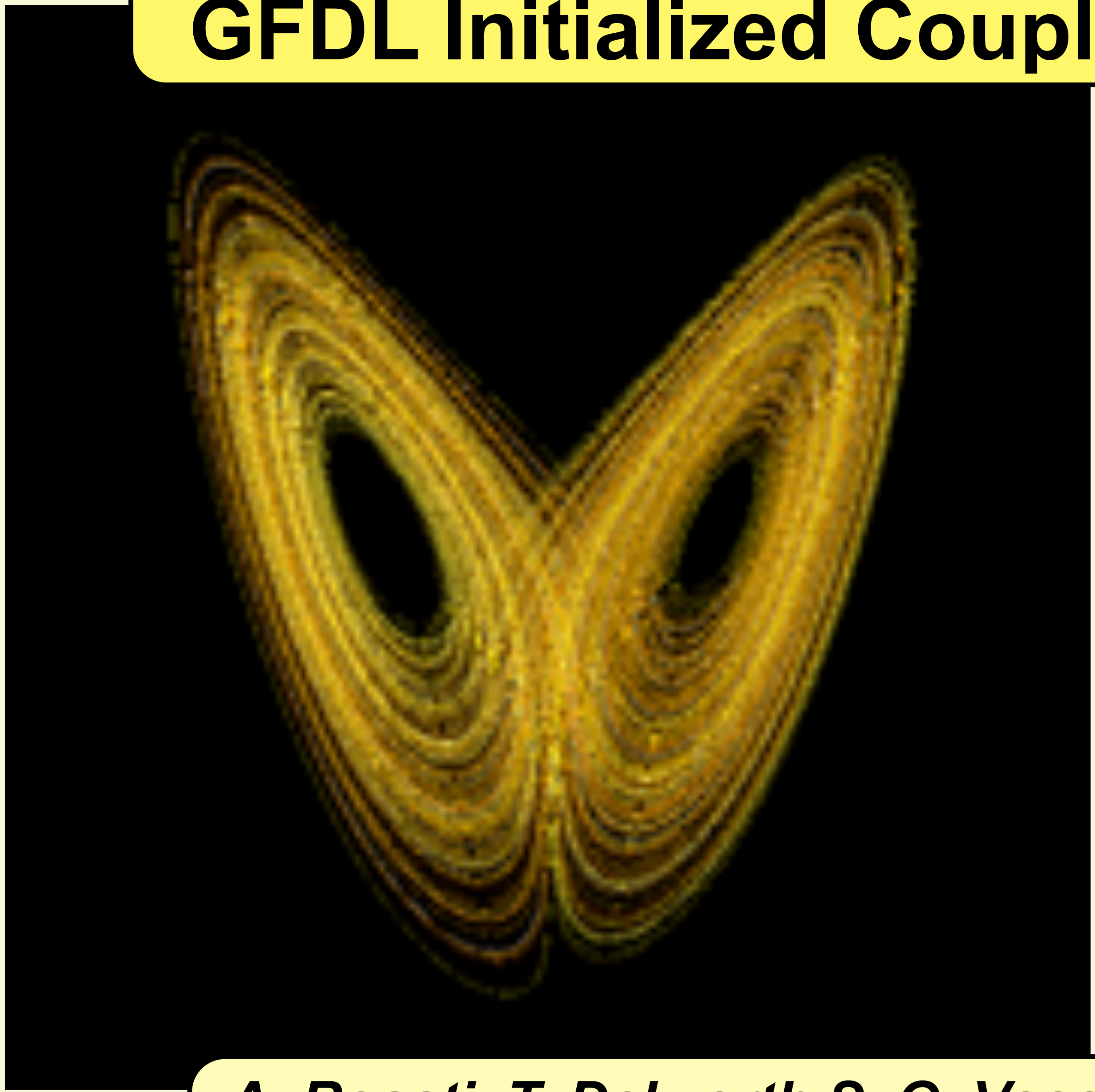
Predicting Atlantic Decadal Variability in the GFDL Initialized Coupled Experiments



Rym Msadek

NOAA/GFDL

A. Rosati, T. Delworth S, G. Vecchi ,S. Zhang, W. Anderson,Y. Chang, K. Dixon, R. Gudgel, W. Stern,, A. Wittenberg, X. Yang, F. Zeng, R. Zhang

Atlantic Sector Climate Variability over the Last Millennium and the Near-Term Future
LDEO Columbia University, October 17, 2012

Motivation for decadal prediction efforts

-Increasing demand for climate projections on time scales of one or two decades and on regional spatial scales (e.g. for water resources, agriculture, fisheries, insurance)

-Concerns about the possibility of abrupt climate changes

Motivating examples:

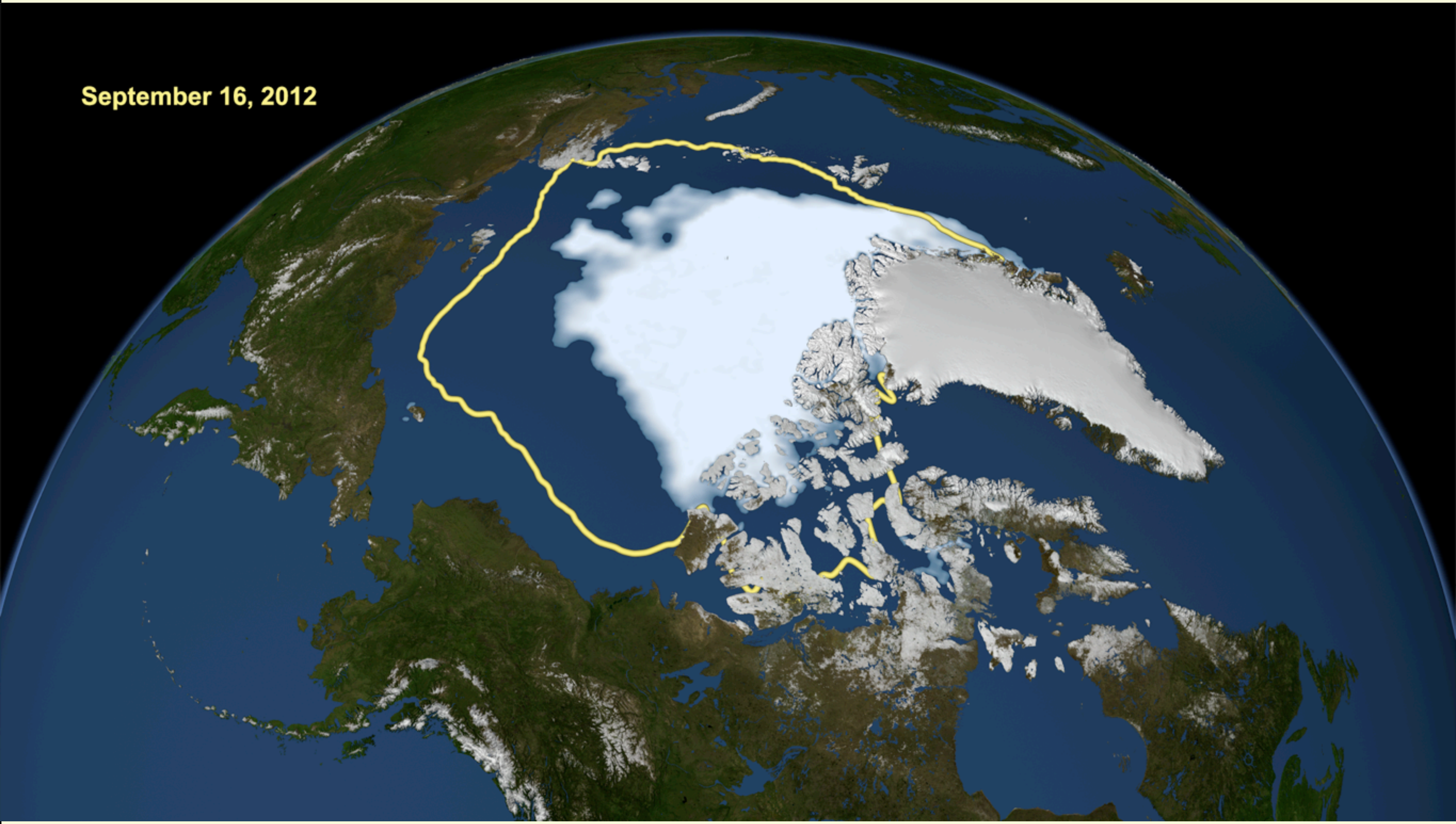
1-Atlantic ocean decadal temperature variations with impacts on droughts, hurricanes

2-Rapid decadal-scale loss of Arctic sea ice

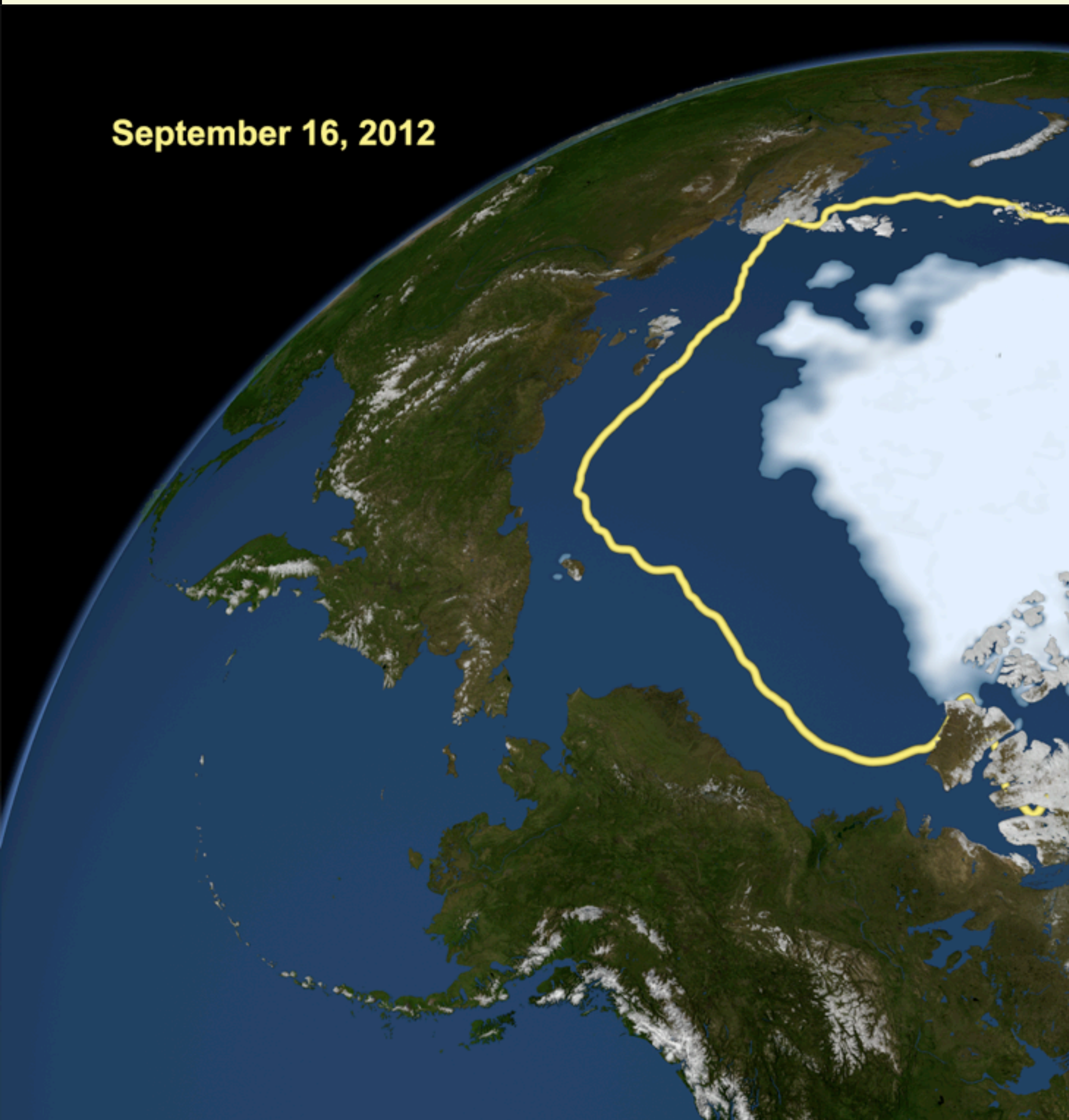
3-Droughts such as Sahel drought of 1970s or SW US drought

