

## OS52B-0222 1330h POSTER

Multi-tracer constraints on ocean storage of anthropogenic CO<sub>2</sub>

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During the second phase of the Ocean Carbon-Cycle Model Intercomparison, 13 models simulated oceanic uptake of anthropogenic CO<sub>2</sub> for the period 1765 to 2000. For the 1980s, models agreed to within +/- 22% (1.99 +/- 0.43 Pg C yr<sup>-1</sup>, half the range over the mean). For the 1990s the OCMIP-2 models predict a 24uptake increase (2.38 +/- 0.53 Pg C yr<sup>-1</sup>), in contrast with the 1980s-to-1990s decrease predicted by the most recent IPCC Third Assessment Report Chapter 3. However, the IPCC's estimates are based on atmospheric O<sub>2</sub> measurements which are susceptible to error due to interannual variations in air-sea O<sub>2</sub> fluxes. It appears likely that the OCMIP-2 range for the modern uptake of anthropogenic CO<sub>2</sub> brackets real ocean uptake for four reasons: (1) the large model diversity; (2) the range of OCMIP-2 models bracket observed tracer constraints (CFC-11 along sections, global mean deep-ocean <sup>14</sup>C); (3) the simulated global storage of anthropogenic CO<sub>2</sub> correlates with the simulated global storage of CFC-11 and the simulated global-mean, deep-ocean natural <sup>14</sup>C; (4) the simulated global inventories of anthropogenic CO<sub>2</sub> bracket data-based estimates for that same tracer. In theory, the CFC-11 and C-14 data constraints should allow us to weight the models, and thus narrow uncertainties, based on how models perform in regards to matching ocean inventories of these independent tracers. Here we will discuss progress on this effort, in regards to global and regional inventories.

URL: <http://www.ipsl.jussieu.fr/OCMIP>

## OS52B-0223 1330h POSTER

## A 3-D Model of the Ocean Carbon Cycle: Sensitivity to the Biological Pump

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At the Canadian Climate Centre, an ocean carbon model is being developed and tested as part of a coupled carbon general circulation model for use in projections of future climate change. Different biotic pumps have been implemented. Initially a biotic pump has been incorporated as in OCMIP-2, generating the export production by restoring surface layer phosphate concentrations to observed levels. Results are much closer to observations than in the abiotic, solubility pump, model - although different initial conditions result in slightly different equilibrium solutions. Maps of sea-air CO<sub>2</sub> exchange for both abiotic and biotic simulations are compared with maps derived from observations. Maps of dissolved inorganic carbon and total alkalinity at different depths are compared with maps derived from recent data analyses. The biotic model replicates the clear differences between the North Pacific ocean and the North Atlantic ocean. A dynamic NPZD (Nutrient-Phytoplankton-Zooplankton-Detritus) biotic pump has also been implemented. Model results are compared to observations and to results from equilibrium solutions involving the phosphate-restoring biotic pump.

## OS52B-0224 1330h POSTER

## A 3-D Model of the Ocean Carbon Cycle: Sensitivity to Mixing Based on Bathymetry Roughness

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Earlier as well as more recent model circulation assessments using natural C-14 have revealed the possibility for large differences between ocean models in simulating deep ocean C-14 penetration, for example in the North Atlantic where many models appear to have too slow deep circulation resulting in an overestimation of the ventilation timescales for deep water renewal. Significant differences between models in simulating the vertical modes of circulation, many at variance with observations, have also been shown in recent studies using CFC-11 as a chemical tracer.

At the Canadian Climate Centre, an ocean carbon model is being developed and tested as part of a coupled carbon general circulation model for use in projections of future climate change. Experiments with the abiotic carbon model that included C-14 and CFC-11 exhibited similar tendencies: the mid to deep ocean circulation, especially in the North Atlantic, appeared to be too slow. As a remedy, a novel mixing scheme was incorporated in the model. It involves spatially variable eddy diffusivity as a function of sub-grid scale bathymetry roughness. Model experiments using this scheme instead of constant background eddy diffusivity resulted in noticeable improvement in the North Atlantic and the Pacific ocean circulations as diagnosed by the Delta-C14 ratio and CFC-11. Model results were compared to data.

## OS52B-0225 1330h POSTER

## New Techniques for the Remote Sensing of Trichodesmium

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Ocean color remote sensing of *Trichodesmium* spp. provides a method to estimate the importance of N<sub>2</sub> fixation in global ocean biogeochemical cycling. In order to do this a globally applicable bio-optical model must exist that relates the in situ *Trichodesmium* biomass to its water leaving radiance signal. A global dataset containing concurrent measurements of *Trichodesmium* abundance and radiometric measurements was compiled and used for model testing and development. Previous efforts have shown that empirical models are not sufficient and that alternative approaches must be developed. Here, state-of-the-art semi-analytic formulations are used to estimate *Trichodesmium*-specific quantities with varying degrees of success. In particular, a *Trichodesmium*-specific inverse reflectance model was developed and tested against available data. Preliminary results point to some fundamental differences between in situ and theoretical optical characteristics of this organism. These differences must be reconciled in order to achieve adequate predictive capability through the use of ocean color data. Additional techniques for estimating *Trichodesmium* biomass are also discussed.

