Simulation of Overflow Entrainment in a Lagrangian Framework

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Introduction:

In places such as the Greenland-Iceland-Norwegian sea, and the Arctic or Antarctic shelves, dense water is formed and flows down topography. As the density current flows down the topography, it entrains ambient fluid. This entrainment modifies the properties of the overflow (e.g. temperature and volume) (Dickson and Brown 1994, Price and Baringer 1994). Accurate representation of this process is important to studies of climate change.

It is well known that a number of models have difficulty representing these overflows. Winton et al. (1998) examined down slope flow in a z-coordinate model. As found in Griffies et al. (2000, z-coordinate models produce excessive diapycnal entrainment. THe model chosen for this study (the Slippery Sacks (SS) model) is not prone to excessive entrainment (Haertel and Randall 2002, Haertel et al 2004). It is a fully Lagrangian model that partitions the fluid into a large number of sacks, which are then followed around the domain (Fig. 1).

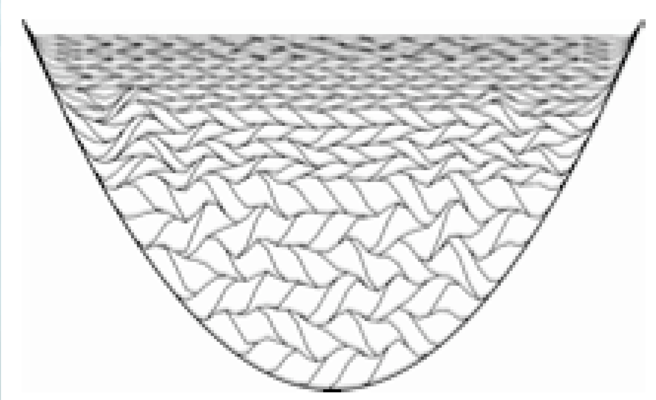
Fig. 1 - Slippery Sacks in a parabolic basin.

Model Set-up:

Ou set-up follows closely to that given in Legg et al. 2006 (hereafter L06). Dense water is injected into a 600m deep and 100 km wide bay (Fig. 2, adapted from L06) with a prescribed temperature and velocity structure (see L06).

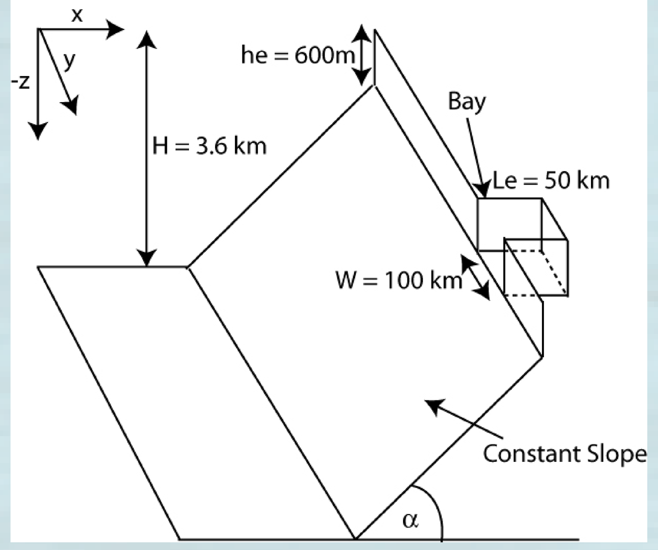

Fig. 2 - Topography for the runs. Adapted from L06. All variables have the same meaning.

The SS model is a free surface model. After the inflow leaves the bay, the free surface will become slanted and the pressure force will drive water back into the bay (Fig. 3). This stops the dense water from entering the domain. Although this is physically correct, we wish to compare our results to those in L06.

