterns of their occurrence are revealed in large databases developed by James F. Lander, Patricia A. Lockridge and their colleagues at the National Geophysical Data Center (NGDC) in Boulder, Colorado." Later in the article, a reference is made to Jim Lander's work in cataloguing tsunamis affecting the United States coastal areas. The NGDC publication, "United States Tsunamis 1690-1988," heads the "Further Reading" list at the conclusion of the article.

Climate reference network proposed

A meeting was convened by NCDC Director Thomas R. Karl at the National Climatic Data Center (NCDC) March 23, 1999, for laying the foundation for accomplishing the work to rebuild the cooperative observers system into a true climate observing system. The meeting was an informal open discussion among NCDC, National Weather Service , U.S. Department of Agriculture representatives, and others to plan necessary Co-op Network improvements. NCDC will manage the proposed Climate Reference Network; NWS will manage Cooperative Modernization Planning, and Replacement of Punched Paper Tape Rain Gauge Recorders. Important items discussed included communication requirements, possible acquisition of up to 8,000 surplus Census PCs, and the additional funds needed in out-years for an adequate cooperative modernization.

IEEE Symposium on mass storage systems

NGDC's John Kinsfather presented a paper titled "The NOAA Virtual Data System, Improving Access to and Management of Federal Environmental Data." Other talks of interest included discussions on various storage media, trends in data storage fields, and industry roadmaps and projections for the next five years.

News briefs

NGDC archives thousand-year climate reconstruction

A new one thousand-year climate reconstruction and supporting data have been archived at the NGDC Paleoclimatology Program. The paper published by Mann, Bradley, and Hughes in *Geophysical Research Letters* concludes that the 1990s was the warmest decade, and 1998 the warmest year, in the past millenium. Warming observed in the 20th century also counters a millennial-scale cooling trend, which is consistent with long-term astronomical forcing.

NESDIS supports Southern African Development Community (SADC)

NESDIS scientists collaborated in an invited submission to the U.S. Agency for International Development, supporting the Southern African Development Community (SADC). The overall theme of the cooperation is capacity-building within southern Africa, in economically beneficial areas of environmental information access and management. SADC comprises most African countries south of the Equator. Major participants in the process were the National Climatic and Geophysical Data Centers, Office of Research and Applications, NOAA and NESDIS Interagency Affairs. Topics suggested included adapting experimental NESDIS dat sets for possible use by SADC, and the fostering of improved environmental data stewardship within SADC countries.

U.S.-Russian Arctic Meteorology Atlas under development

A workshop for the development of the Environmental Working Group (EWG) Arctic Meteorology Atlas took place at NGDC's affiliated National Snow and Ice Data Center (NSIDC) on March 15-18. Two scientist from the Arctic and Antarctic Research Institute in St. Petersburg worked with the NSIDC team to review data and further develop the atlas. The atlas is third in what will be a set of four conceived by the U.S.-Russian Joint Commission Environmental Working Group's Subgroup on Arctic Climatology. The release of the first atlas was announced by Vice President Gore in a press conference at the National Geographic Society in February 1997. That atlas, an oceanography atlas, is especially notable for the fields it contains that were derived from classified Russian and U.S. Navy sources. The meteorology atlas will have no such classified data sources, but will contain previously unavailable Russian meteorology data. The EWG Arctic Atlas series is available through NSIDC.

Urban heat island assessment from satellite

A case study of the assessment of an urban heat island through the use of blended data from the NOAA-AVHRR, Landsat, and DMSP-Operational Linescan System has found the multi-sensor analysis very beneficial for determination of urban and rural climate stations in the Dallas-Ft. Worth, Texas region. The assessment is described in a manuscript entitled "Assessment of Urban Heat Islands: A Multi-Sensor Perspective for the Dallas-Ft. Worth USA Region" by Kevin Gallo and Tim Owen, which has been published in *Geocarto International* (1998, vol.13, pp. 35-41).

GOIN-99 Workshop

The National Geophysical Data Center's (NGDC) Dan Wilkinson and Dr. Herb Kroehl participated in the Global Observation Information 99 Workshop sessions held at the University of Hawaii's East-West Conference Center. GOIN is a 1993 Presidential initiative which established a forum for exchanging global environmental data and information via networks between the United States and Japan. This bilateral program has expanded to include Italy, Thailand, Singapore, China, Indonesia, Canada, Vietnam, Mongolia, Brazil, Korea, Malaysia, Philippines, Taiwan, Chile, and Australia.

The expansion prompted the resolution that the goals of GOIN would be served by integrating those programs with the Committee on Earth Observing Satellites (CEOS) over the next 16 months. Mr. Wilkinson presented two papers on the Satellite Anomaly Database and the support to the International Space Station. Dr. Kroehl co-chaired the Solar-Terrestrial (ST) Subgroup, presented the S-T subgroup activities to the Plenary, the Joint Technical Working Group and the Joint Program Working Group. The S-T subgroup established network requirements for activities in real-time forecasting and numerical modeling of the near-Earth space environment.

▲ **Figure 2.** Coral reef and coastal responsibilities in Hawaii. Management is facilitated by partnerships among diverse organizations.

Coral reef mapping, *from page 2*
managers have focused on aspects of GIS technology and how best to ingest and integrate the desired data layers. Participation includes many governmental agencies as summarized in Table 1 as well as a few private consultants and NGOs such as the Nature Conservancy and the Sierra Club.

The MEGIS is off to a good start due to the availability of a few operational and expanding GIS projects. The DAR-DLNR (see Table 1 for acronyms) are one of the key stewards for preserving coral reefs in Hawaii and have collected significant data and information for creating data layers within a GIS for five hot spots or threatened zones—Hanalei, Kauai; Kaneohe Bay, Oahu; Kihei, Maui; Kealakekua, Hawaii; and Hilo, Hawaii. An example is shown in Figure 3. The USFWS and the USGS both have GIS programs that could benefit the common MEGIS mission. An important monitoring initiative underway in Hawaii is the Coral Reef Assessment and Monitoring Program (CRAMP) through support of the HIMB-UH, UH-Hilo, and various community colleges (*http: www.coralreefs.hawaii.edu/ReefNetwork/ default.htm*).

