Observations and dynamics of seasonal to interannual timescales: perspectives and future challenges

David Marshall (*University of Oxford*)

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2. Opportunities arising from new and continuing observations over the next 5 years.

3. Some (fairly random) thoughts on state estimation, numerical models, conceptual models, AMOC prediction.

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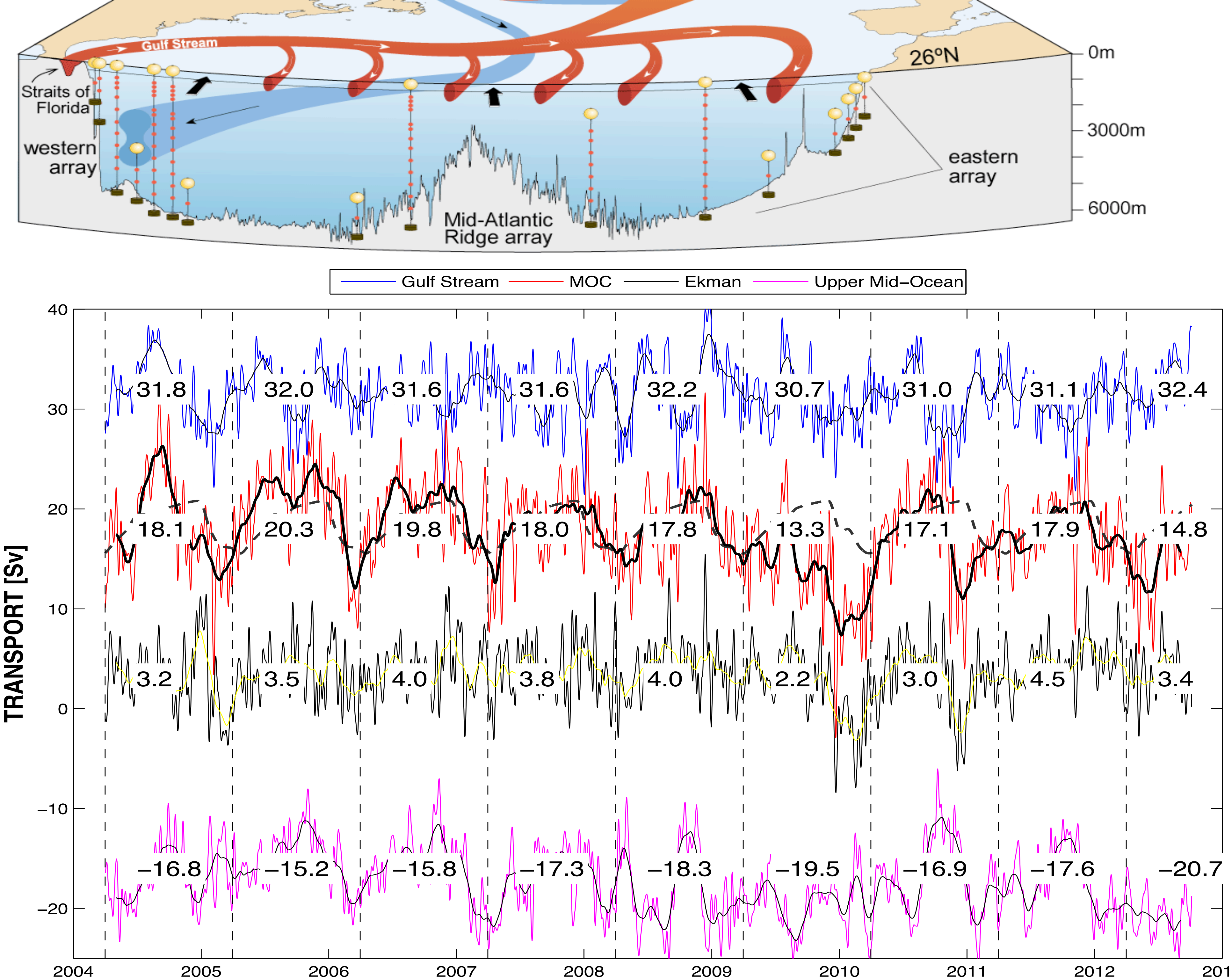
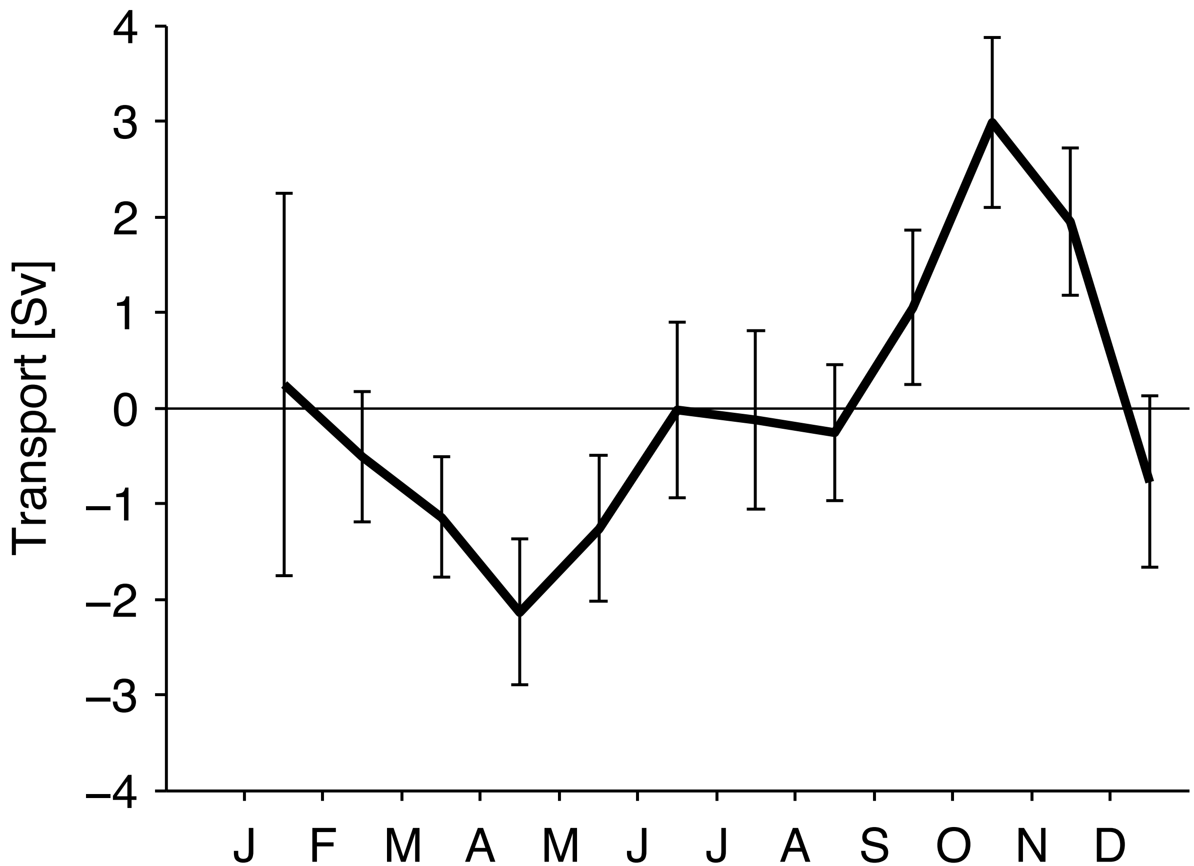


courtesy: Gerard McCarthy

The contribution of eastern-boundary density variations to the Atlantic meridional overturning circulation at 26.5° N

M. P. Chidichimo[1,2], T. Kanzow[3,4], S. A. Cunningham[3], W. E. Johns[5], and J. Marotzke[1]

Monthly-mean contributions of eastern boundary density to seasonal cycle of the AMOC:



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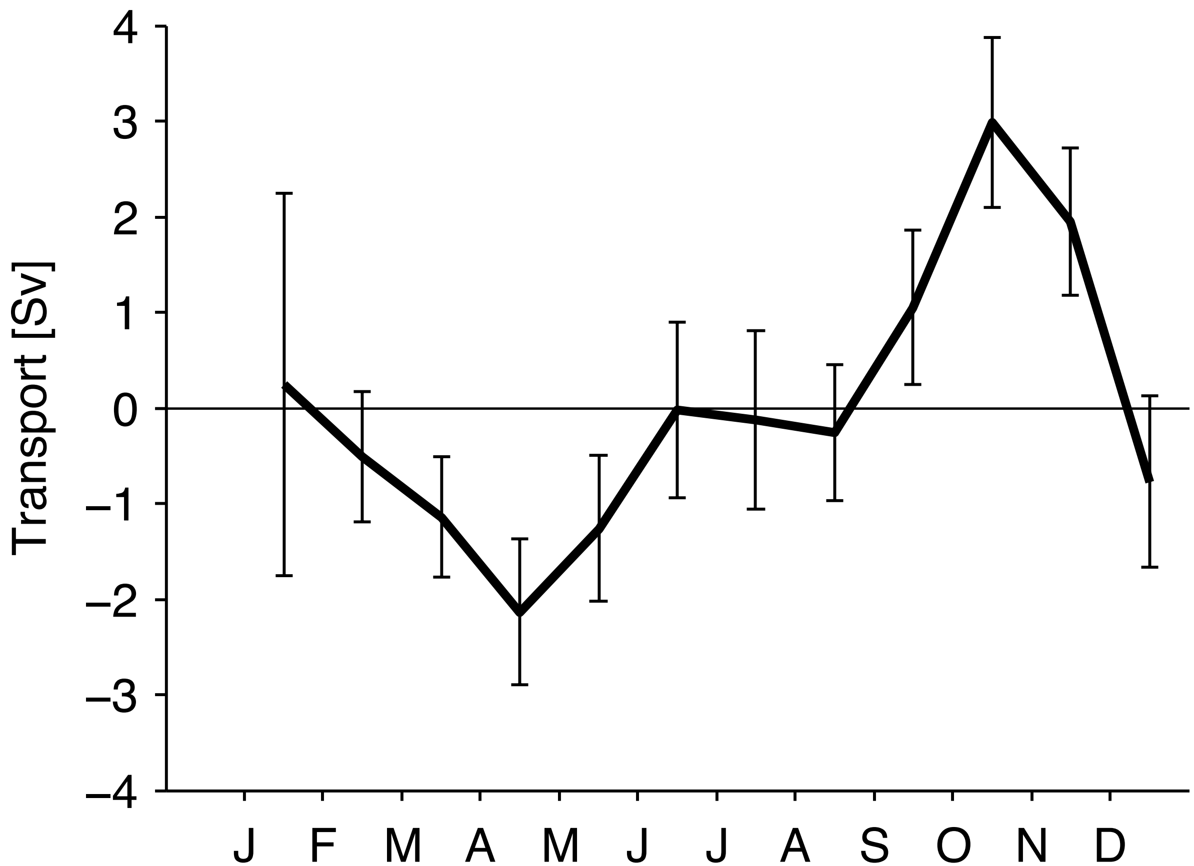
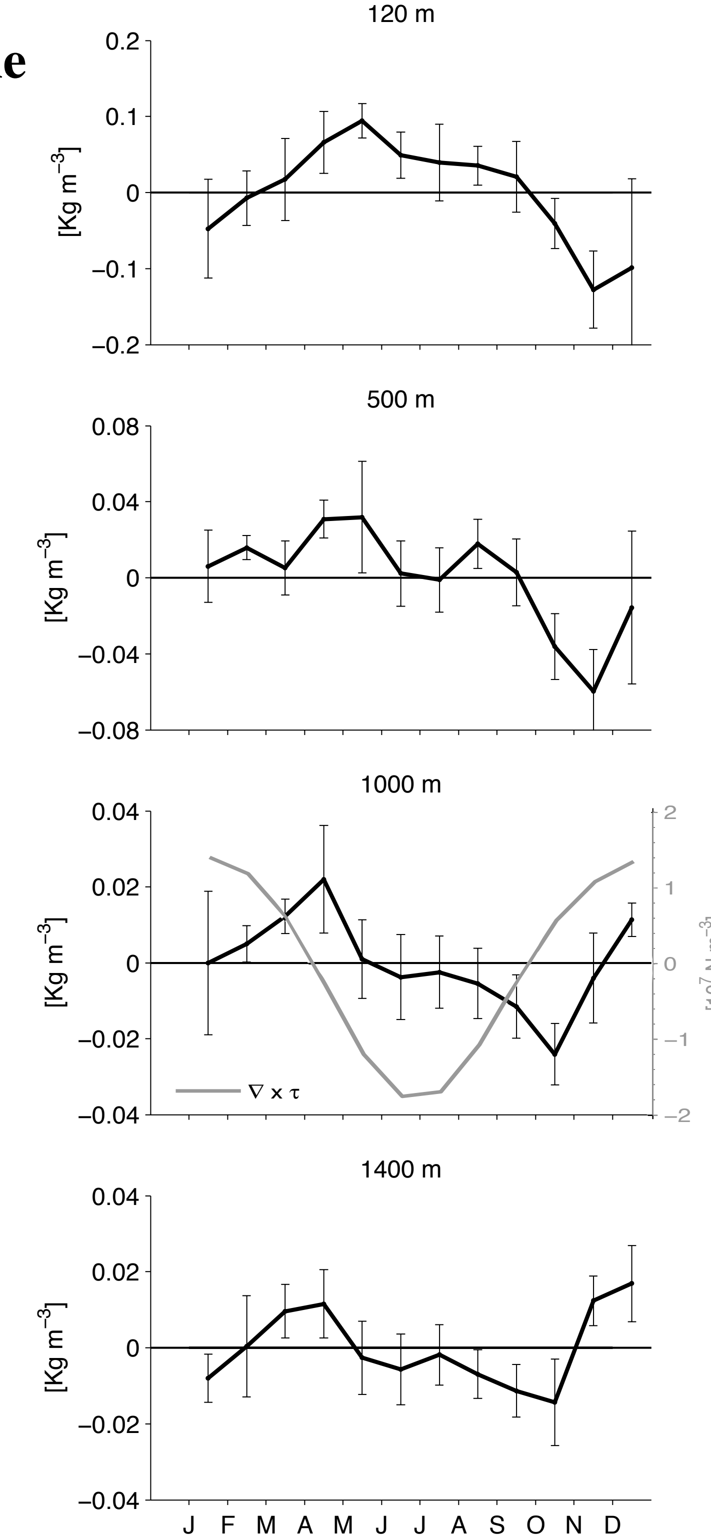
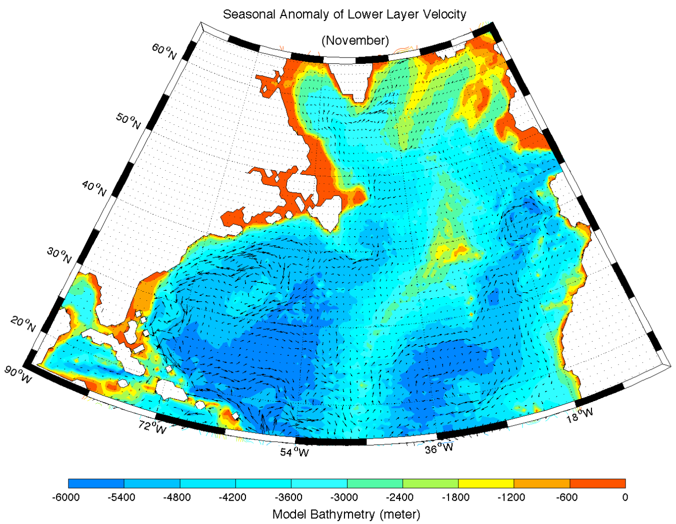
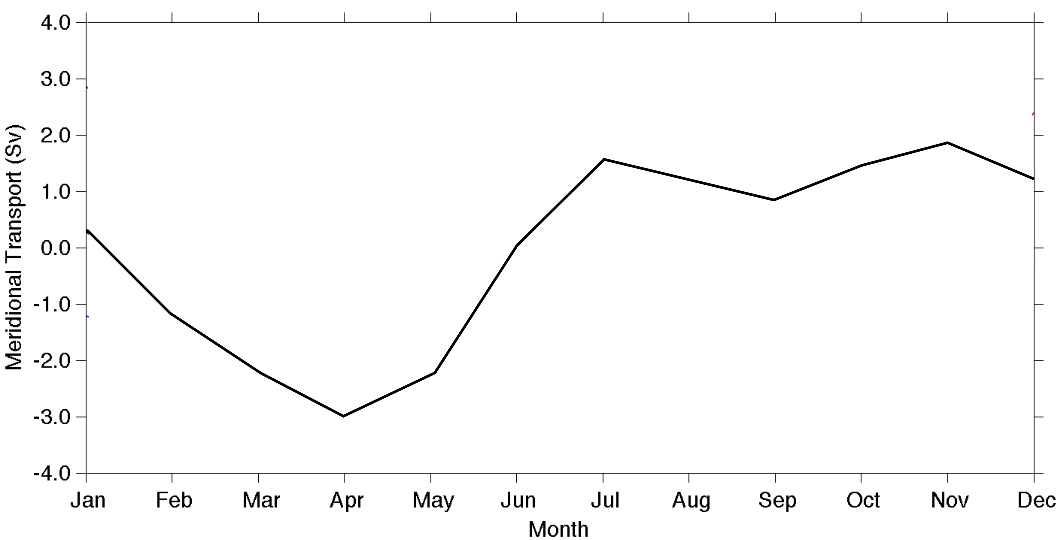




Wind-Stress Forcing of Seasonal AMOC Variability in a Two-Layer Model

Jiayan Yang
Department of Physical Oceanography, Woods Hole Oceanographic Institution





