Thermohaline circulation

Jochem Marotzke

MPI, Hamburg, Germany

Variability and Predictability of the Ocean Thermohaline Circulation

Jochem Marotzke

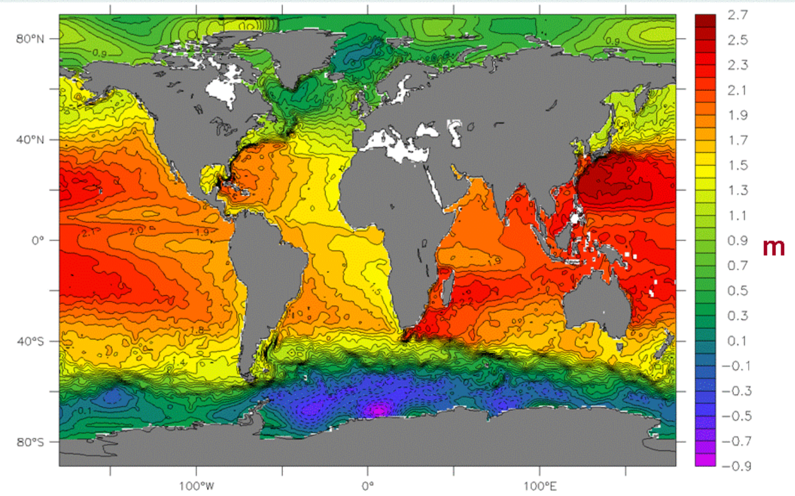
Max Planck Institute for Meteorology (MPI-M)
Centre for Marine and Atmospheric Sciences (ZMAW)
Bundesstrasse 53, 20146 Hamburg, Germany

With contributions by Johanna Baehr, Felix Landerer, Johann Jungclaus, Maria Paz Chidichimo (MPI-M), Stuart Cunningham, Joël Hirschi, Torsten Kanzow, Harry Bryden (NOCS, Southampton)

Overview

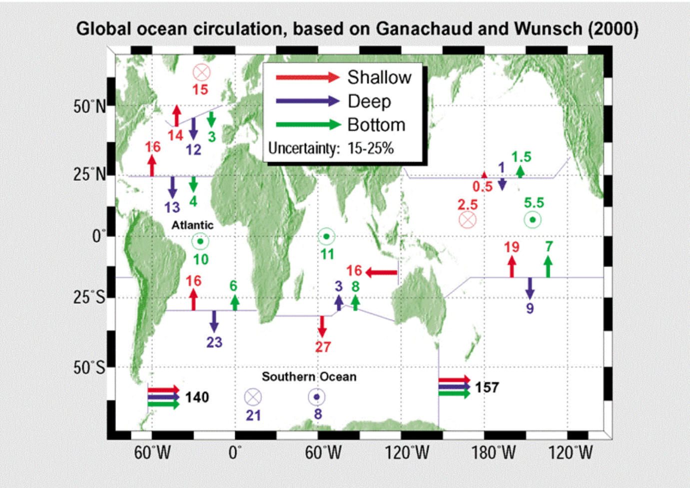
1. Setting the Scene
2. Decadal Climate Variability and Predictability
3. Observations of THC Change in the North Atlantic

Observed Sea Level (⇔ Surface Circulation)



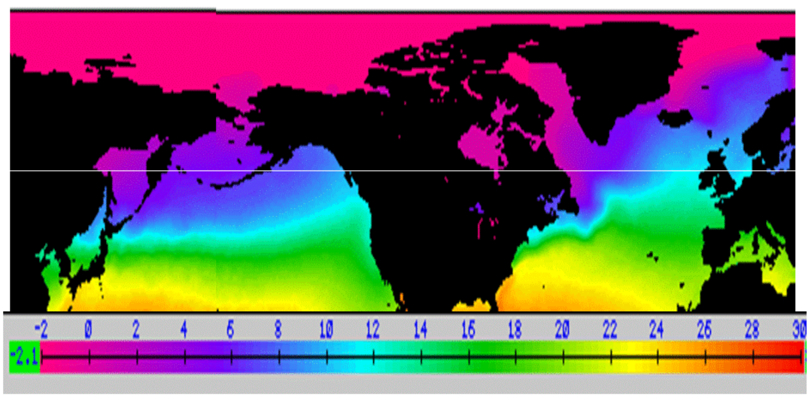
Rio & Hernandez (2004)

Observed Global Ocean Circulation



U.S. National Research Council (NRC, 2002)
Abrupt Climate Change – Inevitable Surprises

