between years in offshore populations (lower in 2000). These results suggest that while strong winds drive the upwelling and productivity of this system, sustained strong winds are at the same time detrimental to euphausiid population maintenance on the inner and middle shelf.

### OS41O-12 1140h

## Temporal Variability of Wind: Effects on Primary and Secondary Production in a Simplified Coupled Biological-Physical Model

Louis W. Botsford[1] (5307526169; lwbotsford@ucdavis.edu)

Cathryn A. Lawrence[1] (5307521270; clawrence@ucdavis.edu)

Alan Hastings[2] (amhastings@ucdavis.edu)

John Largier[3] (jll@coast.ucsd.edu)

[1]UC Davis, Dept. of Wildlife, Fish and Convervation Biology; 1 Shields Ave, Davis, CA 95616, United States

[2]UC Davis, Dept of Enviromental Science and Policy, Davis, CA 95616, United States

[3]Scripps Institution of Oceanography, 2224 Sverdrup Hall, La Jolla, CA 92093-0209, United States

One of the primary goals of CoOP WEST (Wind Events and Shelf Transport) is to understand how temporal wind variability influences primary and secondary production on the northern California shelf. We present results from several NPZ models, under various wind forcing scenarios, embedded within a simplified physical model designed to capture the dominant wind processes likely to be important in this system. The physical model represents upwelling as a series of nutrient-rich parcels moved to the surface in a conveyor-belt fashion. Upon reaching the surface, the parcels are transported cross-shore and subjected to vertical mixing using the PRT scale to set the depth of the surface mixed layer. Both synthetic and real wind time series are used to explore the effects of the magnitude, duration and frequency of upwelling favorable winds upon primary and secondary production within the NPZ models . The countervailing effects of high winds supplying nutrients to the surface at a high rate, while reducing light availiabilty by increasing the depth of the mixed layer and transporting nutrients and plankton off the shelf, are examined.

# OS41P HC: 315 Thursday 0830h

## Climate Impacts on Estuaries and Nearshore Environments

*Presiding:* **W Kimmerer,** Romberg Tiburon Center**; J A Newton,** Washington State Dept. Ecology

### OS41P-01 0830h

## How Will Climate Change Affect the Ecosystem of the San Francisco Estuary?

Wim Kimmerer (415 338-3515; kimmerer@sfsu.edu)

Romberg Tiburon Center, San Francisco State University 3152 Paradise Drive, Tiburon, CA 94920, United States

Recent developments in forecasting have improved confidence in quantitative predictions of global warming and a rise in sea level. However, scaling these forecasts down to regional and local effects may increase uncertainty in three ways: high uncertainty of regional responses to global effects, influence of local anthropogenic effects, and opposing effects of likely mechanisms. For example, precipitation in central California can either increase or decrease with increasing sea surface temperature. Similarly, several effects of regional climate on seasonal timing of precipitation may offset each other. These potential influences on the estuary should be considered in the regional context, such as the evidence of drought periods within the last few millennia of much longer duration than those in the historical record.

Except in the case of a catastrophic drought, local anthropogenic effects may have a greater influence on the San Francisco Estuary than those arising through regional or global influences. Known human influences include a long-term reduction in sediment, historical and current inputs of contaminants, introduction of invasive species, modification of freshwater flow regimes, and large-scale restoration efforts. In addition, it is reasonable to anticipate an increase in urban population and land use, construction of infrastructure, idling of farmland, and future introductions of invasive species.

