A reversal of climatic trends in the North Atlantic since 2005

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Summary

- **Since 2005 a large area of the North Atlantic has cooled significantly, in stark contrast to the 1990s rapid warming.**
- **The total cooling is ~ 0.45°C, or 1.5x10^{22} J, which is equivalent to a heat budget deficit of 0.05PW sustained over a decade.**
- **The cooling *is not* readily explained as a direct response to contemporaneous atmospheric variability.**
- **The cooling *is* consistent with a slowdown in ocean circulation related to anomalously low deep Labrador Sea Density.**

1. Background

- Ocean circulation, and particularly the Atlantic Meridional Overturning Circulation (AMOC), is thought to be an important driver of Atlantic Multidecadal Variability (AMV, e.g 1). However, a dominant role for surface flux changes has also been forwarded (2).
- Observations of deep Labrador Sea density suggest that a decadal time-scale slowdown of the AMOC is now underway (3).
- Here we use recent observations to quantify the recent changes in upper ocean, and use a model to interpret the important processes involved.

2. Recent upper ocean trends

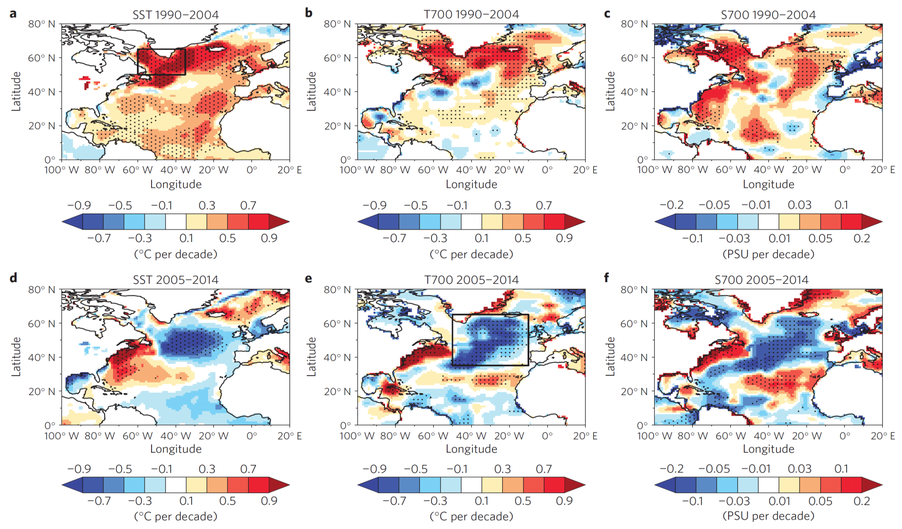


Figure 1. Recent upper ocean trends. *a) shows the 1990-2004 linear trends in sea surface temperature (SST, °C). b) and c) the same but for 0-700m temperature (T700, °C) and salinity (S700, PSU), respectively. d-f) shows the same as a-c, but now for the 2005-2014 time period. Stippling shows where the trends are significant. SST is taken from HadISST (4) and upper ocean observations are taken from the EN4 data set (5).*

- Over 1990-2004 the sea surface temperature (SST) and upper ocean (0-700m) heat content (T700) warmed, especially in the subpolar gyre (SPG). The Atlantic also became more salty (S700, figure 1 a-c).
- After 2005 the SST and T700 cooled over the North East Atlantic and the upper ocean became fresher, (figure 1d-f). T700 and S700 increased along the North American east coast.
- The cooling of the North East Atlantic (box on figure 1e) is ~ 1.5x10^{22} J. Equivalent to a sustained surface flux cooling of 4.5Wm^{-2}, or a heat budget deficit of 0.05PW, sustained over a decade (see figure 2).
- *Is the cooling related to ocean circulation changes or contemporaneous changes in atmospheric circulation ?*

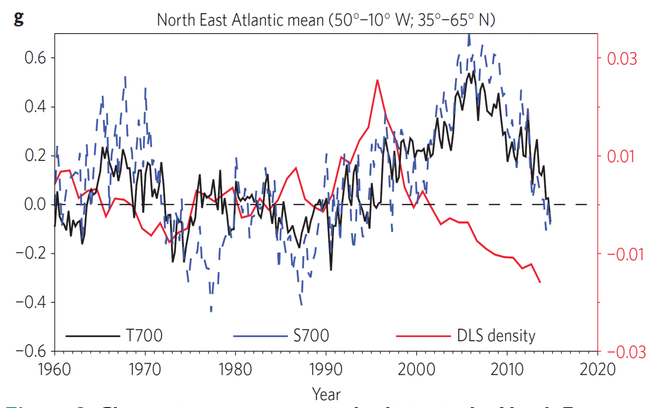


Figure 2. *Change in temperature and salinity in the North East Atlantic (50-10°W; 35-65°N).* *Figure shows the 0-700m mean temperature (T700, black) and salinity (S700x10, blue) averaged over the North East Atlantic (shown as a box on panel 1e). Also shown is the deep Labrador Sea density index (red), which is the 1000-2500m density (σ2) averaged over the Labrador Sea (60-35°W,50-65°N; shown as a box on panel 1a)*

