OS51G HC: 317 B Friday 0830h

Kuroshio Extension and North Pacific Circulation

Presiding: **M Foreman,** Institute of Ocean Sciences**; G - Auad,** Scripps Institution of Oceanography - UCSD

OS51G-01 0830h

Numerical Simulation of the Transient Response of the Kuroshio Leading to the Large Meander Formation South of Japan

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Using a three-dimensional, primitive equation numerical model that takes realistic topography into account, we successfully reproduce the observed transient response of the Kuroshio south of Japan during the transition from the non-large meander path to the large meander path. The transient response is triggered by the generation of what is called the "trigger meander" off the south-eastern coast of Kyushu resulting from the supply of cyclonic vorticity through vertical stretching caused by the interaction between the Kuroshio and the anticyclonic mesoscale eddy approaching the Tokara Strait. The trigger meander thus generated propagates eastward south of Shikoku while inducing an anticyclone-cyclone pair in the lower ocean. After the trigger meander passes Cape Shiono-misaki, it slows down and rapidly amplifies so that the Kuroshio loops back west of the Izu-Ogasawara Ridge. Then, the sharpness of the meander trough gradually relaxes and the large meander path is attained. During the rapid amplification of the trigger meander off Cape Shiono-misaki, the abyssal anticyclone develops while being trapped by the local topographic feature, Koshu Seamount, located about 200 km to the south of Cape Shiono-misaki. This abyssal anticyclone plays a crucial role in intensifying the trigger meander trough in the upper ocean via cross-frontal advection; the intensified trigger meander trough then further amplifies the abyssal anticyclone over Koshu Seamount. This joint evolution of the upper ocean meander trough and the abyssal anticyclone suggests that baroclinic instability enhanced by Koshu Seamount is the dominant mechanism for the rapid amplification of the trigger meander leading to the large meander formation south of Japan.

OS51G-02 0845h

Synergistic Use of ADCP and Altimetric Data for Short-Range Forecasts of the Kuroshio Variations South of Japan

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A simultaneous assimilation system employing satellite altimeter data and acoustic Doppler current profiler (ADCP) data into a regional 1 1/2-layer primitive equation model has been constructed using a variational initialization method to correct both the mean sea surface height (SSH) and the temporal evolution of the Kuroshio path south of Japan. This is useful for assessing the efficiency of velocity data on the correction of mean SSH and the capability of short-range forecasts of strong western boundary currents.

For monitoring and short-range forecasting of the Kuroshio path variations, it is beneficial to reproduce the mesoscale vorticity fields associated with the meandering path and energetic eddies by assimilating observational data into ocean circulation models. Although the SSH data from satellite altimeters are very attractive for this purpose because of their temporal repetition, the usefulness of satellite-derived SSH data may be restricted in narrow western boundary current regions if the geoid is not well known on a length scale of a few hundred kilometers (Qiu, 1994; Ishikawa et al., 1996). Consequently, the assimilation of satellite-derived SSH data is applicable only to the study of time-varying components of ocean ciculations. Thus, to extend the usefulness of the altimetric data, the mean component of SSH must be supplemented by information derived from *in situ* observations or model outputs. In contrast, velocity data obtained from the ship-borne ADCP technique have the advantage of relating to the absolute (mean plus time-varying) circulation fields. This is true in the nearshore region, where the satellite-derived SSH data may be influenced by the accuracy of the tidal correction, and in the region around the current axis, where the spatial changes of the mean SSH are comparable to those of the time-varying ones.

A five-year assimilation experiment from 1993 to 1997 successively corrected the mean SSH which was then combined with the time-varying SSH data to make an absolute SSH field. The "final" mean velocity field calculated from this 5-year analysis is in quantitatively good agreement with that derived from independent drifting buoy data. A series of short-range forecasts of the Kuroshio variations south of Japan using results from the 5-year re-analysis field with the "final" mean SSH show a significant improvement in accuracy over those obtained with the un-corrected mean SSH. In addition, the period over which reliable forecasts could be made was extended considerably. These results suggest that our simultaneous assimilation system is a very powerful tool for short-range forecast of the Kuroshio variations south of Japan.

