Atlantic Overturning Circulation variability from decades to multi-decades

Gerard McCarthy

WITH THANKS TO

MOLLY BARINGER, ADAM BLAKER, AURÉLIE DUCHEZ, ELEANOR FRAJKA-WILLIAMS, JEREMY GRIST, IVAN HAIGH, JOEL HIRSCHI, WILLIAM JOHNS, SIMON JOSEY, TERRY JOYCE, ELAINE MCDONAGH, JENNY MECKING, CHRIS MEINEN, MATT MENARY, BEN MOAT, DARREN RAYNER, JON ROBSON AND DAVID SMEED

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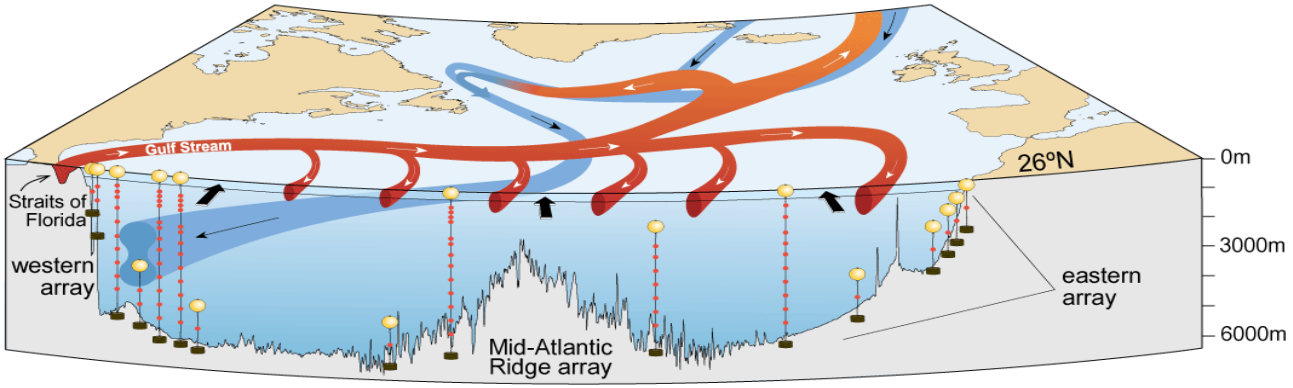
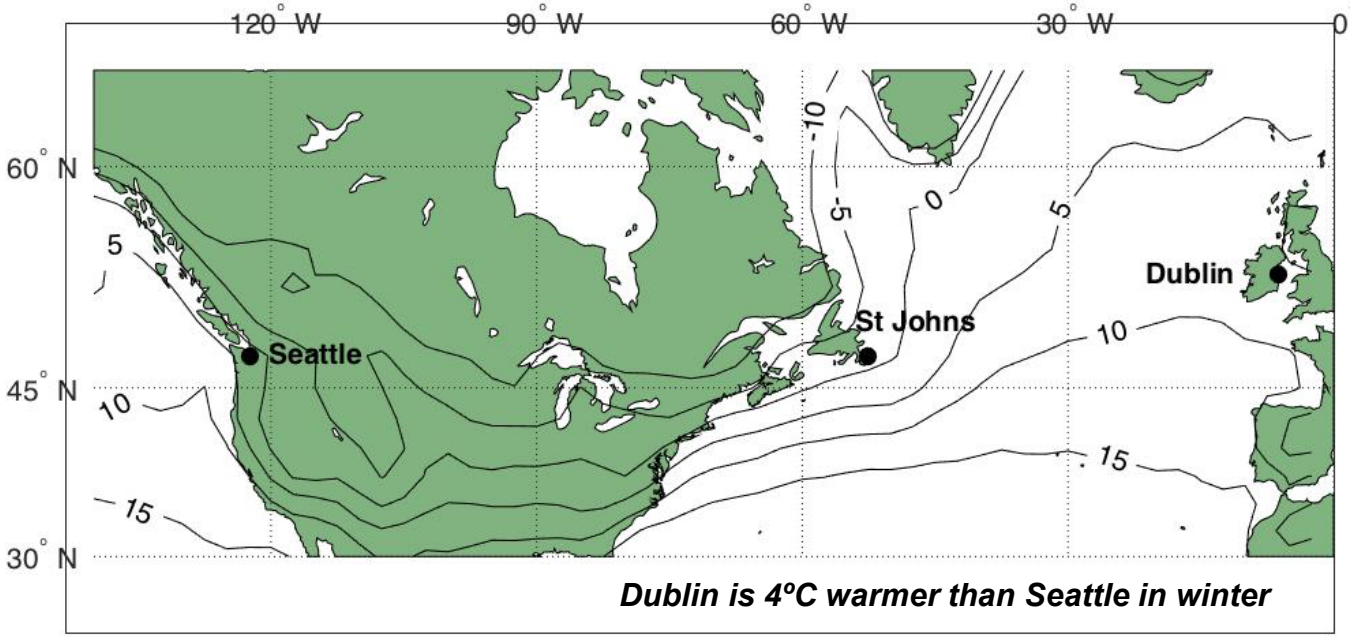
NERC SCIENCE OF THE ENVIRONMENT

The AMOC and its importance



The Atlantic Meridional Overturning Circulation (AMOC):

- a system of currents
- carrying warm, shallow water northwards and
- returning cold, deep water

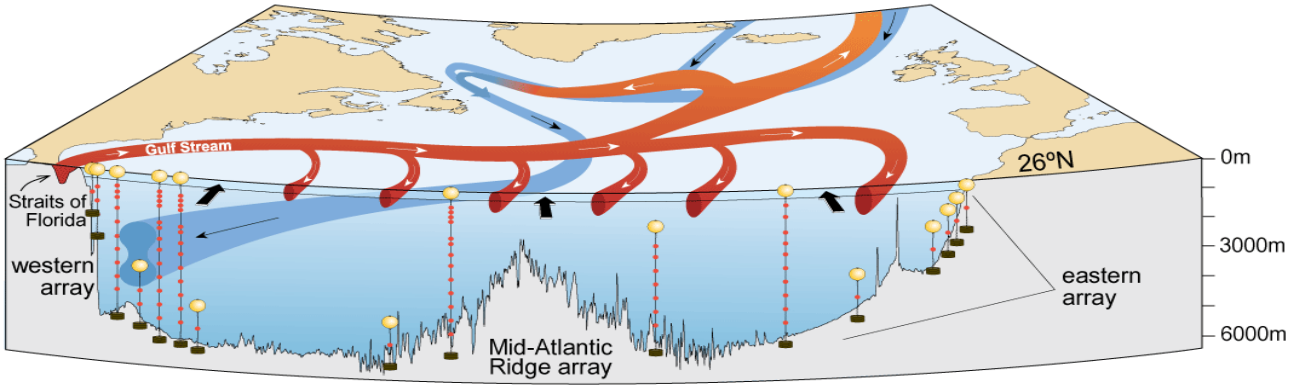


Dublin is 4ºC warmer than Seattle in winter

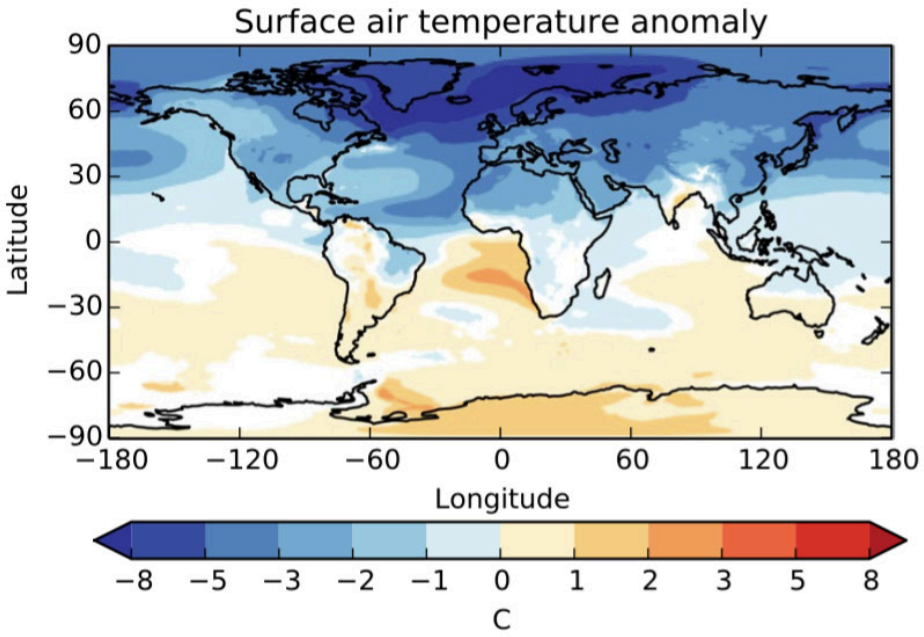
- A mechanism of the climate system in redistributing heat globally
- Key to maintaining mild winter climate in northwest Europe

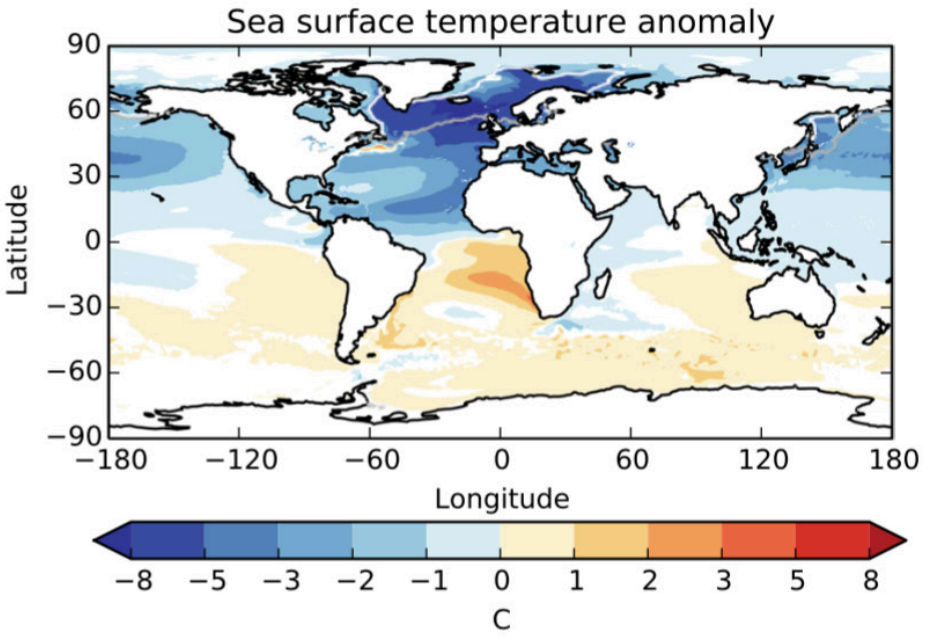
McCarthy et al. (2015), The influence of ocean variations on the climate of Ireland, *Weather*, 70(8), 242-245.

