Modelling the Circulation Under the Amery Ice Shelf

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Introduction

We will describe the application of a modified version of the Princeton Ocean Model (Blumberg and Mellor, 1987; Hunter, 2002; Mellor, 2003) to the ocean cavity under the Amery Ice Shelf, Eastern Antarctica. The model simulates the circulation, the water properties and the pattern of melting and freezing at the ice/water interface. Simulations have been carried out for present conditions and for a warmer climate.

The Amery Ice Shelf Cavity and Prydz Bay

Figure 1 shows the bathymetry under the Amery Ice Shelf and in Prydz Bay. The bold segmented line heading northnortheast across the figure represents the location of the vertical section shown in Figure 2. The location of the ice front is shown by the serrated line at about 69°S in Figure 1. The ice shelf has an area of about 60,000 km^2 and a mean draft of about 700 m. The average water column thickness is about 230 m. In comparison, Prydz Bay (defined here by the open water region of Figure 1) has an area of about 110,000 km^2 and a typical depth of about 600 m. The bathymetry (and hence the water column thickness) under the ice shelf is poorly known from about 80 seismic observations, of which there were none south of 71° 35′ S. The oceanography of Prydz Bay has been reviewed by Nunes Vaz and Lennon (1996) and Wong et al. (1998). Recent oceanographic observations in Prydz Bay in the vicinity of the Amery Ice Shelf, and through two drill holes through the shelf, have been described by Leffanue and Craven (2003).

Modelling the Cavity Under the Ice Shelf

The cavity under the Amery Ice Shelf has previously been modelled by Williams (1999) and Williams et al. (1998, 2001, 2002). They used the model of Gerdes et al. (1999) which uses sigma-coordinates and is based on the Cox-Bryan model (Cox, 1984). Since it employs a rigid-lid model, it cannot represent tides.

The application of the Princeton Ocean Model to the Amery Ice Shelf region has been described by Hemer (2003). This sigma-coordinate model has a free-surface and can therefore represent tides. The thermodynamics at the ice/water interface was prescribed using the two-equation formulation of Holland and Jenkins, 1999.

The first model run excluded tidal forcing, and the initial and open boundary conditions were prescribed at the surface freezing temperature. This is representative of

