

Processes Coupling the Upper and Deep Ocean Over Topography: Towards Improving Model Initialization and Data Assimilation

Isaac Ginis
Graduate School of Oceanography
University of Rhode Island
Narragansett RI 02882
phone: (401) 874-6484 fax: (401) 874-66728 email: iginis@gso.uri.edu

Grant Number: N000140010404

LONG-TERM GOAL

Our long-term goals are to improve understanding of physical processes in energetic jets and eddies, and feedbacks between motions in the thermocline and deep abyss over topography; and to develop new model initialization and data assimilation techniques based on more adequate representation of the physical processes in both the main thermocline and deep ocean.

SCIENTIFIC OBJECTIVES

The specific scientific objectives of this project are focused on studying the dynamical coupling between meandering baroclinic jets with the deep flow over steep topography. Emphasis is placed on the initialization of baroclinic jets in numerical models and improving our understanding of the life cycle of energetic flow perturbations excited by meandering of baroclinic jets. The gained knowledge would allow us developing new model initialization and data assimilation techniques.

APPROACH

Our approach relies on advanced numerical modeling to gain understanding and efficient representation of the most important processes in baroclinic flows over topography. Primitive equation and multi-layer intermediate numerical models are used for numerical experiments in this project.

WORK COMPLETED

We have further advanced the balanced PV-gradient model of Sutyrin et al. (2001) for initializing a baroclinic jet over topography in a primitive equations ocean model. The balanced PV-gradient model is designed to find an initially balanced solution in terms of the isopycnal layer dynamic pressure. However, for many practical applications, the initial conditions have to be expressed in terms of initial density (temperature/salinity) and velocity fields. Therefore, we have developed a procedure to convert the balanced model solution from dynamic pressure in isopycnal layers to density and velocity fields in the coordinate system of a primitive equations model. This procedure has been successfully applied for Gulf Stream initialization and the results are compared with available observations. We have also demonstrated the advantages of the PV-based initialization approach for initializing baroclinic jets with steep meanders and closely located mesoscale features.

RESULTS

a. Initialization of a baroclinic front in a primitive equation model

In the developed initialization procedure a baroclinic front is initialized in two steps. First, we use the PV-gradient model based on the balanced equations of Sutyrin et al. (2001) and Logoutov et al. (2001). Second, we convert the PV-gradient model solution into a primitive equation model. A set of discrete densities in the balanced model is converted into a continuous vertical density profile. The density in each layer is assumed to change linearly with depth in such a way that the densities at the layer interfaces are matched, so that the individual profiles would form a continuous vertical profile throughout the entire water column. The conversion of the obtained density field into 3-d temperature and salinity fields is accomplished using T-S relationships. An iterative procedure is applied to calculate the initial velocity field which would be in balance with the specified density field. The initial geostrophic balance is first calculated using the truncated primitive equations. The obtained geostrophic velocities are used to calculate the nonlinear momentum advection terms. The geostrophic balance is then recalculated taking into account those terms. For illustration, the cross-stream temperature and velocity fields resulting from applying the described initialization process to the Gulf Stream are shown in Figure 1 (left).

b. Improved structure of a modeled baroclinic jet with steep meanders

We have found that using the PV approach structural changes to the velocity and density fields in the Gulf Stream between crests and troughs can be more accurately reproduced. The most recent and robust observational evidence of structural changes to the Gulf Stream velocity field between crests and troughs comes from the Oleander project (Rossby and Gotlieb 1998). For the purpose of this study we derived the vertically averaged velocity profiles over the upper 250 meters from the Oleander data. The resulting crest and trough velocity profiles are shown in Figure 2 (left panels). In the figure the cross-stream distance is negative north of the stream and positive south of the stream. It can be clearly seen that the cyclonic shear, i.e., the slope of the velocity profile on the northern side of the stream, is higher in a crest, while the anticyclonic shear is higher in a trough. It also can be observed that the anticyclonic shear increase in a trough is substantially larger than the cyclonic shear increase in a crest, which implies that the stream is wider in a crest and narrower in a trough. These features are realistically reproduced by the PV-based feature model (Figure 2, right panel).

