

Model-Data Intercomparison for Marginal Sea Overflows

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Award #: N00014-01-1-0023

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LONG-TERM GOALS

The primary goal of this project is to enhance our understanding of the dynamics of oceanic overflows, which are characterized by high levels of turbulence and mixing near strategic straits connecting various marginal seas and oceans.

OBJECTIVES

- 1) To complement field studies and to develop a better understanding of the characteristics of mixing and its influence on the subsequent fate of the overflows.
- 2) To address the fundamental issue of entrainment of a plume in the presence of rotation and ambient stratification.
- 3) To develop parameterizations of mixing for ocean general circulation models.
- 4) To explore the large-scale impact of mixing in overflows.

APPROACH

The research is being carried out primarily by comparing results from a high-resolution two-dimensional nonhydrostatic numerical model to field measurements. Ocean general circulation models and analytical techniques are also being used.

WORK COMPLETED

The primary accomplishments during this grant period are as follows:

- 1) Successful validation and benchmarking of a two-dimensional, nonhydrostatic numerical model using laboratory experiments bottom gravity currents. This study led to a manuscript that is accepted for publication in the Journal of Physical Oceanography (Ozgokmen and Chassignet, 2001).
- 2) Publication of a paper in the Journal of Physical Oceanography describing the large-scale impact of the Mediterranean overflow on the upper-level circulation in the North Atlantic Ocean (Ozgokmen et al., 2001).

Report Documentation Page				Form Approved OMB No. 0704-0188	
Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.					
1. REPORT DATE 30 SEP 2001		2. REPORT TYPE		3. DATES COVERED 00-00-2001 to 00-00-2001	
4. TITLE AND SUBTITLE Model-Data Intercomparison for Marginal Sea Overflows				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) Division of Meteorology and Physical Oceanography,,Rosenstiel School of Marine and Atmospheric Science,,4600 Rickenbacker Causeway,,Miami,,FL, 33149				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 primary goal of this project is to enhance our understanding of the dynamics of oceanic overflows, which are characterized by high levels of turbulence and mixing near strategic straits connecting various marginal seas and oceans.					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT Same as Report (SAR)	18. NUMBER OF PAGES 7	19a. NAME OF RESPONSIBLE PERSON
a. REPORT unclassified	b. ABSTRACT unclassified	c. THIS PAGE unclassified			

3) Detailed quantification of the characteristics of beta-plumes driven by localized mixing in overflows. This study is accepted for publication in the Journal of Physical Oceanography (Ozgokmen and Crisciani, 2001).

4) An intercomparison study is in progress between the field data collected in the Red Sea overflow under the NSF-funded REDSOX program (led by W. Johns) and the two-dimensional numerical model.

5) A workshop called Dynamics of Overflow Mixing and Entrainment (DOME) was organized in Miami in February 2001, and was attended by some 35 international scientists. Details can be found in: <http://www.rsmas.miami.edu/personal/tamay/DOME/workshop.html> .

RESULTS

1) Validation and benchmarking of the numerical model (Ozgokmen and Chassignet, 2001):

In light of previous numerical studies demonstrating a strong sensitivity of the strength of thermohaline circulation to the representation of overflows in ocean general circulation models, the dynamics of bottom gravity currents are investigated using a two-dimensional, nonhydrostatic numerical model. The model explicitly resolves the Kelvin-Helmholtz instability, the main mechanism of mixing in nonrotating bottom gravity currents.

A series of experiments were conducted to explore the impact of density difference and slope angle on the dynamics of bottom gravity currents in a nonrotating and homogeneous environment. The features of the simulated currents, i.e., a characteristic head at the leading edge and lumped vortices in the trailing fluid, agree qualitatively well with those observed in laboratory experiments. Quantitative comparisons of speed of descent indicate that laboratory results remain valid at geophysical scales.

Two distinct regimes of entrainment of ambient fluid into bottom gravity currents are identified: (a) the laminar entrainment regime is associated with the initial growth of the characteristic head due to the drag exerted by the fresh fluid in front, and (b) the turbulent entrainment is associated with the Kelvin-Helmholtz instabilities. The turbulent entrainment is found to be much stronger than the laminar entrainment, and entrainment in the turbulent regime is less sensitive to the slope angle than that in the laminar regime. The entrainment is quantified as a function of basic parameters of the system, the buoyancy flux and the slope angle, for the purpose of parameterizing the mixing induced by bottom gravity currents.

