

IMPACTS OF CLIMATE CHANGE ON LARGE SCALE OCEAN PROCESSES

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Executive Summary

The [meridional overturning circulation \(MOC\)](#) is part of a global ocean circulation that redistributes heat from Equatorial to Polar Regions. In the Atlantic the MOC carries heat northward which is released to the atmosphere and maintains UK temperatures between 5-10°C higher than elsewhere at similar latitudes. However, the present strength and structure of the MOC may not continue: climate models suggest that increasing atmospheric greenhouse gas could lead to an abrupt rearrangement of the MOC and climate models and [paleoclimate](#) records indicate that the MOC has undergone large and rapid changes in the past 20,000 years. Recent observational evidence suggests that since the early 1990s the MOC has slowed by up to 30%, with a significant adjustment of ocean water masses. The interpretation of a 30% slowing is controversial because of our lack of understanding of the natural variability of the MOC, and possibly conflicting evidence of warmer North Atlantic sea surface temperatures. There is a broad scientific consensus that continuous observations of the strength and structure of the MOC are required: a UK/US consortium installed a continuous monitoring system in 2004 and the first results are expected in October 2006.

Level of Confidence

Low. Large amount of disagreement between studies and there are limitations to models and observations.

Key Sources of Information

See supporting evidence

Supporting Evidence

The Atlantic Meridional Overturning Circulation (MOC)

Summary of report

This report describes what the MOC is, why it is important for climate and observational evidence for the state of the MOC from the 1950s to present. A recent summary of the importance of the MOC, its possible response to global warming, uncertainties in these predictions, and policy issues for the UK government may be found in Trumper, 2005 available online at http://www.parliament.uk/parliamentary_offices/post/pubs2005.cfm .

Introduction

Short-wave solar radiation is more intense in Equatorial Regions and less intense at the poles. The earth is almost in radiation balance – so that the globally averaged temperature is approximately constant. To maintain a balanced temperature the earth re-radiates long-wave radiation back to space. It does this uniformly over the surface of the globe (like a heated cannon ball cooling by radiating heat uniformly – this is known as black body radiation). Because of this latitudinal asymmetry in short-wave heating and long-wave cooling, the atmosphere and oceans must transfer heat from equatorial to Polar Regions. This is the single most important part of the earth's climate system. The atmosphere responds and circulates rapidly, whilst the ocean is more important for long-term climate because of its slow circulation and enormous heat capacity: the top one metre of the ocean contains as much heat as the whole atmosphere.

Global warming is caused by a change in the balance of incoming and outgoing radiation, primarily through anthropogenic carbon emissions reducing the outgoing long-wave radiation leading to an increase in global average temperatures.

The oceanic response to the equatorial heating results in a global ocean current system – known as the [thermohaline circulation \(THC\)](#), in which the global distribution of fresh water also plays a important role. The THC transfers warm surface water at the Equator to the Polar Regions where the water cools. Cold water is denser and at the poles sinks to great depth where it then spreads equatorward, so forming the lower limb of the THC. This circulation is often described as a global ocean conveyor belt.

In the Atlantic at 25°N (roughly between the Canaries and the Bahamas) there is a northward transport of heat of 1.3 PW (1 PW is 10 to the power 15 Watts, which is roughly the same as the power output from one million power stations). The heat transport is a balance of the northward flow of a warm Gulf Stream plus a warm surface wind-driven layer, and a southward flow of [thermocline](#) and cold North Atlantic Deep Water. At 60°N (roughly between Scotland and the southern tip of Greenland) the Atlantic heat flux is only 0.3 PW. The difference in heat transport between 25°N and 60°N (1.3–0.3=1.0 PW) is transferred from the ocean to the atmosphere, and this heat is transferred by the atmosphere to western Europe resulting in our relatively benign maritime climate: the ocean is acting as a giant radiator (Bryden and Imawaki, 2001). As a consequence of this circulation north-west Europe enjoys a mild climate for its latitude: annual mean air temperatures over the northern North Atlantic and Western Europe are 5–10°C higher than elsewhere at the same latitude. However, the present strength and structure of the MOC may not continue: climate models suggest that increasing atmospheric greenhouse gas could lead to an abrupt rearrangement of the MOC and climate models and paleoclimate records (e.g., Manabe and Stouffer, 1993; Wood *et al.*, 1999) indicate that the MOC has undergone large and rapid changes in the past 20,000 years (Broecker and Denton, 1989; Dansgaard, 1993). The state of knowledge on past abrupt climate change is surveyed in Alley *et al.*, 2002.

The Atlantic MOC has become a focus for a wide international research effort – partly driven by the NERC strategic programme RAPID Climate Change (<http://www.noc.soton.ac.uk/rapid/>). Significant advances in our understanding of the dynamics of the MOC and its role in climate can be expected over the next five to ten years.