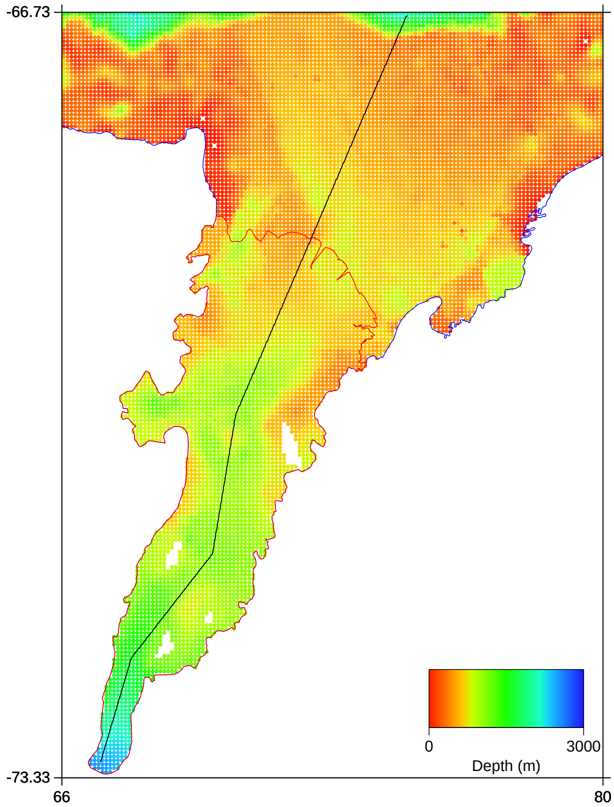

Figure 1: Bathymetry of the Amery cavity and Prydz Bay

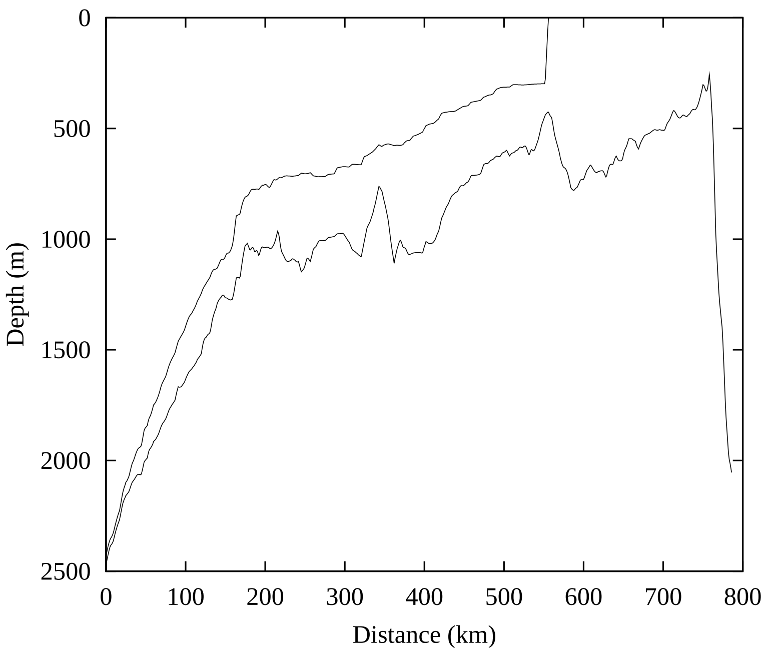

Figure 2: Section through the Amery cavity and across Prydz Bay

the coldest winter conditions that would be experienced. Figure 3 shows the time evolution of spatially-averaged potential temperature for each sigma-level, indicating a spin-up time of tens of years. The following results are for a simulation time of 6000 days (16.4 years) after which the model is at approximately steady state.

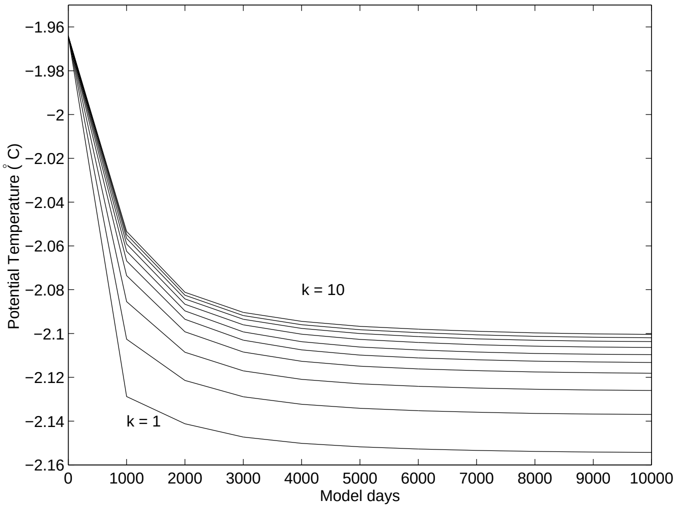

Figure 3: Time evolution of spatially-averaged potential temperature for each sigma-level for a model run with no tides and 'coldest' boundary conditions. Top level is k=1, bottom level is k=10.

Figure 4 shows a vertical section of potential density approximately along the same transect shown in Figures 1 and 2. Figures 5 and 6 show the vertically-integrated streamfunction and freezing rate, respectively. Figure 6 indicates the strong melting that occurs in the deep water (at around 2000 m below sea level) in the south of the cavity. Most of the ice shelf is melting with only a relatively small area of re-freezing.