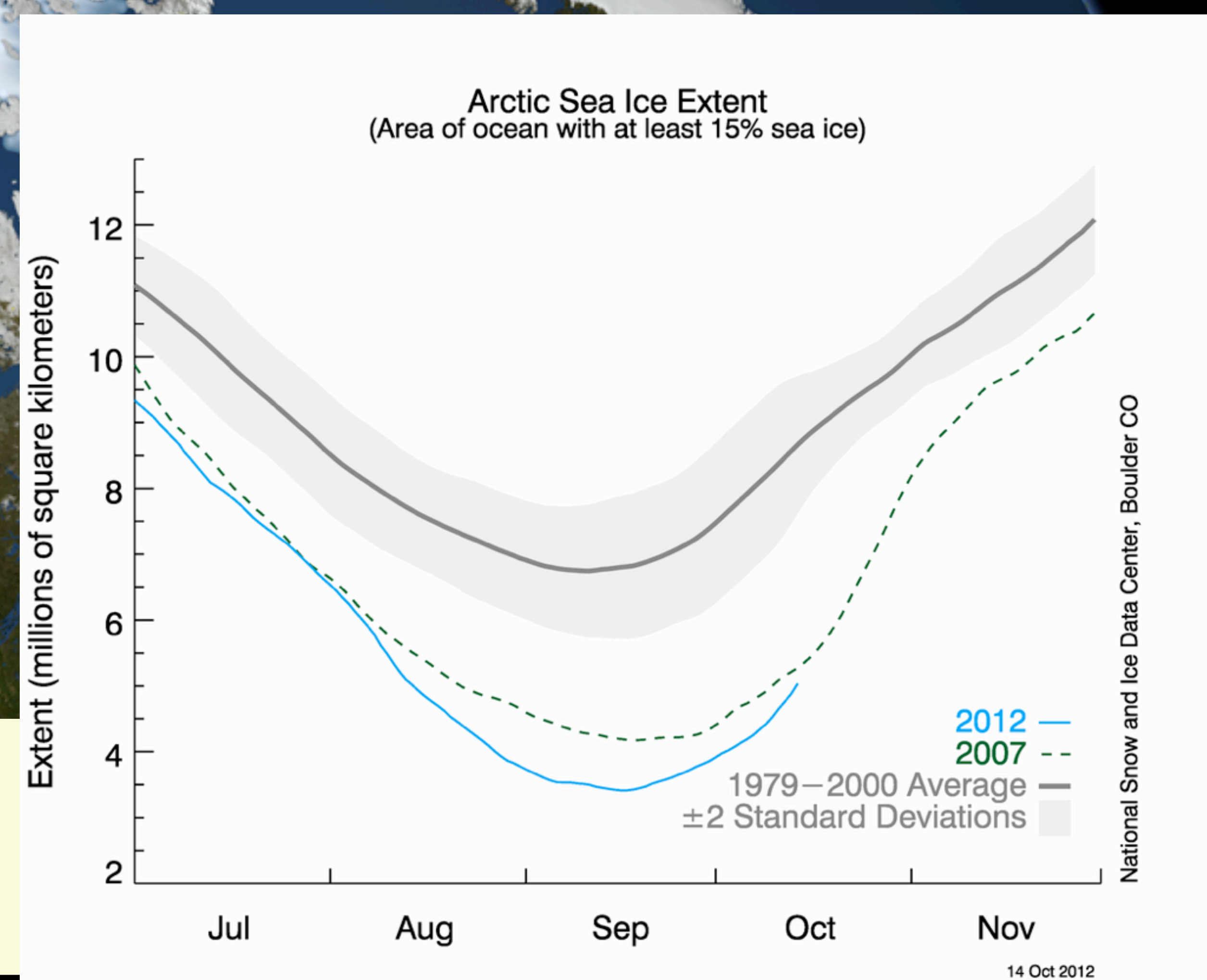
For each case, how much was a response to radiative forcing and how much was internal variability? Could they be predicted?

Could we have predicted the minimum of sea-ice?

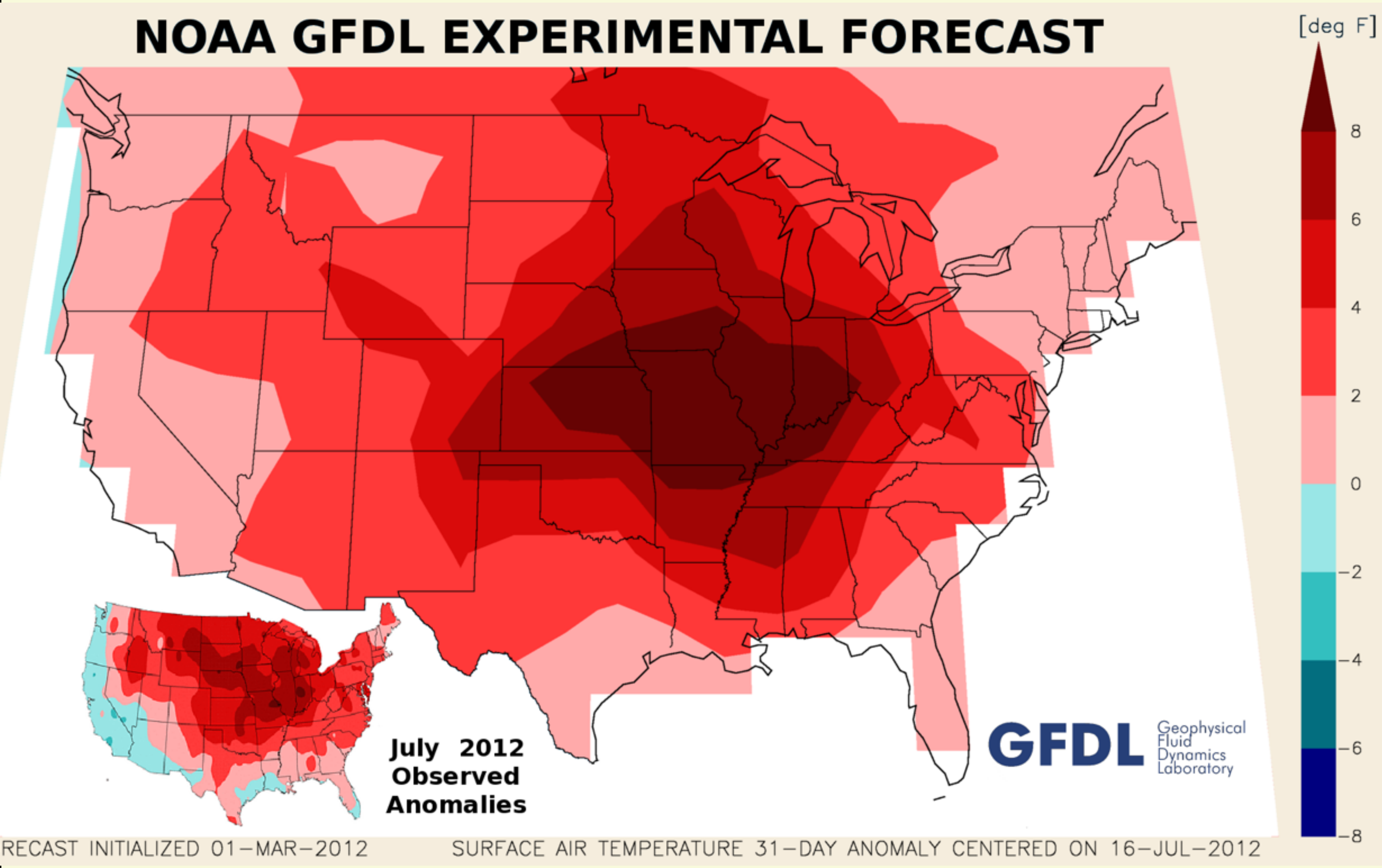


Could we have predicted the minimum of sea-ice?





Could we have predicted the US drought?



Decadal predictions: a initial/boundary value problem

Decadal climate variations arise from

-Internal variability of the climate system (e.g. slow changes in the ocean)

-Response of the climate system to external forcing changes (greenhouse gases, aerosols, etc.)

Observing systems

Assimilation systems

Models

Changing radiative forcing

Weather and seasonal predictions (initial value problem)

Centennial projections (boundary value problem)

Decadal predictions

Goal: Unified system for predictions and projections from seasonal to decadal to centennial time scales

GFDL decadal prediction system/Experimental design

Most climate projections focused solely on the response to radiative forcing changes.
Key question: Can we produce better predictions if we use information describing the initial state of the climate? Part of CMIP5 and IPCC AR5

Model:
Currently use of CM2.1 model (2°atm, 1°ocean, Delworth et al. 2006)

