Reno Abstracts

The TOS 1999 Scientific Meeting was conducted in Reno, Nevada, from April 27-30. The meeting theme was "Extreme and Unexpected Phenomena in the Ocean." Session topics were 'The Ocean in Commotion: Climate and Circulation Change on Long Time Scales,' 'From the Sea Floor to the Sky: Biological Ramifications,' 'Geological Perturbations and Consequences,' and 'Technology and More.' Abstracts from both the oral plenary sessions and the poster sessions follow below.

The Ocean in Commotion (A)

A-01: Abrupt Global Warming in the Early Cenozoic: An Assessment of the Evidence for an Oceanographic Mechanism

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One of the more extreme and abrupt episodes of global warming in Earth history occurred approximately 55 Mya. This event, often referred to as the Late Paleocene Thermal Maximum (LPTM), lasted roughly 100 ky, and is characterized by several significant climatic changes including a 4-8(C increase in ocean temperatures, and a multi-fold increase in precipitation rates on land. Furthermore, the LPTM was accompanied by a prominent change in the ratio of stable carbon isotopes (13C/12C) in the global marine, atmosphere, and terrestrial carbon reservoirs. The carbon isotope excursion (CIE) as well as other geochemical anomalies have become crucial in formulating and testing hypotheses for the cause(s) of this unique event. One hypothesis in particular, the clathrate dissociation model of Dickens et al. (1996), calls for the sudden release of >1000 Gt of methane from marine hydrates as the primary cause of warming. Here, I review the proposed oceanographic mechanisms for the LPTM in light of the most current data on the physical and geochemical changes that occurred 55 Mya. In particular, I will present data from deep sea cores drilled in the Caribbean, South Atlantic, and Southern Ocean which show evidence of a rapid shoaling of the CCD, and a reduction of dissolved oxygen concentrations during the CIE. These findings are critical as they support greenhouse gas models such as the clathrate hypothesis which would predict both a decline in ocean pH and increased consumption of dissolved oxygen.

A-02: Effects of the Formation of the Isthmus of Panama on Thermohaline Circulation, Oceanic Nutrient Distributions, and Climate

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The Late Cenozoic closure of the central American seaway by the emergence of the Panamanian Isthmus caused profound changes in ocean circulation and Northern Hemisphere climate since 4.6 Ma. New benthic and planktonic oxygen and carbon isotope records from the Caribbean Sea (ODP Site 999), when compared to Atlantic and Pacific proxy records indicate that the shoaling of the seaway intensified the Gulf Stream and introduced warm and saline water masses to high northern latitudes. This favored the formation of North Atlantic Deep Water (NADW) as indicated by an increased deep water ventilation and carbonate preservation in the Caribbean Sea and ODP records from the deep Atlantic. Enhanced deep ocean circulation of this form would drive a stronger interbasin gradient in deep ocean nutrients-with lower concentrations in the Atlantic and high concentrations in the Pacific. Indeed, between 4.6 and 2.73 Myr, opal accumulation rates in the Subarctic Pacific were as much as a factor of four higher than during the last 2.73 Myr, comparable to those observed in the modern Antarctic. During this period, opal accumulation was apparently controlled by the nutrient content of upwelling North Pacific deep water, which was modulated by the strength of Atlantic-sourced deep circulation. At 2.73 Myr, coincident with the onset of major Northern Hemisphere

Glaciation (NHG), opal accumulation in the Subarctic Pacific dropped abruptly and irreversibly by a factor of four, most likely caused by the development of the permanent halocline which dominates the modern Subarctic Pacific. The presence of the halocline suddenly reduced the upwelling of nutrient-rich deep water into the euphotic zone, leading to a decrease in biological production but an increase in the completeness of nutrient utilization, as indicated by higher sediment d15N values. This increase in the efficiency of the biological pump in the Subarctic Pacific would have lowered the rate of CO2 evasion to the atmosphere, which would have reduced atmospheric CO2 concentrations from the suggested higher levels of the mid-Pliocene.

A-03: Abrupt, High-Frequency Changes in the Ocean and Climate During the Past 50,000 Years

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Ice cores have proved beyond a doubt that atmospheric temperatures and other properties of climatic importance have oscillated on millennial timescales over the past 100ka. In Greenland ice these oscillations are most prominent in the interval ~20-60ka, and repeat with quasi periods of ~1 to 4ka; on Antarctica only the longer periods are clearly resolved. Thus, at least the lower frequency events are probably global. Many sediment cores from the North Atlantic region show variability in proxy data such as percent of the polar planktonic fauna, abundance of ice-rafted grains, and oxygen isotope ratios that is similar to ice core variability. In cores with the highest rates of deposition, and thus the highest temporal resolution, it is clear that these oscillations in surface ocean properties correlate exactly with the ice core data. Carbon isotope and trace metal data on benthic foraminifera from some of these same cores are also used to infer that during these cold stadial events the deep component of North Atlantic Deep Water shoaled. Thus, it is likely that the North Atlantic heat flux was interrupted repeatedly during the last glacial cycle, beginning abruptly with an event at the end of the last interglacial at about 118 ka. Millennial scale variability in climate has continued from deglaciation through the present interglacial, although the amplitude of the signal is greatly reduced during the present interglacial. Nevertheless, by comparison to the last interglacial, it is expected that the present one should end with a bang. Unfortunately, geochemical evidence is ambiguous for decreased production or shoaling of NADW during the Little Ice Age, the cooling which occurred over the past few centuries.

A-04: Radiocarbon Constraints on Past Deep Circulation Rates

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Bereft of instrumental records of such important climate parameters as past ocean temperatures, atmospheric composition and dynamic circulation patterns, paleoceanographers have had to develop tracers for these variables. This tracer data has shown that the last glacial and deglacial climate experienced many rapid and large amplitude shifts in atmospheric and sea-surface temperature. However, the mechanisms that bring about these abrupt climate changes are not well constrained. This gap in our understanding is partially due to our inability to record deep ocean behavior with the same temporal fidelity as sea-surface and atmospheric records. I will present a new archive, deep-sea corals, that can overcome this problem and also provide a new measurement of past deep circulation rates. Coupled radiocarbon and U-series ages from the same deep-sea coral constrain the D14C of the past ocean. Additionally, radiocarbon ages from contemporaneous benthic and planktonic foraminifera, constrain the past oceanic surface to deep age difference. Using these two measurements of past circulation rate, I will try to place constraints on several aspects of the North Atlantic's past deep ventilation, which extends our previous understanding about water mass positions and volumes. Coral data shows that during the beginning of the deglaciation, water mass positions in the North Atlantic change at nearly the rate of surface ocean and atmospheric variations. On the other hand, the Last Glacial Maximum seems to have been a time of very stagnant circulation and very little heat transport in the deepest parts of the Atlantic.

A-05: Possible Role of Climate in the Collapse of the Akkadian Empire: Evidence from Gulf of Oman Marine Sediments

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High resolution mineralogic and geochemical analyses on a high accumulation rate sediment core (14 cm/kyr) from the Gulf of Oman document an abrupt increase in Mesopotamian aridity associated with the 4200 cal. yr. BP collapse of the Ancient Near Eastern Akkadian Empire, the world's first empire. Age control for core M5 422 (24.23N, 59.02E, 2732m) from the Gulf of Oman is constrained by nine AMS 14C dates and a detailed

18O stratigraphy. Satellite imagery, sediment trap, and mineralogic/geochemical analyses indicate that terrigenous deposition at this core location reflects hemipelagic contributions from the Iranian Zagros mountains and windblown eolian dust from the Mesopotamian drainage axis (Syria, Iraq, Northern Arabia, and Kuwait). These two terrigenous sources have markedly different mineralogic and Nd, Sr, and Pb isotopic compositions. The dust-laden northwesterly Shamal winds provide a sediment transport vector linking paleoenvironmental change in the earliest sites of complex, agriculturally-based Mesopotamian city-states with the sedimentary record in this Gulf of Oman core. The core was sampled at 2 cm (~140 years) intervals and analysed for magnetic susceptibility, carbonate percent, quantitative mineralogy, and Nd, Sr, and Pb isotopic composition of the extracted terrigenous fraction. Following the markedly arid conditions of the Last Glacial Maximum and Younger Dryas periods, the more humid Holocene is punctuated by several minor arid episodes. One particularly large event, with a calibrated 14C age of 4200 cal. years BP, documents that dolomite, quartz, carbonate and susceptibility records reach or exceed Younger Dryas values. This dust increase occurs within a single sample interval and returns to low Holocene values by 3800 cal. yr. BP. Nd, Sr, Pb isotope analyses of these sediments, as well as mineral aerosol sample obtained from Iraq, confirm that this event reflects an increase in Mesopotamian dust. Microprobe analyses of disseminated volcanic ash shards may provide a time-correlative link with specific occupation sites.

A-06: Inferences about the Paleocean in the Context of Understanding the Modern Ocean

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Many of the issues that paleoceanographers grapple with have counterparts in the study of the modern ocean. Under the assumption that scientific progress occurs most rapidly when one is most fully aware of the central problems, I will discuss some of the difficulties that oceanographers would regard as being central to our lack of understanding the modern system and which simultaneously appear to be important for deducing the past history of the ocean. Some of these modern problems are those of sampling: inadequate coverage in space and time. Some of them relate to physical understanding of basic elements of the general circulation: e.g., why does the ocean carry about 2 PW of heat poleward? What sets the rate? Some are combinations of issues: is the uptake of carbon by the ocean really uncertain by 1 GT/year? If so, is it reasonable to calculate what happened to carbon in the remote past? Some problems are numerical: is it true that a coarse resolution ocean model can be integrated with climate skill for 100 years? For 1000 years? Where is the limit, and how does it manifest itself? Do high resolution ocean models exhibit the same kind of massive instabilities seen in the low resolution ones?

A-07: Mesozoic Changes in Ocean Salinity Correspond to Major Episodes of Formation of Petroleum Source Rocks

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The salinity of the ocean in the past can be reconstructed by using knowledge of the existing evaporite deposits on land and in the offshore. The DSDP showed that evaporites can occur in the early deposits of an opening ocean basin. The salt deposits documented by DSDP and ODP are very large in comparison to those found on land, and indicate that there have been significant changes in ocean salinity during the Phanerozoic. A preliminary reconstruction for the Phanerozoic indicates that ocean salinities reached their maximum in the Late Paleozoic and at present are at their lowest during the Phanerozoic. Unusually large extractions of evaporites occurred during the Late Jurassic and Early Cretaceous as the Central Atlantic, the Gulf of Mexico, and the South Atlantic formed. These time of major salt extraction correspond to the brief period (less than 10% of Phanerozoic time) when about 60% of the world's petroleum source rocks formed. The coincidence of these two extreme events suggests that they are related. One possibility is that the change in the physical properties of seawater was sufficient to cause it to go through a time when high productivity and anoxia were common. Another possibility is that the ocean plankton that existed during the time of salinity decline were particularly effective in producing organic compounds that could become petroleum.

A-08: Global Conveyors: who's driving?