The AMOC and its importance



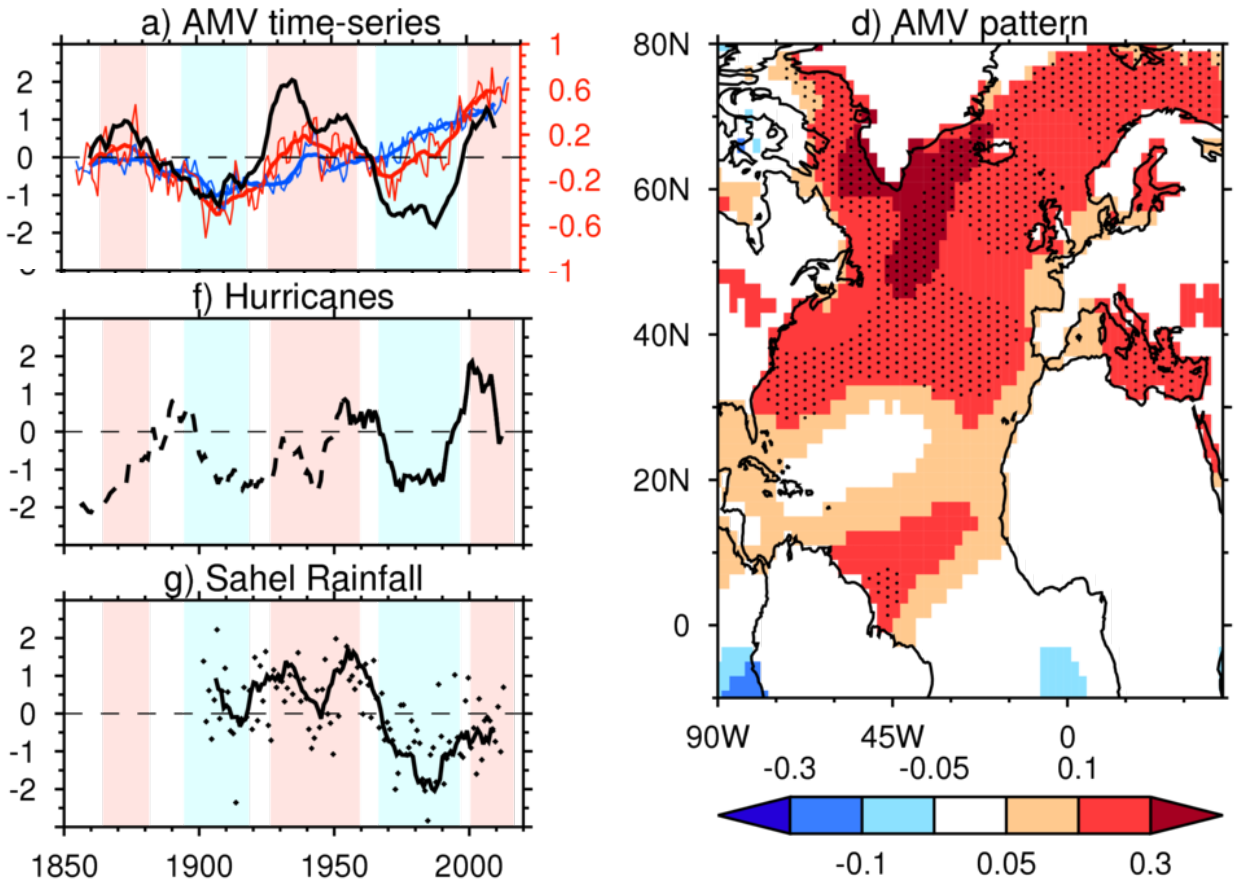
A collapse of the AMOC would lead to cooling throughout the Northern Hemisphere and most extremely in northwest Europe





Jackson et al. (2015), Global and European climate impacts of a slowdown of the AMOC in a high resolution GCM, *Clim. Dyn.*, 45(11-12), 3299-3316.

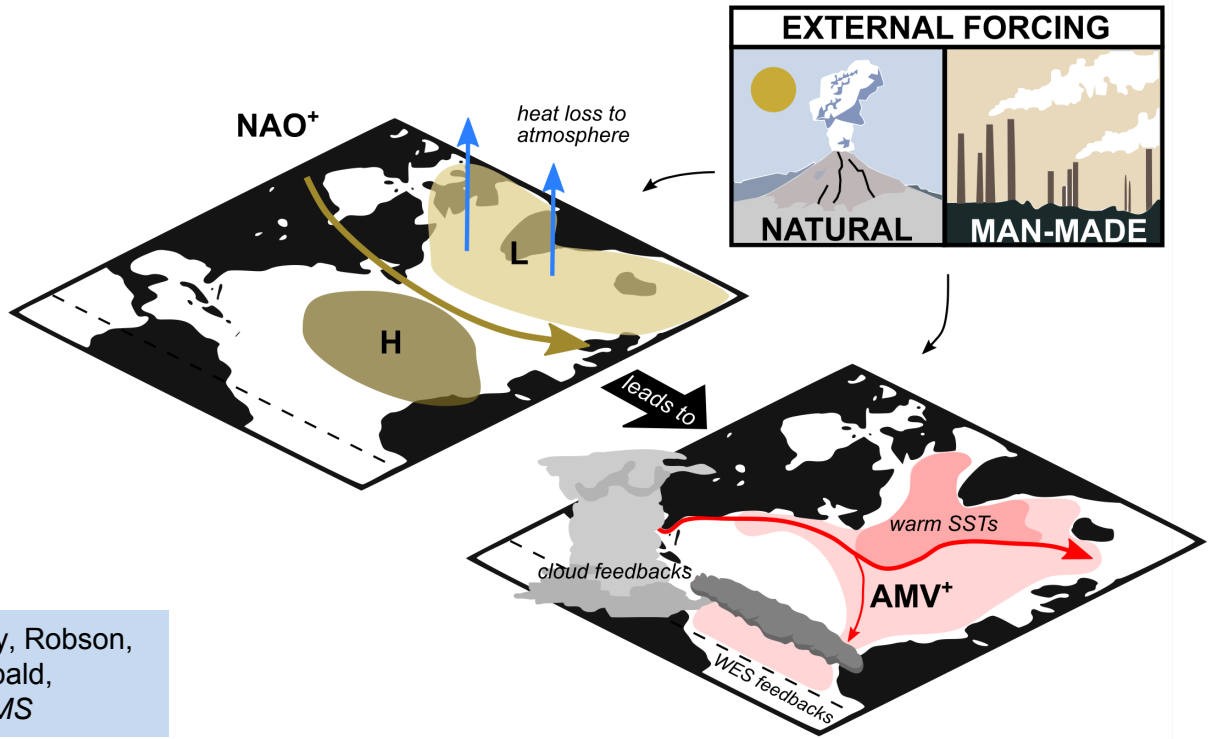
Atlantic Multidecadal Variability



Sutton, McCarthy, Robson, Sinha and Archibald, *submitted to BAMS*

- The Atlantic is a place of large multi-decadal variability esp. the Atlantic Multi-decadal Variability (AMV) of sea-surface temperatures (SST) with a large range of climate impacts
- e.g. Negative AMV is associated with droughts in the Sahel, linked to Ethiopian famines of the 1980s
- e.g. Positive AMV is associated with increased hurricane activity in the Caribbean

Atlantic Multidecadal Variability

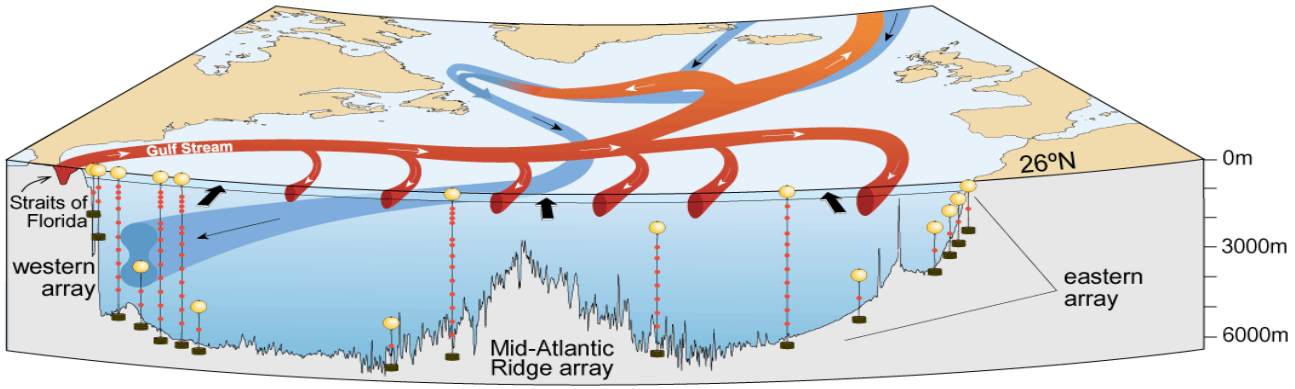


Sutton, McCarthy, Robson, Sinha and Archibald, *submitted to BAMS*

- It is widely hypothesised that ocean circulation (esp. the AMOC) controls the phases of the AMV through control of ocean heat content
- Many other forcings have been linked with the AMV (see schematic)
- We will consider the role of the AMOC in AMV using direct observations and reconstructions

Direct Observations

The AMOC at 26ºN

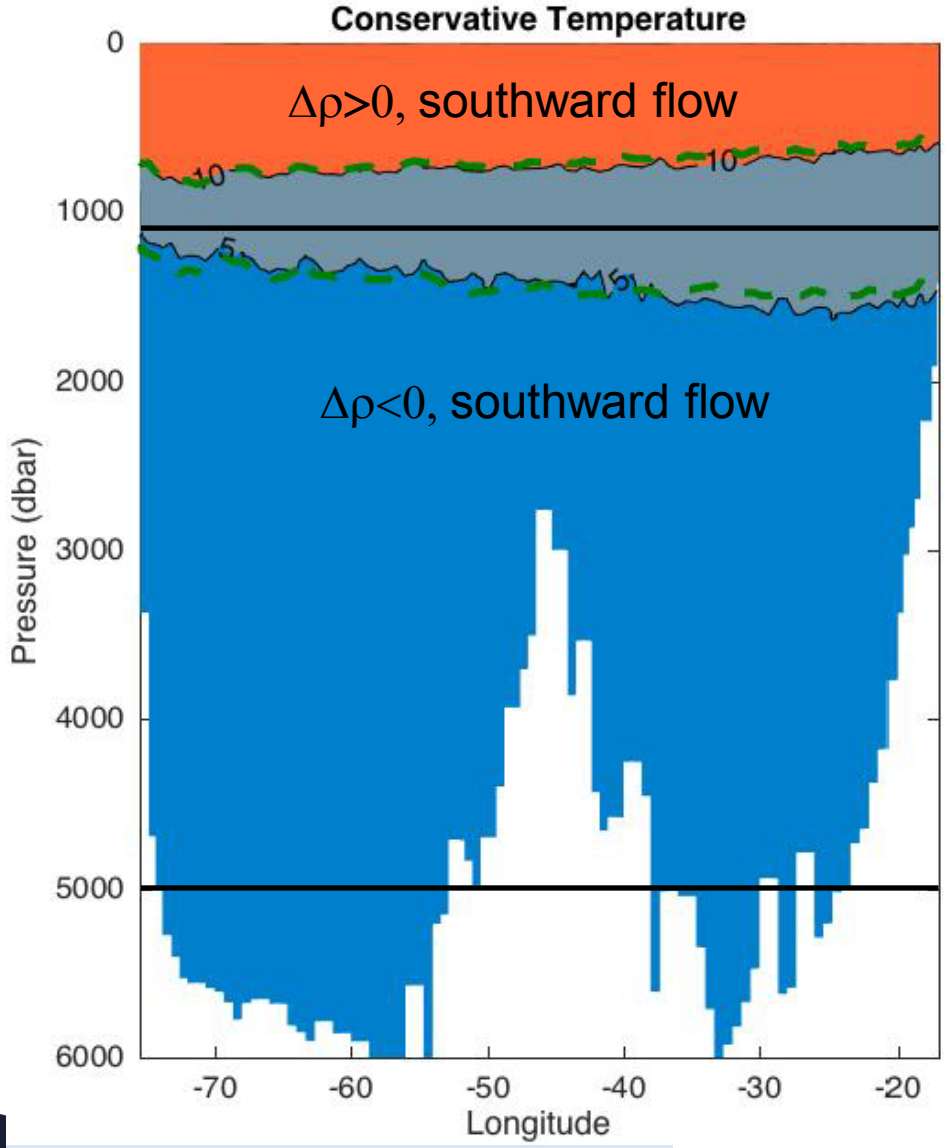


How we observe the AMOC at 26ºN:

- RAPID makes basinwide, full-depth measurements of the overturning

With the Florida Current measurements capturing the western boundary current, the fundamental dynamic captured by RAPID is the partition between southward flow in the gyre and southward flow in the North Atlantic Deep Water

Deep, basinwide measurements



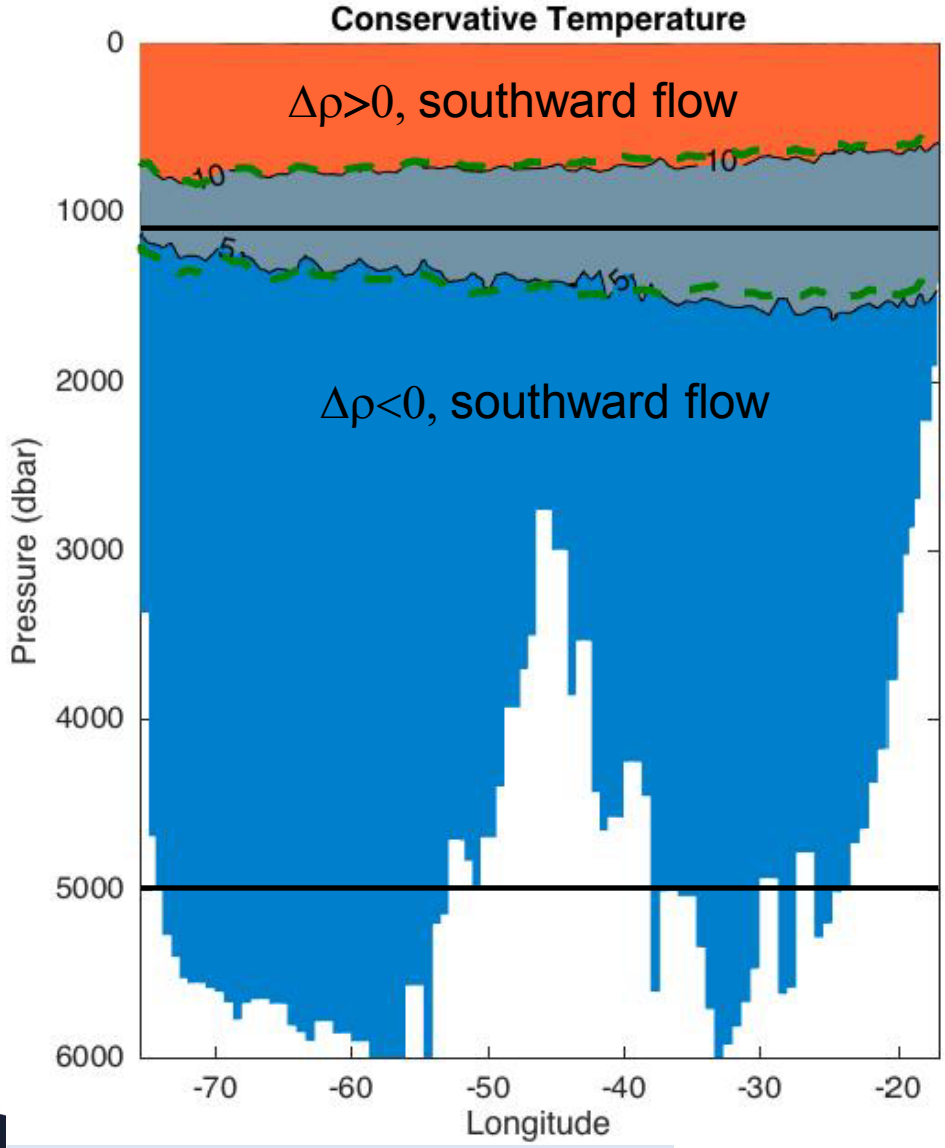
Less dense water on the west in the thermocline defines southward gyre circulation

More dense water on the west defines southward flow of North Atlantic Deep Water (particularly of Labrador Sea water)

This shear reversal must be captured requiring (at least) a 3 layer model

McCarthy et al. (2017), The importance of deep, basinwide measurements in optimised Atlantic Meridional Overturning Circulation observing arrays. *in press at JGR: Oceans*

Deep, basinwide measurements



McCarthy et al. (2017), The importance of deep, basinwide measurements in optimised Atlantic Meridional Overturning Circulation observing arrays. *in press at JGR: Oceans*

Not captured by satellite SSH measurements or thermocline-only measurements

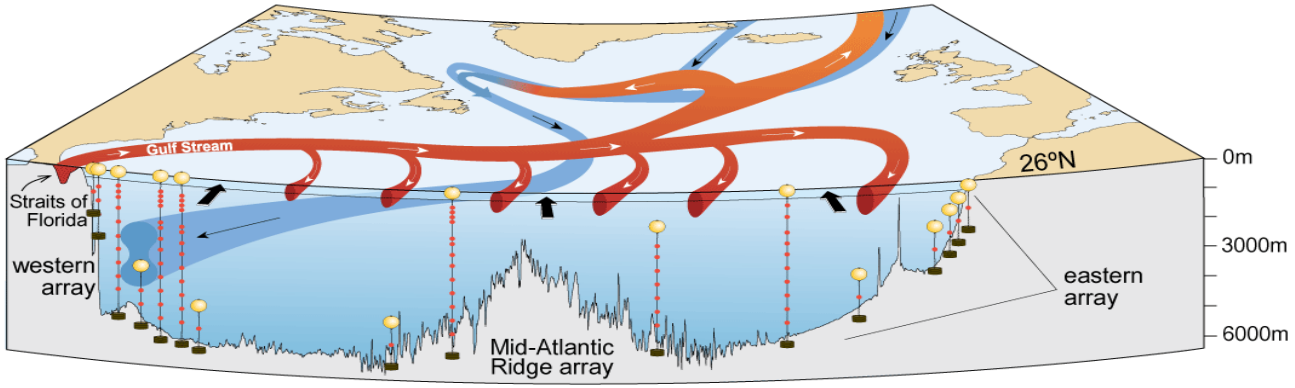
e.g. estimates based on zonal SSH gradient (h_e-h_w) would link increased southward flow with reduced density of Labrador Sea Water

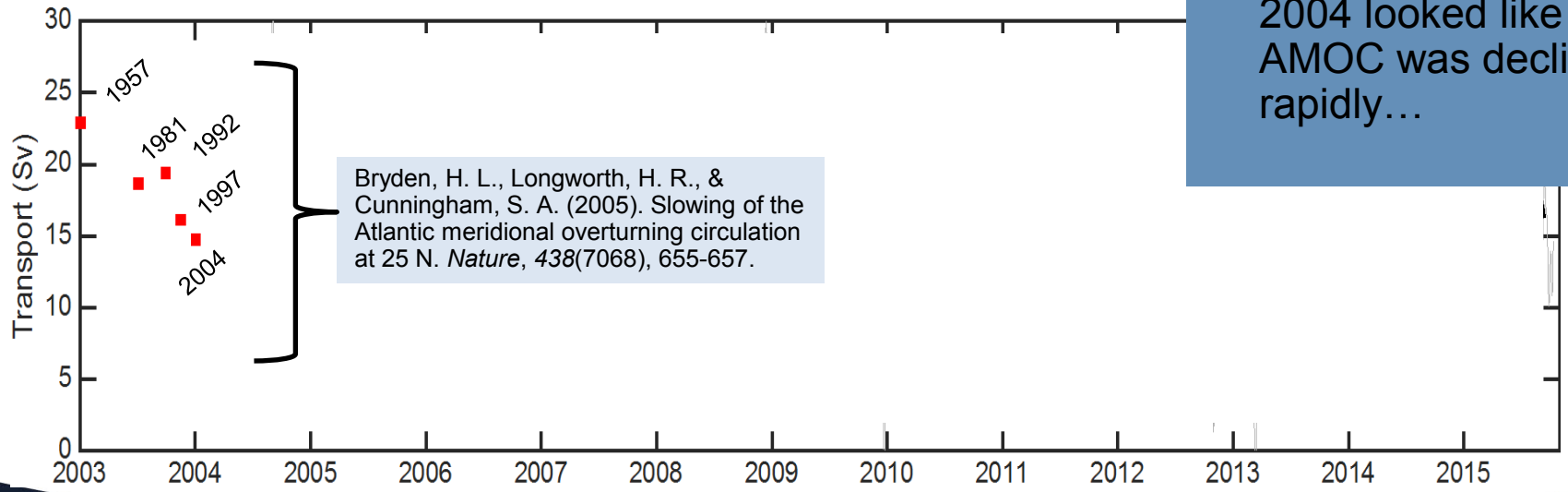
Not captured with a fixed reference level as this doesn't allow for shear reversal

Measurements on one side of the basin can be very misleading

e.g. climate change predicts a general warming of the deep ocean but what matters for the AMOC is the difference across the basin

The AMOC at 26ºN



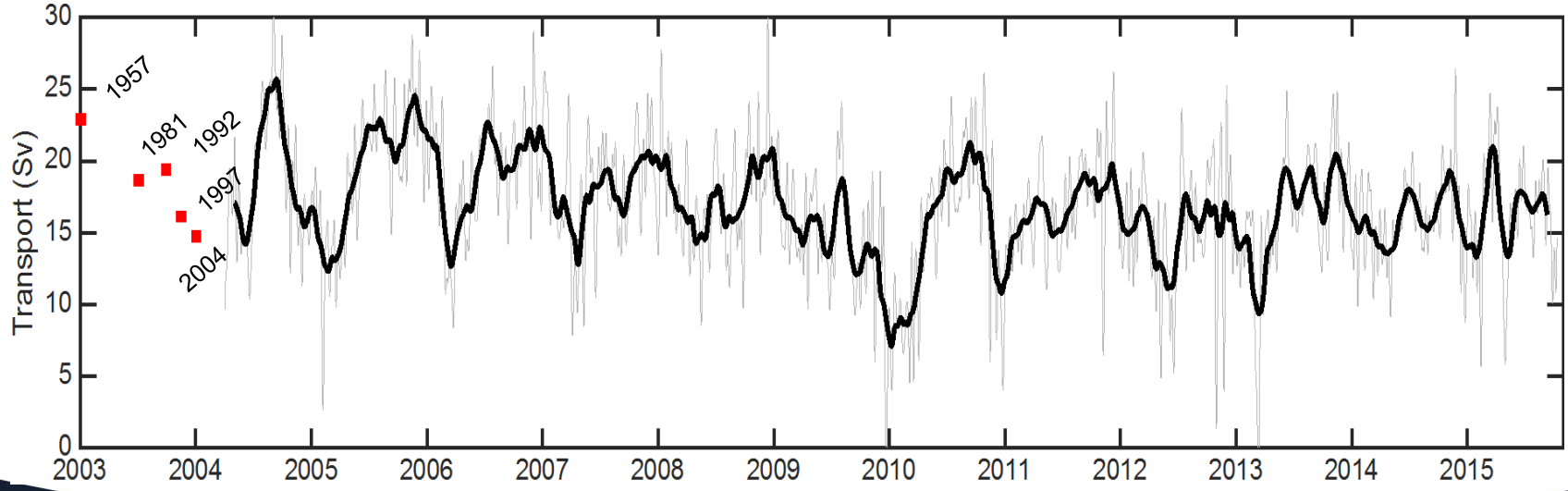


Bryden, H. L., Longworth, H. R., & Cunningham, S. A. (2005). Slowing of the Atlantic meridional overturning circulation at 25 N. *Nature*, *438*(7068), 655-657.

