EPOC 2007: Abstracts

54th Eastern Pacific Oceanographic Congress
Sept 15-18, 2007
Sleeping Lady Mountain Retreat
Leavenworth, WA

Abstracts are listed alphabetically by presenting author.

Bio-physics of seabird occurrence in the northern California Current

D. Ainley (Harvey & Associates), K. Dugger, R. Brodeur, D. Presser, J. Barth, S. Pierce, G. Ford, C. Tynan, L. Spear

Using data from Northeast Pacific GLOBEC 2000 and 2002 process cruises, we modeled the biological and physical factors that explain seabird occurrence during the upwelling season off Oregon. Seabird densities were derived from strip censuses conducted whenever ships were underway during daylight. Explanatory variables were derived from SeaSoar and HTI (acoustic arrays), as well as fish trawls conducted along cruise tracks. In past excercises using some of these data (Ainley et al. 2005, DSR II), we explored relationships only for the 2000 cruise and only with SeaSoar and uncorrected acoustic data. The acoustic data now converted to actual biomass estimates of micronekton, along with direct results of prey availability from trawls, and for both cruises (one of which occurred during El Nino), should provide much greater insight into why seabirds occurred where they did and what explained variation in numbers.

Numerical simulation of hypoxia in Hood Canal, Puget Sound

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Hood Canal is one of Puget Sound sub-basins. Material exchange is mainly through the northern entrance of the Canal. Numerical modeling was applied to hindcast long-term mean seasonal variation of dissolved oxygen (DO) and a planktonic ecosystem in the Canal, with a simple nitrogen-based bio-geochemical model, coupled in a circulation model, Regional Ocean Modeling System (ROMS). Physical forcing included were seasonal climatology of salinity at the northern open boundary, seasonal climatology of river discharge at the 8 rivers. Bio-geochemical tracer boundary conditions included were seasonal climatologies of nitrate, ammonium, chlorophyll, phytoplankton and dissolved oxygen at the northern boundary. At the surface was seasonal climatology of solar radiation applied for photosynthesis. Also was seasonal climatology of wind stress applied at the surface to study wind effect. The model inputs were constructed with a set of historical monitoring, field cruise and weather station data. The results of the

base run compare well with the observed data from a moored profiler located at one station in the southern Canal, even though the two sets have different frames of seasonality: long-term mean vs. real time, respectively. The model reproduced seasonal and vertical patterns of chlorophyll and DO compared to the fluorescence and DO from the profiler. Overall, however, model chlorophyll values are lower than those of the observed fluorescence near the surface, while model DO values show higher than those of the observed near the bottom. The results indicate the followings: The degree of hypoxic/anoxic condition at depth is more likely controlled by local eutrophication farther from the open boundary. Spring phytoplankton bloom is more likely to start at the regions of estuarine entrainment and/or weaker circulation. Wind can play a role to sustain a stronger spring bloom through enhanced vertical mixing and exchange circulation.

Green crab larval retention in Willapa Bay: An intensive Lagrangian modeling approach

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The European green crab (*Carcinus maenas*) is invasive on the U.S. West Coast. This study uses a high-resolution circulation model (implemented using GETM: General Estuarine Transport Model) to determine the likelihood that green crab larvae spawned in Willapa Bay, Washington could be retained by circulation and behavior long enough to reach maturity. Several behavioral scenarios were tested: larvae as passive particles, stage-dependent tidal-stream transport, and stage-dependent diel migration. For each scenario, 50 particles subject to this behavior were released in each grid cell of the model—54,000 in all—and tracked in three dimensions with both advection and vertical mixing included. Summary maps of likelihood of retention are presented for each case. This approach also yields a comprehensive, high-accuracy approximation to the full model (a “Lagrangian return map”) that runs in seconds in a web browser and allows non-specialists to reproduce our summary of transport pathways and retention patterns on their own.

Continental Shelf retention regions: indices and implications for biological processes in the Northeast Pacific Ocean

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Biological processes in the ocean are sensitive to small fluctuations in physical conditions operating at scales of a few meters through the mesoscale to scales of hundreds of kilometers (megascale). Biological production, recruitment, nearshore retention, growth capacity, transport and predator-prey interactions may all be affected by physical processes operating at these scales. We are interested in quantifying mesoscale structures, by developing indices of mesoscale structures using particle tracking methods. We will illustrate our approach using examples from 10 km resolution Northeast Pacific (NEP) and 3 km resolution California Current System (CCS) ROMS models. We examine indices derived by considering (1) advection only, and (2) advection and dispersion.

Match-mismatch between parturition and winter upwelling: identifying oceanographic conditions that favor larval survival of winter-parturition rockfishes

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Recruitment variability to populations of winter-spawning rockfish arises primarily as a consequence of highly variable survival through the larval stage. To identify conditions that favor survival of larval rockfishes, we developed simple models to relate variation in growth rates and survival of rockfish from parturition through the pelagic juvenile stage to environmental forcing of the coastal ocean, and compared the predictions from such models to the distribution of survivors' backcalculated birthdates derived from pelagic juvenile rockfishes collected off central California from 1983 to 2004. Results from this analysis indicate that wind-driven coastal upwelling, although often intermittent or of relatively low intensity, is a key determinant of whether larval rockfish released into the plankton encounter favorable conditions during the winter months. Given a relatively constant distribution of parturition dates, these results provide a further step towards forecasting recruitment to winter-parturition rockfishes on the basis of environmental observations.

Depleted Oxygen Levels in the Nearshore Waters of Northern Washington's Olympic Coast National Marine Sanctuary

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In 2004 the Olympic Coast National Marine Sanctuary (OCNMS) initiated dissolved oxygen (DO) monitoring to determine the timing, severity, and extent of depleted oxygen levels along the Olympic Coast. In 2004 and 2005, CTD-DO casts were taken off the RV Tatoosh biweekly between June and early October along 3 cross-shelf transects at Cape Alava, Teahwhit Head and Cape Elizabeth. In 2006 and 2007, OCNMS deployed moorings with continuous CT-DO recorders approximately 1 meter off the seafloor along two of these transects and continued casts along the third. No measured oxygen levels recorded in 2004 or 2005 could be characterized as hypoxic (<2mg/L). However, in 2004, near hypoxic conditions (<3mg/L) were routinely measured. In 2005, a few near hypoxic events were measured at >50m depths off Cape Elizabeth in May-July. In 2006, hypoxic conditions occurred in May and June as far north as Cape Alava and as far south as Cape Elizabeth. Hypoxic conditions were more extensive at Cape Elizabeth, extending into shallower and deeper waters and for longer durations. Data co-occurring with fish and crab mortality events reported by the Quinault Indian Nation in late July 2006 near Cape Elizabeth are supported by DO concentrations that got as low as 0.0245 mg/L between 16 and 30 July 2006. No observations of invertebrate or fish mortalities were reported by observers during the May, June, August, September or October 2006 hypoxic events. The data for 2007 is currently being collected and processed. From early May through 10 July 2007, hypoxic conditions occurred briefly at the end of June into early July at the Cape Elizabeth 42m station, and in early July at the Cape Elizabeth 15m depth station. Invertebrate (crab) mortalities have been reported to OCNMS as far south as Roosevelt Beach and as far north as Kalaloch Beach in late June 2007.

Climate and ecosystem pathways to hypoxia on the Oregon shelf

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Across upwelling systems, low oxygen zones can arise from elevated rates of export production and/or the shoreward transport of oxygen-poor subsurface water. While these fundamental biogeochemical and physical processes can strongly predispose upwelling shelves to the risk of hypoxia or anoxia, the occurrence of such oxygen-deficient zones can vary greatly across time and space. On the Oregon shelf, hypoxia has recently emerged as recurring summertime phenomenon with strong interannual variability in its extent and intensity. We used 9 years of dissolved oxygen (DO) and associated hydrographic measurements to examine the relative importance of shelf respiration and changes in sourcewater chemistry in controlling the risk and severity of hypoxia events. Cross-shelf transects between offshore shelf-break or outer-shelf stations and the inner-shelf revealed the respiratory loss of DO to hypoxic levels as water transited shoreward during the upwelling season. The effects of shelf respiration on hypoxia risks were strongly modulated by temporal variations in upwelling forcing and sourcewater DO content, and by mesoscale along-shore differences in water-column production and residence times. Relatively small changes in sourcewater DO content resulted in large shifts in observed risk of hypoxic or anoxic events on the inner-shelf. The importance of sourcewater variability further reflected effective wind-driven transport of offshore subsurface water to shallow depths on the inner-shelf. Major variations in sourcewater DO content corresponded to broad-scale climate forcing that affected water mass properties in the California Current and upwelling wind forcing. Because sourcewater DO content and the strength of shelf respiration can vary in concert, climate forcing can strongly accentuate the sensitivity of this upwelling system to the frequency and severity of hypoxia events. These results highlight the importance of hypoxia as a pathway of climate-mediated ecosystem change on productive upwelling shelves.