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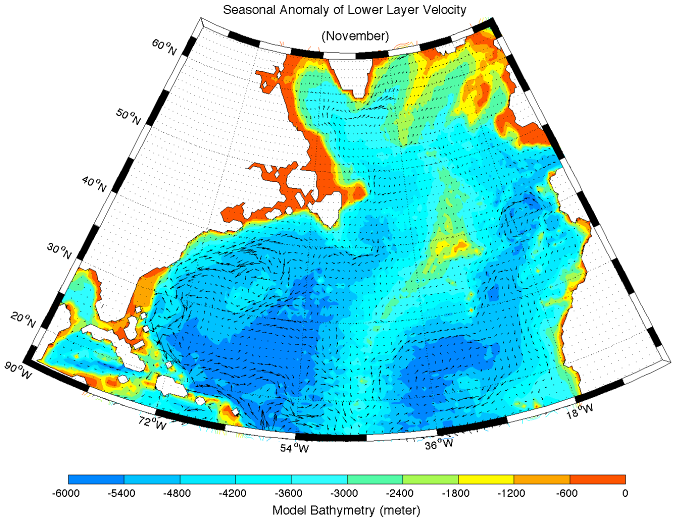

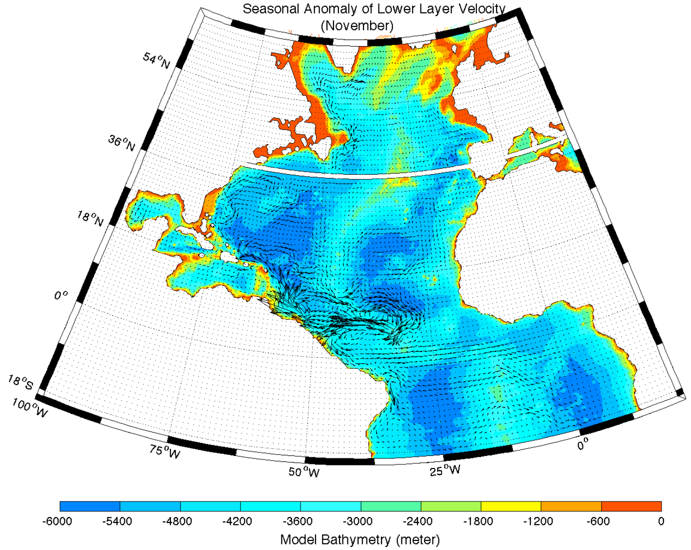

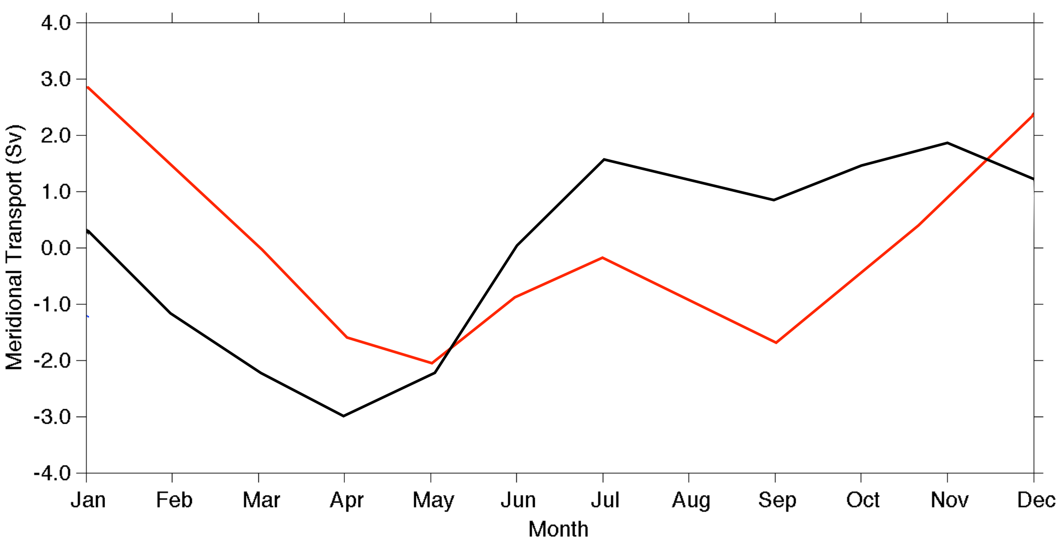

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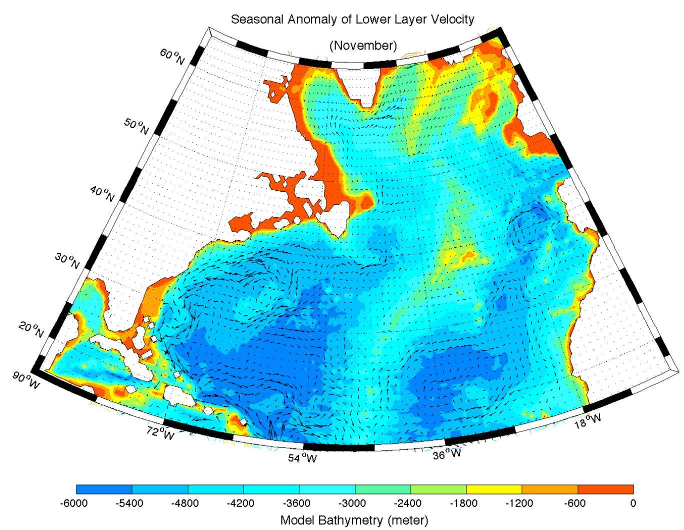
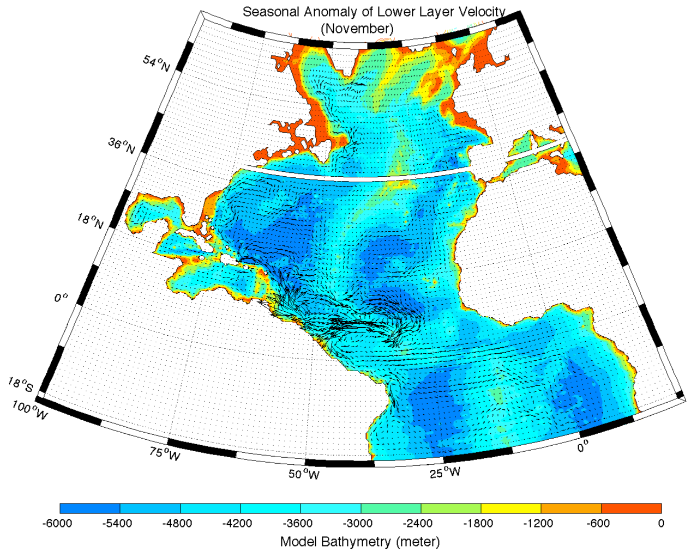
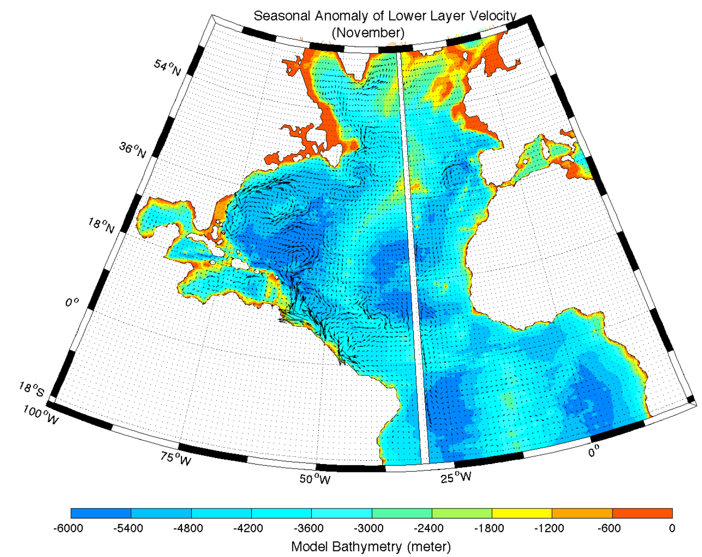
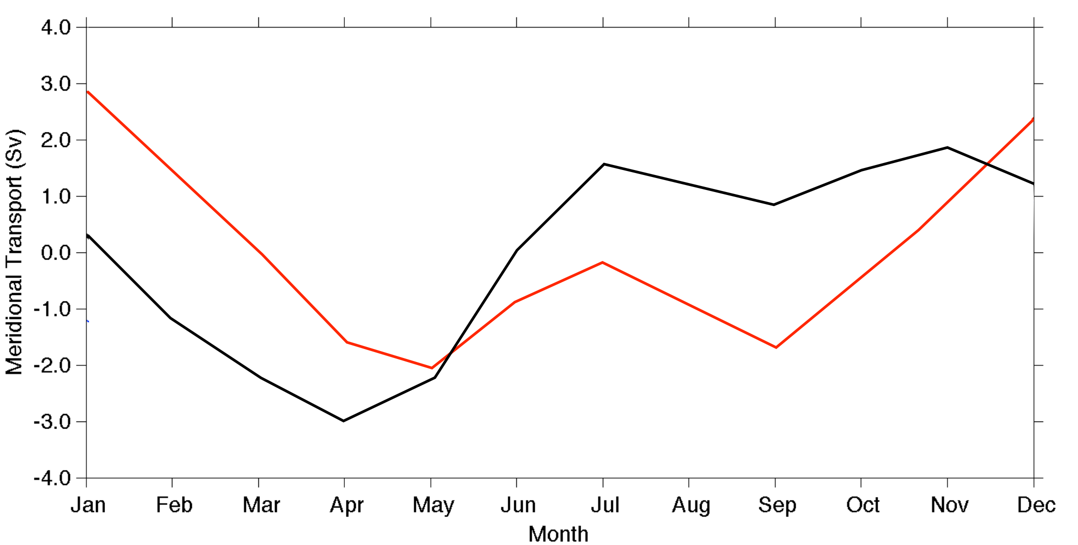
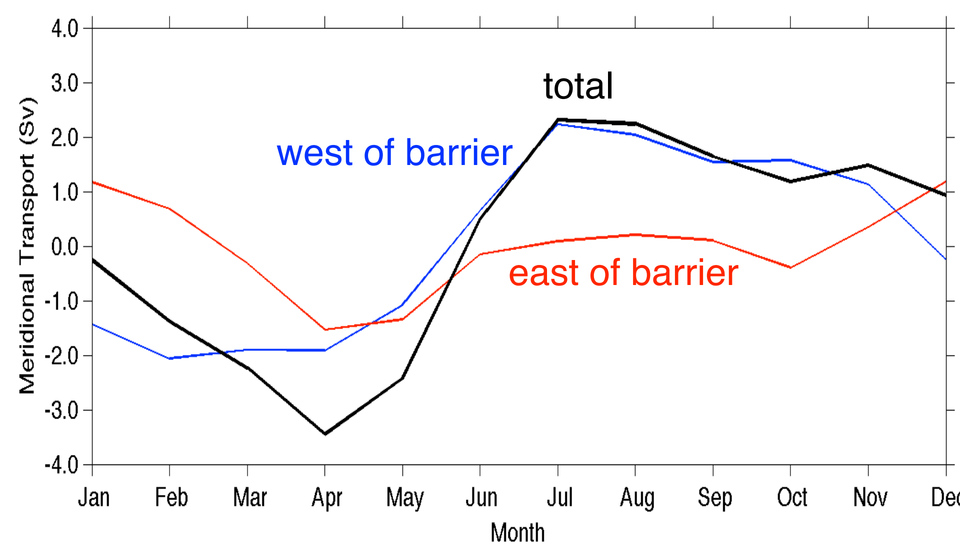
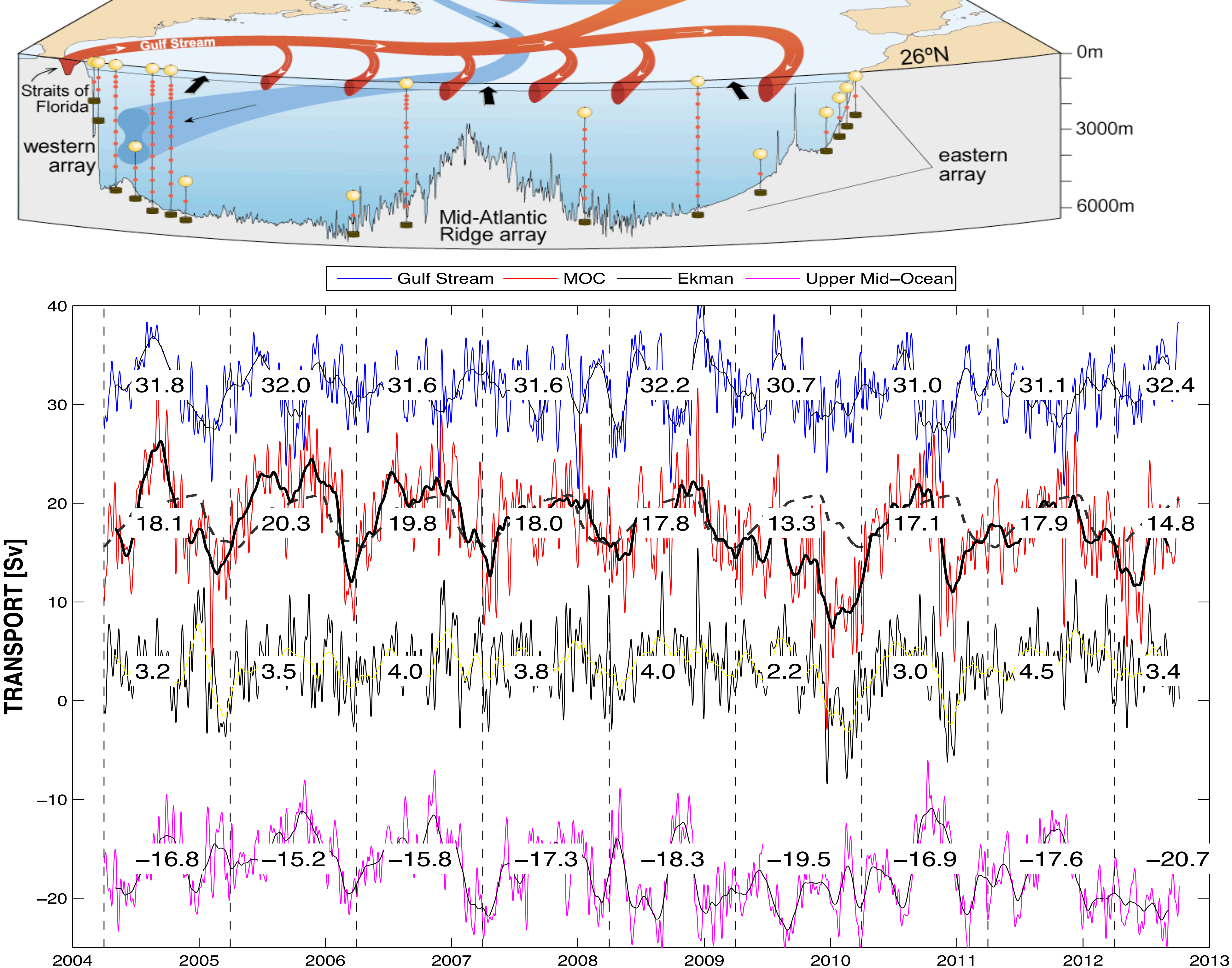