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The idea of a globe-girdling conveyor excites imagination. How does it work? Is it interruptible under altered forcing? Who's driving? What's driven? We think of sinking plumes or overflows travelling from high latitudes along continental margins right-(left-)bounded in N(S) hemispheres. But these succumb to fictional slumping and eddy shredding. Perhaps interior dw/dz helps sustain western boundary currents of the conveyor? Although the boundary currents exist, dw/dz is

hard to test. Alternatively, consider: If eddies are excited in the ocean (from any sources whatever), and Earth rotates and there's bottom topography, then eddies encounter the bottom shape and force boundary currents (due to gradients of entropy with respect to the currents, where entropy $S = -\int \log(P)dP$ is evaluated over probability P of all possible currents). This reflects aggregate influence of zillions of degrees of freedom that we cannot include (explicitly) in theory or on computers. We come to view the conveyor in two linked parts. Surface forcing induces sinking as a vertical part while entropy gradient forcing sustains a lateral circulation that evacuates newly formed deep water, feeding back upon further vertical exchange. We see a new mechanism of climate and climate change. While vertical conveyor processes are influenced by altered surface forcing, lateral circulation is more persistent than previous theories or models suggest. The conveyor more effectively evacuates NADW (undetected by overturning streamfunction) while conveyor branches also sweep beyond Nordic seas and through the Arctic.

A-09: Sensitivity of the Ocean Mixed Layer to Operational Wind Products

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Surface wind products from operational atmospheric models provide useful forcing functions for ocean general circulation models (OGCM). An important issue is the accuracy of such winds and the sensitivity of OGCM mixed layer dynamics to them, particularly for time scales on the order of a day or less. Surface meteorological and sub-surface oceanographic observations from a year-long time series of 1994-95 mooring observations in the central Arabian Sea provide an excellent opportunity to independently compare both the operational winds and OGCM mixed layer sensitivity. Findings from such comparisons will be presented for 12-hourly wind products from two operational weather forecast models: the European Centre for Medium-Range Weather Forecast (ECMWF), and the Navy's Fleet Numerical Meteorology and Oceanography Command (FNMOC). The sensitivity of mixed layer evolution to these operational winds will be presented for simulations performed with the Naval Research Laboratory Layered Ocean Model (NLOM). Wind time series comparisons will reveal that the FNMOC winds agree most closely with the observed winds. Corresponding time series comparisons of sea surface temperature (SST) and mixed layer depth (MLD) will show that NLOM simulations are sensitive to differences in operational winds, and that using the FNMOC surface wind stresses and 10m wind velocities yields the best prediction.

A-10: A Ten-year Time Series from Monterey Bay, California: Seasonal, Interannual and Long-term Patterns

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Atmospheric scientists and physical oceanographers have long realized the importance of establishing mean seasonal fields to assess interannual and longer scale variations. In addition the processes that determine the mean seasonal conditions are needed to predict the effects of climate and global change. Here we present a ten-year time series of ship occupations of five major stations in Monterey Bay that began in 1989 and includes data from the 1992-93 and 1997-98 El Niño's. The ship observations are supplemented by moored observations of currents and winds. Satellite observations of temperature and ocean color provide spatial coverage. Our primary focus is phytoplankton, the organisms that form the base of the Monterey Bay ecosystem. Here we report the seasonal mean fields and use these fields to quantitatively assess the consequences of El Niño as well as long term trends. There is clear physical-biological coupling in the time series, starting with the seasonal cycle. There is a maximum in nutrients, centric diatoms, chlorophyll and primary production associated with the upwelling season. The so-called oceanic and winter seasons also have characteristic physics and biology. During the warmer El Niño years chlorophyll levels dropped (-19% in 1992 and -21 % in 1997), and during colder years levels have risen (+19% in 1991 and +11% in 1994). Results indicate sea surface temperature has gradually risen over the course of the ten-year study, while chlorophyll, primary production and subsurface nitrate levels are decreasing.

A-11: Bubbles and the Global Carbon Flux

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An estimate has been made of the volume of the oceanic mixed layer that has been swept out by the bubbles that burst each second on the surface of the world ocean. This estimate of 250 cubic km per second was obtained using recent descriptions of the bubble concentration spectrum found in the high void fraction

alpha-plumes beneath spilling wave crests and the findings of Monahan and O'Muircheartaigh detailing how the fraction of the sea surface covered by spilling wave crests (Stage-A whitecaps) varies with wind speed. Additional, published, data on the characteristic scale depth of alpha-plumes and on the rise velocity of "dirty" bubbles were likewise used in arriving at this estimate. Using conservative published estimates of the efficiency of bubbles at scavenging the dissolved organic matter in the sea water that they sweep out as they rise (0.00035), and of the concentration of DOM in the surface waters of the ocean (0.0007 kg per cubic meter), leads to an estimate of 1.9 Gt Carbon per annum swept up by bubbles and transformed into sinking particles. This estimate of the carbon collected annually on bubbles is consistent with the amount of carbon present in the carbon dioxide the ocean must absorb if it is to serve as the "sink" for the "missing" fraction of the carbon dioxide released into the atmosphere each year by human activity.

A-12: The Need for Analytical Intercalibration for Long Time Series Analysis: Dissolved Organic Matter

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There is growing need to be able to assess impacts of global change in the world ocean over time periods of a few years to a few decades. For such long-time series analysis, analytical consistency and accuracy in measurement of biogeochemically responsive parameters are essential. Historically, oceanographic research has been pursued with fairly strict certified calibration for hydrographic parameters such as temperature, salinity, and dissolved oxygen. However, most other commonly measured parameters had been measured with relative independence within individual laboratories until very recently. Because of interest in the global carbon flux, dissolved inorganic carbon is now measured with a very high level of accuracy and precision. We have also made considerable progress over the past few years in instituting international intercalibration for the measurement of dissolved organic carbon (DOC) and are in the process of similar efforts with measurement of dissolved organic nitrogen (DON). In the past few years, more accurate DOC measurements have yielded details and processes of the oceanic carbon cycle that were obscured by unreliable analyses over the previous 3-4 decades. Progress and near future plans for continued international consistency in DOC measurements will be reviewed. The current status of the DON effort will also be discussed.

A-13: The Maury Project: an Innovative Approach for Teaching the Physical Foundations in Oceanography

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The Maury Project was established in 1994 by the American Meteorological Society (AMS) in cooperation with the United States Naval Academy, with funding from the National Science Foundation, as a pre-college teacher enhancement program on the physical foundations of oceanography. Since its initiation both the Navy (Naval Meteorology and Oceanography Command and the Office of Naval Research) and NOAA (National Environmental Satellite, Data, and Information Service and the National Ocean Service) have become supporting members in this unique educational partnership. The primary activity of the Maury Project has been annual two-week summer workshops for teachers on various aspects of physical oceanography. The participant teachers then become peer-trainers, conducting workshops for their colleagues, normally at statewide science teachers conferences, using teacher guides on various topics on the physical aspects of oceanography as the subject matter area of the workshops. These workshops have reached thousands of teachers nationwide over the past five years. The presentation will focus on the accomplishments of the Maury Project over the past five years. Additionally, there will be a look to the future directions of the Maury Project. In particular, the Maury Project is exploring the development of a distance learning course using web-based instruction and activities utilizing actual oceanographic databases to enhance teachers' backgrounds on the physical foundations of oceanography. Such an approach would enable the Maury Project to reach even greater numbers of teachers with the power and versatility of the Internet.

From the Sea Floor to the Sky (B)

B-01: Extreme, Unpredictable Phenomena from the Non-Linear Perspective.

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The field of nonlinear dynamics has long held interest to ecologists because of the possibility that apparently

complicated patterns in nature may arise from a small number of variables interacting in a complex, nonlinear fashion. Although nonlinear techniques have been applied historically to terrestrial problems, there is a recent and growing trend to approach biological signals in the ocean in a similar fashion. Such data tend to be highly variable, and have often proved difficult to describe (and therefore predict) with linear techniques. Here, we review the basic philosophy behind the search for nonlinearity in oceanographic time series and spatial transects, and provide an overview of recent applications of the approach. Our survey takes us from time series of diatom abundance to spatial transects of chlorophyll concentration; from models of fish populations and harvesting to time series of the supply of larval propagules to open marine populations; and from coral bleaching episodes to the physical variables themselves to which the biology responds. Although these systems have little in common, the same basic set of questions applies to each: are the processes underlying the variability we observe linear, or are there important nonlinearities that must be taken into account before the data can be understood? And if so, what is the origin of the nonlinearity - physical forcing, density dependence, or physical-biological interactions?

B-02: Hydrothermal Event Plumes: Deciphering the Oceanographic Effects of Seafloor Spreading Events

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Over the last 20 years, investigations of submarine hydrothermal vent systems have changed our view of seafloor spreading centers from quiescent and lifeless ridges to major pathways for the exchange of chemicals and energy between the earth's crust and its oceans. We now realize that in addition to creating new ocean crust, seafloor spreading events trigger a linked series of physical, chemical, and biological processes that profoundly affect the deep-sea environment. Among the most spectacular of these is the generation of event plumes, or "megaplumes." The most immediate effect of event plumes is to produce extraordinary vertical mixing in the deep sea, Over a period of a few hours or days following a volcanic eruption, the discharge of 107-108m3 of high temperature hydrothermal fluids can form a plume up to 20 km in diameter rising 1 km above the seafloor. These fluids evolve into a coherent, rotating eddy that maintains its integrity for months. Chemically, the eight event plumes sampled since 1986 have all had a similar chemical signature distinct from conventional black smoker fluids. Still debated is whether this signature represents preexisting hydrothermal fluids trapped in the crust or seawater reacting with freezing lava during an eruption. Biologically, event plumes supply exploitable reduced chemical substrates to the water column and samples of previously unknown hyperthermophilic microbes to scientists.

B-03: Ecological Consequences of Seafloor Eruptions and Hydrothermal Event Plumes

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Eruptions along mid-ocean ridges occur periodically on timescales that depend on seafloor spreading rate and vary from 10 to 10,000 years. An initial consequence of an eruption is a large buoyant pulse of hydrothermal fluid, called an event plume, into the water column. Event plumes rise up to 1000 m above the seafloor, entraining large volumes of near-bottom water, and may also entrain many larvae of vent organisms. As event plumes reach neutral buoyancy, they may exhibit anticyclonic circulation that maintains the water mass as a discrete unit as it is advected by horizontal currents. The potential event plume dispersal pathway may transport larvae in a different direction than usual dispersal, and result in a recruitment pulse to the seafloor. Subsequent to the event plume, chronic plumes may develop from seawater heated by the shallowly placed magma chamber and discharged continuously from the seafloor as hydrothermal fluid. Chronic plumes provide consistent larval transport pathways, preventing genetic isolation of populations. If an eruption establishes a new hydrothermal site, community development follows rapidly; vent organisms are not only adapted to deep sea and hydrothermal conditions, they are also adapted to an ephemeral and patchy habitat. Rapid maturation and high fecundity are characteristics of "weedy" species that flourish in this habitat type. Eruptions create and maintain the patchy and ephemeral nature of vent habitats.

B-04: Time Scales of Environmental Variability and Populations of Salmon and Crab in the California Current

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Changes in the ocean environment have a dramatic, defining effect on abundance of chinook salmon, coho salmon and Dungeness crab populations in the California Current. The population response to different time scales of environmental variability varies

temporally and spatially in ways that are determined by the different life history characteristics of these species. Here we describe how variability in the ocean on time scales on the order of 5-10 years influences these populations, and how these effects interact with the effects of variability on multi-decadal time scales.

