Initialized climate predictions of the mid 1990s rapid warming of the North Atlantic subpolar gyre

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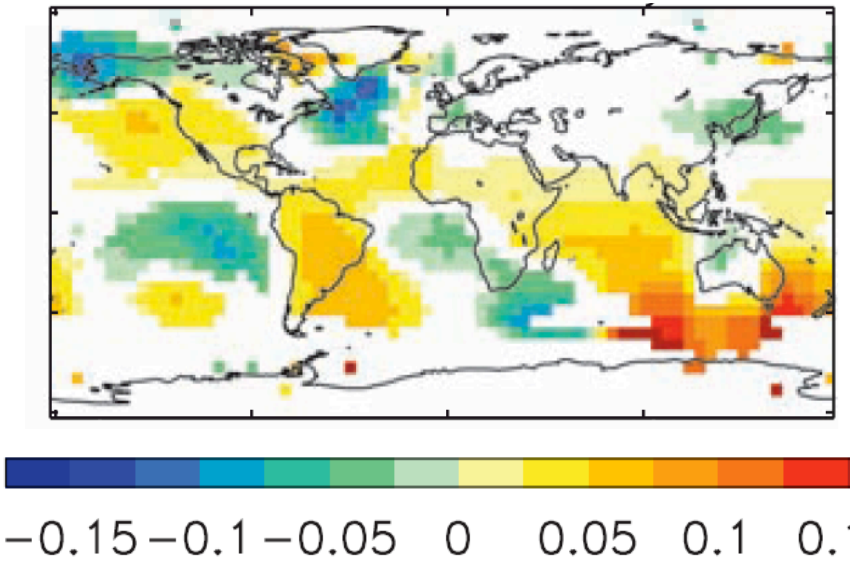
Introduction and motivation

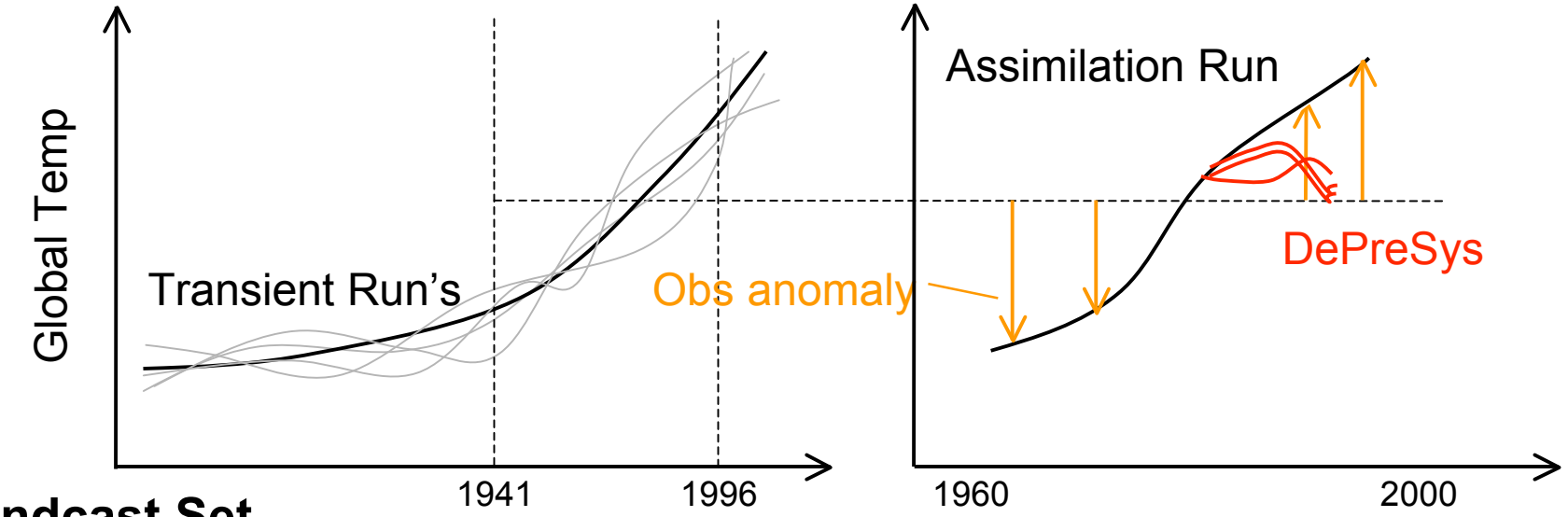
- Smith et al, 2007. showed that assimilating in the observed state improved forecasts of global mean surface temperature for the next decade relative to forecasts that do not assimilate information.
- However, they do not improve everywhere. Initialised predictions perform worse in the North Atlantic – an area where you might expect the biggest improvement due to the presence of the AMOC – **why?**
- Does this show that the North Atlantic is un-predictable, or are the predictions not living up to their potential?

RMSE of 9 year mean Surface tempera
Uninitialised – Initialised



DePreSys

- Fully coupled decadal forecast system, based on HadCM3
  - Atmosphere = 2.5° x 3.75°, 19 levels, Ocean = 1.25° x 1.25°, 20 levels
- Initialised from the observed climate but also forced by anthropogenic emissio (SRES B2 scenario), previous 11 year solar cycle and volcanic aerosol (which decayed in the forecast).
- **Assimilates observed anomalies onto the model climate to avoid drift**
- **Ocean relaxed to anomalies of T and S using a strong relaxation (6 hours**



Hindcast Set

- 4 member ensemble DePreSys hindcasts initialised seasonally (March, June, and December) over the years 1982-2001

What actually happened over the hindcast period (eg 1982 - 2001)