3. Recent atmospheric trends

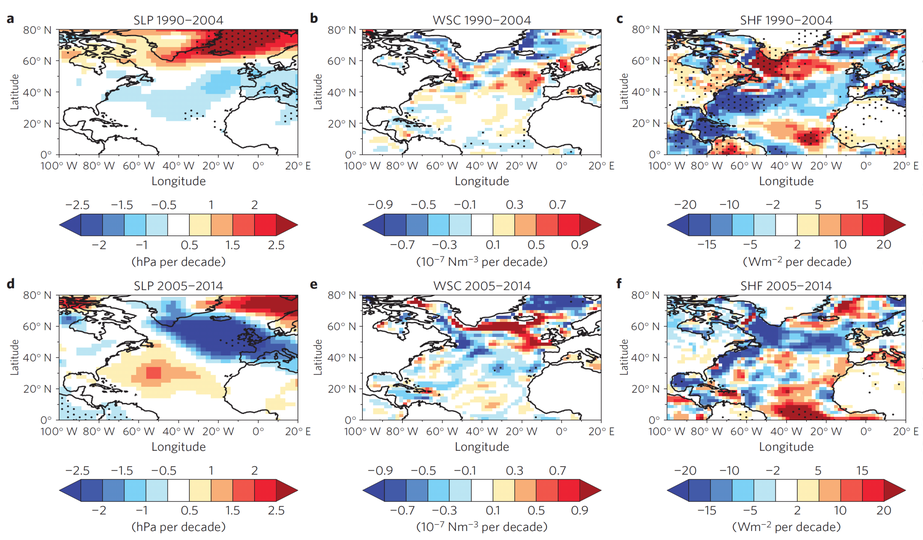


Figure 3. Recent atmospheric trends. *a) shows the 1990-2004 linear trends in sea level pressure (SLP). b) and c) the same but for wind stress curl (WSC) and surface heat fluxes (SHF), respectively. Positive values for b represent increased Ekman upwelling. In c, positive values represent a warming of the ocean. d-f) shows the same as a-c), but now for the 2005-2014 time period. Stippling shows where the trends are significant at the 2-sigma level. Based on NCEP reanalysis (6).*

- The 1990-2004 trend was to negative NAO and reduced heat loss over the Labrador sea (see figure 3 a-c). However, ocean likely dominated the warming (1).
- The 2005-2014 trend was to low pressure over eastern SPG. Hence, increased wind stress curl (and Ekman upwelling) and surface heat fluxes (SHF) likely played a role in the cooling of the ocean (see figure 3 d-f).
- However, evidence, including the sensitivity of SLP and SHF trends to start and endpoints (whereas T700 is not), and the different patterns of SHF and T700 trends (compare fig.1e and fig.3f) (not shown), suggests that the atmosphere can not readily account for the total cooling.

