The Atlantic Overturning circulation at 26ºN as observed by the RAPID array

GERARD MCCARTHY, WILLIAM JOHNS, ELAINE MCDONAGH, CHRIS MEINEN, MOLLY BARINGER, BEN MOAT, DARREN RAYNER AND DAVID SMEED

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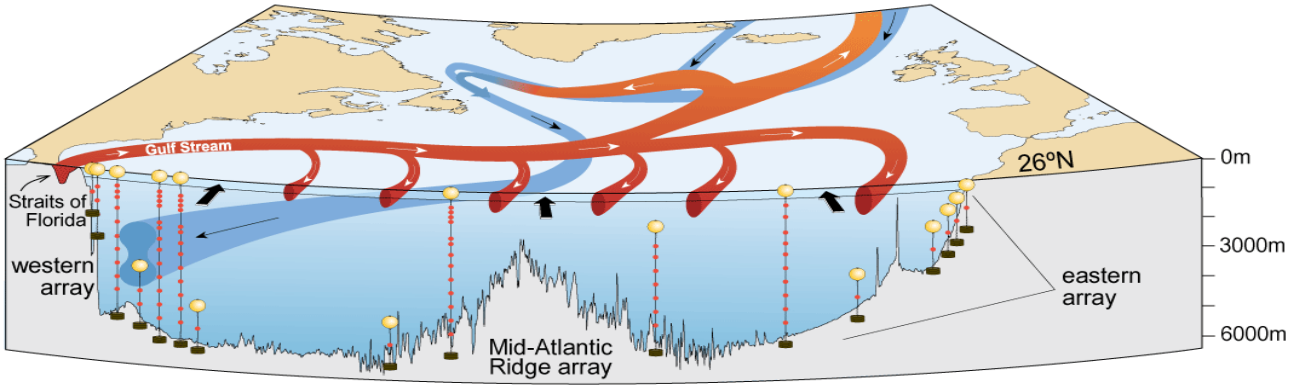
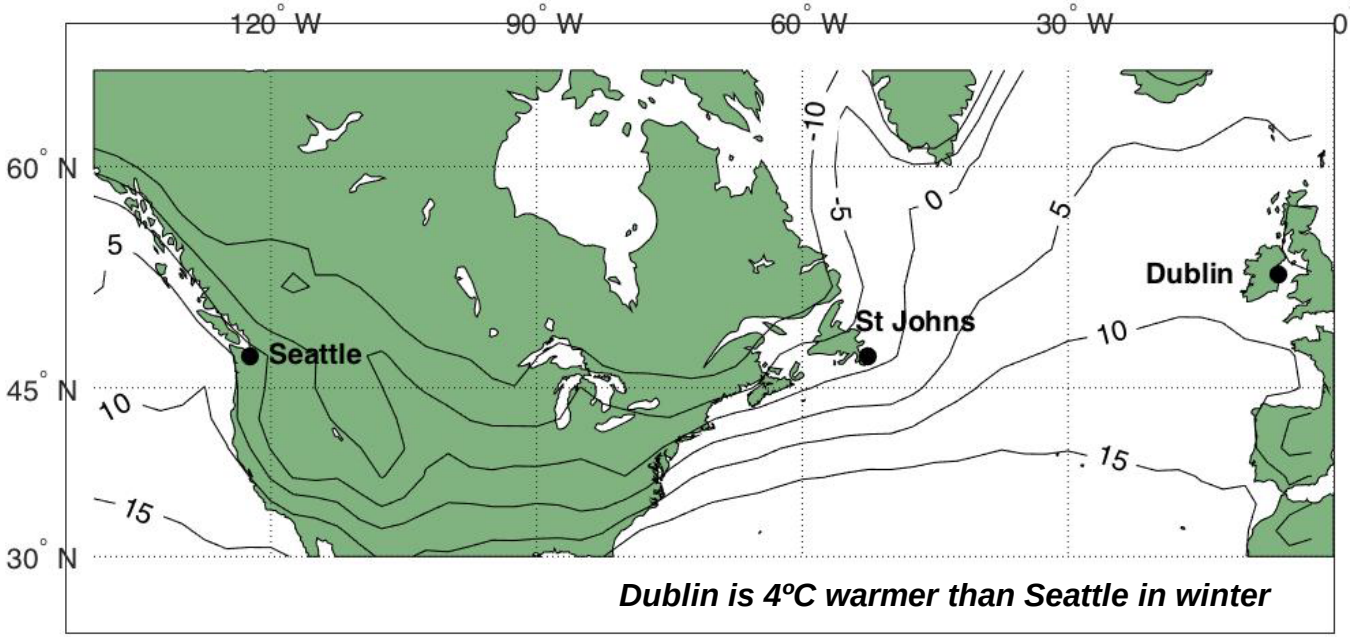
The AMOC and its importance



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.

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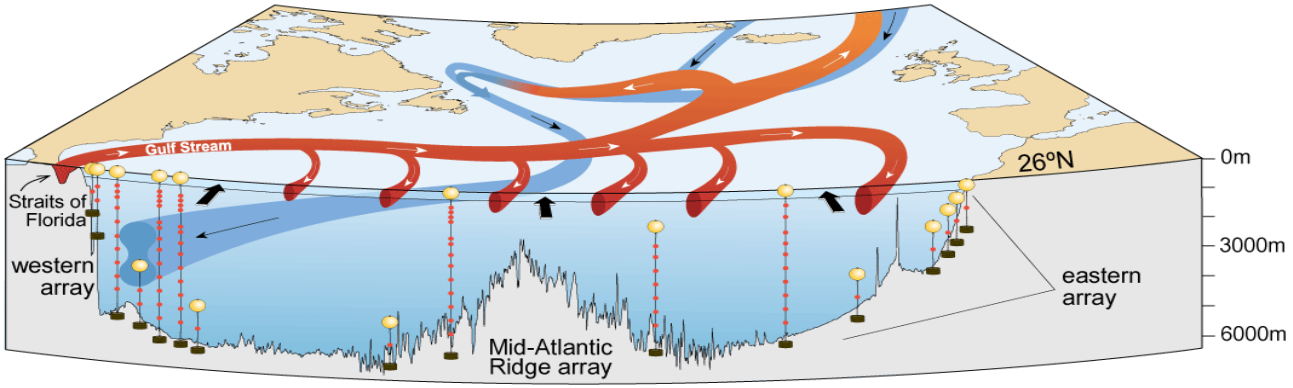
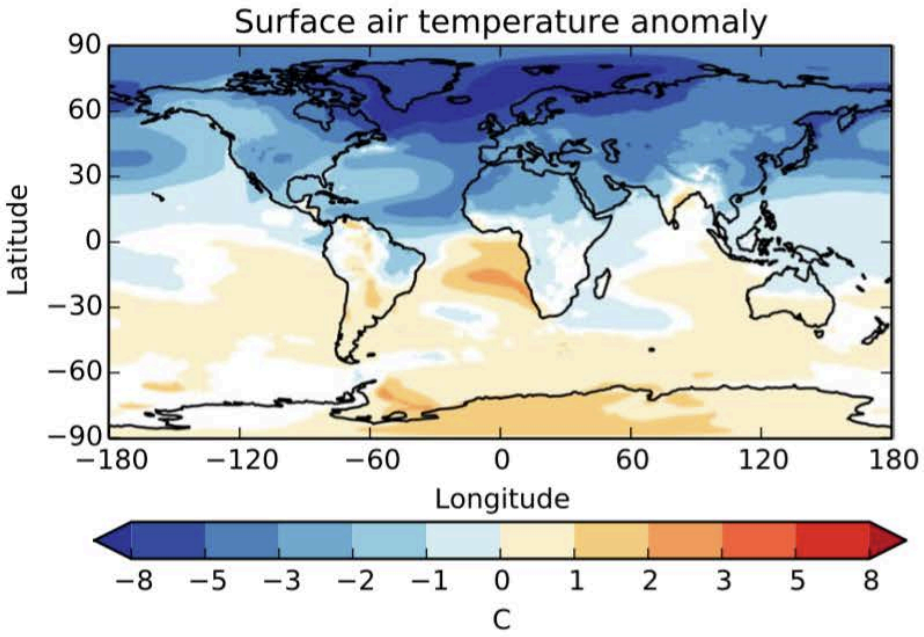
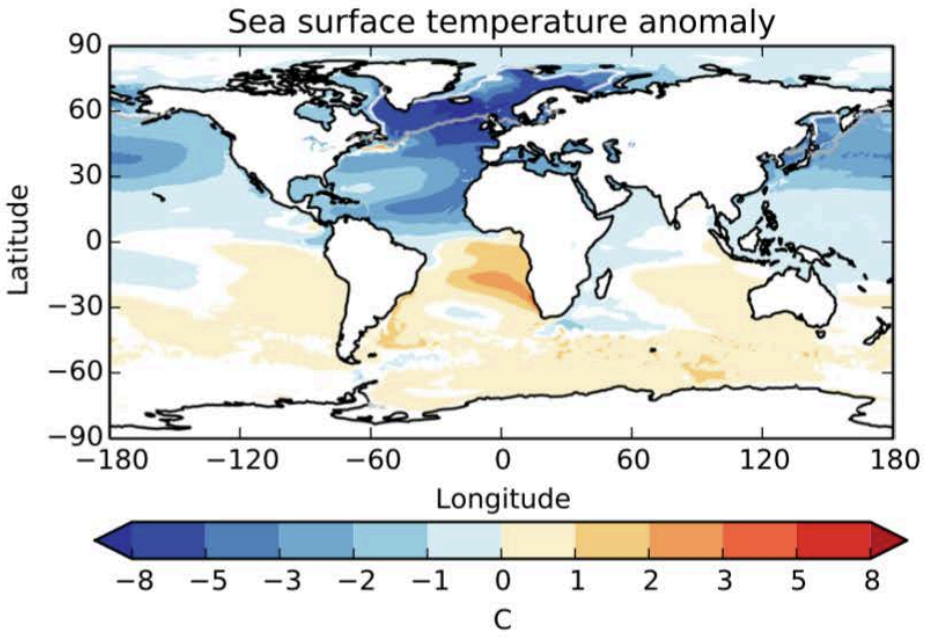


