The effect of McMurdo Sound topography on water mass exchange across the Ross Ice Shelf front

Karen M. Assmann
Alfred-Wegener-Institute for Polar and Marine Research, Postfach 12 01 61, 27515 Bremerhaven, Federal Republic of Germany

Introduction

The southwestern Ross Sea continental shelf acts as formation site for highly dense shelf waters because of strong brine release due to vigorous sea ice production in the Ross Sea polynya (Jacobs & Guilivi 1998, Assmann et al. 2003). In this context it has been debated whether the topography of McMurdo Sound permits exchange with the cavity and if so which effect this might have on the shelf hydrography and circulation. Following the acquisition of new information about the cavity configuration in the Ross Island and McMurdo Sound area (U. Nixdorf, personal communication) a previous analysis of circulation and water mass distribution on the Ross Sea continental shelf (Assmann et al. 2003) was extended to explore their sensitivity to various topographic configurations of McMurdo Sound.

A detailed description of the coupled sea ice-ice shelf-ocean model BRIOS2.2 is provided in Assmann et al. (2003) and Timmermann et al. (2002). For atmospheric forcing, daily NCEP Reanalyses from 1978-1987 were used as spin-up and the mean annual cycle of the years 1988-1997 was used for analysis. Comparisons were drawn between the standard model landmask configuration for McMurdo Sound (Fig. 1 a) and two sensitivity studies: (Fig. 1 b) McMurdo Sound narrowed by introducing a peninsula known as Minna Bluff and (Fig. 1 b) closing the passage completely.

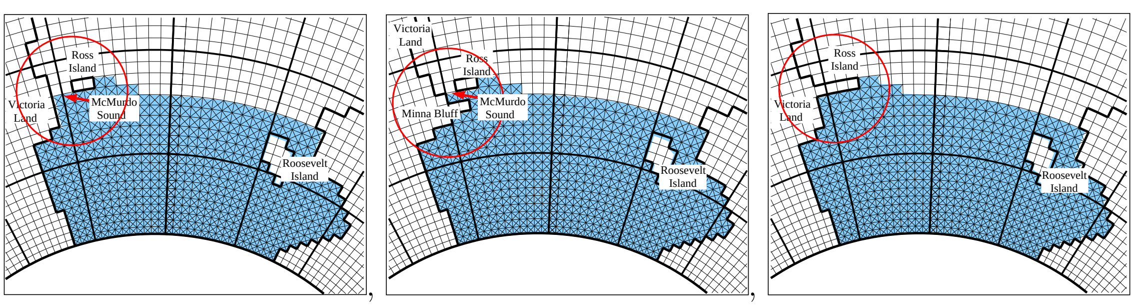

Figure 1: Model landmasks used for sensitivity studies: a) Standard run, b) Minna Bluff, c) No Sound.

Water mass distribution along the Ross Ice Shelf front

The typical salinity structure along the ice shelf edge of predominantly Low Salinity Shelf Water (LSSW) in the eastern and High Salinity Shelf Water (HSSW) in the western Ross Sea (Jacobs & Giulivi 1998) is preserved in all three runs (Fig. 2). It reflects the strong gradient in sea ice growth rates along the ice shelf front (Assmann et al. 2003) and is hence unaffected by the change in landmask. Observations (Barry & Dayton 1988) and the previous model study with BRIOS2.2 show that a northward current of low-salinity water exists all winter in the western McMurdo Sound carrying glacial meltwater out of the cavity.

This near-surface current appears to be necessary to lower salinities in the western Ross Sea sufficiently for the observed dome of HSSW near 170°E to appear (Jacobs & Giulivi 1998). With progressive closure of McMurdo Sound the isohalines, e.g. 34.8, on the western side of the dome start to level out due to the supression of the freshwater input (Fig. 2 a-c). Narrowing McMurdo Sound also prevents the drainage of HSSW along the bottom in winter leading to increased salinities in the western Ross Sea (Fig. 2 d-f). The changes in HSSW salinities induced by the alteration of McMurdo Sound topography, however, prove to be smaller than the interannual variability of the model displayed over the 10-year period 1988-1997.