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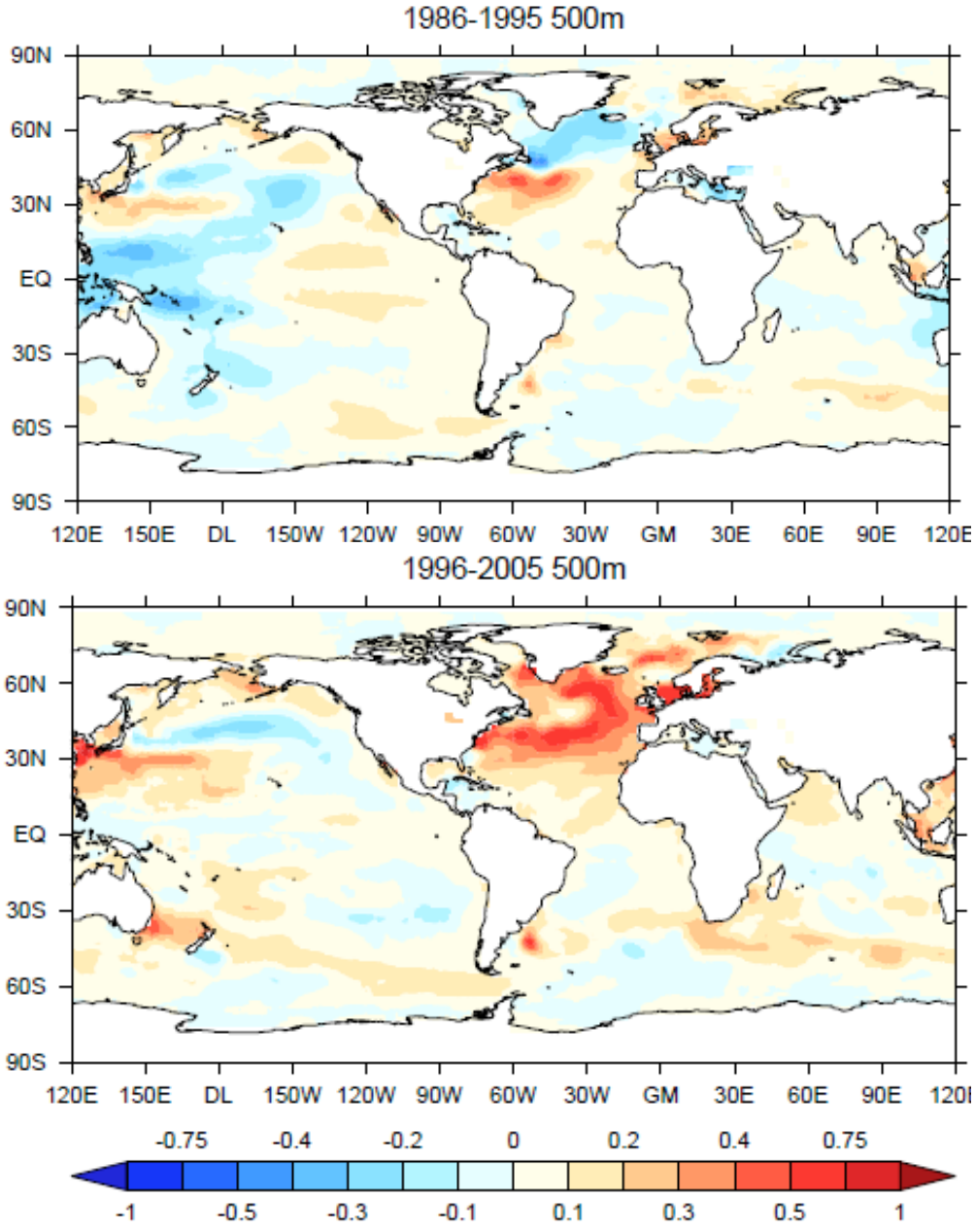
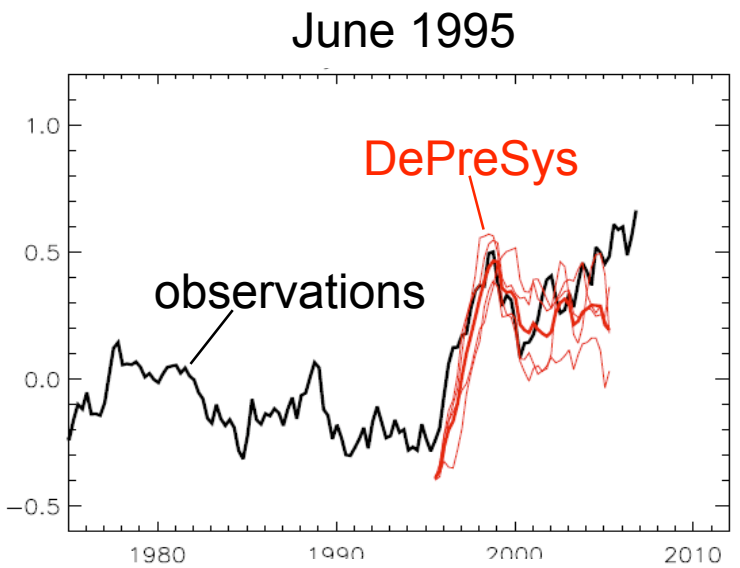
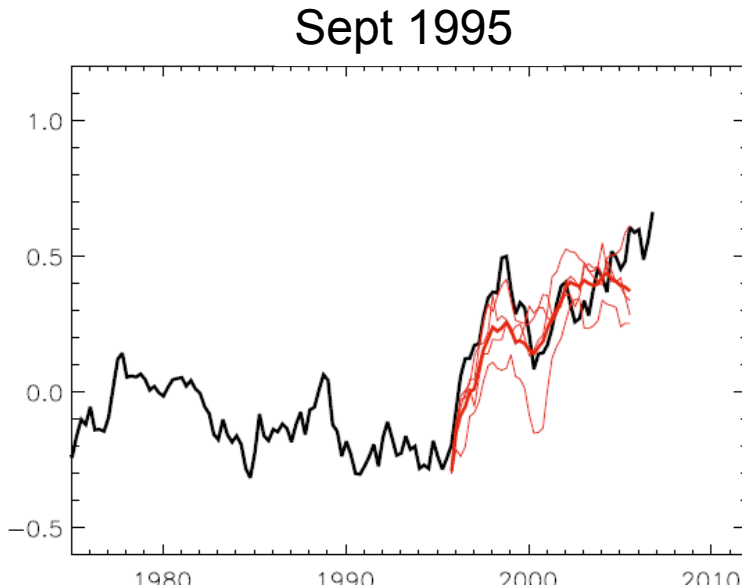