Decadal Variations in the California Current Upwelling Cells

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We investigate decadal variations in the three-dimensional structure of the California Current System (CCS) upwelling cells as a potential mechanism for explaining observed ecosystem changes after the mid-1970s. To this end, we track the origin of upwelled water masses using adjoint passive tracers during time periods corresponding to the positive and negative phase of the Pacific Decadal Oscillation (PDO) in a 55 year regional ocean model simulation of the CCS. Results show that in the PDO "cool" phase (pre mid-1970s), the upwelling cell is deeper while during the "warm" phase (post mid-1970s), the upwelling cell is shallower with more horizontal entrainment of surface waters from the north. These changes in the

coastal upwelling cell exhibit a latitudinal non- uniformity and may result in significant changes of the nutrient flux, which would have important impacts on the biological productivity of the coastal ocean.

Seasonal and event-scale processes contributing to hypoxia on the continental shelf of Washington

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During summer 2006, fish and crab mortalities associated with hypoxia (dissolved oxygen concentrations lower than 1.4 ml/l) appeared on the Pacific coast of Washington. Typically, upwelling of oxygen poor water onto the continental shelf leads to a seasonal oxygen minimum in summer in these regions. However, during late September 2006, near bottom concentrations on Washington's inner shelf, defined as total depth less than 30 m, fell below 0.5 ml/l, lower than any previous observations. This study aims to quantify 1) the frequency and spatial distribution of hypoxia over the historical record and 2) the relative contribution of physical and biological processes at seasonal and event time scales during recent years (2003 - 2006) on the Washington coast.

Recent hydrographic data from ships and fixed moorings resolves a wide range of spatial and temporal scales, allowing for estimation of physical and biological processes during hypoxic events. For the years 2003-2006, shipboard surveys reveal large areas of hypoxia over the Washington shelf during summers 2005 and 2006. Results from intensive shipboard sampling throughout summer 2005 illustrate the seasonal evolution of dissolved oxygen concentrations over the continental shelf during a year when local upwelling winds were delayed. In addition, during summers 2005 and 2006, moored sensors deployed near the inner shelf provide time series of temperature, salinity, near surface chlorophyll and near bottom dissolved oxygen. Current meter measurements are used to compute time series of advective dissolved oxygen flux and to estimate the advective component of temporal changes throughout the water column during hydrographic surveys. These time series complement changes in water masses as inferred from shipboard profiles, showing how processes differ between years, and between locations on the continental shelf. Furthermore, dissolved oxygen samples from historical archives (1949 - 1983) show that concentrations have frequently reached hypoxic levels in this region throughout the period of record, including on the inner shelf.

State of the Ocean Reporting

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Pacific coast oceanographers and fisheries scientists have reported annually on ocean conditions for the past eight years, concentrating mainly on Canadian waters. These reports are based on individual contributions from 25 to 35 scientists on topics such as changes in Gulf of Alaska winds, temperatures and coastal currents, timing of zooplankton blooms, success of seabird rearing, numbers of juvenile salmon and other species, and presence of new species such as Humboldt squid. In most cases the recent observations are compared with similar observations over many years, enabling interpretation of changes among many species and indicators. This presentation will focus on some of the significant changes in the past eight years, and will ask viewers to offer suggestions for improvement and to comment on possible expansion of these reports to other regions of the northeast Pacific, especially to ocean basins that span international borders. Reports can be viewed at this Internet site: http://sci.info.pac.dfo.ca/PSARC/OSR's/OSR.htm

Extracting Power from the Tides

Patrick Cummins, Institute of Ocean Sciences
Chris Garrett, University of Victoria

There are increasing pressures to develop carbon neutral sources of energy. For the ocean sector in British Columbia this will may entail the installation of turbine fences in energetic tidal streams. For example, a demonstration project consisting of a single turbine was deployed in September 2006, near the Race Rocks Ecological Reserve in Juan de Fuca Strait. Other projects of this sort are being contemplated for the Salish Sea. The first step in attempting to harness power from the tides is to develop an assessment of the available power. In this talk, I will discuss recent theoretical advances and numerical studies on assessing the power potential of tide currents in channels, with application to the coastal waters of British Columbia.

Short-term dynamics of a harmful algal bloom in Monterey Bay

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NOAA has considered flying an ocean color imager on the next series of GOES satellites to address its needs for data to assess the state of and manage coastal ecosystems and fisheries. The Coastal Ocean Applications and Science Team (COAST) was formed by NOAA to assess the need and utility of measuring coastal ocean color from a geostationary satellite. The first COAST experiment was conducted in Monterey Bay September 3-15, 2006. The goal of this experiment was to collect data that exceeds all possible requirements for a geostationary ocean color imager so that the data may be binned spatially or spectrally to create a simulated data set for any possible set of requirements. For the Monterey Bay experiment we used the Florida Environmental Research Institute's (FERI) Spectroscopic Aerial Mapper with On-board Navigation (SAMSON). SAMSON collects a full hyperspectral dataset covering 256 bands in the VNIR (3.5 nm resolution over 380 to 970 nm range) at 75 frames per second. It is designed with a Signal-to-Noise Ratio (SNR), stability, dynamic range, and calibration sufficient for dark target spectroscopy. Monterey Bay was sampled at 5 m Ground Sample Distance (GSD) as frequently as every 30 minutes. At the time of the COAST experiment there was a large Harmful Algal Bloom in the North-

East corner of Monterey Bay. Here we use the SAMSON data to describe the short term dynamics of that bloom. Driven by tides and currents the bloom was seen to move kilometers on a time scale of hours. There is also evidence of vertical migration with the bloom concentrating on the surface near noon.

North Pacific gyre-scale oscillation: mechanisms of ocean's physical-biological response to climate forcing

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Understanding past climate fluctuations in the North Pacific is critical to predicting the ocean's physical-biological response to 21st century climate change. We find that previously unexplained decadal variations of salinity and nutrients in the Southern California Current reflect an oscillation in the North Pacific gyre-scale circulation (NPGO), which is independent of the Pacific Decadal Oscillation (PDO). Along the California coast, changes in alongshore wind stresses associated with the NPGO, rather than PDO, cause low-frequency variations in nutrient upwelling and surface chlorophyll-a. The NPGO and PDO both exhibit sharp transitions associated with major North Pacific ecosystem shifts, suggesting that both modes contribute to decadal variations in zooplankton and fish populations. Therefore observed amplifications of the NPGO decadal variance during global warming may be critical to accurate ecosystem forecasts.

Circulation in Southern California Bight

C. Dong (IGPP, UCLA), M. Blaas, A. Hall, M. Hughes, J. McWilliams, Y. Chao and K. Stolzenbach

The Nested Regional Ocean Model System (ROMS/UCLA) is applied to study the equilibrium structure and dynamics of Southern California Bight (SCB) Current System. The model is configured to two-level nesting grids with the parent grid (20km) covering the whole US west coast and child grid (6.0m) covering the southern California Bight. Its external forcing is by momentum, heat, freshwater flux at the surface and adaptive nudging to gyre-scale fields at the boundaries. The momentum flux is 1996-2003 three-hourly nested MM5 wind (6km for the finest grid in the SCB). The model starts from an equilibrium state, which is obtained from a multiple-year cyclic run, and then is intergrated from 1996 to 2003. The eight-year solution shows realistic mean and seasonal mean circulation,interannual variability and the mesoscale structure of the circulation in SCB, comparable with with CalCOFI data and satellite-observed SST and SSH data. The strong possitive wind curl in the Santa Barbara Channel and the south of the Channel not only intentifies the local upwelling but also might introduce a domain scale pressure gradient which plays an important role in the SCB circulation. The relationships among the surface wind stress, wind stress curl, and SCB circulation and other physical variables are analyzed. The interaction between wind-driven circulation, complicated SCB bottom topography is studied. The mesoscale eddy activies and energy balance is discussed.

Insights into Larval Dispersal and Recruitment along the Central California Coast from a High-Resolution ROMS Model

Drake, Patrick T. and C. A. Edwards, UCSC, Ocean Sciences Dept.

The supply and transport of marine larvae are important processes influencing the success, connectivity and eventual fate of many coastal populations. To better understand these processes, we used a high-resolution numerical model of the central California coast to simulate the trajectories of thousands of passive larvae released from the inner shelf during the 2002 upwelling season. The fate of the larvae was found to be dramatically dependent on their depth distribution in the near-shore water column. Larvae released near-bottom on the inner shelf and constrained to follow a constant depth had a relatively high probability of remaining near-shore and eventually recruiting to nearby habitats. In contrast, larvae released near-surface were systematically swept offshore. The difference can be understood in terms of the classic two-dimensional upwelling picture, with offshore flow at the surface and onshore flow at depth. The small fraction of near-surface larvae that returned to the coast recruited almost exclusively to Monterey Bay, regardless of origin. Larvae free to be advected vertically recruited in even smaller numbers than their constant-depth counterparts, and also preferentially to Monterey Bay and regions to its immediate north and south. Thus Monterey Bay is found to be a key retention zone and larval sink for central California. We will present individual trajectories as well as statistics quantifying the spatial connectivity and recruitment variability along the coast.

