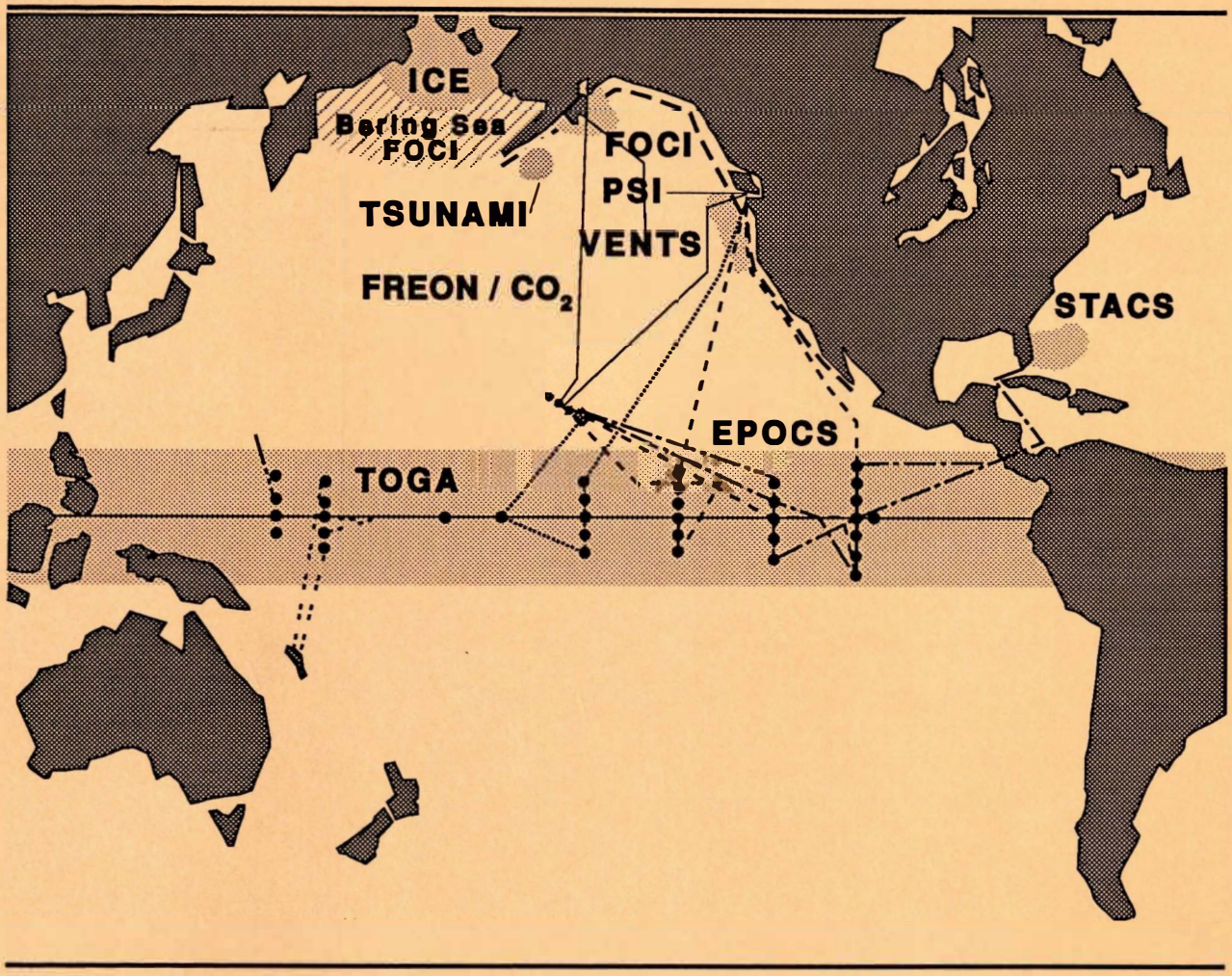
Pacific Marine Environmental Laboratory

Summary Report for FY 91



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PACIFIC MARINE ENVIRONMENTAL LABORATORY
SUMMARY REPORT FISCAL YEAR 1991

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7600 Sand Point Way NE
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INTRODUCTION

E.N. Bernard, Director

The Pacific Marine Environmental Laboratory (PMEL) carries out interdisciplinary scientific investigations in oceanography, marine meteorology, and related subjects. Current PMEL programs focus on climate, coastal and arctic observation, and prediction and research into the ocean environment. Studies are conducted to improve our understanding of the complex physical and geochemical processes operating in the world oceans, to define the forcing functions and the processes driving ocean circulation and the global climate system, and to improve environmental forecasting capabilities and other supporting services for marine commerce and fisheries.

PMEL complements its research efforts through two ERL cooperative institutes: the Joint Institute for Study of the Atmosphere and Ocean (JISAO), with the University of Washington; and the Joint Institute for Marine and Atmospheric Research (JIMAR), with the University of Hawaii. PMEL also complements its research through NOAA's National Marine Fisheries Service (NMFS) and the Cooperative Institute for Marine Resources Studies (CIMRS), a joint organization with Oregon State University.

CLIMATE RESEARCH

The NOAA Ocean Climate Program was developed following passage of the National Climate Program Act in 1978 in response to increased public awareness of the effects of short- and long-term climatic changes and a concern about the potential effects of technology and population growth on world climate. More recently, NOAA and other Federal agencies initiated the Climate and Global Change (CGC) Program to study oceanic thermohaline circulation and its climatic impact. These two major NOAA programs form the backbone of much of the research conducted at PMEL.

Understanding and forecasting climatic change requires an understanding of the processes of heat, moisture, and momentum exchange between the ocean and atmosphere as well as the large-scale transports of heat within the atmosphere and ocean. PMEL's climate and global change research program conducts studies of both local and basin-wide ocean dynamics and the coupled ocean-atmosphere circulation. The goal of this research is to determine the physical mechanisms that generate anomalies in sea-surface temperature (SST) distributions in the tropical ocean. A crucial step is to develop and validate ocean circulation models that are capable of simulating the evolution of globally important events such as the El Niño-Southern Oscillation (ENSO).

Heat transport by major western boundary currents (the Gulf Stream and the Kuroshio in the Northern Hemisphere) is postulated to have an important effect on world climate. Western boundary current studies at PMEL continue to focus on the Florida Current as part of the Subtropical Atlantic Climate Studies (STACS).

Oceanic chemistry is another aspect of climate change investigations. Man's addition of chemical constituents to the atmosphere and the potential consequences of these changes create a need for improved understanding of the ocean's absorption, transport, and emission of the important trace gases. PMEL research in these areas focuses on the carbon cycle in the ocean-atmosphere system and the air-sea exchange of other radiatively important trace species. These studies involve integrated chemical and physical measurements at the oceanic and atmospheric interface.

Accomplishments FY 91

EQUATORIAL DYNAMICS

In support of the Equatorial Pacific Ocean Climate Studies (EPOCS) and Tropical Ocean-Global Atmosphere (TOGA) programs, PMEL maintains an array of moored and island stations in the tropical Pacific. Thirty-four moored stations measuring parameters such as the vertical distribution of temperature and current velocity in the upper ocean and surface wind velocity and air temperature are in place. These moorings transmit much of their data in real time via Argos satellite. Automated wind stations are also maintained on islands in the western and central Pacific (Kapingamarangi, Nauru, Baker, and Christmas Islands). Data from these stations are used to diagnose oceanic and atmospheric processes in the tropical Pacific, to validate the

operational general ocean circulation model at the National Meteorological Center (NMC), and to study air-sea interaction processes responsible for annual and interannual variability of the tropical Pacific Ocean.

Equatorial SST Variations

A central focus of the TOGA and EPOCS programs is to understand the mechanisms responsible for variations in the equatorial Pacific Ocean on ENSO time and space scales. During FY 91, analyses focused on the upper ocean heat budget for 1986 to 1988, which encompassed a moderate ENSO event. Results of the observational analysis indicate that seasonal and interannual variability of SST in the eastern Pacific cannot be accounted for solely by the observed surface heat flux; i.e., oceanic processes play an important role in the heating of surface water. Although no single process dominated the 1986–1988 SST change, the most important processes in the mean balance were the net incoming surface heat flux, the penetrative solar radiation, and the vertical turbulent flux out the bottom of the mixed layer. Mean vertical entrainment could not be estimated with the available data. On seasonal time scales, both vertical turbulent heat flux and vertical entrainment variations could be correlated with SST change. Zonal advection made a significant contribution to the heat flux variability, but its fluctuations were poorly correlated with mixed layer heating. In particular, it was found that zonal advective heat flux tended to be out of phase with the spring warming. At higher frequencies, little zonal advective heat was associated with the passage of a kelvin event in January 1987. Surprisingly, meridional heat advection appeared to be more important than zonal heat advection in modifying the local SST as the event passed.

TOGA-TAO Project Office

In support of the Climate and Global Change Program, the TOGA-TAO (Tropical Atmosphere-Ocean) Project Office was established in FY 90 by the Oceanic and Atmospheric Research (OAR) and National Ocean Service (NOS) arms of NOAA. The project office is responsible for maintaining the TOGA-TAO array, which is planned to include 65 ATLAS moorings spanning the equatorial Pacific from 95°W to 130°E. By the end of FY 91, the array was 45% completed with 29 moorings in place. Expansion of the TOGA-TAO array is the highest priority for the global ocean observing system in the second half of the TOGA decade. Reports were prepared on wind sampling strategies for TAO, the response of the ocean to westerly forcing in the western Pacific, the meridional pressure gradient near the Equator, and the description of the thermal variability near 170°W.

PROTEUS Mooring System

In April 1990, the first PROTEUS (profile telemetry of upper ocean currents) mooring was deployed at 0°, 140°W. A PROTEUS mooring consists of a downward-looking 153.6-kHz acoustic Doppler current profiler interfaced to a buoy-mounted microprocessor and an Argos satellite transmitter. Hourly data are internally recorded; the microprocessor on the buoy forms daily averages of these hourly data and transmits them during two 4-hour periods every day.

The profiles extend from 10 to 250 m below the surface with 8-m vertical resolution. The time series at 140°W has continued with two subsequent mooring deployments and is now more than 16 months long. PROTEUS systems have subsequently been deployed at 165°E, 110°W, and 155°E on the Equator, making a total of four in place at the end of FY 91. Also, the University of South Florida has acquired a PROTEUS system for deployment at 0°, 170°W as part of the TOGA observing array. Details of the PROTEUS system appeared in two recent publications. PROTEUS data have been used in a preliminary validation study of the NMC operational ocean general circulation model and were presented at the annual EPOCS meeting in Miami in January 1991. The data are now routinely acquired by NMC for its operational ocean model development efforts. The international satellite consortium, service Argos, is expected to make the PROTEUS data stream available on the global telecommunication system (GTS) as part of an agreement with the World Meteorological Organization.

Modeling of the Tropical Pacific

Scientific manuscripts were submitted for publication describing use of the Geophysical Fluid Dynamics Laboratory (GFDL) ocean circulation model to study (1) the seasonal cycle of the equatorial Pacific, (2) the influence of westerly wind bursts on basin-wide circulation, and (3) the disappearance of the Equatorial Undercurrent at 160°W during the 1982–83 ENSO. These analyses are critical for the planning of TOGA COARE (Coupled Ocean-Atmosphere Response Experiment) and improving predictions of ENSO events. Development continued on FERRET, an interactive display and analysis system for studying gridded data sets. FERRET was converted for use on UNIX workstations and is being tested by a number of other university and NOAA researchers.

WESTERN BOUNDARY CURRENTS

Estimates of transport by the Florida Current are derived using electromagnetic cable techniques on active and inactive submarine cables. During FY 91, motional induction models were developed to provide guidance for evaluating whether a site is suitable for monitoring transport and for locating the cable-ocean contacts in order to minimize meandering effects. Model studies show that moving the Key West cable-ocean contact beyond the shelf region reduces current variability by more than 50%. Consequently, meandering effects can be greatly reduced by having electrodes beyond the shelf region. Use of such cable measurements is an integral part of the Atlantic Climate Change Program (ACCP).

MARINE AND ATMOSPHERIC CHEMISTRY FOR CLIMATE CHANGE

PMEL conducts two important marine chemistry programs for NOAA under the National Climate Program. One project examines ways in which the ocean affects the atmospheric concentration of several radiatively important trace species (RITS), and focuses on the biogeochemical cycles of carbon, sulfur, nitrogen, and oxygen. The other program measures the changing concentration of anthropogenic fluorocarbons in the ocean to elucidate pathways and rates of thermocline ventilation and circulation.

Biogeochemical Cycles

It has been proposed that the ocean plays a major role in mitigating global climate change by absorbing and retaining carbon dioxide and other greenhouse gases. Oceanic influx of these compounds depends on the detailed space- and time-dependent air-sea exchange of CO_2, the oceanic processes of thermocline ventilation, and the action of the marine biological "pump" by which carbon is fixed in particulate form in near-surface water, settles, and then decomposes at depth.

During FY 91, PMEL scientists compiled delta-PCO_2 data for the South Pacific Ocean based on measurements obtained on NOAA cruises between 1984 and 1989. The CO_2 data were obtained to constrain present and future models of the air-sea exchange of CO_2 in an area of the world oceans where no data were available before the present study. The delta-PCO_2 map for the South Pacific during austral autumn shows the expected source regions in the equatorial Pacific and a large sink in the midlatitudes of the western South Pacific. In addition, high source regions were documented in the eastern portion of the basin where upwelling and warming of surface water predominate. When the CO_2 data are integrated to obtain the total flux of CO_2 in the basin, the net result is that the range of estimated fluxes is from –0.03 to 0.09 GT C per year for austral autumn. These results indicate that the South Pacific Ocean is not as large a sink for CO_2 during austral autumn as previously believed, and are consistent with the atmospheric models that indicate smaller sinks for CO_2 in the South Pacific. PMEL researchers also contributed to development of a plan for long-range study of the atmosphere-ocean exchange of carbon in the oceans. Implementation of this plan will provide a world-wide data base of CO_2 measurements designed to constrain present and future models of the global carbon budget.

A 1-month cruise was conducted in the north Pacific along 150°W to investigate the RITS gases in surface waters and the marine boundary layer. Analysis continued on data collected on previous RITS cruises and laboratory studies. Results from these analyses document the diurnal cycle of atmospheric ozone concentrations in wide regions of the marine boundary layer over the Pacific Ocean. The existence of a seasonal minimum of very low ozone concentrations in the equatorial mid-Pacific boundary layer was established by these data. Another major cruise was carried out off the Washington coast to continue the interdisciplinary, multi-institutional study (PSI-3) of the processes by which dimethylsulfide production in the ocean might influence climate. This experiment documented the formation and growth of cloud nucleation particles in the atmosphere that will be used to qualitatively link marine sulfur emissions with atmospheric aerosol particle populations.

CFC tracer program

The PMEL chlorofluorocarbon (CFC) Tracer Group played a lead role in planning and executing the first U.S. hydrographic section in the World Ocean Circulation Experiment (WOCE) along 150°W, from Hawaii to Kodiak. The full set of WOCE tracer and hydrographic measurements was obtained on this section by NOAA and university-based investigators. The analytical capability of the CFC group was approximately doubled during FY 91. A program was

established at PMEL to prepare and distribute CFC gas standards to groups participating in WOCE (twelve organizations from seven countries).

Plans FY 92

EQUATORIAL DYNAMICS

- Continue implementation of the TOGA-TAO array.
- Complete analysis of North Equatorial Counter Current (NECC) data.
- Complete description of seasonal cycle in the eastern tropical Pacific.
- Conduct a high-frequency internal wave experiment at 0°, 140°W.
- Use moored data to examine the interaction of equatorial Rossby waves with mean zonal flows.
- Cooperate with U.S. Joint Global Ocean Flux Study (JGOFS) investigators during FY 92 equatorial experiment.
- Develop TOGA-TAO Analysis Center with the University of Washington.
- Complete analysis of model seasonal cycle with idealized wind fields.

WESTERN BOUNDARY CURRENTS

- Continue Key West and West Palm Beach electromagnetic measurements.
- Upgrade West Palm Beach shore station.
- Examine feasibility of laying a new cable across the Florida Straits east of Jupiter Inlet.

MARINE AND ATMOSPHERIC CHEMISTRY FOR CLIMATE CHANGE

- Participate in WOCE sections in the Southern Ocean on Australian and Soviet expeditions.
- Organize a NOAA-supported WOCE cruise in the western Pacific.
- Initiate a long-term tracer study in the Greenland/Norwegian Seas as part of NOAA's Atlantic Climate Change Program.
- Document and publish CFC data sets collected during the last decade.

- Participate in the first International Global Atmospheric Chemistry-Marine Aerosol and Gas Exchange Program (IGAC-MAGE) field program with the JGOFS Program.

- Complete analysis of Soviet-American Gas and Aerosol Study (SAGA-3) and PSI-3 expeditions.

COASTAL AND ARCTIC RESEARCH

The Fisheries-Oceanography Coordinated Investigations (FOCI) 5-year plan is to provide the scientific basis for understanding of recruitment variability of walleye pollock in Shelikof Strait. This study has been expanded to the Bering Sea as part of NOAA's Coastal Ocean Program–Coastal Fisheries Ecosystem Project. Walleye pollock is the most abundant fish in the Bering Sea ecosystem, and its harvest supports a major domestic fishing industry worth well over $1.0 billion per year. By volume, the catch is the largest single-species fishery in the United States and the world. By 1988, American fishermen fishing in the U.S. Exclusive Economic Zone (EEZ) caught approximately 1.2 million metric tons. Before 1980, however, most of the pollock resources in the North Pacific were taken by foreign fleets fishing in the U.S. and Soviet EEZ. Implementation of the Magnuson Fishery Conservation and Management Act eventually forced all foreign fishing out of U.S. waters by the mid-1980s. As a consequence, these fleets moved into the international waters of the central Aleutian Basin (the "doughnut hole"), and by 1988, the foreign-dominated catch exceeded 1 million metric tons in these waters. This high seas fishery is unregulated, and the effect of extensive harvest exploitation on U.S. EEZ fisheries is largely unknown.

