The value of case studies for evaluating initialised decadal climate predictions

Rowan Sutton, Jon Robson

National Centre for Atmospheric Science (Climate division)

Department of Meteorology, University of Reading

Doug Smith

Met Office Hadley Centre

The value of case studies for evaluating initialised decadal climate prediction

- Average skill scores of limited use for decadal prediction:
  - Short observational record (=> large sampling uncertainty)
  - Non-stationary observing system
  - Non-stationary climate
  - State dependent predictability
- Case studies offer an alternative, complementary, approach to evaluating and improving the performance of a decadal prediction system

The value of case studies in initialised decadal climate prediction

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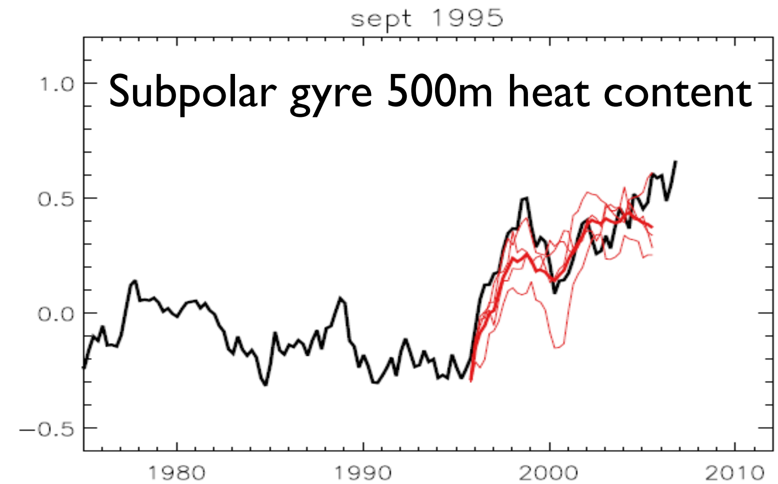
- Of particular interest is the capability to predict the unexpected, e.g.:
  - '76 climate "shift"
  - Mid 90s warming of the N. Atlantic



- Opportunity to take a detailed process-focused approach:
  - Why did the event happen?
  - To what extent was it predictable, and through what mechanisms?
  - To what extent does the prediction system capture these mechanisms (and if not why not)?

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Causes of the rapid warming of the North Atlantic in the mid 1990s

Jon Robson

(j.i.robson@reading.ac.uk)

Rowan Sutton, **Katja Lohmann**, Doug Smith and Matt Palmer

University of Reading

Warming of the N. Atlantic in the 1990s

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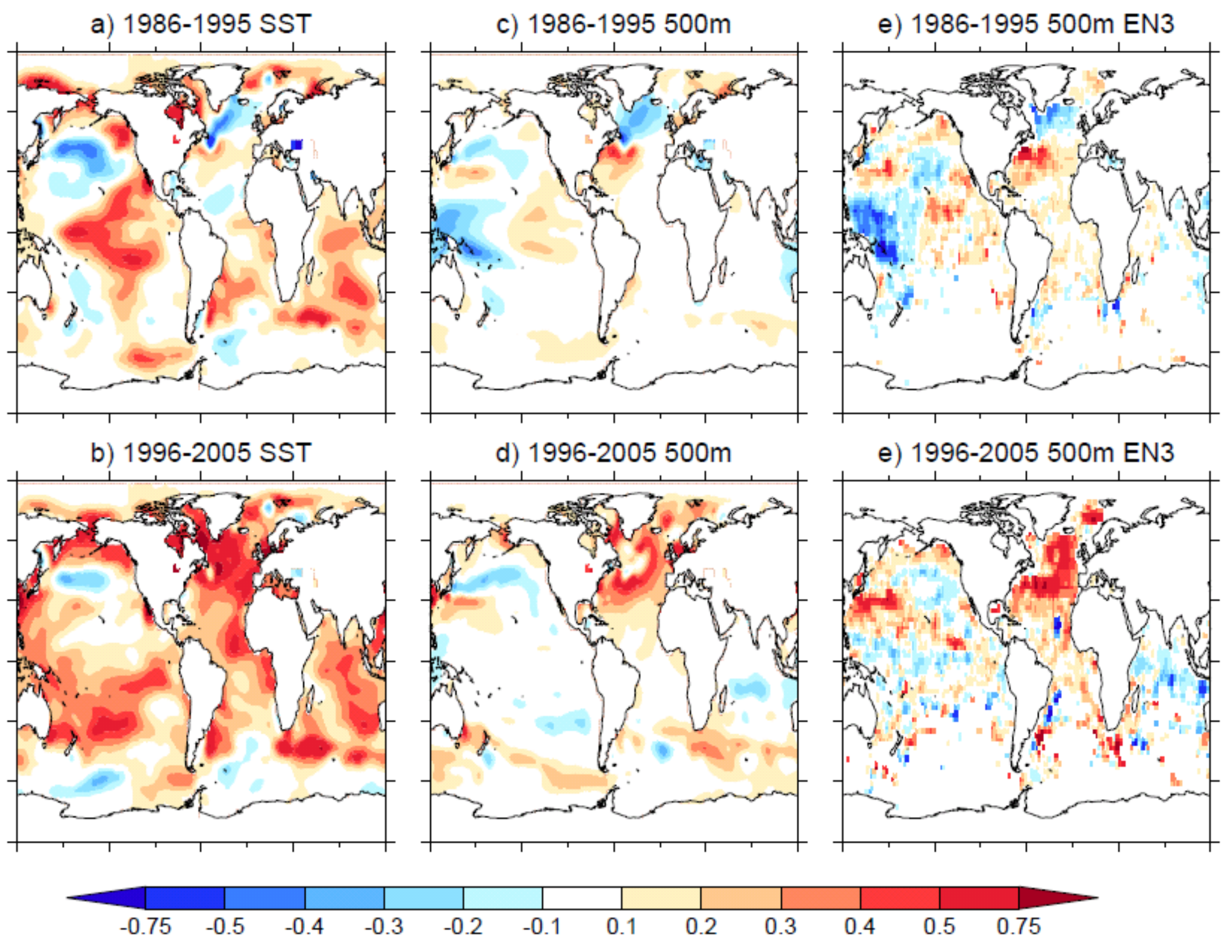
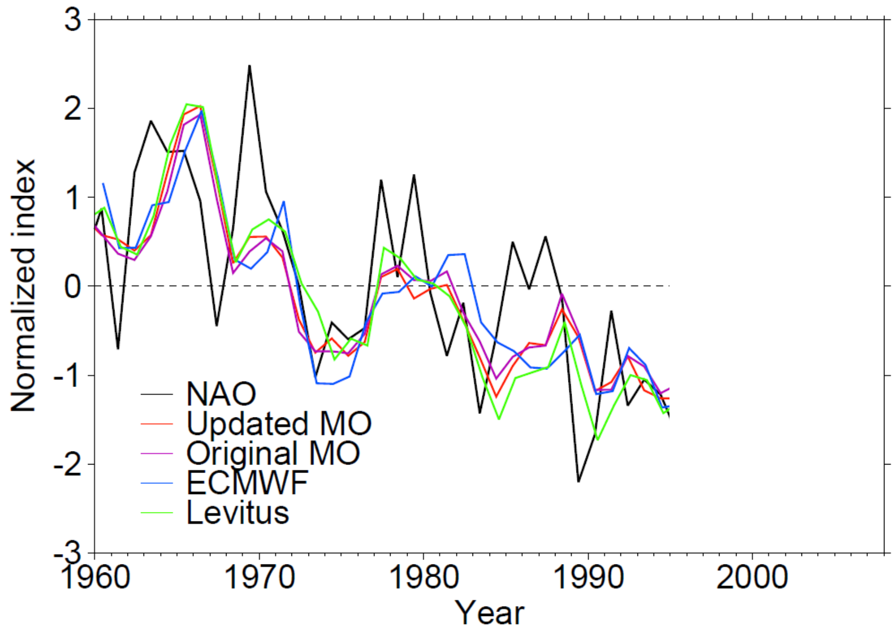
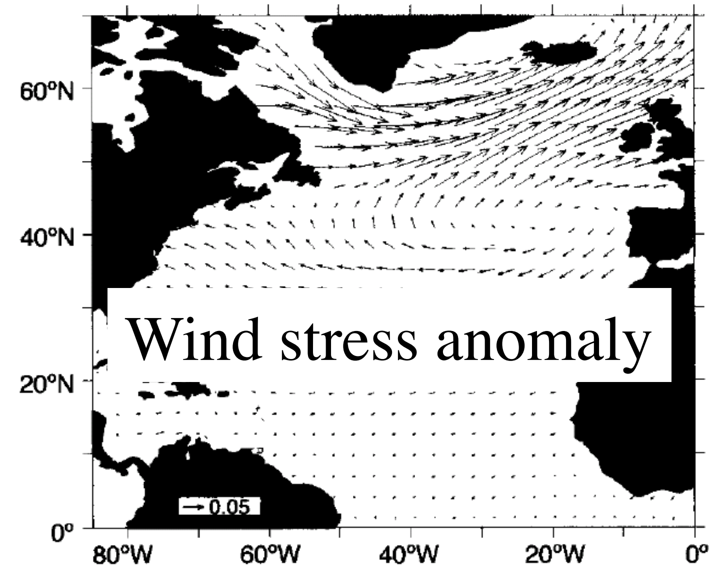
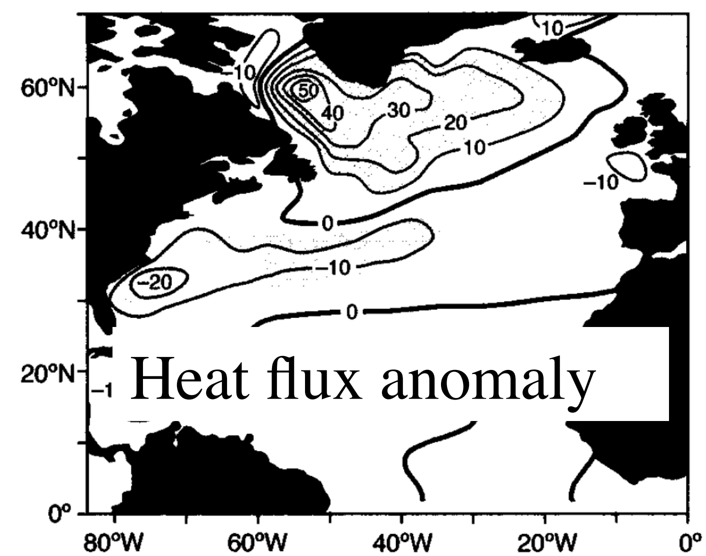


- Impacts on Greenland glaciers, CO_2 uptake, fisheries etc

Role of the North Atlantic Oscillation





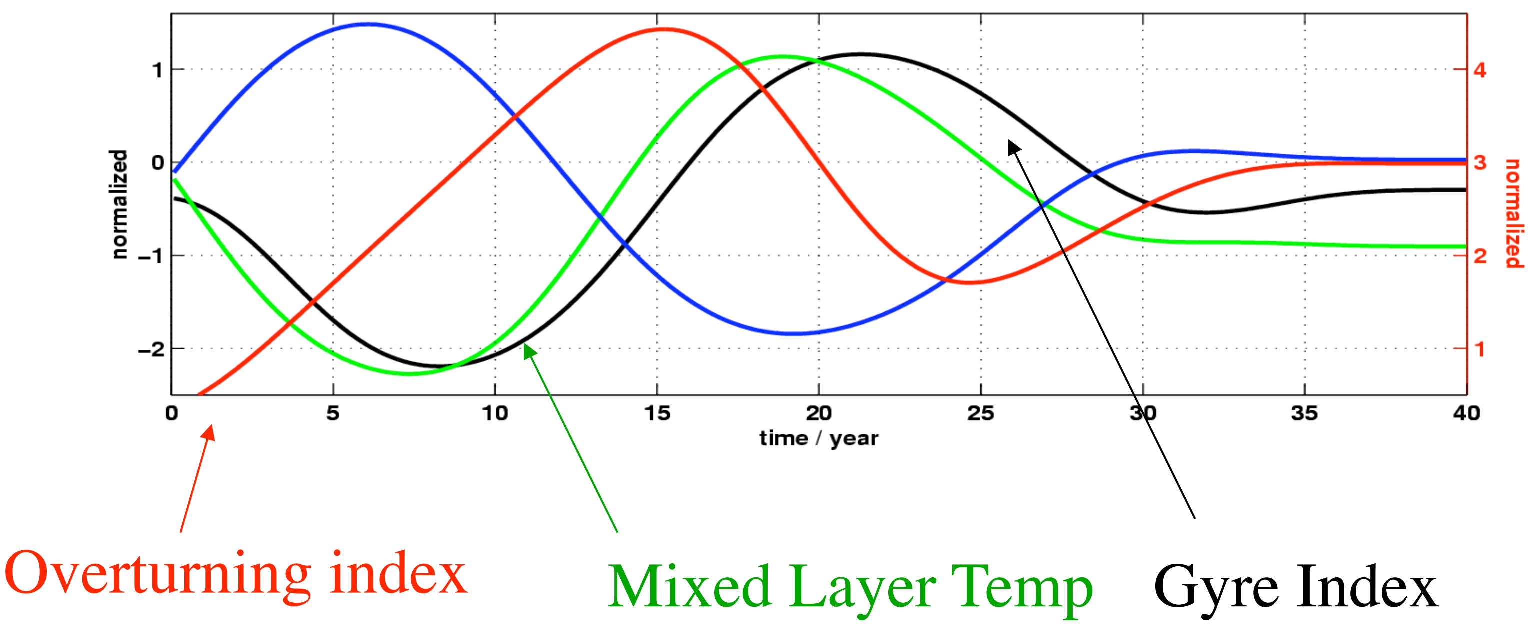


BLACK: *Inverted* NAO

Temp anomaly of Subtropical gyre (60W-10W,50N-66N) from Levitus, ECMWF and Met Office

Dynamical response to NAO

- Lagged responses to NAO variability:
  - Gyre circulation
  - AMOC (e.g. Eden and Wilibrand, 2001)
- Associated changes in heat transport influence energy budget of subpolar gyre.
- Lohmann et al, 2009:



Hypotheses for the warming

A. Direct response to the decline in the NAO (esp 95/96):

- Thermodynamic response to surface buoyancy fluxes
- Dynamic response?

