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Coastal polynyas in the southwestern Weddell Sea: sea ice production and bottom water formation

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Coastal polynyas are areas in the ice-covered ocean from which the sea-ice cover has been mechanically removed, primarily by winds. They are areas of enhanced exchange processes between ocean and atmosphere. The increased heat flux allows for exceptionally high freezing rates, which lead to locally increased brine-rejection. In the southwestern Weddell Sea, wide continental shelves and a weak exchange with the open ocean provide conditions that allow for substantial salinity enrichment, forming the cold and saline High Salinity Shelf Water (HSSW), which is the densest water mass in the region. HSSW is one of the ingredients of Weddell Sea Bottom Water (WSBW) and is thus essential for the formation of Antarctic Bottom Water, which covers large parts of the World Ocean's abyss. Thus, production rates of HSSW and WSBW are of crucial importance in the ocean's global thermohaline circulation.

To study the influence of coastal polynyas on ice production and water mass formation in the southwestern Weddell Sea, we performed simulations using 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, focussing on the southwestern Weddell Sea coastline with 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 daily reanalysis data. In addition, a hindcast for the year 2008 was computed with GME 6-hourly data forcing. For the winter period 2008, the (hourly) output from the high-resolution regional atmosphere model COSMO of the University Trier was nested into the GME fields, covering the area of the western Weddell Sea. For data evaluation and analysis the period 1990-2009 is used. A comparison of model results to AMSR sea ice concentration shows good agreement in spatial and temporal polynya extent. Also, simulated vertical temperature and salinity profiles agree well with CTD measurements.

The total area of coastal polynyas is very small compared to the area of the Weddell Sea continental shelf. Winter sea ice production within the coastal polynyas, however, exceeds the ice production of the surrounding ice-covered area by a factor of 8 in the 20-year mean, so that the polynya contribution to total sea ice formation is always larger than their areal fraction. When looking at ice production, it should be kept in mind that also in the so-called ice-covered ocean, leads and small polynyas exist with an areal fraction of typically 5 %, which integrates to a total area that is much larger than the total area of coastal polynyas - but consists of small and transient elements. Thus this "fractal polynya" in the offshore Weddell Sea yields a major contribution to sea ice production, but does not contribute to bottom water formation, whereas coastal polynyas are spatially coherent for days or even weeks, which is essential to achieve the necessary salinity enrichment. Only in coastal polynyas and directly adjoining areas does surface salinity exceed 34.65, which is the defining minimum salinity for HSSW. From our simulations we derive a formation rate of $4.2 \cdot 10^5$ km^3/yr (13 Sv) of HSSW as a 20-year mean, with peak formation rates of $3 \cdot 10^5$ km^3/month (116 Sv) in the autumn months. The WSBW formation rate in our model was found to be $6.3 \cdot 10^4$ km^3/yr (2 Sv) which is on the low side although not unrealistic when compared to observation-based estimates.