## OS52C MCC: Hall D Friday 1330h

## Quantitative Developments in Coastal Oceanography II Posters

Presiding: K Brink, Woods Hole

Oceanographic Institution; E

Thornton, Naval Postgraduate School; J

Barth, Oregon State University

## OS52C-0226 1330h POSTER

## Chalk-Ex: An Ocean Optics Manipulation Experiment on the Fate of Calcite Particles

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Large-scale manipulation experiments such as Iron-Ex have allowed the testing of fundamental hypotheses about the ocean, not easily approachable with typical bench-style experimentation. Manipulation experiments provide tremendous insight by integrating the entire biogeochemical system into the results; they arguably give some of the most valuable tests for today's complex numerical models, at relatively fine spatial scales. One poorly understood biogeochemical cycle is that of CaCO<sub>3</sub>. About one quarter of the earth's marine sediment is CaCO<sub>3</sub>, much of which is composed of small coccoliths. How these particles are transported to the sea floor is still an open question. In this talk, we will present an overview of experiments from November 2001 from Continental Shelf and Slope waters off the NE U.S., in which Cretaceous coccolith chalk was dispersed into a patch of about 1.5 km<sup>2</sup> (dubbed "Chalk-Ex"). The chalks extremely well-defined light scattering and stable isotope properties made it possible to monitor the patch evolution and examine the importance of physical processes (horizontal shear, vertical mixing), grazing (macro- and micro-zooplankton), aggregation, interactions with dissolved organic carbon and sinking (estimated with drifting sediment traps). Lagrangian drifters were used to follow the patch and an instrumented drifter was used to characterize T-S properties over several days. From a particle perspective, the power of Chalk-Ex was that it simplified particle turn-over calculations. That is, while most particle experiments must simultaneously quantify both the

production and loss terms of the particles in question (often with limited statistical precision), in Chalk-Ex, the production term was known almost exactly, so that we could focus on subsequent loss terms. The process that appeared to be most important to the patch evolution was horizontal dispersion at the "injection density", driven by shear between the surface and the maximum injection depth of about 25 m. We observed a shift in the size spectrum of sub-micron particles in the patch as dissolved organic matter appeared to bind to the chalk. Aggregation of chalk particles was observed, but did not result in particles large enough to sink out of the mixed layer during the 48h trap deployment. Mesozooplankton did not appreciably consume chalk based on laboratory feeding experiments, but shipboard bottle experiments suggested that microzooplankton grazing may have been an important loss term for the chalk particles from the surface waters. Nonetheless, isotope analyses revealed that negligible Cretaceous chalk was collected by the drifting traps below the mixed layer. This indicated that the chalk was never concentrated into large enough particles (either biologically or physically) to rapidly sink and be intercepted by the traps. If it was concentrated into large particles, then an alternative hypothesis is that the chalk dissolved above the traps (associated with microbial or grazing activity). The patch was eventually "lost" between two horizontal intrusions. This talk will serve as an introduction to a series of posters to be presented in a parallel session.

#### OS52C-0227 1330h POSTER

##### Evolution of stratification and shear during ChalkEx-2001

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ChalkEx-2001 was a manipulative experiment wherein a known quantity of CaCO<sub>3</sub> (chalk) was injected into the surface mixed layer from a ship and tracked with the aid of Lagrangian drifters. After injection, the "chalk patch" was identified from spatial surveys using optical backscattering sensors on the ship and on a towed, undulating vehicle. The goal of the experiment was to identify and quantify the relevant physical and biological processes that remove CaCO<sub>3</sub> particles from the mixed layer. Observations of temperature, conductivity and horizontal velocity in the upper 100 m of the water column were used to characterize the evolution of stratification and shear during the experiment. The mixed layer depth and density at the time of chalk injection, and the subsequent development of stratification and shear were used to diagnose the development of the chalk patch due to vertical mixing and horizontal advection. The expected patch development was compared to the observed patch distribution as determined from spatial surveys. Although vertical mixing dictated the initial penetration depth of the chalk, patch development during the first 48 hours was controlled primarily by horizontal advection during a period of restratification. The horizontal displacement estimated from the shear between the surface and the maximum injection depth was consistent with the observed size and orientation of the patch.

#### OS52C-0228 1330h POSTER

##### Optical Results From the November 01 "Chalk-Ex" Ocean Optics Manipulation Experiment

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Suspended calcium carbonate particles in the sea create a significant amount of backscattered light and are highly relevant to a wide variety of processes ranging from radiative transfer to biogeochemical cycles. A large-scale ocean optics manipulation experiment (dubbed "Chalk-Ex") was performed in November of 2001 which involved adding Cretaceous coccolith chalk to seawater and following its fate over time (see overview abstract by Balch et al.). The chalk had extremely well-defined optical backscattering properties,

which allowed us to precisely map its distribution using several approaches: a towed, undulating, Scan-Fish equipped with a backscattering sensor, shipboard measurements of inherent optical properties, plus above-water radiometry measurements. We will present vertical sections and aerally-integrated estimates of the chalk during patch evolution. High-altitude images of the patch provided synoptic estimates of the patches shape and size. Moreover, the images illustrated the importance of wind-induced surface shear and confirm shipboard optical results. Backscattering of the chalk spread from its "injection isopycnal" and was gradually sheared into other density horizons, spreading in various horizontal directions. There was evidence of dissolved organic matter binding to the chalk, which, in a few cases produced significant "holes" in the spatial distribution of colored dissolved organic matter (as evidenced by results of the 412nm absorption for the <0.2m filtered size fraction). The patch was observed by the MODIS sensor aboard NASAs Terra spacecraft and the satellite estimates of calcite were within a factor of 2 of the values measured aboard ship. In terms of the mass conservation of chalk, it decreased exponentially through time (both on a mass-specific and area-specific basis). This was likely due to the combination of our ability to find the ever-expanding chalk patch as well as the possibility that microzooplankton were grazing on the chalk (see McManus et al. poster). Nonetheless, in a few specific regions, the integrated chalk per m<sup>2</sup> remained relatively constant over the first 32h (only decreasing about 25 percent). This suggested that the various loss processes (i.e., dissolution, grazing, aggregation and sinking) were negligible in these select areas over that time period.

