Japan (East) Sea Dynamics Using Numerical Models With 1/8° to 1/64° Resolution

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LONG-TERM GOALS

Investigate the circulation dynamics in the Japan/East Sea with a suite of numerical ocean circulation models of progressively increasing complexity, and verify numerical results via model-data comparisons wherever possible.

OBJECTIVES

Investigate Japan/East Sea circulation dynamics in a systematic and progressive fashion using a sequence of increasingly complex ocean models and model-data comparisons. Investigate the impact of upper ocean - topographical coupling and isopycnal outcropping on the mean pathways of the major current systems, including those over the continental shelf region. Also, to assess the impact of different wind forcing products on the simulated JES circulation, with emphasis on the separation of the East Korea Warm Current and the branching of the Tsushima Warm Current (TWC).

APPROACH

This is a modeling study that utilizes a sequence of progressively sophisticated ocean models to investigate circulation dynamics in the JES. In each case a range of resolutions is used, 1/8° to 1/64°, to assess the impact of resolution on model realism and model dynamics. During the first year the NRL Layered Ocean Model (NLOM), which is mainly isopycnal in design, was used to investigate the roles of upper ocean – topographical coupling and isopycnal outcropping. These simulations included features like nonlinearity, bottom topography, multiple vertical modes, flow instabilities, isopycnal outcropping, diapycnal mixing, overturning cells in the vertical, thermodynamics, and thermal forcing. This first phase was followed with simulations performed using the Miami Isopycnal Coordinate Ocean Model (MICOM), which allows the interfaces to intersect the bottom topography, the existence of zero-thickness layers, and includes the shelf circulation with limited vertical resolution. Current studies utilize the HYbrid Coordinate Ocean Model (HYCOM), a generalized vertical coordinate ocean model under joint development with the University of Miami and the Los Alamos National Laboratory. HYCOM was developed from MICOM using the theoretical foundation for implementing such a coordinate system that was set forth in Bleck and Boudra (1981) and Bleck and Benjamin

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15. SUBJECT TERMS

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(1993). This model has the advantage of total generality of the vertical coordinate system, i.e. it is isopycnal in the open, stratified ocean, but reverts to a terrain-following coordinate in shallow coastal regions, and to z-level coordinates near the surface in the mixed layer. This generalized vertical coordinate approach is dynamic in space and time, and extends the range of applicability of traditional isopycnal coordinate ocean models such as NLOM and MICOM to shallow shelf regions and unstratified parts of the ocean. The use of the layered continuity equation to dynamically determine the vertical coordinate system in space and time is an important attribute of HYCOM, and the parameters of the vertical structure have been carefully chosen. In particular, sufficient vertical resolution is maintained near the surface, but isopycnal surfaces are also able to exist near the surface locally. Additionally, sigma layers exist only over the shallow shelf regions to avoid pressure gradient errors associated with steeply sloping bottom topography.

WORK COMPLETED

Several simulations with resolutions ranging from 1/8° to 1/32° have been completed in the JES. Most of the coarser resolution versions were used to test basic model design concepts (i.e. vertical coordinate configuration), sensitivity to external forcing, and exploration of parameter space. A comprehensive exploration of diffusivity and viscosity coefficients was carried out with the high resolution simulations. Many of these issues are now well defined, the result being that HYCOM is now being used as a bona fide research tool for investigating the deep and shallow water mesoscale dynamics of the JES. Additionally, evaluation of model results via model-data comparisons has begun in earnest. The results from several of these comparisons are described in the RESULTS section.

An East Asian Seas (EAS) model domain has been extracted at 1/32° resolution and nested into a 1/6° basin-scale Pacific HYCOM (being developed by Joe Metzger of NRL). Unlike the JES model domain, the EAS model domain removes the influence of the open boundary condition within the Korea Strait. This will allow investigation of the seasonal and interannual volume transport through the strait, its impact on the mean and eddy circulation within the JES, and comparison to ADCP measurements taken within the strait during 1999-2000 as part of the NRL LINKS project. The inclusion of the shallow Yellow Sea region and adjacent deep Japan/East Sea region demonstrate the advantages of being able to retain isopycnals over the shelf as the water column seasonally changes from unstratified to stratified. Additionally, this domain provides a robust test case to assess the ability of the generalized hybrid vertical coordinate scheme to simulate the shelf and deep water simultaneously.