Attempting to predict the net effect of all these changes on the estuarine ecosystem reveals several difficulties. For example, rising sea level combined with an increase in strong wind events and storm surges should increase resuspension and erosion. The net effect is complicated by the ongoing net sediment deficit, which should increase water clarity, with a consequent increase in phytoplankton growth rates and nutrient uptake. However, changes in the overriding influence of benthic filter-feeding on phytoplankton cannot be predicted. Responses of higher trophic levels will probably be even more complex. Striped bass may survive poorly when the ocean is warm, but estuarine conditions and hatchery production could offset that effect. Chinook salmon may be affected by a variety of pathways, but an increase in air and therefore river temperature, a shift toward earlier spring runoff, and an increase in sea surface temperature may all contribute to decreasing populations. However, changes in management and hatchery practices or habitat restoration may offset some or all of these changes. Without considering the multiplicity of causal pathways and uncertainties in each, predictions of even the sign of long-term changes in the estuarine ecosystem will remain elusive.

### OS41P-02 0845h

## Sensitivity to Climate Variability in a Box Model of Puget Sound Circulation

Amanda L Babson[1] (206-221-6734; babsona@ocean.washington.edu)

Mitsuhiro Kawase[1] (kawase@ocean.washington.edu)

[1]University of Washington, School of Oceanography Box 355351, Seattle, WA 98195

A prognostic, time-dependent box model of Puget Sound, Washington is developed in order to investigate sensitivity to variability of river input and ocean salinity. These forcing factors have a large degree of interannual variability and are influenced by larger climate signals such as ENSO and the PDO. By varying forcing, the model can study the local effects of various scenarios of climate variation on circulation, resolving inter-basin differences. The circulation is modeled as two layer exchange flow, for six basins, three receiving river input and two connecting to the Strait of Juan de Fuca, the outlet to the ocean. Advective fluxes are determined by a combination of the Stommel approximation and by conservation of mass and salt. Model salinities exhibit a seasonal cycle consistent with a composite of 1990s monthly salinity data for each basin. This is achieved with parameterized forcing functions based on salinity data from the eastern Strait of Juan de Fuca and river flow from USGS historical stream gauge data over the same time period. Amplitude variation of peak river flows significantly affect only the basin into which they enter and their effects are limited to the time of perturbation. All of the basins are sensitive to changes in forcing salinity; the responses are rapid and persist past a return to the unperturbed salinity.

### OS41P-03 0900h

## Climte Variability, Mississippi River Discharge, and Hypoxia in the Gulf of Mexico

Nancy N Rabalais[1] (985-851-2836; nrabalais@lumcon.edu); Dubravko Justic[2] (225-578-6394; djusti1@lsu.edu); R Eugene Turner[2] (225-578-6454); Donald A Goolsby[3] (303-236-5950 x 209; dgoolsby@usgs.gov); William Battiglin[3] (wbattagl@usgs.gov); Ben Cole[1] (985-851-2835; bcole@lumcon.edu); J Kevin Craig[4] (kevin.craig@duke.edu); William J Wiseman[2] (wwiseman@nsf.gov)

[1]Louisiana Universities Marine Consortium, 8124 Hwy. 56, Chauvin, LA 70344, United States

[2]Department of Oceanography and Coastal Sciences, Louisiana State University, Baton Rouge, LA 70803, United States

[3]U. S. Geological Survey, Mail Stop 406, Denver, CO 80225, United States

[4]Duke University Marine Laboratory, Duke University Marine Laboratory, Beaufort, NC 28516, United States

Extensive areas of hypoxic bottom water form seasonally on the continental shelf of the northern Gulf of Mexico. The size is minimal during drought and large, up to 20,000 sq km, during periods of high flow and nitrate flux. Hypoxia is related to the discharge and nitrate flux of the Mississippi River system and is influenced by climate variability. Simple regressions relate the 2-dimensional extent of hypoxia to freshwater or nitrate flux for May in the current year, and more closely to integrated flow or nitrate flux for the 75-d period before the shelfwide mapping of hypoxia. The 75-d period is based on an average freshwater fill time for the shelf. This integrative factor captures the complexity of the biological/physical interactions of carbon production and flux, respiratory consumption of oxygen, stratification, and currents prior to deriving the estimated size of the zone in mid-summer during a 5-day cruise. We examine these relationships with the estimated size of the hypoxic zone for the period 1985-2001 as reported previously, from computer generated contours of the hypoxic zone size, for volume estimates from the same cruises, and for independently derived estimates from SEAMAP and other cruises.