B. Dynamic response to the persistent high NAO conditions that preceded the warming

B best for predictability

Experimental design

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- MICOM 2.4° resolution, ~150km in the Atlantic

Experiments:

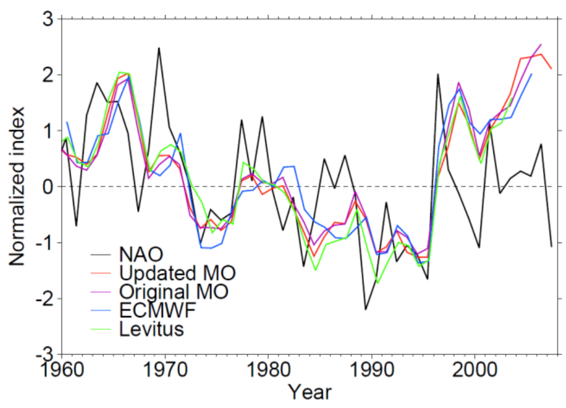
- Ocean forced with daily fluxes from NCEP reanalysis (CONTROL) from 1948-2006
- Two extra experiments started in 1980 from CONTROL:
  - CLIM WIND – climatological wind stress - buoyancy fluxes vary
  - CLIM BUOY – climatological buoyancy fluxes – wind stress varies

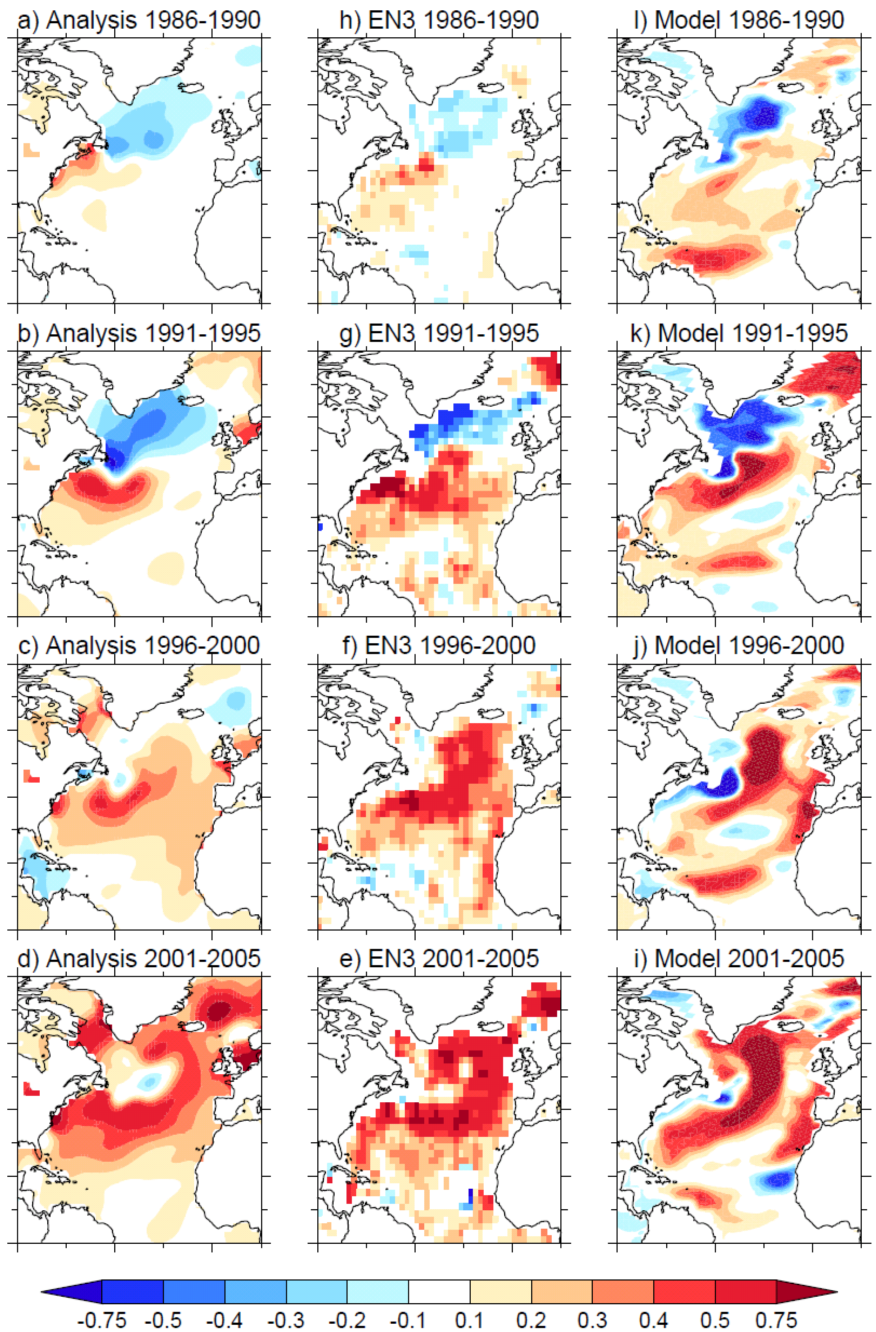
Ocean analysis:

- Comparison with Met Office ocean analysis, and raw EN3

Evolution of heat content anomalies in the Control

- Captures major characteristics of rapid warming
- **All anomalies are relative to the 1961-1990 climatology**





Sub surface temperature evolution

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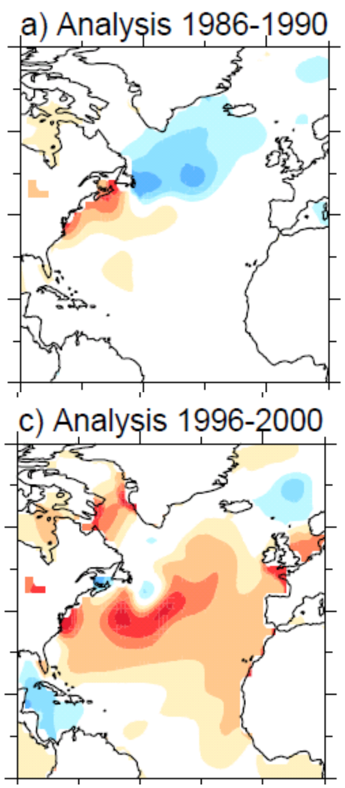
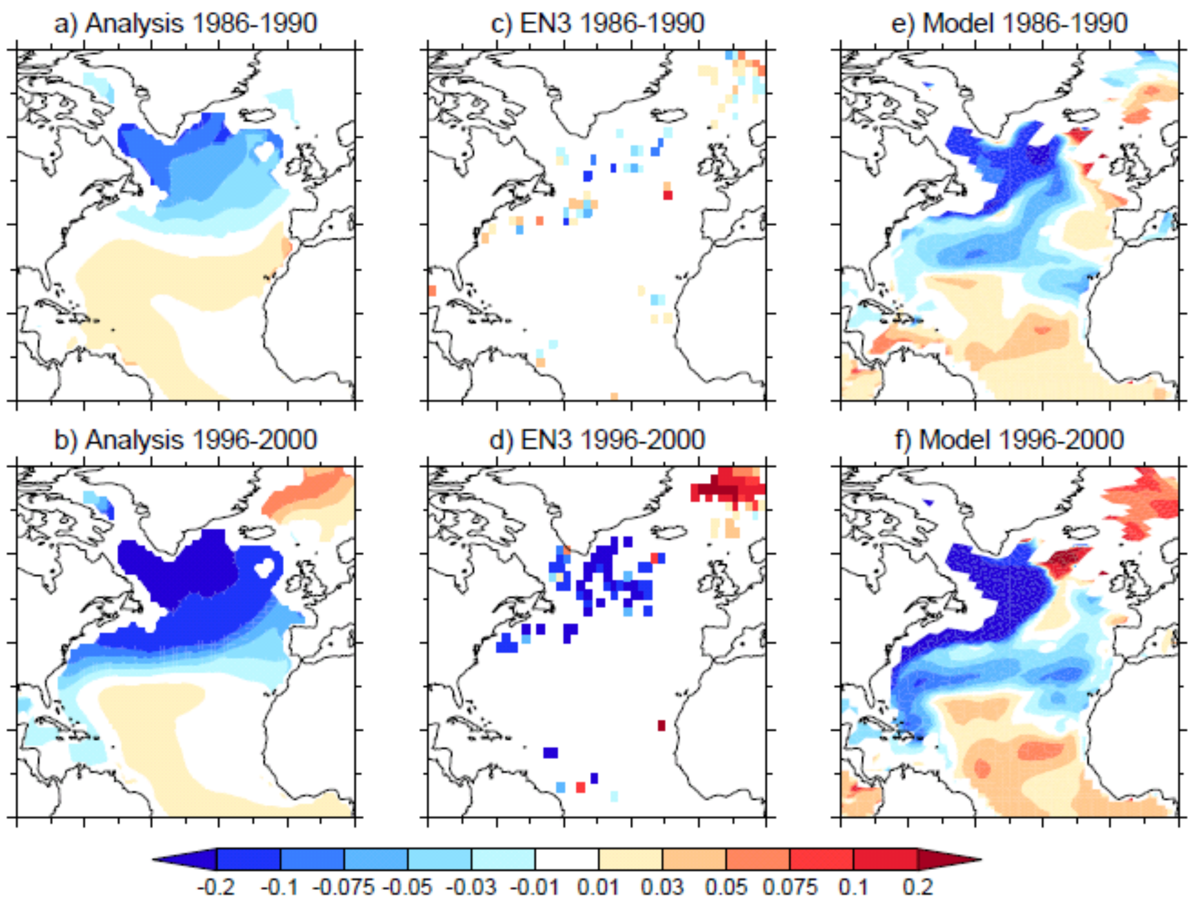