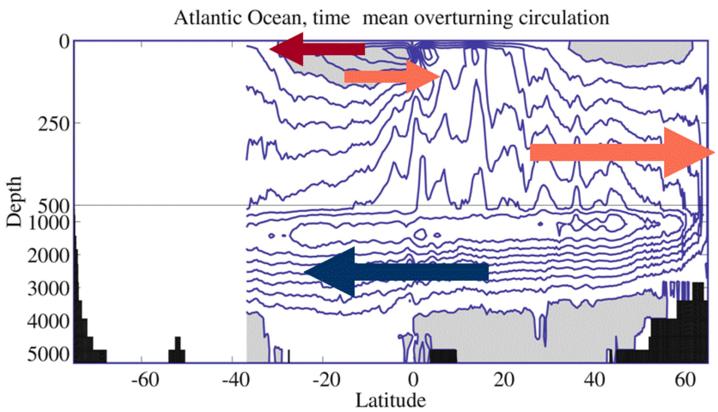
Sea Surface Temperature, 4 – 9 November 2002



Nomenclature

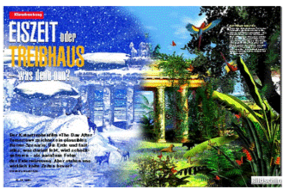
- **Gulf Stream:**
  - Narrow boundary current off North American coast (Florida)
  - Pacific has counterpart (Kuro-shio)
  - Gulf Stream cannot collapse, as long as winds blow, continents exist, and the Earth rotates
- **Meridional Overturning Circulation (MOC):** Total northward/southward flow, over latitude and depth
- Counterpart to MMC in the atmosphere
- **Thermohaline Circulation (THC):** Part of MOC driven by heat & water exchange with atmosphere
- **MOC** is observable quantity; **THC** an interpretation
- Often used synonymously, not rigorously correct
- Here: Use **THC** when confident of interpretation, **MOC** when rigour is required

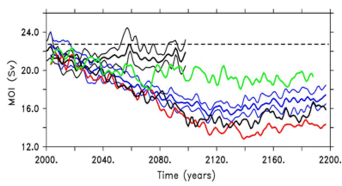
Meridional Overturning Circulation (MOC)



Jayne & Marotzke 2001

2. Decadal Climate Variability and Predictability





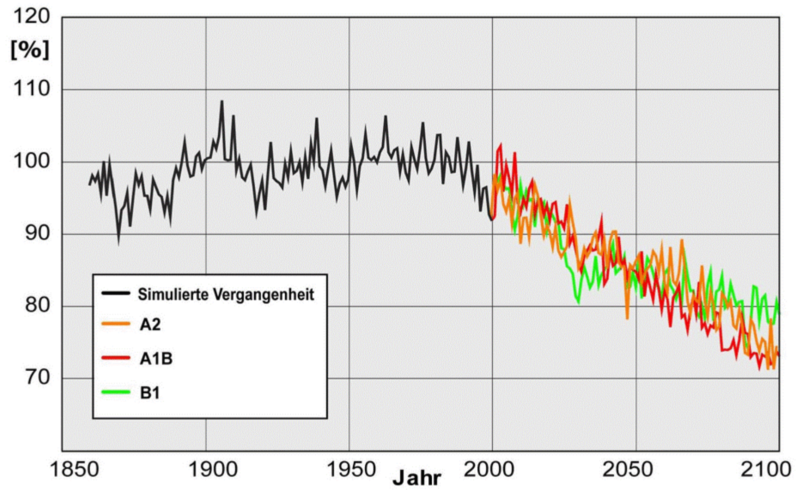
Decadal Climate Variability and WCRP

- Decadal variability crucial for both main objectives of WCRP:
  - ***to determine the predictability of climate*** – start decadal climate predictions as an initial-value problem (WCRP Strategic Framework)
  - ***to determine the effect of human activities on climate*** – need to filter out natural decadal variability
- Arguably: Ocean processes enhance decadal predictability
  - Longer timescales: Large heat capacity (e.g., winter mixed layers)
  - Longer timescales: Slower dynamical processes
- Arguably: THC, rather than wind-driven circulation, enhances decadal climate predictability
  - THC more likely to be governed by slower oceanic processes
- THC important for **climatic influence** and for **predictability**

