# Operational Modeling And Data Assimilation Studies Of The North Atlantic And The Coastal Zone


George L. Mellor
Program in Atmospheric and Oceanic Sciences
P.O.Box CN710, Sayre Hall
Princeton University
Princeton, NJ 08544-0710
phone: (609) 258-6570 fax: (609) 258-2850 email glm@splash.princeton.edu

Tal Ezer
Program in Atmospheric and Oceanic Sciences
P.O.Box CN710, Sayre Hall
Princeton University
Princeton, NJ 08544-0710
phone: (609) 258-1318 fax: (609) 258-2850 email ezer@splash.princeton.edu



Award #: N000149310037
http://www.aos.princeton.edu/WWWPUBLIC/htdocs.pom


## LONG-TERM GOAL

Our long term goals are to improve the modeling and prediction capabilities of numerical ocean models and data assimilation systems in support of operational coastal and ocean forecasting.

## OBJECTIVES

We wish to systematically evaluate the skill of basin-scale and coastal ocean models, in producing the observed climatologies and variabilities of the North Atlantic Ocean. We also wish to test data assimilation methodologies, in particular those involving satellite-derived surface data, in order to improve the skill of nowcasting and forecasting meso-scale features in the open ocean, in the Gulf Stream region and the coastal zone.

## APPROACH

For modeling and data assimilation studies we rely on the sigma coordinate Princeton Ocean Model, POM (Blumberg and Mellor, 1987; Mellor, 1996) using various configurations ranging from high resolution coastal ocean grids to a low resolution climate grid of the entire Atlantic Ocean. The approach of using different model domains allows us to inmprove open boundary conditions in regional models by using information obtained from larger domains. Curvilinear orthogonal grids are used to provide higher resolutions near the coast and near eddy-rich regions. Sensitivity studies evaluate the sensitivity of the model climatology and variability to various parameters and configurations. The data assimilation approach is based on previously developed optimal interpolation methodologies of using satellite-derived surface data to update subsurface fields (Mellor and Ezer, 1991; Ezer and Mellor, 1994). The emphasis during the reported period was on two new areas of research: 1. To test the assimilation approach, previously tested only with regional Gulf Stream models, with basin-scale models and 2. To test the approach within a real-time operational coastal forecast system. An important part of the research was done through our participation in the Coastal Ocean Forecast System, COFS, project

# Report Documentation Page

*Form Approved*
*OMB No. 0704-0188*



| | | |
|---|---|---|
| 1. REPORT DATE **1998** | 2. REPORT TYPE | 3. DATES COVERED **00-00-1998 to 00-00-1998** |
| 4. TITLE AND SUBTITLE **Operational Modeling and Data Assimilation Studies of the North Atlantic and The Coastal Zone** | | 5a. CONTRACT NUMBER |
| | | 5b. GRANT NUMBER |
| | | 5c. PROGRAM ELEMENT NUMBER |
| 6. AUTHOR(S) | | 5d. PROJECT NUMBER |
| | | 5e. TASK NUMBER |
| | | 5f. WORK UNIT NUMBER |
| 7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Princeton University,Program in Atmospheric & Oceanic Sciences,Princeton,NJ,08544** | | 8. PERFORMING ORGANIZATION REPORT NUMBER |
| 9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) | | 10. SPONSOR/MONITOR'S ACRONYM(S) |
| | | 11. SPONSOR/MONITOR'S REPORT NUMBER(S) |

12. DISTRIBUTION/AVAILABILITY STATEMENT
**Approved for public release; distribution unlimited**

13. SUPPLEMENTARY NOTES
**See also ADM002252.**

14. ABSTRACT

15. SUBJECT TERMS

| 16. SECURITY CLASSIFICATION OF: | | | 17. LIMITATION OF ABSTRACT | 18. NUMBER OF PAGES | 19a. NAME OF RESPONSIBLE PERSON |
|---|---|---|---|---|---|
| a. REPORT **unclassified** | b. ABSTRACT **unclassified** | c. THIS PAGE **unclassified** | **Same as Report (SAR)** | **5** | |

(Aikman et al., 1996) and in the Data Assimilation and Model Evaluation Experiments - the North Atlantic Basin (DAMEE-NAB).