Why we observe the AMOC at 26ºN:

- Near maximum of the overturning used by climate models to define *the* AMOC
- Extensive historical observations that in 2004 looked like the AMOC was declining rapidly…

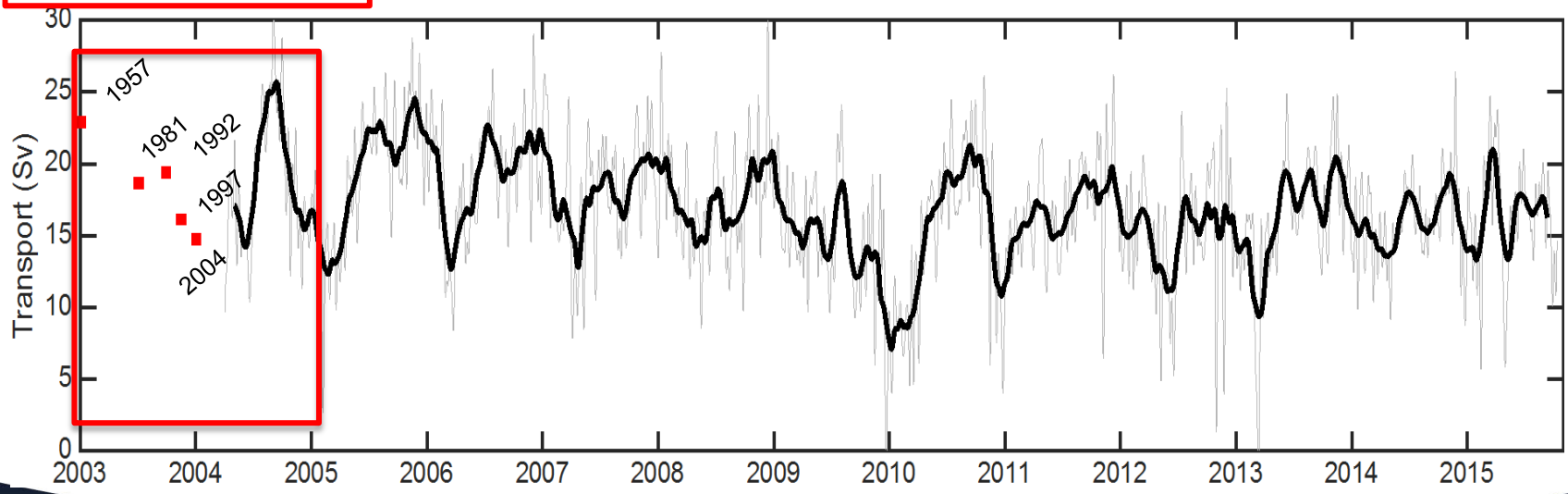
The AMOC at 26ºN



The 11.5 year AMOC record

Large sub-annual variability:
The first year's measurements from RAPID showed that sub-annual variability of the AMOC encompassed more than the full range of the historical measurements.

Cunningham, S. A. et al. (2007). Temporal variability of the Atlantic meridional overturning circulation at 26.5 N. *Science*, *317*(5840), 935-938.



AMOC in Decline

Large sub-annual variability:
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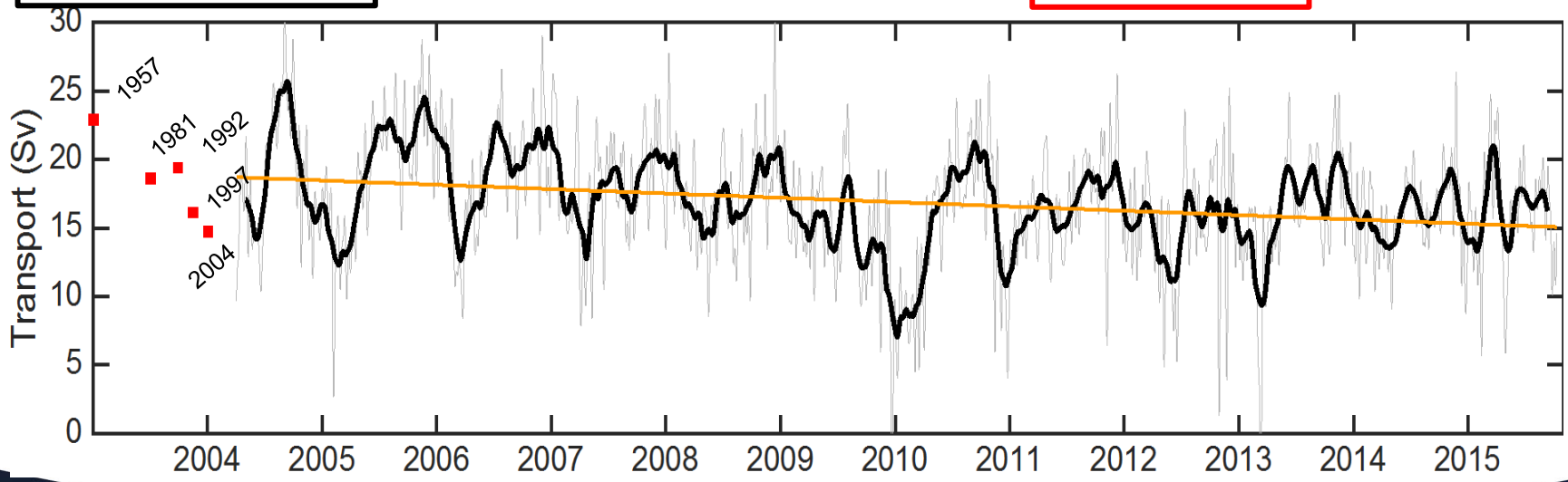
Evidence of a slowdown?
A decline of 0.6 Sv/year was observed over the first ten years. This is ten times larger than long term decline predicted by the IPCC.

Smeed, D. A., et al. (2014). Observed decline of the Atlantic meridional overturning circulation 2004–2012. *Ocean Science*, *10*(1), 29-38.



A new AMV cold phase?

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Smeed, D. A., et al. *in prep*. The changed state of the Atlantic Meridional Overturning Circulation

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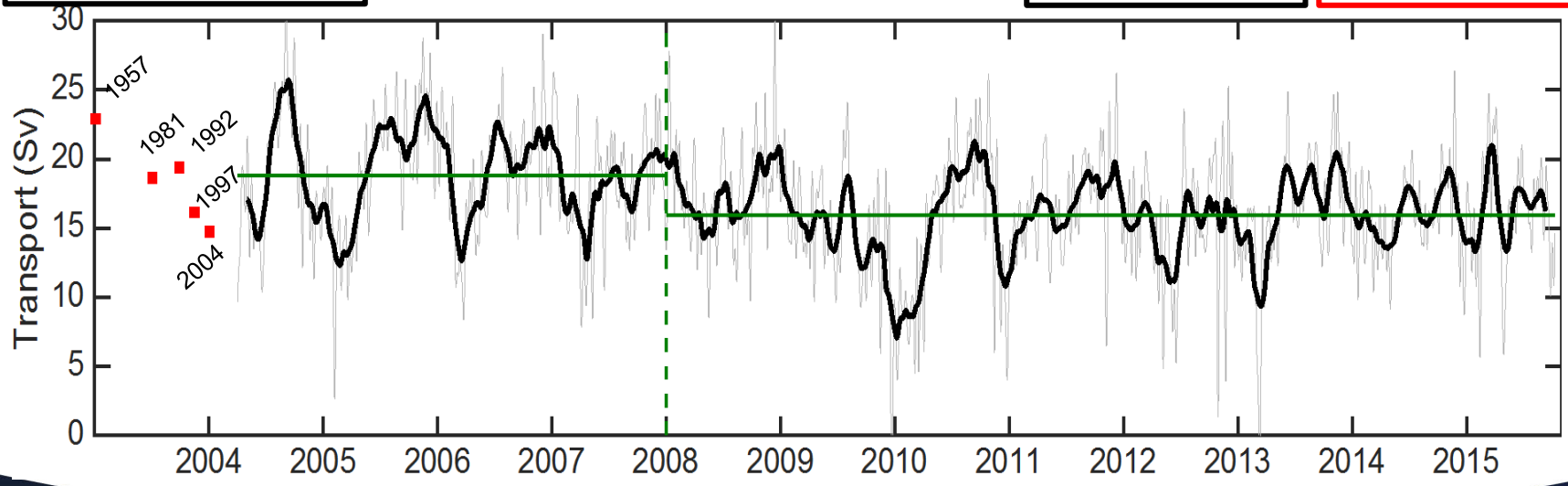
Latest 18 months of data:
Statistical analysis of the timeseries indicates a step change in 2008 with the AMOC having an average of 16 Sv before and an average of 18.8 Sv afterwards.



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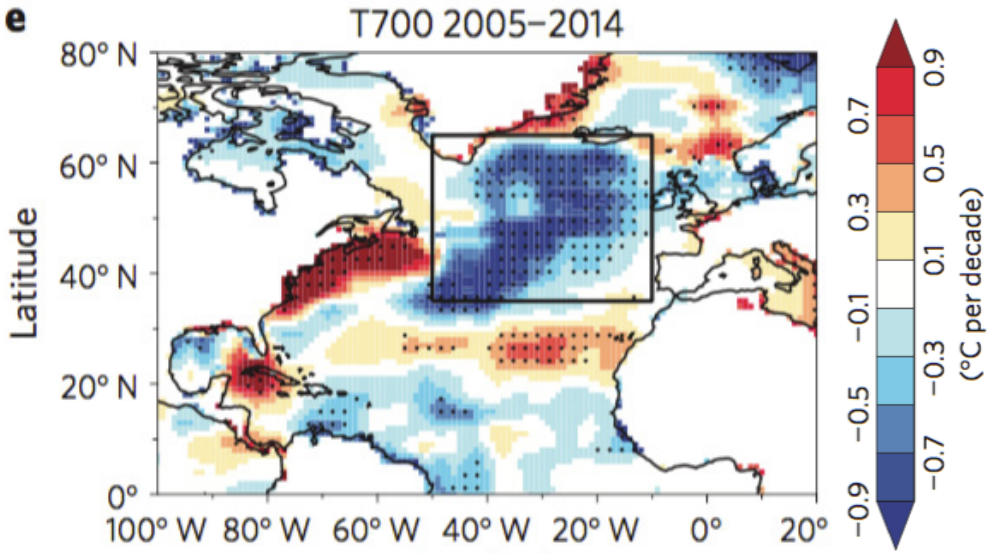
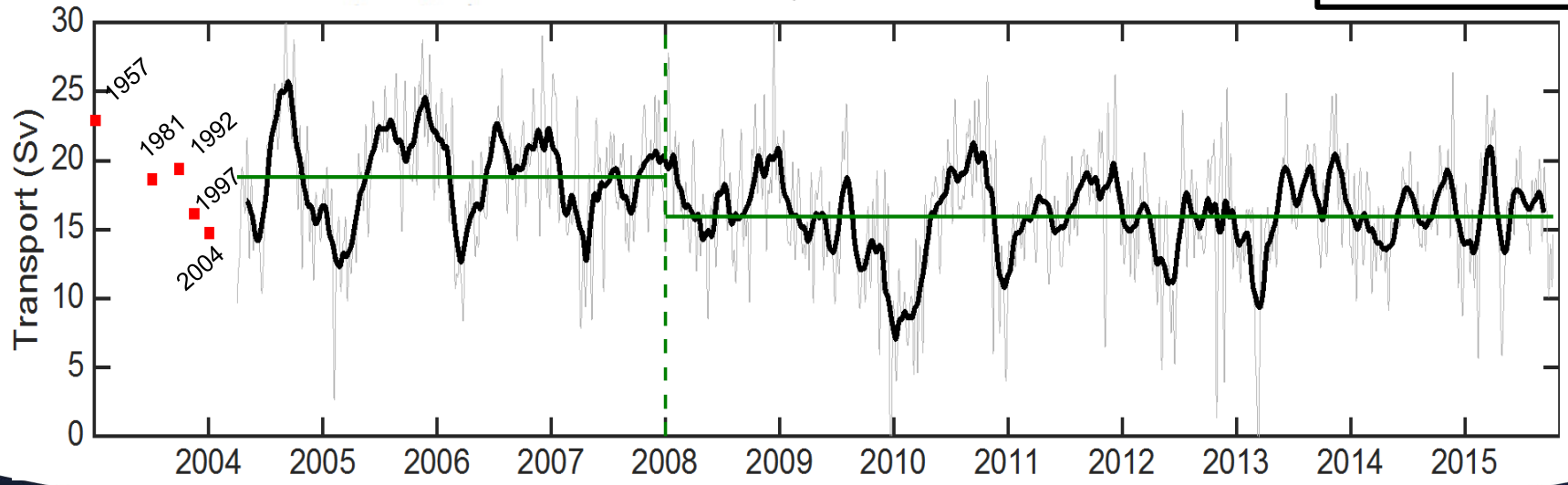