The relationship between off-shelf (Aleutian Basin) and on-shelf components of the eastern and western Bering Sea pollock resource is not understood. Indirect evidence on the reproductive biology and growth of Bering Sea pollock, however, indicate possible stock mixing between all areas. Because of the international boundaries and the complex nature of the aggregations of pollock in the region, allocation of resources to the domestic fishery based solely on an understanding of population dynamics is a difficult management problem.

Phase 1 of the Bering Sea FOCI studies larval transport patterns in relation to oceanographic phenomena, biochemical genetic studies and tagging, concurrent biological and physical sampling in egg and larval aggregations, and numerical modeling. This research builds on experience acquired in successful FOCI studies on pollock conducted in the western Gulf of Alaska by NOAA/OAR and NMFS laboratories. A NOAA-wide partnership with regional academic institutions and foreign government laboratories is coordinated by the project managers.

The PMEL Tsunami Project, as part of the Coastal Hazards element of NOAA's Coastal Ocean Program, seeks to mitigate the effects of tsunami hazards to Hawaii, California, Oregon, Washington, and Alaska. To meet this objective, the Tsunami Project established the Pacific Tsunami Observation Program (PacTOP) to obtain high-quality tsunami measurements in the deep ocean and coastal regions, data that are essential to an improved understanding of tsunami generation, propagation, and inundation dynamics.

Accomplishments FY 91

BERING SEA FOCI

During August 1991, FOCI funds supported the first U.S. research cruise into the Soviet sector of the western Bering Sea since 1974. Pollock samples, conductivity/ temperature/ depth (CTD) data, shipboard acoustic doppler current profiler (ADCP) profiles, and nutrient samples were collected, and five ocean current moorings were placed in the southern inflow passes to the Bering Sea.

A 0.025° ocean current model was implemented on NOAA's Cray supercomputer in Boulder, CO. Model results and analysis of drifting buoy data show a direct connection in the current field between the shelf and the deep Aleutian Basin, which controverts previous speculation.

Pollock samples were collected on four separate cruises from four Bering Sea sub-basins for genetic and otolith studies.

A 1991 FOCI program implementation plan was completed and approved. A governing management council was established which includes the acting head of the newly ratified North Pacific Marine Science Organization (PICES); this relationship will provide a primary international forum for project coordination and scientific exchange.

Six joint FOCI projects have been established between NOAA scientists and external cooperators with FY 91 funds.

SHELIKOF STRAIT FOCI

During FY 91, efforts were focused on adaptation of a semispectral, primitive equation model (SPEM) to be used for hydrodynamic and biophysical studies related to dispersion and transport of pollock eggs and larvae in the western Gulf of Alaska. Requirements on the model include an estuarine type flow field and the capability of generating eddies. High concentrations of larvae are often associated with the eddies observed in the region, and those larvae are in better condition than those found outside the eddy.

An experiment was designed to provide boundary conditions for SPEM "upstream" of the area where eggs and larvae are prevalent. In addition, moorings were deployed at two locations within the model field to provide current information to compare with model results. The three locations are all in the Alaska Coastal Current and will provide estimates of continuity along this current, which dominates transport of larvae.

Analysis of estimates of abundance of early life history stages of walleye pollock was conducted on the long-term FOCI time series. Results show that year-class strength was clearly set by the young-of-the-year stage in late summer. During some years, year-class strength was established during the larval stage in May. Data collected during the 1991 field season indicate differences from conditions observed during the last good year-class, 1988: water temperature was significantly colder, mixed-layer depth was significantly greater, and transport out of the sea

valley appeared to be stronger. Ongoing analysis of wind mixing energy and hatch dates of successful larvae show that the survivors hatched during periods of relative calm. Therefore, the observation of a deeper mixed layer suggests that juvenile pollock survival during 1991 may be low.

Unlike previous years, in 1991, there were no patches containing large concentrations of larvae observed. This was most likely caused by anomalous physical conditions experienced during spring 1991. Because of the low larval abundances, planned process studies within a larval patch were not conducted. Instead, fine-scale physical and biological measurements were made. A section across the sea valley indicated spatial correlation between fluorescence (an index of zooplankton abundance) and water properties.

ARCTIC RESEARCH

Joint U.S./U.S.S.R. Chukchi Sea Circulation Study

A joint study of the ocean circulation from Bering Strait northward over the Chukchi Shelf and into the Arctic Basin was undertaken during 1990–91 by researchers from the Arctic and Antarctic Research Institute in St. Petersburg and from PMEL, using the Soviet research vessel *Professor Khromov* and the NOAA ship *Surveyor*. A total of 16 instrumented moorings were deployed and a thorough study of the hydrodynamic properties of the shelf was undertaken to provide a detailed history of the currents, sea-surface elevation, temperature, salinity, nutrients, and dissolved oxygen. The program provides the first look at the circulation of the Chukchi Sea undertaken without the restrictions of national boundaries.

Additional observations were made by researchers from the University of Alaska and University of Texas, including a broad seabird census, mapping of stable isotope concentrations related to the feeding of bowhead whales, and measurements of trace chlorinated organics. This comprehensive observation program is expected to give an integrated view of a globally important conduit from the Pacific into the Arctic. Additional supporting work included a modeling study of the transport of ice and energy in winter from the Bering Strait region into the Arctic via the Chukchi Sea.

Atlantic Climate Change Program (ACCP)

A principal thrust of the ACCP is to examine the variability of vertical overturning of the global ocean, which appears to be strongly driven from the North Atlantic. Attention has been drawn to the upper high-latitude ocean, since the salinity structure there seems to control the convection. With this in mind, the decision was made to measure and monitor freshwater flux from the Arctic Ocean through Fram Strait between Greenland and Spitsbergen, the principal connection between the Arctic and the North Atlantic. During the summer of 1991, three moorings were deployed on the Greenland Slope at 79°N. Other moorings were deployed by Norwegian and German investigators. The moorings are all scheduled for recovery by a Norwegian research vessel during the summer of 1992, at which time a new set will be deployed.

Sea Ice-Troposphere Interaction

A typical winter vertical temperature structure of a polar air mass is composed of a cold (–30°C) surface-based inversion or mechanically mixed surface layer and a broad temperature maximum layer, with a negative lapse rate aloft. Because the emissivity of the temperature maximum layer is less than the snow surface, radiative equilibrium maintains this inversion structure. Model calculations and analyses of Coordinated Eastern Arctic Experiment (CEAREX) atmospheric soundings from the fall of 1989 north of Svalbard were used to show that heat fluxes through the ice are insufficient to maintain Arctic air temperatures and that northward temperature advection by transient storms is required to maintain the balance. PMEL researchers were able to show that leads and thin ice contribute only 12% to the high Arctic winter tropospheric heat budget.

TSUNAMI

Field Experiments

Three oceanographic cruises were carried out to recover and redeploy bottom pressure recorders (BPRs) of the PacTOP network. In collaboration with Scripps Institution of Oceanography, a high-frequency (1 Hz) BPR was also deployed in the Shumagin Seismic Gap on the Aleutian Trench slope to measure microseisms and, in the event of a tsunamigenic earthquake, provide additional information on the seismic source mechanism.

Alaskan Bight Tsunamis

Existing analytic theory and an optimization approach to wave ray construction are being combined to develop a methodology for BPR data analysis. This technique was applied to the 6 March 1988 Alaskan Bight tsunami data. Observed waveforms agree well with theory, and the analysis may also provide estimates of the length scales characterizing seismic sources.

U.S.-Japan Collaboration on Marianas Trench Tsunami

On 5 April 1990, a small tsunami was measured by U.S. and Japanese tide gauges, by offshore BPRs of the Japanese Earthquake Phenomena Observation System (EPOS), and by PacTOP instrumentation located more than 8000 km distant from the source—a magnitude 7.6 earthquake in the Marianas Trench. An informal data exchange agreement was established, and a collaborative analysis of these data has begun.

Hilo Harbor Inundation Modeling

Tsunami inundation modeling of Hilo Harbor, HI has begun. This activity is in direct support of the Coastal Ocean Program, which provided funding for the contract awarded to JIMAR at the University of Hawaii.

Plans FY 92

BERING SEA FOCI

- Evaluate otolith and genetic samples for evidence of walleye pollock stock separation between regions of the Bering Sea.
- Evaluate pollock stock structure from summer 1991 joint cruises.
- Combine ocean model results, wind statistics, and altimetry data to estimate variability of flow between the Soviet and U.S. continental shelves and the doughnut hole.
- Conduct a spring/summer experiment on coupling of larval survival and turbulence. Begin modeling this interaction.

SHELIKOF FOCI

- Use SPEM to investigate generation, translation, vertical velocities and fate of mesoscale eddies.
- Complete analysis of bottom pressure and coastal sea level data to provide information on the dominant patterns of sea level change.
- Complete analysis of comparison between observed winds and computed winds derived from a surface atmospheric pressure grid.
- Recover the thirteen moorings deployed in spring 1991.
- Design and deploy an experimental system to examine upper mixed layer dynamics in light of the relationship between larval survival and wind mixing.

ARCTIC RESEARCH

- Complete the second set of cruises in the Chukchi Sea in support of the Joint U.S./U.S.S.R. Circulation Study, process the current meter and pressure gauge data from the first full year's moorings, and calibrate and process the hydrographic data set from the second set of cruises.
- Measure and monitor the fresh water flux from the Arctic Ocean through Fram Strait between Greenland and Spitsbergen as a part of the Atlantic Climate Change Program by recovering the first year's moorings, replacing the moorings, processing the sonar ice thickness and current meter data from the first year's moorings, and developing an analysis package for the upward-looking sonar ice thickness data.

- Continue analysis of circulation and mixing in the Greenland Sea, including the interactions between convective overturn and the distribution of sea ice.

- Complete a numerical study on the transport of ice and energy in winter over western arctic shelves, based on a decade of ice drift, current, and wind observations over the Bering and Chukchi continental shelves and funded by the Office of Naval Research.

- Deploy two sets of four Argos drifting ice stations during November 1991 and March 1992 to measure winds, currents, and ice drift in the Beaufort Sea, as a component of the LEADS Experiment funded by Office of Naval Research and as a furtherance of the sea ice-troposphere interaction observations.

TSUNAMI PROJECT

- Maintain the PacTOP network by recovery and redeployment of deep-ocean BPRs.

- Continue development of methodology for BPR analysis.

- Acquire and digitize U.S. tide gauge data for the Marianas Trench tsunami; provide these data to collaborating Japanese scientists.

- Complete inundation modeling of Hilo Harbor.

OCEAN ENVIRONMENT RESEARCH

VENTS PROGRAM

The VENTS Program is in its seventh year of research focused on determining the oceanic impacts and consequences of submarine hydrothermal venting. In pursuit of these objectives, the program directs most of its efforts toward achieving an understanding of the chemical and thermal effects of venting along northeast Pacific seafloor spreading centers on the North Pacific Ocean.

Accomplishments FY 91

Research results obtained during FY 91 continue to augment the case for hydrothermal venting at seafloor spreading centers having global significance in terms of the chemical and thermal state of the ocean. NOAA VENTS Program scientists, together with their non-NOAA research collaborators, are continuing to achieve major successes in quantitatively documenting these effects as they occur in the ocean over a very wide range of temporal and spatial scales. During the year, VENTS research was concentrated in two general categories of activity:

- determining patterns and pathways for the regional transport of hydrothermal emissions as well as source strengths of the emissions and their relationships to the geology and tectonics of spreading centers; and

- establishing capabilities for monitoring hydrothermal activity at a wide range of temporal and spatial scales.

Transport and Source Strengths of Hydrothermal Emissions

One of the most interesting and potentially significant VENTS Program discoveries of past years has been that of large-scale, episodic hydrothermal bursts generally known as megaplumes. Several of these events have now been observed, and it is necessary to determine just how important such episodic processes are in terms of their contributions to ocean hydrothermal chemical and heat budgets. The amount of silica contained in the first megaplume event observed, for example, was equivalent to that produced in 1 year by the entire large, steady-state vent field located in the same area. It appears likely that megaplumes are a relatively common hydrothermal consequence of discrete volcanic and tectonic events signaling episodes of active seafloor spreading. This hypothesis is supported by the recent discovery by VENTS investigators of a series of volcanic mounds that erupted in the megaplume region sometime between 1981 and 1987, a period that includes the times when two large megaplume events were observed. This discovery is important because it provides the first opportunity to study hydrothermal (and biological) evolution processes that are a consequence of a documented seafloor spreading event.

This year, a study was completed that showed that hydrothermal activity along the Juan de Fuca Ridge is a significant factor affecting the concentration and distribution of silica in the northeast Pacific water column. Silica is an important nutrient in seawater, and hydrothermal venting increases the concentration of silica (H_4SiO_4) in the water column anomaly west of the Juan de Fuca Ridge by 17–27%. The distribution of silica in the water column is further affected by venting because biologically derived silica, which normally resides near the seafloor in northeast Pacific deep water, is entrained in buoyant hydrothermal plumes and is thereby transported into midwater depths.

Hydrothermal Monitoring

One of the most important accomplishments during FY 91 was achieving operational status for the VENTS T-phase event detection system. T phases are acoustic signals that are generated by, among other things, submarine earthquakes and shallow submarine volcanic eruptions. One of the most important goals of the VENTS T-phase project is to detect events that either may be or are associated with episodic hydrothermal events such as megaplumes. From past research it is known that clusters of T phases, i.e., earthquake swarms, can be traced to loci on northeast Pacific spreading centers. Earthquake swarms often accompany volcanic eruptions, so the ability to detect and locate such activity will be a major step toward giving us the ability to study episodic hydrothermal activity while it is active. An important unresolved question, however, is whether or not either episodic hydrothermal events or deep volcanic eruptions generate distinctive acoustic signals.

The VENTS T-phase event-detection project is the first of its kind in the United States and provides the VENTS Program with an important means to continuously monitor not only the northeast Pacific but virtually the entire Pacific basin. Moreover, since T-phase event detection both requires and provides very detailed information about water-column sound velocities, Ocean Environment Research Division scientists are also considering using such data to help determine whether or not gradual, long-term changes in sound velocities are occurring in response to ocean warming.

Plans FY 92

- Reduce, analyze, and interpret physical, chemical, and geological oceanographic data obtained during the FY-91 VENTS *Discoverer* and *Atlantis II/Alvin* field season.

- Conduct the FY-92 VENTS *Discoverer* field season.

- Continue the decadal-scale monitoring of hydrothermal venting variability on the Cleft Segment of the Juan de Fuca Ridge, including ^{3}He-heat-silica relationships, through the use of existing instrumentation and techniques as well as through the development of new instrument systems. Examples of both include mooring arrays consisting of sediment traps, standard and ADCP current meters, and temperature sensors; a continuous chemical scanning system that detects and measures manganese, iron, and silica in hydrothermal plumes; an acoustic horizontal-strain measurement system; an

enhanced BPR that will include a tilt meter and a vertical seismometer; tow-yo surveys with a CTD/transmissometer system; repeat Sea Beam swath sonar system bathymetric surveys; and seafloor gravity measurements.

- Continue development of software to refine automated detection and location of T-phase events.

- Study the frequency and power spectra of T-phase signals in an attempt to classify events as to specific sources.

- Continue numerical model of physical and chemical processes in buoyant hydrothermal plumes.

- Compare seafloor roughness statistics derived from Sea Beam backscatter information with those generated by spectral techniques and fractal measures.

JIMAR

The Joint Institute for Marine and Atmospheric Research (JIMAR) was formed in 1977 by a Memorandum of Understanding between NOAA and the University of Hawaii. JIMAR is located at the University of Hawaii at Manoa and is part of the School of Ocean and Earth Science and Technology. The principal research interests of JIMAR are equatorial oceanography, climate and global change, tsunamis, and fisheries oceanography.

Accomplishments FY 91

FISHERIES OCEANOGRAPHY

Seamounts/island flow

Analysis and manuscript preparation on the effects of currents on micronekton populations near Hancock Seamount continued. In September 1990, a cruise was made to Palmyra Atoll to study flows near the island and their effect on larval fish populations. Significant progress was made in analyzing physical data from the cruise, and a manuscript is being prepared. Analysis of the biological samples is under way.

North Pacific transition zone

An oceanographic data base on the North Pacific transition zone (NPTZ) is being established. The data base includes XBT data, CTD data, currents, and satellite derived SST. The scope of the project is being broadened so that it can be included in a CoastWatch proposal for a data node in Hawaii.

Lobster larvae and sea level

A significant correlation was found between interannual sea level variability and lobster larval recruitment in the Hawaiian Archipelago. Major geographic variations were found. Sea level variations appear to be useful for predicting variability of adult lobster populations up to 4 years in advance. GEOSAT altimeter data were used in this study.

TSUNAMI RESEARCH

Inundation maps

Revised tsunami inundation evacuation maps were completed. These charts are now published in the telephone directories of each of the Hawaiian islands.

T-phase (acoustic) spectral amplitudes

Preliminary work on the relationship of T-phase spectral content and the occurrence of tsunamigenic earthquakes was completed. Alaskan and Aleutian earthquakes were studied. Both seismic moment and T-phase strength in the 10–35 Hz frequency band are larger for tsunamigenic than for nontsunamigenic earthquakes. The use of T-phase to estimate seismic moment in near real time is being studied.

Tsunami modeling

Pacific basin-wide tsunami modeling in support of Pacific Tsunami Observing Program (PacTOP) continued. A new modeling study of Hilo Harbor was undertaken. A variable grid is used to model the inundation on increasingly finer scales as the waves come in. The 1946, 1960, and 1964 Hilo tsunamis are being modeled.