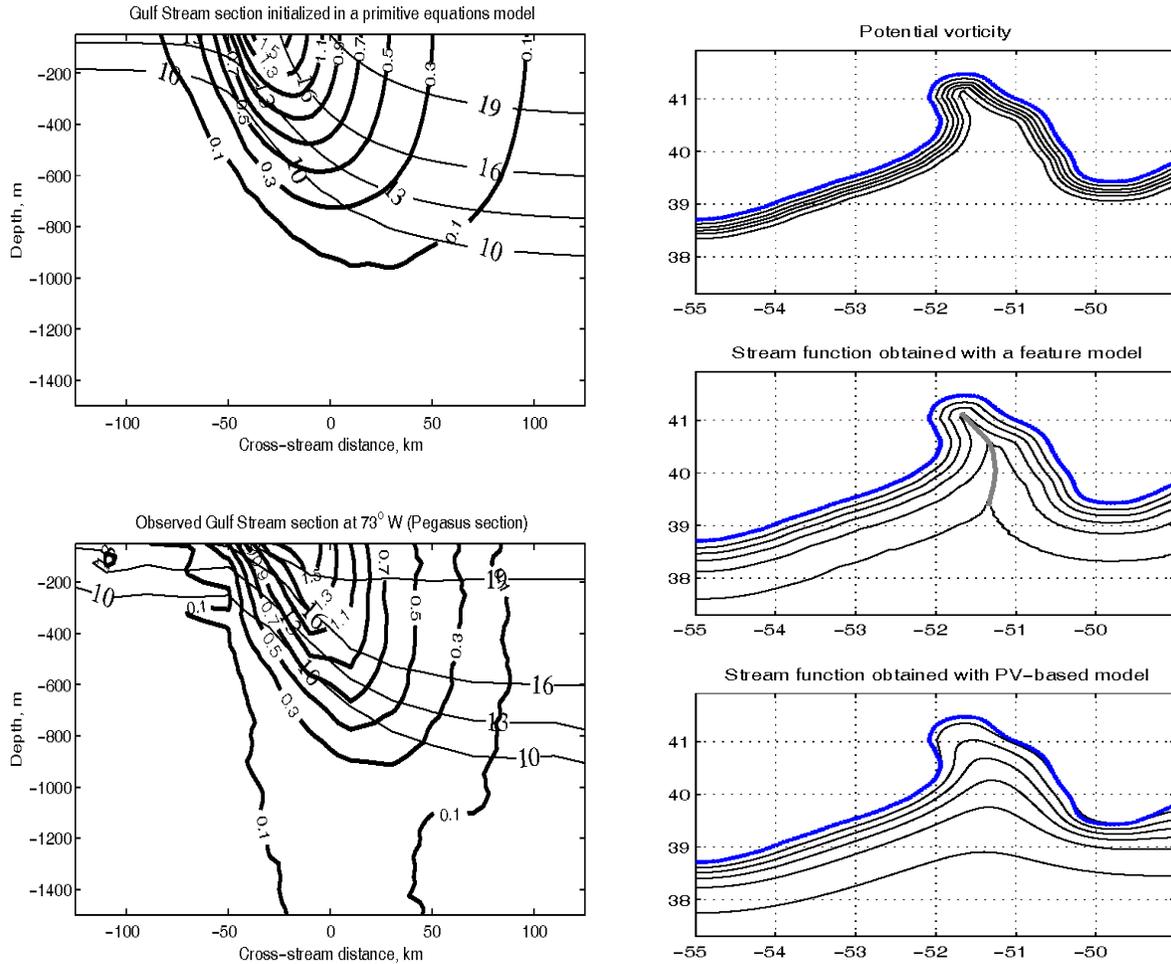


Fig. 1 Left panels: Temperature and velocity cross-sections of the Gulf Stream initialized in the Princeton Ocean Model (left) compared to the observed mean section at 73W (Halkin and Rossby 1985). Right panels: A fragment of the Gulf Stream north wall position observed on Aug. 18, 1996 using AVHRR infrared satellite imagery (courtesy of P. Cornillon) and the initialized Gulf Stream structure using the PV-based feature model (upper and lower panels) and a stream function-based feature model (middle panel). The Gulf Stream path is shown by the thick blue line. The lighter thick line on the middle panel indicates the location of the singularity in the velocity field initialized with stream function-based feature model.

