RAPID/MOCHA/WBTS

RESULTS FROM THE 26ºN MOORING ARRAY

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INTRODUCTION

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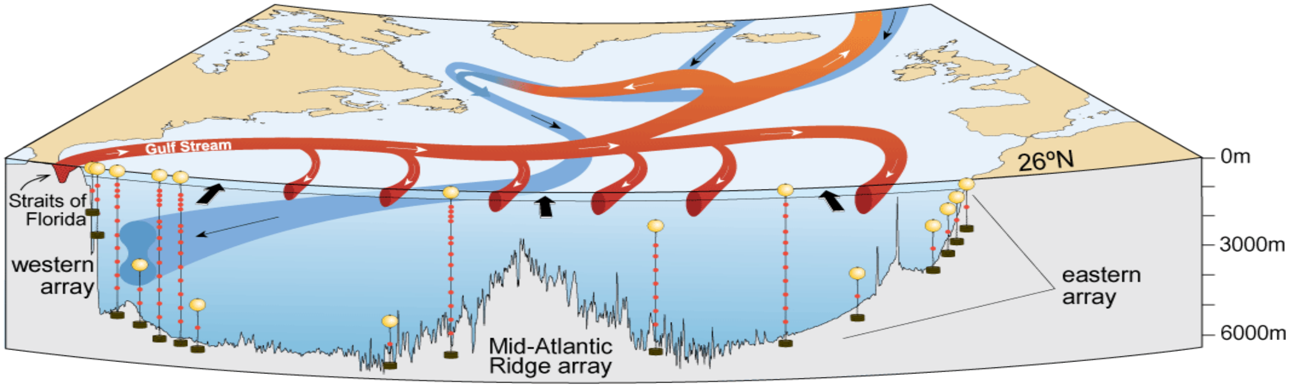
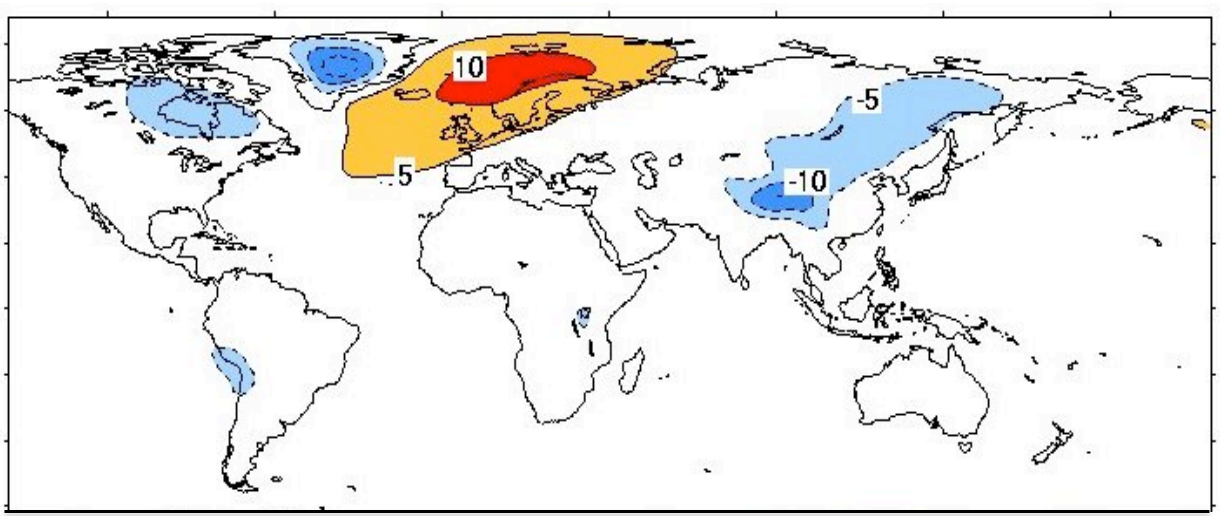


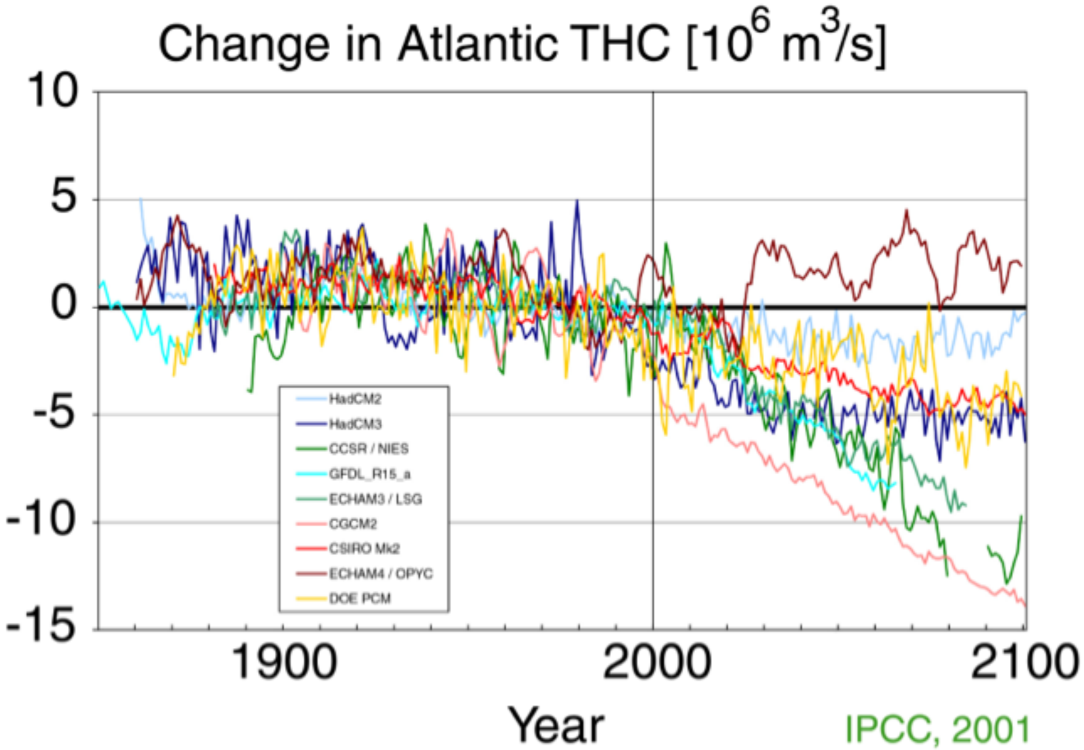


Why we study the AMOC:

- Impact on climate
- Evidence of major shifts in the past associated with major climate events

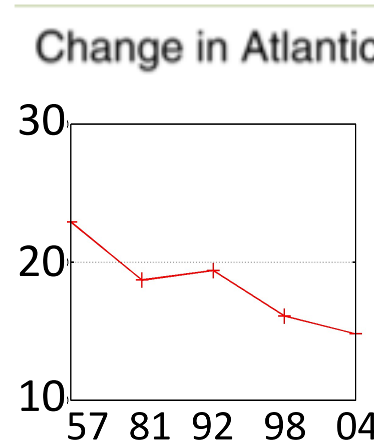
from Rahmstorf, S. and A. Ganopolski, *Long-term global warming scenarios computed with an efficient coupled climate model.* Climatic Change, 1999. **43**: p. 353-367.

The AMOC in a changing climate



In a changing climate

- The AMOC is predicted to slow in a warming climate

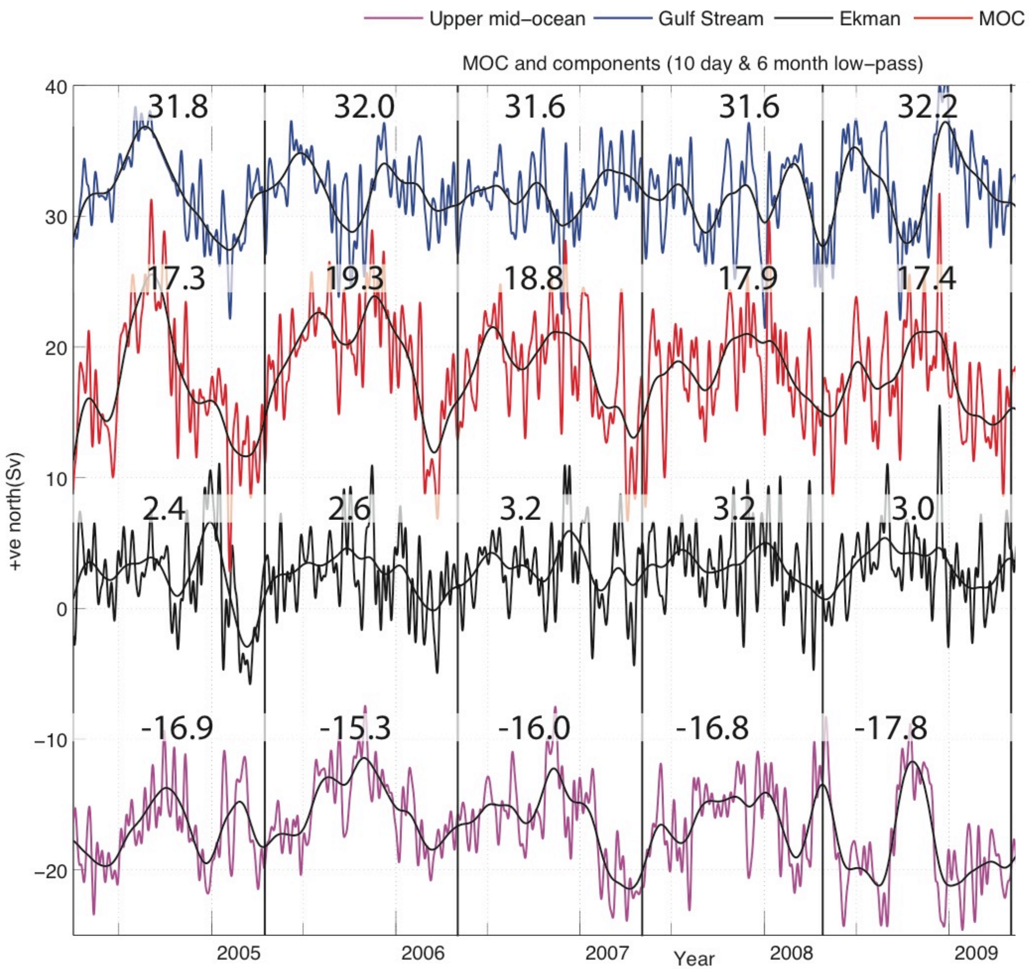


Bryden, H. L., H. Longworth and S. Cunningham (2005), Slowing of the Atlantic meridional overturning at 25N, 438, Nature

Suggestions of a slowdown:

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

The impact of the 26ºN measurements



Mean [Sv]

GS

31.8±3.1

MOC

18.1±4.3

Ekman

2.9±3.0

UMO

-16.6±3.4

- AMOC timeseries and related data products are available from www.rapid.ac.uk/rpdmoc
- Data from individual instruments are available from www.bodc.ac.uk