## WORK COMPLETED

A basin-scale North Atlantic model, extending from 5°N to 50°N, has been set up and tested, as part of an intercomparison study (DAMEE) that involved two sigma coordinate models, two z-level models and two layer models. We evaluated the sensitivity of POM to various parameters and configurations and compared the results with observations and with other models. The lateral boundary condition plays an important role in the model climatology and variability; thus we compared closed and open boundary conditions and found that better Gulf Stream separation and more realistic recirculation gyres are obtained with open boundary conditions using transports imposed from a larger model domain compared with closed boundary conditions and a buffer zone, a result consistent with previous Gulf Stream separation studies using a smaller domain (Ezer and Mellor, 1992). Two different grid resolutions were tested, both having a curvilinear orthogonal grids with higher resolution in the Gulf Stream and the Gulf of Mexico regions and lower resolution grids in the eastern Atlantic region. Since POM uses the grid-dependent Smagorinsky diffusivity formulations, each grid has been tested with different values of diffusion and viscosity, thus with different values of the turbulent Prandtl number. Of particular importance to sigma coordinate models is the evaluation we performed on the effect of the along-sigma diffusion formulation on the model climatology (Ezer, 1998).

Our data assimilation scheme has been tested with a basin-scale POM domain for the first time, assimilating three years of Topex/Poseidon altimeter data, from 1993 to 1995, into the North Atlantic ocean model and evaluating the assimilated model against unassimilated model and against observed fields (Ezer and Mellor, 1998). A procedure to assimilate frontal position data, such as the Gulf Stream north wall analysis derived from AVHRR images, has been completed and soon will be integrated within the operational forecast system (COFS) running at NCEP, using the U.S Navy's daily frontal analysis data.

The problem of the pressure gradient errors in sigma coordinate models (Mellor et al., 1994) has been revisited and analyzed in more detail. The study shows that previous descriptions of these errors are incomplete or are in error (Mellor et al., 1998a). Development of a generalized vertical coordinate configuration of POM has been completed (Mellor et al., 1998b); it will enable the combined use and the intercomparison of *z*-level, sigma-level and possibly isopycnal models using otherwise identical numerics.

## RESULTS

Sensitivity studies with a basin-scale POM configuration show that the effect of the Smagorinsky horizontal diffusivity and viscosity on the model variability becomes less significant as resolution improves. A change in grid size of 50% has a larger effect on the variability than an order of magnitude change in the diffusivity. The along-sigma diffusion together with removal of climatological fields results in a slight reduction of the model long-term climate drift, but does not affect the short-term seasonal and mesoscale variabilities; in fact, the results of a standard Smagorinsky parameterization are very similar to those of no diffusion at all (the sigma coordinate model was found to be numerically stable even with zero horizontal diffusion). The model variability compares well with the observed variability only in areas where model grid is small enough (around 10 km) such as in the Gulf of Mexico and in portions of the Gulf Stream.

