OS41E-81 0830h POSTER

Ten Years of Shipboard ADCP Data Along the Northwestern Hawaiian Islands

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Analyses of 10 years of shipboard acoustic Doppler current profiler data collected along the Northwestern Hawaiian Islands from October 1990 to November 2000 are presented. Over this period, 105 transects have been analyzed to provide spatial and temporal variability of the current structure in the depth range of 20-300 m. Most of the transects occur from February through November, with few in January and December. There are typically 10-11 transects per year. The analyses include spatial means and variances of velocities on a quarter degree latitude and longitude grid rotated along the ridge, and the mean RMS vertical shears at 16 m resolution over 20 km rotated longitude of the entire data set. Time series at selected banks, atolls, and channels along the ridge are presented to examine seasonal and interannual variability. This work was conducted as part of the National Science Foundation funded Hawaii Ocean Mixing Experiment to examine historical data to identify likely regions of enhanced tidal mixing associated with the Hawaiian Ridge. In addition, these analyses are being utilized to support studies of coral reef ecosystem dynamics, such as transport and recruitment of larval fishes, crustaceans, corals, and algae.

OS41E-82 0830h POSTER

An Internal Tide Climatology from the Hawaii Ocean Time-Series

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Thirteen years of CTD and ADCP profiles at the Hawaii Ocean Time-Series (HOT) Station ALOHA 100 km north of Oahu have been analyzed for tidal variations. During most of the approximately monthly cruises, CTD profiles were made to 1000 m every 3 hours for 36 hours. Hourly ADCP profiles extend to about 200 m. Least squares regression using either two or 8 tidal constituents was used for the analysis, depending on the length of the record.

The long-term record allows estimation of the internal tides that are coherent with the barotropic tides, and permits separation of neighboring diurnal and semidiurnal tidal constituents. For surface dynamic height relative to 1000 dbar, M2 dominates (2.5 dynamic cm) and S2 is the next most energetic (0.8 dynamic cm). K1, O1 and P1 are all in the range 0.2-0.4 dynamic cm. The dominance of the M2 tide is consistent with results of previous studies. Depth-dependent isopycnal displacement amplitudes show about the same ratio of constituent amplitudes, with M2 displacements peaking at 10 m near 250 m depth. Only M2 and N2 show nearly constant vertical phase expected of a standing mode, while K1, S2, O1, K2 and Q1 show upward phase propagation, but at different rates.

Tidal displacements of isopycnals during individual cruises are generally much more energetic than the long-term coherent signals, suggesting that stochastic processes strongly modulate the coupling of internal and barotropic tides in the generation regions and/or the propagation of internal tides from these regions to Station ALOHA. The vertical phase structure varies considerably, sometimes exhibiting downward phase propagation. During one cruise, a submesoscale vortex appeared to scatter internal tidal energy upward and downward. The robustness and the implications of these observations of non-stationary internal tides will be discussed.

OS41F HC: Hall III Thursday 0830h

Maintaining Deep Ocean Stratification III

Presiding: **D Luther,** University of Hawaii at Manoa

OS41F-83 0830h POSTER

Observations of Enhanced Diapycnal Mixing Near the Hawaiian Ridge and Its Relationship to Tidal Cycles

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As part of the Hawaii Ocean Mixing Experiment (HOME), evidence of enhanced diapycnal mixing near the Hawaiian Islands Ridge, and its relationship (if any) to tidal cycles, has been sought in CTD data obtained by the Hawaii Ocean Time-series (HOT) program. Profiles of potential density over the slope of the Ridge at 2500 m near Oahu and from 110 km north of Oahu in water deeper than 4500 m have been examined for evidence of diapycnal turbulent mixing as indicated by density inversions and internal wave vertical strain. Ensemble averages of the number of inversions and the Thorpe scale have been obtained as a function of depth. Both parameters are found to be higher at the Ridge site than at the deep ocean site. Over the slope of the Ridge, Thorpe-scale based estimates of the rate of dissipation of turbulent kinetic energy and turbulent vertical diffusivity are elevated by an order of magnitude above background levels. The vertical distributions are non-uniform and exhibit signs of localized (in depth) enhancement of dissipation, possibly due to tidal rays generated at the Ridge. At the deep station, turbulence is at well-known background levels from the surface down to 2000 m. Below 2000 m, a localized (less than 1000 m wide) zone of enhanced mixing was observed, perhaps due to an internal tide ray originating at the Ridge. And near the bottom, enhanced mixing is inferred, in agreement with previously reported enhanced eddy diffusivities near the bottom associated with episodic cold bottom water flows into the Kauai Deep.