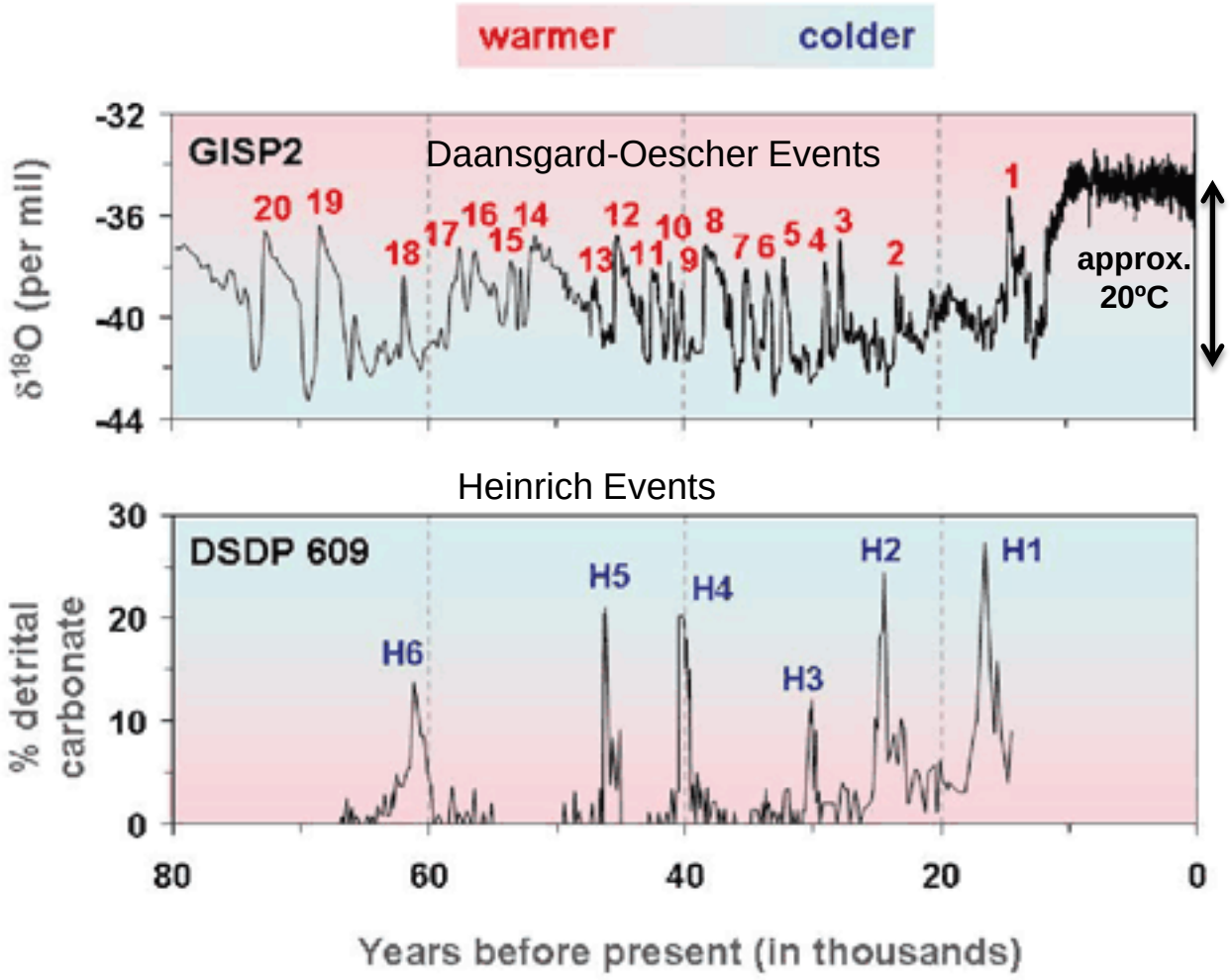
A collapse of the AMOC would lead to cooling throughout the Northern Hemisphere and most extremely in northwest Europe





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

Past changes in the AMOC



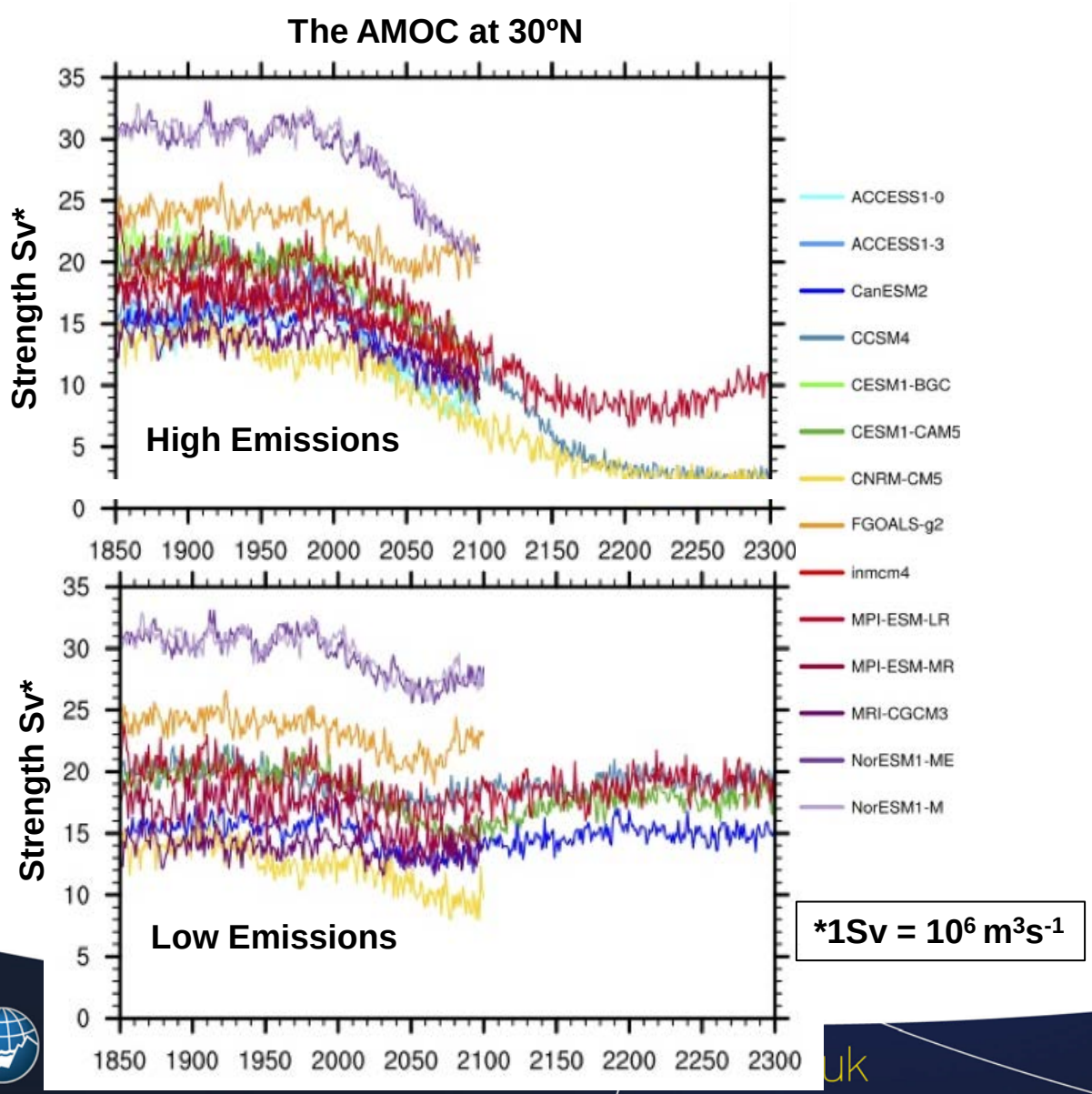
Ice core evidence of abrupt changes in temperature in the past

