OS31Q-08 1020h

Diapycnal Mixing and Deep Stratification in an Idealized Ocean General Circulation Model

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The effect of diapycnal mixing on deep stratification and abyssal flow is examined in an idealized single-hemisphere ocean general circulation model. Horizontally, diapycnal mixing is confined to the margins, crudely mimicking boundary mixing. Where deep mixing is located, the stratification is maintained largely through vertical advective-diffusive balance with the vertical velocity a function of the mixing strength. We present three runs, control (diapycnal diffusivity independent of depth), strong deep mixing (exponential increase in diffusivity with depth below the thermocline), and weak deep mixing (exponential decrease in diffusivity with depth below the thermocline). As compared to our "control" run, stratification is weaker for both our experimental "strong" and "weak" deep mixing scenarios. Diffusive mixing plays only a small role in the deep ocean heat budget. Rather, the balance is largely between advective transport of downwelling buoyant flow into the abyss and cooling through convective mixing and vertical eddy transport (the latter represented through the Gent-McWilliams mesoscale eddy parameterization). These results suggest that deep mixing is not necessary to support a strong deep MOC, as is widely thought; moreover, these results question whether strong deep mixing in the real ocean can explain the observed deep stratification, implying that other mechanisms for stratification may be necessary.

OS31Q-09 1035h

Spurious diapycnal mixing of the deep waters in an eddy-resolving global ocean model

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Recent idealized studies have shown that both explicit horizontal diffusion and the implicit diffusion associated with the advection scheme in high resolution z-coordinate models may drive unrealistically high rates of diapycnal mixing. Our aim here is to see whether the diapycnal mixing associated with the advection scheme in a global eddy-permitting ($1/4^{\circ}$ by $1/4^{\circ}$) z-level model is sufficiently strong to corrupt the thermohaline circulation. We diagnose the diapycnal fluxes by using the ideas of water mass transformation.

In the Southern Ocean, the model deep and bottom waters drift rapidly away from the Levitus climatology, with dense isopycnals moving downwards at rates of up to 35 m year^{-1}. The strong upward flux (up to 50 Sv) through the dense isopycnals cannot be explained by the incorrect surface forcing (as a result of poor surface fluxes and no ice model) as most of the anomalous diapycnal fluxes are occurring in the deep ocean far from surface forcing. Hence, the excessive diapycnal flux is driven by diffusion in the model, both explicit and implicit.

The 'effective' diapycnic diffusivity driven by the numerical diffusion (associated with the horizontal advection scheme) is found to be the same order, 1–10 cm^{2}s^{-1}, as that driven by the explicit horizontal diffusion. For strong vertical velocities ($\sim$ 20 m day^{-1}) as in models forced by high frequency winds, the vertical advection scheme also gives similar effective diffusivities. These effective diffusivities are considerably greater than suggested by observations. To alleviate these problems, we suggest that eddy-resolving z-level climate models will require (1) less diffusive horizontal advection schemes and (2) better vertical resolution throughout much of the water column.

OS31Q-10 1050h

Water mass formation and transformation in the Pacific

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Water mass formation is defined in terms of subduction, calculated by following the Lagrangian trajectories downstream for one year. The process opposite to water mass formation is water mass elimination: it is defined in terms of obduction, calculated by following the Lagrangian trajectories upstream for one year (backward in time and space). The subduction and obduction rates integrated over a closed basin should be balanced, while diapycnal mixing can only transform water masses within different density ranges. Although subduction has been widely accepted as the accurate way for counting water mass formation, so far an appropriate counting method for the water mass elimination has not been adopted in our community.

Using the Lagrangian definitions of subduction and obduction, water mass formation and elimination rates for the Pacific are calculated, based on results obtained from an oceanic general circulation model. There is strong subduction and obduction in both the tropics and the subtropics, and they contribute to strong tropical–subtropical cells and a subpolar cell of intermediate strength in the Pacific.