Factors affecting the distribution of *Beggiatoa spp.* bacterial mats in Hood Canal, WA

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Bacterial mats were observed during the summer of 2006 on the surface of sediments in Lynch Cove, Hood Canal, an area that has been described as a “dead zone” due to persistence of low oxygen levels. The objectives of this study were to 1) take sediment samples to identify the bacteria making up the mats, 2) use underwater videography to map the distribution and abundance of the mats, and 3) examine the sediment and water conditions influencing their distribution and abundance in space and time. The mats were composed of Beggiatoa spp., a type of sulfide-oxidizing bacterium. Video surveys indicated that the mats occurred at water depths of 10-25 m and covered an area of 8.4 km^2 in the fall of 2006. The spatial coverage of the bacterial mats was highly reduced to small patches during the subsequent winter but began to increase in size the following spring (1 km^2 in June 2007). The sediments in the area of the mats had a flocculent surface layer of organic material (5 cm depth), which had low redox levels (<-200 mV), indicative of high sulfide and low oxygen conditions. The prolonged seasonal occurrence of plankton blooms in these areas likely contributes to the high levels of organic material in the bottom substrate (up to 15% total volatile solids), where decomposition results in high sediment sulfide levels. Continued monitoring is being conducted to determine the environmental factors influencing the distribution and abundance of the bacterial mats, and whether they are having an impact on the local ecosystem through the production of ammonium.

Evidence for Upwelling of Corrosive 'Ocean Acidified' Water onto the Continental Shelf

Richard A. Feely, Christopher L. Sabine, J. Martin Hernandez-Ayon, Debby Ianson, and Burke Hales

We observed 'ocean acidified' seawater that is corrosive to calcifying organisms upwelling onto the continental shelf of western North America. The ocean uptake of anthropogenic CO2 has shoaled the aragonite saturation horizon so that seasonal upwelling exposes significant portions of the shelf to waters that are undersaturated with respect to aragonite. The corrosive waters reached mid-shelf depths of approximately 40-120 m along most transect lines, and reached all the way to the surface on two transects off northern California. While little is known about how these seasonal processes might impact the development of calcifying organisms or the finfish that populate this region, results from laboratory studies show that these organisms are sensitive to these changes and suggest that further research is needed.

Tidally-forced exchange between Elkhorn Slough and Monterey Bay

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John Ryan and Erich Rienecker, Monterey Bay Aquarium Research Institute
Laurence Breaker and Nicholas Welschmeyer, Moss Landing Marine Laboratories

The Elkhorn Slough, a tidally-forced estuary, serves as a significant year-round link between Monterey Bay and the surrounding coastal watersheds. The plume that exits the slough can directly influence coastal ocean biogeochemistry, sediment budgets and nearshore ecology. There is, however, limited knowledge of this land-sea exchange, due mainly to its ephemeral and dynamic nature. In this study, we characterize the physical dynamics, biological and chemical content of the slough discharge plume. The plume was sampled in three dimensions, at various tidal stages, for sediment, temperature, salinity, nitrates, and surface flow patterns using several in-situ, remote and autonomous instruments. Water samples were analyzed for pigments and fatty acids. Results reveal a ten meter deep, jet-like, sediment laden plume extending one kilometer offshore at low tide, which becomes entrained in the prevailing nearshore circulation. Nitrates and water temperatures, in the plume were 25 times greater and 2.3C warmer than surrounding bay waters, respectively. Plume samples show distinct populations of phytoplankton with high concentrations of bacterial fatty acids. This talk will address the content and transport of the Elkhorn Slough plume and its influence on the neashore ecology of Monterey Bay.

The Columbia River plume influences vertical structure in biological communities

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The microplankton communities in the coastal waters off Washington and Oregon are composed in large part of a predictable mixture of recurring species and taxonomic groups. The exact composition of the communities varies in time and space due to both biological and physical forces. Occasionally, rare or

new species will become dominant. For example, Fibrocapsa sp. in early summer 2005 and Cochlodinium sp. in late summer 2006, both harmful algal species, were abundant on the southern Washington coast. In addition to horizontal patchiness, there is often vertical structure in community composition. This vertical structure in part is a reflection of physical structure, for example due to the meeting of fresher, warmer Columbia River Plume water with cooler and saltier oceanic waters at the mouth of the river. But there is more at work than physical processes, as evidenced by several vertical profiles where non-motile diatoms show a different vertical distribution than motile dinoflagellates. In this study we attempt to tease out the biological factors, such as relationships between microzooplankton grazers and different phytoplankton species, which influence overall community patterns, in concert with the physical effects of the Columbia River Plume (mixing, turbidity, nutrient-input) that inhibit or augment these biological interactions.

Coastal Upwelling and Climate Variability in California

Marisol Garcia-Reyes and John Largier, University of California at Davis

The climatology of upwelling forcing and response is obtained analyzing buoy data (wind, sea surface temperature and sea level pressure) from the coast of California, characterizing its seasonal cycle through harmonic analysis. Anomalies from this seasonal cycle are studied to identify the relation with known climate cycles as El Niño and its influence for different latitudes along California.

Although El Niño is the most prominent event influencing coastal central California, resulting in low upwelling and low productivity, it explain less than 50% of the cases of low upwelling. other cycles and factors are important when accounting for the anomalies; in this work these other factors are also revised.

Anomalies include deviations in magnitude but also in timing of ocurrence, as they might be important for biological productivity. When available, chlorophyll concentration data is be used to asses the primary productivity and therefore related to climate cycles.

Delivery and Quality Assurance of Short-Term Trajectory Forecasts from HF Radar Observations

Newell Garfield, San Francisco State University
Jeffrey D. Paduan, Naval Postgraduate School
Carter Ohlmann, UC Santa Barbara

The Coastal Ocean Currents Monitoring Program is developing, assessing, and documenting the use of real-time ocean surface current maps from high frequency (HF) radar installations. Specifically, we are evaluating the use of these data in support of oil spill response activities. As a case study, we are documenting our experiences integrating real-time HF radar data products within the NOAA Safe Seas 2006 oil spill exercise offshore of San Francisco in August. Beyond that, we are quantifying the performance of the short term (24-48 hour) surface trajectory prediction method that was developed for the Safe Seas 2006 exercise by comparing observed and predicted currents under a wide range of environmental conditions. To aid that assessment, we will conduct a multi-day, multi-deployment field experiment using an array of GPS-tracked drifters. Finally, we are documenting our results in the form of a set of recommended procedures for the integration of HF radar-derived products into real-time spill response protocols.

Effect of the river discharge and spring/neap cycling on the salinity of the Fraser River plume

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We utilize an instrumented ferry to study the effect of varying river discharge and spring/neap cycling on the mean salinity of a buoyant river plume. The high temporal resolution and length of the data record allow us to study the plume from hourly to annual scales. Our test piece is the Fraser River plume, located in the Strait of Georgia, a semi-enclosed sea lying between Vancouver Island and the BC mainland. The Fraser River displays highly seasonal flows, dominated by a summer freshet and winter rainfall events. Mean summer flows exceed winter flows by a factor of 10. River discharge of water is strongly modulated by the tide, which range from roughly 2 meters during neap tides to 4.5 meters during spring tides.

Our results show that the plume salinity is inversely proportional the river discharge, and that it responds to fluctuations of discharge on timescales of a day. Spectral analysis of plume salinity reveals a significant peak in energy at 14 days, suggesting that spring/neap cycling is important. Previous work in the Fraser estuary has shown that mixing is proportional to the strength of the ebb, and thus the structure of the salt wedge and the degree of mixing should be sensitive to spring/neap variations. Coherence analysis shows that the relationship between plume salinity and the spring/neap cycle holds only during summer, when the Fraser discharge is high. One hypothesis for this observation is based on the river-flow modulated position of the salt-wedge.

A census of mesoscale eddies in the Gulf of Alaska

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In the Gulf of Alaska, mesoscale eddies play an important role in promoting off-shelf transport of heat, nutrients and biological populations into the HNLC water of the northeast Pacific. However, the spatial and temporal distribution of these eddies and their characteristics remains largely unkown. Here we apply an objective method for identifying and tracking eddies to fifteen years (1993-2006) of satellite Sea Level Anomaly data, allowing the spatial and temporal variability in eddy activity to be defined. Seasonal maps of eddy density show fewest eddies in winter, maximum in spring/summer. The Haida and Yakutat eddy corridors are clearly defined, as is an 'eddy desert' in the southwest of the basin, where the probability of an eddy being observed is zero. Maps of eddy trajectories for each year show substantial interannual variability in number and propagation paths. Interannual variability in eddy characteristics (number, magnitude, propagation speed, diameter and duration) is assessed for the basin as a whole, and separately for the Haida and Yakutat regions. In general, Yakutat eddies are more numerous, larger and more intense than Haida eddies. Periods of increased eddy activity do not necessarily correspond to El Nino events, but are associated with strong downwelling wind conditions. Some conjectures on the impact of eddies on chlorophyll concentration will also be discussed.

A Tale of Three Interacting River Plumes in the Northern California Current

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The continental shelf in the northern California Current system is impacted by two sources of freshwater flux: the Strait of Juan de Fuca and the Columbia River. The plume from the Columbia is frequently bi-directional from spring to fall, with one branch southwest of the river mouth, another north of the river mouth. In this paper we describe a sequence of events in June 2006 that resulted in the interaction of all three of these buoyant plumes. The interaction occurred when a strong spring storm period was followed by persistent and strong upwelling. In this case, the northward Columbia plume that developed under the downwelling wind conditions extended along the Washington coast all the way to the strait of Juan de Fuca and into the strait, as confirmed by both satellite images and moored sensor data off the Washington coast and in the strait. The plume water subsequently folded around Juan de Fuca strait water in the cyclonic eddy that generally occurs in this region. Drifters deployed in the Columbia plume near its origin tracked plume water northward all along the coast from near the mouth to the Strait, then reversed at the onset of upwelling favorable winds and tracked the plume water southward past the river mouth once again. At this point "aged" plume water from the Washington coast was observed to mix with the newly emerging southwest tending plume on the Oregon coast, forming a distinctive "sock" shaped Columbia plume inshore of the Juan de Fuca "plume" flowing southward along the outer shelf and upper slope.

