RAPID/MOCHA/WBTS
RESULTS FROM THE 26ºN MOORING ARRAY

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INTRODUCTION
INTRODUCTION

Why we study the AMOC:
• Impact on climate
• Evidence of major shifts in the past associated with major climate events

The AMOC in a changing climate

In a changing climate
• The AMOC is predicted to slow in a warming climate

Suggestions of a slowdown:

To understand how the AMOC varies, we need to measure it...

Bryden, H. L., H. Longworth and S. Cunningham (2005), Slowing of the Atlantic meridional overturning at 25N, 438, Nature
The impact of the 26ºN measurements

- **Mean [Sv]**
  - GS: $31.8\pm3.1$
  - MOC: $18.1\pm4.3$
  - Ekman: $2.9\pm3.0$
  - UMO: $-16.6\pm3.4$

- AMOC timeseries and related data products are available from [www.rapid.ac.uk/rpdmoc](http://www.rapid.ac.uk/rpdmoc)
- Data from individual instruments are available from [www.bodc.ac.uk](http://www.bodc.ac.uk)
The impact of the 26ºN measurements

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Seasonal Cycle

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Heat Transport

- Heat transported north in GS is recirculated by mid-ocean and overturning circulation
- Overall MHT of 1.3 PW similar to hydrographic estimates

<table>
<thead>
<tr>
<th>Component</th>
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Large downturn in 2009/10 driven by short term Ekman variability (3 months) and long term strengthening of the gyre/UMO (18 months)

Double dip in winter 2010/11

ERA winds is a difference from previous release
How we measure the AMOC at 26.5°N?
Boundary Currents and the mid-ocean Dynamic Height and Bottom Pressure Array


The AMOC Streamfunction

\[ T_{AMOC}(t,z) = T_{GS}(t,z) + T_{Ek}(t,z) + T_{WBW}(t,z) + T_{INT}(t,z) + T_{AABW}(z) + T_{comp}(t,z) \]

Internal Transport:

\[ T_{INT}(t,z) = \frac{\Delta D_{ref=4820}(t,z)}{f} \]

The AMOC:

\[ \Phi_{MAX}(t) = \int_{h_{y,MAX}}^{0} T_{AMOC}(z,t) dz \]
Mass compensation

$T_{flo}(t, z) + T_{ek}(t, z) + T_{wbw}(t, z) + T_{int}(t, z) = -T_{ext}(t, z)$

$T_{ext}(t, z) = v(t)_{comp, ref} \cdot w(z),$

- Mass compensation is highly correlated with BPR derived transport ($r > 0.8$) at the western boundary
- Residual has seasonal signal indicating seasonal compensation at the east

Kanzow, T., et al. (2007), Observed Flow Compensation Associated with the MOC at 26.5°N in the Atlantic, *Science*
Basinwide transports in an eddying ocean

- SSH variability decreases towards close to the western boundary
- We measure a small variance of 4 Sv whereas an eddy dominated signal would display a variance of around 16 Sv

Recent Changes

1. Impact of time varying AABW
2. Moving from EOS-80 to TEOS-10
3. Improved extrapolation above shallowest measurement

- Little impact using time-varying AABW
- Formerly, 2 Sv of AABW was included
- Now, 1 Sv more representative of both northward flowing AABW and southward flowing DWBC below 4820 dbar, west of 72°W
- Increases AMOC by 0.2 Sv

Frajka-Williams et al., (2011) Variability of Antarctic Bottom Water at 24.5°N in the Atlantic. JGR
Recent Changes

1. Impact of time varying AABW
2. **Moving from EOS-80 to TEOS-10**
3. Improved extrapolation above shallowest measurement

- Change of equation of state decreases the AMOC by 0.4 Sv
- Change due to absolute salinity difference in deep east and west
- Maximum change of 0.7 Sv at 2700 m

Recent Changes

1. Impact of time varying AABW
2. Moving from EOS-80 to TEOS-10
3. Improved extrapolation above shallowest measurement

- Shallowest measurement often at 100 m depth
- Linear extrapolation can miss 1 Sv in the summer
- Argo based monthly extrapolation reduces to <0.2 Sv

Haines et al., (2013). Atlantic meridional heat transports in two ocean reanalyses evaluated against the RAPID array, GRL

Summary: 0.2 Sv AABW change, -0.4 Sv TEOS-10 and improved seasonal extrapolation
SEASONAL CYCLE
The Seasonal Cycle due to the East

- Largest seasonal influence in mid-ocean transports due to the east
- Recent variability hasn’t changed this

Wind Stress Curl drives density anomalies at the Eastern Boundary

HEAT TRANSPORT
**HEAT TRANSPORT**

Net Heat Flux = $1.27 \pm 0.30$ PW (uncertainty 0.14 PW)

- Overall MHT of 1.3 PW similar to hydrographic estimates
- Seasonal variability is in the mid-ocean heat transport
- 47% variance in Ekman

Heat transported north in GS is recirculated by mid-ocean and overturning circulation.

90% is in the overturning.
INTERANNUAL VARIABILITY
Slowdown in winter 2009/10

Ekman shift associated with negative Arctic Oscillation/NAO
Only explains 3 month downturn
Slowdown in winter 2009/10

Longer time scale changes: 18 month weakening of MOC

Anomalous southward UMO: shift from overturning to gyre circulation

*Seasonal cycle was removed, and data smoothed with 180-day filter

Expect for a balanced heat budget, the thick pink curve (total predicted heat content change) would match the black curve (observed heat content change).

Heat budget for 26–41°N, above 4°C

Cunningham, Frajka-Williams, Roberts, Palmer et al., in prep

Cunningham talk Today 14.30
Second large dip in AMOC transport in winter 2010/11 following Arctic oscillation low

This is largely explained by Ekman contributions

Ocean re-emergence of SST links the two events

Taws SL, Marsh R, Wells NC, Hirschi JJM (2011) Re-emerging ocean temperature anomalies in late-2010 associated with a repeat negative NAO. GRL
In an ensemble of NEMO runs, double dips of MOC have occurred previously in 1969/70 and 1978/79.

Extreme negative Arctic Oscillation (AO) correspond with double dip analogues

Corresponds with Ekman lows

Blaker et al. in prep, Historical analogues of the recent extreme minima observed in the Atlantic meridional overturning circulation at 26°N. Clim. Dyn.
Double Dip: Winter 2010/11

- Reemerging SSTs are observed in 1969/70 as well as in 2010/11
- These were conducive to the development of the negative NAO in winter 2010


- Evidence that this second negative is predictable due to the ocean


Winters of 2010/11 (green), 1969/70 (blue) and 1978/79 (red). Black shows mean (1960-2011) with 1, 2 std envelopes
Evidence of a downturn

- IPCC predicts a downturn of 0.5 Sv per decade
- We see a decline of 0.6 Sv per year
- Even excluding the extreme of 2009, this is significant at 90% level
CONCLUSIONS

• The 26°N array has revolutionised our understanding of the AMOC and its variability
  • The variability observed in the first year gave context to the 5 previous hydrographic estimates and painted a picture of a noisy AMOC
  • A 30% decline in a single year 2009/10 including the brief cessation of northward flowing warm water
  • Re-emergent patterns driving a double dip in 2010/11

• IPCC projects a 0.5 Sv per decade decline this century, we are seeing a decline of 0.6 Sv per year. Is this a long term decline? The only way to know is to measure.

• The array should not only be seen as a long-term monitoring tool e.g. the potential to improve seasonal forecasts.