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The Effects of Surface Temperature and Salinity on Convection in the Atlantic Meridional Overturning Circulation

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1. INTRODUCTION

The Atlantic Meridional Overturning Circulation (AMOC) plays a crucial role in the global climate system by transporting heat, salt, and nutrients across ocean basins [1]. In the North Atlantic, there is an interconnected, three-dimensional circulation comprising of horizontal gyres and meridional overturning. In the northern regions, deep convection connects the surface to the ocean depth and provides the downwelling leg of the overturning circulation.

The deep convection is driven by heat loss to the atmosphere, however, salinity is theorised to affect the flow by pre-conditioning near-surface waters. There are questions remaining on how convection and circulation will adjust in a changing climate, in particular an amplifying water cycle that is expected to result in freshening in northern deep convection regions. There are inherent difficulties in capturing turbulence and convection in ocean observations, and in large-scale ocean models where they cannot be resolved and therefore must be parameterised. This highlights the need for systematic investigations, including high-resolution simulations, to better understand and predict AMOC behaviour in a changing climate.

2. APPROACH

In this study, we consider turbulence-resolving Direct Numerical Simulations (DNS) of a laboratory-scale model of the North Atlantic Ocean (see [2] for more information on this type of model). The DNS is a closed rectangular box, with no-slip and insulating boundaries for all sides except for the top. The top boundary is a free-slip to mimic the ocean surface, and with an imposed temperature profile (heating neat the equator and cooling near the pole) and salinity profile (freshening at the equator and near the pole, and salinification in the sup-tropical region). There is a Coriolis parameter included for the Earth's rotation.

There are several governing parameters in the system, with the most important being the global Rossby number (comparing flow velocity to the Coriolis parameter) and the density ratio (a measure of the strength of salinity to temperature forcing). We use dynamical similarity arguments to connect the laboratory-scale model to the large-scale ocean circulation, by matching the global Rossby number and the density ratio. All simulations are run for a long time to reach an equilibrated state, where the total buoyancy in equals the buoyancy out. The focus of our study is examining how the amplifying water cycle, which changes the freshwater forcing, and surface ocean warming influence deep convection and large-scale ocean circulation.

3. RESULTS

The simulations show a basin-scale flow, including near-surface gyres and an overturning circulation, which is similar to the AMOC. Processes such as a Gulf Stream-like jet, baroclinic eddies, deep convection and small-scale turbulence are all present in the laboratory-scale DNS. Both salinity and temperature are active tracers in the system and can drive flow. The control case, with density ratio set to the present ocean state, delivers an AMOC largely driven by surface temperature differences.

The temperature field shows a stratified boundary layer in the subtropical region (Figure 1 top panel; $0 < y/L < 0.5$) which is consistent with the thermocline in the ocean. The salinity field shows interesting double-diffusive effects, due to the heat diffusivity being notably stronger than salt diffusivity (Figure 1 lower panel). In particular, there is salt-finger convection occurring in the sub-tropical regions, however for the control case this does not drive a strong circulation compared to the overall temperature-driven AMOC cell.

The relative impacts of the water cycle and ocean warming are examined by increasing the strength of the surface salinity forcing (i.e. increasing the density ratio). We find that this amplifying water cycle slows down the AMOC by weakening deep convection and shifting the subtropical gyre southward. This slowdown reduces northward heat and salt transport, leading to warming and salinification in the northern subtropics and cooling in subpolar regions. Strengthening salt-finger convection further amplifies subtropical warming and salinification.

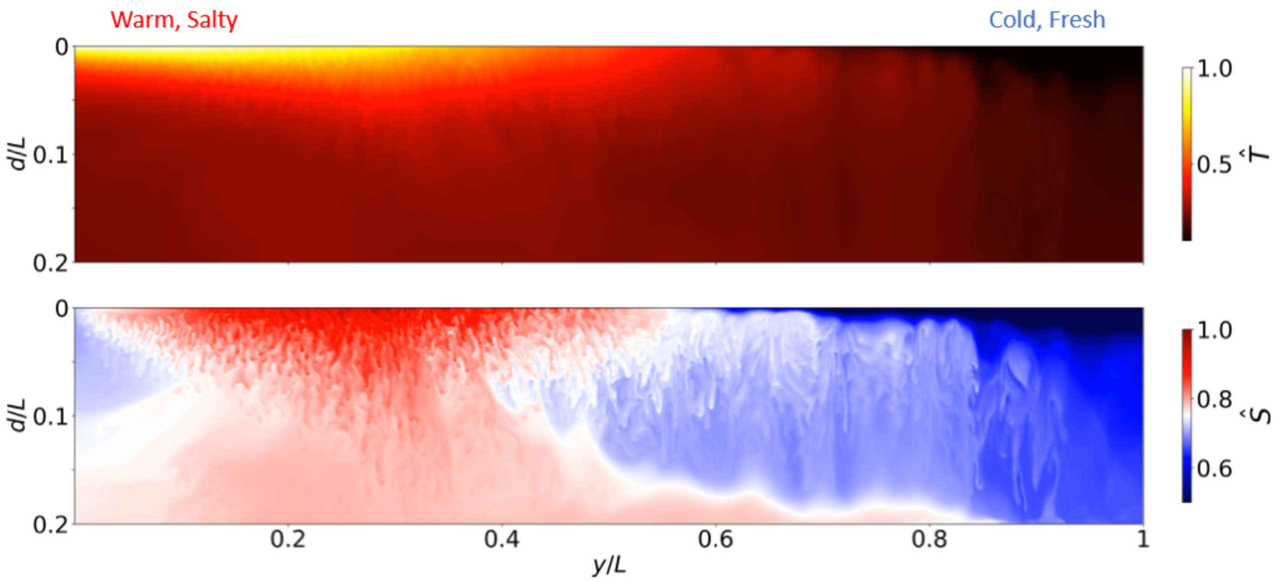

Figure 1. Snapshots of the Direct Numerical Simulations, where the slices are taken from the equator ($y/L = 0$) to the northern pole ($y/L = 1$). The top panel shows normalised temperature (T) and the lower panels shows normalised salinity (S). Both longitude (y) and depth (z) have been non-dimensionalised by the basin length (L).

4. CONCLUSIONS

Future climate projections indicate that the amplifying water cycle will become increasingly significant, and our results suggest that this will weaken deep convection and slow down the AMOC. These findings are helpful for improving large-scale ocean models and advancing our understanding of temperature-salinity feedback mechanisms in global ocean circulation. Future work will consider the influence of wind stress on the system.

REFERENCES

[1] Zhang, R., Sutton, R., Danabasoglu, G., Kwon, Y. O., Marsh, R., Yeager, S. G., ... & Little, C. M. (2019). A review of the role of the Atlantic meridional overturning circulation in Atlantic multidecadal variability and associated climate impacts. *Reviews of Geophysics*, *57*(2), 316-375.

[2] Ghasemi, B., Vreugdenhil, C. A., & Gayen, B. (2025). The role of wind and buoyancy in a turbulence-resolving model of the Atlantic meridional overturning circulation. *Journal of Geophysical Research: Oceans*, 130(3), e2024JC021790.