B-05: Wave Forces and Evolution: Life in the Surf Zone

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The surf zone of wave-swept rocky shores is one of the most stressful habitats on earth. Water velocities as high as 25 m/s (55 mph) and water accelerations in excess of 500 m/s/s (50 gravities) have been recorded, and one might assume that these extreme flows would place severe constraints on the morphology of wave-swept plants and animals. In such a stressful environment, shouldn't only optimally designed organisms survive? In fact, surf-zone organisms display a surprising diversity of sizes and shapes. Examples from kelps, limpets, and sea urchins provide insight into the possibilities and limitations of optimality and evolution.

B-06: Ecosystem Responses of the Southeastern Bering Sea to Abnormal Weather Patterns in 1997 and 1998.

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In response to unusual weather patterns in both 1997 and 1998, the physical and biological regimes of the southeastern Bering Sea differed greatly from what was expected. In 1997, there was ice present until April, an ice-related bloom with draw-down of nutrients, and a mixing event in mid-May that renewed production. Unusually warm, calm weather and deep depletion of nutrients followed. Subsequently the first-documented Bering Sea coccolithophore bloom and a shearwater die-off occurred. In 1998, sea ice was present briefly in February, and storms following ice retreat prevented a strong thermocline until late June. Rather than a short pulse, production was moderate and constant from May through June. The coccolithophore bloom was still present, apparently having over-wintered. Although again malnourished, no unusual shearwater mortality was found. Uncharacteristically warm surface temperatures (> 14° C) occurred in 1997, but the highest heat content was in 1998. In 1998, strong southwest winds resulted in cross-shelf transport of surface waters and plankton. Export of coccoliths and warm water to the Arctic was evident from SeaWiFS imagery.

B-07: Wind Stress and Satellite Chlorophyll Patterns in the Atlantic Ocean

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Vertical mixing in the upper ocean is one of the important processes regulating biological productivity in the ocean, and satellite sensors now offer the possibility of studying relations between wind stress and phytoplankton biomass at ocean basin scales. The ADEOS satellite mission operated from September, 1996 until June, 1997, and carried the NASA scatterometer (NSCAT) to measure ocean wind vectors and two ocean color scanners (OCTS and POLDER) to measure phytoplankton biomass. We used these measurements, as well as SeaWiFS imagery, to study wind stress and phytoplankton biomass relations in the North Atlantic Basin at seasonal time scales focusing on the winter-spring transition of 1997 and 1998. Wind stress was of course stronger in the winter at mid (30 deg.) to high (60 deg.) latitudes, and the spring transition to more moderate winds began in the south and gradually spread north over a ca. 100-day period. This general pattern differed somewhat across the basin and was interrupted at times by periods of more intense wind stress. The seasonal increase in phytoplankton biomass generally tracked the northerly spread of moderating wind stress, as predicted from Sverdrup's critical depth and related theories.

B-08: SeaWiFS Observation of a Large Multi-year Coccolithophore Bloom in the Bering Sea: Possible Implications and Consequences.

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A multi-year bloom of Emiliania huxleyi, which had previously been unreported from the Bering Sea, is documented using in situ measurements and SeaWiFS satellite data. This bloom is in its third year, having persisted over two winter periods. The bloom was first observed in summer of 1997, when surface observations

noted it during July. By September it had been documented by the new SeaWiFS satellite, which showed its areal extent to be on the order of 240,000 km2. By 1998, the bloom had grown in area reaching a size of at least 280,000 km2. It had also been carried by the prevailing currents northward through the Bering Sea into the Chukchi Sea bordering the Arctic Ocean. The bloom had an impact on water clarity. Phytoplankton primary production in the bloom was not very high. The bloom was initiated during a period of extraordinarily warm surface temperatures in the Bering Sea. The relation to climate change is that the bloom serves as a model response to higher temperatures and water column conditions that might be expected in the future. Food web alterations may also take place in view of the fact that E. huxleyi are much smaller than the normal diatom community. Microzooplankton grazers may replace the larger zooplankton in dominance, with a resulting rearrangement of all of the food webs.

B-09: Anomalous Weather Events in the Southeastern Bering Sea: The Conditions of Short-tailed Shearwaters in 1997 and 1998

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Both 1997 and 1998 were marked by unusual weather conditions in the southeastern Bering Sea, however the patterns were strikingly different. In 1997, a high pressure anomaly occurred over the Bering Sea and resulted in low winds and few severe storms in June and July, an unusually warm mixed-layer in summer, and depletion of macronutrients to greater than 60m depth. In 1998, a low pressure anomaly occurred over the same area which resulted in frequent spring storm events that lasted into late June, a delayed setup of thermal stratification, and prolonged production in the water column. Lack of mixing, higher sea surface temperatures, and early cessation of production in 1997 may have contributed to the lack of available euphausiid prey to short-tailed shearwaters (Puffinus tenuirostris). The result was that hundreds of thousands of short-tailed shearwaters died in August and September 1997, apparently of starvation. In 1998, we observed lower overall body condition of short-tailed shearwaters compared to 1997, yet no large scale mortality event occurred. When adjusted for overall body size, net body mass, lipid mass, and pectoralis mass was lower in June 1998 than June 1997. Between 1997 and 1998, we also observed a shift in the diet of shearwaters from primarily euphausiids, Thysanoessa spp., in September 1997, to fish, specifically, sandlance and age-0 pollock, in September 1998. We hypothesize that the availability of these alternative food sources in 1998 may have prevented the occurrence of another large-scale mortality event.

B-10: Recent Hypoxia-induced Mortalities of Rocklobsters in the Southern Benguela Upwelling Region

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Recent mortalities of the rocklobster, Jasus lalandii along the southwest coast of South Africa are not unexpected as similar events have taken place in the past. Such mortalities have however become extreme in terms of their severity, frequency of occurrence and extent. Possible climatic and biogeochemical reasons and their implications are discussed.

B-11: How Do Extremes in Climate Variability Affect Biological Production in Estuarine Systems?

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There is increasing evidence that extremes in climate variability correlate with major changes in coastal ecosystems, culminating in large variations in marine fish stocks. Any such correlations presumably arise through effects of atmospheric forcing on ocean processes, which in turn shape the environment within which biological systems function. Considering an estuarine coastal environment characterized by a simple phytoplankton-zooplankton food chain, we explore mechanisms by which variability in atmospheric forcing could "control" zooplankton production. Climate-induced changes in physical ocean processes could exert "control" on zooplankton production (i) from below, if physical processes set the level of primary production available to support higher trophic levels, (ii) from within, if physical processes determine zooplankton growth rates, or (iii) from above, if physical processes affect the rate at which zooplankton are themselves cropped. These are explored using a simple N-P-Z biological model in a physical box model of the Strait of Georgia/Haro Strait/Strait of Juan de Fuca system of southern British Columbia. Model results indicate that while observed levels of interannual variation in the physical forcing of this system reproduce observed levels of variability in the annual cycles of characteristic physical parameters such as salinity, stratification etc., there is very little associated variation in the embedded biological system. However large changes in annual cycles of biological variables are

observed; comparable changes can be produced in our model by relatively minor changes in biological rate parameters (phytoplankton growth rate, zooplankton feeding and/or mortality rate). Our model results strongly suggest that climate variability does not affect estuarine ecosystems directly, ie. by effects on advective flows, nutrient re-supply rates etc., but rather indirectly, through modification of characteristics of the physical environment which affect crucial biological rate parameters. In strongly estuarine systems, turbidity is likely a major cause of such rate modification.

B-12: Patterns of Bioluminescence in the Arabian Sea: Ecological Interpretations

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Bioluminescence, light from living organisms, is ubiquitous in the world's oceans. During a 1994-1995 series of cruises in the Arabian Sea as part of the Naval Research Laboratory's Forced Upper Ocean Dynamics Accelerated Research Initiative, the brightest stimulated bioluminescence measured by Navy bathyphotometers was recorded. Recordings, with concomitant physical measurements, were made during the Southwest Monsoon, Northeast Monsoon, and Fall Intermonsoon seasons to a depth of 200m. Isolated net tows were also made to identify likely emitters in the in situ plankton population. Using the net tows and bioluminescence signal, changes in the seasonal makeup and spatial distribution (vertical and horizontal) within the emitter population have been identified. Additionally, seasonal changes in the interaction between the plankton and physical features such as the oxygen minimum zone were identified. This poster will discuss the seasonal and spatial changes in emitter populations as represented by vertical bioluminescence profiles, vertical relationships between different emitter populations, and relationships between emitters and physical features. Finally, issues related to using bioluminescence measurements in field-based, ecosystem dynamics studies will be discussed.

B-13: Effects of Elevated Temperature and UV-B Radiation on Zooxanthellae *in hospite* and Expelled from the Tropical Sea Anemone *Aiptasia pallida.*

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The tropical symbiotic anemone *Aiptasia pallida* was exposed to elevated temperatures and UV-B radiation to investigate the nature of coral bleaching. Anemones received either 30°C with enhanced UV-B (+UV), or 31°C with no UV-B (-UV) for up to 5 days. Expelled zooxanthellae (EZ; up to 12%) and those remaining in the animal (AZ) were compared. Anemones exposed to UV showed a decrease in protein and zooxanthellar density, and a 10-fold increase in zooxanthellae expulsion. Photosynthesis of expelled algae was affected: Pmax and alpha of EZ decreased from 1.62 to 0.46 pgC/pgchla/hr, and from 0.012 to 0.002 pgC/pgchla/hr/(umol.$m^{-2}s^{-1}$), respectively. EZ pigments did not change over time; however, EZ consistently had less chlorophyll c than AZ. AZ division, productivity, and pigments did not change during exposure to UV. Temperature stress alone did not affect protein, zooxanthellar density, % expulsion, and photosynthetic parameters. EZ pigments decreased while AZ pigments did not. Decreased productivity of expelled zooxanthellae +UV shows that the animal protects zooxanthellae from UV damage *in hospite*. Zooxanthellae expelled during bleaching events are likely to sustain extensive damage due to UV radiation.

B-14: Temperature and UV Stress Interact to Change the Pigment Composition of Coral Zooxanthellae.

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Experiments conducted on the coral *Montastraea faveolata* at the Caribbean Marine Research Center on Lee Stocking Island, Bahamas, showed that ultra violet (UV) and temperature stress had significant effects on the pigment content of zooxanthellar algal symbionts. Two experiments were conducted, one at 29°C (ambient ocean temperature), and another at 31(C. Three different light treatments were investigated for each experiment: in situ photosynthetically active radiation (PAR) and ultraviolet B (UVB), in situ PAR and enhanced UVB, and enhanced PAR and enhanced UVB. The coral samples were taken from a reef 16.5m deep, exposed to the aforementioned treatments, and sampled over time during each 120 hour experiment. Analysis by HPLC showed a decrease in concentrations of the photosynthetic pigments (chlorophyll a and c, peridinins, and B-carotene). Concentrations of photoprotective pigments (diadinoxanthin and dinoxanthin) remained constant or increased slightly. Comparison of samples from different temperature and light treatments showed that there is a UV dose threshold which, once reached, induces a

stress response in the coral's zooxanthellae. The UV dose needed to induce a stress response appeared to be lower at increased temperatures.

