First Results From The Overturning In The Subpolar North Atlantic Program

A sea change in our view of overturning in the subpolar North Atlantic

M.S. Lozier, Feili Li, S. Bacon, F. Bahr, A. Bowe, **S. Cunningham**, F. de Jong, L. de Steur, B. DeYoung, J. Fischer, **S. Gary**, B. Greenan, N.P. Holliday, A. Houk, **L. Houpert**, **M. Inall**, W. Johns, H. Johnson, **C. Johnson**, J. Karstensen, G. Koman, I. LeBras, X. Lin[1], N. Mackay, D. Marshall, H. Mercier, M. Oltmanns, R.S. Pickart, A. Ramsey, D. Rayner, F. Straneo, V. Thierry, D.J. Torres, R.G. Williams, C. Wilson, J. Yang, **I. Yashayaev**, J. Zhao. *Science **363**, 616-521 (2019)*.

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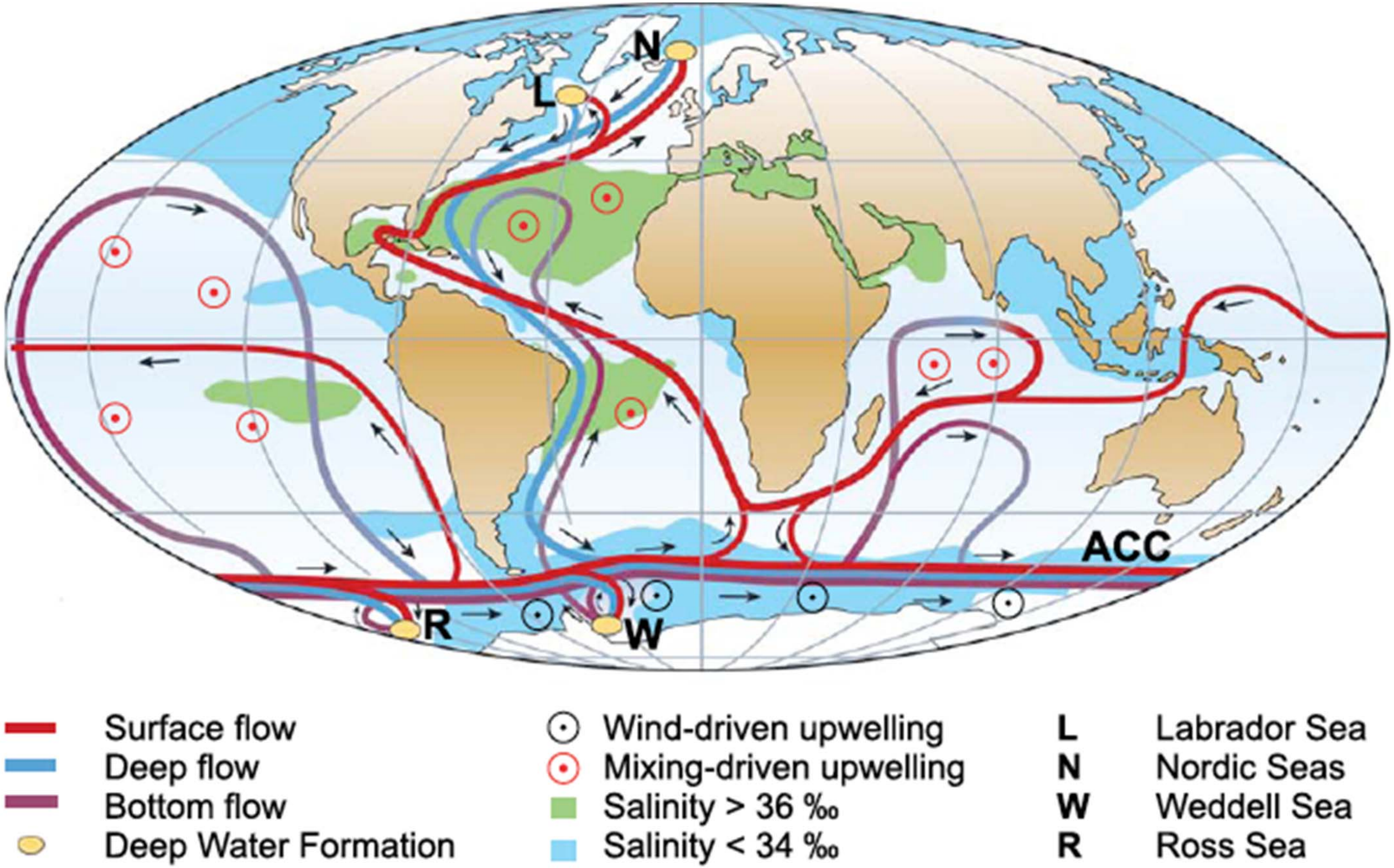
Stuart Cunningham, ATLAS GA 1-4th April 2019,

The Global Thermohaline Circulation

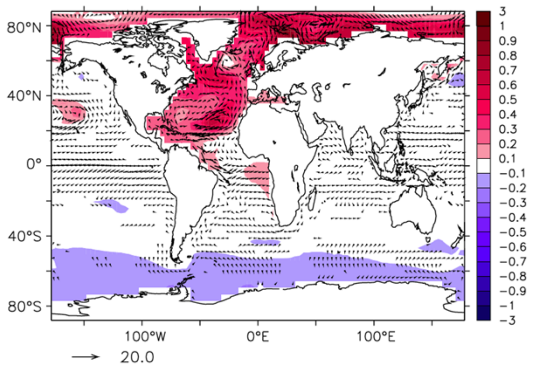
(Kuhlbrodt 2004)

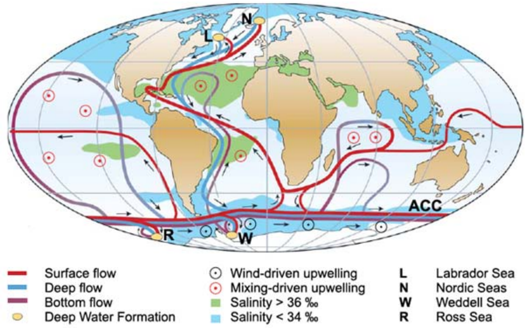


Global Thermohaline Circulation Impacts

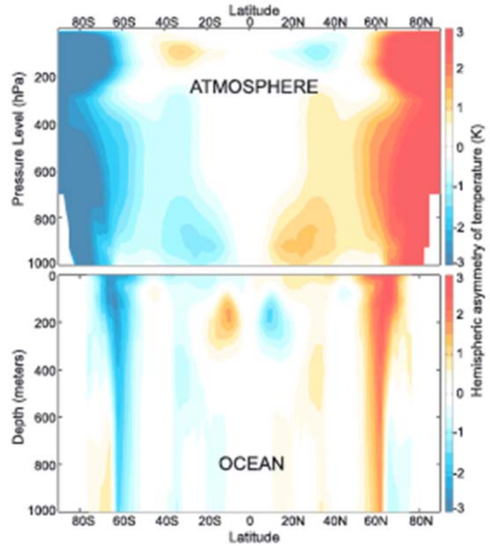
(Kuhlbrodt 2004)

ΔSea-Level 2150 [m]

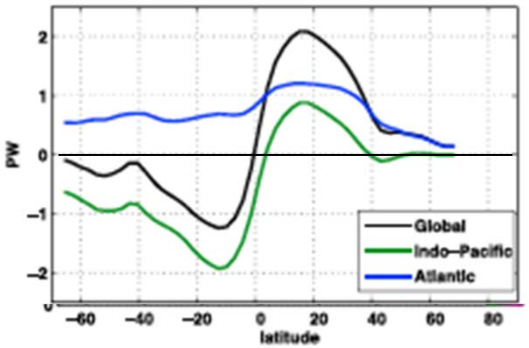


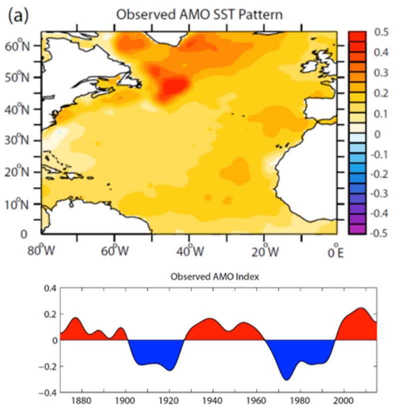


Observed hemispheric asymmetry of temperature in the atmosphere and ocean (Buckley 2015)

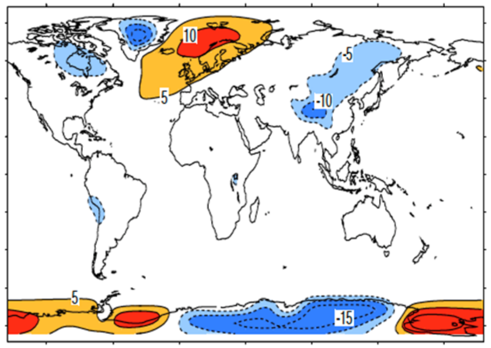


Meridional Heat Transport (Buckley 2015)