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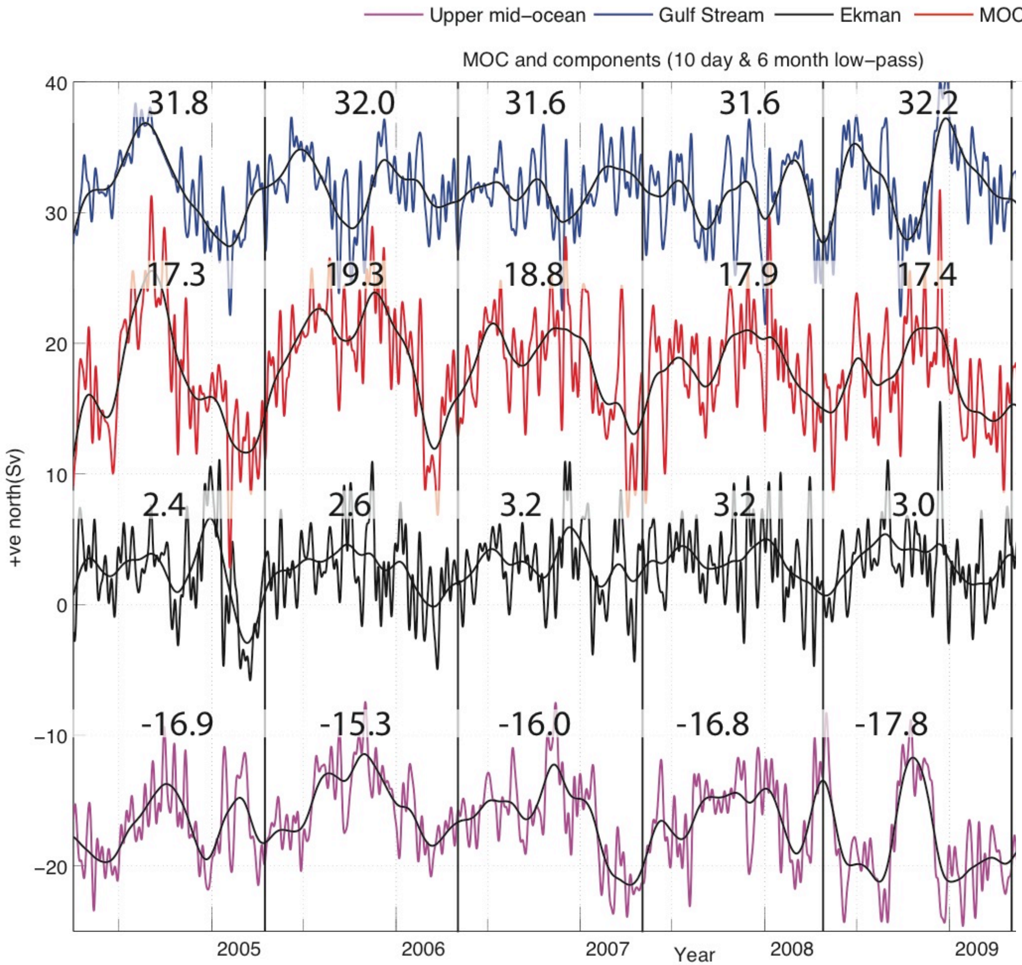

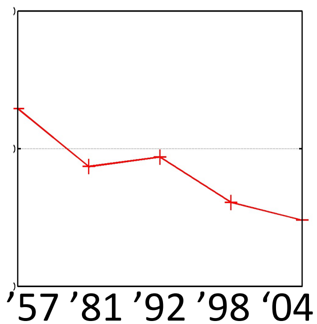

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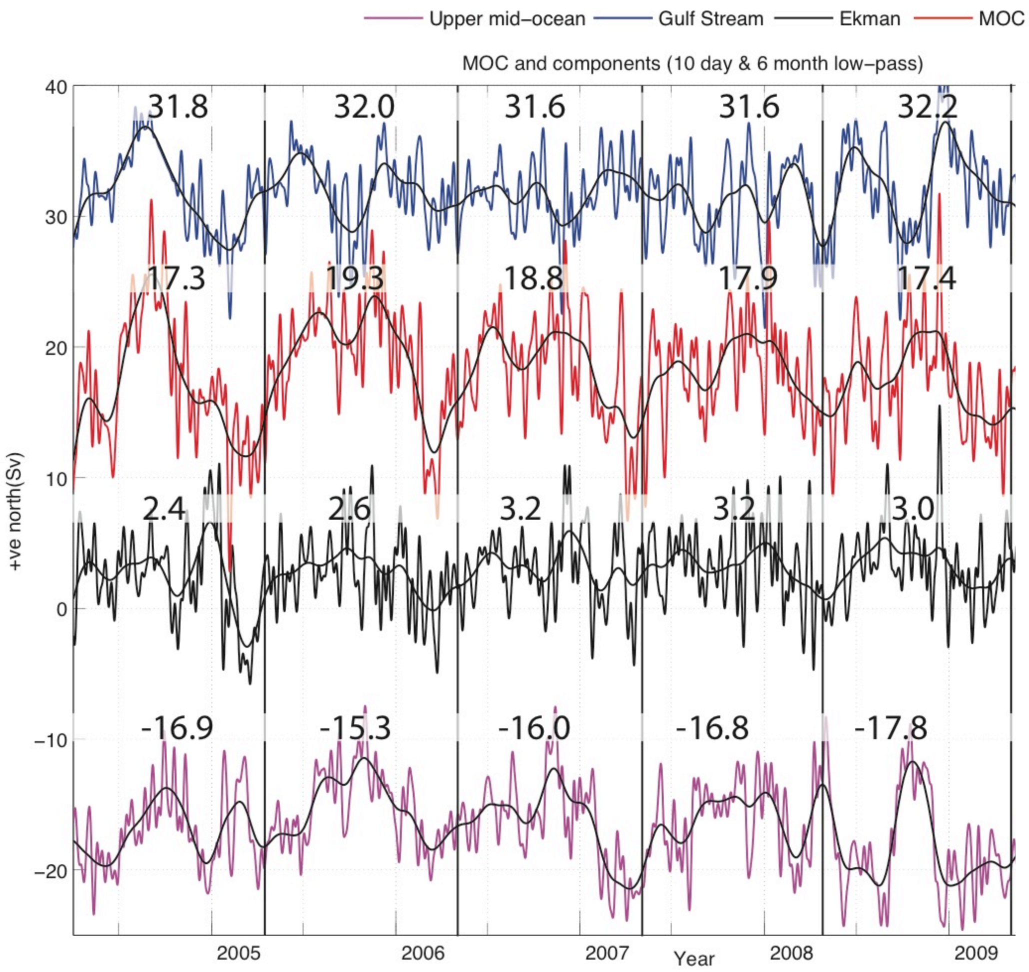
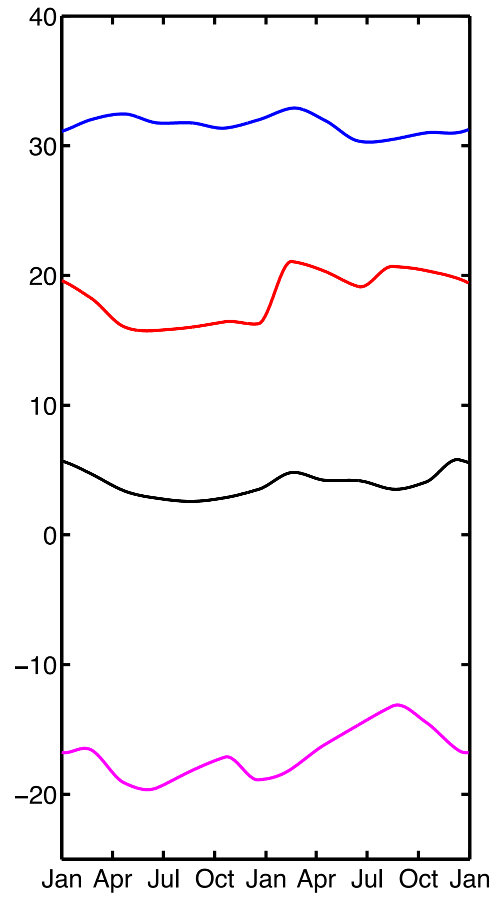
Seasonal Cycle





Seas. Amp.

GS

3 Sv

MOC

6 Sv

Ekman

3 Sv

UMO

6.5 Sv

- AMOC timeseries and related data products are available from www.rapid.ac.uk/rpdmoc
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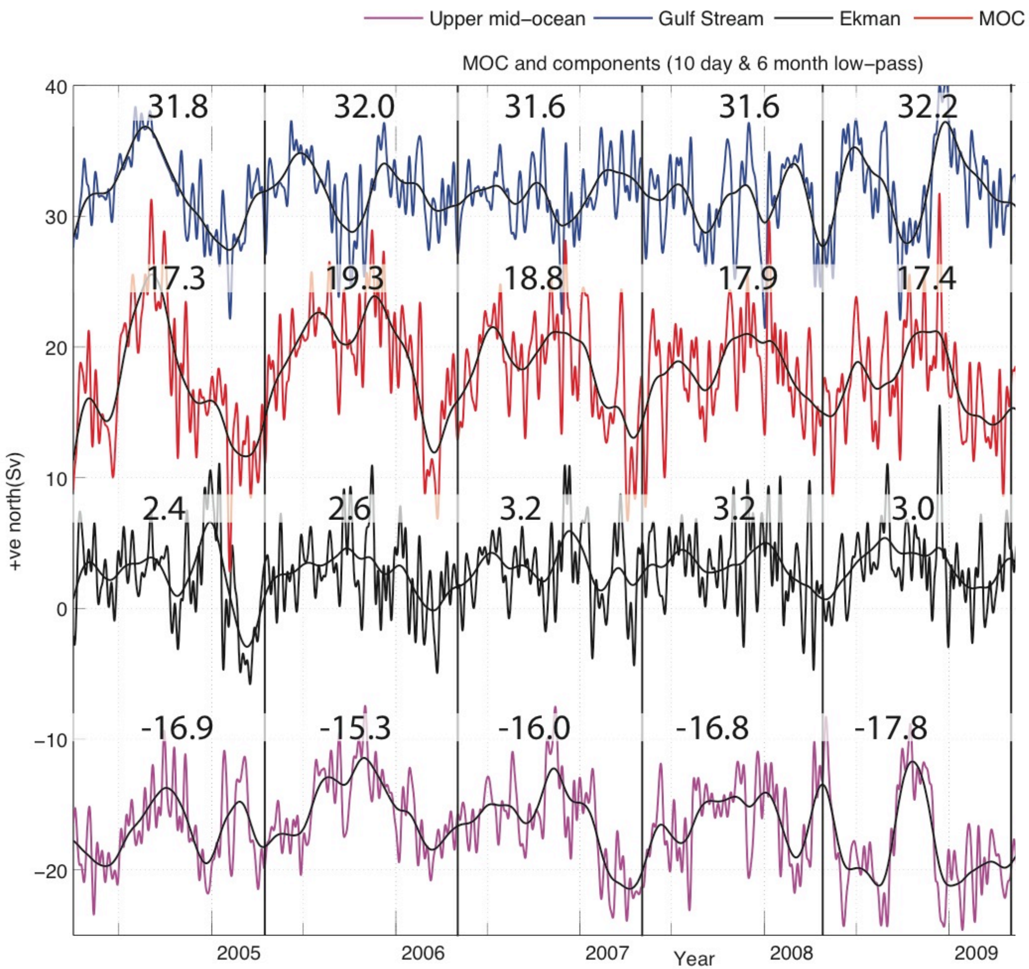
Heat Transport



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

Mean [Sv]