B-15: Changes in Optical Reflectance and Pigmentation of the Coral *Montastraea faveolata* in Response to Elevated Temperature and Ultraviolet Radiation.

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Elevated temperature and ultraviolet-B (UVB) radiation can induce coral bleaching, i.e. the loss of symbiotic zooxanthellae and their pigments. It may be possible to detect bleaching by remote sensing through measured changes in the reflectance spectra. We examined the relationship between coral pigments and in vivo optical spectra. We collected 2.1 cm diameter cores of *Montastraea faveolata* at 16.5 m depth (29.5°C) from Lee Stocking Island, Bahamas in July 1998. Replicate samples from three colonies were exposed in an outdoor incubator for 96 hours at 31°C at three levels of solar radiation. Radiation treatments included *in situ* doses of photosynthetically active radiation (PAR) and UVB, *in situ* PAR and enhanced UVB, and enhanced PAR and UVB. Coral pigments were measured by HPLC analysis and *in vivo* reflectance of coral was measured using a portable fiber optic spectrofluorometer. After four days of enhanced UVB treatment, chl-a surface densities decreased 43% while reflectance in the chl-a region increased 90%. These UVB doses were 1 to 2 orders of magnitude greater than the *in situ* dose. Results suggest that small changes in pigmentation can be detected *in vivo* as changes in optical reflectance.

B-16: The Effects of Elevated UV-B Radiation on Productivity and Bleaching of Zooxanthellae in the Coral *Montastraea faveolata*

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Enhanced UV-B radiation has a detrimental effect on productivity of zooxanthellae from the coral *Montastraea faveolata*. Experiments were performed on coral samples collected from 16.5 m in the Bahamas. Corals were subjected to three different treatments for up to 120 hours at 29(C: Enhanced PAR and UV-B, *in situ* PAR and enhanced UV-B, and *in situ* PAR and UV-B. Less than 1% of the zooxanthellae were expelled in bleaching corals. This indicates that the initial bleaching response results from pigment loss by zooxanthellae and not from expulsion. Zooxanthellae removed from the coral after 48 hours of enhanced UV-B showed a consistent 25% reduction in P_{max} while the P_{max} of zooxanthellae removed from corals in the other treatments showed no reduction. Photosynthesis of zooxanthellae expelled by the corals in the enhanced PAR and UV-B treatment was substantially reduced (78%), expelled zooxanthellae in the *in situ* PAR and enhanced UV-B treatment showed a 38% reduction in comparison to zooxanthellae in the corals in these treatments. These results show that UV-B radiation damages zooxanthellae, but that the coral provides some protection against damage to the photosynthetic apparatus.

B-17: Salp Swarms: Will They Always Be Unpredictable?

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Salp swarms have been found in all oceans from tropical to polar, and have been documented to have a major role in vertical flux of biogenic material. Usually, observations of these swarms have been serendipitous and represent only snapshots in time. Repeated observations at some locations, however, suggest that some regions and seasons may be salp "hot spots", and a few studies have been able to document part of the physical and biological context for these events. Energetic considerations dictate that such large populations must have a sufficient food supply, but paradoxically salps are known for their ability to exist in oligotrophic waters, and for at least one species, too much particulate food can clog the mucous filter, block ingestion, and cause "starvation in the midst of plenty". What triggers salp blooms? Does there seem to be a single scenario or several? Are there physiological or life-history traits that make some species bloom and not others? Presently our "answers" are mostly speculation, but this summary of existing observations clarifies patterns that may lead to testable hypotheses.

B-18: Elephant Seals as a Biological Autonomous Underwater Sampling System

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Using elephant seals as autonomous samplers we have been able to obtain temperature-depth profiles for the northeastern Pacific Ocean over three years prior to and during the 1998 El Niño event. Elephant seals offer a unique system to carry instrumentation as they range widely over the northeastern Pacific to the Aleutian Islands. They dive continuously, exhibiting long duration dives (mean = 22 min.) with short surface intervals (1-3 min). Dives are routinely to 600 m, with dives as deep as 1600 m. Our existing database of elephant seal diving behavior and water temperature measured depth and temperature every 30 sec with a temperature accuracy of 0.1°C and a lower limit of 4°C with a depth resolution of 4m. We have obtained satellite tracks and diving patterns of the round trip migration of 24 adult females and 21 adult males over much of the Northeastern Pacific Ocean. In addition we have acquired data on the ambient acoustic environment from two adult male elephant seals that were instrumented with passive acoustic recorders as they transited from their Central California Rookery to the Aleutian Islands. This work was supported by research grants from ONR and the ATOC research program.

B-19: Impact of the 1997-98 El Niño on the Foraging Behavior of Northern Elephant Seals, a Large Marine Predator

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The foraging behavior of northern elephant seals, *Mirounga angustirostris*, was examined during the 1997-1998 ENSO using a combination of ARGOS satellite tracking and time-depth recorders. Given their deep diving and spatial distribution, we expected ENSO events to have lesser impacts on elephant seals than other more coastal pinnipeds. Their response to severe El Niños should provide important clues to both the scale and the impact of rapid ecosystem change on a large marine predator. Instruments were deployed on nine females in February and March 1998. Trip duration and rates of mass gain were compared to data from females carrying instruments in 1983-1996 and to data on diving behavior collected during 1990-1996. Rates of mass gain in 1998 were the lowest ever measured suggesting that foraging trip duration increased to compensate for decreases in mass gain. Tracks of females in 1998 covered much of the northeast Pacific Ocean and were typical of those observed in non-ENSO years. Elephant seals had a harder time finding prey during the recent El Niño event and attempted to compensate by increasing foraging effort. As elephant seals forage in deep water far offshore, these data confirm that the impact of the 1997-98 ENSO was not limited to the nearshore coastal margin, but extended far out into the North Pacific Ocean.

B-20: A Modeling Study of Rectified Flow in the Vicinity of a Spreading-Center Ridge.

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Observations of currents across the Juan de Fuca Ridge in the NE Pacific show that mean flow is anomalously large (~3-4 cm/s) near the ridge with a southerly direction east and a northerly direction west of the ridge crest. While topographic rectification of flow first comes to mind as the likely cause, matching forcing to the magnitude and distribution of the observed means is another matter. In this study a primitive equation numerical model is used to examine the circulatory response about the ridge to a range of oscillatory forcings. The model shows that neither diurnal or semi-diurnal forcing of realistic amplitude can reproduce the observed means. Forcing at longer time scales is the key. Pressure data from a triangle of NDBO buoys was used to create time series of horizontal pressure gradients for the region. That gradient data show significant spectral peaks in the 4-5 day interval. When pressure gradients of 4-5 day period with the spectra-derived magnitude are used to force the flow, the resulting mean flows near the ridge are similar in magnitude and pattern to those observed. The conclusion is that weather systems passing above cause the sheared mean flow distribution across the ridge. That mean flow has significant consequences for the advection of hydrothermal effluent, in both chronic and event plume form, away from the ridge and into the interior ocean.

B-21: Animation of Sea Surface Temperatures from GOES

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The return of La Niña in May 1998 was marked by the appearance of cooler water along the equatorial Pacific from the coast of South America to the dateline. A detailed record of this event has been captured in daily images of sea surface temperatures (SST) as measured by geostationary weather satellites at a spatial resolution of 4 kilometers. The Geostationary Operational Environmental Satellite (GOES) is usually used for meteorological observations. However, the GOES can also provides oceanic observations by the creation of daily composites of the warmest hourly water samples to partially remove clouds. When viewed rapidly on a

computer monitor, the daily SST composites allow the viewer to visually separate the low frequency oceanic SST motions from the relatively high frequency residual clouds. This new method of viewing the ocean in motion allows oceanographers to monitor the daily evolution of oceanic thermal patterns associated with the Gulf Stream, the Loop Current, the Brazil and Falkland-Malvinas Currents as well as coastal and equatorial upwelling. Baroclinic wave propagation, entrainment, interactions with islands and even tidal effects appear in the SST animations. The viewer is captivated by the unexpected complexity of oceanic variability. It is proposed that future improvements of the spatial resolution and the quality of GOES infrared scanners could advance the monitoring of the ocean surface. Examples of the SST animations are at: http://www.goes.noaa.gov

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B-22: The Master Environmental Library: Easy Access to Oceanographic & Meteorological Data

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The Master Environmental Library (MEL) is an Internet-based information discovery and retrieval system that provides access to geographically-distributed oceanographic and meteorological data in standard WMO formats. MEL (http//mel.dmso.mil) provides access to an expanding archive of Fleet Numerical Meteorology and Oceanography Command (FNMOC) model output including the Navy Operational Global Atmospheric Prediction System (NOGAPS), Coupled Ocean Atmosphere Mesoscale Prediction System (COAMPS), tropical cyclone model predictions and global/regional WAM wave model forecasts. In addition, MEL provides access to Digital Bathymetric Data Base Variable Resolution (DBDB-V), Modular Ocean Data Assimilation System (MODAS) 3-dimensional ocean analyses for regional and global scales for dates 1993-present, Multi-Channel Sea Surface Temperatures (MCSST) 1993-1998, and reference data sets for exercises which support the operational and simulation-based community. Data can be delivered locally via ftp, or can be picked up via anonymous ftp at the appropriate MEL resource site. MEL can also send data to the user by "subscription" to support a live exercise or field tests. In the future, MEL will provide access to non-digital sources, such as port studies, and expanded archives including FNMOC data at the Major Shared Resource Center at the Naval Oceanographic Office.

Geological Perturbations and Consequences (C)

C-01: Impact of Extreme River Events on the Coastal Ocean

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Initiation of a sustained turbidity current from the direct delivery of sediment into the ocean by a river is not common. For a "dirty" river to be able to plunge into a large body of water and form a hyperpycnal plume/turbidity current, the sediment-laden water must be heavier than the ambient fluid. Sea water poses a strong density barrier to the formation of a turbidity current. There are only nine "dirty" rivers on a world-wide basis that produce frequent hyperpycnal flow into the ocean. Some moderately dirty rivers can produce hyperpycnal plume during large flood events (every hundred years or less). The Eel River in the Pacific Northwest falls into this category. A hyperpycnal event can significantly affect the morphology of the coastal ocean bed by transporting and depositing large volume of sediment on the continental shelf and slope. In the present study a numerical model of spreading hyperpycnal plume has been developed. Depth-integrated governing equations describing the physics of a turbidity current evolving in time, and space are solved using an implicit finite difference scheme. Three grain-size ranges - clay, silt, and sand are considered. The effects of long-shore current and Coriolis force are incorporated in the model. The model is applied to the hyperpycnal plume generated during the 1995 Eel River Flood. The long shore current has been found to profoundly influence the spread of the plume and the resulting sediment deposition.