OS51G-03 0900h

Heat budget in the Kuroshio Extension region:1993–1999

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Processes responsible for the seasonal and interannual variations of the sea surface temperature and upper-ocean heat content in the Kuroshio Extension region are examined from a 3D advection-diffusion model in finite elements, with an embedded bulk mixed layer. The horizontal advective field is specified externally from TOPEX/Poseidon altimeter data. The thermal field from the model shows reasonable agreement with observations. On interannual time scales, while heat storage rate is dominated by horizontal advection/diffusion, consideration of both atmospheric and oceanic processes are required to explain the observed nonseasonal SST changes. In particular, the transition between an elongated and a contracted state of the Kuroshio caused by geostrophic advection has a clear signature on the SST. There is indication that this process is accompanied by consistent changes in nonseasonal entrainment: When the Kuroshio is in an elongated state and warmer waters are present below the mixed layer, entrainment appears less efficient in exporting heat out of the mixed layer.

OS51G-04 0915h

Interdecadal heat budget in the Kuroshio-Oyashio extension.

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Simulated and observed sea surface temperatures in the Kuroshio Oyashio Extension (KOE) are used to calculate the decadal and interdecadal heat budget there. The possible interaction of the KOE with the atmosphere and the KOE role in the broader context of the North Pacific climatic variability are studied and will be presented at the meeting.

OS51G-05 0930h

Modeling the Bimodality of the Kuroshio Path

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The general circulation of the oceans is dominated by the spatial wind-stress pattern. The winds' temporal variability also has an effect on the ocean currents' changes in time. Still, ocean models driven by steady winds exhibit substantial variability with realistic features.

Intrinsic ocean variability cannot be understood in the context of a purely linear theory. Complex nonlinear behavior on basin scales has been found in a full hierarchy of models, from highly idealized to fairly detailed.

The most obvious and well-documented signature of nonlinear behavior in the mid-latitude ocean is the formation, persistence and decay of the Kuroshio meander off Japan. Limited-area models and basin-scale models exhibit this bimodal behavior, apparently for different reasons. In some models, the bimodality appears as a consequence of multiple stable equilibria. In others, the presence or absence of the meander is but a phase of a slow oscillation that encompasses the entire basin.

These apparently contradictory theories may represent complementary features of a bigger picture. We use available hydrographic data, along with a suite of models, in an attempt to present the beginnings of a synthesis.

OS51G-06 0945h

Seasonal Variability of the Upper Subpolar Pacific Ocean

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Recent studies in the subpolar Pacific have shown that chemical components observed below the mixed layer are correlated with atmospheric indices. The clarification of mechanisms requires a better understanding of the subsurface subpolar gyre circulation in the Pacific. To this end, this study uses the White (1995) hydrographic data (monthly values, 0–400m, 1955-2000) to characterize the upper oceanic component of the variability.

From previous modelling studies, the location of the mixed layer front (MLF) (where the mixed layer depth changes rapidly from north to south in the subpolar/subtropical boundary region) is one of the key factors determining the characteristics of subducted water in a steady state regime. The analysis shows that the MLF starts to develop in December, centered on the dateline at around 42° N, moving north-eastward after March and disappearing in June. In June there is a ball-shaped region with relatively deep mixed layer corresponding to the region where the MLF starts to develop in December (this region is considered to be a source of the Central Mode Water.) The seasonal variability of SST in the subpolar gyre is approximately sinusoidal, with a minimum in March and a maximum in September. Hence, seasonal variability of subsurface temperature is expected to follow SST variability with some lag. However, in the region with relatively deep mixed layer, subsurface temperatures follow the SST until the mixed layer reforms in July. After this, temperatures decrease or stay the same until September, then increase again. This seasonal cycle is seen in the Levitus (1998) data as well. On longer time scales, periods with warmer subsurface temperatures are characterized by deeper mixed layer depths in June, indicating the importance of mixed layer formation to the upper subpolar Pacific thermocline structure.

OS51G-07 1000h

The Origin of Waters Observed along 137°E

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Using the World Ocean Atlas data set, we examine the origins and flow paths of subducted waters observed along 137°E section in the western North Pacific. The

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waters studied consist mainly of the water mass known as North Pacific Tropical Water, but includes much of the water of the mid-latitude thermocline. A method is developed to trace these waters from 137°E back through the subtropical gyre to their outcrops. Subducted waters are aged using this technique and found to be between 0.5 and 35 years old by the time they reach 137°E. For this subducted regime, waters on a given isopycnal observed along 137°E increase in age with decreasing latitude, with waters at the southern end of the section being 2-3 times older than waters at the northern end. This estimate of age is consistent with previous estimates calculated from chlorofluorocarbon measurements. It is found that subducted water masses are strongly homogenized by the time they reach 137°E. That is, the originally subducted waters have a wide variation in θ-S characteristics, but by the time they reach 137°E, they form a coherent water mass with a tight θ-S relation. It is shown that isopycnal mixing is not a plausible mechanism for this homogenization but diapycnal mixing is a more likely process.