Other authors have suggested the AMOC changed in 2005 and that we are entering a cool Atlantic phase with weaker overturning

Robson, J., Ortega, P., & Sutton, R. (2016). A reversal of climatic trends in the North Atlantic since 2005. *Nature Geoscience*.

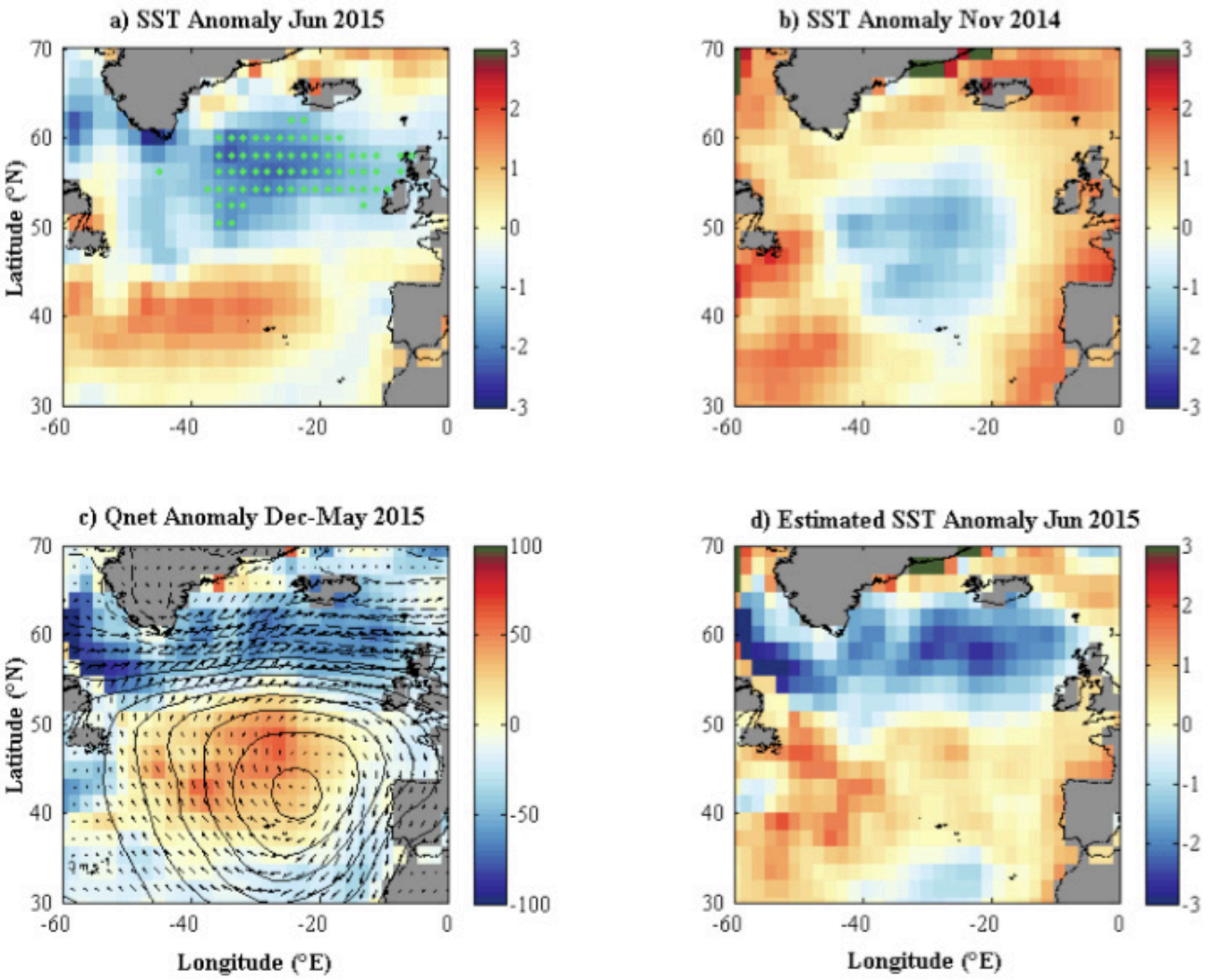
Latest 18 months of data: Statistical analysis of the timeseries indicates a step change in 2008 with the AMOC having an average of 16 Sv before and an average of 18.8 Sv afterwards.



Other drivers of the Cool Atlantic

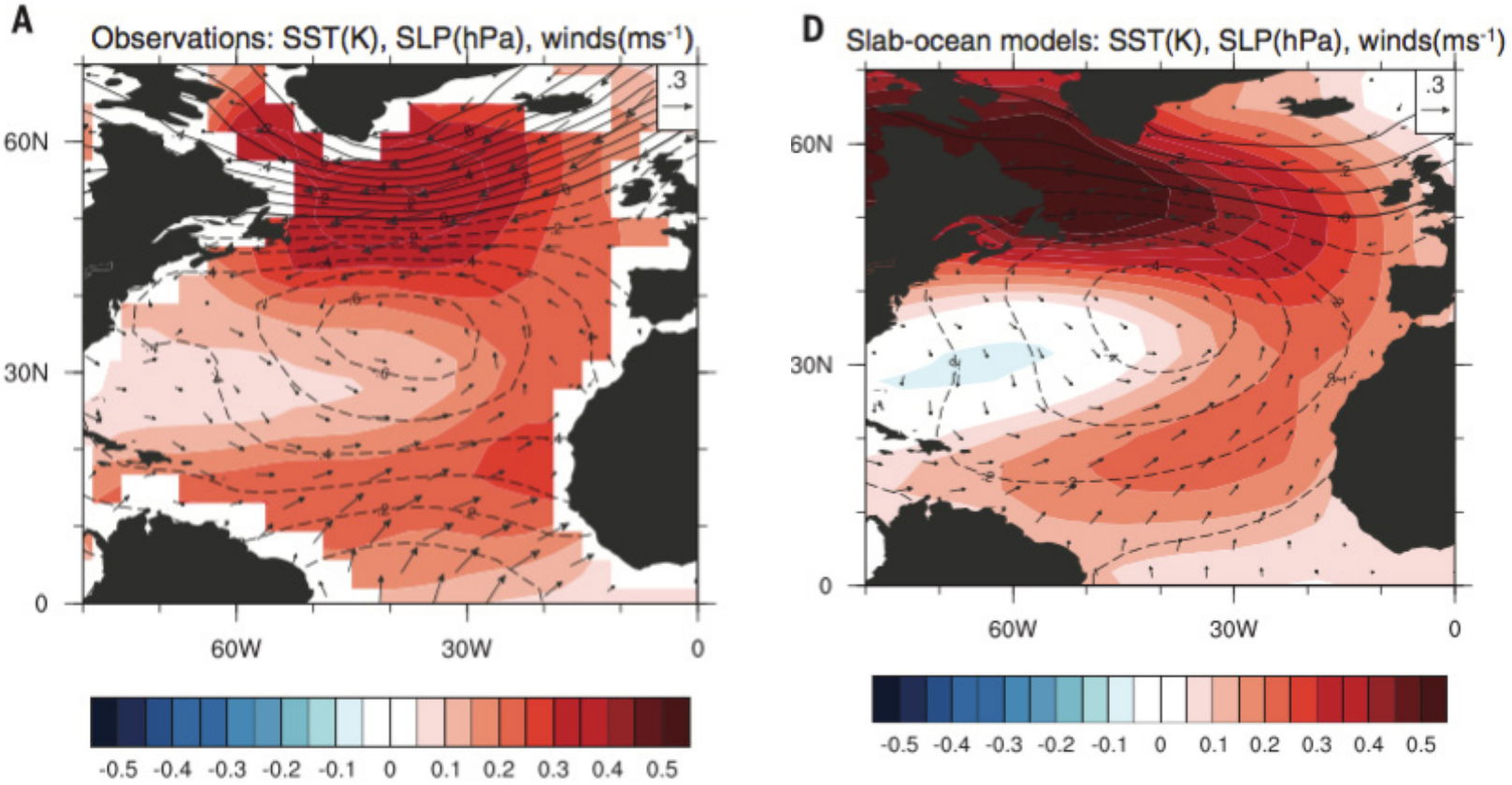
Was the recent Atlantic cold blob all due ocean-atmosphere fluxes?

The timescales considered are important



Duchez, A. et al. (2016). Drivers of exceptionally cold North Atlantic Ocean temperatures and their link to the 2015 European heat wave, *Enviro. Res. Letters*

Does the AMOC have a role in AMV?