#### OS52C-0229 1330h POSTER

##### Aggregation and Downward Export of Particles During Chalk-Ex 2001

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About one quarter of all marine sediment on earth is CaCO<sub>3</sub>, with a large fraction being composed of small coccoliths. Chalk-Ex is an interdisciplinary effort designed to identify and quantify the relevant physical and biological processes that remove CaCO<sub>3</sub> particles from the mixed layer (see overview presentation by Balch et al.). In November 2001 in waters from the continental shelf and slope waters off the NE U.S., Cretaceous coccolith chalk was dispersed into a patch of about 1.5 km<sup>2</sup>, and the calcite particles were tracked for several days. One of the possible fates of the dispersed particles was aggregation and subsequent sinking from the mixed layer. Here we present results of aggregation experiments and drifting sediment trap collections made during this experiment. On-board aggregation experiments were performed in Couette devices with water collected from the chalk patch and in later independently seeded with the Cretaceous chalk. GPS-equipped drifting sediment traps, located at the base of the mixed layer, were deployed within and outside the chalk patch. The inside-patch trap drifter appeared to track the major chalk layer which was concentrated between 5-20 m. The Couette device experiments revealed that the calcareous particles indeed underwent significant aggregation, possibly aided by colloidal pumping and DOM binding onto the chalk particles (see presentation by Goes et al.). However, the inside-patch and outside-patch traps collected similar fluxes of CaCO<sub>3</sub> and organic carbon which were not significantly different. Additionally, stable oxygen and carbon isotope analyses and microscopic observations of the collected sediment trap material revealed that negligible Cretaceous chalk in the form of aggregates or biogenic fecal pellets was collected by the drifting traps below the mixed layer. Hence, aggregate-induced particle sinking did appear to be a major mechanism of calcite removal from the mixed layer during the November Chalk-Ex program. This situation may change in the upcoming 2003 spring chalk experiment in which we anticipate higher zooplankton abundance and organic aggregate formation relative to the late fall.

#### OS52C-0230 1330h POSTER

##### Evidence of DOM Removal by Cretaceous CaCO<sub>3</sub> Particles During Chalk-Ex 2001

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Any process that regulates the distribution of dissolved organic matter (DOM) in seawater assumes considerable significance, given the role of the DOM pool in radiative transfer, remote sensing and carbon sequestration into the oceans. Since particles that constitute the DOM pool are not dense enough for sinking to be the dominant removal process, their transport into the deep ocean interior has often been associated with advection of the source water mass. In recent years, a growing body of evidence linking DOM with inorganic particles has led to the belief that scavenging and ballasting of DOM by inorganic mineral particles could play an important role in DOM removal from the upper ocean. ChalkEx-2001 was a largescale manipulative experiment, which involved dispersing a known quantity of Cretaceous chalk into seawater and following its fate by shipboard optical surveys, Lagrangian drifters and sediment traps (see Balch et al. presentation for experiment overview). These experiments provided us with the opportunity to assess the importance of DOC binding onto CaCO<sub>3</sub> particles. Flow Field-Flow Fractions of sub-micron particles and dissolved organic carbon measurements in samples obtained from discrete depths prior to, and following deployment of the chalk, provided clear evidence of DOM scavenging by CaCO<sub>3</sub> particles. Proof of DOM binding onto the chalk particles was also apparent from the continuous absorption measurements at 412nm of 0.2m pre-filtered seawater, which showed extreme lows in the distribution of colored dissolved organic matter coincident with patches of chalk (see also poster by Bowler et al.). The DOM scavenging capacity of the cretaceous coccolith chalk particles was also evident in independent laboratory investigations. The significance of these findings is that CaCO<sub>3</sub> particles, by virtue of their ability to scavenge DOM, could potentially accelerate the transport of DOM to the deep sea.

#### OS52C-0231 1330h POSTER

##### The Role of Sea-Breezes in Nearshore Cold Water Events a Southern California Case Study.

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Nearshore cold-water events lasting a few hours or less have been observed at many locations in southern California and around the world. These cold surges are normally associated with the internal tide, and understood as a run-up of an internal bore to depths shallower than the mean thermocline depth. However, at a number of locations in the mid-ocean, Chile and South Africa, it has been noted that the diurnal signal is surprisingly strong and often stronger than the semi-diurnal variability in observed nearshore temperatures, in spite of the fact that diurnal frequencies are sub-inertial at latitudes above 30 degrees. The diurnal signal is particularly strong near-surface and near to the shore. Although this could be partly due to local surface heating, the amplitude of the diurnal heat gain is generally too large and it is concluded that cross-shore advection plays an important role in the observed thermal nearshore. Data collected from an array of thermistors and acoustic current profilers off Huntington Beach allow for a detailed description of this diurnal signal. Analysis of these data indicates the importance of the daily sea-breeze in forcing diurnal movements of the thermocline that result in daily intrusions of sub-thermocline water into nearshore waters.

