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TipESM – Exploring Tipping Points and their Impacts Using Earth System Models

The Danish Meteorological Institute

Linking surface air temperature changes to a slowing AMOC in a multimodel approach

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1. Abstract

The **Atlantic Meridional Overturning Circulation** (AMOC) is a key regulator of global climate, and its potential slowdown due to anthropogenic forcing poses significant risks to climate stability. This study analyzes global and regional surface air temperature (SAT) changes associated with AMOC variability using an ensemble of CMIP6 climate models. We investigate regional warming patterns over the Atlantic and Arctic in relation to AMOC fluctuations and examine how these patterns evolve under different global warming levels. While our analysis identifies correlations between AMOC variability and SAT changes, it does not establish concrete early-warning signals or tipping points but lays the groundwork for future research. Future work will focus on assessing potential **precursors of AMOC weakening** through detailed lagged correlation and trend analyses.

2. Method and Data

By analyzing historical simulations (1850-2014) and simulations across diverse scenarios (2015-2100 or 2300), we investigate the relationship between SAT changes and AMOC variability. Our objective is to examine whether specific regional warming patterns are consistently associated with AMOC weakening across different climate models. First results are presented for annual mean maximum AMOC at 26°N and global and regional mean SAT. The two selected regions are the Nordic Seas (NS) and the North Atlantic (NA), described in Figure 1.

Nordic Seas = longitude [-20W ; 10E], latitude [65N ; 77N] / North Atlantic = longitude [-70W ; -10W], latitude [30N ; 60N]

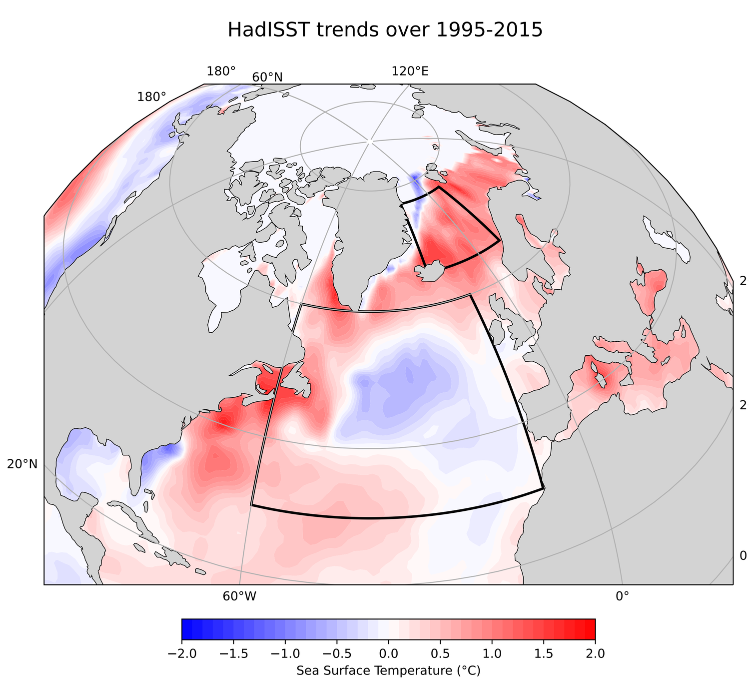

Figure 1: Sea surface temperature trends (HadISST product) over the period 1995-2005. Black trapezes represent the regions selected in the study

All available CMIP6 historical simulations were collected if the SSP245 or 585 scenarios were available for the same member for SAT and AMOC. Reanalysis ERA5 and RAPID observations are compared to the models over 2005-2021.

3. Results

Figure 2 presents a scatter plot illustrating the relationship between global annual mean SAT and maximum AMOC at 26°N for corresponding CMIP6 model members. Our results confirm an overall weakening of AMOC associated with warming, with differences in sensitivity across climate models. Notably, non-NEMO models (GFDL-ESM4 and MRI-ESM2-0) exhibit a steeper decline in AMOC per degree of warming, while the NEMO-family models show a more moderate response, potentially reflecting structural or parameterization differences across modeling frameworks, leading to distinct model sensitivity to warming.