The full-depth topographical enhancement of mixing near the Ridge also appears in the vertical strain field. Estimates of dissipation rate and turbulent diffusivity, based on internal wave-wave interaction theory, give results similar to direct Thorpe scale methods, except in weakly stratified environments where both methods are subject to uncertainty.

At the Ridge, the variation in mixing intensity observed between casts is sensitive to sporadic large mixing events which are triggered by internal wave displacements associated with the spring tide. The upper portion of the water column (stronger stratification) is more responsive to the tide than the deeper waters.

OS41F-84 0830h POSTER

Characteristics of Deep Currents in the Japan Trench

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In the deep sea area of the Japan Trench, located about 150 km east from northern Honshu, one observes southward flow on the landward slope and the northward flow on the oceanward slope. To confirm above currents system, current meters were deployed at the landward slope of the Japan Trench off Iwate in 1994 and 1995. One mooring deployed for 275 days at depth of about 5800m and another mooring deployed for 20 days at depth of about 4200m. Deep western-boundary current, such as SSW-ward flow along the trench axis above the landward slope, was measured through the observation. Inferences from benthic fauna observed using manned submersible and deep tow camera, oppositely directed flow along the oceanward slope of the trench, forming a trench countercurrent.

In 1998, two current meter moorings were deployed at the landward slope and the oceanward slope of the Japan Trench at depths of about 6000m off Miyagi to compare with deep currents above landward and oceanward slopes. Three months current data, which were measured at 30m above the each seafloor, indicated SSW-ward flow above the landward slope as a mean speed 4.2cm/sec and NNE-ward flow above the oceanward slope as a mean speed 7.9cm/sec.

The similar deep current systems are known in the Aleutian Trench and the Izu-Ogasawara Trench. Deep current system of the Japan Trench is one of the systems in North Pacific Trench Deep Current Chain, which is expected continuously existing along the trenches.

In addition, there is no difference carbon-14 age between the bottom waters on the each slope, which is measured in 2000. This result suggests that the time scale of deep current circulation in the trench is less than several decades that estimated from measurement error of carbon-14.

OS41F-85 0830h POSTER

Richardson Number and Ocean Turbulence; Towed Thermistor Chain Observations

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A 7.2 km tow in the upper seasonal thermocline of the Sargasso Sea with an 80-m aperture thermistor-conductivity chain and shipborne 150-kHz ADCP is examined to determine the relationship between patches of scalar activity and buoyancy frequency, vertical shear, and gradient Richardson number (Ri). The horizontal temperature gradient variance in the 0.5 - 3 m band normalized by the mean gradient squared is used as our measure of scalar activity to remove bias due to high gradient regions. Two-dimensional images show qualitative coincidence between patches of activity and low Ri computed over 10-m vertical scales. Hypothesis testing quantifies and supports these visual results. The null hypothesis, "scalar activity is independent of Ri number" fails at the 90% confidence interval for $Ri<0.8$ for a threshold representing $\sim$ 9% of the most active regions. The probability increases rapidly as Ri approaches 0.25. The results are quite robust for vertical smoothing from 4 - 20 m, although the details of the probabilities are dependent upon the scalar activity threshold and vertical smoothing. It is shown that the most intense scalar activity occurs for $Ri < 0.3$ and that including less intense activity results in probabilities greater than the null hypothesis for Ri as high as 1.2 - 1.5.

These results are strong evidence for the Kelvin-Helmholz shear instability but no single critical Ri, either 0.25 (Miles and Howard) or 1 (Abarbanel et al.) is identified. Increased scalar activity for part of the tow with enhanced short wavelength ($\sim$ 125 m) internal waves and Ri near 1 is suggestive of the advective instability enhanced by low Ri.

OS41F-86 0830h POSTER

Relationships among Tracer Ages

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Measurements of chemical tracers whose spatial gradients are primarily due to the time dependence of sources and/or sinks ("transient tracers") can be used to estimate transport time scales in geophysical systems. However, a major problem with interpreting these "tracer ages" is that different tracers can yield different ages and, at present, it is not clear what aspects of the transport is measured by the different tracers. We use the concept of a distribution of transit times ("age spectra") to compare the timescales derived from different transient tracers (including CFCs, tritium-helium, and radioactive tracers). By performing a systematic study over a wide range of age spectra we examine under what conditions two tracers yield similar or different ages. It is shown that there can be

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significant differences in tracer ages and that, in general, tracer ages are not fundamental timescales of the flow. Furthermore, even if ages from two tracers are similar these ages can be very different from the mean (ideal) age or the age of a third tracer. It is also shown that significant temporal variations in tracer ages can occur for steady transport (with only moderate mixing), and that these changes are of similar magnitude to the observed changes in CFC and tritium-helium ages in North Atlantic and North Pacific over the 1980s and 1990s. Accounting for the changes in tracer ages caused by steady transport is necessary before attributing changes in tracer ages to changes in transport. The possibility of using the differences in ages from different tracers to infer information about the age spectra (transport) or the infiltration of unmeasured tracer (e.g., pollutant) into the system is also examined.