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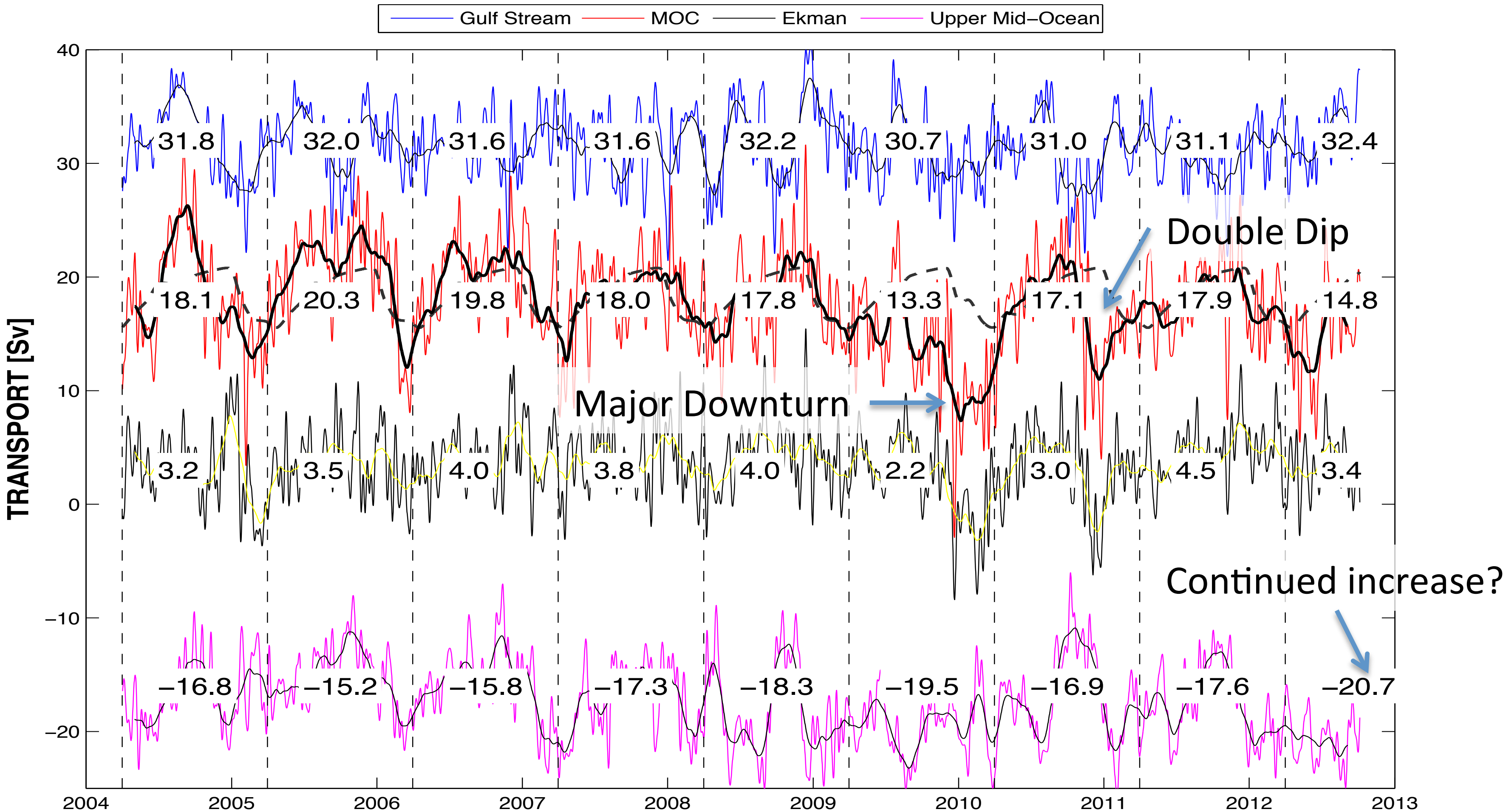
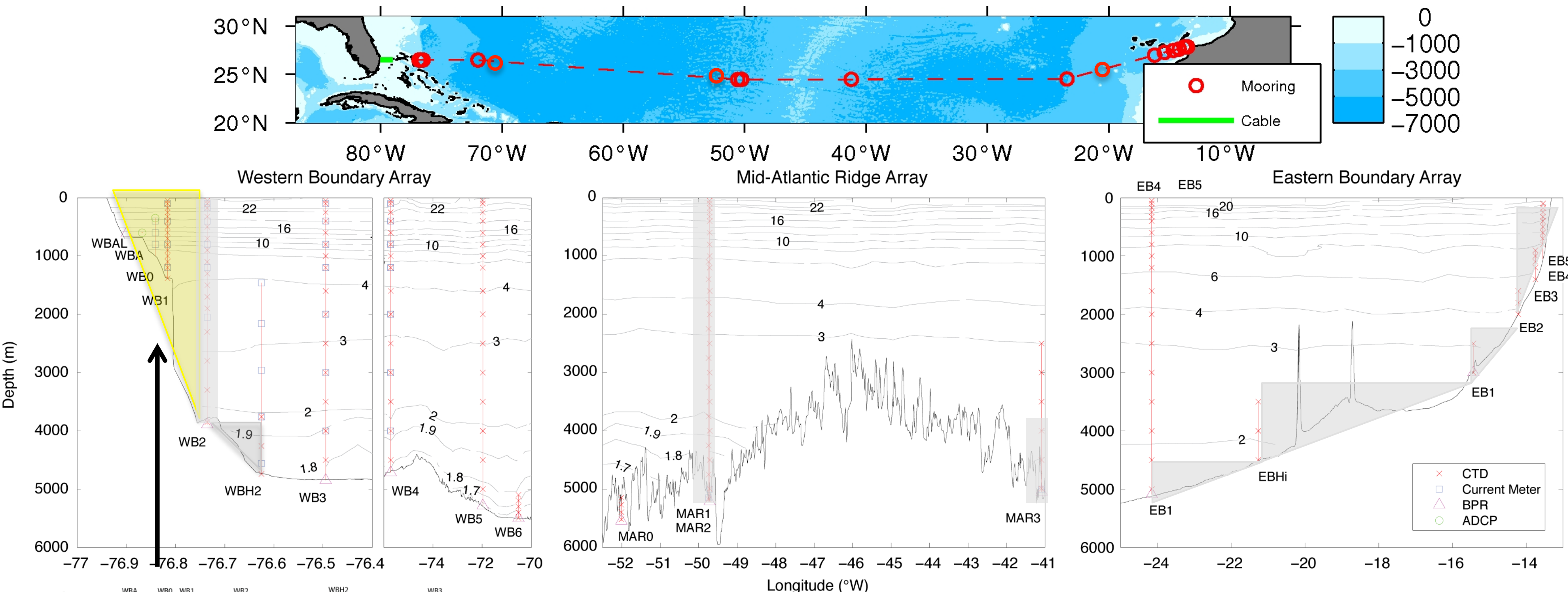
Interannual Variability

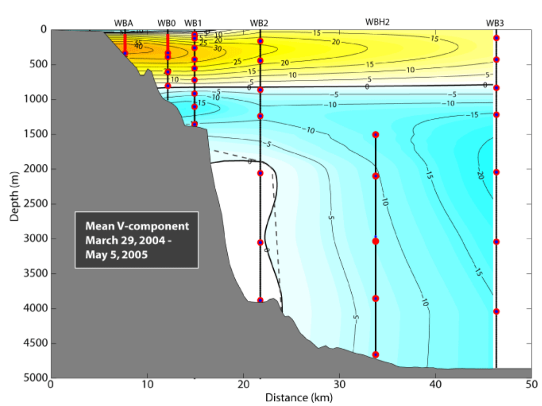


- Large downturn in 2009/10 driven by short term Ekman variability (3 months) and long term strengthening of the gyre/UMO (18 months)
- Double dip in winter 2010/11
- ERA winds is a difference from previous release

How we measure the AMOC at 26.5°N?

Boundary Currents and the mid-ocean Dynamic Height and Bottom Pressure Array

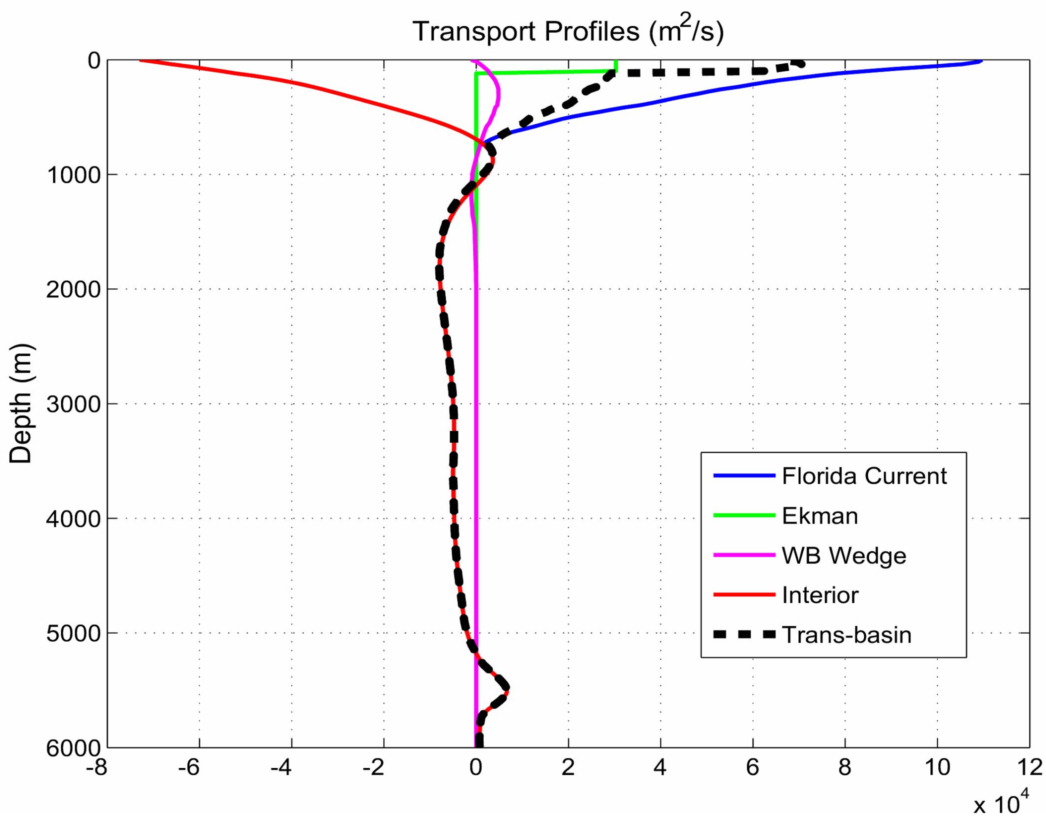


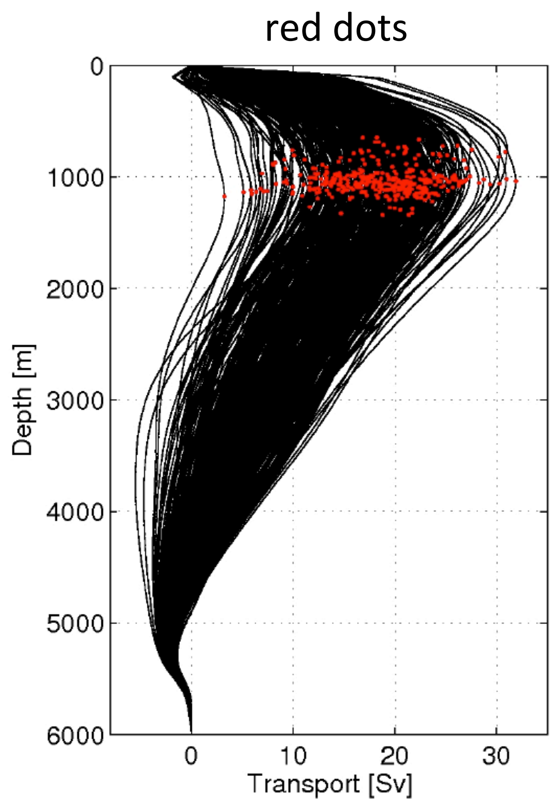


Johns, W. E., L. M. Beal, M. O. Baringer, J. Molina, D. Rayner, S. A. Cunningham, and T. O. Kanzow (2008), Variability of shallow and deep western boundary currents off the Bahamas during 2004-2005: First results from the 26°N RAPID-MOC array, *J. Phys. Oceanog.*, *38*(3), 605-623.