CLIMATE AND EQUATORIAL OCEANOGRAPHY

Modeling and analysis

An observational study of El Niño-Southern Oscillation (ENSO) variability in the atmosphere, focusing on the 1982/83 and 1986/87 warm episodes, was completed. The data set for this study spanned eleven years, 1979–1989. The structure of the ENSO anomaly was explored using empirical orthogonal function analysis. The 30–60 day oscillations between the western Pacific and the Indian Ocean were analyzed and documented using pentad means, plus winds at both 200 and 850 mb levels. A numerical study on the drift of tropical cyclones was completed. The phase relationships among outgoing longwave radiation and other meteorological variables along the Equator were investigated.

A noncontiguous rain-gauge method for calibrating satellite-based rainfall algorithms was developed, and the method was applied to two algorithms.

Sea level network

The first satellite transmitting sea level gauge in the Indian Ocean network was installed at Salalah, Oman. This gauge reports through METEOSAT. A satellite station was installed at Guadalupe in the Pacific. Numerous data requests were filled by the Tropical Ocean and Global Atmosphere (TOGA) Sea Level Center. Progress was made on understanding the errors in tide-gauge measurements and developing new satellite orbit error algorithms for sea level height using water vapor and rain fall corrections.

Hawaii ocean time series station

Monthly cruises to the site to collect hydrographic data, acoustic Doppler current profiles, and biogeochemical data in support of the World Ocean Circulation Experiment (WOCE) and the Joint Global Ocean Flux Study (JGOFS) were carried out. Dissolved inorganic carbon, alkalinity, and pH were added to the list of observed properties.

Equatorial observations and theory

Analysis continued on data sets from a variety of equatorial programs, including the U.S./Peoples' Republic of China TOGA project, the Western Equatorial Pacific Ocean Climate Study (WEPOCS), and the Line Islands Array. A WEPOCS cruise to measure temperature and current profiles in the Mindanao Current and the New Guinea Coastal Undercurrent was made in the spring of 1991.

Planning for the TOGA Coupled Ocean-Atmosphere Response Experiment (COARE) continued. The COARE science plan was completed.

Conductivity sensors were added to four ATLAS moorings on the 156°E line.

A new study to understand deep equatorial circulation was begun. Simple thermohaline forcing was used to drive a high-resolution numerical model, and the results were extensively analyzed.

A WEPOCS workshop was held in the spring of 1991 to discuss recent results of studies of low-latitude western boundary currents. This workshop represents an effort to initiate serious intercomparison of WEPOCS data and numerical modeling simulations.

Plans FY 92

FISHERIES OCEANOGRAPHY

- Manuscripts on the effect of currents on micronekton populations near Hancock Seamount will be completed and submitted.

- The analysis of data on the flow near Palmyra Atoll and its relation to larval fish populations there will be completed. Another cruise to the same area is scheduled for February 1992 during the annual minimum of the North Equatorial Counter Current.

- A CoastWatch proposal including expansion of the North Pacific transition zone (NPTZ) data base will be submitted.

- Studies of the relationships between localized eddies near the Hawaiian Island chain, sea level variability, and lobster larval abundances will continue.

TSUNAMI RESEARCH

- The relationship between T-phase and seismic moment will be investigated in Pacific regions other than those already studied. The feasibility of using T-phase information to improve warning system reliability will be investigated.

- The Hilo Bay modeling effort will continue. High-resolution models with individual buildings and structures will be used to study the details of the flooding, focusing on the 1952 and 1957 events. The effect of the islands in focusing and shadowing tsunamis that have distant sources will be studied as well.

CLIMATE AND EQUATORIAL OCEANOGRAPHY

Modeling and analysis

- The development of a model that includes a free atmosphere and atmospheric and oceanic boundary layers, applicable to both ENSO and seasonal variability, will continue. Observational studies of annual and ENSO variability of the coupled ocean-atmosphere climate system will be carried out. A theoretical study of the influence of the monsoon basic flow on the intraseasonal wave will be undertaken. The existing model for tropical cyclone drift will be extended to include the effects of large-scale background flows.

- The development of the monsoon over southern equatorial Africa and its relation to the 30–60 day oscillation and ENSO variability will be analyzed from available wind, pressure, and convection data.

Sea level network

- The Pacific Ocean and Indian Ocean sea level networks will continue. Additional Indian Ocean satellite gauges will be installed at Gan, Port Louis, and Zanzibar.

- The TOGA Sea Level Center will continue to archive data and fill data requests. Research efforts will concentrate on developing methods for blending in situ sea level data and GEOSAT altimetry data.

Hawaii ocean time series

- The monthly observations in support of WOCE and JGOFS will continue. A data report for the first year's work will be published.

Equatorial observations and theory

- WOCE hydrographic cruises, to map hydrographic and tracer data on a large number of sections (20 in the Pacific), will begin. This data will be used in inverse models to infer the general (mean) ocean circulation. Acoustic Doppler current profiles will be made on these sections, as an ancillary measurement, not central to the WOCE objectives.

- The COARE planning will continue. The experimental design for COARE will be finalized. Planning for JIMAR involvement in the maintenance of the TOGA TAO array will be pursued.

- Analysis of WEPOCS and Line Island Array data will continue.

- The equatorial deep circulation modeling effort will continue. Model results using three different models will be analyzed to seek common features and understand model differences.

JISAO

The Joint Institute for the Study of Atmosphere and Ocean (JISAO) fosters collaboration between NOAA and the University of Washington's Department of Atmospheric Sciences and School of Oceanography. Its Director reports to the Vice Provost for Research.

JISAO emphasizes four core research areas: climate, environmental chemistry, estuaries, and recruitment of fish stock. Of these four areas, only climate has enjoyed the benefit of ongoing block funding. Of the 25 Senior Fellows associated with the Institute, 16 are involved in various aspects of climate research. Most of the visitors, and all but two of the postdoctoral fellows who have been funded through this program over the past 12 years, have had primary interests in climate. Seven Senior Fellows are currently involved in the Environmental Chemistry core program and two in the Estuaries program.

During the past 3 years, JISAO has played an active role in University and NOAA efforts to establish interdisciplinary research directed toward an understanding of the global climate system and its sensitivity to human activities. The Institute's Environmental Climate Forecast Center falls within the scope of this effort.

JISAO's climate research focuses on two main themes: large-scale atmosphere-ocean interaction in the tropics and planetary-scale wave/mean flow interaction. The existence of JISAO has substantially increased the level of activity in these areas on the University campus, and it has served to promote collaboration between Pacific Marine Environmental Laboratory (PMEL) scientists involved in Equatorial Pacific Ocean Climate Studies (EPOCS) field programs and University scientists and postdoctoral fellows involved in theoretical and modeling studies of the phenomena under investigation in EPOCS. It has also resulted in increased interaction between atmospheric scientists and physical oceanographers on the University faculty.

Accomplishments FY 91

- Simulation of geographic variations in atmospheric $^{14}CO_2$ using a three-dimensional global tracer transport model. The findings will help define the natural geographic distribution of oceanic CO_2 sources and sinks as well as the dynamics of stratosphere-troposphere exchange and the 11-year solar-induced ^{14}C cycle. First results were presented in May at the 14th International Radiocarbon Conference.

- Development of a new global atmosphere model for climate studies in collaboration with Lamont-Doherty Geological Observatory. FY 91 efforts involve development of a planetary boundary layer parameterization for use in the model.

- Investigations of oceanic mixing and convection processes, large-scale thermohaline circulations, and equatorial undercurrents. This effort involves numerical model studies of the role of mixing between Northern Atlantic deep water (NADW) and Antarctic bottom water (AABW) in large-scale ocean circulations in the South Atlantic. A tracer

study of a four-layer ocean model suggests that most mixing between NADW and AABW occurs near the mid-Atlantic ridges, which might be one of the factors that control the "retroflection" flow pattern of NADW in the South Atlantic.

- Experimental Climate Forecast Center. The Experimental Climate Forecast Center studies the predictability of the ENSO phenomenon, and the role of the ocean in determining the predictability of long-term climate beyond the decadal time scale. A UNIX computer installation was developed at the Center during this year.

- Completion of two case studies of mesoscale storm structures for OCEAN STORMS. Work has been started on a climatological study of the wind forcing of the Bering Sea for FOCI. An observational study of the tropical planetary boundary layer supported by the EPOCS program was submitted for publication.

- Numerical study to characterize the 30-day waves of the tropical Pacific as modeled in a climatological run of the Philander-Pacanowski model, and compared with observations taken by PMEL at the equator at 140°W and 110°W from 1984–1987 and the meridional section observations of the Hawaii-to-Tahiti shuttle experiment in 1979–1980.

- Analysis of moored buoy time series data, drifting buoy measurements, expendable bathythermograph data, conductivity-temperature-depth (CTD) data, and ship drift data in support of NOAA's climate mission, with emphasis on tropical Pacific Ocean variability.

- Research on the oxidation products of ocean-derived biogenic dimethylsulfide and the role that these products play in new particle production, with emphasis on the improvement of the following sampling and analysis methods: (1) a tandem sampling system for the collection of gaseous and submicron particulate sulfur species, (2) an impactor for the collection of size-segregated aerosol particle samples, and (3) ion chromatography as applied to the analysis of air sample-derived filter extracts.

- Arctic program emphases in FY 91 have been circulation and climatology of the Chukchi Sea, the outflow of fresh water from the Arctic Ocean, sea ice and convection in the Greenland Sea, and ocean climate variability in the Polar Basin.

- Five separate oceanographic cruises on vessels of Canada, the Federal Republic of Germany, the United States, and the U.S.S.R. In the Chukchi Sea alone, 16 U.S. and 7 U.S.S.R. year-long instrumented moorings were installed.

- Adaptation of a semispectral, primitive equation model for use in hydrodynamic and biophysical studies of Shelikof Strait off Alaska. The concepts developed during this year's analyses of modeling results related to deep convection, which focus especially on the energetics of baroclinic instabilities versus geostrophic adjustment, will be utilized in forthcoming studies of hydrodynamic instabilities in Shelikof Strait. These results were presented at the International Union of Geodesy and Geophysics (IUGG) Symposium in Vienna, Austria, during the summer of 1991.

- Evaluation of numerical modeling techniques for representing open boundary conditions in limited-area vertically integrated models of shelf circulation. The models were tested for the Bering and Chukchi Sea shelves adjacent to Bering Strait, where results of other modeling efforts were available. An eddy-resolving layered basin model has been acquired from the U.S. Naval Oceanic and Atmospheric Research Laboratory (NOARL) for use on the new Cray YM-P computer at Gaithersburg, MD. The model was installed, some preliminary runs were made, and progress was made toward implementing visualization tools at PMEL.

Plans FY 92

- In response to last year's request for proposals from the Climate and Global Change Program Office, in collaboration with PMEL, JISAO will continue to set up the TOGA TAO Analysis Project, designed to accelerate and enhance the scientific payoff from NOAA's large investment in an ocean observing system; the project addresses the need for immediate and intensive scrutiny of the data from the TAO array in relation to problems of interannual climate variability in the tropical Pacific.

- The Department of Energy, through the National Institute for Global Environmental Change, is funding the design and installation of a monitoring station for assessing the impact of anthropogenic aerosols on climate, resulting in an upgrade of the Cheeka Peak Research Station.

- A new JISAO research scientist/programmer will be involved in the development of user-friendly software for accessing and manipulating the large data bases used in climate research and for preparation of graphical displays of fields of mapped climate variables. Climate Monitoring and Diagnostics Laboratory (CMDL) software will be adapted for use on DEC workstations running under the UNIX protocol, and scientists will be instructed in its use. Analogous software will then be developed for other data sets as well as for more convenient user interface for the part of the NCAR graphics software used to create maps.

CIMRS

The Cooperative Institute for Marine Resources Studies (CIMRS) was established in 1982 to foster collaborative research between NOAA and Oregon State University in the areas of oceanography, fisheries, aquaculture and other marine-related fields, and to serve as a center at which researchers may address problems of mutual interest relating to the living and non-living components of the marine and estuarine environment and their interrelationships. Oregon State University is currently involved in research efforts that parallel NOAA/PMEL's VENTS Program objectives in the area of assessing the effect of spreading-center hydrothermal vents on the marine environment and defining the tectonic and volcanological processes producing oceanic crust at the Juan de Fuca Ridge (JdFR). The research that CIMRS is involved with in NOAA's VENTS Program falls into three main areas: photogeologic characterization of the seafloor, acoustic imaging and interpretation of the seafloor, and T-phase event detection. Specifically, studies include the interpretation of geologic structure via seafloor remote-sensing techniques, determining seafloor physical properties from acoustic backscatter data, and the inference of plate boundary mechanics from acoustical/seismological investigations.

Four CIMRS research assistants and two research associates contribute directly to the VENTS Program in various components of computer support and scientific research on the Juan de Fuca Ridge. A profound discovery made this year by CIMRS and NOAA scientists was evidence of volcanic eruptions on the northern Cleft segment of the Juan de Fuca Ridge between 1981 and 1987. Comparison of camera tow and Sea Beam data sets between these years revealed significant anomalies in the data and led to the discovery. The evidence of volcanic eruptions during this time period coincides with observed megaplumes on the JdFR in 1986 and 1987, supporting earlier models that megaplumes are caused by seafloor spreading events.

In the spring of 1991, NOAA's Undersea Research Program agreed to fund a joint PMEL-CIMRS proposal to design and build a new seafloor instrument array called an acoustic extensometer. This system is presently being built by PMEL's engineering group, and will be designed to precisely measure extension associated with tectonic or magmatic events along the ridge crest. The distances between instruments in the array will be measured acoustically, once per day, during the 1-year deployment period. This type of measurement is a common monitoring method on land volcanoes, but has never been attempted on ocean-floor volcanic systems. Such monitoring will help detect the timing and location of future volcanic events along the ridge, and their possible connection to megaplume emissions. The array is scheduled to be deployed in the summer of 1992.

The collection of T-phase data this year has required an enormous amount of time dedicated to special programming tasks. After considerable modification, an Interactive Data Language (IDL) program is now in place which graphically displays spectrograms of the acoustic data on UNIX workstations, automatically detects the presence of earthquake events, and derives information required for later location of the events. Other programs developed in FORTRAN or IDL are being written to compute source locations of T-phase events. In the course of developing a program to compute beam patterns of acoustic waves generated by T-phase events, another feature of T-phase sound generation was discovered: that large-scale roughness of the seafloor

radiates sound more omnidirectionally than previously thought, thus allowing more horizontal rays to reach receivers at a longer distance.

Several major breakthroughs were made in the backscatter project. Several required corrections were applied to the data which removed artifacts due to engineering and environmental effects. A simulated annealing method is being used to generate robust estimation of Kirchhoff scattering theory parameters. Initial observations indicate that the model parameters are controlled by seafloor morphology. A significant correlation between model parameters, which had been observed in the data, was traced to a mathematical construct within the theoretical model.

Accomplishments FY 91

- Comparison of camera tow data between 1987 and 1981 revealed significant anomalies leading to the discovery of the occurrence of volcanic eruptions during that time period.
- Source location programs written for T-phase project that display hyperbolic curves to determine the position of an "event" given an initial location, heading and distance from hydrophone location.
- Developed data files of seasonal differences in sound velocity at different ocean depths that include global and local minimum sound speeds, speed at sea surface, depths, latitude and longitude.
- Conducted field experiments by detonating underwater explosive charges to determine the detection threshold of SOFAR hydrophones at Oahu and Wake Islands.
- Discovered a relationship between fault length and earthquake magnitude for oceanic strike-slip faults.
- Thorough analyses of acoustic backscatter data successfully discriminated tectonic provinces on the Juan de Fuca Ridge.

Plans FY 92

- Continue development of models and signal processing software for analysis, detection and location of T-phase events along the Juan de Fuca Ridge.
- Continue to refine Kirchhoff approximation of SeaBeam backscatter data to determine the physical characteristics of the seafloor using the echo strength of the acoustic beam in coordination with Navy sponsors.
- Initiate development of a Geographical Information System (GPS) to incorporate all types of VENTS Program data.

- Compare photogeologic and microbathymetry data of seafloor from camera tows during 1981 and 1991 to look for evidence of other possible volcanic eruptions on a broader area of the southern Juan de Fuca Ridge.

- Continue design and construction of acoustic extensometer in coordination with PMEL's Engineering Division for deployment in FY 92 field season.

- Routine processing and analysis of T-phase data.