In addition to new sites, CRAMP is re-surveying various historic sites that have not been explicitly georeferenced for inclusion in a GIS. Remote sensing projects with application to mapping of coral reefs are being made available by researchers at the School of Ocean Earth Science and Technology (SOEST) of UH (*http://www. soest.hawaii.edu/ coasts ogg_projects.html*) and at the Natural Sciences Department of the Windward Community College (*http:// imiloa.wcc.hawaii.edu/krupphoaaina. html*). Research at the East-West Center has also resulted in mapping products for Molokai and several U.S.-affiliations in the Pacific. MEGIS has only been together for six months, but has gained sufficient momentum to catch the eye of a larger national effort with similar goals.

The U.S. Coral Reef Task Force

An executive order was given on June 11, 1998, as part of the Monterey National Ocean Conference, on the preservation and restoration of coral reefs in the United States and its Pacific and Caribbean affiliations. The Secretary of the Interior and the Secretary of Commerce are named to co-chair the

U.S. Coral Reef Task Force (CRTF). The duties of the group will be to map and monitor U.S. coral reefs, identify the major causes and consequences of their degradation, and design and implement plans to restore reefs that have suffered damages. The CRTF is directed to cooperate with agencies worldwide who have similar goals.

For the mapping tasks, the Mapping and Information Synthesis Working Group (MISWG) has been formed. Their overall goal is to develop a strategy for creating a digital set of comprehensive and consistent coral reef ecosystem maps and a map information synthesis capability. Both short-term (1-5 years) and long-term objectives are being addressed.

The MISWG will also define and coordinate the development of map information products to support the CRTF and its related user community. One of their initial tasks was to distribute to as many contacts as possible a questionnaire regarding the present and potential availability of mapping products. This information was summarized into a report and presented to the CRTF meeting in Maui, Hawaii in early March 1999. This gave the steering committee of the CRTF a clearer picture on what has been accomplished and where emphasis should be placed for future monitoring endeavors.

Within the national arena, another agency is also partnering with these coral reef initiatives. The Coastal Ocean Laboratory of the National Oceanographic Data Center designated Dr. Anthony Picciolo in 1998 to lead an endeavor to archive coral reef information. The NODC is the perennial NOAA archive for ocean data—preservation is ensured by periodically recopying digital data records onto the most recent information technology for mass storage.

Data from coral ecosystems pose a new challenge to data management relative to the historic oceanographic data sets such as ocean profiles of temperature and salinity. Due to the disparity in monitoring techniques, metadata, which is simply information about the data, is critical. NODC focuses great attention to properly documenting data sets, weaving this information into a catalog system for ease of access, and publicly advertising the availability. To assist data acquisition and servicing of the archive, the NODC has placed liaison officers at key oceanographic institutions around the country. The liaison for Hawaii is based at SOEST-UH, participates in the MEGIS,and has been supporting the CRTF MISWG by significantly increasing the potential contacts of coral reef players in Hawaii and affiliated Pacific islands.

Partnerships are coalescing

The MEGIS hosted a meeting in mid-January 1999 coinciding with the visit of Dr. Steve Brown and Dr. Steve Rohmann of the CRTF MISWG. The meeting provided an excellent opportunity for the MEGIS to learn more about Dr. Rohmann's experience in developing mapping products and about the evolving CRTF. It was also a timely occasion for the MISWG to learn about the efforts that have been gaining momentum in the Pacific through the MEGIS.

Several of the key issues were addressed, such as the critical need for precise bathymetric information in the nearshore regimes and the best means of handling historic data sets that are not accurately georeferenced for ease of input into a GIS. Both groups were encouraged by the expanding technologies for mapping with multi- and hyper-spectral aerial photography. This topic will be the focus of the International Workshop on the Use of Remote Sensing Tools for Mapping and Monitoring Coral Reefs to be held at the East-West Center of the University of Hawaii June 7-10, 1999.

The MEGIS and the CRTF MISWG are both beginning their endeavors and look forward to continuing cooperation. The meeting of CRTF experts on Maui in March 1999 resulted in clearer directions for the national effort which will inherently be of interest to the Pacific initiatives. These cost-effective, synergistic partnerships that have formed among the local, state, federal, and non-governmental offices will certainly enhance mankinds efforts for better understanding and preservation of one of Earths most important finite natural habitats in the coastal zone—coral reef ecosystems.

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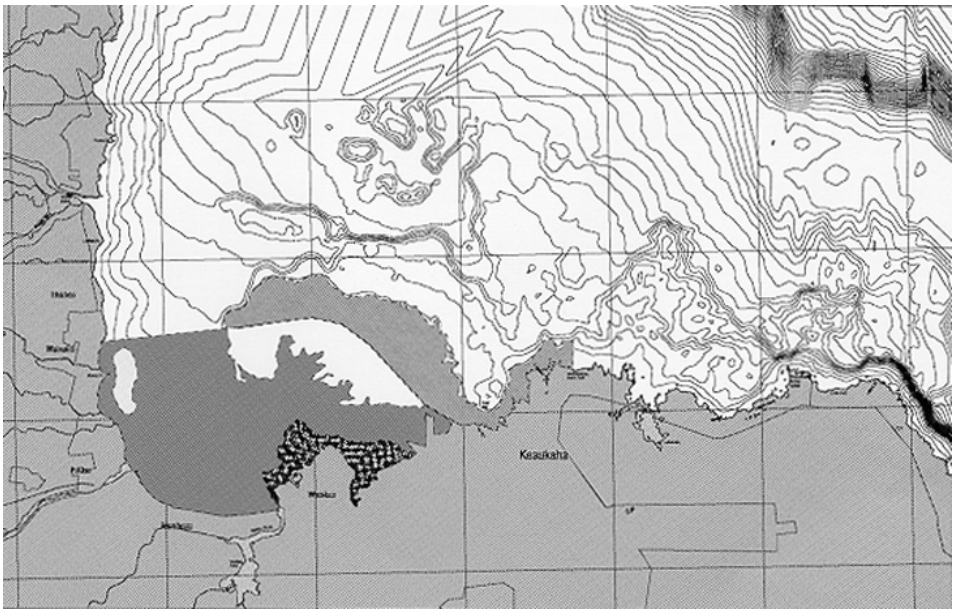

▲ **Figure 3.** An example of GIS output for Hilo Bay, Hawaii used to monitor changes in ecosystem habitats. Bathymetric contours are in meters and the shading is a function of substrate and reef composition. Source: Division of Aquatic Resources, Department of Lands and Natural Resources, State of Hawaii.