OS31Q-11 1105h

Southeast Pacific Subtropical Mode Water

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In the eastern subtropical South Pacific south of 15°S, the mixed layer in the boreal winter reaches a depth of at least 150 dbar and has high surface salinity values. In the boreal summer, a warmer and fresher layer caps off the water column, but the winter mixed layer characteristics persist as a subsurface mode with a core potential density anomaly near σ_θ = 25.3 kg m^{-3}. This feature is called Southeast Pacific Subtropical Mode Water. Within the formation region, the mode water core is generally cooler, fresher, and denser towards the southeast. The mode water is swept northwestward by the South Pacific subtropical gyre, and underlies the subtropical salinity maximum north of about 15°S. We study these shallow subtropical water masses, their circulation, and their formation using a combination of historical hydrographic data, synoptic WOCE sections and Argo float profiles.

OS31Q-12 1120h

The Effect of Mesoscale Eddies on the Subtropical Thermocline

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Understanding the structure of the subtropical thermocline is an important, indeed classical, problem in dynamical oceanography. Such classical theories have fallen into two camps — diffusive theories, following Robinson and Stommel, and advective theories, following Welander. And more recently it has been shown that, at least in the absence of mesoscale eddies, the subtropical thermocline consists of an advective upper part (a 'ventilated thermocline') with a diffusive base — that is, the lower part of the main thermocline is an internal boundary layer.

However, these theories are not complete. Among the most egregious omissions is that of the potential effect of mesoscale eddies, and here we explore that problem. We integrate to equilibrium a wind- and buoyancy-driven eddy resolving primitive-equations ocean model, set in idealized basin. We find that mesoscale eddies do have a significant quantitative affect on the structure of the subtropical thermocline, but that the signature of the two-thermocline model (an advective upper thermocline and a diffusive base) remains, even in the presence of vigorous eddying activity. We discuss the dynamics and thermodynamics of the flow, and present some simple theoretical ideas, drawing on notions of geostrophic turbulence, to partially explain some of our results.

OS31R HC: 316 C Wednesday 0830h

Transport and Transformation of Biogeochemically Important Materials in Coastal Waters II

Presiding: **B J Eadie,** NOAA - Great Lakes Environmental Research Laboratory**; S A Green,** Michigan Technological University

OS31R-01 0835h

The Use of a Mesoscale Meteorological Model to Downscale Observations in Coastal Waters

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In coastal waters, the transport of materials is strongly linked to meteorological conditions. However, owing to the difficulty of maintaining observing platforms in the marine environment, meteorological observations are relatively sparse. In this work, we will show how a mesoscale meteorological model can be used to downscale existing meteorological observations in a way that enhances the characterization of hydrodynamic conditions in coastal waters.

The process is as follows. All available observations are incorporated into a gridded meteorological analysis. This analysis then used in a meteorological model simulation employing the four dimensional data assimilation technique known as Newtonian Relaxation or nudging. This technique, in which the model solutions are weakly forced towards the analysis, provides a dataset in which time continuity and dynamic coupling among the various model fields is achieved. Hence, the model solution remains bounded by the observations and the horizontal resolution of the observations is effectively enhanced by the added time dimension.

This process is described for the passage of a major storm (cyclone) across the lower Great Lakes, an event that led to substantial resuspension of sedimentary material in Lake Michigan. A triply nested model domain structure was established, with an outer domain covering the Continental United States at 54 km grid spacing and an innermost domain covering Lake Michigan and surrounds at 6 km grid spacing. The four dimensional data assimilation was applied only on the 54 km domain, to ensure that the synoptic-scale meteorological conditions remained consistent with the analysis over a 7-day simulation period prior to and following the passage of the cyclone. By nudging only on the outermost domain, however, the solution on the interior domain is allowed to evolve within the constraints provided by the synoptic environment along the boundaries and the high-resolution model physics within the interior. Verification results, supplied by in-situ current observations for this case, show that the output from the hydrodynamic model forced by the meteorological model is significantly better than the output from this same model when forced by interpolated observations.