Mechanisms of Decadal THC Variability

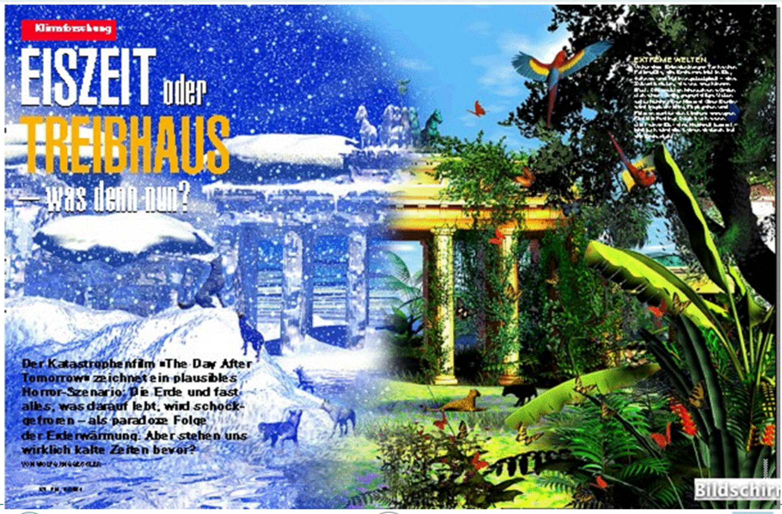
- Modelling THC variability far more mature than observations – worrisome!
- Still not clear whether coupled mode (Timmermann et al. 1998) or stochastically driven (Delworth et al. 1993), possibly enhanced by damped (Griffies and Tziperman 1995) or self-sustained (Marotzke 1990, Weaver and Sarachik 1991) ocean modes
- Mainly heat flux-driven as a robust result?
- Effect of decadal THC variations on European climate seen in models (Pohlmann and Keenlyside 2004, Sutton and Hodson 2005) and observations (Czaja and Frankignoul 2002)

Simulated Atlantic MOC



Roeckner et al. (2006)

Ice Age or Hothouse – Which Is It to Be?

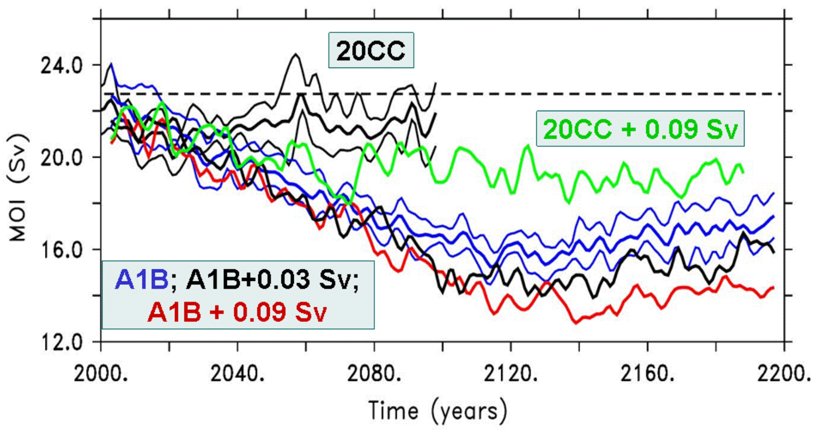


PM September 2004 Title

Can We Predict a Possible THC Downturn?

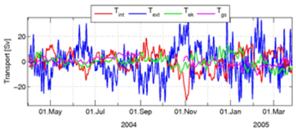
- Are all important processes included in the models?
  - **Influence of Greenland meltwater on THC stability (not included in the protocol for IPCC AR4 runs)**
- Necessary for prediction: continuous observation of the very quantity that is to be predicted
  - **Starting point of the proposal to UK NERC to establish the RAPID programme (Marotzke et al., 2000)**

"Greenland Melts," MOC Strength

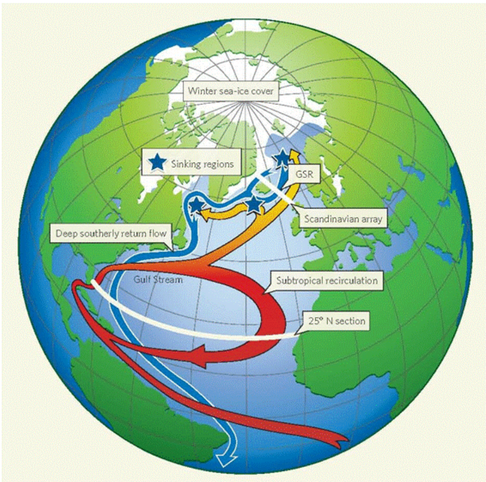


Jungclaus et al. (2006)

3. Observations of MOC Change in the North Atlantic



North Atlantic Circulation

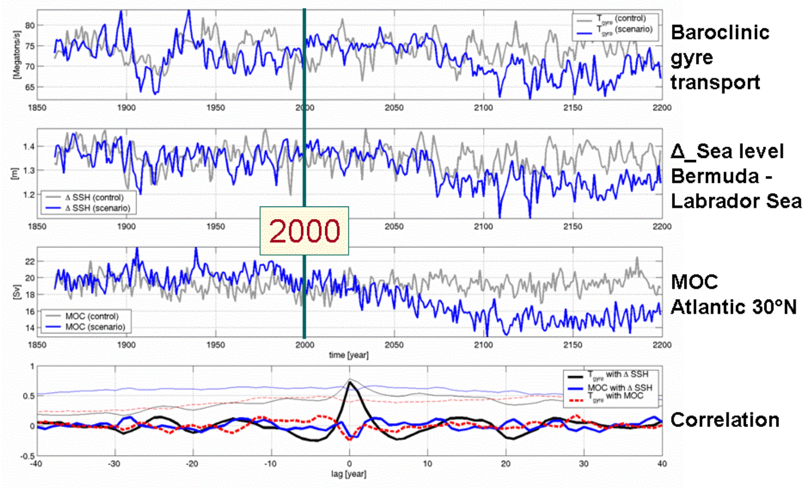


Quadfasel (2005)

