Oceanographic conditions beneath Ronne Ice Shelf: a comparison between model and field data

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Introduction

Within the cavity beneath Filchner-Ronne Ice Shelf (FRIS), High Salinity Shelf Water (HSSW) is transformed into Ice Shelf Water (ISW) by a combination of melting and freezing at the ice shelf base and mixing within the water column. Evidence of these processes is abundant, both in the distribution of meteoric and marine ice in the ice shelf and in the properties of the water masses occupying the continental shelf. Quantitative information on the rate of water mass transformation is harder to come by, and more elusive still are indications of the rate-controlling factors. Is the circulation primarily "pulled" by the injection of meltwater deep beneath the ice shelf, or "pushed" by the production of dense waters at the ice front? Are there dynamical constraints on the rate of exchange at the ice front? Answers to these questions are highly relevant to the problem of how sensitive the sub-ice cavities are to externally forced climatic change.

During the mid 1990's a series of instrument strings were deployed through FRIS, in and near to the Ronne Depression (Nicholls and Makinson, 1998). Temperature and current records from the two sites within the depression showed a clear seasonality in the strength of the HSSW inflow; evidence of the importance of external forcing even deep within the cavity. The nature of the seasonal cycle, in particular the rapid increase in the HSSW flux associated with wintertime freezing north of the ice front, was further suggestive of some dynamical control on the inflow.

In this paper we attempt to explain some of the key features of the seasonal signal using the results of a three-dimensional numerical model of ocean circulation within the FRIS cavity. We use a version of the Miami Isopycnic Coordinate Ocean Model (MICOM) that we have adapted for sub-ice-shelf domains (Holland and Jenkins, in press). The domain we use in this study is identical to that described by Jenkins and Holland (2000). The forcing is also almost identical, except that we have slightly modified the mid-winter surface salinity (Figure 1) to reflect the lower salinities that are currently generated over Berkner Bank (Nøst and Østerhus, 1998). The model was run for 10 years.

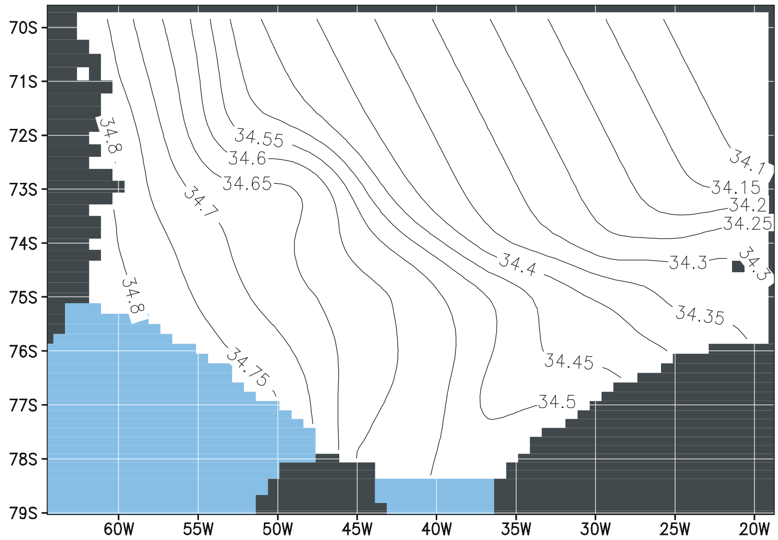

Figure 1: Surface salinity restoring field at the mid-winter maximum.

Time series data from the cavity

We focus on data from sites 2 and 3 (Figure 2). Two year, asynchronous temperature records from instruments suspended 30 to 80 m above the seabed at each site are shown in Figure 3. Both show relatively long periods with high temperatures, approaching the surface freezing point at site 2, followed by a gradual cooling and abrupt warming. Nicholls and Makinson (1998) interpreted the cooling trend as a weakening of the inflow to Ronne Depression, resulting from cessation of HSSW production at the ice front in summer. The warming was interpreted as the arrival of newer HSSW triggered by the onset of sea ice production and overturning of the water column north of the ice front.

