

# **Model-Data Intercomparison for Marginal Sea Overflows**

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## **LONG-TERM GOALS**

The long-term goal of this project is to enhance the level of understanding of the dynamics of overflows, which are characterized by high degree of variability 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 has been carried out using a combination of oceanic data, and high-resolution nonhydrostatic 2D and 3D numerical models.

## **WORK COMPLETED**

The primary accomplishments during this grant period are as follows:

- 1) A model-data intercomparison study is completed between a 2D nonhydrostatic model and part of the Red Sea overflow from REDSOX field program. This paper is published in the Journal of Physical Oceanography.
- 2) Fully 3D nonhydrostatic simulations of bottom gravity currents are conducted in comparison to those from laboratory experiments and previous 2D nonhydrostatic model results. This manuscript is submitted for publication in the Journal of Physical Oceanography.

3) Design and construction of a 34 processor Beowulf parallel cluster based on 2 GHz Athlon nodes and 1 Gbps ethernet connectivity is completed. This computer cluster was necessary for the 3D computations and is supported in part by this grant.

## RESULTS

### 1) *Realistic simulations of the Red Sea overflow:*

Motivated by the fact that overflow processes, which supply source waters for most of the deep and intermediate water masses in the ocean, pose significant numerical and dynamical challenges for ocean general circulation models, an intercomparison study is conducted between field data collected in the Red Sea overflow and a high-resolution, nonhydrostatic process model. The intercomparison study is focused on the part of the outflow that flows along a long narrow channel, referred to as the “northern channel”, which naturally restricts motion in the lateral direction such that the use of a two-dimensional model provides a reasonable approximation to the dynamics. This channel carries about two-thirds of the total Red Sea overflow transport, after the overflow splits into two branches in the western Gulf of Aden.

The evolution of the overflow in the numerical simulations can be characterized in two phases: the first phase is highly time-dependent, during which the density front associated with the overflow propagates along the channel. The second phase corresponds to that of a statistically steady state. The primary accomplishment of this study is that the model adequately captures the general characteristics of the system: (i) the gradual thickening of the overflow with downstream distance, (ii) the advection of high salinity and temperature signals at the bottom along the channel with little dilution, and (iii) ambient water masses sandwiched between the overflow and surface mixed layer.

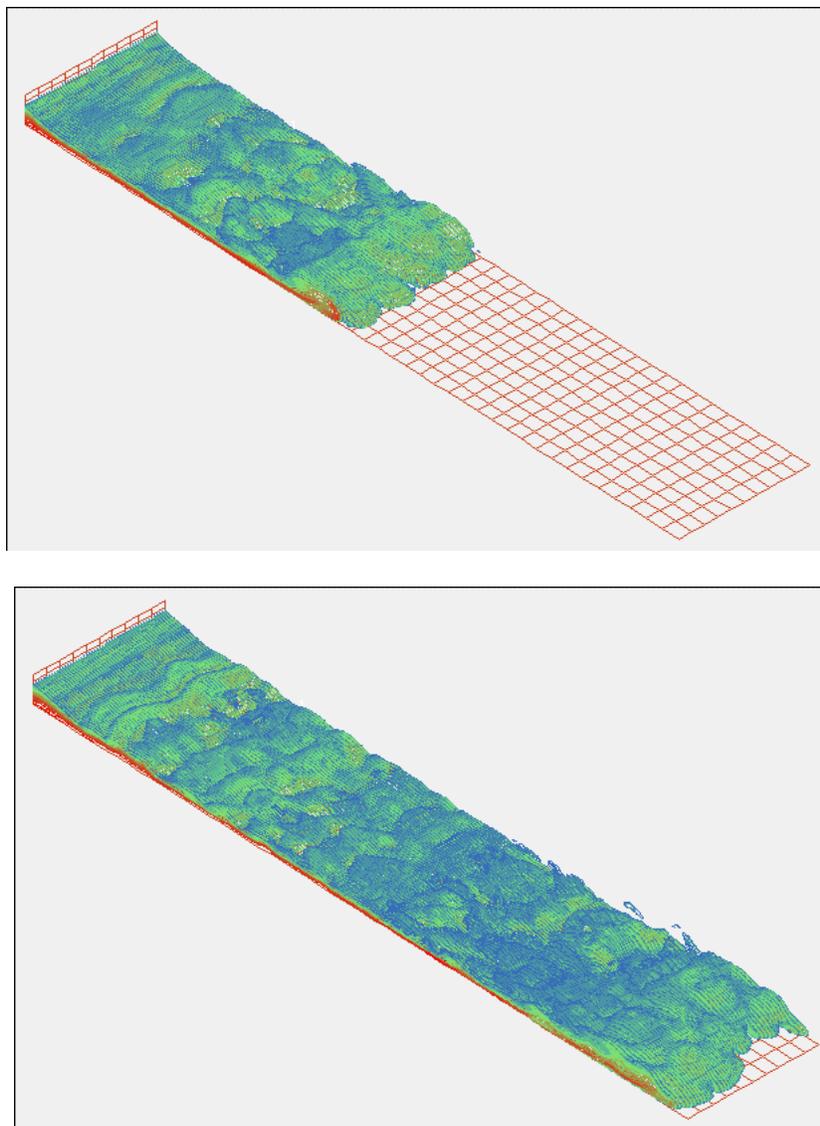
To quantify mixing of the overflow with the ambient water masses, an entrainment parameter is determined from the transport increase along the slope, and expressed explicitly as a function of mean slope angle. Bulk Richardson numbers are estimated both from data and model, and are related to the entrainment parameter. The range of entrainment parameter and its functional dependence on bulk Richardson number in this study are found to be in reasonable agreement with those reported from various laboratory experiments, and that based on measurements of the Mediterranean overflow.