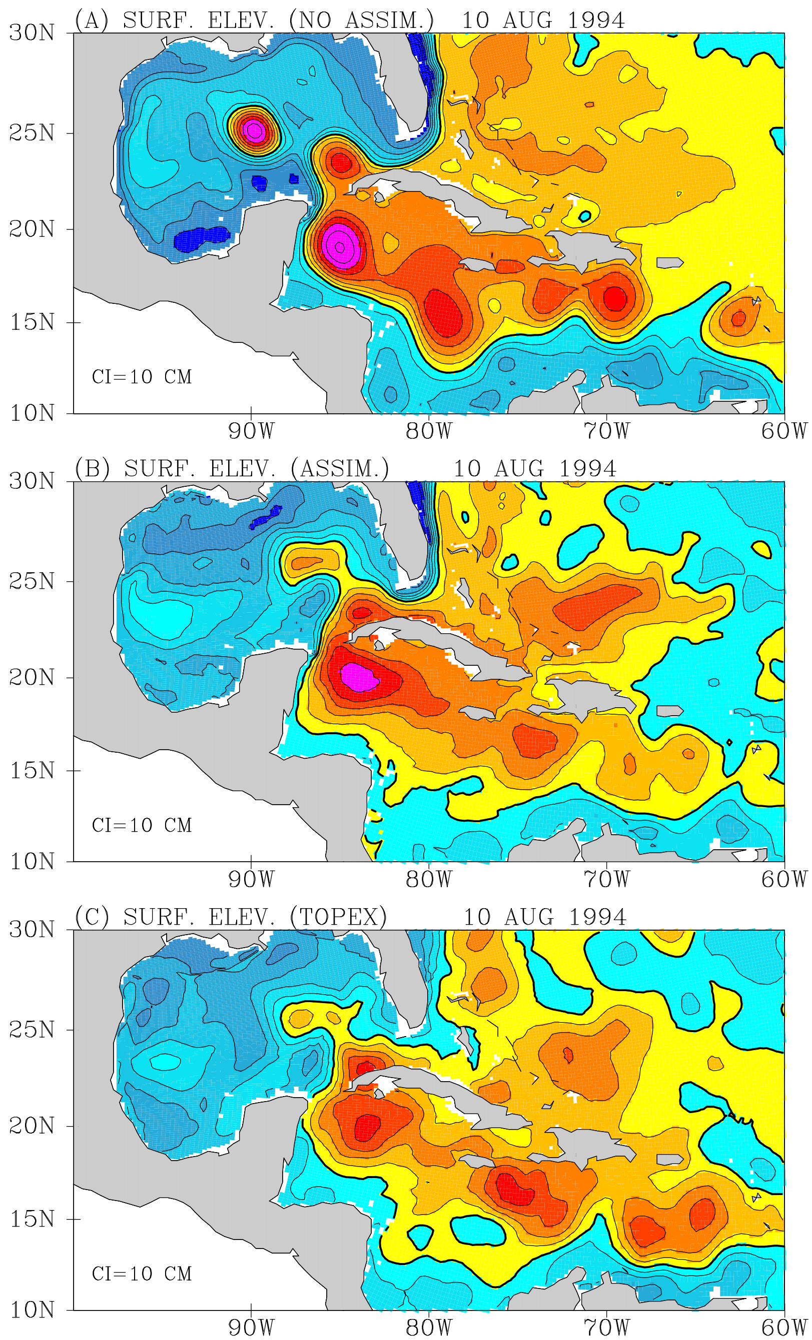


Fig. 1. Surface elevation over the Gulf of Mexico and the Caribbean Sea on 10 August, 1994 from a basin-scale North Atlantic model. (a) Model prediction without assimilation, (b) model hindcast with assimilation, and (c) Topex/Poseidon altimeter data interpolated into the model grid without involvement of model dynamics. Note that the assimilated model produces the observed meso-scale features while maintaining a more realistic Florida Current than that of the altimeter analysis.

Data assimilation studies show considerable improvement in the model variability compared to an unassimilated model and some nowcast skill in producing the observed mesoscale features, but only in regions with sufficient model resolution. The Topex/Poseidon altimeter data were used together with surface-subsurface correlations to continuously update the temperature fields in the entire water column and then the model surface elevation was compared with objective analysis of the altimeter data without a dynamic model in order to test the vertical projection approach and the contribution of the dynamical model. An example of such a comparison is shown in Fig. 1, for a small portion of the North Atlantic model domain; this example shows the importance of the model dynamics in improving the nowcast based on data alone.

## IMPACT/APPLICATION

The improvements in the numerical model itself and in the data assimilation techniques will continue to advantagely affect the POM user community in particular, and prediction systems in general. For example, the now accepted fact that one must project surface information into the entire water column followed our 1991 paper on the subject. The assimilation scheme that is soon to be implemented in the operational COFS will provide an important test bed for other Navy's forecast systems that use POM.

## TRANSITIONS

The transition of model and data assimilation algorithms as well as knowledge from the research and development stage to the operational environment has been going on during the past few years and will continue. Continuous transition of model developments from the Princeton group to the ocean modeling community is done through our internet-based POM users group, which includes more than 360 registered users from 30 countries.

## RELATED PROJECTS

We have fruitful collaborations with many scientists through our involvement in the National Ocean Partnership Program (NOPP), the Data Assimilation and Model Evaluation Experiments (DAMEE), the Coastal Ocean Forecast System (COFS) for the U.S. east coast and the POM-based forecast system for the U.S. west coast..