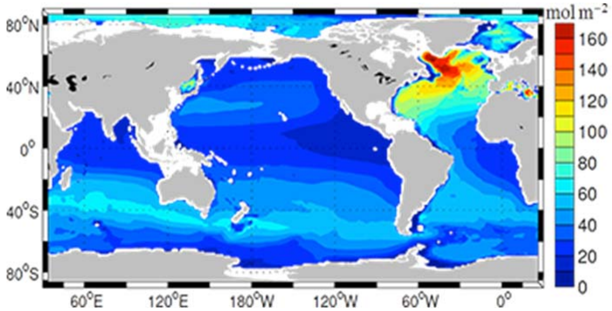




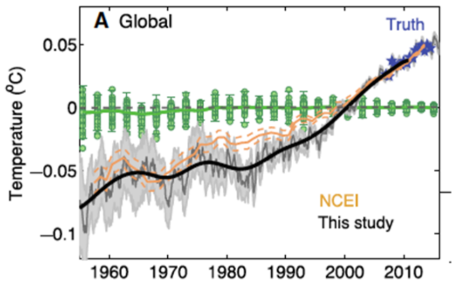
Deviation of surface air temperature from the zonal mean (Rahmstorf, 2000)



Anthropogenic Carbon (Khatiwala 2013)

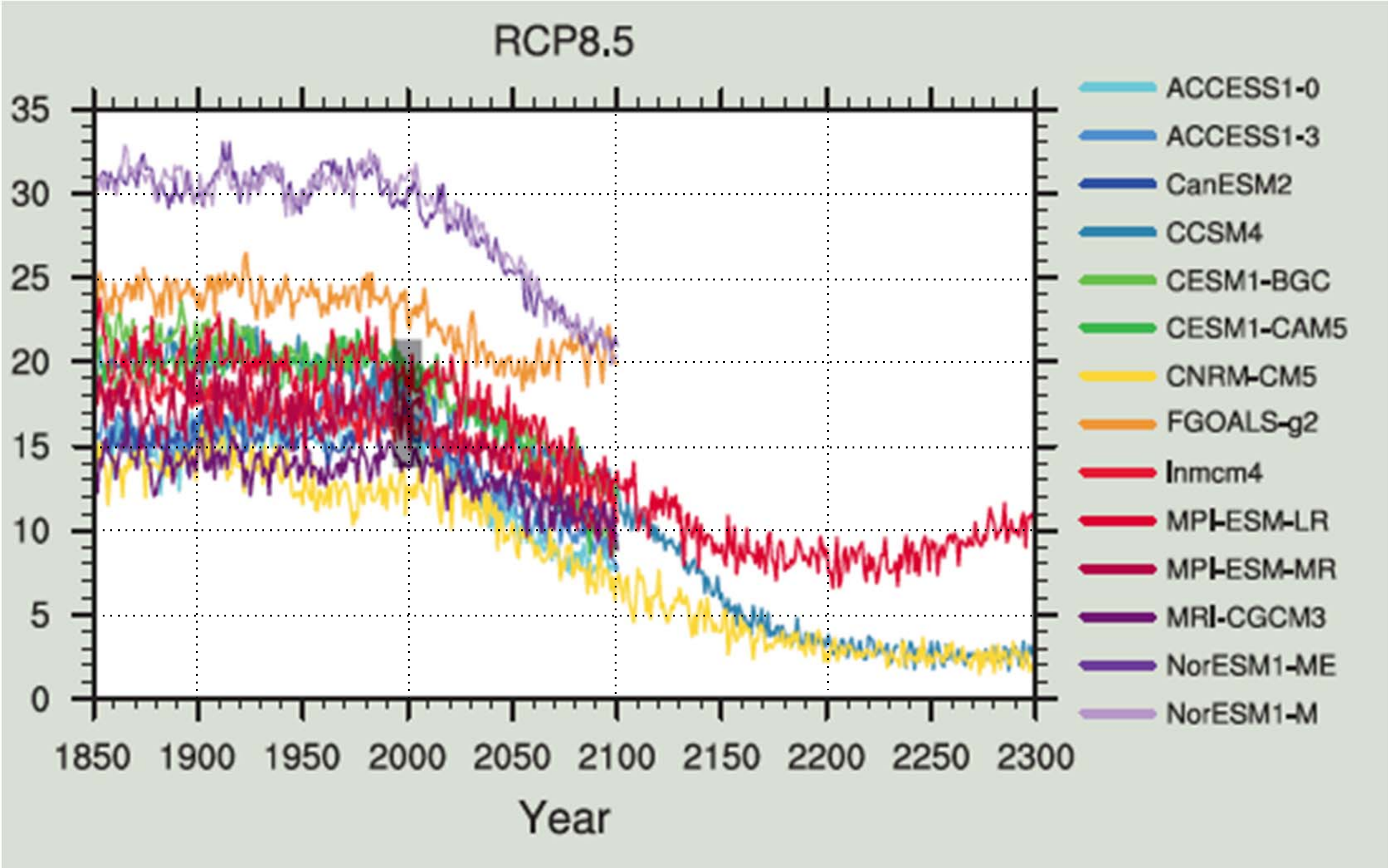


Global Ocean Heat Content (Cheng 2017)