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CAPT Michael A. McCallister, Associate Director

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PMEL SEMINARS

1990

18 October	Dr. Edward Cokelet Ocean Environment Research Division PMEL	Puget Sound circulation, refluxing and predictions of tracer concentrations and ages
8 November	Dr. Harold Mofjeld Coastal and Arctic Research Division PMEL	Analyzing extreme sea level events
29 November	Dr. Jack Hardy College of Environmental Studies Western Washington University Pullman, WA	Stratospheric ozone depletion: Implications for the South Pacific
13 December	Anthony Paulson Ocean Environment Research Division PMEL	Cu interactions with dissolved and particulate organic matter in Puget Sound

1991

10 January	Dr. Roger Colony Polar Science Center University of Washington	The seasonal circulation of pack ice in the Arctic basin
15 January	Dr. William Kessler Department of Physical Oceanography Woods Hole Oceanographic Institution Woods Hole, MA	Can reflected extra-equatorial Rossby waves drive ENSO?
17 January	Dr. James Simpson Scripps Institution of Oceanography La Jolla, CA	Automated cloud screening of AVHRR imagery using split-and-merge clustering

7 February	Scott Doney Woods Hole Oceanographic Institution Woods Hole, MA	A chlorofluorocarbon section in the northeast Atlantic
7 March	Dr. Edward Baker Ocean Environment Research Division PMEL	Notes from the underground: Geological insights from hydrothermal plumes
14 March	Professor Thomas Dickey Department of Geological Sciences University of Southern California Los Angeles, CA	Concurrent high resolution time series observations of physical and bio-optical variables in the upper ocean
4 April	Dr. Stephen Hammond Ocean Environment Research Division, PMEL Oregon State University Newport, OR	T-phase event detection and characterization: Large-scale acoustic ocean monitoring
8 April	Dr. David Gardner Naval Postgraduate School Monterey, CA	Developments in compact fiber optic sensors and thermo-acoustic engines
18 April	Dr. Al Hermann Coastal and Arctic Research Division PMEL	Energetics of gravitational adjustment for mesoscale chimneys
30 May	Dr. Knut Aagaard Coastal and Arctic Research Division PMEL	The maintenance of the north Atlantic thermohaline circulation
4 June	Dr. Karen Von Damm Oak Ridge Environmental Laboratory Oak Ridge, TN	Seafloor hydrothermal activity at 9–10° north of the East Pacific Rise: First results from a new system
6 June	Dr. William Kessler Woods Hole Oceanographic Institution Woods Hole, MA	The annual wind-driven Rossby wave in the sub-thermocline equatorial Pacific Ocean

18 June	Dr. John E. Lupton Department of Marine Sciences University of California at Santa Barbara	Hydrothermal systems: Relation to ridge crest magma supply and possible oceanic effects
9 September	David Stevenson Geophysical Fluid Dynamics Laboratory Princeton, NJ	Global simulation of the electric and magnetic fields produced by the oceans
12 September	Dr. Andrew T. Walden Imperial College of Science, Technology and Medicine London, UK	Analysis of extreme high sea level events on the British coast
16 September	Dr. Stuart Godfrey Division of Oceanography CSIRO Hobart, Tasmania	The role of the Indonesian throughflow in a global ocean GCM

JISAO SEMINARS

1990

5 October	Dr. Tom Braziunas JISAO	Simulating change (or lack of it) in the holocene atmosphere and ocean with a one-dimensional ^{14}C model
30 October– 13 November	Dr. Edward N. Lorenz Massachusetts Institute of Technology Cambridge, MA	Life histories of prediction errors
		Can chaos and intransitivity lead to interannual climate variability?
		Chaos and its relatives
		Our chaotic weather
		The ubiquity of chaos
14 November	Dr. Neil Price Massachusetts Institute of Technology Cambridge, MA	Trace element dependency of nitrogen utilization and growth of marine phytoplankton
28 November	Dr. Peter Niiler Scripps Institution of Oceanography La Jolla, CA	Pan Pacific surface current study: drifter results of the first two years

1991

13 February	Dr. Rana Fine University of Miami	Climate-related aspects of the deep western boundary current
13–17 February	Dr. Brian Farrell Harvard University Cambridge, MA	An adjoint method for obtaining the most rapidly growing perturbation to oceanic flows
		Perturbation growth in the presence of stochastic forcing

		The dynamics of equable climates
22 February	Dr. In-Sik Kang Seoul National University Seoul, South Korea	Global angular momentum fluctuations
8–10 May	Robert Dickenson University of Arizona Tucson, AZ	Climate effects of Amazon deforestation
22 May	Edward Boyle Massachusetts Institute of Technology Cambridge, MA	Paleochemical evidence for changes in deep ocean circulation patterns during the last glacial maximum
23 May	David Neelin University of California at Los Angeles	Modes of tropical air-sea interaction—toward a unified understanding
20 June	Dr. Yochanan Kushnir Lamont-Doherty Geological Observatory Palisades, NY	GCM experiments with a prescribed SST anomaly pattern: effects of time scale and pattern polarity
5 August	Dr. Noburo Nakamura Geophysical Fluid Dynamics Laboratory, NOAA Princeton, NJ	An analytic model of meridionally and vertically sheared flows

JIMAR SEMINARS

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8 October	Tim Ragen National Research Council National Marine Mammal Laboratory National Marine Fisheries Center Honolulu, HI	Problems in estimating maximum net productivity level in northern fur seals
29 October	Nick Graham Scripps Institution of Oceanography La Jolla, CA	Decadal climate variability over the Pacific during the 1970s—Observations and model results
25 November	Fred Singer Environmental Sciences University of Virginia Charlottesville, VA	Global climate change: Facts and fiction
10 December	Hengyi Weng Geophysical Fluid Dynamics Institute Florida State University Tallahassee, FL	The effects of asymmetric Ekman dissipation and sloping boundaries of baroclinic waves

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9 January	Yoshifumi Kuroda Japanese Marine Science and Technology Agency (JAMSTEC) Yokosuka, Japan	Equatorial current structure during JAPACS cruise in 1989 and 1990
7 February	Cheryl Greengrove EG&G WASC Oceanographic Services Waltham, MA	The Northern California Coastal Circulation Study

9 March	Zong-Ci Zhao Climate Research Center Academy of Meteorological Science Beijing, PRC	Human activity and climate change: Impacts in China
23 March	Fred Bingham Department of Geophysics Tohoku University Sendai, Japan	The formation and spreading of subtropical mode water in the north Pacific
16 April	Hyungmoah Yih Department of Oceanography University of Washington Seattle, WA	Velocity and temperature fluctuations of Vancouver Island
27 April	Mark Jury Department of Oceanography University of Cape Town Rondebosch, South Africa	Analysis of summer convective anomalies and synoptic events in the tropical SE Africa–SW Indian Ocean region
6 July	Peter Janssen Royal Netherland Meteorological Institute De Bildt, Netherlands	The interaction of wind and waves
10 July	Guoxiong Wu Institute of Atmospheric Physics Academia Sinica Beijing, PRC	Tropical circulation and storm formation in response to sea surface temperature anomaly

PMEL PUBLICATIONS

AAGAARD, K., and A.T. ROACH. Arctic Ocean-Shelf exchange: Measurements in Barrow Canyon. *Journal of Geophysical Research, 95*(C10), 18,163–18,175 (1990).

Two closely instrumented arrays were deployed within Barrow Canyon during 1986–1987 in an attempt to measure the outflow of dense, hypersaline plumes created during sea ice formation along the Alaskan coast. However, no hypersaline plumes were observed. Rather, we found cold, relatively fresh waters advected downcanyon by the mean flow alternating with upcanyon flow of warm and saline water upwelled onto the shelf. Upwelling was most frequent in the fall, and upcanyon speeds reached 60 cm s^{-1}. At times the resulting onshore heat and salt fluxes were large enough to be of possible local significance, for example, to the surface heat budget. Contrary to earlier findings, the flow was only weakly correlated with the wind and the atmospheric pressure gradient. Instead, we found both upwelling and flow reversals to be coherent along the coast at sites 400 km apart, with phase differences corresponding to a typical speed of 2.3 m s^{-1}. We suggest that the majority of these events are manifestations of shelf waves propagating eastward along the Arctic Ocean margin.

BERNARD, E.N. (editor). *Tsunami Hazard: A Practical Guide for Tsunami Hazard Reduction.* Reprinted from *Natural Hazards,* 4(2,3). Kluwer Academic Publishers, Dordrecht, 326 pp. (1991).

No abstract.

BERNARD, E.N. Assessment of Project THRUST: Past, present, future. *Natural Hazards, 4,* 285–292 (1991).

Project THRUST (*T*sunami *H*azards *R*eduction *U*tilizing *S*ystems *T*echnology) was a demonstration of satellite technology, used with existing tsunami warning methods, to create a low cost, reliable, local tsunami warning system. The major objectives were successfully realized at the end of the demonstration phase in September 1987. In June 1988, the Chilean Government held a workshop to assess the value of THRUST to national interests. Two recommendations came forth from the workshop: (1) the technology was sufficiently reliable and cost-effective to begin the development of an operational prototype and (2) the prototype would be used as the Chilean Tsunami Warning System. As of August 1989, the equipment was in operational use. In September 1989, major improvements were made in the satellite operations that reduced the response time from 88 to 17 sec and enlarged the broadcast area by 50%. The implications of the recent improvements in satellite technology are discussed for application to reductions in disaster impacts.

BERNARD, E.N. Meeting Reports, Fourteenth International Tsunami Symposium, Novosibirsk, USSR, 31 July–3 August 1989. *Natural Hazards, 4*, 87–97 (1991).

No abstract.

BOGRAD, S.J. Sea level and bottom pressure measurements in the northern Gulf of Alaska. NOAA DR ERL PMEL-29 (PB91-184135), 58 pp. (1991).

No abstract.

BOND, N.A., and M.A. SHAPIRO. Polar lows over the Gulf of Alaska in conditions of reverse shear. *Monthly Weather Review, 119*(2), 551–572 (1991).

The formation of two polar lows over the Gulf of Alaska are studied, using observations taken during the OCEAN STORMS field experiment. Synoptic-scale and mesoscale analyses were constructed using NOAA P-3 aircraft flight-level and radar data and dropwindsonde profiles, in addition to conventional data sources. The synoptic-scale analyses show that polar low development occurred in a low-level mesoscale baroclinic zone near the center of a mature, occluded synoptic-scale low pressure system. The disturbances propagated along the zone in the reverse shear sense, i.e., in the direction opposite to the thermal wind within the zone. The mesoscale analysis reveals a boundary layer jet of 38 m s^{-1} on the cold side of the baroclinic zone accompanying the leading polar low. Indirect evidence suggests that a Sawyer-Eliassen secondary circulation was present; polar low development occurred in the region of a frontogenetical geostrophic deformation. Convective activity was not prominent during the growth phase of the polar lows, as determined from satellite imagery and radar reflectivity measurements. Extremely high ocean waves (~13 m) occurred in response to intense wind forcing on the mesoscale on a sea state preconditioned by moderate forcing on the synoptic scale. The observed synoptic-scale and mesoscale structures are compared with results from previously studied polar lows. This case appears to represent an example of polar low development due primarily to moist baroclinic processes.

CANNON, G.A., D.J. PASHINSKI, and M.R. LEMON. Middepth flow near hydrothermal venting sites on the southern Juan de Fuca Ridge. *Journal of Geophysical Research, 96*(C7), 12,815–12,831 (1991).

Long-term moored current measurements around the southern end of the Juan de Fuca Ridge show that flow parallels the ridge and may be intensified by its presence. The mean flow is northward on the west side and southward on the east. Thus plumes emanating from the ridge probably are advected along the ridge before flowing away from the ridge. Other topographic features may be responsible for westward or eastward turning. Along the west side of the ridge, we hypothesize a regional flow pattern with southward flow north of Axial Seamount, northward flow south of Axial; and a convergence somewhere south of Axial resulting in westward flow. Along the east side, the flow may be southward everywhere. Above the ridge crest the long-term mean flow is weaker and more variable, and it includes

tidal, inertial, and a dominant broadband 4-day oscillation. This 4-day energy is maximum in the rift valley (where the inertial is least), decreases upward and away from the ridge, and is more energetic in winter. This oscillation is predominately a clockwise rotating feature which, along with the presence of inertial oscillations, suggests that it may be storm-induced from the sea surface. These observations along with those by Cannon and Pashinski (1990) suggest northward propagation. Flow variations across the ridge lasting one to a few months have mean speeds of 1–3 cm/s and are capable of transporting plumes off axis to the west or east into the northerly or southerly flows, respectively.

Chadwick, Jr., W.W., R.W. EMBLEY, and C.G. FOX. Evidence for volcanic eruption on the southern Juan de Fuca ridge between 1981 and 1987. *Nature, 350,* 416–418 (1991).

The formation of new ocean crust at mid-ocean ridges is known to be a discontinuous process in both space and time, but little is known about the frequency and duration of eruptions along an active ridge segment. Here we present evidence, from Sea Beam surveys and underwater photography, for the eruption of lavas along a segment of the Juan de Fuca ridge between 1981 and 1987. Although previous studies have inferred volcanic activity on ridges in areas where recent seismicity or young lava flows have been observed, none has yet had direct evidence to date such a recent submarine eruption. The temporal coincidence between this eruptive episode and the megaplumes (huge, sudden emissions of hot mineral-laden water) observed over this part of the ridge in 1986 and 1987 supports previous suggestions that megaplumes are caused by sea-floor spreading events.

Coale, K.H., C.S. Chin, G.J. MASSOTH, K.S. Johnson, and E.T. BAKER. *In situ* chemical mapping of dissolved iron and manganese in hydrothermal plumes. *Nature, 352,* 325–328 (1991).

Hydrothermal vents along mid-ocean ridges are an important source of elements such as lithium, silicon, manganese and iron to the world's oceans. The venting produces both episodic and steady-state hydrothermal plumes with unique thermochemical signatures in the mid-water column. The particulate phases in these plumes (predominantly iron oxides and hydroxides) also scavenge phosphorus, vanadium, arsenic, lead, polonium and several rare-earth elements from sea water. Thus, on a global scale, hydrothermal plumes are both a source for some elements and a sink for others. Ultimately, the particulate metals precipitated from plumes form extensive regions of metalliferous sediments over the crests and flanks of mid-ocean ridges. Although the metalliferous sediment coverage is vast and well documented, only a tiny fraction of the vents responsible for these sediments have been located. To date, both the number and location of hydrothermal vents and the detailed distribution of chemical constituents within the resultant plumes are poorly understood because of under-sampling of the mid-ocean ridges and the overlying waters. Here we present the results of high-resolution mapping of the chemical and thermal characteristics of hydrothermal plumes in near real time using a novel submersible chemical analyser (Scanner) and a conductivity/temperature/depth/transmissometer instrument package (CTDT). We show that the kinetics of iron oxidation in the plume can be used to constrain estimates of the plume's age, and that variation in the ratio of manganese content to excess heat can be explained by the mixing of several different vent fluids.

COKELET, E.D., R.J. Stewart, and C.C. Ebbesmeyer. Concentrations and ages of conservative pollutants in Puget Sound. Proceedings, Puget Sound Research '91, Seattle, WA, January 4–5, 1991, Puget Sound Water Quality Authority, 99–108 (1991).

No abstract.

Cowen, J.P., G.J. MASSOTH, and R.A. FEELY. Scavenging rates of dissolved manganese in a hydrothermal vent plume. *Deep-Sea Research, 37*(10A), 1619–1637 (1990).

The biogeochemical scavenging of dissolved manganese (Mn) from hydrothermal plumes was investigated using radiotracer (^{54}Mn) techniques. The measured scavenging rate constant, k_1, was lowest in the buoyant plume (<0.2 y^{-1}), increasing to ~2 y^{-1} in the non-buoyant plume at distances of 20 km from the ridge valley axis. The direct biological contribution to the dissolved Mn scavenging rate (i.e., the fraction suppressed by the addition of a metabolic poison) also increased over the same distances, being minor or absent at plume depths in the proximal plume, yet the major component at distal plume stations. These and other data suggest that the capacity for scavenging dissolved Mn onto particles evolves with increasing age of the plume, suggestive of a microbial response to changing conditions within the plume. Estimated maximum scavenging rates of dissolved Mn onto particles ($R_{DMn} = k_1$ [DMn]) were noted at plume depths for all stations, a function of very high dissolved Mn concentrations in the case of the buoyant plume and proximal non-buoyant plume. R_{DMn} values, integrated over plume depths, ranged from 3.4 to 1.7 mM m^{-2} y^{-1} for the non-buoyant plume at on-axis and off-axis stations, respectively. The application of the data to the dispersal of hydrothermal constituents and to plume aging is discussed.

CUDABACK, C.N., A.J. PAULSON, and J.W. LAVELLE. A modeling study of the vertical distribution and transport of manganese in Puget Sound. NOAA TM ERL PMEL-93 (NTIS PB92-128644), 21 pp. (1991).

A one-dimensional vertical distribution and transport model tracing the fate of Mn in dissolved and fine particulate forms and Mn associated with rapidly settling aggregates is developed and results are compared with measurements. Those measurements take the form of vertical profiles of dissolved and particulate Mn concentrations measured in the water column at one station in central Puget Sound. The model provides a framework relating sources, sinks, distributions and fluxes of Mn in a quantitative manner. The model accurately reproduces the vertical distributions of dissolved and particulate Mn, but shows excessive vertical flux of Mn. The model suggests that particles in each of two size classes should carry nearly the same loading of Mn, but measurements show significantly less Mn loading on macroaggregates than on fine particles. Mn budgets from model results allow comparison of major Mn fluxes in Puget Sound. The flux of Mn into the central main basin in particulate form is about half the diffusive flux of dissolved Mn from the bottom. A significant fraction of the riverine flux of particulate Mn is advected out of Puget Sound in dissolved form.

CURL, JR., H.C., and A.J. PAULSON. The biogeochemistry of oxygen and nutrients in Hood Canal. Proceedings, Puget Sound Research '91, Seattle, WA, January 4–5, 1991, Puget Sound Water Quality Authority, 109–105 (1991).

Although organic loadings to the nation's estuaries have declined as result of improved waste treatment practices, loadings of nutrients (e.g., phosphates, nitrogen compounds) continue to increase. Increased nutrients are responsible for, or have been implicated in, hypoxic/anoxic events, red and brown tides, and altered food chains. Hood Canal offers an ideal situation in which to examine some of the fundamental processes in nutrient dynamics because of its circulation features and nutrients sources. The chemical oceanography of Hood Canal is reviewed, based on data spanning nearly 40 years. Hood Canal is a somewhat smaller, simplified version of Puget Sound proper, with a vigorous circulation. Intrusions of high density water via Admiralty Inlet and several sources of fresh water produce strong near-surface stratification within the euphotic zone throughout much of the year. Most striking is the occurrence of a persistent subsurface oxygen minimum layer typified by *in situ* nitrification. Increased organic and nutrient loadings to Hood Canal could easily lead to periods of extensive hypoxia and anoxia as well as other problems.

EBLE, M.C., and F.I. GONZALEZ. Deep-ocean bottom pressure measurements in the northeast Pacific. *Journal of Atmospheric and Oceanic Technology, 8*(2), 221–233 (1991).