C-02: When the Sea Shakes

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As human occupation, industry and recreation increase in the coastal zone, tsunamis may take increasing tolls. Most tsunamis have a natural warning for local populations (the preceding earthquake), and long-distance warning systems are now well established. However, despite recent advances in hazard planning, many people in potentially at-risk coastal zones are not yet educated about tsunamis, and real-time prediction of tsunami magnitude remains a challenge. In today's

world, "unnecessary" evacuations might be deemed more costly than no evacuation. Advances in tsunami warning and in magnitude prediction include underwater sensors and improved numerical models, as well as electronic, global-information systems. Destructive tsunamis are most commonly produced by (subduction-zone) earthquakes and associated large landslides; the majority have occurred around the Pacific Rim, as well as in the Caribbean and Mediterranean. The last very large tsunami events were 1960 (Chile) and 1964 (Alaska). However, smaller tsunamis in the 1990s have killed thousands of people and done millions of dollars in damage. Several of these events were in areas with little prior history of tsunamis; paleotsunami studies are extending the historical catalogues. The role of landslides in tsunami generation is a pioneering research area. Landslides have been implicated in a number of cases, and postulated in others. In particular, in addition to historically tsunamigenic areas, tectonically active continental margins with thick wedges of sediment are being studied for their tsunami risk, both from "tsunami earthquakes" (slow earthquakes which arc not necessarily felt by at-risk populations) and from landslide-generated events.

C-03: The Perfect Storm: Formation and Reworking of Storm Beds on the Continental Shelf

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Erosion, transport and deposition of sediment on the continental margin has produced sedimentary deposits that reflect margin processes through geologic history. Sedimentologists have interpreted discrete beds in these deposits as event beds, produced by single storms and/or floods. Preservation of these beds depends on rates of accumulation and physical and biological bed reworking. The event beds with the greatest preservation potential are those produced by the largest storms because they are thicker and therefore more likely to escape reworking. If event bed characteristics could be related to their formational processes, they would offer a means of interpreting the nature of events reflected in the stratigraphic record. Making this link, however, requires going beyond the established conceptual models of storm bed formation and reworking to a direct connection between storm characteristics and the event beds they produce at a given location. Several decades of effort now have been directed toward establishing this connection through field and modeling studies. Through these combined efforts, we are developing an understanding of the kinds of event beds that typical and extreme storms can produce. This allows us to ask the question of what kind of storm could produce an event bed that has the potential to escape subsequent reworking and make it into the longer term record, and what is the likelihood that such a storm would occur?

C-04: Ocean Volcanoes and Life

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A remarkable advancement in the study of submarine volcanic activity arises from the unexpected and recent evidence that this extreme environment supports a substantial, high-temperature microbial biosphere. Seafloor spreading along mid-ocean ridges is characterized by the combination of processes such as normal faulting, volcanic accretion and cooling of newly-formed oceanic crust by hydrothermal circulation. These events are the principal mechanisms by which a large portion of the oceanic crust is accreted. Along mid-ocean ridges, hydrothermal fluids circulate in the subsurface and transport dissolved materials and thermal energy that mix with seawater. For the last twenty years, seafloor hydrothermal vent sites have been the focus of deep-sea exploration and of multi-disciplinary studies to better understand the geological, physical, chemical and biological processes that interact in this environment. Hydrothermal vent sites represent a small subset of the seafloor that support significant biomass in the ocean. Intermittent eruptive events such as the emplacement of dikes can cause vigorous bursts of hydrothermal fluids to suddenly escape from within the oceanic crust and have given rise to spectacular microbial blooms. Consequences of geological perturbations in hydrothermal systems and during diking events along the Juan de Fuca Ridge, NE Pacific Ocean will illustrate the interconnection between submarine volcanic systems and the microbial biosphere that thrives in the depths of our planet.

C-05: The Role of Hydroplaning in Subaqueous Mass Transport as Ascertained by Integrating Field Data with Experimental and Theoretical Studies.

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Submarine sediment transport is known to take place in several regions around the world. This represents a potential natural hazard (e.g. leading to tsunamis) and poses a threat to off-shore structures, e.g. platforms, cables and pipelines. The studies of subaqueous mass transport have revealed that although the sediment mass submerged in water has lower density (due to buoyancy) and higher resistance to flow (increased viscous drag) as compared to its subaerial counterpart, its mobility is much greater than the later. Submarine

flows on very gentle slopes (slope angle <1°) often cover distances of hundreds of kilometres. The great run-out distances in the presence of extremely low gradients represent an enigma in the studies of submarine flows. In the classical theory of subaqueous mass transport, the sediments are envisaged to start off as a high density, cohesive mass (debris flow) which, as it moves downslope, incorporates water and becomes more and more fluidal and lower density in nature (turbidity current) throwing the solid particles into suspension. As the mass comes to rest, the solid sediment particles settle down according to their densities forming a sedimentary deposit in which the diameter of the sediment grains progressively decreases towards the top. Such deposits in the geological records are known as turbidites. Recent experimental studies have however shown that sediments can cover great distances on gentle slopes as high-density, cohesive flows (debris flows). This is especially true of clay-rich sediments. Hydroplaning of the moving mass facilitates this mode of transport. As the sediment mass begins to move down a slope in subaqueous environments, a thin layer of water is incorporated beneath the moving mass. This water layer acts as a lubricant by decreasing the friction between the overriding sediment mass and the underlying stationary ground allowing the mass to be transported to great distances with its density more or less unaffected. This phenomenon which has been studied in detail in the laboratory, is supplemented by analytical techniques and has been shown to be true at natural scales. This integration of experimental and theoretical studies together with field data has opened up new and exciting avenues for investigating subaqueous sediment transport.

C-06: Extreme Variability in the Flux of Icebergs and Sediments to the North Atlantic on Millennium Timescales

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It is important when discussing this topic to distinguish clearly between what we know and what we assume. As an example, we know the present iceberg flux into the North Atlantic (ca 350 km3/yr), but we have no measurements on the associated sediment flux (IRD). In late Quaternary marine records from the North Atlantic we see abrupt changes in the various non-biogenic sand fractions and associate these with changes in iceberg flux. These are most spectacular during Heinrich (H-) events at ca. 14.5, 21, 27, and 35 ka (and two older events). However, these abrupt changes in IRD might also reflect changes in iceberg sediment concentrations, in the drift trajectories, or in the rates of iceberg melting. Thus although we can describe these dramatic events, an understanding of the underlying glaciological and oceanographic controls is elusive. This presentation will examine records of IRD from Baffin Bay, the Labrador Sea, the East Greenland shelf and slope, and the Iceland shelf. A fundamental question is the leads or lags in IRD delivery from the various ice sheet components. Within the North Atlantic context, three hypotheses are presently supported: 1) abrupt IRD events are synchronous and driven by some climate mechanism; 2) the process is driven by basal instabilities in the Laurentide Ice Sheet (LIS) which trigger changes in other ice sheets, possibly by rapid changes in sea level; and 3) apart from H-events associated with the LIS, iceberg and IRD fluxes were random in the eastern North Atlantic.

C-07: Sedimentation in the East China and Yellow Seas during Tropical Cyclone Janis

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This study examines advection, changes in seafloor properties, and changes in the bed texture during Tropical Cyclone Janis, which crossed the Yellow Sea between Aug. 22 and Aug. 27, 1995. Trans98, a coupled bottom boundary layer/sedimentation model developed by Keen and Glenn (1,2), computes combined wave and current bottom stresses and suspended sediment profile patterns. The sediment distributions in the Yellow Sea, which are initialized using observations, range between 1 mm and 0.0039 mm (0^{-8} phi). The NOGAPS winds drive the Princeton Ocean Model (POM) which is used to predict the near-bottom boundary current. The surface wave field is calculated using the FD-wave model of Graber (3) as modified by Keen and Slingerland (4). The wave and near-bottom current field are used to drive the Trans98 model during the storm. A one-hour model time step is used for this study, along with a 10 km. horizontal grid. Time series of the suspended sediment distribution predicted by Trans98 model, are examined for temporal variations. The evolving bed structure during TC Janis demonstrates the changing pattern of erosion and deposition during and after the storm, along with other seafloor properties.

1. Glenn and Grant (JGR,V. 92, 8244-8264, 1987)
2. Keen and Glenn (Estuarine and Coastal Modeling 5, Conference Proceedings, ASCE, 1998)
3. Graber and Madsen (JPO, VI 8, 1465-1483, 1988)
4. Keen and Slingerland (JGR, V. 98, 4775-4792, 1993)

C-08: Particle Size Dynamics in the Coastal Optics and Mixing Experiment: Measurements with LISST and BASS Instruments Reveal a Complex Dependence on Stress and History

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A suite of instruments, consisting of LISST particle size-distribution sensors on one tripod, and BASS velocity sensors on another tripod, was deployed in the bottom boundary layer at 70m depth in the CM&O experiment fielded on the New England shelf. The temporal dynamics of particle size and volume concentration were examined in terms of the relevant hydrodynamic forcing parameters: stress, and wave energy. Mean particle sizes during storm events were found to be generally between 63 to 180 microns, consistent with photographic data of P. Hill who had a floc camera on the LISST tripod. As bottom samples revealed a cohesive sediment, containing no sand or (disaggregated) morphology larger than 63 microns, it appears that the particles observed under storm conditions were tightly bound micro-aggregates. At the beginning of a particularly interesting storm under energetic waves, but with low current stress, larger particles (Dsauter=60 microns) appeared first in the LISST data. As the storm progressed in intensity, the particle size first became smaller (Dsauter=20 microns) suggesting disaggregation, later increasing to 60 microns as the mean current and stress increased further, now suggesting resuspension. We shall present the observations and preliminary comparison with model results.

Technology and Miscellaneous Topics (TM)

TM-01: Tethered Sensor Systems

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Recent advances in technology have enabled tethered sensor systems to become powerful tools of ocean science. There are several types of tethered systems including bodies that are towed or cast, as well as remotely operated vehicles. All systems have several components in common: the body or main frame of the system contains a suite of sensors specific to the scientific application and the tether provides both a significant source of power to the sensors and associated electronics as well as provides a means by which data can be transmitted to the host platform (the "host" is usually a ship). There have been major advances in technology including standard use of optical fibers in the tether so that large volumes of data can flow rapidly through the tether, reduced size of electronics so that powerful computers and data acquisition electronics can reside in pressure housings inside the body, and high density storage media that contain large amounts of information in a small space. As a result of these advances, tethered systems can house a diverse array of sensors giving rise to a steady stream of data available to the scientist. Simultaneous acquisition of data from all of the sensors helps make possible measurements of many aspects of the process under investigation which can give rise to new understanding of the process.

TM-02: Autonomous Mobile Sensor Systems

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Ten years ago, the only Autonomous Underwater Vehicles (AUVs) in existence were either very expensive, very large systems, or laboratory test-beds. However, in recent years, a class of small, high performance systems have been developed for oceanographic applications. Initial AUV operations were one-time events, demonstrating some new sensor or operational capability. Part of the process of introducing these new platforms has been the identification of appropriate missions and operational scenarios. There is a temptation to fit new technologies into old roles. However, to consider an AUV to be an ROV without a tether, or an oceanographic vessel without a crew, is a mistake. The economic opportunities and technical challenges shaping the emerging class of vehicles are fundamentally different from those of the existing stable of platforms. To take advantage of the unique opportunities posed by such vehicles, new modes of operation have emerged. For example, ocean observatories are an emerging class of facilities for making measurements in the ocean, and AUVs are likely to play an important role in ocean observatories of the future. A docking capability is key to making AUVs an integral component of ocean observatories. The motivation for such observatories includes: a desire to promote interdisciplinary work on ocean processes, the need to coordinate time-series studies to obtain spatial coverage, the requirement of having in-place assets to respond to episodic events, and the opportunity to obtain real-time data from instruments on the sea floor. As feasibility for using AUVs for various oceanographic applications is proven by ground-breaking research, more focused AUV projects are coalescing to design systems for specific missions. Today, AUVs are operated routinely by a number of groups for obtaining oceanographic data, and commercial AUVs are in various stages of development.

