Initialised predictions of the rapid Warming of the North Atlantic Ocean in the mid 1990s

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Summary

▪**The Met Office decadal prediction system (DePreSys) is able to predict the mid 1990s Atlantic warming**

▪**The initialisation of an anomalously strong Atlantic Overturning circulation, and hence ocean heat transport, was key to the successful predictions**

▪**Successful prediction of the warming enables DePreSys hindcasts to also predict a shift in the wider climate that is similar to that observed, even over land**

1. Background

• Since the early 1990s the North Atlantic has warmed significantly, especially in the North Atlantic subpolar gyre (SPG, see Fig. 1), which underwent a rapid warming in the mid 1990s
• There is evidence that the warming was due to a strengthening of the Atlantic Meridional Overturning Circulation (AMOC) and so could be predictable **(1,2)**
•This study attempts to learn about the predictability of this event by using initialised near term climate predictions
•We analyse initialised decadal predictions using the Met Office Decadal Prediction System (DePreSys), which assimilates observations into an ensemble of 9 perturbed physics versions of HadCM3 **(3)**.

2. Initialised predictions

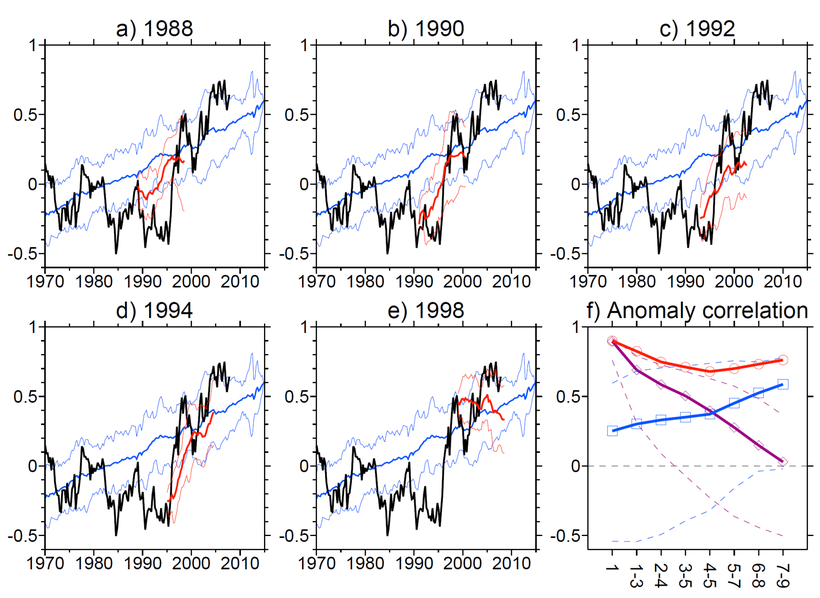


Figure 1. ***The evolution of the observed and predicted subpolar gyre (SPG, 60W-10W, 50N-66N) 0-500m average temperature anomaly.*** *It shows Met Office Ocean analysis (**black, (4)**), DePreSys (**red**) and NoAssim (**blue**) hindcasts. All NoAssim hindcasts have been averaged together. Thick and thin lines show the ensemble mean and 2σ spread. f) shows the anomaly correlation skill scores evaluated over 1960-2005 hindcasts. The thick lines denote the ensemble mean and the thin lines show the 95% confidence intervals. The purple line shows the skill of persistence.*

•Analysis of DePreSys shows that predictions initialised before 1996 are able to capture the warming of the SPG (see fig.1) and also the spatial evolution of the warming (see fig.2).
• In comparison, hindcasts that do not assimilate observations (NoAssim), are not able to capture the warming with as much skill (see fig.1 & 2)
• **What is the Mechanism for improved predictions?**