Rayner, D., et al. (2011), Monitoring the Atlantic Meridional Overturning Circulation, *Deep Sea Research II*, *in press*.

The AMOC Streamfunction





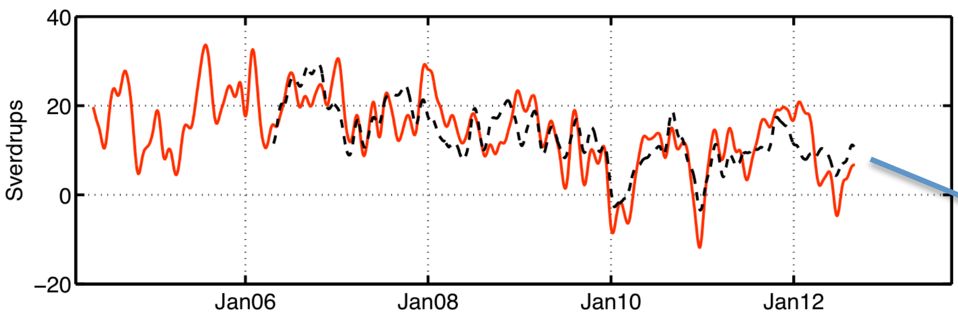
$$T_{AMOC}(t,z) = T_{GS}(t,z) + T_{Ek}(t,z) + T_{WBW}(t,z) + T_{INT}(t,z) + T_{AABW}(z) + T_{comp}(t,z)$$

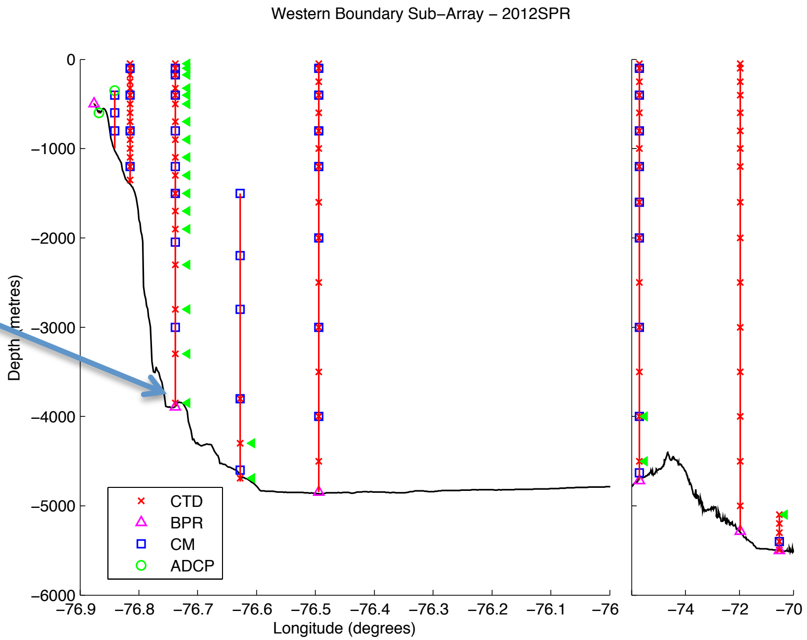
Internal Transport: $$T_{INT}(t,z) = \frac{\Delta D_{ref=4820}(t,z)}{f}$$

The AMOC: $$\varphi_{MAX}(t) = \int_{h_{\varphi MAX}}^{0} T_{AMOC}(z,t)\,dz$$

Mass compensation

BPR transport (black, dashed) and Mass compensation (red)





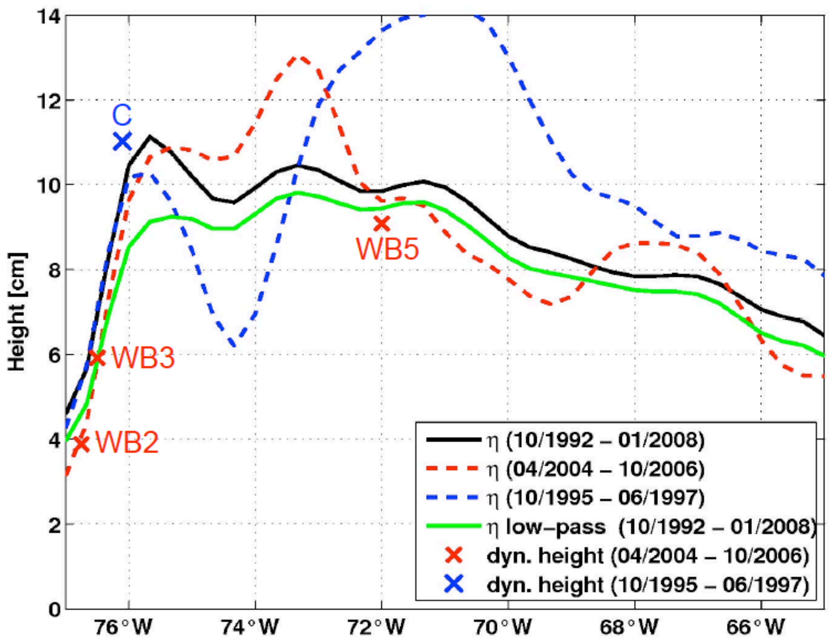
$$T_{flo}(t,z) + T_{ek}(t,z) + T_{wbw}(t,z) + T_{int}(t,z) = -T_{ext}(t,z)$$

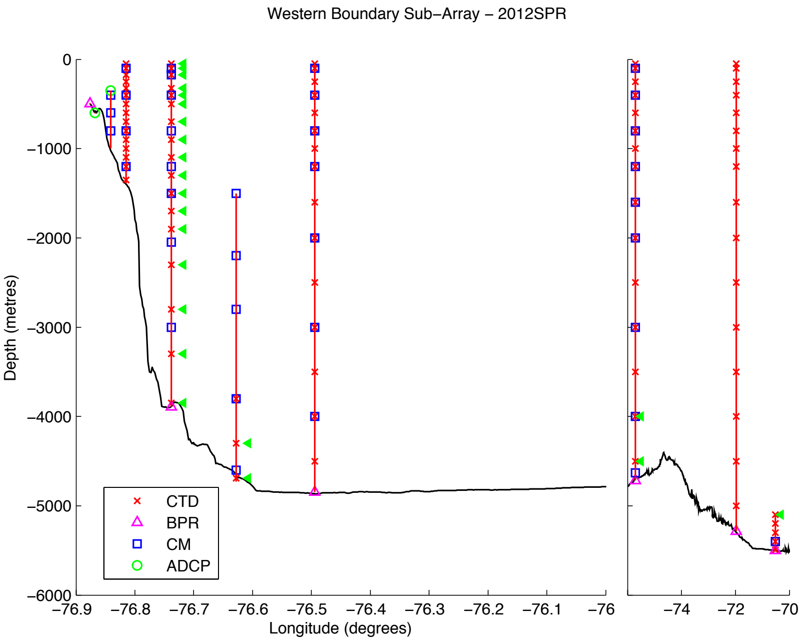
$$T_{ext}(t,z) = v(t)_{comp,ref}.w(z),$$

- 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

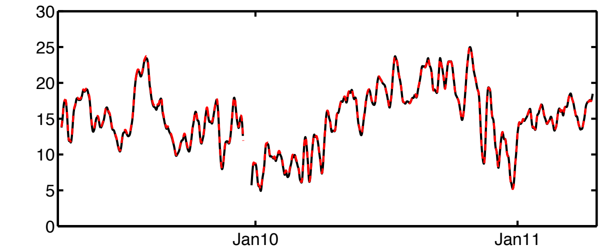
Kanzow, T., H. Johnson, D. Marshall, S. A. Cunningham, J. J.-M. Hirschi, A. Mujahid, H. L. Bryden, and W. E. Johns (2009), Basin-wide integrated volume transports in an eddy-filled ocean, *J. Phys. Oceanog.*, *39*(12), 3091–3110.

Recent Changes

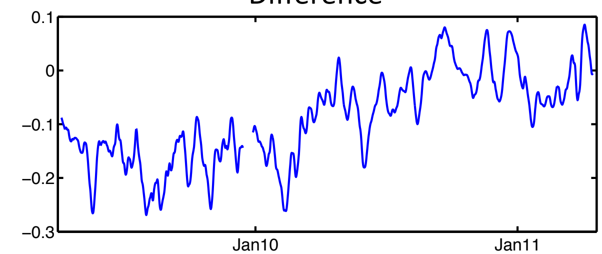
1. **Impact of time varying AABW**
2. Moving from EOS-80 to TEOS-10
3. Improved extrapolation above shallowest measurement

- 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 72ºW
- Increases AMOC by 0.2 Sv

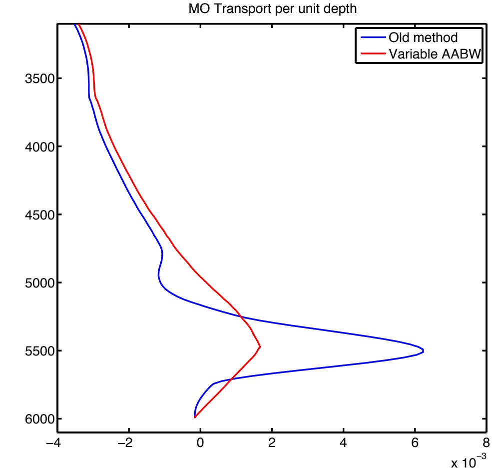
AMOC with time-varying AABW (red) and non-varying AABW (black)



Difference



MO Transport per unit depth

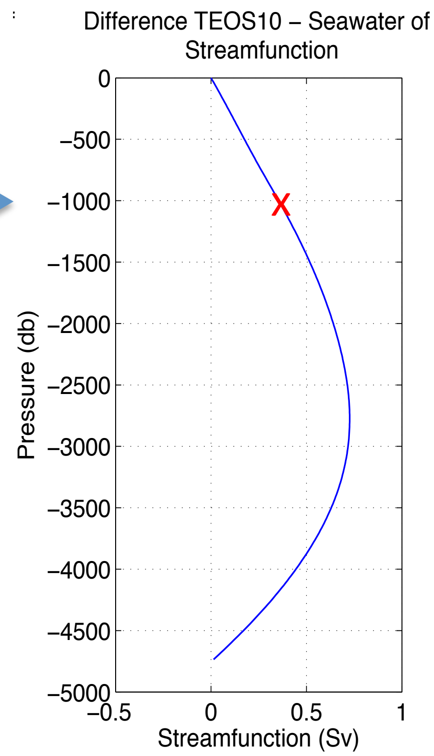


Frajka-Williams et al., (2011) Variability of Antarctic Bottom Water at 24.5°N in the Atlantic. *JGR*

