

Modeling of Coupling the Upper and Deep Ocean Over Topography in Marginal Seas

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LONG-TERM GOAL

Our long-term goal is to achieve deeper understanding of physical processes of vertical coupling over topography and apply it to the development of more physically accurate model initialization and data assimilation techniques for ocean nowcasting and short and medium range forecasting in marginal seas.

SCIENTIFIC OBJECTIVES

Specific scientific objectives for this study are motivated by extensive observational programs in Japan/East Sea (JES) which provide a unique data set to develop practical application of our previous theoretical studies and clarify major physical mechanisms of vertical coupling over topography. This project is focused on studying the dynamical coupling between baroclinic jets and cut off eddies with the deep flow over variable topography. The gained knowledge would allow us developing new model initialization and data assimilation techniques.

APPROACH

Our approach combines theoretical investigation with advanced numerical modeling to gain understanding and efficient representation of the most important physical processes in marginal seas. In collaboration with the Profs Watts and Wimbush's (URI) project, we use analytical and numerical models for comparison with the observational data in the JES (Mitchell et al., 2002).

WORK COMPLETED

We suggested a new initialization procedure assuming conservation of potential vorticity (PV) along a baroclinic jet, and investigated the evolution of a Subpolar Front-type jet in a two-layer model. We also analyzed the flow structure created by deep eddies beneath a meandering jet. The jet was prescribed as a PV front in the upper layer overlying an initially quiescent bottom layer. An iterative balanced model was developed to obtain the density and velocity fields. A graduate student, A. Shybanov, works on setting up more realistic simulations using HYCOM.

RESULTS

a. Dynamics of Subpolar Front initialized from potential vorticity.

A procedure has been developed for the Subpolar Front initialization in a two-layer model. It combines the cross-stream layer PV structure derived from long term observational data with a currently observed front position assuming along-stream preservation of PV. A similar initialization technique was successfully used for the Gulf Stream initialization in a primitive equation model (Sutyryn et al., 2001). Using the frontal PV structure instead of its density or velocity fields allows for better representation of well developed meanders and cut-off eddies in the vicinity of the front. In addition, a balanced approximation (Sutyryn, 1994) is applied to calculate the Subpolar Front density and velocity structure, allowing centrifugal force to be taken into account in steep meanders.

Evolution of the Subpolar Front has been simulated in a two-layer intermediate model of JES over realistic topography. This model has been recently used for Loop Current Eddy modeling in the Gulf of Mexico (Sutyryn et al., 2002). In the JES upper layer the PV front is assumed to separate two water masses characterized by the depth $\bar{h}_S = 200$ m in the southern basin and $\bar{h}_N = 100$ m in the northern basin. Corresponding transport by the geostrophic flow is given by $M = g'(\bar{h}_S^2 - \bar{h}_N^2)/2f_0 = 4$ Sv for reduced gravity $g' = 0.02$ m/s² and Coriolis parameter $f_0 = 7.5 \times 10^{-4}$ s⁻¹. The inflow through the Tsushima Strait, P , is prescribed to be equal to the outflow through the Tsugaru Strait (taking into account that additional outflow through the shallow Soya Strait has only a small effect). Both flow through these straits and wind forcing have profound impacts on the circulation features within the JES.

To investigate the basic features of Subpolar Front dynamics, we simulated the JES circulation without wind forcing for $P = M$, when the inflow forms the East Korean Warm Current (EKWC) along Korean shore and continues along the Subpolar Front until outflow through Tsugaru Strait. Unlike simulations by Hogan and Hulbert (2000) where the inflow distribution was prescribed, in this model the formation of EKWC near the shore is a result of homogeneous PV distribution in the inflow water mass.

Meanders develop along the front and eventually a large cyclonic meander pinches off forming a detached eddy (Fig. 1). The eddy moves southwestward and subsequently interacts both with the EKWC and the Subpolar Front decreasing in size after each interaction. These interactions are responsible for highly variable dynamics in the southern JES. Smaller eddies also pinch off north of the Subpolar front as seen in Fig. 1. Note, that the intrinsic variability of the Subpolar Front is obtained with constant inflow, while in reality the inflow varies strongly (Teague et al., 2002a). Inflow variations will be taken into account in our further investigations.