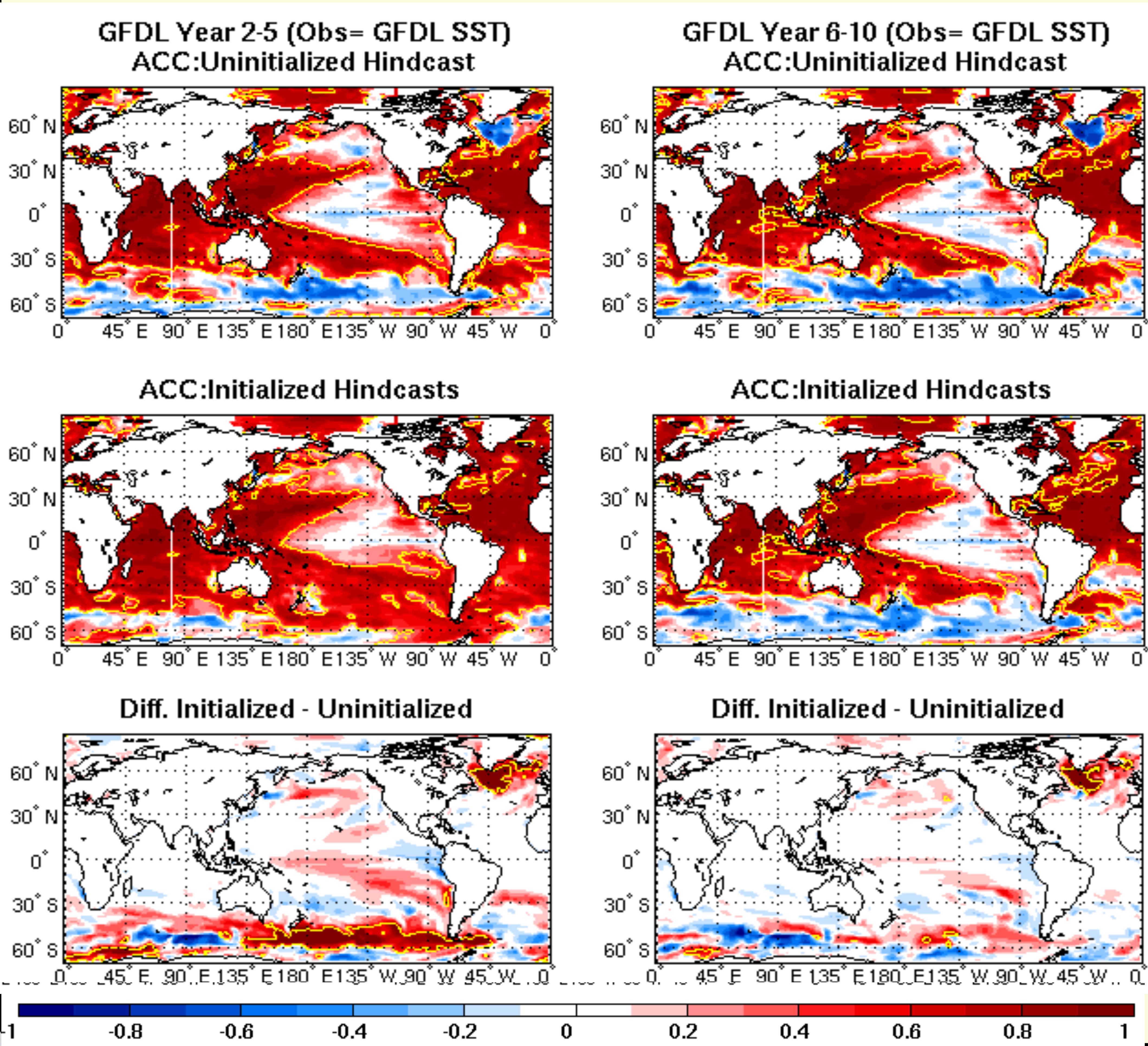
Initial conditions:
Ensemble Coupled Data Assimilation (ECDA) reanalysis (Zhang et al. 2007)
.Atmosphere NCEP reanalysis (T,u,v,ps)
.Ocean XBT,CTD, satellites, Argo
.Radiative forcing GHG, solar, aerosols,volcanoes

Initialized runs
10 members ensemble, starting every year from 1960-2012, run for 10yrs (total of more than 5000 model years). Use observed estimates of radiative forcings 1960-2005, RCP4.5 thereafter

Uninitialized runs:
10 members ensemble, from 1861-2040. Use observed estimates of radiative forcings 1960-2005, RCP4.5 thereafter

Model outputs available at
http://nomads.gfdl.noaa.gov:8080/DataPortal/cmip5.jsp

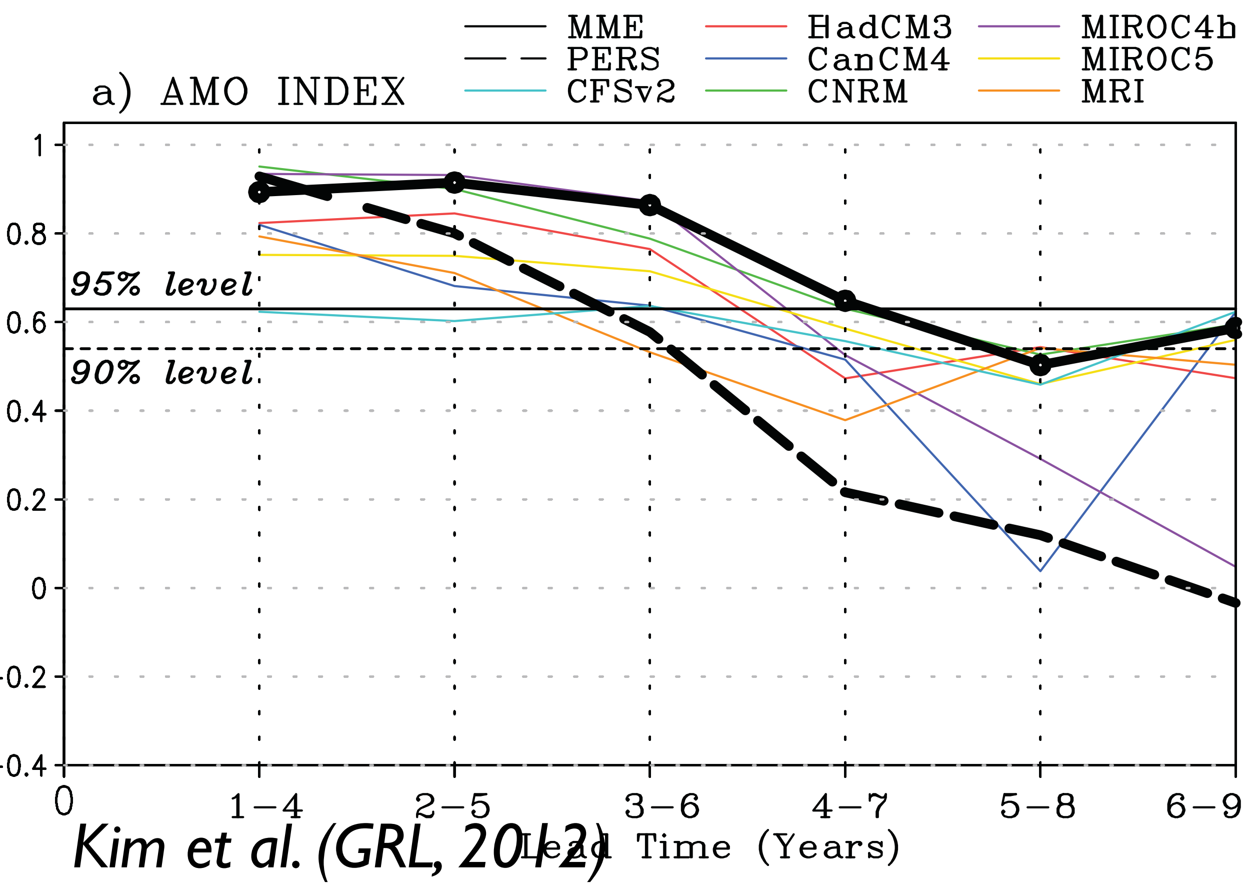
Results: SST anomaly correlations



Red:improvement due to initialization

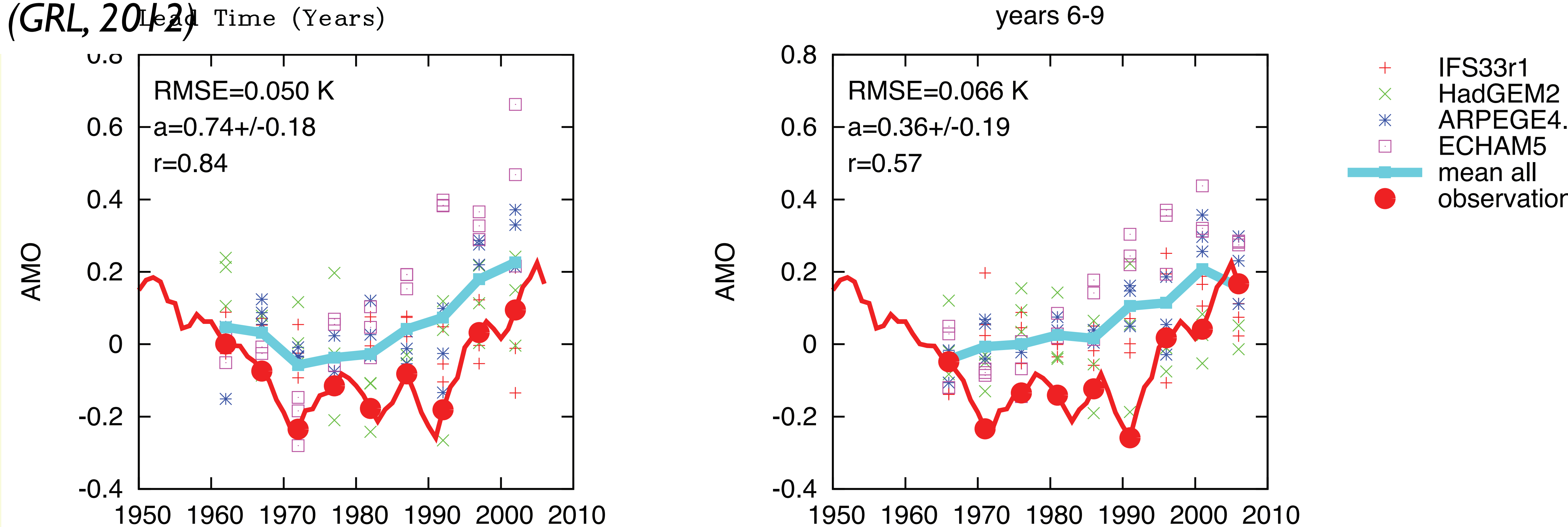
Rosati et al. (2012, submitted)
Yang et al. (2012)

Other CMIP5 results



Kim et al. (GRL, 2012)

Overall good skill in predicting the AMO in CMIP5 models (if measured by correlation). But mainly due to the trend. We don't predict the "swings" we are interested in

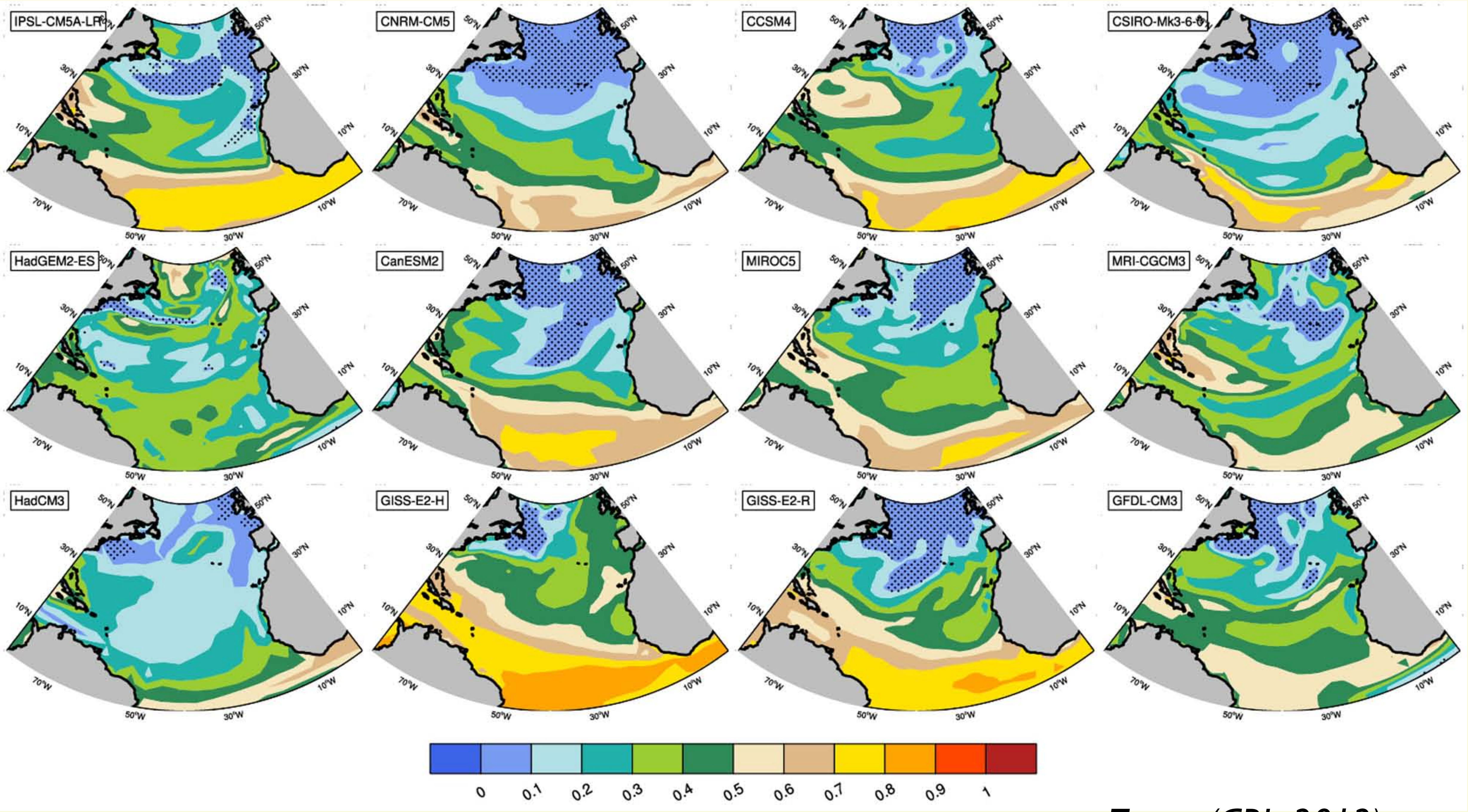


Van Oldenborgh et al. (Clim. Dyn 2011)