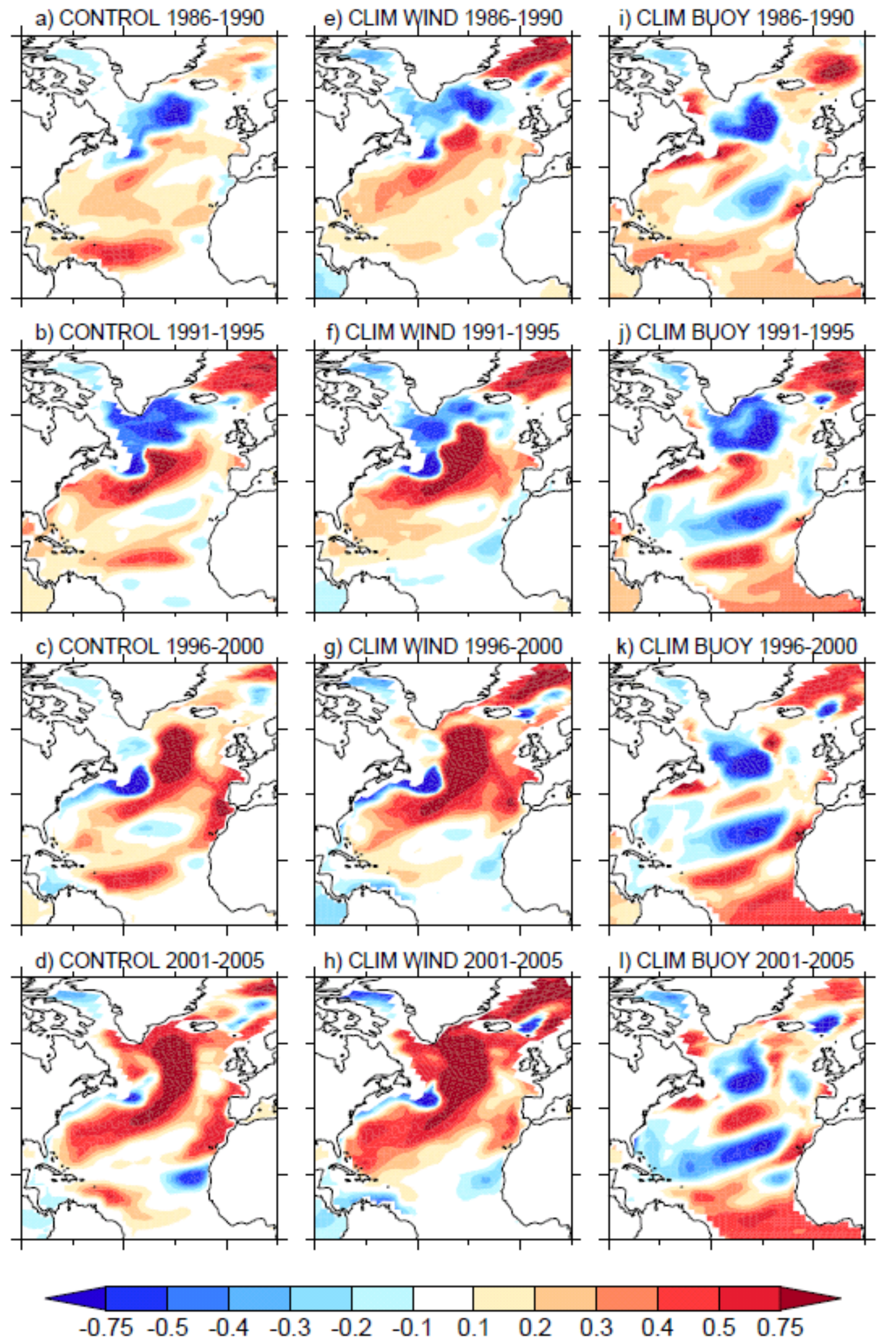


0-500m anomalies

1000-2500m anomalies

Response to buoyancy flux or wind stress forcings

- 0-500m temperature anomalies



Subpolar gyre evolution

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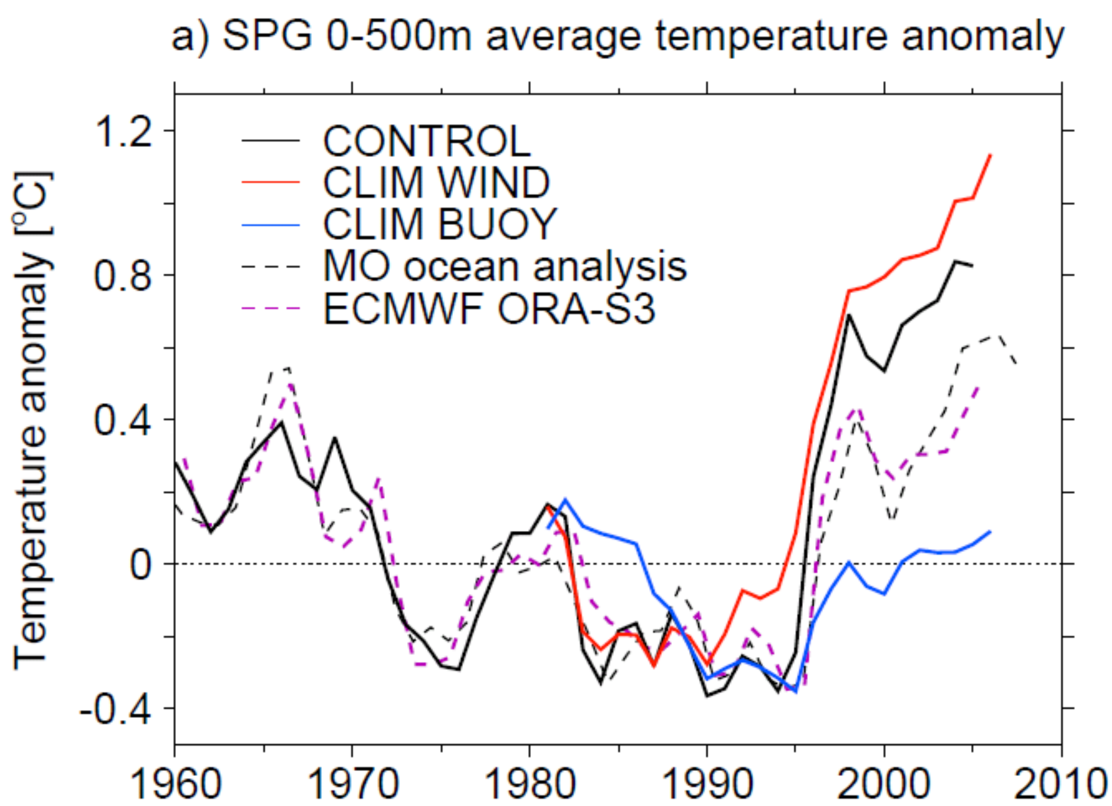
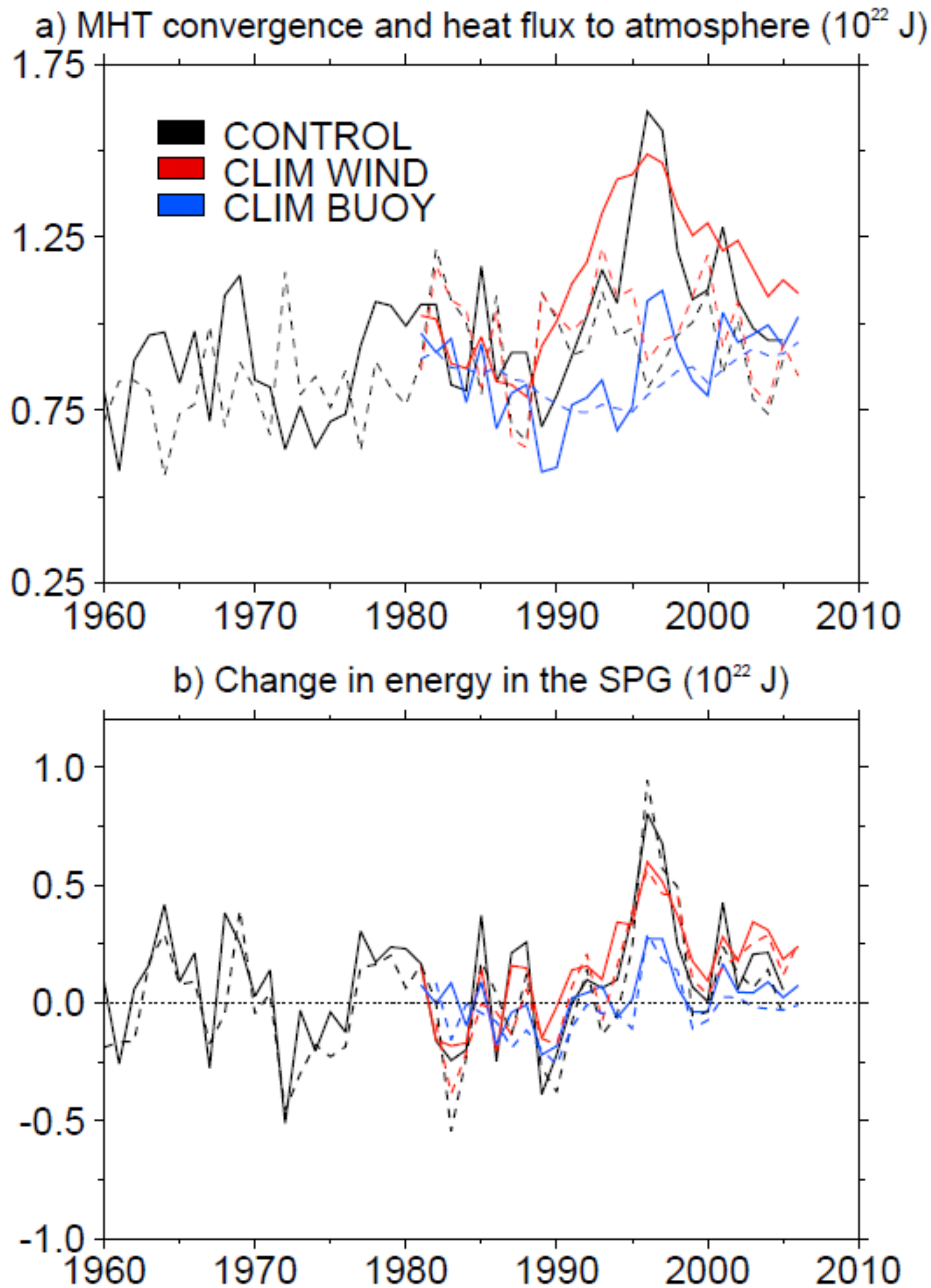


What is the relative importance of local surface heat fluxes versus changes in ocean heat transport?

Energy budget of the subpolar gyre

- Solid = ocean heat transport convergence (H_O)
- Dashed = energy lost to atmosphere (H_A)

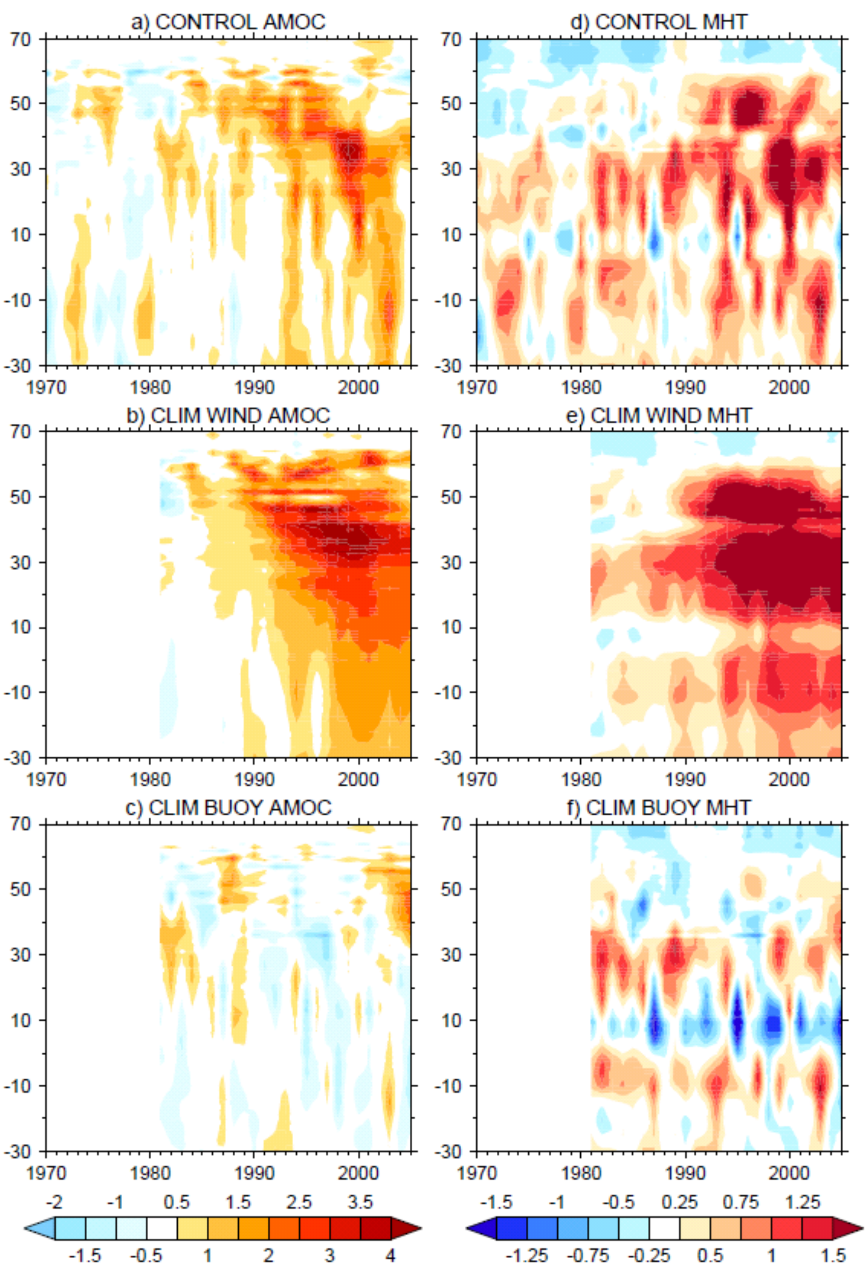


- Solid = difference in H_O and H_A
- Dashed = delta E calculated from the models T

What is the reason for the increase in the ocean heat transport convergence?

Changes in the AMOC

- CONTROL shows an increase in the AMOC and an increase in MHT
- Low frequency strengthening of the AMOC is due to the buoyancy forcing
- Wind forces higher frequency variability which modulates the AMOC and MHT



The role of the NAO

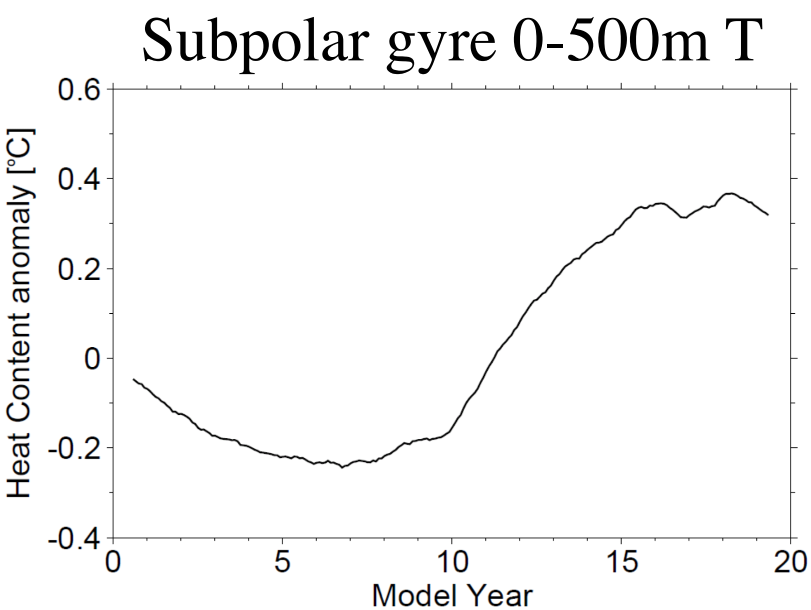
- The experiments show that the buoyancy forced variability was key for the warming of the SPG in the mid 1990s, particularly the forcing that preceded the warming which spun up the ocean circulation & increased ocean heat transport

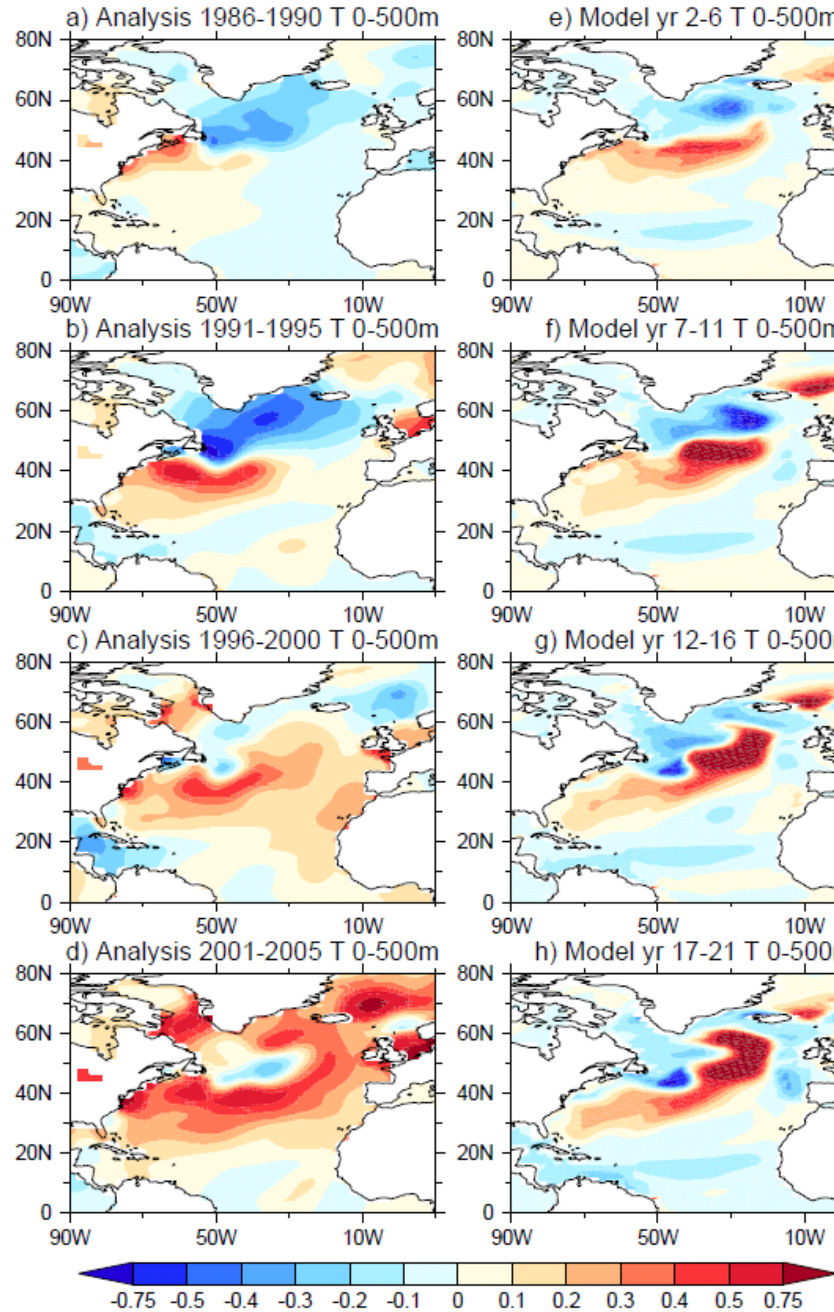
- But, how important was the negative NAO?

- Idealized NAO forcing runs
- Model is forced with persistent positive NAO forcing for 40 years

Can we recreate the warming with just NAO + forcing?

- Forcing the ocean with persistent positive NAO also recreates the warming of the North Atlantic
- However, the warming of the subpolar gyre is not as rapid.