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



Millero et al., (2008). **The composition of Standard Seawater and the definition of the Reference-Composition Salinity Scale** *DSR1*

Recent Changes

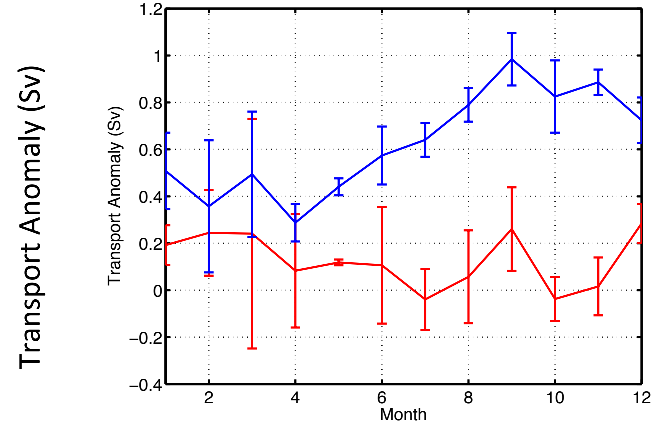
1. Impact of time varying AABW
2. Moving from EOS-80 to TEOS-10
3. **Improved extrapolation above shallowest measurement**

Ben Moat
Poster Session 1

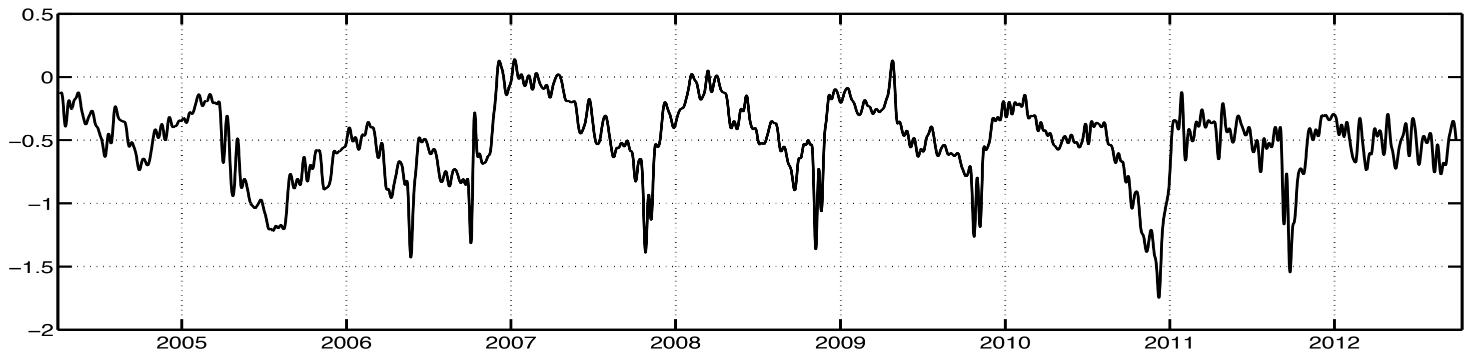
Haines et al., (2013). **Atlantic meridional heat transports in two ocean reanalyses evaluated against the RAPID array,** *GRL*

- 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

Old (blue) and new (red) methods

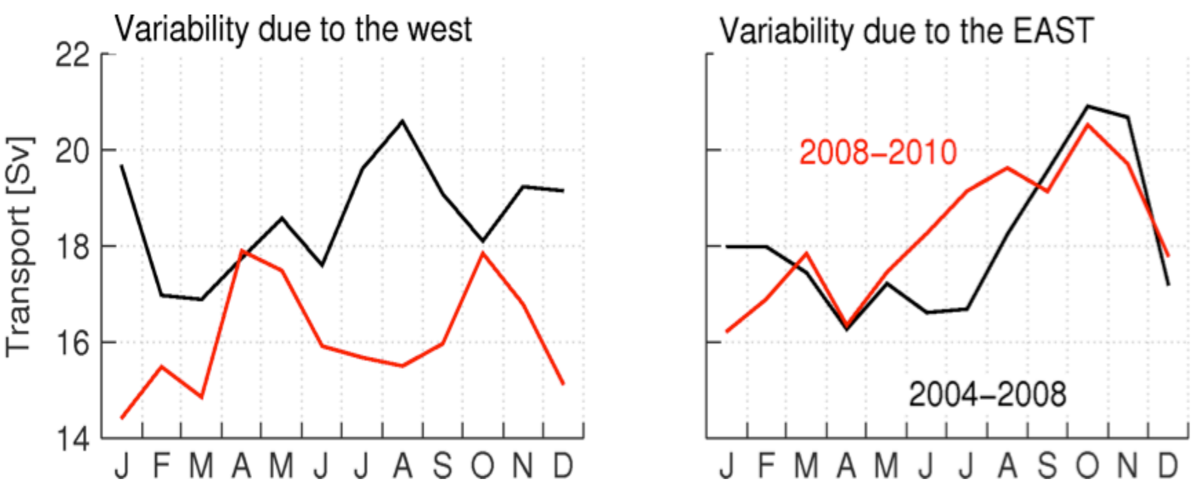


Summary: 0.2 Sv AABW change, -0.4 Sv TEOS-10 and improved seasonal extrapolation

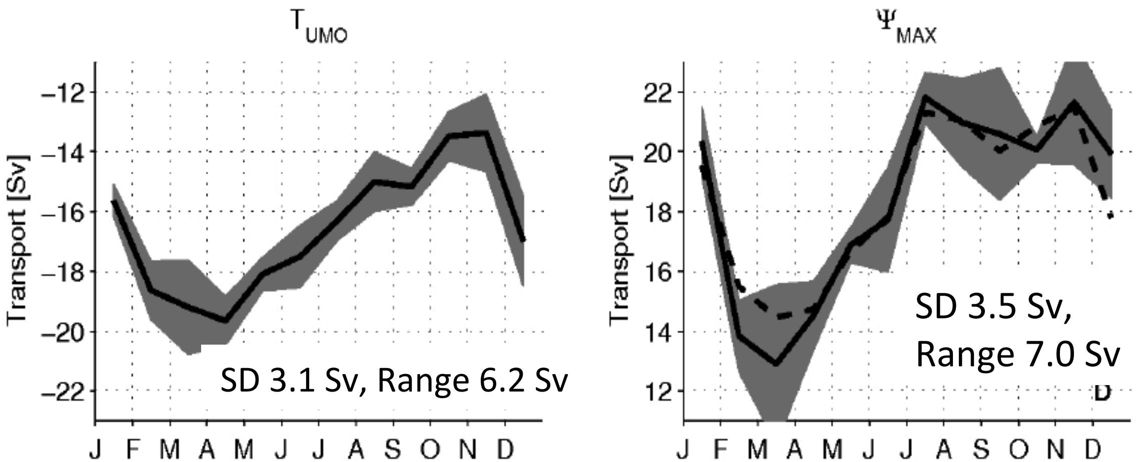


SEASONAL CYCLE

The Seasonal Cycle due to the East

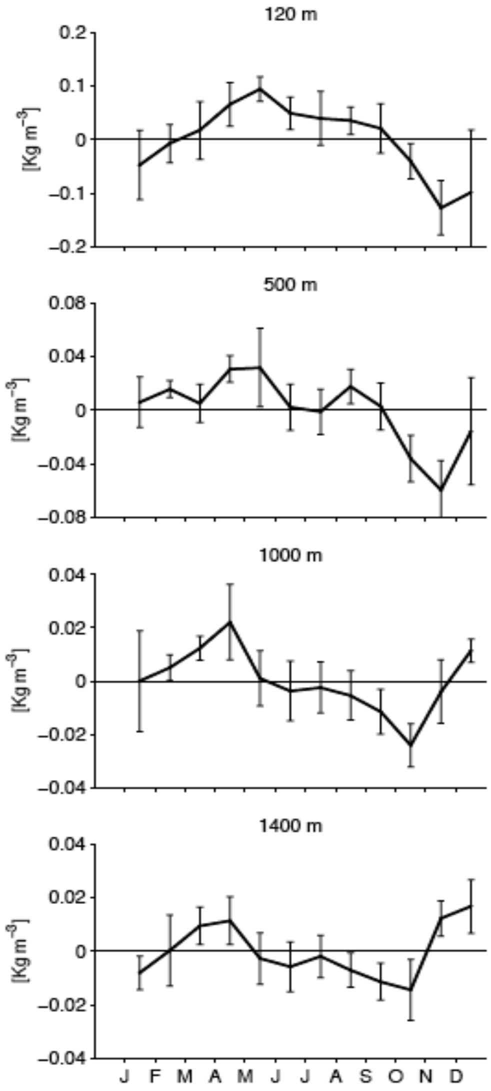


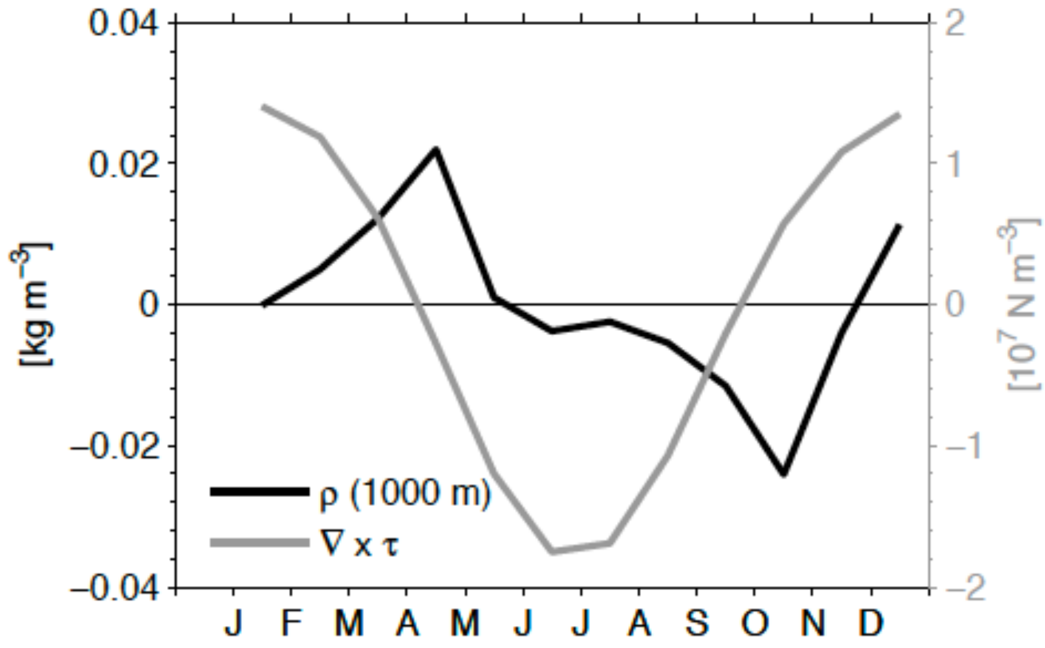
Kanzow, T., et al. (2010), Seasonal variability of the Atlantic meridional overturning circulation at 26.5°N, *J. Clim.*, *23*(21), doi: 10.1175/2010JCLI3389.1171.



