An Observed Rapid Warming of the North Atlantic Ocean in the 1990s

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Summary

▪ **A rapid warming of the North Atlantic is observed in ocean analyses in the mid 1990s**

▪ **Comparison of the observations with an idealised ocean modelling study suggest the warming was likely a lagged response to the strong positive NAO forcing that preceded it**

▪ **A strengthening of the AMOC following the positive NAO forcing led to a surge in the northward heat transport and hence warmed the North Atlantic**

1. Background

The North Atlantic underwent a rapid warming in the mid 1990s with annual mean sea surface temperatures (SST's) increasing by around 1°C in just two years. The rapid warming followed a prolonged positive phase of the North Atlantic Oscillation (NAO) but also coincided with a large negative NAO in the winter of 1995/96.

Was the rapid warming:-

A) A direct response to the low NAO index of the winter of 95/96, or

B) A lagged response to the previous persistent positive NAO forcing ?

If the rapid warming was a result of B) then this is good for potential predictability.

2. Rapid warming

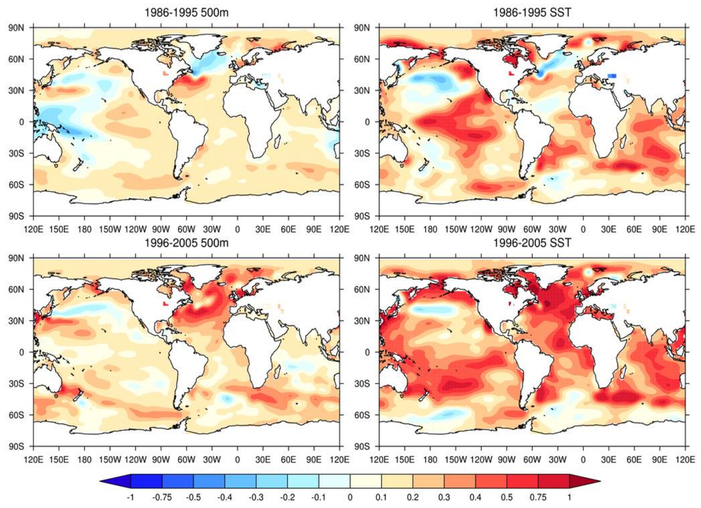


Figure 1. Left: Decadal mean top 500m heat content anomalies. Right: SST anomalies. Both are from the Met Office ocean analysis **(1)** and are relative to 1961 – 1990 climatology

•The Rapid warming of the North Atlantic in the mid 1990s is clearly visible in **Fig. 1.**

•The North Atlantic subpolar gyre (NASPG) is initially seen to be cold in the 1986-1995 mean, but there is a large increase in upper ocean heat content and SST's in the 1996-2005 mean.

3. NAO forcing

•NASPG top 500m heat content is anti correlated with the NAO (see **Fig. 2.**) due to a correlation of the NAO with surface fluxes and Ekman pumping, which both act to cool the surface.

•However after 1995 the correlation of the heat content and the NAO breaks down and the NASPG warms more persistently than the simple correlation with the NAO would suggest.

Here we compare the observations with an idealised modelling study to find out whether Hypothesis A or B is correct.

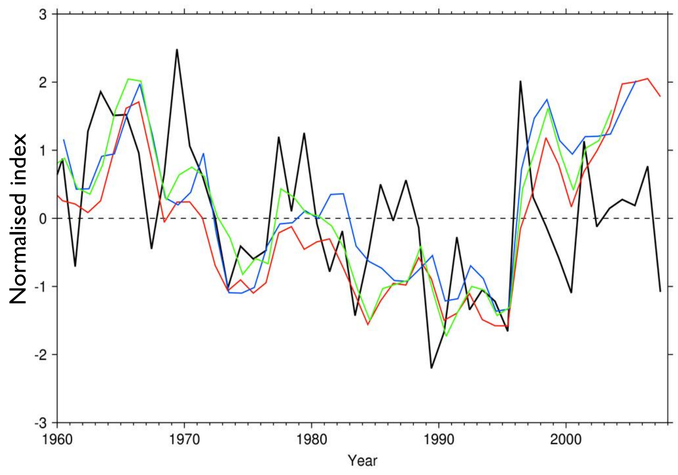


Figure 2. A comparison between normalised annual mean indexes of NASPG (50°N-66°N, 60°W-10°W) top 500m heat content from three different ocean analyses (Met Office (red), ECMWF (blue) and Levitus (green) and the NAO index (black, NB the NAO index has been inverted).