2) Study of mixing-induced beta-plumes (Ozgokmen and Crisciani, 2001):

In light of recent evidence that the entrainment of Atlantic water into the Mediterranean overflow may lead to the formation of the Azores Current and the Azores Counter Current, the dynamics of zonal recirculating flows (beta-plumes) driven by a source of potential vorticity, or a sink of mass, located at the eastern boundary of an ocean basin are investigated using analytical solutions of the simplest possible governing equation of oceanic flow, the equivalent-barotropic, linear, steady quasigeostrophic equation. The effect of classic dissipation parameterizations, bottom and lateral friction, are explored on the solutions in a wide parameter space.

In addition to the result from theories based on inviscid equations, which indicate that the strength of a beta-plume is inversely proportional to the meridional extent of the sink, two new regimes emerge

from the present study. First, it is shown that the ratio of the strength of the recirculation to that of the sink becomes independent of the friction coefficient, when the friction coefficient is small enough. Second and more importantly, there appears to be a regime for sinks with small size, in which the strength of the recirculation decreases with the decreasing meridional extent of the sink. Therefore, it is shown that the recirculating flow component disappears due to frictional effects when the meridional extent of the sink becomes infinitesimally small. The difference between dissipation parameterizations is highlighted in that the lateral dissipation mechanism leads to a secondary intensification of the recirculating flow, independently of no-slip or free-slip boundary conditions, at small meridional scales. Finally, a stability analysis is conducted to determine the parameter regime in which the beta-plumes are candidates for instability.

3) Model-data intercomparison in the Red Sea overflow:

An intercomparison study is being conducted between the field data collected in the Red Sea overflow during the February 2001 cruise of the NSF-funded observational program (REDSOX-1, led by W. Johns) and the two-dimensional model. The area of the intercomparison study is selected to be the northern channel, which carries about 2/3rd of the total transport of the Red Sea overflow, after the overflow splits into two in the Gulf of Aden.

The salinity, temperature, density anomaly and velocity distributions from REDSOX-1 field data in the northern channel are shown in Figure 1. The domain is approximately 70 km long extending from Station 58 near the entry to the channel to Station 39, where the overflow equibrates near the Tadjura Rift. The primary characteristics of interest in Figure 1 are: (i) the overflow carries high salinity (>39 psu) water along the channel, (ii) there is significant thickening of the overflow due to variation of topographic slope between stations 83 and 84, and (iii) the surface mixed layer, which is approximately 150 m thick, may play an important role in the dynamics for geometric reasons.

Preliminary models results are shown in Figure 2. The model is driven by temperature, salinity and flow profiles obtained only from Station 58 along the left boundary. Such a forcing leads to the formation of two gravity currents, one at the bottom representing the propagation of the overflow, and the other at the surface representing the spreading of the mixed layer. These water masses leave the domain via the radiation boundary conditions along the right boundary and interior solution reaches a statistically steady state. The time-averaged properties shown in Figure 2 indicate that the model is able to qualitatively reproduce both the overflow and surface mixed layer properties. Of particular interest is the response of the overflow to topographic variations, and the formation of a mid-depth jet supplying ambient fluid for the mixing of the overflow and mixed layer. Deficiencies of the model, such as the lack of mixing between Station 58 and 82, and excessive mixing downstream, are being addressed using higher-resolution simulations.

IMPACT/APPLICATIONS

Oceanic overflows are characterized by high levels of turbulence and mixing near strategic straits connecting various marginal seas and oceans. A detailed understanding of such phenomena is not only important for submerged equipment but also for large-scale ocean circulation and climate-related studies.

TRANSITIONS

Simulation results complement the understanding and interpretation of field data from REDSOX-1.