Finally, the results reveal a complex dynamical interaction between shear-induced mixing and internal waves, and illustrate the high computational and modeling requirements for numerical simulation of overflows to capture (at least in part) turbulent transports explicitly.

### 2) *3D nonhydrostatic experiments:*

In this study, nonhydrostatic 3D simulations of bottom gravity currents are carried out (e.g. Fig. 1), as a continuation of an effort to develop appropriate process models for overflows, that would complement analysis of dedicated observations and large-scale ocean modeling. Nek5000, a parallel higher order spectral element Navier-Stokes solver is used as the basis of the simulations. Numerical experiments are conducted in an idealized setting focusing on the start-up phase of a dense water mass released at the top of a sloping wedge. 3D results are compared to results from 2D experiments and laboratory experiments based on propagation speed of the density front, growth rate of the characteristic head at the leading edge, turbulent overturning length scales and entrainment parameters (e.g., Fig. 2).

Results from 3D experiments are found to be in general agreement with those from laboratory tank experiments. In 2D simulations, the propagation speed is approximately 20% slower, the head growth rate is 3 times larger, Thorpe scales are 30-50% larger, and entrainment parameter is up to 2 times higher than those in the 3D experiments. The differences between 2D and 3D simulations are entirely due to internal factors associated with the truncation of the Navier-Stokes equations for 2D approximation. It is concluded that in the absence of external factors that will trigger 3D circulation patterns, such as topographic features and/or rotation, 2D dynamics still represent a reasonable approximation to the general evolution of bottom gravity currents.



*Figure 1: Evolution of a bottom density current in 3D nonhydrostatic simulations using a high order spectral element model Nek5000.*