Other CMIP5 results

Largest impact on the improvement in AMO related skill over the area where the Atlantic SPG operates (Garcia Serrano et al. GRL 2012)

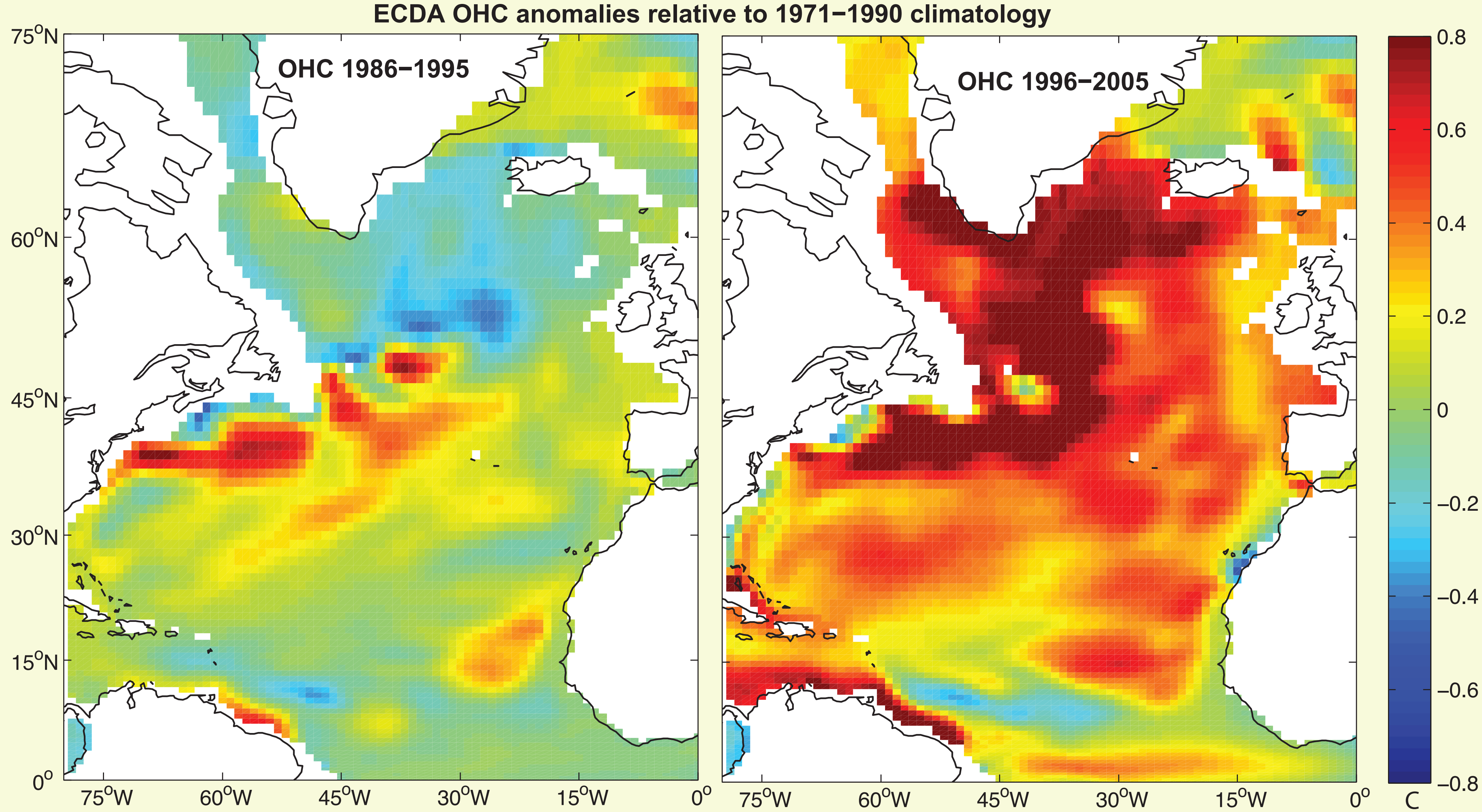
Internal variability is the main driver of subpolar NA SST changes in the CMIP5 projections
Strongest signal to noise ratio likely to be found there

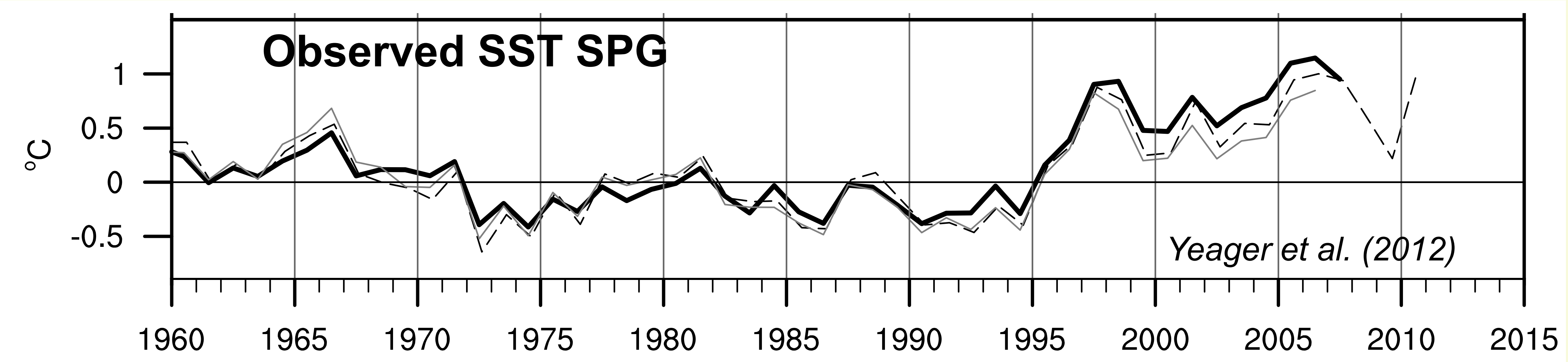


Forced variance/decadal variance

Terray (GRL, 2012)
Ting et al. (JOC 2009)

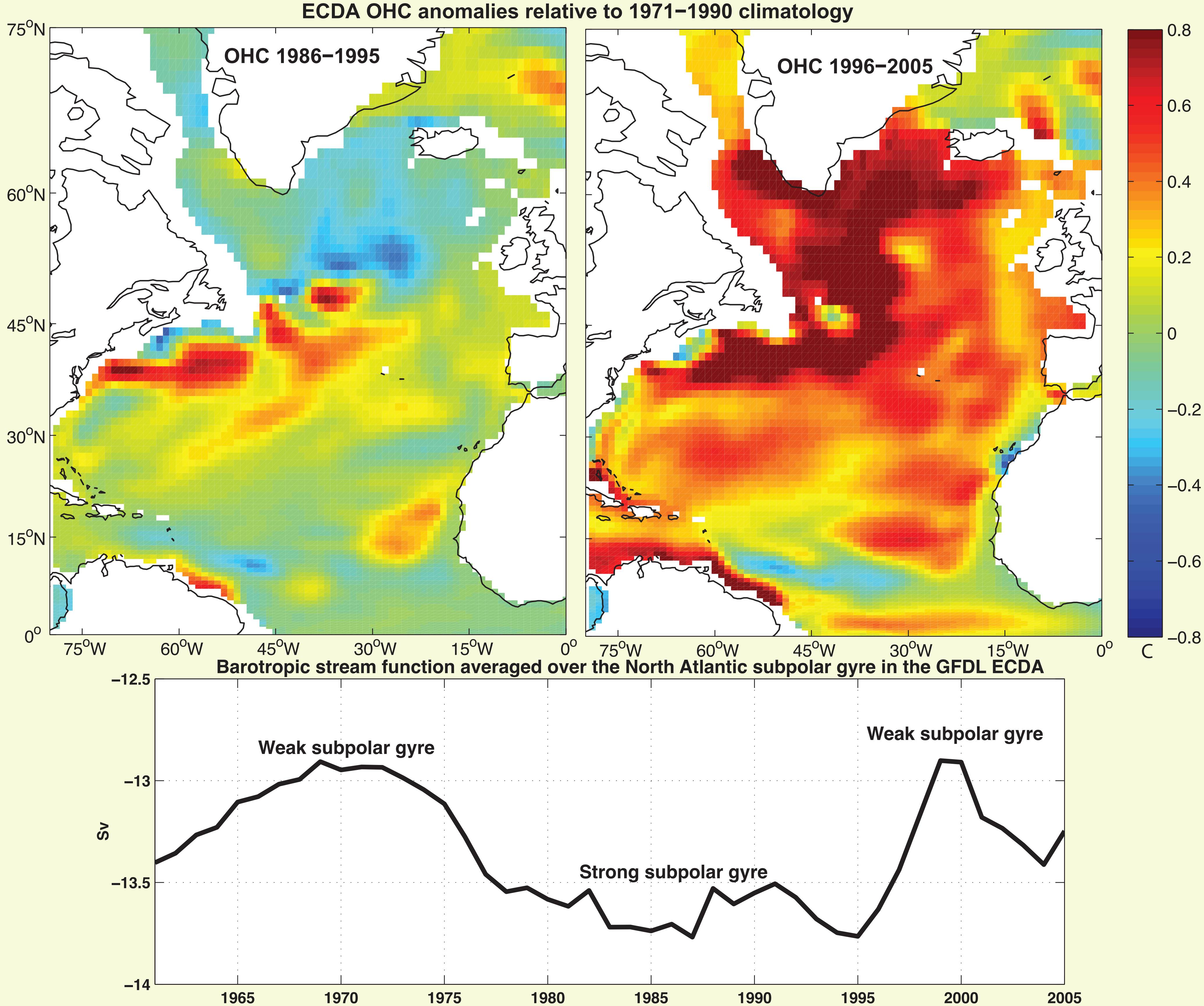
An interesting case study: the 1995 Subpolar gyre abrupt warming