## REFERENCES


Aikman, F., G. L. Mellor, T. Ezer, D. Shenin, P. Chen, L. Breaker, K. Bosley, and D. B. Rao, 1996: Toward an operational nowcast/forecast system for the U.S. east coast. *Modern Approaches to Data Assimilation in Ocean Modeling*, edited by P. Malanotte-Rizzoli, Elsevier Publ., 347-376.

Blumberg, A. F., and G. L. Mellor, 1987: A description of a three-dimensional coastal ocean circulation model. *Three-Dimensional Coastal ocean Models*, edited by N. Heaps, American Geophysical Union, 1-16.

Ezer, T., and G. L. Mellor, 1992: A numerical study of the variability and the separation of the Gulf Stream, induced by surface atmospheric forcing and lateral boundary flows. *J. Phys. Oceanogr.*, **22**, 660-682.

Ezer, T., and G. L. Mellor, 1994: Continuous assimilation of Geosat altimeter data into a three-dimensional primitive equation Gulf Stream model. *J. Phys. Oceanogr.*, **24**, 832-847.

Ezer, T., 1998: Sensitivity studies with the North Atlantic Princeton Ocean Model. *Deep-Sea Res.*, Special issue on Data Assimilation and Model Evaluation Experiments, Submitted.

Ezer, T., and G. L. Mellor, 1998: Simulation of meso-scale variability with a sigma coordinate North Atlantic ocean model assimilated with three years of Topex/Poseidon altimeter data. *Deep-Sea Res.*, Special issue on Data Assimilation and Model Evaluation Experiments, Submitted.

Mellor, G. L., 1996: User's guide for a three-dimensional, primitive equation, numerical ocean model. Prog. in Atmos. and Ocean. Sci, Princeton University, 35 pp.

Mellor, G. L., and T. Ezer, 1991: A Gulf Stream model and an altimetry assimilation scheme. *J.Geophys. Res*, **96**, 8779-8795.

Mellor, G. L., T. Ezer, and L. Y. Oey, 1994: The pressure gradient conundrum of sigma coordinate ocean models. *J. Atmos. Oceanic. Technol.*, **11**, 1126-1134.

Mellor, G. L., L.-Y. Oey and T. Ezer, 1998a: Sigma coordinate pressure gradient errors and the seamount problem, *J. Atmos. Ocean Tech.* **15(5)**, 1122-1131.

Mellor, G. L., S. Hakkinen and T. Ezer, 1998b: A generalization of a sigma coordinate ocean model and an intercomparison of model vertical grids, In: Ocean Forecasting: Theory and Practice, Springer Pub., N. Pinardi (Ed.), Submitted.

**PUBLICATIONS**

Ezer, T., 1994: On the interaction between the Gulf Stream and the New England Seamount Chain. *J. Phys. Oceanogr.*, **24**, 191-204.

Ezer, T. (Ed.), 1996: Proceedings from the Princeton Ocean Model (POM) Users Meeting. Program in Atmospheric and Oceanic Sciences, Princeton University, 56 pp.

Ezer, T., and G L Mellor, 1994: Diagnostic and prognostic calculations of the North Atlantic circulation and sea level using a sigma coordinate ocean model. *J. Geophys. Res.*, **99**, 14,159-14,171.

Ezer, T., G. L. Mellor, and R. J. Greatbatch, 1995: On the interpentadal variability of the North Atlantic Ocean: Model simulated changes in transport, meridional heat flux and coastal sea level between 1955-1959 and 1970-1974. *J. Geophys. Res.*, **100**, 10,559-10,566.

Ezer, T., and G. L. Mellor, 1997: Simulations of the Atlantic Ocean with a free surface sigma coordinate ocean model. *J. Geophys. Res.*, **102**, 15,647-15,657.

Ezer, T., and G. L. Mellor, 1997: Data assimilation experiments in the Gulf Stream region: How useful are satellite-derived surface data for nowcasting the subsurface fields? *J. Atmos. Ocean Tech.*, **14**, 1379-1391.

Ezer, T., 1998: On decadal variabilities of the upper layers of the subtropical North Atlantic: An ocean model study. *J. Phys. Oceanogr.*, Submitted.

Mellor, G. L., and T. Ezer, 1995: Sea level variations induced by heating and cooling: An evaluation of the Boussinesq approximation in ocean models. *J. Geophys. Res.*, **100**, 20,565-20,577.