Intrusion of Atlantic Water on an Arctic Shelf

Frank Nilsen[1,2], Ragnheid Skogseth[1], Neil Fraser[3] & Stefan Muckenhuber[4,1]

1. The University Centre in Svalbard (UNIS), Longyearbyen, Norway. 2. Geophysical Institute, Bergen, Norway. 3. The Scottish Association for Marine Science, Oban, UK. 4. Nansen Environmental and Remote Sensing Centre, Bergen, Norway

Introduction

The rapid decline in Arctic sea ice is one of the most striking manifestations of climate change, and in the recent decades, Svalbard fjords have experienced a substantial reduction in winter sea ice extent. The reduced sea ice cover has been linked to an increased transport of warm Atlantic Water (AW) into the fjords. AW from the West Spitsbergen Current (WSC; all red arrows in Figure 1) is able to reach the upper shelf along western Spitsbergen on Svalbard, and eventually flood into the fjords. Wind forcing on the West Spitsbergen Shelf (WSS) on timescales from days to months is one of the mechanisms starting a circulation of warm AW towards the fjords.

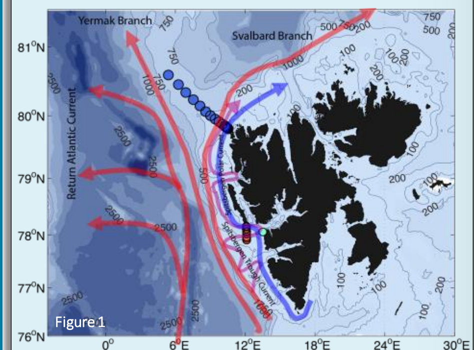


Figure 1

Here, model results are compared with observations in the Isfjorden Trough (Isfjordrenna) on the WSS (Figure 1 and 2). Repeated hydrographic cross section data (Figure 2), direct current measurements and results from a simple barotropic potential vorticity model indicate that a steady, cyclonic, topographically trapped vortex resides over the Isfjorden Trough.

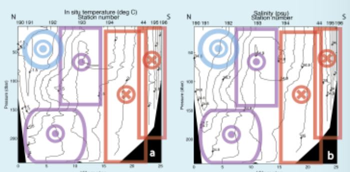
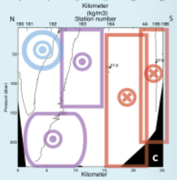



Figure 2: Temperature (a), salinity (b) and potential density (c) in the Forlandet Section for April 2011 (red dots in Figure 1 and 5). The red boxes on the southern side of the section illustrate the two routes of AW that are topographically guided towards the mouth of Isfjorden. The modified AW flowing westward on the northern side is illustrated with purple boxes. The cold surface current on the northern side is the Spitsbergen Polar Current (SPC), illustrated by blue circles.

The Slope in Eastern Fram Strait

The upper slope branch of the WSC can be described as a topographically guided barotropic jet flowing along isolines of planetary potential vorticity f/H and is referred to here as the barotropic WSC branch. Figure 3 (a) shows the time averaged (October 2007-June 2008) jet current profile of the fitted skewed jet WSC profile, constructed from observations of the WSC across Fram Strait at 78.83N. In (c), a fitted skew jet time series of the WSC (every hour) is shown, from October 2007 to June 2008, at the 200-250 m level at mooring F0-F5. Mooring positions are marked in all figures and the mooring depth is given in parenthesis in (a).

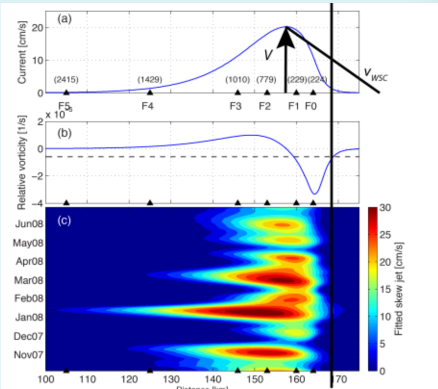


Figure 3

In our simplified version of the barotropic WSC branch, the y axis is a streamline and fixed at the seaward boundary on the 500-m isobath (Figure 4) where the average maximum current speed position of the WSC is found, V_{max}. The simplified representation of the barotropic WSC branch (Figure 3) is the boundary condition for our shelf circulation model.

The model equation, the inertial potential vorticity equation, states that potential vorticity is conserved along a stream-line:

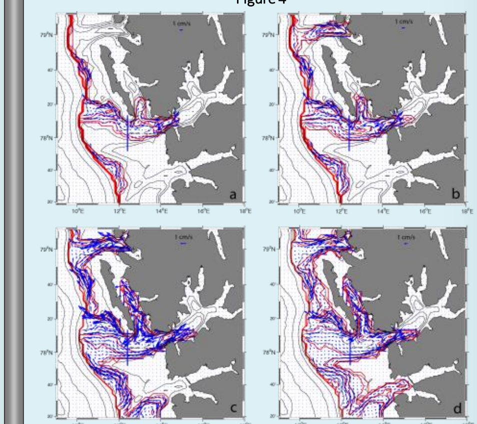
$$\nabla^2\psi + \frac{h_B}{\varepsilon D} = K(\psi), \qquad \varepsilon = \frac{V_{max}}{fL},$$

where ψ is the stream function, ε is the Rossby radius, V_{max} is the maximum current over the 500m isobath in the barotropic WSC, D is the bottom depth at max WSC velocity and reference depth, h_B is the trough height above the reference depth, and L is the Length scale (width of the barotropic WSC profile).