anomalies relative to 1941-1996 climatology

Subpolar gyre 500m heat content

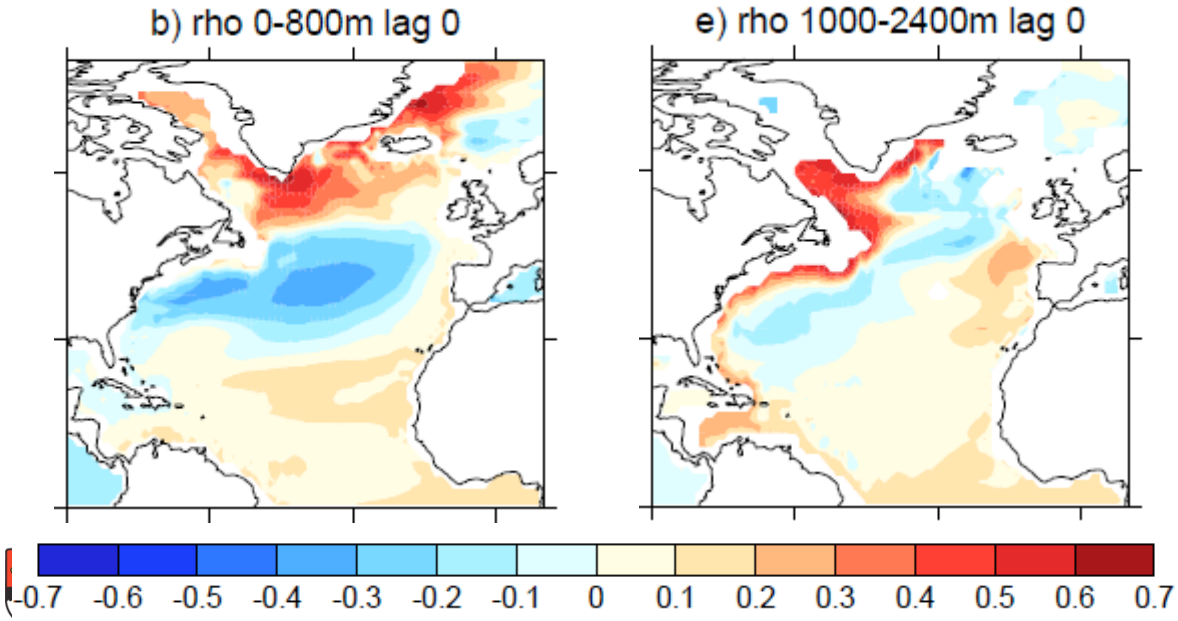


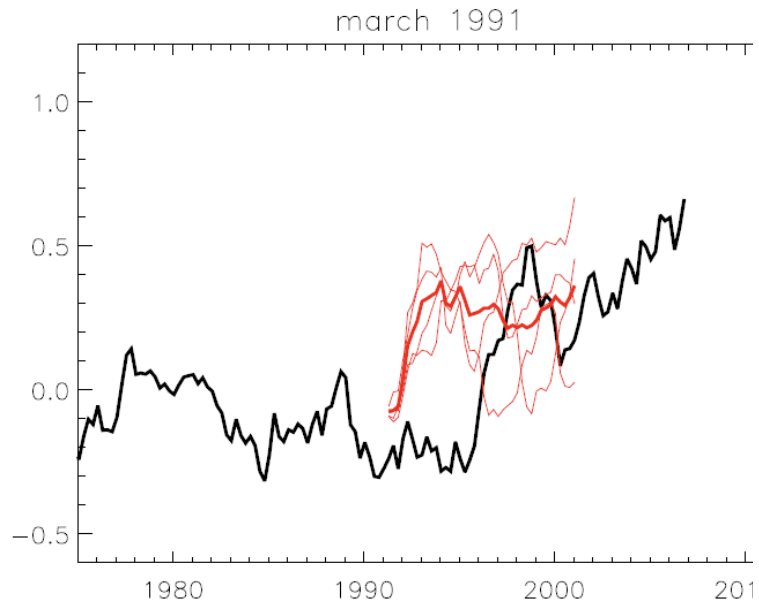


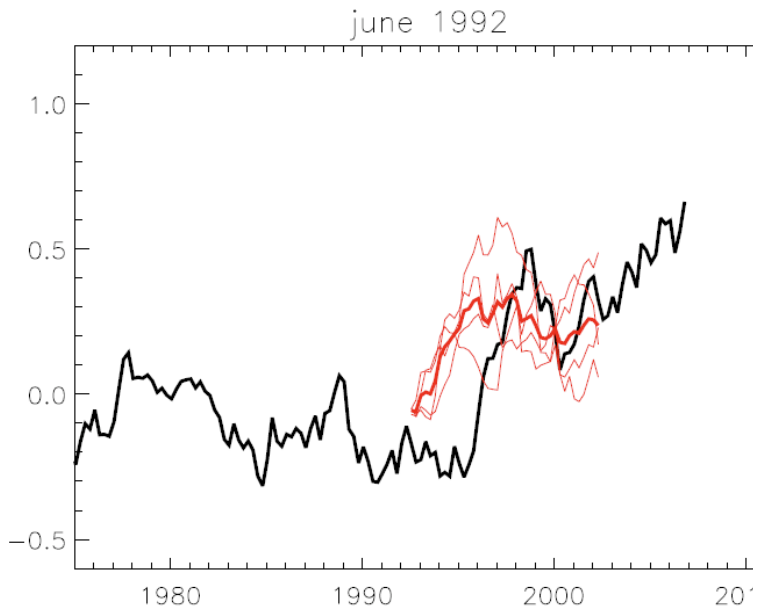
However it doesn't get it right all the time….