OS31R-02 0850h

Coastal Circulation and Exchange Characteristics During Winter in Southern Lake Michigan

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The intermittent satellite images has revealed episodic late winter-spring sediment plumes coinciding with northerly storms in southern Lake Michigan. A major inter-disciplinary observational program (Episodic Events Great Lakes Experiment, EEGLE)

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was initiated by NSF and NOAA to study the importance of these episodic events on the cross-margin transport and subsequent ecological consequences. As a part of EEGLE program instrumented moorings were deployed during the winter of 1999-2000 in southern Lake Michigan. The time series data of currents, winds, and temperature obtained from 1 January to 28 April, 2000 are analyzed to provide the kinematics description of the coastal flow and cross-isobath exchange characteristics in southern Lake Michigan. The data shows several current reversals coupled with changes in surface wind stress. The observations also show the signature of forced two-gyre circulation in the southern basin. The low pass filtered currents for the winter season shows significantly higher alongshore currents compared to cross-shore flow, however, during a particular southerly storm event cross-shore flow increased. This storm episode depicts a slightly higher horizontal turbulent exchanges and increased vertical current shear in comparison to the overall winter conditions.

OS31R-03 0905h

Modeling the episodic resuspension and transport of fine-grained sediments in Lake Michigan

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Recurrent storm-generated resuspension events in Lake Michigan have recently been the subject of a large multidisciplinary study sponsored by NOAA-COP and NSF-CoOP. Each of these events resuspends up to several million metric tons of fine-grained sedimentary material, which is several times the estimated total annual input of fine-grained material to the lake from the combined sources of shoreline erosion, atmospheric deposition, and tributary runoff. This presentation describes the development of an integrated hydrodynamic, wind-wave, and sediment dynamics modeling system to simulate these events. The numerical models used in this study are the Princeton Ocean Model for hydrodynamics, the GLERL/Donelan parametric wind-wave model, and a simple two-dimensional sediment dynamics model with one particle size class. The results for the large resuspension event which occurred in March of 1998 show many of the characteristics of the lake-wide turbidity pattern as observed in satellite imagery. However, a large vortex-like feature about 20 km in diameter, which is prominent in the satellite imagery, is not reproduced in the model simulations. The modeled net sediment transport during this episode shows a similar distribution to the observed long-term net sediment deposition rate in southern Lake Michigan, possibly indicating that most of the net fine-grained sediment transport occurs during these episodic events.

URL: http://www.glerl.noaa.gov/eegle

OS31R-04 0920h

U-238/Th-234 Tracer Studies of Sediment Resuspension and Horizontal Transport in Nearshore Lake Michigan

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In the nearshore coastal margin of southern Lake Michigan, the "resuspendible" pool of particles which fuel episodic coastal turbidity plume events, exists primarily as a thin flocculent veneer or layer of sediments over rock, cobble, hard clay, and sandy bottoms. Quantitative collection of this material has been achieved in situ using an ROV-deployed sampling device. Measurements of Th-234 (1/2 life, 24 d) inventories, within this nearshore resuspendible sediment pool have been applied to the problem of determining the residence time of particles in the nearshore water column, the frequency and duration of particle resuspension, and the rate of transport of fine-grained sediments within this coastal plume zone. Circulation and particle transport models developed by Schwab and others indicate transport of this material within the southern basin in a counter-clockwise fashion, consistent with observations of the long term sediment accumulation patterns. Comparison of inventories within surficial sediments and the overlying waters with the supported production of excess Th-234 from U-238 decay in the water column also follows a counter-clockwise trend from Th-234 depletion ($\sim$ 20%) along the western boundary to Th-234 excess ($\sim$30%) on the eastern side, implying a relatively rapid transport of active particles from west to east. Initial calculations, using a simple box model to estimate the mean rate of transport, yield net advection on the order of a few km per day.

OS31R-05 0935h

Sediment Resuspension and Cross-Margin Transport within the Coastal Zone West of Lake Superior's Keweenaw Peninsula.