#### OS52C-0232 1330h POSTER

##### Low Frequency Modulations in the Response of Coastal Sea Level to Winter Storms

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One of the predicted consequences of global warming is an increase in the "storminess" of the atmosphere. This could be manifested as more frequent or more intense storms, for example. Clear evaluations of such a trend, however, have been difficult to make. Recently Zhang et al. (2000, *Journal of Climate*, vol. 13, 1748-1761) attempted to make such an evaluation using coastal sea levels from the Atlantic coast of the United States, but did not find evidence of a trend.

We have modified the techniques used by Zhang et al. somewhat, and have extended the spatial area to include the Gulf of Mexico and Atlantic coasts of the southeast United States. In the areas affected by a storm track due to cyclogenesis in the northeast Gulf of Mexico, the de-tided hourly sea level data from the coastal tide gauges show a remarkable response to these winter storms, with sea level changes on the order of a meter in less than 12 hours being common. While the dynamics of this response is inherently interesting, we instead focus on the low frequency modulations of these storm events. The coastal sea level records are well-suited for this purpose because of the long record length, and the homogeneity of the observing system over time.

We find a marked increase in the energy in the events in the latter half of this century. There is evidence of a slight increase in the average intensity of the storms, but the increase is primarily due to a substantial increase in the frequency of these events. While a change is easy to document, it is unclear whether this change is part of an interdecadal variation or a long-term trend due to global warming.

#### OS52C-0233 1330h POSTER

##### The Onshore Transport of Cold Water During an Upwelling Regime on the New Jersey Shelf

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A comprehensive dataset obtained in summer of 1996 on the New Jersey shelf off Atlantic City is analyzed to determine the pathway for cold water during a period of sustained upwelling. The data include shipboard CTD/ADCP surveys, time series from three across-shelf lines of moorings and remote sensing. An upwelling event that occurred from June 30 through July 11, 1996, is studied. The event comprised three stages: first, the cold water was upwelled through the bottom Ekman layer; second, the onshore flow concentrated in the pycnocline; third, mesoscale eddy-like features developed. The first gust of upwelling-favorable wind that lasted approximately 2 days generated a northward alongshelf current through the whole water column with corresponding onshore Ekman transport in the bottom mixed layer. After that, an alongshelf pressure gradient was set, which forced alongshelf flow in the opposite direction compared to the wind stress. As a result, southward flow was observed near the bottom until the end of upwelling cycle prohibiting onshore Ekman transport. The onshore flow was maintained through the pycnocline, with the maximum velocities at 10-12 m depth. At the same time, the temperature anomaly transport (pathway for colder water) was centered at 14-17 m depth that corresponded to the lower part of the pycnocline. This onshore flow was primarily balanced by alongshelf pressure gradient while the acceleration of alongshelf current was less important. Approximately six days after the onset of upwelling, mesoscale currents began to dominate the study area, thus establishing three-dimensional flow field with spatially localized (in alongshelf direction) onshore currents. In particular, the cyclone of approximately 25 km in diameter occupied the northern part of the study area.

#### OS52C-0234 1330h POSTER

##### Hydrographic Conditions in the Gulf of Carpentaria During Australian Monsoon Experiment

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Gulf of Carpentaria located in the northern Australia, is a shallow wide basin with the deepest bottom depths of approximately 60 m. It is connected to Arafura Sea to the north and west, and to the Torres Strait to the east. Hydrographic surveys of the Gulf of Carpentaria were carried out in January and March, 1987 as part of Australian Monsoon Experiment. During the January survey, Tropical Cyclone (TC) Irma was formed in the Gulf of Carpentaria. An east-west CTD section at 13052S was occupied twice, one prior to and during, and the other after the formation of TC Irma. In addition, two post-Irma east-west sections were occupied at 12040S and 11030S. The pre-cyclone section indicates a well-defined stratified two-layer system, while the post-cyclone sections show deepening of the surface warm layer due to significant mixing by TC Irma. Overall, significant cooling of near surface warm water on the order of more than 10°C was observed. Significant heat loss estimated for the water column has presumably contributed toward the development of TC Irma. In February 1987, TC Jason was formed in the gulf. During the March survey, two east-west CTD sections were occupied at 11030S and 13052S. The March survey reveals notable warming of the bottom water. Detailed discussion of the CTD data from the two cruises will be presented.

#### OS52C-0235 1330h POSTER

##### Near-Inertial Current Variability During the Coastal Mixing and Optics Experiment, August 1996 through June 1997.

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Observations from the Coastal Mixing and Optics moored array (deployed from August 1996 through June 1997) are used to describe near-inertial current variability over the New England shelf. Inertial band current variability is large, approximately 20% of the total observed variance, and episodic with peak speeds exceeding 40 cm s<sup>-1</sup>. Near-inertial current variability during CMO is characterized by a first baroclinic mode vertical structure and constant phase over 20 km separations. Several characteristics of inertial current variability co-vary with the seasonal variation in stratification over the New England shelf. Inertial band variability is stronger during stratified periods (late spring through early fall). The vertical structure is also surface intensified. Episodes of inertial variability during the fall occur at subinertial frequencies (5-10% less than the local inertial frequency,  $f$ ), while spring variability occurs at or above the inertial frequency. Wavelet analysis is used to identify the intrinsic frequency of bursts of inertial variability and compared to the effective inertial frequency estimated from the subtidal relative vorticity. Relative vorticity over the shelf during fall is approximately -0.05 $f$ , due to a seasonal strengthening of the along-shelf flow and cross-shelf gradients. The intrinsic and effective inertial frequencies are very similar.