The link has been associated with abrupt changes in the AMOC

The record hints at an AMOC that fluctuates between ‘on’ and ‘off’ states with associated major climate impacts

Figure from NOAA Paleoclimatology http://www.ncdc.noaa.gov/paleo/abrupt/data3.html

The AMOC in a changing climate



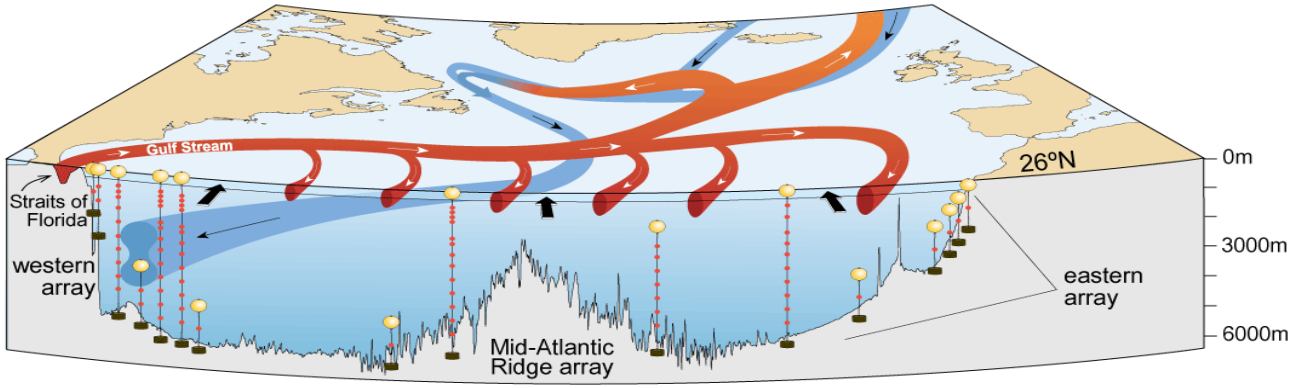
It is 'very likely' that the AMOC will weaken over the 21st century

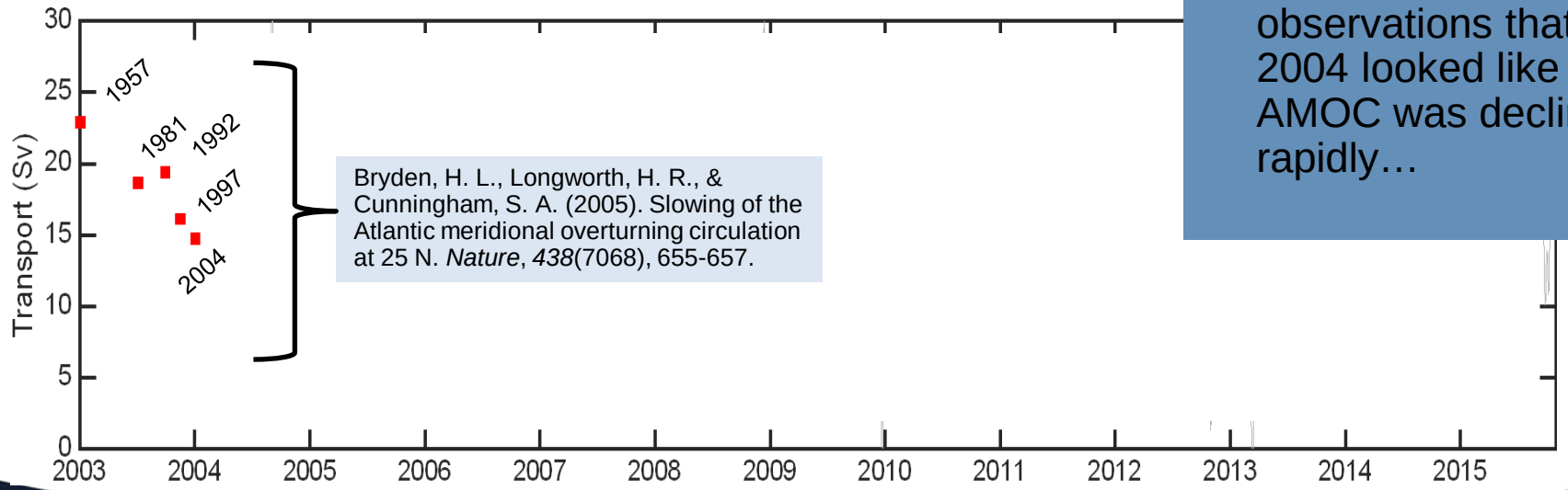
No evidence of collapses that charachterise the paleo record

Given the importance, it is crucial we observe the AMOC

Stocker et al. (2014), Climate change 2013: The physical science basis, *Cambridge University Press*.

The AMOC at 26ºN



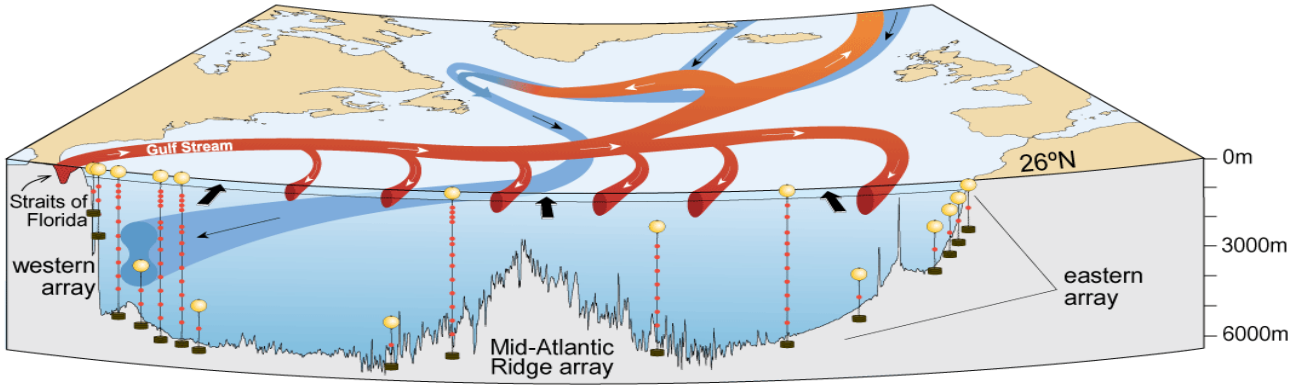


Bryden, H. L., Longworth, H. R., & Cunningham, S. A. (2005). Slowing of the Atlantic meridional overturning circulation at 25 N. *Nature*, *438*(7068), 655-657.

Why we observe the AMOC at 26ºN:

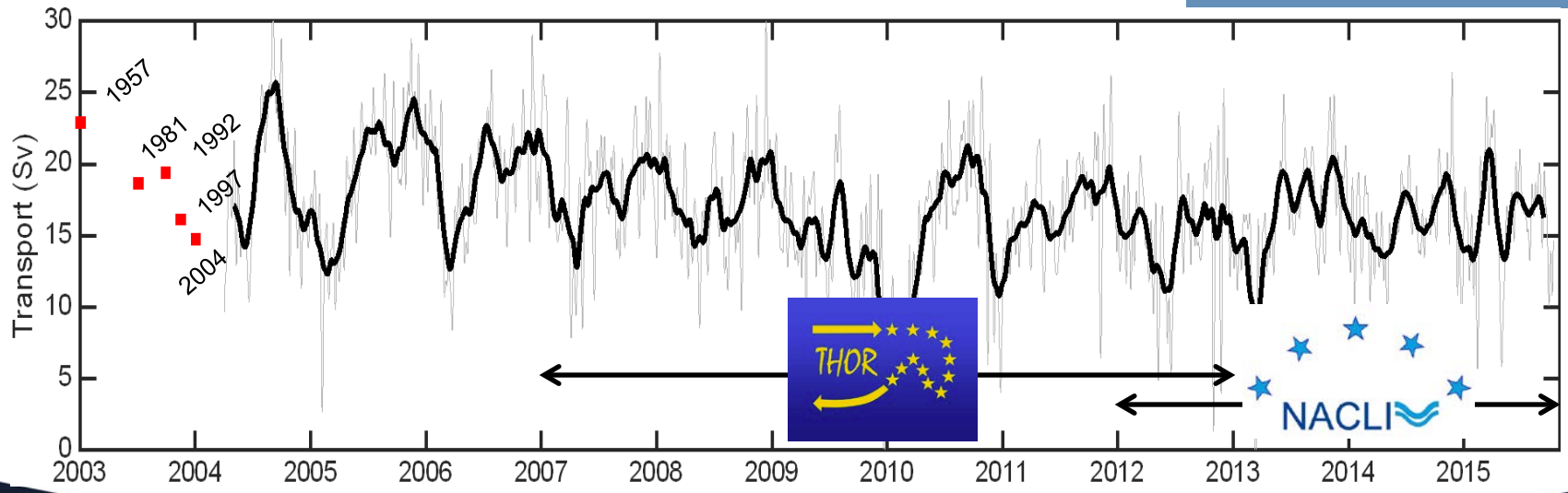
- Near maximum of the overturning used by climate models to define *the* AMOC
- Extensive historical observations that in 2004 looked like the AMOC was declining rapidly…