Summary

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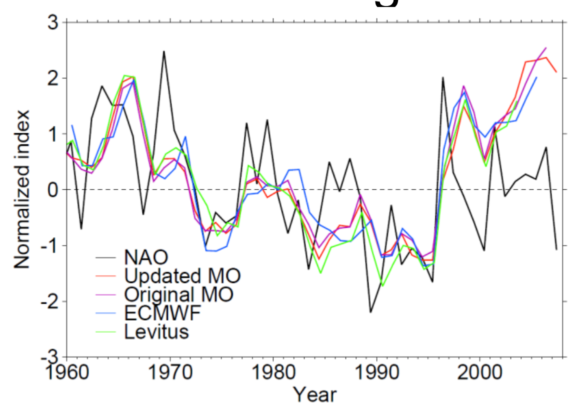
- The North Atlantic Subpolar gyre underwent a large and rapid warming in the mid-1990s

- The warming was primarily due to a surge in the northward ocean heat transport, associated with an acceleration of the MOC and significant changes in the gyre circulation.

- The surge in heat transport and acceleration of the MOC were caused by anomalous buoyancy forcing over the subpolar gyre associated with the prolongued positive phase of the NAO during the 1980s and early 1990s.

- The negative NAO winter of 95/95 contributed to the rapidity of the warming, but was *not* the primary cause.



- Potential predictability arising from the delayed, and integrated, ocean circulation response to the positive NAO forcing.

Performance of the Met Office Decadal Prediction System for the rapid warming of the North Atlantic in the mid 1990s

Jon Robson, Rowan Sutton

National Centre for Atmospheric Science (Climate division)

Department of Meteorology, University of Reading

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Performance of Met Office DePreSys system for the rapid warming of the North Atlantic in the mid 90s

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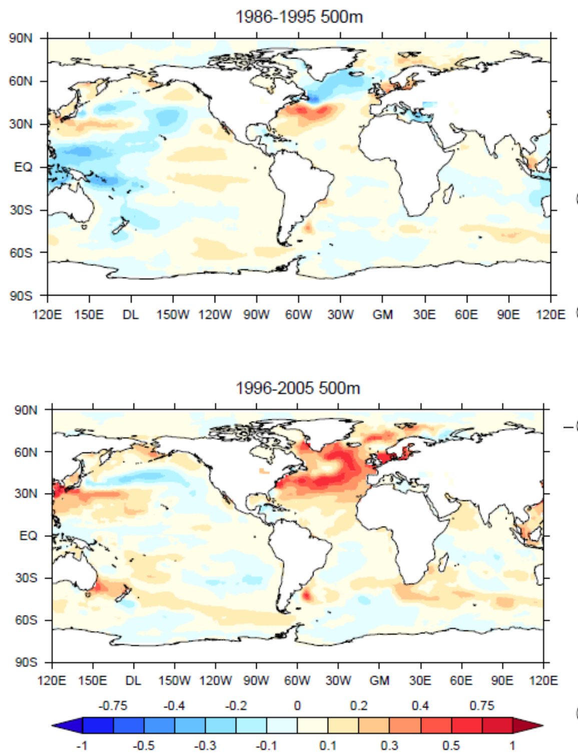
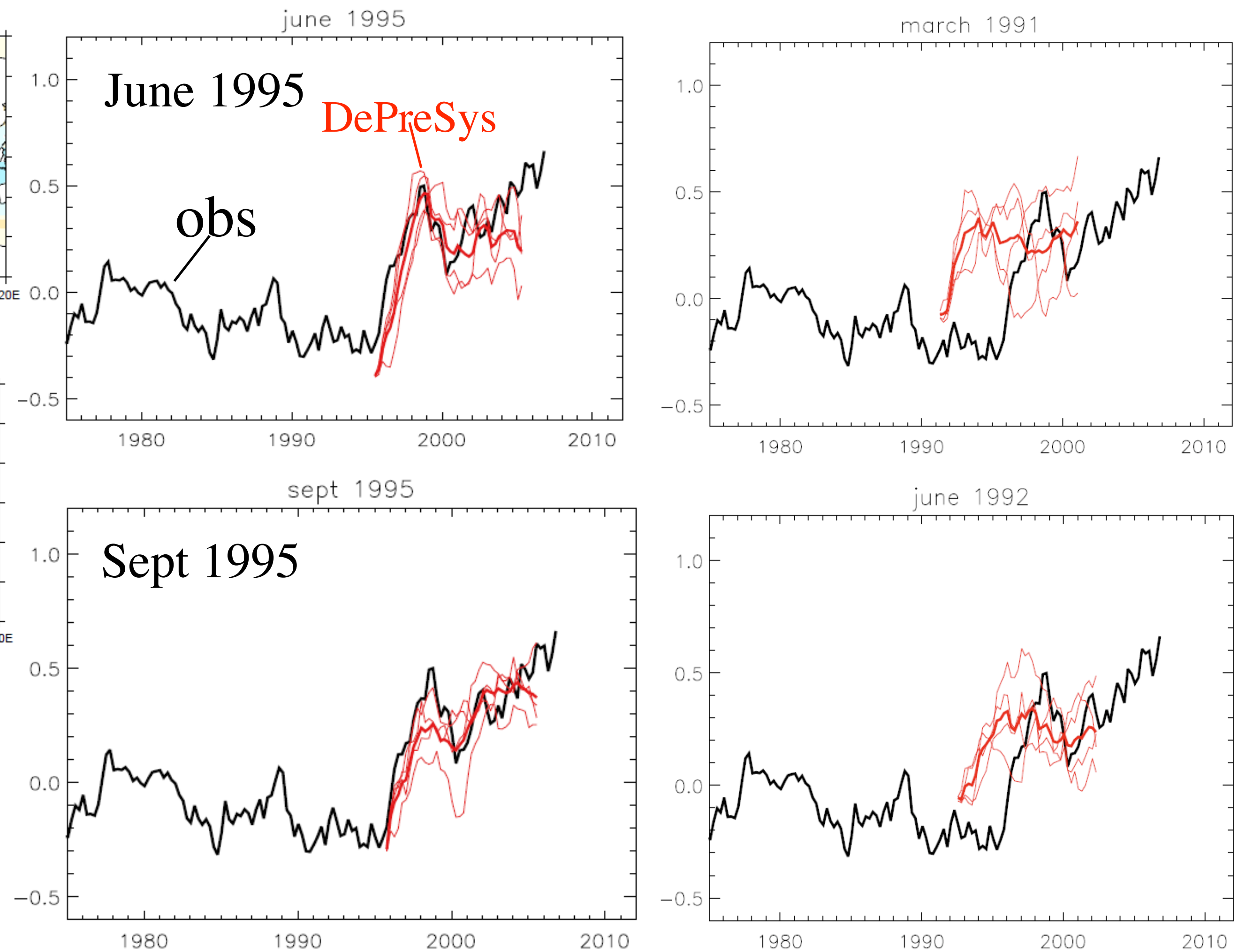
Subpolar gyre 500m heat content





Questions

- When the hindcasts look good:
  - Is the system doing the right thing for the right reasons?
- When the hindcasts look bad:
  - What went wrong?

Problems with the initialisation?

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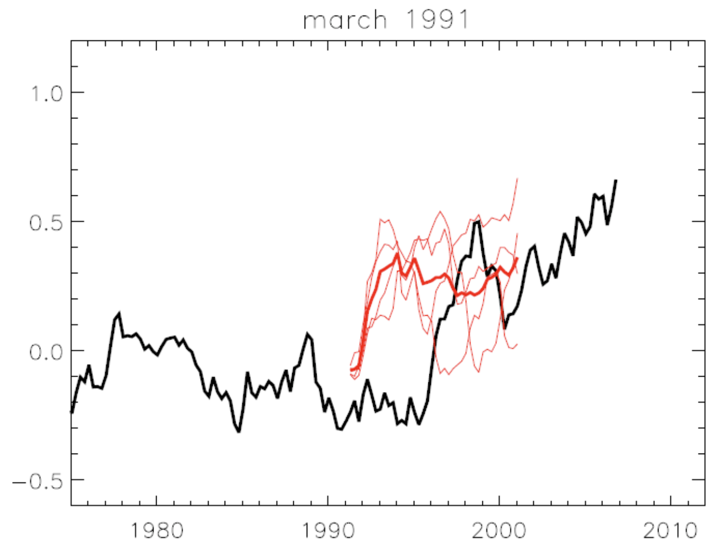
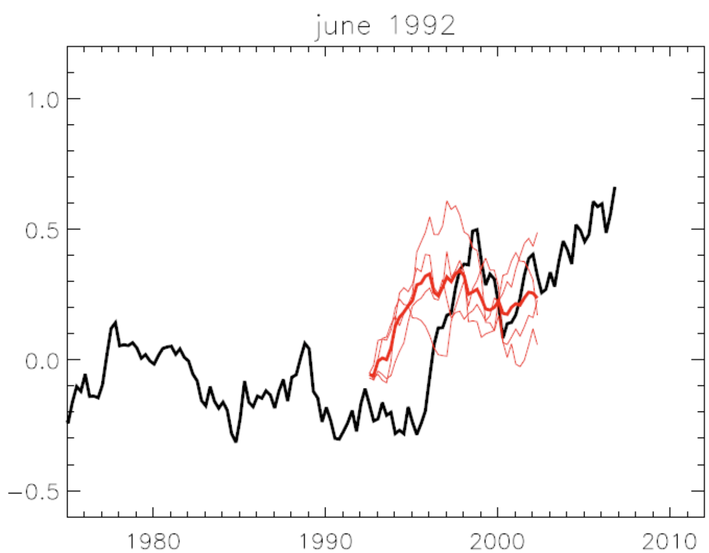


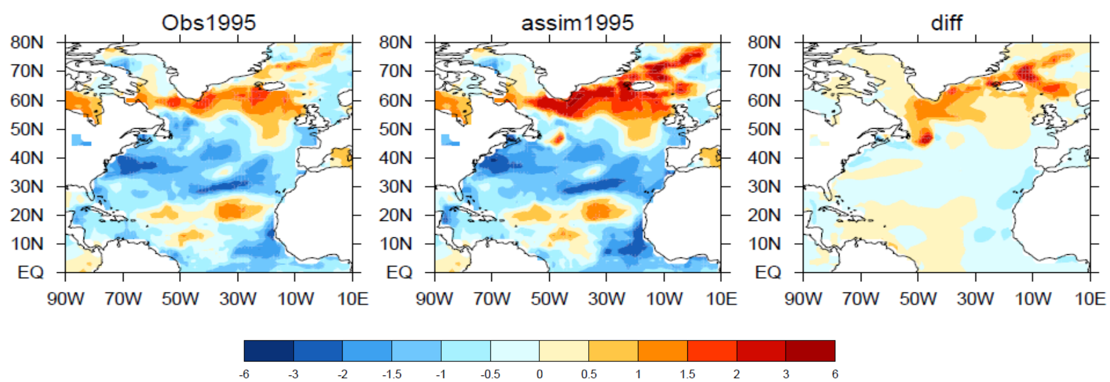


Anomaly assimilation method is based around a model climatology

<u>Hypotheses</u>

1. Problem with the model climatology
2. Errors in assimilated density anomalies arising from non-linearities in the equation of state

$$\rho' = \rho(\overline{T} + T', \overline{S} + S', P) - \overline{\rho}$$



The effect of correcting density errors: 1991 start

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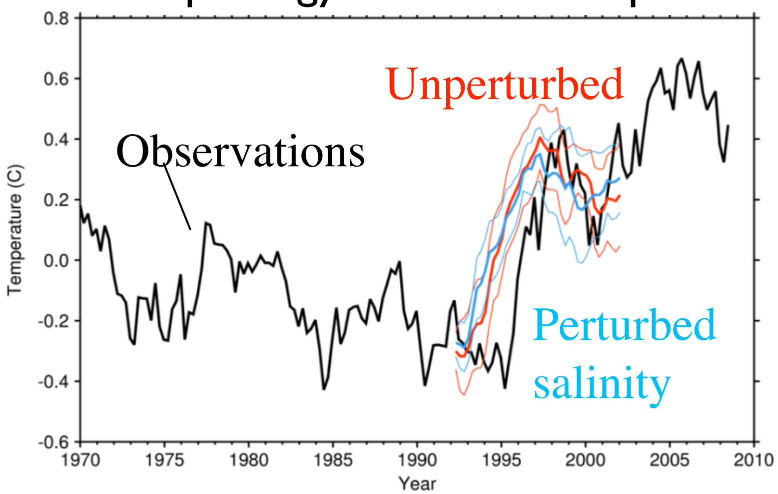
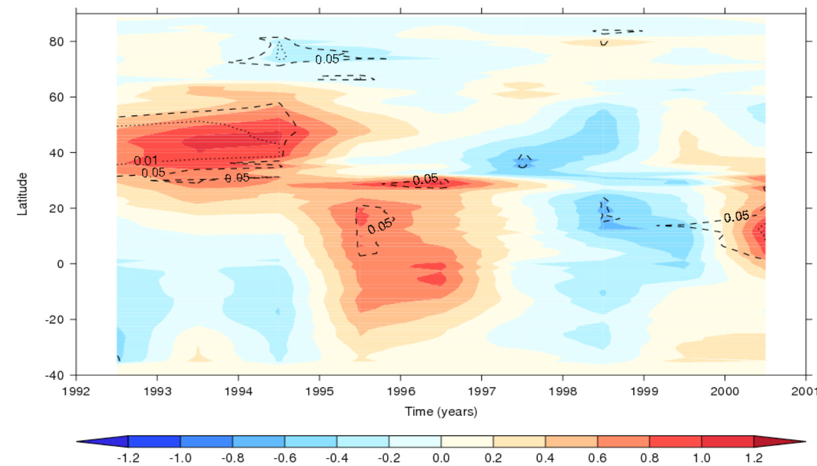
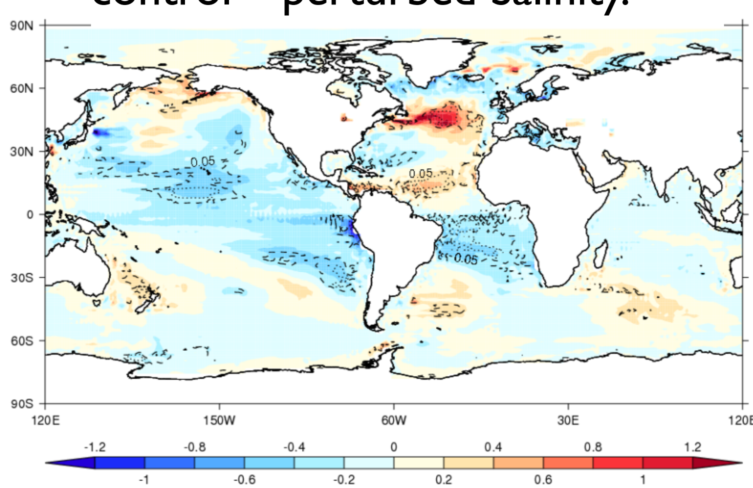
Subpolar gyre 0-500m Temp



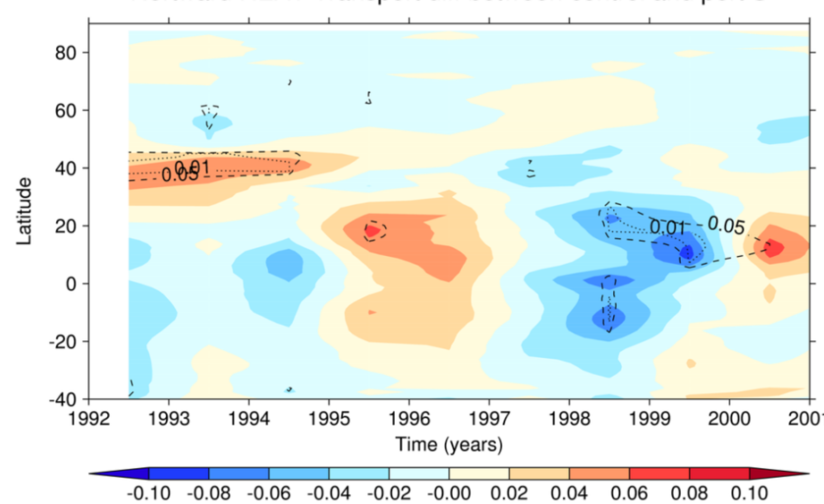
Control – Perturbed Salinity overturning stream function



2nd year SST forecast difference control – perturbed Salinity.