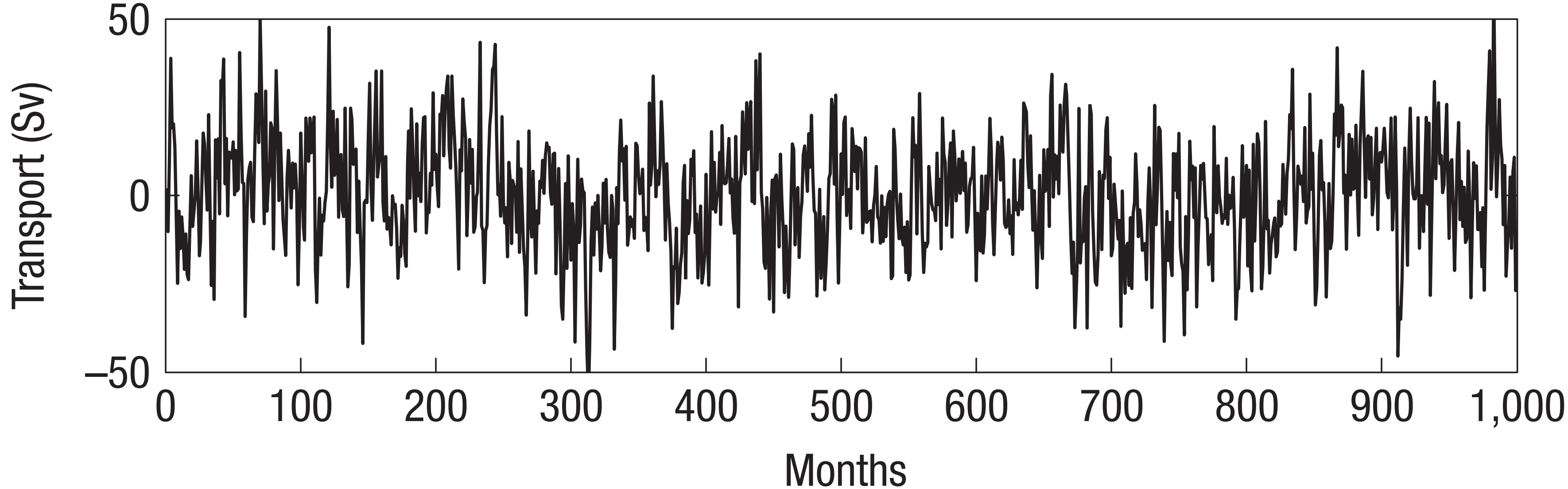


courtesy: Gerard McCarthy

Mass and volume transport variability in an eddy-filled ocean

CARL WUNSCH

claimed AMOC signal should be swamped by eddies



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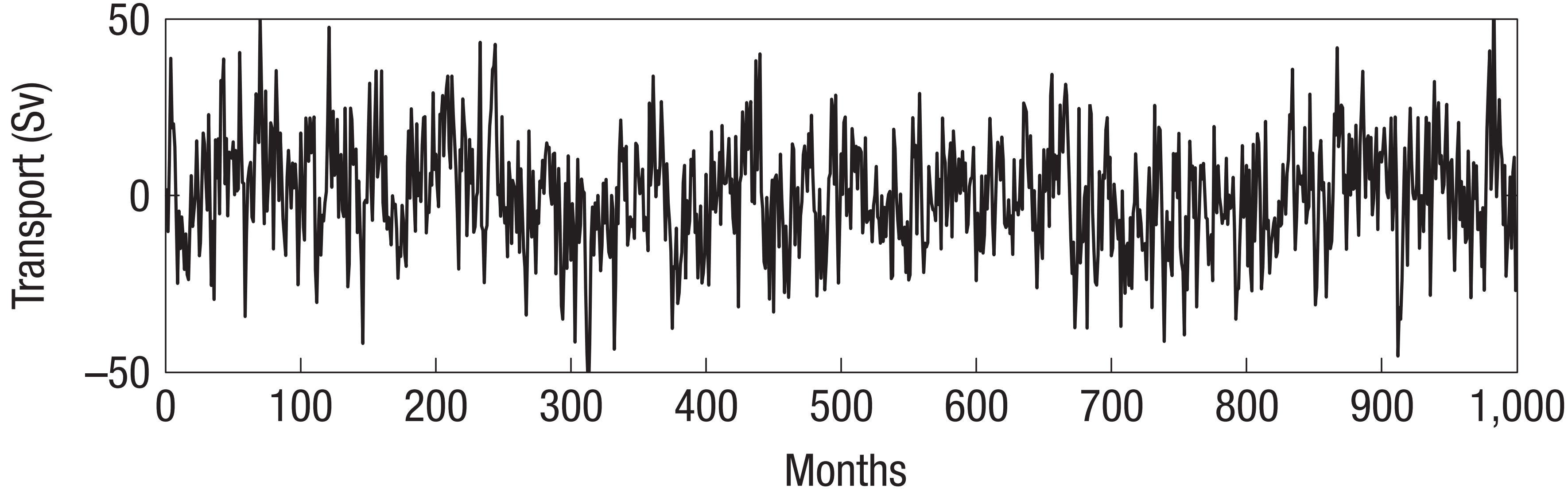
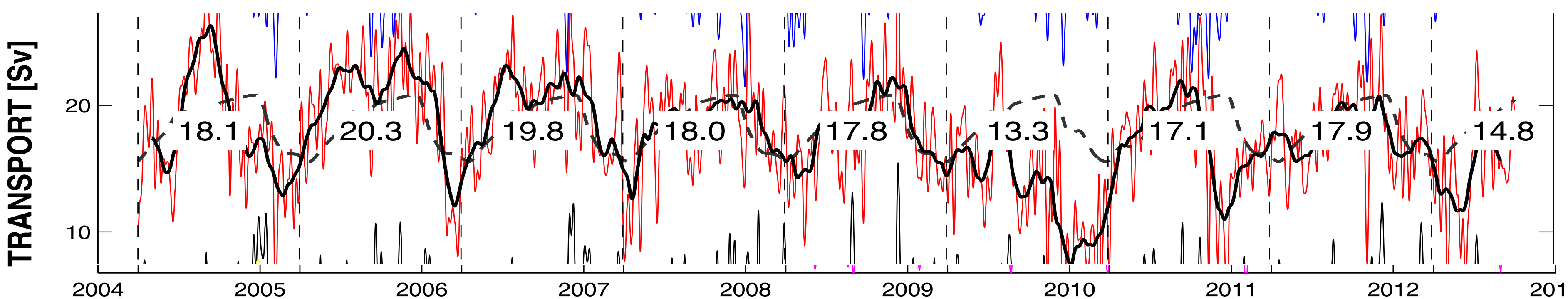
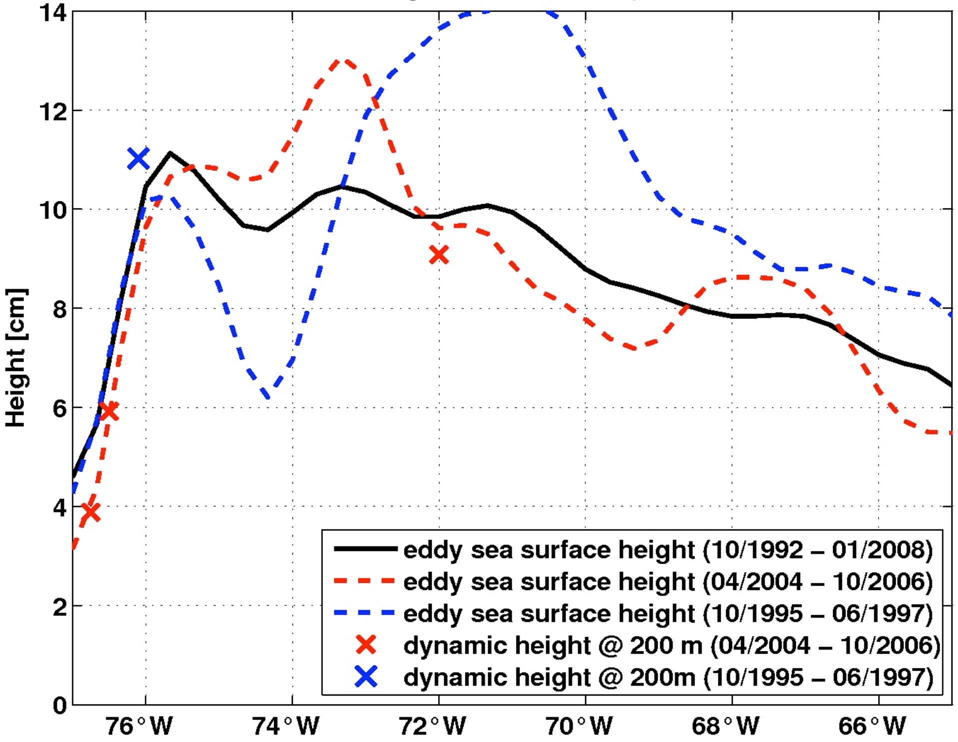




Kansow et al (2009)

rms sea surface height variability from altimeter:



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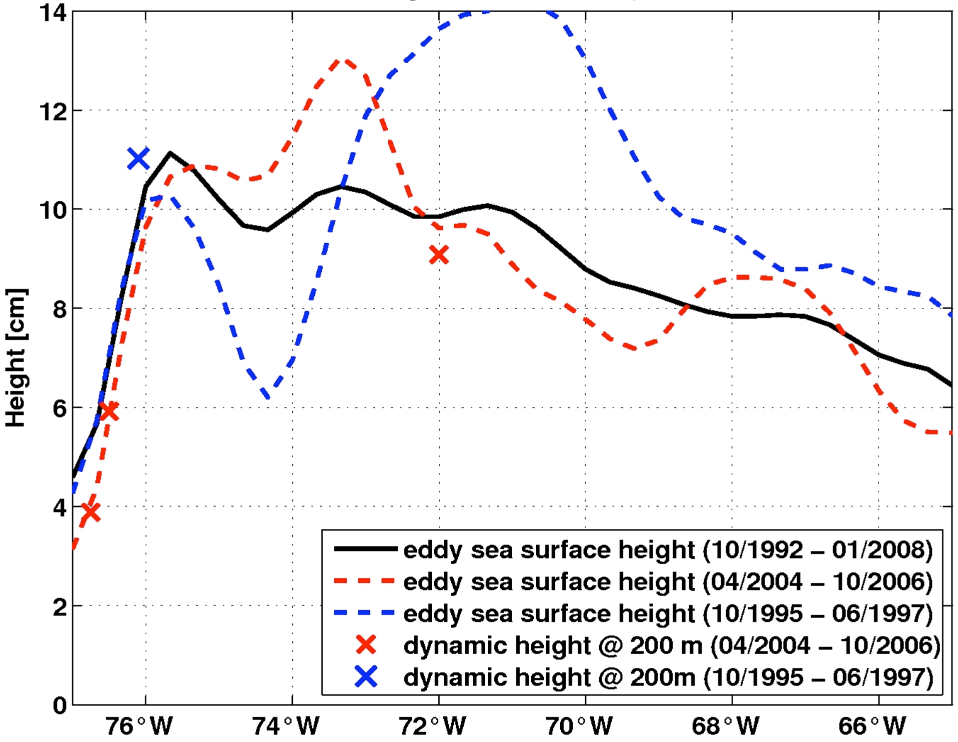
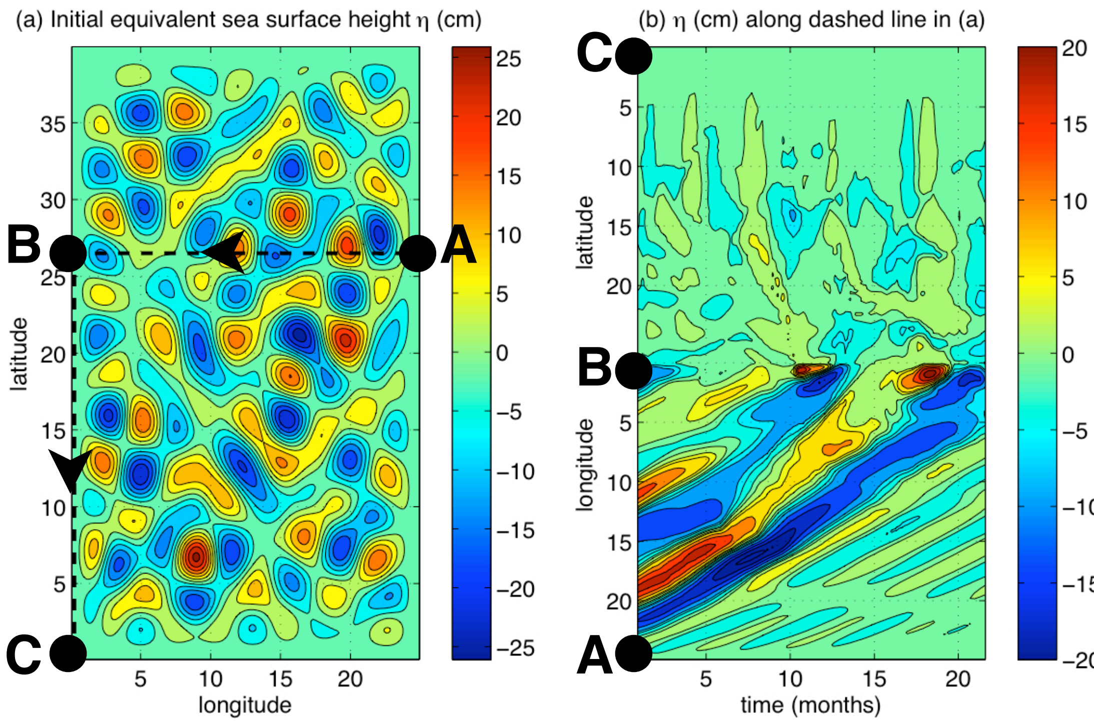


idealised numerical model experiments:



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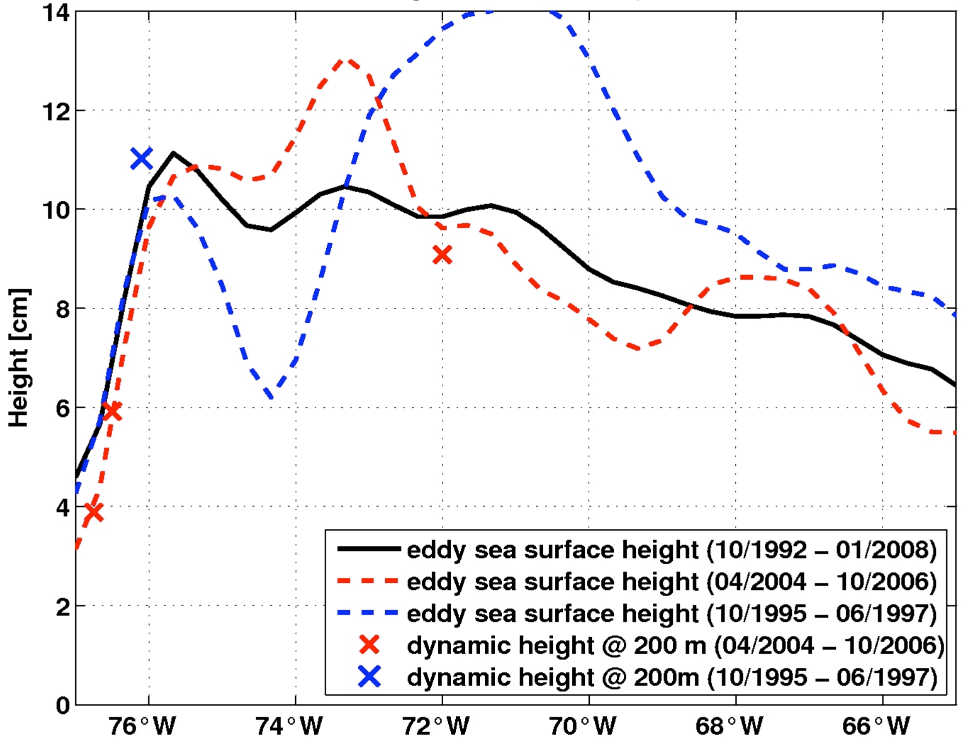