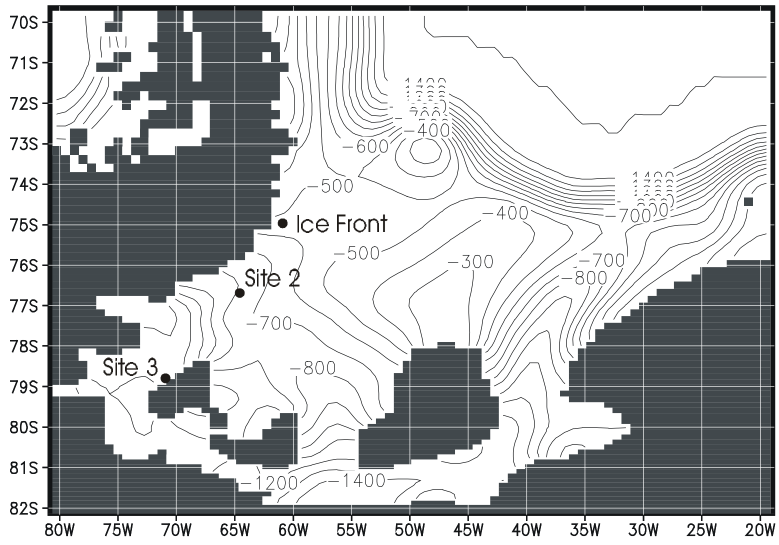

Figure 2: Sites mentioned in the text and bathymetry (m) throughout the model domain.

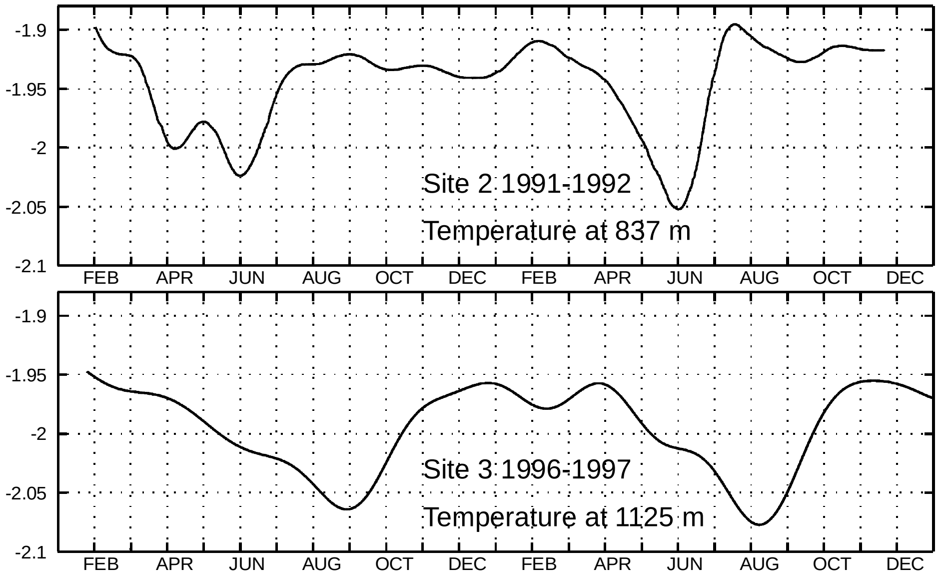

Figure 3: Time series of temperature (°C) recorded near the seabed at sites 2 and 3.