URL: http://www.fredbingham.com/wep/ReverseTrajectory

OS51G-08 1035h

Upper Ocean Hydrographic Structure and Determination of Fronts in the Subarctic North Pacific

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The abundance of sea surface temperature (SST) measurements from satellite data has increased our ability to determine surface ocean thermal frontal boundaries, but the determination of subsurface fronts is still hampered by relatively sparse and infrequent subsurface temperature and salinity measurements. Consequently the relationships between sea surface and subsurface fronts are still poorly defined. Frontal boundaries are not precise lines, but are actually zones where horizontal property gradients change rapidly, are usually associated with enhanced currents, and are often related to ecological zones. In the North Pacific, the subarctic frontal boundary has also been distinguished by the limit of the subsurface temperature minimum, or dichothermal layer. Here we use hydrographic data from the NODC World Ocean Database to estimate the properties of the upper mesothermal layers in the North Pacific. These are compared to derived horizontal gradient estimates and frontal determinations from synoptic sections (including WOCE), and to satellite SST gradients. A method is developed to determine the subarctic fronts from properties of the temperature minimum layer, with error limits estimated by differences from the other determinations. Relationships between the surface and subsurface features are examined, and the method is applied to all available hydrographic data since 1950 to indicate annual, interannual, and decadal subarctic frontal variability.

OS51G-09 1050h

Mesoscale processes at the Subarctic Front in the northwestren Pacific Ocean

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We present a detailed analysis of eddies and fronts monitored in September-October, 1987 by intense shipboard observations of the region between 150°-158°E and 38°-43°N. Data from 623 hydrocasts and 118 moorings are synthesized with GEOSAT altimetry and ECMWF winds in the framework of a variational data assimilation scheme to produce a dynamically and statistically consistent analysis of oceanic circulation. The 3d baroclinic QG model controlled by the initial and open lateral boundary conditions fits all the data types within prescribed error bars (2 cm/sec for velocity, 3 cm for sea surface height anomalies and 30% for relative density variations at all levels). The dynamically interpolated fields demonstrate a number of events which shed light on the mechanism of cross-frontal exchange of water properties and on the origin of instable modes of the Subarctic Front. Eddy-mean flow interactions, potential vorticity and energy budgets are quantitatively assessed and analyzed.

OS51G-10 1105h

A Mean Sea Level for Satellite Altimetry in the Northeast Pacific

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Climatological salinity and temperature data from a variety of sources are combined with the offshore winds from fifteen buoys to force a diagnostic, finite element model calculation of seasonal sea surface elevations and flows from Oregon to the Alaska Panhandle. Additional barotropic components in the flow field, such as the California Undercurrent, are included through the inversion of long-term current measurements off Vancouver Island. The resultant seasonal elevations are validated against coastal tide gauge observations and a mean sea level is computed. This reference level is then combined with satellite altimeter anomalies to estimate "true" sea levels and surface currents at particular times.

OS51G-11 1120h

PDO-related Changes in the Thermocline Heat Budget in a Model of the North Pacific

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The Pacific Decadal Oscillation is characterized by changes in both the sea surface temperature and windstress fields of the North Pacific. Changes in the windstress field can influence the temperature field, both through direct Ekman advection and by changes in the geostrophic transport of the subtropical gyre due to Ekman pumping. The largest interannual variability of the SST field in the North Pacific occurs in the Kuroshio Extension. PDO-related thermocline heat budget changes in the Kuroshio current system are analyzed using an eddy-permitting isopycnal model coupled to a mixed layer model. In particular, two runs are compared, the first driven by positive-PDO-like atmospheric windstress and thermal forcing and the second with negative-PDO-like forcing. Changes to the geostrophic and Ekman advection of temperature are compared in the two cases, as well as changes in mode water properties and formation rate. Ocean-atmosphere heat exchange is calculated using bulk parameterization of air-sea fluxes.