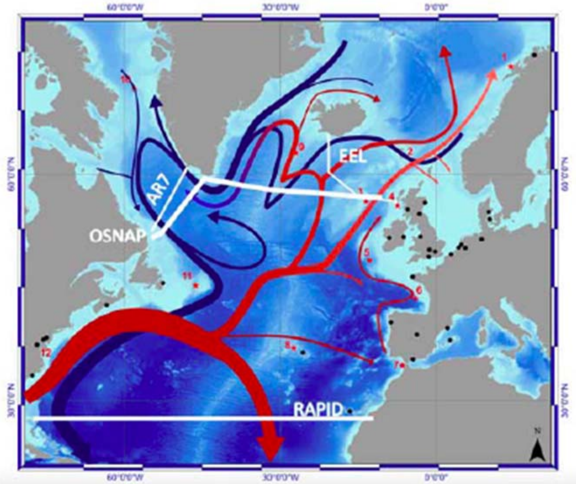
IPCC AR5 CMIP

Atlantic Meridional Overturning Circulation strength at 30°N

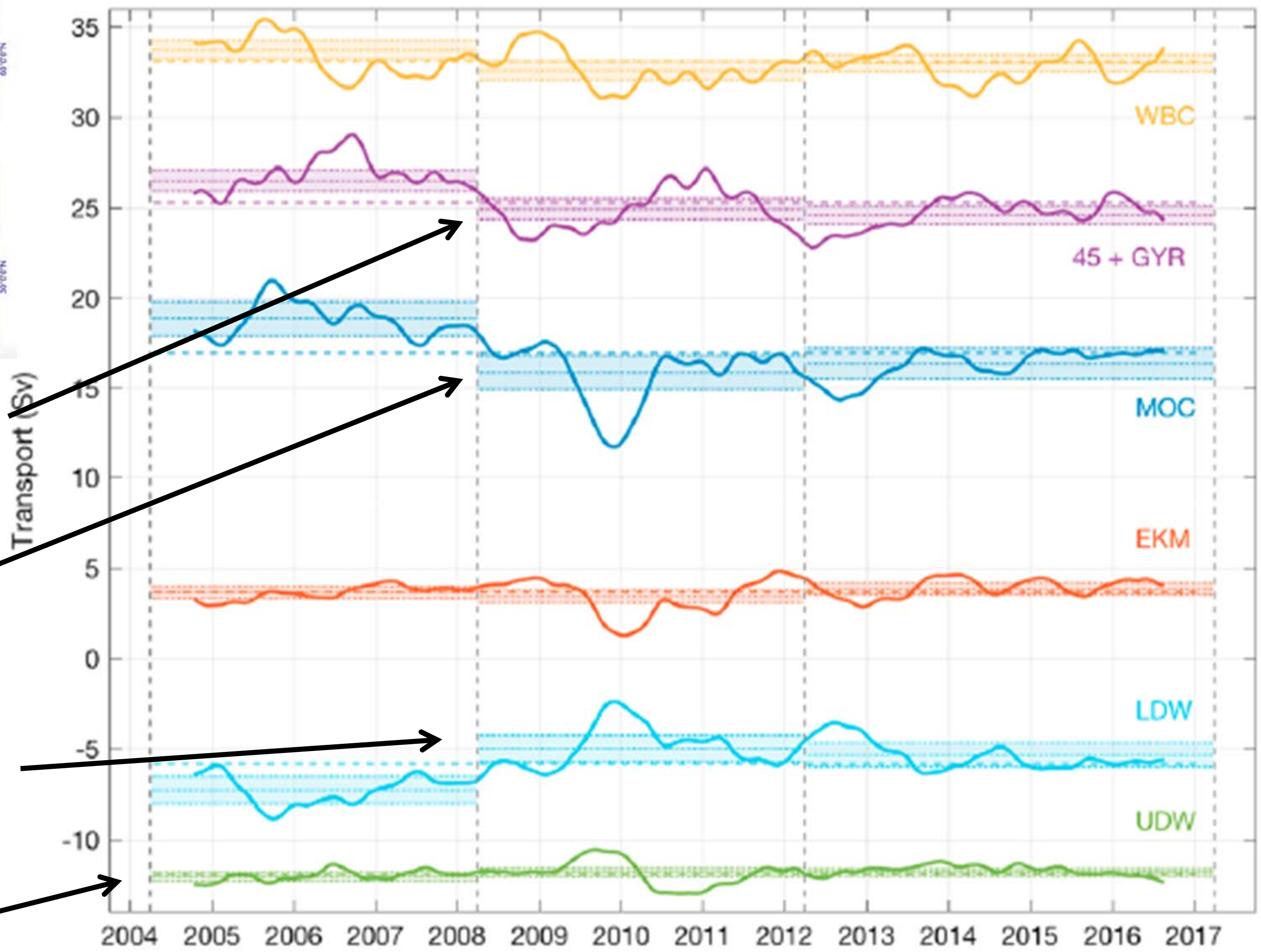


- It remains ***very likely [90–100% probability]*** that the AMOC will weaken over the 21st century relative to 1850-1900 values by 34% (12 to 54%) for RCP8.5.
- It remains ***very unlikely [0–10% probability]*** that the AMOC will undergo an abrupt transition or collapse in the 21st century.

The North Atlantic Ocean Is in a State of Reduced Overturning



RAPID-MOCHA Array Transports at 26.5°N



Gyre decreased (0-1000m)

AMOC
Step change: 18.8 Sv to 15.9 Sv [15.5% reduction]

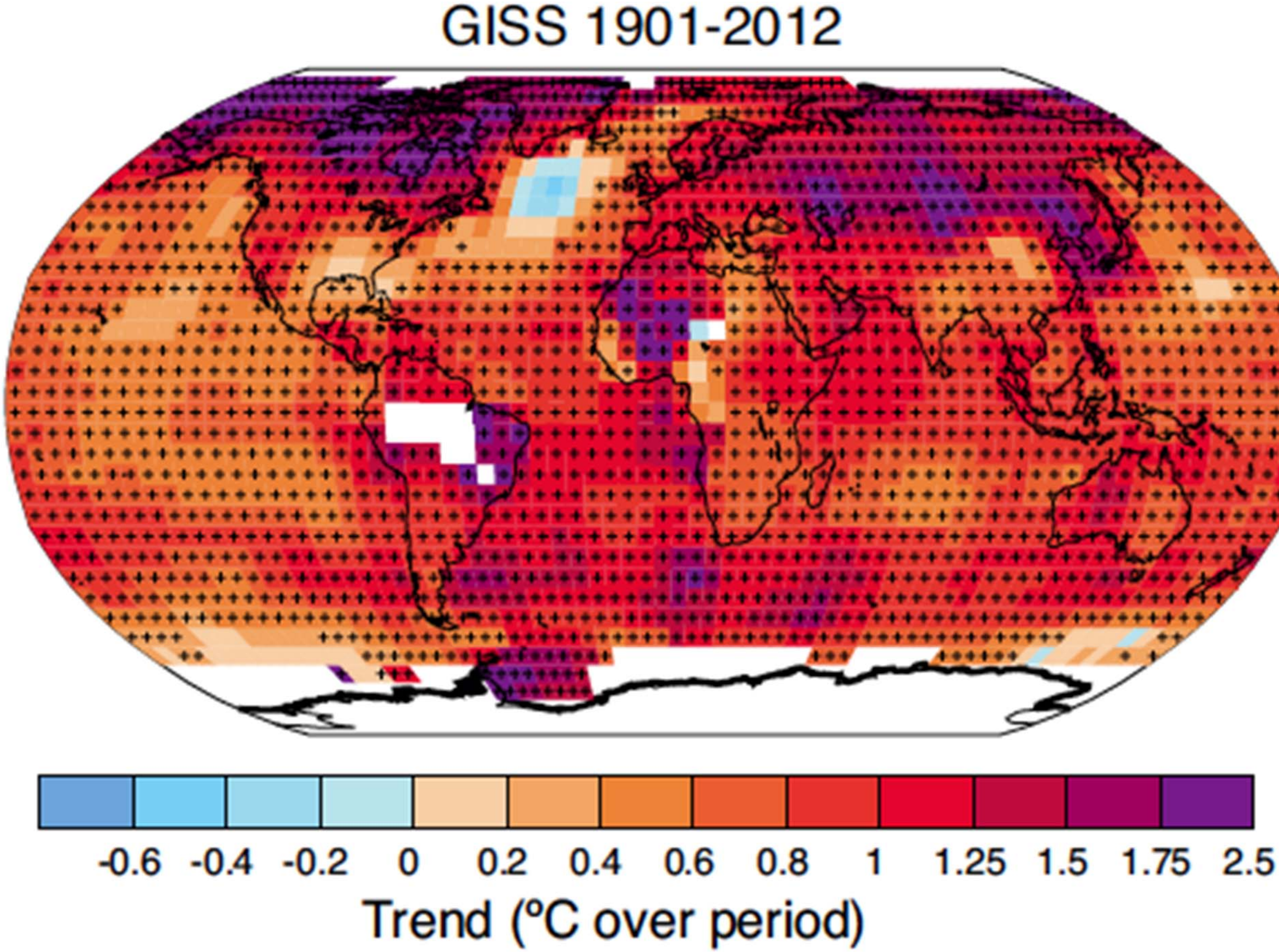
Lower North Atlantic Deep Water (3000-5000m)

Labrador Sea Water (1100-3000m) No Change.

Smeed 2018, GRL 10.1002/2017GL076350

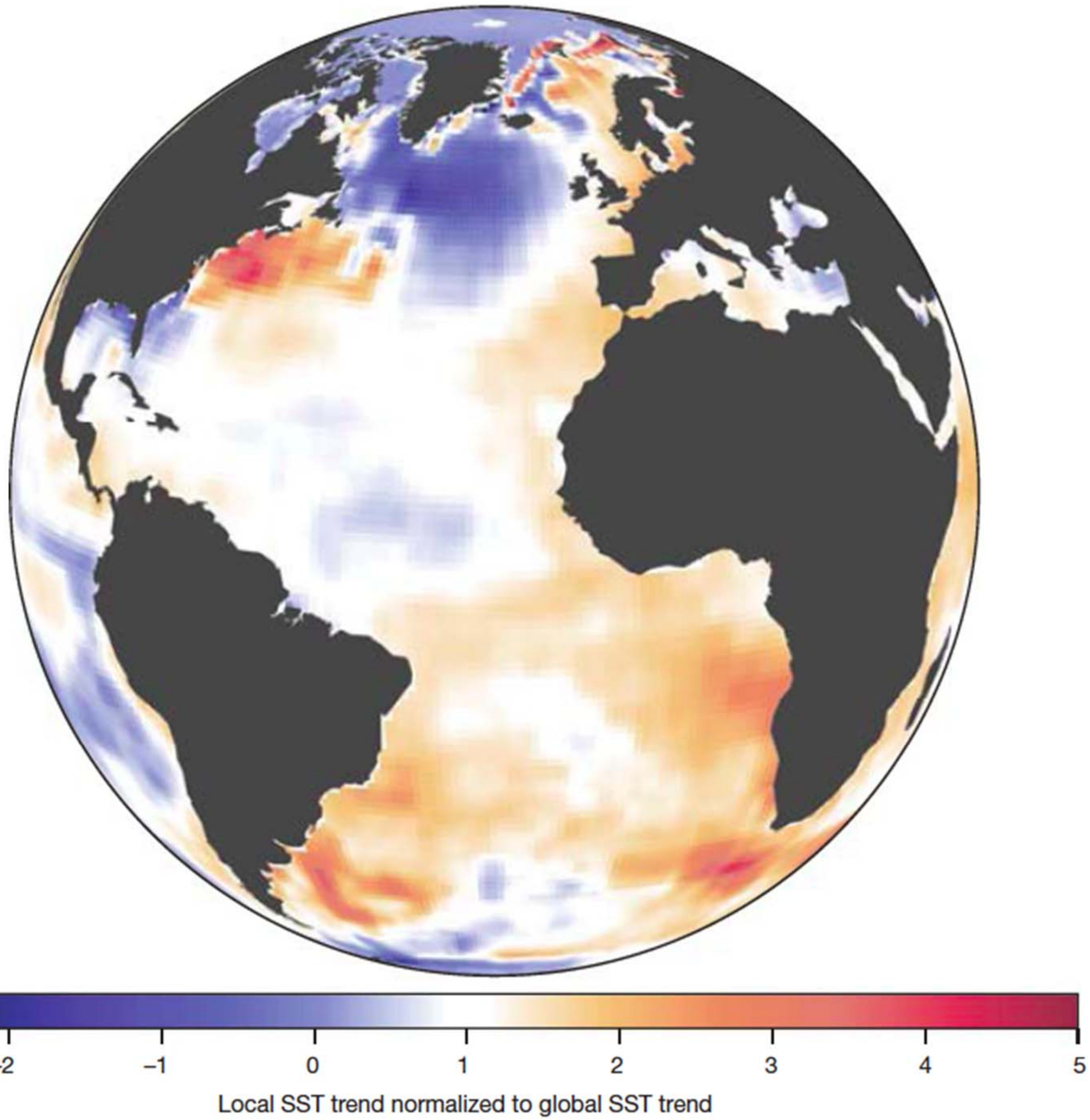
Observations of Surface Air Temperature Change