4. Idealised model comparison

•The evolution of the observed 500m heat content anomalies (**Fig. 3**, left) is very similar to the heat content anomalies found in an idealised modelling study (**Fig. 3**, right) which force an ocean model (MICOM) with persistent positive NAO surface forcing **(4)**.

•The surface forcing was calculated from ERA-40 by compositing the 7 most positive NAO years.

•Initially, the positive NAO cools the surface of the NASPG and warm anomalies build up in the Gulf Stream Extension (GSE) region.

•The warm anomalies in the GSE intensify over the first 10 years before they begin to move Northward into the NASPG.

•The warm anomalies then move further around the NASPG and fill up the gyre to the Irminger sea.

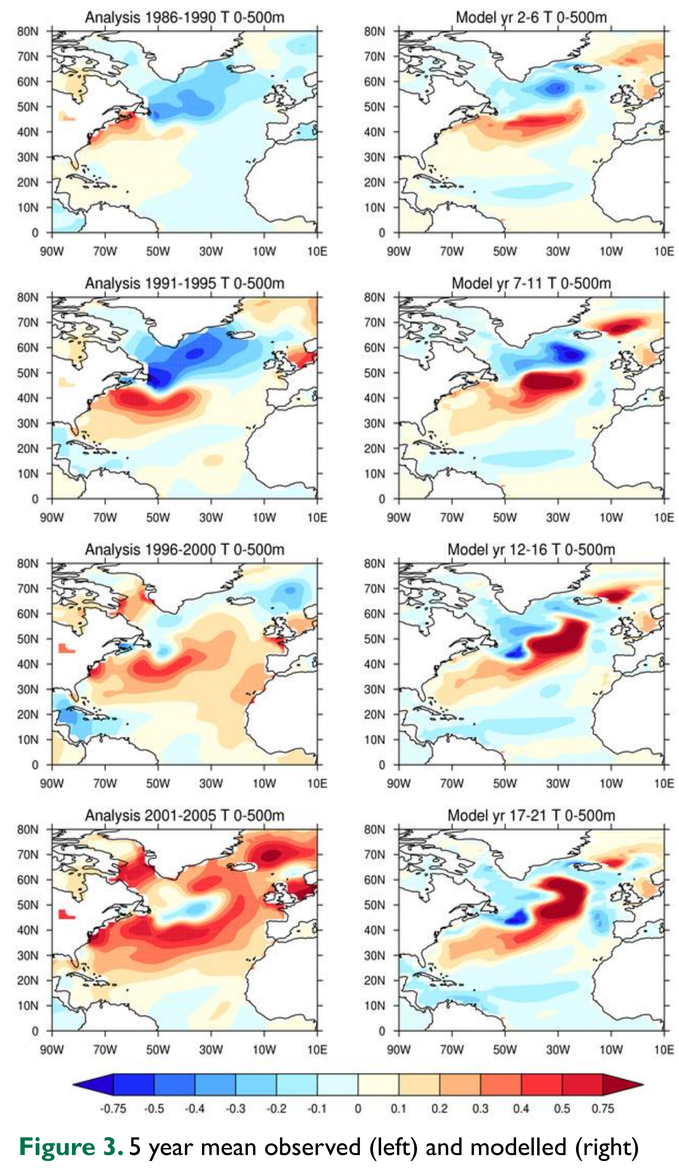


Figure 3. 5 year mean observed (left) and modelled (right) top 500m heat content. A linear global mean trend has been removed from the observations. The model anomalies have been scaled down to be similar to the observed