Analysis of coastal circulation in the California Current System from a large array of HF Radars along the coast of northern California

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As part of the Coastal Ocean Currents Mapping Program (COCMP), a large array of HF Radar surface current mapping devices has recently been installed along the coast of northern California. These instruments provide hourly surface current measurements from the coast to beyond the shelf edge along over 350 km of coastline. Here we present an analysis of the first year of continuous data from the northern California array, with an emphasis on mesoscale patterns of tidal and subtidal current variability. Our analysis includes a detailed assessment of cross-shore and alongshore gradients in currents and in the response to wind forcing. We also examine a period of intense surface flows during the early part of the upwelling season, suggesting the initial development of the coastal upwelling jet and/or the intrusion of mesoscale features into the study region. We present a Lagrangian analysis of spatial connectivity in this

region and relate this to satellite and in situ oceanographic observations, as well as to patterns of primary productivity and larval transport in the area.

Interannual variability in mesoscale circulation and cross-shelf advection of zooplankton

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In coastal upwelling ecosystems, wind-driven Ekman transport has traditionally been considered the dominant mechanism of cross-shelf transport during upwelling. However, mesoscale circulation features such as ‘squirts,’ eddies, and filaments of the upwelling jet are now recognized as potentially much more important contributors. As part of the U.S. GLOBEC Northeast Pacific Program, we are studying how variability in mesoscale circulation affects zooplankton biomass and distribution in the northern California Current System (CCS). We use satellite altimetry to study interannual variability in circulation; we use zooplankton collected off Oregon and northern California during summers 1996-2005 to study zooplankton variability. In this presentation, we develop and compare indices of both the annual energy in mesoscale circulation and zooplankton biomass in the northern CCS. Our results indicate that there is strong interannual variability in the timing and amplitude of the peak in both mesoscale circulation and zooplankton biomass and that the amplitudes of the two do not co-vary. The lack of co-variance between the two processes implies that there may be large interannual variability in the transport of biomass across the slope to the deep sea. This variability will have implications for the productivity and ecosystem structure of the deep, offshore regions of the CCS.

Formation and evolution of the Columbia River plume front

Levi Kilcher, Jonathan Nash and Jim Moum, OSU

The Columbia River emerges onto the Oregon-Washington shelf in tidal pulses. Highly resolved measurements of velocity, density and turbulence are used to describe the evolution of the plume front. Over the shallow (<25m) near-field region, the structure of the release event is highly complex. Multiple fronts of decreasing density are released serially at the Columbia River bar. Due to increasing stratification each front propagates faster than the one before it so that, within the near-field, multiple fronts converge to form one. This front has a very sharp leading edge, displacing isopycnals over 25 m in its leading bulge. Behind the front, the plume is (10m) deep. Shipboard X-band radar tracks the the initially quarter-circular - river mouth attached to north, trailing off to south - horizontal structure of the front. As this front propagates offshore it spreads radially, from a nearly constant origin, and thins to less than a few meters. In spite of this spreading and thinning, the front continues to propagate at a nearly constant speed (O(1 m/s)) for nearly 20 km. This result, along with frontal propagation, plume lift-off, and front convergence are interpreted in terms of theoretical internal wave speeds.

Long-term surface chlorophyll variation and nutrient supply in the Southern California Bight

Hey-Jin Kim, Arthur J. Miller, and John McGowan

Surface chlorophyll measured at the Scripps Pier in the Southern California Bight (SCB) for eighteen years (1983 – 2000) reveals that the spring bloom occurs with irregular timing and intensity each year, unlike sea surface temperature (SST), which is dominated by a regular seasonal cycle. In the 1990's, the spring blooms occur earlier in the year and with larger amplitude compared to those of the 1980's. The annual mean Pier chlorophyll consequently exibits an increasing trend over these two decades, with no concomitant trend evident in the Pier SST. Chlorophyll magnitudes at the Pier, which in in the narrow coastal band on the continental shelf, is about one or two order greater than offshore chlorophyll observed by CalCOFI. The seasonal and interannual variation of the Pier chlorophyll is correlated with changes in the upper ocean nutrient content observed in the nearby CalCOFI stations. The nutrient supply from the deeper waters beyond the continental shelf must therefore play an important role for the high chlorophyll on the shelf in the coastal band where the Pier is positioned.

Numerical simulation of the separation of a coastal upwelling jet from a submarine bank

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Separation of a coastal upwelling jet from a submarine bank is explored in a primitive-equation numerical simulation (ROMS). The numerical simulations are of wind-driven coastal ocean circulation along the Oregon coast, in which 3 different spatially uniform wind stresses are applied as forcing for 50 days: constant southward wind, 5-day periodic wind with southward mean, and wind time series from mooring data from the early part of the upwelling season of 2001. All simulations exhibit flow separation defined by the occurrence of maximum speed offshore of the 200-m isobath for more than 5 continuous days at Latitude 43.51 N, just south of the Heceta Bank topographic feature. The transition to the separated flow is associated with the formation of cold-core eddies, which travel two major paths, one following topographic contours and one crossing them. The dynamics of these eddies and their role in jet separation are analyzed in these simulations and compared to available observations over Heceta Bank.

Time-varying across-shelf Ekman transport and vertical eddy viscosity on the inner-shelf

Anthony Kirincich and John A. Barth
COAS, Oregon State University

We investigated the event-scale variability of across-shelf transport using observations made in 15 m of water on the central Oregon inner-shelf. Hydrographic and velocity observations from the study area, located in an area of intermittently upwelling-favorable winds and significant density stratification that is

sheltered from the larger regional circulation, show rapid across-shelf movement of water masses and variable residence times. Conditions change from weak stratification and strong northward currents during downwelling favorable winds to stronger stratification and southward currents in thermal wind balance with density gradients during upwelling favorable winds over event timescales of 2-7 days. To better understand the time variability of across-shelf exchange, an inverse calculation is used to estimate eddy viscosity and vertical turbulent diffusion of momentum from profiles of velocity and wind forcing. Depth-averaged estimated eddy viscosity varied over a large dynamic range, averaging 0.8 x 10^{-3} m^2 s^{-1} during upwelling winds and 2.1 x 10^{-3} m^2 s^{-1} during downwelling winds. The fraction of full Ekman transport present in the surface layer, a measure of the efficiency of across-shelf exchange at this water depth, was a strong function of the eddy viscosity. Transport fractions ranged from 80-100% during times of rapidly changing stratification and forcing, and low eddy viscosity, to 10-20% during times of weak stratification, strong forcing, and high eddy viscosity. The difference in eddy viscosities between upwelling and downwelling led to varying across-shelf exchange efficiencies and, potentially, increased net upwelling over time. These results quantify the variability of across-shelf transport efficiency and have significant implications for ecological processes (e.g., larval transport) in the inner-shelf.

Models of passive dispersal inform reserve design in the Strait of Juan de Fuca

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Larval dispersal can influence the success of spatially-explicit management strategies for living marine resources. To explore this relationship, we characterized patterns of passive dispersal in the eastern basin of the Strait of Juan de Fuca, Washington and interpreted the results in the context of marine reserve network design and connectivity. We used the surface current model GNOME to describe the dispersal of passive particles released from 16 sites over periods of 4 and 30 d in the spring of three consecutive years. We then used this approximation to evaluate the design and potential connectivity between existing marine reserves and protected areas in the eastern basin. Release site location accounted for the greatest amount of variation in dispersal distance, exceeding variation due to year, month, or tidal phase. After 30 d, release sites could be assigned to one of three groups defined by distance and variance. One group was characterized by short distance, low variance dispersal; a second was characterized by long distance, low variance dispersal; and a third was characterized by intermediate to long distance, high variance dispersal. We suggest that the high-variance condition is likely to make the greatest contribution to regional network connectivity and population persistence in this system. Consequently, estimates of variance in dispersal distance are important to consider in the development of spatially-explicit management strategies.