- After 1990 DePreSys hindcasts become very eager to warm rapidly in the subpolar gyre region.
- Are these early warmers caused by changes in the Atlantic Meridional Overturning Circualtion (AMOC)?
- Look at the initialised density anomalies

Correlation density anomalies with the AMOC index at 50N from the HadCM3 control run



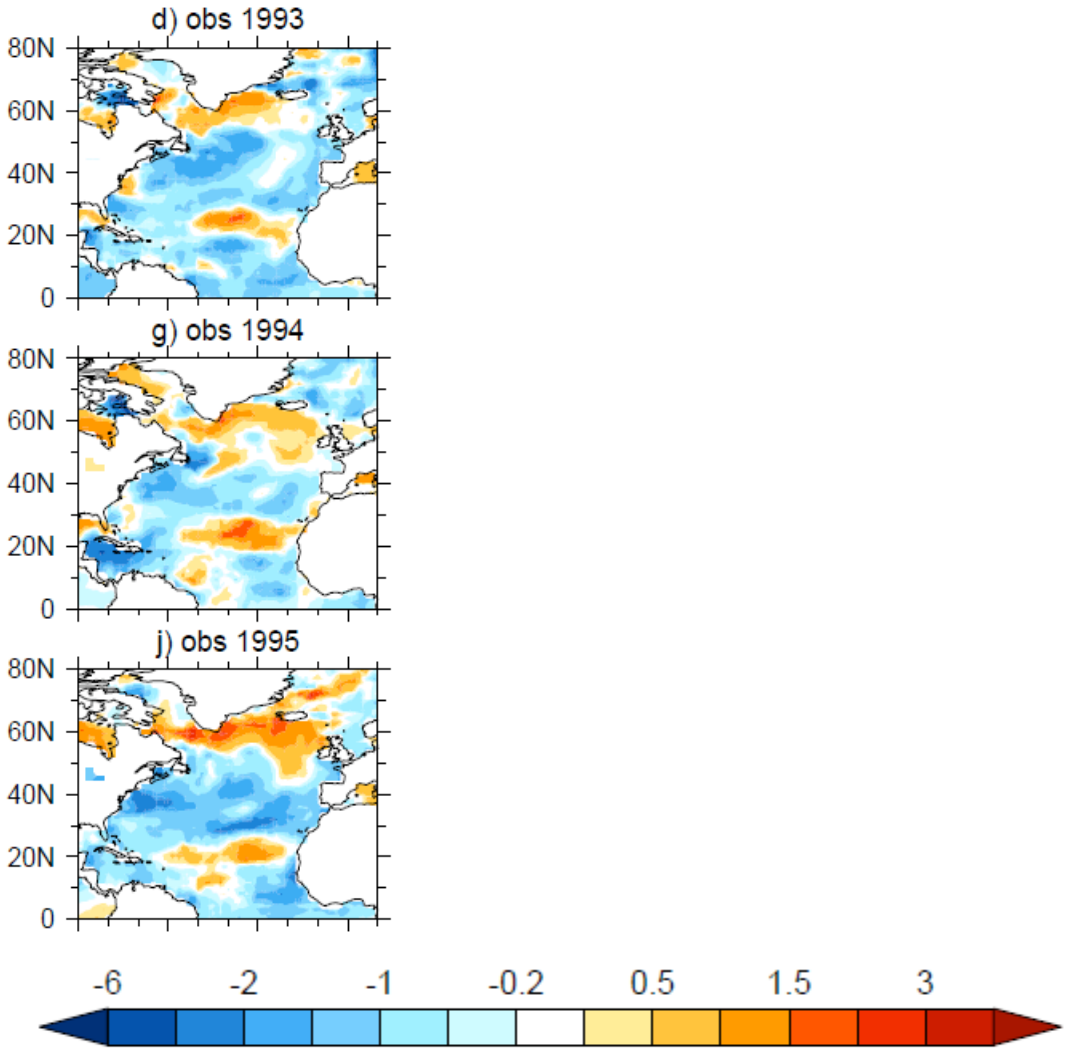




Density anomalies

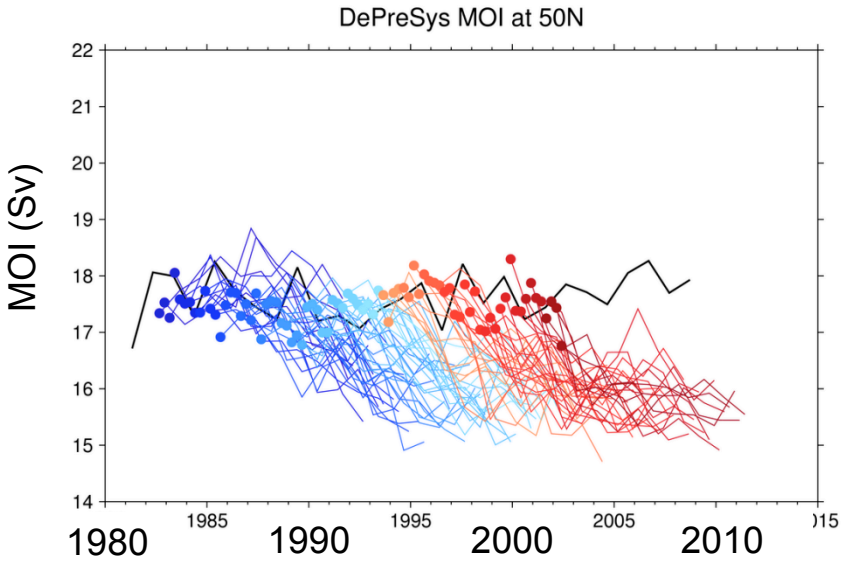
$$\rho' = \rho(\overline{T} + T', \overline{S} + S', P) - \overline{\rho} \longrightarrow \rho'_{\mathrm{mod}} - \rho'_{obs} \neq 0$$

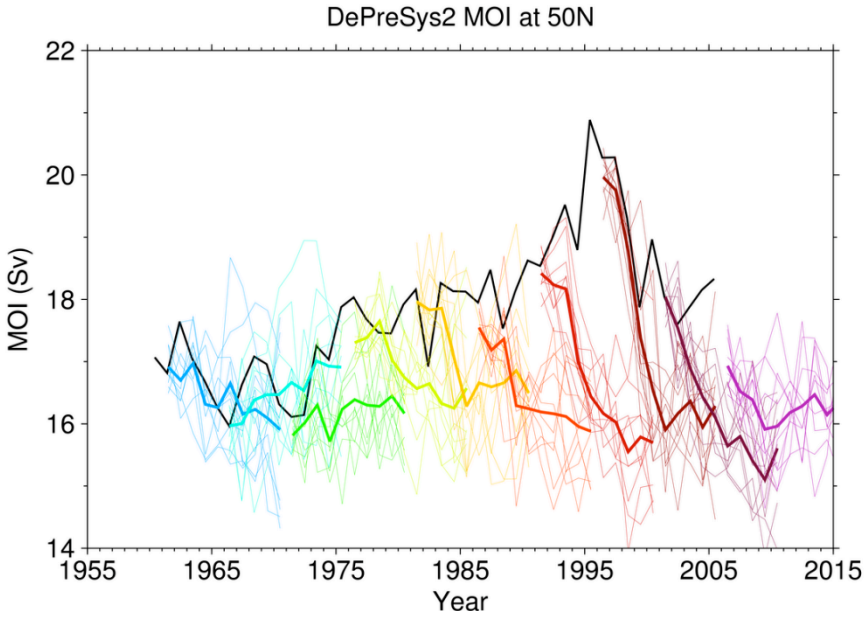
150-1000m density anomalies normalised by observed interannual standard deviation