The 11.5 year AMOC record



How we observe the AMOC at 26ºN:

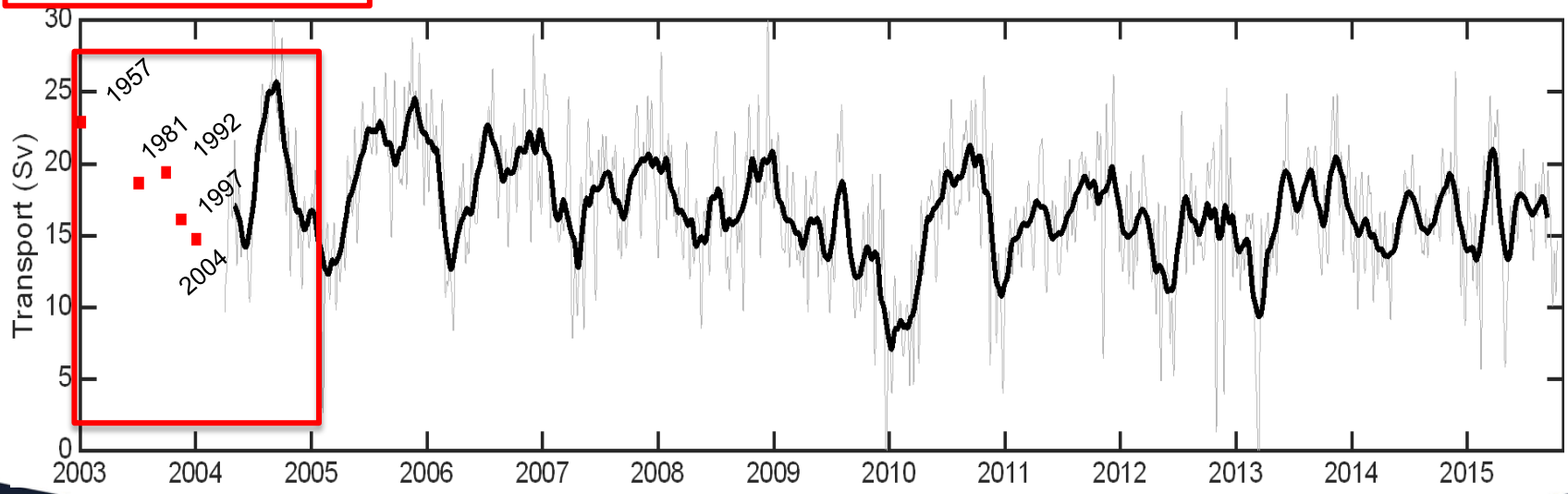
- Moorings estimating dynamic height and currents
- Funded by NERC in UK and NSF and NOAA in US



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.



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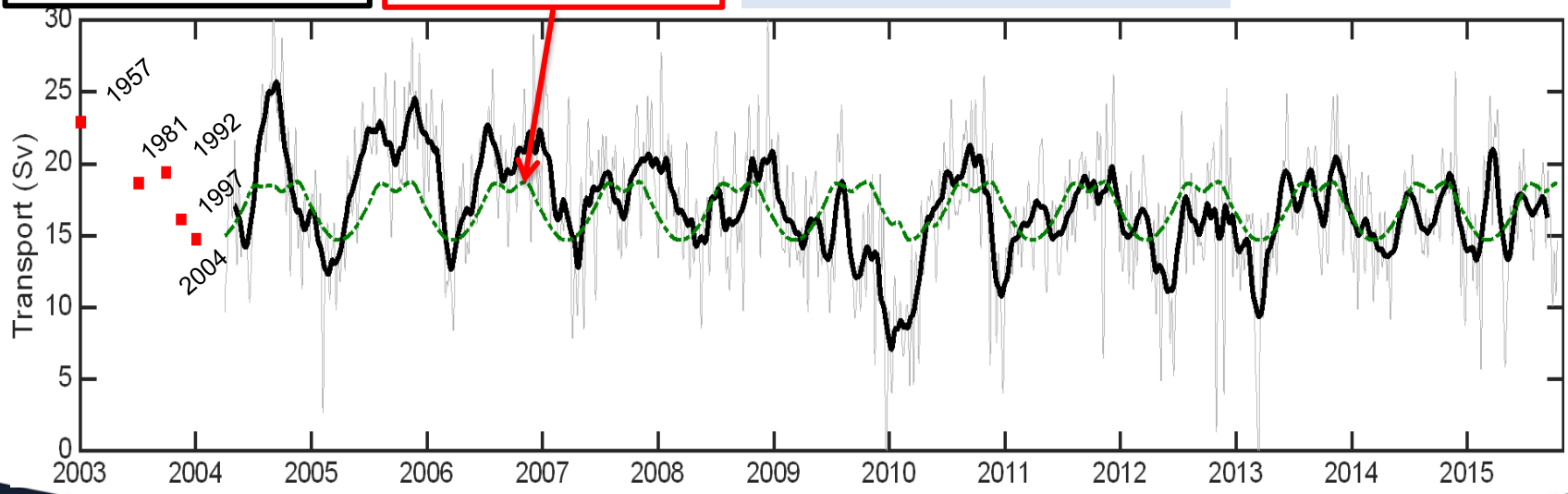
A large seasonal cycle:
A seasonal cycle of 6 Sv was observed (green, dashed). This is driven by density variations at the eastern boundary.

Kanzow, T., et al. (2010). *Journal of Climate*, *23*(21), 5678-5698.

Chidichimo, M. P., et al. (2010). *Ocean Science*, *6*(2), 475-490.

Duchez, A., et al. (2014). *JGR: Oceans*, *119*(3), 1843-1860.

Pérez-Hernández, M. D. et al. (2015). *JGR Oceans*, *120*(11), 7237-7252.



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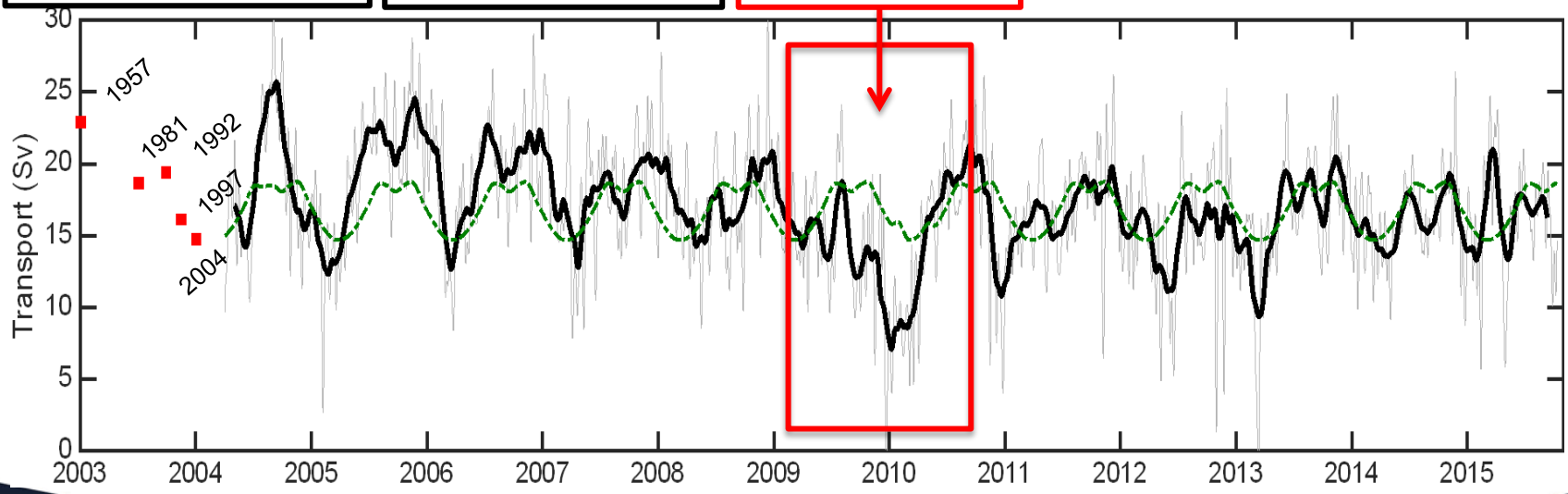
Interannual Variability:
From 2009, the AMOC weakened dramatically. This 30% slowdown persisted for 18 months and cooled the whole of the subtropical North Atlantic.

