The North Atlantic’s response to Greenland melting: Role of atmospheric feedbacks and mesoscale ocean dynamics

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Introduction
Will enhanced melting of the Greenland ice sheet under global warming lead to a considerable weakening of the Atlantic Meridional Overturning Circulation (AMOC)? Greenland meltwater is considered to be a major player in past rapid climate transitions. Release of large amounts of freshwater into the subpolar North Atlantic can affect the strength of the Atlantic Meridional Overturning Circulation (AMOC)—and thus global climate—when getting entrained into the water masses of the deep convection regions. For the entrainment mesoscale ocean dynamics are likely very important. These are poorly resolved in climate models typically used for 21st century projections or paleo simulations however.

To isolate the impact of Greenland runoff as well as the effects of mesoscale eddies and air-sea interaction, we ran a suite of coupled pre-industrial control and ocean-only hindcast simulations with prescribed enhanced runoff at rates of 0.05 Sv and 0.1 Sv over 100 years.

Summary & Conclusion
With 2 Sv and 6 Sv the standard climate model shows the largest range in AMOC weakening for the two Greenland runoff scenarios. Resolving the mesoscale reduces major biases related to the North Atlantic. Current, but 1/10° is not sufficient to simulate the full range of eddy mixing in the deep convection regions. The eddying simulations yield very similar responses at 4.5 Sv however. The same holds for the ocean-only experiments.

The response of the AMOC to Greenland meltwater depends on the sensitivity of the AMOC, i.e. how close the model AMOC is to its bifurcation point. A generally stronger circulation—as in the nested simulations—does not guarantee a more stable AMOC. To better understand AMOC sensitivity, we must ask: where is deep water actually formed and does Greenland meltwater interfere with this process, does it put a lid on the ocean or rather generally dilute denser water masses.

AMOC response to enhanced Greenland runoff

Is the standard climate model the outlier?

Nesting: reduced North Atlantic cold bias results in greater ocean heat loss and less precipitation. Coupling: less heat loss and slightly enhanced precipitation over deep convection regions.

Model mean states:

<table>
<thead>
<tr>
<th>Model</th>
<th>AMOC (Sv)</th>
<th>SPG (Sv/°C)</th>
<th>FWC (Sv)</th>
<th>MLD (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>coupled</td>
<td>17.7 ± 1.0</td>
<td>42.4 ± 1.95</td>
<td>2744 ± 2.1</td>
<td>1340 ± 420</td>
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<tr>
<td>coupled nested</td>
<td>19.8 ± 1.2</td>
<td>57.0 ± 2.62</td>
<td>2734 ± 0.2</td>
<td>1280 ± 330</td>
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<tr>
<td>ocean-only</td>
<td>12.7 ± 0.8</td>
<td>33.0 ± 1.52</td>
<td>2742 ± 1.6</td>
<td>920 ± 370</td>
</tr>
<tr>
<td>ocean-only nested</td>
<td>14.1 ± 1.0</td>
<td>46.8 ± 2.04</td>
<td>2735 ± 0.6</td>
<td>1290 ± 420</td>
</tr>
</tbody>
</table>

AMOC: maximum of Atlantic zonal mean overturning stream function at 26.5° N
SPG: subpolar gyre minimum of horizontal stream function at N. Atl. area within -20 Sv contour
FWC: freshwater content of SPG excl. shelf areas
MLD: March mean mixed layer depth in the Labrador Sea exceeding 500 m

Effect on surface fluxes

Explicitly resolved mesoscale eddies mix the meltwater much more efficiently into the subtropical gyre.

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