The changing sea

Long-term biogeochemical variability in the subtropical North Pacific

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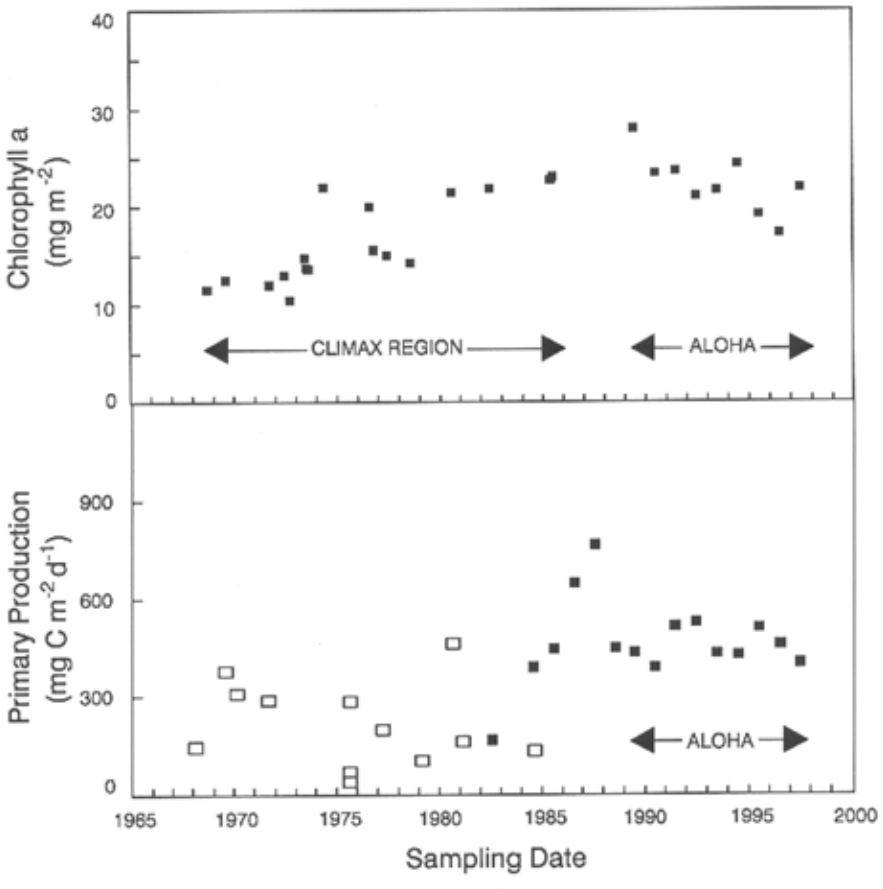
The accretion and subduction of oceanic plates, the rise and fall of sea level and the emergence and subsidence of islands are part of the geological history of the Pacific basin. On shorter time scales, tides wax and wane, seasons pass and climate patterns change. For the organisms that inhabit the North Pacific Subtropical Gyre, nothing is constant except change and nothing is certain except stratification of the water column, low nutrients and low biomass.

Because of the role the ocean plays in the global carbon cycle, it is imperative to study and understand ecological processes in open ocean ecosystems like the North Pacific gyre. Once considered to be a homogeneous, static habitat, this region exhibits substantial physical, chemical and biological variability on many time scales. Currents and mesoscale eddies can interact to produce vigorous vertical motions that deliver short-lived pulses of nutrients, without warning, to an ecosystem that is otherwise starved of nutrients. These physical processes can alter the status quo abruptly, stimulating pulses of primary production and particle export and providing brief opportunities for carbon sequestration. Because of the stochastic nature of these events, occasional cruises to the gyre have failed to observe the system under these conditions.

In 1988, a deep-ocean station was established north of Hawaii within the North Pacific gyre to support the scientific goals of both JGOFS (Joint Global Ocean Flux Study) and the World Ocean Circulation Experiment. By the end of 1998, the Hawaii Ocean Time-series (HOT) program will have completed 100 cruises to Station ALOHA, located at 22° 45'N, 158° W, with comprehensive seasonal coverage. The HOT program, which has already assembled the largest and most comprehensive ecological data set for the region, is now funded for continuation into the next millenium. This serial measurement program, with a focus on physical-biogeochemical coupling and microbial processes, has yielded unexpected results that challenge past views of biogeochemical cycles in the oligotrophic North Pacific.

The HOT program core measurements for U.S. JGOFS were selected to validate and improve existing biogeochemical models of element cycles. Among the ecosystem processes under investigation are the flux of carbon at the air-sea interface and the rates and controls of the biological pump. Equally important are the time-dependent changes in microbial biomass and biodiversity and the relationships of these ecosystem changes to extratropical ocean-atmosphere interactions such as the El Niño-Southern Oscillation (ENSO) cycle. The HOT data set is unique, robust and rich with previously undocumented phenomena, and the scientific results of this decade-long study are providing an unprecedented view of biogeochemical cycles in a previously undersampled region of the world ocean.

When the HOT program began, we thought that we had a good understanding of the biogeochemical pro-



▲ **Figure 1.** Phytoplankton community parameters for the subtropical North Pacific based on data from the CLIMAX and HOT time-series programs. The upper panel shows depth-integrated chlorophyll concentrations in the euphotic zone. The lower panel shows depth-integrated rates of primary production in the euphotic zone.