Circulation pattern and basal melt rates

On the Ross Sea continental shelf an anticyclonic circulation cell extends from the southern model boundary to the shelf break (Assmann et al. 2003). Its strength increases from 1.5 Sv in summer to 2.5 Sv in winter accompanied by a shift of the main cavity inflow from east of Ross Island to McMurdo Sound (Fig. 3 a & d). The winter steepening of the east-west density gradient across the Ross Sea suggests that the horizontal circulation is predominantly thermohaline-driven (Pillsbury & Jacobs 1985).

In summer, when the main cavity inflow is located near the surface east of Ross Island, closing McMurdo Sound does not have much of an effect on the circulation pattern (Fig. 3 a-c). In winter, however, HSSW mainly drains south into the cavity over the whole water column through McMurdo Sound in the standard run (Fig. 3 d). In the "Minna Bluff" run there is some southward flow through McMurdo Sound, but the near surface inflow east of Ross Island still shows large current speeds (Fig. 3 e). For McMurdo Sound closed, the picture remains much as in summer, but with a large area of weak southward flow around 180° (Fig. 3 f). The peak strength of the anticyclonic circulation cell does not reflect the substantial changes in inflow location in winter (Fig. 4). This finding again supports the hypothesis by Pillsbury & Jacobs 1985 that the horizontal circulation on the Ross Sea continental shelf is predominantly thermohaline driven. The change of McMurdo Sound topography hence causes a change in inflow location, but does not change the circulation strength.

In the inner cavity, the bimodal seasonal cycle of basal melting with maxima in March and August and minima in May and December is preserved for all three runs (cf. Assmann et al. 2003, Fig. 7). The "Minna Bluff" and "No Sound" runs show lower melt rates during winter, when strong basal melting occurs south of McMurdo Sound in the standard run due to a shift in inflow location.

Overall this leads to a 5% reduction in melt rate for the inner cavity which supplies about 60% of the total freshwater flux from the cavity (Table 1). Closing McMurdo Sound leads to a lowering of the total basal mass flux of the cavity by about 10 %. Again, this change is smaller than that caused by interannual variability.

