University of Reading
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Scenario
DOCTORAL TRAINING PARTNERSHIP
UKRI Natural Environment Research Council

Understanding the diversity in the AMOC response to climate change

Lead Supervisor: Jonathan Gregory, University of Reading, NCAS, Department of Meteorology
Email: j.m.gregory@reading.ac.uk

Co-supervisors: Jon Robson and Tillys Petit, NCAS, University of Reading; Stephen Yeager, NCAR, USA.

The Atlantic Meridional Overturning Circulation (AMOC) is a system of currents in the North Atlantic which involves warm water flowing northward in the upper ocean, balanced by a southward ‘return’ flow of cold water at depth. Thus, the AMOC plays an important role in moving heat through the climate system, as well as in the transport of freshwater and carbon. Therefore, variations in the strength of the AMOC are thought to be important for global and regional climate, and can affect changes in surface temperature and precipitation, coastal sea level, and extreme weather such as hurricanes.

The main driver of the AMOC is the sinking of dense water in the North Atlantic. This happens because the northward-moving water becomes cooler and hence denser at higher latitudes. As the world warms due to human-made climate change, we expect the densification to become less effective. For example, a warmer atmosphere will lead to less cooling of the North Atlantic, while accelerated melting of the Greenland ice sheet will add fresh water to the North Atlantic, which will make it less dense by diluting its salinity.

Consequently, we expect the AMOC to weaken significantly in a warming world. Furthermore, we also know from paleo evidence that the AMOC has undergone rapid shutdowns at times of large climatic change. Given the important role that the AMOC plays in the climate, we expect AMOC weakening to significantly affect regional climate in many regions, including the UK and Europe. Therefore, we would like to know how the AMOC will respond to human-made climate change.

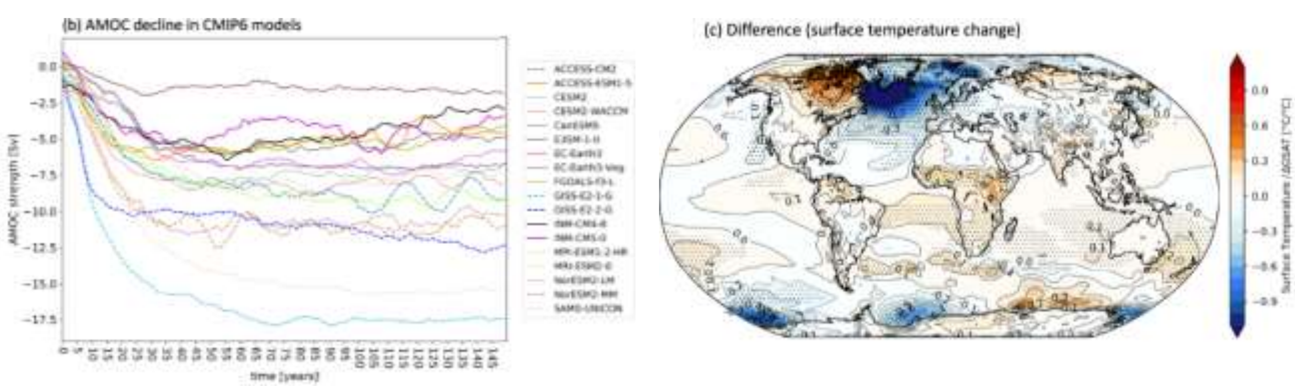

Figure 1. Left shows the AMOC response to an abrupt increase in atmospheric CO_2 in an ensemble of coupled climate models made for the sixth coupled model intercomparison project (CMIP6). Note the large diversity in the size of the response – note AMOC strength given in Sverdrups (Sv) where 1 Sv is equal to $1x10^6 m^3 s^{-2}$. Right shows the differences in surface temperature change between models with a large or small change in AMOC highlighting the uncertainty in projections over many regions. Figure taken from Bellomo et al, 2021.

However, the climate models that we currently use to predict AMOC give very different answers in how sensitive the AMOC is to climate change (figure 1 left). Furthermore, this diversity in AMOC response can have a large impact on surface temperature predictions (see figure 1 right). Some of these differences in AMOC come from how much each model warms in the North Atlantic, due to the sensitivity of the global climate is to CO2 increase, and the regional patterns of temperature and precipitation change. But uncertainties also arise from differences among models in how the AMOC reacts to the same changes in heat and freshwater fluxes over the ocean.

The aim of this project is to understand how these large uncertainties in predictions of AMOC change for coming decades and centuries. We will do this by exploring novel climate model experiments in which the changes in surface heat and freshwater fluxes over the ocean are prescribed to be the same in all models. This way, the only differences in the AMOC changes are due to how the models respond to these changes in fluxes, rather than differences in the fluxes themselves.

The student will use a surface water mass transformation to diagnose the primary drivers of the declining AMOC, and understand the differences between models. However, a major focus will be on characterizing and understanding what oceanic and atmospheric feedbacks shape the overall AMOC response. For example, if freshwater changes are important, they will explore questions of whether the amount of heat or salt is transported by the AMOC is a good predictor of the final AMOC response.

The outcome of the project will be further understanding of how to improve models or constrain projections. To that end the final phase of the project will likely involve either hypothesis testing by carrying out new model experiments or exploring the possibility of using observations to constrain projections. The student will have freedom to develop the trajectory of their research as their project progresses.

Training opportunities:
The student will gain hands on experience in analysing and understanding climate model projections as well as learning about the oceanic and atmospheric processes that drive the AMOC. At the University of Reading the student will join an active research group and will be able to present their work at focused collaborative workshops and international conferences. There will also be opportunities to attend relevant summer schools, such as the NCAS climate modelling summer school. A brief visit to co-supervisor Stephen Yeager at the National Center for Atmospheric Research in Boulder, Colorado, should also be possible.

Student profile:
We seek a highly motivated student who has a keen interest in the physics of the natural world, especially oceanography, and a good degree in physics, mathematics, computer science, or a closely related environmental or physical science.

References:

- Bellomo, K., Angeloni, M., Corti, S. *et al.* Future climate change shaped by inter-model differences in Atlantic meridional overturning circulation response. *Nat Commun* **12**, 3659 (2021). https://doi.org/10.1038/s41467-021-24015-w
- Couldrey, M. P., Gregory, J. M., Dong, X., Garuba, O., Haak, H., Hu, A., Hurlin, W. J., Jin, J., Jungclaus, J., Köhl, A., Liu, H., Ojha, S., Saenko, O. A., Savita, A., Suzuki, T., Yu, Z. and Zanna, L., in press. Greenhouse-gas forced changes in the Atlantic Meridional Overturning Circulation and related worldwide sea-level change. *Clim. Dyn.* 10.1007/s00382-022-06386-y

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