A model-based assessment of the climate impacts of the observed AMOC weakening and their sensitivity to model resolution

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Motivation

Observations from the RAPID array show an **AMOC weakening of nearly 2 Sv** since 2004, yet **isolating its climate impacts remains difficult** due to confounding anthropogenic trends. Studies of AMOC-driven impacts typically rely on freshwater-forced perturbation experiments, but their idealised design and predominant use of low-resolution models limits their relevance to the recent historical period.

We address this by analysing **control simulations from HighResMIP and EERIE** models, selecting periods of RAPID-comparable AMOC decline and comparing the associated atmospheric and precipitation composites.

Models

We use data from 5 **eddy-rich** models (~8 km ocean) and 4 **low resolution** models (~25-100 km ocean). Their atmospheric resolution ranges from 10 km to 50 km for the eddy-rich models and from 100 km to 250 km for the low resolution models. The selected models are those in which the full-period AMOC trend did not exceed its standard deviation.

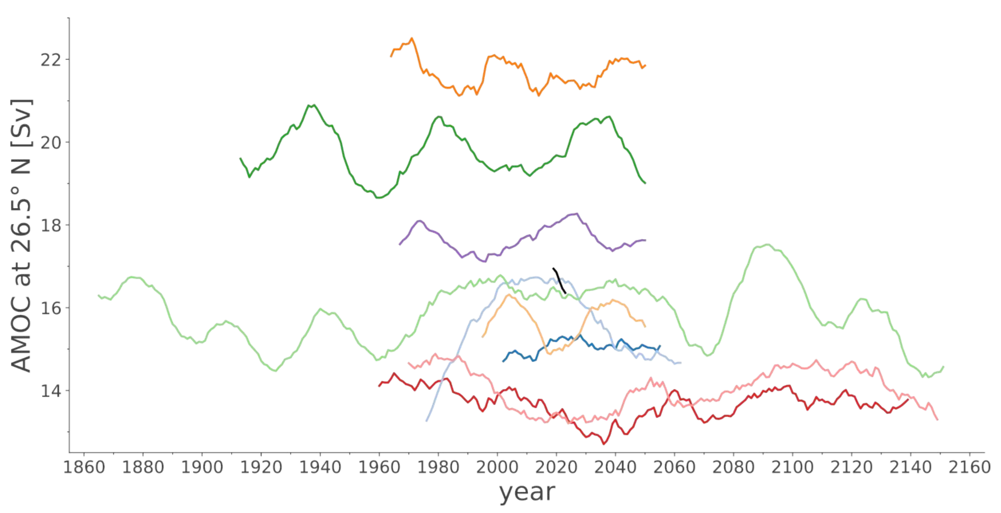

Figure 1. Time series of the AMOC at 26° N for the control experiments (colors) and the RAPID observations (black). The annual averages have been smothed with a 15-year moving average.

Challenges

- An important caveat is that it can be challenging to unravel the drivers from the consequences of the AMOC weakenings in the composite plots.
- There are few severe weakening events, with limited model representation, which can bias the results
- Some events may overlap, which may provoke the accounted signals not to be independent

Results

Eddy-rich vs low resolution

We select the events where the 19-year trends are between -0.75 and -1.25 Sv per decade, in line with the RAPID trends. We group the models between the eddy-rich and low resolution and study the response of surface temperature, precipitation, and sea level pressure for December-January-February (DJF) and June-July-August (JJA).

The results show **quantitatively and qualitatively different responses** in low resolution than in eddy-rich models. There is a general cooling across the North Atlantic and surroundings for the low resolution models, not including the Gulf Stream region, while in the eddy-rich models the cooling is limited to the eastern part of the North Atlantic. Precipitation signals are stronger east of the Maritime Continent in DJF, especially for the eddy-rich models; a southward shift of the ITCZ is also hinted in JJA for both resolutions. Both resolutions also show a strengthening of the southern annular mode in DJF, stronger for the eddy-rich ensemble, which also shows a widespread blocking system over Eurasia. The sea level pressure response in JJA is weaker and noisier.

