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The effect of external forcing on meridional modes in the tropical Atlantic

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Variability in the tropical Atlantic region arises from coupled internal variability in the ocean and atmosphere and external forcing. Two major modes of interannual to decadal variability have been identified in the literature: a zonal mode related to sea surface temperature (SST) anomalies in the southeastern tropical Atlantic and a meridional mode related to an anomalous inter-hemispheric SST gradient associated with latitudinal shifts in the ITCZ location. However, from the limited length of the observational record it is difficult to identify variability on decadal to multi-decadal timescales, analyse how external forcing affects the variability and how remote regions affect the tropical Atlantic.

In our study, we use a 100-member ensemble of historical (1850-2005) model simulations with the Max Planck Institute for Meteorology Earth System Model (MPI-ESM) to identify patterns of coupled variability between precipitation, atmospheric circulation, and SST. The focus of our study is on anomalous meridional shifts of the oceanic ITCZ that are separated into different patterns using an EOF analysis. To investigate the effects of global warming on these patterns, we employ an additional ensemble of model simulations with stronger external forcing (1% CO_2-increase per year, same integration length as the historical simulations) with 68 ensemble members. For certain modes, we find a northward shift of the variability, which is not related to an ITCZ-shift in the mean state. A common finding for all modes is that the probability distributions of the explained variance change in response to strong external forcing.

The large ensembles allow us to do a statistically robust differentiation between the changes in variability that can be explained by internal variability and those that can be attributed to the external forcing.

To disentangle the mechanisms driving the interannual to decadal variability and its changes, we estimate the contributions of ocean dynamics and thermodynamic coupling between the ocean and atmosphere by incorporating idealised simulations into the analysis. We compare three types of experiments: the fully coupled simulations, full atmosphere simulations coupled to a mixed-layer ocean and full atmosphere simulations forced with prescribed SST.

By combining large ensemble simulations of a complex Earth system model and idealised simulations, this study provides an insight into the mechanisms of tropical Atlantic variability beyond what can be deduced from observations and thus contributes to a more profound understanding of the variability in the tropical Atlantic and its changes under global warming.