The Atlantic Meridional Overturning Circulation: observations and projections

This guidance note was originally prepared in response to an article by Bryden *et al.* that appeared in the 2005 December 1st issue of *Nature* (see reference below), the conclusions of which have often been reported in the media. The note has now been updated to incorporate findings from a subsequent publication, Cunningham *et al*., in *Science*, (August 17th 2007), findings reported at the 2006 Rapid International Science Conference and findings from the Fourth Assessment Report by the Intergovernmental Panel on Climate Change (hereafter IPCC).

What is the "Atlantic Meridional Overturning Circulation?"

The Atlantic Overturning Circulation (AMOC) is an ocean circulation system that carries warm upper waters north and returns cold, deep water south. This process is also known as the North Atlantic "thermo-haline circulation" or sometimes, imprecisely, as the "Gulf Stream" (which, in reality, is only one part of the AMOC system). It is widely accepted that the AMOC is partially responsible for the UK's relatively mild climate (especially in winter).

Summary of the RAPID Research Programme and the paper by Bryden *et al.*, (2005)

The 2005 results reported by Bryden *et al*., came from the NERC-funded RAPID programme which has deployed an array of sensors to study the AMOC across a section of the Atlantic Ocean at 25°N. Previously, measurements from ships have been used as a means of estimating the overturning circulation and associated heat transport and it is from these ship-based measurements that Bryden *et al*., (2005) based their analysis. A recent 2004 ship-based profile was compared with 4 other profiles taken over the past five decades (1957, 1981, 1992 and 1998). Initial results suggested that the AMOC had slowed by about 30%, mostly between 1992 and 1998. However, it is hard to establish whether these changes are due to natural variability or a real long-term trend. Investigating this requires a longer, continuous observational record, ideally of many years, which is currently unavailable. However, analysis of the first year's observations from the RAPID moorings (see below) provides some preliminary indication of the natural variability of the system.

Cunningham *et al*., (2007)

Cunningham *et al*. (*Science* August 17th 2007) recently published an analysis of the first year's observational record recovered from the RAPID 25°N array. Analysis of these data shows the mooring system can successfully measure the AMOC to within 1.5Sv (1Sv = $10^6 m^3$ of water per second). This record provides daily, observed AMOC strength from April 2004 to April 2005 and thus indicates

the day-to-day variability of the system that may occur throughout one year. The analysis reveals that the day-to-day variability of the system is large – large enough to encapsulate the 5 measurements reported by Bryden *et al*., in 2005. At first glance, this suggests that the long-term trend implied by the Bryden *et al*. (2005) results may be an artefact of the natural variability present in the system. Further data and analysis will help clarify this.

Future Projections of AMOC strength

Results of modelling future changes in AMOC strength presented at the 2006 RAPID International Science Conference showed a projected slowing of the circulation in the 21st century with a recovery in the 22nd century in simulations where CO2 concentrations are held fixed after 2100. Reported results indicate that any weakening could be substantially increased by the melting of the Greenland Ice Sheet and, especially, the melting rate. Modelling this freshwater input suggests the impact may not be as dramatic as previously thought, with a 42% weakening of the AMOC for a high-melt estimate, according to one climate model. Results from a study by Jungclaus *et al*. indicate that abrupt climate change relating to the shut-down of the AMOC via Greenland Ice Sheet melting does not appear to be a realistic possibility.

The IPCC analysed results from a number of state-of-the-art coupled ocean and atmosphere climate models for the 2007 Fourth Assessment Report and concluded it *very likely* (> 90% possibility) that the AMOC will slow down during the 21st century. The range of this slow-down is estimated to be between 0 and 50%, although temperatures in the Atlantic region are still projected to increase, as a result of the much larger warming associated with the rise in greenhouse gases. A large, abrupt change in the AMOC during the 21st century is considered *very unlikely* (< 10% possibility).

What do these findings mean?

The RAPID observational programme has not been running long enough to provide conclusive results in terms of understanding and predicting the behaviour of the AMOC. Some points to note in relation to these preliminary observations and related predictions are below:

- It is now known that the AMOC is quite variable from day-to-day. It is possible that the apparent 30% slow down reported by Bryden *et al*., 2005, is an artefact of this variability: further statistical analysis and data are needed to investigate this. It is not known how variable the AMOC is from year-to-year.
- A 30% slow down in the AMOC could be expected to result in a cooling of 1°C in the British Isles and 2°C in Scandinavia. Such a cooling has not been recorded in the Central England Temperature record over recent years.
- These results do not, in themselves, change the overall projection of the UK climate throughout the 21st century. The UKCIP02 scenarios are based on the

Hadley Centre climate model that includes a dynamic AMOC which weakens over the 21st century and in which warming due to increased greenhouse gas concentration exceeds any AMOC-related cooling.

- Models developed within the RAPID programme and all other comprehensive climate models (including those used by the IPCC) suggest a shutdown of the AMOC within the 21st century is very unlikely (< 10% possibility, IPCC, 2007).

Monitoring of the AMOC will continue under the RAPID programme until 2014, providing an extended time series which will better place us to interpret the significance of the results reported to date and their implications to date. Other research on this subject, some of which is also part of the RAPID programme, is continuing and is expected to shed further light on the historical relevance and predictability of the AMOC.

The issues highlighted by this paper do not provide a reason to avoid, or delay, taking action to adapt to the impacts of climate change. They instead emphasise why it is important to implement flexible adaptive options and seek no-regret and low-regret responses.

Link to the RAPID programme homepage: http://www.noc.soton.ac.uk/rapid/