Barents Sea atlantification induces bathymetric, frontal constraint on winter ice extent

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Motivations:
- The Barents Sea is the region where the greatest decline in winter Arctic sea ice extent has been observed since 1979(1).
- The Barents Sea has been getting warmer under the increase in Atlantic influence(2). This has caused the reduction in winter sea ice area(3).
- BSW produces 50 – 80 % of Arctic Intermediate Water which contributes to Atlantic Meridional Overturning Circulation (AMOC)(4).
- Changes in winter sea ice south of the Polar Front will affect the properties of BSW.
- Predictability of sea ice affects shipping and naval deployments. Water column structure affects submarine deployments.

Methods:
- The gradient in OSTIA SST is calculated in both the latitude and longitude directions, then the magnitude of the two components is computed.
- The sea ice edge is defined by the point that the sea ice fraction in the OSTIA dataset drops below 15%.
- Empirical orthogonal functions (EOF) were calculated using the singular value decomposition (SVD) method for monthly mean SST data over the Barents Sea. The data was prepared for this analysis by removing data points close to land, de-seasoned, de-trended and had the standard deviation from the time series at each grid point removed.
- Potential density, thermal expansion (ocean) and haline contraction (b–ocean) have been calculated on the MIMOC and EN4 dataset using TEOS-10.

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<thead>
<tr>
<th></th>
<th>Atlantic Water</th>
<th>Barents Sea Water</th>
<th>Arctic Water</th>
</tr>
</thead>
<tbody>
<tr>
<td>T (°C)</td>
<td>7 – 3</td>
<td>2 – 0</td>
<td>0 – 2</td>
</tr>
<tr>
<td>S (‰)</td>
<td>35.0</td>
<td>34.7</td>
<td>34.7</td>
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<tr>
<td>σ (g/cm³)</td>
<td>27.85</td>
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Variability in SST:
- Primary Component 1 (PC 1, 56.9% of variability) has a large spatial extent over the Barents Sea (Figure 2). This is significantly correlated with AW at 50 – 200 m in the Kola section in the Barents Sea, surface air temperature over the Barents Sea (SAT) and sea ice concentration (SIC) in the Barents Sea.
- PC 2 (16.6% of variability) shows the east and west Barents Sea vary out of phase. This is significantly correlated with SAT over the Norwegian Sea when SAT, AW temperature at 50 – 200 m in the Fugloya-Bear Island section, and SIC in the Kara Sea.
- PC 3 (9.0% of variability) shows the north and south vary out of phase. This is significantly correlated with SAT over the south eastern Barents Sea, SIC in the south eastern Barents Sea, and sea level pressure over Novaya Zemlya.

Polar Front:
- SST variability is dominated by the seasonal cycle (σ = 1.76 °C). The interannual signal amplitude is 0.33 °C.
- The Polar Front forms the barrier between Arctic and BSW and is a salinity-driven feature (Figure 3).
- As AW is transformed into BSW it is cooled by atmospheric heat loss and freshened by sea ice melt water. Figure 4 shows the area extent over which seasonal heat loss that takes place and Figure 2 shows homogeneity of the AW meaning the heat loss occurs throughout the water column.
- The Polar Front does not move north with the sea ice edge in summer and stays at 76.5° N (Figure 4).

Atlantification of BSW:
- Before 2005 sea ice crosses the Polar Front; after 2005 it does not (Figure 5). The change in sea ice regime responds to an intensification of the Polar Front temperature gradient and increased AW temperature (atlantification).
- The Polar Front defines the surface area for interaction between BSW, sea ice and the atmosphere before it sinks below AW. The constraint on sea ice post-2005 reduces the freshwater input to BSW, a potential 0.043 freshening.
- A significant 0.056 increase in BSW salinity is observed in EN4 data as well as a significant 0.38 °C increase resulting in a significant density increase of 0.05 kg m⁻³.

Figure 5: (a) Magnitude of the meridional gradient in zonally averaged SST for the region in Figure 1. The magnitude is normalized on a daily basis by its standard deviation to show the changes in the position of the front over time but note that changes in intensity over time should only be deduced from (c) Dashed line shows the Polar Front, (b) salinity extent for the same zonally averaged region. (c) Each with 1 year running mean: mean SST gradient between 76.3° N and 76.7° N for (a) before normalization, Atlantic Water (AW) temperature from Kola section. (d) Barents Sea Water (BSW) temperature and salinity between 100 and 250 m from EN4 data for the region in Figure 1.

Conclusions:
- The Polar Front is a stationary salinity driven feature independent of the sea ice edge. Temperature is dependent on the location of this front.
- Due to increased AW temperature in the Barents Sea the frontal temperature gradient has strengthened, forcing a constraint on sea ice post-2005 which was exported south of the Polar Front in pre-2005 winters.
- The loss of seasonal sea ice melt water south of the Polar Front has caused the salinity, temperature and density of BSW (a water mass that features in AMOC) to increase.

References:

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