Issues with anomaly assimilation in DePreSys: Case study of the North Atlantic rapid warming in the mid 1990s

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Summary

- **Analysing the ability of DePreSys to forecast the rapid warming of the North Atlantic in the mid 1990s highlighted that:**

1. **Many DePreSys hindcasts warm too early**
2. **DePreSys hindcasts are undergoing significant drifts**

- **The problems seem to be caused by fundamental draw backs of the anomaly assimilation method and highlight the need for more research into the initialisation of decadal forecasts**

1. DePreSys

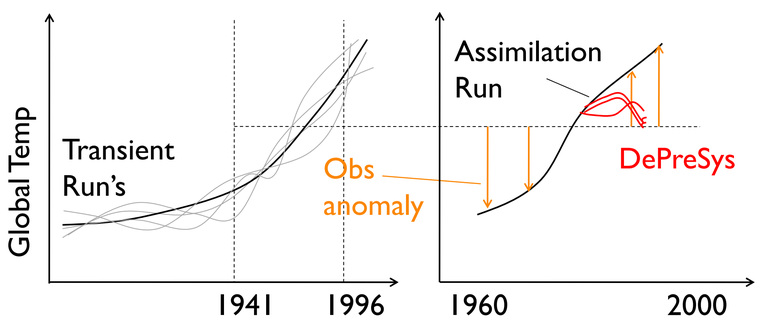


Figure 1. *Schematic of the anomaly assimilation method used to initialise DePreSys. Anomalies are assimilated onto the model climatology to avoid forecast drift. The assimilation run is relaxed (nudged) to a model climatology, calculated from transient integrations, **plus** the observed anomalies (referenced to the same period). For the ocean, anomalies of T and S are assimilated using a climatological period of 1941-1996.*

• The UK Met Office has developed a Decadal Prediction System (DePreSys) which has been shown to give improved predictions of surface air temperature relative to forecasts that do not assimilate information **(1).**

•To avoid model drift DePreSys assimilates anomalies of temperature (T) and salinity (S) onto the models climate of the ocean (see figure 1).

•The analysis of DePreSys has mainly focused upon mean skill scores, and has not been informative to what mechanisms are responsible for the improved predictions

•This analysis presents a case study approach to understanding how the DePreSys hindcasts perform and highlights fundamental problems with the anomaly assimilation method