### OS41P-04 0915h

## Interannual variability of circulation and hydrography in Puget Sound, Washington and its relationship to the regional climate, 1933 - Present

Mitsuhiro Kawase (kawase@ocean.washington.edu)

University of Washington, School of Oceanography, Seattle, WA 98195, United States

Historical and contemporary hydrographic data from various locations in Puget Sound, Washington are analyzed for signals of variability with interannual and longer time scales, and compared with indices of regional and global climatic regimes. For each variable, a canonical seasonal cycle is constructed from a yearly composite, then subtracted from the raw time series to obtain an anomaly time series. In order to exclude aliasing of high-frequency variability, anomaly time series from multiple locations are compared and combined for an anomaly series representing the entire Sound.

Temperature anomaly time series show no overall trend in the Sound's waters for the period but shows significant correlation with the Pacific Decadal Oscillation (PDO) Index, indicating that the Sound's temperatures reflect that of the regional climatic regime. Salinity anomaly time series show influence of regional precipitation/river discharge and oceanic conditions along the Pacific coast of Washington and Oregon. Anomalously high wintertime salinity values are observed in drought winters such as year 2000; however, high river discharge does not necessarily result in anomalously fresh conditions. Instead, fresh anomalies appear to result from reductions of upwelling water arriving from the Pacific coast, which may occur in years of anomalous atmospheric circulation associated, for example, with El Nino. A quantitative assessment of the Sound's hydrographic conditions in relation to these and other climate indices will be reported.

### OS41P-05 0930h

## Climate Impacts on Primary Production and Water Properties of Pacific Northwest Estuaries.

Jan A. Newton[1,2] (360 407 6675; newton@ocean.washington.edu)

[1]Washington State Dept. Ecology, PO Box 47710, Olympia, WA 98504, United States

[2]University of Washington, Box 357940, Seattle, WA 98195, United States

Modes of climate variability, such as El Nino-Southern Oscillation and Pacific Decadal Oscillation, are known to affect local weather in the Pacific Northwest. The impacts of variable weather patterns on water properties and biological properties in PNW estuaries, however, are not well known. Some of the emerging patterns are that upwelling intensity and the depth of the coastal ocean thermocline are important factors governing estuarine water properties such as dissolved oxygen, nutrients, and phytoplankton biomass. Effects of river flow and local air temperature are also important but vary as to relative impact on spatial (i.e. different estuaries) and temporal (i.e. seasonal) scales. The recent 1997-1998 El Nino and the 1999 and 2000 La Nina events were observed to exhibit strong effects on two PNW estuaries, Puget Sound and Willapa Bay. In general, colder, saltier waters and higher chlorophyll and primary production were representative of the post 1998 data, and these were associated with a shallower ocean thermocline and upwelling favorable winds. Primary productivity and biomass in Willapa Bay during 1997-1998 were 60-70 percent of 1999 and 2000 values although nitrogen limitation was evident for all years. This difference was less profound in some parts of Puget Sound. Regional responses varied regarding the balance between oceanic, watershed, and local forcings for different PNW estuaries and sub-basins.

