

The Role of Air-Sea Forcing in Causing Rapid Changes in the North Atlantic Thermohaline Circulation

Outline

- 1) Project Overview
- 2) Background
- 3) Research Plan

Project Overview

Aim: Determine role of surface flux variability in causing rapid changes in the ocean circulation.

Method: Combined analysis of coupled model output and observational datasets.

Focus: Rapid changes in the North Atlantic thermohaline circulation (THC) where 'rapid' refers to changes of order 20% on decadal to centennial timescales.

Research Group

Recognised Researcher: Jeremy Grist (SOC). Funded for 3 years from 2/04 - 2/07.

Principal Investigator: Simon Josey (SOC)

Collaborators: Bablu Sinha, Bob Marsh, Peter Taylor (SOC)

Mat Collins (University of Reading)

Michael Vellinga (Hadley Centre)

Background / Motivation

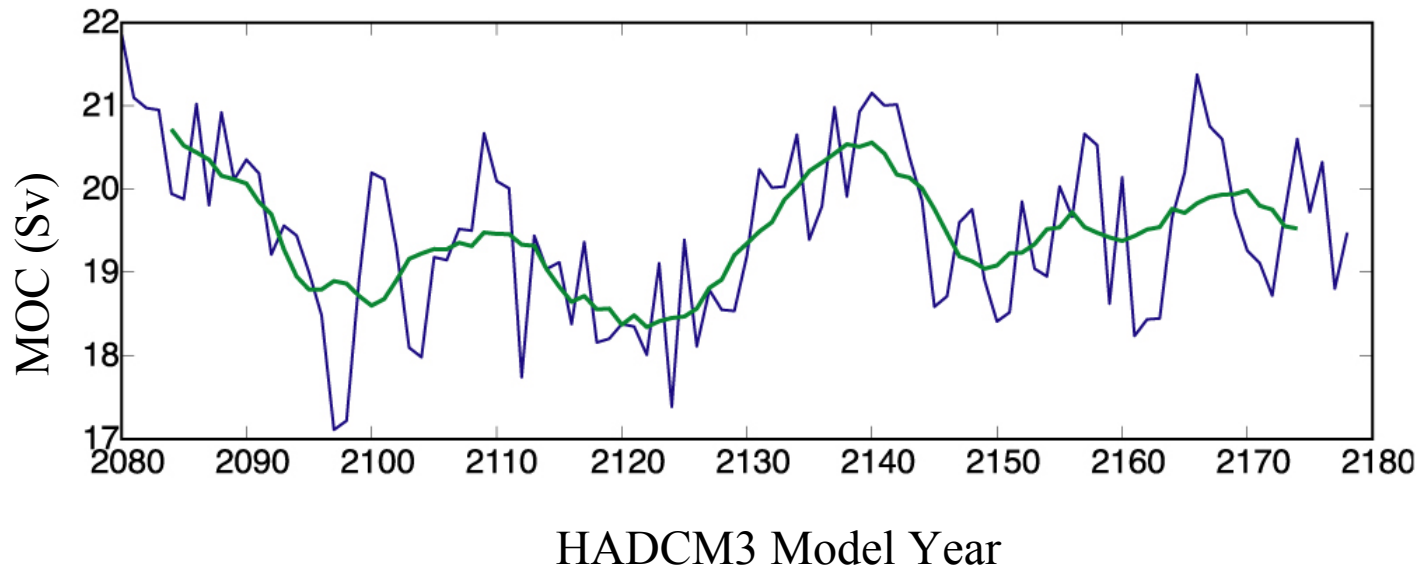
Variations in air-sea fluxes of heat, momentum and freshwater may be expected to cause rapid changes in ocean circulation through influence on deep convection at high latitudes.

Delworth and Greatbatch (2000) found surface fluxes play a significant role in causing multidecadal THC variability.

However, role of different modes of surface forcing in causing rapid variations in the THC has yet to be established.

