Atlantic Meridional Overturning Adjustment in a High Resolution Coupled Climate Model.

D. L. R. Hodson and R. Sutton . *d.l.r.hodson@reading.ac.uk*

NCAS-Climate, Department of Meteorology, University of Reading, UK

National Centre for Atmospheric Science
NATURAL ENVIRONMENT RESEARCH COUNCIL
University of Reading
Walker INSTITUTE

Introduction

Decadal variability within the Atlantic arises partly from large scale modes of oceanic variability such as the Atlantic Meridional Overturning Circulation (MOC). MOC variability is thought to be partly governed by small scale processes such as boundary waves and high latitude ocean convection. Such processes are only coarsely represented in the current cohort of global coupled climate models used for climate projections (*Hawkins and Sutton, GRL 2008*).

A new generation of high resolution climate models is being developed that seek to better resolve such small scale processes and in turn provide new insights into their role in Atlantic decadal variability. HiGEM is a pioneer of this new generation; a high resolution coupled global climate model with a 1/3 degree resolution ocean and ~1 degree resolution atmosphere. (see **www.higem.nerc.ac.uk**)

In this study we examine the precursors and impacts of a change in the MOC within a 90 year HiGEM control run.

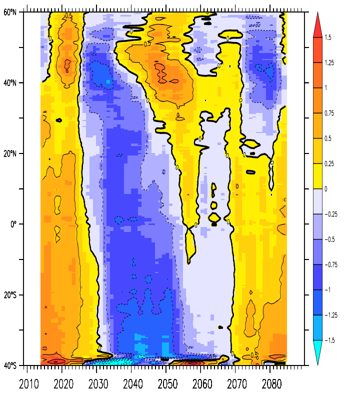
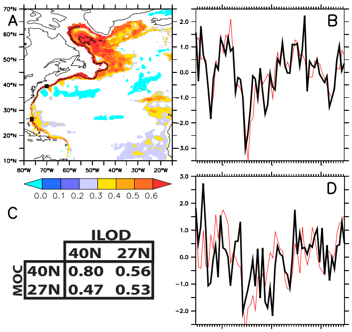


Figure 1: Annual mean MOC anomaly index at all latitudes in the Atlantic Basin. MOC index is the Southward Meridional ocean velocity integrated from 1500m to ocean floor (southward branch of MOC in HiGEM) and across the Atlantic basin. (Units: Sv). A 10 year running mean smoothing was applied at each latitude.



	ILOD 40N	ILOD 27N
MOC 40N	0.80	0.56
MOC 27N	0.47	0.53

Figure 2: A) Annual mean Integrated lower ocean density (ILOD) (800m-3000m) correlated with detrended index of ILOD (2009-2069) on western boundary at 40N (ILOD-40).Boxes show locations of ILOD-40 and ILOD-27. Contour line shows correlation of 0.7. Note: Correlations are high (>0.7) along much of western boundary. Shading shows areas where the correlation is significant at the 5% level (p<0.05). B) Red line: ILOD-40 (70.5W:69.5W,39N:40N) (detrended). Black line: MOC at 40N (as Fig. 1) dentrended. D) as B) but for 27N. C) Correlations between indices. Strongest correlation between ILOD40 and MOC at 40N.

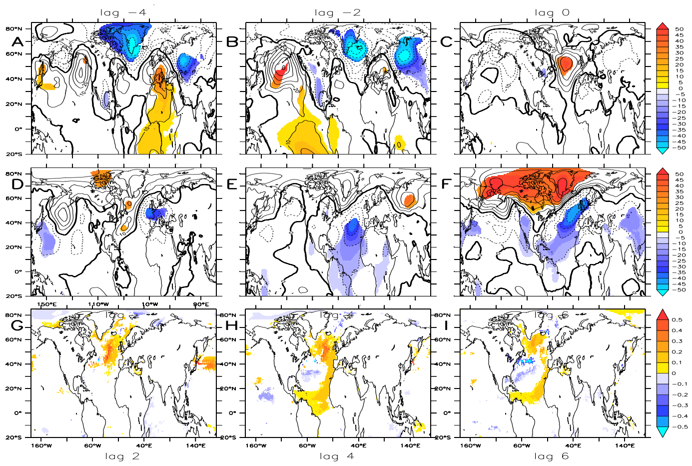


Figure 4: As Figure 3 but for Annual mean Mean Sea Level Pressure. MSLP field lags MOC index. (Units Pa/Sv, contour interval is 10 Pa/Sv). g-i) as a-f) but for Annual mean Sea Surface Temperature (SST). SSTs lag MOC.

Model and Methods

HiGEM is a new high resolution coupled climate model, based on the latest Hadley Centre coupled climate model, HadGEM1, with the horizontal resolution increased to 1.25 x 0.83 degrees in longitude and latitude in the atmosphere and 1/3 x 1/3 degrees in the ocean. HiGEM was initialized from the Levitus World Ocean Atlas and integrated for 90 years using fixed Greenhouse gas concentrations. The ocean density field was computed from from the model ocean temperature and salinity fields using functions from the CSIRO Seawater routines library. Ocean density anomalies are then constructed by subtracting the time mean ocean density from each grid point.