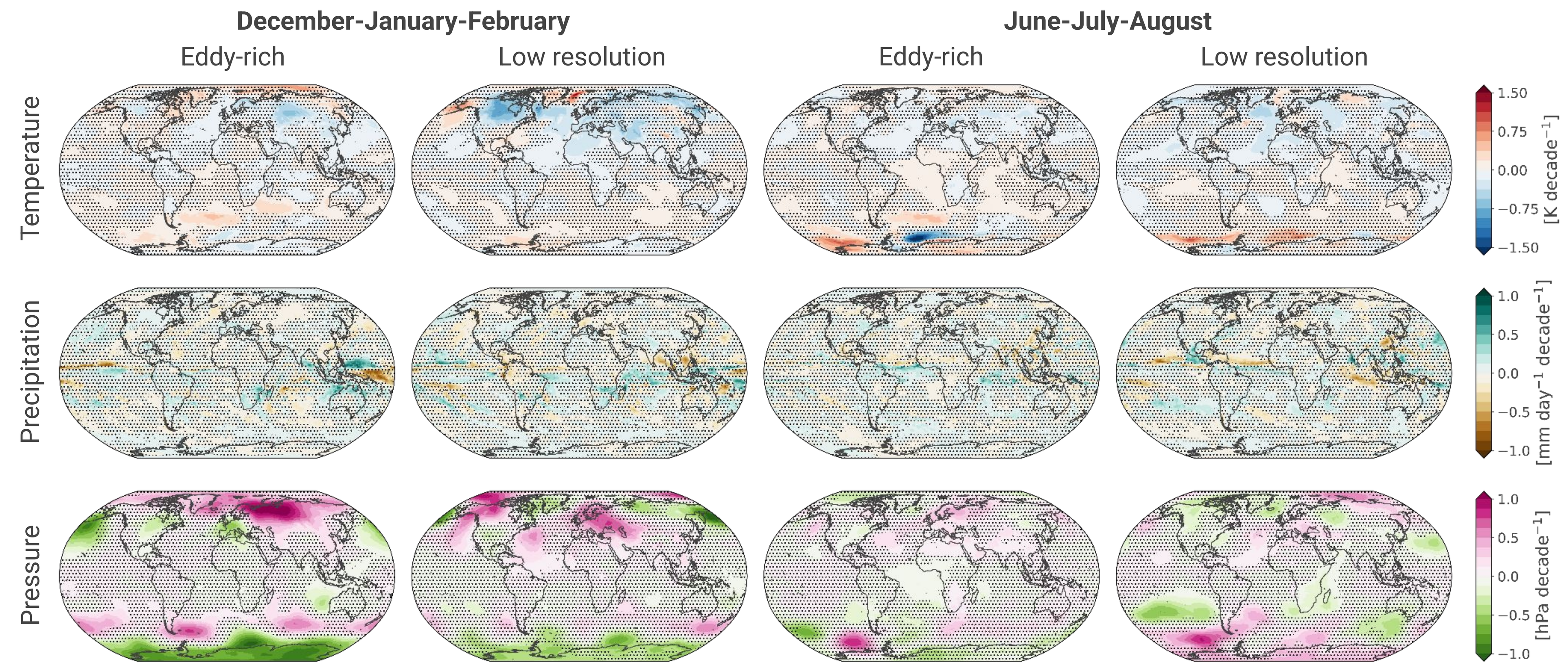

Figure 2. Composite analysis for 19-year trends of surface temperature (first row), precipitation (second row) and sea level pressure (third row) for AMOC 19-year trends between -0.75 Sv and -1.25 Sv; for DJF (first and second columns) and JJA (third and fourth columns); for eddy-rich (first and third columns) and low resolution (second and fourth columns) models. Significance is computed with a bootstrap method, dots mask the non-significant regions.

Moderate vs Strong AMOC weakening

We also extent the analysis to compare the impacts of moderate (0.75 to 1.25 Sv) vs strong (>1.25 Sv) weakenings of the AMOC, in all the 19-year windows available in the eddy-rich models. These strong events are only present in HadGEM models (HadGEM-GC3.1-HH & HadGEM-GC5E-HH).

The results show generally **stronger and wider areas of significant responses to the strong AMOC weakenings**, even if the number of events is comparatively smaller. Overall, the spatial pattern of the responses is similar in both ensembles, which suggests that they have the same dynamical origin. We note, however, that the stronger responses of the winter atmospheric circulation over Eurasia following the strong AMOC weakenings, lead to a much strong cooling over Scandinavia and a precipitation reduction over the Mediterranean, which are not reproduced in the moderate cases.