#### OS52C-0236 1330h POSTER

##### Short-Term Variability on the Scotian Shelf

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The traditional view of the production cycle on the continental shelf of Nova Scotia features a spring bloom followed by a period of low production and a less intense fall bloom. The annual cycle of primary productivity thus has a large, low frequency component. However, there is increasing evidence that the production cycle has significant variability on shorter time scales.

Physical, chemical and biological variability on the Scotian Shelf is examined on a daily to weekly timescale. This is accomplished through the use of a newly developed mooring platform (SeaHorse) that uses surface wave energy to enable the instrument to climb down the mooring wire and then float upwards while sampling the water column. This provides bi-hourly

profiles of temperature, salinity, pressure and chlorophyll at one location over month-long periods. Results from the three-week deployment in October 2000 indicate a subsurface chlorophyll maximum below the pycnocline during the first part of the time series. An event occurred in mid-October during which the temperature, salinity and density iso-surfaces rose approximately 25 m. During this event, a small bloom, with peak chlorophyll concentrations of about 2 mg m<sup>-3</sup> and duration of several days, began as nutrients were brought into the upper part of the water column by upwelling-favorable winds. SeaWiFS ocean color satellite images were valuable in providing a spatial context for chlorophyll concentrations, however, the lack of temporal resolution due to poor quality images means that this data set provided limited information for short-term chlorophyll variability. Gradient Richardson Numbers were estimated for 2 m vertical bins using SeaHorse CTD data and nearby ADCP current measurements. A trend of decreasing Ri in the ocean mixed layer with increasing surface wind stress is suggested.

#### OS52C-0237 1330h POSTER

##### Form Drag on Flow Across a Sloping Ridge

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Observations and numerical simulations of tidal flow past a sloping ridge are presented, focusing on the form drag. The ridge is Three Tree Point, in Puget Sound, WA, which at the surface is a sharp, 1 km wide headland. Subsurface, the Point is a ridge sloping down to 230 m depth. Stratified, tidal flow past this feature gives rise to both a horizontal vortex and an internal lee wave. The vortex is associated with form drag on the ridge due to the surface height deformation, while the lee wave has form drag associated with the baroclinic structure. On three recent cruises we have gathered data using drifters, ship and moored ADCP, CTD, and microstructure profilers. From these we may view the 3D flow field as it evolves over the flood tide, and we may calculate estimates of both types of form drag. These are compared quantitatively with numerical simulations from the Hallberg Isopycnic Model. Modeled and observed flows differ in some details, particularly near the boundary at the ridge crest, but also show good agreement in the overall flow structure. We find in observations and simulations that both types of form drag predominate over the frictional boundary layer drag, by factors of 6 to 14. This is not just for the Point itself, but for a 9 km segment of the channel (a distance over which such headlands are distributed in the Sound). This large enhancement of the net drag over a standard boundary layer formulation is consistent with previous barotropic, section-averaged, modeling of tides in Puget Sound, which found that a very high effective drag coefficient was required in order to match observed tidal phase and amplitude. Our findings imply that such topographic features may provide the main mechanism for extracting energy from the barotropic tide in such regions, instead of the bottom boundary layer. Further, the extracted energy is put into large eddies which rapidly stir tracers, and into breaking lee waves which cause diapycnal mixing at all depths.

URL: [http://www.ocean.washington.edu/people/faculty/parker/rough\\_topography.htm](http://www.ocean.washington.edu/people/faculty/parker/rough_topography.htm)

#### OS52C-0238 1330h POSTER

##### Estimates of Form Drag from Drifter Tracks

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Estimates of the barotropic component of the form drag due to tidal flow past a sharp headland are presented. The calculation uses GPS drifter data obtained over a nine-day period in June 2002, at Three Tree Point (TTP) in Puget Sound, WA. Ten drifters were drogued at 20 meters depth and seeded throughout the

flood tide near the headland. Daily drifter tracks were time-referenced to maximum flood and all tracks were then combined in order to map the surface height deformation around TTP. The surface height field is estimated (to within a constant) using the horizontal momentum equations. The Lagrangian acceleration and Coriolis terms are measured directly by the drifters. The baroclinic contribution to the pressure gradient is negligible because the drogues are shallow relative to the bathymetry. The frictional contribution is also negligible, because the drogues are below the surface boundary layer, leaving only the barotropic pressure gradient to balance the acceleration. The resulting surface height anomaly field may be used with bathymetric information to arrive at estimates of the form drag. Variations in the form drag along TTP, and in time, are discussed. The net form drag is at least an order of magnitude greater than the frictional boundary layer drag in this location.