- 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





Chidichimo, M. P., T. Kanzow, S. A. Cunningham, and J. Marotzke, 2010: The contribution of eastern-boundary density variations to the Atlantic meridional overturning circulation at 26.5°N. *Ocean Science*, **6,** www.ocean-sci-discuss.net/6/2507/2009/.

HEAT TRANSPORT

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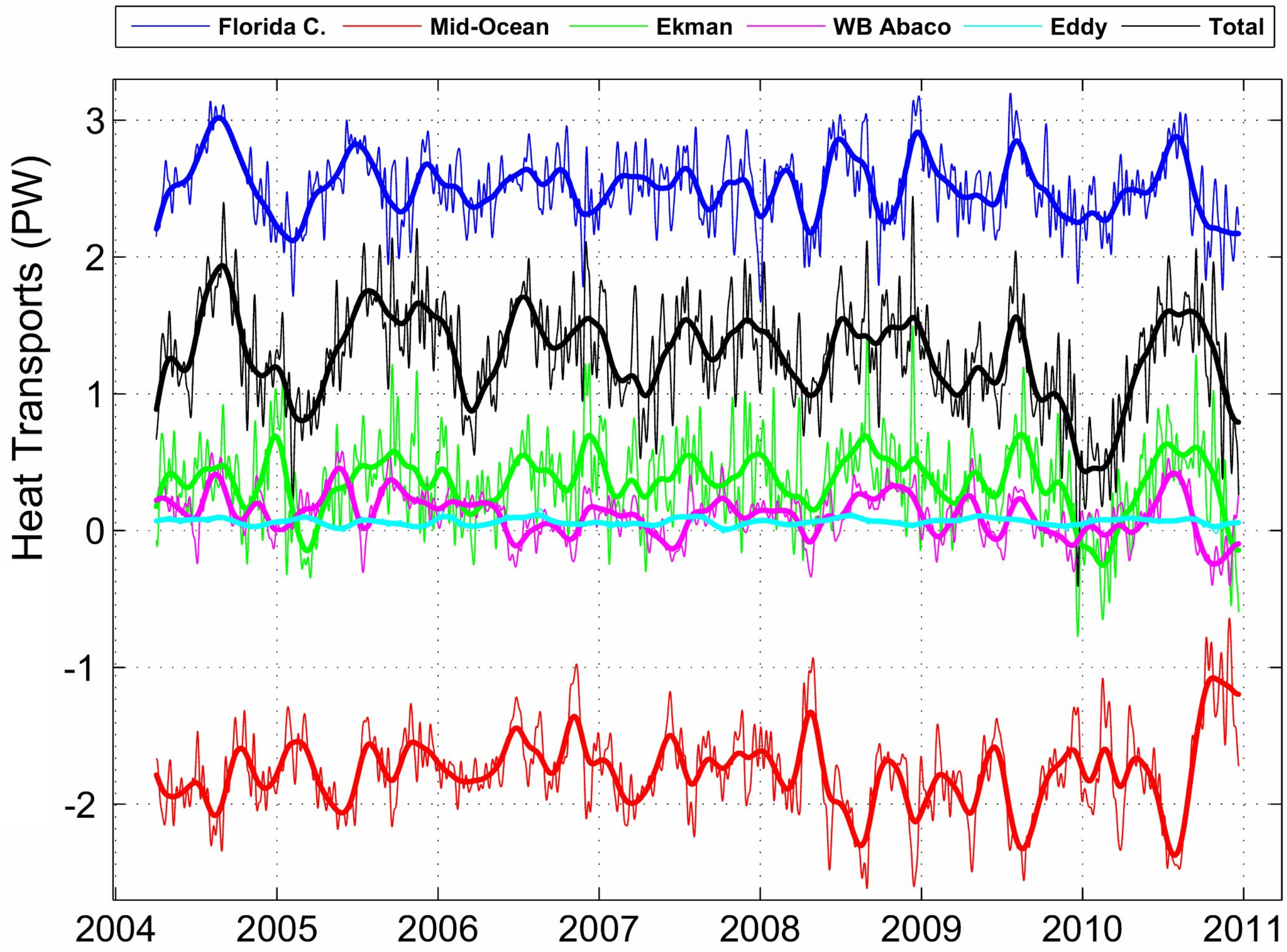
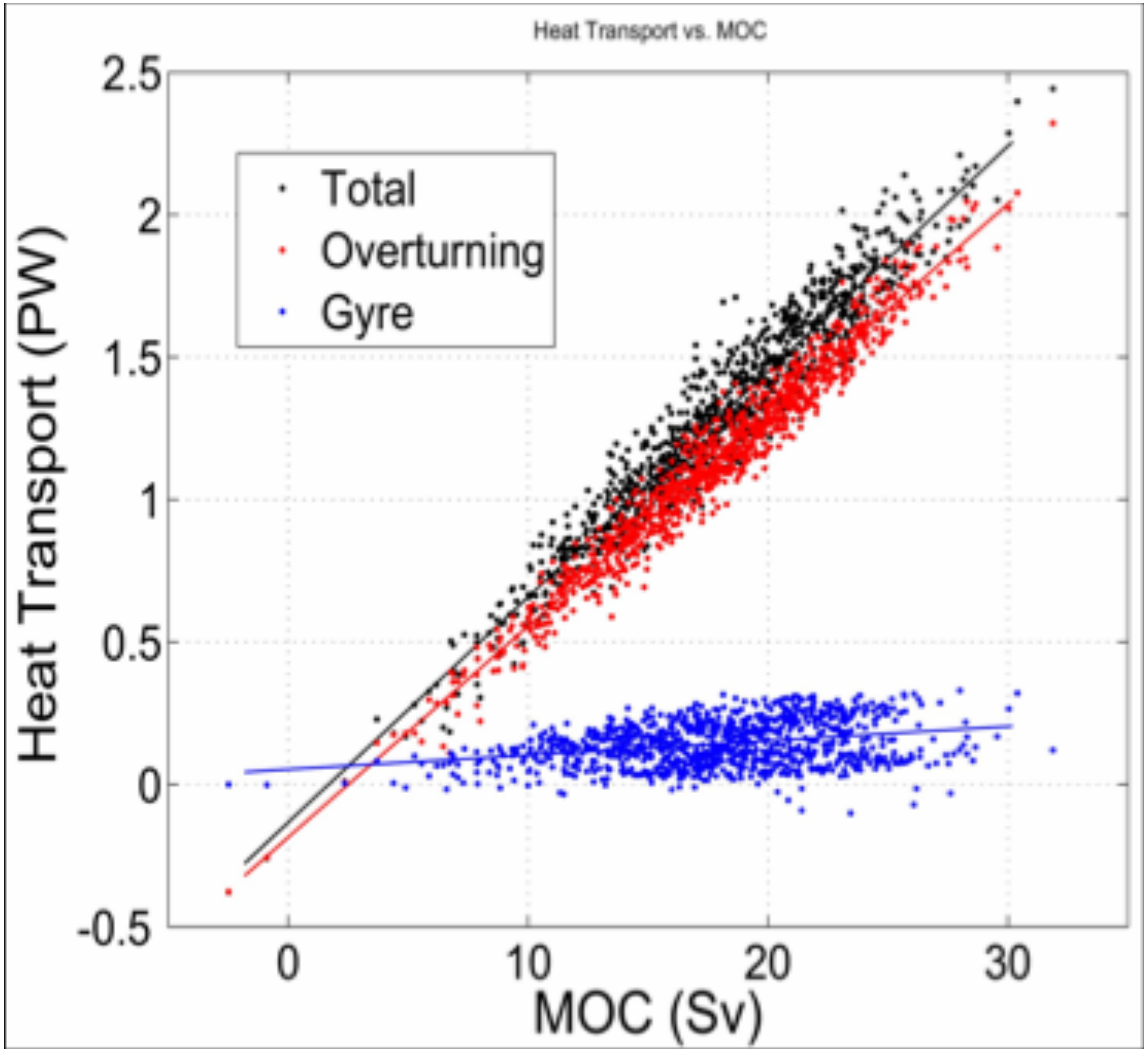
Net Heat Flux = 1.27 ± 0.30 PW (uncertainty 0.14 PW)



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

Johns, W. et al. (2011), Continuous, Array-based Estimates of Atlantic Heat Transport at 26.5°N, *J. Clim.*, *24,* pp. 2429–2449.

HEAT TRANSPORT

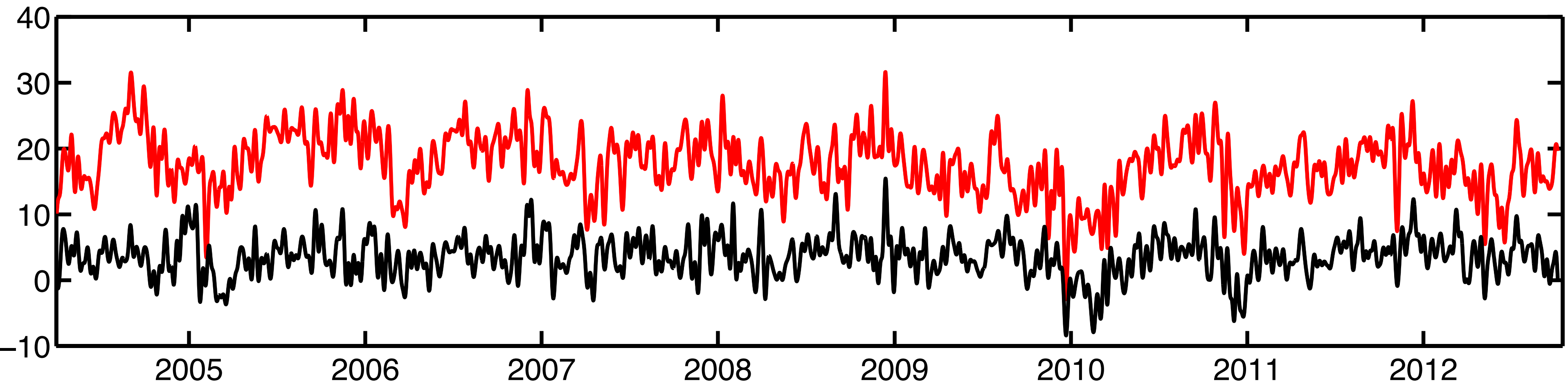


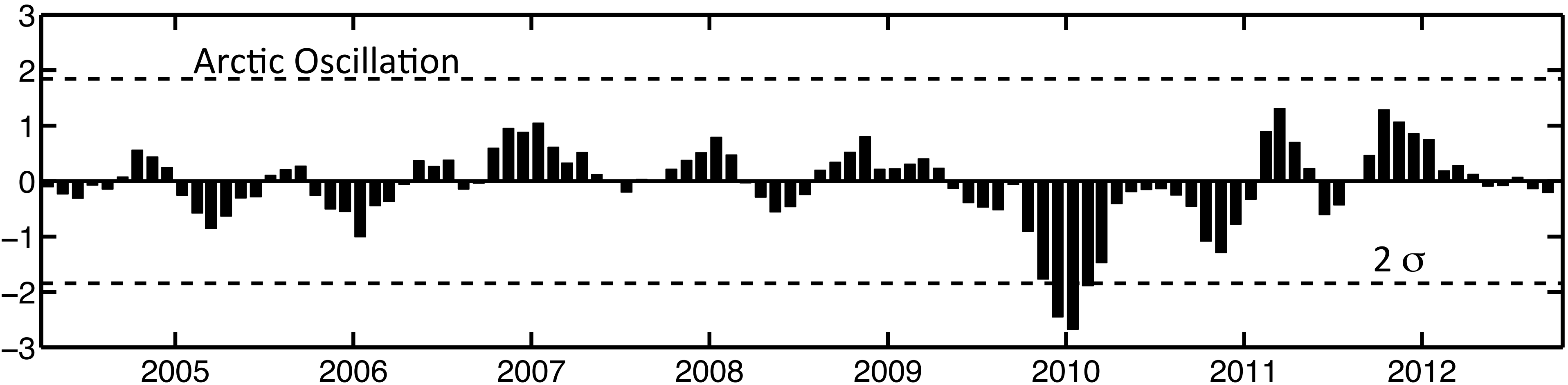
- Heat transported north in GS is recirculated by mid-ocean and overturning circulation
- 90% is in the overturning