"The Cold Blob"



Trend in Sea Surface Temperature from 1870-2016 (Nov-May Season)

Observations
The subpolar cold patch as an AMOC indicator relative to the large-scale temperature trend. [Rahmstorf 2015 and Caesar 2018].

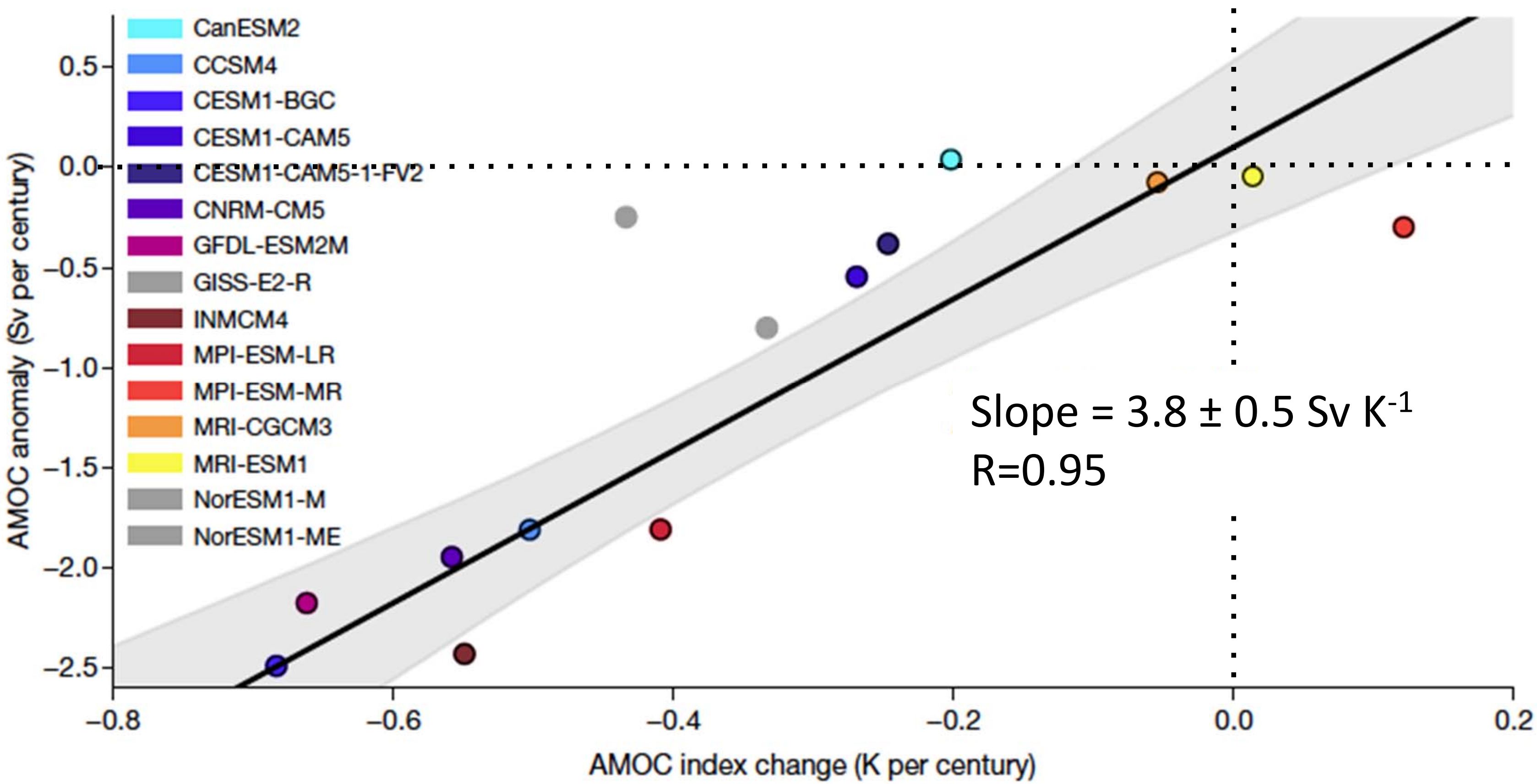


HadiSST Local SST trend normalised to global SST trend

AMOC Reconstructions

Models

The subpolar cold patch as an AMOC indicator relative to the large-scale temperature trend. [Rahmstorf 2015 and Caesar 2018].