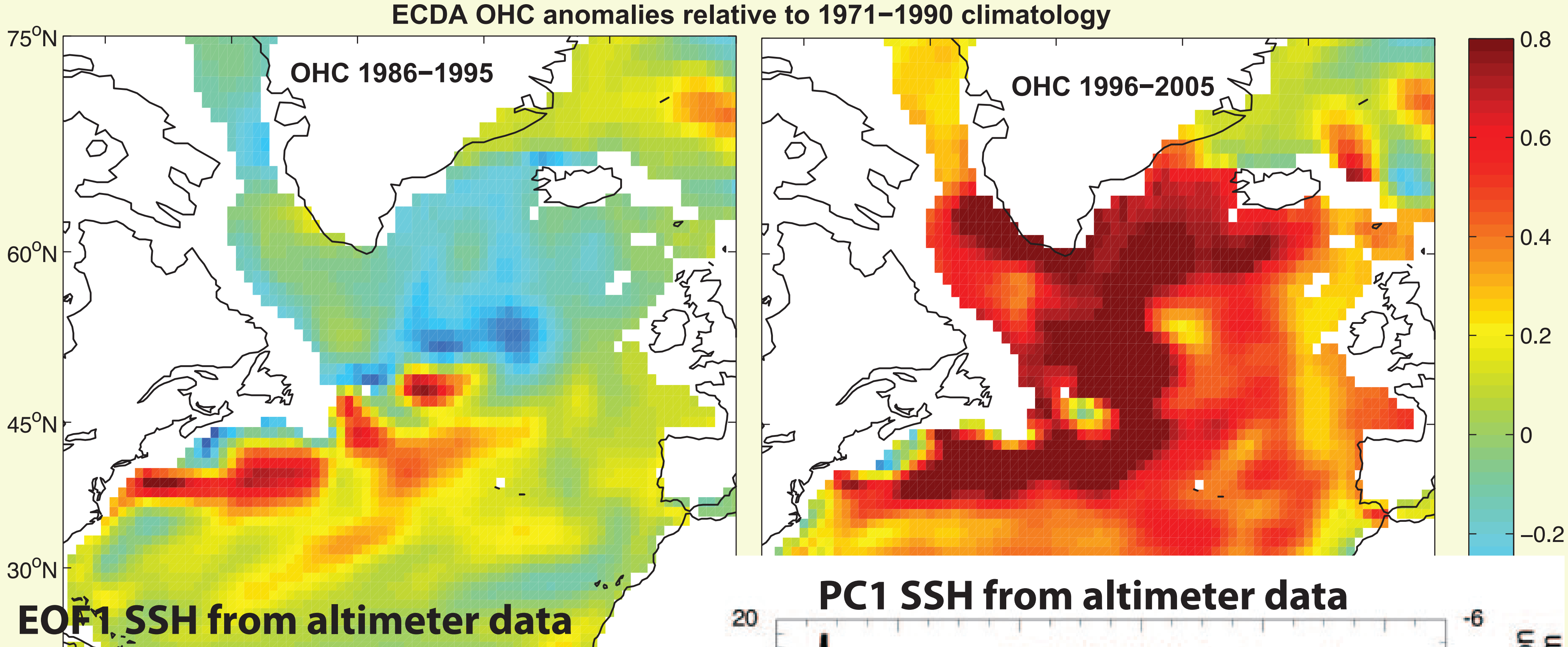
Observed warming of the North Atlantic subpolar gyre after 1995

An interesting case study: the 1995 Subpolar gyre abrupt warming

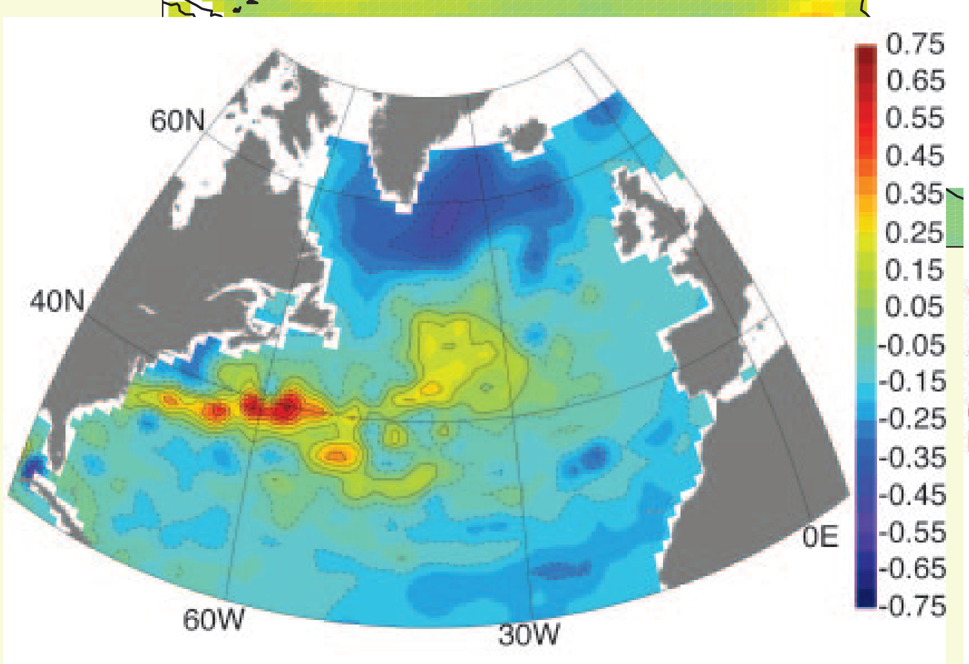


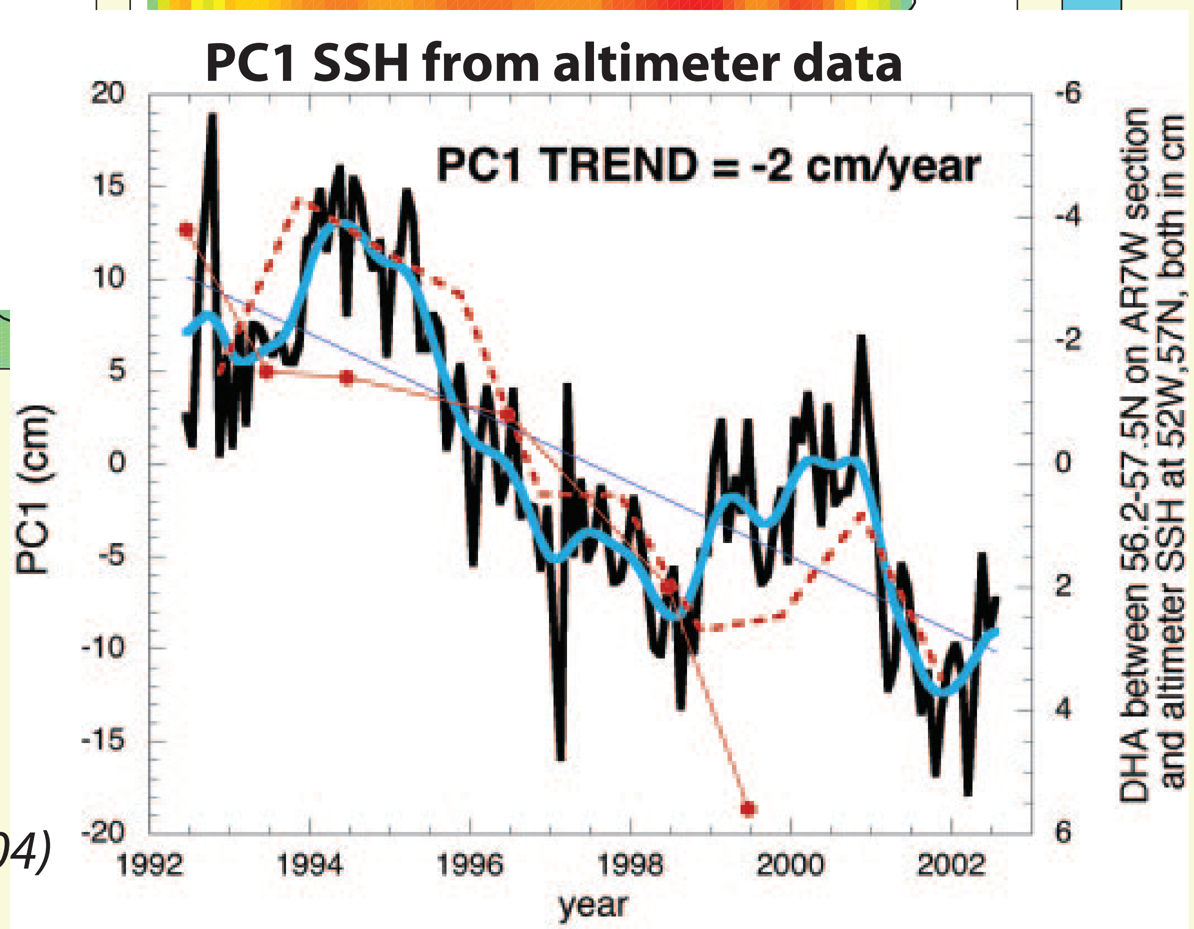
and decline of the SPG circulation after 1995