Pressure transducers with quartz-crystal resonators are being used to measure deep-ocean bottom pressure in the northeast Pacific as part of a long-term monitoring program. In principle, instrument sensitivity is less than 1 mm for sea-level oscillations of periods greater than a few minutes; in practice, however, system resolution is limited by long-term sensor drift and background noise. Data are digitally recorded at a rate of 64 samples per hour but selectable intervals ranging from 4 to 128 samples per hour are possible. The field program has focused on the maintenance of five permanent stations in the northeast Pacific since 1986. During this time, phenomena over a wide range of time scales have been recorded, including tides and the seismic surface waves and tsunamis generated by three earthquakes in the Alaskan Bight.

EMBLEY, R.W., W. Chadwick, M.R. Perfit, and E.T. BAKER. Geology of the northern Cleft segment, Juan de Fuca Ridge: Recent lava flows, seafloor spreading, and the formation of megaplumes. *Geology, 19*, 771–775 (1991).

Geologic mapping and lava sampling were carried out after the discovery of large bursts of hydrothermal fluids (megaplumes) over the southern Juan de Fuca Ridge in 1986 and 1987. Our investigations of the northernmost section of the Cleft segment have discovered: (1) semicontinuous low-temperature venting and one major high-temperature vent site along 17 km of the neovolcanic zone and (2) very glassy, lightly sedimented sheet flows and pillow mounds superimposed on older terrain over about 24 km along the northernmost part. The pillow mounds are documented to have erupted between 1981 and 1987. The occurrence of the megaplumes during this same time period strengthens the hypothesis that megaplumes are caused by sea-floor extension events. Although the basalts from the entire length of the

neovolcanic zone of the Cleft segment appear to have been derived from the same mantle source, a systematic northward increase in Mg number along the segment within the neovolcanic zone indicates less shallow-level differentiation to the north, possibly related to the development of new magma chambers during the recent phase of sea-floor spreading that has occurred there.

EMBLEY, R.W., S.L. Eittreim, C.H. McHugh, W.R. Normark, G.H. Rau, B. Hecker, A.E. DeBevoise, H.G. Greene, W.B.F. Ryan, C. Harrold, and C. Baxter. Geological setting of chemosynthetic communities in the Monterey Fan Valley system. *Deep-Sea Research, 37*(11), 1651–1667 (1990).

Alvin dives and camera tows within the "meander area" of the Monterey and Ascension Fan Valleys have located nine chemosynthetic communities over depths ranging from 3000 to 3600 m over a distance of 55 km. Most of the observed communities consist largely of *Calyptogena phaseoliformis*, but *Solemya* (species unknown) and a pogonophoran (genus *Polybrachia*), have also been identified. The $\delta^{13}C$ values (–35.0 to –33.6 per mil) and the presence of APS reductase and ATP sulfurylase in the *C. phaseoliformis* tissue is consistent with sulfur chemoautotrophy. Two reduced organic matter sources for the H_2S are proposed: (1) older beds exposed by the deep erosion (up to 400 m) of the fan valleys and (2) concentrations of anaerobically decomposed organic matter buried in the valley floor.

FEELY, R.A., J.H. Trefry, G.J. MASSOTH, and S. Metz. A comparison of the scavenging of phosphorus and arsenic from seawater by hydrothermal iron oxyhydroxides in the Atlantic and Pacific Oceans. *Deep-Sea Research, 38*(6), 617–623 (1991).

Studies of hydrothermal plumes on the Juan de Fuca Ridge and the Mid-Atlantic Ridge indicate that newly-formed Fe oxyhydroxides, formed as a consequence of hydrothermal venting, readily scavenge P and As from seawater in proportion to the dissolved concentrations of these elements. The Fe content of the suspended matter decreases from ~40% near the vents to <5% in ambient seawater, with particulate P and As concentrations correlating well with Fe throughout this range. The P/Fe ratio in the oxyhydroxide phase is about 1.8 times higher in Juan de Fuca Ridge samples relative to samples from the Mid-Atlantic Ridge. In contrast, the As/Fe ratio in the oxyhydroxide phase is about the same for both regions. Calculated distribution coefficients for P and As in the Fe oxyhydroxide phase show remarkable agreement between the Atlantic and Pacific Oceans. Thus, inter-ocean variations in the element/Fe ratios are a function of dissolved concentrations of the chemical species.

FREITAG, H.P., M.J. MCPHADEN, C.S. COHO, and A.J. SHEPHERD. Equatorial wind, current and temperature data: 108°W to 140°W; April 1983 to October 1987. NOAA DR ERL PMEL-35 (NTIS PB92-119817), 116 pp. (1991).

No abstract.

Frick, W.E., C.A. Bodeen, D.J. Baumgartner, and C.G. FOX. Empirical energy transfer function for dynamically collapsing plumes. Proceedings, International Conference on Physical Modeling of Transport and Dispersion, E.E. Adams and G.E. Hecker (eds.), Massachusetts Institute of Technology, August 7–10, 1990, 2A.25–2A.30 (1991).

Dynamic collapse is recognized as one of several processes that determine far-field plume behavior; therefore, models that use the round plume assumption become invalid there. To overcome this limitation, a conservation of energy approach is used to model collapsing plumes in stratified ambient flows. A common time scale governing rise and collapse is found that further proves the importance of collapse.

Giese, B.S., and D.E. HARRISON. Eastern equatorial Pacific response to three composite westerly wind types. *Journal of Geophysical Research, 96*(Sup), 3239–3248 (1991).

It has been suggested recently that episodes of westerly wind near the international date line in the western Pacific tend to fall into one of four types. Three of the types have enough equatorial zonal wind variation to be able to induce an eastern Pacific response by forcing equatorial waves. In this note we examine the central and eastern Pacific waveguide response to idealized representations of these three types of westerly wind episodes, using a combination of linear theory and results from an ocean general circulation model. The idealized westerly wind types are the C type (maximum anomalies centered on the equator), the N type (maximum anomalies just north of the equator), and the S type (maximum anomalies just south of the equator). The composite C-type event excites equatorially trapped Kelvin pulses that alter sea surface temperature in the central and eastern Pacific. Warm anomalies caused by the C-type episode have approximately equal contributions from a zonal advection of heat by the Kelvin pulses and a meridional advection of heat by an altered instability wave field. Because the center of forcing of the S-type event is displaced off of the equator, the Kelvin pulses excited by the S-type episode have smaller amplitude than those of the C-type episode, even though the maximum wind anomaly is the same in the two cases. The S-type anomaly also excites weak Rossby-gravity waves that can propagate into the eastern Pacific. Because the Rossby-gravity waves are dispersive, their amplitude diminishes as the waves propagate into the eastern Pacific. The N-type episode, as observed in winds from the western tropical Pacific, is much weaker and of shorter duration than the C and S types, and therefore excites only a very weak eastern Pacific response. Although all types of westerly wind excite a local western Pacific response, only the C- and S-type events excite a significant eastern Pacific response.

GONZALEZ, F.I., and Ye.E. Kulikov. On frequency modulation observed in two PacTOP deep ocean tsunami records. Proceedings, 2nd UJNR Workshop, Honolulu, HI, 5–6 November 1990, A.M. Brennan and J.F. Lander (eds.). NGDC Geophysical Record Document No. 24, 27–29 (1990).

Deep ocean tsunami waveforms measured by PacTOP bottom pressure recorders on 30 November 1987 and 6 March 1988 display amplitude and frequency modulation. An analysis of the temporal evolution of spectral energy suggests that frequency dispersion as predicted by classical linear wave theory is an important process governing the evolution of these waveforms.

GONZALEZ, F.I., C.L. Mader, M.C. EBLE, and E.N. BERNARD. The 1987–88 Alaskan Bight Tsunamis: Deep ocean data and model comparisons. *Natural Hazards, 4*, 119–139 (1991).

Excellent deep ocean records have been obtained of two tsunamis recently generated in the Alaskan Bight on 30 November 1987 and 6 March 1988, providing the best available data set to date for comparison with tsunami generation/propagation models. Simulations have been performed with SWAN, a nonlinear shallow water numerical model, using source terms estimated by a seafloor deformation model based on the rectangular fault plane formalism. The tsunami waveform obtained from the model is quite sensitive to the specific source assumed. Significant differences were found between the computations and observations of the 30 November 1987 tsunami, suggesting inadequate knowledge of the source characteristics. Fair agreement was found between the data and the model for the first few waves of the 6 March 1988 tsunami. Model estimates of the seismic moment and total slip along the fault plane are also in fair agreement with those derived from the published Harvard centroid solution for the 6 March 1988 event, implying that the computed seafloor deformation does bear some similarity to the actual source.

HARRISON, D.E. Equatorial sea surface temperature sensitivity to net surface heat flux: Some ocean circulation model results. *Journal of Climate, 4*(5), 539–549 (1991).

Several primitive-equation ocean general circulation model experiments have been carried out in order to explore the sensitivity of equatorial sea surface temperature (SST) results to uncertainty in the net surface heat flux (Q) imposed at the surface. Both climatological seasonal cycle experiments and hindcasts of the 1982/83 ENSO event are considered. It is found that regions of light winds, which typically reach values of SST in excess of 31°C using this ocean model and past Qparameterizations, attain more realistic SST values of 29°–30°C when Q is reduced by as little as 10 W m^{-2}. Sensitivity in this regime is about 0.1–0.2°C (W m^{-2})$^{-1}$ for low-frequency SST changes. In regions of easterly winds with their associated upwelling, horizontal advection, and stronger mixing, changes of Q in excess of 50 W m^{-2} produce SST changes typically of 0.7°C, for a sensitivity of about 0.02°C (W m^{-2})$^{-1}$. These results apply equally well to the ENSO hindcasts and the seasonal cycle studies. The reasons for the large variation in sensitivity and the very large sensitivity under light winds are described. To the extent that these results are representative of oceanic conditions, very accurate Q information will be required for studies of the low-frequency variability of SST

in light wind regions like the western Pacific; much less accurate fluxes appear needed for studies of comparable variability in upwelling regions.

HARRISON, D.E. Tropical ocean circulation models: Sensitivity to surface fluxes. Proceedings, International TOGA Scientific Conference, WCRP-43, October 1990 (WMP/TD #379), 169–177 (1990).

No abstract.

HARRISON, D.E., and B.S. Giese. Episodes of surface westerly winds as observed from islands in the western tropical Pacific. *Journal of Geophysical Research, 96*(Sup), 3221–3237 (1991).

We describe the characteristics of surface westerly wind episodes in the tropical Pacific between mid-1957 and 1980, as they can be determined from a collection of daily average wind records from islands. Several types of frequency of occurrence and duration statistics are presented; events in which the maximum westerly anomalies exceed 7 m s^{-1} are not common, but are prominent in the records. There is strong seasonal and geographical variation in frequency of occurrence. Four types of westerly episodes are found; we call them types N, C, S, or FS, according to whether the maximum westerly wind is found north of, centered on, south of, or "far south" of the equator near the international date line. Sixteen, 45, 47, and 47 events of type N, C, S, and FS are identified, respectively. The strongest westerly winds are associated with type C and S events; maximum daily average values can exceed 20 m s^{-1}. Only type C and S events are found to have substantial equatorial zonal wind anomalies. Several examples of type C and S events are presented. Composite events of each type have been computed, and their characteristics are described. In order to explore relationships between equatorial westerly events and cyclones, all of the named tropical cyclones within a region encompassing the near-date line islands have been identified; various statistics are presented, but no absolute relationships have been identified. The similarity between the composite type C and S anomaly patterns and patterns of the El Niño-Southern Oscillation monthly mean zonal wind anomaly previously documented in the literature is striking; evidently, the westerly events often dominate in the monthly average anomaly.

HAYES, S.P. (editor). Equatorial Pacific Ocean Climate Studies (EPOCS) Progress Report, June 1991. NOAA Special Report ERL PMEL (NTIS PB92-114628), 94 pp. (1991).

No abstract.

HAYES, S.P., P. Chang, and M.J. MCPHADEN. Variability of sea surface temperature in the eastern equatorial Pacific during 1986–1988. *Journal of Geophysical Research, 96*(C6), 10,553–10,566 (1991).

Time series of surface wind and upper ocean temperature and velocity, obtained from equatorial moorings along 110°W, are used to assess the importance of various oceanic and atmospheric processes in the variation of the mixed layer temperature for the period January 1986 to June 1988. This period coincides with the onset and development of the 1986–1987 El Niño-Southern Oscillation warm event and a subsequent cold event in 1988. Results of the temperature equation analyses indicate that seasonal and interannual variability of sea surface temperature (SST) in the eastern Pacific cannot be accounted for by observed surface heat flux; oceanic processes play an important role in the heating of the surface water. Although no single process dominated SST change, the most important processes in the mean balance were the net incoming surface heat flux, the penetrative solar radiation, and the vertical turbulent flux out the bottom of the mixed layer. The mean vertical entrainment could not be estimated with the available data. On the seasonal time scales, both the vertical turbulent heat flux and the vertical entrainment variations were well correlated with SST change. Zonal advection was a significant contribution to the heat flux variability, but its fluctuations were poorly correlated with the mixed layer heating. In particular, it was found that zonal advective heat flux tended to be out of phase with the spring warming. At higher frequencies, little zonal advective heat was found to be associated with the passage of a Kelvin event in January 1987. Surprisingly, meridional heat advection appeared more important than the zonal heat advection in modifying the local SST as this event passed the mooring location.

HAYES, S.P., L.J. MANGUM, M. McPHADEN, and J. Picaut. Thermal structure variability along 165°E. *Air-Sea Interaction in Tropical Western Pacific,* Proceedings, US-PRC International TOGA Symposium, Beijing, 1988, China Ocean Press, 101–111 (1990).

No abstract.

HAYES, S.P., L.J. MANGUM, J. Picaut, A. Sumi, and K. Takeuchi. TOGA-TAO: A moored array for real-time measurements in the tropical Pacific Ocean. *Bulletin of the American Meteorological Society, 72*(3), 339–347 (1991).

The importance of the El Niño-Southern Oscillation phenomenon in year-to-year fluctuations of the global climate has led to efforts to improve the real-time ocean observing system in the tropical Pacific. One element of this improved system is the TOGA-TAO (Tropical Atmosphere-Ocean) Array of wind and upper ocean thermistor chain moorings. This array, the result of an international effort, has already provided the rudiments of a basin-wide, real-time observing system and plans call for a major enhancement during the second half of the TOGA decade. The development of the TAO array is discussed, recent results from the pilot measurements are described, and plans for the expanded array are presented.

HAYES, S.P., L.J. MANGUM, and O.F. Steffin. The Tropical Atmosphere Ocean Array. Proceedings, Oceans '91, Honolulu, HI, October 1–3, Ocean Technologies and Opportunities in the Pacific for the 90's, IEEE 91CH3063-5, 835–838 (1991).

The focus of the international Tropical Ocean and Global Atmosphere (TOGA) program has been the investigation of the oceanic and atmospheric dynamics relating to the El Niño phase of the Southern Oscillation phenomenon in the equatorial Pacific Ocean and its importance in the year-to-year variability of global climate. As part of the TOGA program, efforts have been made to enhance the real-time ocean observing system in the tropical Pacific Ocean. One element of this improved system is the TOGA-Tropical Atmosphere Ocean (TAO) array of wind and upper ocean thermistor chain moorings. Measurements from these moorings include surface parameters (wind, air and sea surface temperature) as well as subsurface temperatures down to a depth of 500 meters. These data are transmitted to shore in real-time using the ARGOS system on NOAA's polar orbiting satellites, processed by Service ARGOS, and placed on the Global Telecommunications System. Post recovery processing and analysis of the data is performed at NOAA's Pacific Marine Environmental Laboratory, Seattle, Washington. This array and its planned expansion is the result of international collaboration with scientists from France, Japan, Korea and USA. The TAO array, its development, and plans for an expanded array are discussed.

Hebert, D., J.N. Moum, C.A. Paulson, D.R. Caldwell, T.K. Chereskin, and M.J. MCPHADEN. The role of turbulent stress divergence in the equatorial Pacific zonal momentum balance. *Journal of Geophysical Research, 96*(C4), 7127–7136 (1991).

From a comprehensive set of upper ocean measurements made during a moderate El Niño in boreal spring 1987, we reassess the role of turbulence in transporting momentum vertically at the equator. An examination of the terms in the vertically integrated zonal momentum equations indicates that on short time scales the zonal pressure gradient is not balanced by the surface wind stress despite an apparent balance of these terms on longer (seasonal) time scales. The vertical redistribution of zonal momentum is complex. The strength of the wind determines both the magnitude and, likely, the mechanisms of momentum transport between the surface and the core of the undercurrent. During low wind conditions in April 1987 the turbulent stress divergence was significantly different in magnitude and vertical structure from that found during strong winds in November 1984. In November 1984 the turbulent stress divergence was much too large above 40 m to balance the residual term in the zonal momentum budget of Bryden and Brady (1984, 1989) and decayed exponentially with depth from the wind stress value at the surface. In April 1987 the turbulent stress divergence was smaller than that required by Bryden and Brady and decayed linearly from the surface wind stress. For a proper comparison with Bryden and Brady's zonal momentum balance, it is necessary to determine the annual average turbulent stress divergence.

Hinckley, S., K.M. Bailey, S.J. Picquelle, J.D. SCHUMACHER, and P.J. STABENO. Transport, distribution, and abundance of larval and juvenile walleye pollock (*Theragra chalcogramma*) in the western Gulf of Alaska. *Canadian Journal of Fisheries and Aquatic Sciences, 48*(1), 91–98 (1991).