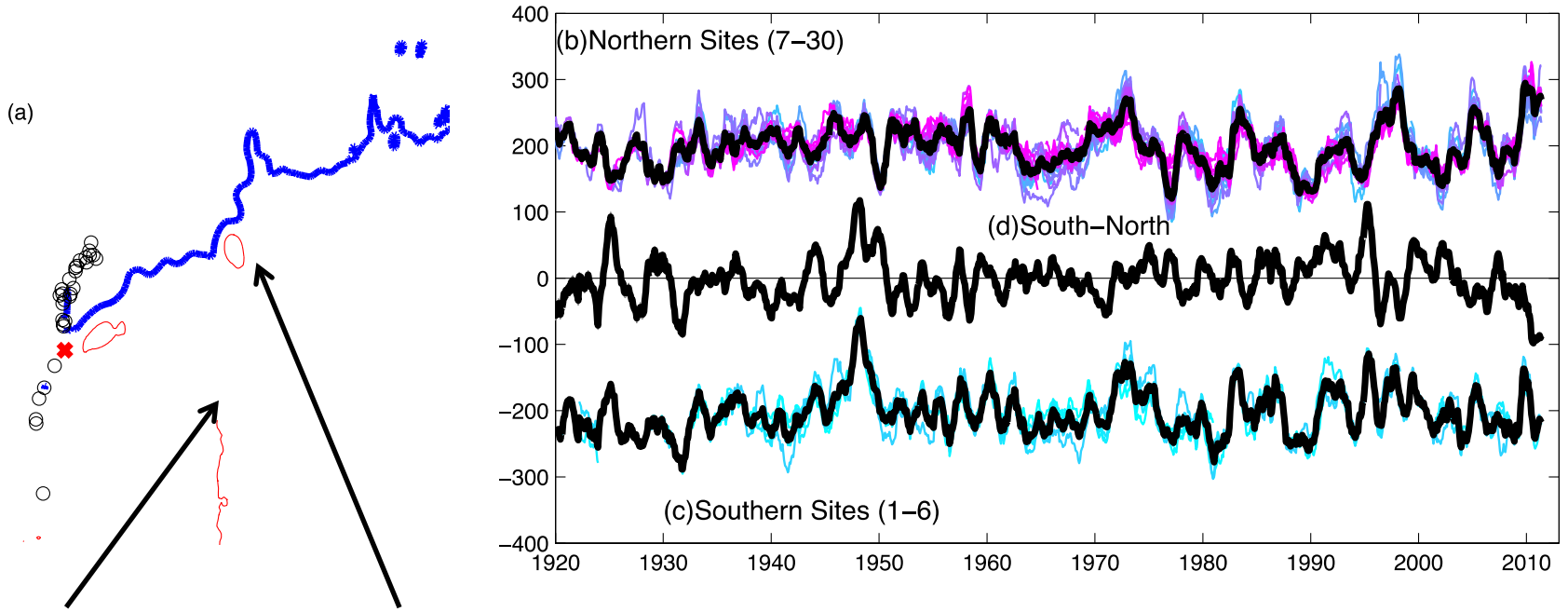
The lack of long ocean circulation timeseries has lead to prominent challenges to the paradigm of ocean circulation controlling the AMV

Clement et al. (2015). Atlantic Multidecadal Oscillation without a role for ocean circulation, *Science*

Estimating Multi-decadal Ocean Circulation

A sea-level index of circulation

- We estimate the sea-level gradient as an average of the southern minus an average of the northern gauges
- This straddles the intergyre boundary/transition region between the subtropical and subpolar gyres

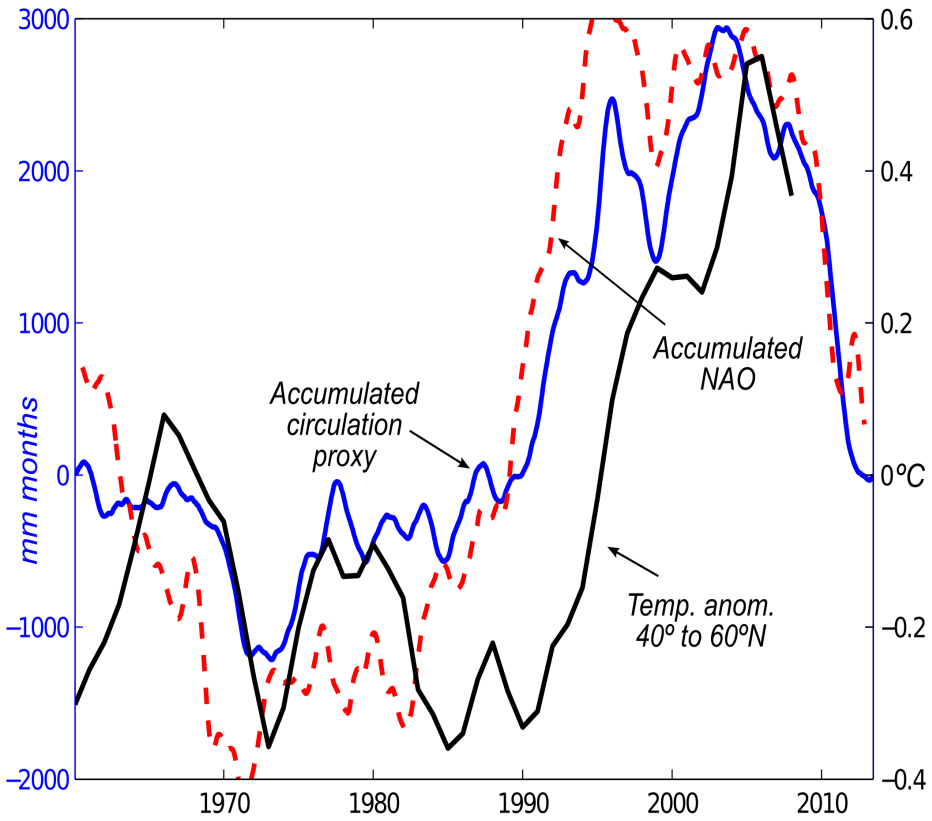


mean dynamic topo contours

SST anomalies >0.5ºC during warm AMO phase (hatched)

McCarthy et al., *Nature,* 2015
Ocean control of decadal Atlantic climate variability revealed by sea-level observations

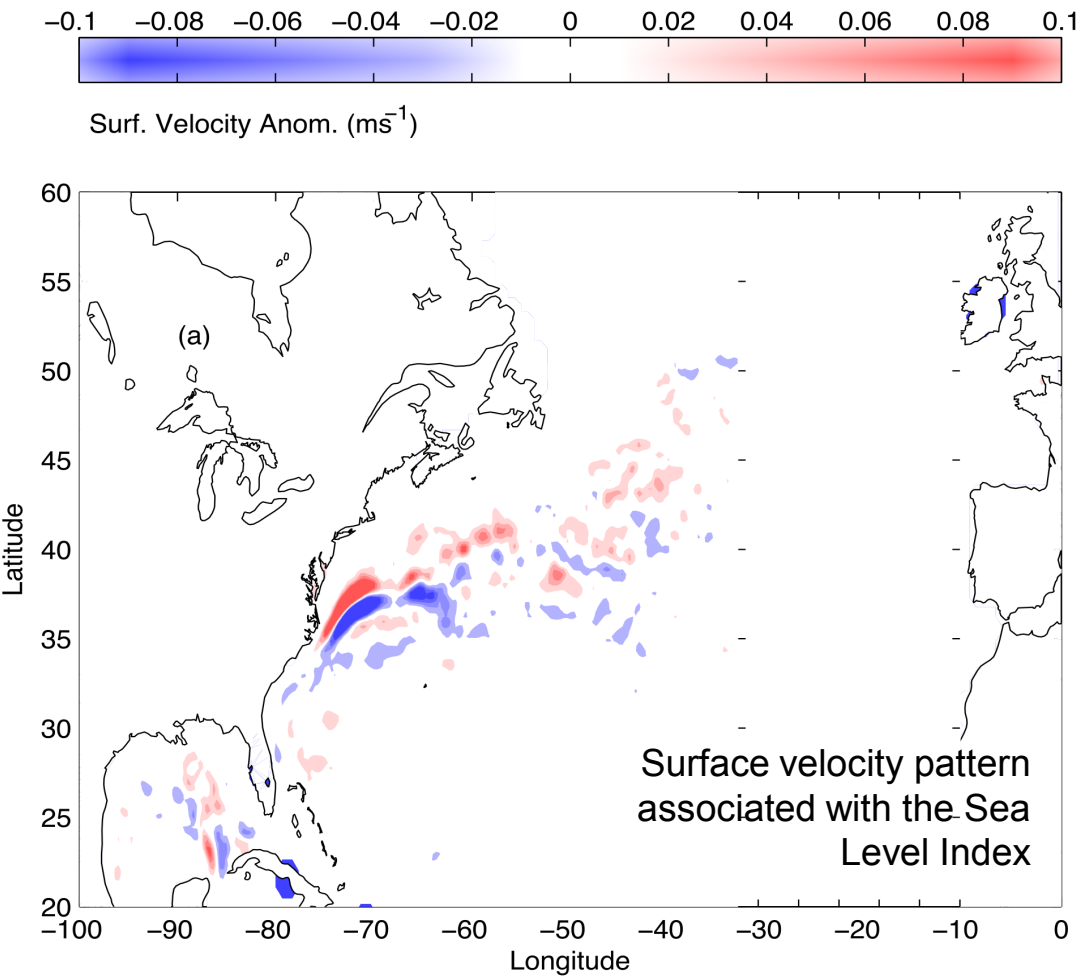
The Sea Level index in a Climate Context

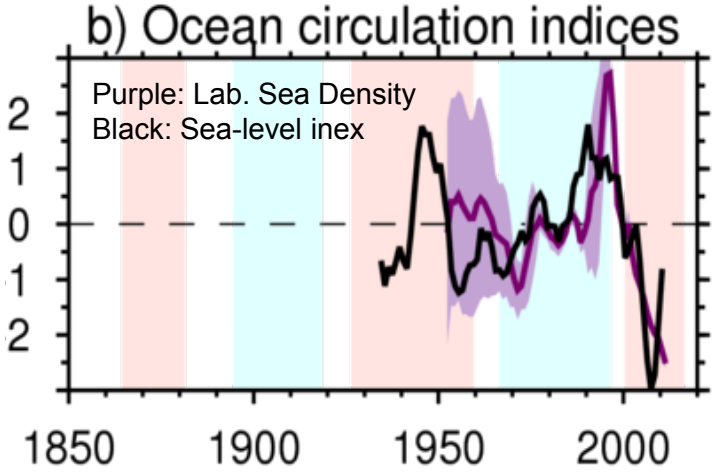


- The accumulation in time of the sea-level index estimates heat content. Circulation is proportional to heat transport
- In fact, it leads subpolar heat content and the rate of change of the AMO by 2 years
- The NAO leads the sea-level index by a year and is significantly correlated

McCarthy et al., *Nature,* 2015
Ocean control of decadal Atlantic climate variability revealed by sea-level observations

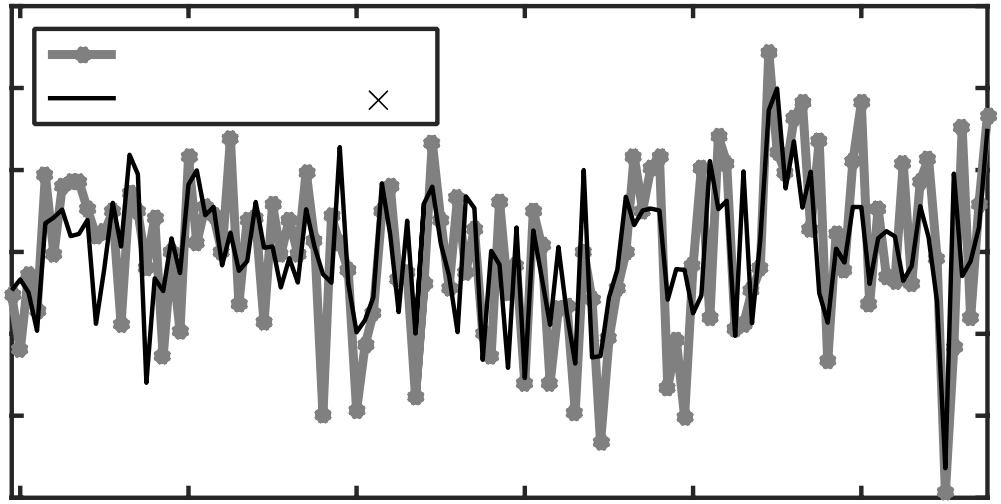
The Sea Level index in a Climate Context



