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

Dr. Harley E. Hurlbut
Naval Research Laboratory, Ocean Dynamics and Prediction Branch
Stennis Space Center, MS 39529-5004
phone:(228) 688-4626 fax:(228) 688-4759 email: hurlburt@nrlssc.navy.mil

Dr. Patrick J. Hogan
Naval Research Laboratory, Ocean Dynamics and Prediction Branch
Stennis Space Center, MS 39529-5004
phone:(228) 688-4537 fax:(228) 688-4759 email: hogan@nrlssc.navy.mil

Document Number "N0001401WX20196"
http://www7320.nrlssc.navy.mil

LONG-TERM GOALS

Investigate Japan/East Sea circulation dynamics with a suite of numerical ocean circulation models, and verify numerical results via model-data comparisons.

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 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 (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 1/8° and 1/16°simulations have been completed in the JES. Most have been used to test basic model design concepts (i.e. vertical coordinate configuration), sensitivity to external forcing, and exploration of parameter space. 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. Several of these investigations are described in the RESULTS section.

A fully scalable and portable version of HYCOM (version 2.0) has been developed by Alan Wallcraft (NRL) and is available to the ocean modeling community. Several enhancements were also included, such as a one-way nesting capability, two-level parallelization (openMP and/or MPI), and 32-bit REAL*4 input/output. The 1/8° and 1/16° JES model domains were the primary domains used to test the scalability, portability, and added features in HYCOM version 2.0.

Mercator grid projections for 1/8°, 1/16°, and 1/32° resolution JES domains were extracted from ETOP05 and confirmed for accuracy (earlier versions had used an "NLOM-style" grid). The Mercator projection allows the JES simulations to be consistent with all other HYCOM modeling efforts, and allows the use of existing diagnostic software applications. The model diagnostics are a work in progress, but many baseline capabilities exist, including layer and cross-section snapshots, means, variabilities, domain-wide averages, and volume transports, in layer by layer or layer averaged combinations.

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). The EAS model domain includes the Yellow and East China Seas with the southern boundary in the Taiwan Strait. 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 Acoustic Doppler Current Profiler (ADCP) measurements taken within the strait during 1999-2000 as part of the NRL LINKS project. Additionally, the inclusion of the shallow Yellow Sea region and adjacent deep Japan/East Sea region will provide a robust test case to assess the ability of the generalized hybrid vertical coordinate scheme to simulate the shelf and deep water simultaneously. To date, the EAS model domain has run in nested mode for only a very short time.

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. Several simulations with 1/8° and 1/16° resolution (and a few with 1/32°) have been performed, most with monthly climatological forcing. However, a 1/16° simulation forced with synoptic (6 hourly) ECMWF 10m wind and thermal flux components was run from 1979 through 2000. The results from this simulation successfully depict many of the circulation features that were observed during the DRI field program. Some of these comparisons are discussed in the following paragraphs.

A substantial improvement of HYCOM over NLOM is the inclusion of the shelf area. This is particularly evident in the depiction of the Nearshore Branch, 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, 1999). In both seasons, however, the bulk of the transport is seaward of the shelf break.

Temperature, salinity, and density measurements made with the SeaSoar instrument (Craig Lee) reveal the existence of mid-thermocline eddies co-located with the quasi-stationary meanders of the subpolar front. These lens shaped features are characterized by colder, less saline water mass characteristics than the surrounding ambient water, suggesting subduction of winter mixed layer water to the south below the subpolar front. Vertical cross sections of temperature and salinity from the 1/16° synoptically forced simulation show similar features in approximately the same locations. 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 no surface expression. However, at this time it is unclear whether the simulated mid-thermocline eddies are formed via a similar subduction mechanism.

Situated between 200-400m, 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 sea-ice brine rejection and/or near Vladivostok in response to brine rejection and 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 (Figure 1) 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.

