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The piercing of the Atlantic Layer by a dense water cascade in an idealised modelling study inspired by the Storfjorden overflow

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The Storfjorden in the Svalbard Archipelago (Norwegian Arctic Ocean) is a sill-fjord with an active polynya where intense sea ice formation produces significant amounts of near-freezing brine-enriched shelf water, which flows over the sill and sinks into Fram Strait down the continental slope of Western Svalbard as a dense plume from the sill depth of 115m. On its downward descent the dense water encounters a layer of warm, saline Atlantic Water that occupies the upper layer of the West Spitsbergen current within a depth range of approximately 200-500m.

Hydrographic observations in the Storfjorden overflow region have been carried out over the past 30 years. In some years the Storfjorden cascade has been observed to reach depths of over 2000m in Fram Strait, where it shows up within the Norwegian Sea Deep Water as a temperature maximum due to the heat gained by turbulent mixing as the plume pierces through the warm Atlantic Water. At other times the cascade was arrested within the layer of Atlantic Water. It has been unclear what parameters control whether the piercing would take place or not. The eventual depth of the cascaded waters has a proven effect on the maintenance of the Arctic halocline and (when piercing occurs) the ventilation of the deep Arctic basins. Due to its location at the gateway into the Arctic Ocean, the Storfjorden cascade plays an important role in modifying the properties of the Atlantic Water inflow into the Arctic.

We use a high-resolution 3-D numerical ocean model (NEMO) to simulate the descent of a cascade of saline and near-freezing shelf water into simplified, yet realistic, ambient stratification on an idealised conical slope based on the bathymetry of western Svalbard and Fram Strait. The model uses 1 km horizontal resolution and 42 layers in the vertical. The vertical grid is a complex combination of s- and z- coordinates specifically designed for this study. In a series of model runs we vary mainly the inflow rate 'Q' and the salinity 'S' of the simulated Storfjorden overflow to investigate both strong (high Q and/or S) and weak (low Q and/or S) cascading conditions.

The model reproduces well the mixing of the plume with Atlantic Water and the lateral dispersal of cascaded waters at intermediate depths. In case of strong cascading it also shows the piercing of the Atlantic layer and a resulting temperature gain in deep waters. We further investigate modifications of the ambient waters and quantify cascading-driven upwelling of Atlantic Waters onto the shelf, which results in warming of the surface waters. The model identifies the depth ranges into which the flow intrudes under different initial conditions and quantifies the fluxes of shelf waters into the different layers of the ambient waters. The model results compare well with previously measured characteristics of cascaded and ambient waters in Fram Strait, revealing the capability of the model to predict the fate of cascaded shelf waters under a variety of initial conditions.

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