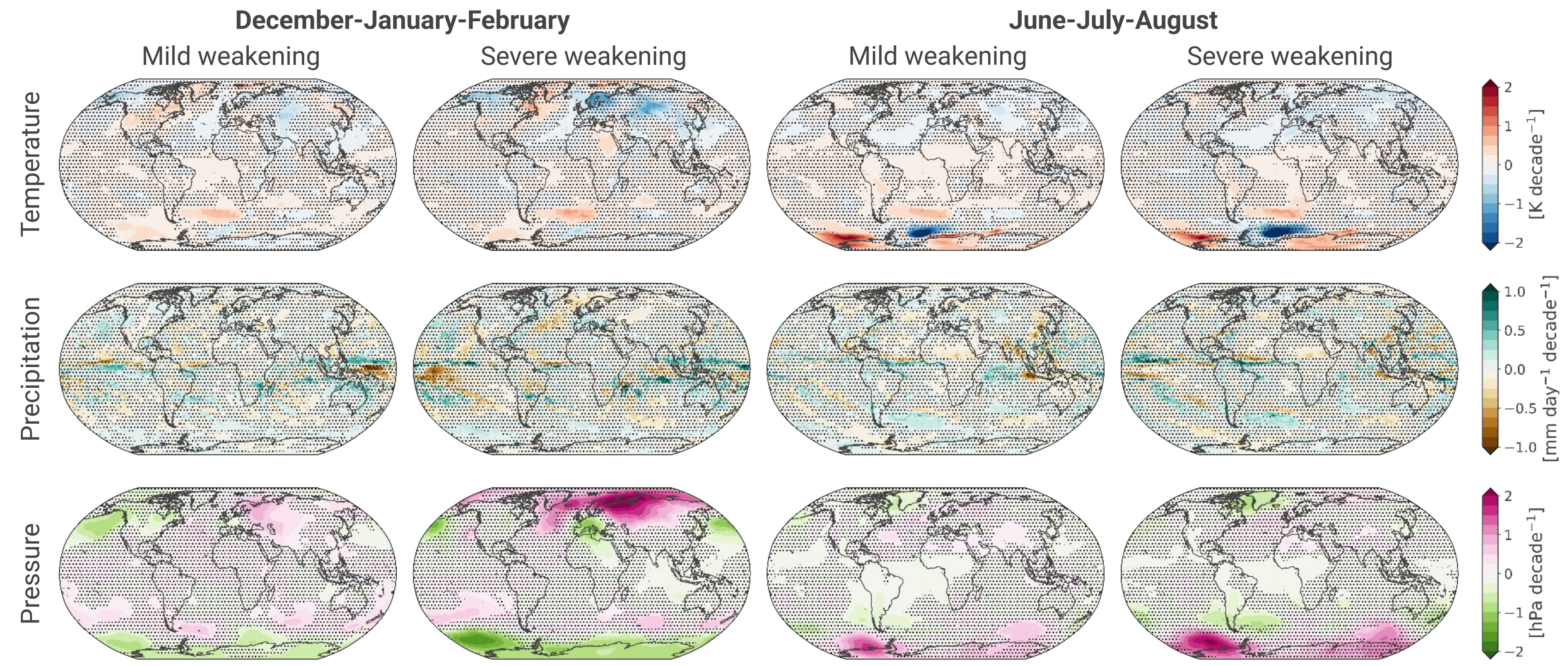

Figure 3. Composite analysis for 19-year trends of surface temperature (first row), precipitation (second row) and sea level pressure (third row) for AMOC 19-year trends between -1.25 Sv and -1.75 Sv (first and third columns) and between -0.75 Sv and -1.25 Sv (second and fourth columns); for DJF (first and second columns) and JJA (third and fourth columns); for HadGEM-GC3.1-HH and HadGEM-GC5E-HH models. Significance is computed with a bootstrap method, dots mask the non-significant regions.

Discussion

Some signals are resolution dependent, while others are only significative with severe weakening. Moreover is it important to separate the drivers from the impacts of the AMOC weakening. For example, the eastern SPNA warming cold be driver of the AMOC slowdown, as it may contribute to reduction in meridional temperature gradient and feshening due to sea ice melting.

Further analysis is needed to conclude wether some signals are directly related to the AMOC slowdown, such as the changes in the Philippine Sea.

Next steps

- Include more models in the analysis
- Produce composites with lags
- Study coherence between models
- Open to any other suggestions!

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North Atlantic response to a quasi-realistic Greenland meltwater forcing in eddy-rich EC-Earth3P-VHR hosing simulations

Today, 17:30h at room 0.31/32

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