### OS41P-06 1005h

#### Decadal Oscillations And Regime Shifts, An Empirical Characterization Of The Chesapeake Bay Marine Climate

Herbert M. Austin (804 684 7321; haustin@vims.edu)

Virginia Institute of Marine Science, College of William and Mary, Gloucester Pt., VA 23062, United States

The Chesapeake Bay spawning activity can be characterized by a progression from up-river spring anadromous spawning to summer Bay spawning, and finally to fall-winter shelf spawning. Although there is significant interannual variability, important low frequency patterns in temperature, discharge and wind characterize the Bay climate as regimes (warm-wet or cool-dry) of decadal oscillatory waves, and sudden regime shifts. The most characteristic regimes are the cool-dry 1960's and warm-wet 1970's and 1990's. Principal Components Analysis of environmental data from 1960 to 2000 reveal abrupt climatological regime reversals in 1972 and 1977. These climatological regime shifts are reflected by impacts in the ecosystem through variation in oyster condition and spatfall, and juvenile fish and blue crab recruitment. The 1972 reversal is most pronounced in the Maryland riverine system by non existent on the shelf, where as the 1977 reversal is significant on the shelf but not recognizable up-river. Knowledge of the prevailing background climate regime can provide managers the relative chance for success of a management plan as reflected by recruitment patters or water quality to be expected during the dominant production regime.

### OS41P-07 1020h

#### Spawning and Habitat Responses of the Bay Anchovy (*Anchoa mitchilli)* to ENSO-related Variation in Inflows to Florida Estuaries

Ernst B Peebles[1] (727-553-3983; epeebles@seas.marine.usf.edu)

Mark E Luther[1] (727-553-1528; luther@marine.usf.edu)

[1]University of South Florida, College of Marine Science 140 Seventh Avenue South, St Petersburg, FL 33701, United States

During the 1997-98 ENSO period, a high-resolution sampling routine was used to track daily spawning responses to an isolated inflow event of exceptional magnitude. Spawning was initially interrupted at the onset of the event, which lowered salinities in the spawning ground by >10 psu. Within 5 d, the large, event-generated plume front began to retreat landward toward its more typical position. As the front retreated, spawning intensified landward of the front, despite the strong reduction in salinity that had occurred there. Other studies evaluated ENSO-related shifts in habitat use by larvae, juveniles and adults. Stage-specific distributions shifted upstream and downstream in response to inflow variation, with the upstream shifts being associated with decreased abundance. In general, the bay anchovy was found to be highly adaptive to the large-scale inflow variations associated with climatic oscillation, and high inflow levels were found to be associated with improved juvenile recruitment.

### OS41P-08 1035h

#### Potential Impact of Climate Change on Susquehanna River Flow and Chesapeake Bay Salinity

Jody Gibson[1] (jrg205@psu.edu)

Raymond G Najjar[2] (814-861-5611; najjar@essc.psu.edu)

[1]Department of Soil Science, The Pennsylvania State University, University Park, PA 16802, United States

[2]Department of Meteorology, Department of Geosciences, 503 Walker Building, The Pennsylvania State University, University Park, PA 16802-5013

Models of Chesapeake Bay salinity and flow of the Susquehanna River were developed with the aim of predicting how these variables will respond to future climate change. Temperature, precipitation and streamflow observations between 1900 and 1987 from the Susquehanna River basin were analyzed and used to calibrate a simple, spatially lumped water balance model. The model reproduces the mean annual cycle in streamflow and captures 75% of the monthly mean streamflow for the 88-year record. Autoregressive statistical models of monthly salinity variations in Chesapeake Bay were developed from salinity and streamflow observations between 1984 and 1994. Up to 93% of the variance in salinity is captured by these models. Output of four climate models run for a doubling of atmospheric carbon dioxide was used to drive the water balance model. Three of the models predict annual mean streamflow increases of approximately 30%, while the fourth predicts a 4% decrease. The response of salinity to these changes is simulated to be between +3.5% and -27.5% near the mouth of the Susquehanna River, to between +0.1% and -0.7% near the ocean. In the highest streamflow increase scenario, mid-bay isohalines recede by approximately 55 km, about 17% of the length of the bay.