TM-03: The Scientific Motivation for Data Assimilation

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The sea-going oceanographers' penchant for charting goads them to devising better and better ways to interpolate their scarce and precious data. The theoretical oceanographers' drive for better and better models has made the insertion of the data into the model very tempting. The preparation of analyses guided by dynamical constraints and the improvement of models using data have become the activity known as "data assimilation". Fantastically intricate and expensive algorithms now exist for doing data assimilation. The considerable experience of operational meteorologists has been a great benefit. They are motivated by the need for dynamically consistent weather maps, to be used as initial conditions for their forecast models. Oceanographers are still some way from issuing operational ocean forecasts, except for the tropics. Thus a scientific motivation for data assimilation is needed. It is there: a carefully assembled assimilation scheme is a rigorous test of a model, once the concept of a 'model' is extended to include assumptions about the statistics of the errors in the model dynamics, and in its initial and boundary conditions. If the test is passed at a suitable level of significance then the analyses or maps resulting from the assimilation represent the extent of our knowledge about the circulation. An assessment of the efficiency of the observing system may be made by unravelling details of the assimilation, and error statistic for the analyses may be estimated. If the test is failed then the analyses and array assessments and error statistics lose credibility, but we will have learned something about the circulation dynamics. This learning process is enhanced by our algorithmic ability to test each parameterization in a model, term by term. Marine biologists will notice that this is just classical regression theory. Indeed, the subject is most simply introduced using biological examples. Many biologists are interested in assimilating biological, chemical and physical data into coupled bio-chemical-physical models of the ocean. One of the most valuable parts of the experience may well be the preliminary formulation of quantitative hypotheses that could be objectively tested by the assimilation process.

TM-04: Spirals on the Sea

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Early satellite shuttle photographs taken thirty years ago with handheld Hasselblad cameras showed spiral vortices in the sun glitter. Paul Scully-Power, the first and last (so far) Oceanographer-Astronaut found them to be ubiquitous. Yet they have not been explained (to the best of our knowledge). We have collected 300 of the best images of which I will show a few. The spirals are always cyclonic, and have typical dimensions of order 10 km. Time scales are of order 1 day, The questions are: (i) what rolls up the spirals? (ii) what breaks their symmetry? and (iii) what do we see on the images?

TM-05: A Globally Relocatable Tide/Surge Forecast System

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A globally relocatable tide/surge model, driven by winds from a globally relocatable mesoscale atmospheric model has been developed and is presently being tested and validated against tide station data. The tide/surge models are both 2- and 3-dimensional barotropic ocean models developed by Global Environmental Modeling Services (GEMS). These models can be driven by tidal forcing at the boundaries obtained from the Grenoble global tide model and/or wind forcing. This system has the capability of assimilating tidal height field information obtained from the Canadian International Hydrographic Office (IHO) tide station data into the ocean model. The mesoscale atmospheric model, also developed by GEMS, is a hydrostatic primitive equation model using sigma coordinates in the vertical. Although the model includes parameterization of the boundary layer, horizontal and vertical diffusion, cumulus convection, latent heating and radiation, its use in this system is limited to providing surface wind fields. Initial conditions and boundary conditions for the atmospheric model are provided by the output of the Navy Operational Global Atmospheric Prediction System (NOGAPS) analysis and forecasts. Ocean bathymetry for this system, at a resolution of 5 minutes or greater, comes from the U.S. Navy database DBDBV. The land topography is provided at 3 minute resolution and is derived from a USGS data base. Both the atmosphere and ocean models have nesting capabilities. Model results from various locations around the globe are compared to observation. In the case of the ocean model, to tide station data and in the case of the atmospheric model, to various coastal stations providing wind speed and direction. This model is scheduled to provide real-time operational products to the U.S. Navy in the coming year.

TM-06: The Use of a Globally Relocatable Forecast System in Naval Exercises

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Within the past two years, the Navy's version of the Global Environmental Modeling Systems' (GEMS) relocatable atmospheric/tide/surge forecast system has been run during two real-time Naval exercises; Pacific Fleet Joint Task Force Exercise (JTFX) 97 off the southern California coast and Rapid Response (RR) 98 off the southwest coast of Spain. The GEMS atmospheric model is a hydrostatic primitive equation model using sigma coordinates in the vertical. Initial boundary conditions for the atmospheric model were provided by the output of the Navy Operational Global Atmospheric Prediction System (NOGAPS) analysis and forecasts. During JTFX 97 (July 15-25, 1997), the atmospheric model was run which produced high resolution wind forecasts (14.5 km) over a 48 hour period at 6 hour intervals. Comparison studies were made between the GEMS high resolution winds and both the NOGAPS and regional NOGAPS surface winds. The tide/surge forecast models are both 2- and 3-dimensional barotropic ocean models. These models can be driven by tidal forcing at the boundaries obtained from the Grenoble global tide model and/or wind forcing from the atmospheric model. During RR 98 (Feb-March 1998), both the atmospheric and tidal forecasts were run daily. High resolution winds (14.3 km) and tidal sea surface height were produced over a 48 hour period at 6 hour intervals. Real time observations were collected during these two exercises and later compared to the model forecast results, including wind speed and direction for the atmospheric system and tidal height and period for the tidal forecast system. Comparison studies of sea surface heights were made between the GEMS forecasts and the Spanish tide tables. Validation studies were also performed comparing the GEMS high resolution winds and the NOGAPS surface winds. During both of these exercises, daily forecasts were posted to a website and used by the participates of the exercises.

TM-07: The Seasonal Cycle of the California Current System as Depicted by a High Resolution Coastal Model.

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A high resolution model of the U.S. Pacific Coast is utilized to examine the seasonal variation of the California Current System (CCS) circulation patterns. The model is a sigma coordinate formulation (the Princeton Ocean Model) with 30 levels in the vertical and 1/12 degree resolution in the horizontal. The model domain extends from 30N to 49N and from 115W to 135W and is embedded into the NRL 6-layer global layered model to obtain boundary information. The simulation is forced by the FNMOC Navy Operational Global Atmospheric Prediction System (NOGAPS) 12-hourly winds from 1993 to 1998. The model simulation displays a coastal jet generated by upwelling favorable winds during the Spring and Summer seasons followed by offshore propagation of the jet south of Cape Blanco during the Summer and Fall. Although the California Current (CC) exhibits significant meandering and eddy shedding during this period, it remains a continuous flow as depicted by its low salinity core. A pronounced inshore countercurrent also develops and persists into the winter season. The spatial and temporal variability of these seasonal features is compared with observations and discussed.

TM-08: A Study of the Dynamics of Wind-Driven Transports into the Yellow Sea

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Synoptic wind stresses force a 3-dimensional numerical ocean model of the Yellow Sea/East China Sea dynamics and thermodynamics. The basin response to winter winds is examined through the model output fields. Northerly wind bursts are a frequent winter occurrence in this region. The wind bursts develop a southward flowing current along the Chinese coast as the wind stress forces fluid out of the Bohai Sea. A north/south pressure gradient develops as surface water flows southward, decreasing the elevation in the north relative to the elevation in the south. The southward pressure gradient forces a bottom flow in the direction opposite to the wind stress. The wind stress along the Korean coast often deviates from the northerly wind stress over most of the Yellow Sea. Thus the flow along the Korean coast is not as closely related to the northerly wind bursts. There is mean northward flow into the Yellow Sea through the trough. Northward flow does not penetrate far into the Yellow Sea before turning eastward north of Cheju and then passing through the Cheju-Korea Strait. During strong northerly wind events, transport into the Yellow Sea occupies the entire trough and extends considerably northward. After the northerly wind ceases, the inertial northward transport increases pressure in the north, and frequently pressure increases sufficiently to force a southward return flow.

TM-09: Real-Time Systems for Global Ocean Nowcasting and Forecasting

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The Ocean Dynamics and Prediction Branch of the Naval Research Laboratory (NRL) has been conducting a coordinated program of Research and Development (R&D) in support of Navy operational ocean nowcast and prediction since the early 1980's. The advent of real time altimetry data has advanced the state of the art in global ocean nowcasting. NRL has developed two systems that assimilate altimetry data. The Modular Ocean Data Assimilation System (MODAS) is an optimum interpolation analysis system built around a climatological data base that has the ability to produce synthetic temperature and salinity profiles from sea surface height and sea surface temperature data. MODAS is currently undergoing testing in real time at the Naval Oceanographic office. The MODAS 3-D analysis is used to initialize a version of the Princeton model that performs short-term upper ocean predictions. The NRL Layered Ocean Model (NLOM) is also running in real time using a nudging data assimilation scheme to assimilate altimetry data. This model is currently running globally at 1/4 degree resolution and is undergoing testing at Fleet Numerical Meteorology and Oceanography Center (FNMOC). Results from both systems will be shown.

TM-10: Current Response to Strong North Winds in the Yellow Sea

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Strong north wind bursts during winter in the Yellow Sea result in an upwards sloping sea-surface towards the south and a northward current response. The northward flow, referred to as the Yellow Sea Warm Current (YSWC), is observed using measurements of current profiles, pressure, and temperature, and a wind climatology for the time period July, 1995 through January, 1996. During fall transition and winter, the northward flow in the Yellow Sea interior occurs as a response to pulses of strong north winds that drive a north-to-south rise in pressure extending from a relatively deep trough over to the Korean coast. The rise in pressure and corresponding YSWC begin at the end of October for this measurement period. These measurements also suggest that the northward flow in the surface layer during summer is a direct response to the south winds. Observations presented here show that northward flow in the Yellow Sea trough is related to wind events and not to a branching of the Tsushima Current.

TM-11: Surface Fluorescence in the Coastal Regime

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The complexity of the coastal regime, where fresh and marine waters mix, can produce a wide variation in the biology and nutrient distributions. The variations in temperature and salinity may not always track with the organics due to mixing, upwelling, mobility and sunlight. The fluorescence signature of different organic pools can be used to characterize these water masses. With the development of WETLabs SAFire (Spectral Absorption and Fluorescence meter) a method for rapid continuous measurement of spectral fluorescence is now in use. The instrument is capable of measuring the emission of 16 wavebands excited at 6 wavelengths. Preliminary work has shown that the chlorophyll can be distinguished from dissolved organics, and other pigments. Distinguishing between the sources of dissolved organics may be crucial in determining the labile nutrients from the refractory dissolved organics. Two data sets are presented from the near surface waters (~1 meter depth). The first set is from the coastal waters near the mouth of the Chesapeake Bay in the Spring of 1997 and the second is from the water at the mouth of Tampa Bay in the Fall of 1998. The SAFire was incorporated into the ship's flow through sea water system along with salinity, temperature (Sea-Bird Electronics, Inc.) and a chlorophyll-a fluorometer (Turner Designs, Inc.). The implications for these measurements range from ocean color to primary productivity.