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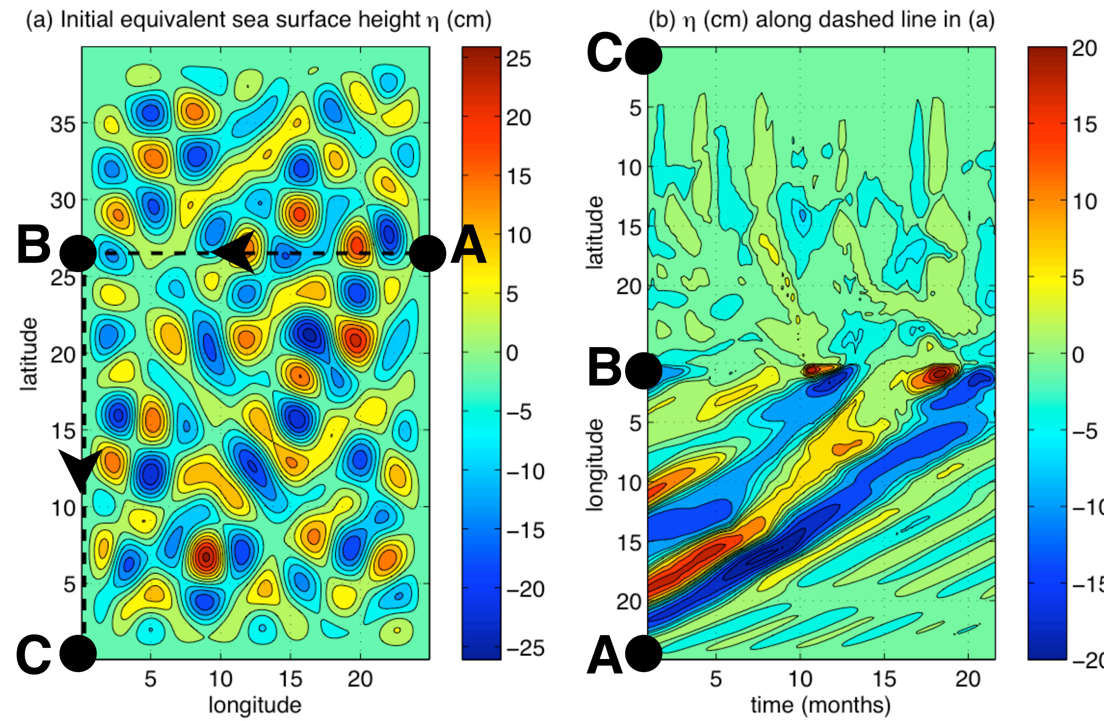
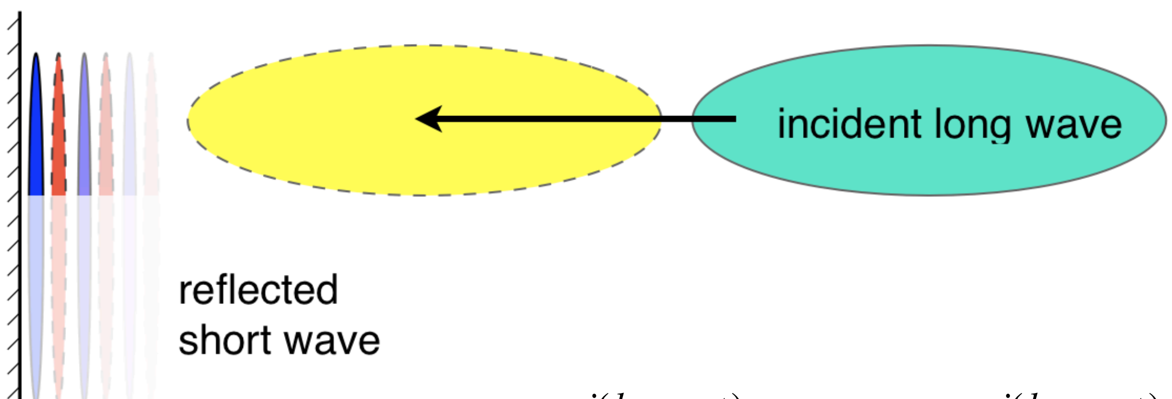
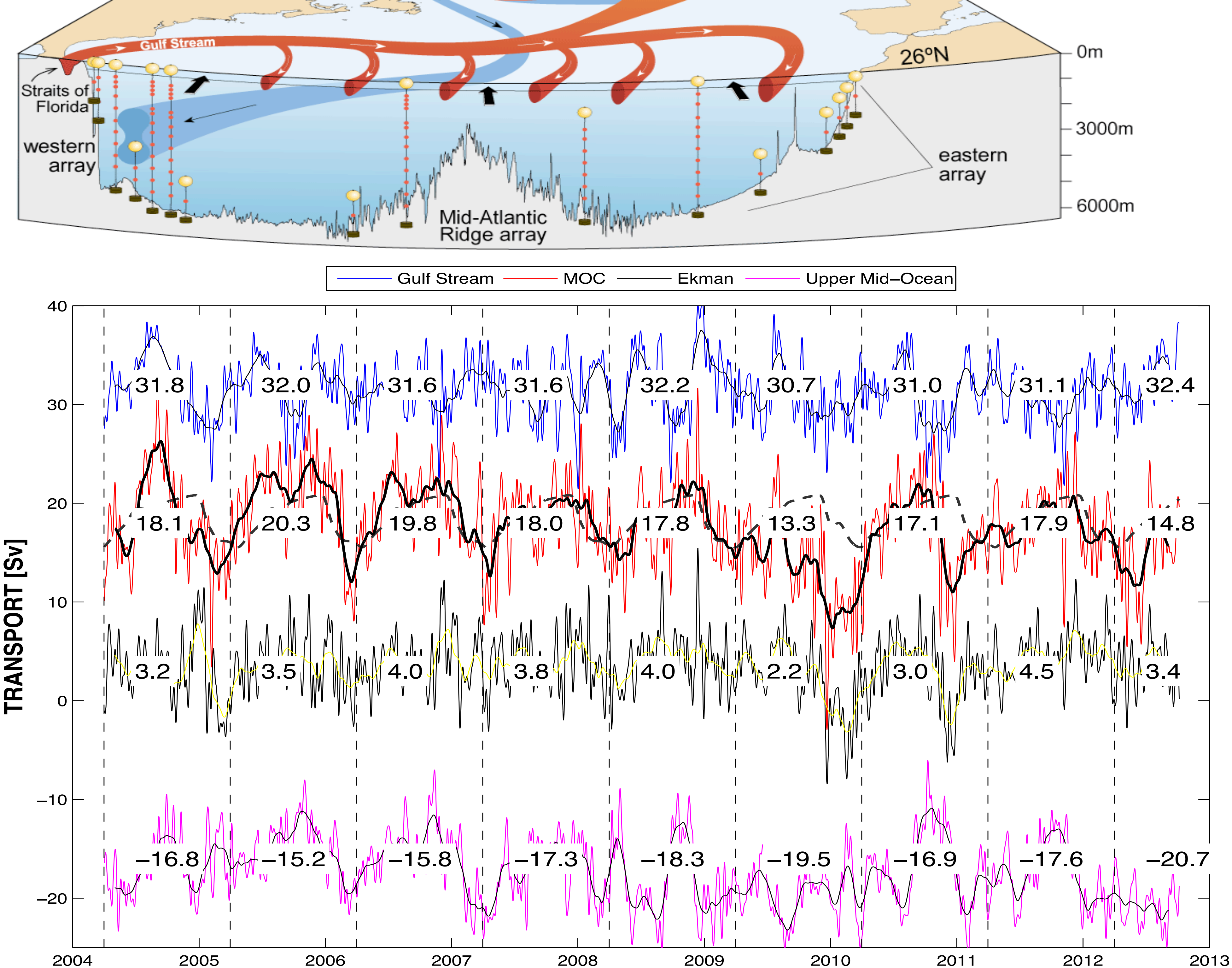


linear wave theory:



$$\boxed{A_l + A_s \sim \frac{\beta \Delta y}{f} |A_l|}$$

$$h' = A_l(y) e^{i(k_l x - \omega t)} + A_s(y) e^{i(k_s x - \omega t)}$$



courtesy: Gerard McCarthy

Double Dip: Winter 2010/11

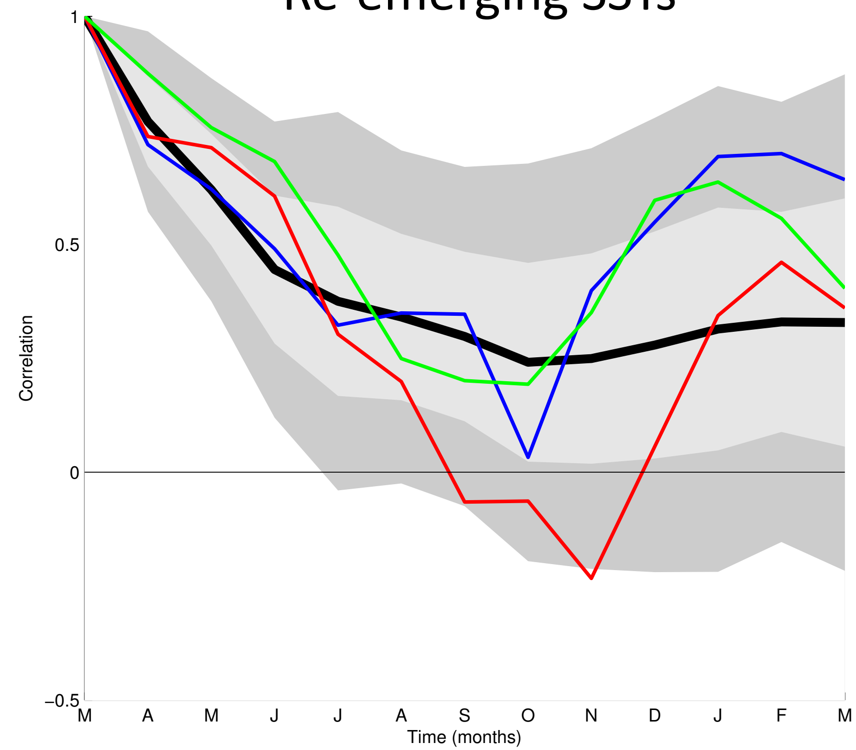
- Reemerging SSTs are observed in 1969/70 as well as in 2010/11
- These were conducive to the development of the negative NAO in winter 2010

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

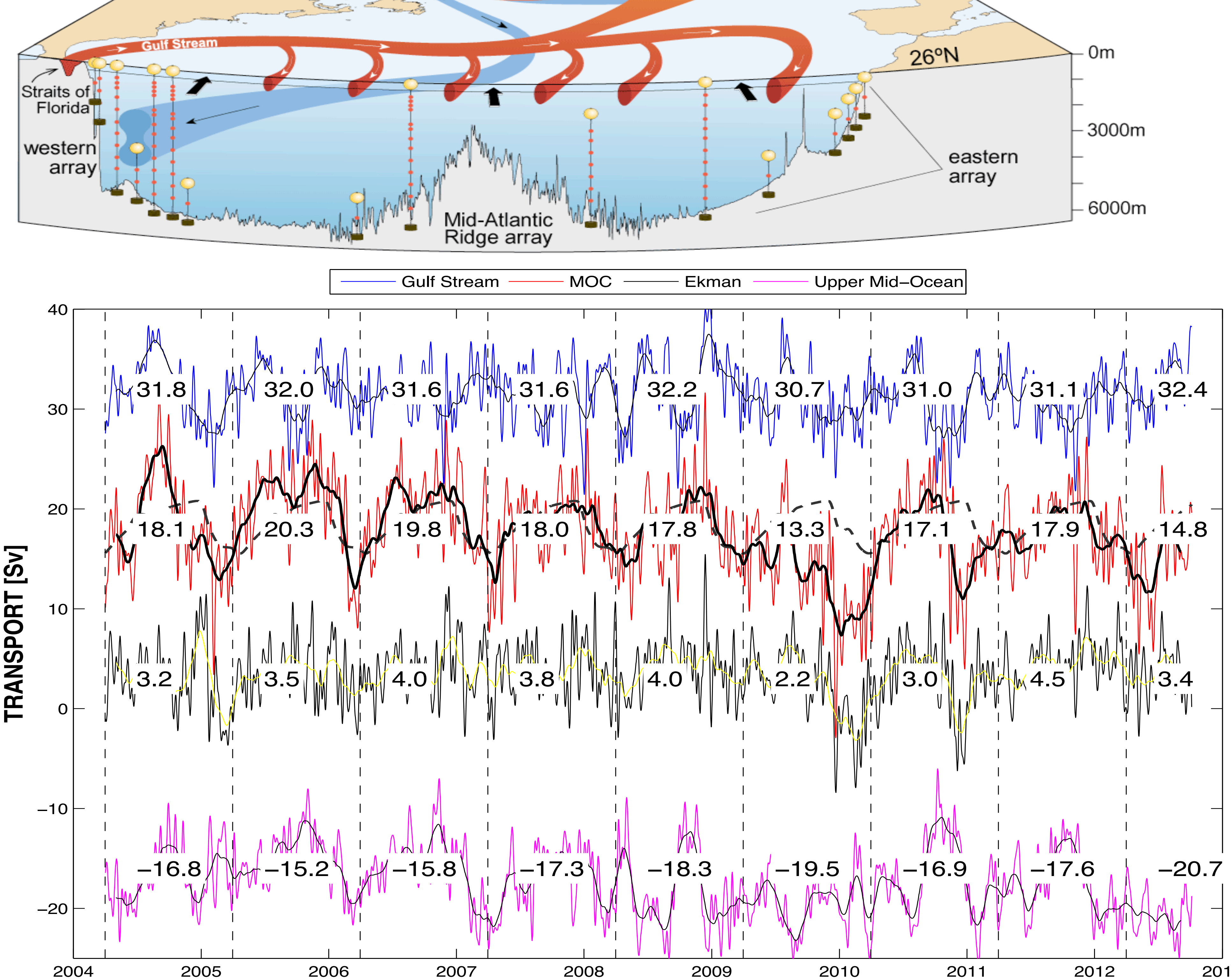
Maidens et al. in prep, The Influence of Surface Forcings on Prediction of the North Atlantic Oscillation Regime of Winter 2010-11. *submitted to Monthly Weather Review*

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

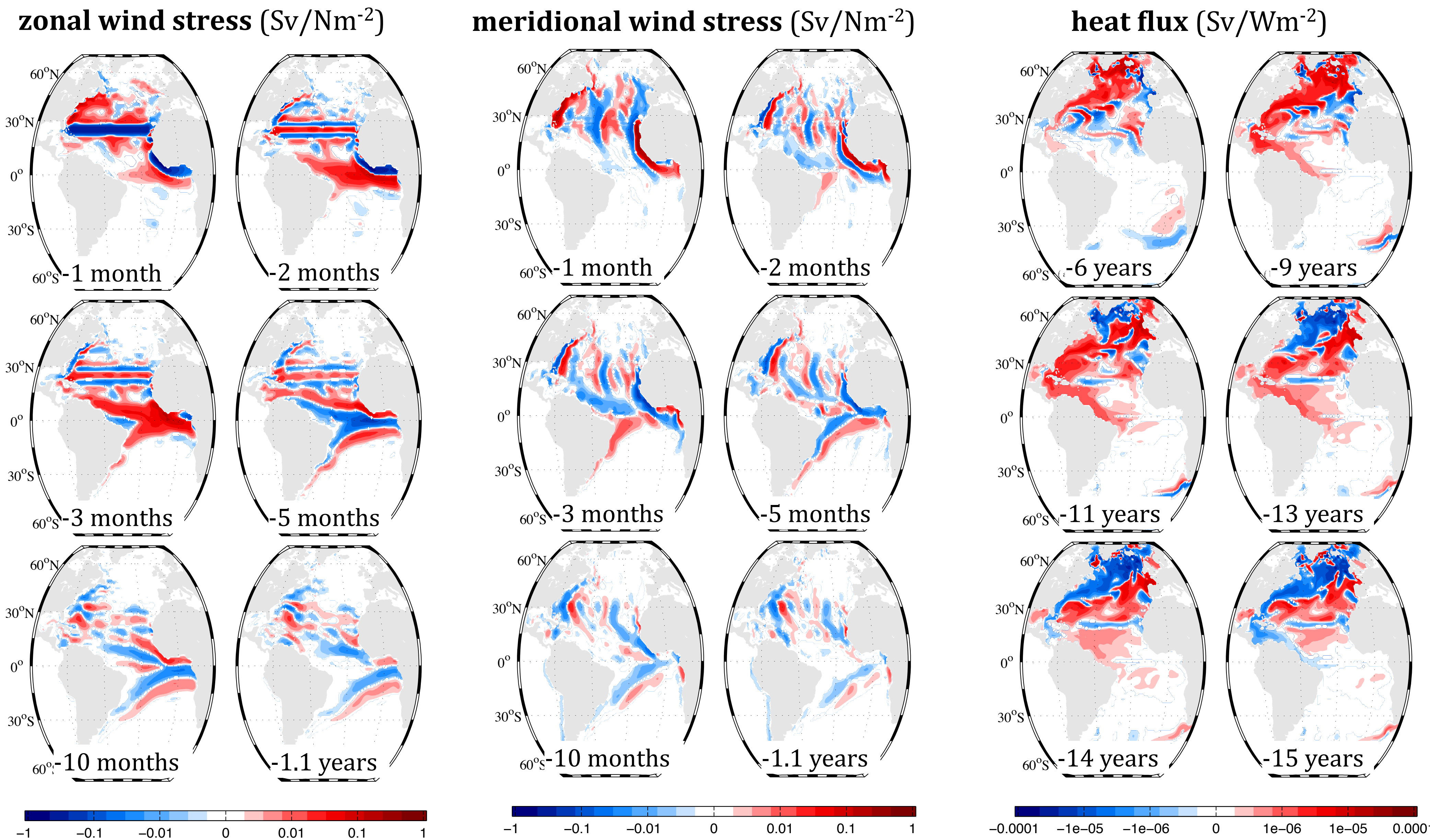
courtesy: Gerard McCarthy



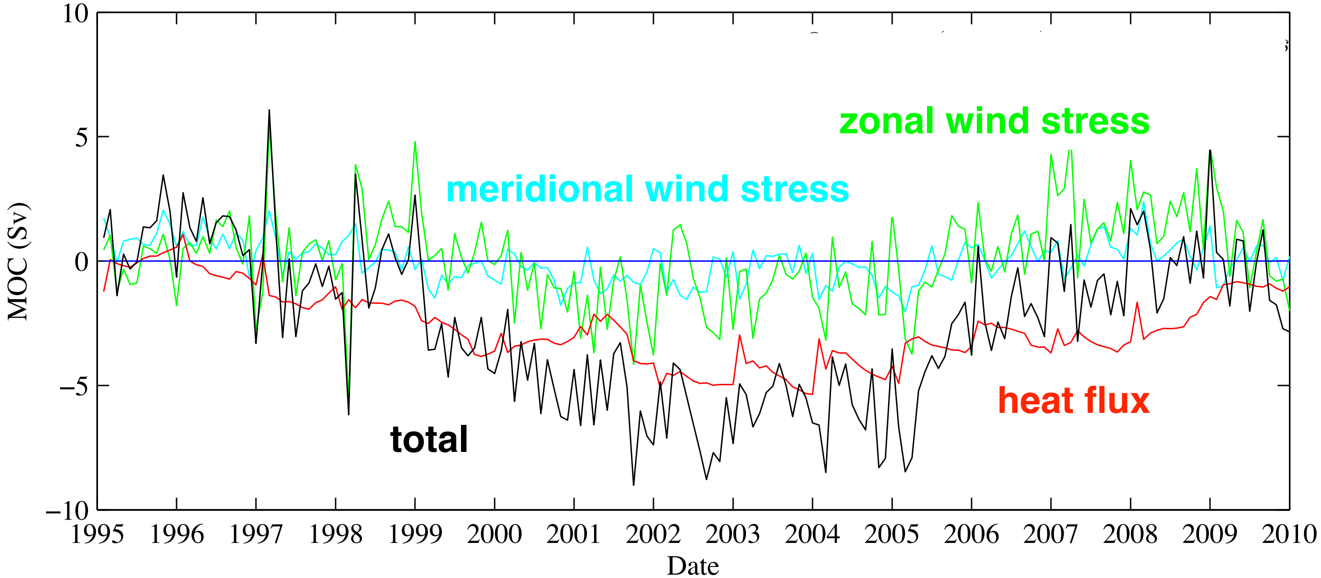
courtesy: Gerard McCarthy

Pillar, Johnson and Marshall (in prep.): **Attribution of AMOC variability** at 25N (in 1° MITgcm)

Maps of linear sensitivity of AMOC (25N) to surface forcing at different time lags:



AMOC response = $\sum$ (monthly sensitivities) x (forcings) ... over all grid points, preceding 15 years:



