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Impact of coastal polynyas on sea ice production and water mass modification in the southwestern Weddell Sea

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The thermohaline circulation of the world ocean is partly driven by deep water formation at high-latitudes. In the Southern Ocean, deep and bottom water formation in the marginal seas is induced by high freezing rates as generally found at coastal polynyas. Atmospheric cooling and brine-release enable the production of very cold and saline water masses. In the southwestern Weddell Sea, wide shelves allow for a strong salinification of the whole water column and the formation of High Salinity Shelf Water (HSSW).

The impact of coastal polynyas on ice production and water mass formation in the southwestern Weddell Sea was studied employing the Finite Element Sea ice-Ocean Model (FESOM) of the Alfred Wegener Institute, Bremerhaven. FESOM is a coupled system of a primitive-equation, hydrostatic ocean model and a dynamic-thermodynamic sea ice model. Simulations were conducted on a global unstructured mesh with a strong focus on the southwestern Weddell Sea coastline (up to 3 km resolution). In vertical direction, the grid features 37 z-coordinate depth levels of which 6 are within the uppermost 100 m. The model runs were initialised in 1980 and forced with NCEP reanalysis data (daily resolution). The year 2008 was also simulated with higher-resolution GME and regional COSMO forcing data. For data evaluation and analysis the period 1990-2009 is used. A comparison of AMSR sea ice concentration and model results shows good accordance in spatial and temporal polynya extent. Also, calculated vertical temperature and salinity profiles agree well with CTD measurements.

Our simulations feature a 20-year winter mean area of coastal polynyas of $6.7 \cdot 10^3$ km^2 (0.4% of the continental shelf area) in the southwestern Weddell Sea which is in good agreement with observations. Winter sea ice production within the coastal polynyas exceeds the ice production of the surrounding ice-covered area by a factor of 7 in the 20-year mean, so that the polynya contribution to total sea ice formation averages at about 3%. This small percentage is due to their even smaller areal percentage and the existence of leads and small polynyas in the so-called ice-covered ocean. The latter give a major contribution to sea ice production, but do not contribute to bottom water formation since they are transient elements that open, move and close dependent on the ice drift, whereas coastal polynyas are spatially fixed and open often for days, which is essential to achieve the salinification necessary for the formation of HSSW. From our simulations we derive a 20-year mean HSSW-formation of $4.2 \cdot 10^5$ km^3/season, but only 0.5 Sv thereof are exported over the shelf break, the rest stays on the shelf and is warmed and diluted during summer. The WSBW formation rate for the southwestern Weddell Sea continental shelf in our simulation is about $6.3 \cdot 10^4$ km^3/yr (2 Sv), which is on the low side but still reasonable compared to independent estimates. We conclude that in the Weddell Sea the role of coastal polynyas for sea ice production is not as big as is widely assumed, but they are indispensable for the formation of HSSW and thus for bottom water formation.