The spawning distribution of walleye pollock (*Theragra chalcogramma*) and subsequent southwesterly drift of eggs, larvae, and juveniles were investigated in Shelikof Strait, March–September 1987. In mid-March, a hydroacoustics survey found that spawning adults were concentrated in the deeper parts of Shelikof Strait, as were eggs collected in this area during an ichthyoplankton survey about 1 mo later. In May, a concentration of young larvae was found 100–150 km to the southwest of the spawning area. In late June and early July, the center of distribution of late larval and early juvenile walleye pollock was further to the southwest, between the Shumagin and Semidi Islands. By August and September, juveniles were mostly distributed downstream of the Shumagin Islands. The rate of drift of eggs and larvae through June was estimated at 4–6 cm/s. The trajectories of satellite-tracked buoys deployed in the region of greatest egg abundance revealed similar patterns to those of the early life stages of walleye pollock. These observations demonstrate that transport is an important factor determining the distribution of pollock larvae in downstream coastal nursery areas.

Ingraham, Jr., W.J., R.K. REED, J.D. SCHUMACHER, and S.A. MACKLIN. Circulation variability in the Gulf of Alaska. *Eos, Transactions of the American Geophysical Union, 72*, 257–264 (1991).

We have recently found a connection between the effects of large-scale atmospheric forcing over the Gulf of Alaska and deep-water properties (temperature and salinity) below the southern sill depth (~200 m) in Shelikof Strait, through studies under the Fisheries Oceanography Coordinated Investigations (FOCI) program. Started in 1984 by the National Oceanic and Atmospheric Administration, most FOCI research has been conducted in Shelikof Strait, Alaska, a large estuarine-like system located between Kodiak Island and the Alaska Peninsula, where vast numbers of walleye pollock spawn each spring.

JOHNSON, J.E., and W. Mitchell. Structure of the marine boundary layer over the Pacific Ocean during the RITS 88 and RITS 89 cruises. NOAA DR ERL PMEL-27 (PB91-176412), 105 pp. (1991).

No abstract.

LAVELLE, J.W., E.D. COKELET, and G.A. CANNON. A model study of density intrusions into and circulation within a deep, silled estuary: Puget Sound. *Journal of Geophysical Research, 96*(C9), 16,779–16,800 (1991).

A laterally averaged hydrodynamical model is used to investigate episodic intrusions of denser, more oceanic water across the shallow double-silled entrance of Puget Sound and the resulting circulation within the interior deep basin. Tidal, freshwater discharge and wind effects are also encompassed in model results. Model simulations were made of the 4-month period from December 1983 through March 1984. During that period, hourly measurements

of currents and salinity were made at the estuary entrance and on four moorings in the interior basin. The first 60 days of salinity data were used with the model to choose rates of vertical turbulent mixing and the lag times between fresh water appearance at river gauges and its arrival in the main basin of the sound. Comparison of model results with the full 120 days of salinity and velocity data shows that the model incorporates the important circulation features of this estuary. The model was then used to study intrusions and mixing in the sill region. The model identifies these factors as controls on the occurrence and strength of intrusions: the trans-sill salinity gradient, the intensity of tidal stirring and mixing over the sills, the supply of fresher surface water resulting from river runoff, and the winds. Time series of salinities in the interior basin show local maxima following local maxima in the trans-sill salinity difference. Vertical transport in the sill region at both tidal and subtidal time scales is dominated by advection rather than diffusion. Though much of the vertical exchange occurs over the shallower sill, a depth depression between the two entrance sills appears to be the site of significant overturning. Downwelling of surface water occurs on the landward side of both sills. Substantial freshening of the interior basin occurs during the winter months because river discharges are large and are stirred downward in the sill region to be entrained into landward bottom flows. Extraordinarily large river discharges can suppress the effect of large trans-sill salinity differences with the effect of weakening potential intrusions. Winds can indirectly influence intrusions by longitudinally positioning fresher, river-influenced surface water in the sill region. Winds can directly influence intrusions via bottom compensation flows in Admiralty Inlet, with northward winds encouraging intrusions, and by changing salinities at the entrance to the sound, and thus the trans-sill salinity gradient.

LAVELLE, J.W., C.N. CUDABACK, A.J. PAULSON, and J.W. Murray. A rate for the scavenging of fine particles by macroaggregates in a deep estuary. *Journal of Geophysical Research, 96*(C1), 783–790 (1991).

^{234}Th activity profiles in Puget Sound have been studied using a model that incorporates reversible exchanges between dissolved, fine particulate, and macroaggregate Th reservoirs. Macroaggregate settling is made responsible for the downward flux of Th and the vertical gradients of activity in measured profiles. Least squares fits of model to data yield rates/time scales for the exchange processes involved. Fine-particle scavenging by macroaggregates is found to occur with a time scale of 4–6 days over a large range of macroaggregate settling speeds, w_s. Macroaggregate-disaggregation time scales are 1–4 days when w_s is 100 m/d. Rates of sorption and remobilization characterizing the exchange between dissolved and fine-particulate forms of the isotope cannot be individually identified from these data, but acceptable model values include those measured in the laboratory. Rates of sorption that depend on particulate concentrations which increase to the sea floor result in profiles of dissolved Th having above-bottom maxima. Based on inferred exchange rates, the residence time for fine particles introduced at the surface of this deep (~200 m) estuary is estimated to be 11–16 days when w_s = 100 m/d.

LAWRENCE, L.A., J. GRAY, and D.M. Blood. Fisheries-Oceanography Coordinated Investigations (FOCI) Field Operations—1987. NOAA DR ERL PMEL-28 (PB91-176230), 61 pp. (1991).

No abstract.

MACKLIN, S.A., N.A. BOND, and J.P. Walker. Structure of a low-level jet over lower Cook Inlet, Alaska. *Monthly Weather Review, 118*(12), 2568–2578 (1990).

During February 1982 a NOAA research aircraft investigated a cold, low-level jet blowing from a gap between mountain ranges on the west side of Cook Inlet, Alaska. The jet blew 200 km southeastward across Cook Inlet between the Kenai Peninsula and the Kodiak archipelago, passing into the Gulf of Alaska where it merged with the large-scale marine wind field. Measurement commenced ~35 km downstream of the seaward end of the gap. The jet's internal boundary layer accelerated by 5% and grew 20% in depth for ~50 km; thereafter, wind speed and boundary-layer depth were nearly constant for the next 100 km. The strongest winds (>20 m s^{-1} at a height of 80 m) were observed on the south side of the jet's thermal axis and 90 km downstream from the coast. Budget analyses reveal that the down-gradient acceleration within the jet was principally opposed by surface friction, and the cold air advection was balanced by a strong upward-directed sensible heat flux from Cook Inlet and entrainment of warmer air from aloft.

MANGUM, L., J. LYNCH, K. MCTAGGART, L. STRATTON, AND S. HAYES. CTD/O_2 data measurements collected on TEW (Transport of Equatorial Waters) June–August 1987. NOAA DR ERL PMEL-33 (PB91-224527), 375 pp. (1991).

Summaries of Neil Brown Instrument System (NBIS) CTD/O_2 measurements recorded on the TEW (Transports of Equatorial Waters) cruises during 1987, a description of the acquisition and processing systems, and a discussion of calibration techniques are presented. The major portion of these data was collected from 150°W to 150°E in the latitude range of 12°S–15°S. Additional casts collected across the Samoan Passage, in the Coral Sea Basin, across the Solomon Sea, and in the Pacific Basin along longitude 165°E between 5°S and 8°N are also presented. Station locations, meteorological conditions, and profiles of potential temperature, salinity, σ_θ and oxygen are shown for each cast. In addition, potential temperature-salinity diagrams for each cast and section plots of oceanographic variables are given.

McPHADEN, M.J., D.V. HANSEN, and P.L. Richardson. A comparison of ship drift, drifting buoy, and current meter mooring velocities in the Pacific South Equatorial Current. *Journal of Geophysical Research, 96*(C1), 775–781 (1991).

In this note we compare mean seasonal cycles of zonal and meridional velocity in the Pacific South Equatorial Current based on current meter mooring data, drifting buoy data, and ship drift data. Monthly averages of ship drift and drifting buoy data were computed over 2° latitude by 10° longitude rectangles centered at the positions of multiyear current meter

moorings near 0°, 110°W, and 0°, 140°W. All three representations of the flow field show the basic character of the annual mean and its variations, provided that the sampling characteristics associated with each measurement technique are taken into account. In particular we find that more than 15 days of drifter data (regardless of year) are required on a 2° latitude by 10° longitude basis to produce monthly mean estimates that agree with moored estimates to within about 5–10 cm s^{-1} rms. We also infer that windage affects climatological monthly mean ship drift velocities, although uncertainties in the data limit a precise determination of the windage magnitude. An upper bound appears to be about 3% of the surface wind speed, though the actual effect of windage may be considerably smaller.

McPHADEN, M.J., and S.P. HAYES. Moored velocity, temperature and wind measurements in the equatorial Pacific Ocean: A review of scientific results, 1985–1990. Proceedings, International TOGA Scientific Conference, Honolulu, HI, 16–20 July 1990. Report WCRP-43, World Meteorological Organization, Geneva, Switzerland, 59–69 (1990).

In this paper we review the technical and scientific evolution of moored measurement programs during the first half of the Tropical Ocean-Global Atmosphere (TOGA) program. The emphasis will be on the Pacific where the TOGA observing array is most developed; and on the upper ocean which is most relevant in the discussion of air-sea interaction. The review is based on publications which have appeared between the start of TOGA in 1985 and the present. Among these are 65 papers that have utilized TOGA (and in some cases pre-TOGA) mooring data in the refereed literature, plus numerous contributions that have appeared in meeting proceedings, newsletters and technical reports.

McPHADEN, M.J., and S.P. HAYES. On the variability of winds, sea surface temperature, and surface layer heat content in the western equatorial Pacific. *Journal of Geophysical Research, 96*(Sup), 3331–3342 (1991).

In this study we examine the surface layer heat balance using wind, current, and temperature data from equatorial moorings along 165°E. The analysis focuses primarily on daily to monthly time scale variations during the 1986–1987 El Niño/Southern Oscillation event. The period is one of high mean sea surface temperatures ($\geq$29°C) and frequent outbreaks of westerly winds. We infer that evaporative cooling related to wind speed variations accounts for a significant fraction of the observed sea surface temperature (SST) and upper ocean heat content variability. This evaporative heat flux converges nonlinearly in the surface layer, giving rise to larger temperature variations in the upper 10 m than below. Other processes examined (wind-forced vertical advection and entrainment, lateral advection) were negligible or of secondary importance relative to evaporative cooling. A large fraction of the SST and surface layer heat content variance could not be directly related to wind fluctuations; this unexplained variance is probably related to shortwave radiative fluxes at the air-sea interface.

McPHADEN, M.J., S.P. HAYES, L.J. MANGUM, and J.M. Toole. Variability in the western equatorial Pacific Ocean during the 1986–1987 El Niño/Southern Oscillation event. *Air-Sea Interaction in Tropical Western Pacific*, Proceedings, US-PRC International TOGA Symposium, Beijing, 1988, China Ocean Press, 41–58 (1990).

No abstract.

McPHADEN, M.J., H.B. MILBURN, A.I. NAKAMURA, and A.J. SHEPHERD. PROTEUS: Profile Telemetry of Upper Ocean Currents. *Sea Technology Magazine*, February 1991, 10–19 (1991).

No abstract.

McPHADEN, M.J., and J. Picaut. El Niño-Southern Oscillation displacements of the western equatorial Pacific warm pool. *Science, 250*, 1385–1388 (1990).

The western equatorial Pacific warm pool (sea-surface temperatures >29°C) was observed to migrate eastward across the date line during the 1986–1987 El Niño-Southern Oscillation event. Direct velocity measurements made in the upper ocean from 1986 to 1988 indicate that this migration was associated with a prolonged reversal in the South Equatorial Current forced by a large-scale relaxation of the trade winds. The data suggest that wind-forced zonal advection plays an important role in the thermodynamics of the western Pacific warm pool on interannual time scales.

MCPHADEN, M.J., A.J. SHEPHERD, W.G. Large, and P.P. Niiler. A TOGA array of drifting thermistor chains in the western equatorial Pacific Ocean: October 1989–January 1990. NOAA DR ERL PMEL-34 (PB91-224535), 171 pp. (1991).

This report presents data collected from 19 drifting thermistor chains in the western equatorial Pacific Ocean between October 1989 and January 1990. The drifters were deployed as part of the TOGA program to study variability in the western equatorial Pacific warm pool. All drifters were equipped with 300 m long thermistor chains and 3 drifters were equipped with wind sensors. Data were telemetered in real-time to satellite via Service Argos. Drifter design, Argos data stream, data processing procedures, and overall system performance are described in detail.

Moritz, R.E., K. AAGAARD, D.J. Baker, L.A. Codispoti, S.L. Smith, W.O. Smith, R.C. Tipper, and J.E. Walsh. Arctic System Science: Ocean-atmosphere-ice interactions. Report of a Workshop held at the U.C.L.A. Lake Arrowhead Conference Center, March 12–16, 1990. ARCSS Workshop Steering Committee, Joint Oceanographic Institutions Incorporated, 132 pp. (1990).

No abstract.

PAULSON, A.J. Cu interactions between dissolved and particulate organic matter in estuarine waters. Ph.D. Dissertation, University of Washington, Seattle, 252 pp. (1991).

The partitioning of Cu by organic matter was investigated in estuarine waters. When whole primary sewage effluent was mixed with seawater, flocculation of dissolved Cu occurred initially, followed by remobilization of 25% of the total effluent Cu. A simple box model using the calculated remobilization rate of Cu (750 μg Cu m^{-2} day^{-1}) correctly predicted an accumulation of 0.08 μg/l observed in the bottom waters of Puget Sound during a quiescent flow period. When 64Cu was added to whole seawater samples, the KD's of ^{64}Cu were twice that of natural Cu. A limited number of hydrophobic organic sites that strongly complex Cu is postulated. The similarity in a K_D for natural and added Cu based on the non-hydrophobic component of dissolved Cu indicates that Cu in solutions containing inorganic anions and possibly hydrophilic organic compounds is in equilibrium with estuarine particles. In a set of experiments with suspensions containing estuarine suspended matter, comparisons of the partitioning of natural Cu and ^{64}Cu added in the ionic form were used to identify two components of natural Cu that did not completely equilibrate with dissolved ionic Cu: 1) Cu associated with dissolved hydrophobic organic matter; and 2) Cu contained in the residual component of the particulate phase. An understanding of the importance of dissolved organic matter in controlling the partitioning of Cu between the dissolved and particulate phases was obtained by comparing the partitioning of added Cu in a suspension made from filtered seawater with that made from filtered seawater in which the hydrophobic organic matter was removed. For the suspensions containing abiotic sediment trap particles, the removal of hydrophobic dissolved organic matter resulted in a two-fold increase in the particulate distribution coefficient (K_D) of added ^{64}Cu (from $10^{4.50}$ kg/l to $10^{4.81}$). The partitioning ^{64}Cu in the suspensions was controlled by chemical equilibria dominated by complexation with particulate and dissolved organic matter. In three similar sets of suspensions containing biotic particles, organisms indirectly controlled the partitioning of added Cu by excreting dissolved organic ligands and by coating particulate inorganic surfaces with organic matter. The behavior of natural Cu in these biotic suspensions indicate that biological processes are operating to retain particulate Cu against an opposing extra-cellular chemical driving force.

PAULSON, A.J., and H.C. CURL, JR. The biogeochemistry of trace metals in Hood Canal. Proceedings of Puget Sound Research '91, Seattle, WA, January 4–5, 1991, Puget Sound Water Quality Authority, 116–122 (1991).

The Puget Sound Ambient Monitoring Program found elevated concentrations of iron, chromium, and vanadium at its Hood Canal site. Are these enrichments a result of rural development of the Hood Canal watershed or a result of natural processes occurring in this classic sub-oxic/anoxic fjord? This question is addressed using water column data from August 1986. In bottom waters the combination of organic matter decomposition and low oxygen can trap and redistribute redox-sensitive constituents and trace constituents that exist in marine particulate organic matter. Manganese is presented as an example. The low dissolved oxygen in bottom waters allows dissolved manganese diffusing from the sediments to remain in the water column. At the Great Bend where a strong horizontal oxygen gradient exists, dissolved manganese concentrations decreased dramatically. In this region, the

precipitation of dissolved manganese results in particulate manganese concentrations as high as 40,000 ppm. Thus, manganese in the sediments near Lynch Cove enters the water column, precipitates near the Great Bend, and is trapped within the sediments of greater Hood Canal. This trapping and redistribution mechanism may also be affecting the distribution of other redox-sensitive metals such as iron, vanadium, and chromium.

PAULSON, A.J., H.C. CURL, JR., and E.D. COKELET. Remobilization of Cu from marine particulate organic matter and from sewage. *Marine Chemistry*, 33, 41–60 (1991).

The possible causes of enrichments of dissolved Cu in the bottom waters of Puget Sound were examined in a series of experiments designed to measure the release of Cu from surface marine organic suspended matter and from sewage-derived particles under ambient conditions. Decomposition of organic matter and ion-exchange controlled the release of about one-third of the Cu bound to large particles (>53 μm). In contrast, no Cu was released from smaller particles (<53 μm) suspended in natural seawater and only 5% of the Cu on small particles was released into artificial seawater with a low dissolved Cu concentration. Within 15 min of mixing primary effluent with natural seawater, 40% of the dissolved Cu was lost from solution by flocculation. Between 15 min and 4 days, 25% of the total effluent Cu was released back into solution. This release could have originated either from particulate Cu on the original sewage particles or from the flocculated Cu that was formed from dissolved Cu within the first 15 min. The release of Cu into the bottom waters of Puget Sound from settling marine organic matter was calculated to have been between 1 and 8 μg Cu m^{-2} day^{-1}, which is comparable with the diffusion of Cu from sediments. In contrast, the release of sewage-derived Cu could have been as high as 725 μg Cu m^{-2} day^{-1} within 10 km of outfall.