#### OS52C-0239 1330h POSTER

##### Three-Dimensional, Time-Dependent Flow near a Continental Shelf Submarine Bank

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Recent advances in towed, undulating vehicle capabilities have allowed rapid, high spatial resolution surveys of physical and bio-optical properties to be made over the continental shelf and slope. Together with shipboard acoustic Doppler current profiling, this has made possible the exploration of three-dimensional, time-dependent processes in regions with alongshore variations in coastline geometry or bottom bathymetry. The summertime wind-driven flow off central Oregon to the north of and over a substantial submarine bank has been the focus of several recent studies. The equatorward, wind-driven, mid-shelf upwelling jet flows offshore following the isobaths as they widen around the bank. On the downstream side of the bank, some recirculation is observed, but most of the flow continues equatorward albeit displaced seaward of the continental shelf break. Inshore in the "lee" of the bank, currents are weaker throughout the water column and a low-temperature, high-salinity bottom water pool is supplied from both upstream and from recirculation. The flow-topography interaction results in an along-shore pressure gradient that can drive northward currents on the inner part of the shelf when winds relax. Strong northward winds during the summertime upwelling season lead to downwelling within 15 km of the coast accompanied by significant ( $\geq 0.2 \text{ m s}^{-1}$ ) wind-driven northward currents. Seaward of this northward flow, the equatorward jet and isopycnals sloping up toward the coast still remain. The time-dependent and three-dimensional aspects of this system can lead to recirculation around or retention of water on the bank, significantly influencing the coastal ecosystem response in this shelf region.

URL: <http://damp.coas.oregonstate.edu/coast>

#### OS52C-0240 1330h POSTER

##### Quantifying the Effects of Small-Scale Processes on the Circulation of the Coastal Ocean

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Because of the great range of small-scale variability coexisting with the larger scale current system, obtaining meaningful measurements of small-scale processes in the coastal ocean is an experimental challenge. Over the past few years, we have attempted to make progress by investigating individual phenomena in isolation. Using our vertical turbulence profiler, Chameleon, ADCP and ancillary other observations, we have devised strategies to try to determine the effects of small-scale topography and internal solitary waves. By profiling into the ocean bed, we obtain measurements to within 1 cm of the bottom. This has helped us in quantifying bottom drag and allows a new view of the behavior of the bottom boundary layer in response to variable upwelling conditions. Three sets of experiments are briefly reviewed. The challenge to modelers is to determine how to incorporate spatially local and temporally intermittent states of high drag and fluxes into coastal circulation models.

URL: <http://mixing.coas.oregonstate.edu>

#### OS52C-0241 1330h POSTER

##### High-Resolution Measurement of Density and Velocity in a Laboratory Scale River Plume

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River inflows are an important source of nutrients, sediments and contaminants to the coastal ocean and initiate much of the buoyant along-coast transport. In large-scale, surface trapped inflows (e.g. the Columbia and Niagara Rivers), the circulation near the mouth is dominated by an anticyclonic eddy, or bulge, that accumulates a significant fraction of the river discharge. The dynamics of this bulge region are therefore important in determining the distribution of buoyancy and river-borne matter along the coast.

We carry out laboratory experiments on a 2-meter rotating table combining Particle Image Velocimetry and Laser Induced Fluorescence to obtain simultaneous, high-resolution measurements of density and velocity in an idealized buoyant plume. The results of these experiments demonstrate how vorticity is partitioned in the plume and explain why transport away from the river mouth is higher for plumes with lower inflow Rossby number. We also compare the laboratory results directly with results from field scale numerical model runs using ECOM3D. We find that leftward turning tendency often observed near the river mouth in numerical models (and rarely observed in the field) does not occur in the laboratory model indicating that the vorticity dynamics are significantly different in this region.

#### OS52C-0242 1330h POSTER

##### Observations of Energetic Internal Waves in and Under the Kuroshio

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Western boundary currents have been studied for a long time, although most of the work has been done in measuring the mean structure and mean transport. Observations obtained as part of the ASIAEX Program in Spring 2000 pointed out the presence of highly coherent small shear structures in the Kuroshio. The geostrophic shear associated with the Kuroshio front constituted less than half of the observed rms shear, the majority being associated with large baroclinic wavelike features found in and under the core of the current.

To further investigate the nature and importance of these structures, new hydrographic and velocity measurements of the Kuroshio were taken in April 2002 South-East of Kyushu. Both shipboard and lowered-ADCP were used to measure the current. Several transects were obtained as well as a 30-h time series in the core of the Kuroshio. Energetic shear structures were again seen and appeared to propagate across isopycnals. The geostrophic vorticity at the site significantly modifies waves generated both locally and remotely. Dynamical models of the Kuroshio must account for the dissipative aspects of these very high shear wave groups.

#### OS52C-0243 1330h POSTER

##### Frontogenesis at the Mouth of Block Island Sound Evaluated by a Primitive Equation Model Incorporating ADCP Data

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In the shelf waters of the New York Bight, near the southern boundary of Block Island Sound and just east of Long Island, fronts in temperature and salinity are frequently observed in remotely sensed data and hydrographic surveys. We explore the dynamics of these features using a 3-dimensional primitive equation

model forced by tides, wind stress, thermal fluxes and large-scale buoyancy gradients. Quantified model/data agreement is substantially increased by applying additional low-frequency boundary velocities deduced using a linear, depth-averaged inverse model that incorporates observations from two upward-looking ADCPs. The area is dynamically rich with several processes that contribute to and/or alter the structure and location of the fronts. Salinity gradients are established by the relatively fresh outflow from Long Island Sound merging with shelf waters. Temperature gradients develop through vertical mixing generated by tidal bottom stresses. These gradients are sharpened and shifted by the subtidal flow. One component of this motion is the tidally-induced residual flow which includes an eddy just south of the headland, Montauk Point. Larger-scale, low-frequency motion results from both the temporally varying wind stress and the data-derived boundary velocities. We discuss the relative role of each of these processes toward the formation and positioning of fronts observed in the region.