INTERANNUAL VARIBILITY

Slowdown in winter 2009/10

Ekman shift associated with negative Arctic Oscillation/NAO
Only explains 3 month downturn

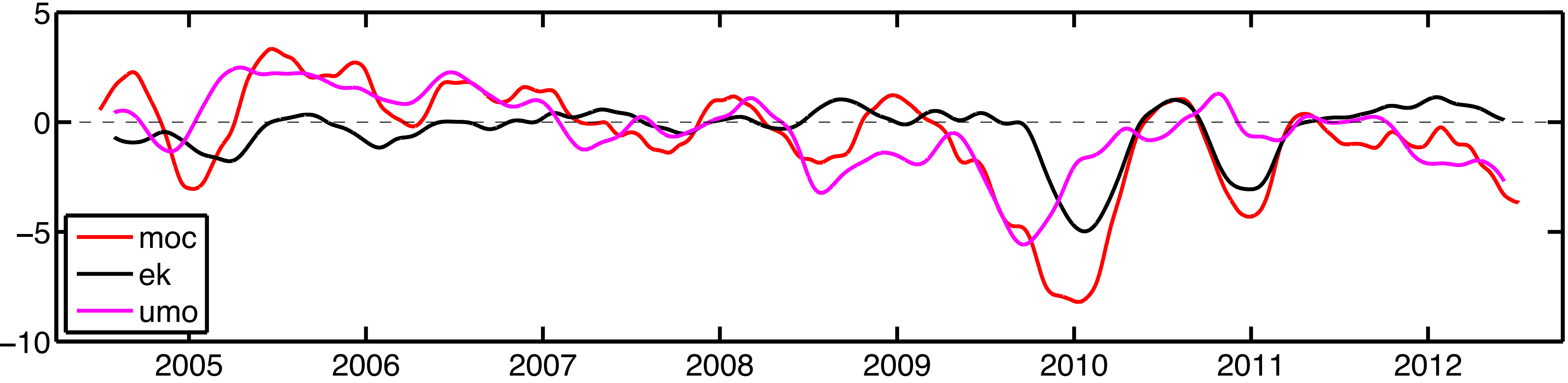




Slowdown in winter 2009/10

Longer time scale changes: 18 month weakening of MOC

Anomalously southward UMO: shift from overturning to gyre circulation



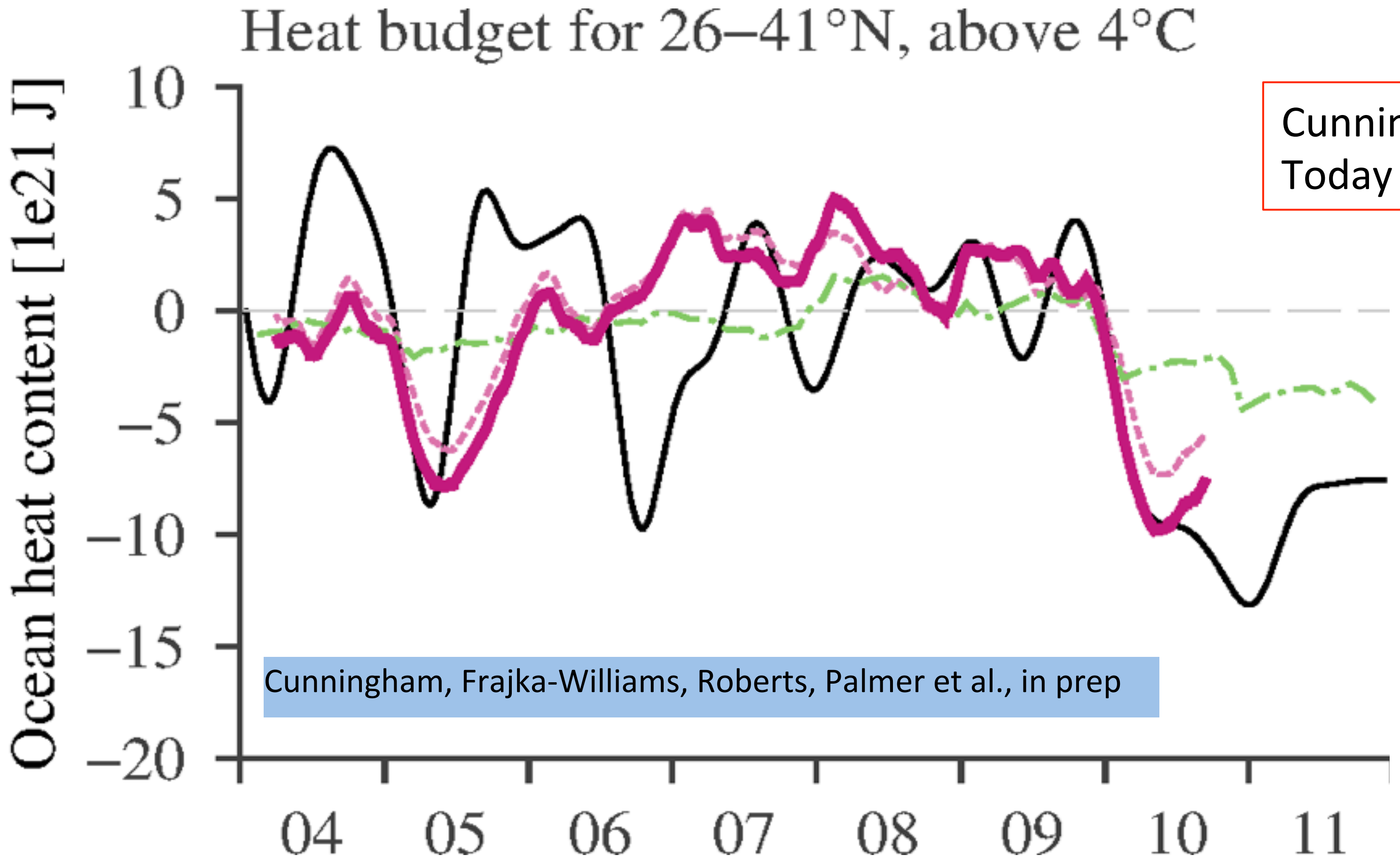
*Seasonal cycle was removed, and data smoothed with 180-day filter

McCarthy, G., et al. (2012), Observed Interannual Variability of the Atlantic Meridional Overturning Circulation at 26.5N, Geo. Res. Lett.

Implications for Heat Content

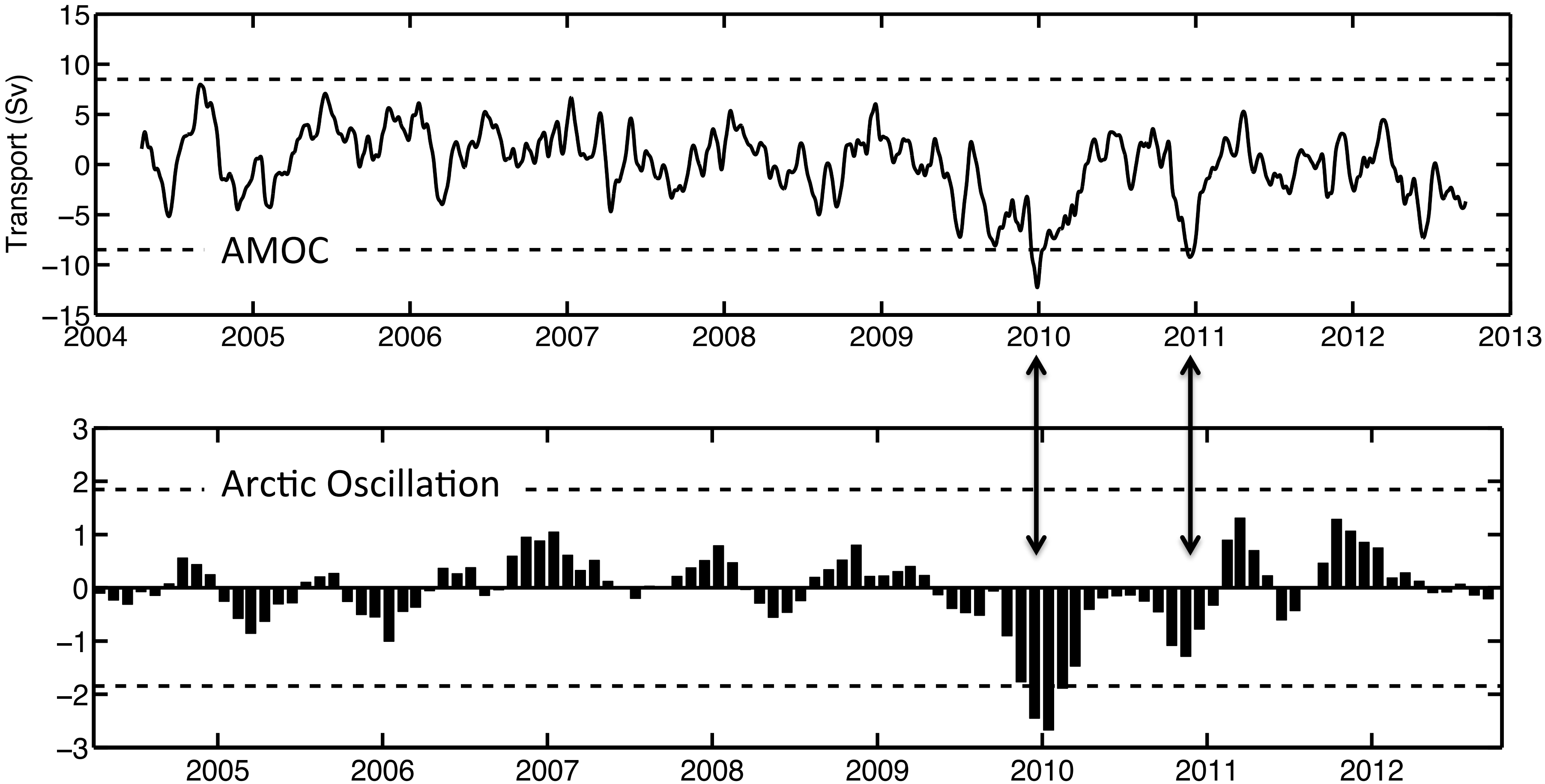
Expect for a balanced heat budget

the thick pink curve (total predicted heat content change) would match the black curve (observed heat content change)