5. Deep ocean signals and the AMOC

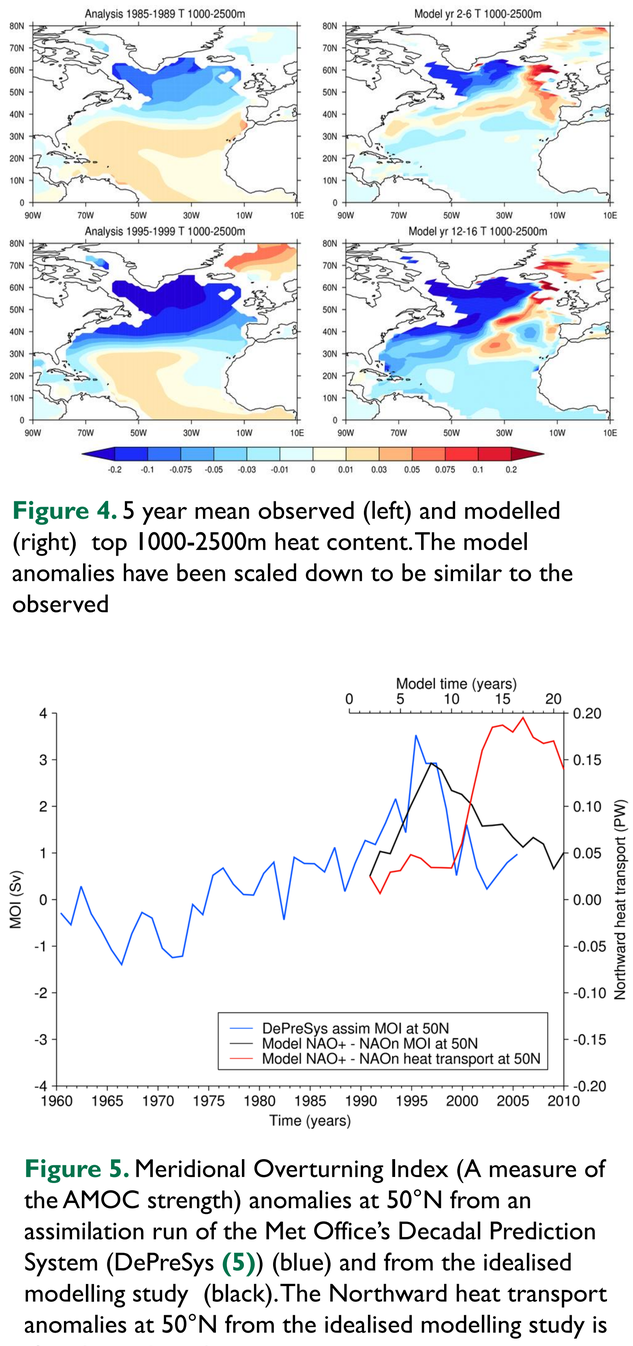


Figure 4. 5 year mean observed (left) and modelled (right) top 1000-2500m heat content. The model anomalies have been scaled down to be similar to the observed

Figure 5. Meridional Overturning Index (A measure of the AMOC strength) anomalies at 50°N from an assimilation run of the Met Office's Decadal Prediction System (DePreSys **(5)**) (blue) and from the idealised modelling study (black). The Northward heat transport anomalies at 50°N from the idealised modelling study is also shown in red.

•In the model, the cooling of the NASPG causes an increase in deep convection which cools the deeper NASPG before propagating down the deep western boundary (**Fig. 4,** right).

•The increase in the deep convection strengthens the Atlantic Meridional Overturning Circulation (AMOC), increasing the northward heat transport (see **Fig. 5**), hence causing the warming seen in **Fig. 3.**

•A similar anomaly pattern is seen in the observations in the 1980s and 1990s, as the NAO becomes more positive (**Fig. 4,** left).

•There are no direct observations of the AMOC strength at the time of the warming, but assimilating the observational analyses into a model integration can yield an estimate. **Fig 5** shows that the AMOC strength increases and peaks in the 90s, with a similar evolution as the AMOC increase seen in the idealised modelling study.

•An increase in the real worlds AMOC in the 1990s would likely cause a surge in the northward heat transport which would warm the North Atlantic.

References

(1) Smith, DM, JM Murphy (2007), *J. Geophys. Res.* // (2) Eden, C, J Willebrand (2001), *J. Of. Climate.* // (3) Dong, B, RT Sutton (2005), *J. Of Climate.* // (4) Lohmann, K, H Drange, M Benson, (2009) , *Climate Dynamics* // (5) Smith DM, S Cusack, AW Colman, CK Folland, GR Harris JM Murphy (2007), *Science* //