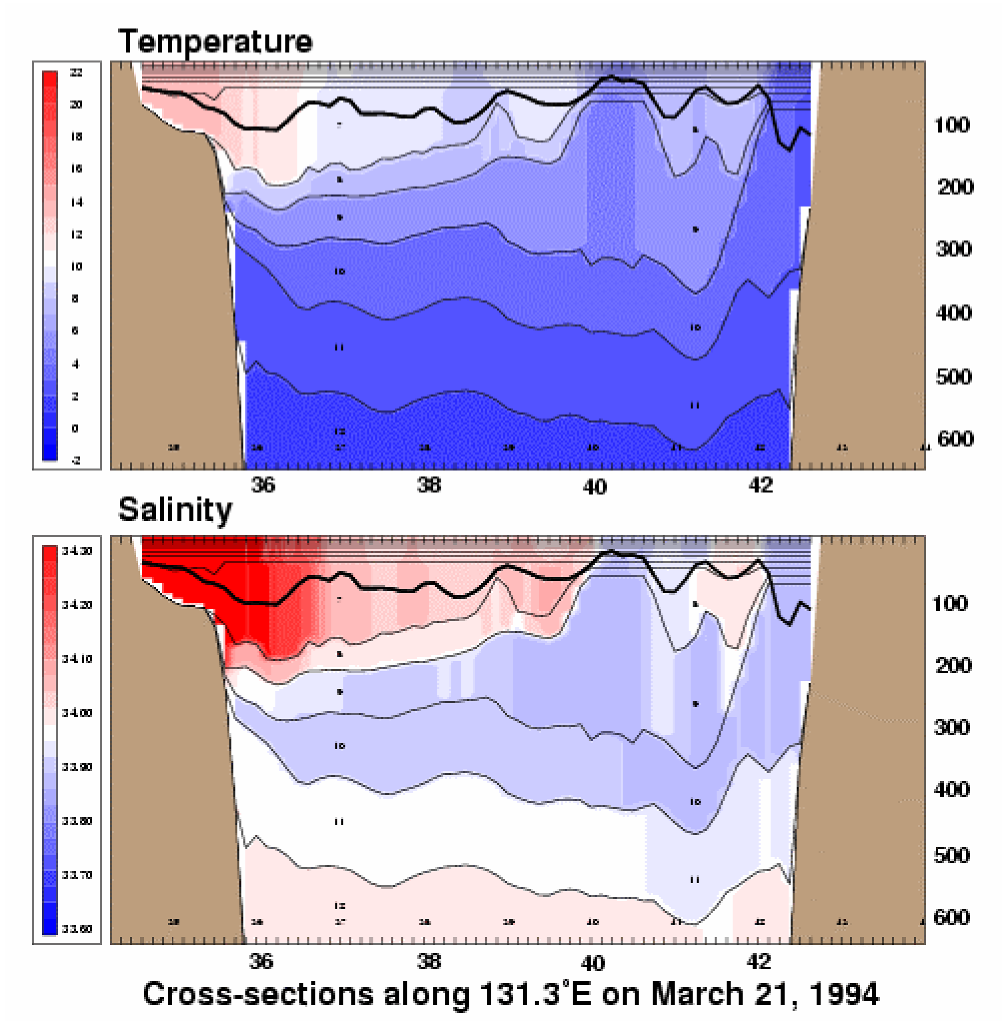

Figure 1. Simulated cross-sections of temperature and salinity along 131.3°E from a 1/16° 15-layer HYCOM simulation in the JES. The Tsushima Strait is to the left, Vladivostok is to the right. The simulation was forced with 6 hourly 10m winds and thermal fluxes from the ECMWF reanalysis product, as well as throughflow through the straits. These snapshots, for March 21, 1994, show a deep mixed layer near Vladivostok and the associated cold water extending from the surface to intermediate depth (300-400m). The bottom panel shows the relatively low salinity ESIW (blue) forming at the surface near Vladivostok, sinking to intermediate depth, and advecting southward towards the Ulleung Basin.

IMPACT/APPLICATIONS

The generalized vertical coordinate approach used in HYCOM allows both shallow and deep water regimes to be modeled simultaneously, with a single ocean model source code. 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. In particular, a 1/16° simulation driven by synoptic wind and flux forcing successfully reproduces the formation of the low salinity ESIW. This water mass forms near the Siberian coast during the winter, advects southward as part of the Liman Current, and retains its unique water mass characteristics as far south as the Ulleung Basin, before loosing its characteristics via mixing with the surrounding water. Additionally, the simulation depicts episodic ESIW formation off of Vladivostok in response to extreme cold air outbreaks.

TRANSITIONS

NRL has two funded 6.4 SPAWAR projects to develop a 1/8° global Navy Coastal Ocean Model (NCOM). However, the results presented in the JPO article suggest that higher horizontal resolution will be needed in the JES. Therefore, a nested 1/32° JES model based on HYCOM, taking boundary conditions from the global model, could be transitioned as the JES component of this system.

RELATED PROJECTS

Matching funds provided by 6.1 LINKS in FY01. Interaction with CREAMS international research program. Funded participant in the HYCOM/NOPP project. 6.2 Global HYCOM and Advanced Data Assimilation are using model results from this project as a test bed for advanced data assimilation.

REFERENCES

Bleck, R. and S. Benjamin, 1993. Regional weather prediction with a model combining terrain-following and isentropic coordinates. Part I.: Model description. Mon. Wea. Rev., 121, 1770-1785.

Bleck, R. and D. Boudra, 1981. Initial testing of a numerical ocean circulation model using a hybrid (quasi-isopycnic) vertical coordinate. *J. Phys. Oceanogr.*, 11, 755-770.

Kim, C.H., H.J. Lie, and K.S. Chu, 1991. On the Intermediate Water in the southwestern East Sea (Sea of Japan). P. 129-141. In *Oceanography of Asian Marginal Seas*, ed. By K. Takano, Elsevier, Amsterdam.

Kim, K and J.Y. Chung, 1984. On the salinity-minimum and dissolved oxygen-maximum layer in the East Sea (Sea of Japan). P. 55-65. In *Ocean Hydrodynamics of the Japan and East China Seas*, ed. By T. Ichiye, Elsevier, Amsterdam.

PUBLICATIONS

Hogan, P.J. and H.E. Hurlburt, 2000. Impact of upper ocean - topographical coupling and isopycnal outcropping in Japan/East Sea models with 1/8° to 1/64° resolution, *J. Phys. Oceanogr.,* 30, 2535-2561.

Jacobs, G.A., H. Perkins, W.J. Teague, and P.J. Hogan, 2000. Summer transport through the Tsushima-Korea Strait, *J. Geophys. Res*., 106, 6917-6929.

Hogan, P.J. and H.E. Hurlburt, 1999. A possible mechanism for the formation of the boundary current along the coast of Honshu in the Japan/East Sea, *Proceedings of the 10th PAMS/JECSS Workshop,* Kagoshima, Japan, 7-9 Oct. 1999, pp. 6.8-6.11.