OS41F-87 0830h POSTER

Increased Resolution in a Coarse Resolution Global Ocean GCM: Effects on Equilibrium, CFC, and Sequestration Solutions

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We examine the effects of changing horizontal and vertical resolution on the equilibrium and time-dependent solutions of a z-coordinate ocean general circulation model in non-eddy-resolving configurations. Our comparison emphasizes large-scale features relevant to global climate change and carbon sequestration. Since none of our simulations resolve ocean eddies, our results do not address the possible importance of resolving eddies in ocean-climate simulations.

Using a coarse resolution of 4 degrees in longitude by 2 degrees in latitude and a fine resolution of 1 degree in both longitude and latitude, we compare the near-equilibrium solution and solutions of direct injection of fossil-fuel CO_2 and uptake of CFC-11. The large-scale features of the model solutions are very similar at the two resolutions and in many cases are more sensitive to a large difference in horizontal viscosity than to the difference in resolution. There is no persuasive evidence of improvement of large scale results with finer resolution in these non-eddy-resolving simulations. However, when local details are of interest, there is still a need for higher resolution, as we show with calculations of pH change in the direct injection results.

Similar comparisons are made between simulations made with differing vertical resolutions, ranging from 24 to 80 vertical levels, with emphasis on decreasing the layer size of the deepest levels. These simulations all use the coarser 4 degree by 2 degree horizontal resolution. Again, the large scale results are very similar between the different resolution simulations. However, when looking at features that are poorly resolved, such as water masses with large changes in pH, the use of higher vertical resolution can have a significant impact.

OS41F-88 0830h POSTER

A New Mixed Layer Formulation for Isopycnic-Coordinate Ocean General Circulation Modeling

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Implementation of a mixed layer model in isopycnic coordinate general circulation models has been a difficult problem. Existing 1-d mixed layer models assume a continuous density variable, while isopycnic-coordinate models assume a discrete density variable. Attempts to reconcile these differences lead to compromising the integrity of the density variable used as the vertical coordinate of the general circulation model.

A new approach to mixed layer modeling is based on an algorithm for solving the diffusion equation in isopycnic coordinates. This scheme allows vertically adjacent layers to have widely disparate layer diffusivities while maintaining positive layer thicknesses. In particular, a near-surface vertical interval of high diffusivity can overlie deep ocean layers of low diffusivity. The high diffusivity in the upper ocean selects one of the isopycnal layers to occupy the entire vertical interval, creating a "mixed layer", and beneath this selected layer a set very thin layers constitute a sharp pycnocline. The specification of the high diffusivity value and its vertical extent control the dynamics of the mixed layer.

This new algorithm, together with a Kraus-Turner specification of mixed layer depth, was implemented in a three dimensional, isopycnic-coordinate ocean general circulation model. Idealized experiments with a linear meridional gradient of surface buoyancy flux and a cosine wind stress were used to study the role of the mixed layer model in the ocean response. The model ocean develops realistic features, such as a warm, shallow mixed layer in the subtropics and a deep, cold mixed layer in the subpolar region. Seasonal restratification is also represented realistically.

The important role of a realistic representation of the mixed layer is demonstrated by a comparative study of the production of annual Rossby waves in the general circulation model both with and without the mixed layer model.

OS41F-89 0830h POSTER

Atmospherically Forced Mesoscale Motions: Influence of Scales on the Relationship Between Wind Stress Curl and Barotropic Currents

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The surface wind stress is now well established as an important source of energy for mid-latitude barotropic mesoscale motions at periods of days to months. Depending on the time and space scales of the forcing and the degree of scattering by rough topography, the ocean's response will be evanescent in space or as freely-propagating Rossby waves with a wide range of relative vorticities. At large time scales the local balance between the wind stress curl and the ocean's response can be expected to approximate the Sverdrup balance. Simple theoretical considerations and previous modeling studies suggest that the Sverdrup balance will be generally observable only after substantial horizontal averaging of point observations of currents has removed the smaller scale waves carrying most of the relative vorticity. However, there have been occasional and unexpected observations of a Sverdrup balance at free wave periods as short as 10 days. Using observations of barotropic currents obtained during the Barotropic Electromagnetic and Pressure Experiment (BEMPEX), the presence of atmospherically forced mesoscale variability, including evanescent oscillations at periods shorter than a few days and free Rossby waves at longer periods to six months, is confirmed. By averaging the BEMPEX current observations over a succession of increasingly larger spatial domains, it is shown that at large scales the ocean approaches a topographic Sverdrup balance, per the modeling expectations, even though the Sverdrup balance is only sporadically indicated at similar periods at the individual mooring sites.