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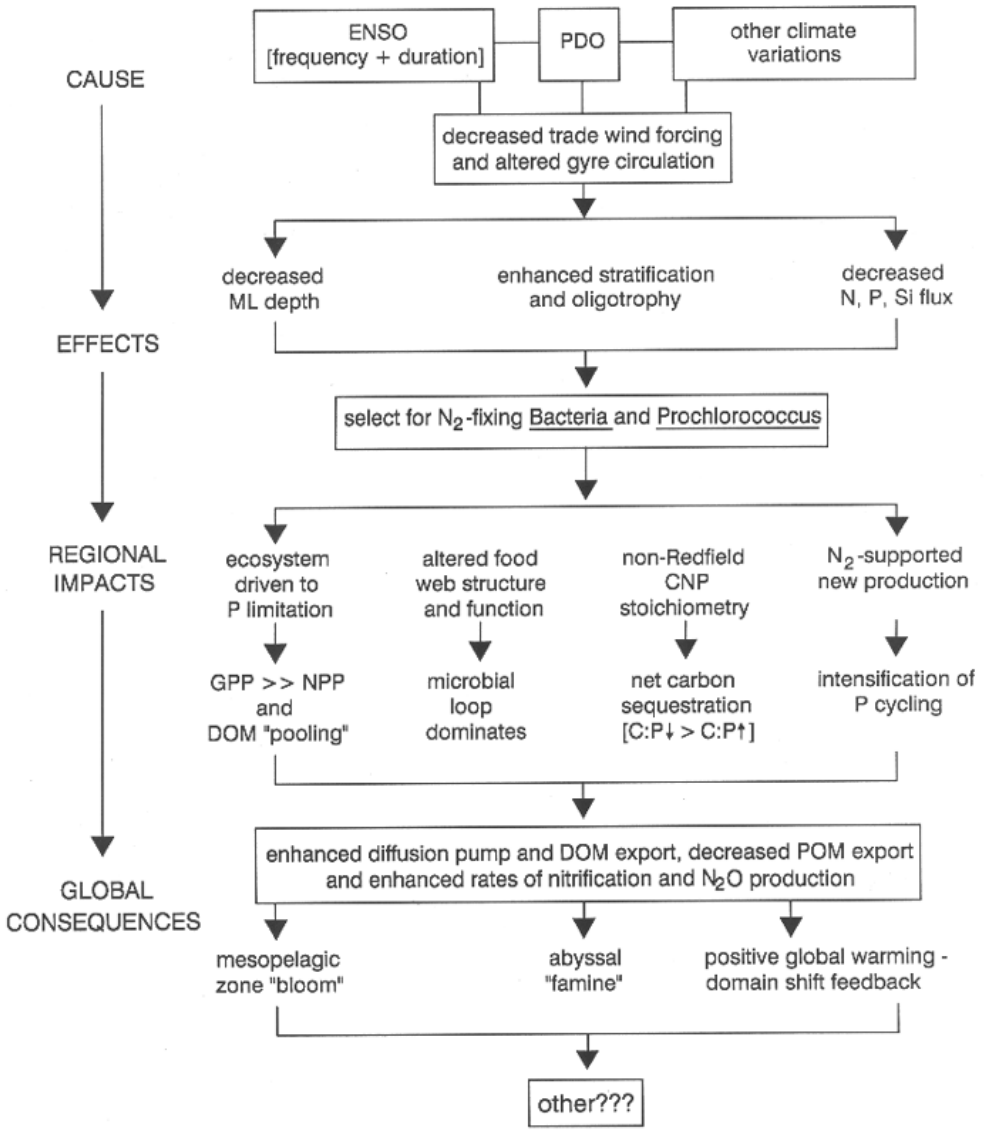
cesses in the North Pacific gyre. New and export production were limited by the supply of nitrate from below the euphotic zone, and rates of primary production were thought to be largely supported by a local supply of regenerated nitrogen in the form of ammonium. Photosynthetic rates were low, less than 200 milligrams of carbon per square meter per day (mg $C/m^2/d$), and eucaryotic micro- and nano-phytoplankton assemblages dominated the photoautotrophic biomass. Neither *Prochlorococcus*, now recognized as the most abundant oxygenic photoautotroph in terms of numbers and biomass, nor planktonic *Archaea* had yet been discovered. Potentially important biogeochemical fluxes such as photosynthetic production of dissolved organic matter (DOM), nitrification and nitrogen fixation were thought to be negligible.

We now recognize that the contemporary North Pacific gyre is a very different ecosystem. Based on our decade-long data set, we hypothesize that a fundamental shift from nitrogen limitation to phosphorus limitation has taken place. Changes in the physical environment, especially increased density stratification, favor bacteria that can fix free nitrogen (N_2) from the atmosphere, including *Trichodesmium*, selected species of *Synechococcus* and perhaps other free-living and symbiotic *Bacteria*. We believe that these habitat changes are a direct consequence of the increased frequency and duration of ENSO cycles and related atmosphere-ocean interactions.

Nitrogen budget estimates for Station ALOHA suggest that N_2 fixation may currently supply up to half of the nitrogen required to sustain particulate matter export from the euphotic zone. However, this relatively high percentage of N_2-supported new production appears to be a transient condition, reflecting either natural oceanic variability or perhaps a new state established in response to the changes in environmental conditions.

The influence of climate variability on oceanic biogeochemical cycles, especially on decade-to-century time scales, is not well understood. Although there are several case studies documenting the effects of climate variability on the



▲ **Figure 2**. The effects of climate variability on ecosystem structure and function in the North Pacific Subtropical Gyre. Results obtained from the HOT program and other time-series studies in the region indicate that changes in the stratification of the surface ocean have affected nutrient and trace-element budgets. These changes have also selected for nitrogen-fixing bacteria and *Prochlorococcus*, resulting in a shift in domain from predominantly *Eucarya* to predominantly *Bacteria*.

structure and function of selected marine ecosystems, especially fisheries, few data exist on changes in new or export production pathways or rates that could be incorporated into global carbon sequestration models.

One major obstacle is the potential temporal offset between physical perturbation and ecological response and the general resiliency of natural communities in response to external physical forces. One might therefore predict an abrupt, threshold response that is delayed in time rather than a slow, gradual ecological change. This feature complicates cause-and-effect interpretations.