The influence of Columbia River on the upwelling dynamics off Oregon

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Regional Ocean Modeling System (ROMS), based on the nonlinear hydrostatic primitive equations, has been utilized to study the possible effects of the Columbia River (CR) plume on the dynamics of summer upwelling over the Oregon shelf, south of the river mouth. The model has 3-km resolution in horizontal and 40 terrain-following layers in vertical. The model domain spans between 41N and 47N in the alongshore direction, and 300 km in the offshore direction. The study period is summer 2001, for which extensive observations from the COAST field program are available to verify the model accuracy. Atmospheric forcing comes from COAMPS, and open boundary conditions from the 9-km resolution NCOM-CCS (J. Kindle); we also include barotropic tidal forcing (8 dominant harmonics) at the open boundaries. The effects of CR are analyzed by comparing model simulations with and without CR. During the study period, predominantly southward winds force the southward shelf currents and upwelling. The fresher water originally discharged from CR is transported to the Oregon shelf. The presence of the plume off Oregon is most notable in May-June, when both southward winds and the river discharge are relatively larger, then in July-August. During a strong upwelling event (days 167-169, 2001), we provide analysis of the alongshore currents, vertical shear in horizontal velocities, stratification, and turbulent kinetic energy (TKE) in the cross-shore sections at 46N (approximately 30 km to the south of the river mouth) and 45N (140 km to the south of the river mouth). The depth of the surface boundary layer (SBL) and the level of TKE in that layer are the determined by the competition of two mechanisms. First, enhanced vertical stratification tends to suppress turbulence and decrease the depth of the SBL. Second, the horizontal gradient of density introduced by the plume causes the increased vertical shear in the alongshore velocity (by thermal wind balance), which enhances turbulent production. At 46N, the SBL can be 3 times thinner in the area of the plume than at the offshore side of the plume. Since the cross-shore Ekman transport is approximately the same in the plume and away from it, the cross-shore surface currents associated with upwelling can be 3 times as strong on the surface of the plume, creating convergence and downwelling in the SBL at the offshore edge of the plume. To confirm this, we run the model in an idealized alongshore-uniform configuration and compute streamfunctions of cross-shore flows. These analyses also show that if the plume is attached to the coast, upwelling is concentrated closer to the coast than in the case without the fresh water layer. In the fully three-dimensional case, at 45N, the CR plume is more diffused in the vertical than at 45N. Here the depth of the SBL is only slightly smaller as an effect of the plume. However, since the vertical shear is increased, the TKE is larger throughout the layer.

Internal set-up and sub-tidal circulation driven by a shoaling and breaking internal tide

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We use a fully-nonlinear, non-hydrostatic, rotating, two-dimensional (cross-shelf/vertical) numerical model to study on-shore propagating, high-frequency internal waves on a linearly-shoaling continental shelf. High-frequency internal waves and internal undular bores are frequently observed to propagate onshore on continental shelves. For example, in southern California, on the inner shelf off of Mission Beach (water depths ranging from 10 to 30 m and within three kilometers from the coast), packets of large amplitude (pycnocline displacements ~ 1/3 the water depth), high-frequency internal waves are observed to propagate onshore roughly once per semidiurnal period, without being reflected back offshore. These waves ride on a pycnocline that is tilted upward toward the coast. Above wave troughs, near-surface onshore current speeds are close to the wave propagation speed and the waves have been observed to contribute to the onshore transport of barnacle larvae with upward-swimming capability. These observationsistent with the waves observed off of southern California. Preliminary model runs show that waves significantly influence the sub-tidal circulation and density field on the inner shelf. For example, when a Smagorinsky sub-grid scale closure is used, the dominant sub-tidal cross-shore momentum balance is between nonlinear terms (internal radiation stress divergences), cross-shore baroclinic pressure gradients and the Coriolis term. The internal waves drive a sub-tidal cross-shore and along-shore circulation, both with amplitudes of about 5 cm/s.

Patterns in phytoplankton growth and microzooplankton grazing on the Washington and Oregon coasts

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To better understand the patterns and controls of phytoplankton chlorophyll, community composition and production in the northern California Current system off Washington and Oregon (~45°- 48°N), we determined phytoplankton carbon to chlorophyll ratios and measured over 160 size-fractionated phytoplankton in situ growth rates and microzooplankton grazing rates on ten cruises in early and late summer 2003-2006. Carbon to chlorophyll ratios were found to vary over an order of magnitude (~10-160), indicating that chlorophyll should not be considered a simple or accurate indicator of phytoplankton biomass in this hydrographically and biologically complex region. Phytoplankton growth rates ranged from <0 to 2.0 d^{-1}, and were hyperbolically related to nitrate concentration. Microzooplankton grazing largely balanced the growth of small phytoplankton (<5 m), and consumed most of the daily small phytoplankton production. Although microzooplankton did not typically consume all the large (>5 m) phytoplankton production, microzooplankton consumption was substantial (average = 47%), and capable of restricting phytoplankton accumulation about one-third of the time. The lowest microzooplankton biomass and grazing and the highest phytoplankton growth rates were found in lower salinity waters (the Columbia River Plume, the Juan de Fuca eddy region), but this was not a consistent observation due to the highly variable nutrient supply and sources in different years, seasons and upwelling regimes.

Influences of the Juan de Fuca Eddy on circulation, nutrients and HABs in the northern California Current System

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We present results from three years of field studies in the Juan de Fuca eddy, a highly productive region at the northern end of the California Current. The presence of the Juan de Fuca eddy causes large inputs of dissolved nutrients to the region through two mechanisms: doming of California Undercurrent water within the eddy and enhanced cross-shelf advection of Juan de Fuca Strait outflow. The combination of

these sources results in a persistent, broad (100 km offshore) region of elevated nutrients on the northern Washington shelf. We examine variability in the structure and circulation of the eddy using both circulation models and water mass analyses and illustrate some regional impacts of this variability. Results demonstrate that the eddy increases in spatial extent from early to late summer as the proportion of California Undercurrent source water grows. Typical near-surface eddy radii range from ~15 km early in the summer to ~30 km in September and increase with depth. Below 100 m, eddy radii are ~40 km. Fresher water, associated with the estuarine outflow from the Juan de Fuca Strait, is advected around the eddy margin. During southward wind conditions, the combination of cyclonic geostrophic flow and wind-driven currents in the surface Ekman layer cause the eddy to be “leaky” on its southern perimeter. Eddy surface circulation becomes more retentive (up to ~32 days observed) during periods of weak winds or frequent northward reversals. Recent studies have also indicated that the eddy is an initiation site for toxic Pseudo-nitzschia blooms which negatively impact key Washington state benthic fisheries, notably, recreationally harvested razor clams (Siliqua Patula). The retentive circulation patterns combined with persistent nutrient supply may favor the development of toxigenic diatom blooms of Pseudo-nitzschia species in this region.

Chlorophyll distribution in a temperate estuary: the Strait of Georgia and Juan de Fuca Strait

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Data collected during 6 years of seasonal surveys are used to map the spatial distribution of phytoplankton biomass within the estuarine waters of the Strait of Georgia and Juan de Fuca Strait. Seasonal changes in the chlorophyll distribution are presented as well as a discussion of the determining characteristics of the water column such as density stratification, nutrient concentration and light availability. Both the horizontal and vertical distribution of chlorophyll are found to be closely linked with the near surface density stratification. A sub-surface peak in mean chlorophyll distribution is observed around 10 m depth over most of the Strait of Georgia, corresponding to the depth of maximum value of the Brunt-Väisälä frequency, an indicator of water column stability. The maximum amount of chlorophyll is found in the northern Strait of Georgia where the moderate near-surface stratification appears to be the most favourable for phytoplankton growth. Elevated near-surface chlorophyll concentrations appear to be linked to the seasonal development of increased density stratification near the surface. Accordingly, the seasonal cycle of the chlorophyll distribution is strongly dominated by the large values associated with the spring bloom in the Strait of Georgia. The depth of the euphotic zone is estimated along the thalweg of the estuary from transmissometer profiles. During the growing season, the mean depth of the euphotic zone is shown to vary from a minimum of 20 m in spring, near the Fraser River mouth, to a fall maximum of about 28 m in the northern Strait of Georgia. Mean nutrient concentrations within the euphotic zone are presented and indicate that, in general, nutrients are abundant in this coastal system. The one exception is for the Strait of Georgia in summer, where low nitrate concentration values near the surface are potentially limiting for phytoplankton growth.

Jet-like structures in the eastern North Pacific

Nikolai Maximenko and Oleg Melnichenko (IPRC/SOEST, UH)

Peter Niiler (SIO, UCSD)

Persistent quasi-zonal jet-like structures have been recently detected in the high-resolution multi-year mean dynamic ocean topography calculated using the data of drifters, satellite altimetry, GRACE and NCEP/NCAR re-analysis wind. The structures are distinct in many regions including the eastern North Pacific between Hawaii and California selected for this study because of the abundance of in situ observations. We confirm the realism of the structures using drifter statistics extending beyond the satellite years and also with the historical set of XBT profiles stored in the World Ocean Data Base 2001. The 'jets' have the wavelength of about 350 km and extend more than 1400 km off the California coast. They are tilted in the northeast-southwest direction at 15 degrees to the parallel. Below the sea surface, the 'jets' are best seen in the depth of isotherms. The thermal signal associated with the 'jets' is coherent vertically at least from below the winter mixed layer to 400m depth and also well correlated with the shape of the expression in the sea level. We discuss connection of the 'jets' to quasi-stationary meanders of the California Current and their dynamics in the open ocean, where they seem to be the stationary Rossby waves standing in the meridional geostrophic flow of the Subtropical Gyre, a kind of a wake from the remote disturbance in the east. This hypothesis is further strengthened by comparing between different regions with somewhat similar 'jets', i.e, South Pacific, Hawaiian Lee Countercurrent and Azores Current.

Observations and model results of Columbia River plume entrainment

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An analysis of surface drifter data leading to estimates of entrainment into the tidally-pulsed Columbia River plume is presented. Drifter data were taken as part of the River Influences on Shelf Ecosystems (RISE) project with field seasons spanning spring/summer 2004 – 2006. Drifters were deployed across the river mouth on ebb tides and were outfitted with conductivity and temperature sensors allowing for salinity estimates along their paths. Columbia River water exits the estuary mouth during ebb tides forming a pulsed plume. Near the mouth, ebbing surface water with velocities of 2-3 m s-1 and salinities of 10-12 are routinely observed. As plume water transits offshore it expands laterally and entrains underlying ambient fluid with salinity ≥ 26. This process is described as the outflowing water evolves for ~ 20 km seaward of the river mouth. Entrainment is largest near the river mouth at O(10-3 m s-1) and decreases seaward, but remains significant between the river mouth and the ocean-plume frontal boundary. Beyond ~ 20 km our entrainment analysis breaks down as the surface drifters begin a return loop shoreward, in a bulge-like circulation. For comparison, results from realistic 3D simulations with numerical drifters seeded in a manner similar to field deployments are also discussed. Plume momentum budgets are examined to relate observed and modeled mixing to the dynamics.