RESULTS

Results obtained during the first two years of this DRI using NLOM are described in a journal article (Hogan and Hurlburt, JPO, Oct. 2000) that demonstrates how high horizontal grid resolution, baroclinic instability, bottom topography, and isopycnal outcropping are crucial for realistically simulating the mean circulation and eddy field in the JES, particularly the separation of the East Korea Warm Current from the coast. Currently, all simulations use HYCOM with resolution up to 1/32°. The types of changes that were seen in NLOM as horizontal resolution was increased are also seen in HYCOM, namely overshoot of the East Korea Warm Current at coarser resolution but robust separation at higher resolution.

The sensitivity of model results to wind forcing was investigated using a series of 1/8° NLOM solutions forced with seven different wind stress climatologies as well as a case without winds. These simulations exhibit tremendous variability depending on which wind forcing data set is used. A series of linear solutions reveal the deterministic ocean model response to the external forcing. A complimentary set of nonlinear solutions demonstrate the impact of higher order dynamics and generally depict cyclonic circulation in the subpolar gyre in response to positive wind stress curl in that region. Substantial variability in the separation latitude of the East Korea Warm Current and the Nearshore Branch of the Tsushima Warm Current is evident between the different cases. Finally, a series of synoptically forced simulations with 1/32° resolution are used to examine the model variability due to wind forcing (deterministic) and flow instabilities (non-deterministic). In many ways, this paper compliments the Hurlburt and Hogan (2000) paper in that there are two primary mechanisms for driving the surface flow and the separation of the East Korea Warm Current; upper ocean – topographical coupling (Hurlburt and Hogan (2000)), and surface wind curl forcing (this paper).

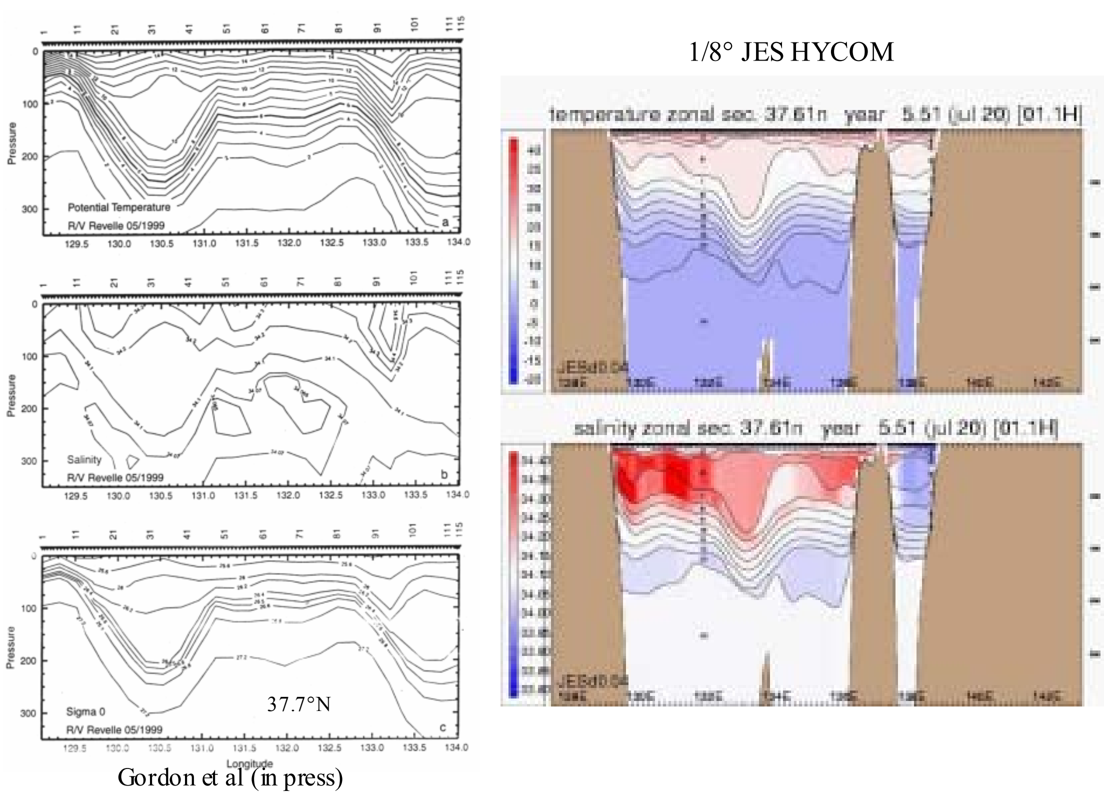

Figure 1. (a, left panel) Cross-sections of observed temperature, salinity and density along 37.7°N during July 2000 as observed by the SeaSoar instrument. The lens shaped features contain relatively warm saline water relative to surrounding ambient water. Similar features are seen (b, right panel) in a cross-section of temperature and salinity from a 15-layer 1/8° simulation from HYCOM.