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The near-shore region west of Lake Superior's Keweenaw Peninsula is often host to a strong coastal flow known as the Keweenaw Current. To study near-bottom sediment and fluid dynamics within this region, we set out heavily instrumented tripods offshore of the Peninsula in several deployments spanning the 1998-2000 period. The tripods were either placed at the edge of the Keweenaw shelf, a gently sloping region extending to about the 25 m isobath, or over the adjacent slope. The data revealed a distinct seasonality of the near-bottom dynamics of the region. During spring, near-shore waters were weakly stratified, and near-bottom currents over the shelf and slope were largely driven by the local wind stress. Solar warming during summer produced stratification that effectively isolated near-bottom flows from the surface wind stress resulting in very weak near-bottom currents. During Autumn, vigorous near-bottom current were observed, driven partly by the surface wind stress and partly by the cross-shore pressure gradient associated with temperature difference between near-shore and offshore waters. Near-bottom currents due to surface waves contributed significantly to bottom stress generation during this period. At 60 m depth, the effect of surface wave currents often increased the bottom stress above the estimated 1.1 dy/cm^2 resuspension threshold. Episodes of sediment resuspension were nearly completely confined the fall and early winter period. Statistically significant offshore fluxes of sediment were consistently observed during this period. This was apparently due to a dichotomy in the near-bottom flow in response to upwelling and downwelling favorable winds. Near- bottom current speeds were significantly greater during times of downwelling favorable winds as these tended to accelerate the northeastward thermally driven coastal flow of the region.

OS31R-06 0950h

Basin-Scale Responses to Major Episodic Sediment Resuspension Events in Lake Michigan

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Intense winter and early spring storms massively resuspend materials with characteristics of sediment from depositional regions in southern Lake Michigan. Estimates show that these events can resuspend over one million MT of particulate matter and this material is transported both alongshore and offshore into the center of the lake. Sediment traps were used to record the offshore passage of this material. Several years of trap collection at offshore sites show a range in mass and nutrient fluxes that span a factor of ten. Carbon isotope analysis of trapped material indicates a correlation between the size of the annual event and primary productivity. The implication is that large events are crucial in the cycling of particle-associated constituents and basin-scale ecology.

OS31R-07 1025h

Intense Microbial-Driven Benthic-Pelagic Coupling Stimulated by Winter Storms

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High-energy episodic storm events can have strong impacts on coastal ecosystems, particularly in the absence of thermal stratification, but their biological effects remain poorly studied. In southern Lake Michigan, late winter storms induce a large-scale (greater than 3000 km2) recurrent turbidity plume (Eadie et al. 1996), which invokes a severe light limitation to phytoplankton (Fahnenstiel et al. 2001) and injects large amounts of labile organic matter into the water column resulting in seasonal decoupling of autotrophic and heterotrophic processes (Cotner et al. 2001). In sediment-impacted waters, enhanced bacterial production was nearly matched by bacterivory and small heterotrophic oligotrichs and tintinnids became predominant, forming a large proportion of total zooplankton biomass. Two over-wintering calanoid copepods, Diaptomus sicilis and Limnocalanus macrurus, had high clearance rates on these ciliates. Our data suggest that opportunistic ciliates can make resuspended carbon available to mesozooplankton via a simple, two-step food chain thus forming a strong benthic-pelagic coupling during the critical winter-spring transition. These findings also may have implications for other productive coastal systems such as Georges Bank and the inner shelf of the Bering Sea, where similar seasonal climatic disturbances are common.

URL: http://www.glerl.noaa/gov/eegle

OS31R-08 1040h

Carbon and Nutrient Cycling in a Coastal Freshwater System: Western Lake Superior

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Between September 1998 and September 2001 we measured a number of physical, chemical, and biological parameters to characterize the cycling of organic carbon and associated nutrients in the coastal zone of western Lake Superior. The particulate flux of material was measured using moored sediment trap arrays. In addition, benthic incubation studies in combination with sediment pore water studies and material burial rates were used to estimate the efficiency of nutrient burial. Sediment traps were deployed on two separate moorings in combination with an array of thermistors. The temporal pattern of particle export suggests two productivity maximums during the year that correspond to periods of water column stratification minimums. The composition and flux of biogenic material imply that production in Lake Superior is tightly coupled to both light and nutrient availabilityessentially, during periods of low nutrient availability, but high light, carbon production can be twice that expected based on available phosphorus (high C:P and Si:P ratios). At our mooring site, benthic carbon decomposition rates (effluxes) are 1.33 0.07 mmole m $^{-2}$ day $^{-1}$, nitrate effluxes are 0.11 0.02 mmole m $^{-2}$ day $^{-1}$, phosphate effluxes are 0.006 0.001 mmole m $^{-2}$ day $^{-1}$, and silica effluxes are 1.18 0.06 mmole m $^{-2}$ day $^{-1}$. Comparison of sinking fluxes and benthic regeneration rates suggest recycling efficiencies of approximately 60% for organic carbon, 50% for nitrogen, 75% for silica, and 25% for phosphorus. Benthic carbon and nitrogen remineralization rates are generally higher at our near shore sites than offshore suggesting spatial variations in carbon export. Phosphorus

remineralization rates however appear to be extremely variable, with a number of near-shore cores showing no significant P remineralization.