A major and abrupt shift in the North Pacific climate system occurred during 1976-1977 that manifested itself as an intensification and eastward shift of the Aleutian low-pressure system during winter. This shift resulted in a decade-long cooling phase in surface waters. In 1987, Elizabeth Venrick of

— *continued on page 12*

Busy Atlantic hurricane season foreseen

This year's Atlantic hurricane season will bring more tropical storms, hurricanes and intense hurricanes than usual, say scientists in the first hurricane outlook ever released by the National Oceanic and Atmospheric Administration at the beginning of the June-November season.

The outlook says there are increased chances for greater-than-average hurricane activity and three or more intense storms. A normal Atlantic hurricane season includes nine to 10 tropical storms, of which five to six are hurricanes and two are classified as intense hurricanes.

"The intensified hurricane activity may be influenced in part by a lingering La Niña episode, which our scientists expect to continue at its current strength through the hurricane season, and which could help maintain conditions favoring increasing hurricane activity," said D. James Baker, NOAA administrator. La Niña refers to cooler-than-average sea-surface temperatures across the central and eastern tropical Pacific Ocean, which historically have contributed to a greater number of hurricanes in the Atlantic during a given season.

In June, all National Weather Service forecast offices will be fully upgraded with advanced interactive computer systems, a centerpiece of the $4.5 billion modernization program that has been a priority of the Clinton Administration. The modernization also includes new technologies such as Doppler radars, satellites, and a state-of-the-art hurricane surveillance jet.

"The increased capabilities provided by these technologies enable us to better forecast hurricane-related weather and flooding, and get out more timely warnings that may save lives," said John J. Kelly Jr., National Weather Service director. "But warnings mean nothing if people don't get the word," he added.

Kelly said one of the best ways to get official National Weather Service warnings and severe weather information instantly is through NOAA Weather Radio. The newest models of these special radio receivers can be programmed to sound an alarm when dangerous weather for your area is imminent.

With increased potential for catastrophic property damage and loss of life along the coasts, it has become even more important for federal, state and local governments, individuals and local businesses to take preventative actions. Programs such as the Federal Emergency Management Agency's Project Impact: Building Disaster Resistant Communities have helped communities better prepare for hurricane season. Through this effort, both the public and private sectors are beginning to take greater responsibility for their lives and property during natural disasters.

"Through this key partnership, we are using advancing technology to reduce the impact of hurricanes and other natural disasters," said FEMA Director James Lee Witt. "FEMA is encouraging communities to take action now to prevent possible damage and to reduce losses that might occur this hurricane season."

Last year, NOAA's Climate Prediction Center issued its first-ever Atlantic hurricane outlook in early August, to indicate whether the remaining season would bring increased, lessened, or normal activity. The scientists accurately predicted that there would be an above-normal number of tropical storms and hurricanes in the Atlantic between August and October, the busiest period of the hurricane season.

The 1998 Atlantic hurricane season brought 14 tropical cycles, including three major hurricanes. These storms inflicted $7.3 billion in damages and 23 fatalities in the United States alone.

NOAA will issue another outlook in August, which will update the outlook. The 1999 Hurricane Outlook can be found at: *http://www.cpc.ncep.noaa.gov*. Information about FEMA and its programs can be found at *http://www.FEMA.gov*.

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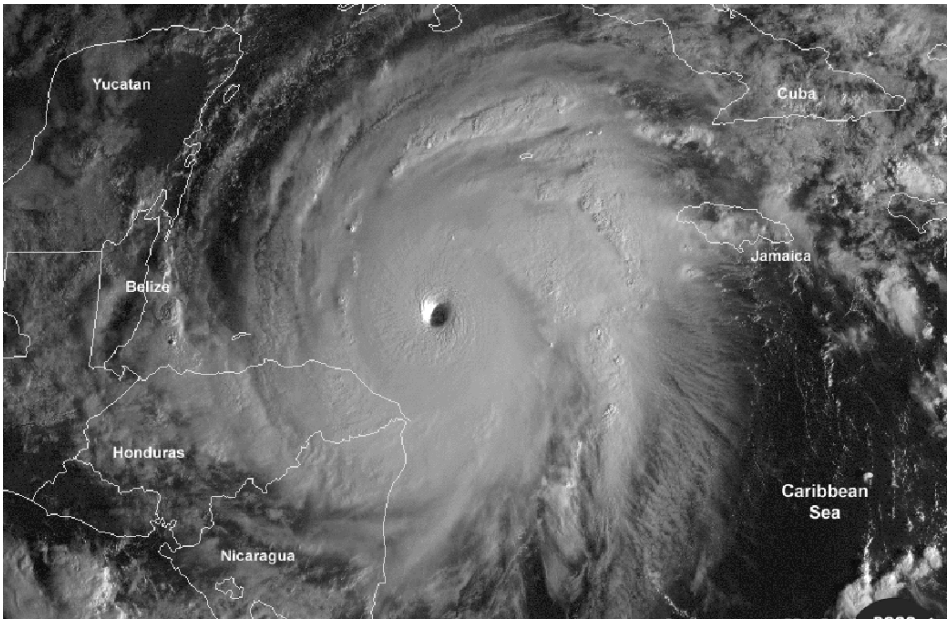

▲ **Figure 1.** Hurricane Mitch at category 5 strength in October 1998.

Ten years of BATS Data

A unique opportunity to observe the variability of biogeochemical phenomena

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Bermuda Biological Station for Research

The Bermuda Atlantic Time-series Study (BATS) passed a significant milestone on October 27 when *R/V Weatherbird II* docked at the Bermuda Biological Station for Research (BBSR) after a visit to the BATS station, located 80 kilometers southeast of the island. This cruise, the 173rd to the BATS station, marked the tenth anniversary of the launching of the U.S. JGOFS (Joint Global Ocean Flux Study) time-series study in the Sargasso Sea.

The decade-long BATS data set provides the oceanographic community with a unique opportunity to observe the variability of biogeochemical phenomena on seasonal, annual and interannual time scales. The continuous time-series record amassed during BATS enables researchers to detect subtle changes in ocean biogeochemistry that would not be apparent otherwise.