An interesting case study: the 1995 Subpolar gyre abrupt warming



EOF1 SSH from altimeter data



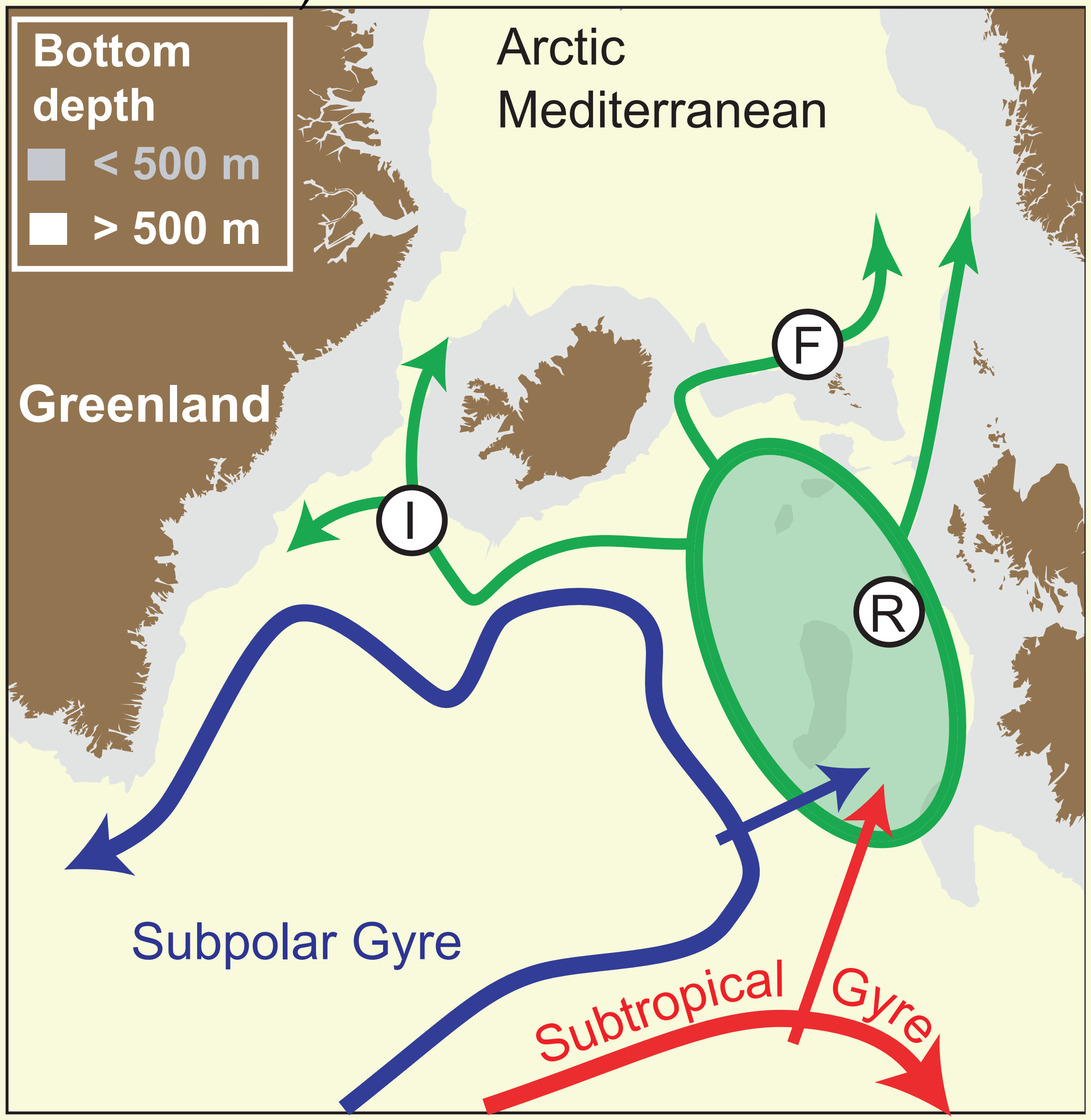


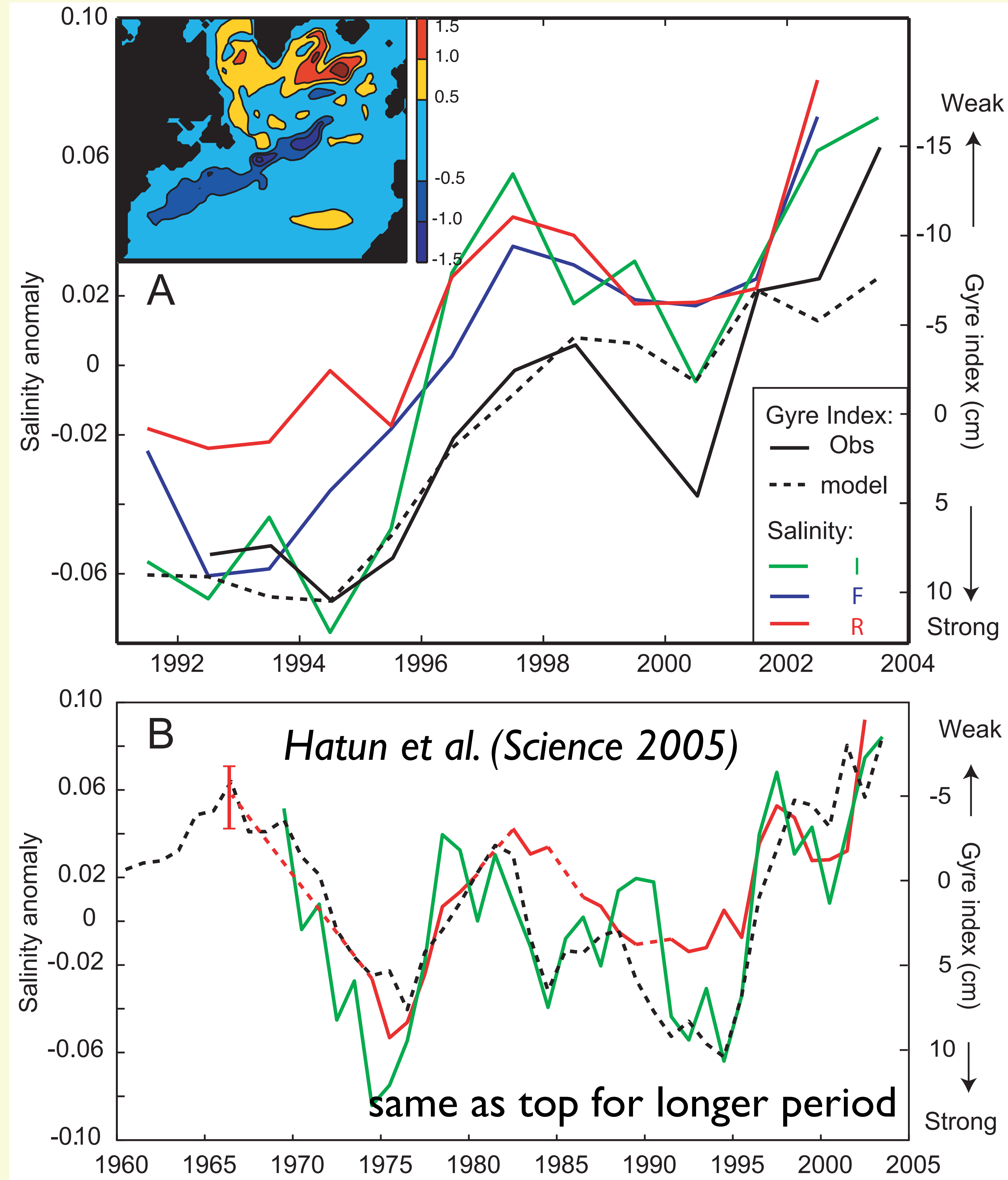
from Hakkinen and Rhines (2004)

seen in altimetry

Hatun et al. (Science 2005)

Observed shift in surface salinity



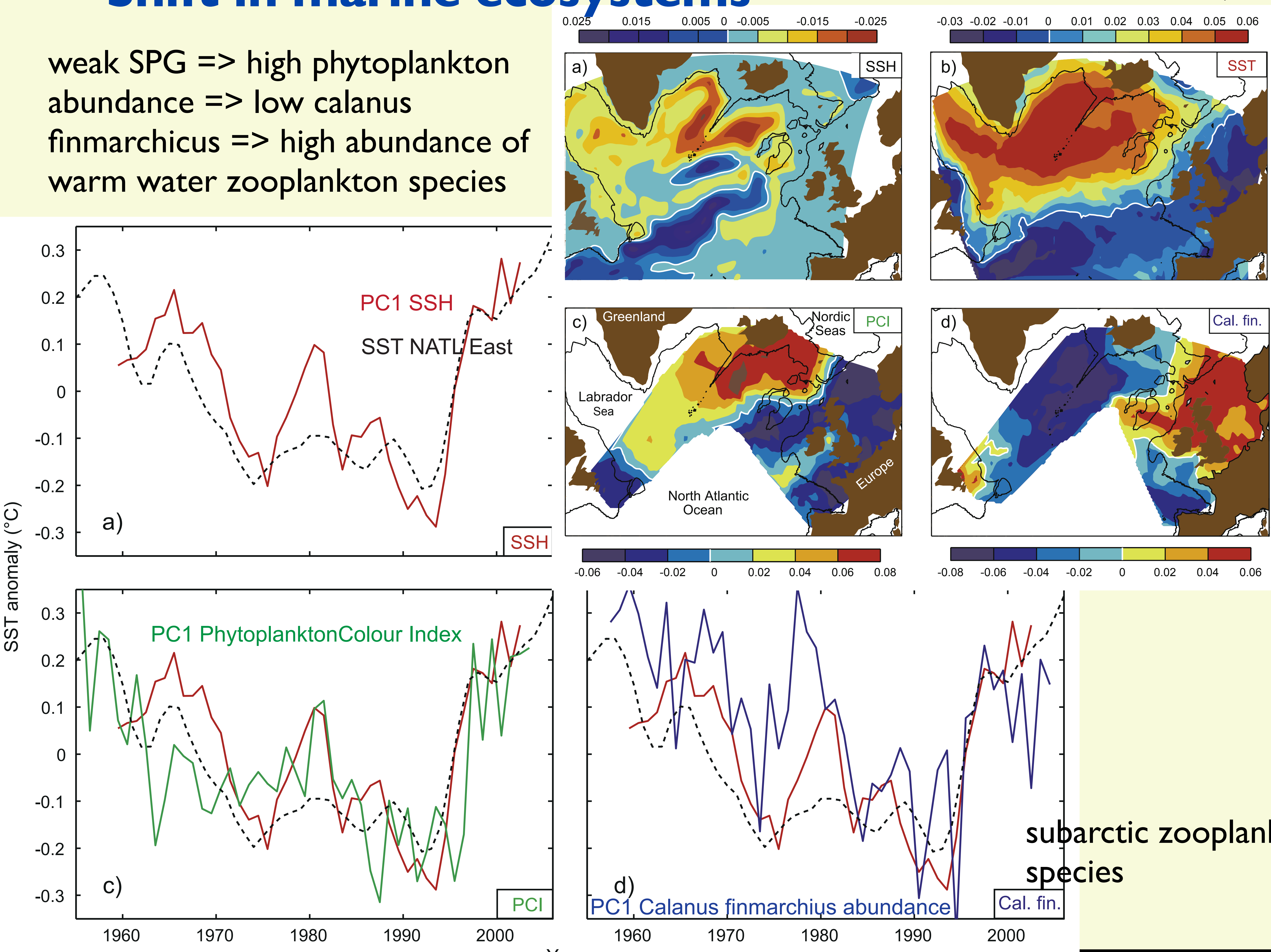


Observed increase in salinity since 1996 in inflow areas R,F,I (Holliday et al. 2008). Cannot be explained by surface fluxes. Requires changes in circulation that bring more saline and warm water masses to the region. Hatun et al. (2005) showed that it could be due to dynamic changes in the relative contributions of the two gyres.