OS31R-09 1055h

Relationship Between Periodic Resuspension Events and Phytoplankton Community Structure in Lake Michigan: A Field and Laboratory Investigation

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Lake Michigan provides an ideal location for comparing episodic physical forcing events (storms) on phytoplankton processes and the more persistent seasonal variability of phytoplankton communities. This is due to the duration and extent of a highly turbid, recurrent coastal plume (RCP) in the lake during the winter/early spring. Although the RCP can coincide with initiation of the basin wide spring bloom, linkages between duration and intensity of the plume and the prominent role of light availability in regulating Lake Michigan phytoplankton growth during the spring isothermal period have been postulated, but not verified. As such, the concurrent physical and biological events provide a novel opportunity to examine phenomena associated with the RCP affecting distribution and abundance of species and the subsequent evolution of assemblages in Lake Michigan phytoplankton flora. In this study, phytoplankton assemblages from pre, post and active plume events during spring were examined from stations along Lake Michigans southern shoreline. The assemblages included chlorophytes and chrysophytes, but were dominated by diatoms. Species abundance changed rapidly during storm events. Sediment resuspension via storm activity created a sub-optimal growth environment. Post-storm event phytoplankton communities were floristically distinct from pre-storm event communities, with resting cell-forming taxa playing a significant role in these community-restructuring periods. Laboratory simulations of resuspension events using Lake Michigan sediments were conducted under a variety of environmental conditions. Parameters varied included day length, temperature, and silica. The resulting assemblages were quantitatively counted. A statistically significant relationship was identified between day length and vegetative growth of many resting cell-forming diatom species. When day length was calculated for post-storm event field data, it revealed a high correlation between post-storm event communities and those predicted by the laboratory simulations. Both timing of storm events and latitudinal position of the system determine day length, which is an important element to consider when predicting phytoplankton community structure.

OS31R-10 1110h

Optical Properties Across the Coastal Margin of Lake Superior

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This study was conducted as part of the Keweenaw Interdisciplinary Transport Experiment in Superior (KITES), and is based on three years of field data focusing on cross margin transport in western Lake Superior. In this paper we examine the apparent optical properties of this coastal margin on a seasonal basis. In particular we compare spectral 1% light level depths, normalized spectral K_d, K_d spectral ratios, spectral Rrs, and spectral Rrs ratios across the range of water types existing in this coastal margin. The objectives of this work were (1) to compare our intensive survey to past optical research on the lake to document any changes in the optical properties that may have occurred; (2) to study the spectral characteristics of the light field, including the UV radiation, which have not been thoroughly documented with modern instrumentation; and (3) to establish the context for the application of remote sensing to aid in understanding the seasonal and spatial variability of chl a, TSS, and CDOM over temporal and spatial scales.

OS31R-11 1125h

The Effects of a Spring Resuspension Event on In-situ Optical Parameters and Phytoplankton Light Utilization