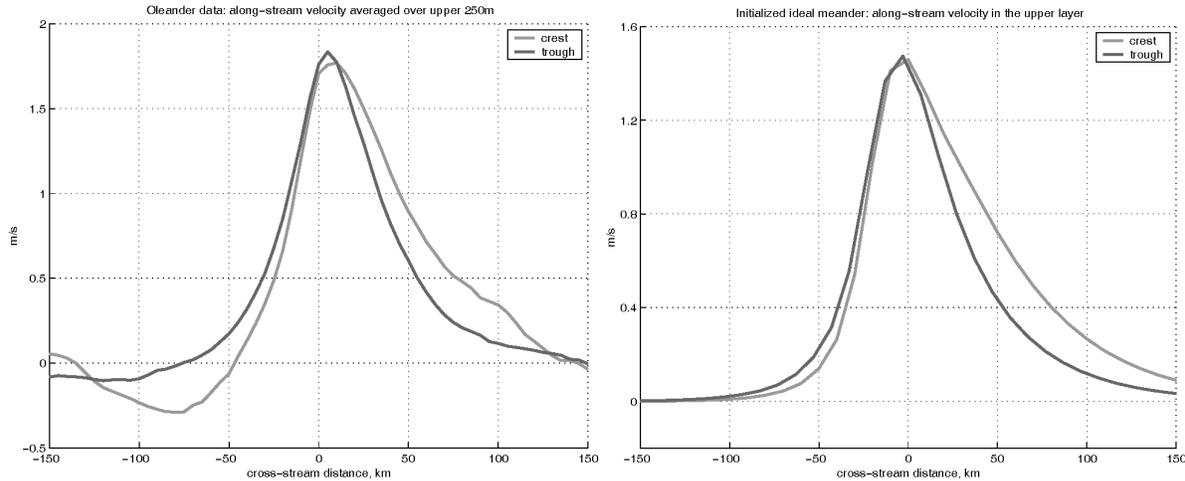


Fig. 2. Left panel: Along-stream velocity in the Gulf Stream vertically averaged over upper 250 meters obtained from the Oleander data . The lighter line indicates the velocity profile obtained by stream-coordinate averaging of all Oleander sections with velocity maximum (center of the stream) north of $37.9^{\circ}N$, i.e., meander crests. The darker line indicates the velocity profile obtained by stream-coordinate averaging of all sections with velocity maximum south of $37.4^{\circ}N$, i.e., meander troughs. Right panel: The same as in the left panel, but derived from the PV-based feature model.

c. Initialization of closely located mesoscale features

The width of the Gulf Stream as it is seen in the velocity field is more than 150 km (Figure 2) while the width of the associated potential vorticity front is only several tens of kilometers (Logoutov *et al.* 2001). This property of the Gulf Stream PV structure gives another important advantage to the PV oriented initialization techniques. Quite often the stream path comes close to intersecting itself or other ocean features like rings. This usually happens during the final stages of ring formation process or during the process of ring reabsorption by the stream. It is difficult to distinguish between two ocean features if the distance between these features is less than the width of the stream looking just at velocity or density fields. Since the width of the stream is more than 150 km, it puts a limitation on the number of realistic scenarios that can be initialized using velocity or density based feature model. If the features are defined in terms of their PV they can be easily distinguished even when they are less than 100 km apart. This is illustrated in Figure 1 (right panels). A fragment of the Gulf Stream path observed on Aug. 18, 1996 is used for initialization in both PV-based and stream function-based procedures. This particular fragment is selected because of the sharp meander which is about to form a warm-core ring. The middle panel shows the stream function which results from applying a stream function-based feature model. While the sharp anticyclonic meander is well resolved in the PV field (upper panel), the application of a stream function-based feature model produces an abnormal region indicated with the lighter thick line on the figure. The gradient of the stream function, i.e., the velocity field, has a singularity at this location. For comparison, the stream function shown in the lower panel and calculated from the PV field shown on the upper panel while still following the specified stream path does not display any velocity anomalies.

IMPACT/APPLICATION

This research has direct implication toward improving our forecast skill of baroclinic fronts. The means by which we have initialized the baroclinic front structure and analyzed the evolution of baroclinic meanders and deep eddies over topography in this study are novel and can be used in ocean nowcasting and forecasting.

TRANSITIONS

Our three-pronged work (observations / theory / modeling) in collaboration with the Dr. Watts and Dr. Sutyrin indicates that it is crucial to know the deep eddy current field in order to successfully initialize and predict the evolution of the upper baroclinic front. The balanced PV-gradient model is mature enough to be implemented for modeling and forecasting of baroclinic fronts at NRL. The new understanding and technology developed in this project will benefit present observational and model studies in the Japan/East Sea jointly conducted by URI and NRL and future collaborations with NRL in the Gulf of Mexico.

REFERENCES

- Halkin, D. and H. Rossby, 1985: The structure and transport of the Gulf Stream at 73°W. *J. Phys. Oceanogr.* 15, 1439-1452.
- Gangopadhyay, A., A. Robinson, and H. Arango, 1997: Circulation and dynamics of the western north atlantic. Part 1: Multiscale feature models. *J. Atmos. Oceanic Technol.* 14 (6). 1314-13332.
- Logoutov, O.G., Sutyrin, G.G., and D.R. Watts, 2001: Potential vorticity structure across the Gulf Stream: Observations and a PV-gradient model. *J. Phys Oceanogr.* **31**, 637-644.
- Rossby, H., and E. Gotlieb, 1998: The Oleander project: Monitoring the variability of the Gulf Stream and adjacent waters between New Jersey and Bermuda. *Bulletin of the AMS*, **79**, 5-18.
- 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.

PUBLICATIONS

- Frolov, S.A., Sutyrin, G.G., and I. Ginis, 2002: Asymmetry of the stabilized Gulf Stream system. Submitted to *J. Phys Oceanogr.*