Shift in marine ecosystems

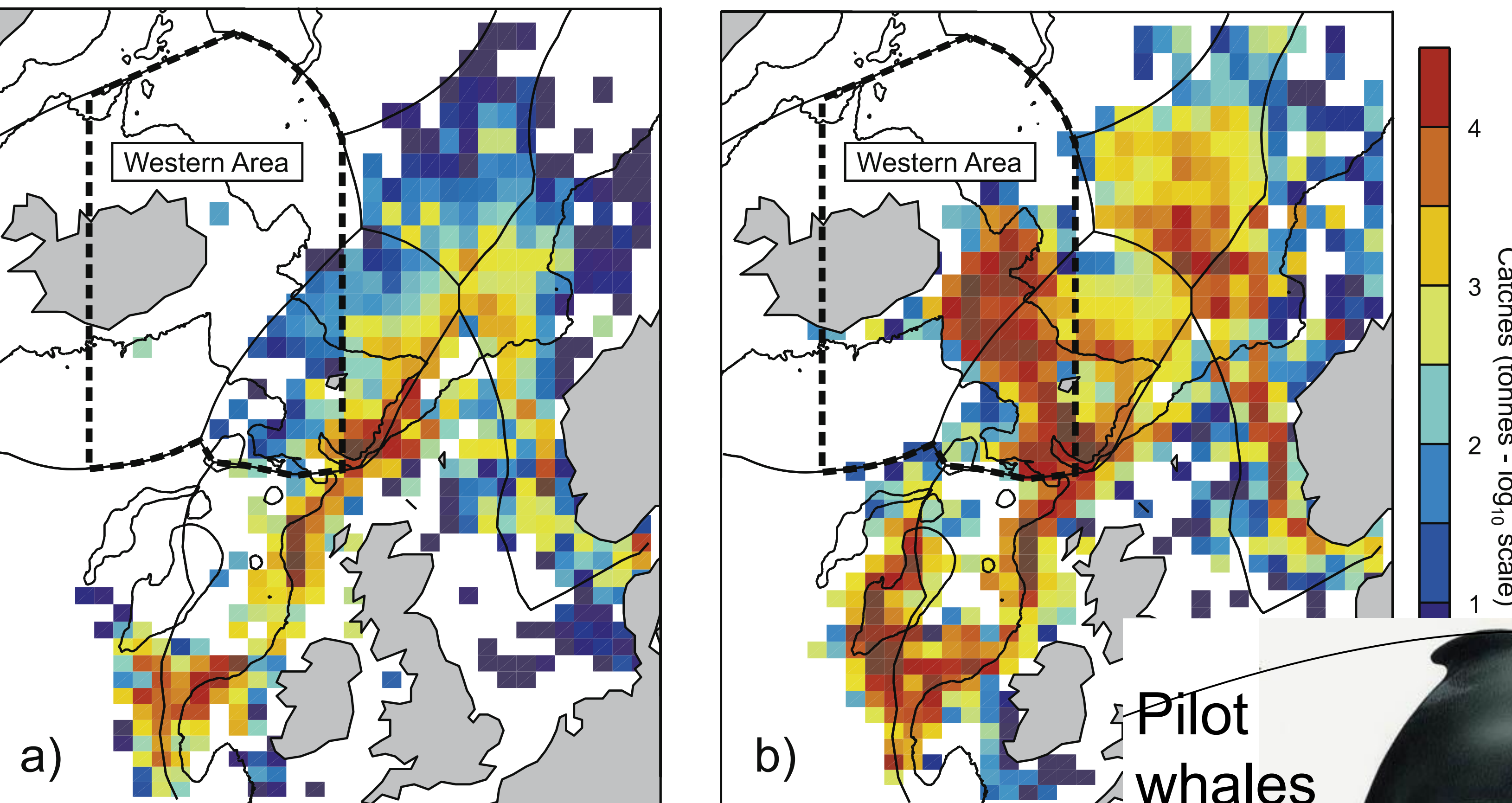
Hatun et al. (PO 2009)

weak SPG => high phytoplankton abundance => low calanus finmarchicus => high abundance of warm water zooplankton species



subarctic zooplankton species

Shift in marine ecosystems



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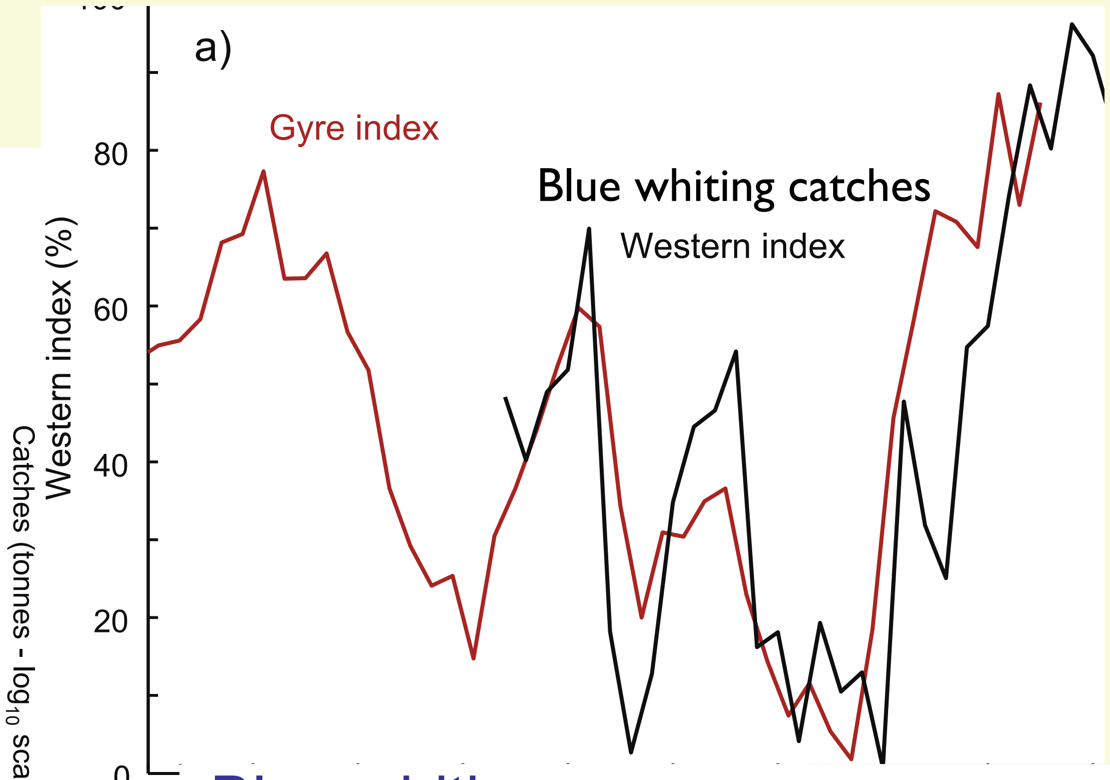
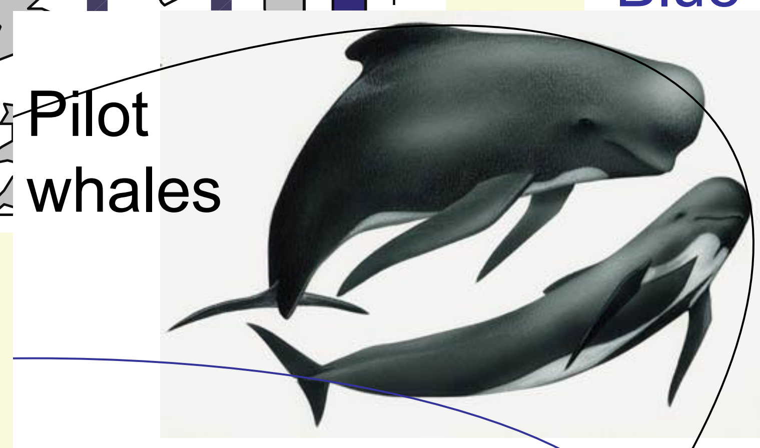
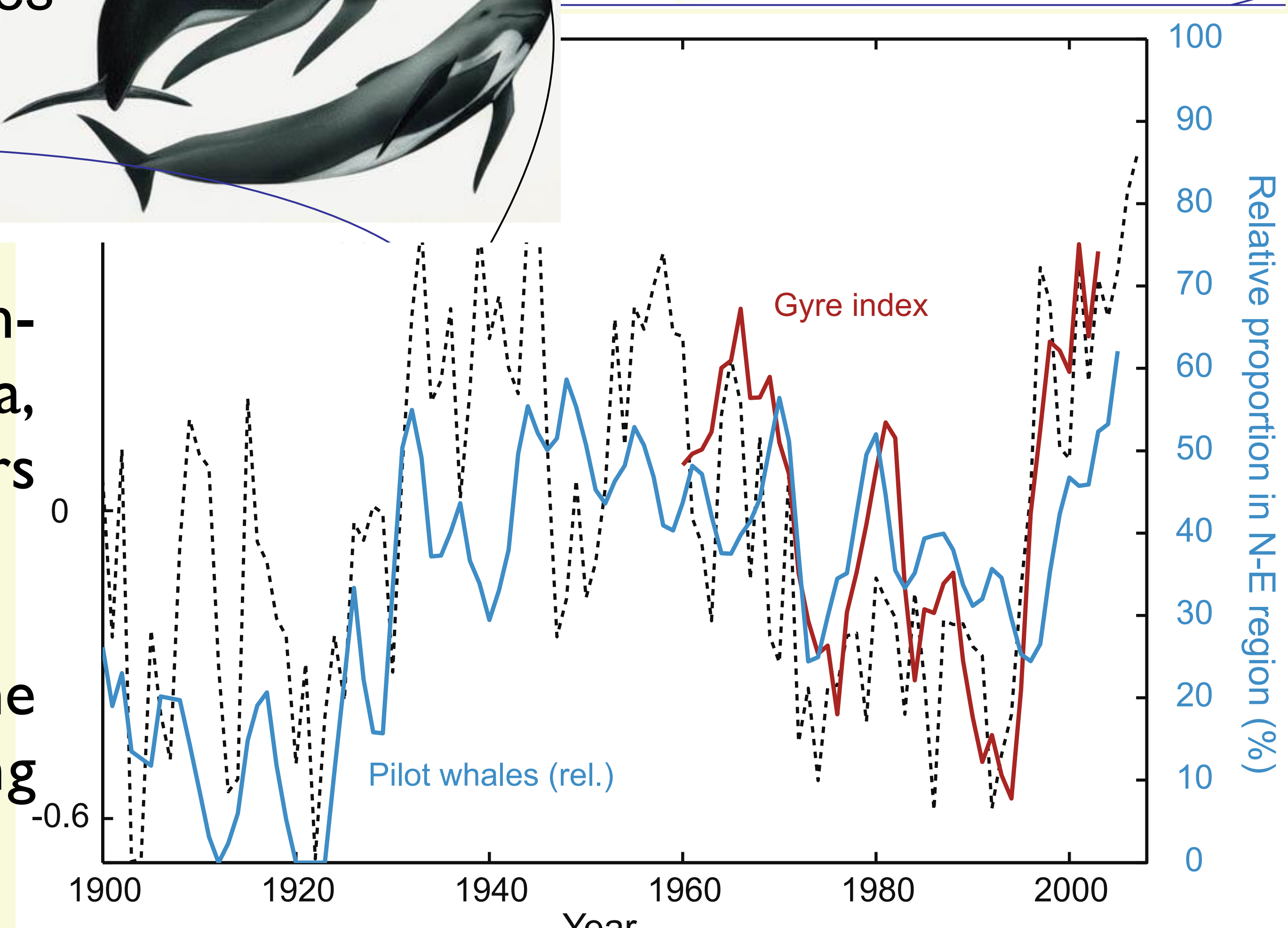






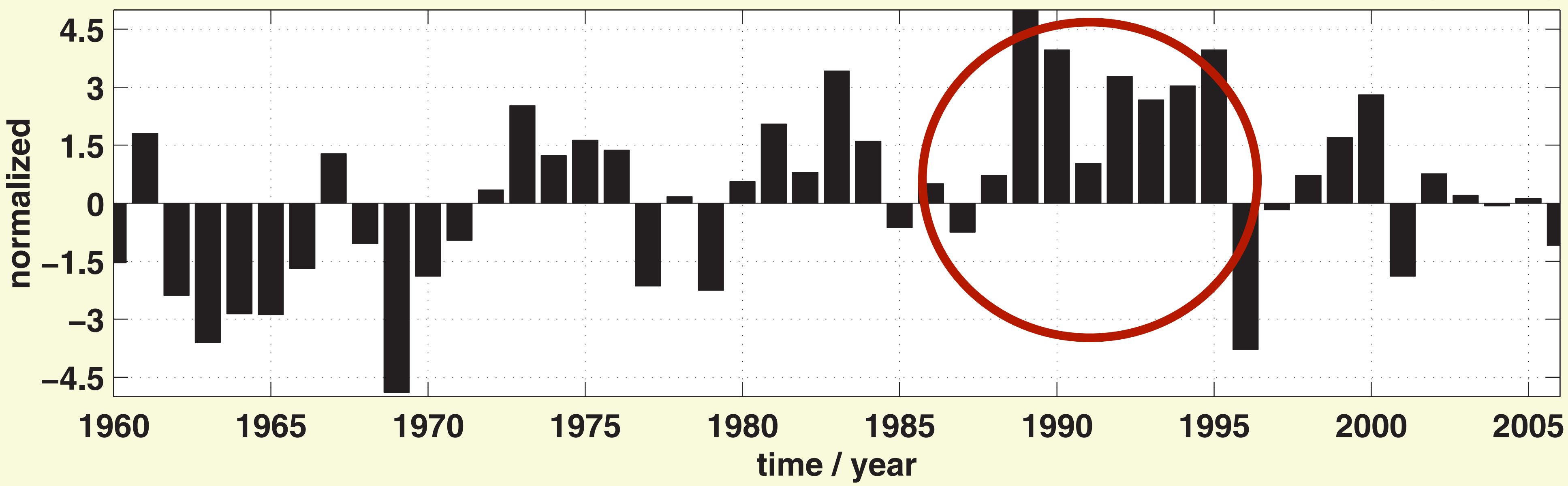
Negligible catches of blue whiting during high-gyre index (1990-1995) in the western area, large catches during the low-gyre index years (1998-2003)

Total catches covary with western index.

