Variabilitity and trend of the North Atlantic ocean circulation in past and future climate

Carl-Friedrich Schleussner

The Atlantic Meridional Overturning Circulation (AMOC) is one of the most prominent components of the global climate system and substantial changes in the AMOC are found to have global impacts. Hence, improving our understanding of the AMOC, its future evolution under anthropogenic global warming scenarios and its natural variability is crucial to understand the past and future of Earth's climate. Here I present probabilistic projections of the AMOC under different scenarios of future global warming based on two different approaches.

In the first approach I calibrated an emulator model to resemble the output of Atmosphere Ocean General Circulation Models (AOGCMs), whereas in the second approach, I applied a linear response ansatz with two free parameters to express the AMOC as a function of global mean temperature (GMT) change for an ensemble of AOGCMs. Although also the underlying AOGCM ensembles used for calibration are very different, I report similar results for both methods and the two lower emission representative concentration pathways (RCPs) of 11 % (10 %) median AMOC weakening under the RCP2.6 for the emulator (linear response) approach and of 22 % (20 %) under the RCP4.5. While the emulator approach is limited to the two lower pathways, the linear response approach allows for probabilistic projections also for high emission scenarios and I project a median weakening of 42 % under the RCP8.5 scenario with an upper limit of the likely range of 67 %.

I find the AMOC dynamic over the 21st century to be dominated by thermal forcing and by analyzing the AMOC in unperturbed climate simulations, I also find substantial changes in North Atlantic deep-ocean heat content related to multi-decadal AMOC variability. My findings compare well with observed changes over the last decade that showed an increase in deep-ocean heat uptake eventually leading to a reduced GMT warming trend. While most of the resulting density signal is compensated by salinity changes, a coupled North Atlantic deep-ocean density -AMOC mode is found to contribute to AMOC multi-decadal variability in at least three out of seven models in the ensemble investigated.

Variable subpolar convection has been identified as a source of multi-decadal variability in numerous model studies. By using the model of intermediate complexity Climber 3a, I find subpolar variability to be greatly enhanced by a multi-stability in the subpolar gyre (SPG). This multi-stability is directly related to convection in the gyre center. Increased convection leads to a cooling and densification of the SPG center and to a density-driven spin-up of the circulation. A strengthened SPG entrains more saline waters of subtropical origin stabilizing the convection. In such a strong-SPG state I find the AMOC to weaken by about 6.5 % in equilibrium, which leads to overall North Atlantic cooling.

I report such a SPG regime shift at the vicinity of the transition of the warm Medieval Climate Anomaly to the so-called Little Ice Age in last-millennium ensemble simulations with Climber 3a. Forcing decomposition reveals that a coupled sea-ice -ocean mechanism triggered by decadally-paced volcanic forcing could have led to this circulation switch and North Atlantic cooling as a consequence. I report very good agreement between my model simulations and high-resolution ocean sediment records from the central subpolar basin and the Nordic Seas and by applying time-series reversibility analysis, I find clear signatures of non-reversibility in both time series. Non-reversibility is an indicator for an underlying non-linearity, which gives additional support for the hypothesis that the Little Ice Age originated from a subpolar circulation regime shift.