Preliminary Results

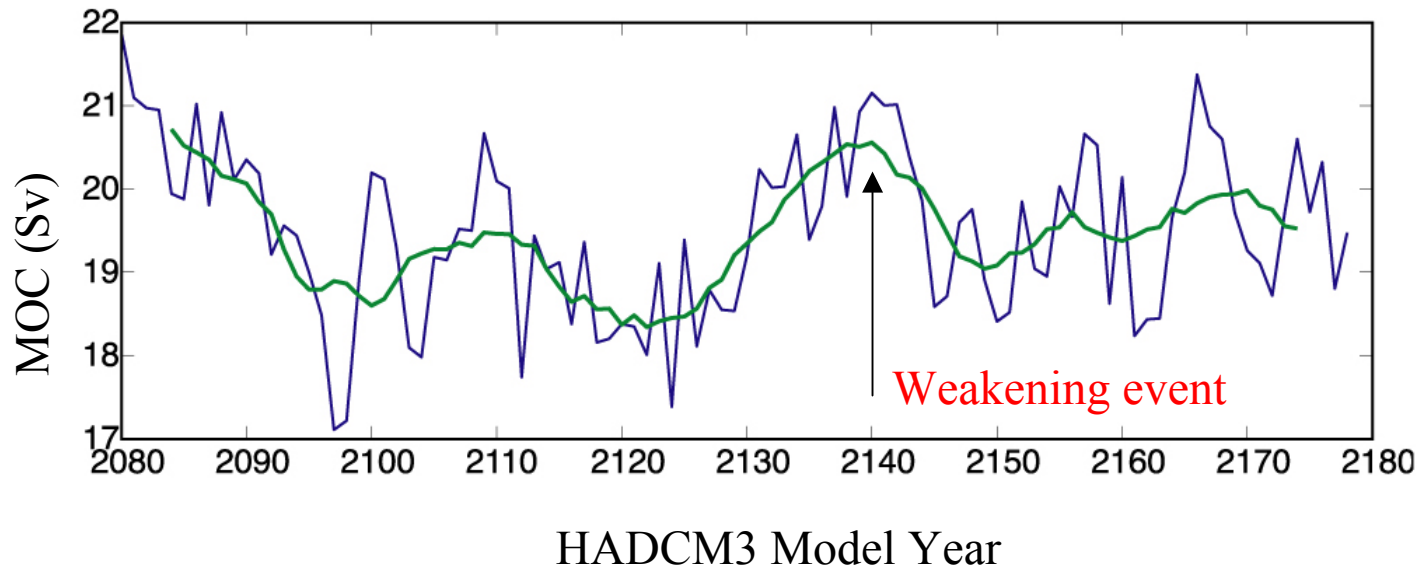
Preliminary analysis of 100 years of output from HadCM3 show rapid variations in the THC related to air-sea forcing.



Time series of Meridional Overturning Circulation (MOC) strength in the North Atlantic.