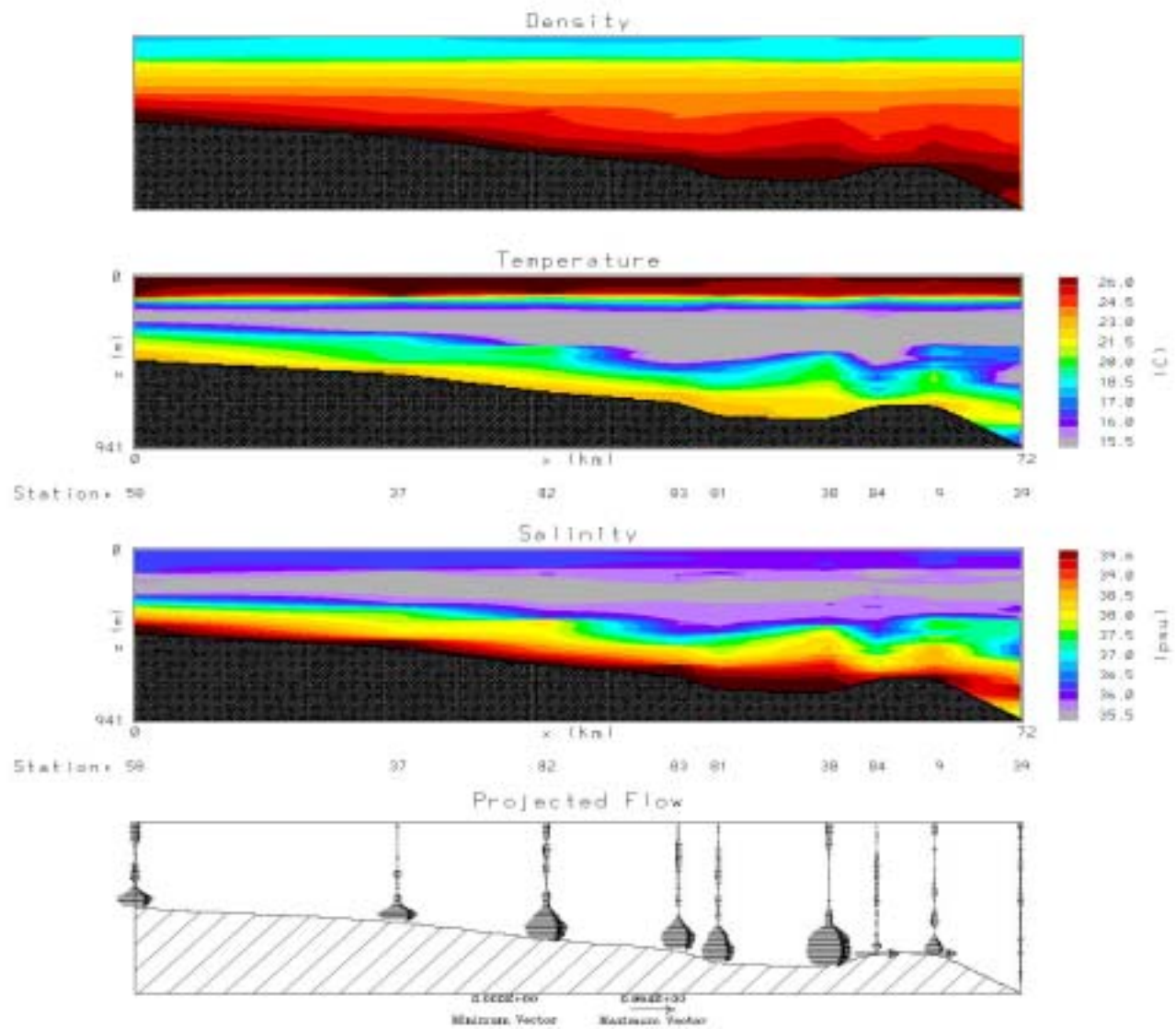


Figure 1: Density anomaly, temperature, salinity and flow in the Red Sea northern channel from REDSOX-1 cruise observations.