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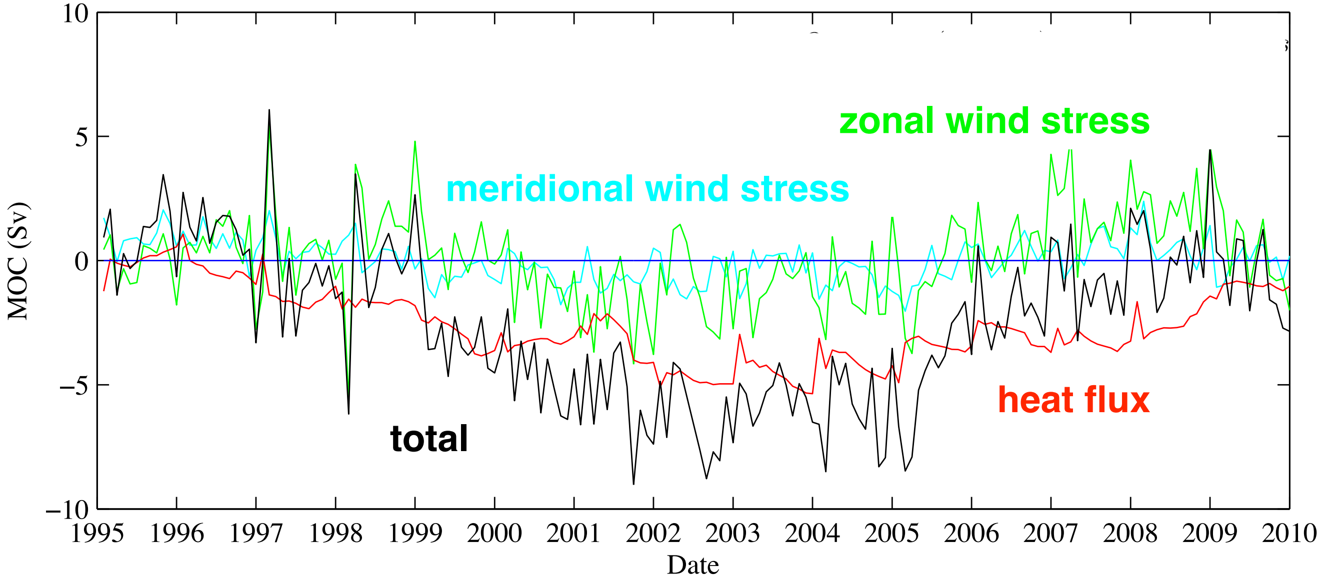
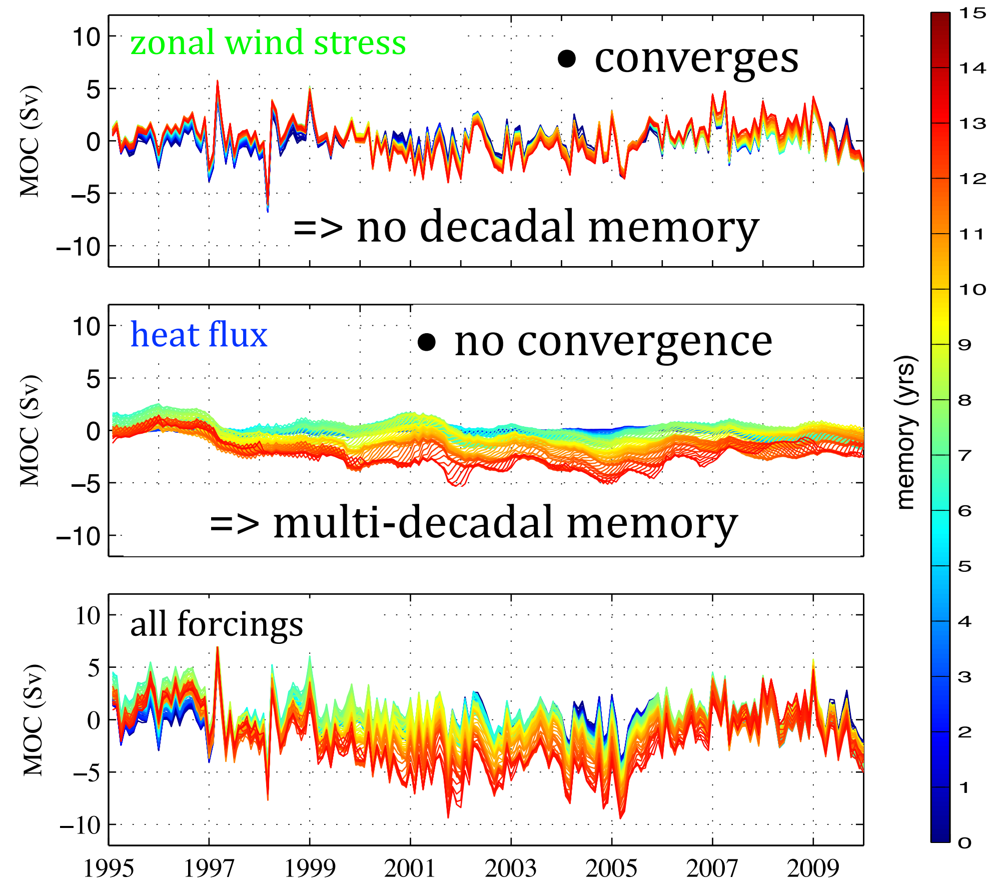
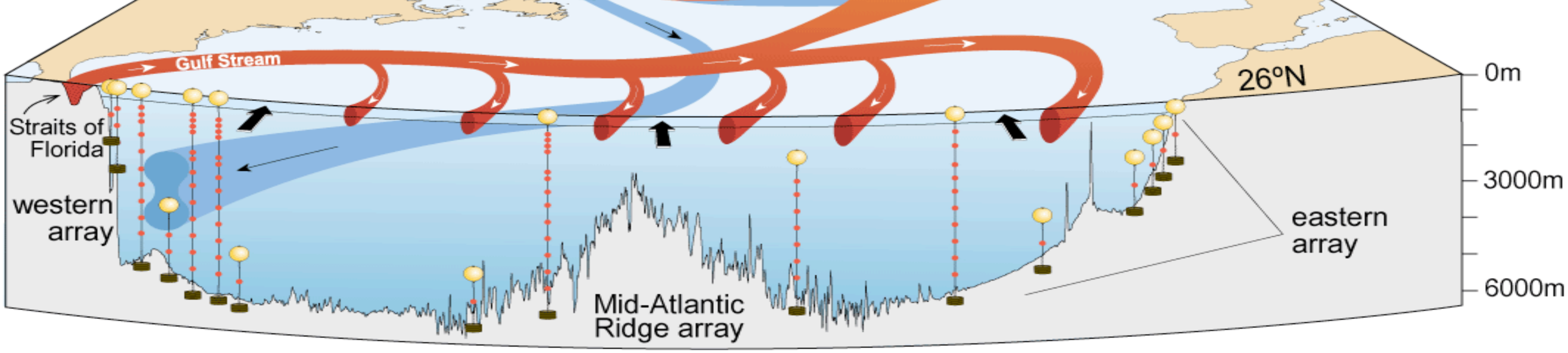
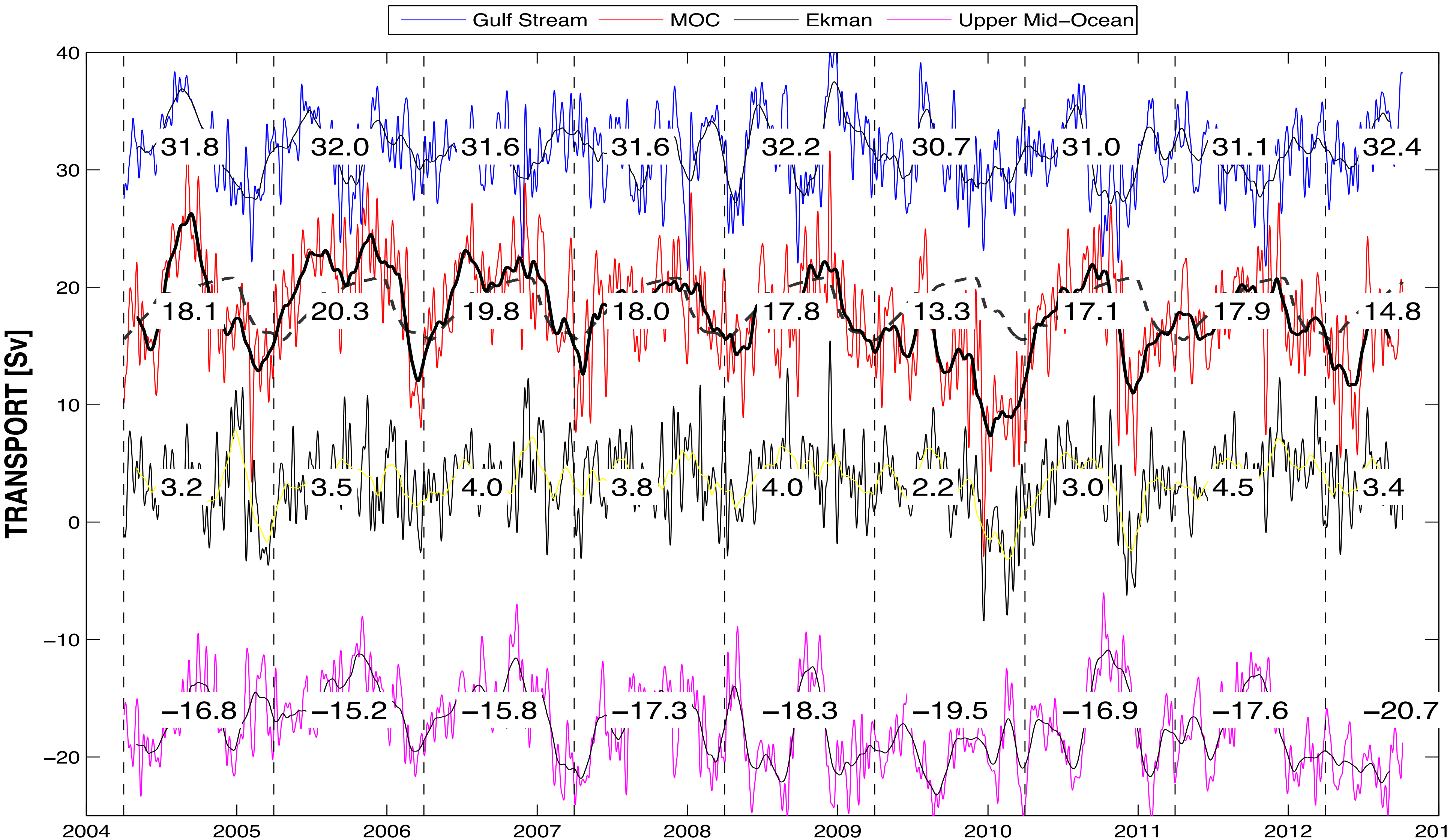


Dependence of AMOC response on integration period:
(= **memory** of past forcing)

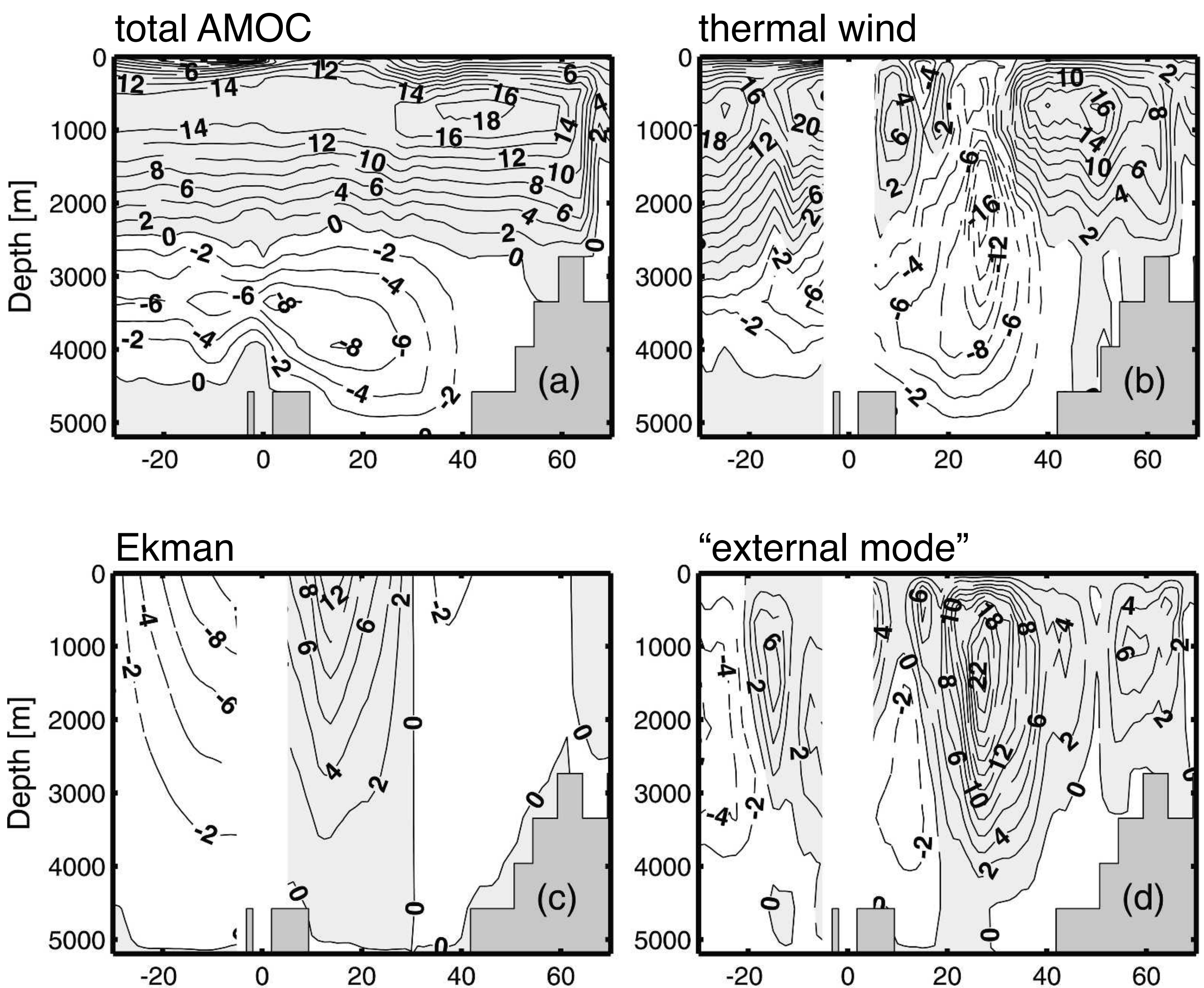


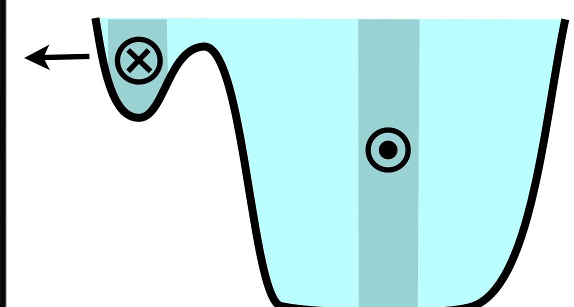




courtesy: Gerard McCarthy

Decomposition of the AMOC in HadCM3 (Sime et al., 2006)





variability in the external mode?

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OSNAP

U.S. : Susan Lozier (Duke); Bill Johns (U. Miami); Amy Bower, Bob Pickart and Fiamma Straneo (WHOI)

UK: Sheldon Bacon, Penny Holliday and Chris Wilson (NOC); Stuart Cunningham and Mark Inall (SAMS); David Marshall and Helen Johnson (Oxford) and Ric Williams (Liverpool)

Netherlands: Laura de Steur (NIOZ)

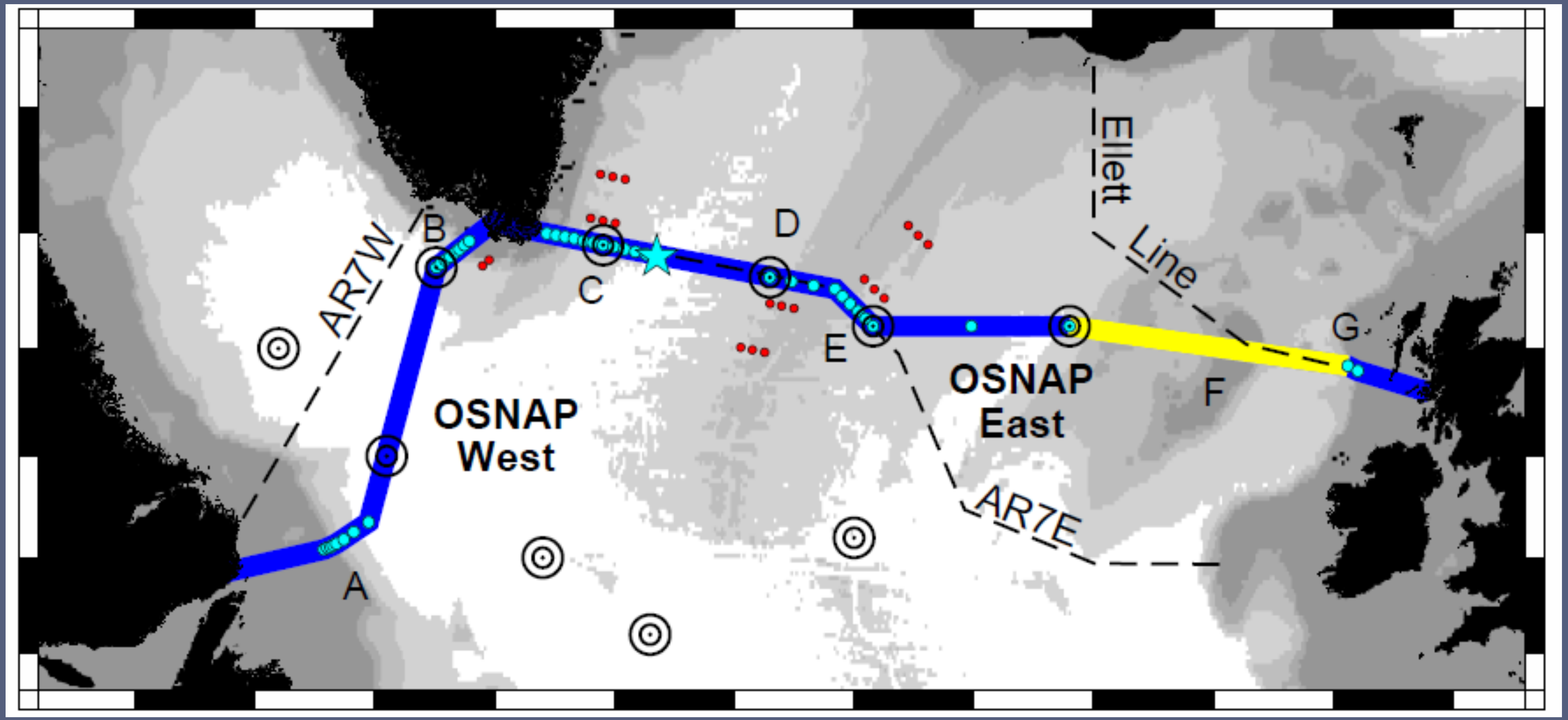
Germany: Jürgen Fischer, Johannes Karstensen and Martin Visbeck (GEOMAR) and Torsten Kanzow (AWI)

Canada: Blair Greenan (BIO); Brad de Young (Memorial U.)