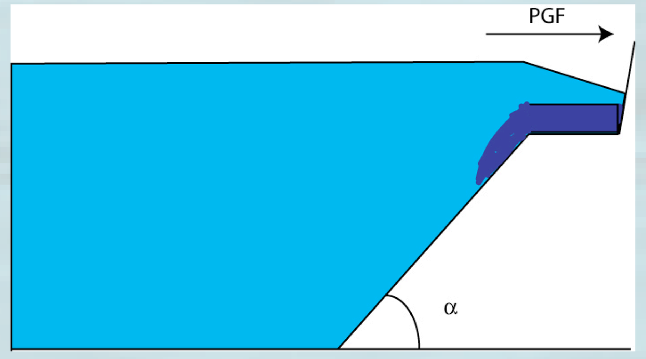

Fig. 3 - Schematic of water in the bay.

Therefore, an open boundary condition is implemented.

The diffusion code is described in Haertel et al 2004. The sacks are partitioned into columns, and any standard eulerian diffusion scheme may be used.

Results:

We have performed two runs, and the parameters we used are summarized in the table. The initial condition is given in L06 and is plotted in Fig. 4. These are the sack outlines and red represents the location of the dense inflow.

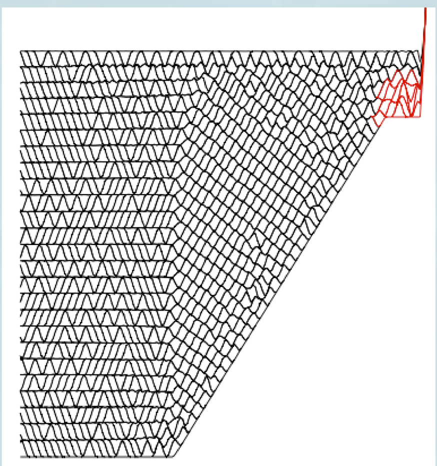
Fig. 4 - Initial condition for two dimensional runs. Red represents the dense inflow.

	Interior Stratification N	Momentum diffusion isopycnal	Momentum diffusion diapyncal	Diapycnal Diffusion Ri > 0.8	Diapycnal Diffusion Ri < 0.8	Isopycnal Diffusion
Run 1	2.3 x 10^{-5} s^{-1}	0.5 m^2s^{-1}	1 x 10^{-4} m^2s^{-1}	0	$w_e = \Delta u \frac{0.8 - 0.1Ri}{1+5Ri}$	0 for tracers
Run 2	2.3 x 10^{-5} s^{-1}	1 x 10^{-4} m^2s^{-1}	1 x 10^{-4} m^2s^{-1}	0	As in Run1	As in Run 1

Table 1 - Summary of the parameters used in the two runs. Both simulations are done in two dimensions.

