Dense shelf water formation at coastal polynyas in the Weddell Sea

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Sea ice – ocean – atmosphere interactions

The global ocean's thermohaline circulation is partly driven by high-latitude deep water formation. Deep and bottom water formation in the marginal seas of the Southern Ocean is induced by high freezing rates as generally found at coastal polynyas, which enable the production of very cold and - due to brine-release - very saline water masses. In the southwestern Weddell Sea, frequent katabatic winds shift the sea ice away from the shoreline and wide shelves allow for a strong salinification of the whole water column and the formation of High Salinity Shelf Water (HSSW), the precursor of Weddell Sea Deep Water and Antarctic Bottom Water.

The model

Simulations are performed on a global grid with the Finite Element Sea ice-Ocean Model (FESOM; Timmermann et al., 2009) of the Alfred Wegener Institute (AWI). FESOM is a coupled system of a primitive-equation, hydrostatic ocean model and a dynamic-thermodynamic sea ice model. A global unstructured mesh with a strong focus on the southwestern Weddell Sea coastline (up to 3 km resolution) was chosen with 36 depth levels (z-coordinates) with 6 levels in the uppermost 100 m. The model is initialized in 1980 with data from the Polar science center Hydrographic Climatology (PHC2) and forced with daily NCEP reanalysis data. The period 1990-2009 is used for data analysis.

Locations of relevance

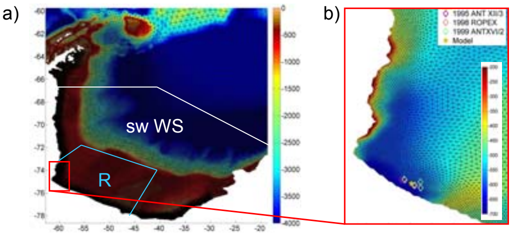


Figure 1: The model grid, bathymetry and regions of interest in the southwestern Weddell sea are displayed. The region referred to as southwestern Weddell Sea (Fig. 4) is marked white and the Ronne region (Fig. 7) is marked light blue. Also, in panel b) the locations of the CTD stations (Fig. 3) are marked with diamonds and the simulated profile with a star.

Verification

Simulated ice concentration — spring 1992

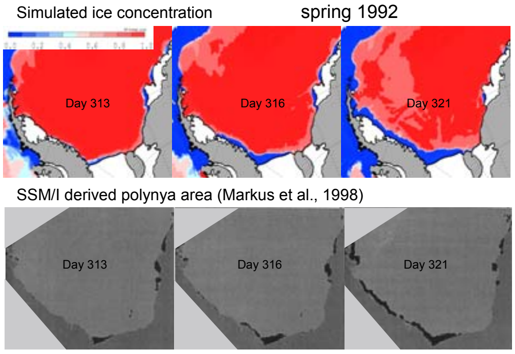


Figure 2: Modeled ice concentration and SSM/I derived polynya area (Markus 1998) on three days in spring 1992. While the process of northward elongation is well represented, simulated polynya area tends to be too large; probably a result of the model's overestimated surface heating due to an underestimation of the mixed layer depth during the melt season (see Fig. 3).

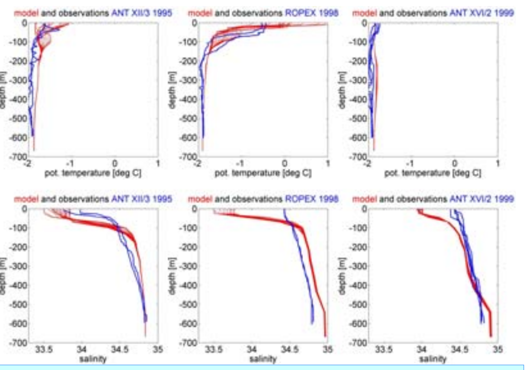


Figure 3: Simulated and observed temperature and salinity profiles close to the Ronne Ice Shelf front (locations see Fig. 1) from February 1995, 1998 and 1999. The profiles show the model's underestimation of mixed layer depth during the melt season, which is accompanied with overly warm and fresh surface waters. In winter the on-shelf mixed layer reaches the bottom (cf. Fig. 6). Thus, winter values, on which this study is focussing, are not critically affected.

Sea ice and surface fluxes: mean year and mean winter distribution

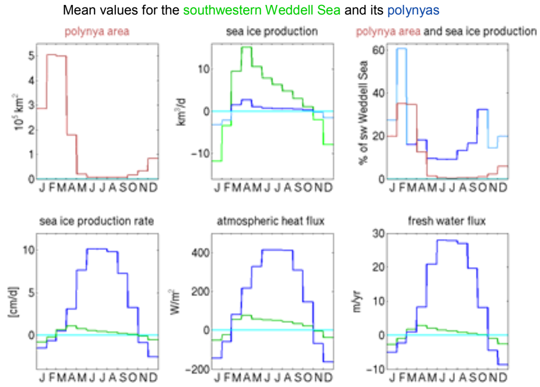


Figure 4: Mean seasonal cycle of open water area, sea ice production, atmospheric heat flux and fresh water flux of the south-western Weddell Sea and the polynyas within. In the winter months (May-Sept.) polynyas cover an area of 0.5 % of the southwestern Weddell Sea but produce 11.5 % of its newly formed ice. At polynyas the heat and fresh water flux exceed the average by a factor of 8.6 and 25, respectively.

