Toward Realistic Modeling of a Shelfbreak Front: Lagrangian Metrics and Process Studies for the Middle Atlantic Bight

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LONG-TERM GOALS

A region where predictive capability is sought for tactical concerns is the flow field in the vicinity of the continental shelfbreak. Sound propagation from the continental slope to the continental shelf is a complex process that is highly dependent upon the oceanographic environment. A strong thermal shelfbreak front, and its associated current, are the key features that influence acoustic propagation in many shelf regions. Theory and field data suggest that acoustic propagation is strongly affected by frontal features that can evolve on rapid temporal scales (1-2 days) and small spatial scales (10-20 km). The overall aim of this proposed work is to improve our ability to realistically model and predict the evolution of the shelfbreak front so as to advance the predictive capability of this region.

OBJECTIVES

This work focuses specifically on ascertaining the dominant mechanisms for the frontal variability in the Middle Atlantic Bight and on establishing the degree of predictability of the ocean in the vicinity of the shelfbreak front. While this work is specifically focused on the environmental conditions of the Middle Atlantic Bight, its applicability extends to other geographic locales where relatively robust shelfbreak frontal jets exist, such as in the South China Sea, the Black Sea and in some shelf regions of the Antarctic.

APPROACH

To address the objectives of this work, two projects are being pursued. The first project involves the study of the stability of the shelfbreak frontal current. A dynamic model developed by Moore and Peltier (1987), and modified by Xue and Mellor (1993) to include bathymetry, is employed. The model uses linearized primitive equation dynamics to determine the growth of three-dimensional perturbations along a two-dimensional background front. As discussed by Xue and Mellor (1993) and Moore and Peltier (1987) the use of primitive equations successfully captures the cyclonic-scale modes. These modes are filtered out with the geostrophic momentum approximation, which is commonly used in shelf dynamics. For each model configuration, wavenumber space is explored to establish the stability/instability of each selected flow field. From the unstable waves the dominant wave is identified and the evolution of the front is characterized with a wavelength, phase speed, growth rate and modal structure. Model configurations include changes in the horizontal and vertical structure of the velocity and density fields and changes in the topographic slope. Dr. Mark Reed, a computational scientist at the North Carolina Supercomputing Center, works on the development and implementation of this modeling project.

A second project involves an evaluation of the predictability of the shelfbreak front in the Middle Atlantic Bight using nonlinear time series analysis. The use of nonlinear techniques will allow for the determination of whether the system behaves principally as a stochastic or deterministic system, a determination that has direct bearing on our attempts to model, and analyze, this ocean flow field. Nonlinear time series analysis is being applied to historical current meter data from the Nantucket Shoals Flux Experiment. Briefly, the essential goal of this analysis is to build a deterministic model by using time-delay vectors obtained from the time series. To first assess whether a nonlinear analysis is appropriate for this data, we have created surrogate time series from the original time series. A comparison of the nonlinear prediction errors generated by the surrogate time series to those of the original time series lends insight into whether a deterministic or stochastic model is more appropriate for the prediction of the flow field and its properties. Dr. Guocheng Yuan, a research associate in the Department of Applied Mathematics at Brown University, is performing the computations for this project. Dr. Larry Pratt (Woods Hole Oceanographic Institution) and Dr. Christopher Jones (Brown University) are collaborators on this project.

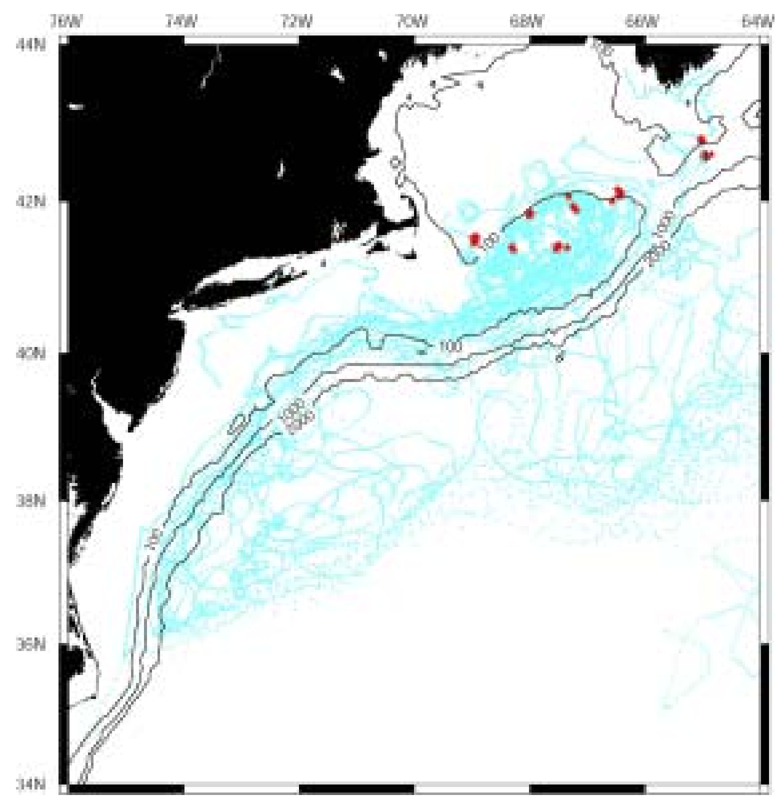

Figure 1: Surface Drifters in the Middle Atlantic Bight
[plot: Lagrangian pathways showing continuity and variability of the shelfbreak current]

WORK COMPLETED

During the past year a study on the influence of topography on the stability of the shelfbreak frontal current in the Middle Atlantic Bight has been completed. The results of this comparison were presented at the Ocean Sciences Meeting in February 2002 and are contained in a manuscript, *The Influence of Topography on the Stability of a Shelfbreak Front*, which will be submitted to the *Journal of Physical Oceanography* in the fall of 2002.