#### OS52C-0244 1330h POSTER

##### Frontal Scales in the Coastal Ocean and Laboratory

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Regions of rapid change in the salinity, temperature and color in the coastal ocean have been referred to as fronts. Because of the small length scales, they are frequently unresolved by hydrographic surveys. Only recently have field campaigns been able to quantitatively depict the smallest scales of the coherent structures. Lab experiments on dynamically analogous flows but the relationship to the field observations are unclear. We report a synthesis of the results of several field campaigns conducted in the last few years and compare the results to those of lab experiments. We find good agreement. On the basis of these results, we comment on the scales that models need to resolve in order to adequately describe the circulation and mixing in the coastal ocean.

#### OS52C-0245 1330h POSTER

##### Decay of the Intraseasonal Sea Level Signal in the Gulf of California

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The Gulf of California is wider than twice the baroclinic radius of deformation for most of its length and so in theory allows an incident intraseasonal (1-2 month period) sea level signal to propagate around its coast without significant change in amplitude. But analysis of coastal sea level shows that the intraseasonal signal is strongly attenuated in the Gulf of California in the direction of Kelvin wave propagation. The attenuation is approximately linear and the sea level amplitude at the tip of Baja California is only 50% of the incident amplitude.

This attenuation may be due to the decreasing water depth along the Gulf from its entrance to its end. A low-frequency ( $\omega \ll f$ ) linear theory for a continuously stratified ocean with Gulf bottom topography approximated by a series of steps is used to test this hypothesis. At each step the transmitted signal propagating northward along the eastern coast and the reflected signal propagating across the Gulf and then southward along the western coast are determined.

The model predicts that sea level amplitude decreases along the eastern coast due to the decreasing transmitted signal. As the wave reflects from the end of the Gulf and travels back into deeper water along the western coast, it combines with the reflected energy and, depending on frequency, coastal sea level can increase or decrease as the waves interfere with each other. Strong alongshore intraseasonal currents, deep in the water column, are generated by reflection from the shoaling Gulf topography.

OS52C-0246 1330h POSTER

### Equatorial to Mid-Latitude Connections in Eastern Boundary Currents

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Over twenty years ago, Enfield and Allen (1980, *J. Phys. Oceanogr.*, 10, 557-578) used tide-gauge sea level height data to show the connection between the equator and the mid-latitude coastal ocean in the eastern Pacific. Careful selection of tide gauges and quality control of the data allowed both seasonal and interannual time scales to be examined over a period of 24 years. Today, 10 years of TOPEX/POSEIDON altimeter data allow us to re-examine the seasonal and non-seasonal connections between the equator and higher latitudes in the eastern boundary currents (EBC's) along the coasts of the Pacific and Atlantic Oceans. We present the seasonal progressions in both basins and hemispheres, showing the low-to-high latitude development of the seasonal cycle and also the offshore propagation of annual Rossby waves. This brings out several general tendencies: 1) The signals are stronger in the Northern Hemisphere basins, due to the fact that the ITCZ is located north of the equator in both basins; 2) The signals are stronger in the NE Pacific than in any of the other basins; and 3) There is an annual signal of high sea surface height that propagates down both Southern Hemisphere EBC's in austral spring (September-November) as the SW trade winds weaken along the equator and the equatorial cold tongue collapses. This last feature is somewhat like an annual "El Nio" effect and acts to suppress the onset of wind driven upwelling in the Peru-Chile and Benguela Current Systems.

OS52C-0247 1330h POSTER

### Sea-Surface Topography and Precise Geodesy From Aircraft: Applications to Coastal Oceanography

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Highly dynamic coastal ocean processes occur at temporal and spatial scales that cannot be captured by present or planned satellite altimeters. Space-borne gravity missions such as CHAMP, GRACE and GOCE also provide time-varying gravity and a geoidal msl reference surface at resolution that is too coarse for many coastal applications. The Naval Research Laboratory and the Naval Oceanographic Office have been testing airborne measurement techniques, gravity and altimetry, to determine sea-surface height and height anomaly at the short scales required for littoral regions. We have developed a precise local gravimetric geoid over a test region in the northern Gulf of Mexico from historical gravity data and recent airborne gravity surveys. The local geoid provides a msl reference surface with a resolution of about 10-15 km. A series of altimetry reflights over the region with time scales of 1 day to 1 year reveal a highly dynamic environment with coherent and rapidly varying sea-surface height anomalies. Although wind-driven topography may also be a factor, airborne expendable bathy-thermograph (AXBT) data collected at the same time show apparent correlation with wave-like temperature anomalies propagating up the continental slope of the Desoto Canyon. The observed variability may be responsible for some part of the long-term average topography calculated by differencing the gravimetric geoid with a satellite altimetry msl reference.

OS52D MCC: Hall D Friday 1330h

### Ocean Eddies, Mixing, and Turbulence Posters

**Presiding: P A Rona, Rutgers University; D M Fratantoni, Woods Hole Oceanographic Institution**

OS52D-0248 1330h POSTER

### The Reddy Maker

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For years I have been looking for an explanation for eddy formation in the absence of both classical instability and a detachment from a corner. I have been interested in such a process because some eddies are formed without any of the above two processes being present. The "Reddy maker" represents such a new mechanism. Specifically, we propose a new process for the formation of high-amplitude anticyclonic eddies (lenses) from outflows emptying into the ocean at mid-depth. The essence of the new mechanism is that, in order for an inviscid outflow to exist as a continuous (uninterrupted) current, the condition  $g'S/f > \alpha(g'H)^{1/2}$  [where  $g'$  is the "reduced gravity",  $S$  the bottom slope,  $f$  the Coriolis parameter,  $\alpha$  a coefficient of order unity whose value depends on the potential vorticity and  $H$  is the maximum thickness] must hold. When this condition is not met, the outflow can only exist as a chain of propagating eddies.