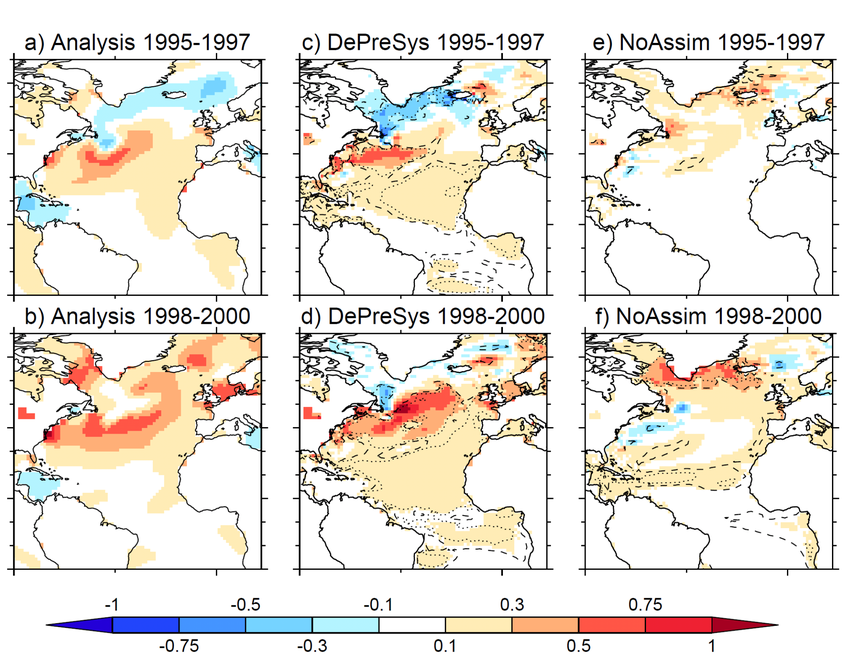


Figure 2. ***Shows the spatial evolution of the observed 0-500m temperature anomalies, and anomalies simulated by November 1994 hindcasts.*** *a) and b) shows 3 year mean temperature anomalies from the Met office ocean analysis for the period 1996-2001. Also shown is the predicted anomalies from the November 1994 DePreSys and NoAssim hindcasts. The black contours show where the ensemble mean anomaly is significant at the 5% (dashed) or 1% (dotted) level. All anomalies are relative to a 1951-2006 climatology.*

3. Subpolar gyre Energy Budget

• The importance of both the ocean heat transport convergence (**Ho**) and the atmospheric heat loss (**Ha**) is evaluated over the first three years of the hindcasts i.e. **ΔEnergy = Ho – Ha**
•The 1990s warming in **DePreSys** is due to a large *increase* in **Ho**, that peaks for the 1995 hindcast (see fig.3 top)
• *A decrease* in **Ha** also contributes to the warming, but is less important
•**NoAssim** *does not* simulate an increased **Ho** in the mid 1990s (see fig.3 bottom)

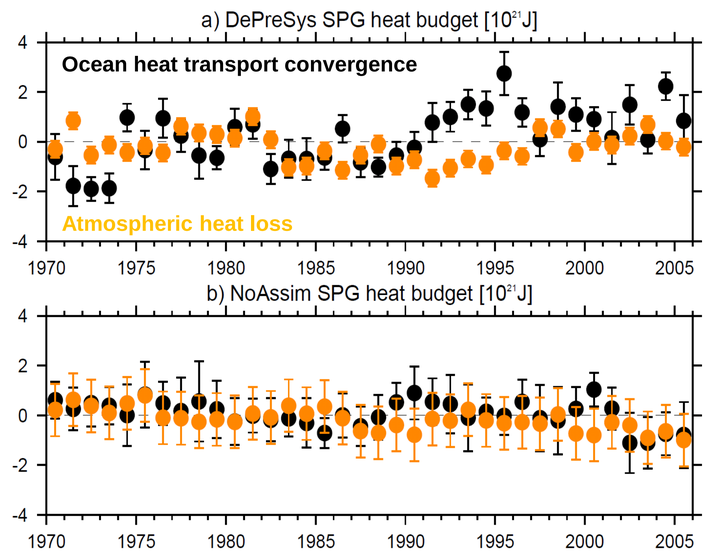


Figure 3. ***Shows the SPG heat budget.*** *Anomalous ocean heat transport convergence (Ho, black) and atmospheric heat flux (Ha, orange) integrated over the first three years of the DePreSys (a) and NoAssim (b) hindcasts. The circle shows the ensemble mean for the hindcast started in that year, and the 95% confidence intervals are shown with the error bars. Where Ho is larger than Ha, there is a warming of the SPG.*

What is the cause of the increase in ocean heat transport convergence?

4. Ocean heat transport and AMOC

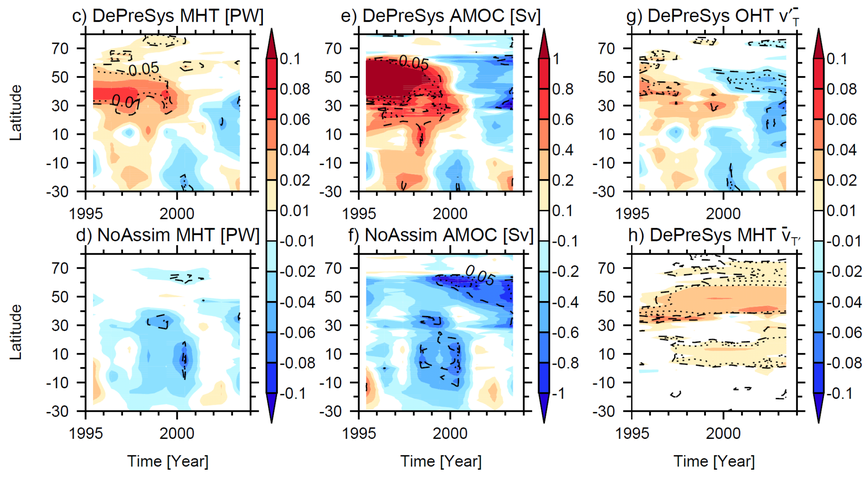


Figure 4. ***shows the evolution of ocean heat transports and AMOC in the 1994 hindcasts.*** *c) shows the anomalous ocean Meridional Heat Transport (MHT) as a function of latitude and time for the 1994 DePreSys hindcast. d) as c) but now for the 1994 NoAssim hindcast. e) and f) same as c) and d) but now show the AMOC. g) and h) the same as c) cut now show the heat transport associated with anomalous ocean circulation (v') and anomalies in temperature (T'). All anomalies are relative to 1961-2006.*