During the past year nonlinear and linear prediction models were successfully developed for the observed time series from current meter data from the Nantucket Shoals Flux Experiment. Changes in predictability as a function of cross-shelf location were assessed. This work was presented at the Fall 2001 AGU meeting in San Francisco. Additionally, a paper with these results has been submitted to the *Journal of Physical Oceanography.*

RESULTS

A stability analysis of a two-dimensional geostrophic jet overlying shelfbreak topography has found the jet to be unstable to perturbations for a wide range of background conditions (Lozier *et al*., 2002). While earlier studies of shelfbreak frontal instabilities found growth rates to be prohibitively small to be of consequence in the energetic shelfbreak region, the model growth rates from this study are on the order of one day. Such rapid growth would clearly lead to substantial temporal and spatial variability for the shelfbreak front. The inclusion of continuous horizontal and vertical shear for the background density and velocity field, as well as the use of primitive equation dynamics, are believed to be responsible for the capture of physical modes with rapid growth rates. While the perturbations with the shortest wavelengths generally had higher growth rates, often the growth rate curves were relatively flat at high wavenumbers, suggesting a range of wavelengths might be present in the shelfbreak vicinity, rather than one dominant wavelength. Indeed, past observations of spatial variability in the Middle Atlantic Bight have not narrowly defined the dominant spatial scale of the eddy motions. Collectively, these past studies have reported a range of from 10 to 75 km for the spatial scale, a range that is consistent with our model results.

While our study focused specifically on the Middle Atlantic Bight, with model topography based on the shelfbreak bathymetry just south of Nantucket Shoals, a wide range of background conditions for the velocity and density fields were examined. However, shelfbreak currents are characterized not only by differences in background conditions of the velocity and density field, but also by their underlying topography. Thus, the extent to which our results are generally applicable to other shelfbreak frontal currents is dictated by the effect of topography on the stability of those currents. To test the applicability of these results to shelfbreak frontal currents other that the MAB, we assessed the degree to which topography influences the nature and strength of the instability of an idealized, baroclinic, shelfbreak frontal current. The role of topography in destabilizing or stabilizing the flow was investigated for both retrograde and prograde jets. For a weakly stratified jet, the retrograde jet is more unstable than the flat bottom case, which is more unstable than the prograde jet. Overall, for weakly-stratified jets, topography destabilizes retrograde jets and stabilizes prograde jets. For a highly stratified jet, there is no difference in growth rates between the retrograde and prograde jets. For a retrograde jet, as you increase the stratification, the jet is stabilized. For a prograde jet, increasing stratification destabilizes the jet. These results are consistent with the argument that the slope of the isopycnals relative to the bottom topography affects the instability. For a baroclinic jet (where $U(z)$ is sufficiently large such that jet strength is negligible near the bottom), topography apparently plays little to no role in the instability. Stratification (even a slight amount) is enough to isolate the jet from the bottom. Modes are generally surface-intensified.

During this past year we established a series of tests to examine the relative utility of nonlinear time series analysis for oceanic data. The methods were applied to current meter data from the Nantucket Shoals Flux Experiment as a first step towards evaluating the predictability of the shelfbreak front in the Middle Atlantic Bight. For the time series garnered from the nearly year-long moorings placed across the shelf and slope, prediction errors using nonlinear and linear methods were determined for both alongshelf and cross-shelf velocities. In general, the slope velocities are much less predictable than shelf velocities. On the slope, predictability after several hours is no better than the statistical mean. On the other hand, significant predictability of shelf velocities can be obtained up to at least 12 hours.

A comparison of results from the nonlinear and linear methods shows that there is no significant advantage of applying the nonlinear methods to the Middle Atlantic Bight time series. Evidence for this conclusion includes the results that a) the observed time series is indistinguishable from linear surrogates and b) predictions based on linear and nonlinear methods yield errors of similar magnitude. Failure of surrogate data tests suggests that the underlying dynamics is highly dimensional and the available data are insufficient to construct skillful nonlinear models.

IMPACT/APPLICATIONS

The collective impact of this work is/will be on the prediction of the physical environment through which sound propagates.

TRANSITIONS

The instabilty model used in this study and the associated expertise have been transferred to Dr. Glen Gawarkiewicz and Mr. Chris Linder, both of the Woods Hole Oceanographic Institution. Dr. Gawarkiewicz and Mr. Linder plan to use the model to test seasonal differences in the Middle Atlantic Bight and base the background fields on observed fields from the ONR PRIMER program.

The nonlinear time series analysis has also been applied to data collected in the South Atlantic Bight by Dr. Harvey Seim of the University of North Carolina.

RELATED PROJECTS

Dr. Glen Gawarkiewicz's work on both the modeling of the Middle Atlantic Bight and the analysis of observational data are strongly related to the work from this grant.

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