PAULSON, A.J., H.C. CURL, JR., R.A. FEELY, T. GEISELMAN, K.A. Krogslund, G.J. MASSOTH, M.F. LAMB, and K. KELLY. Trace metal and ancillary data in the open waters of Puget Sound: 1980–1985. NOAA DR ERL PMEL-31 (PB91-201582), 56 pp. and 10 microfiche (1991).

No abstract.

PAULSON, A.J., H.C. CURL, JR., R.A. FEELY, K.A. Krogslund, and S. Hanson. Trace metal and ancillary data in Puget Sound: August 1986. NOAA DR ERL PMEL-32 (PB91-201590), 35 pp. and 5 microfiche (1991).

No abstract.

PAULSON, A.J., H.C. CURL, JR., R.A. FEELY, G.J. MASSOTH, K.A. Krogslund, T. GEISELMAN, M.F. LAMB, K. KELLY, E.A. Crecelius, and J.F. GENDRON. Trace metal and ancillary data in the watersheds and urban embayments of Puget Sound. NOAA DR ERL PMEL-30 (PB91-201574), 72 pp. and 7 microfiche (1991).

No abstract.

REED, R.K. A year-long observation of water exchange between the North Pacific and the Bering Sea. *Limnology and Oceanography, 35*(7), 1604–1609 (1990).

Knowledge of the exchange of waters between the North Pacific Ocean and Bering Sea is limited because of the lack of reliable measurements. Existing estimates of flow through the major pass (Amchitka) in the Aleutian Islands were disparate and based on short-term data. A 1-yr series of direct current measurements was obtained in this pass, which revealed a northward flow of warm Alaskan Stream water into the Bering Sea. An estimate of volume transport gave 2–3 $\times$ 10^6 m^3 s^{-1}, which is 10–15% of the transport of the Alaskan Stream.

REED, R.K. Circulation and water properties in the central Bering Sea during OCSEAP studies, Fall 1989–Fall 1990. NOAA TR ERL 446–PMEL 41 (NTIS PB92-122878), 13 pp. (1991)

Data from three CTD surveys conducted during Outer Continental Shelf Environmental Assessment Program (OCSEAP) cruises in the central Bering Sea during fall 1989, spring 1990, and fall 1990 are used to examine circulation and property distributions. Geostrophic flow was quite variable, except in Pribilof and Zemchug Canyons where it was consistently westward. The variability of flow and small transports are difficult to reconcile with any permanent current system. The relatively cold temperatures near the temperature maximum suggest the absence of inflow through Amukta Pass near 172°W. The distributions of nutrients in fall 1989 and spring 1990 are also presented and discussed.

REED, R.K., and P.J. STABENO. Flow trajectories in the Bering Sea: Evidence for chaos. *Geophysical Research Letters, 17*(12), 2141–2144 (1990).

A set of trajectories from drifting buoys in the Bering Sea is analyzed for evidence of chaos. The separation distance between drifters was found, in most cases, to have regions of exponential increase, which strongly suggests Lagrangian chaos. Analysis of the Kolmogorov entropy indicated a fractal dimension of 1.2 and a time scale of $(22\ d)^{-1}$.

ROACH, A.T., and J.D. SCHUMACHER. Observations of seasonal and interseasonal variability in Shelikof Strait, Alaska. Coastal Zone '91, Proceedings of 7th Symposium on Coastal and Ocean Management, ASCE/Long Beach, CA, July 8–12, 1991, 3304–3317 (1991).

Nearly five years of monthly mean current data from two locations (one nearshore on the shallow shelf and one in the Shelikof sea valley) are used in conjunction with surface geostrophic winds and indices of freshwater discharge and sea-level atmospheric pressure to quantify the relative importance of these forcing terms on the ocean currents. The Alaska Coastal Current, a baroclinic jet formed upstream of Shelikof Strait, has a strong baroclinic signal with a maximum in the fall due to the seasonal freshwater cycle. This current is the primary influence on the nearshore currents. The Aleutian Low pressure system, an index of cyclones propagating into the Gulf of Alaska, dominates the meteorological field in the winter and causes a strengthening of currents in the sea valley. The currents in the sea valley are in approximate geostrophic balance. NEPPI FOCI, an index of the strength and

persistence of the Aleutian Low, is a good index both of current fluctuations in the sea valley and of year-to-year variability of the mean currents.

SCHUMACHER, J.D., W.E. Barber, B. Holt, and A.K. Liu. Satellite observations of mesoscale features in Lower Cook Inlet and Shelikof Strait, Gulf of Alaska. NOAA-TR-ERL 445–PMEL 40 (PB92-101633), 18 pp. (1991).

The Seasat satellite launched in summer 1978 carried a synthetic aperture radar (SAR). Although Seasat failed after 105 days in orbit, it provided observations that demonstrate the potential to examine and monitor upper oceanic processes. Seasat made five passes over lower Cook Inlet and Shelikof Strait, Alaska, during summer 1978. SAR images from the passes show oceanographic features, including a meander in a front, a pair of mesoscale eddies, and internal waves. These features are compared with contemporary and representative images from a satellite-borne Advanced Very High Resolution Radiometer (AVHRR) and Coastal Zone Color Scanner (CZCS), with water property data, and with current observations from moored instruments. The results indicate that SAR data can be used to monitor mesoscale oceanographic features.

Shuzhen, P., Y. Huiling, J. Toole, B. Millard, M.J. McPHADEN, and L.J. MANGUM. Comparison among autoregression models for forecasting El Niño events. *Air-Sea Interaction in Tropical Western Pacific,* Proceedings, US-PRC International TOGA Symposium, Beijing, 1988, China Ocean Press, 59–66 (1990).

SST (Sea Surface Temperature) data in a large area is used for spacial averages from which annual variation is subtracted to obtain a time series of SST anomalies of the cold tongue in the Tropical Eastern Pacific Ocean (Jan. 1951–Dec. 1985). An autoregression model, a self-exciting threshold autoregression model and an open loop autoregression model were developed, based on the time series. The interannual variations are simulated by those models. Results of simulations show that all the three models give good hindcasting of the nine El Niño events since 1951. To test reliability of the open loop threshold model, forecasting was extended to the period Jan. 1986–Feb. 1987. It can be seen from the forecasting that the model can forecast the beginning stage and strengthening stage of the recent El Niño event (1986–1987). Correlation coefficients of estimations to observations are respectively 0.84, 0.88 and 0.89, for the three models. All the models obviously work well. The open loop threshold autoregression model is the best and most useful for monitoring the interannual variation of the cold tongue SST in the Eastern Tropical Pacific Ocean and for estimating El Niño strength.

Springer, S.R., M.J. MCPHADEN, and A.J. Busalacchi. Oceanic heat content variability in the tropical Pacific during the 1982–1983 El Niño. *Journal of Geophysical Research, 95*(C12), 22,089–22,101 (1990).

Anomalous heat transport and storage during the 1982–1983 El Niño are investigated using a linear, multimode model forced by observed winds. Heat transport is decomposed into

symmetric (about the equator) and antisymmetric components. The former was dominated by anomalous northward Ekman transport which represented an enhancement of the usual seasonal cycle. The latter involved both Ekman and geostrophic transports. Near-equatorial wind anomalies forced Kelvin and Rossby waves usually associated with El Niño; together these waves set up antisymmetric, geostrophic transport which tended to oppose direct Ekman transport. Because the opposition was imperfect, there was net heat convergence which caused variations in heat content in bands of latitude centered on the equator. Within a fairly narrow band (±5°) heat content was anomalously high preceding El Niño and was depleted following the event. Equatorial heat content anomalies were largely compensated by opposing anomalies in low latitudes of the extraequatorial ocean so that variability over broader bands of latitude about the equator was relatively small. A sampling study employing the model suggests that observational evidence for a heat content variations over the region ±15° is an artifact arising from inadequate spatial resolution offered by the sea level measurement network.

STABENO, P.J., and R.K. REED. Recent Lagrangian measurements along the Alaskan Stream. *Deep-Sea Research, 38*, 289–296 (1991).

During 1986–87, 26 satellite-tracked drifting buoys were deployed on the shelf in the northern Gulf of Alaska; nine of these buoys entered the Alaskan Stream. The buoy trajectories showed a well-formed, narrow, high-speed current. Southern deviations from the high-speed core were generally wind-induced. All but one of the drifters eventually went aground on one of the Aleutian Islands or entered the Bering Sea. Some meandering of the path of the Alaskan Stream was evident just west of Kodiak Island but was not apparent farther downstream.

TAFT, B.A., S.P. HAYES, G.E. Friederich, and L.A. Codispoti. Flow of abyssal water into the Samoa Passage. *Deep-Sea Research, 38*, S103–S128 (1991).

On the TEW Expedition a hydrographic section was made in June 1987 across the Samoa Passage; in addition, south of the Passage, a section was made through the Penrhyn and Samoa Basins and the Tonga Trench. In this paper the flow of the deep water with North Atlantic Deep Water and Antarctic characteristics below 3500 m is discussed. Temperature-salinity-oxygen relationships show a similarity of properties between the Tonga Trench and western boundary of the Samoa Basin. The salinity and silicate data show distinct signatures of North Atlantic Deep Water and Antarctic Bottom Water flowing into the Samoan Passage. Salinity and silicate data in the Samoa Basin and Passage are similar to those measured on the STYX Expedition (1968). Oxygen data show that the water along the Samoa Basin's western boundary is oxygen-rich relative to water in the eastern Basin, but with no oxygen maximum in deep water, as was observed on STYX. Geostrophic flow, based on a reference surface determined from T–S, O_2 curves, shows strong northward components (>10 cm s^{-1}) in the Samoa Passage. On the west side of the Passage the flow was southward (<1 cm s^{-1}) below 4600 m. This flow reversal was associated with a reversal of the sign of the horizontal potential temperature gradient and also with lower values of oxygen, salinity and silicate next to the boundary. The northward transport of Lower Circumpolar Water between the Manihiki Plateau and the Tonga Trench was $12.3 \pm 3.6 \times 10^6$ m^3 s^{-1}; the flow into the Samoa

Passage was 6.0 ± 1.1 × 10^6 m^3 s^{-1}. Assuming that only flow above 4800 m can exit the northern Samoa Basin because of topographic restrictions, the total northward transport into the north Tokelau Basin was 9.6 ± 1.8 × 10^6 m^3 s^{-1}.

TAFT, B.A., and W.S. KESSLER. Variations of zonal currents in the central tropical Pacific during 1970 to 1987: Sea level and dynamic height measurements. *Journal of Geophysical Research, 96*(C7), 12,599–12,618 (1991).

The annual and interannual variations of the major zonal currents of the central tropical Pacific for the period 1970–1987 are described by analyzing two data sets: sea level data from a few selected island stations and ship-of-opportunity expendable bathythermograph (XBT) observations. The annual cycles of geostrophic surface current indices (dynamic height or sea level difference between the ridge and the trough defining the current) in the North Equatorial Current (NEC) and North Equatorial Countercurrent (NECC) are found to be in phase (maxima in November), to be strong, and to explain about 50% of the total variance. The annual cycle of volume transport relative to 400 dbar in the NECC is also strong, but NEC volume transport has a weak annual cycle. The discrepancy between the NEC surface current and the transport is due to the variation of the surface current being larger than that of the deep currents. The annual cycle of the transport of the South Equatorial Current (SEC) is 6 months out of phase with that of the NEC and NECC. Phases of the annual cycles of the sea level and dynamic height indices of flow agree well in general, but there are significant differences between the annual amplitudes of the two types of measurements. These differences arise from a variety of sources: dynamic height reference level assumptions, longitudinal spacing of sea level guages, meridional resolution of sea level array, and different signal to noise ratios for the two sets of indices. The NECC shows marked flow maxima during the peaks of the strong Niños of 1972 and 1982, which were followed by near disappearance of the current the following year; these fluctuations are clearly present in both the surface current indices and the volume transport. In 1976 and 1986–87 (moderate Niños) the same pattern is not marked. The El Niño signal in NEC transport is weak. There was a strong rise of equatorial sea level during the early phases of the 1972 and 1982 Niños followed by a fall the next year. This resulted in a decrease of the transport of the SEC in the first year followed by an increase to a maximum during the second year; the maximum coincides with a minimum in NECC transport.

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Toole, J., T. Delcroix, G. Eldin, E. Firing, M. Francis, C. Henin, S. Jiang, L. MANGUM, R. Millard, J. Picaut, S. Pu, M. Radenac, Z. Wang, E. Zou. Evolution of the western Pacific Ocean during the 1986–1987 El Niño. *Air-Sea Interaction in Tropical Western Pacific*, Proceedings, US-PRC International TOGA Symposium, Beijing, 1988, China Ocean Press, 79–90 (1990).

A series of 12 meridional transects along longitude 165°E in the western equatorial Pacific Ocean were made between mid-1986 and mid-1988: a time interval spanning an El Niño/Southern Oscillation (ENSO) event. Data collected on these cruises provide a detailed (albeit temporally sparse) view of the oceanic changes which occur in the western Pacific during an ENSO event. The present work focuses on the evolution of the upper ocean thermohaline and zonal velocity fields as revealed by high resolution hydrographic casts and direct near surface velocity measurements. Onset of the El Niño was characterized by anomalous eastward transport of warm surface waters equatorward of 10° latitude (where anomalies are relative to a mean state defined by historical hydrographic data and recent observations during non-ENSO periods). The thermocline in the western Pacific shoaled in response to this export of surface water; near-equator surface dynamic height relative to 10^5 hPa at event peak was 20 dyn cm below historical non-El Niño levels. Vertical displacements of the water column which resulted in the dynamic height changes were confined to the upper 300–400 m of the ocean. Later in time, strong westward transport anomalies were observed and by mid-1988, sea level had recovered to its historical mean level.

Wolfe, G.V., T.S. BATES, and R.J. Charlson. Climatic and environmental implications of biogas exchange at the sea surface: Modeling DMS and the marine biologic sulfur cycle. In *Ocean Margin Processes in Global Change*, R.F.C. Mantoura, J.-M. Martin and R. Wollast (eds.). Wiley, New York, 383–400 (1991).

The direct and indirect climatic effects of trace gas emission by oceanic biota are considered; it is shown that the highest potential sensitivities derive from the change in remote marine stratus cloud albedo due to dimethyl sulfide (DMS) emissions. As a paradigm for modeling trace biogas emissions, a hierarchy of box models is employed to explore the controlling variables on the biogenic production of this gas in the global ocean. This remote marine scenario is contrasted with the climatic and environmental impacts of coastal regions, and the coupling of the sulfur cycle with those of other trace gases is considered. The need to understand controlling variables and processes is stressed as a means to understand the stability of the system.

Young, R.W., K.L. Carder, P.R. Betzer, D.K. Costello, R.A. Duce, G.R. DiTullio, N.W. Tindale, E.A. Laws, M. Uematsu, J.T. Merrill, and R.A. FEELY. Atmospheric iron inputs and primary productivity: Phytoplankton responses in the north Pacific. *Global Biogeochemical Cycles*, 5(2), 119–134 (1991).

As part of the Asian Dust Inputs to the Ocean System (ADIOS) project, atmospheric dust fluxes and primary productivity were monitored during the dusty season (spring) of 1986 at 26°N, 155°W, in the North Pacific Ocean. The arrival of major pulses of dust from Asia was followed by major increases in primary production. Extensive chemical analyses of the

atmospheric particles showed that they were iron-rich (10–15%) and, further, that if only a small proportion (e.g., 10%) of this iron dissolved in the euphotic zone, it would be sufficient to support the increases in carbon production at this location. The systematic increases in production noted with increasing depth and time may result from a continual release of iron from the settling particles in the euphotic zone. At all depths, systematic decreases in production followed the initial surge in production, indicating that the phytoplankton may have evolved from being iron-limited to being nitrogen-limited. Comparison of particle concentrations calculated by a particle settling model with primary productivity profiles indicated that mineral particles with settling velocities equivalent to those of 14 to 18-μm-diameter spherical quartz particles were the most likely source for the iron stimulating the increases in primary production.

Zongshan, W., Z. Emei, J.M. Toole, L.J. MANGUM, X. Bochang, and Y. Keqi. Oceanic event during the 1986–1987 El Niño. *Air-Sea Interaction in Tropical Western Pacific*, Proceedings, US-PRC International TOGA Symposium, Beijing, 1988, China Ocean Press, 15–26 (1990).

In this paper, the oceanic event of the generation, development and decay of the 1986–1987 El Niño, is analyzed according to the data obtained in four cruises of the Sino-US joint air-sea interaction studies in the Western Tropical Pacific Ocean, together with the data of wind and SST provided by NOAA and that of sea level presented by Dr. Wyrtki of the University of Hawaii. It is pointed out that the 1986–1987 El Niño is a little bit stronger than the medium. The macroscropic variations of SSTs and sea levels are synchronous and similar. Meanwhile, they relate to the features of wind fields. The variations of subsurface temperature structures corresponded to the eastward transport of the warm water in the upper layer and the structures and directions of the current system changed extraordinarily in the western tropical Pacific during this El Niño. In the precursor of the event, SEC was strong and the warm water piled up in the western Pacific. In the onset phase, a wide-range (12.5° lat) eastward current was formed, resulting in the eastward transport of the warm water. In the decline phase, NECC became weak and SECC became strong. After the El Niño ended the ocean was in dynamical adjustment and the westward currents occupied a wide-range area (about 12° lat) near the equator. During this El Niño, total eastward volume transport in the western tropical Pacific is 11.4×10^{14} m^3, which is 1/3 greater than that of the 1976 El Niño and about 2/5 less than that of the 1982/1983 El Niño.