2. Rapid warming

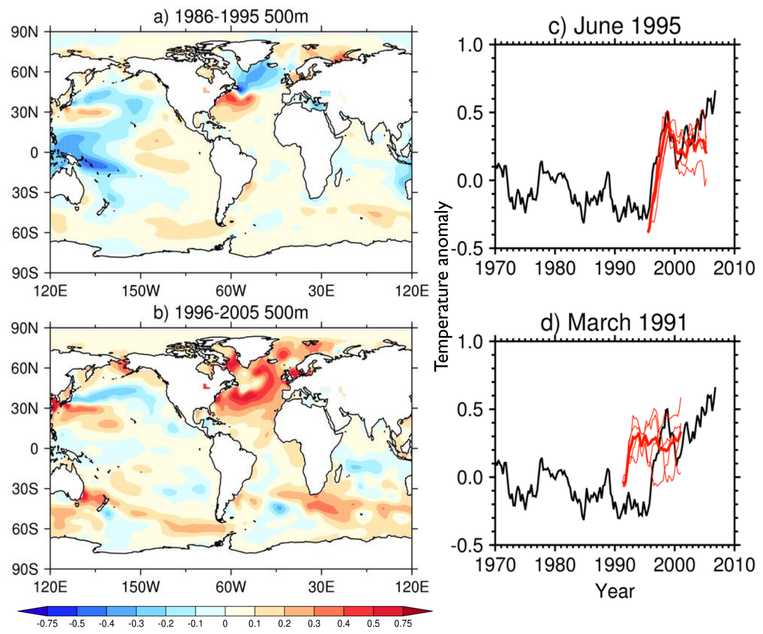


Figure 2. *a) and b) show decadal mean top 500m average temperature anomalies, relative to 1961-1990, from the Met Office Ocean analysis **(2)**. c) shows the evolution of the North Atlantic Subpolar gyre (NASPG; 50°N-66°N, 60°W-10°W) top 500m average temperature anomaly (black) and a DePreSys hindcast initialised in June 1995 (red) which shows remarkable skill in predicting the warming of the NASPG, the anomalies here are relative to a 1941-1996 climatology d) is the same as c) but shows a DePreSys hindcast that was initialised in March 1991.*

•The North Atlantic underwent a large and rapid warming in the mid 1990s (see figure 2 a and b) which was likely caused by a lagged spin up of the Atlantic Meridional Overturning circulation (AMOC) in response to the persistent positive forcing of the North Atlantic Oscillation (NAO) in the 1980/90s **(3)**

•DePreSys hindcasts initialised in 1995 capture the warming of the North Atlantic subpolar gyre (NASPG) with remarkable skill (see figure 2 c). However *not* all the DePreSys hindcasts perform so well. Many hindcasts initialised after 1990 begin to warm rapidly (see March 1991 hindcast in figure 2 d)

•The early warming hindcasts will degrade the mean skill of DePreSys in the North Atlantic. **It is therefore key to understand what caused these hindcasts to warm rapidly → two problems with the assimilation are highlighted**

References

(1) Smith DM, S Cusack, AW Colman, CK Folland, GR Harris JM Murphy (2007), *Science* //(2) Smith, DM, JM Murphy (2007), *J. Geophys. Res.* // (3) Robson, JI, RT Sutton, K Lohmann, DM Smith (2009) *submitted* //

3. Assimilated density errors

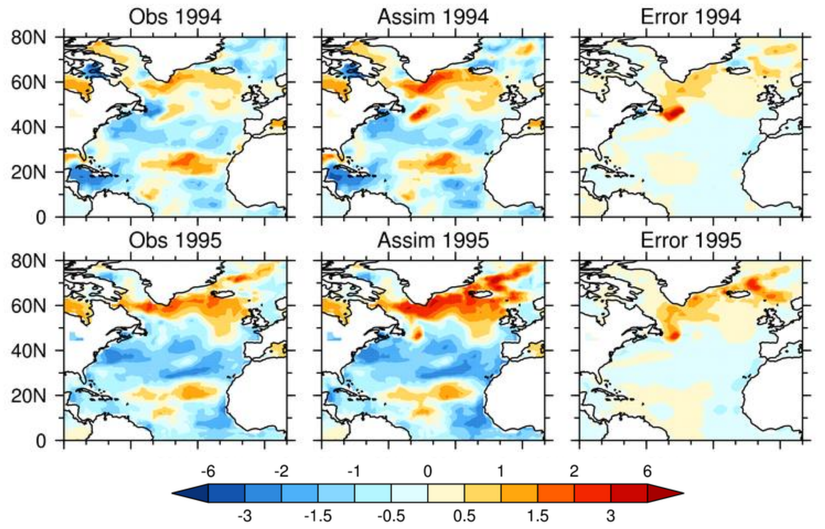


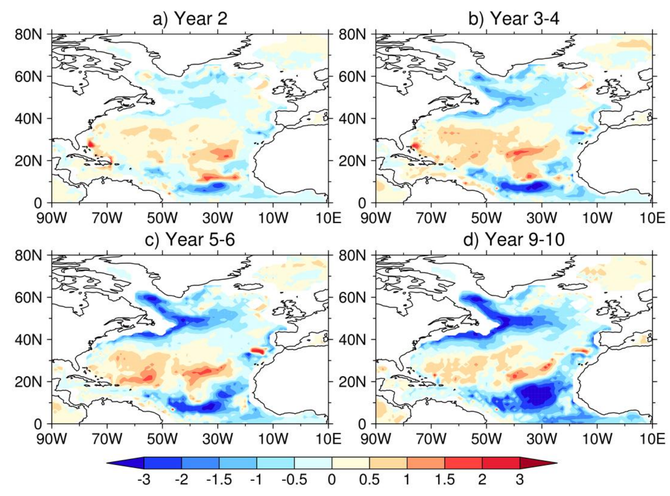
Figure 3. *shows annual mean observed and assimilated 100-1200m density anomalies calculated by placing the observed anomalies of T and S onto the observed and model climatologies separately. The error in the assimilated density anomaly is given as the assimilated density anomaly minus the observed density anomaly. All the density anomalies have been normalised by the observed interannual standard deviation.*