Nortward HEAT Transport diff between control and pert S



The effect of a new climatology: 1991 start

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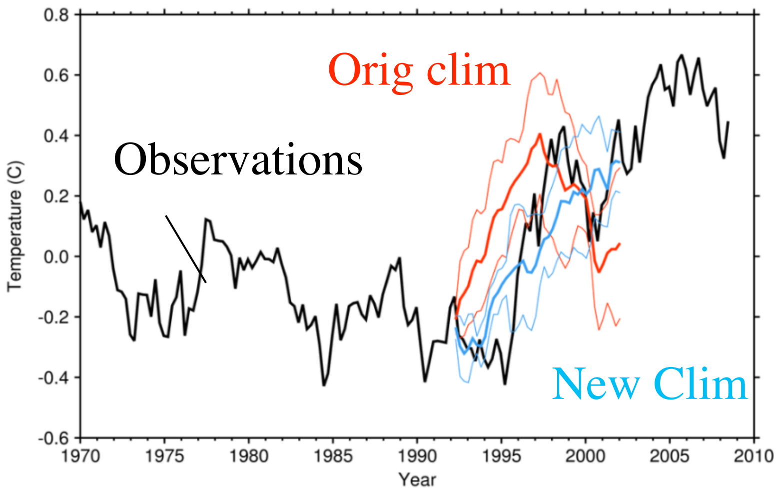
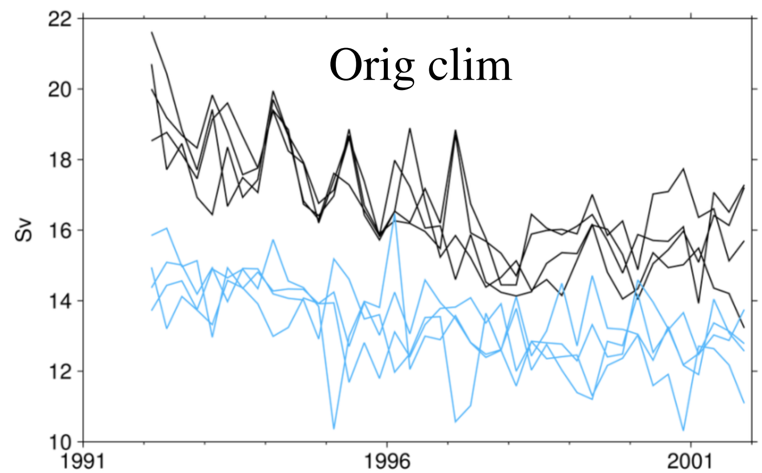
Subpolar gyre 0-500m Temp



MOI at 50N



- Original climatology was imbalanced, with very high MOC which declined rapidly
- High MOC => excess northward heat transport => excess warming
- Correcting climatology reduces MOC and heat transport, and improves prediction of the warming

The effect of a new climatology: 1991 start

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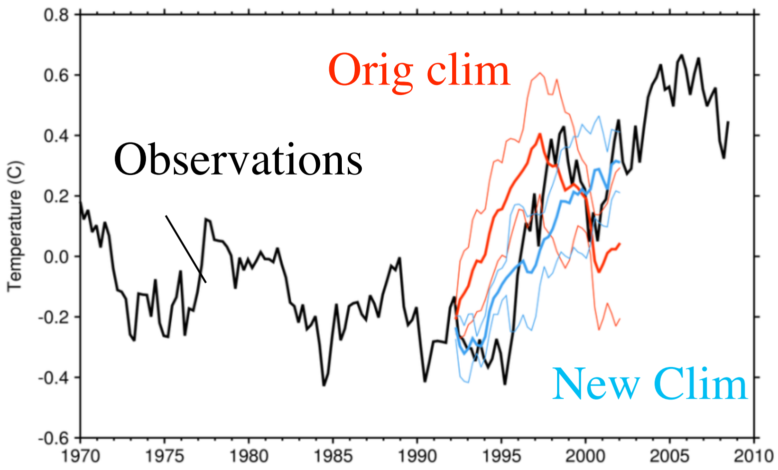
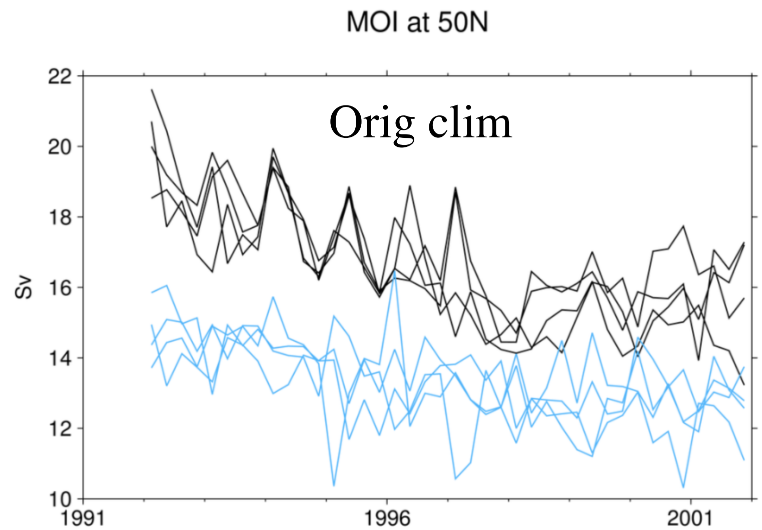
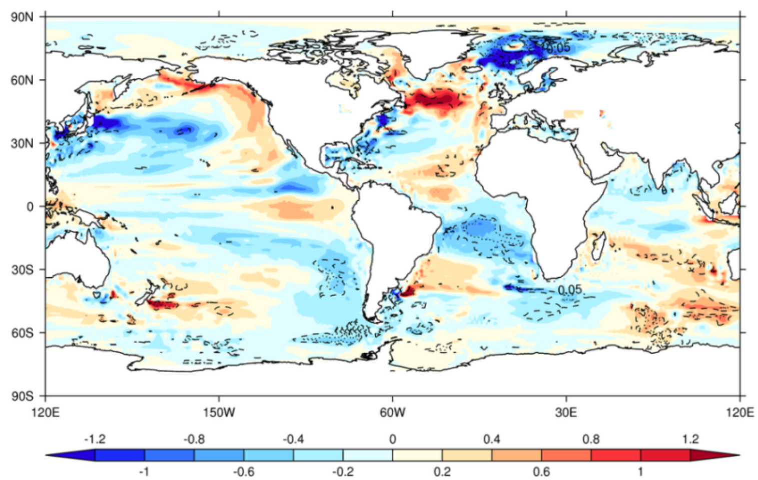
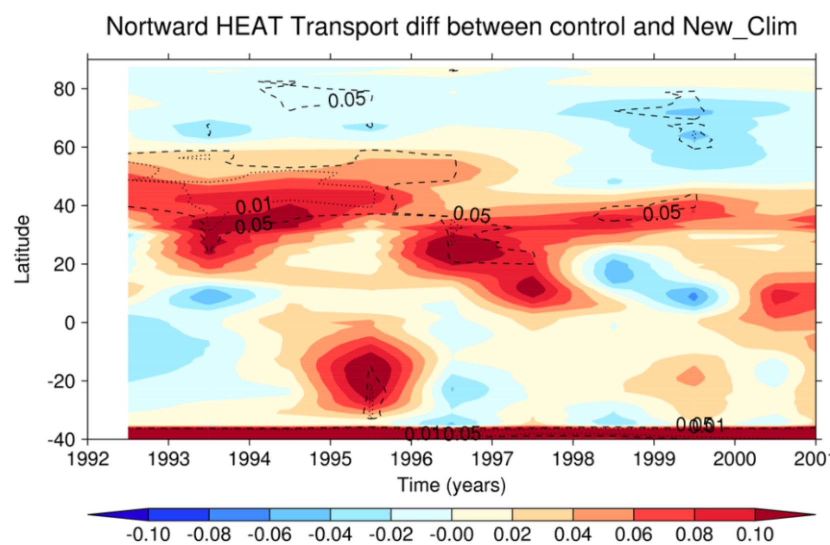
Subpolar gyre 0-500m Temp





2nd year SST forecast difference control – new clim.





The effect of a new climatology: 1991 start

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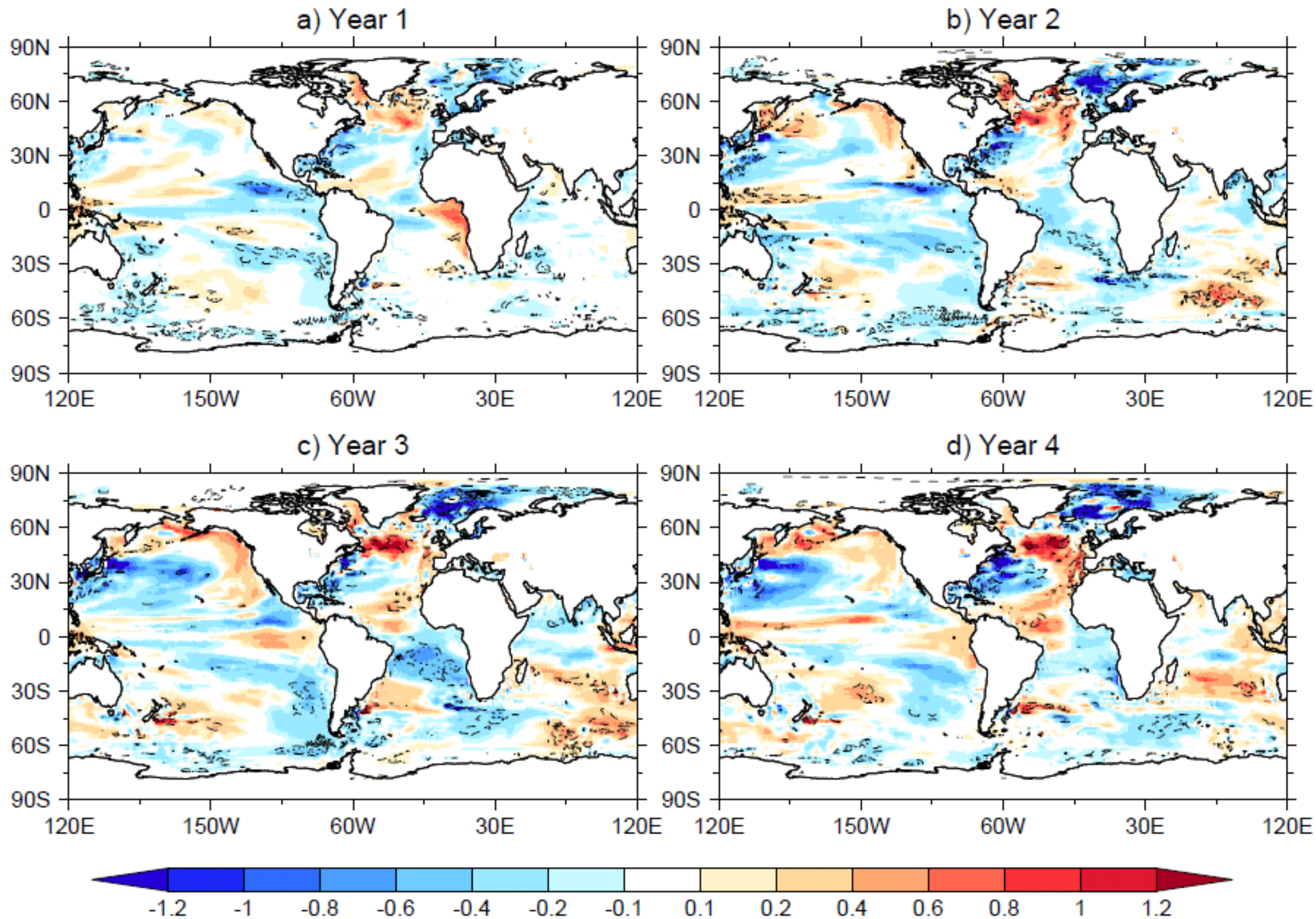
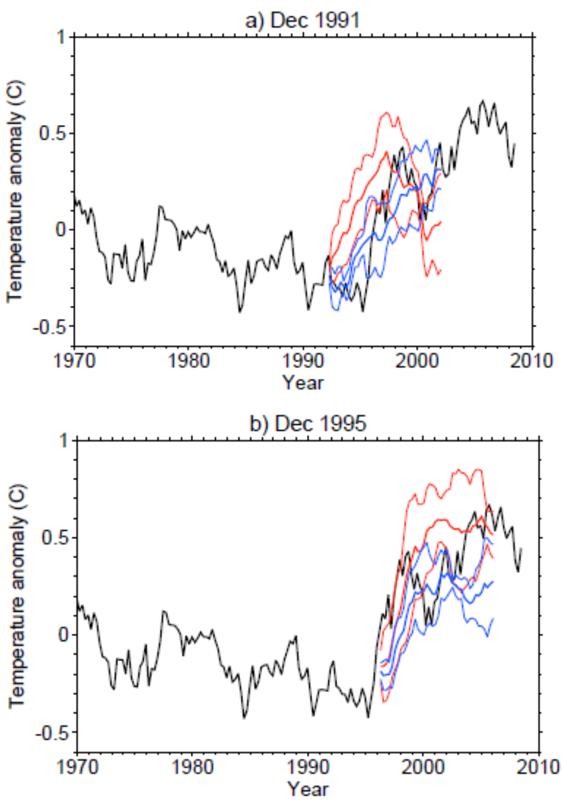