Observations of Change Related to the MOC

- Dickson et al. (2002), Curry et al. (2003): Freshening in northern North Atlantic over last 4 decades (hydrography)
- Hansen et al. (2001): Reduction in overflows (hydrography + hydraulic control theory)
- Häkkinen and Rhines (2004): Slowdown of subpolar gyre surface circulation, 1992-2003 (altimetry)
- All high-profile papers (*Nature*, *Science*); public discussion seemed to imply a corresponding weakening of MOC
- BUT: No indication these measures are valid proxies of MOC – on the contrary (HadCM3; ECHAM5/MPI-OM):
  - Wu et al. (2004): Freshening coincides with stronger MOC
  - Landerer et al. (2006): No correlation subpolar gyre strength-MOC

Control (Grey) & IPCC 20C + A1B Simulations (Blue)



Landerer et al. (2006)

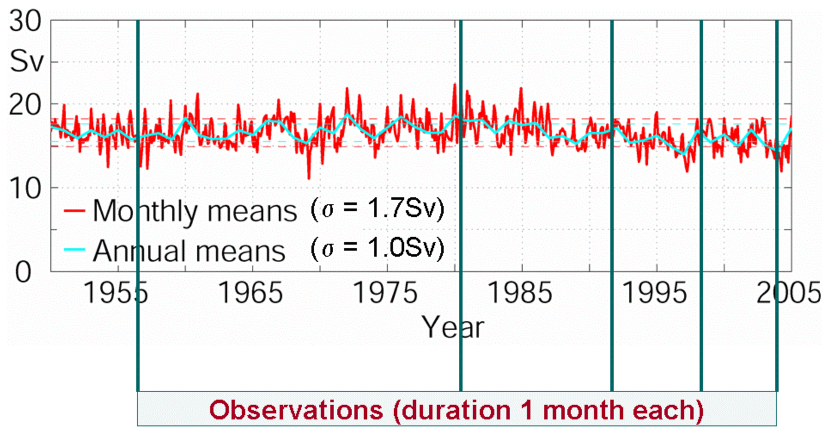
Nature, 1. December 2005 LETTERS

Slowing of the Atlantic meridional overturning circulation at 25° N

Harry L. Bryden[1], Hannah R. Longworth[1] & Stuart A. Cunningham[1]

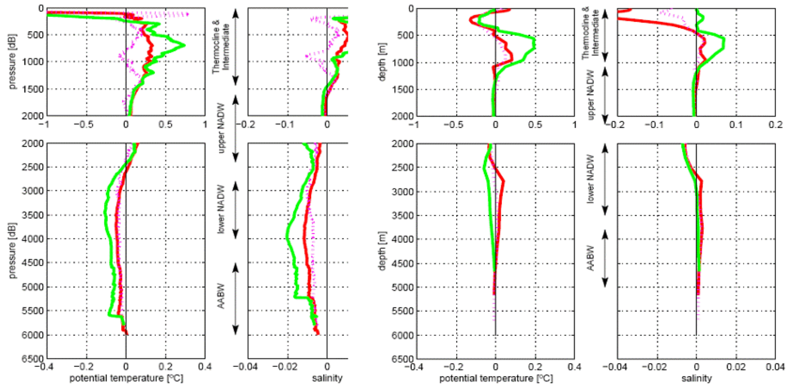
- Bryden et al. (2005): Weakening of MOC at 25°N by 30%, 2004 relative to 1957 (and relative to 1992)
- But: No changes in boundary currents, whether in subtropical (Baringer and Larsen 2001) or subpolar gyre (Schott et al. 2006)
- But: Why was the 1°C cooling expected with such an MOC slowdown (R. Wood, in Kerr 2005) not observed?
- But: Do 5 “snapshots” (Oct 1957, Jul/Aug 1981, Jul/Aug 1992, Feb 1998, April 2004) allow us to distinguish between trend and variability?