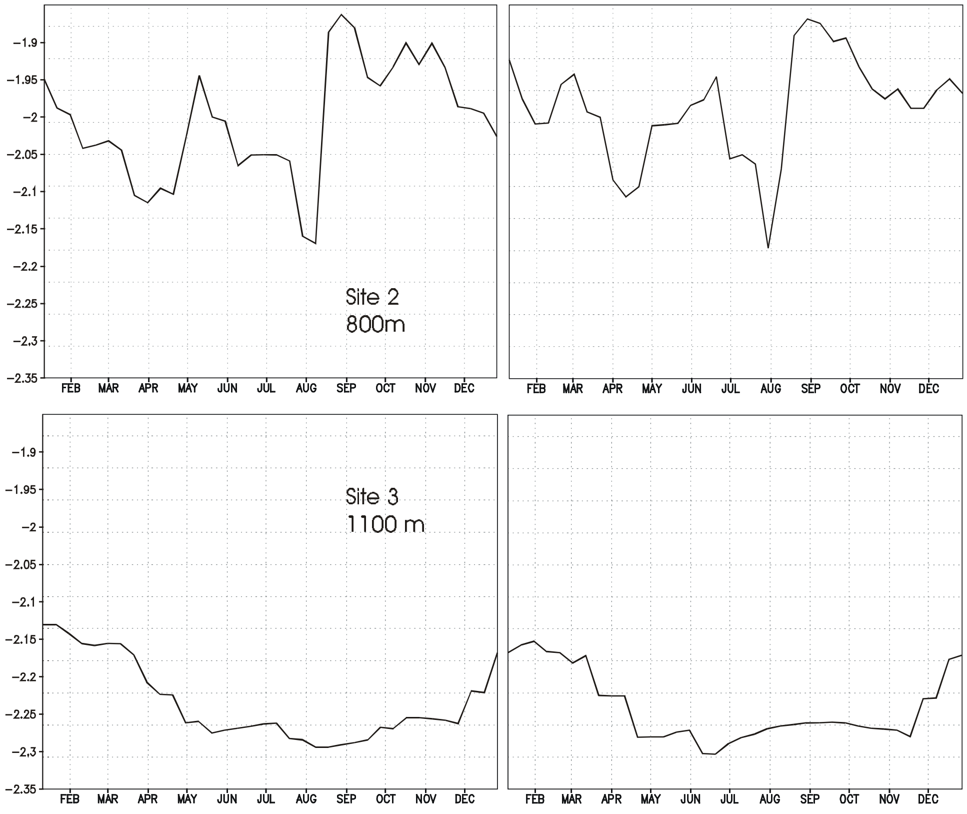

Figure 4: Time series of model temperatures (°C) from grid points close to the seabed at the locations shown in Figure 2.

The changes in temperature were assumed to reflect changes in the thickness of a lower layer of HSSW having relatively constant properties. The cooling was assumed to reflect the sinking of the thermocline past the level of the instrument. Of particular interest are the phasing and abruptness of the warming, associated with a thickening of the lower layer. The delay in arrival of the new HSSW was assumed to be related to the advection timescale from the ice front to the locations of the moorings, but the asymmetry between the abrupt warming and more gradual cooling was not explained.

Figure 4 shows the temperature signal from the last two years of the model run at the grid points corresponding to the positions of the instrumental records described above. While some features of the model results, such as the amplitude of the variability at site 2 and the mean temperature at site 3, do not match the observations, other features, such as the asymmetry of the cycles and relative phasing of the warming at the two sites, show quantitative similarities with the instrumental records. The absolute timing of the model temperature minima is about 2 months out, but this is not surprising given the simple symmetrical forcing that is applied north of the ice front. Given that symmetry in the forcing, the asymmetry in the model response is a particularly interesting feature, the source of which may give insight into the processes affecting the observations.

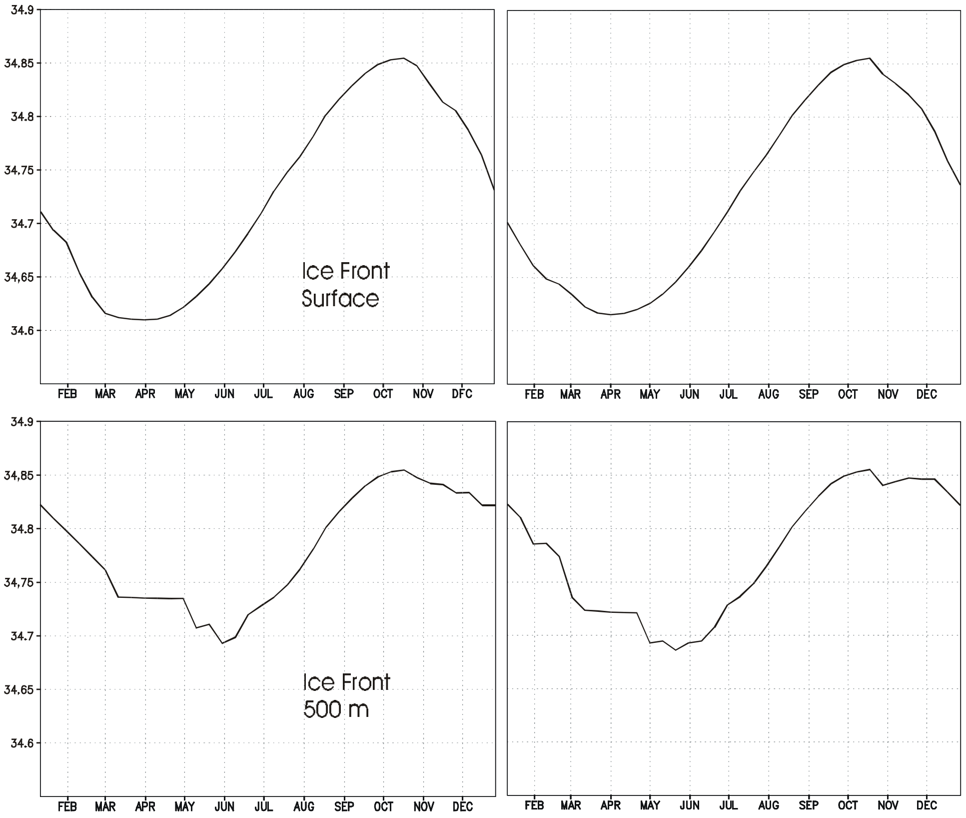

Figure 5: Time series of model salinity for grid points at the surface and near the seabed at the ice front location shown in Figure 2.