OS41F-90 0830h POSTER

Confirmation and Quantification of Strong, Deep Poleward Boundary Flow off Chile, a Major Branch of the Pacific Mid-depth Outflow

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From hydrographic data, deep poleward boundary flow off Chile was identified by Warren in the 1970's and found by Reid in the 1980's to carry a large part of a net southward flow leaving the Pacific Ocean at mid depths (about 1000 - 3000 m). Recent analyses of WOCE sections across the South Pacific in the 1990's paint a mixed picture of the boundary flow off Chile and its role in the Pacific Mid-depth Outflow. For the last ten years we have maintained a recording current meter mooring near 30°S at a deep ocean site (water depth 4300 m) about 150 km off the Chilean coast and about 70 km seaward of the Peru-Chile trench. During the last eight years of this period, current meters at 2450 m and 3750 m registered mean southward flow of 0.6 and 0.1 cm s^{-1}, respectively. Upon this mean flow was superimposed significant interannual variability with strongest southward flow (about 1.5 and 0.7 cm s^{-1}, respectively) during the 1997-1998 ENSO event and northward flow (about 0.5 and 0.5 cm s^{-1}, respectively) during 1994-1995. This result implies that, ideally, 5-10 year long current observations should be used in this region for referencing geostrophic estimates of mean circulation. We used our direct current observations, together with heat balance constraints on the inflow into the deep Chile and Peru basins, to reference geostrophic flow estimates from the WOCE P6 line hydrographic data (along 32°S) between the coast of Chile and the East Pacific Rise (112°W). We find a mean southward, mid-depth transport of about 10 Sv within 1500 km of the Chile coast and a northward, mid-depth transport of about 3 Sv east of the East Pacific Rise. This flow pattern agrees well with deep property distributions, for example, of dissolved oxygen, silicate and carbon 14. The implied net southward flow of about 7 Sv represents at least half of current transport estimates of the Pacific Mid-Depth Outflow. This flow structure is unexpected in terms of the simplest application of Stommel-Arons dynamics of deep ocean flow and is not found in state-of-the-art Ocean General Circulation Models. We suggest that large horizontal variations in diapycnal mixing and, perhaps, in geothermal heating in the region may need to be considered to capture this observed flow structure in ocean models.

OS41F-91 0830h POSTER

Testing an Empirical Flux Model For Convective Mixing in Lake Biwa

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Microstructure experiment was conducted to study nighttime cooling convection, on August 30-31 1999 in Lake Biwa, Japan. We made 131 vertical profiles at 10 minutes interval using a newly developed microstructure profiler TurboMAP (Turbulence Ocean Microstructure Acquisition Profiler). The instrument measures a horizontal velocity shear component, temperature, conductivity, turbidity, and pressure.

During the experiment, moderate west-southwest winds varied between 1 5 m/s. The net upward heat flux in nighttime from surface of the lake, J_b^0, is calculated from an empirical formulation, and the value was about 10^{-7} [W/kg]. After sunset, the diurnal mixed layer started to deepen, forming homogeneous warm water layer that was more than 27.2 [^{o}C] near the surface. Just before the dawn in early morning the diurnal mixed layer reached approximately 10 m depth. We observed relatively high dissipation rate ($\epsilon \sim 10^{-7}$ [W/kg]) in the deepening diurnal mixed layer. In the seasonal thermocline, dissipation rate up to 10^{-8} [W/kg] was also observed.

The dissipation rate to surface heat flux ratio:ϵ/J_b^0 was about 0.4 on average. This value is smaller than previous measurements being 0.6. We examined an empirical relationship obtained by Kantha (1980) for flux ratio, R, and bulk Richardson number, Ri. Our field data are consistent with the empirically established relationship from a laboratory experiment.

OS41G HC: 318 A Thursday 0830h

Biogeochemical Evolution of the Phanerozoic Ocean II

Presiding: **E Gaidos,** University of Hawaii at Manoa**; F Mackenzie,** University of Hawaii at Manoa

OS41G-01 0830h

Uranium-Series and Radiocarbon Geochronology of Deep-Sea Corals: Implications for Southern Ocean Ventilation Rates and the Oceanic Carbon Cycle

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