The focus of this year's U.S. JGOFS Synthesis and Modeling Program (SMP) workshop, held in Durham, New Hampshire, during July, was on the response of ocean biology and biogeochemistry to climate change. Atmospheric general circulation models (GCMs) have predicted a warming of the atmosphere by more than 2° C by the middle of next century. Ocean GCMs predict increased vertical stratification of the upper water column as a result of warming in the lower latitudes and freshening of surface waters at higher latitudes. This increased stratification is likely to have an effect on biological processes in the surface ocean and the flux of materials between surface and deep waters.

Trends observed during BATS and its sister time-series study near Hawaii (the Hawaii Ocean Time-series study, or HOT) allow oceanographers and modelers to improve their understanding and thus their ability to predict potential changes in the processes of the upper ocean as a result of changes in climate variables. In this article, we are focusing our attention on potential changes in the cycling of organic and inorganic carbon.

BATS data can be used to examine the potential effects of increased stratification on biological activity in surface waters. The Sargasso Sea undergoes wintertime convective mixing and seasonal thermal stratification each year. Mineral nutrients, vertically mixed into the euphotic zone every winter, disappear as stratification begins. The absence of inorganic nutrients affects the structure of the phytoplankton community, which in turn affects the cycling of organic matter.

The phytoplankton community in this region is dominated by picoplankton, organisms smaller than two microns. Models developed by Anthony Michaels of the University of Southern California and Mary Silver of the University of California at Santa Barbara suggest that picoplankton are minor contributors to particle export. They are primarily involved in regenerative production and an active microbial foodweb.

Several studies have suggested that picoplankton production and processing of organic matter through the microbial foodweb affect the quality of dissolved organic matter (DOM). A significant portion of the DOM produced in communities dominated by picoplankton is not available for rapid microbial degradation; thus DOM accumulates in the upper 100 meters of the water column during the warmer months. A portion of this seasonally accumulated organic matter is mixed or exported to deep depths in the winter, reducing the concentrations of DOM in the surface waters. The amount of DOM removed from the upper 100 meters depends on the intensity of the winter mixing or the depth to which it occurs.

We also use BATS data to examine the relationship between winter mixing and the dissolved organic carbon (DOC) cycle. From 1995 to 1998, the depth of the winter mixing has decreased by more than 100 meters. Dennis Hansell and Craig Carlson of BBSR have observed that the amount of DOC

—continued on page 10

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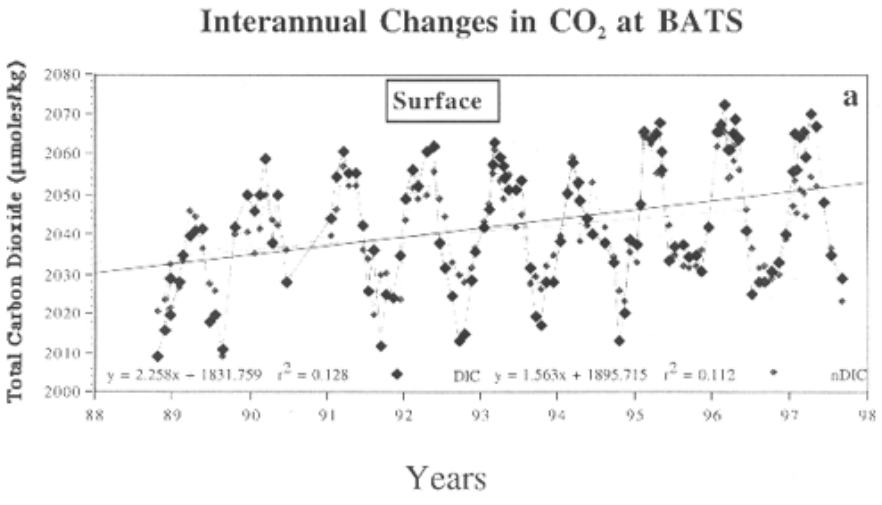


▲ **Figure 1**. Interannual variablilty of total CO_2 at the BATS site. TCO_2 concentrations have increased at a rate of approximately two micromoles per kilogram per year, or about 0.1% per year.

Ten years of BATS, *from page 9*

retained in the surface waters during this period has increased by approximately 300 millimoles of carbon per square meter. The annual export of suspended organic carbon in both dissolved and particulate form from the surface 100 meters has decreased from over 1 mole of carbon per square meter per year (1 mol C/m^2/yr) during 1992, 1993 and 1995 to approximately 0.5 mol C/m^2/yr for 1996 through 1998.