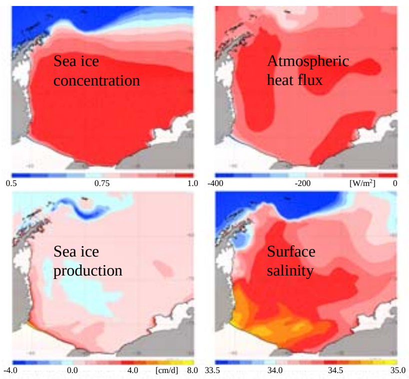


Figure 5: Mean distribution of ice concentration, atmospheric heat flux, freezing rates and surface salinity in winter (May-Sep. 1990-2009). The southern Antarctic Peninsula, the Ronne Ice Shelf and Brunt Ice Shelf show high polynya activity. The Ronne Polynya has the highest freezing rates and forms the densest waters.

5 years at Ronne ice front

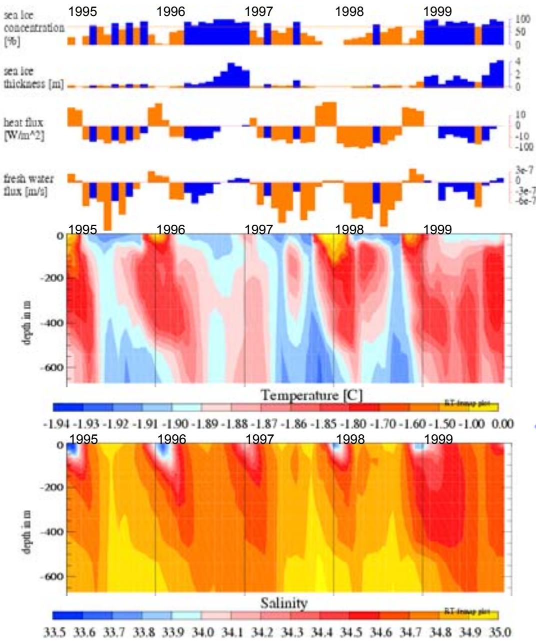
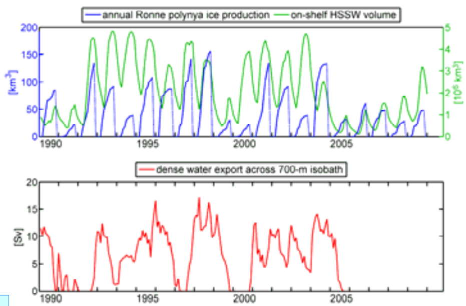


Figure 6: 1995-1999 time series of sea ice conditions, surface fluxes (orange if ice concentration <70%) and temperature and salinity profiles at a location close to the Ronne ice front (star in Fig. 1b). Polynyas are necessary for dense water formation. Heavy ice conditions in winter lead to less freezing and consequently the water column stays relatively fresh and warm. Differences between years can easily amount to 0.3 psu and 0.5 K. Summertime heating and freshening is amplified by polynyas since the absence of sea ice lowers the albedo from ~0.7 to 0.1.

HSSW volume + dense water export

Figure 7: Accumulated Ronne polynya ice production (Mar.-Oct.), on-shelf volume of HSSW ($T_{freezing}<\theta<-1.6$, $S>34.65$) and export of dense water ($\theta<-0.5$, $S>34.67$) across the 700m-isobath. A season of very active polynya ice production leads to a strong increase in HSSW volume (although not always in Ronne polynya e.g. in 2000). The export of dense water sets in only when a large bulk of HSSW is present. Interfering with this annual cycle of dense water export are 'flushing' events of 2-3 year duration e.g. 98/99 and 04/05. These events diminish the on-shelf HSSW volume severely. The 20-year mean export of dense water gives 5.2 Sv crossing the 700-m isobath.



Summary

While in summer polynyas present locations of strong energy uptake for the ocean, during winter they cool and salinify the water column. Their dependence on the wind field leads to a pronounced interannual variability easily causing local differences of 0.5 K and 0.3 psu between years. On average 11.5 % of the southwestern Weddell Sea winter ice production originates from polynyas covering 0.5 % of the area. HSSW production is strongly connected to the winter polynya ice production and in the 20-year mean 5.2 Sv of dense water are exported over the 700m-isobath.

References

Markus, T., C. Kottmeier, and E. Fahrbach, 1998. Ice formation in coastal polynyas in the Weddell Sea and their impact on oceanic salinity. In Jeffries, O., editor, Antarctic sea ice: Physical processes, interactions and variability, pages 1-54. Antarct. Res. Ser., vol. 74, AGU, Washington, D. C.

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