Cunningham talk
Today 14.30

Double Dip: Winter 2010/11



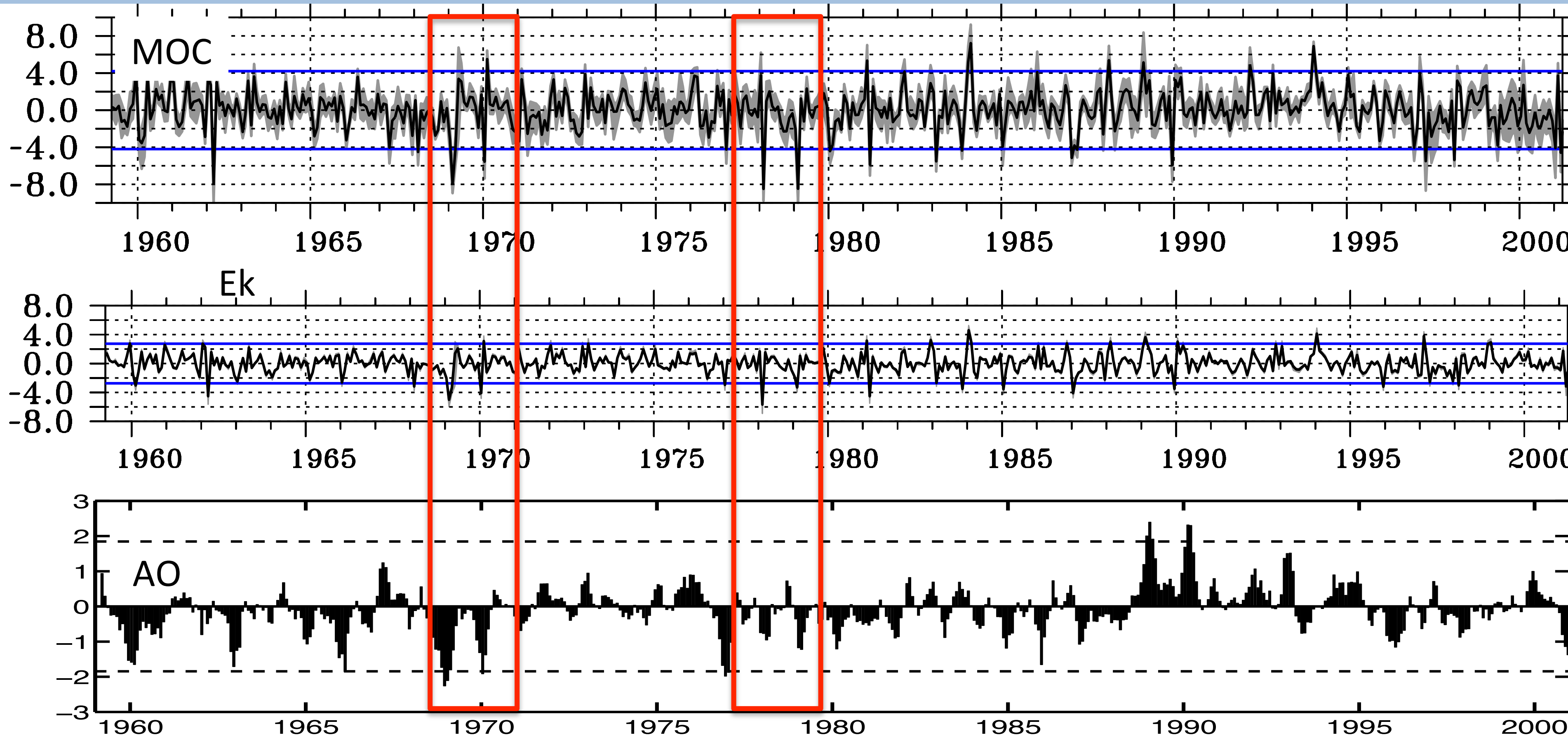
Second large dip in AMOC transport in winter 2010/11 following Arctic oscillation low

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

Historical Analogues



In an ensemble of NEMO runs, double dips of MOC have occurred previously in 1969/70 and 1978/79

Blaker talk
Today 14.50

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

Blaker et al. in prep, Historical analogues of the recent extreme minima observed in the Atlantic meridional overturning circulation at 26◦N. Clim. Dyn.

Corresponds with Ekman lows

Double Dip: Winter 2010/11

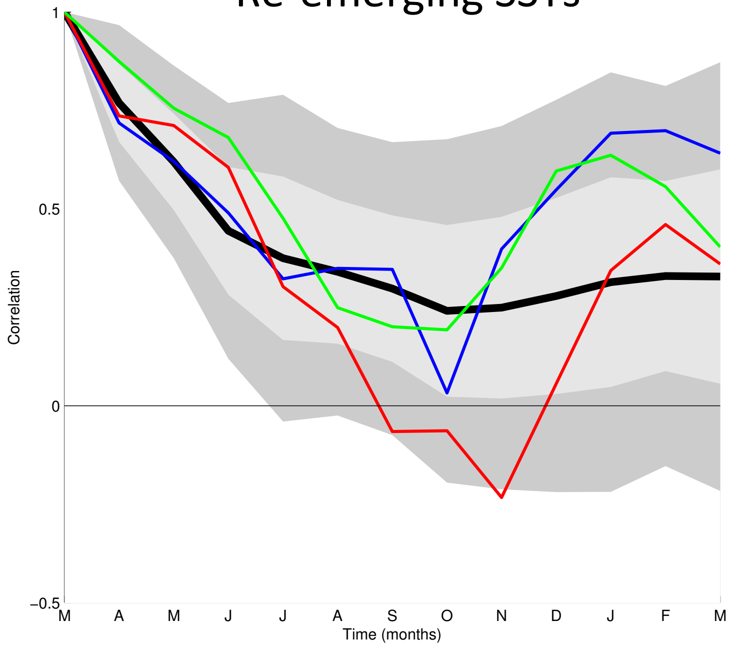
- Reemerging SSTs are observed in 1969/70 as well as in 2010/11
- These were conducive to the development of the negative NAO in winter 2010

Buchan et al. submitted, North Atlantic SST anomalies and the cold north European weather events of winter 2009/10 and December 2010. *submitted to Monthly Weather Review*

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

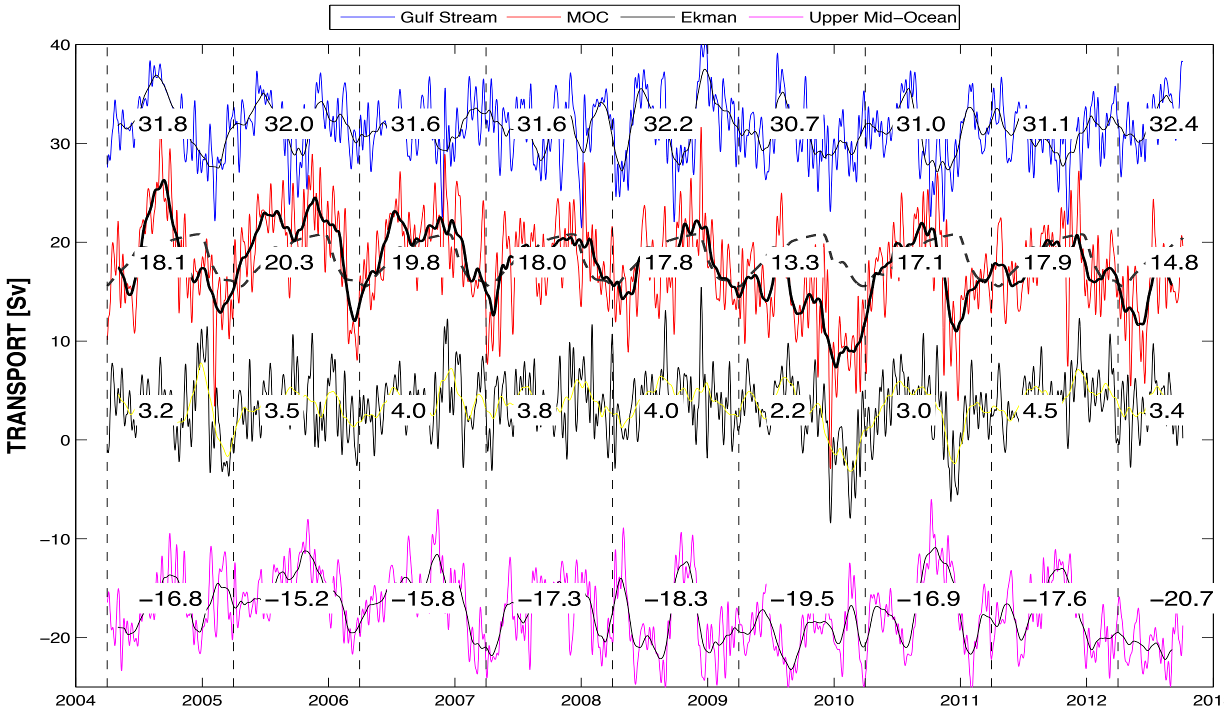
Maidens et al. in prep, The Influence of Surface Forcings on Prediction of the North Atlantic Oscillation Regime of Winter 2010-11. *submitted to Monthly Weather Review*

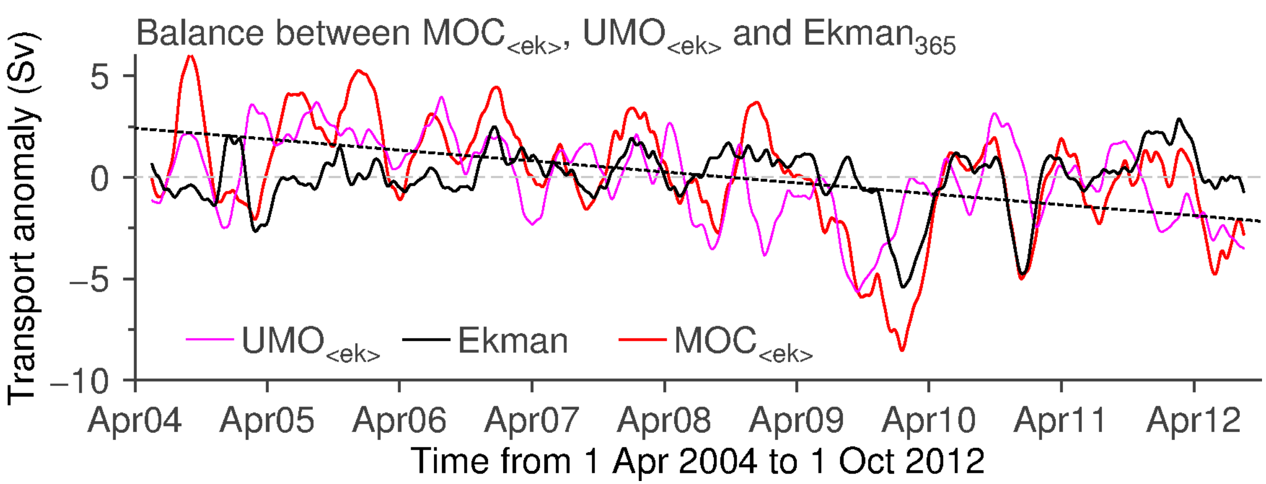
Re-emerging SSTs



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 26ºN 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.

End