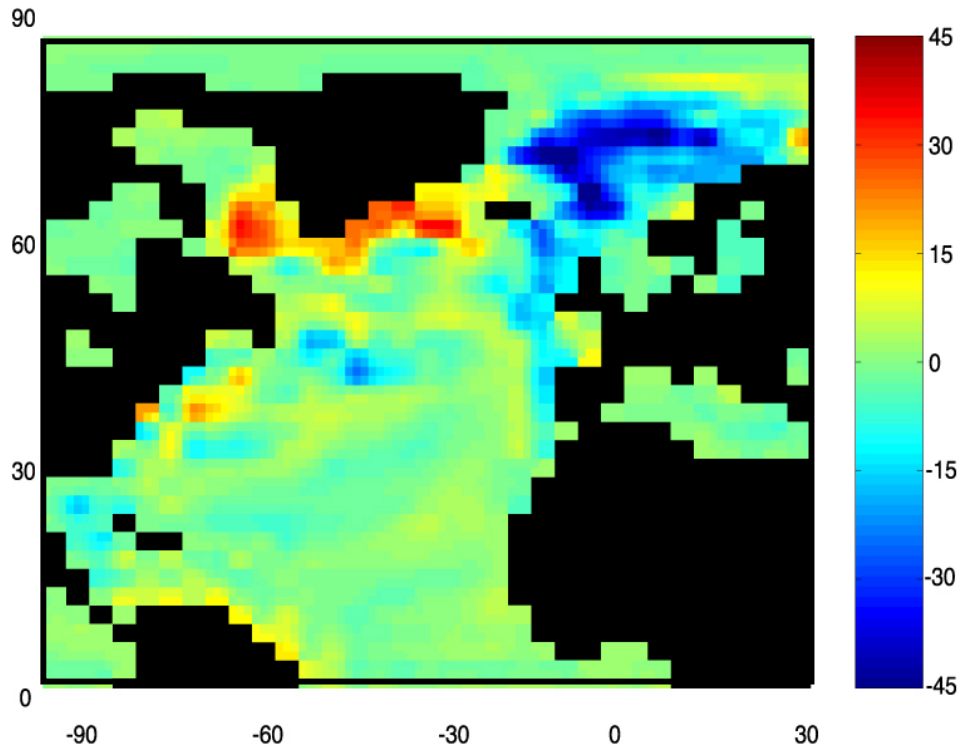
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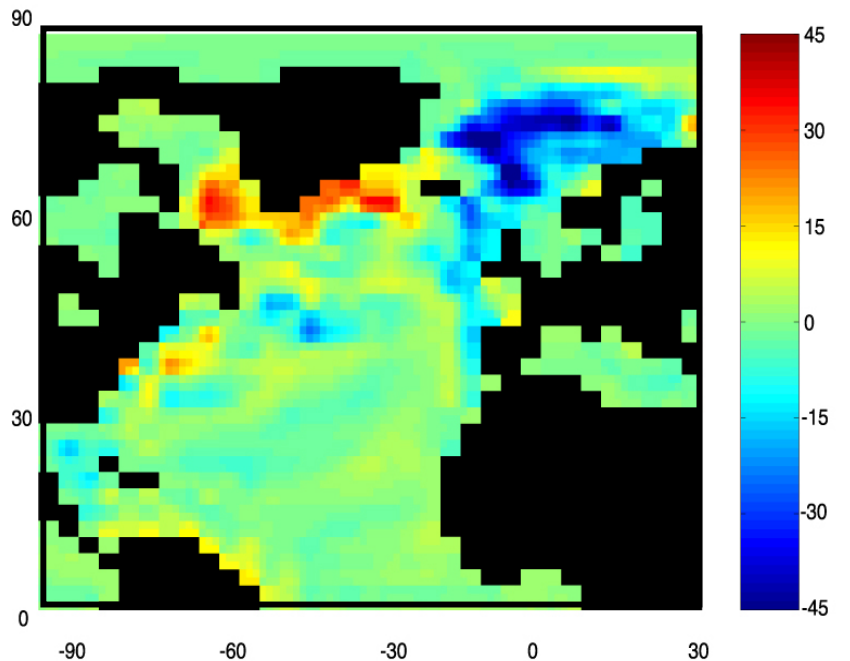
Surface Flux Field Prior to MOC Weakening



Anomalous Heat Flux for 5 year period prior to weakening event at year 2140 (units Wm^{-2}).

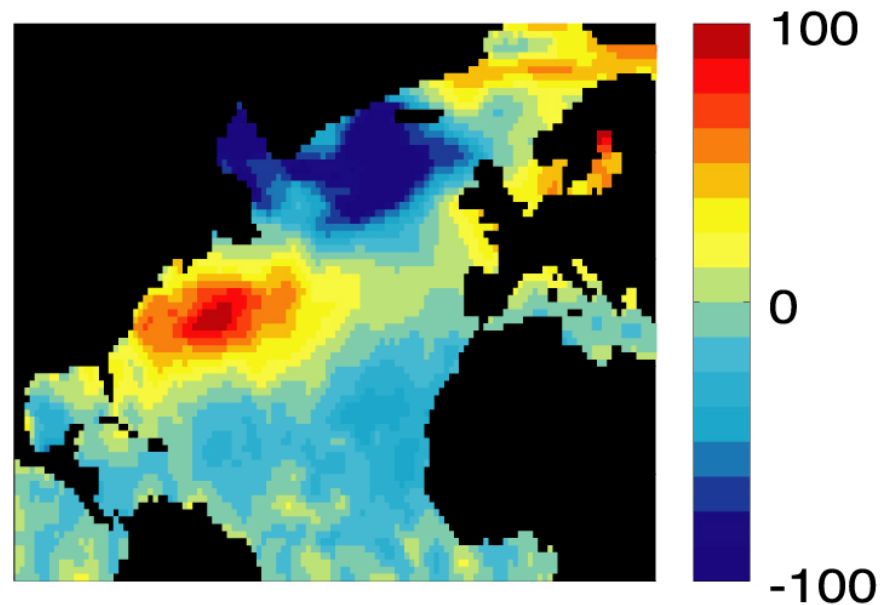
Weakened heat loss over Labrador Sea / Irminger Basin, enhanced heat loss over Norwegian Sea. Similar to that associated with the North Atlantic Oscillation (NAO). However,

Heat flux pattern lacks region of anomalous forcing in the Gulf Stream region characteristic of NAO.