Simulated Atlantic MOC at 26°N



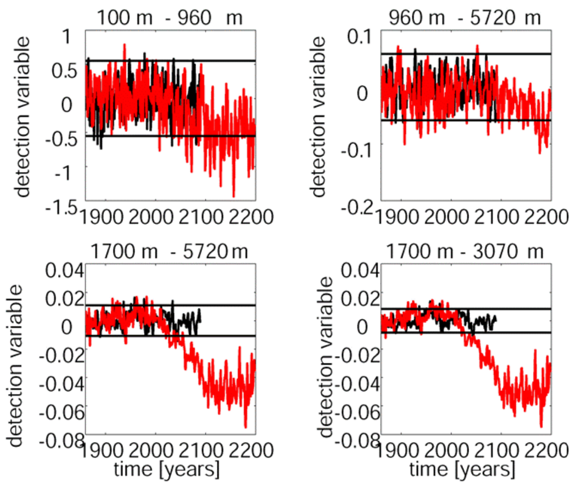
Johanna Baehr (2006)

Observed vs. modelled variability



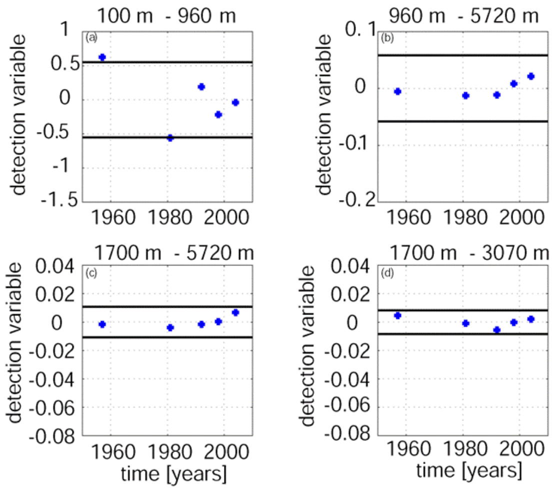
Baehr et al. (2006)

Detecting Modelled MOC Change



Baehr et al. (2006)

Observed vs. modelled variability



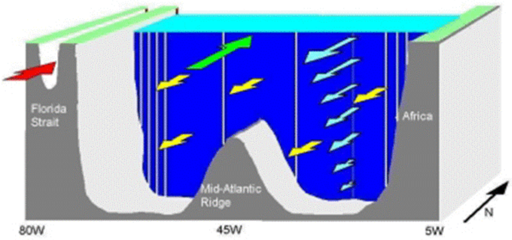
Baehr et al. (2006)

Why 26.5°N?

- Near Atlantic heat transport maximum – captures total heat transport convergence into North Atlantic
- South of area of intense heat loss from ocean to atmosphere over Gulf Stream extension
- MOC dominates heat transport (Hall & Bryden '82)
- Heat transport variability dominated by velocity fluctuations (Jayne & Marotzke, 2001)
- Florida Strait transport monitored for >20 years (now: Johns, Baringer, Meinen & Beal, Miami, collaborators)
- 5 modern hydrographic sections ('57, '81, '92, '98, ´04)

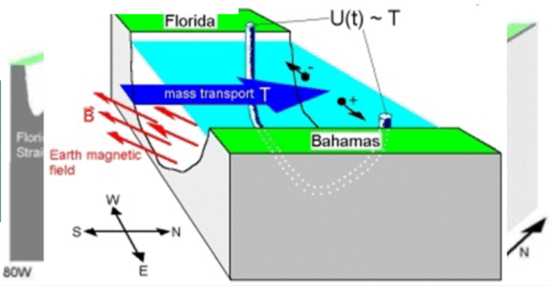
Monitoring the Atlantic MOC at 26.5°N

(Marotzke, Cunningham, Bryden, Kanzow, Hirschi, Johns, Baringer, Meinen, Beal)



Yellow: Uniform correction for mass conservation

Hirschi (2005)

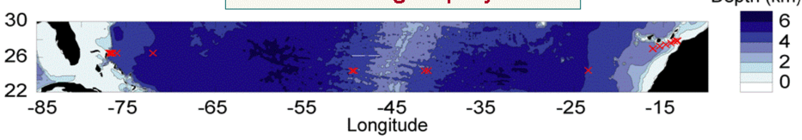


Red: Florida Strait transport measurements with telephone cable

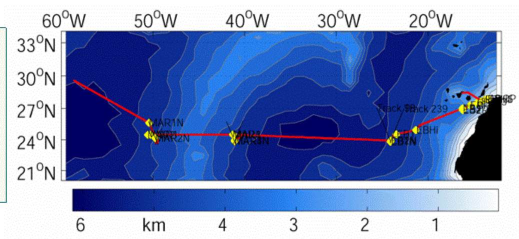
Monitoring the Atlantic MOC at 26.5°N

(Marotzke, Cunningham, Bryden, Kanzow, Hirschi, Johns, Baringer, Meinen, Beal)