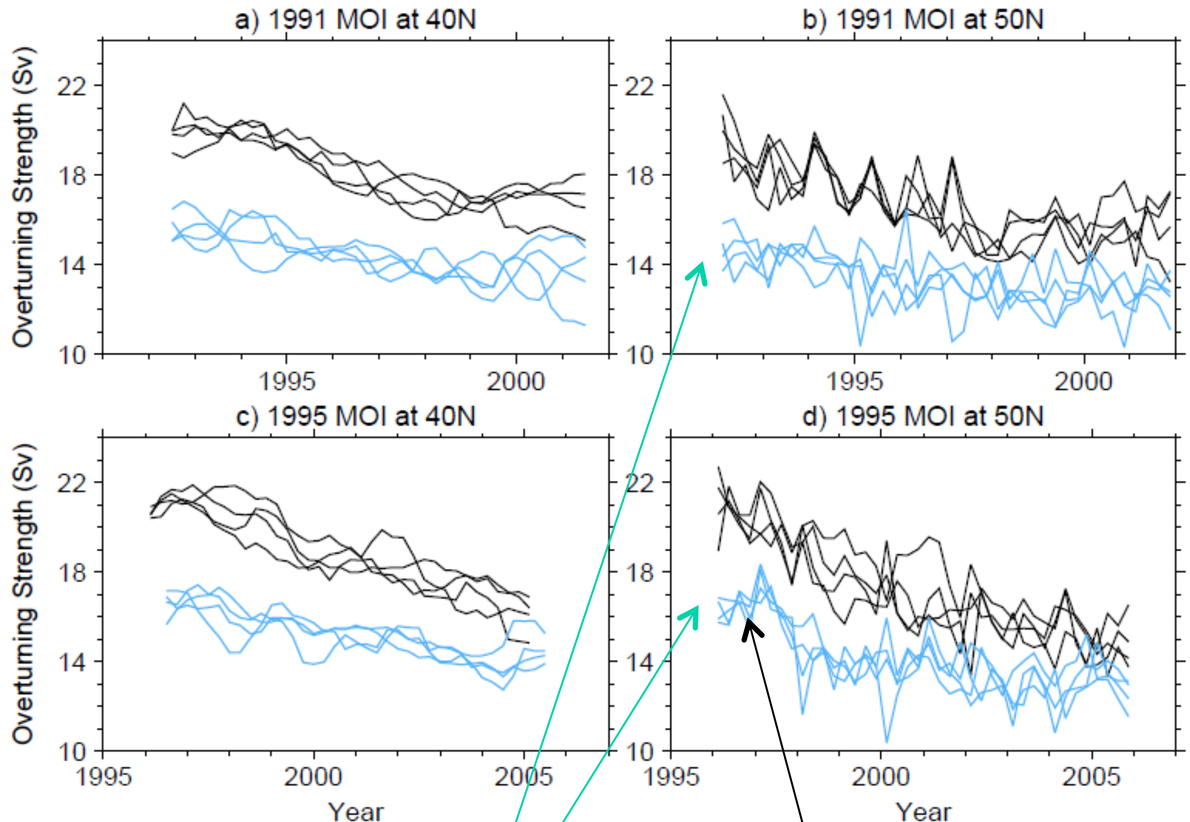
Questions

- When the hindcasts look good:
  - Is the prediction system doing the right thing for the right reasons?
- When the hindcasts look bad:
  - What went wrong?

Compare 91 and 95 starts



MOC at 40N MOC at 50N



MOC initialised ~2SV higher for 95 start

Initialised acceleration of the MOC

Northward heat transport for '95 start

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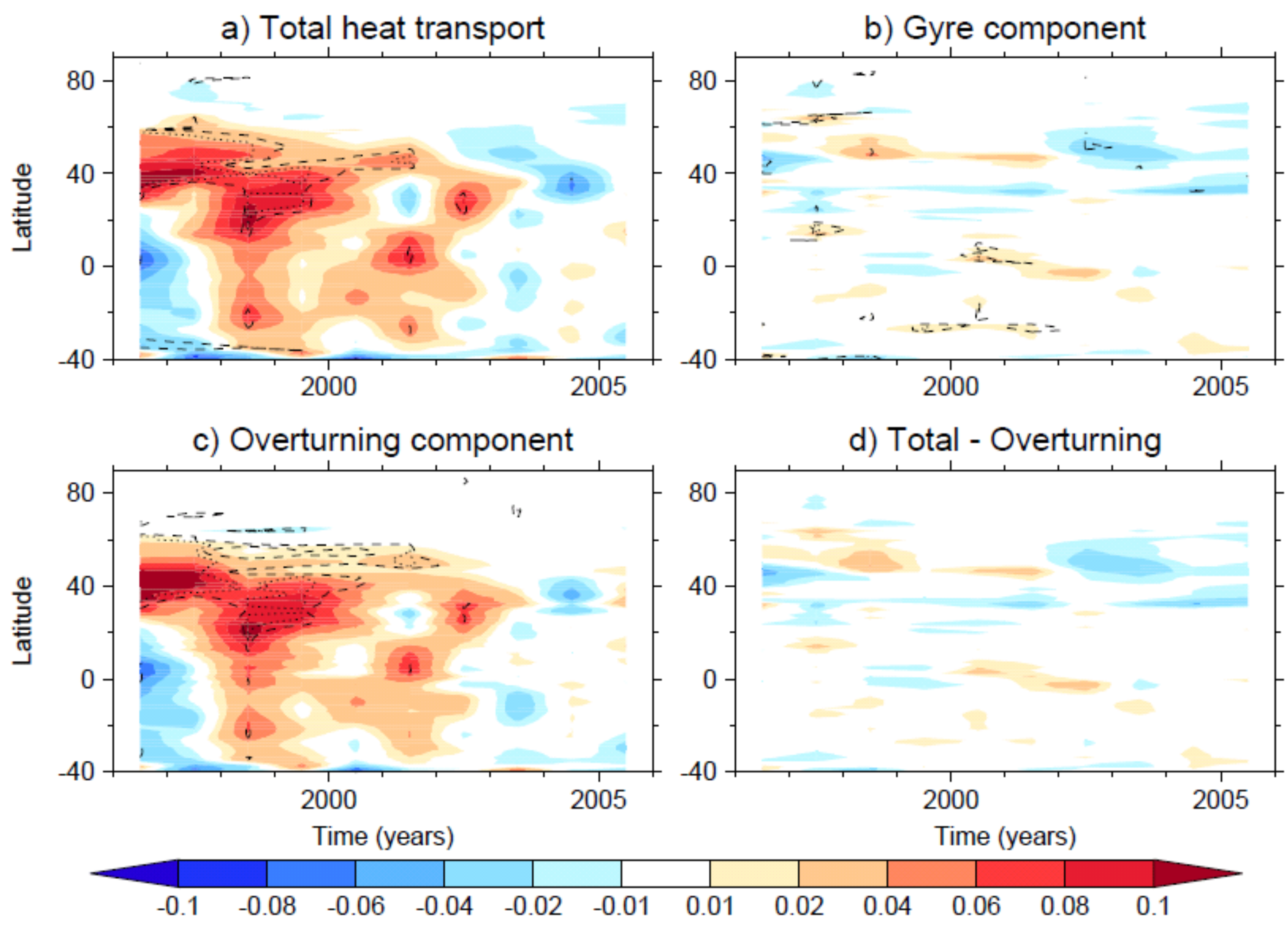
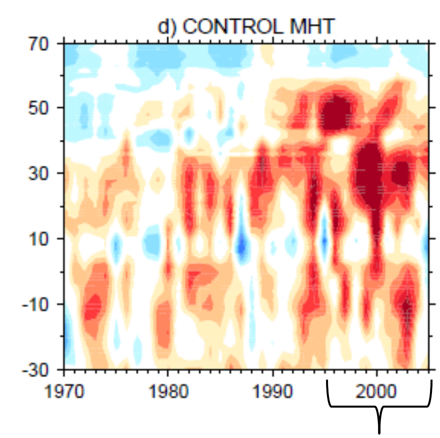
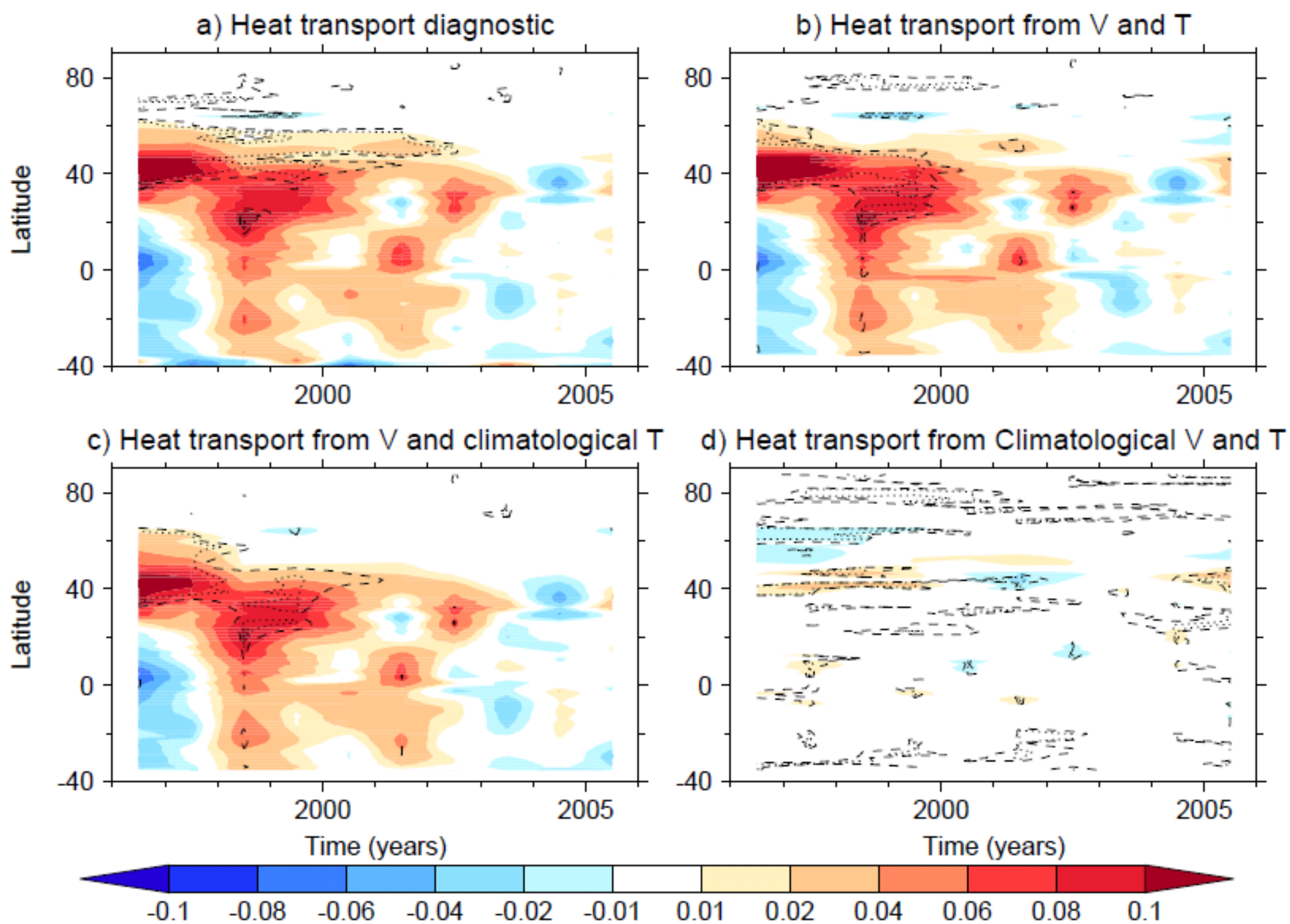


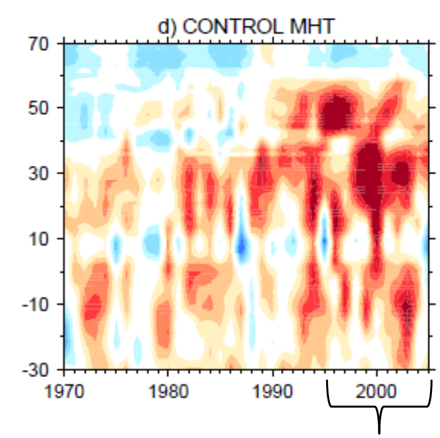
Anomalies relative to model climatology



Northward heat transport for '95 start



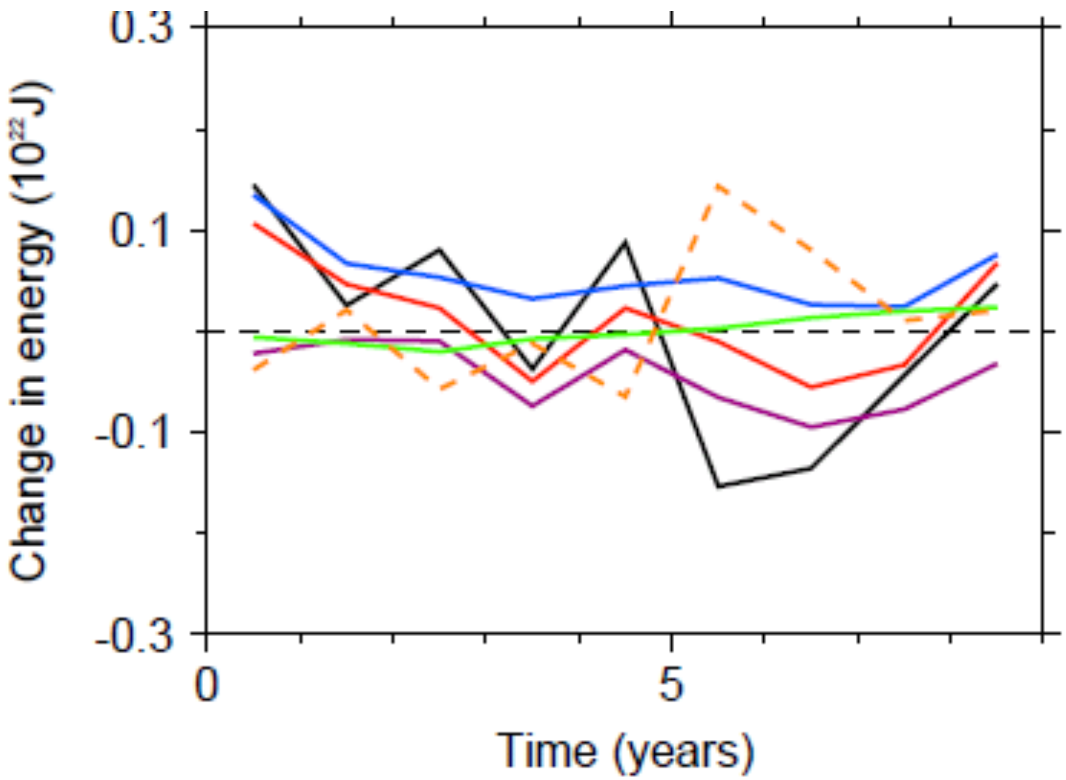
Anomalies relative to model climatology



$v'\overline{T}$ dominates heat transport variation in DePreSys: initialisation of ocean dynamics critical for prediction of the warming

