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The surface circulation in the Japan/East Sea (JES) can be influenced by external forcing such as flow through the straits, surface wind stress, and surface heating and cooling. All are believed to have a significant effect on the presence and/or strength of the large scale circulation features such as the East Korean Warm Current (EKWC), the Liman and North Korea Cold Currents (LCC and NKCC), the Polar Front (PF), and the Nearshore Branch (NB) of the Tsushima Warm Current.

In this paper, we examine the impact of seven different seasonal wind stress forcing sets on the mean surface circulation in the JES via a layered circulation model. The simulations also include seasonal forcing through the straits. Previous modeling studies give some indication of the sensitivity of numerical models to external forcing, but the extent is difficult to quantify because of differences in model design and model parameters. To eliminate these differences we use the same (identical) ocean model to elucidate the model sensitivity to the choice of atmospheric forcing set.

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# Impact of different Wind Forcing on Circulation in the Japan/East Sea

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## Introduction

The surface circulation in the Japan/East Sea (JES) can be influenced by external forcing such as flow through the straits, surface wind stress, and surface heating and cooling. All are believed to have a significant effect on the presence and/or strength of the large scale circulation features such as the East Korean Warm Current (EKWC), the Liman and North Korea Cold Currents (LCC and NKCC), the Polar Front (PF), and the Nearshore Branch (NB) of the Tsushima Warm Current.

In this paper, we examine the impact of seven different seasonal wind stress forcing sets on the mean surface circulation in the JES via a layered circulation model. The simulations also include seasonal forcing through the straits. Previous modeling studies (Sekine, (1991); Seung (1992); Kim and Yoon (1996)) give some indication of the sensitivity of numerical models to external forcing, but the extent is difficult to quantify because of differences in model design and model parameters. To eliminate these differences we use the same (identical) ocean model to elucidate the model sensitivity to the choice of atmospheric forcing set.

## The Ocean Model and Forcing Fields

The simulations discussed in this study were performed using the Naval Research Laboratory (NRL) Layered Ocean Model (NLOM). NLOM is a semi-implicit primitive equation ocean model where the layered model equations are cast in transport form and the interfaces between layers are isopycnal surfaces. The model retains the free surface and can include realistic bottom topography as long as it is confined to the lowest layer. Hurlburt and Thompson (1980) describe the original model design, although the model has been significantly enhanced by Wallcraft (1991). Hogan and Hurlburt (1999) discuss implementation of NLOM for the JES in detail. All of the simulations used in this study have 4 Lagrangian layers in the vertical and 1/8° horizontal resolution between like variables on the C-grid. Hence these nonlinear models are eddy-resolving and contain higher order dynamics such as isopycnal outcropping and the possibility of flow instabilities. However, this resolution is too coarse to generate the mesoscale flow instabilities required for the upper ocean – topographical coupling discussed by Hogan and Hurlburt (1999).

The models were forced with the monthly wind climatology formed from the seven different wind stress products listed in Table 1 as well as seasonal forcing through the straits. The mean throughflow is 2 Sv, and a seasonal signal is superimposed so that the maximum (minimum) throughflow occurs in summer (winter). Na et. al (1992) discuss the so-called "Na" wind stress. Detailed information on the other wind stress products is contained in Townsend et. al (1999).

| Wind stress product | Native grid resolution | Time period |
|---|---|---|
| Hellerman-Rosenstein | 2.0° x 2.0° | historical |
| COADS | 2.0° x 2.0° | historical |
| Na | 0.5° x 0.5° | 1978-1995 |
| NCEP | 2.5° x 2.5° | 1958-1997 |
| ECMWF 10 m | 2.5° x 2.5° | 1979-1993 |
| ECMWF 1000 mb | 2.5° x 2.5° | 1979-1993 |
| FNMOC | 1.25° x 1.25° | 8/90-7/97 |

Table 1. Native grid resolution and time period covered for the wind stress products used to form the monthly climatological wind stresses for forcing the ocean model.

## Results

Figure 1a shows the mean SSH for the simulation forced with straits throughflow forcing only and Figs. 1b-1f show the mean SSH from the cases forced with the seven different monthly wind stress climatologies in addition to straits throughflow forcing. The case forced with straits throughflow only (Fig. 1a) is able to reproduce all of the major current systems remarkably well. The major exception is unrealistic "overshoot" of the EKWC. It is noteworthy that this simulation reproduces the southward flowing LCC and the overall cyclonic flow of the subpolar gyre (albeit weakly) in the absence of *any* wind forcing.

Mean SSH from the simulations forced with the Hellerman-Rosenstein and COADS climatology are shown in Fig. 1b and 1c, respectively. The mean SSH in these simulations is quite similar to that shown in Fig. 1a, except that the strength of the subpolar gyre is enhanced due to overall positive wind stress curl in that region. However, the strength of the subpolar gyre in both simulations is insufficient to suppress the latitude of separation of the EKWC, and significant overshoot persists.

Mean SSH from the simulation forced with the Na monthly wind stress climatology is shown in Fig. 1d. It is likely that this wind stress data set is the most widely used in numerical modeling of the JES. In this simulation the LCC continues southward as the NKCC until its confluence with the EKWC at about 38°N, consistent with observed latitude of separation of the EKWC. Part of this flow continues eastward along the polar front but some recirculates to the south before flowing northward along the coast of Honshu.

Figure 1e and 1f show the mean SSH from the simulations forced with the ECMWF (10 m and 1000 mb, respectively) reanalysis winds. Both of these depict the EKWC separating near the observed latitude, even though the strength of the NKCC is noticeably diminished in both when compared to the Na wind stress case. A bifurcation of the flow along the PF is seen in Fig. 1f, a configuration unique to this simulation.