•Increased ocean heat transport in the 1994 DePreSys hindcast is associated with an increase in the strength of the AMOC (see fig.4c & 4e)
• The increased AMOC is absent in NoAssim (see fig.4f)
• The initial increase in **Ho** in the1994 DePreSys hindcast is due to anomalous ocean Velocity (V', see fig.4g). However, advection of anomalous Temperature (T') also contributes → **the initialisation of ocean dynamics is important for successful predictions of the warming**

5. Climate impacts

•DePreSys Hindcasts that predict a warming of the SPG (1991-1996 start dates) also simulate a significant shift in the wider climate (see Figure 5)
•The simulated shift in climate is similar to that which was observed

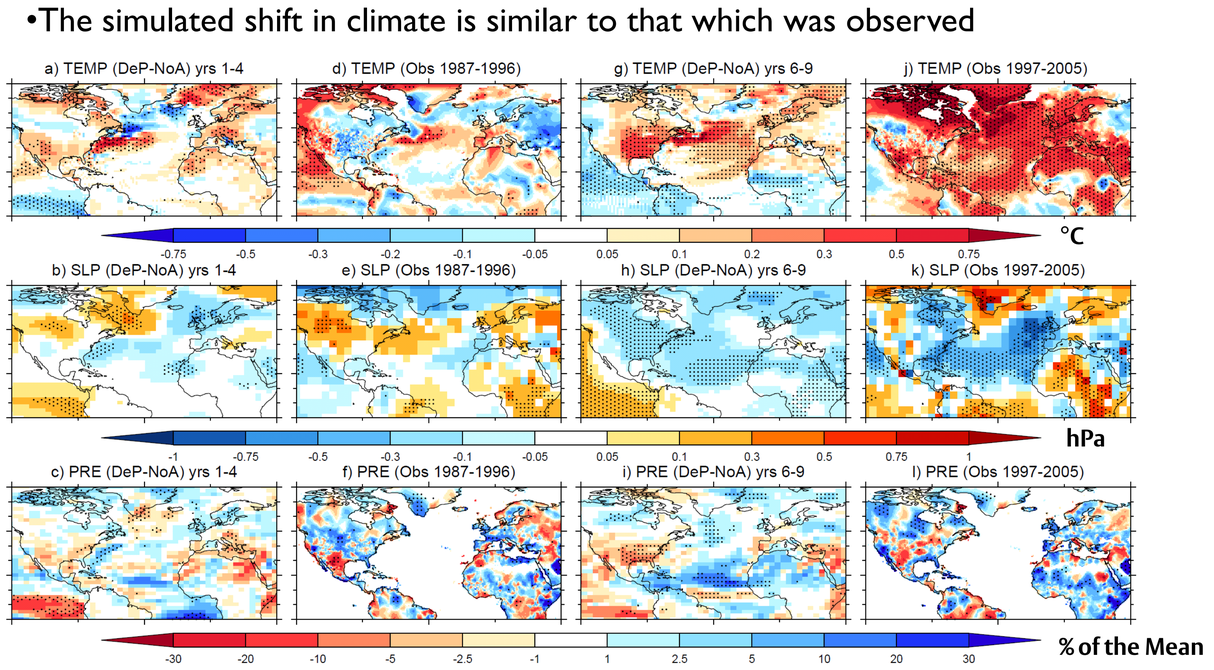


Figure 5. ***shows the predicted March-November climate impact in hindcasts that predict a warming (1991-1996) compared to the observed change in climate.*** *a) shows surface temperature for years 1-4 for DePreSys hindcasts started between 1991-1996, minus years 1-4 from hindcasts started between 1960-1990. Finally, anomalies are relative to the same difference in NoAssim. b) and c) are the same as a) but now for Sea Level Pressure (SLP) and Precipitation (PRE). d-f show the same as a-c, but now for the 1987-1996 observed anomalies, relative to a 1961-1991 climatology. The observed temp has been detrended over 1951-2009. g-l shows the same as a-c, but now for years 6-9. j-l shows the same as d-f, but now for years 1997-2005. Stippling shows where the difference is significant at p≤0.1.*

References

(1) Robson, J. et al, Causes of the Rapid Warming of the North Atlantic ocean in the mid 1990s , (2012) // **(2)** Yeager, S. et al, *A decadal prediction case study: Late 20th century north Atlantic ocean heat content.* (2012) // **(3)** Smith D.M., *et al, skilful multi-year predictions of Atlantic hurricane frequency* (2010) // **(4)** Smith, D.M., and J.M. Murphy (2007), *J. Geophys. Res.* //

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