Heat budget of the subpolar gyre

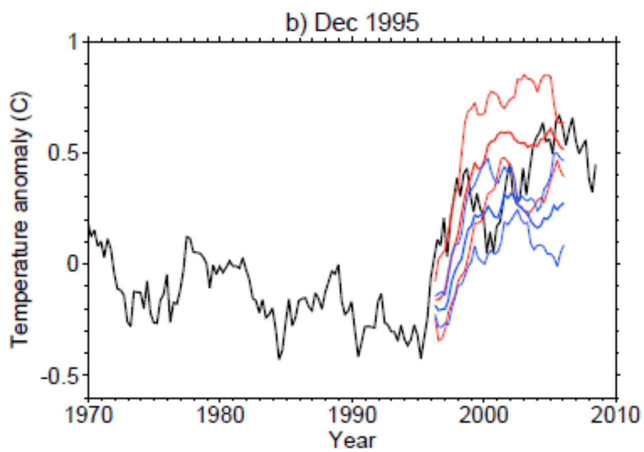
1995 starts -1991 starts



- Warming attributable to changes in overturning component of ocean heat transport convergence

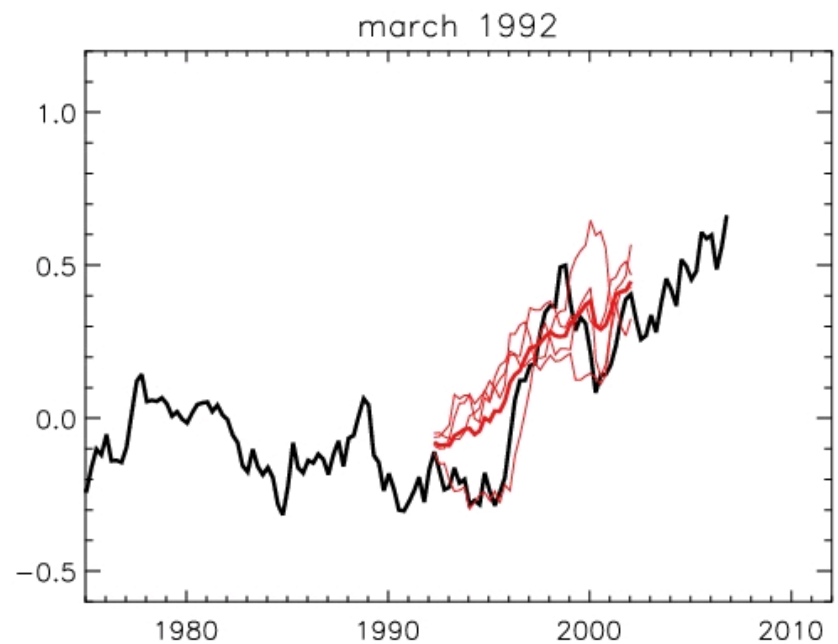
- Anomalous air sea flux air sea fluxes act to *damp* the warming

Timing of the warming



95 start appears to predict warming later than observed

But!...



Conclusions 1: Performance of DePreSys

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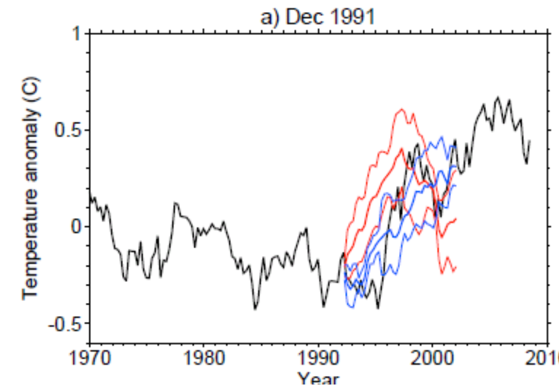
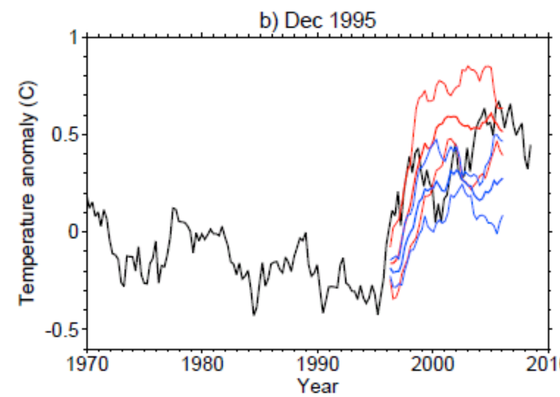
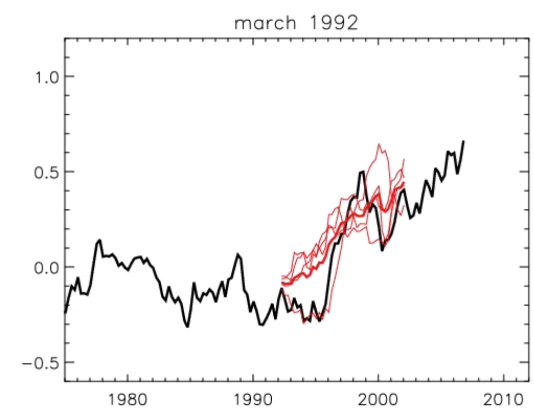
- When initialised using a balanced climatology, DePreSys does a pretty good job of predicting the rapid warming event:
  - Magnitude and timing consistent with observations
  - Warming is attributable to a surge in the northward ocean heat transport, associated with an acceleration of the MOC
  - Exact timing and rapidity is sensitive to interannual fluctuations in the NAO
- Some room for improvement,e.g. v'T'



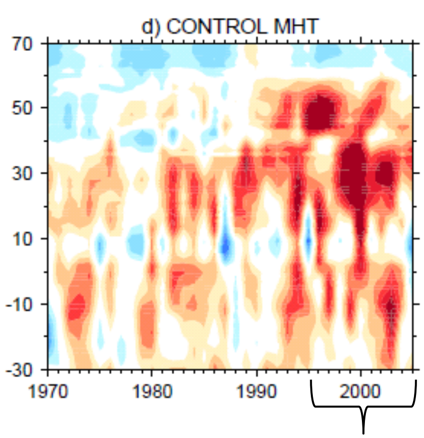


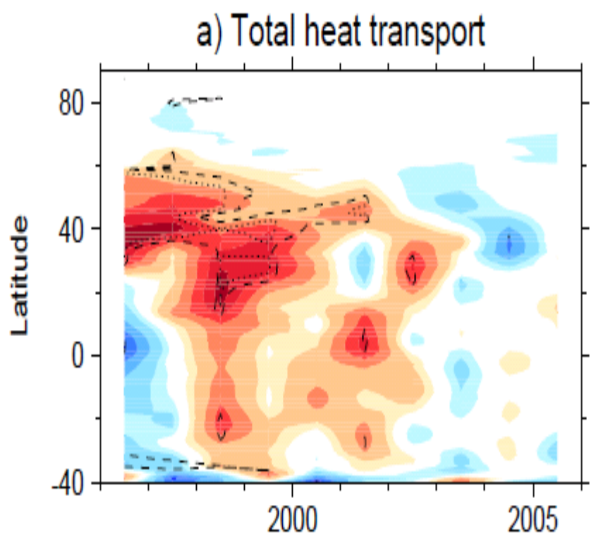


Conclusions 2: Metrics for case studies

- Generic metrics:
  - Time series of key indices (SST, heat content etc)
  - Do the observations fall within the spread of the ensemble (“reliability”)
  - Needs large ensembles to capture non-Gaussian behaviour
- Key process-based metrics for the specific event, e.g.:
  - Northward heat transport
  - MOC
  - NAO

Is the prediction system doing the right thing for the right reasons?





The role of initialisation in decadal climate prediction

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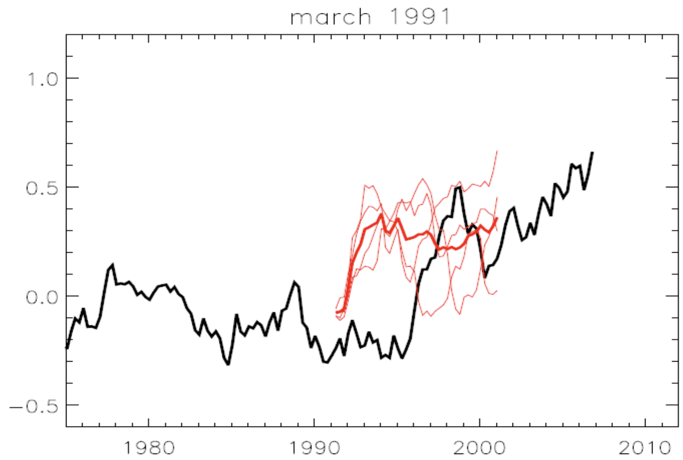
- Initialisation usually motivated by the need/opportunity to predict aspects of internal variability.
- Arguably it will prove *more important* as a tool to identify and understand model errors
- Analysis of error growth provides a powerful new way to test climate models and prediction systems *at a process level,* and thereby improve them.
- Long used in NWP; a big opportunity in climate prediction



See also Ed’s talk

VALOR: Value of the RAPID array for climate predictions

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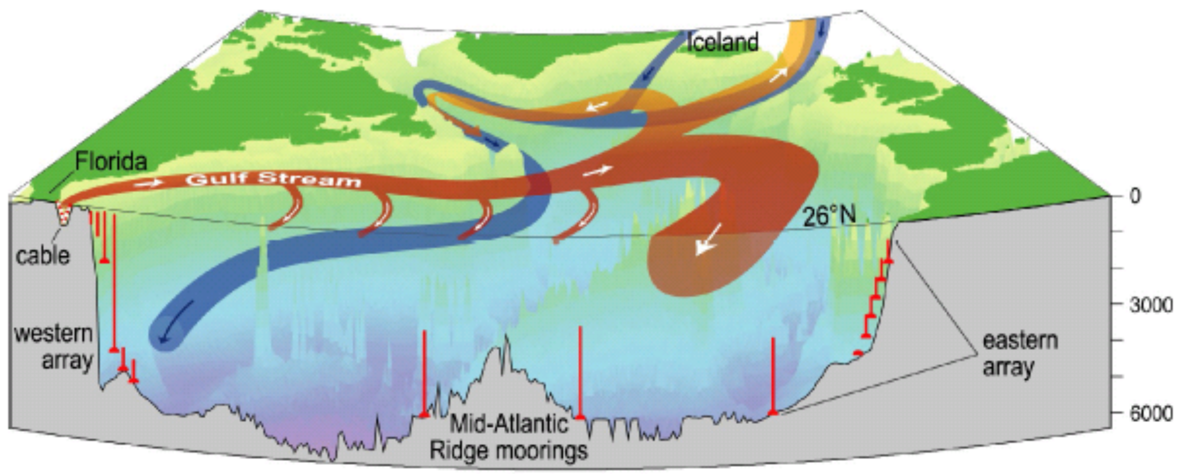
What is the value of the RAPID array observations for:
- Evaluating predictions?
- Initialising predictions?

VALOR



Skematic of RAPID MOC monitoring array at 26N, couresy Louise Bell & Neil White, CSIRO