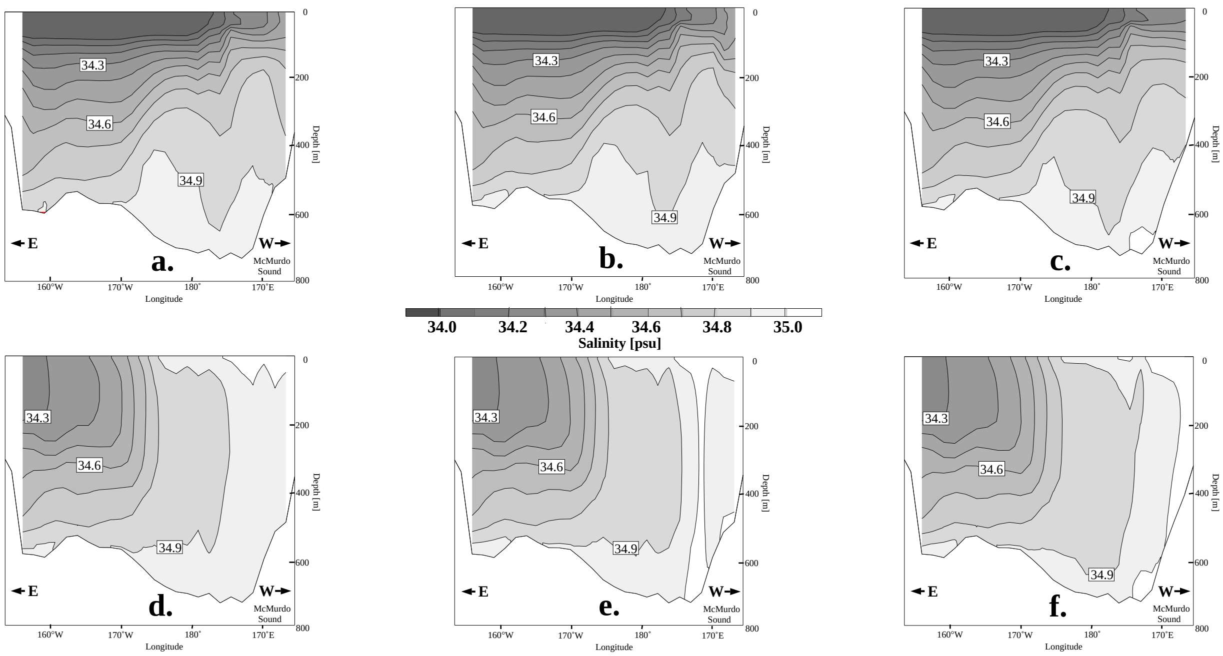

Figure 2: Salinity section along the Ross Ice Shelf front, facing south. Top row: Summer. February (1988-1997) 10-year mean. Bottom row: Winter. September 10-year (1988-1997) mean. a) & d) Standard run, b) & e) Minna Bluff, c) & f) No Sound.

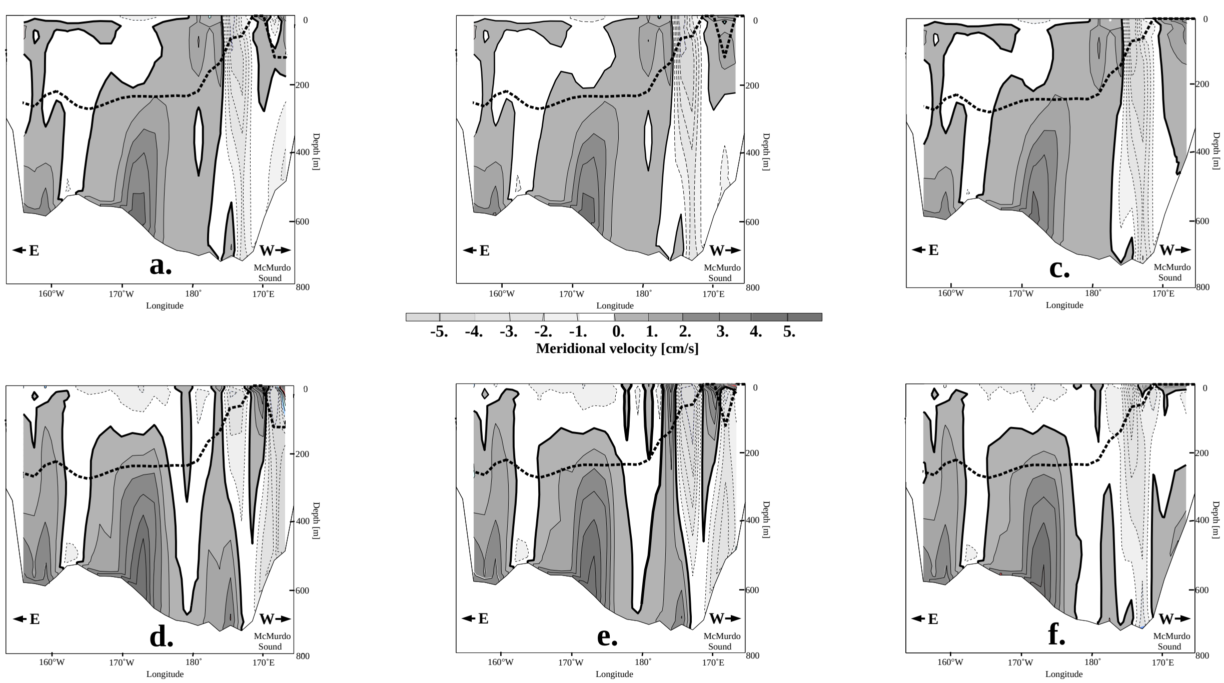

Figure 3: Meridional velocity section along the Ross Ice Shelf front, facing south. Top row: Summer. February 10-year mean. Bottom row: Winter. September 10-year mean. a) & d) Standard run, b) & e) Minna Bluff, c) & f) No Sound. Positive values denote northward velocities, negative southwards. The ice shelf draft is marked by the thick, black, dashed line. The zero contour is drawn bold and negative contours are dotted.