The West Spitsbergen Shelf

The continental shelf adjoining the west coast of Spitsbergen is complex, with alternating shallow banks (50–100 m depths) and deep troughs (200–400 m depths) cutting across the shelf. Figure 4 shows the modeled shelf circulation where the maximum current of the WSC is shifted an eastward distance of a) a=2 km, b) 3 km, c) 8 km and d) 14 km. Contoured streamlines/circulation pattern ψ (red lines) are plotted on top of the bottom topography (black lines). The blue arrows are the geostrophic velocity vectors and a velocity scale is given in the upper right corner. Note that c) has a larger velocity scale.

Figure 4



The WSC connects easier to the Isfjorden Trough than anywhere else along the shelf because the Isfjorden Trough is deeper than the other troughs. When increasing a in the model runs, Figure 4 shows that the AW finds new paths into the trough toward Isfjorden (illustrated in Figure 5). Hence, some of the AW in the barotropic WSC branch is forced to circulate in these troughs. This represents a longer and slower route of AW towards the Arctic Ocean as illustrated with a pink arrow in Figure 1, and we name this flow the **Spitsbergen Trough Current (STC)**.

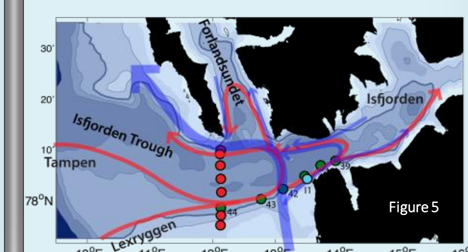
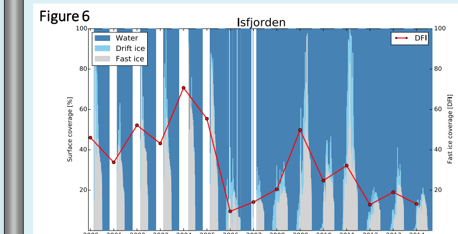


Figure 5

Effects of Atlantic Water Intrusion

Passages of strong cyclones in the Fram Strait pile up water along the West Spitsbergen coastline that modulates the SSH-driven barotropic WSC branch at the shelf break. This sets up topographically guided currents into the troughs indenting the WSS. Here, this flow is named the **Spitsbergen Trough Current (STC)**. The position of the WSC over the shelf break is controlling the STC. The maximum current of the WSC is on average found over the 500 m isobath. If the maximum current of the WSC increases and the WSC is forced eastward over the shelf on the order of 2 km, AW starts to flow onto the shelf in the STC and the warm and saline water is guided into troughs and towards the fjords along the west coast of Spitsbergen, as demonstrated by our simple shelf circulation model. Since atmospheric forcing of the WSS is strongest during the winter months, the intrusion of AW is often largest during these months and plays a decisive role for the sea ice cover in fjords and shelf areas. Hence, there is a significant link between the wind forced circulation on the WSS (Ekman transport and pumping), the observed wintertime intrusion of AW on the WSS and into the fjords, and the lack of sea ice around Svalbard. In 2006, a distinct reduction in the sea ice cover took place in all the fjords along the West Spitsbergen. Satellite data time series from Isfjorden (Figure 6) show a clear reduction in 'Days of Fast Ice' from 2006 that has persisted in the following years.

Figure 6



Relevant references

- Nilsen F., Skogseth R., Vaardal-Lunde J. & Inall M.E. (2016), A simple shelf circulation model: intrusion of Atlantic Water on the West Spitsbergen Shelf. Journal of Physical Oceanography 46, 1209–1230.
- Muckenhuber S., Nilsen F., Korosov A. & Sandven S. (2016), Sea ice cover in Isfjorden and Hornsund, Svalbard (2000 2014) from remote sensing data. The Cryosphere 10, 149–158.
- Teigen, S. H., Nilsen, F., and Gjevik, B. (2010), Barotropic instability in the West Spitsbergen Current. J. Geophys. Res., 115, C07016, doi:10.1029/2009JC005996.
- Fraser, N. J., Skogseth, R., Nilsen, F. & Inall, M. E. (2018), Circulation and exchange in a broad Arctic fjord using glider-based observations, Polar Research, 37:1, 1485417, DOI: 10.1080/17518369.2018.1485417.

Photography encouraged

UNIS
Post Box 156
9171 Longyearbyen
Norway
+47 79023300
+47 79023338
frank.nilsen@unis.no
www.unis.no