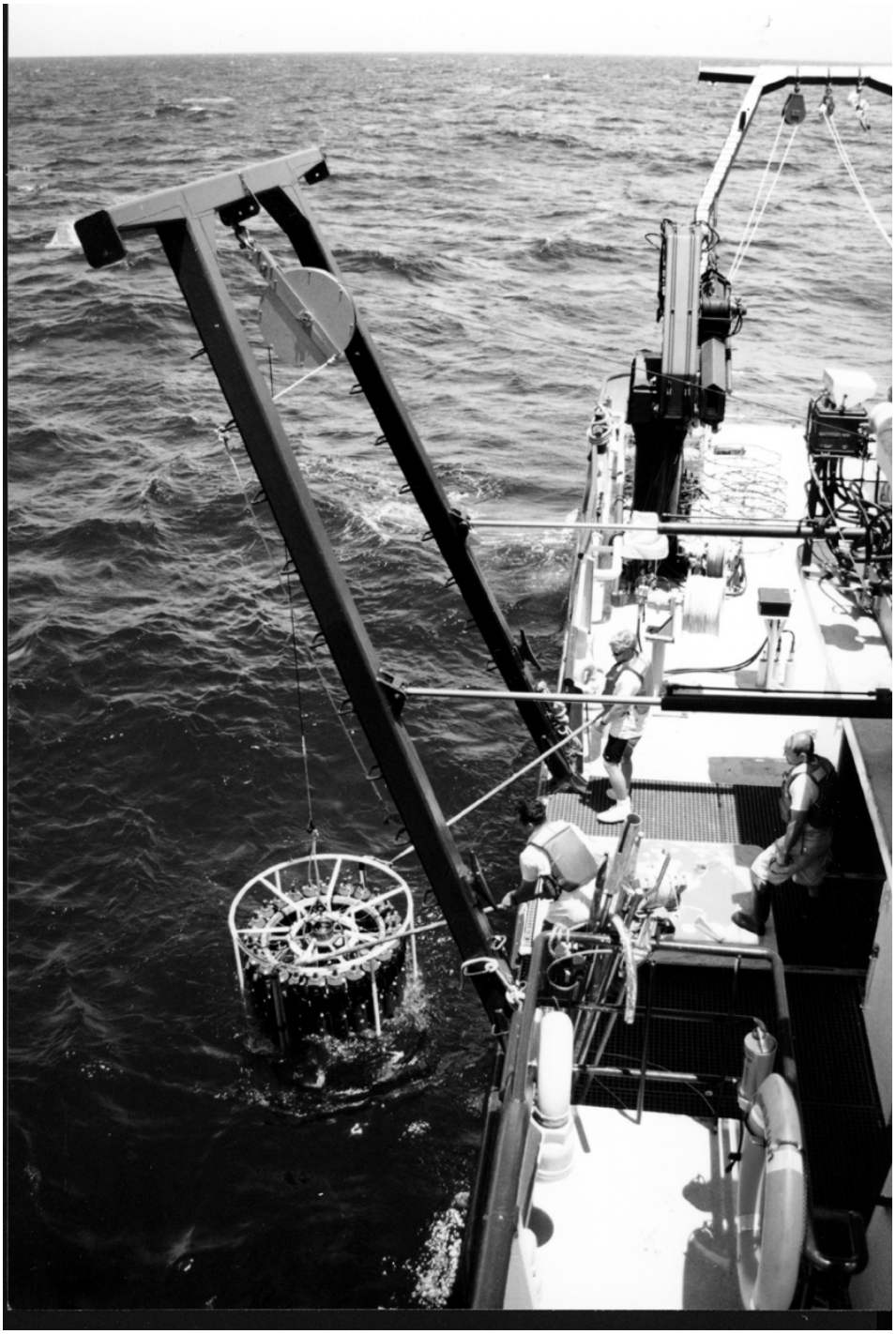
These observations demonstrate that during periods when the depth of seasonal deep mixing is reduced, less DOM is exported from the surface water. These changes suggest that increased stratification in picoplankton-dominated systems could lead to an increased accumulation and storage of organic carbon in the surface waters of subtropical and temperate regions as the atmosphere warms.

BATS data have also been valuable for investigating long-term changes in inorganic carbon cycling. For example, long-term observations of carbon dioxide (CO_2) concentrations in seawater at time-series sites provide a direct means of determining the rate of oceanic accumulation of anthropogenic CO_2 as well as information on natural variability.

At the BATS site, Nicholas Bates of BBSR has observed significant changes in oceanic CO_2 concentrations and the exchange of CO_2 between ocean and atmosphere over the last decade. Concentrations of total carbon dioxide (TCO_2) in the upper ocean have increased at a rate of approximately two micromoles per kilogram per year (µmol/kg/yr) or about 0.1% per year (Figure 1). At the same time, the partial pressure of carbon dioxide (pCO_2) in the surface waters at BATS has increased at twice the rate of the atmospheric CO_2 increase over the Sargasso Sea. The interannual increase in pCO_2 that we have observed at BATS is about double that observed at the HOT site north of Hawaii.

To our surprise, the increase in oceanic TCO_2 is greater than we would expect to see if sequestration of anthropogenic CO_2 from the atmosphere were the only source. The additional changes appear to be related to natural variability in the subtropical gyre. From 1988 to 1998, TCO_2 concentrations in the 18° C mode water, a water mass that lies below the seasonal thermocline, have increased at a rate of approximately two µmol/kg/yr. At the same time, the uppermost boundary of 18° C mode water has moved to shallower depths in the Sargasso Sea. Biogeochemical changes in this water mass appear to be an important contributor to the natural variability in TCO_2 concentrations in the upper ocean of the Sargasso Sea.

The mechanisms that cause changes in 18° C mode water properties are unclear at present. Undertaking specific biogeochemical studies along with the long-term measurements at the BATS site will potentially allow oceanographers to identify and quantify sources of natural variability. ■



▲ **Figure 2.** Launching a CTD rosette on a BATS cruise.

GLOBE digital elevation model released

The Committee on Earth Observation Satellites Task Team on the Global Land One-km Base Elevation (GLOBE) digital elevation model placed GLOBE Version 1.0 on its Website recently. This is the definitive global digital elevation data set, at better than 1-kilometer gridding. The GLOBE Task Team is headquartered at NGDC; the Website is *http://www.ngdc.noaa.gov/seg/topo/globe.shtml*
Contact: NGDC

NCDC data saves hotel $8000

The maintenance director for a large hotel organization in Charlotte, NC, noticed unusually high heating costs for a portion of the company's property during January 1999. The National Climatic Data Center (NCDC) provided the manager with December 1998 and January 1999 heating degree-day data for Charlotte to use in this energy analysis study. The NCDC heating degree-day data showed little difference between the two months and the utility company refunded $8,000 from the original gas bill. The director shared his company's good experience with other attendees at a Charlotte meeting of the Contingency Planning Association of the Carolinas (CPAC), an organization chaired by an NCDC meteorologist.
Contact: NCDC

DMSP article on nighttime lights

The Defense Meteorological Satellite Program (DMSP) has published an article (in *Remote Sens. Environ.*, vol. 68, pp. 77-88) which describes the methods used to generate the first radiance-calibrated nighttime lights data set.

Normally the sensor gain is turned up so high that the cores of cities and large towns are saturated and cannot be calibrated. NGDC worked with the Air Force Weather Agency to reduce the gain setting, avoiding saturation. The pre-flight sensor calibration is used to convert the observed values into radiance (brightness) units. Previous "stable lights" data sets produced by NGDC showed the locations of lights and their detection frequency. A preliminary examination of the radiance-calibrated lights indicates they are more highly correlated to "human activity" levels than the stable lights.
Contact: NGDC

Data products and services

NGDC paper on Lake Erie geomorphology attracts press coverage

Dr. Troy Holcombe of the National Geophysical Data Center (NGDC) was interviewed by Mr. Frank Lichtkoppler, a media specialist with Ohio Sea Grant, who prepared press releases for the May 1999 meeting of the International Association of Great Lakes Research (IAGLR) held in Cleveland. Dr. Holcombe presented a paper at this meeting, entitled "Aspects of Lake Erie Geomorphology".