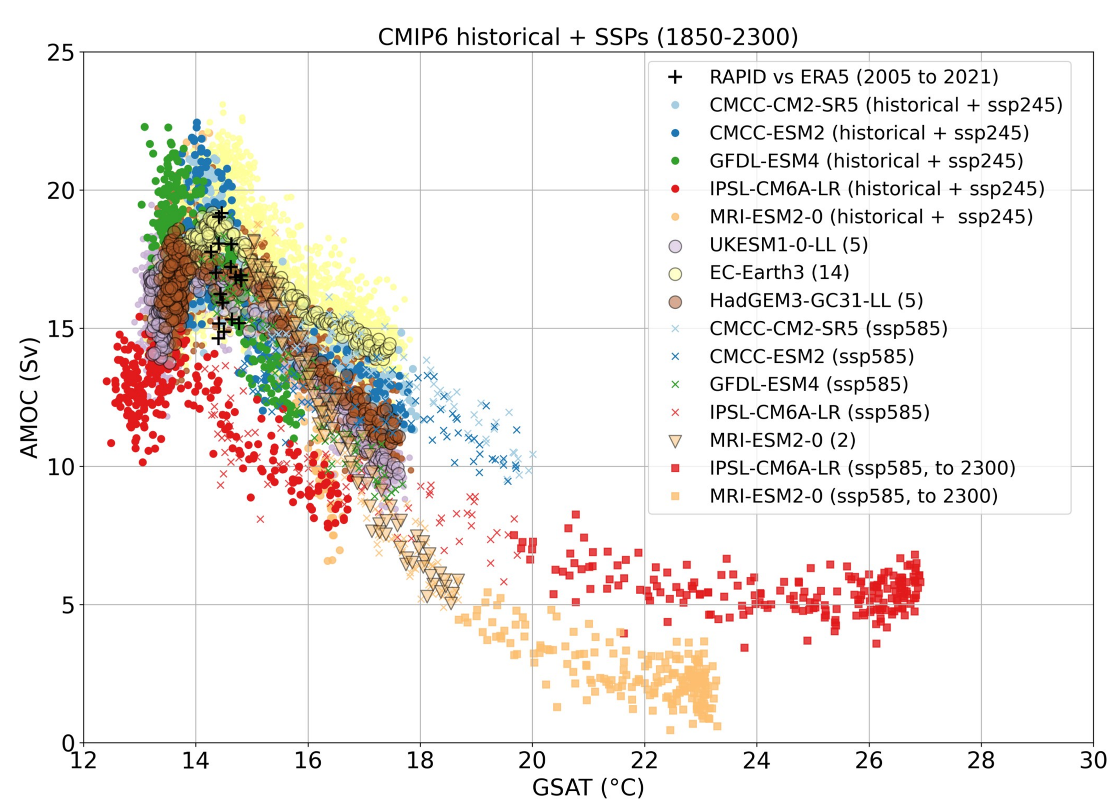

Figure 2: Scatter plot where each point represents one year of data, showing the relationship between annual mean GSAT and max AMOC at 26°N for corresponding CMIP6 model members.