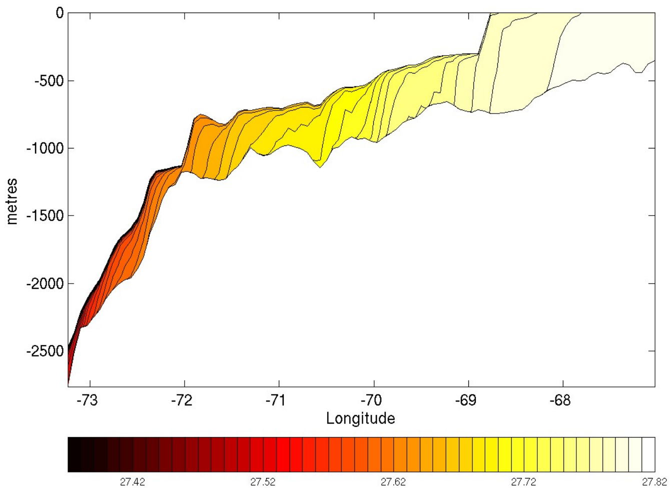

Figure 4: Vertical section of potential density for model simulation with no tides and 'coldest' boundary conditions.

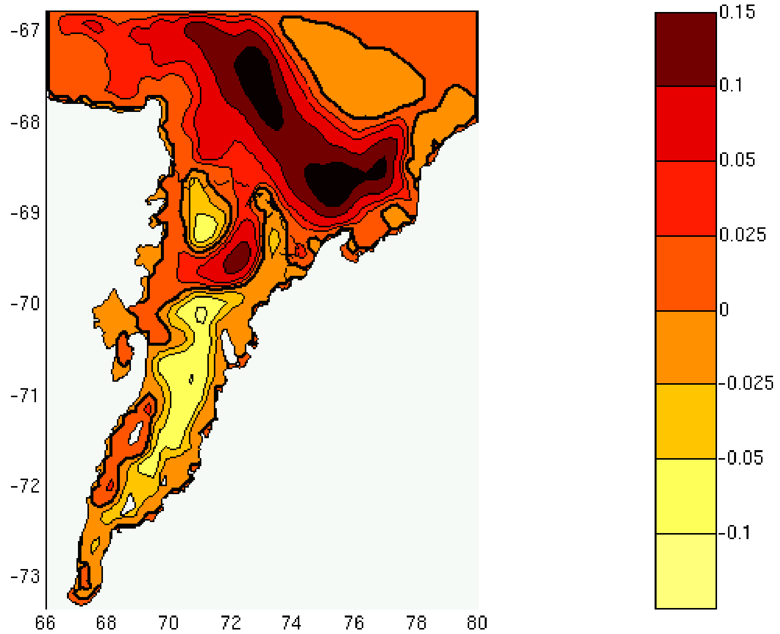

Figure 5: Vertically-integrated streamfunction (Sverdrups) for model simulation with no tides and 'coldest' boundary conditions. Circulation is clockwise around positive features.