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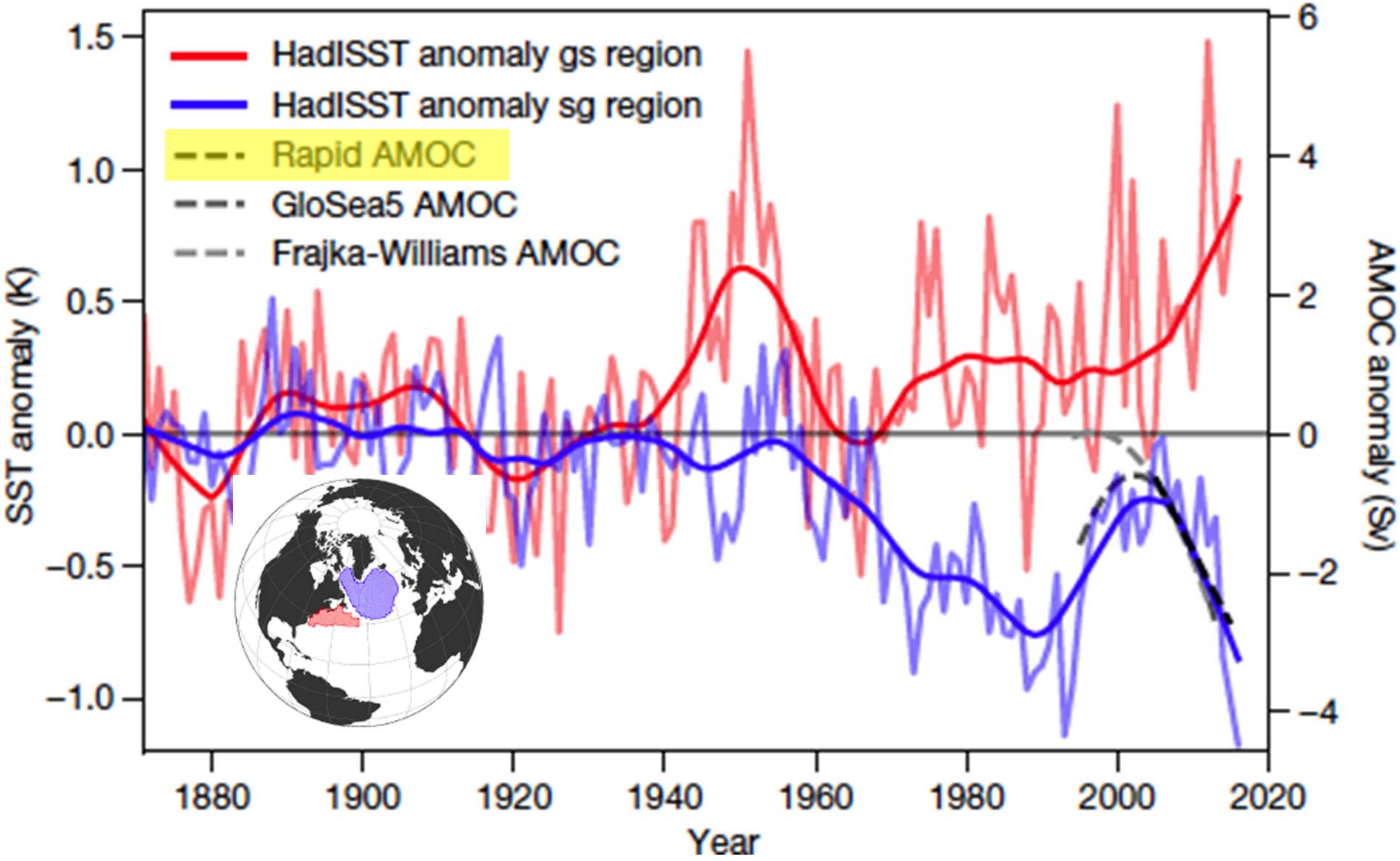
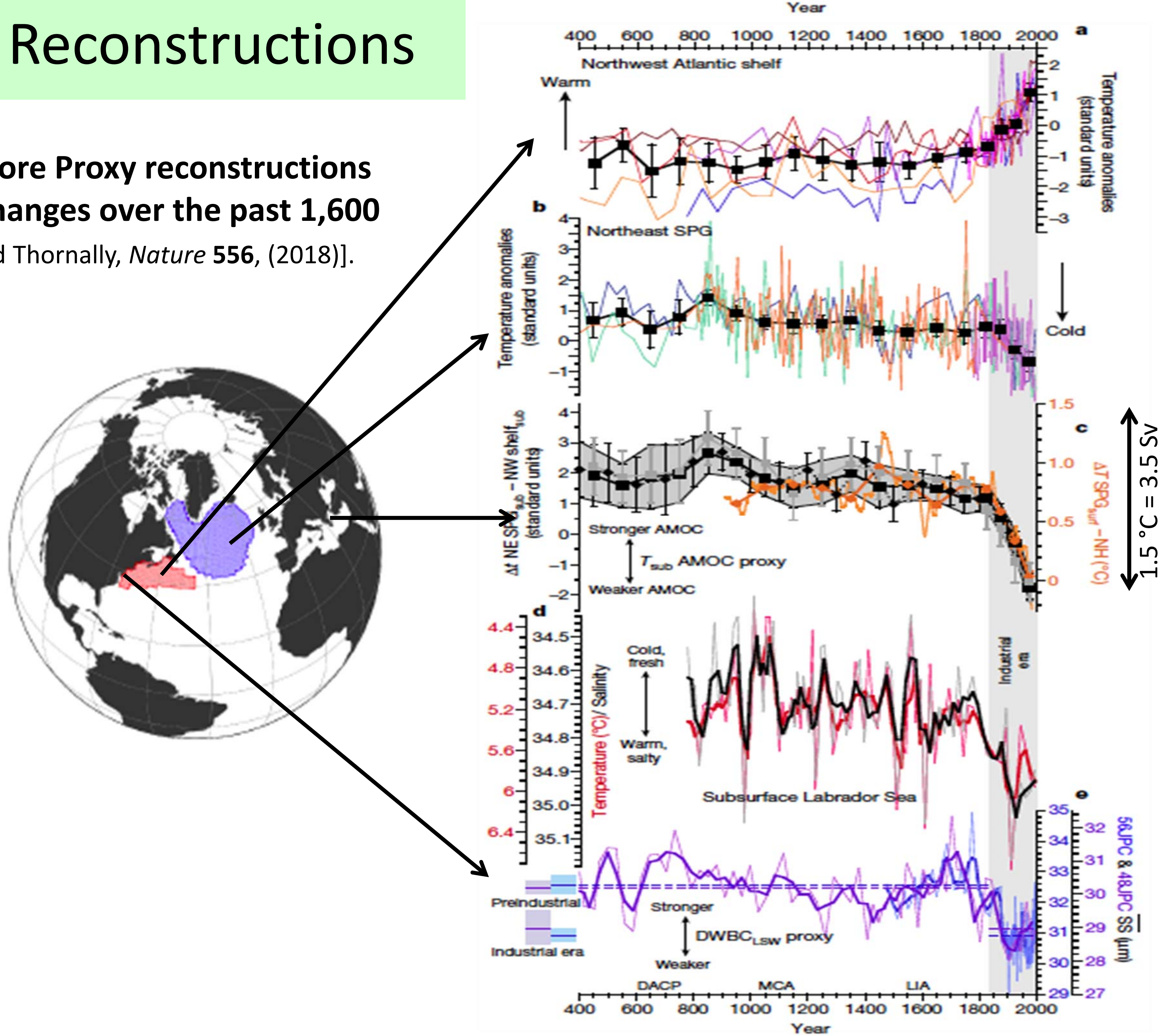
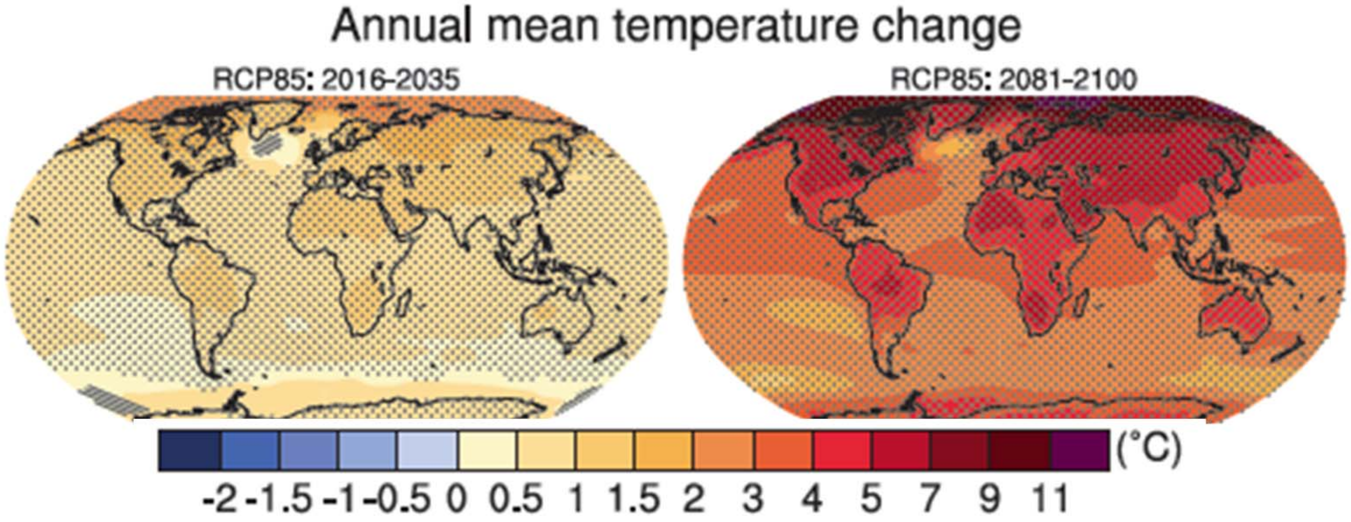


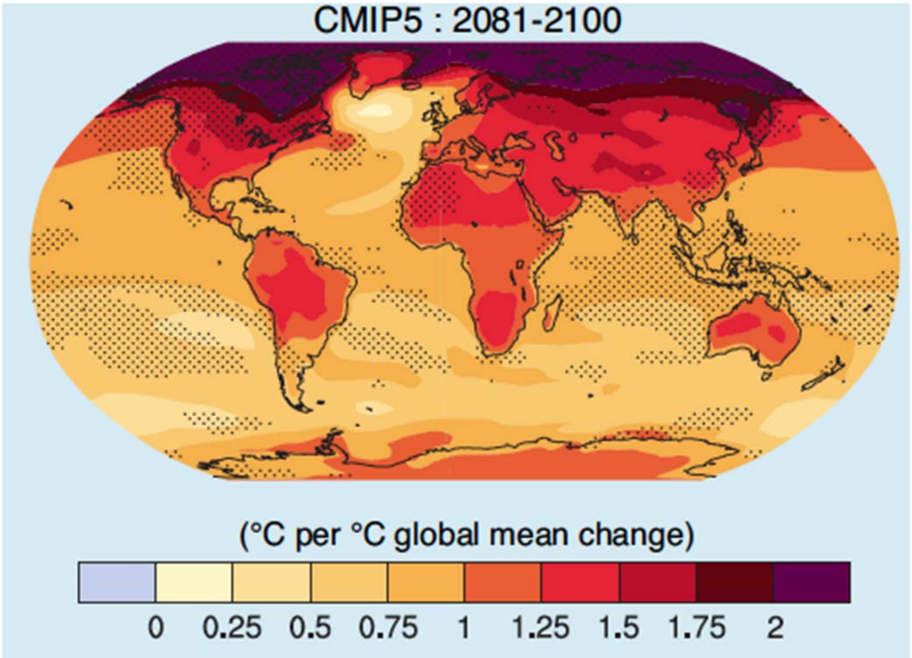
AMOC Reconstructions

Sediment Core Proxy reconstructions of AMOC changes over the past 1,600 years. [David Thornally, *Nature* **556**, (2018)].