2004 mooring deployment:



Data recovery: April, May, Oct. 2005; March, May 2006



CD170 2005 cruise track and mooring stations

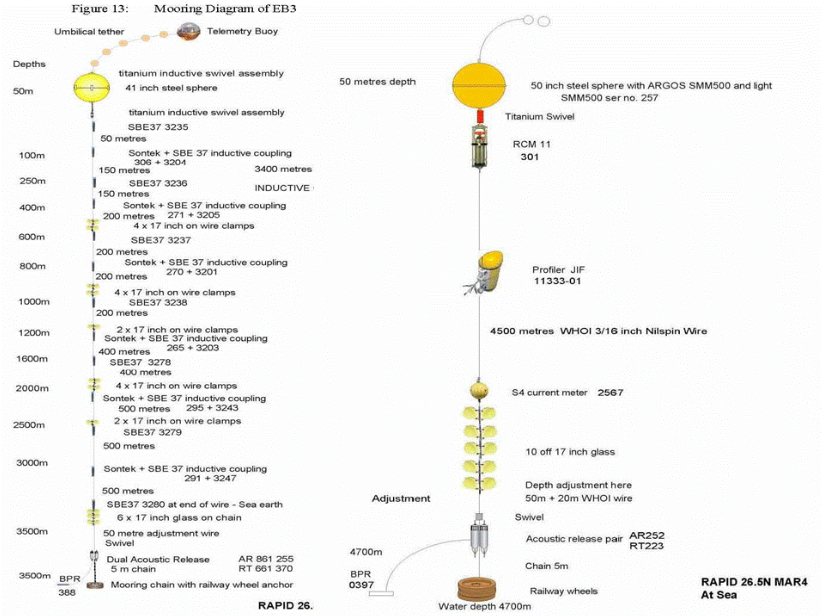
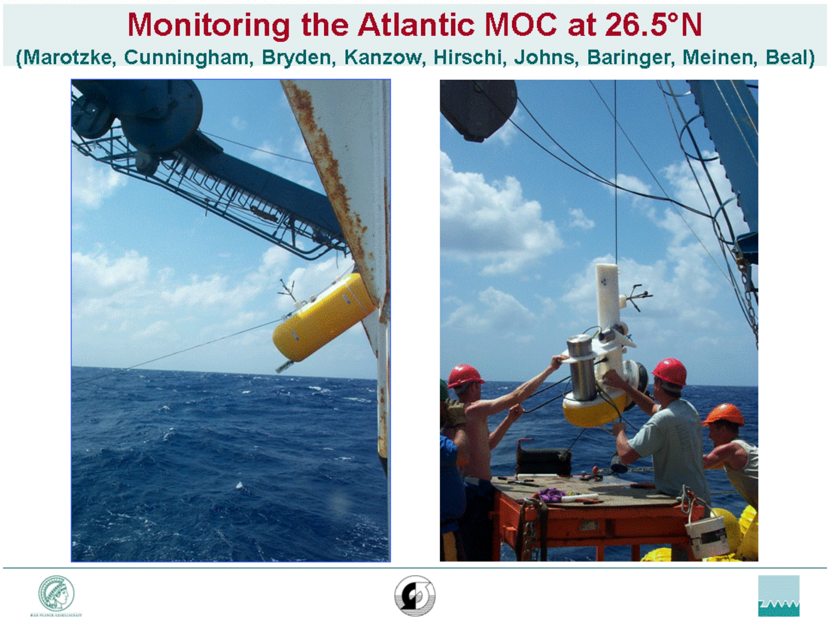
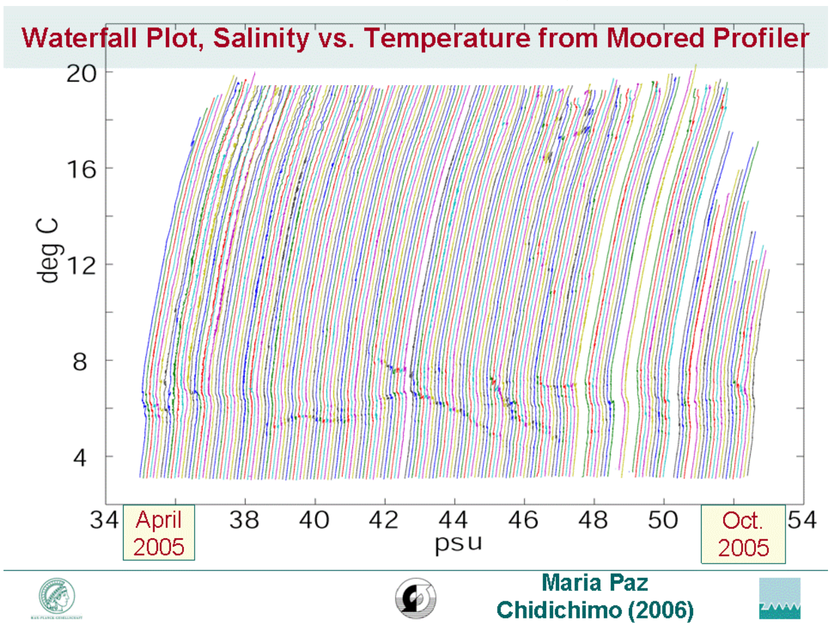
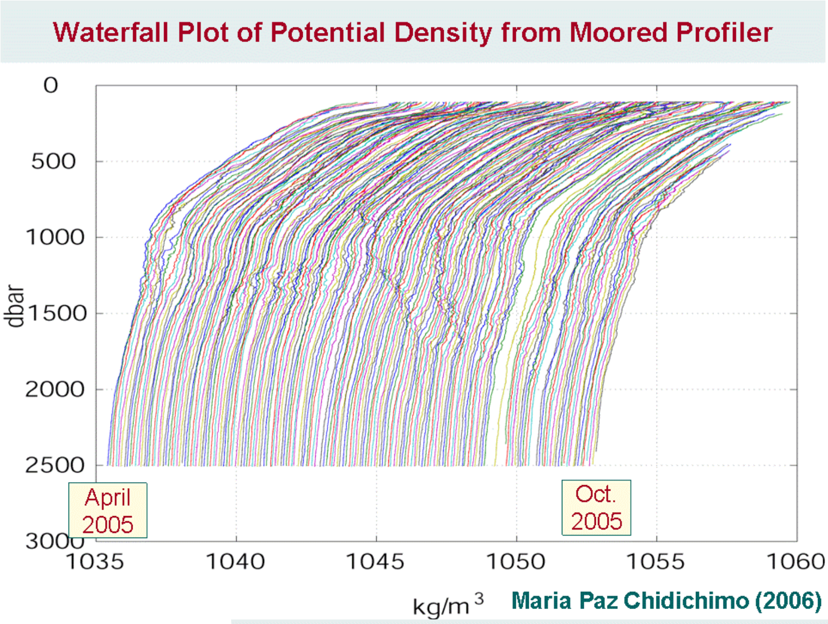
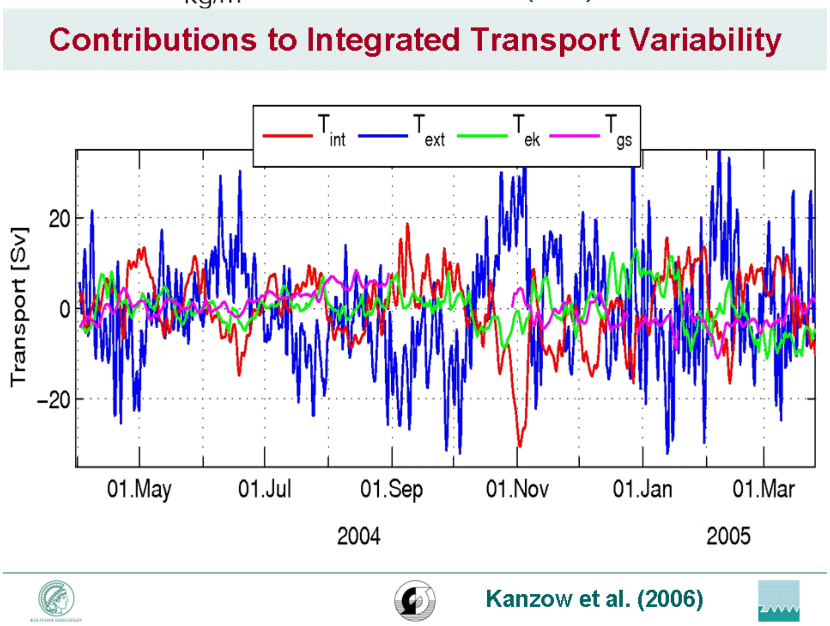