Boundary layer intrusions from the outer shelf: Intermediate Nepheloid Layers around Monterey Bay

Erika McPhee-Shaw (MLML), John Ryan (MBARI), Lauren Sassoubre (MLML), and Steve Ramp (NPS)

We present a preliminary descriptive investigation of the spatial characteristics and temporal variability of intermediate nepheloid layers (INLs) detaching from the outer shelf around Monterey Bay and the Central California coast. Layers of elevated suspended particulates spread along-isopycnal away from the shelf at depths of 50 to 100 meters, and are frequently observed by MBARI repeat autonomous underwater vehicle (AUV) surveys. Water sample analysis reveals that the layers are characterized by lower percent organic carbon than waters above and below. This and other evidence substantiate the assumption that the particulates are lithogenic material originating at the shelf mud belt rather than accumulations of biogenic particles delivered from surface blooms. Boundary layer material spreads several kilometers offshore from its source detachment region, and we are interested in the fate of this material as it is dispersed to these scales. Time series from mid-canyon and outer-shelf moorings, and satellite and HF-radar fields, when available, are used to assess whether mesoscale dynamics play a role in either (i) setting the conditions leading to detachment, or (ii) determining the trajectory of suspended particulates following initial INL formation.

Moored observations of tidal and subtidal internal motions in Hood Canal, WA

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Mixing is postulated to be of key importance to modulating anoxic conditions in Hood Canal, an enclosed reach of Puget Sound, WA; yet, its distribution and mechanisms are relatively unknown. Recent observations with a moored profiler and moored ADCP's reveal two types of wave motions previously undiscovered in Hood Canal, each of which may impact the distribution of mixing and therefore the transport of nutrients and oxygen into Hood Canal's anoxic southern end. First, upward phase propagation is seen in velocity signals with ~10 cm/s and period 4-11 days, well below the lower limit for free internal waves in a rotating reference frame. The dynamics of these signals is unknown, but they may potentially represent a means of transferring energy to the estuary's deep layer. Second, an energetic internal tide is clearly observed propagating southward from the Hood Canal sill. Observations are presented, and implications discussed.

Latitudinal gradients in copepod community composition in the Northern California Current and S. Gulf of Alaska during years of varying ocean conditions

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During summer from 1998 to present, zooplankton have been sampled by various research programs from the central California Current north to the southern Gulf of Alaska, a distance of 2000 km. Comparisons among these programs are of interest because there is a strong latitudinal gradient in ocean conditions among regions, particularly in the strength of coastal upwelling. Off California and southern Oregon upwelling is strong and occurs over most months of the year. Upwelling is less strong and highly seasonal off central and northern Oregon, relatively weak off Washington and Vancouver Island, and completely lacking off northern British Columbia and southeast Alaska. Due to latitudinal gradients in hydrography, we would expect to identify faunal gradients. Sufficient sampling occurred during the 1998 El Niño event, the relatively warm year of 2003, and during the cold years of 1999, 2000, & 2002 to allow for comparison of differences in climatic forcing and ecosystem response among regions.

We examine copepod species density, species richness, distribution, and community composition and relate these to temperature, salinity, mixed layer depth, water column stratification, and chlorophyll-a concentration. We use multivariate ordination and cluster analysis to describe spatial and interannual relationships between copepods and differences in physical conditions as well as responses to different climatic conditions among contrasting years.

Variability of Nonlinear Internal Waves on the Continental Shelf

Jonathan Nash (OSU), Tim Duda, Jim Lynch, Jim Irish, Emily Shroyer, and Jim Moum

Nonlinear Internal Wave (NLIW) packets are ubiquitous features of the coastal ocean. With large vertical and horizontal velocities, they may significantly impact the surface and benthic environments, and are often highly turbulent. Yet while they arrive like clockwork in some regions (like the South China Sea), they occur with a high degree of variability on most continental shelves. Here we present moored observations from the New Jersey Shelf obtained during the ONR Shallow Water '06 (SW06) experiment. During a 50-day period, NLIW activity was found to be both spatially and temporally variable. Wave packets propagated in many different directions, producing highly 3D wave fields and irregular wave timing. Initial results indicate that NLIW energy levels do not scale with the strength of the barotropic tide. Instead, NLIW activity is found to be linked to the strength of the internal tide, which was strongest during the neap barotropic tide.

The Status and Understanding of Hypoxia in Hood Canal

J. A. Newton (Applied Physics Laboratory, University of Washington)
C. Bassin, A. Devol, M. Kawase, J. Richey, M. Brett, D. Hannafious

Hood Canal is a sub-basin of Puget Sound, with direct input from the Pacific Ocean via the Strait of Juan de Fuca. An increase in the persistence and distribution of low dissolved oxygen concentrations in Hood Canal observed during the 1990-2000's and repetitive fish kills observed during the 2000's led to the conclusion that hypoxia is increasing over levels observed historically. However, understanding the cause for the change is complex, with several factors that could be driving the present situation, including natural factors (e.g., climate, ocean, and freshwater dynamics), as well as human factors (e.g., carbon and nutrient loadings from a variety of sources). The Hood Canal Dissolved Oxygen Program-Integrated Assessment and Modeling effort arose out of the need to know whether human activities, and which ones, are significant causes for the increasing hypoxia. In this talk I will present our current understanding of the dynamics and the primary factors driving the condition.

Macroalgal bloom and hypoxia in an eutrophic estuary, Upper Newport Bay, California

Nikolay P. Nezlin (Southern California Coastal Water Research Project, CA 92683, U.S.A.),
Eric D. Stein, Krista Kamer, Amanda Carr, Jim Hyde, Doug Shibberu

Newport Bay is a large estuary in southern California that is subject to anthropogenic nutrient loading, eutrophication and hypoxia. The abundance of exposed macroalgae in the Upper Newport Bay (UNB) intertidal zone was assessed from June to December 2005 using color infrared aerial photography and ground-based sampling. According to these assessments, the macroalgal coverage in UNB increased from 37% in July to 57% in September to 80% in October, and during this time green algae Ulva spp. replaced red algae Ceramium spp. as the dominant species. To study the influence of macroalgal bloom on dissolved oxygen (DO) concentration, the data on temperature, salinity and dissolved oxygen (DO) were collected in surface and bottom layers at three locations of UNB. The time-series analysis of the dataset (data filtering, reconstruction of missing data using a new EOF method, principle components, wavelet analysis and time-lagged correlations) revealed the processes regulating DO concentration, including freshwater discharge, horizontal and vertical mixing by tides and wind stress (correlated with solar radiation and air temperature). Short residence time in UNB resulted from horizontal and vertical mixing produced by tidal oscillations, transporting rich or poor in DO waters from the head of estuary downstream. Net ecosystem metabolism estimated from diurnal DO dynamics characterized UNB as mostly heterotrophic estuary. Maximum oxygen production was concentrated in surface waters at the head of estuary and maximum oxygen consumption in the bottom layer of the same region, where most pronounced hypoxia events occurred. Hypoxia was most pronounced in late summer-early fall, following algal blooms. Each hypoxia event was caused by a combined effect of increased freshwater discharge (resulting from rainstorm events in the San Diego Creek watershed), low solar radiation, and diminished bottom water ventilation during neap tides.

Coastal ocean transport patterns in the central Southern California Bight

Marlene Noble, Kurt Rosenberger, Peter Hamilton, and Jingping Xu

In the past decade, several large programs that monitor current and transport patterns for periods from a few months to a few years were conducted by a consortium of university, federal, state, and municipal agencies in the central Southern California Bight, which is a heavily urbanized section of the coastal ocean off the west coast of the United States. These measurement programs were designed to determine how along- and cross-shelf currents move sediments, pollutants, and suspended material through the region. It was found that although the dominant current patterns in the Bight have marked changes in frequency and amplitude with location, in part because the topography in the Bight varies rapidly over small spatial scales, the current patterns in any particular locality are reasonably stable. Divergent patterns in the regional mean flow caused near-surface waters to be carried from the slope onto the shelf in localized areas, such as over the northwestern portion of the San Pedro shelf, while near-bed mean currents in the same area may carry material from the shelf onto the slope. Water and suspended material were also carried off the shelf by the mean and subtidal flow field in areas where the orientation of the shelf break changed abruptly. There are significant vertical structures in the subtidal flow fields; modal analysis shows that surface current patterns cover much broader areas of the shelf than near-bottom current patterns. Surface current patterns are much more correlated with the deeper subtidal flows on the San Pedro, compared to the Palos Verdes, shelf. It is clear that there are a large variety of processes that transport sediments and contaminants along and across the shelf in the central Southern California Bight. However, because these processes have relatively small spatial scales, one cannot necessarily infer that the dominant transport processes will be similar even in adjacent regions of this small part of the coastal ocean.