- ***Hypothesis A***:- *The early warming hindcasts are caused by the presence o errors in the assimilated density anomalies, which arise due to the* ***non-linea*** *equation of state, and cau an increase in the AMOC is too early or too large*

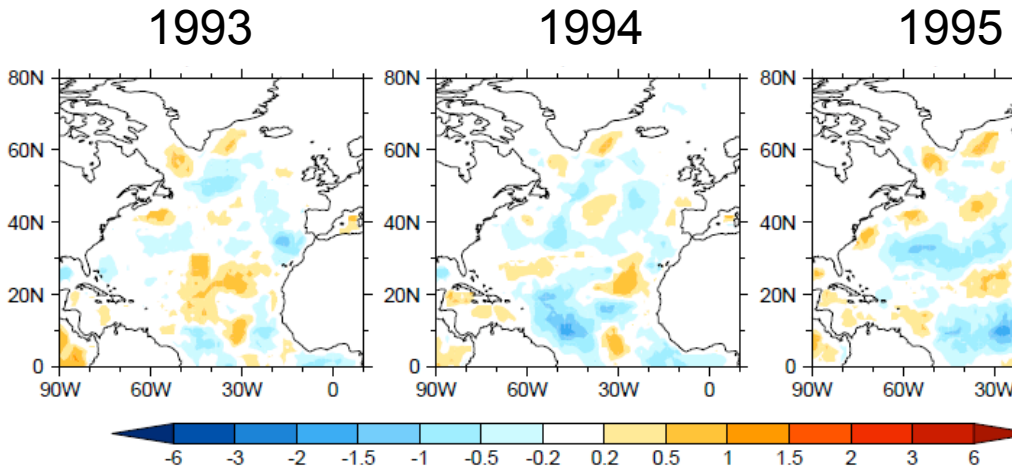
AMOC in DePreSys





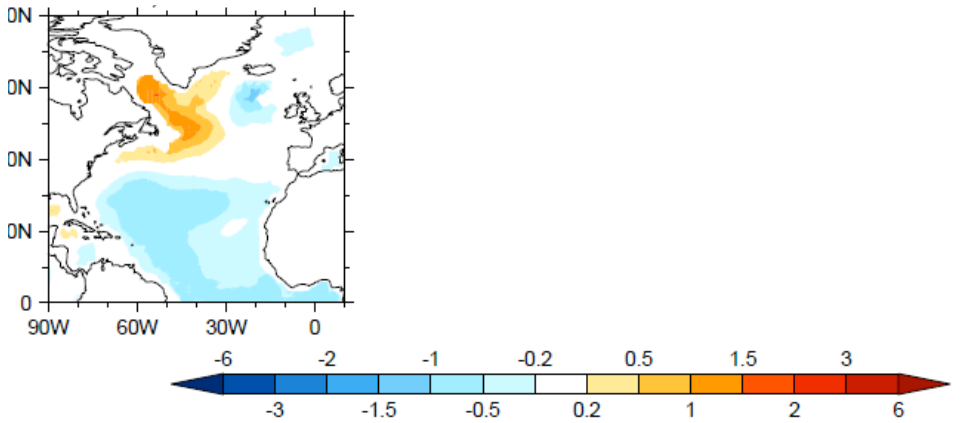
800-3000m average density anomalies normalized by model density variability