France: Herlé Mercier and the OVIDE group (IFREMER)

courtesy: Susan Lozier

OSNAP overall goal: To quantify the large-scale, low-frequency, full water-column net fluxes of mass, heat and fresh water associated with the meridional overturning circulation in the subpolar North Atlantic.

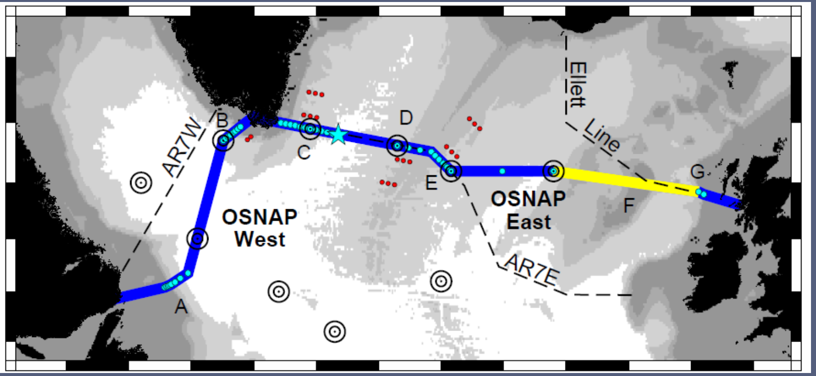


(A) German 53°N western boundary array and Canadian shelfbreak array;
(B) US West Greenland boundary array;
(C) US/UK East Greenland boundary array;
(D) Netherlands western Mid-Atlantic Ridge array;
(E) US eastern Mid-Atlantic Ridge array;
(F) UK survey over the Hatton-Rockall Bank and Rockall Trough;
(G) UK Scottish Slope current array.
Red dots: US float launch sites.
Blue star: US OOI Irminger Sea global node.
Black concentric circles: US sound sources.

In the water: Summer 2014

courtesy: Susan Lozier

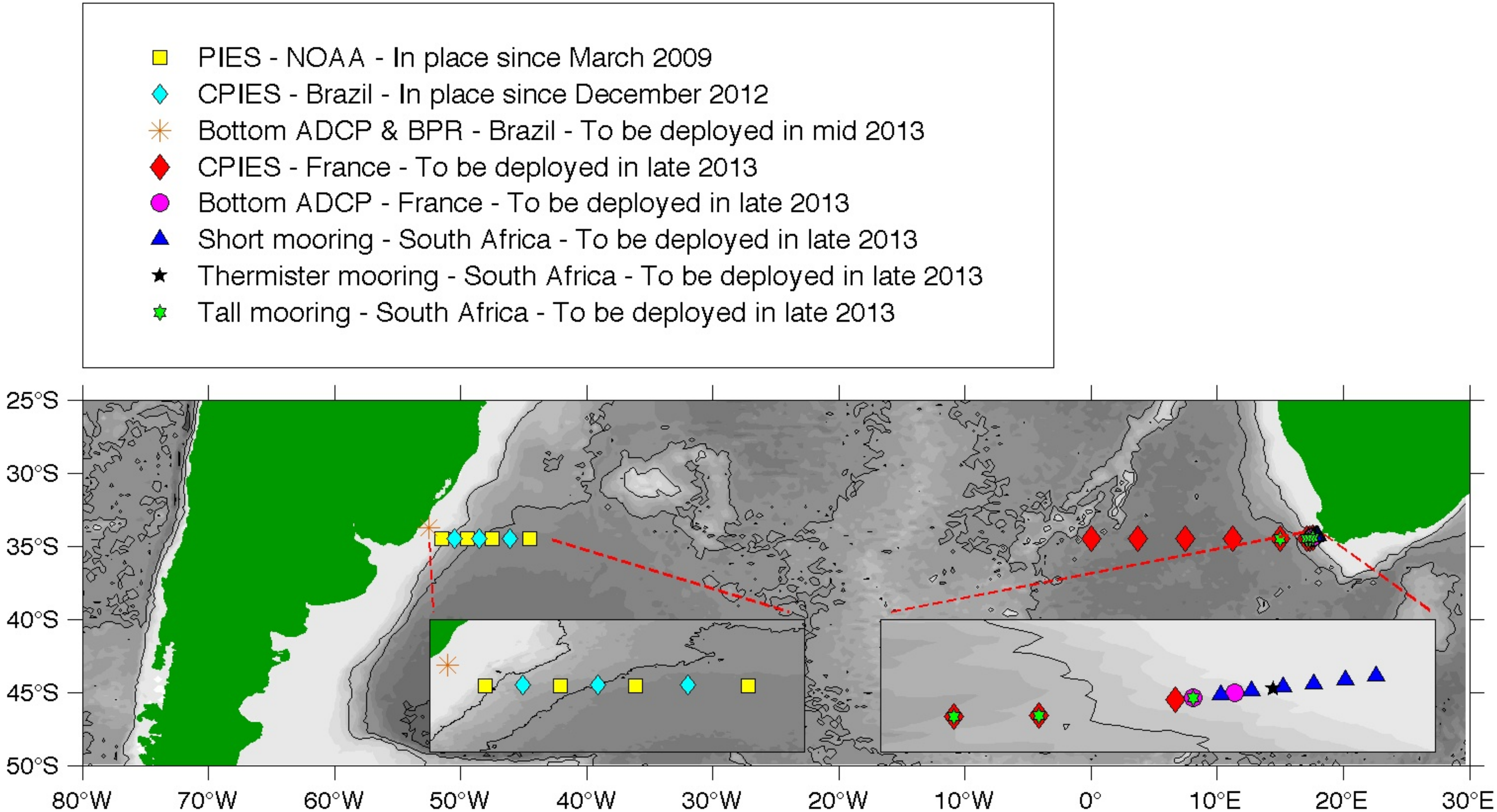
Specific OSNAP objectives:



1. Quantify the subpolar AMOC and its intra-seasonal to interannual variability via overturning metrics, including associated fluxes of heat and freshwater.
2. Determine the pathways of overflow waters in the NASPG to investigate the connectivity of the deep boundary current system.
3. Relate AMOC variability to deep water mass variability and basin-scale wind forcing.
4. Determine the nature and degree of the subpolar-subtropical AMOC connectivity.
5. Determine from new OSNAP measurements the configuration of an optimally efficient long-term AMOC monitoring system in the NASPG.

courtesy: Susan Lozier

South Atlantic MOC array (SAMOC):

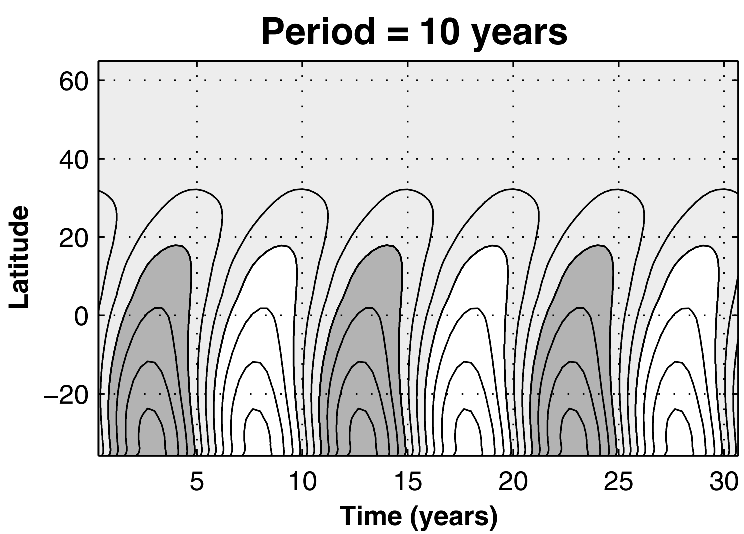


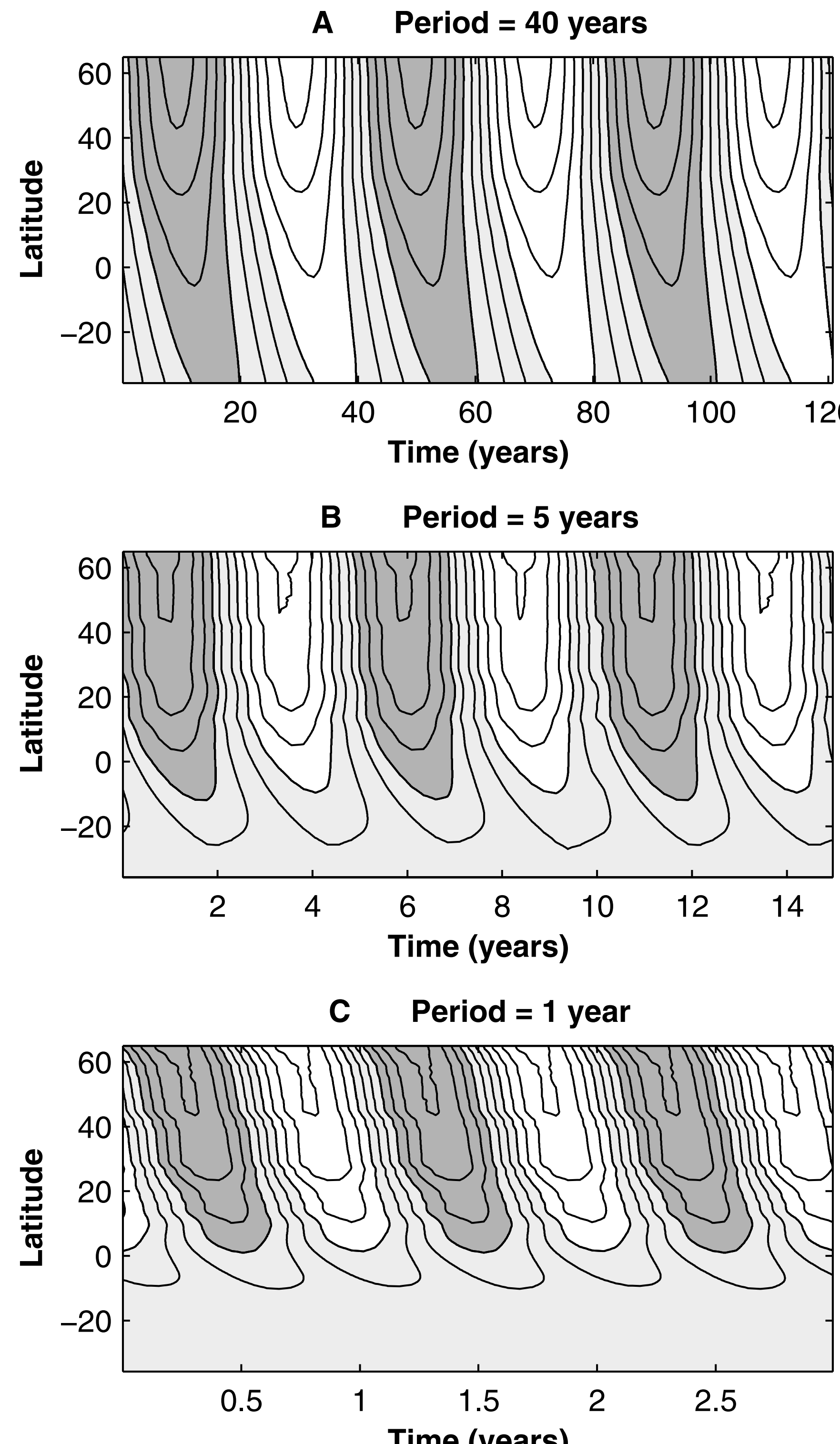
courtesy: Chris Meinen

Equatorial buffer

=> limited coherence between
North and South Atlantic on
seasonal to interannual time scales:

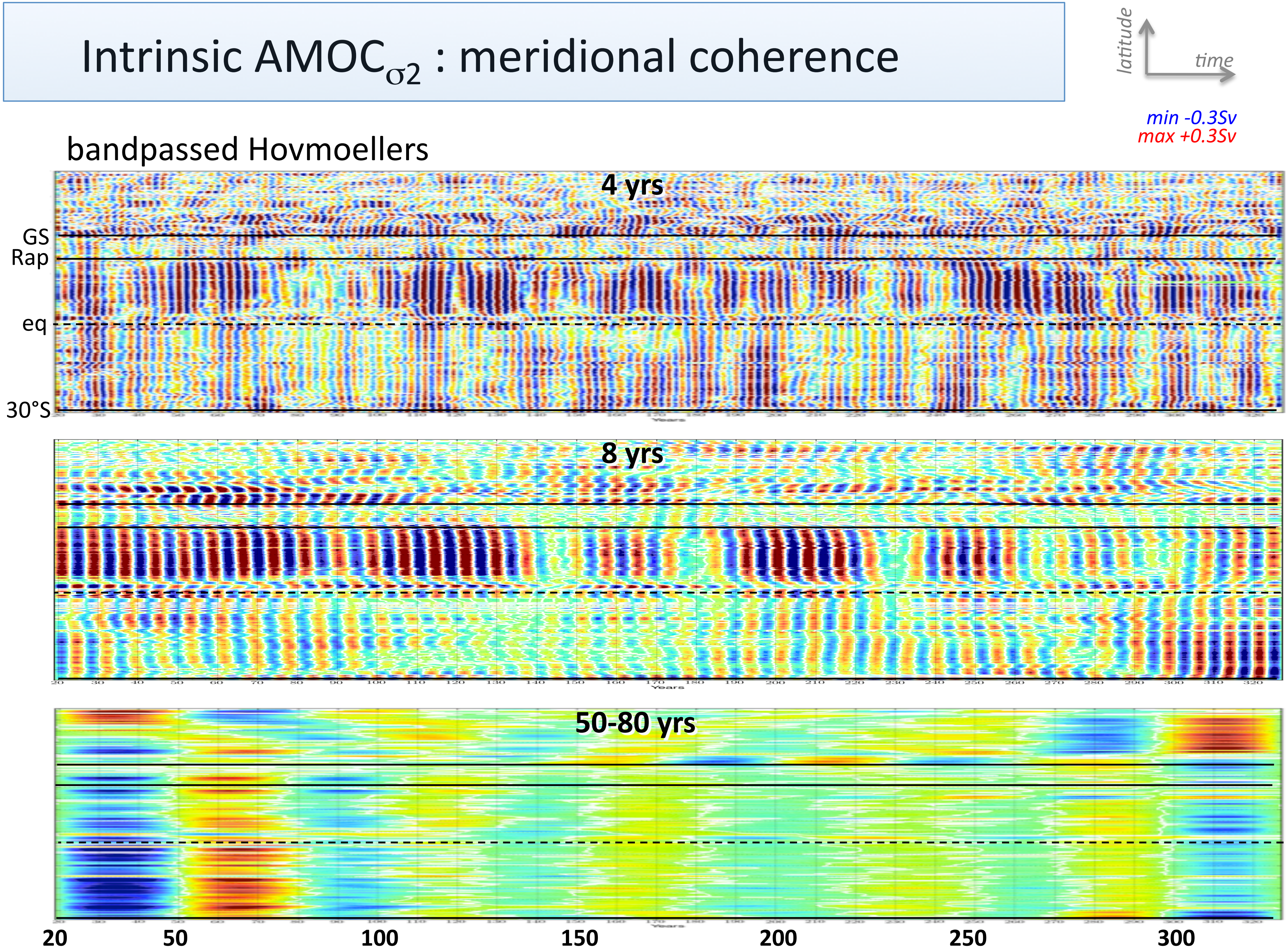
(Johnson and Marshall, 2002)





but ....