TM-12: Baroclinic Tilting of Separated Flow Past a Headland

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Tidal flow past irregular coastlines often leads to flow separation. Differential mixing on either side of the separation can lead to a transverse pressure gradient. What happens when this pressure gradient acts on the sheared flow? Observations of tidal flow past an island in Haro Strait show that close to the separation point the boundary layer forms a vertical vortex sheet. The shear

zone is subject to instability of the Rayleigh type leading to eddy formation. As the eddies move downstream, a transverse density difference interacts with the evolving shear zone. In a plane orthogonal to the shear zone, the boundary between the two layers on either side of the front is initially vertical, but bits and stretches with time due to effects of the density gradient; the tilting can be described in terms of the classical lock exchange problem. As the eddies are stretched, their circulation intensity increases, while the corresponding vortex tilting transforms horizontal into vertical circulation. This effect becomes so strong that vertical current speeds up to 0.5m/s draw bubble clouds to depths of over 120m. Such violent mixing must be responsible for modification of water properties and may play a significant role in aeration of water masses exchanged between semi-enclosed basins and the open ocean.

TM-13: Optical Variability of the Chesapeake Bay

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This project investigates the seasonal variation in the in-water optical properties of the Chesapeake Bay estuary. Understanding this variability allows for the proper employment of optical measurement techniques as well as a foundation for accurate interpretation of remotely sensed visible imagery. The absorption and scattering properties of the Bay water column can be expected to change with major physical variations. The most significant source of physical variation in the Bay is associated with the fall destratification or mixing event. As autumn progresses, atmospheric cooling causes a temperature inversion in the water column, thereby weakening the salinity-stratified pycnocline. Combining this inversion with increased winds associated with fall storm systems causes a top to bottom mixing of the water column. An intensive study combining in situ hydrographic and optical measurements as well as laboratory characterization of the suspended load is performed across a destratification event in the northern Bay. This data and analysis is combined with theoretical modeling to characterize the physical variation in terms of changes in the absorption, scattering, and hence suspended load properties of the Bay.

TM-14: Ra-226 as a Tracer of Ground Water Input to the Coastal Waters of Southern Rhode Island

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Submarine ground water discharge (SGWD) is an important, yet poorly constrained source of fresh water and dissolved material to coastal waters. Quantification of this term therefore proves important with respect to coastal hydrological and geochemical mass balances. In order to better constrain SGWD to southern Rhode Island's coastal environment, the naturally occurring radionuclide Ra-226 was used as a tracer of ground water input. Activities of Ra-226 were determined in river water, salt ponds, coastal ocean and ground water in southern Rhode Island during the summer of 1997 (June - August). Coastal lagoons and shelf waters were analyzed to quantify excess radium inventories, signifying an input of ground water. Using these results, a radium balance was constructed from which the ground water flux to the salt ponds and/or shelf waters was calculated. The estimated ground water fluxes to the salt ponds, corresponding to 1-42 x 105Ld-1, are in most cases an order of magnitude less than inputs of river/stream water.

TM-15: Exact Measurement of Suspended Sediment Concentration and Sauter Mean Diameter with a New-Principle Laser Sensor

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It is a widely acknowledged fact that all historical in-situ data on suspended sediments (i.e. excepting grab samples) are contaminated by effects of changes in size distribution on sensor calibration. This is known for transmissometers, optical backscatter sensors, and for single-frequency acoustic sensors as well. Because all these data were based on a single parameter - a scattering or attenuation cross-section - that was not proportional to total sediment volume, the historical measurements carry unknown errors. We have found a new exact mathematical solution that relates the total sediment volume concentration to a measure of laser scattering by suspended sediment particles. It is found that the volume concentration of particles is rigorously proportional to the weighted sum of observed small-angle scattering in the focal-plane of a receiving lens. A similar solution obtains the total particle area concentration. From the total volume and area, the ratio defines a Sauter Mean Diameter, SMD. In the presentation, we shall describe the new instrument LISST-25 (patent pending) and show the results of laboratory tests on fidelity of concentration and size measurements with calibrated scatterers.

TM-16: Sharp Frontal Interfaces and Temperature-Salinity Relationship in the Oceanic Mixed Layer

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Measurements during the Coupled Ocean-Atmosphere Experiment (COARE) revealed numerous cases of sharp frontal interfaces within the oceanic mixed layer (Soloviev and Lukas 1997; Wijesekera et al. 1998). According to Rudnik and Ferrari (1999), the compensated fronts prevail within the mixed layer, resulting in density ratio R~1. However, a 1-month statistics acquired during COARE in the warm pool area indicate that when the frontal interface is sharp, the important factor is its interaction with wind stress. The wind stress directed along the buoyant spreading of the frontal interface may keep it far from the compensated state. In the opposite situation, the enhanced cross-frontal mixing may expedite the achieving of a compensated state (or the full degradation) of the frontal interface. The latter situation is illustrated by the observation of an unusually sharp (supposedly uncompensated) front in the warm pool area in Summer 1997 from the R/V *Kaiyo* (JAMSTEC). An estimate with the model of Soloviev and Lukas (1997) suggests that an internal bore develops (substantially increasing the cross-frontal mixing), which is consistent with the observation of intensively breaking surface waves in the frontal region.

TM-17: Cobble Dynamics in the Wave-breaking Region along an Impermeable Slope

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The motion of large bottom particles, (cobbles) in the laboratory under simulated surf conditions. The primary objectives of the experiments were to obtain data which could be used to (i) modify theoretical models [1,2] obtained for periodic but spatially independent flows to cases in which the flow, while periodic, is also space dependent and (ii) test and modify the models as appropriate for the entire surf zone. A series of experiments were conducted in a large wave tank, 104.5 x 3 x 6 ft, equipped with a computer-controlled wave maker and a sloping beach. This facility permits one to investigate phenomena in all three regions of the surf zone: i.e., wave-induced oscillatory flow, breaking waves and swash. As a first step, a solid impermeable beach with artificial toughness was used in the experiments. Cobbles of different size were placed along the floor and their evolution with time was studied and compared with the theoretical predictions.

1. Luccio, P.A., S.I. Voropayev, H.J.S. Fernando, D.L. Boyer, and W.N. Houston, 1998: The motion of cobbles in the swash zone on an impermeable slope. *Coastal Eng.*, 33,41-60
2. Voropayev, S.I., J. Roney, D.L. Boyer, H.J.S. Fernando, and W.N. Houston, W.N. 1998: The motion of large bottom particles (cobbles) in a wave-induced oscillatory flow. *Coastal Eng.*, 34, 197-219.

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TM-18: A Three-dimensional Wave-current Coupled Model

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A coupled wave-current model is developed based on the three-dimensional Princeton Ocean Model (POM) and WAM III Cycle 4. The coupling is implemented via three processes: 1) direct wave-current interaction via radiation stress; 2) effects of waves on wind stress; and 3) coupled effects of waves, tides and currents on bottom stress. The effect of wave-induced wind stress is incorporated into the circulation model by using the empirical model of Donelan (1993) to compute the surface roughness length which is then used to estimate the drag coefficient over the water surface. The effect of surface waves on bottom stress is estimated via a drag-splitting formulation (Christofferson et al., 1985). The formulation for radiation stress is according to Longuet-Higgins et al. (1964). The coupled model has been tested under idealized forcing conditions, in hindeast mode during Hurricane Fran of 1996, and in real-time prediction mode during Hurricane Bonnie of 1998. Verification of model predicted storm surge and significant wave height with available NOAA tidal surge data and offshore wave data showed close model-data agreement.

TM-19: Ocean Drilling after 2003

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Drilling and recovering cores of sediment and crystalline rock from the deep sea has become the most

effective tool in advancing marine geology. The JOIDES (Joint Oceanographic Institutions for Deep Earth Sampling) ocean drilling programs began as a US multi-institutional effort in 1965, followed by the Deep Sea Drilling Project (DSDP) in 1967, using the D/V Glomar Challenger as platform. The DSDP became an international program in 1972. After a 14 month hiatus in 1983-84, the work was continued by the Ocean Drilling Program, using the D/V SEDCO 471 ("JOIDES Resolution") as platform. The ODP will end in 2003. Continuation of Ocean Drilling in the future is like to be a multi-platform international venture. Japan has committed itself to construction of a new drilling vessel with capabilities for return circulation and well control initially using a 2500 meter riser. The targets for drilling with this "OD21 " vessel will lie beyond the capabilities of the platforms used in the past, and were defined at a meeting (CONCORD) in Tokvo, Japan, in July, 1997. Another meeting (COMPLEX), to be held in Vancouver, BC, Canada, in May, 1999, will define objectives that can be achieved with simpler technologies. The new program is likely to include objectives in shallow waters and polar seas, which will require platform capabilities different from those of the vessels used in the past.

TM-20: Distributed Oceanographic Data System

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The Distributed Oceanographic Data System (DODS) is a scientific data transport mechanism based on the protocols that the World Wide Web uses to move data and information across the Internet. The formulation of DODS is based on two principles:

1. Scientists, as well as national archives, are data providers;
2. Users should have access to data directly from their analysis packages.

DODS makes scientific data accessible over the Internet, through familiar data analysis and visualization packages (e.g., MATLAB), converting transparently from a number of commonly used data formats (e.g., netCDF) into the format appropriate for the analysis package. The data transport mechanism utilized within DODS links a data-handling application with disparate, distributed datasets located anywhere on the Internet. DODS uses the client-server model, with a client sending a data request (coded in a URL) across the Internet to a server, which answers with the requested data. The DODS client is an application that uses DODS library functions to retrieve data from DODS servers regardless of the format in which the data are stored. Users can create customized DODS clients using IDL or MATLAB (analysis packages), using netCDF or JGOFS (APIs), or using C++ or Java (Object Oriented Programming). The server is a specially-enhanced Web server that can retrieve and subset data from DODS-compatible datasets in response to requests made by a DODS-enabled client.

INDEX

ABSTRACT TITLES

By order within session with first author and talk/poster presentation day.

The Ocean in Commotion: Climate and Circulation Change on Long Time Scales

Zachos, J.C. (invited talk) A-01
Abrupt Global Warming in the Early Cenozoic: An Assessment of the Evidence for an Oceanographic Mechanism

Haug, G.H. (invited talk) A-02
Effects of the Formation of the Isthmus of Panama on Thermohaline Circulation, Oceanic Nutrient Distributions, and Climate

Keigwin, L.D. (invited talk) A-03
Abrupt, High-frequency Changes in the Ocean and Climate during the Past 50,000 Years

Adkins, J. (invited talk) A-04
Radiocarbon Constraints on Past Deep Circulation Rates

Cullen, H. (invited talk) A-05
Possible Role of Climate in the Collapse of the Akkadian Empire: Evidence from Gulf of Oman Marine Sediments

Wunsch, C. (invited talk) A-06
Inferences about the Paleocean in the Context of Understanding the Modern Ocean

Hay, W.W. A-07
Mesozoic Changes in Ocean Salinity Correspond to Major Episodes of Formation of Petroleum Source Rocks

Holloway, G. A-08
Global Conveyors: who's driving?