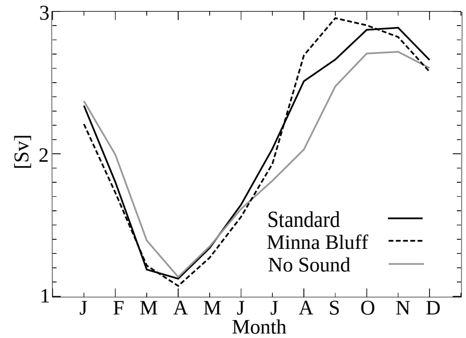

Figure 4: Seasonal cycle of the circulation strength of the main anticyclonic circulation cell on the Ross Sea continental shelf.

Ice Shelf Water outflow from the Ross Ice shelf cavity

The November temperature section along the Ross Ice Shelf front shows two central cores of Ice Shelf Water (ISW), the main at ∼ 200m depth and a smaller near the bottom (Fig. 5 a). I will concentrate on these two central cores, rather than the much colder one emerging east of Roosevelt Island, since they are more likely to be affected by changes around McMurdo Sound due to the existence of separate circulation regimes in the eastern and western cavity (Locarnini 1994). Also, the central ISW core is thought to participate in the formation of Low Salinity Bottom Water (Jacobs 1970), because it consists of HSSW modified through interaction with the ice shelf base, and is consequently saline and dense enough. Since the ISW outflow is underestimated in the model (Assmann et al. 2003), the -1.88°C isotherm was defined as the upper temperature limit for ISW.

The March to June minimum in ISW export (Fig. 5 b) can be attributed to the presence of a strong westward wind-driven current near the surface along the ice shelf front. In addition, deep convection and the associated destruction of the stratification during the sea ice growth season prevent ISW from exiting the cavity. At the November maximum the water column has started to regain a stable stratification at the onset of summer melting along with sea ice cover still present reducing wind influence. This permits ISW to leave the cavity at a rate of about 750 mSv (1mSv = 10^3 m^3s^{-1}).

Closing McMurdo Sound results in a 50% reduction of the ISW emerging from the cavity in the annual mean and a lowering of the November peak by 33 % (Fig. 5 b). This is

	Standard	Minna Bluff	No Sound
Cavity [ma^{-1}]	0.276	0.261	0.256
[mSv]	3.28	3.06	3.05
Edge [ma^{-1}]	3.28	3.06	3.05
[mSv]	2.39	2.28	2.09
Total [ma^{-1}]	0.45	0.43	0.40
[mSv]	5.67	5.34	5.14
[Gta^{-1}]	178.7±26.5	168.6±23.6	162.3±20.8

Table 1: Mean basal melt rates and freshwater fluxes for standard and sensitivity runs. Edge denotes the mean over the front row of grid boxes defined as ice shelf, cavity over the rest.

rather large in comparison to the changes seen in other variables, especially since the overall circulation strength is almost unaffected. The shift of the main cavity inflow westward to McMurdo Sound supports the ISW export in the standard run. In the sensitivity runs this shift cannot take part at all or only to a lesser degree, while the overall circulation strength increases just as before. This results into weak southward flow over a broad area reaching as far east as the location of the ISW cores, hence weakening the ISW outflow considerably.