Observations of temperature, salinity, and density made with the SeaSoar instrument (Craig Lee) reveal the existence of intra-thermocline eddies co-located with the quasi-stationary meanders of the subpolar front (Fig. 1a). These lens shaped features are characterized by warmer, more saline water mass characteristics than the surrounding ambient water. Vertical cross sections of temperature and salinity from a 1/8° synoptically forced simulation show similar features in approximately the same locations (Fig. 1b). Similar to the observed features, the simulated mid-thermocline eddies are characterized by concave (convex) isopycnal structure at the top (bottom) of these features, with little surface expression. Gordon et al (in press) suggest these features form via slantwise convection of winter mixed layer water along the southern side of the subpolar front. These model results also indicate that formation mechanism, but also indicate that the features can form as a result of seasonal restratification of the column accompanied by more saline water masses being overridden by less saline water that enters through the Tsushima strait.

A comparison of deep currents in the Ulleung Basin observed by 2 years of current meter measurements with the deep currents simulated by a 1/32° NLOM simulation is described in a paper by Teague et al (submitted to DSR). Both the observations and model results show overall cyclonic circulation in this region. The Intra-Ulleung Gap is the narrow trough that feeds flow into and out of the Ulleung Basin. The observations are limited in this area, particularly on the eastern flank (the outflow component), so there is speculation of widespread upwelling in this region to compensate for the lack of outflow. The model results, however, indicate clearly depict flow into and out of the basin. Because widespread upwelling is not observed in this region, this is a case where the model can credibly describe the deep flow where the observations are sparse.

Situated between 200-400 m depth, the East Sea Intermediate Water (ESIW) is characterized by high dissolved oxygen and relatively low salinity (Kim and Chung, 1984). Hydrographic measurements indicate that the ESIW originates in the northern part of the JES near the Tatar Strait in response to riverine runoff and sea-ice melting and/or near Vladivostok in response to extreme cold air outbreaks. The anomalous water mass is subsequently advected southward, and has been clearly identified within the Ulleung Basin (e.g. Kim et al., 1991). The synoptically forced 1/16° simulation realistically reproduces the formation of the ESIW in both the northern JES as well as near Vladivostok. A cross-section of temperature and salinity on March 21, 1994 (not shown) depicts the vertical distribution of the cold, fresh water originating at the formation region near Vladivostok. The ESIW forms in this location and at this time due to an extreme cold-air outbreak coming off of the Siberian land mass. The low salinity ESIW, with salinity of 34.0-34.1, is overlain by much more saline Tsushima Warm Water and underlain by slightly more saline Japan Sea Proper Water. It retains its characteristic salinity between 200-400m all the way to the Japanese coastline.

A substantial improvement of HYCOM over NLOM is the inclusion of the shelf area. This is particularly evident in the depiction of the TWC Nearshore Branch along the northern coast of Honshu, an eastern boundary current that has both on-shelf and off-shelf components. In HYCOM, during both winter and summer, vertical resolution via z-levels is always maintained near the surface, but more of the z-levels turn into isopycnal surfaces during the summer because of the less dense water near the surface. During the winter, the Nearshore Branch is largely barotropic over the shelf, but mostly baroclinic during the summer as indicated by tilting isopycnals near 36°N. This suggests that over the shelf topographic control may be the dominant process associated with this boundary current during the winter, but that isopycnal outcropping may be more important during the summer (Hogan and Hurlburt, 2000). In both seasons, however, the bulk of the transport is seaward of the shelf break.

IMPACT/APPLICATIONS

The generalized vertical coordinate approach used in HYCOM allows both shallow and deep water regimes to be modeled simultaneously using the optimal vertical coordinate in each. This represents a significant increase in capability over traditional ocean circulation models that use a single vertical coordinate system. The HYCOM simulations performed under this DRI demonstrate the ability of HYCOM to realistically reproduce the major current systems in the JES, as well as the mesoscale eddy field, deep water circulation, and formation of characteristic water masses. A suite of simulations demonstrated the wide range of variability due to different wind forcing data sets. Additionally, synoptically forced HYCOM simulations (and some climatologically forced) were able to reproduce observed pycnostads and East Sea Intermediate Water formation. Most were also able to realistically reproduce the deep circulation, particularly in the Ulleung Basin.

TRANSITIONS

None.

RELATED PROJECTS

Matching funds were provided by the 6.1 LINKS in FY02. Interaction with CREAMS international research program. Funded participant in the HYCOM/NOPP project. 6.2 Global HYCOM and Advanced Data Assimilation isusing model results from this project as a test bed for advanced data assimilation.

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