# No critical slowing down in the Atlantic Overturning Circulation in historical CMIP6 simulations

Maya Ben-Yami[1,2], Lana Blaschke[1,2], Sebastian Bathiany[1,2], Niklas Boers[1,2,4]

[1]Potsdam Institute for Climate Impact Research, Potsdam, Germany; [2]Earth System Modelling, School of Engineering and Design, Technical University of Munich, Munich, Germany; [3]Department of Mathematics and Global Systems Institute, University of Exeter, Exeter, UK

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EGU abstract

## Motivation

Previous studies have found significant signs of **Critical Slowing Down (CSD)** in sub-polar North Atlantic (SPNA) sea-surface temperatures (SSTs), including in **the AMOC SST Index (ASSTI)** [Boers 2021, Ben-Yami et al. 2023]. The Atlantic Meridional Overturning Circulation (AMOC) is strongly connected to these SSTs through ocean heat transport and is theorized to have the ability to tip to a weak state due to global warming. A loss of stability in the AMOC could thus explain the observed CSD. However, **the destabilization of the AMOC, as well as the robustness of the ASSTI for detecting AMOC destabilization, are not certain**.

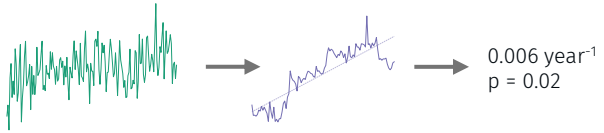
## Methods

We look for CSD in **historical CMIP6 AMOC timeseries**, both in the ASSTI and in the AMOC streamfunction strength.

ASSTI = Sub-polar gyre SSTs – global mean SSTs

* Based on Caesar et al. 2018

26 CMIP6 models' historical runs – 133 ensemble members – 399 time series




**Time series**
- Streamfunction at 35°N
- Streamfunction at 26.5°N
- ASSTI

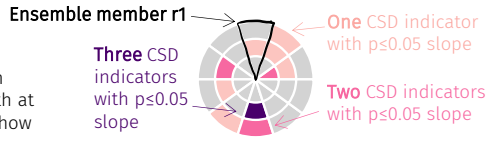
**CSD indicator**
- restoring rate
- AR(1)
- variance

**Slope of CSD indicator**
P-value using Fourier surrogates

As we have a large number of time series, we need to consider the combined significance of multiple CSD indicator slopes. By construction, for each time series there is a 5% chance that it will have p≤0.05. We thus use the probability mass function of the binomial distribution to calculate statistical significances for groups of time series and for individual models.

## Results

For each model we represent the ensemble members with pie slices divided into layers. The layers from inside out represent: ASSTI, strength at 35N, strength at 26N. The colours show the number of CSD indicators with p≤0.05 slope

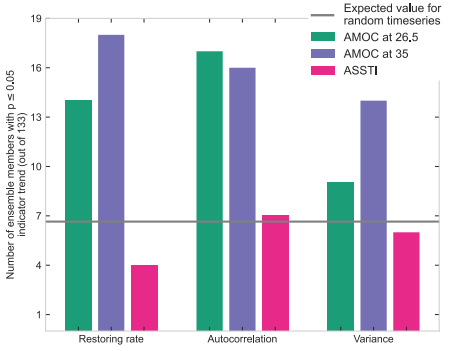



The large pie chart plot on the right shows the number of time series with p≤0.05 slopes for each ensemble member. It is visually clear that **there are not many p≤0.05 slopes**, and those that exists are **unevenly distributed** amongst the models. We thus view the significance of CSD signs in two ways: for all the CMIP6 models, and for each model individually.

### Overall

The bar plot shows the number of increasing indicator slopes with p≤0.05. The grey line is at the expected value, 133*0.05 = 6.65

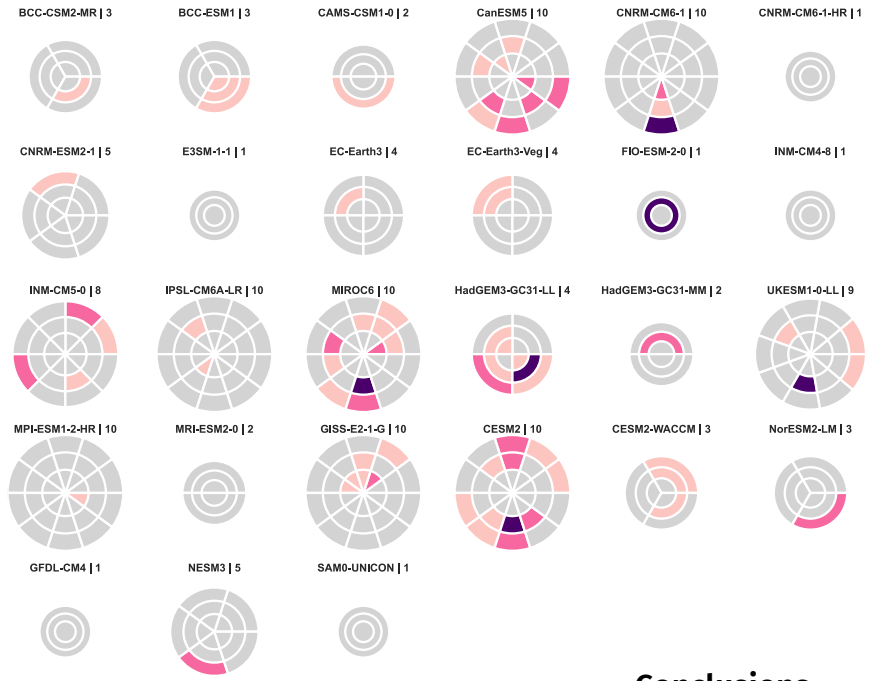
→ **For the ASSTI the results are not significant.**




### Individual models

When considering how likely a model outcome is to occur amongst 27 models, we get only **4 models with significant probabilities**. The table shows the probabilities for these models, noting which indicator and time series it applies to

| | λ of AMOC@35°N | AR1 of AMOC@35°N | AR1 of AMOC@26.5°N |
|---|---|---|---|
| CanESM5 | 2.57e-02 | | |
| CESM2 | 2.57e-02 | | 2.57e-02 |
| HadGEM3-GC31-LL | | 1.27e-02 | |
| MIROC6 | | 2.57e-02 | |




## Conclusions

**CMIP6 CSD**
- Overall, **the historical AMOC in CMIP6 is not losing stability**
- The most likely explanation for significant CSD in some models is that the AMOC there is only beginning to lose stability, and may be further away from the tipping point than the real-world AMOC

**ASSTI**
- No CMIP6 model shows the same significant increase in the ASSTI CSD indicators that the observational ASSTI has
- As there is no overall significant sign of CSD in either the ASSTI or the AMOC streamfunction strengths, we can conclude that **the ASSTI is not prone to "physical false positives"**

If we assume that any non-AMOC related processes that could cause ASSTI CSD are well represented in at least *some* CMIP6 models:

**→ observed CSD in the AMOC SST Index likely indicates that the real-world AMOC is losing stability**

Ben-Yami, M., Skiba, V., Bathiany, S. et al. Uncertainties in critical slowing down indicators of observation-based fingerprints of the Atlantic Overturning Circulation. Nat Commun 14, 8344 (2023). https://doi.org/10.1038/s41467-023-44046-9
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