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Reconstructing extreme AMOC events through nudging of the ocean surface: A perfect model approach

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While the Atlantic Meridional Overturning Circulation (AMOC) is thought to be a crucial component of the North Atlantic climate and its predictability, past changes in its strength are challenging to quantify, and only limited information is available. In this study, we use a perfect model approach with the IPSL-CM5A-LR model to assess the performance of several surface nudging techniques in reconstructing the variability of the AMOC. Special attention is given to the reproducibility of an extreme positive AMOC peak from a preindustrial control simulation. Nudging includes standard relaxation techniques towards the sea surface temperature and salinity anomalies of this target control simulation, and/or the prescription of the wind-stress fields.
Surface nudging approaches using standard fixed restoring terms succeed in reproducing most of the target AMOC variability, including the timing of the extreme event, but systematically underestimate its amplitude. A detailed analysis of the AMOC variability mechanisms reveals that the underestimation of the extreme AMOC maximum comes from a deficit in the formation of the dense water masses in the main convection region, located south of Iceland in the model. This issue is largely corrected after introducing a novel surface nudging approach, which uses a varying restoring coefficient that is proportional to the simulated mixed layer depth, which, in essence, keeps the restoring time scale constant. This new technique substantially improves water mass transformation in the regions of convection, and in particular, the formation of the densest waters, which are key for the representation of the AMOC extreme. It is therefore a promising strategy that may help to better initialize the AMOC variability and other ocean features in the models, and thus improve decadal climate predictions. As this restoring technique only uses surface data, for which better and longer observations are available, it opens up opportunities for improved reconstructions of the AMOC over the last few decades.