OS51G-12 1135h

The Response of the North Pacific Ocean to Decadal Variability in Atmospheric Forcing: Wind Versus Buoyancy Forcing

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Both wind variability and buoyancy forcing result in thermocline variability in the North Pacific. Wind variability forces mostly a first baroclinic mode response while buoyancy forcing, since it is applied in a different part of the water column, forces a higher baroclinic mode response. A vertical modal analysis of the density deviations in an ocean general circulation model of the North Pacific is used to identify the spatial and temporal patterns of the different baroclinic modes. The different dynamic vertical modes show distinct propagation characteristics, with the first baroclinic mode exhibiting consistent westward propagation at latitudes south of 40N, while the higher baroclinic modes show westward phase propagation at low latitudes, but propagate eastward at higher latitudes. The propagation characteristics of each mode can be understood by the inclusion of the zonal mean flow in the vertical structure equation.

Projection of the Ekman pumping and diapycnal fluxes in the quasi-geostrophic potential vorticity equation for each dynamic vertical mode distinguishes their effects on the thermocline variability. Ekman pumping is important throughout the North Pacific for forcing first mode variability. Diabatic pumping, or that associated with thermal forcing, is important in the Kuroshio Extension, and much less so further to the south. The spatial distribution of the forcing is consistent with the structure of the energy in the baroclinic modes. The first baroclinic mode energy increases to the west, while the second baroclinic mode has a band of positive energy emanating westward from the eastward end of the Kuroshio Extension and ends at the western boundary at 20N, reflecting the strong effect of the mean flow on wave propagation.

The results confirm the importance of inclusion of the first baroclinic mode as well as higher baroclinic modes in studies of the decadal variability in the ocean. The analysis suggests that at least the first three baroclinic modes should be included and that 2 and one half layer models of the ocean may be inadequate for understanding the role of the ocean in mid-latitude coupled modes of variability in the ocean-atmosphere system.

OS51G-13 1150h

Model-based upper ocean climatology for the North Pacific

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A fifty-three year (1948-2000) simulation of the North Pacific from 25^oN to 65^oN at a coarse $1^{\lfloor}o$ horizontal resolution, but high vertical resolution (51levels), is used to generate a climatology of the upper ocean and characterize the seasonal and interannual variability of the mixed layer and upper pycnocline. The model is initialized from Levitus' climatology and forced by fluxes from the NCEP reanalysis dataset. The mixed layer is parameterized using the KPP formulation of Large, et al. (1994). Comparison with the time series at Hawaii and Papa show surprising fidelity between the model mixed layer depth (MLD) and sea surface temperature (SST) and the observations. At HOT, the 20^oC isotherm during the 1990's is 40 m deeper than the Levitus climatology, which is reproduced by the model. Comparisons with the TAO buoy data in the tropics is less favorable. Again large differences are observed between the depth of the 20^oC isotherm between the buoy data and Levitus climatology. However, the model is unable to reduce these differences significantly.

An EOF analysis of the model SST and MLD shows dominance of the low modes by the seasonal cycle in the subtropical gyre. Interannual variability is dominated by El Nino and La Nina cycles. One mode dominates the decadal variability with a transition in sign in the late 1970's and near zero amplitude in 2000.

Results from coupling this model with an ecosystem will be presented in another paper.

OS51H HC: 314 Friday 0830h

Marine Ecosystem Responses to Climate: The Responses of Large Marine Ecosystems to Interdecadal-Scale Climate Variability II

Presiding: **W T Peterson,** National Marine Fisheries Service**; A J Miller,** Scripps Institution of Oceanography

OS51H-01 0830h

North Pacific Regime Shifts and the Pacific Decadal Oscillation

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Changes in the marine environment and ecosystems that persist for multiple years have been termed "regime shifts" by both fishery and climate scientists. A special class of Pacific regime shifts has been dubbed the Pacific Decadal Oscillation (PDO. The PDO has been described by some as a long-lived El Nio-like pattern of Pacific climate variability, and by others as a blend of two sometimes independent modes having distinct spatial and temporal characteristics of North Pacific sea surface temperature (SST) variability. A growing body of evidence highlights a strong tendency for PDO impacts in the Southern Hemisphere, with important surface climate anomalies over the mid-latitude South Pacific Ocean, Australia and South America. Several independent studies find evidence for just two full PDO cycles in the past century: "cool" PDO regimes prevailed from 1890-1924 and again from 1947-1976, while "warm" PDO regimes dominated from 1925-1946 and from 1977 through (at least) the mid-1990's. Interdecadal changes in Pacific climate have