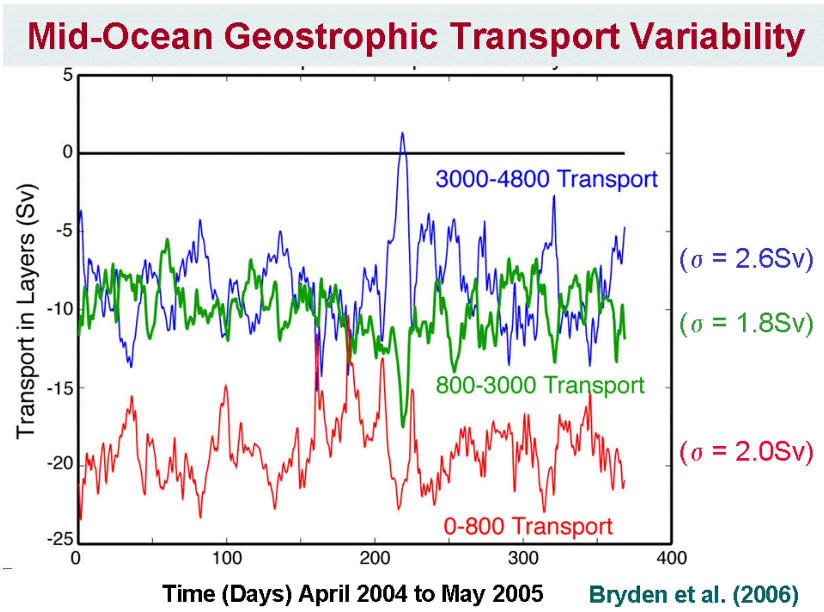
Figure 13: Mooring Diagram of EB3
Umbilical tether
Telemetry Buoy
Depths
titanium inductive swivel assembly
41 inch steel sphere
titanium inductive swivel assembly
SBE37 3235
Sontek + SBE 37 inductive coupling
3400 metres
INDUCTIVE
4 x 17 inch on wire clamps
2 x 17 inch on wire clamps
6 x 17 inch glass on chain
50 metre adjustment wire
Swivel
Dual Acoustic Release
5 m chain
Mooring chain with railway wheel anchor
RAPID 26.
50 metres depth
50 inch steel sphere with ARGOS SMM500 and light
SMM500 ser no. 257
Titanium Swivel
RCM 11
301
Profiler JIF
11333-01
4500 metres WHOI 3/16 inch Nilspin Wire
S4 current meter 2567
10 off 17 inch glass
Adjustment
Depth adjustment here
50m + 20m WHOI wire
Swivel
Acoustic release pair AR252 RT223
4700m
BPR
0397
Chain 5m
Railway wheels
Water depth 4700m
RAPID 26.5N MAR4
At Sea