•The anomaly assimilation method effectively *ignores the non-linear equation of state* for the ocean by placing anomalies of T and S onto different climatologies (see figure 3).

•Does an **over estimation of the density anomalies** in the NASPG cause a **spin up of the AMOC** that is too early, or too large, which leads to the rapidly warming DePreSys hindcasts in the early 1990s? → **We test this by perturbing the salinity to ensure the assimilated and observed density anomalies are the same.**

4. DePreSys forecast drift

Figure 4. *Shows the mean evolution of 1200-3000m average density anomalies averaged over DePreSys hindcasts initialised from 1994-2001 (a total of 128 individual hindcasts). The density anomalies have been normalised by the interannual standard deviation of density from the HadCM3 control run. The evolution of the low density signal is consistent with a reduction in the AMOC.*



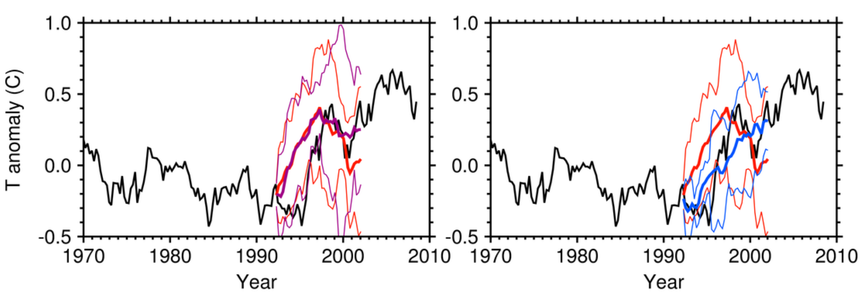
•A rapid reduction of the AMOC strength at 50°N, greater than 2 Sverdrups is seen in almost all DePreSys hindcasts (not shown) as well as deep density drifts in the North Atlantic (see figure 4) which are consistent with a reduction in the AMOC.

•Investigation into the drifts showed that the climatology used for the anomaly assimilation was constructed from a transient run that is undergoing large drifts and is not a stable state from which to initialise hindcasts.

•What is the effect of the drift on the hindcasts? → change the climatology used in the assimilation run to a well spun up state

5. Results and conclusions

Figure 5. *shows the evolution of the observed NASPG 500m average temperature anomaly (black). The evolution of the unperturbed, perturbed density and new climatology DePreSys hindcasts initialised in Dec 1991 are shown in red, purple and blue respectively. Thick and thin lines shows the ensemble mean and ensemble spread respectively*



•Perturbing the initial density **did not stop** the Dec 1991 hindcast warming rapidly (see figure 5 left), but did have a significant effect upon the AMOC strength and SST forecast (not shown) . **Research is needed to minimise the effects of non-linear assimilated density errors in the future.**

•Changing the climatology did reduce the rate of NASPG warming (see figure 5 right), showing that anomaly assimilation is sensitive to the climatology used, However, it *did not* remove the density drift seen in figure 4 completly.

•Further research is currently ongoing which suggests the large drifts may be due to the **relaxation** of the assimilation run to **mean T and S climatologies**, ***not* the mean density climatology,** a fundamental drawback of the anomaly assimilation method, ie. $\rho(\overline{T},\overline{S}) \neq \overline{\rho(T,S)}$