Rochford, PA. A-09
Sensitivity of the Ocean Mixed Layer to Operational Wind Products

Chavez, F.P. A-10
A Ten-year Time Series from Monterey Bay, California: Seasonal, Interannual and Long-term Patterns

Monahan, E.C. A-11
Bubbles and the Global Carbon Flux

Sharp, J. H. A-12
The Need for Analytical Intercalibration for Long Time Series Analysis: Dissolved Organic Matter

Smith, D.R. A-13
The Maury Project: An Innovative Approach for Teaching the Physical Foundations in Oceanography

From the Sea Floor to the Sky: Biological Ramifications

Dixon, P.A. (invited talk) B-01
Extreme, Unpredictable Phenomena from the Non-linear Perspective

Baker, E.T. (invited talk) B-02
Hydrothermal Event Plumes: Deciphering the Oceanographic Effects of Seafloor Spreading Events

Kim, S. (invited talk) B-03
Ecological Consequences of Seafloor Eruptions and Hydrothermal Event Plumes

Botsford, L.W. (invited talk) B-04
Time Scales of Environmental Variability and Populations of Salmon and Crab in the California Current

Denny, M. (invited talk) B-05
Wave Forces and Evolution: Life in the Surf Zone

Hunt, G.L. (invited talk) B-06
Ecosystem Responses of the Southeastern Bering Sea to Abnormal Weather Patterns in 1997 and 1998

Yoder, J.A. B-07
Wind Stress and Satellite Chlorophyll Patterns in the Atlantic Ocean

Zeeman, S.I. B-08
SeaWiFS Observation of a Large Multi-year Coccolithophore Bloom in the Bering Sea: Possible Implications and Consequences

Baduini, C.L. B-09
Anomalous Weather Events in the Southeastern Bering Sea: The Conditions of Short-tailed Shearwaters in 1997 and 1998

Bailey, G. B-10
Recent Hypoxia-induced Mortalities of Rocklobsters in the Southern Benguela Upwelling Region

Gargett, A.E. B-11
How Do Extremes in Climate Variability Affect Biological Production in Estuarine Systems?

Neilson, D. J. B-12
Patterns of Bioluminescence in the Arabian Sea: Ecological Interpretations

Macri, E. B-13
Effects of Elevated Temperature and UV-B Radiation on Zooxanthellae *in hospite* and Expelled from the Tropical Sea Anemone *Aiptasia pallida*

Bynagle, M. B-14
Temperature and UV Stress Interact to Change the Pigment Composition of Coral Zooxanthellae

Schmidt, C. B-15
Changes in Optical Reflectance and Pigmentation of the Coral *Montastraea faveolata* in Response to Elevated Temperature and Ultraviolet Radiation

Rivers, T. B-16
The Effects of Elevated UV-B Radiation on Productivity and Bleaching of Zooxanthellae in the Coral *Montastraea faveolata*

Kremer, P. B-17
Salp Swarms: Will They Always be Unpredictable?

Costa, D.P. B-19
Elephant Seals as a Biological Autonomous Underwater Sampling System

Crocker, D.E. B-19
Impact of the 1997-1998 El Niño on the Foraging Behavior of Northern Elephant Seals, a Large Marine Predator

Lavelle, J.W. B-20
A Modeling Study of Rectified Flow in the Vicinity of a Spreading-Center Ridge

Legeckis, R. B-21
Animation of Sea Surface Temperatures from GOES

Allard, R.A. B-22
The Master Environmental Library: Easy Access to Oceanographic and Meteorological Data

Geological Perturbations and Consequences

Imran, J. (invited talk) C-01
Impact of Extreme River Events on the Coastal Ocean

Bourgeois, J. (invited talk) C-02
When the Sea Shakes

Wiberg, P. (invited talk) C-03
The Perfect Storm: Formation and Reworking of Storm Beds on the Continental Shelf

Robigou, V. (invited talk) C-04
Ocean Volcanoes and Life

Elverhøi, A. (invited talk) C-05
The Role of Hydroplaning in Subaqueous Mass Transport as Ascertained by Integrating Field Data with Experimental and Theoretical Studies

Andrews, J.T. (invited talk) C-06
Extreme Variability in the Flux of Icebergs and Sediments to the North Atlantic on Millennium Time-scale

Keen, T.R. C-07
Sedimentation in the East China and Yellow Seas during Tropical Cyclone Janis

Agrawal, Y.C. C-08
Particle Size Dynamics in the Coastal Optics and Mixing Experiment: Measurements with LISST and BASS Instruments Reveal a Complex Dependence on Stress and History

Technology and More/Miscellaneous Topics

Stanton, T.K. (invited talk) TM-01
Tethered Sensor Systems (Fri)

Bellingham, J.G. (invited talk) TM-02
Autonomous Mobile Sensor Systems (Fri)

Bennett, A. (invited talk) TM-03
The Scientific Motivation for Data Assimilation (Fri)

Munk, W. (invited talk) TM-04
Spirals on the Sea (Fri)

Preller, R.H. TM-05
A Globally Relocatable Tide/Surge Forecast System

Posey, P.G. TM-06
The Use of a Globally Relocatable Forecast System in Naval Exercises

Kindle, J.C. TM-07
The Seasonal Cycle of the California Current System as Depicted by a High Resolution Coastal Model

Riedlinger, S.K. TM-08
A Study of the Dynamics of Wind-driven Transports into the Yellow Sea

Rhodes, RC. TM-09
Real-time Systems for Global Ocean Nowcasting and Forecasting

Teague, W.J. TM-10
Current Response to Strong North Winds in the Yellow Sea

Kennedy, C.D. TM-11
Surface Fluorescence in the Coastal Regime

Farmer, D. TM-12
Baroclinic Tilting of Separated Flow Past a Headland

Coleman, J.E. TM-13
Optical Variability of the Chesapeake Bay

Moran, S.B. TM-14
Ra-226 as a Tracer of Ground Water Input to the Coastal Waters of Southern Rhode Island

Pottsmith, H.C. TM-15
Exact Measurement of Suspended Sediment Concentration and Sauter Mean Diameter with a New-Principle Laser Sensor

Soloviev, A. TM-16
Sharp Frontal Interfaces and Temperature-Salinity Relationship in the Oceanic Mixed Layer

Voropayev, S.I. TM-17
Cobble Dynamics in the Wave-breaking Region along an Impermeable Slope

Xie, L. TM-18
A Three-dimensional Wave-current Coupled Model

Hay,W.W. TM-19
Ocean Drilling after 2003

Chinman. R. TM-20
Distributed Oceanographic Data System

INDEX OF AUTHORS

Bold text indicates speakers.
* = First Author

A
Adkins, J. *A-04
Agrawal, Y.C. *C-08
TM-15
Allard, R.A. *B-22
Ando, K. TM-16
Andrews, J.T. *C-06
Armi, L. TM-04

B
Baduini, C.L. *B-09
B-06
Bailey, G. *B-10
Baker, E.T. *B-02
Barron, C.N. TM-09
Bellingham, J.G. *TM-02
Bennett, A. *TM-03
Berger, J. B-13
Boehlert, G. B-18
Bostrom, D. B-13
Botsford, L.W. *B-04
Bourgeois, J. *C-02
Boyer, D.L. TM-17
Brodeur, R.D. B-06
Brown, F. A-05
Buck, K.R. A-10
Bynagle, M. *B-14
B-15

C
Carnes, M.R. TM-09
Case, J.E. B-12
Castro, C. A-10
Cayula, S.C. A-09
TM-07
Cense, A.W. TM-17
Chavez, F.P. *A-10
Chinman, R. *TM-20
Coleman, J.E. *TM-13
Costa, D.P. *B-18
B-19
Coyle, K.O. B-06
Crocker, D.E. *B-19
B-18
Cullen, H. *A-05
Curry, D. A-13

D
Dam, H.G. A-11
Dawson, G.M. C-07

DelCastillo, C. TM-11
DeMenocal, P. A-05
Denman, K.L. B-11
Denny, M. *B-05
DeRuda, S. A-09
Dixon, P.A. *B-10

E
Elverhøi, A. *C-05

F

Farmer, D. TM-12
Fayos, C. A-10
Fernando, H.J.S. TM-17
Fisher, K. TM-04
Fox, D.N. TM-08
Friederich, G.E. A-10

G

Gallagher, J. TM-20
Ganong, J. B-18
Gargett, A.E. *B-11
Geer, I.W. A-13

H

Hardy, J. B-13
B-15
Hastings, A. B-04
Haug, G.A. *A-02
Hay, W.W. *A-07
*TM-19
Hemming, G. A-05
Hemming, S. A-05
Holloway, G. *A-08
Hopcroft, R. A-10
Houser, D.S. B-19
Hubbert, G. TM-05
TM-06
Hundermark, B. B-22
Hunt, G.L. *B-06
B-09
Hyrenbach, K.D. B-09

I

Imran, J. *C-01

J

Jacobs, G.A. TM-08
Jiang, R. TM-12

K

Keen, T.R. *C-07
Kiegwin, L.D. *A-03
Kennedy, C.D. *TM-11
Kennelly, M.A. B-07
Kim, S. *B-03
Kindle, J. *TM-07
A-09
B-12
Kremer, P. *B-17
Kudela, R. A-10
Kuroda, Y. TM-16

L

Lavelle, J.W. *B-20
LeBoeuf, B.J. B-18
B-19
Legeckis, R. *B-21
Li, M. B-11
Lukas, R. TM-16

M

Macri, E. *B-13
B-16
Madin, L.P. B-17
Markus, T. B-13
Matsuura, H. TM-16
Mauri, E. A-10
McCann, K. B-04
McEachern, G.B. TM-17
McKagan, S. B-13
McManus, D.E. A-13
Michisaki, R.P. A-10
Miller, A. B-16
Monahan, E.C. *A-11
Moran, S.B. *TM-14
Muller-Parker, G. B-13
B-16
Munk, W. TM-04

N

Napp, J.M. B-06
Neilson, D.J. *B-12
TM-07

P

Pawlowicz, R. TM-12
Pedersen, T.F. A-02
Pennington, J.T. A-10
Peterson, E. B-14
B-15
Pietrafesa, L.J. TM-18
Posey, P.G. *TM-06
TM-05
Pottsmith, H.C. *TM-15
Preller, R.H. *TM-05
TM-06

R

Rhodes, R.C. *TM-09
Riedlinger, S.K. *TM-08
Rivers, R. *B-16
Robigou, V. *C-04
Rochford, P.A. *A-09
Roelke, D.L. TM-11

S

Sakamoto, C. A-10
Schilling, B. A-10
Schmidt, C. *B-15
Schumacher, J.D. B-06
Scott, M.K. TM-14
Sharp, J.H. *A-12
Sigman, D.M. A-02

Siquig, R.A. B-22
Sirocko, F. A-05
Smedstad, O.M. TM-09
Smith, D.R. *A-13
TM-13
Soloviev, A. *TM-16
Spinrad, R.W. TM-13
Stabeno, P.J. B-06
Stanton, T.K. *TM-01
Steely, T. B-15
Stockwell, D.A. B-06
Strom, S. B13
B-14
B-15
Sugihara, G. B-01
Syvitski, J. C-01

T
Teague, W.J. *TM-10
Tiedmann, R. A-02
Traykorsld, P. C-08

V
Voropayev, S.I. *TM-17

W
Wallace, B. B-13
Walz, P. A-10
Webb, P.M. B-19
Whitledge, T.W. B-06
Wiberg, P. *C-03
Wood, M. B-12
Wu, K. TM-18
Wunsch, C. *A-06

X
Xie, L. *TM-18

Y
Yoder, J.A. *B-07

Z
Zachariasen, F. TM-04
Zachos, J.C. *A-01
Zahn, R. A-02
Zeeman, S.I. *B-08
B-06
Zhang, C. TM-18