What are the physical processes controlling the existence of bistable overturning circulation and climate?

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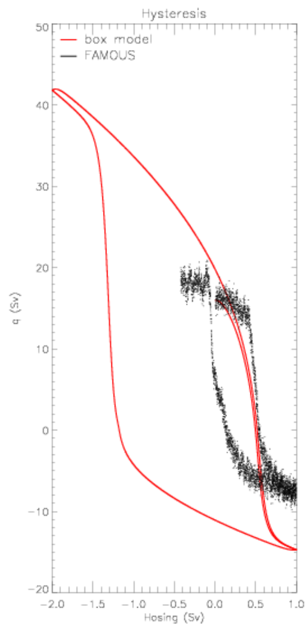
The meridional overturning of the world's oceans is an important feature of the climate system. Dense water can sink in certain areas of the world, flow at depth to other latitudes and return to the surface elsewhere, setting up a slow, global circulation of waters. Today, the observed meridional overturning circulation (MOC) results in the northward flow of warm tropical surface water in the Atlantic, supplying significant amounts of heat to north-west Europe.

On the basis of a hieararchy of ocean models of various complexities, it is widely thought that the MOC could possess at least two stable equilibra: an ' 'on" state, with a significant amount of poleward ocean heat transport (corresponding to climate conditions today), and an "off" state with a very weak circulation and less heat transport, associated with colder climate conditions in the northern hemisphere. The question of MOC stability is associated with several abrupt climate changes that are known to have occurred in the past, and is also relevant for our future climate, as the heat and freshwater cycles that help drive the modern MOC are disrupted through anthropogenic climate change.

The existence of MOC bistability has, however, not yet been demonstrated in reality or in the most realistic complex global coupled climate models, and a robust theory of the physical processes behind the stability of the MOC has yet to emerge. It is clearly important to understand whether MOC bistability could occur in the real world, or whether it is an artefact seen only in some models, arising from over-simplifying the physics of ocean/climate interactions. To make progress, a physical understanding of the processes responsible for the existence of bistability is needed. Drawing on resources ranging from basic theories of ocean energetics to experiments with the most complex climate model that has shown MOC bistability to date, this PhD will explore a number of approaches towards investigating the physical processes that are key for the existence of a bistable MOC, and move towards robust evaluations of the probability of abrupt climate change in the future.



The figure shows MOC hysteresis loops from experiments with FAMOUS (the most complex climate model that has shown MOC bistability to date) and a simple box-model of the global ocean. The strength of the Atlantic MOC is given on the vertical axis, and a measure of the freshwater balance of the North Atlantic on the horizontal (Sv=Sverdrups=millions of cubic metres of water per second). In FAMOUS, (moving right along the black curve from the top left corner) as the North Atlantic is made fresher the strength of the MOC reduces, collapsing when we add around +0.4Sv of water. If we make the Atlantic saltier again (moving left), the MOC does not recover at the+0.4Sv mark, and we need to remove almost all the freshwater we have added before the MOC will start again. The box model, representing a simple theory of ocean circulation, has been designed to reproduce the behaviour of FAMOUS in this experiment, with only partial success. (figure from Jose Rodrigues and Robin Smith)

Student profile:
This project would be suitable for students with a degree in mathematics, physics or a closely related physical or environmental science. A strong interest in combining theoretical analysis of simple models with realistic numerical ocean modelling is highly desirable.

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