McCarthy, G., et al. (2012). Observed interannual variability of the Atlantic meridional overturning circulation at 26.5 N. Geophysical Research Letters, 39(19).



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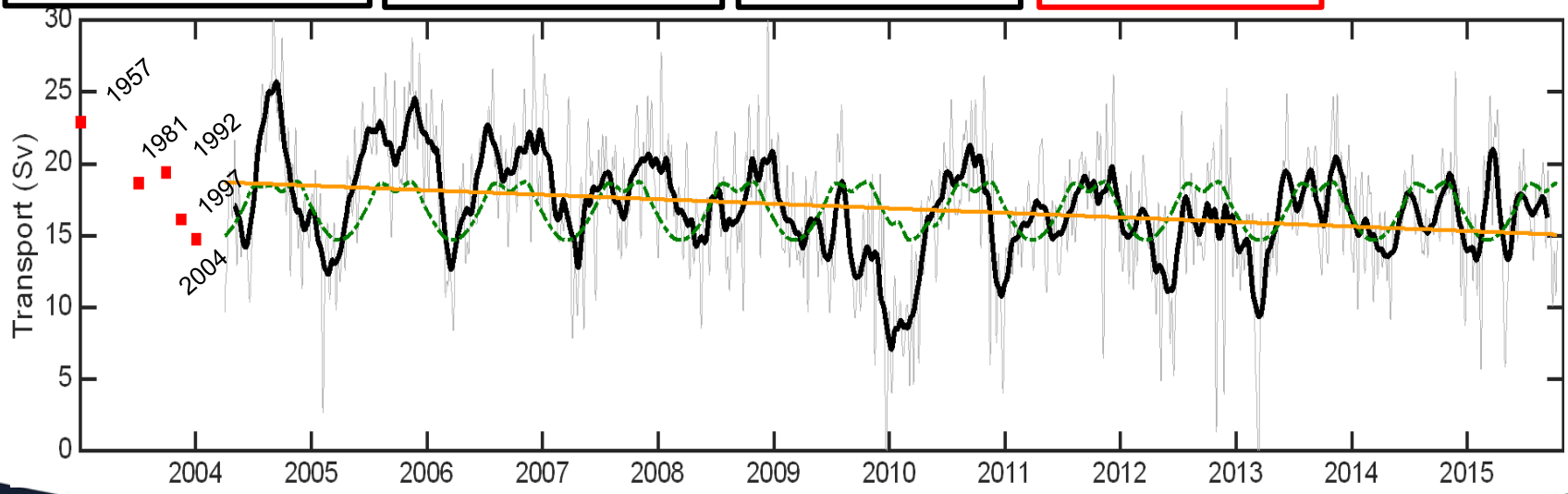
Evidence of a slowdown?
A decline of 0.6 Sv/year was observed over the first ten years. This is ten times larger than long term decline predicted by the IPCC.

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



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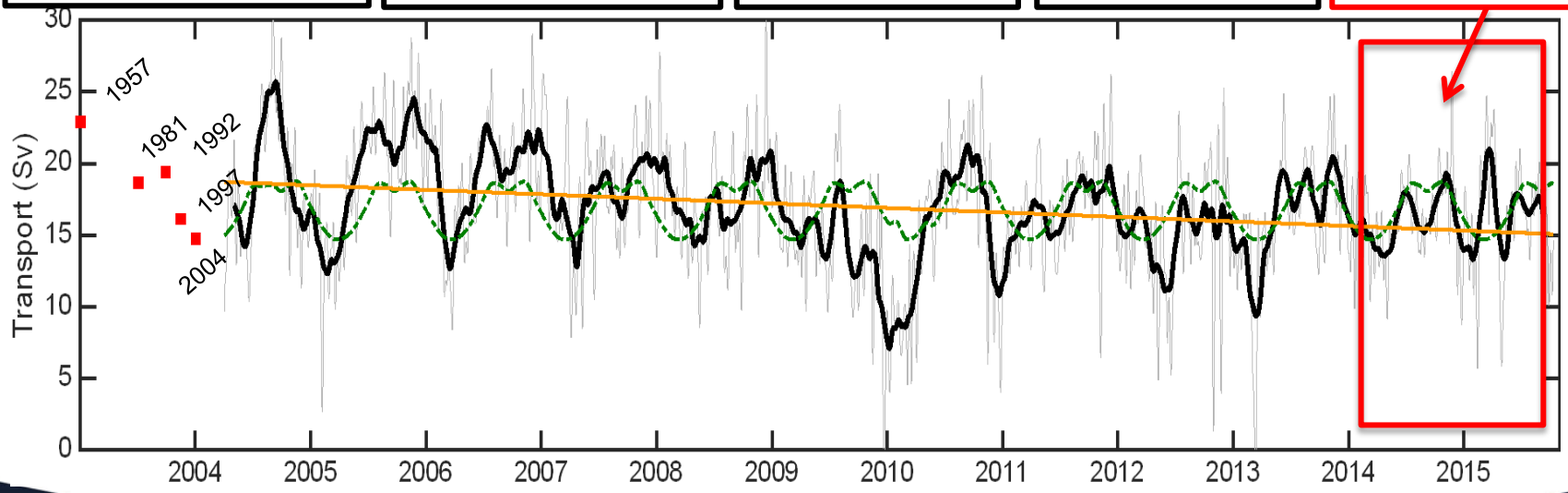
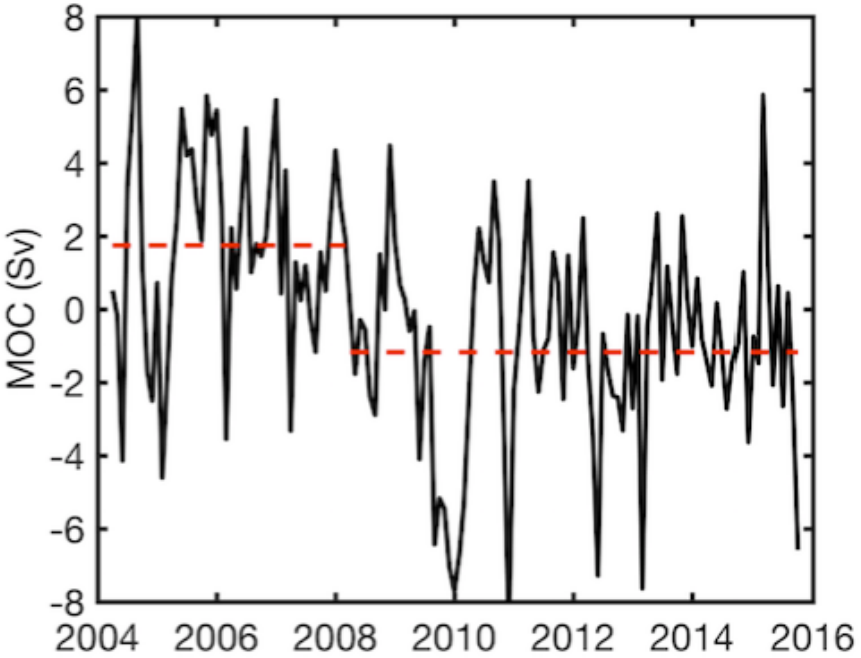
Latest 18 months of data:
The AMOC has remained low at an average of 15.5 Sv. This is the same average as from 2009 to 2014 but much lower than the 18.5 Sv observed from 2004 to 2009



A step change in 2008



- Statistical analysis of the timeseries indicates that a step change in 2008 is the model of best fit