Original Met Office Analysis



Updated Met Office Analysis

1995 obs



Drifts present in DePreSys

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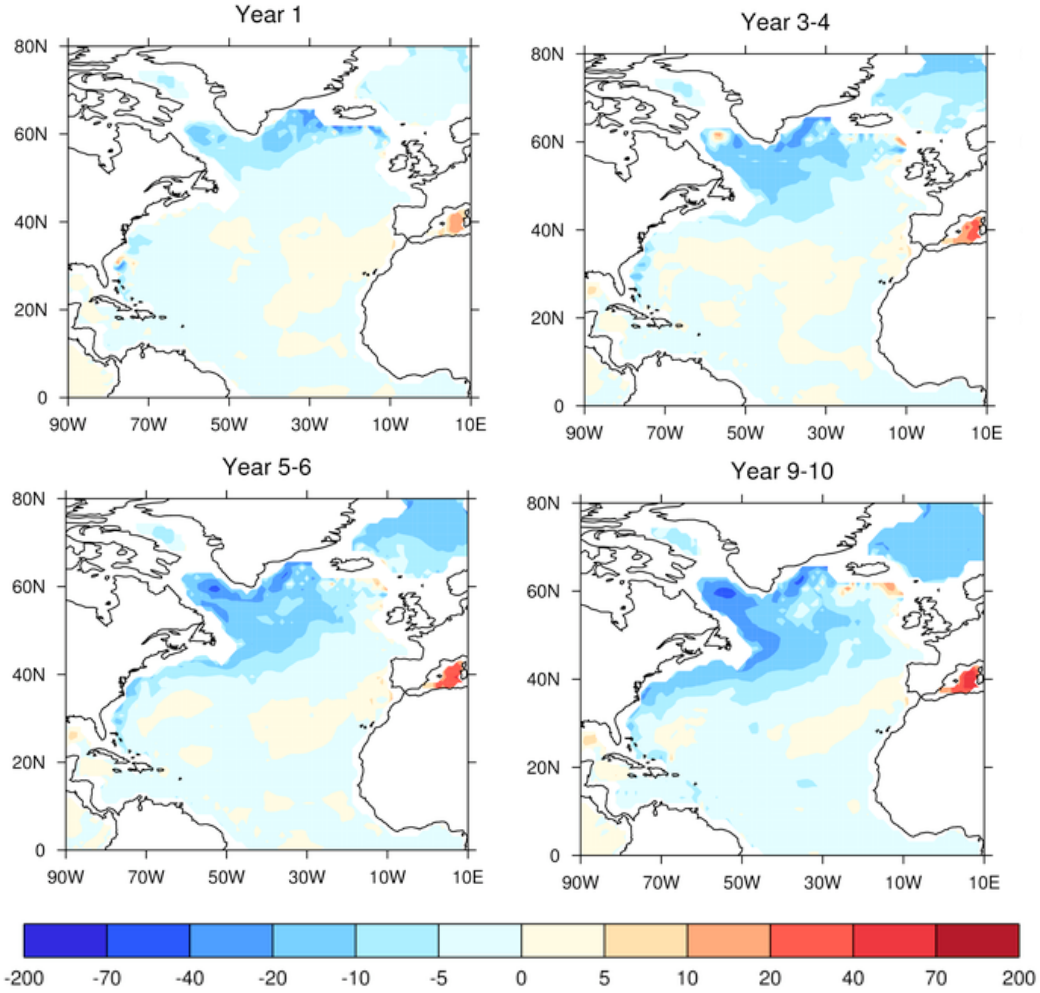
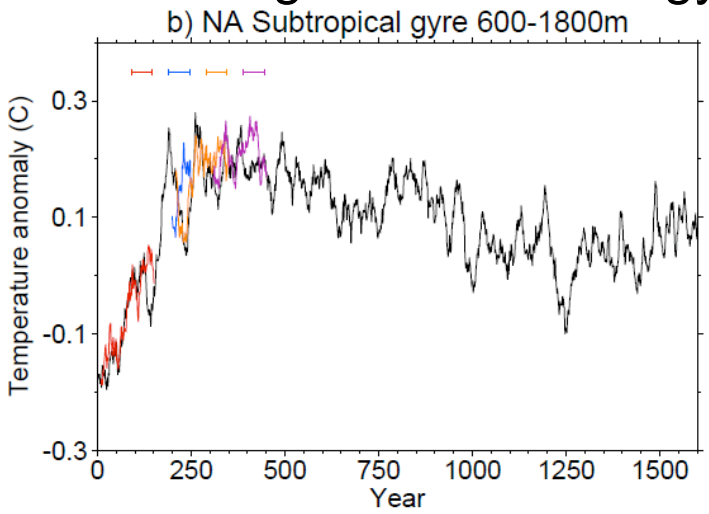
800-3000m mean hindcast density anomalies

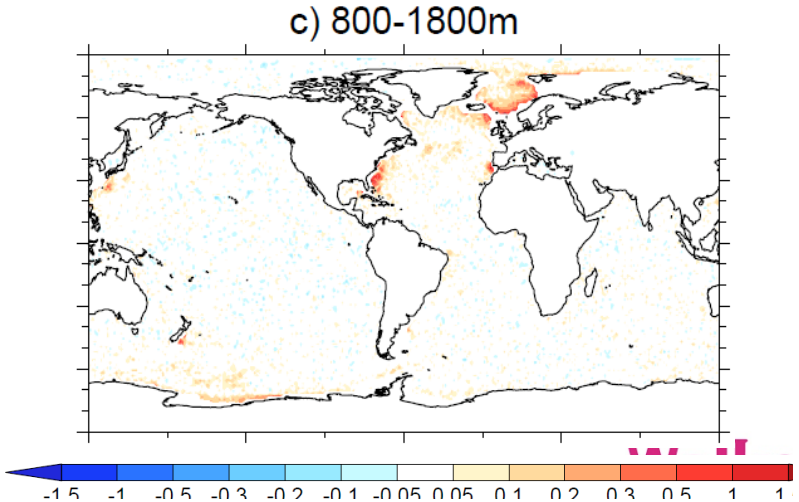


What is the cause of the imbalanc

Drift in the background climatology?



Non-linear eqn of state $\rho(\overline{T}, \overline{S})$



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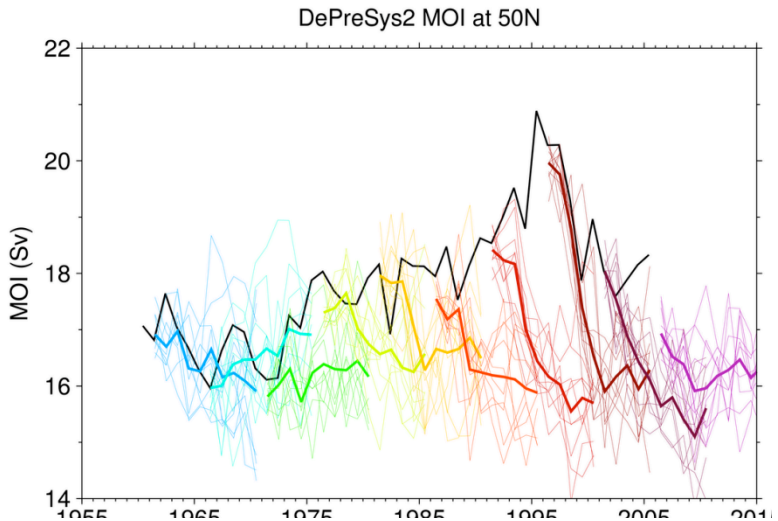
Testing the hypotheses

A. The early warming hindcasts are caused by the presence of errors in the assimilated density anomalies that arise due to the non-linear equation of state, and cause an increase in the AMOC that is too early or too large

- Perturb the assimilated density so that the density anomalies are the same as observed, by perturbing salinity anomalies