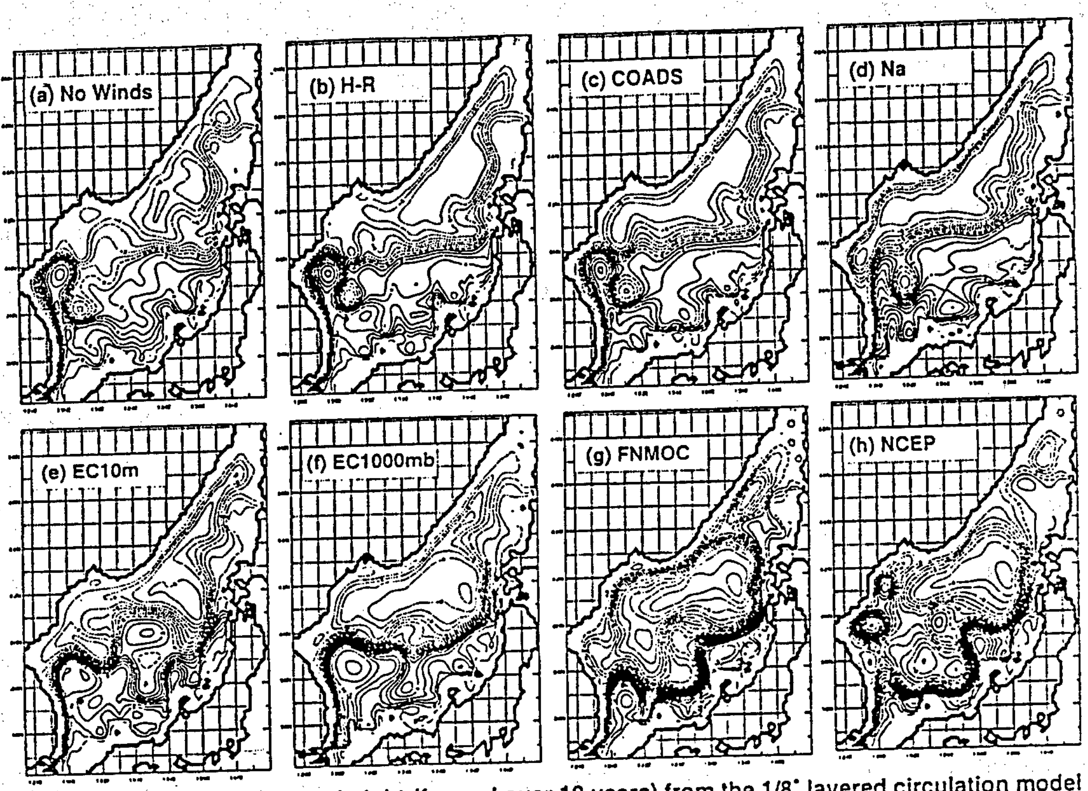

Figure 1. Mean sea surface height (formed over 10 years) from the 1/8° layered circulation model for (a) the case with no wind forcing and (b-h) for the cases forced with the different wind stress data sets and straits throughflow. Contour interval is 1 cm.

The solutions forced with the FNMOC wind stresses (Fig. 1f) and NCEP reanalysis stresses (Fig. 1g) are characterized by strong cyclonic flow over a large part of the JES basin. In fact, in both of these simulations, the PF exists only to the extent that it forms the southern boundary of the subpolar gyre. Accordingly, the strength of the NB is stronger in these two solutions than in any of the others. Indeed, one could surmise that these simulations reproduce the separation of the EKWC from the Korean coast and northward flow along the coast of Honshu reasonably well. However, other aspects of the solution, such as the relatively strong anticyclonic eddy near East Korea Bay in Fig. 1h are more suspect.

## Summary

All simulations in Figure 1 depict the major circulation features of the JES when compared to schematic charts of the circulation (e.g. Naganuma (1977) and Yarachin (1980)) which are believed to be accurate to first order. For instance, all depict cyclonic circulation in the northern part of the JES associated with the subpolar gyre. The cyclonic circulation is the result of relatively strong wind stress flowing off of the Siberian landmass during the wintertime in all of the wind stress data sets. The wind stress produces strong positive wind stress curl, which results in locally intense upwelling due to Ekman suction. However, as Fig. 1 demonstrates, substantial variability in the strength, size and location of the subpolar gyre exists. This variability is mainly due to differences in the strength and pattern of the positive wind stress curl in the subpolar gyre region.

All simulations also depict the presence of realistic northward flow along the coast of Honshu, although there is large variation in the magnitude. This is primarily due to isopycnal outcropping, which occurs through ventilation of model interfaces via diapycnal mixing. In some simulations, especially those forced with the FNMOC and NCEP monthly wind stress, the strength of the NB is significantly increased due to the strengthening of the basin-scale cyclonic circulation in these simulations. Indeed, in those the simulations, the distinction between the PF and NB becomes obscure.

In summary, these results qualitatively demonstrate the impact that different wind stress data sets have on the mean surface circulation simulated with a 1/8° layered ocean model. Clearly, some wind stress data sets more realistically reproduce the large scale circulation than others, but the knowledge of the JES circulation is insufficient to make definitive statements and the relative merits are also dependent on the model and model resolution. For example, five of the wind sets reproduce EKWC separation at approximately the observed latitude due to the strength and pattern of positive wind stress curl while two do not along with the case without winds. However, Hogan and Hurlbut (1999) show that even these can give realistic EKWC separation by a different mechanism, upper ocean – topographical coupling via flow instabilities, when the grid resolution is increased to 1/32° (3.5 km).

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