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

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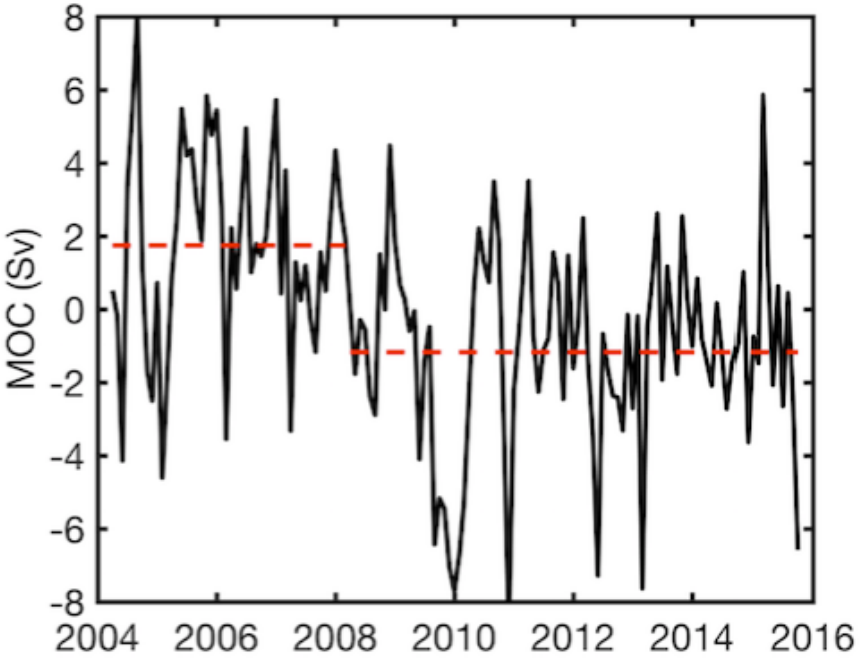
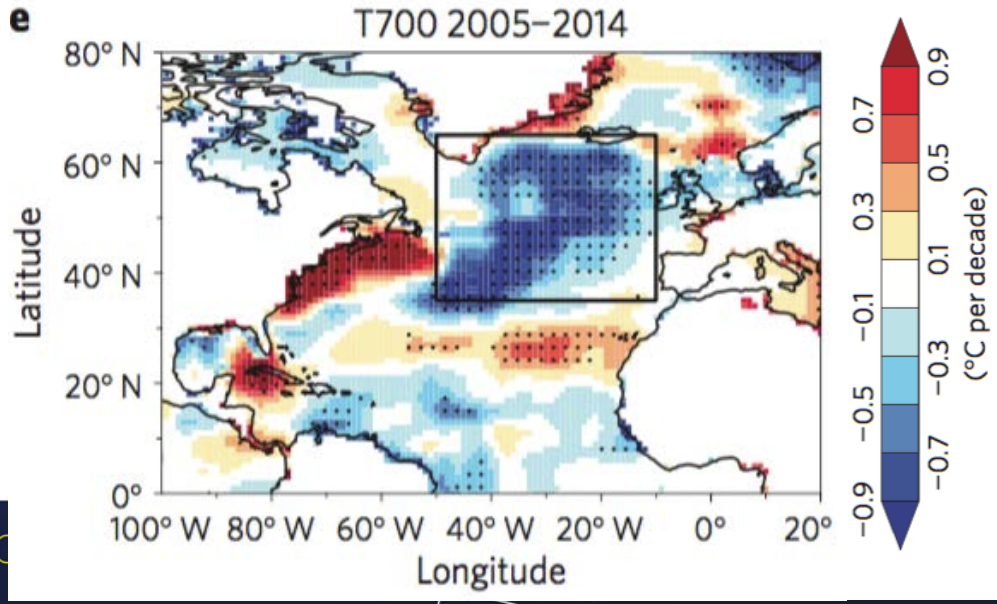


- Statistical analysis of the timeseries indicates that a step change in 2008 is the model of best fit

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

- 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*.



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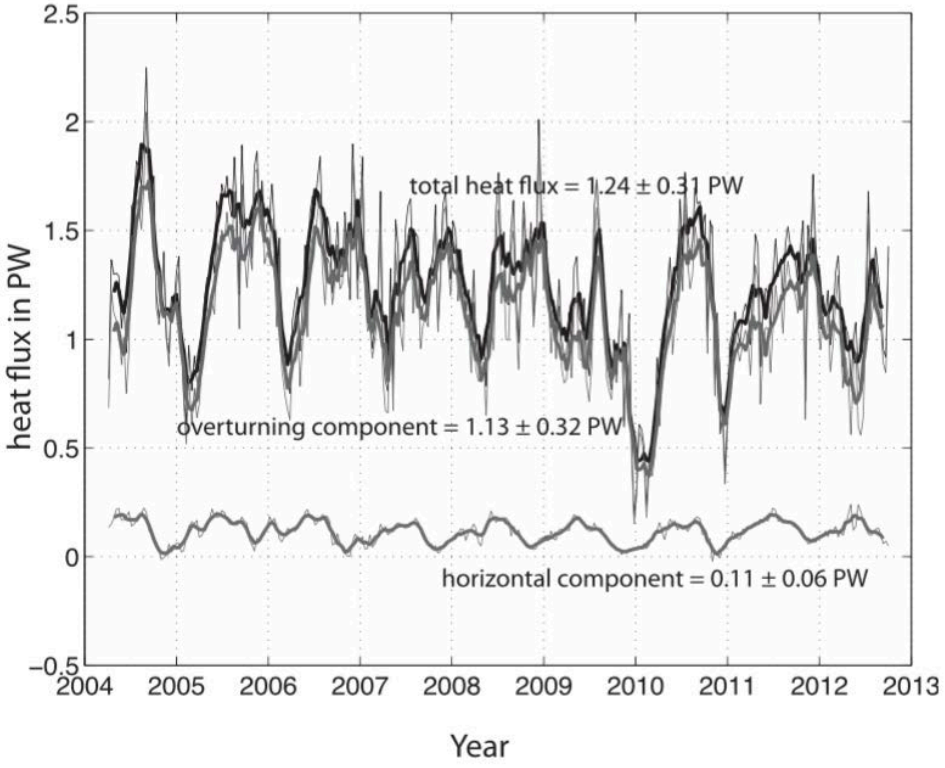
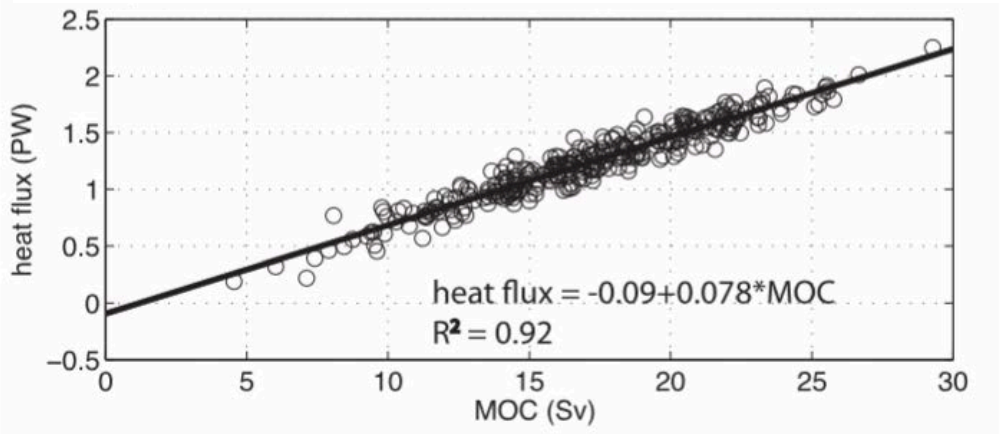
Heat Transport





- Overall MHT of 1.2 PW similar to hydrographic estimates
- 90% carried in overturning circulation

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

updates in McCarthy et al. (2015), Measuring the Atlantic Meridional Overturning Circulation at 26N, *Prog. Oc.*

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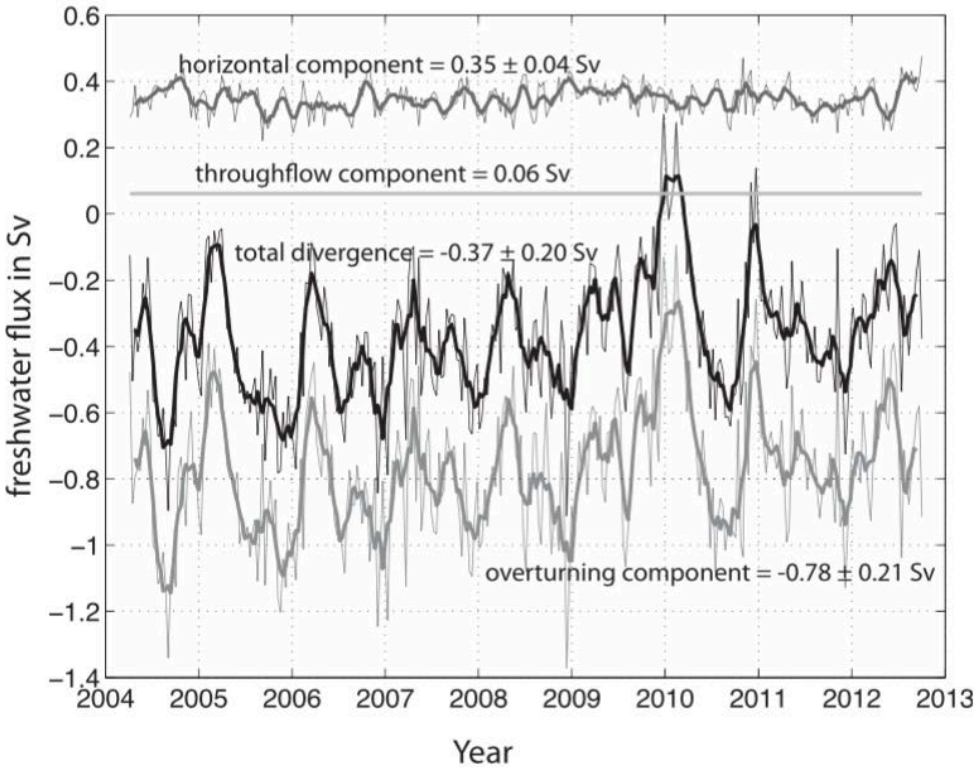
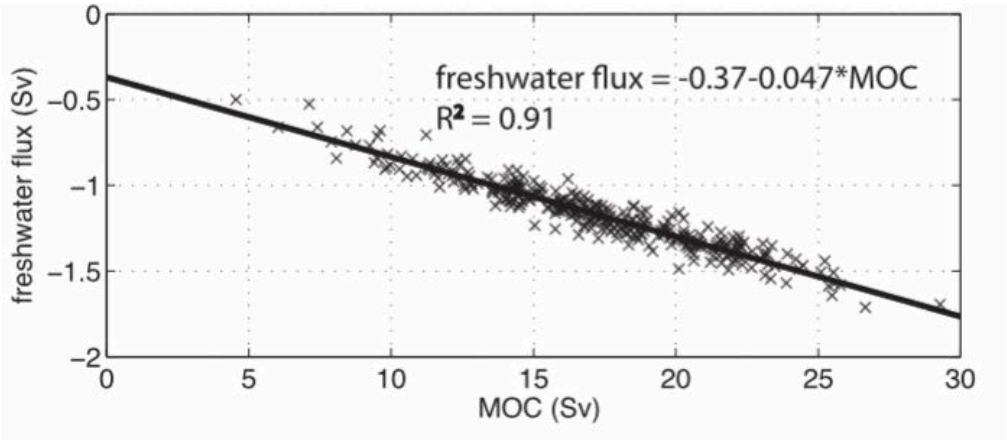
Freshwater Transport