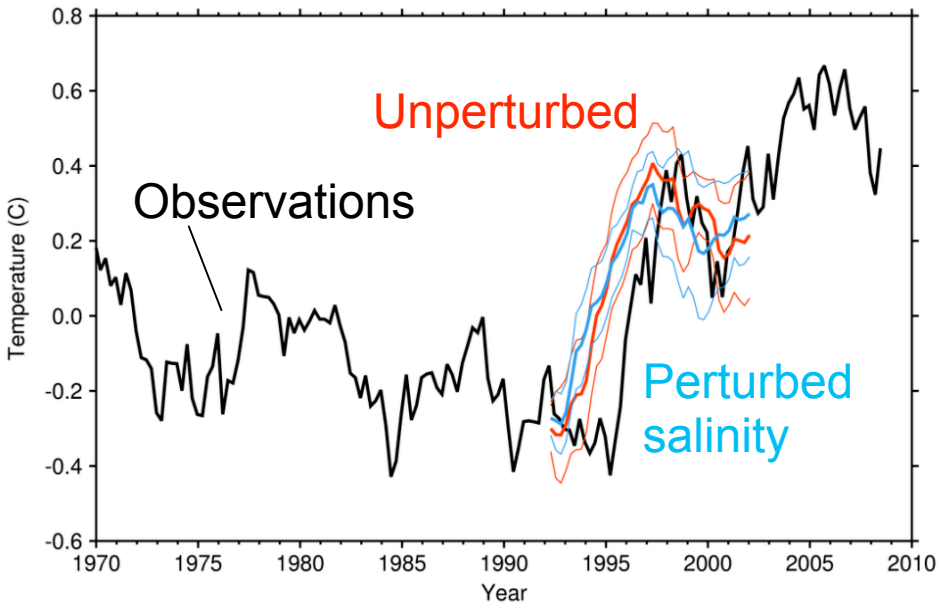
B. Imbalances in the climatology due to climate drift leads to adjustment that corrupt the hindcasts in the North Atlantic

- Use a different "well spun up" climatology to test the sensitivity of hindcasts to the climatology
- Re-run the December 1991 hindcast