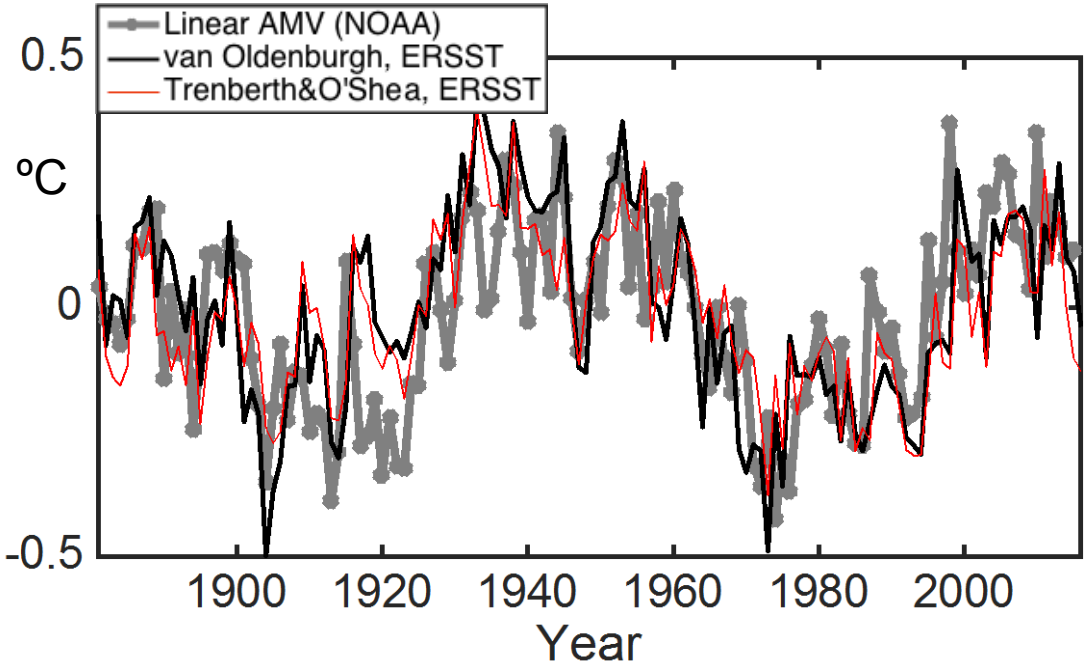


- The sea-level index is closely related to (a) the Gulf Stream North Wall and (b) Labrador Sea density
- Both of these are indices associated with ocean circulation and the AMOC
- Both of these indices have an established connection with the NAO

NAO and AMV



Long timeseries of the NAO and AMV exist which we can examine to consider relative roles of direct atmospheric and ocean circulation influences

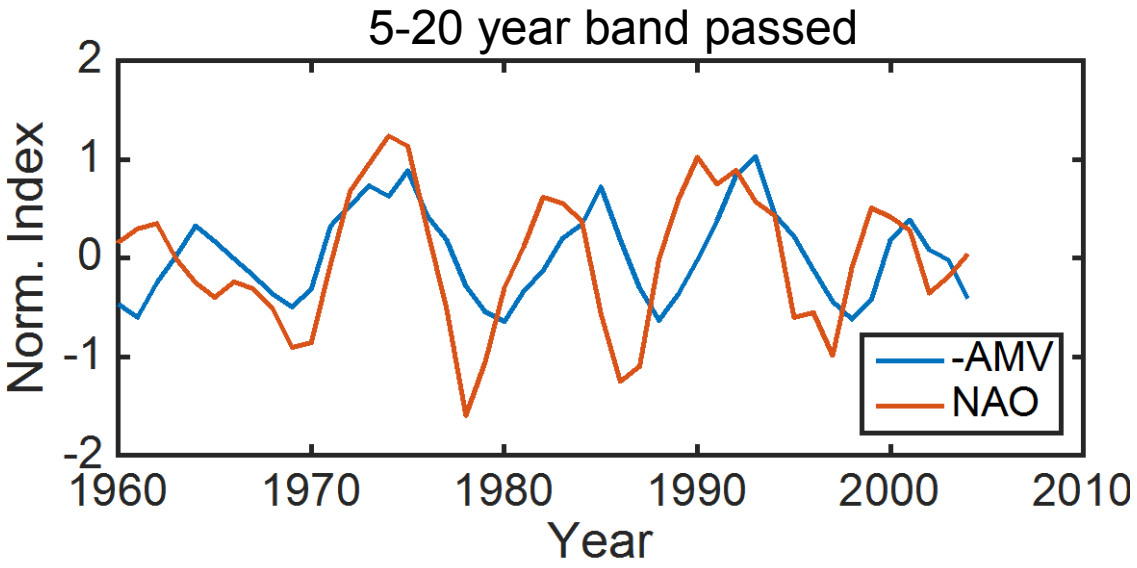


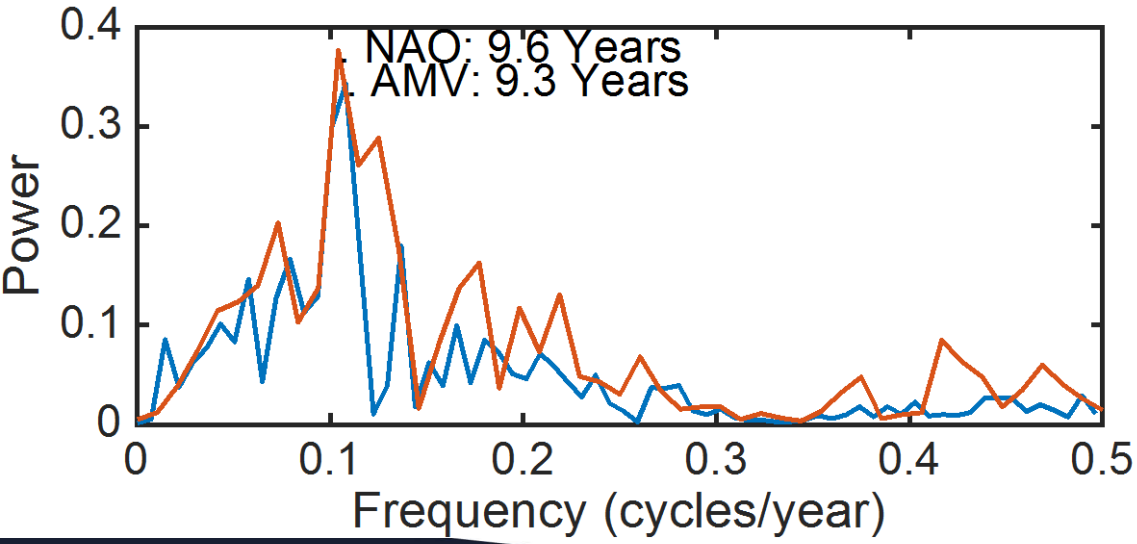
Multidecadal variability dominates the AMV

Multidecadal variability is present but weaker in the NAO

McCarthy, G. D. and Joyce, T. (in prep), The Gulf Stream North Wall and decadal to multidecadal climate fluctuations

NAO and AMV: Decadal





A quasi-decadal mode is common to the NAO and AMV and visible in band passed data

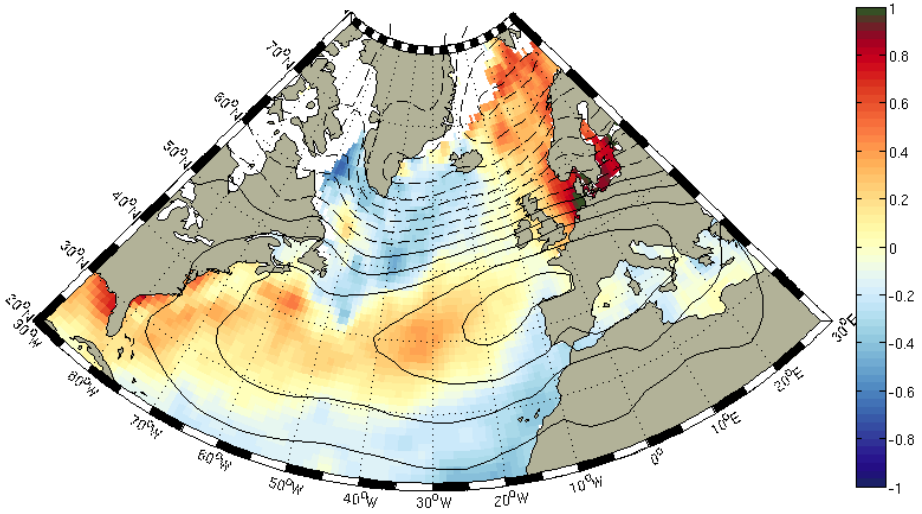
The relationship is inverted pointing to the role of ocean-atmosphere fluxes

Quasi-decadal modes have been identified in NAO at 11 years (related to solar forcing) and 7.7 years. And in SST from 8.5 years to 14 years

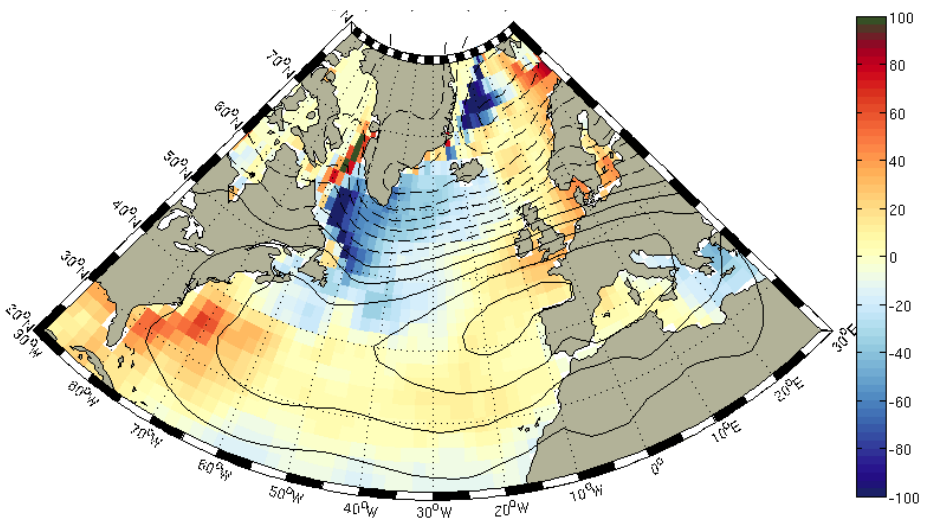
McCarthy, G. D. and Joyce, T. (in prep), The Gulf Stream North Wall and decadal to multidecadal climate fluctuations