- Divergence of freshwater between 26.5ºN and Bering Strait of 0.37 Sv
- 90% carried in overturning circulation



McDonagh, E. et al. (2015), Continuous Estimate of Atlantic Freshwater Flux at 26.5°N, *J. Clim.*, *28,* pp. 8888–8906.

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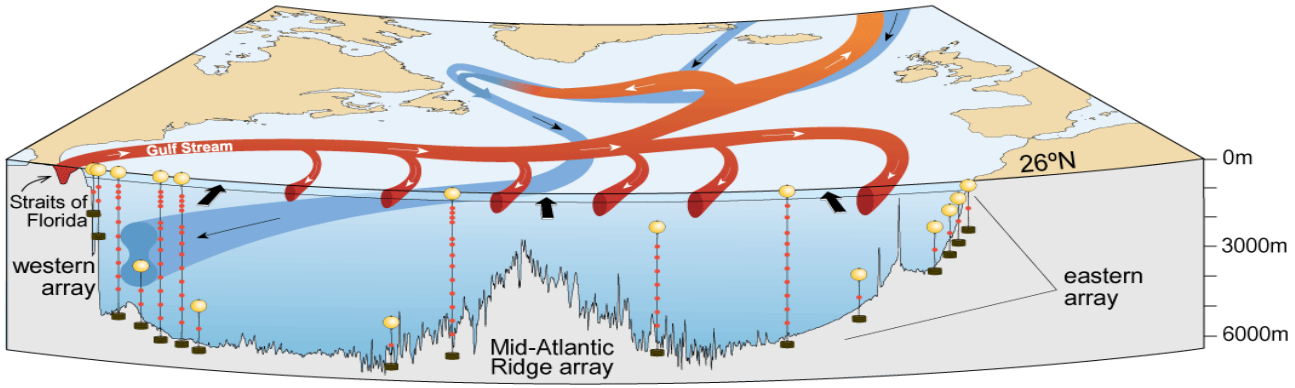
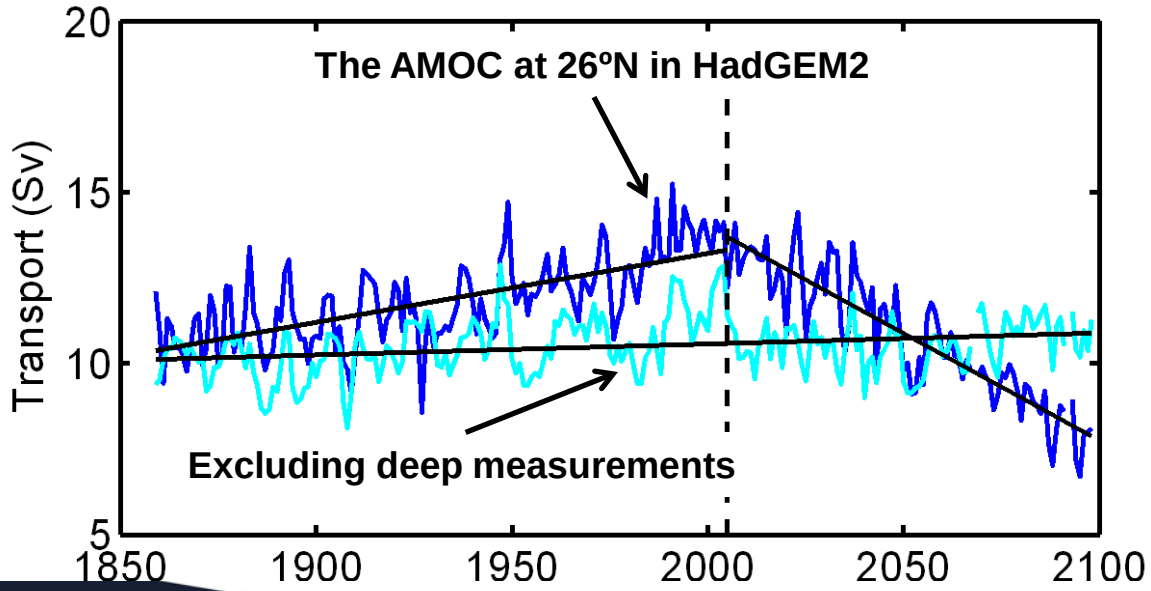
Deep measurements needed

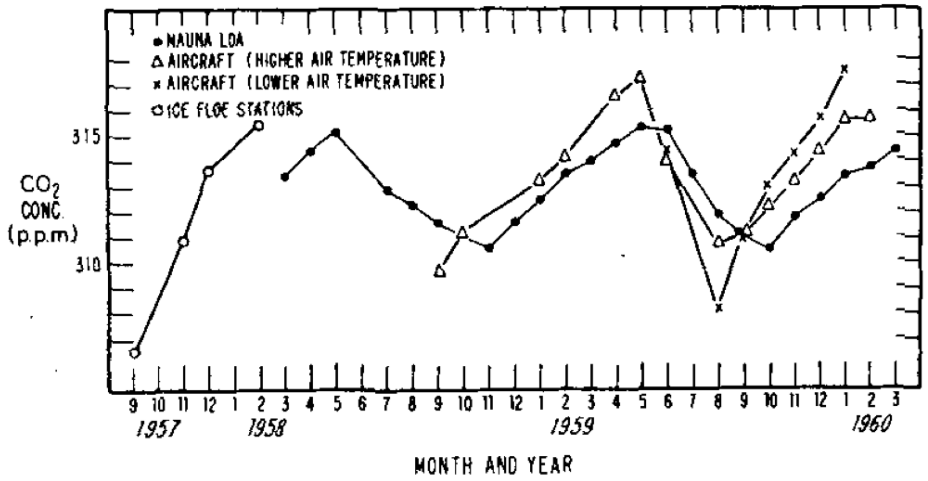




- The variability observed in 11.5 years can be recreated using only measurements in the top 1000 m
- However, deep measurements are needed to capture future changes in the AMOC related to anthropogenic climate change

McCarthy et al. (2016), The importance of deep, basinwide measurements in optimised Atlantic Meridional Overturning Circulation observing arrays. *submitted to JGR: Oceans*

