nature portfolio

https://doi.org/10.1038/s41558-022-01342-4

Supplementary information

Natural variability has dominated Atlantic Meridional Overturning Circulation since 1900

In the format provided by the
authors and unedited

Supplementary information: Natural variability dominates Atlantic Meridional Overturning since 1900

Mojib Latif*[1, 2], Jing Sun*[1], Martin Visbeck[1, 2], and M. Hadi Bordbar[3]

[1]GEOMAR Helmholtz Centre for Ocean Research Kiel, Kiel, Germany

[2]Christian-Albrechts University Kiel, Kiel Germany

[3]Leibniz-Institut für Ostseeforschung Warnemünde – IOW, Rostock, Germany

*Correspondence to mlatif@geomar.de; jsun@geomar.de

Supplementary text

In order to investigate the sensitivity of the results to the statistical method, we additionally employed two other methods to identify the externally forced signal in SST. Moreover, we investigated satellite-sea levels.

POP analysis

Principal Oscillation Pattern (POP) analysis is applied to the observed annual Atlantic SSTs 1900-2019 (Methods), which is a multivariate statistical technique designed to simultaneously inferring the characteristic spatial patterns and timescales of a vector time series [1]. The leading mode (POP1, Extended Data Fig. 5) accounting for 44.3% of the total Atlantic-SST variability, is a real mode and has an e-folding time of 10.7 years. POP1 is consistent with EOF1 (Fig. 2). The time series of POP1 (PC1) well follows the long-term evolution of the net effective radiative forcing (ERF, Methods), with a correlation coefficient of 0.86 (Extended Data Fig. 5a). The regression pattern upon PC1 exhibits positive anomalies over most of the global ocean, with the exception of the NAWH (Extended Data Fig. 5b). POP1 accounts for up to 80% of the SST variability in the subtropical Northwest Atlantic but hardly any in the NAWH. In the other regions of the Atlantic, the explained variances amount to at least 40%. The map of local regression coefficients upon PC1 reproduces in large parts the SST-trend pattern 1900-2019 (Extended Data Fig. 1a).

Signal-to-noise ratio maximizing EOF analysis

We also use the ensemble of historical simulations 1900-2014 with the CMIP6 models (Methods) to derive the externally forced SST variability. A signal-to-noise ratio (S/N) maximizing EOF analysis (Methods) is applied to the global SSTs from the models (Extended Data Fig. 6). The leading mode (S/N-EOF1) accounts for 64.3% of the total SST variance. The corresponding time series (S/N-PC1, Extended Data Fig. 6a) is governed by an accelerating upward trend with a strong rise after 1990. The map of local regression coefficients of the modeled SSTs upon S/N-PC1 (Extended Data Fig. 6b) is consistent with EOF1 (Fig. 2b) and POP1 (Extended Data Fig. 5b) and reproduces in large parts the observed pattern of linear SST trends 1900-2019 with significant warming over most regions except the NAWH (Extended Data Fig. 1a). S/N-PC1 accounts for a relatively large fraction of the SST variability over most of the global ocean, typically more than 40%. Explained variances are small in the NAWH region and over parts of the subpolar Southern Ocean, consistent with the results obtained from the EOF and POP analysis. When applying S/N-EOF analysis only to the model SSTs over the Atlantic domain, the leading mode explains less variance, suggesting that the externally forced signal can be estimated from the models more effectively by using global SSTs.

Sea level variability

Finally, satellite-sea levels have been analyzed. They feature a globally averaged rise of about 9 cm since 1993 but no trend in the NAWH. The leading EOF of sea-level variability 1993-2019 ($EOF1_{SL}$; Extended Data Fig. 1c, d) can be taken as the global-warming signal. When removing the global average to obtain dynamic sea level (DSL) linked to $EOF1_{SL}$, negative anomalies appear in the subpolar NA (Extended Data Fig. 1e). A sharp drop is observed prior to 2010 southeast of Greenland (box in Extended Data Fig. 1e, Extended Data Fig. 1f), concurrent with the AMOC-slowing event and reduction in heat transport at 26.5°N [2]. This event may be a manifestation of internal variability [3], without excluding it being part of a long-term trend.

References

[1] von Storch, H., Bürger, G., Schnur, R. & von Storch, J.-S. Principal Oscillation Patterns: A Review. *J. Clim.* **8**, 377–400 (1995). doi:10.1175/1520-0442(1995)008<0377:POPAR>2.0.CO;2

[2] Bryden et al. Reduction in Ocean Heat Transport at 26°N since 2008 Cools the Eastern Subpolar Gyre of the North Atlantic Ocean. *J. Clim.*, **33 (5)**: 1677–1689 (2020).

[3] Latif M et al. Decadal Atlantic Meridional Overturning Circulation slowing events in a climate model. *Clim. Dyn.*, **53**, 1111–1124 (2019).