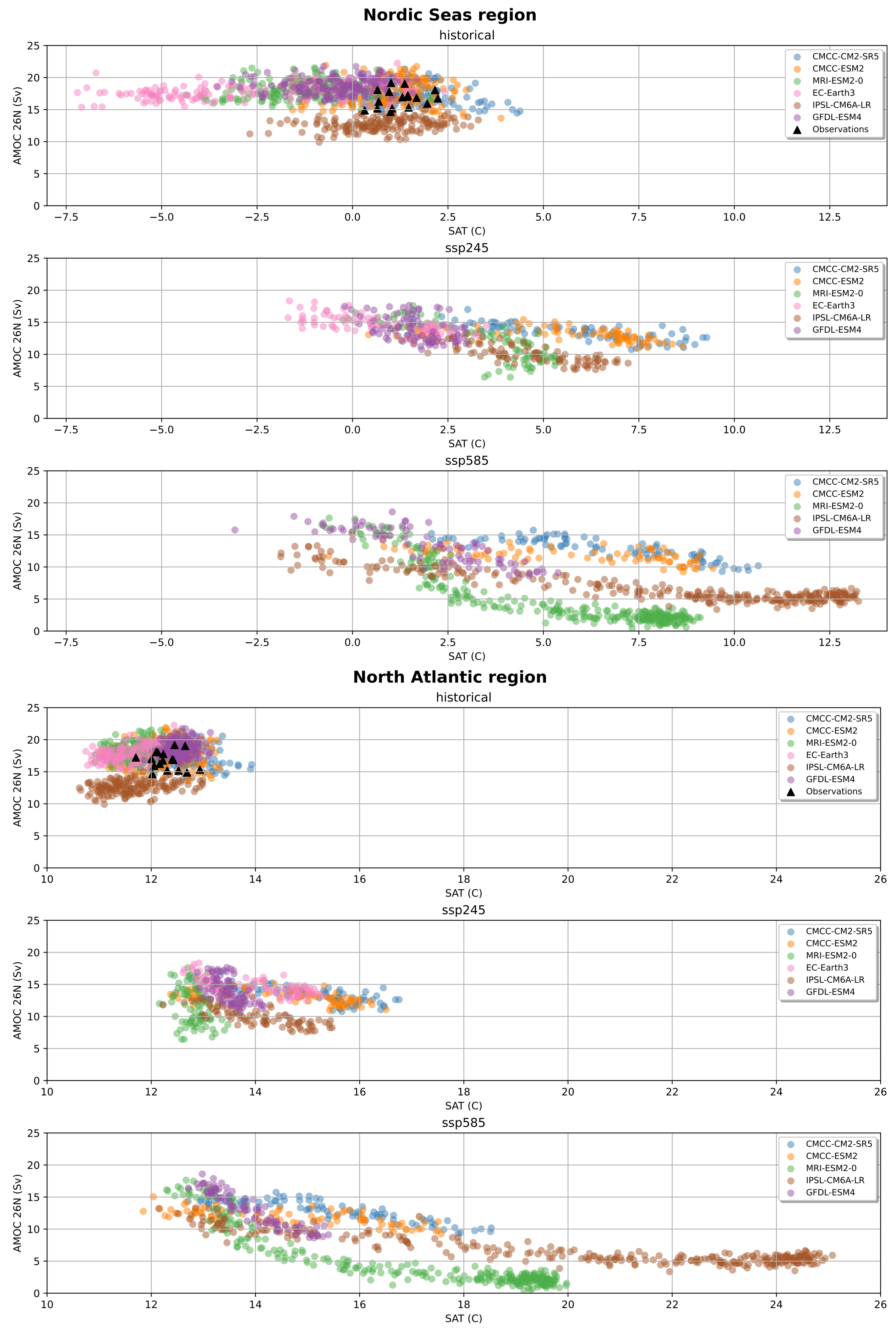

Figure 3: Scatter plot of the regional SAT and AMOC for corresponding CMIP6 model members for historical and future scenarios (SSP245 and SSP585). One member only is used by model.

Regional SAT-AMOC relationships (Figure 3) reveal substantial variability in NS and NA regions. In the Nordic Seas, SAT trends show a large spread across models, making it challenging to establish a consistent precursors to AMOC weakening. NA region exhibits a clearer link between AMOC variability and SAT, suggesting its potential as a more reliable region for further investigation. Model availability is a limitation, as only a few CMIP6 members provide both AMOC and SAT data, restricting the robustness of inter-model comparisons. The IPSL-CM6-LR and MRI-ESM2-0 models are the only ones for which simulations are provided through 2300 for the SSP585 scenario. In IPSL-CM6-LR, the AMOC stabilizes at a strength of 5 Sv, with surface air temperature (SAT) reaching 25°C in the NA, while in MRI-ESM2-0, SAT never exceeds 20°C and the AMOC nearly shuts down. Warming in the NS is also more limited in the MRI-ESM2-0 model.

4. Conclusions and Forthcoming Research

- Our analysis confirms that AMOC weakening is associated with distinct SAT patterns, but the strength of this relationship varies between models and regions.
- NA appears to be a promising region for identifying early-warning signals, whereas the Nordic Seas show high model spread. The analyse will be expanded to additional regions.
- Structural differences between climate models influence their sensitivity to AMOC changes, highlighting the need for model intercomparison studies.
- Our current work does not establish concrete early-warning indicators or tipping points for AMOC weakening. Instead, we focus on correlations between SAT and AMOC variability.
- Future work will include lagged correlations and trend analysis to assess potential lead-lag relationships between SAT anomalies and AMOC slowdowns, potentially leading to the identification of early-warning indicators.