Advanced Numerical Methods for Realistic River Plume Modeling in Coastal-Scale Domains

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N00014-01-1-0200

LONG-TERM GOAL

The long-germ goal of this research is to realize the potential for realistic-domain numerical models as tools for prediction and understanding of the dynamics and transport processes in the coastal ocean.

OBJECTIVES

The overall objective of this research program is to improve the robustness and fidelity of three-dimensional models of river plumes. This involves several steps, including:

- Development of idealized and realistic "test problems" involving the dynamics of river plumes;
- Application of ROMS to these test problems, using it to investigate sensitivity to forcing, boundary conditions, resolution, and model algorithms (e.g., advection scheme);
- Comparison of the model with specific data sets.

APPROACH

This project is a cooperative effort between Rob Hetland at Texas A&M and me. Hetland has been involved primarily with model development, running and testing, while I provide guidance and oversight.

The initial modeling involves an idealized domain, performing a set of tests to define the appropriate input conditions for a river plume. It was not known a priori how much detail in the estuary was required to provide a realistic specification of the river-mouth flow and salinity, so a study of an idealized estuary was performed. This idealized estuary was intended to be similar to the simplistic type of estuary used in simulations where the focus is oceanic flow. After the model configuration has been established, we address specific components that lead to realistic simulations. These include wind stress forcing, tides, and ambient flow in the coastal ocean. The final step is to perform realistic simulations, using data sets from the Gulf of Maine and the Eel River shelf.

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **30 SEP 2002**	2. REPORT TYPE	3. DATES COVERED **00-00-2002 to 00-00-2002**

4. TITLE AND SUBTITLE **Advanced Numerical Methods for Realistic River Plume Modeling in Coastal-Scale Domains**	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) **Woods Hole Oceanographic Institution,,Woods Hole,,MA, 02543**	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

14. ABSTRACT
The long-germ goal of this research is to realize the potential for realistic-domain numerical models as tools for prediction and understanding of the dynamics and transport processes in the coastal ocean.

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)**	**4**	

WORK COMPLETED AND RESULTS

We have completed the study of an idealized estuary, and are preparing a manuscript to be submitted to the Journal of Physical Oceanography shortly. Grid-converged experiments (i.e., increasing the numerical resolution until the solution does not change) have been performed, determining the resolution requirements for simulating river plumes in the absence of other forcing. Also, a suite of experiments examining plume response to wind forcing were performed to examine the changes in plume bulk metrics (e.g., fresh water transport, surface salinity, and along- and cross-shore length scales) to various forcing. Numerical simulations of the Gulf of Maine have been run and compared with measurements. A manuscript is being prepared discussing our ability to accurately simulate the buoyancy driven coastal current system in the Gulf of Maine.

RESULTS

The manuscript on the idealized estuary simulations deals with, in part, the details of the estuarine outflow that are critical to the structure of the near-field river plume that forms seaward of the estuary mouth. The steady state results show a striking similarity with the 'overmixed' limit predicted by Stommel and Farmer (1952). The implication of these results is that for quasi-steady estuaries, the density anomaly of the outflow depends principally on the magnitude of the river outflow and the cross-sectional area of the estuary mouth, and *not* on the intensity of mixing within the estuary. This non-intuitive result is explained as follows: increased mixing leads to a proportionate reduction in the length of the estuarine salinity intrusion, which leads to the same net volume of mixing for a given level of freshwater outflow. The results are more complicated for unsteady regimes, for example when there is significant spring-neap modulation in the intensity of mixing or when there are variations in river outflow. Nevertheless, these results provide valuable constraints on the estuarine outflow conditions for regional numerical simulations.

Another area of inquiry was to determine the amount of resolution required to accurately resolve a river mouth. Grid-converged simulations indicate approximately 5 grid points across the estuary mouth are required to consistently simulate a river plume in the absence of other forcing. The setup for this problem will be uploaded to the ROMS test-case website. Idealized studies of plume response to wind forcing suggest that wind increases the sensitivity of the plume, in particular the downcoast transport of fresh water, to the magnitude of background flow.

The grid-converged results seem to contradict the results of the realistic Gulf of Maine simulation, in which the simulated river plume is in good agreement with measurements despite a poorly resolved estuary only one grid-point wide. This inconsistency may be explained by the difference in forcing between the two models. I have put forward the hypothesis in a proposal recently submitted to ONR that wind forcing stabilizes the properties of the river plume through mixing, thereby decreasing the sensitivity of the river plume to the details of flow near the estuary mouth.

IMPACT/APPLICATION

Our improved understanding of the estuarine boundary condition for river plumes will provide significant improvements in the realistic modeling of river plumes in the near-field. The realistic simulation of the coastal-current system in the Gulf of Maine will be used as a foundation for numerical simulations of regional harmful algal blooms.

TRANSITIONS

Hetland has developed numerical algorithms for implementing fresh water sources (i.e., rivers) and tides, both of which have become part of the standard ROMS releases. He has also developed new boundary conditions for estuarine simulations, which will become part of the ROMS distribution, and have also been active in testing the new pressure gradient routines that have been released in the latest version of ROMS.

RELATED PROJECTS

I am involved with the EURO-STRATAFORM project, which involves the comparison of observations and numerical model results in application to sediment transport in the Adriatic Sea.

REFERENCES

Stommel, H. and H. G. Farmer. (1952) Control of salinity in an estuary by a transition. J. Mar. Res., **12**, 13-20.