An outflow advances primarily along the isobaths but usually slowly descends toward the bottom of the ocean due to frictional effects. Most of the time, this descent is accompanied by a reduction in the bottom slope and by entrainment, both of which bring the outflow closer and closer to the above critical condition. It is, therefore, argued that most outflows ultimately reach the critical point and break into chains of propagating eddies (unless they are first destroyed by diffusion and mixing). This is not the usual instability process associated with the breakdown of a steady solution, because, in this case, a steady solution cannot exist.

URL: <http://www.doronnof.net/features.html#video>

OS52D-0249 1330h POSTER

### North Brazil Current Ring Collisions With the Lesser Antilles

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The earth's largest ocean rings are spawned near 8°N in the western tropical Atlantic from the equator-crossing North Brazil Current (NBC). NBC rings, which can exceed 450 km in diameter and 2000 m in vertical extent, translate northwestward parallel to the South American coastline until they collide with the Lesser Antilles in the southeastern Caribbean Sea. The rings entrain filaments of nutrient- and sediment-rich Amazon and Orinoco River discharge, impact the distribution of ichthyoplankton, and pose a physical threat to expanding offshore oil and gas exploration. The six rings generated annually are also responsible for up to one-third of the equatorial-to-subtropical mass and heat transport associated with the Atlantic meridional overturning circulation, a fundamental component of the earth climate system. Recent RAFOS float and surface drifter trajectories illustrate the translation and structural evolution of several NBC rings and enable the determination of the downstream fate of South Atlantic water trapped within the ring core. These results indicate that NBC rings do not enter the Caribbean Sea intact as simulated by numerical ocean models but are instead sheared apart through topographic interaction along the eastern flank of the Lesser Antilles.

URL: <http://science.whoi.edu/users/dfratantoni>

OS52D-0250 1330h POSTER

### Influence of Multiple Islands and Their 3-D Geometry on the Bifurcation of Eddies

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A recent study investigated the interaction of a self-propagating barotropic cyclonic eddy with a right vertical cylinder and determined the conditions for an eddy to bifurcate into two eddies. In the present study we performed two series of idealized laboratory experiments. The first series investigated the importance of the geometry of the obstacle, in particular its height, the slope of the side walls and the geometry of the horizontal cross sectional area. As in the previous study, after a self-propagating cyclonic eddy came in contact with the obstacle, fluid peeled off the outer edge of the vortex and a so called "streamer" went around the cylinder with a counterclockwise velocity. Under the right conditions, this fluid formed a new cyclonic vortex in the wake of the cylinder, causing bifurcation of the original vortex into two vortices. The present results suggest that bifurcation occurs only when the obstacle height is more than 0.85% of the eddy height and that fairly steep sloping walls do not influence the bifurcation mechanism. In addition, an elliptical horizontal cross section of the obstacle brought into light that an important parameter for the bifurcation to occur is the length the "streamer" has to travel around the obstacle and not the dimension of the obstacle in the direction orthogonal to the flow. The second series of experiments investigated the importance of two obstacles to the bifurcation of the self-propagating cyclonic eddy. Multiple eddies were generated by the interaction of a single cyclonic eddy with two right vertical cylinders. The exact number of eddies depends on the ratio of the obstacle separation to the eddy size and the geometry of the encounter. Furthermore, we observed the formation of an eddy of opposite sign, anticyclonic, at the downstream side of the gap between the two obstacles. This last observation in the laboratory is in agreement with recent observations of North Brazil Current Rings, suggesting that these very idealized laboratory experiments may bring some insights to the fate of mesoscale vortices in the Ocean.

OS52D-0251 1330h POSTER

### Gravitational potential energy sinks/sources in the oceans

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Gravitational Potential Energy (GPE) is lost during convective adjustment. Using climatological datasets, the annual mean GPE loss due to convective adjustment in the world oceans is estimated as 0.11TW. GPE conversion from the mean state to eddies is also estimated, using the commonly accepted Gent-McWilliams scheme. Our estimate is that about 1.7TW is converted from mean state into eddy GPE.

The known sources of GPE are: wind stress work on the geostrophic current (1.3TW, but it is unclear how much of this energy can be converted into GPE) and tidal dissipation rate in the deep ocean (0.9TW, corresponding to 0.18TW after conversion through mixing), near-inertial gravity waves (0.7TW, corresponding to 0.14TW after conversion through mixing), and gravitational GPE generated by geothermal heating (0.05TW).

This indicates a large imbalance in the GPE balance in the oceans. It is speculated that there might be large source of GPE that has not been counted in the current estimates. For the current climate setting, a large amount of heat is lost in the North Atlantic. As a result, the mixed layer penetrates deep and the amount of GPE loss due to convective adjustment is large. In addition, conversion through the baroclinic instability is relatively strong in the North Atlantic. In order to maintain the balance of heat and GPE, northward transport of heat and GPE is required.