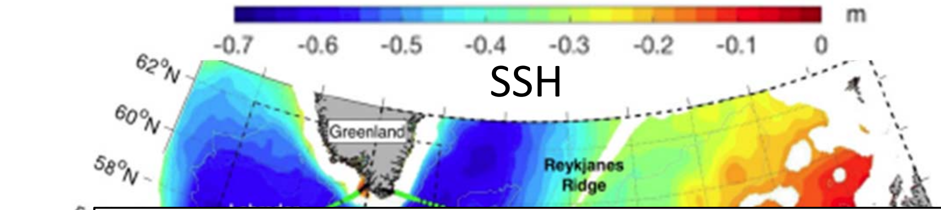


IPCC AR5 Projections





OSNAP Observing System

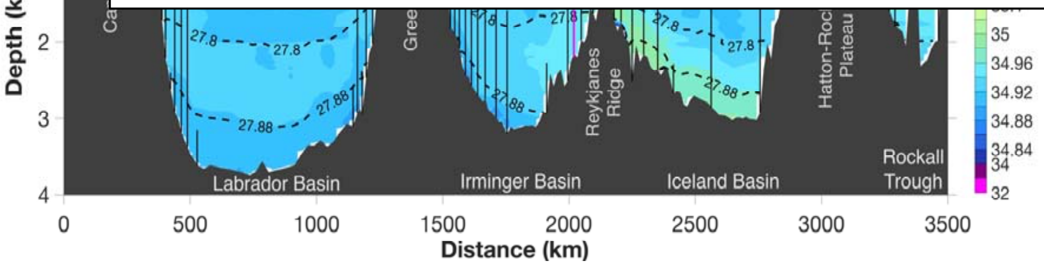


- Purposefully designed array.
- $32M over first 5-years.
- US, UK, Germany, Netherlands,

SCIENTIFIC OBJECTIVES

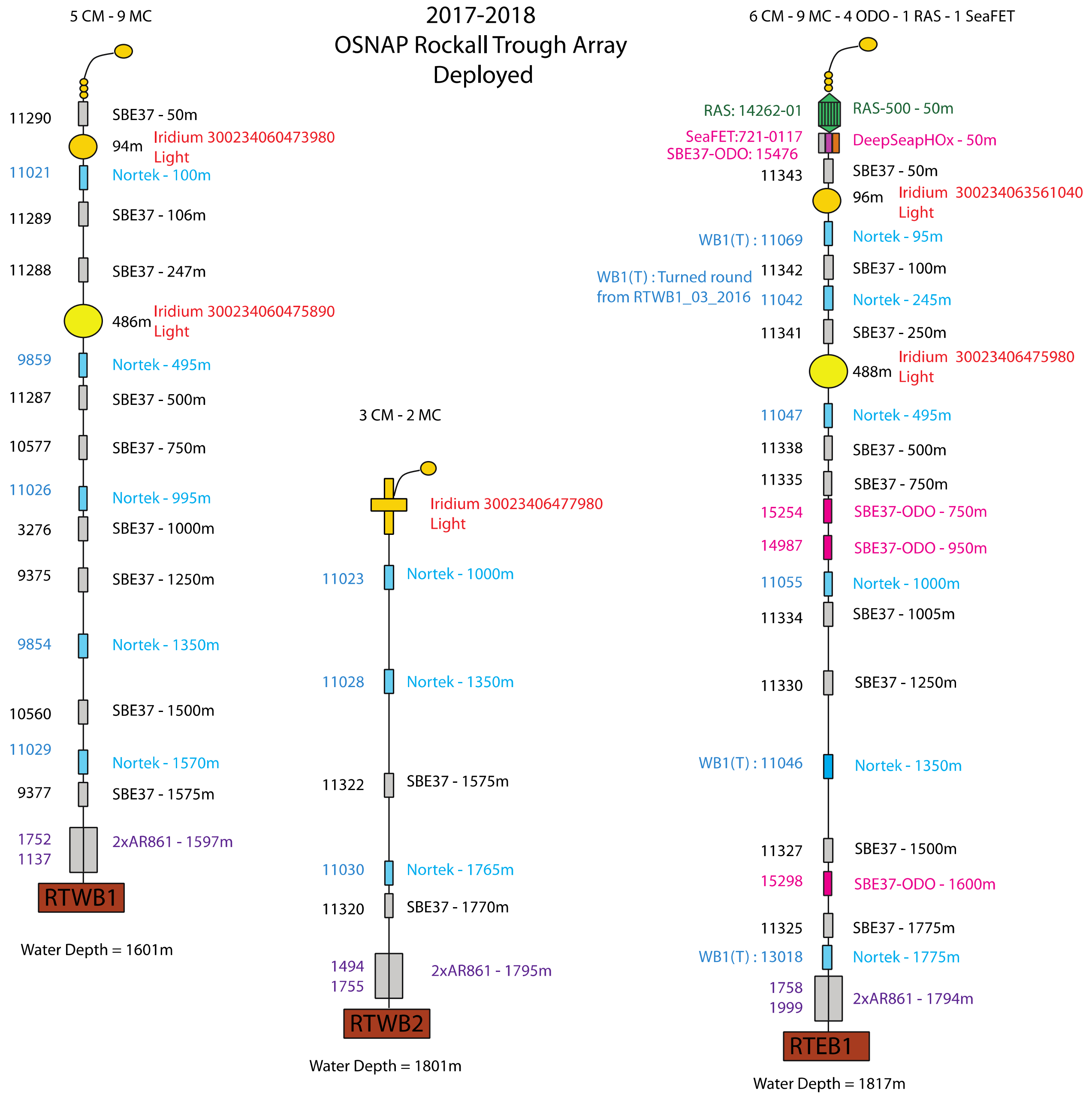
1. Obtain observational evidence of deep-winter mixing linked overturning and AMOC variability.
2. Provide observational evidence for IPCC CMPI predictions of a slowing AMOC in the 21st C.

current meters; 33 ADCPs.

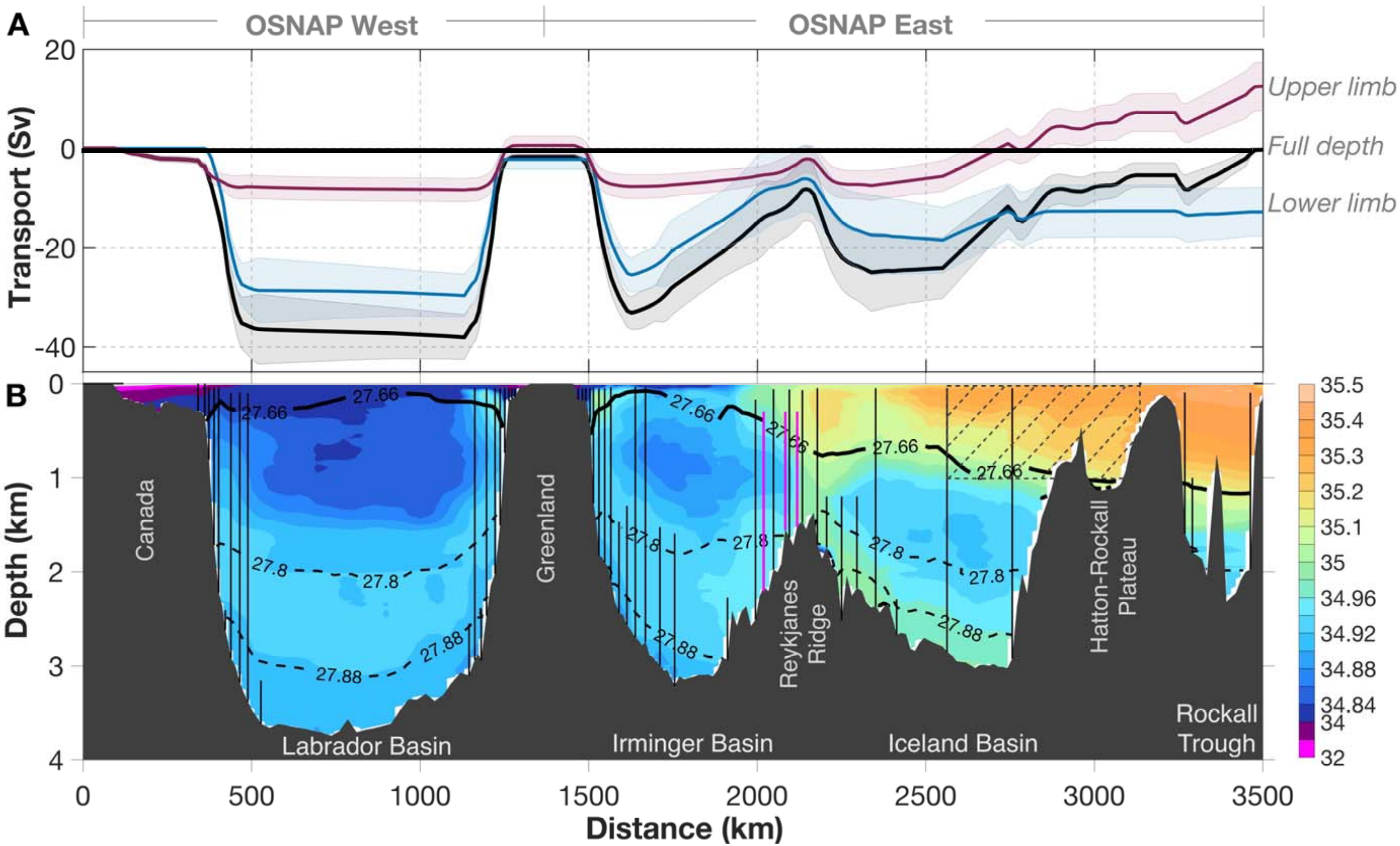


- Deployed summer 2014.
- LS deep winter convection in winter 2014/15 – first since the mid 1990s.