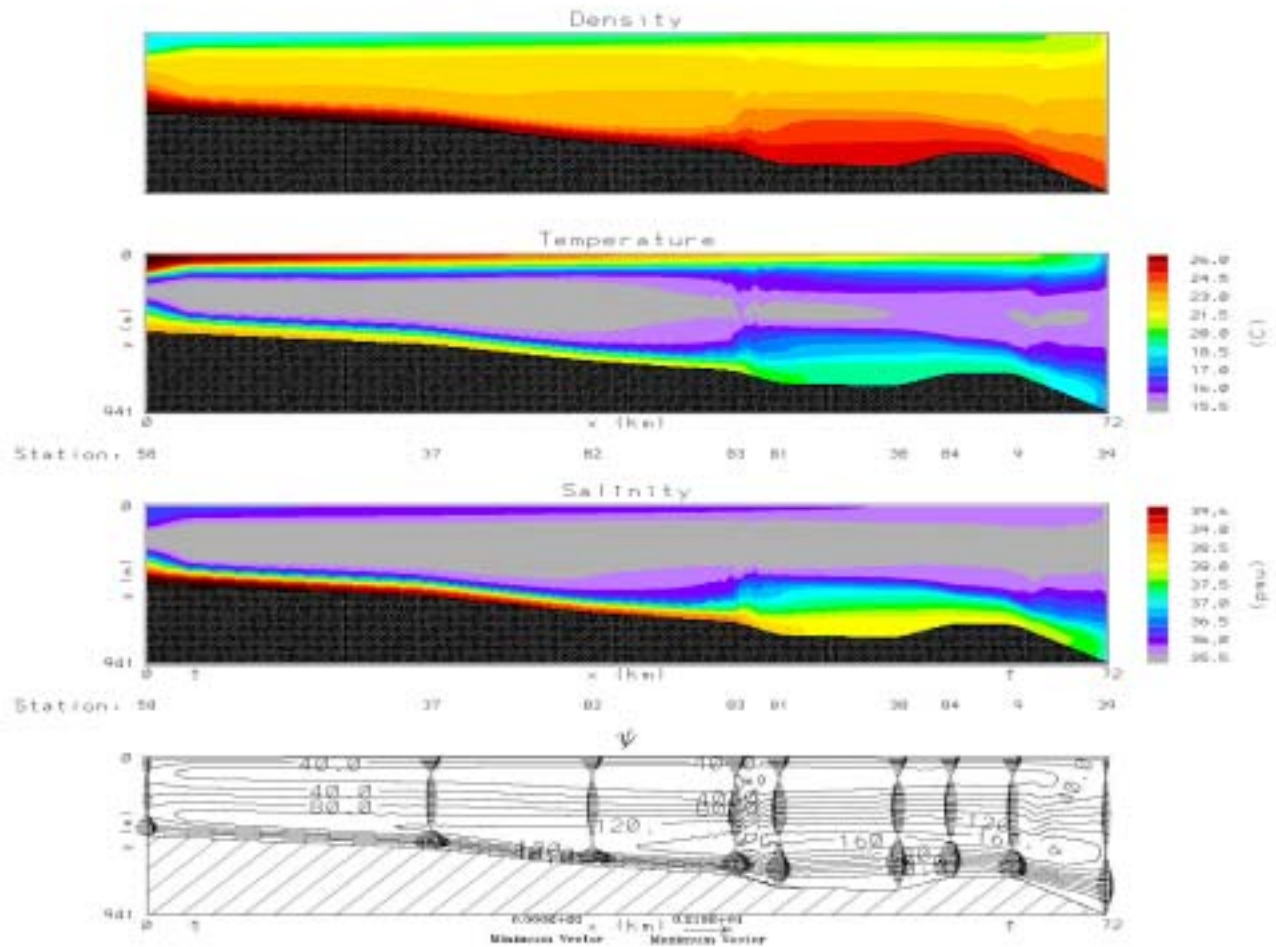


Figure 2: Density anomaly, temperature, salinity and flow in the Red Sea northern channel from numerical simulations.

RELATED PROJECTS

Red Sea Outflow Experiment (REDSOX), PIs: W. Johns and H. Peters, NSF-OCE.

Dynamics of Boundary Currents and Marginal Seas, PI: W. Johns, N00014-95-1-0025.

PUBLICATIONS (2000-2001)

Ozgokmen, T.M., E.P. Chassignet and C. G. H. Rooth, 2001: On the connection between the Mediterranean outflow and the Azores Current. *J. Phys. Oceanogr.*, 31, 461-480.

Ozgokmen, T.M., and F. Crisciani, 2001: On the dynamics of beta-plumes. *J. Phys. Oceanogr.*, in press.

Ozgokmen, T.M., and E.P. Chassignet, 2001: Dynamics of two-dimensional turbulent bottom gravity currents. *J. Phys. Oceanogr.*, in press.