4. Ocean circulation changes?

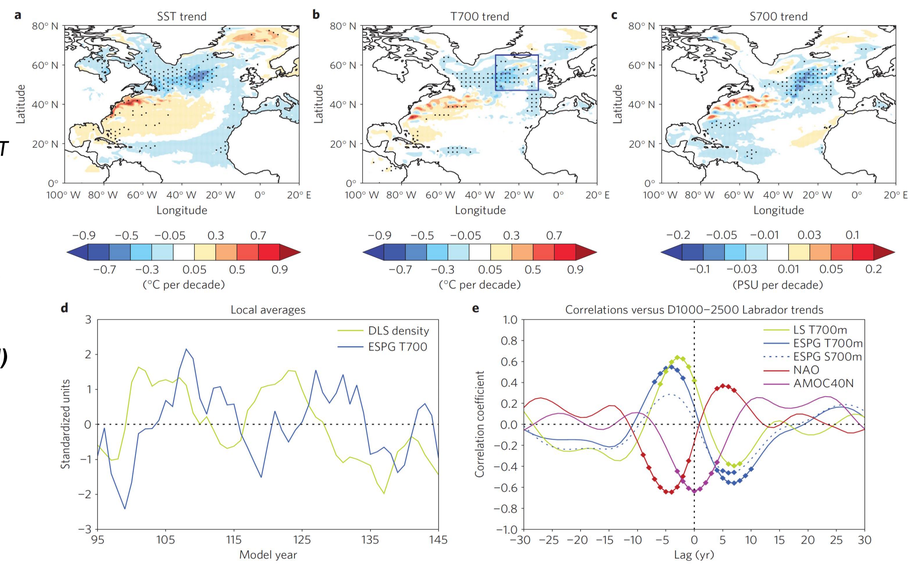
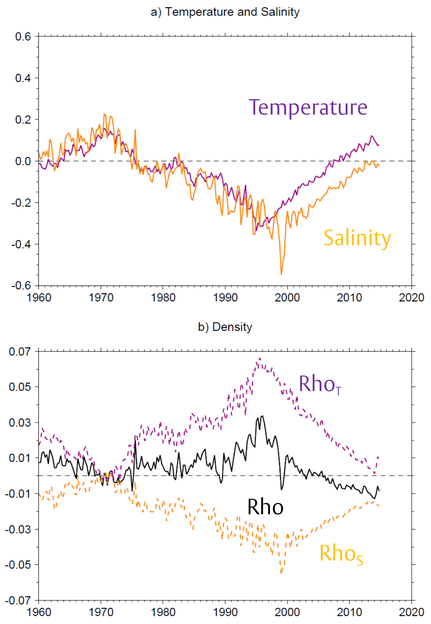


Figure 4. The changes in upper ocean properties expected following a decrease in deep Labrador Sea density. ***a)*** *shows a composite of 15-year trends in SST in the model, HadGEM3-GC2, following the 9 largest decreasing 15-year trends in deep Labrador Sea density at a lag of 5 years.* ***b)*** *and* ***c)*** *are the same as a) but for 0-700m ocean heat and salt content. Stippling shows where trends are significant. the model.* ***d)*** *gives an example of the model variability.* ***e)*** *shows the lead-lag relationship between the deep Labrador Sea density, and other key variables (see legend).*

- Deep Labrador Sea density has been declining since its peak in 1995 (see figure 2, red), consistent with a declining AMOC (2).
- Figure 4 shows the relationship between deep Labrador Sea density and other variables in a high-resolution coupled model (HadGEM3-GC2 (7)).
- SPG SST and 0-700m temperature and salinity decrease following a decline in deep Labrador Sea density. However, they increase over the Gulf stream extension (see figure 4 a-c), consistent with a reduction in AMOC (8).
- The changes in SST and 0-700m heat and salt content (T700, S700) are consistent with the observed trends over 2005-2014 (compare with fig.1).

5. Deep Labrador Sea density



- The observed decrease in deep Labrador Sea density since 1995 is primarily due to a warming (see figure 5).
- Temperatures are not (yet) warmer than they were in the early1970s, *but they are fresher*.
- A long-term freshening has played a small, but important, role in generating record low density.

Figure 5. Water mass properties in the deep Labrador Sea. *a) shows seasonal-mean temperature (purple, °C) and salinity (orange, PSUx10) anomalies, relative to 1961-1990, in the deep Labrador Sea (1000-2500m; 60-35°W,50-65°N) from the EN4 dataset (5). b) shows the seasonal-mean density anomalies (black, kg m^{-3}) as well as the contribution of temperature (purple) and salinity (orange) to the total density anomaly. Density anomalies are relative to the 1971-mean.*

Find out more....

- **Robson, et al; Atlantic Overturning in decline?, *Nature Geoscience*, *7, 2-3, 2014***
- **Robson, et al; A reversal of climatic trends in the North Atlantic since 2005, *Nature Geoscience*, 9, 513-517, 2016**

References

(1) Robson, et al, *Journal of Climate*, **25**, 4116–4134 (2012) // **(2)** Clement, et al, *Science, **350**, 320-324* (2015) // **(3)** Robson, et al, *Nature Geoscience, **7**, 2-3* (2014) // **(4)** Rayner et al, JGR:*Atmospheres, **108**, 4407* (2003) // **(5)** Good, et al, *JGR: Oceans*, **118**, 6704-6716 (2013) // **(6)** Kalnay, et al, BAMS, **77**, 437-471 // **(7)** Williams et al, Geoscience model development, **8**, 521-565 (2015) // **(8)** Zhang and Vallis, Journal of Physical Oceanography, **37**, 2053-2080 (2007)

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