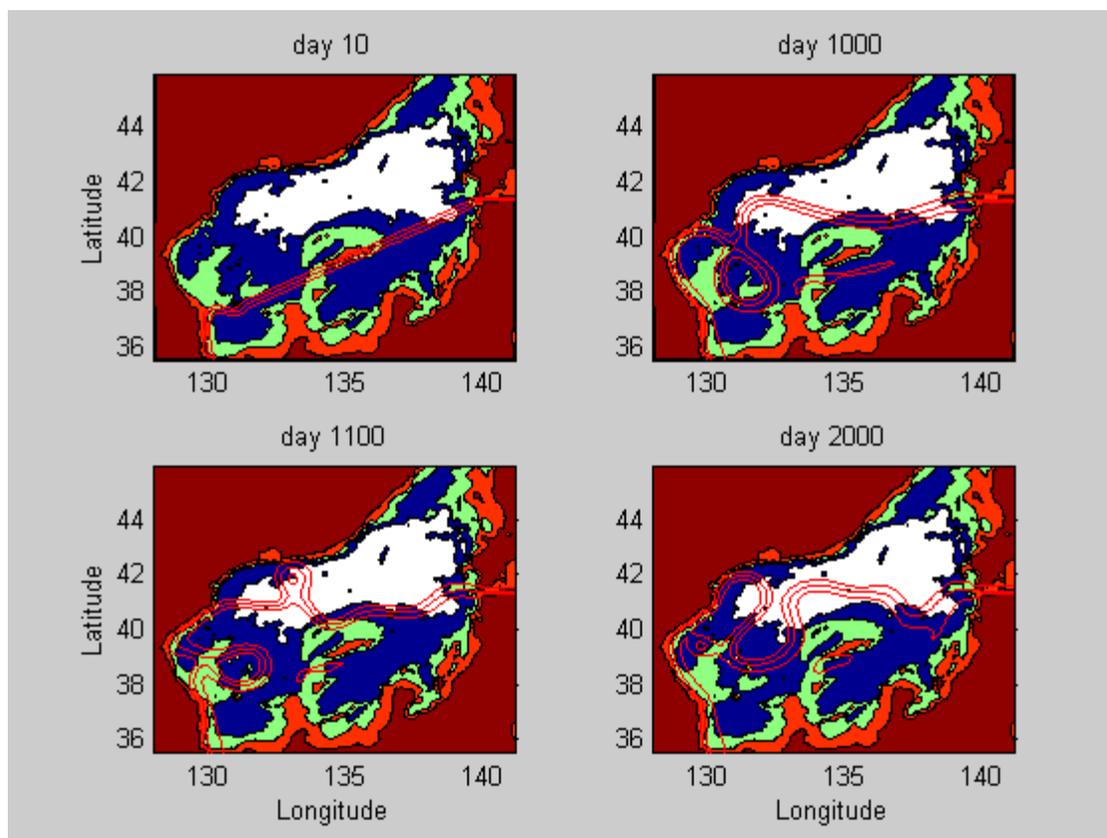


Fig. 1 Sea Surface Height (SSH) (red lines) superimposed by bottom topography (isobaths 10, 500, 1500, 3000 m are shown) when the inflow is equal to the frontal transport ($P = M$).

b. Vertical coupling in the Subpolar Front evolution

During the stage of large cyclonic meander formation in the first three years of model integration the lower layer currents do not contribute essentially to upper layer dynamics; this is apparent from a comparison with reduced-gravity, $1\frac{1}{2}$ -layer simulations. Growth of the large cyclonic meander and its detachment is not related to baroclinic instability, rather it is mostly a result of inertial nonlinear dynamics in the upper layer related to modified KdV equations considered by Nycander et al. (1993). During this stage the deep flow can be obtained diagnostically using the thermocline depth evolution calculated in the reduced-gravity approximation without any deep flow feedback.

The vertical coupling becomes essential in regions with gentle slope where the jet exhibits rapid path changes resulting in more intense deep eddies (Fig. 2). For example, the deep eddies are important in formation of a smaller anticyclone north of the Subpolar Front at day 1100. It would not detach in the reduced-gravity approximation. Proper initialization of deep flow is crucial for an adequate forecast of the flow in such regions.

In this model simulation, the Subpolar Front and eddies evolve mostly outside the Ulleung Basin (UB). Correspondingly, simulated lower layer currents in the UB remain very weak. In our further studies we will consider more realistic vertical structure with intermediate water mass and variable inflow to compare deep currents with observational data (Teague et al., 2002b).

