Geophysical Research Abstracts
Vol. 21, EGU2019-15857, 2019
EGU General Assembly 2019

Observable, low-order dynamical controls on tipping behaviour of the Atlantic Meridional Overturning Circulation

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Is there a threshold in the fresh water forcing of the Atlantic basin beyond which the current strong AMOC becomes unstable? If so, how far is the present climate form such a threshold? Although considered unlikely in the 21st Century, the possibility of the AMOC passing such a tipping point would have major impacts on climate throughout the Northern Hemisphere. Yet there is still substantial uncertainty over whether current coupled climate models (AOGCMs) accurately represent the current stability of the AMOC, due to biases in the fresh water transport by the AMOC itself (often referred to as Mov). Mov<0 is generally thought to indicate a destabilising salinity advection feedback on the AMOC.

Based on a hierarchy of models of differing complexity (box model and coupled AOGCMs), we show that many leading order aspects of the dynamics of AMOC thresholds in the AOGCM can be quantitatively captured by a low-order box model. We show that the traditional Stommel salinity advection feedback is fundamental to AMOC collapse in OAGCMs, but we find that Mov on its own is a poor indicator of how far the AMOC is from a threshold. However Mov in combination with a manageable number of other observable quantities can be used to estimate the threshold position. This opens the possibility of monitoring how close the AMOC is to a threshold, based on observation of the current ocean state.

We find that the AMOC thresholds change in a climate with increased carbon dioxide. In the context of transient climate change this opens up the possibility of different types of state transition, as the position of the stability thresholds may move faster than the AMOC dynamics can keep up. This introduces the possibility of AMOC tipping that is dependent of how fast the underlying climate is changing. Our model hierarchy also allows us to understand the dynamics and timescales of transition between different AMOC states. We find characteristic (and potentially observable) trajectories through a low-dimensional state space that indicate different types of state transition and potentially give early warning that the AMOC is heading towards a collapsed state.