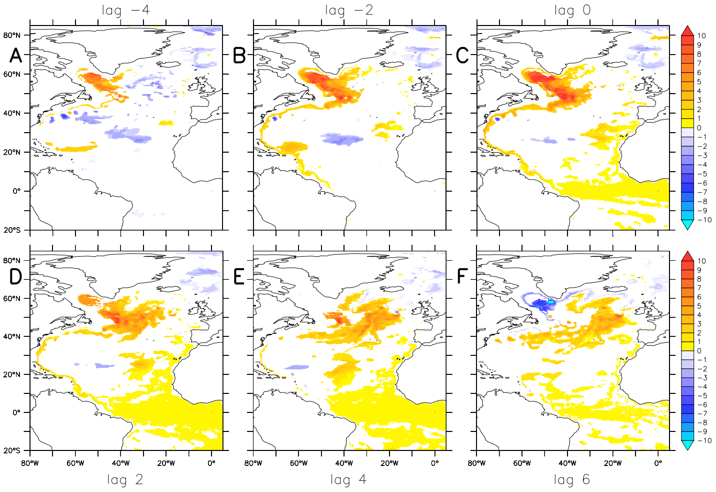


Figure 3: Annual mean integrated lower ocean density anomalies regressed onto dentrended MOC index. MOC index taken from years 31-91 (2009-2069) at 40N and then detrended (without 10 year running mean applied). Density field lags MOC index. (Units kg m^-2/Sv). Shading shows areas where the regressions is significant at the 5% level (p<0.05).

Results

The MOC in the HiGEM Control shows variability with clear coherence between latitudes (Fig. 1). Large amplitude decadal variability signals appear to be confined to the region north of 35N.

Variations in the MOC are thought to be driven in part by deep water formation, and hence density changes, in high latitude regions of the Atlantic, notably the Labrador and GIN seas. These density changes are thought to be communicated to the wider Atlantic basin by propagation of Kelvin waves along the western boundary, across the equator and north and south along the eastern boundary, where the signal is radiated westwards as Rossby waves. Analysis of the HiGEM Control reveals that density anomalies are highly correlated along the western boundary (Fig 2a). Suggesting that signals are rapidly communicated along this boundary. Variations in the MOC are highly correlated with the boundary density in the extratropics (Fig2b) but less so in the tropics (Fig 2d).

Lagged regression reveals that positive density anomalies exist in the Labrador sea four years before a change in the MOC (Fig3a). This signal propagates around the western boundary as described above with Rossby waves appearing between two and four years after a change in the MOC (Fig 3d & e).

In addition to changes along the boundary, the dense water within the Labrador sea appears to propagate out into the wider Atlantic basin. This behaviour is consistent with a recent observational study (*Bower et al, 2009. Nature,459, p243-247*). After six years (Fig 3f) a significant negative density anomaly appears both in the Labrador sea and along the Greenland/Labrador coast.

The Labrador density anomalies as seen in Fig 3a are thought to occur due the production of dense water due to enhanced surface cooling. Figures 4a&b show that significant anomalous pressure gradients, (hence increased north westerly winds and surface cooling) exist over the Labrador sea 2-4 years before a change in the MOC. 4-6 years after a change in the MOC (Fig 4e&f) there is evidence of a possible oceanic impact on the atmosphere. After six years (Fig 4f) a significant MSLP dipole anomaly can be seen over the North Atlantic. This dipole may be a response to surface forcing from Sea Surface Temperature (SST) anomalies that appear in the North Atlantic during this period and spread throught the northern Atlantic basin (Fig 4g-i). The MSLP dipole will be associated with reduced westerly winds and potentially reduced surface cooling in the region and hence maybe the cause of the negative density anomaly (Fig 3f), suggesting the possibility of a negative feedback MOC mechanism mediated by the atmosphere.

Conclusions

We have shown that HiGEM is capable of resolving small-scale ocean density anomalies that originate in the Labrador sea and propagate both along the North Atlantic ocean boundary at depth and out into the wider North Atlantic basin and that these anomalies are associated with changes in the Atlantic Meridional Overturning Circulation (MOC). Mean Sea Level Pressure anomalies over the Labrador Sea precede MOC changes by 2-4 years, suggesting that surface cooling and dense water formation in the region, driven by the atmosphere, are driving changes in the MOC. Six years after a change in the MOC, a significant MSLP dipole is seen over the North Atlantic. This dipole maybe associated with reduced surface winds and is coincident with a negative density anomaly in the Labrador sea. This co-incidence suggests a negative feedback mechanism associated with changes in the MOC, mediated by the atmosphere. Future analysis will try to identify whether similar behaviour exists in lower resolutions models.