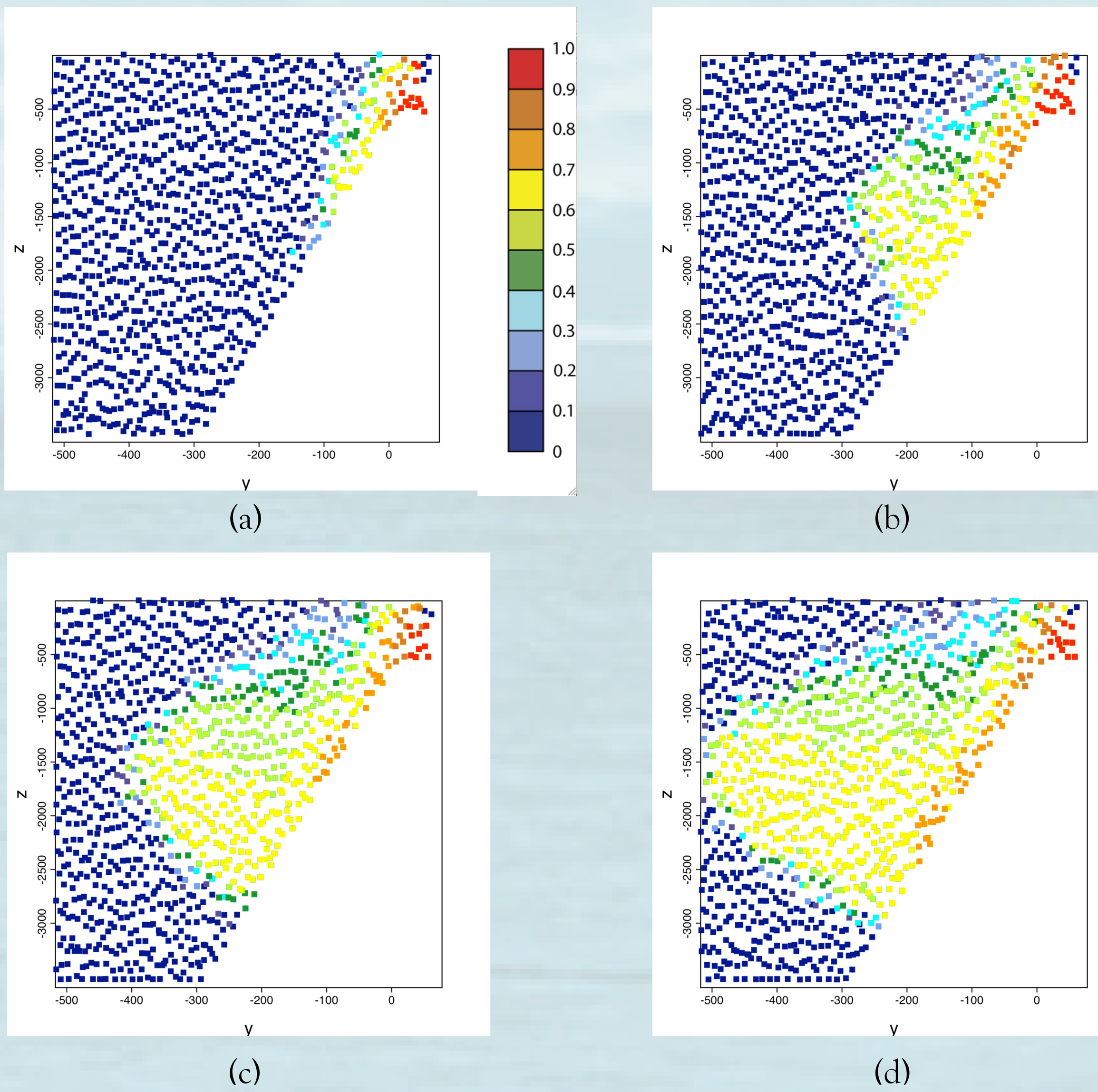

Fig. 5 - Progression of images from run 1. (a) 1 day, (b) 4 days, (c) 7 days, (10) days. The dots in the figure represent the amount of tracer (all figures use the color bar to the right of (a)).

Simulations in L06 were run to 13 days. Fig 6a and 6b are the SS model result and L06 result respectively (both have identical color scales, see Fig. 5a). The results are qualitatively similar, but there are differences as well. Some of these differences are due to the artificial diffusion created by the advection scheme in L06. This is very hard to mimic.