HF Radar Detection of Tsunami Waves Approaching the Continental U.S.

Belinda Lipa, Don Barrick and **Bruce Nyden**

We demonstrate that HF radar systems can be used to detect tsunamis before their arrival at a coastline, the time-to-arrival being dependent on the extent of the continental self. We use models to simulate the signals produced by a tsunami approaching the continental U.S. Height and velocity profiles are derived along with expressions for the radar-observed current velocities in terms of bathymetry and tsunami height and period. Simulated tsunami-generated radial current velocities are superimposed on typical maps of radial velocities generated by HF radar systems. A detection parameter is defined and used in conjunction with custom field software to illustrate the approaching tsunami. Data from the eastern U.S. coast provided by Rutgers University and data from the western U.S. coast provided by University of California-Davis' Bodega Marine Laboratory illustrate the differences between the amount of warning time that can be provided based on the extent of the continental shelf.

Characterizing the spatial and temporal evolution of the Columbia River plume using optical properties

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The quality and quantity of light attenuation by sediment particles and chromophoric dissolved organic matter (CDOM) is variable by river system, annual precipitation level, and season, and therefore imparts upon each river plume a unique optical signature that distinguishes it from the surrounding coastal waters. Some river systems in the U.S., e.g. the Mississippi and Hudson River plumes, have well-characterized optical signatures; however, no comparable data exist for the ecologically and economically-important Columbia River system. The Columbia River Plume is a highly dynamic water mass that supplies silicate and trace metals, fresh water, and dissolved and particulate organic matter to the Oregon/Washington shelves. As part of the CoOP-RISE program, we wished to (1) identify initial optical properties of fresh plume waters at the river mouth, (2) track changes in the optical signature of the water mass as it advects seaward from the mouth, and (3) predict residence time of the water mass on the shelf based on changes in the optical signature. Measurements of in-situ optical properties (CDOM absorption, transmittance, and chlorophyll fluorescence) along a gradient down the plume axis determined in June 2006 revealed that light absorption by CDOM and particles decayed predictably along the plume axis, indicating that changes in these properties can be considered a proxy for time. We conclude that CDOM and sediment particles can be used as tracers of low-salinity river plumes on coastal shelves. Results from this work will be used to refine models that identify the plume using satellite remote sensing.

Physical factors affecting Productivity in the Strait of Georgia

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We have developed a circulation scheme for the Strait of Georgia, British Columbia, which shows a surprising insensitivity to variations in fresh-water inflow. The scheme can be used to identify the sources and sinks of nutrients. Sinks occur at the surface as more nutrients are upwelled than are removed by advection. These sink terms can in turn be used to estimate productivity. By comparison with coincident observations of phytoplankton biomass and species composition we describe the evolution of a number of spring blooms and attempt to quantitatively synthesize a food web in this system.

Mapping Semi-Regular Autonomous Underwater Vehicle Glider Observations onto a Cross-Shelf Section

Tristan Peery, Kipp Shearman, Jack Barth, Anatoli Erofeev, OSU

Two Autonomous Underwater Vehicle Gliders have alternated sampling of a 45-nautical mile transect line (the Newport Hydrographic Line) across the Oregon continental shelf since April, 2006. Seasonally varying waves and currents push the gliders off course, preventing them from sampling the historically

occupied stations exactly. This poster is an explanation of the methods developed to map the semi-regular glider data onto a cross-shelf line, a process which combines the binning of data along-isobaths and objective analysis. The mapping procedure is tested by comparison to moored observations on the Newport Line at about 80 m water depth at varying temporal scales.

Temporal variation in dynamics of central California larval dispersion in a multiyear 3-d lagrangian circulation model

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Multi-annual fish surveys carried out by the National Marine Fisheries Service off the U.S. West Coast exhibit substantial interannual variability in juvenile rockfish abundances. The correlation of multiple species counts within-years suggests that broad scale ocean conditions influence several populations. We use a numerical model to investigate the possibility that dispersion of larvae by coastal currents plays a role in interannual population fluctuations. We use the Regional Ocean Modeling System (ROMS), configured at a nominal 3 km resolution along the central California coast and driven by realistic surface fluxes provided by the Coupled Ocean Atmosphere Mesoscale Prediction Model (COAMPS) as the foundation for this study. For the period 2000-2004, passive floats were released, tracked for 2 months and re-released regularly. Several metrics characterizing the distance travelled and duration of retention within the coastal zone are used to quantify the combined effects of transport and dispersion. Here, we introduce these metrics in detail and describe how they fluctuate over the 5-year period, and discuss their relevance toward the fisheries data set.

Seasonal development and inter-annual variability of hypoxic regions along the Oregon and Washington shelf from 1999 – 2007

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Dissolved oxygen measurements across a broad region of the Oregon and Washington shelf are available from 1999 to present, with the most complete and detailed set of data available from the Newport Hydrographic (NH) Line off Newport, Oregon. Hypoxic waters (<1.4 ml/L dissolved oxygen) along the Newport Line tend to be most prominent in August and September. No hypoxic regions were detected in September 1998, 1999 and 2003, but have appeared annually since 2003 with the lowest oxygen concentration (0.23 ml/L) recorded in 2006 at a mid-shelf station.

This presentation will combine data from several studies to look at the seasonal progression of hypoxia across the Oregon shelf and illustrate the recent broad–scale distribution pattern of hypoxic waters along the Oregon and Washington shelf.

Origins and Dynamics of Poleward Upwelling Relaxation Flows Around Pt. Reyes

James Pringle, University of New Hampshire

Send et al. (1987) noted that during upwelling season, the flows between Pt. Reyes and Pt. Arena are strongly poleward when the wind weakened. This moves warm water northward around Pt. Reyes, causing an upwelling relaxation. Gan and Allen (2002) found that near-shore, a portion of this relaxation was due to pressure gradients formed around Pt. Reyes and other points. Using a similar approach as theirs, but including realistic spatial variability in the winds and a larger non-periodic domain, other sources of upwelling relaxation flows were studied.

During the upwelling season, the flow between Pt. Reyes and Monterey Bay is primarily wind driven. These winds weaken to the south of Pt. Reyes, and the alongshore gradient in the strength of the alongshore winds sets up an alongshore gradient in the strength of upwelling between Monterey Bay and Pt. Arena, with stronger upwelling and colder, denser waters to the north.

The shelf becomes narrower as one moves south from Pt. Reyes until it disappears ear Monterey Bay. As predicted by Pringle (2002), this leads to weak wind-driven alongshore flows just north of Monterey Bay, and the strength of the alongshore flow increases to the north. Because of this gradient in alongshore flows, there is a gradient in the strength of upwelling associated with the alongshore variation in shelf-width, with colder, denser upwelled water near Pt. Reyes and warmer less-dense waters to the south.

The alongshore density gradients associated with both the alongshore gradient in alongshore winds and the alongshore gradient in shelf width persist after the winds have relaxed, and drive strong poleward flows on the shelf. The alongshelf flows attributable to these two sources of alongshore density gradients dominate the upwelling relaxation flow present across the entire shelf, and are stronger than those caused by the coastal geometry. The relaxation flows match observations from WEST and surface currents from CODAR very well, both in magnitude and extent. A simple analytical models are used to explain why denser water to the north drives northward flow, why the poleward upwelling relaxation flows are stronger near the shore, and why the flow becomes primarily onshore on the outer-shelf. This simple model suggests that most of the upwelling-relaxation poleward flow is forced by alongshore density gradients between Pt. Reyes and Monterey Bay, indicating that it is not necessary to invoke basin scale pressure gradients to explain the observed upwelling relaxation.

AUV mapping of particle size spectra in intermediate nepheloid layers

E. V. Rienecker and J. P. Ryan, MBARI

Intermediate Nepheloid Layers (INL) are one of the most commonly encountered features found with Autonomous Underwater Vehicle (AUV) monitoring in Monterey Bay. INL's are of significant importance due to their ability to transport carbon, nutrients, and the resting stages of phytoplankton from below the mixed layer into the photic zone. Our particular interest is the study of how INL's transport particles into the mixed layer, and how these particles influence plankton ecology. Over the last 4 years, Monterey Bay Aquarium Research Institute (MBARI) has conducted monthly AUV surveys, spanning all four seasons, and covering both the Monterey Canyon axis, and the near-shore shelf. The AUV instrument suite includes dual conductivity temperature and depth sensors (CTD), backscatter, fluorescence, oxygen, nitrate, bioluminescence, and a particle size sensor built by Sequoia Scientific; Laser In Situ Scattering and Transmissometery (LISST-100). This particle sensor, combined with the AUV's oceanographic sensors affords MBARI a unique ability to examine INL formation, composition, development and fate. Our presentation will show the results of these measurements and show the effects of INL particles and their potential interaction with phytoplankton ecology.