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GLOSSARY OF ACRONYMS

A&P:	Analysis and Prediction [program] (FSL)
AABW:	Antarctic bottom water
AAOE:	Airborne Antarctic Ozone Experiment
AASE:	Airborne Arctic Stratospheric Experiment
ACC:	Alaska Coastal Current
ACCP:	Atlantic Climate Change Program
ADCP:	Acoustic Doppler Current Profiler
ADIOS:	Asian Dust Input to the Oceanic System
AFTAD:	Analysis-Forecast Transport and Diffusion
AGASP:	Arctic Gas and Aerosol Sampling Program
AI:	Artificial intelligence
AID:	Agency for International Development
AL:	Aeronomy Laboratory (ERL)
AOML:	Atlantic Oceanographic and Meteorological Laboratory (ERL)
APEX:	Arctic Polynya Experiment
APL:	Applied Physics Laboratory
ARGOS:	French satellite used to telemeter data to shore stations (not an acronym)
ARL:	Air Resources Laboratory (ERL)
ASCOT:	Atmospheric Studies in Complex Terrain (DOE)
ASG:	Administrative Support Group (PMEL)
ASHES:	Axial Seamount Hydrothermal Emissions Study
ATLAS:	Automated Temperature Line Acquisition System
AVHRR:	Advanced Very-High-Resolution Radiometer
AVIRIS:	Airborne Visible and Infrared Imaging Spectrometer
AWIPS-90:	Advanced Weather Interactive Processing System for the 1990s
AXBT:	Airborne XBT
AXCP:	Airborne Expendable Current Profiler
BLIPS:	Benthic Layer Interactive Profiling System
BMRC:	Bureau of Meteorology Research Center
BPR:	Bottom Pressure Recorder
BT:	Bathythermograph
CAC:	Climate Analysis Center (NMC)
CAPS:	Center for Analysis and Prediction of Storms
CARD:	Coastal and Arctic Research Division [formerly MSRD] (PMEL)
CASE:	Coordinated Air-Sea Experiment
CCCO:	Committee on Climate Changes and the Ocean
CCIW:	Canada Centre for Inland Waters
CCOPE:	Cooperative Convective Precipitation Experiment
CCRS:	Canada Centre for Remote Sensing
CEAREX:	Coordinated Eastern Arctic Experiment
CFC:	Chlorofluorocarbon
CFM:	Chlorofluoromethane
CG:	Cloud to Ground
CGC:	Climate and Global Change
CILER:	Cooperative Institute for Limnology and Ecosystems Research
CIMAS:	Cooperative Institute for Marine and Atmospheric Studies
CIMMS:	Cooperative Institute for Mesoscale Meteorological Studies
CIMRS:	Cooperative Institute for Marine Resources Studies
CIRA:	Cooperative Institute for Research in the Atmosphere
CIRES:	Cooperative Institute for Research in Environment Sciences

CITE-3:	Chemical Instrumentation and Test Evaluation (NASA)
CLASS:	Cross-chain LORAN Atmospheric Sounding System
CLICOM:	Climate Computing
CMDL:	Climate Monitoring and Diagnostics Laboratory
CME:	Coronal Mass Ejection
CNES:	Centre Nationale d'Etudes Spatiales
CNSD:	Computer and Network Support Division [formerly CSG] (PMEL)
COADS:	Comprehensive Ocean-Atmosphere Data Set
COAP:	Center for Ocean Analysis and Prediction (Monterey)
COARE:	Coupled Ocean-Atmosphere Response Experiment
COPS:	Cooperative Oklahoma P-3 Studies
CPUE:	Catch Per Unit [fish] Effort
CRF:	Cloud Radiation Feedback
CRREL:	Cold Regions Research and Engineering Laboratory
CSES:	Center for the Study of Earth from Space
CSG:	Computer Support Group [now CNDS] (PMEL)
CSIRO:	Commonwealth Scientific and Industrial Research Organization (Australia)
CSU:	Colorado State University
CTD:	Conductivity, Temperature, Depth
CVS:	Cathodic Voltametry Stripping
CZCS:	Coastal Zone Color Scanner
DARE-II:	PROFS meteorological workstation (not an acronym)
DMS:	Dimethylsulfide
DMSP:	Defense Meteorological Satellite Program
DOD:	Department of Defense
DOE:	Department of Energy
D.U.:	Dobson Unit
DWBC:	Deep Western Boundary Current
E-BPR:	Enhanced Bottom Pressure Recorder
EDD:	Engineering Development Division (PMEL)
EEZ:	Exclusive Economic Zone
ENSO:	El Niño-Southern Oscillation
EOF:	Empirical Orthogonal Function
EOS:	Earth Observing System (NASA)
Eos:	Eos, Transactions of the American Geophysical Union
EPA:	Environmental Protection Agency
EPIC:	Extensive PMEL Information Collection
EPOCS:	Equatorial Pacific Ocean Climate Studies
EPOS:	Earthquake Phenomena Observation System (Japan)
ERL:	Environmental Research Laboratories (NOAA)
FAA:	Federal Aviation Administration
FASINEX:	Frontal Air-Sea Interaction Experiment
FAST:	Flow Actuated Sediment Trap
FGGE:	First GARP Global Experiment
FIDES:	Forecaster's Intelligent Discussion Experiment System
FIFE:	First ISLSCP Field Experiment
FIRE:	First ISCCP Regional Experiment
FNOC:	Fleet Numerical Oceanography Center
FOCAL:	French Program Ocean-Climat Atlantique Equatorial
FOCI:	Fisheries-Oceanography Coordinated Investigations
FOCUS:	Fisheries Oceanography Cooperative Users System
FOX:	Fishery-Oceanography Experiment
FREEZE:	Name of arctic ice formation experiment (not an acronym)
FSL:	Forecast Systems Laboratory (ERL)
GALE:	Genesis of Atlantic Lows Experiment

GARP:	Global Atmospheric Research Program
GCM:	General Circulation Model
GEOSAT:	Geodetic Satellite
GEWEX:	Global Energy and Water Cycle Experiment
GFDL:	Geophysical Fluid Dynamics Laboratory (ERL)
GISP:	Greenland Ice Sheet Project
GISS:	Goddard Institute for Space Studies
GLERL:	Great Lakes Environmental Research Laboratory (ERL)
GLOBE:	Global Backscatter Experiment
GMC:	General Circulation Model
GMCC:	Geophysical Monitoring for Climatic Change (ARL)
GOES:	Geostationary Operational Environmental Satellite
GPS:	Geographical Information System
GSFC:	Goddard Space Flight Center
GTN:	Global Trends Network
GTS:	Global telecommunication system
GUFMEX:	Gulf of Mexico [project]
HCFC:	Hydrochlorofluorocarbon
HIBU:	Hydrological Institute and Belgrade University
HIRIS:	High-Resolution Imaging Spectrometer
HIS:	High-Resolution Interferometer Spectrometer
HMSC:	Hatfield Marine Science Center
HOT:	Hawaiian Ocean Time series
HRD:	Hurricane Research Division (AOML)
HRPT:	High-Resolution Picture Transmission
IAMAP/IAPSO:	International Association of Meteorology and Atmospheric Physics/International Association for the Physical Sciences of the Ocean
IAMSLIC:	International Association of Marine Science Libraries & Information Centers
ICES:	International Council for the Exploration of the Sea
ICG/ITSU:	International Coordinating Group for the Tsunami Warning System in the Pacific
ICSU:	International Council of Scientific Unions
IDL:	Interactive Data Language
IEEE:	Institute of Electrical and Electronics Engineers
IFREMER:	Institut Français de Recherche pour l'Éxploitation de la Mer
IGAC-MAGE:	International Global Atmospheric Chemistry-Marine Aerosol and Gas Exchange
IGBP:	International Geosphere-Biosphere Program
IGM:	Interplanetary Global Model
IGOSS:	International Global Ocean Services System
IGP:	Igneous & Geothermal Processes
IGSP:	International Greenland Sea Project
INSAT:	Indian Satellite
IOC:	International Oceanographic Commission
IPS:	Interplanetary Scintillation
IRIS:	International Recruitment Investigations in the Subarctic
IRIS:	Incorporated Research Institutions for Seismology
ISCCP:	International Satellite Cloud Climatology Project
ISEE:	International Sun-Earth Explorer
ITCZ:	Intertropical Convergence Zone
IUGG:	International Union of Geodesy and Geophysics
IUGG/TC:	IUGG Tsunami Commission
JAMSTEC:	Japan Marine Science and Technology Center
JGOFS:	Joint Global Ocean Flux Study
JIC:	Navy/NOAA Joint Ice Center
JIMAR:	Joint Institute for Marine and Atmospheric Research
JISAO:	Joint Institute for the Study of Atmosphere and Ocean

JOI:	Joint Oceanographic Institutions
JPL:	Jet Propulsion Laboratory
JSC:	Johnson Space Center
L-RERP:	Long-Range Effects Research Program
LAHM:	Limited Area HIBU Model
Lamont:	Lamont Doherty Geological Observatory
LAPS:	Local Analysis and Prediction System
LASCO:	Large-angle Spectrometric Coronagraph
LDGO:	Lamont Doherty Geological Observatory
LORAN:	Long-Range Aid to Navigation
MAPS:	Mesoscale Analysis and Prediction System
MARD:	Marine Assessment Research Division [now OERD] (PMEL)
MCLASS:	Mobile CLASS
MCS:	Mesoscale Convective System
MCV:	Mesoscale Convectively Generated Vortices
MHD:	Magnetohydrodynamic
MIT:	Massachusetts Institute of Technology
MIZ:	Marginal Ice Zone
MIZEX:	Marginal Ice Zone Experiment
MLD:	Mixed Layer Depth
MMS:	Minerals Management Service, U.S. Dept. of Interior
MOCNESS:	Multiple Opening and Closing Net Environmental Sampling System
MOU:	Memorandum of Understanding
MRAO:	Mullard Radio Astronomy Observatory
MRD:	Mesoscale Research Division (NSSL)
MRRD:	Marine Resources Research Division [Now OERD] (PMEL)
MSRD:	Marine Services Research Division [now CARD] (PMEL)
MST:	Mesosphere-Stratosphere-Troposphere
mtDNA:	Metochondrial Deoxyribonucleic Acid
NADW:	North Atlantic deep water
NAS:	National Academy of Sciences
NASA:	National Aeronautics and Space Administration
NCAR:	National Center for Atmospheric Research
NECC:	North Equatorial Counter Current
NERC:	Natural Environment Research Council
NESDIS:	National Environmental Satellite, Data, and Information Service (NOAA)
NEXRAD:	Next-Generation Weather Radar
NGDC:	National Geophysical Data Center (NOAA)
NGM:	Nested Grid Model
NHC:	National Hurricane Center (NWS)
NIC:	NOAA Information Center
NIMBUS-7:	NOAA satellite (not an acronym)
NMC:	National Meteorological Center (NOAA)
NMFS:	National Marine Fisheries Service (NOAA)
NOAA:	National Oceanic and Atmospheric Administration
NOAAPORT:	Access to NOAA real-time data base system (not an acronym)
NOARL:	National Oceanographic and Atmospheric Research Laboratory
NODC:	National Oceanographic Data Center
NORPAX:	North Pacific Experiment
NOS:	National Ocean Service (NOAA)
NOSC:	Naval Ocean Systems Center
NPTZ:	North Pacific transition zone
NRC:	National Research Council
NRC:	Nuclear Regulatory Commission
NSF:	National Science Foundation

NSIDC:	National Snow and Ice Data Center
NSSL:	National Severe Storms Laboratory (ERL)
NURP:	NOAA Undersea Research Program
NUSC:	Naval Underwater Systems Center
NWAFC:	Northwest and Alaska Fisheries Center
NWP:	Numerical Weather Prediction
NWS:	National Weather Service (NOAA)
OAR:	Oceanic and Atmospheric Research
OCEAN STORMS:	A JISAO field experiment for the assessment of weather fronts (not an acronym)
OCRD:	Ocean Climate Research Division (PMEL)
OCS:	Outer Continental Shelf
OCSEAP:	Outer Continental Shelf Environmental Assessment Program
ODW:	Omega Dropwindsonde
OERD:	Ocean Environment Research Division [formely MARD and MRRD] (PMEL)
OLR:	Outgoing Longwave Radiation
ONR:	Office of Naval Research
ORSTOM:	Office de la Recherche Scientifique et Technique Outre-Mer
OSU:	Oregon State University
OU:	University of Oklahoma
PacTOP:	Pacific Tsunami Observation Program
PAH:	Polycyclic Aromatic Hydrocarbon
PCB:	Polychlorinated Biphenyl
PEGASUS:	Current velocity profiling instrument (not an acronym)
PENTAFLUX:	Fifth Flux Experiment
PEQUOD:	Pacific Equatorial Ocean Dynamics
PICES:	North Pacific Marine Science Organization
PMEL:	Pacific Marine Environmental Laboratory (ERL)
POSEIDON:	French component of joint U.S./French TOPEX/POSEIDON sea-surface topography satellite mission (not an acronym)
POT:	Program for Operational Trajectories
POTAD:	Program for Operational Transport and Dispersion
PROFS:	Program for Regional Observing and Forecasting Services (FSL)
PROTEUS:	Profile Telemetry of Upper Ocean Currents
PSI:	Pacific Sulfur/Stratus Investigation
QBO:	Quasi-biennial Oscillation
RADM:	Regional Acid Deposition Model
RAMM:	Regional and Mesoscale Meteorology
RASS:	Radio Acoustic Sounding System
Ri:	Richardson Number, a dimensionless number related to stability of stratified flow
RITS:	Radiatively Important Trace Species
RJE:	Remote Job Entry
RSMAS:	Rosenstiel School of Marine and Atmospheric Sciences
S^3T:	Sequentially Sampling Sediment Trap
SA:	Spaced Antenna
SAFER:	Spectral Application of Finite Element Representation
SAGA:	Soviet-American Gas and Aerosol Study
SAIC:	Science Applications International Corporation
SAR:	Synthetic Aperture Radar
SAVE:	South Atlantic Ventilation Experiment
SBUV:	Solar Backscatter Ultraviolet
SCOR:	Scientific Committee on Oceanic Research
SCOPE:	Scientific Committee on Problems of the Environment
Scripps:	Scripps Institution of Oceanography
SEABEAM:	A shipboard multi-transducer swath echo sounding system
SEFC:	Southeast Fisheries Center

SEFCAR:	South and East Florida and Caribbean Recruitment
SEL:	Space Environment Laboratory (ERL)
SELDADS:	SEL Data Acquisition and Display System
SEM:	Space Environment Monitor
SESC:	Space Environment Services Center (SEL)
SHARE:	International program to develop meteorological analysis and display software for developing countries (not an acronym)
SIO:	Scripps Institution of Oceanography
SKYHI:	GFDL stratosphere GCM (not an acronym)
SLAR:	Side-Looking Airborne Radar
SLEUTH:	System for Locating Eruptive Underwater Turbidity and Hydrography
SLP:	Sea Level Pressure
SMM:	Solar Maximum Mission
SMMR:	Scanning Multichannel Microwave Radiometer
SOFAR:	Sound Fixing and Ranging (acoustical system/technique)
SPEM:	Semispectral, primitive equation model
SSD:	Scientific Support Division (NSSL)
SSF:	Semi-Lagrangian and semi-geostrophic finite element [model]
SSM/I:	Special Sensor Microwave/Imager
SST:	Sea Surface Temperature
STACS:	Subtropical Atlantic Climate Studies
STEP:	Stratosphere-Troposphere Exchange Project
STORM:	Stormscale Operational and Research Meteorology
SXI:	Solar X-ray Imager
TAG:	Trans Atlantic Geotraverse
TAMU:	Texas A&M University
TAO:	Thermal Array for the Ocean; Tropical Atmosphere/Ocean
TASD:	Technical and Administrative Support Division (PMEL)
TDWR:	Terminal Doppler Weather Radar
TELSAR:	Tracking and Evolution of Solar Active Regions
THEO:	System for predicting solar flare probabilities, named for Theophrastus (not an acronym)
THRUST:	Tsunami Hazard Reduction Using System Technology
TIROS:	Television and Infrared Observation Satellite
TMAP:	Thermal Modeling and Analysis Project
TO-AN:	Tropical Ocean-Atmosphere Newsletter
TOGA:	Tropical Oceans and Global Atmosphere
TOPEX:	Topographic Experiment (NASA)
TOPS:	Total Ocean Profiling System
TRMM:	Tropical Rainfall Measuring Mission
TVS:	Tornado Vortex Signature
UCAR:	University Corporation for Atmospheric Research
UCM:	Unresolved Complex Mixture
UCSD:	University of California at San Diego
UHF:	Ultrahigh Frequency
UM:	University of Miami
UNISYS:	United Information Systems
UNOLS:	University-National Oceangraphic Laboratory System
URI:	University of Rhode Island
URSI:	Union Radio Scientifique Internationale
USGS:	United States Geological Survey
UTC:	Coordinated Universal Time
UV:	Ultraviolet
UW:	University of Washington
VAS:	VISSR Atmospheric Sounder

VENTS:	Name of hydrothermal venting research program (not an acronym)
VHF:	Very High Frequency
VICBAR:	Code name for barotropic hurricane track prediction model (not an acronym)
VISSR:	Visible and Infrared Spin-Scan Radiometer
VOC:	Volatile Organic Compound
VOS:	Volunteer Observing Ship
WAM:	Wave Modeling
WATOX:	Western Atlantic Ocean Experiment
WDC:	World Data Center
WEPOCS:	Western Equatorial Pacific Ocean Circulation Study
WHOI:	Woods Hole Oceanographic Institution
WMO:	World Meteorological Organization
WOCE:	World Ocean Circulation Experiment
WOTAN:	Weather Observation Through Ambient Noise
WPL:	Wave Propagation Laboratory (ERL)
WRIPS:	Wave Rider Information Processing System
WSFO:	Weather Service Forecast Office
XBT:	Expendable Bathythermograph

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