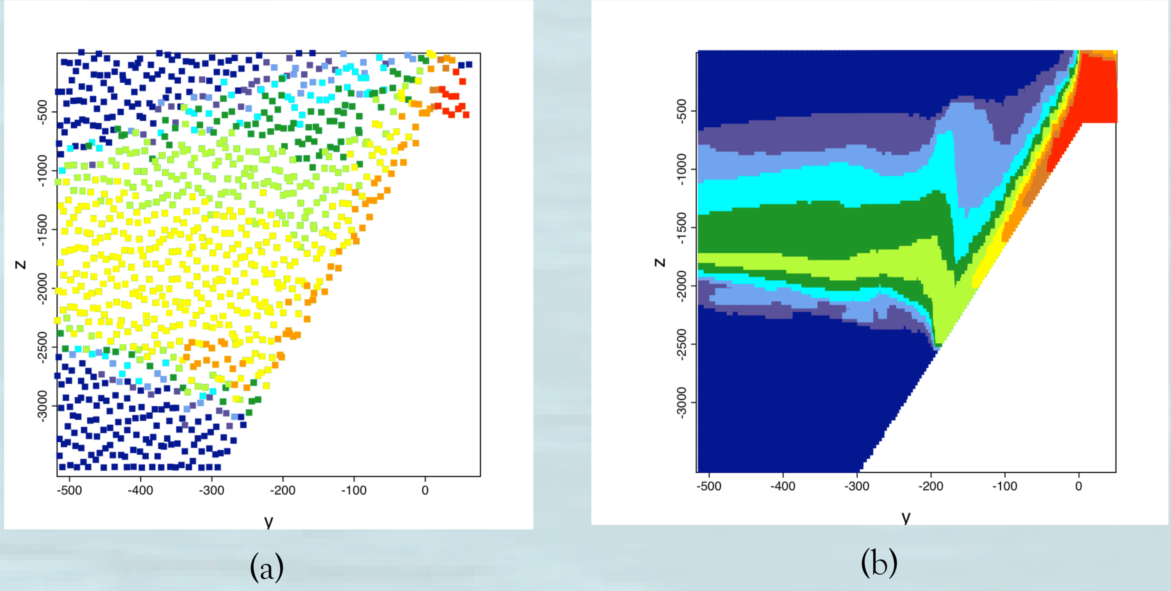

Fig 6 - Comparions of SS model Results (a) and those from the MIT non-hydrostatic-GCM (b) (data provided by Sonya Legg, personal communication)

Since tracer diffusion is proportional to the velocity difference between sacks, we hypothesize that the difference in the detrainment levels may be due to excessive momentum diffusion. Fig. 7 is identical to Fig. 6 but for run 2.

Open Boundary Condition:

Attempts to extend the simulations to three dimensions have been difficult. This is due in part to the open boundary condition. There are numerous points laid out in the domain at which the pressure force is calculated (Fig. 8). The model computes the free surface height at these locations and if it is less than the initial height, a sack is added. This condition does well at maintaining a flat surface in the two dimensional runs, but does not work in the three dimensional runs. Too many sacks are being added to the bay, which creates a situation shown in Fig. 9. This causes the dense inflow to be too quick and could make the model unstable.

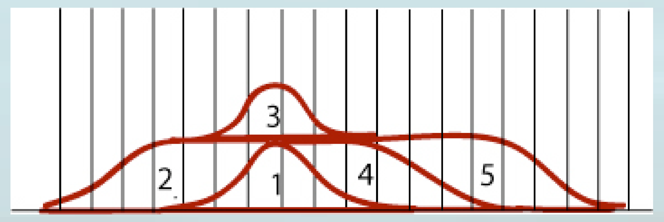

Fig. 8 - Pressure gradient points laid out in the domain

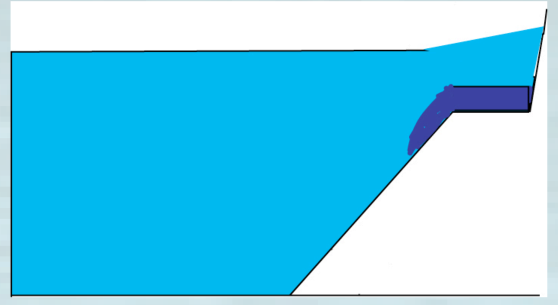
Fig. 9 - Schematic of the open boundary condition in 3-D

Alternatively, since the flow rate out of the bay is prescribed, we can derive how much mass is being added to the domain every second. Sacks can then be added to the domain based on the mass flux into the bay rather than on changes in the surface height.

Future Directions:

The SS model is reproducing the correct qualitative behavior. However, there are numerous quantitative differences. There are many discrepancies between the models that may account for the differences. We hope that simulations in three dimensions and the new mass flux open boundary condition will reduce the differences between our model and that used in L06.

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