Intrinsic AMOC$_{\sigma 2}$: meridional coherence



courtesy: Thierry Penduff

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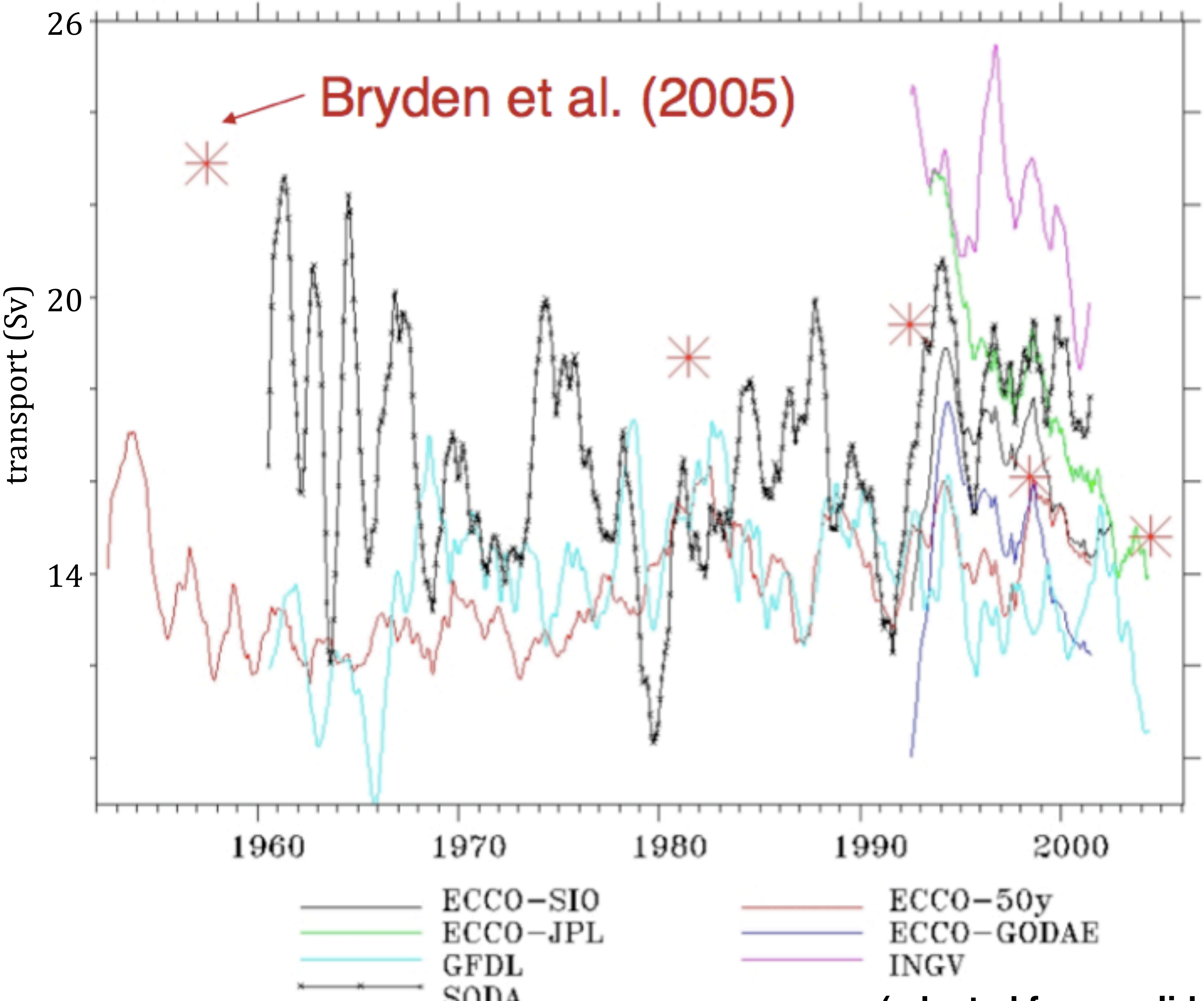
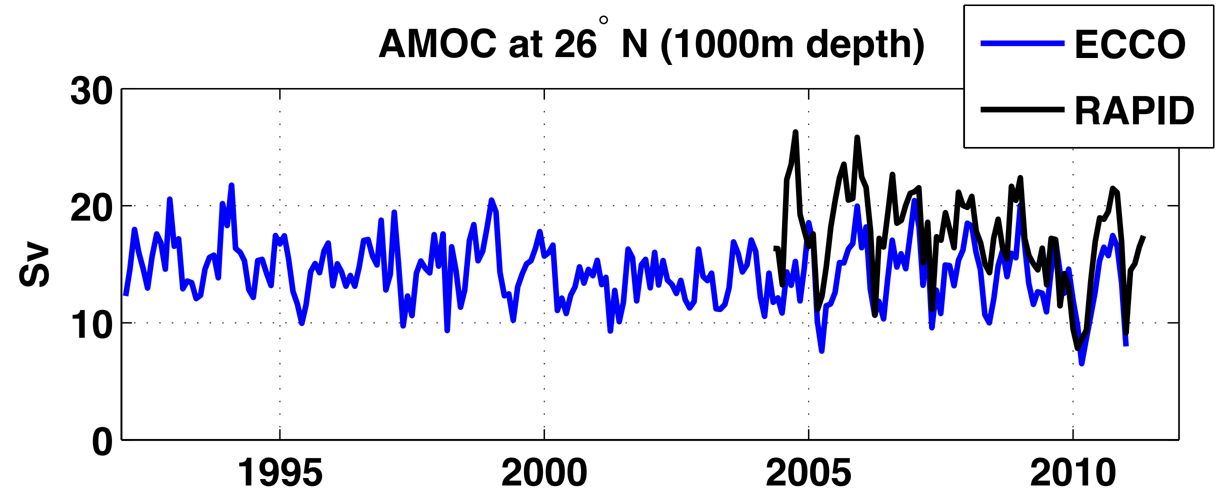
State estimation (reanalysis) - AMOC at 25N in various ocean syntheses (GSOP):

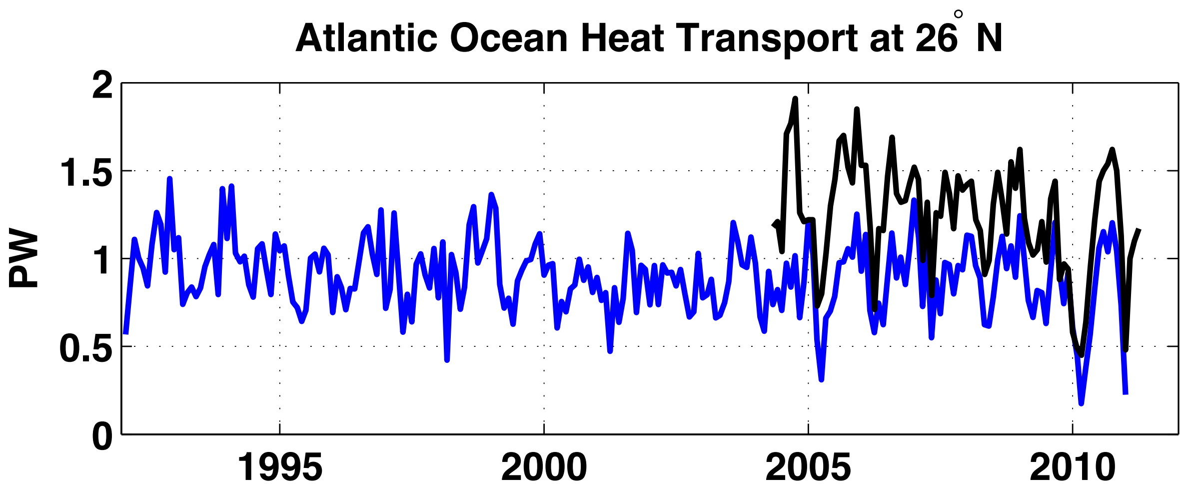


(adapted from a slide by Marotzke)

Monthly AMOC and Atlantic OHT variability



- Mean
  - ECCO: 16.0 Sv
  - RAPID: 17.5 Sv
- Correlation 0.75
- improves w/ time

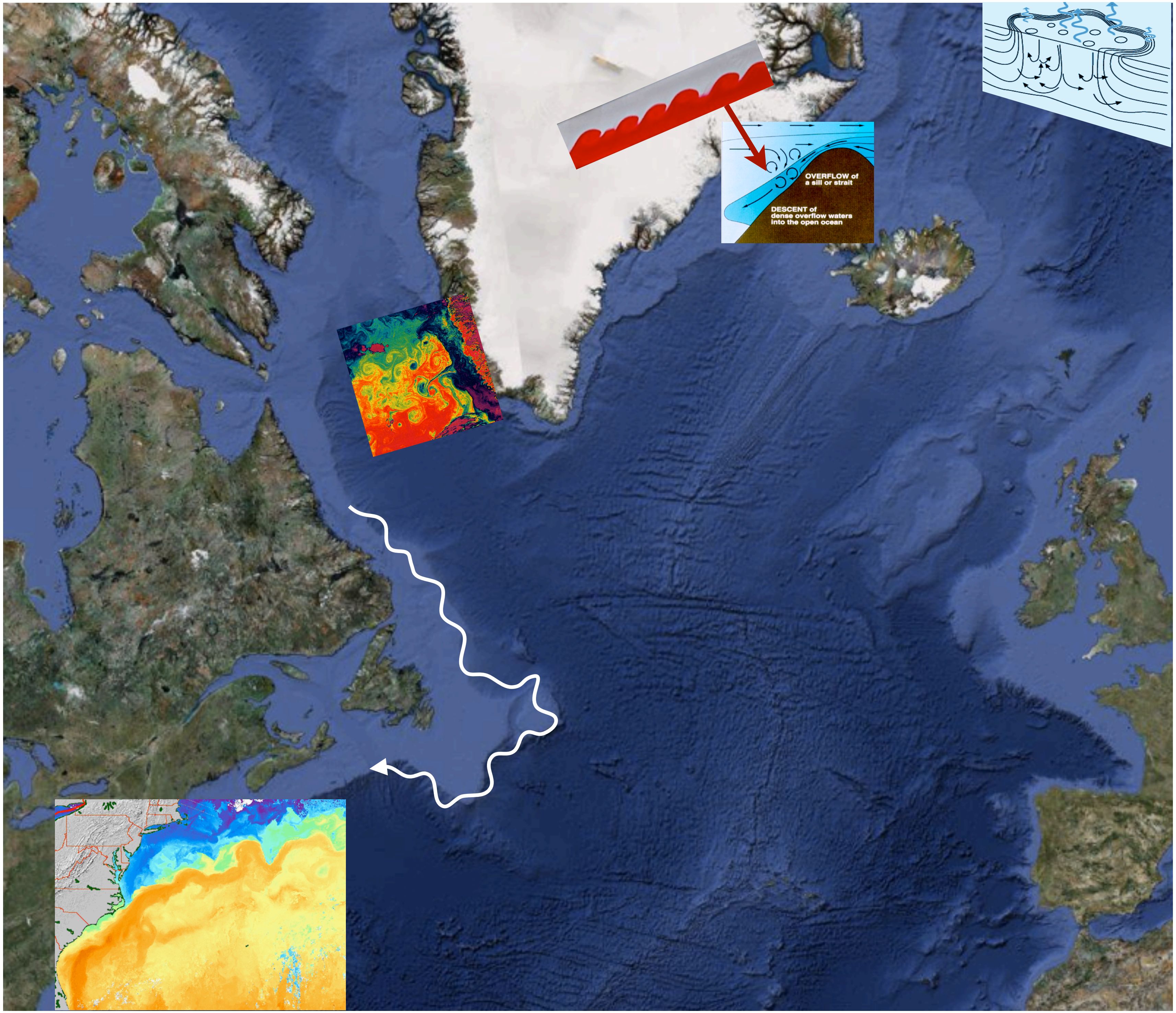


- Means
  - ECCO: 0.86 PW
  - RAPID: 1.2 PW
- ECCO systematically underestimates OHT
- Correlation: 0.81

Note: Neither Florida current transports (cable observations) or RAPID AMOC transport estimates at 26ºN are used as constraints in ECCO

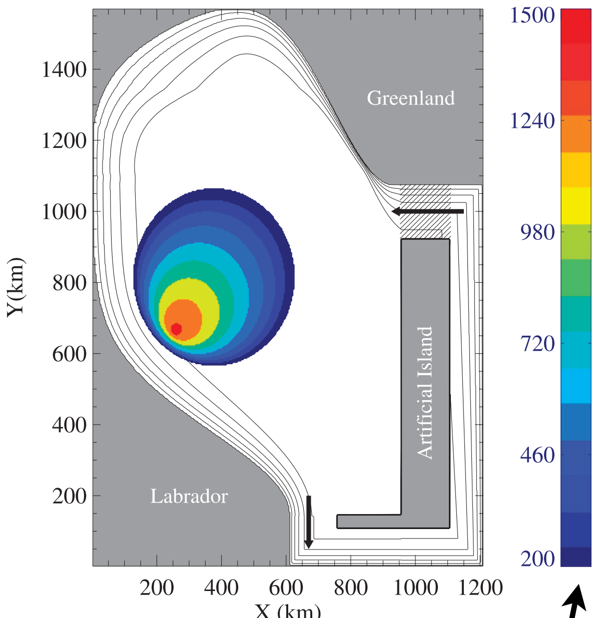
courtesy: Martha Buckley

How many critical processes for AMOC variability are adequately-resolved by current models?



Gelderloos et al. (2011) - “GFD in a GCM”

slumping of initial
mixed layer anomaly



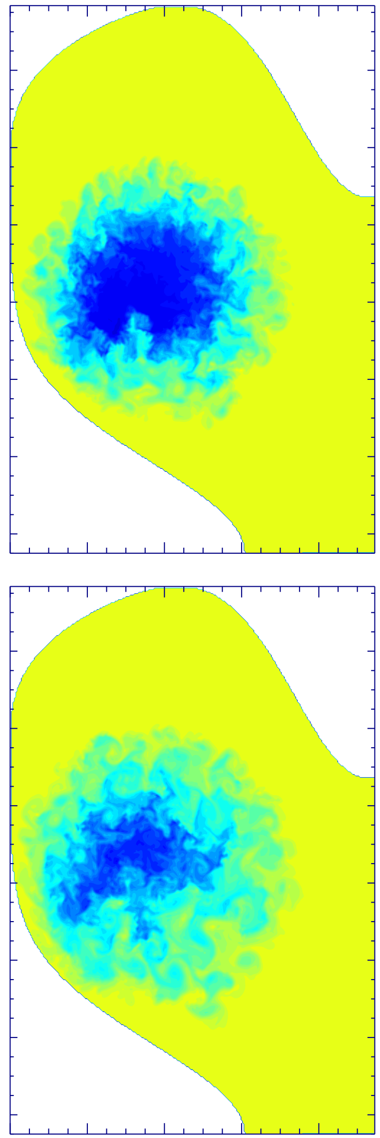
mixed layer depth

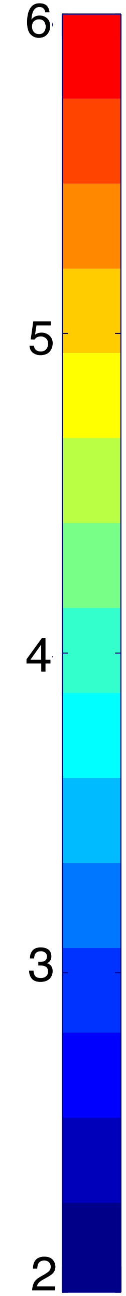
(Δx = 3.75 km)

no boundary current,
no Irminger rings

3 months

6 months





SST

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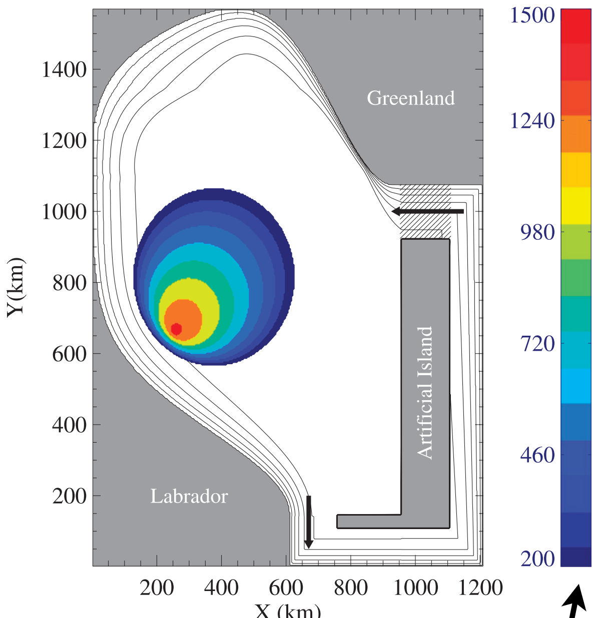