HadCM3 MOC Weakening Composite

SOC Flux Dataset NAO Composite



Josey et al., 2001, GRL, **28**(24), 4543-4546

Suggests other modes of variability besides NAO are likely to prove important in causing rapid changes in the THC.

Main Objectives

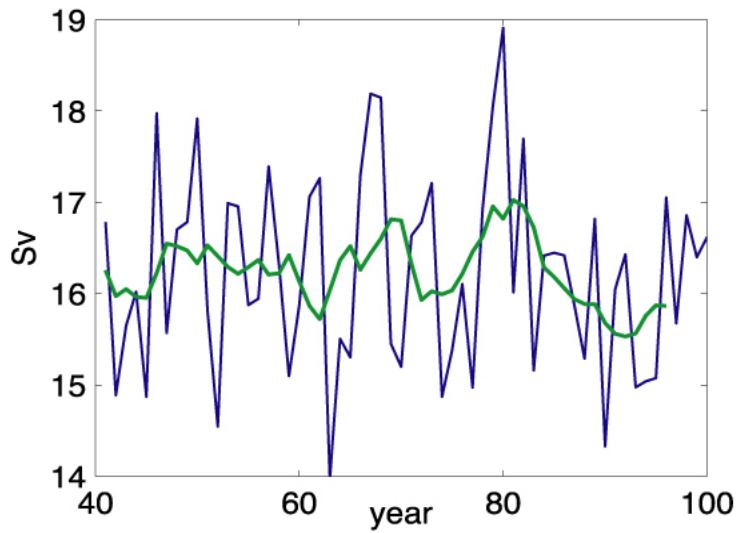
- 1) Determine modes of flux variability linked to rapid THC changes.
- 2) Investigate processes by which surface flux variability causes rapid change.
- 3) Determine impact of changes on climate via modification of ocean heat / freshwater transports and exchanges with atmosphere.
- 4) Identify model patterns of air-sea flux variability corresponding to observational record using ship / reanalysis flux datasets.
- 5) Investigate scaling relationships between air-sea flux modes at decadal to centennial timescales. Hence, estimate extremes of air-sea forcing at longer (\sim millennial) return times.
- 6) Study response of THC in fast models forced with extreme modes.

Coupled Models

Output from following coupled models will be analysed.