### OS41P-09 1050h

#### ENSO Impacts on Fresh Water Input and Salinity in Tampa Bay, Florida

Nancy J Schmidt[1] (727-553-1528; nschmidt@marine.usf.edu)

Mark E Luther[1] (727-553-1528; luther@marine.usf.edu)

[1]University of South Florida College of Marine Science, 140 Seventh Avenue South, Saint Petersburg, FL 33701

Estuarine salinity distributions reflect a dynamic balance among the processes that control estuarine circulation. At seasonal and longer time scales, freshwater inputs into estuaries represent the primary control on salinity distribution and estuarine circulation. El Niño-Southern Oscillation (ENSO) conditions influence seasonal rainfall and stream discharge patterns in the Tampa Bay, Florida region. The resulting variability in freshwater input to Tampa Bay influences its seasonal salinity distribution. During El Niño events, ENSO sea surface temperature anomalies (SSTAs) are significantly and inversely correlated with salinity in the bay during winter and spring. These patterns reflect the elevated rainfall over the drainage basin and the resulting elevated stream discharge and runoff, which depress salinity levels. Spatially, the correlations are strongest at the head of the bay, especially in bay sections with long residence times. During La Niña conditions, significant inverse correlations between ENSO SSTAs and salinity occur during spring. Dry conditions and depressed stream discharge characterize La Niña winters and springs, and the higher salinity levels during La Niña springs reflect the lower freshwater input levels.

### OS41P-10 1105h

#### Contrasts in Particle Flux Below the Southern California Current in Late 1996 and During the El Nino Event of 1997-98

Norman Silverberg[1] ((52)-(112)-2-5344; silverb@ipn.mx); Sergio Aguiniga[1] (saguini@ipn.mx); Nancy Romero[1] (nromero@ipn.mx); Aida Martinez[1] (emartin@ipn.mx); Gilberto Gaxiola[2] (ggaxiola@cicese.mx); Jose D. Carriquiry[3] (jdcarriq@faro.ens.uabc.mx)

[1]CICIMAR-IPN, Av. Instituto Politecnico Nacional s/n, Playa Palo Santa Rita, La Paz, BCS 23096, Mexico

[2]C.I.C.E.S.E., Km. 127 Carretera Ensenada-Tijuana, Ensenada, BC 2372, Mexico

[3]UABC, A.P. 453, Ensenada, BC 22830, Mexico

The vertical flux of particulate matter at 330m depth in the San Lazaro (Soledad) Basin off Baja California ranged from 63 to 587 mg.m$^{-2}$.d$^{-1}$ between 23 August and 26 November, 1996. Organic carbon contents were between 5.6 and 14.8%, yielding organic carbon flux rates of 9-40 mgC. m$^{-2}$.d$^{-1}$. In December 1997 and January 1998, total mass and organic carbon fluxes (47-202 mg. m$^{-2}$.d$^{-1}$ and 3-8 mgC. m$^{-2}$.d$^{-1}$, respectively) indicated unexpectedly comparable vertical fluxes during the height of the strong 1997-98 El Nino event. The February-June records, however, reveal sharply reduced levels of total particle flux (1-6 mg. m$^{-2}$.d$^{-1}$) and organic carbon (0.2-0.8 mgC. m$^{-2}$.d$^{-1}$).

Marine snow made up 20-80% of the trap material. Fecal pellet fluxes were low (18-2350 m$^{-2}$.d$^{-1}$), and roughly followed the changes in total mass flux, with ovoid forms dominating over rod-shaped pellets. The plankton remains indicated a shift from a diatom-rich, radiolarian, silicoflagellate and coccolith assemblage in late 1996 to a coccolith-dominated assemblage (including the contents of fecal pellets), during the El-Nino period. The particulate organic matter (POM) collected in 1996 was predominantly autochonous ($\delta^{13}$C = -22 ppt ; C/N = 8). The variation in $\delta^{15}$N (8.3 to 11 ppt) suggests an alternation of new and regenerated production, possibly associated with fluctuations in the intensity of deep mixing in the fall of the year. The relatively high organic matter fluxes in December 1997 appear to be associated with regenerated production. The average POM composition from February to June 1998 ($\delta^{13}$C = -23.6; $\delta^{15}$N = 11.7; C/N = 10.5), suggests that the sediment trap had collected either degraded material of marine origin or terrestrial material possibly transported over large distances.