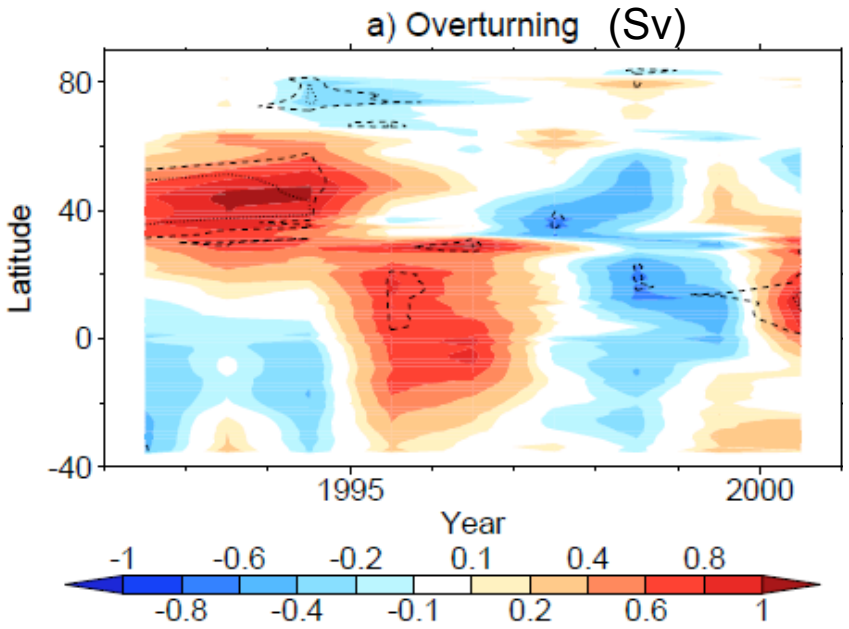
A) The effect of density errors

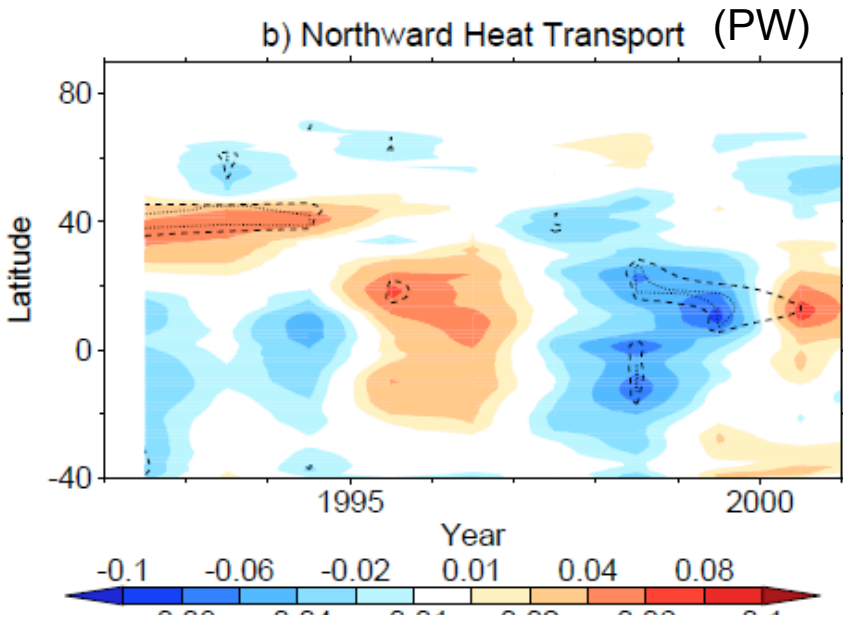
Subpolar gyre 0-500m Temp



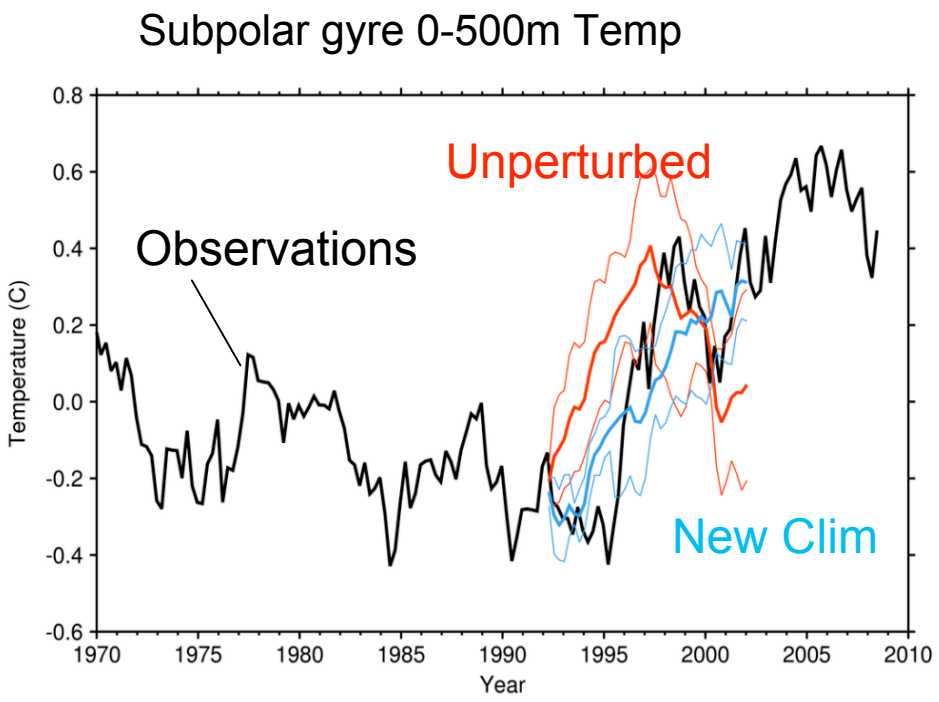
- The AMOC is sensitive to the assimilated density errors
- Evolution of heat content anomalies are sensitive to the density anomalies, especially in the Atlantic (not shown)

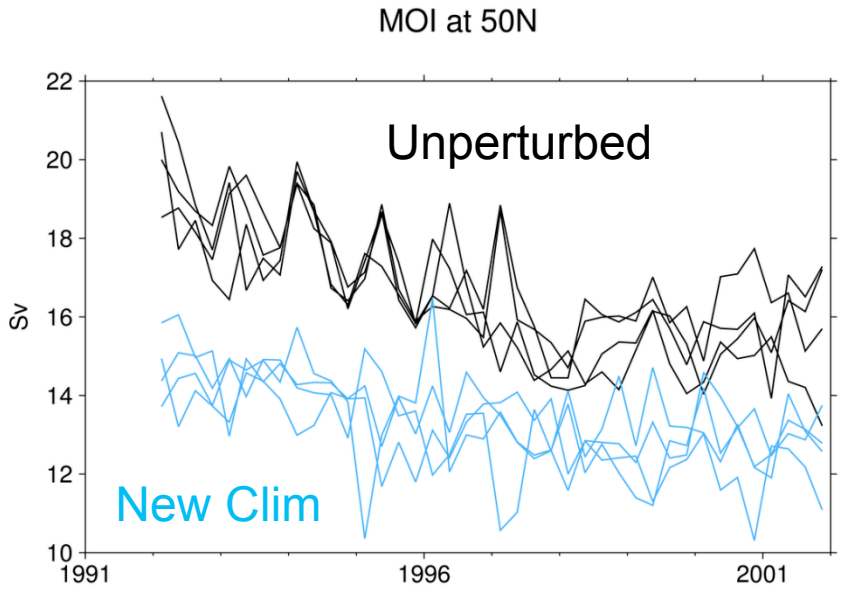
Control – Perturbed Salinity



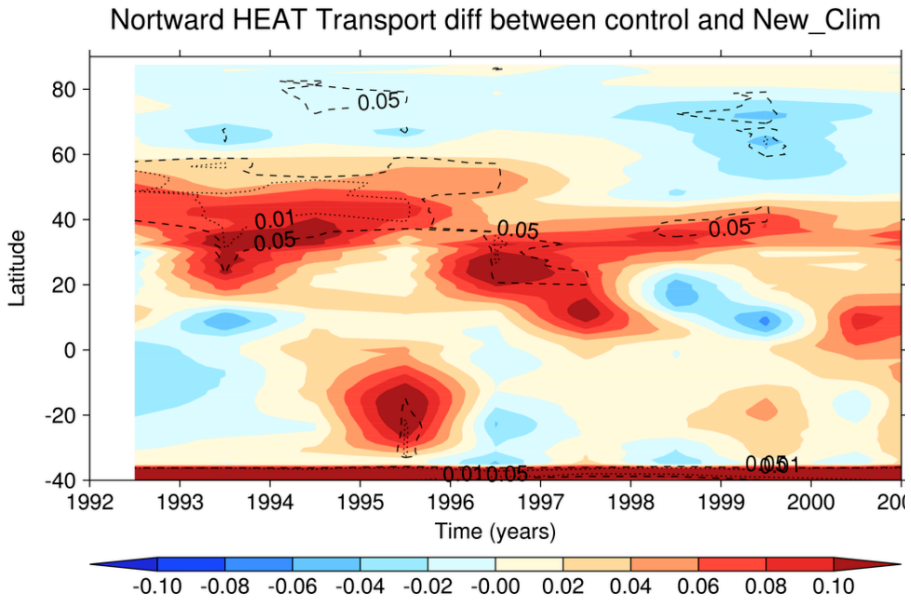


B) The effect of a new climatology





- The AMOC and heat content predictions are sensitive to the climatology used in the assimilation
- The drift in the North Atlantic seems to be reduced, but more testing is needed to understand the causes of the imbalance



Conclusions and implications

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- Looking beyond mean skill scores is an important route for understanding improving decadal prediction systems
- Issues for anomaly assimilation
  - Strong relaxation to obs at all depths removes the models memory
  - Hindcasts can be very sensitive to the choice of climatology used in the assimilation
  - The non-linear equation of state means that some imbalance may be inevitable when climatologies are derived from time mean temperature and salinity

$$\rho(\overline{T},\overline{S}) \neq \overline{\rho}$$

  - Non-linearities also lead to errors in the assimilated density anomalies that can have a significant effect upon the hindcasts
- Therefore, much potential to improve decadal predictions in th Atlantic - More work needed on balanced initialisation for decadal climate prediction
- More work needed on understanding why the model is able to capture the warming of the subpolar gyre in the mid 1990s

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Thank you

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Walke