MOC or THC?

The MOC is commonly defined as the zonally integrated meridional (north/south) flow, as a function of latitude and depth, and is the circulation that is actually measured. While parts of the MOC are wind-driven, the basin-scale Atlantic MOC is largely buoyancy-driven. Hence, observing the Atlantic MOC is the fundamental observational requirement of a programme aiming to assess the role of the Atlantic thermohaline circulation (THC) in climate.

Measuring the MOC

Our current understanding of the average strength and structure of the Atlantic MOC comes from infrequent snapshot measurements made at various locations and at various times throughout the Atlantic in the 20th century. However, the pressing requirement is now to understand how the MOC varies with time, so we

can separate the natural variability from any long-term trends. To do this requires continuous observations of the MOC for many years.

Snapshot measurements

Since the 1950s oceanographers have been making high quality and reliable measurements of ocean temperature and salinity. The usual way of estimating the transatlantic MOC is by using a ship to sample a series of stations across the full width of the ocean. A station consists of lowering an instrument through the water column to measure temperature and salinity with depth. A section is made up of typically 100 such stations – the stations being about 50 km apart. From these measurements the MOC can be estimated. It is important to emphasise that the measurements must be truly transatlantic – that is start near one continent, cross the full width of the Atlantic and finish on the other side. Measurements that do not span the full width of the ocean cannot estimate the MOC because of parts of the circulation not measured.

Transatlantic sections made by ship typically take five years to plan and involve about 20 scientists at sea for approximately six weeks. During the 1990s a global systematic survey called the World Ocean Circulation (WOCE) Experiment completed a number of such sections across the Atlantic, Pacific, Indian and Southern Oceans. Sections taken prior to the WOCE were repeated to help oceanographers understand how the oceans vary with time. One of the most frequently repeated sections is at 25°N in the Atlantic, where sections have been taken five times, in 1954, 1981, 1992, 1998 and 2004.

Continuous measurements

It is not practical to obtain a quasi-continuous estimate of the MOC by constantly manning a section, due to personnel and financial limitations. This requires a radical re-thinking of how to obtain meridional transport estimates, for which hydrographic lines (top to bottom, coast to coast, ensuring a closed mass balance) have proven to be the most reliable strategy (Ganachaud, 2003a, 2003b). Therefore, a basic observational strategy has evolved which relies on a combination of moored arrays (temperature, salinity, currents, and pressure), hydrographic lines, satellite observations (sea level, wind), the opportunistic use of float data, cable measurements (Florida Strait transport) and modelling to synthesise the observations.

Since 2004 a joint UK/US programme (<http://www.noc.soton.ac.uk/rapidmoc>) has installed and maintained a transatlantic array at 25°N. Results from this array are not yet available: the first scientific presentations were due to take place in October 2006 at the RAPID International Science Conference (<http://www.noc.soton.ac.uk/rapid/rapid2006>).

Recent changes in the MOC

Analysis of five hydrographic estimates of the MOC at 24.5°N (Bryden *et al.*, 2005) show that the MOC and associated northward heat transport has been constant from 1957 to 1992. However, from 1992 to 2004 the MOC has slowed by 30%. The structure of the MOC has changed, such that the transport of deep-water southward has halved and has been compensated by an increase in the transport of upper ocean thermocline water. The consequence of this is a reduction in northward heat transport from 1.3 PW to 1.0 PW. Assimilation of ocean observations from 1993 to 2004 in a global model (Wunsch and Heimbach, 2006), have the MOC slowing by 3.36 Sv over 12 years – a slowing of 19%. Thus observations indicate a decrease in MOC strength.

While the results of Bryden *et al.*, 2005 are uncontroversial (i.e. the calculations are accepted as standard within the oceanographic/climate community) the interpretation of a 30% slowing (since 1992) of the Atlantic MOC is controversial. The reason for the controversy is that five measurements are considered by some researchers as insufficient to distinguish natural variability from some significant shift in the ocean circulation. Bryden *et al.*, 2005 argue strongly for significant change based on changes in the deep ocean that cannot in their view be explained by short-term natural variability. The consensus to emerge from this is that continuous observations of the circulation are required to measure the natural variability (Nature, 2006) - and by making these continuous measurements we should be able to tell if changes in circulation are part of the natural variability or some long term decrease in the circulation.

In the North Atlantic, sea surface temperatures have increased since the 1970s and it is thought this would indicate a strong MOC (Knight, 2005). However, the dynamical link between MOC strength and SSTs is not well known. Possible explanations for the warmer SSTs could be increased surface heating due to greenhouse warming or; a stronger North Atlantic Oscillation (Visbeck *et al.*, 2003) and linked to a stronger MOC (Latif *et al.*, 2004) or; a 50 to 100 year multidecadal oscillation found in climate models (Dellworth and Mann, 2000).

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