Regime changes within each of the trap collection periods are evidenced by concurrent shifts in most of the measured parameters (including trace metals). Temperature-salinity profiles, plankton analysis and chlorophyl contents of the upper water column indicated that the large diatom bloom, normally associated with seasonal wind-induced upwelling along the Pacific coast of Baja, did not occur during spring of 1998. Similar mid-day primary production rates in December 1997 and April 1998 (about 60 mgC.m$^{-2}$.h$^{-1}$) are thus surprising. In spring local conditions favored the dominance of nanoflagellates (94%) and apparently limited the export of particles from the photic zone.

## OS41Q HC: 314 Thursday 0830h

## Circulation in Marginal and Semienclosed Seas I

***Presiding:*** **H Peters,** RSMA/MPO, University of Miami**; J D Pullen,** Marine Meteorology Division, Naval Research Laboratory

### OS41Q-01 0830h

#### Red Sea Outflow Experiment (REDSOX): New Energetic, Large-scale Eddies in the Gulf of Aden and the Spreading of Red Sea Water

Amy Bower[1] (508-289-2781; abower@whoi.edu)

David Fratantoni[1] (508-289-2908; dfratantoni@whoi.edu)

William Johns[2] (wjohns@rsmas.miami.edu)

Hartmut Peters[2] (hpeters@rsmas.miami.edu)

[1]WHOI, MS #21, Woods Hole, MA 02540, United States

[2]RSMAS, 4600 Rickenbacker Causeway, Miami, FL 33149, United States

A major objective of REDSOX was to identify the transport mechanisms that spread Red Sea Water (RSW) eastward from Bab el Mandeb through the Gulf of Aden and ultimately to the open Indian Ocean. To meet this goal, two high-resolution CTD/lowered ADCP/shipboard ADCP surveys were conducted in the Gulf of Aden, and 50 acoustically-tracked RAFOS floats were deployed at the RSW level (650 m), during cruises in February-March and August-September 2001. These time periods correspond to the peaks in the NE and SW Monsoons, and to the maximum and minimum outflow RSW transport through Bab el Mandeb. The In situ observations have revealed for the first time the hydrographic and velocity structure of large, energetic, deep-reaching mesoscale eddies in the Gulf of Aden. Both cyclones and anticyclones were observed, with horizontal scales up to 250 km (i.e., the width of the Gulf). Azimuthal velocities were observed to exceed 0.3 m/s, and speeds as high as 0.2 m/s reached down to the RSW level and deeper. The volume transport associated with one large anticyclone was about 20 Sv. Comparison of the velocity and salinity structure indicates that these eddies are vigorously stirring the RSW as it enters the Gulf of Aden, and possibly overwhelming any self-sustaining outflow boundary current. Post-cruise analysis of SeaWiffs imagery suggests that these eddies form in the Indian Ocean and propagate into the Gulf. Float trajectories will further reveal their structure and impact on RSW spreading.

### OS41Q-02 0845h

#### Red Sea Outflow Experiment (REDSOX): New Observations of the Descent and Spreading of Red Sea Water

William E Johns[1] (305-361-4054; wjohns@rsmas.miami.edu)

Hartmut Peters[1] (hpeters@rsmas.miami.edu)

Amy S Bower[2] (abower@whoi.edu)

David M Fratantoni[2] (dfratantoni@whoi.edu)

[1]Rosenstiel School of Marine and Atmospheric Science Division of Meteorology and Physical Oceanography,, 4600 Rickenbacker Causeway, Miami 33149, United States

[2]Department of Physical Oceanography , Woods Hole Oceanographic Institution, Woods Hole, MA 02543, United States

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