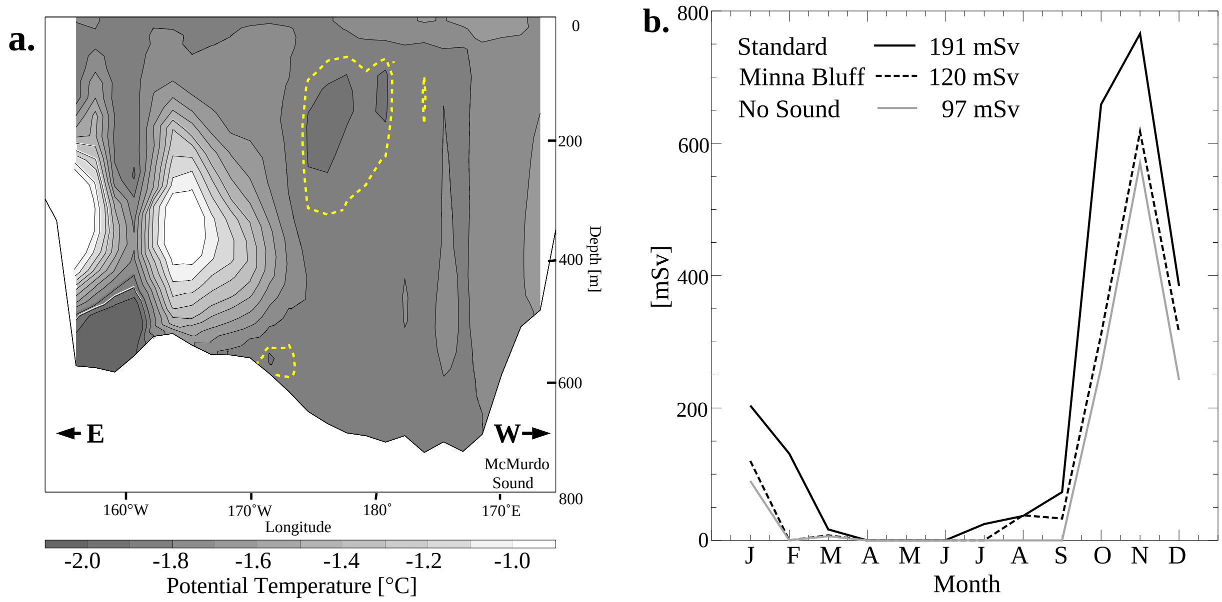

Figure 5: Ice Shelf Water (ISW) outflow from the Ross Ice Shelf cavity: a) Potential temperature section along the Ross Ice Shelf front, mean November distribution (1988-1997). The dashed line marks the -1.88°C isotherm. b) ISW transport across the Ross Ice Shelf front, main core.

Conclusions

Freshwater outflow from McMurdo Sound is responsible for the dome structure in the salinity distribution at the western Ross Ice Shelf edge. Winter drainage of HSSW into the cavity prevents brine accumulation and thus lowers HSSW salinities to the range observed. Basal melting is affected mostly in the region of high melt rates south of Ross Island. The decrease in basal mass flux in the sensitivity runs with a narrower or closed McMurdo Sound does not exceed its interannual variability. Since the westward shift of the main cavity inflow to McMurdo Sound does not take place in the sensitivity runs, the central ISW cores are strongly weakened in winter.This study implies in agreement with observations that flow through McMurdo Sound ought to be possible for the observed salinity structure to appear. The influence on the central ISW core suggests that McMurdo Sound appears to be an important gate for the spreading of HSSW and thus affecting one of the possible sources of AABW in the Ross Sea.

References

Assmann, K., H.H.Hellmer & A.Beckmann, 2003: Seasonal variation in circulation and watermass distribution on the Ross Sea continental shelf. *Antarctic Science*, **15(1)**, 3-11, DOI:10.1017/S0954102003001007.

Bamber, J. & Bentley, C.R. 1994: A comparison of satellite-altimetry and ice-thickness measurements of the Ross Ice Shelf. Antarctica, *Journal of Glaciology*, **20**, 357-364.

Barry, J.P. & Dayton, P.K., 1988: Current patterns in McMurdo Sound, Antarctica and their relationship to local biotic communities. *Polar Biology*, **8**, 367-376.

Jacobs, S.S., Amos, A.F. & and Bruchhausen, P.M., 1970: Ross sea oceanography and Antarctic Bottom Water formation. *Deep-Sea Research*, **17**, 935-962.

Jacobs, S.S. & Giulivi, C.F., 1998: Interannual ocean and Sea Ice Variability in the Ross Sea. *Antarctic Research Series*, **75**, 135-150.

Locarnini, R.A. 1994. Water Masses and Circulation in the Ross Gyre and Environs. PhD Thesis, Texas A&M University, 87 pp.

Pillsbury, R.D. & Jacobs, S.S., 1985: Preliminary observations from long-term current meter moorings near the Ross Ice Shelf, Antarctica. *Antarctic Research Series*, **43**, 87-107.

Timmermann, R., A.Beckmann & H.H.Hellmer, 2002: Simulation of ice-ocean dynamics in the Weddell Sea. Part I: Model configuration and validation. *Journal of Geophysical Research*, **107(C3)**, 10.1029/2000JC000471.