Sustained Observations



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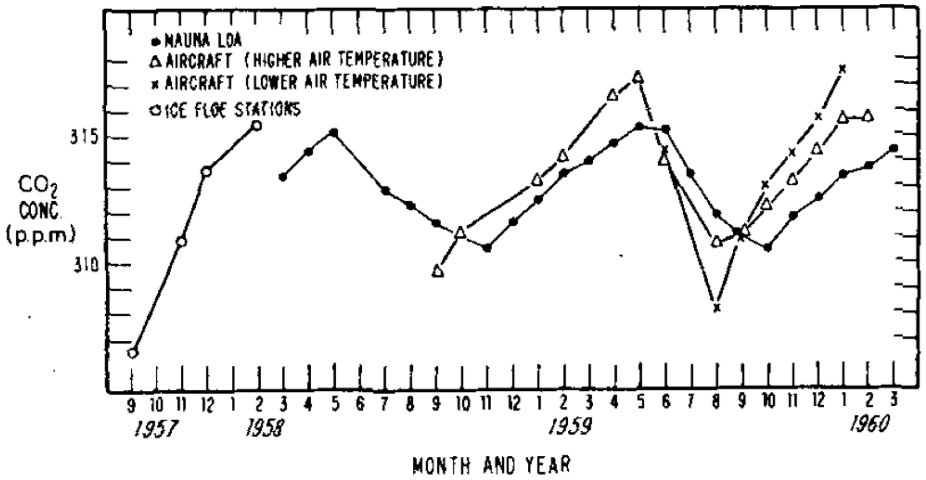
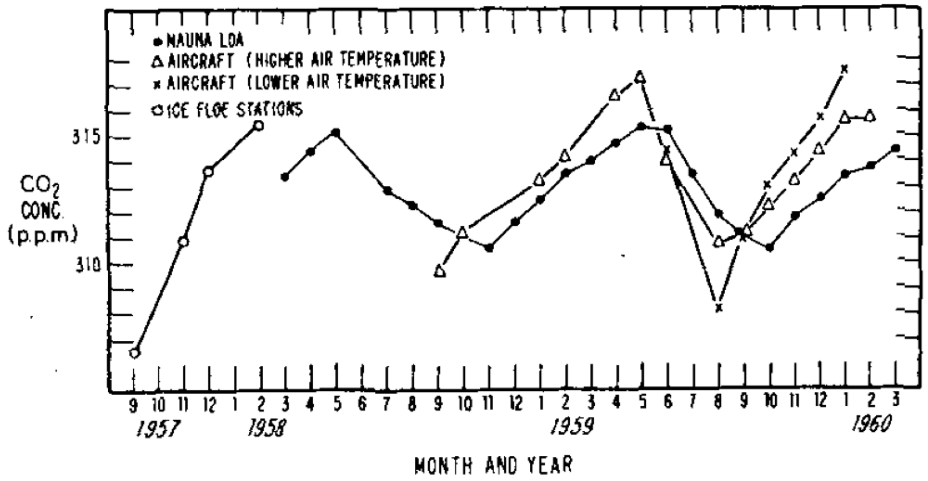


Keeling, C. D. (1960). The concentration and isotopic abundances of carbon dioxide in the atmosphere. *Tellus*, *12*(2), 200-203.

In 1960 Charles Keeling published two years of CO^2 measurements

Much like this talk, he focused on shortish timescales

Sustained Observations



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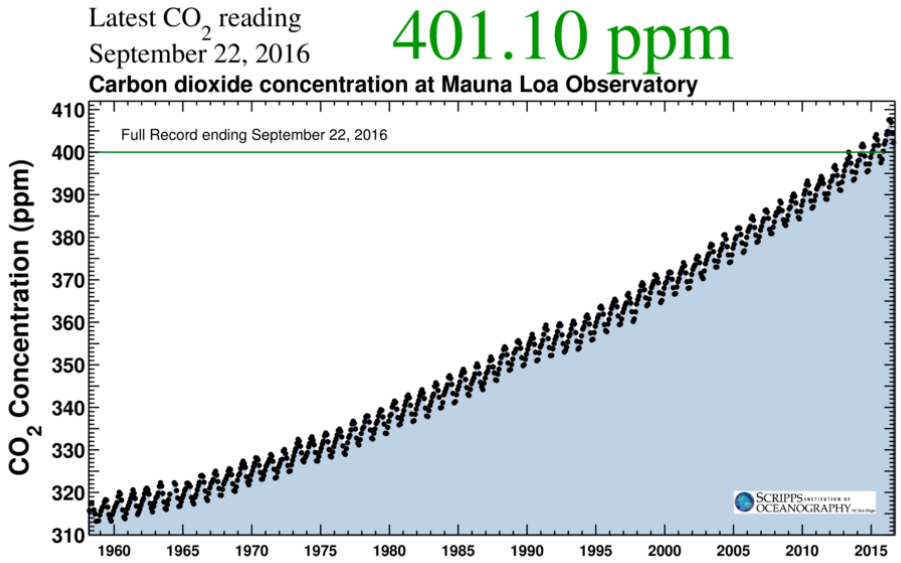
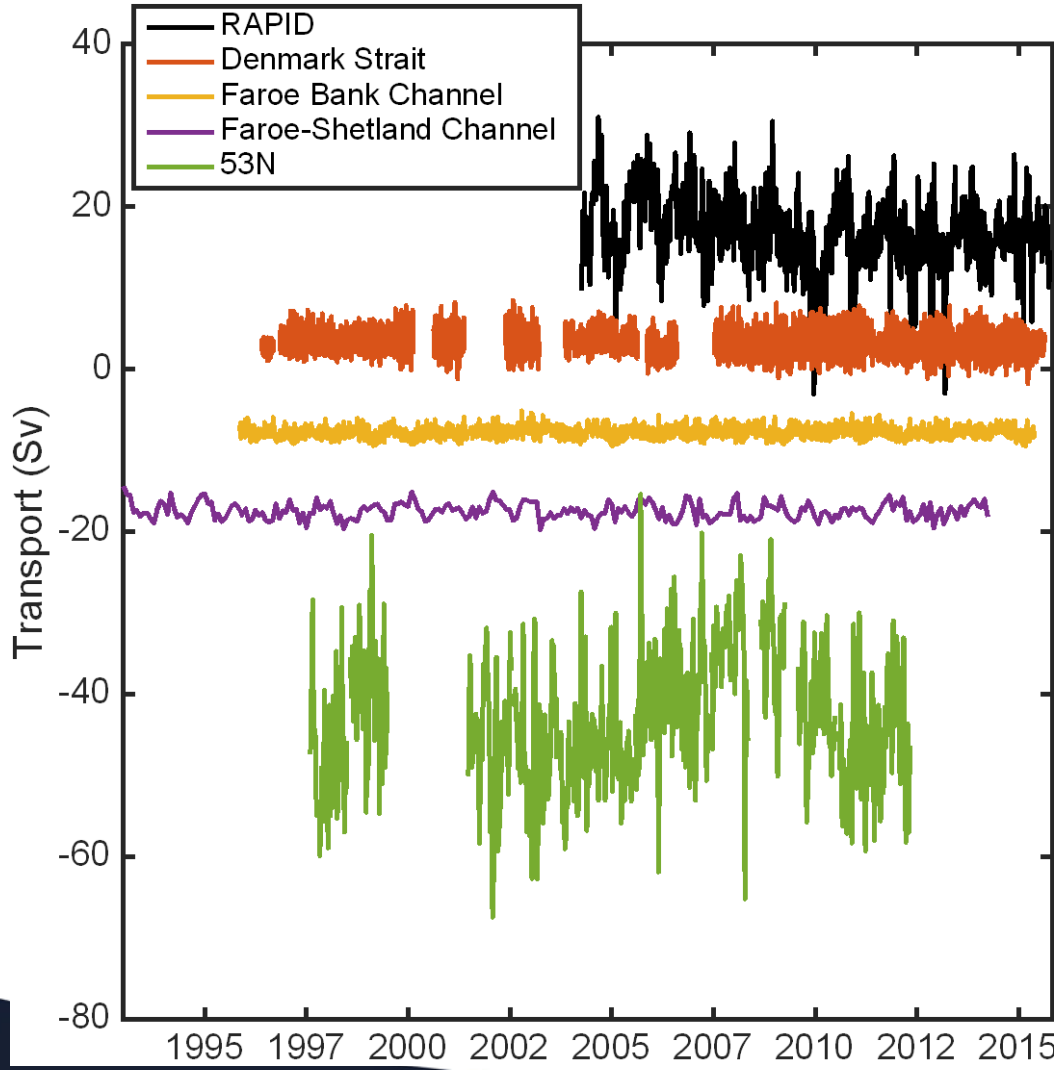


However, as the Keeling curve continued, it is famous as a record of the continual rise of anthropogenic CO^2 in the atmosphere.

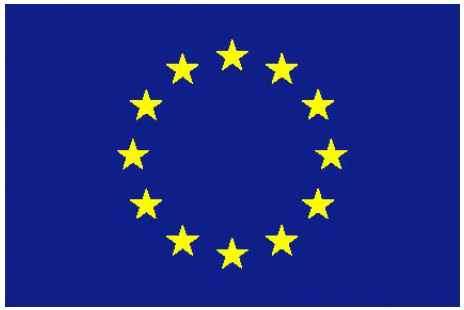
In 50 years time, will the RAPID measurements have documented the predicted AMOC slowdown due to anthropogenic climate change?

Ongoing work



"Understanding of climate change is a problem for multiple generations. One generation of scientists has to make provisions for the needs of successor generations, rather than focusing solely on its own immediate scientific productivity. Today's climate models will likely prove of little interest in 100 years. But adequately sampled, carefully calibrated, quality controlled, and archived data for key elements of the climate system will be useful indefinitely."

Wunsch, C., Schmitt, R. W., & Baker, D. J. (2013). Climate change as an intergenerational problem. *Proceedings of the National Academy of Sciences*, *110*(12), 4435-4436.



The research leading to these results has received funding from the European Union 7th Framework Programme (FP7 2007-2013), under grant agreement n.308299

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