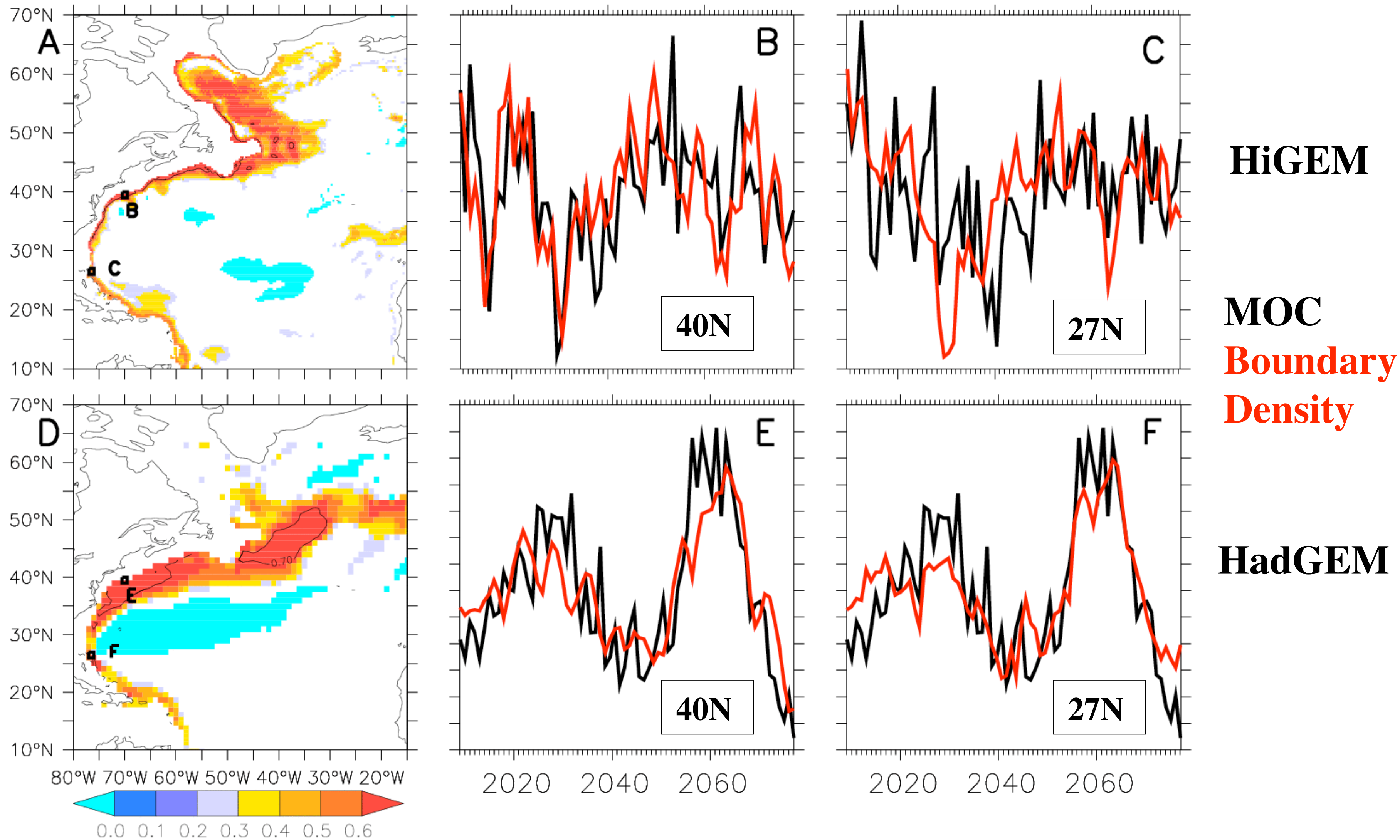
- Reading, NOC, Met Office, ECMWF

- DePreSys & NEMO workstreams

VALOR Aims

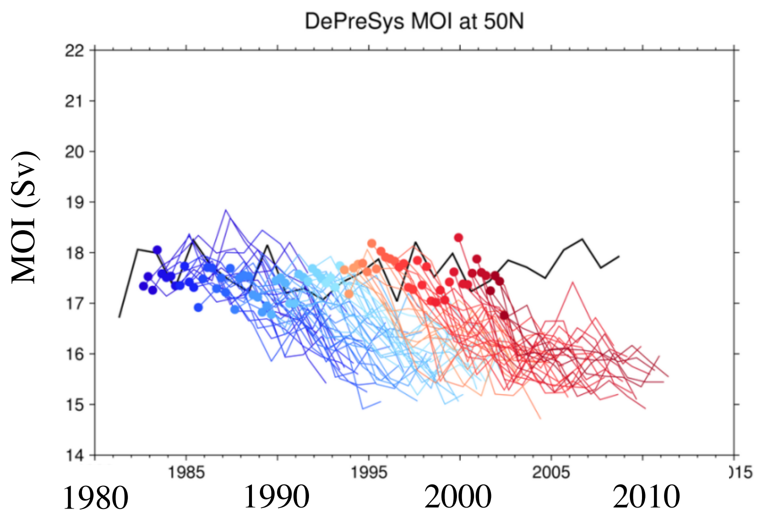
1. To use the RAPID observations as independent data to evaluate the representation of the AMOC in ocean analyses, and to assess the skill of AMOC predictions. **Evaluation**
2. To develop and evaluate strategies for including RAPID observations in ocean syntheses, thereby generating new, improved, ocean analyses. **Synthesis**
3. To determine the impact of assimilating RAPID and other ocean observations on predictions of the AMOC and climate. **Predictions**
4. To develop and evaluate strategies for sampling the initial condition and model-related uncertainty in ensemble predictions of the AMOC and its impacts of climate. **Ensemble design**

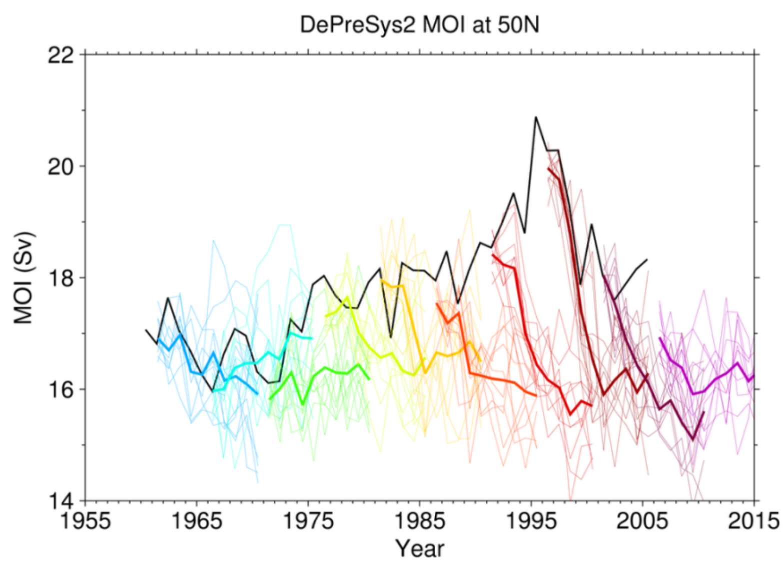
Model uncertainty: sensitivity to resolution



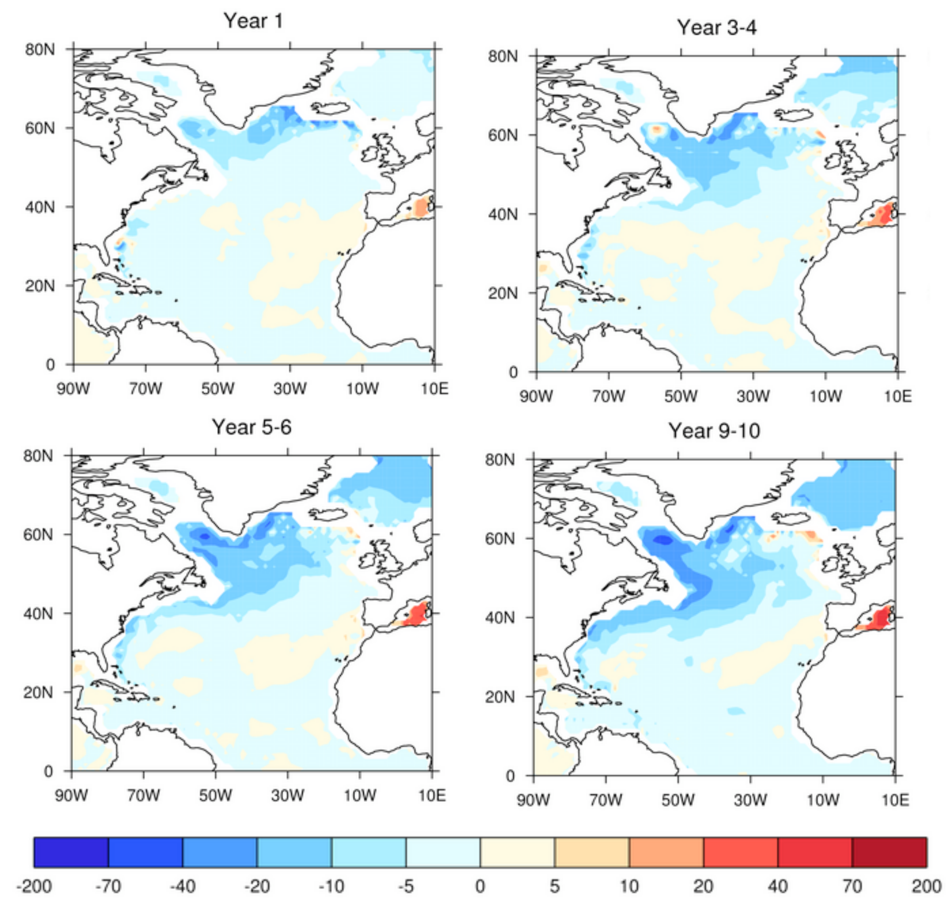
Density Integrated 1500-3000m

AMOC in DePreSys



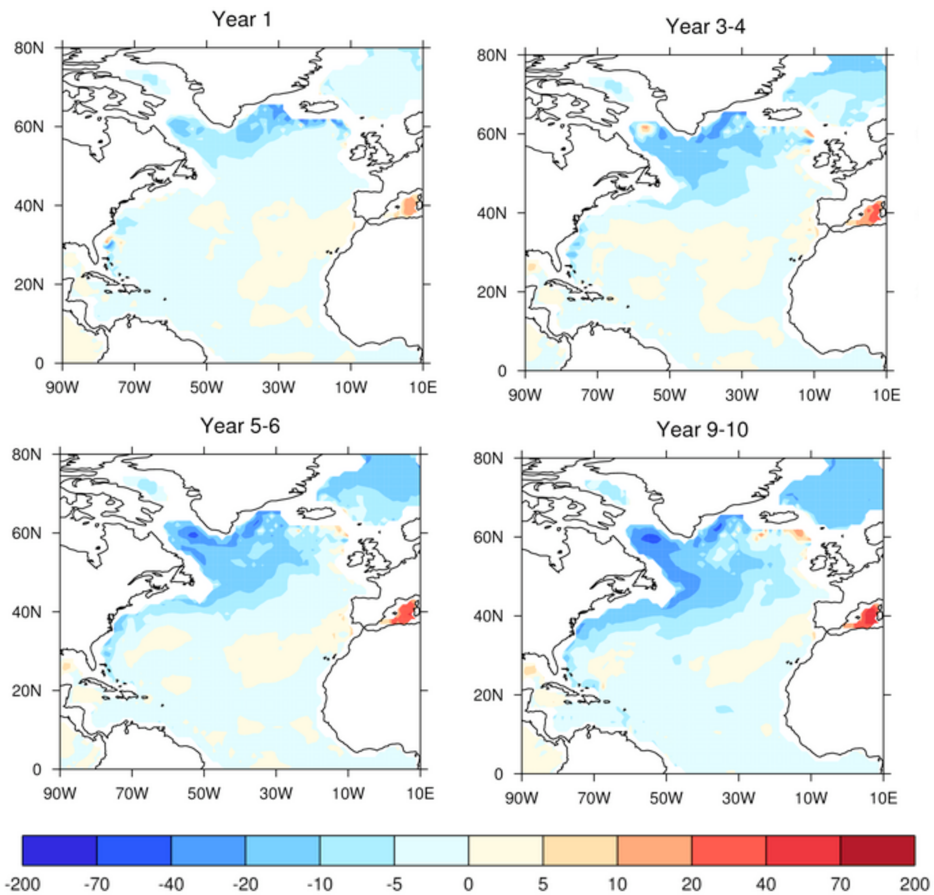


800-3000m mean hindcast



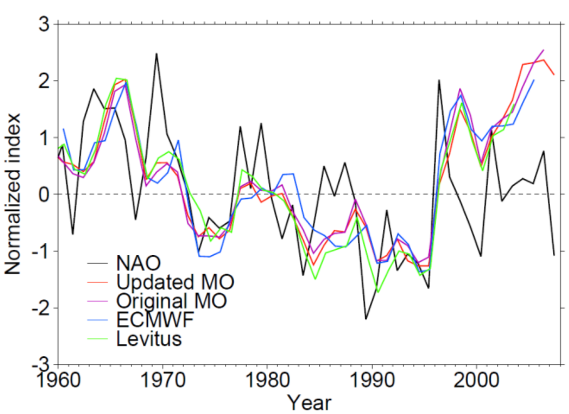
Drifts present in DePreSys

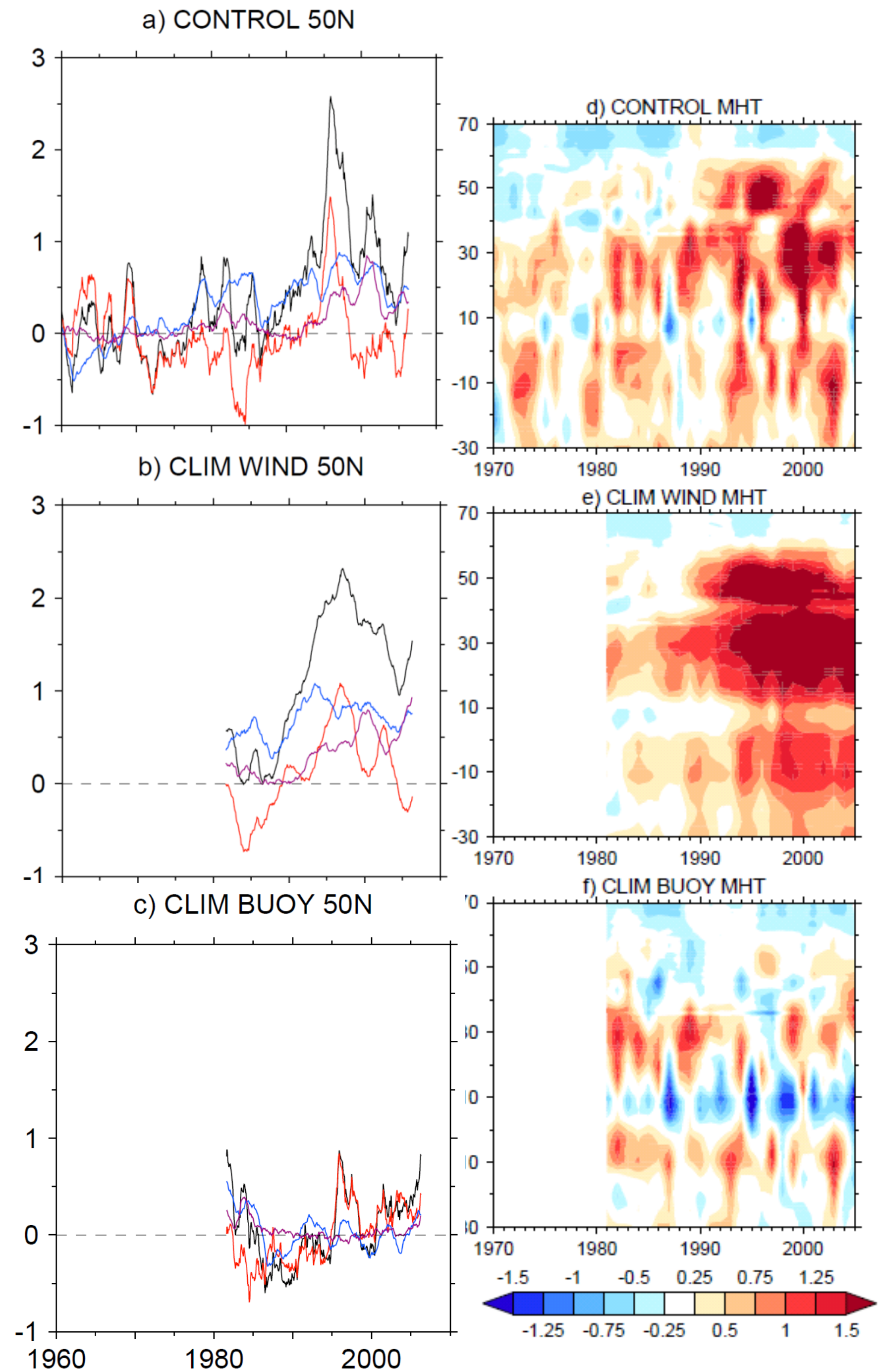
800-3000m mean hindcast



Changes in the AMOC

- CONTROL shows an increase in the AMOC and an increase in MHT
- Low frequency strengthening of the AMOC is due to the buoyancy forcing
- Wind forces higher frequency variability which modulates the AMOC and MHT





Chain of events

- Positive NAO, cools surface of subpolar gyre, increase in southerly Ekman → increased convection
- Wind stress and deep water formation strengthens gyre circulation and AMOC
- Strengthening of ocean circulation (in particular AMOC) → increased northward heat transport
- Increase in northward heat transport initially offset by strong southerly Ekman and strong surface heat loss
- Negative NAO, sudden relaxation in southerly Ekman → sudden increase in northward heat transport, and reduction of surface heat flux
- Warming of the subpolar gyre → decreases doming of isopycnals → sudden weakening and contraction of the gyre → increased intrusion of subtropical waters
- Decrease in deep convection → weakening of the AMOC → reduction in northward heat transport