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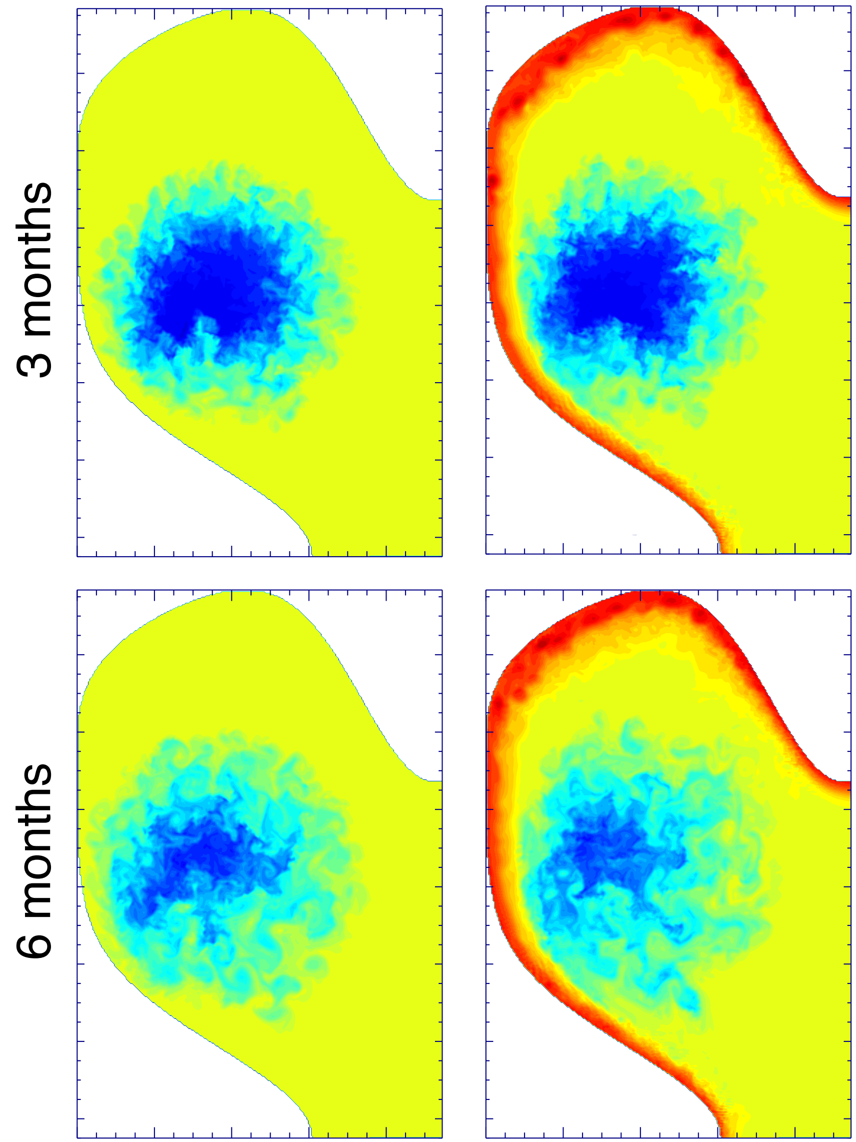

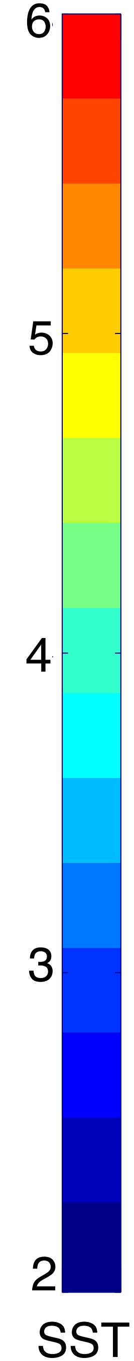

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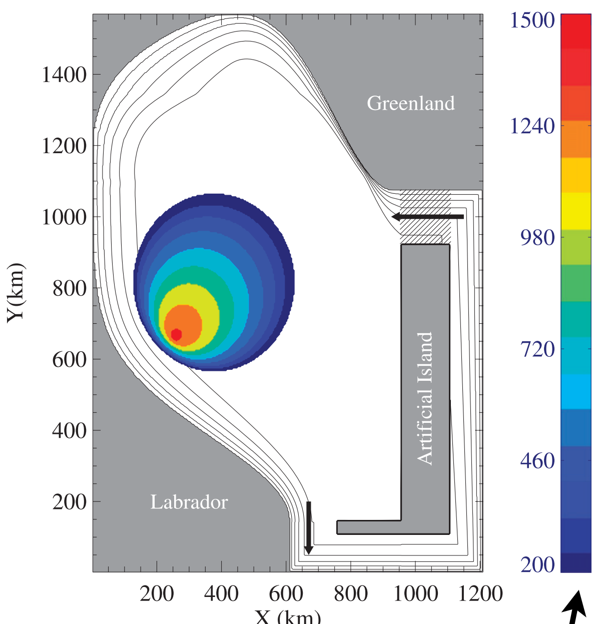

mixed layer depth

(Δx = 3.75 km)

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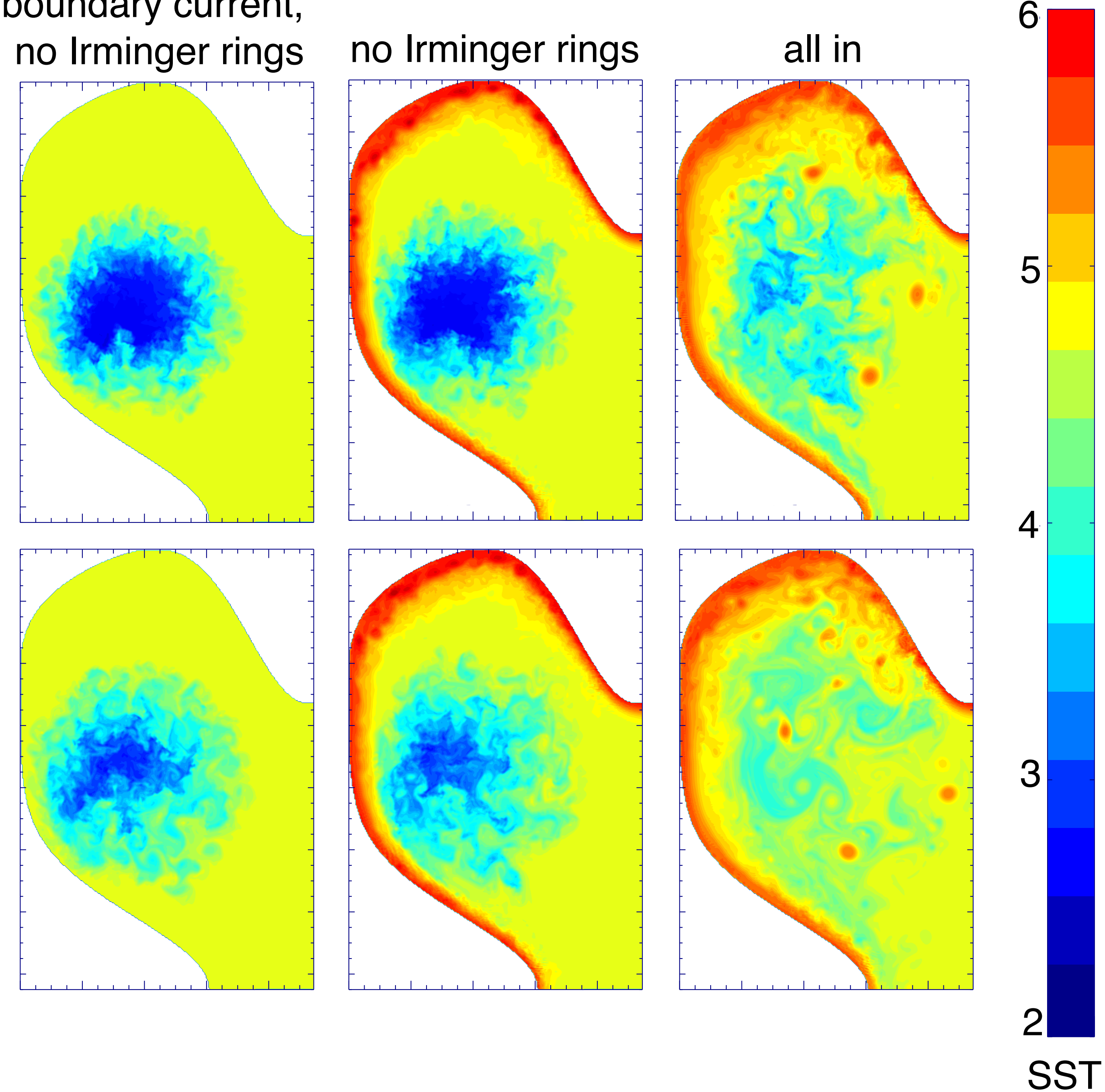
no Irminger rings

no Irminger rings

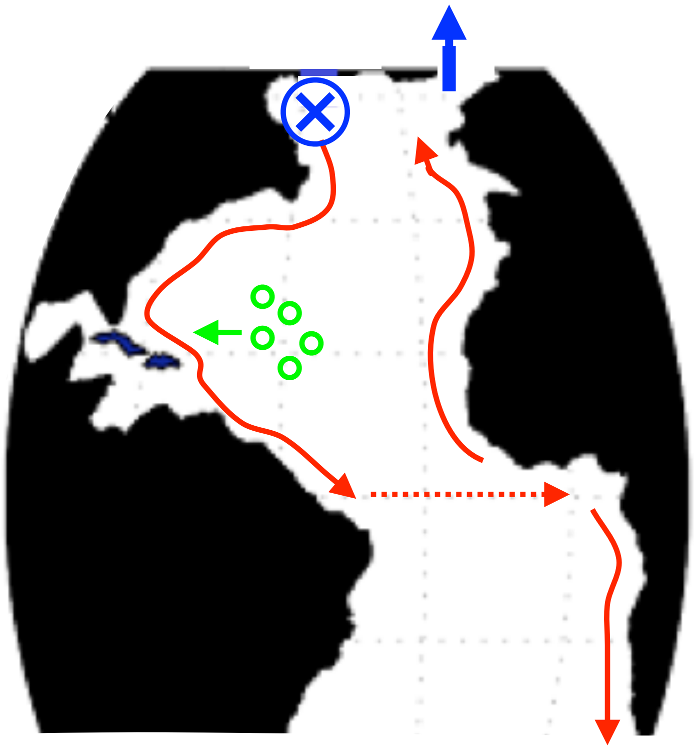
all in

3 months

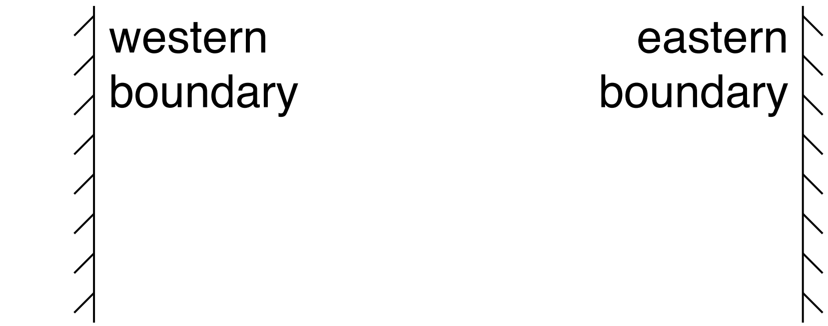
6 months



Marshall and Johnson (2013)



reduced-gravity model:



- adjustment is not by Kelvin waves but Rossby waves that satisfy a lateral boundary condition;

- boundary propagation speed = $c_{Kelvin}\, L_d / \delta$,
  i.e., depends on viscosity (grid spacing);

- in reality, bottom topography likely to dominate.

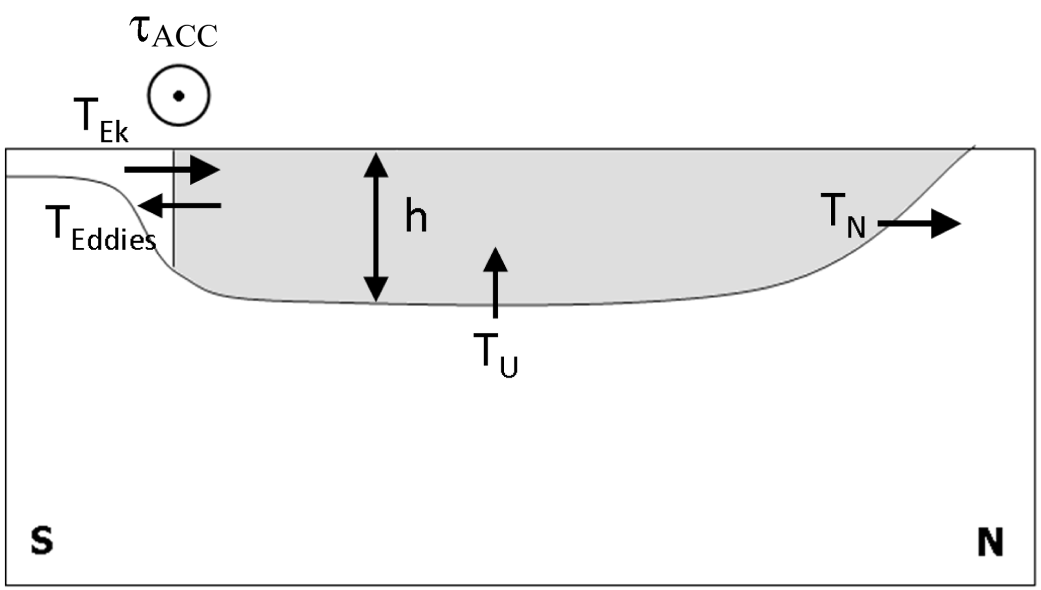
take-home message: boundary propagation speeds may be model dependent

Comment on **equilibration time scale** for models: **O (100s - 1000s years)**

Journal of Marine Research, 69, 167–189, 2011

Spin-up and adjustment of the Antarctic Circumpolar Current and global pycnocline

by Lesley C. Allison[1], Helen L. Johnson[2] and David P. Marshall[3]



Gnanadesikan (1999) with time dependence

time scale set by

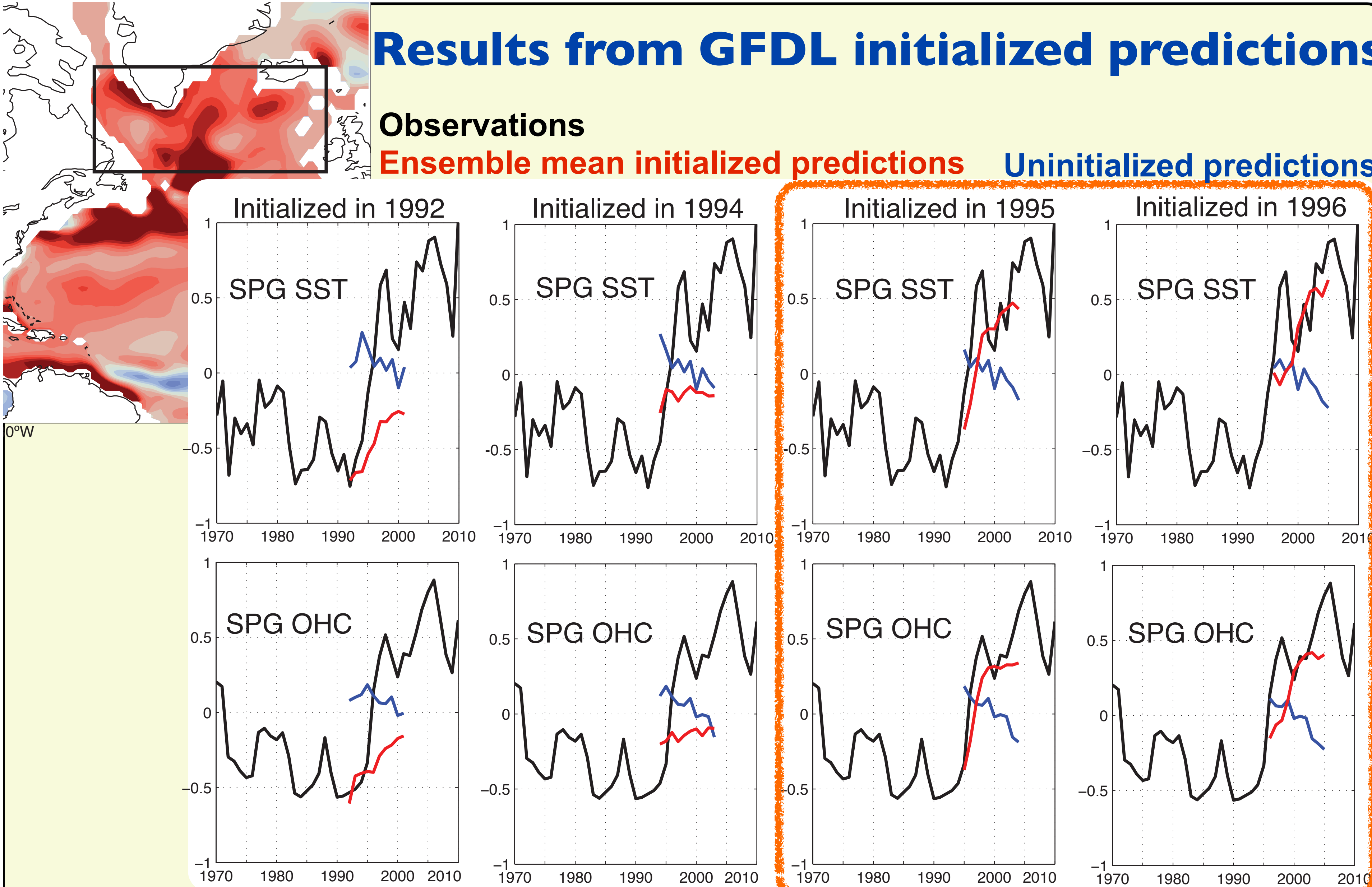
Southern Ocean eddy diffusivity and

d(AMOC)/d(pycnocline depth)

adjustment likely to be faster with explicit eddies

(also see Jones et al., 2011; Samelson, 2011)

Results from GFDL initialized predictions



Hindcasts initialized in the early 90's warm more slowly than observed. Those initialized in 1995 and 1996 lead to successful predictions. No warming in the uninitialized case.

Msadek et al. submitted

courtesy: Rym Msadek

Concluding remarks

- The RAPID/MOCHA observations have led to many new discoveries about the AMOC, many of which were not anticipated at the outset.
- The new and continuing observations (OSNAP, RAPID/MOCHA, SAMOC, ...) will lead to further new discoveries, the most exciting of which have not yet been anticipated.
- Need to think hard about role of new technologies, cheaper array designs, for the longer term.
- Much progress has been made with state estimation, but direct AMOC observations remain essential. Still unclear how to best assimilate boundary hydrographic measurements.
- Some encouraging signs for predictability of the AMOC and its impact on SSTs, etc.
- Attribution of observed changes is also important (e.g., recent hiatus in global warming).
- Don’t forget conceptual models - “all models are wrong, some models are useful”.