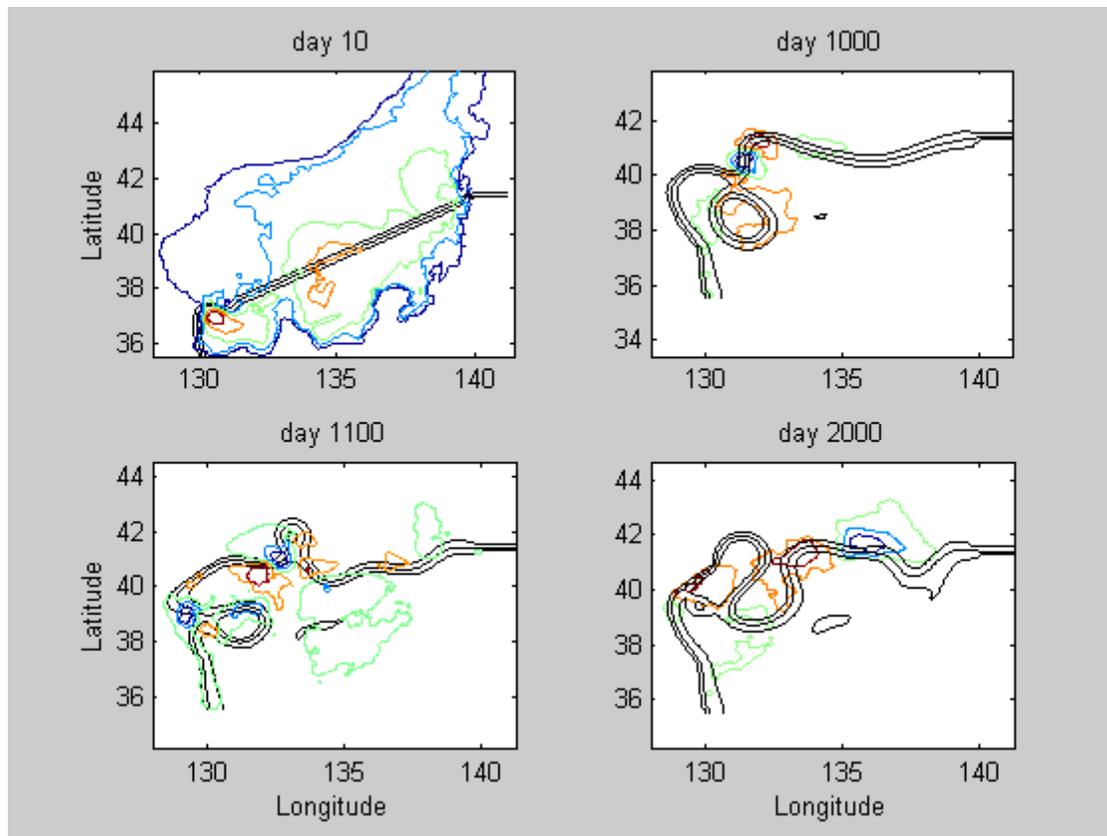


Fig. 2. *Sea Surface Height (SSH) (black lines) superimposed by deep pressure when the inflow is equal to the frontal transport ($P = M$).*

IMPACT/APPLICATION

The means by which we have analyzed the evolution of baroclinic meanders and eddies over topography in this study are novel and useful for future investigations. New physical mechanisms are suggested to explain weak vertical coupling during slow evolution of large meanders. Nonlinear inertial behavior of the jet in marginal seas has not been explained previously. This has implications for our understanding of coupling, horizontal and vertical, of flow over topography in marginal seas.

TRANSITIONS

Our approach to the potential vorticity initialization and vertical coupling analysis has the prospect of use in other ONR-funded studies of the JES (Watts and Wimbush, URI), the NRL's "Linkages of Asian Marginal Seas", and initialization of the Princeton Ocean Model for coupled hurricane - ocean forecasts (Ginis, URI).

RELATED PROJECTS

Drs. Randy Watts and Mark Wimbush (URI) are analyzing observational data in JES.

Drs. Isaac Ginis and Lew Rothstein (URI) are using the PV initialization approach for modeling hurricane - ocean interaction.

Drs. Gregory Reznik (IORAS, Russia) and Georgi Sutyrin (URI) are analyzing mutual effects of topography and baroclinicity on long-lived vortices to improve our understanding of vertical coupling over a sloping bottom.

REFERENCES

- Hogan, P.J., and H.E. Hurlburt, 2000: Impact of upper ocean-topography coupling and isopycnal outcropping in Japan/East Sea model with $1/8^\circ$ to $1/64^\circ$ resolution. *J. Phys. Oceanogr.*, **30**, 2535-2561.
- Mitchell, D.A., D.R. Watts, M. Wimbush, K.L. Tracey, W.J. Teague, J.W. Book, M.-S. Suk, and J.-H. Yoon, 2002: Current structures and variability in the Southwestern Japan/East Sea: Upper layer patterns. *Deep Sea Res.* Submitted.
- Nycander, J., D.G. Dritschel and G.G. Sutyrin, 1993: The dynamics of long frontal waves in the shallow water equations. *Phys. Fluids A*, **5**, 1089-1091.
- Sutyrin, G.G., 1994: Long-lived planetary vortices and their evolution: conservative intermediate geostrophic model. *Chaos*, **4**, 203-212.
- Sutyrin, G.G., I. Ginis, and S.A. Frolov, 2001: Equilibration of the Gulf Stream meanders and deep eddies over a sloping bottom. *J. Phys. Oceanogr.*, **31**, 2049-2065.
- Sutyrin, G., D. Rowe, L. Rothstein, and I. Ginis, 2002: Baroclinic-eddy interactions with continental slopes and shelves." *J. Phys Oceanogr.*, in press.
- Teague, W.J., C.A. Jacobs, H.T. Perkins, J.W. Book, K.-H. Chang, and M.-S. Suk, 2002a: Low Frequency current observations in the Korea Strait. *J. Phys. Oceanogr.*, 1621-1641.
- Teague, W.J., D.R. Watts, J.W. Book, K.-I. Chang, P.J. Hogan, D.A. Mitchell, M.-S. Suk, K.L. Tracey, M. Wimbush, and J.-H. Yoon, 2002b: Deep circulation in the Southwestern Japan/East Sea. *Deep Sea Res.* Submitted.