NAO and AMV: Decadal

5-20 Year SST



5-20 Qnet

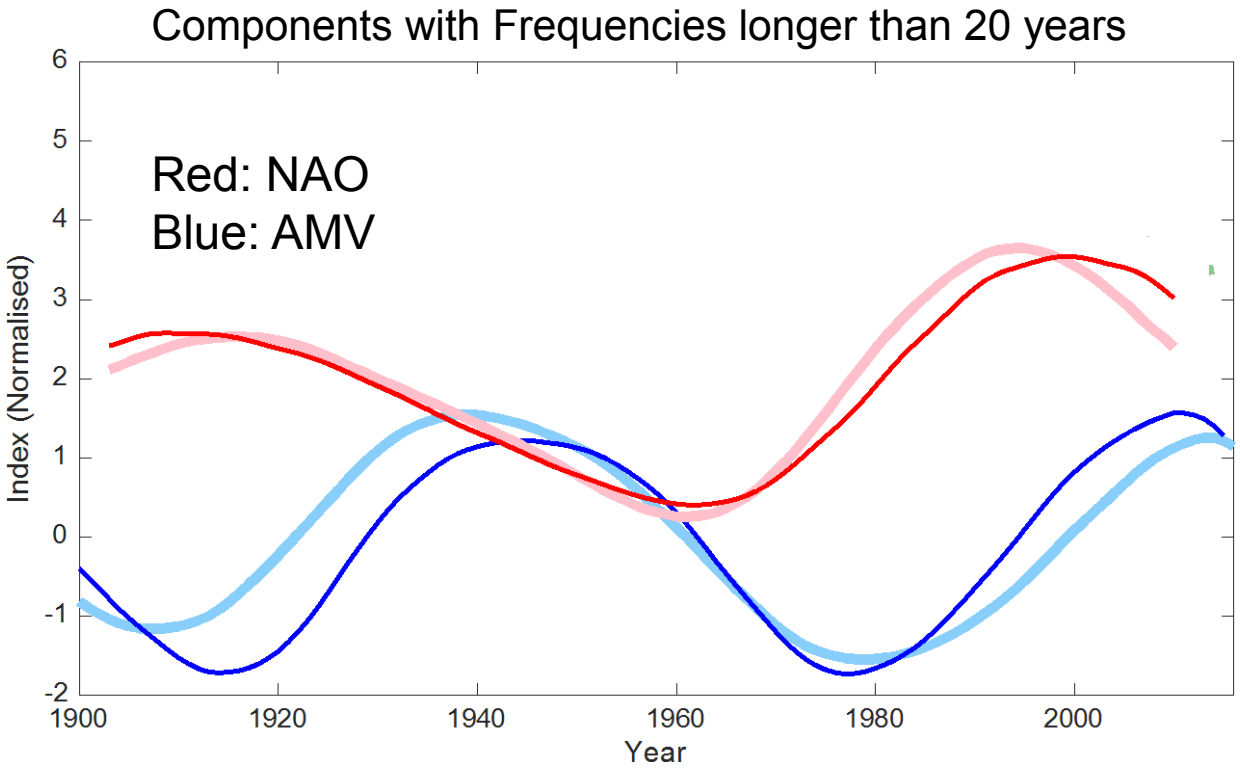


A positive NAO leads to cooling over the subpolar gyre due to air-sea fluxes explaining the inverse relationship between NAO and AMV at this frequency

The pattern of air-sea flux in this band supports this

McCarthy, G. D. and Joyce, T. (in prep), The Gulf Stream North Wall and decadal to multidecadal climate fluctuations

NAO and AMV: Multidecadal

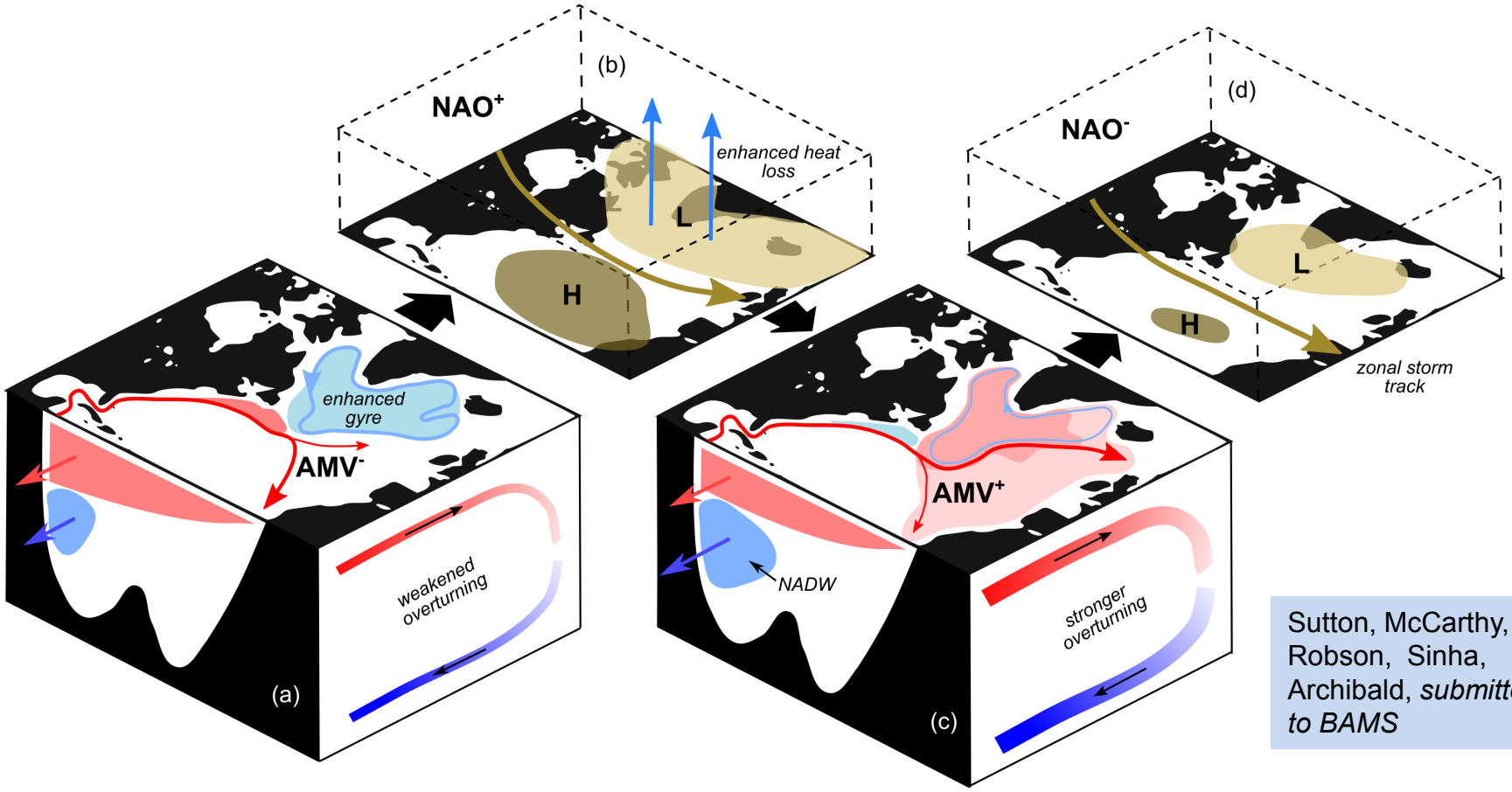


On longer than decadal timescales, the NAO leads the slow variation of the AMV

The influence of the AMOC and ocean heat transport can mechanistically explain this relationship

McCarthy, G. D. and Joyce, T. (in prep), The Gulf Stream North Wall and decadal to multidecadal climate fluctuations

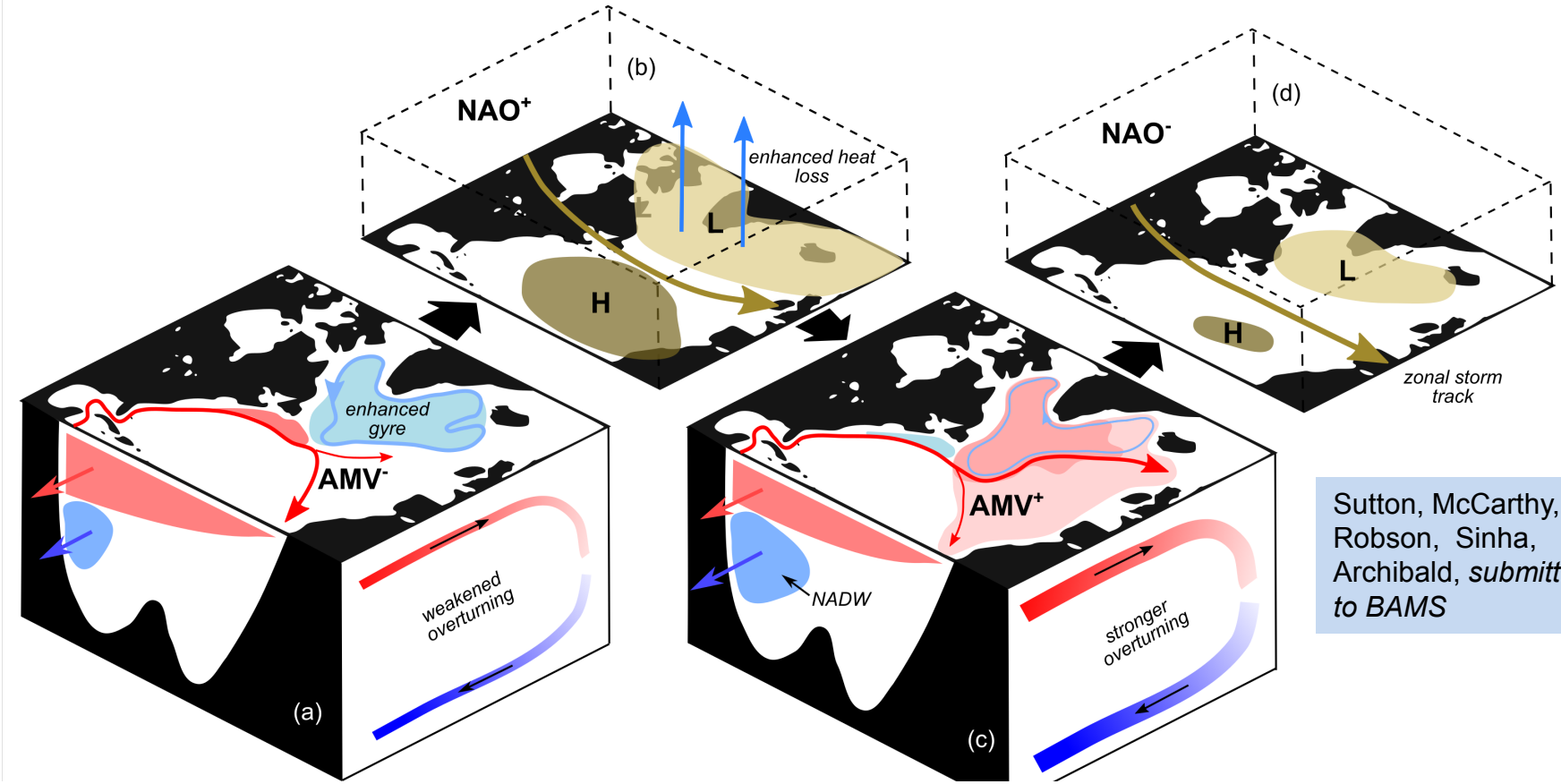
NAO, AMOC and AMV



Sutton, McCarthy, Robson, Sinha, Archibald, *submitted to BAMS*

- Up to decadal timescales, SST variability can be explained by air-sea fluxes
- On multi-decadal timescales, the ocean integrates NAO forcing and changes the AMOC
- This generates the AMV pattern

Summary



Sutton, McCarthy, Robson, Sinha, Archibald, *submitted to BAMS*

Direct observations of AMOC from RAPID and indirect estimates (such as Labrador Sea density) suggest we are entering a cool phase of the AMV

Results point to a key role for NAO forcing in this cycle with direct air-sea fluxes explaining up-to-decadal variability and NAO influence on the AMOC dominating on multidecadal timescales

A key challenge is to keep observing systems in the water long enough to reveal this variability