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As part of the Coastal Ocean Processes-Episodic Events in the Great Lakes Experiment (CoOP-EEGLE) in-situ optical data was collected during an episodic turbidity plume in southern Lake Michigan during spring 1999 and 2000. This recurrent sediment plume is formed onshore before advecting offshore and is characterized by high surface reflectivity. The formation of this offshore optical gradient provides a wide range of optical conditions to help develop remote sensing algorithms and serves as a model testing ground for studying the effects of constrained light parameters on phytoplankton communities. Measured inherent optical properties (IOPs) were used to compute spectral radiance distributions using Hydrolight 4.1 in natural water columns based on collected in water AC-9 (Wetlabs) data. Calculated AOPs and remote sensing reflectances were compared to measured values; in-situ AOPs were measured using Satlantic OCR-200 and hyperspectral TSRB radiometers. Measured and modeled optical properties showed good agreement especially in clearer water offshore stations (R^2 = 0.91). Although absorption and scattering are both increased within the plume (up to 3X), total light attenuation was dominated by scattering and was highest in the blue wavelengths of light. The increased attenuation within the plume alters both the intensity and spectral quality of light available to phytoplankton leading to a decrease in total primary production and a shift in phytoplankton community composition. Diatoms tend to dominate onshore stations while cryptophytes, which are always present, become the dominant species (comprising up to 75% of the population) in the offshore stations and at depth. The light field in these areas is sharply skewed to the green wavelengths of light thus favoring the cryptophytes who are better able to harvest the available light utilizing their accessory phycobilin pigments (max absorption = 545nm). The calculated integrated photon absorption for cryptophytes in this light environment is 2.5X that for diatoms at depth.

OS31R-12 1140h

Bio-Optical Properties of Phytoplankton Communities in Southeastern Lake Michigan and Implications for Modeling Primary Production

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Key parameters for modeling primary production include the maximum chlorophyll-specific rate of photosynthesis (P^Bmax, gC gChl^{-1} h^{-1}), chlorophyll-specific optical absorption cross-section (a^*_{ph}, m^2 mg chlorophyll a^{-1}) and maximum photosynthetic quantum yield for carbon fixation (ϕ_{max}, mol C mol quanta^{-1}). Information about these parameters in the Great Lakes is limited, particularly in areas subject to episodic sediment resuspension. These bio-optical properties were characterized in southeastern Lake Michigan during March through June in 1998, 1999 and 2000. Observations were made during non-stratified periods across optical gradients associated with a recurrent sediment plume as well as following the onset of summer stratification. Despite nearly homogeneous vertical physical structure in March and April, a^*_{ph} and ϕ_{max} varied with depth. This was evidence that photoacclimation occurred on time scales more rapid than that of vertical mixing. General trends were that a^*_{ph} decreased with increasing depth, consistent with the presence of larger or more heavily pigmented cells in deeper waters. In contrast, maximum quantum yield of photosynthetic carbon fixation increased with depth, reflecting increased efficiency of light utilization by deep populations. A decreasing trend with depth in P^Bmax was evident during stratified conditions, an indication that responses of this parameter to environmental variation occur over longer time scales. Other observed trends were related to the time of year, bottom depth, and turbidity. Estimates of primary production will be most sensitive to light-limited photosynthetic parameters (a^*_{ph}, ϕ_{max}) during non-stratified conditions and in high turbidity regions impacted by sediment resuspension or inputs of dissolved organic materials. We consider the impact of observed variations in photosynthetic parameters on primary production in the context of ambient variations in light availability and spectral quality.

OS31S HC: 316 B Wednesday 0830h

The North Atlantic Ocean and Its Changing Climate V

Presiding: **B Dickson,** CFEAS, The Laboratory**; T M Joyce,** Woods Hole Oceanographic Institution

WED

OS31S-01 0830h

The High Frequency Variablity of the North Atlantic, Comparisons Between a 0.1°Resolution Model and Data

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The North Atlantic changes on a variety of scales. To accurately predict changes at frequencies higher than seasonally, a model must be capable of reproducing such features. We investigate the variability on the time scales shorter than a season using both a primitive equation, level numerical model (POP) at 0.1°resolution and data (altimetry and in situ). The model has been forced with a realistic momentum flux (NOGAP winds) spanning the time period of the observations (1992-1998). First, we quantify the realism of the model by comparing its output, sampled either daily or an average of 3 days, to measurements of altimeter/tide gauge SSH or data from current meters and buoys. These sparse time series show that the model reproduces much of the signal seen in observations at these locations. Second, we examine the SSH error fields of the model using a joint (with altimeter data) estimation procedure. Third, the spectra of various model fields are examined and where available, are compared to the spectra of the data. We examine the spatial distribution of the spectra and note the similarities and differences between the model fields and the data. Where possible, we examine SSH, temperatures, and current spectra.

OS31S-02 0845h

Preliminary Results From a Global 1/10th Degree POP Ocean Simulation

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