Time series data from the ice front

We illustrate the impact of the surface forcing at the ice front with time series of model salinity from 0 and 500 m at a point near the centre of Ronne Depression (Figure 2). The temperature at both levels shows relatively little variability, being held close to the surface freezing point for most of the time. At the surface the salinity deviates only marginally from the sinusoidal restoring cycle, but at 500 m an asymmetry is already apparent (Figure 5). The salinity at any depth in the water column is only forced directly by the atmosphere when the surface mixed layer has deepened sufficiently. At 500 m direct atmospheric forcing is felt only between mid-July and the end of October. After this brief period of HSSW renewal, the springtime retreat of the mixed layer leaves a water column consisting of a stack of isopycnic layers. As the HSSW spreads away from its site of formation, the layers thin and, at the 500 m level, the salinity falls with the sinking of each layer interface past this depth. Convection once again reaches this level when the rising surface salinity of the following winter becomes equal to, and eventually exceeds, the salinity at depth.

The impact of the relatively sharp onset of HSSW production is accentuated beneath the ice shelf by a coincident strengthening of the inflow to the cavity (Figure 6). While the flow is approximately parallel to the ice front during summer and autumn, as convection north of the ice front approaches full depth, the flow rapidly turns beneath the ice front. This is followed by a period of steady flow into the cavity, lasting until the mixed layer starts to retreat, at which time a gradual decrease in the inflow velocity begins. The result is the advection of a blob of new HSSW into the cavity, the front of which is particularly sharp. As the blob moves south along Ronne Depression, the domed isopycnals tend to slump, so that the signature of its arrival becomes progressively more diffuse. This thickening and thinning of the HSSW layer is the origin of the temperature variations shown in Figure 4.

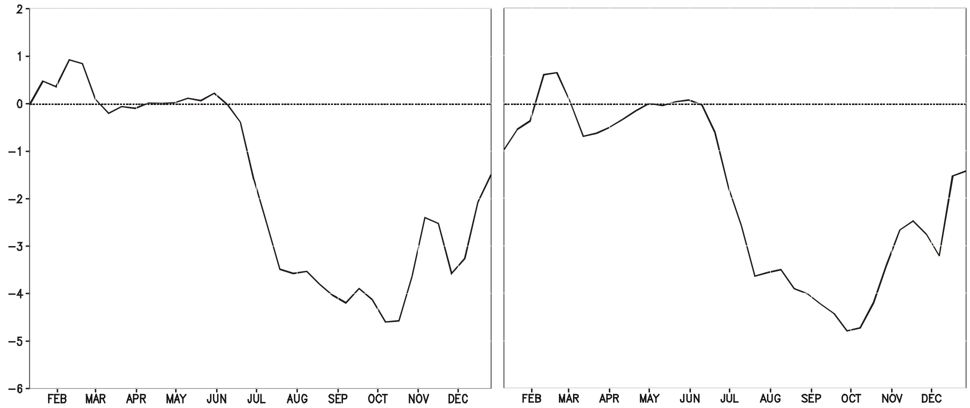

Figure 6: Time series of depth-mean velocity (cm s^{-1}) perpendicular to the ice front at the grid point shown in Figure 2. Negative values indicate flow into the cavity.

Summary

We have explored the propagation of the seasonal signature of HSSW production into the cavity beneath Filchner-Ronne Ice Shelf using MICOM. The focus of our study has been Ronne Depression, from where instrumental records are available for comparison. Agreement between model and observations is not perfect, but the phasing and shape of the annual cycle at two points along the depression is reasonably well simulated. Correct phasing implies that the speed of the inflowing HSSW is about right in the model. The asymmetric response of the model is intriguing, given the simple, symmetric forcing. We find that a combination of two factors is responsible for this. Production of HSSW only occurs for a relatively short period as the surface salinity approaches its maximum. At other times the deep parts of the depression are isolated from the surface buoyancy forcing. As HSSW production begins each year, there is a rapid transition from flow that is predominantly along the ice front, to flow that is directed almost perpendicular to the ice front. The new HSSW propagates into the cavity with a sharp front, that becomes gradually more diffuse with distance from the ice front. The seasonal forcing is felt throughout the model cavity and this, combined with the weak flow reported by Holland and Jenkins (in press) for an ideal cavity with no external forcing, suggests that our sub-ice version of MICOM is more “pushed” than “pulled”.

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