Mooring Design (Rockall Trough)

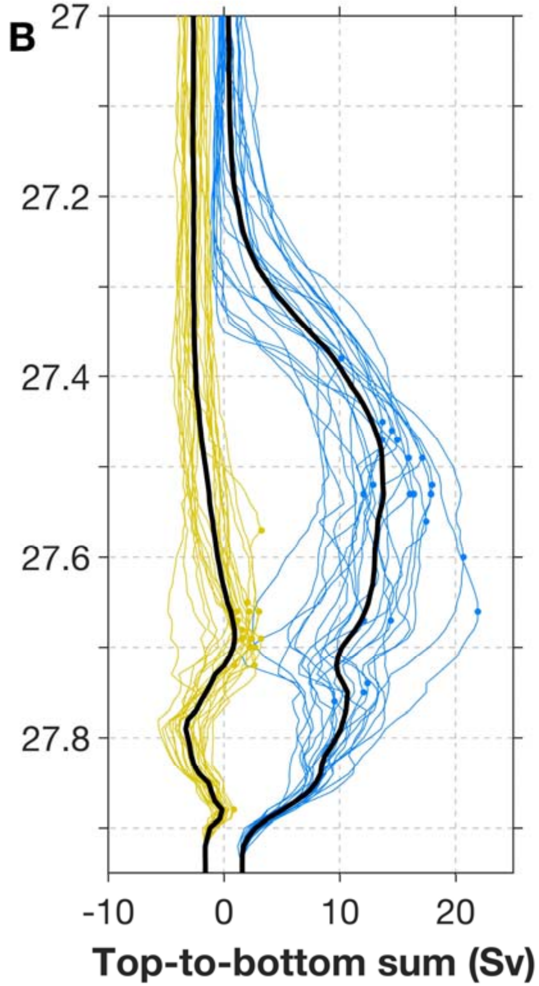


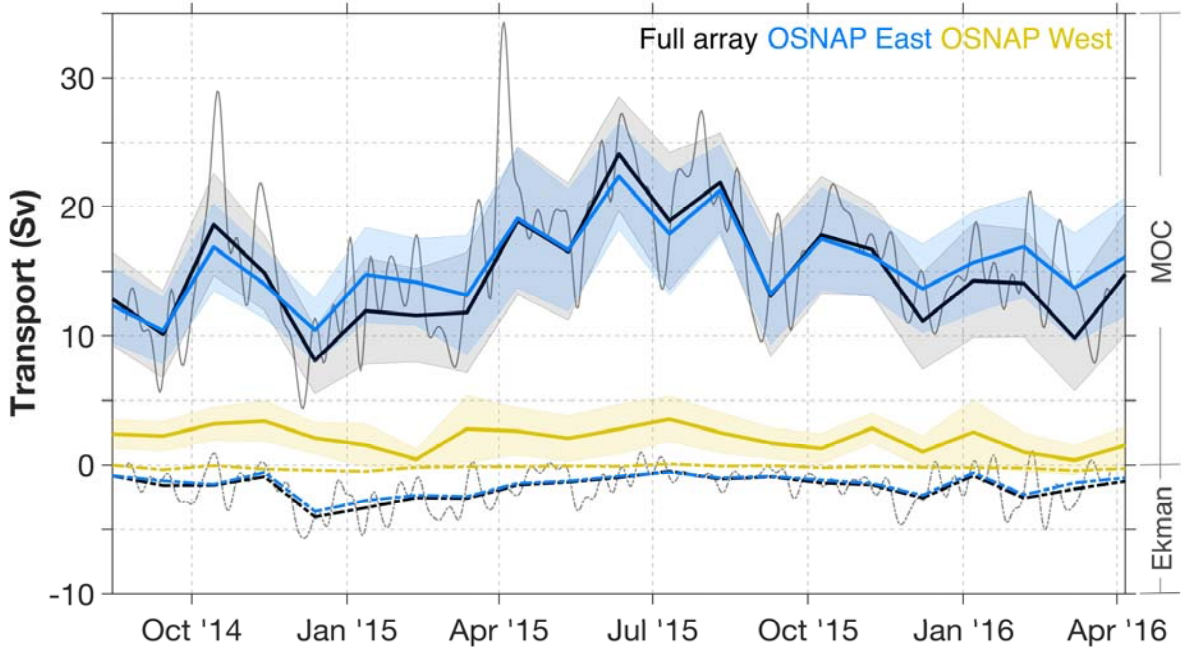
Mean Transport & Salinity across the OSNAP Section



The potential density surface 27.66 kg m^{-3} separates the MOC upper and lower limbs

Streamfunction and AMOC across the OSNAP Section





$$\mathrm{MOC}(t) = \max[\Psi(\sigma,t)] = \max\left[\int_{\sigma_{min}}^{\sigma}\int_{x_w}^{x_e} v(x,\sigma,t)\ dx d\sigma\right]\ (\mathrm{Sv})$$

Streamfunction and AMOC across the OSNAP Section

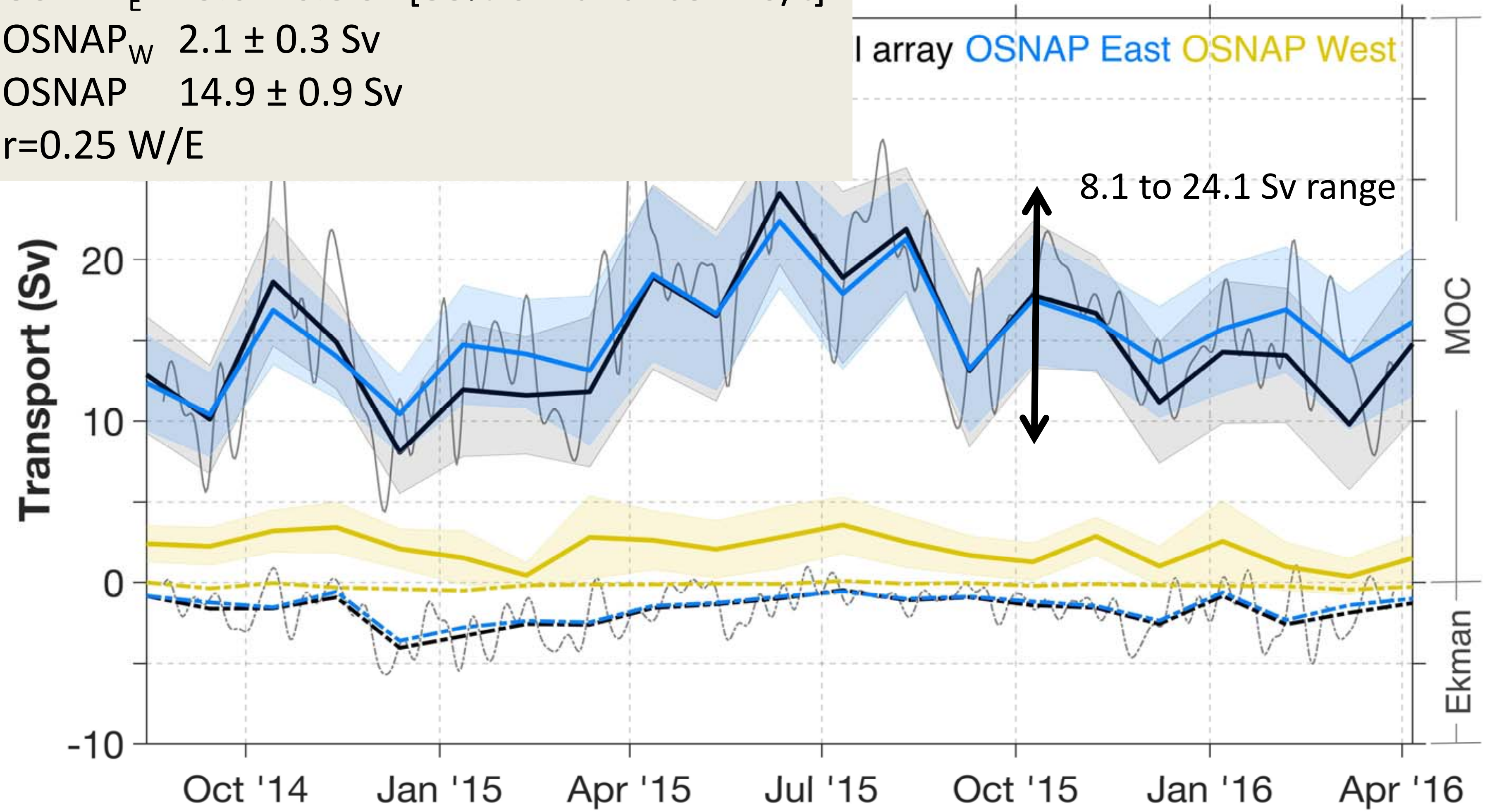
mean ± uncertainty of mean

$OSNAP_E$ 15.6 ± 0.8 Sv [88% of variance in o/t]