The press releases regarding this paper were forwarded to 100 media outlets in the Great Lakes region. One of the highlights of this paper mentions the finding that now-submerged river deltas, offshore bars, and other geological features, shown on the new bathymetry, provide additional evidence that Lake Erie water levels were on the order of 10 to 20 meters (31 to 62 feet) lower 5,000 to 10,000 years ago than at present.
Contact: NGDC

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NBC tornado coverage

The National Broadcasting Company (NBC) contacted the National Climatic Data Center the morning of May 5 (after the multi-tornado outbreak in the Midwest), requesting to do a short interview regarding the NCDC Web Page - Billion Dollar Weather Disasters. See the URL: *http://www.ncdc.noaa.gov/o1/reports/billionz.html*

NBC News cameraman Lewis Bailey taped NCDC meteorologist Neal Lott while Lott was being interviewed via telephone by NBC correspondent Bob Dotson. The interview aired on the "Nightly News" broadcast that evening.

Mr. Dotson had recently seen the Press Release on "Billion Dollar U.S. Weather Disasters 1980-1999" and emphasized that even though the May 4 tornado disaster in Oklahoma and Kansas was very destructive it wasn't the worst natural disaster in recent time. The frequency of occurrences and costs of major natural disasters used in the segment were provided by the NCDC. Topics covered in the interview included:

1) Comparison of natural disasters in the 1980s vs. 1990s
2) Increasing damage amounts from events due to inflation and migration of the population to high risk areas
3) Damage from hurricanes, floods, and droughts tend to be more expensive than tornado damage costs
4) Trends in hurricanes over the last few years and the influence from El Nino and La Nina
5) Increasing frequency of events

Contact: NCDC

CALJET precipitation study

The National Climatic Data Center (NCDC) provided ship, C-MAN, and buoy data observed during the California landfalling Jets Experiment (CALJET) to NOAA's Environmental Technology Laboratory (ETL). The CALJET field experiment, which collected meteorological data from November 1997 through March 1998, was conducted to study orographic precipitation along the U.S. West Coast and to assess the impact of the low level jetstream in enhancing the orographic precipitation.
Contact: NCDC

The changing sea, *from page 7*

Scripps Institution of Oceanography and her colleagues reported that the average euphotic zone chlorophyll *a* concentration in the oligotrophic North Pacific during the summer had nearly doubled from 1968 to 1985 (Figure 1). These investigators attributed their field observations to the North Pacific regime shift. The enhanced nutrient flux that accompanied it had brought about significant long-term changes in the carrying capacity of the regional ecosystem.

Data from Station ALOHA have extended this analysis of euphotic-zone chlorophyll *a* concentrations for nearly another decade. We now have a 30-year chronology for the ecosystem of the North Pacific gyre (Figure 1). If caused by climate variations, these sustained changes could have important implications for biogeochemical and fisheries modeling, especially if they reflect differences in plankton community structure or foodweb interactions. Variations in chlorophyll *a* levels may also affect carbon production and export and benthic processes, thereby altering local rates and pathways of carbon sequestration. Biogeochemical models based on historical or even contemporary observations may not be accurate predictors of future trends.

This abrupt shift in climate, beginning in the mid 1970's, was not unique. It appears to be an example of a recurring pattern of interdecadal climate variability referred to as the Pacific (inter) Decade Oscillation, or PDO, described by Nathan Mantua of the University of Washington and his colleagues. The shift in regime appears to be the result of the presence of persistently warm waters in tropical Pacific caused by a high frequency and long duration of El Niño (warm) conditions and lack of La Niña (cold) periods during the years from 1976 to 1988, but the precise details are still unknown. Regardless of the cause, the documentation of these large scale atmosphere-ocean interactions emphasizes the effect of external physical forces on plankton communities in the North Pacific.

Primary production also appears to have increased in the region. Compared to the 17-year CLIMAX program mean of 200 mg C/m^2/d, the average rate from the HOT program is more than twice as high (Figure 1). Furthermore, the ecosystem supports an even higher rate of gross primary production (750-1000 mg C/m^2/d), much of which is rapidly cycled through microbial food webs, in part because of the shift from a nitrogen-limited to a phosphorus-limited ecosystem.

I have hypothesized that this coupled intensification of both the nitrogen cycle, via N_2 fixation, and the phosphorus cycle has caused major shifts in plankton community structure and in the rates and mechanisms of organic matter production and remineralization. We have seen a selection for *Bacteria* and a dramatic shift from a eucaryote-dominated to a procaryote-dominated photoautotrophic species assemblage with numerous biogeochemical and ecological consequences (Figure 2). Many of these ecological predictions are currently under investigation.

Chronic undersampling, a fact of life in oceanography, constrains the interpretation of field data. Neither spatial heterogeneity nor temporal intermittency are measured well by shipboard sampling, and the dimensions and dynamics of the North Pacific gyre preclude comprehensive sampling. Even decade-long ocean observation programs like HOT are insufficient for unraveling some of the first-order questions regarding biogeochemical response to climate variability and environmental change. But every successful time-series must have a beginning, and HOT program scientists now have an analytical finger on the ecological pulse of this important biome.

Synthesis of HOT program data and modeling efforts are underway in numerous laboratories around the world. The HOT data set is available to all on the World Wide Web (*http://hahana.soest.hawaii.edu*). A major advantage of working with this extensive data set is the rich spectrum of variability observed in an ecosystem that was expected a priori to be homogeneous. A disadvantage is the lack of an accurate conceptual view of ecosystem processes to serve as the basis for future modeling activities. The more we learn about this habitat, the less we seem to understand. These surprises of the sea should keep us busy for at least another decade. ■

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