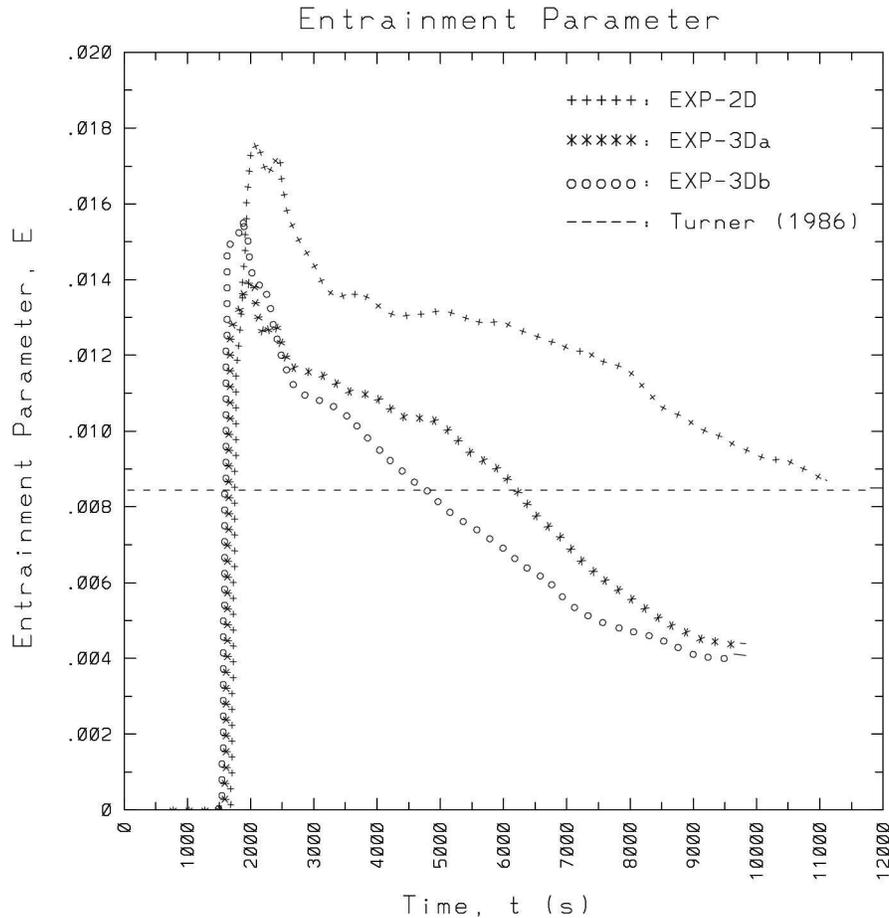


Figure 2: Time evolution of entrainment parameters  $E(t)$  in all experiments. Line with "++++" denotes result from EXP-2D, and lines with "\*\*\*\*\*" and "oooo" denote those from EXP-3Da and EXP-3Db, respectively. Dashed line marks the estimate given by Turner (1986) based on laboratory experiments of Ellison and Turner (1959).

## 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. Results also promote the need for better parameterizations not only in general circulation models, but also in process-oriented models.

## **RELATED PROJECTS**

(i) Red Sea Outflow Experiment (REDSOX), PIs: W. Johns, H. Peters, A. Bower, D. Fratantoni, NSF-OCE.

(ii) Dynamics of boundary currents and marginal seas, PI: W. Johns, N00014-95-1-0025.

## **PUBLICATIONS (2002-2003)**

Refereed publications:

Ozgekmen, T.M., and E.P. Chassignet, 2002: Dynamics of two-dimensional turbulent bottom gravity currents. *J. Phys. Oceanogr.*, 32/5, 1460-1478.

Ozgekmen, T.M., W. Johns, H. Peters, and S. Matt, 2003: Turbulent mixing in the Red Sea outflow plume from a high-resolution nonhydrostatic model. *J. Phys. Oceanogr.*, 33/8, 1846-1869.

Ozgekmen, T.M., P. Fischer, T. Iliescu, and J. Duan, 2003: Three-dimensional turbulent bottom gravity currents from a high-order nonhydrostatic spectral element model. *J. Phys. Oceanogr.*, submitted.

Conference presentations:

Ozgekmen, T.M., W. Johns, H. Peters, and S. Matt, 2002: Turbulent mixing in the Red Sea outflow plume from a high-resolution nonhydrostatic model. AGU Ocean Sciences meeting, QS1Q-04, Honolulu.

Ozgekmen, T.M., 2002: Turbulent mixing in the Red Sea outflow plume from a high-resolution nonhydrostatic model. Second international conference "Oceanography of the eastern Mediterranean and Black Sea", Ankara.

Ozgekmen, T.M., 2003: Turbulent mixing in the Red Sea outflow plume from a high-resolution nonhydrostatic model. Gordon Research Conference - Coastal Ocean Modeling, New Hampshire.