$OSNAP_W$ 2.1 ± 0.3 Sv

OSNAP 14.9 ± 0.9 Sv

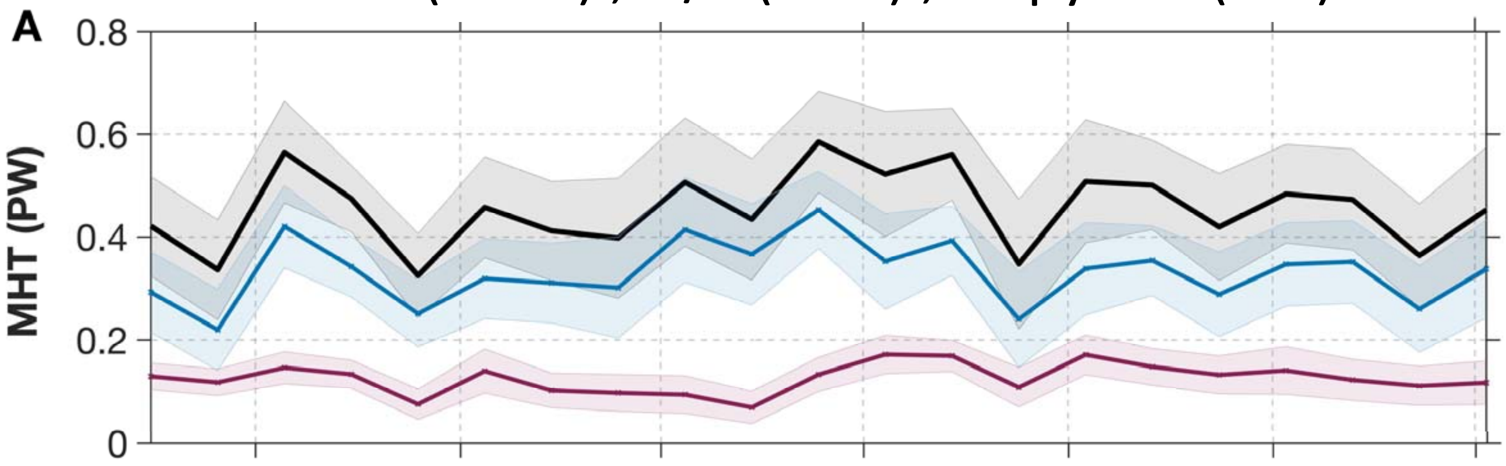
r=0.25 W/E



$$MOC(t) = \max[\Psi(\sigma,t)] = \max\left[\int_{\sigma_{min}}^{\sigma}\int_{x_w}^{x_e} v(x,\sigma,t)\, dx d\sigma\right] \text{ (Sv)}$$

Meridional Heat Transport across the OSNAP Section

TOTAL (black) ; O/T (blue) ; Isopycnal (red)



MHT Total	0.45 ± 0.02 PW
MHT overturning	0.33 ± 0.019 PW
MHT isopycnal	0.12 ± 0.007 PW

- Velocity variance explains 93% of MHT variance.
- O/T MHT accounts for 73% of mean and 87% of variance.

$$MHT_{overturning}(t) = \rho C_P \int_{\sigma_{min}}^{\sigma_{max}} \int_{x_w}^{x_e} < v > (\sigma, t) < \theta > (\sigma, t)\, dx d\sigma \ \ [W]$$

$$MHT_{isopycnal}(t) = \rho C_P \int_{\sigma_{min}}^{\sigma_{max}} \int_{x_w}^{x_e} v'(x, \sigma, t)\, \theta'(x, \sigma, t)\, dx d\sigma \quad [W]$$

Mean Transport Estimates

	MOC (Sv)	MHT (PW)	MFT (Sv)
OSNAP	14.9 ± 4.1	0.45 ± 0.08	-0.33 ± 0.05
OSNAP East	15.6 ± 3.1	0.38[#] ± 0.08	-0.14 ± 0.04
OSNAP West	2.1 ± 0.9	0.080[#] ± 0.016	-0.184 ± 0.041

± is standard deviation of the mean of the 21-month timeseries

temperature flux

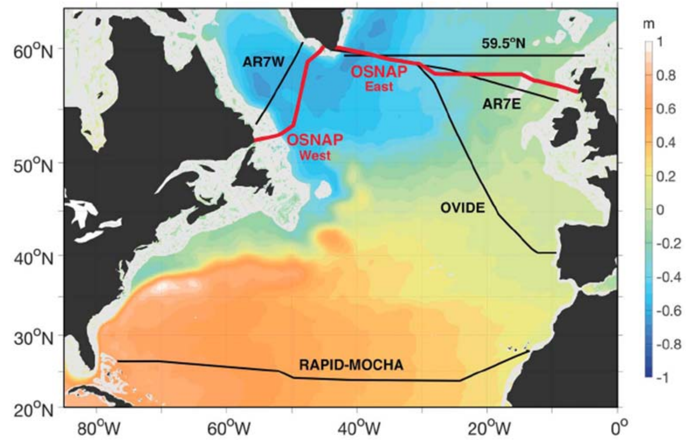
MOC, MHT, MFT and Ekman Transport At OSNAP (57°N) And RAPID-MOCHA (26.5°N)

Mean ± 1 SD uncertainty

	MOC (Sv)	MHT (PW)	MFT (Sv)
OSNAP	**14.9 ± 0.9**	**0.45 ± 0.02**	**-0.33 ± 0.01**
RAPID-MOCHA	16.8* ± 0.5	1.25 ± 0.11	-0.43 ± 0.007&

Meridional Divergence (± RSS uncertainty)**:**

- MHT -0.8 ± 0.11 PW.
- MFT +0.10 ± 0.012 Sv.



Air-sea flux measurements
Top-of-atmosphere radiation + atmospheric model

Summary (It’s the THC, Stupid!)

1. Surface temperature ***observations*** show that the Sub-Polar North Atlantic is the only region in the world that has undergone sustained cooling over the past 100 years.
2. It remains ***very likely [90–100% probability]*** that the AMOC will weaken over the 21st century relative to 1850-1900 values by 34% (12 to 54%) for RCP8.5.
3. The associated SST pattern shows ***warming along the eastern seaboard*** of the US due to a northward shift of the Gulf Streak; and a ***cooling across the eastern Sub-Polar North Atlantic***.
4. Using this pattern to aid interpretation of ***paleo reconstructions*** of surface and subsurface temperatures and Deep Western Boundary Current speeds ***supports the interpretation of a slowing AMOC over the past 150 years***.
5. The ***RAPID*** Sub-Tropical array shows ***an abrupt 15% drop in AMOC strength*** in 2008 (whether part natural decadal variability or anthropogenic change is unclear).
6. There will be ***wide-spread impacts*** on circulation, heat transport, anthropogenic heat and carbon uptake, acidification, aragonite saturation depth, nutrient supplies, sea-level, sea surface temperatures, mixed layer depth ….

Conclusions

OSNAP

1. Conversion of warm, salty waters to cold, fresh, deep water is accomplished north of $OSNAP_{east.}$
2. Despite signatures of substantial water mass modification, Labrador sea contributes minimally to overturning. Hypothesis of LS driving AMOC variability needs to be revised.
3. MOC and MHT are dominated by $OSNAP_{east}$ dynamics.
4. $OSNAP_{west}$ dynamics plays a large role in MFT.
5. Divergence RAPID-OSNAP provides very strong constraints for atmospheric reanalysis and air-sea flux estimates that currently underestimate the heat transport at OSNAP latitudes.

- MHT Divergence -0.8 ± 0.11 PW.
- MFT Divergence +0.10 ± 0.012 Sv.

THANK YOU

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