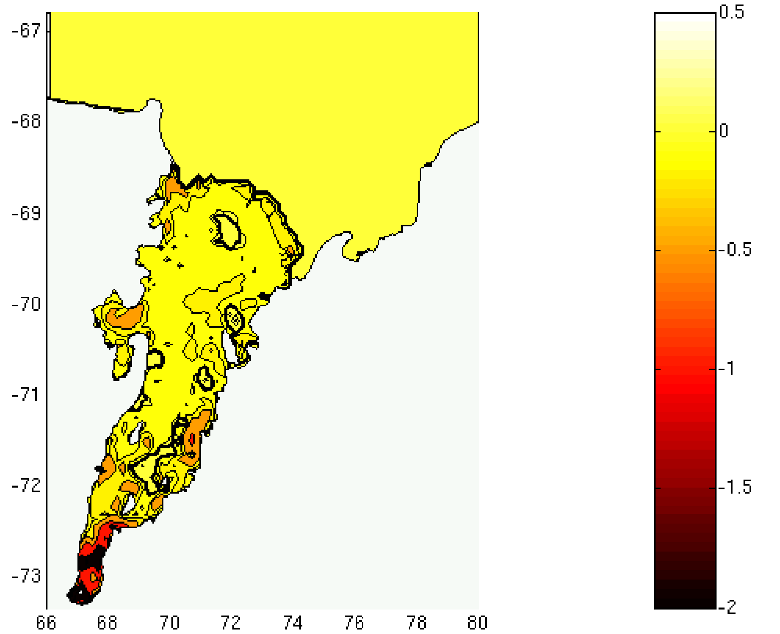

Figure 6: Freezing rate (ma^{-1}) for model simulation with no tides and 'coldest' boundary conditions. Positive regions represent freezing and negative regions represent melting. Contours are at -2.0, -1.0, -0.5, -0.2, -0.1, 0.0, 0.1, 0.2 and 0.5 ma^{-1}. The bold contour represents 0.0 ma^{-1}. White indicates melting rates greater than 2.0 ma^{-1}.

The model was also run under warmer conditions, with and without tides, in order to investigate both the the importance of including tidal motions, and the 'climate sensitivity' of the melting and freezing. Figure 7 shows the total mass loss (Gt a^{-1}) due to melting and freezing for different boundary temperatures. The run for a boundary temperature of 0.2°C above the surface freezing point coincides approximately with present conditions. It is evident that the presence of tidal motions has little effect on the total mass loss. Figure 7 indicates a climate sensitivity of about 44 Gt a^{-1} °C^{-1}, compared with the value of 25 Gt a^{-1} °C^{-1} found by Williams et al. (2002), using a different model and a significantly different cavity size and shape. This sensitivity should be viewed in the context of a mass loss of 40 Gt a^{-1} being able to totally remove the ice shelf in about 1000 years.

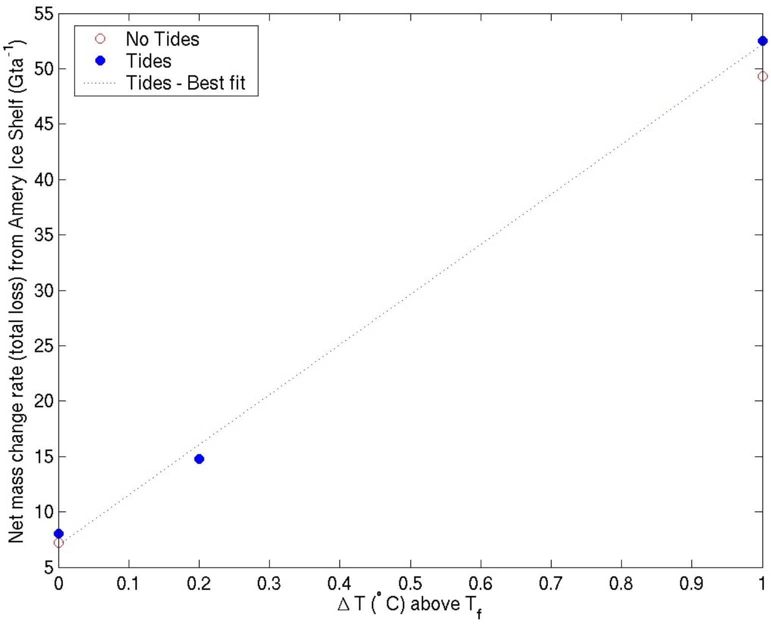

Figure 7: Climate sensitivity of total mass loss by melting and freezing (the ordinate). The abscissa is the excess of the boundary temperature over the surface freezing temperature.

Future Directions

Future model developments will include:

- the development of a coupled cavity/ice shelf model (using the OASIS coupler),
- improved definition of the ice draft using data from radars and satellite altimetry (using a hydrostatic assumption),
- the incorporation of frazil ice, and
- the investigation of the annual cycle (which will require either a sea ice model or prescribed surface fluxes).

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