The current and future ocean science and technology workforce

Leslie Rosenfeld, Naval Postgraduate School, Monterey CA

Deidre Sullivan, Marine Advanced Technology Education Center, Monterey Peninsula College, Monterey, CA

Tom Murphree, Naval Postgraduate School, Monterey, CA

Two projects related to the workforce that supports ocean observing systems and similar ocean science, technology, and operational endeavors will be described and the input of meeting participants will be sought. One project, funded by NOPP, is designed to produce a more complete description of the present state of the ocean science, technology, and operations workforce, anticipate future developments in this workforce, and characterize the educational programs that will be needed to respond to those developments. The other project, funded by NOAA, is assessing whether there is a need for a national certification program for oceanographic professionals. Certification is a way to recognize that an individual has demonstrated professional competence and integrity in an occupational field. This study will address both potential advantages, such as aiding in evaluation of job applicants, encouraging career-long learning, and increasing awareness of, and confidence in, the oceanographic community by users of oceanographic products and services; and possible disadvantages, including the costs and labor involved in setup and administration of a certification program, and the personal effort that certification applicants would need to undertake. Data for both projects is coming from surveys, interviews, workshops, meetings with professional societies with large memberships of people working in marine science and technology, and will draw on results from previous relevant studies. In addition, workforce studies and certification programs in fields similar to the ocean sciences are being reviewed.

Mesoscale dynamics influencing incubation, spread and retention of red tides in Monterey Bay, California

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Dense accumulations of certain phytoplankton cause the ocean to appear reddish. Some of these "red tides" can harm marine life and people. Dinoflagellates comprise half of all red tide species and three quarters of all Harmful Algal Bloom (HAB) species. Dinoflagellate ecology research is thus essential to advancing our understanding of red tide and HAB phenomena in coastal waters. Remote sensing and in situ observations indicate the existence of a red tide incubator in the upwelling shadow of northern Monterey Bay, California. Dense surface aggregations of dinoflagellates are often observed in this region. Transport of these populations by filaments and eddies of the upwelling system circulation have been observed to rapidly spread red tide blooms throughout the bay and out into the adjacent coastal ocean. Remote sensing data show that the upwelling shadow is important to not only bloom initiation, but also retention. Integrating multidisciplinary observations from satellite, aircraft, AUV, and moorings, we present evidence for the existence of a red tide incubator in Monterey Bay, examine natural and anthropogenic influences on this phenomenon, and illustrate how bay-wide red tides can rapidly develop in association with mesoscale dynamics.

Annual evolution and demise of the subsurface chlorophyll maximum layer off Washington, USA: Results from the Seaglider field campaign, 2003-present

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M. J. Perry (University of Maine)
C. C. Eriksen (University of Washington)
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The focus of this talk is the annual evolution and demise of the Subsurface Chlorophyll Maximum layer (first described by G.C. Anderson in 1964) and its interannual variability during the four-plus years of the Seaglider field campaign off Washington, USA. From 2003 – present Seaglider, an autonomous underwater glider, has been performing repeat surveys along a V–shaped track that extends from the continental shelf edge into deeper oceanic waters collecting data along sections which intersect the northern California Current system. During the monthly visits to the outer terminus of this track (47 N, 128 W; 120 nautical miles offshore) Seaglider makes highly resolved measurements of temperature, salinity, and dissolved oxygen to 1000m, and chlorophyll a fluorescence and optical backscattering to 150m. As near-surface density gradients intensify in spring, vertical mixing and re-supply of nutrients to surface waters are reduced and surface phytoplankton concentrations decrease. However, below the thermocline phytoplankton concentrations increase. As mixing increases in the late autumn these deep layers of increased phytoplankton biomass are eroded and eventually disappear until late spring when stratification develops again. The Subsurface Chlorophyll Maximum layer is a ubiquitous feature from late spring to early autumn and is associated with a slightly broader oxygen maximum that is often supersaturated. The horizontal extent of this feature and its oxygen supersaturation suggest an important contribution of the layer to the region’s net primary productivity.

Numerical Simulation of Wind-Driven Oregon Coastal Ocean Circulation

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J. Kindle (NRL)

C. Snyder (NCAR)

Results are presented on nested numerical model simulations of ocean circulation in the Oregon coastal transition zone (CTZ), the region extending several hundred km offshore from the Oregon coast into the northern portion of the California Current System and the eastern interior North Pacific. The CTZ model is nested in the NRL NCOM-CCS model, and impact of these open boundary conditions on the CTZ model is examined. Atmospheric forcing is obtained from the NRL COAMPS product. Validation of the simulated coastal ocean circulation is provided by comparison with in-situ data sets from regional observational programs during 2000-2003 and with satellite and land-based remote-sensing observations. The response to spatially variable winds and the dynamics of remotely forced variability and of topographic interaction and eddy formation are analyzed and discussed.

Canadian Operational Network of Coupled Environmental PredicTion Systems (CONCEPTS)

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Environment Canada (EC), Fisheries and Oceans Canada (DFO), and the Department of National Defence (DND) require environmental information products and capabilities that can be provided by an operational global coupled atmosphere-ocean-ice data assimilation and prediction system. In-situ data from Argo floats together with other observations (e.g., altimeter, remotely sensed sea surface temperature) permit effective ocean data assimilation. A new inter-agency initiative, the Canadian Operational Network of Coupled Environmental PredicTion Systems (CONCEPTS) including Mercator-Ocean participation (France), will provide a framework for research and operations on coupled atmosphere-ocean-ice prediction.

CONCEPTS includes projects on: 1) development of improved data assimilation and prediction systems; 2) their validation on both global and basin scales for the North Atlantic, Arctic, and North Pacific; 3) demonstration of regional ocean prediction capabilities and applications in the context of the Canada – Newfoundland Operational Ocean Forecasting System (C-NOOFS); 4) sea ice and Arctic modelling and data assimilation and 5) improved ocean data assimilation capabilities.

Initial resources have been put in place for the establishment of three major inter-related activities: 1) an operational activity based on coupling the Canadian atmospheric GEM model with the Mercator system;

2) a research and development (R&D) activity consisting of government and academic research networks to develop and maintain a system tailored to Canadian needs in the longer term; and 3) a products activity to identify, develop and disseminate relevant products and outputs. Operational activity is being built upon existing EC infrastructure with R&D activity enhanced through a Global Ocean-Atmosphere Prediction and Predictability (GOAPP) research network funded by the Canadian Foundation for Climate and Atmospheric Sciences since October 2006. This poster will provide an overview of CONCEPTS projects and current activities.

Space scales of chlorophyll patchiness in the California Current

Andrew Thomas and Peter Brickley, University of Maine

Dominant alongshore length scales of chlorophyll patchiness are quantified for the coastal California Current and examined as a function of seasonal evolution, cross-shelf distance and interannual variability. We focus on the upwelling season (May September) when physical and biological interaction is strong and these scales may have trophic significance, exerting influence on near shore biological and ecological community structure. The study area is the region 38-50 N and length scales are extracted from 1km resolution, 8-day SeaWiFS composites after removing the climatological mean to minimize the influence of long-lag spatial trends. Quantification is based on a semivariogram approach from geostatistics, a relatively robust procedure with missing data. Spatial variance is quantified by the semivariogram parameters of sill, range and nugget and is compared to overall data variance. In general, small scale (10-50 km) spatial variance dominates within a few km of the shore where overall variance, both resolved and unresolved, is high. Length scales generally increase to 50-200 km scales farther offshore. Strong interannual variability between each summer is evident, weakest in regions close to shore (0-10 km) and maximum in regions 50-200 km offshore. These signals are compared to basin-scale signals known to modulate overall California Current patterns and to interannual differences in wind forcing.

Anticyclonic eddies in the Alaskan Stream

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Anticyclonic eddies in the Alaskan Stream (AS) were investigated through analysis of altimetry data from satellite observations during 1992–2006 and of hydrographic data from profiling float observations during

2001–2006. Fifteen long-lived eddies were identified: three eddies appeared from the beginning of the satellite observations, another three were first observed in the eastern Gulf of Alaska off Sitka, and another three were first detected at the head of the Gulf of Alaska near Yakutat. The other five eddies formed along the AS between 157º–169ºW and we call these eddies AS eddies. Four of the fifteen long-lived eddies crossed the date line and reached the western subarctic gyre; all four eddies were AS eddies. A Sitka eddy and a Yakutat eddy were observed by profiling float along the AS around 160º–170ºW; warm cores were not detected in both eddies. An AS eddy was observed by a profiling float after it detached from the AS in the western subarctic gyre, although profiles were not obtained within 50 km of the eddy center. Intermediate water 50–100 km off the eddy center had low potential vorticity compared with that in the western subarctic gyre, probably providing the western subarctic gyre with low-potential-vorticity intermediate water in the AS region.

Modeling Tides in the Alaska Coastal Oceans

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Francois Colas, James C. McWilliams (UCLA)
C. K. Shum, Yuchan Yi (Ohio State University)

With its complex coastlines, islands and shallow inlets, Alaska coastal region provides an extreme testing case for tide and ocean circulation modeling. A three level one-way nested model, configured from the Regional Ocean Modeling System (ROMS), is used to simulate tides of the Alaska region. The finest resolution for the focus area, Prince William Sound, is 1km and 40 levels in vertical direction. The model tidal solution is validated against the multi-satellite altimetry in the open ocean and tide gauges along the coast. The accuracy of barotropic tides, as measured by the root of summed squares (RSS) of the RMS discrepancy of sea surface height amplitudes of eight major tidal constituents, is 11.5cm in the open ocean. Along the coastal region, the RSS of tidal amplitudes is 17.8cm, which is about 10% of the amplitude of the most energetic semi-diurnal constituent M2 of the region. The barotropic tidal energetics of the Alaska coastal region will also be discussed. The addition of tides to the three level nested model is the first step to build a data assimilation and forecasting system for the region.