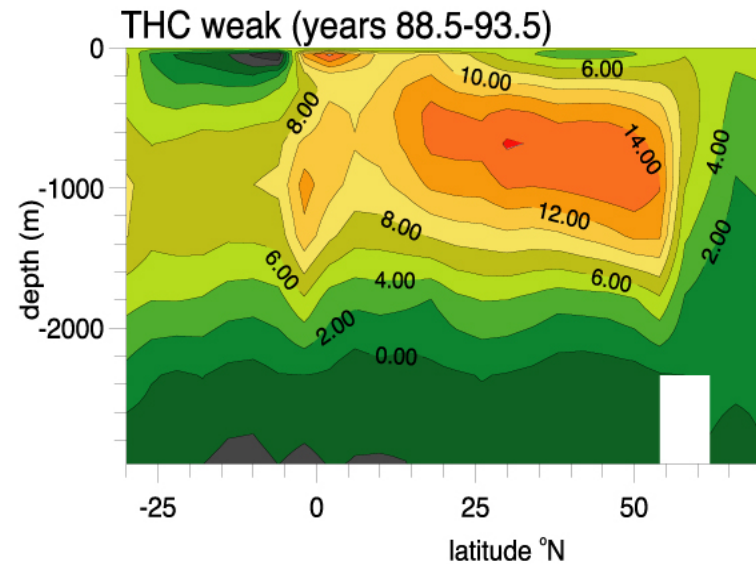
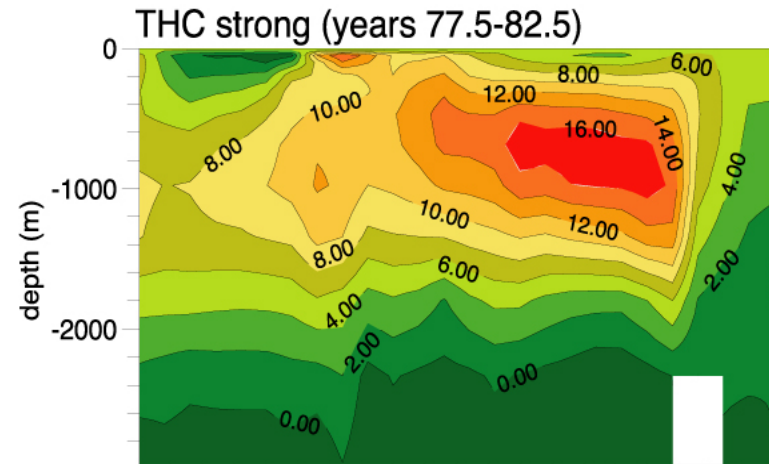
- 1) HadCM3, 1.25° ocean, 3.75° x 2.5° atmosphere, UK Met Office Hadley Centre climate model. 1000 year control and various greenhouse gas scenario runs.
- 2) HadCEM, higher resolution ocean (1/3° ocean, 3.75° x 2.5° atmosphere) version of HadCM3, 150 year run available.
- 3) HadGEM, under development (1/3 - 1° ocean, 1.875° atmosphere) with new dynamical core and improved physics.
- 4) FORTE, coarser resolution (4° ocean, ~5.5° atmosphere) fast coupled model developed at SOC (Sinha and Smith, 2002).

Overturning Circulation for a 60 year Interval from the FORTE Model



Above: Maximum North Atlantic meridional overturning circulation. Blue: unsmoothed annual average values; green : filtered with a 9 point running mean.

Right: Mean North Atlantic meridional overturning streamfunction (contours in Sv) for 0-3000m depth from FORTE for a 5 year interval centered on year 80 (upper panel) and 91 (lower panel).



Summary

Project will employ 1 PDRA, Jeremy Grist at SOC to study:

‘The Role of Air-Sea Forcing in Causing Rapid Changes in the North Atlantic Thermohaline Circulation’

Via a combined analysis of coupled model output and observational datasets.

Starts: February 2004

Research Plan I

- 1) *Rapid change in coupled GCMs.*
 - a.) *Identification of events.* Identify rapid changes in HadCM3, HadCEM and HadGEM control runs using a range of indices. Determine through lead/lagged analyses which changes are associated with anomalous flux patterns. Relate anomalous surface forcing to changes in the atmospheric circulation.
 - b.) *Causal mechanisms.* Investigate processes by which variations in surface forcing cause the rapid changes in ocean circulation identified under Item 1a.
 - c.) *Feedback on climate.* Lagged correlation analysis of various atmospheric parameters (e.g. sea level pressure, air temperature over both land and sea) with the events identified under Item 1a to determine subsequent effect on climate of surface forced rapid changes in the ocean circulation.

Research Plan II

- 2) *Anthropogenic effects.* Examine model output under various greenhouse gas forcing scenarios to determine whether dominant surface forcing patterns and likelihood of rapid changes in the ocean circulation are likely to be different in the near future.

- 3) *Comparison with observations.* Determine dominant patterns of air-sea flux variability in the historical record over the last 50 years using both ship-based observational datasets and the NCEP reanalysis. Identify periods when model surface forcing is similar to that observed. Assess whether model response in such periods agrees with that from hydrographic observations at key locations (e.g. changes in water mass formation rate at high latitudes, Dickson et al., 1996).

Research Plan III

- 4) *Fast coupled model analyses.* Repeat Items 1 and 2 with FORTE. Thereby select the version of FORTE which best represents the principal modes of forcing variability and their effect on climate. Carry out additional FORTE runs with prescribed forcing fields to verify the cause and effect relationships from lead-lag analyses.
- 5) *THC shutdown.* Investigate scaling relationships between air-sea flux modes at decadal and centennial timescales. Use relationships to estimate extremes of air-sea forcing at longer (of order millennial) return times. Carry out a range of experiments with FORTE forced with these extreme modes in order to investigate the possibility that they may lead to shutdown of the THC.