Monitoring the Atlantic MOC at 26.5°N
(Marotzke, Cunningham, Bryden, Kanzow, Hirschi, Johns, Baringer, Meinen, Beal)


Waterfall Plot, Salinity vs. Temperature from Moored Profiler
deg C
20
16
12
8
4
34
36
38
40
42
44
46
48
50
52
54
psu
April 2005
Oct. 2005
Maria Paz Chidichimo (2006)


Waterfall Plot of Potential Density from Moored Profiler
0
500
1000
dbar
1500
2000
2500
3000
April 2005
Oct. 2005
1035
1040
1045
1050
1055
1060
kg/m3
Maria Paz Chidichimo (2006)


Contributions to Integrated Transport Variability
Tint
Text
Tek
Tgs
Transport [Sv]
20
0
−20
01.May
01.Jul
01.Sep
01.Nov
01.Jan
01.Mar
2004
2005
Kanzow et al. (2006)


Mid-Ocean Geostrophic Transport Variability
Transport in Layers (Sv)
5
0
-5
-10
-15
-20
-25
3000-4800 Transport
(σ = 2.6Sv)
(σ = 1.8Sv)
800-3000 Transport
(σ = 2.0Sv)
0-800 Transport
0
100
200
300
400
Time (Days) April 2004 to May 2005
Bryden et al. (2006)

Conclusions

- Greenland meltwater only moderately destabilising for THC during the next two centuries
- No valid proxy for MOC has yet been identified
- Continuous observing system of Atlantic MOC has been put in place at 26.5°N.
- Observations show surprisingly strong high-frequency variability of the MOC
- "Observations" of MOC slowdown likely to be artefact of temporal subsampling of noisy system

Outlook

- *MOC time series needs to be continued*
  - Alternative observing systems? Cheaper technologies (obviate moorings? Full-depth gliders?)
  - Transfer to operational agencies after (likely) RAPID-WATCH phase ends in 2014
  - Complementary locations (northern North Atlantic? South Atlantic?)
- *Development of MOC proxies*
  - Simple proxies (e.g., SST, Latif et al. 2004)
  - Multiproxies (ultimate multiproxy: ocean re-analysis)

Outlook

- *Decadal predictability of MOC and climate*
  - Move decadal predictability studies from pure modelling exercises into initialisation of global coupled models with observations, including global data assimilation (ocean & coupled re-analysis)
  - Measurements of MOC, MOC proxies, quantities influenced by MOC crucial
- *Mechanisms of interdecadal MOC variability*
  - Picture still very unclear, but many groups work on it
  - Too much focussed on pure modelling studies?
  - Learn from ENSO theory to consider superposition of effects?