Not limited by political regulations, reflects the temporal variability of the blue whiting migration pattern

What happened in 1995?

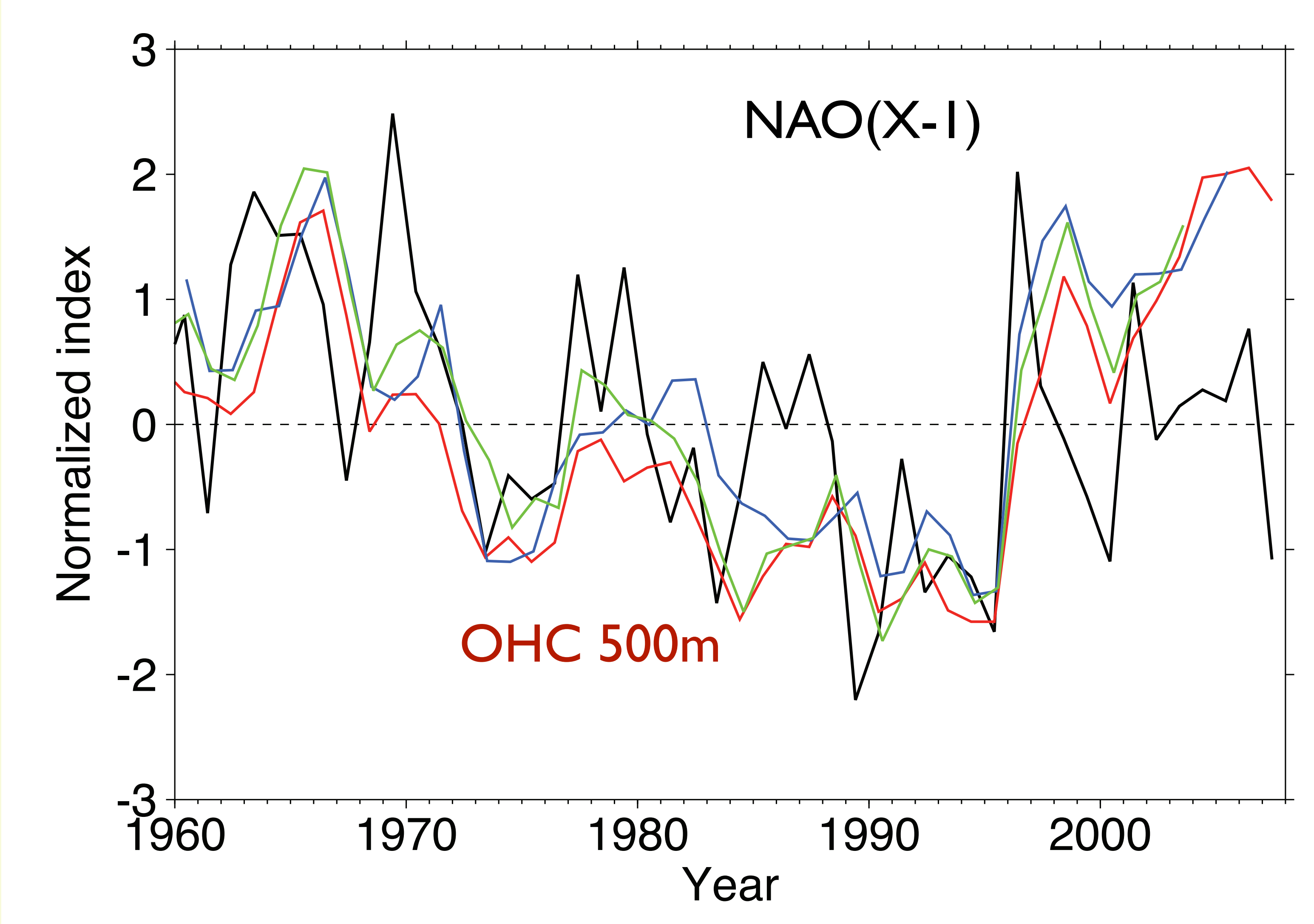
Observed NAO index *from Lohmann et al. (2009)*



Instantaneous response to the NAO decline?

Or lagged response to the positive NAO?

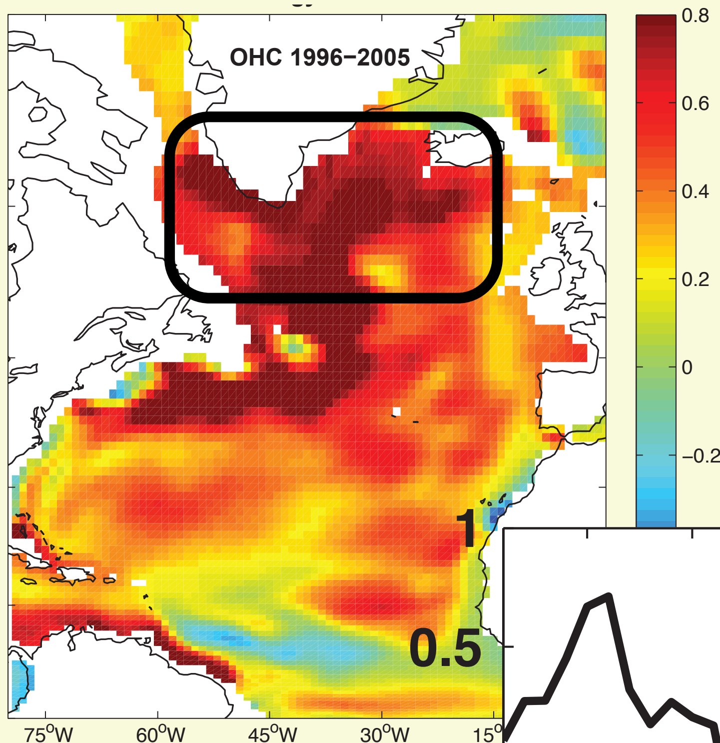
AMOC



Robson et al. (JOC 2012)

Srokosz et al. (BAMS,2012)

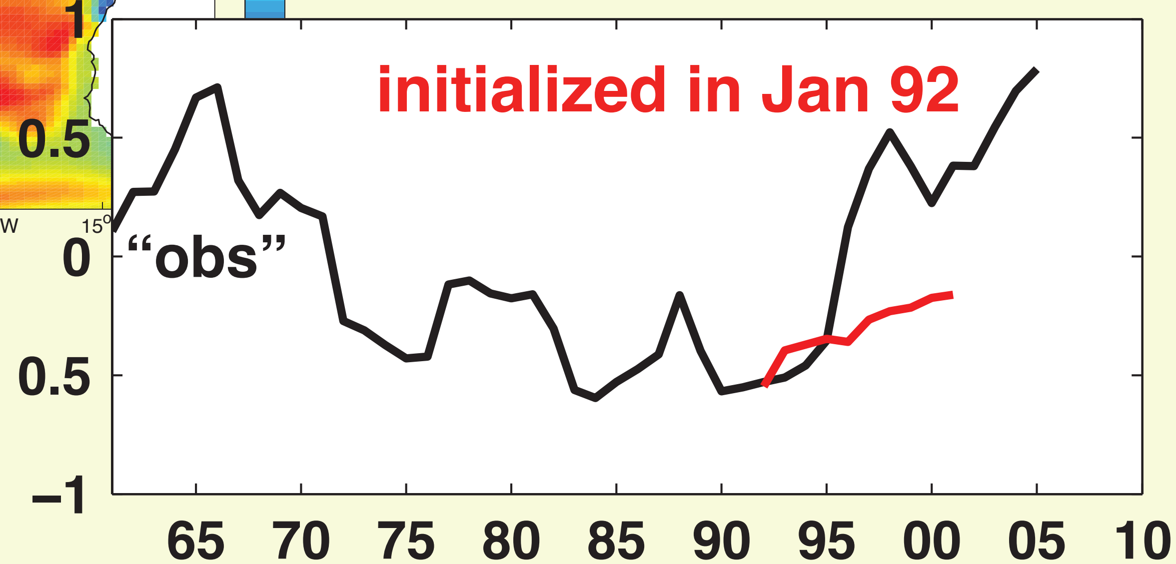
Results: OHC predictions

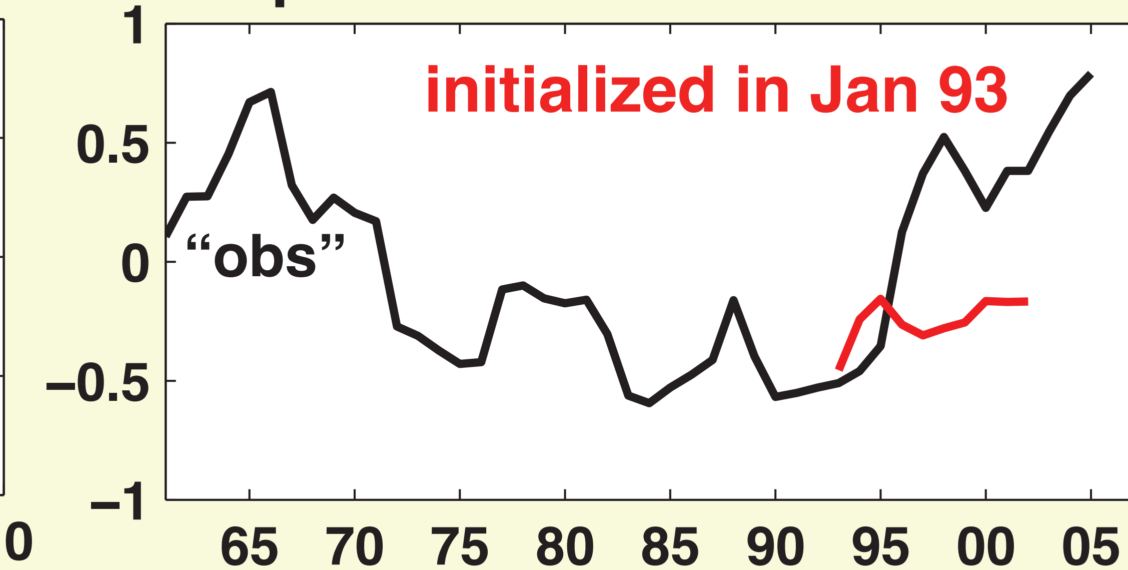


SPG box
(50W-10W;50N-65N)

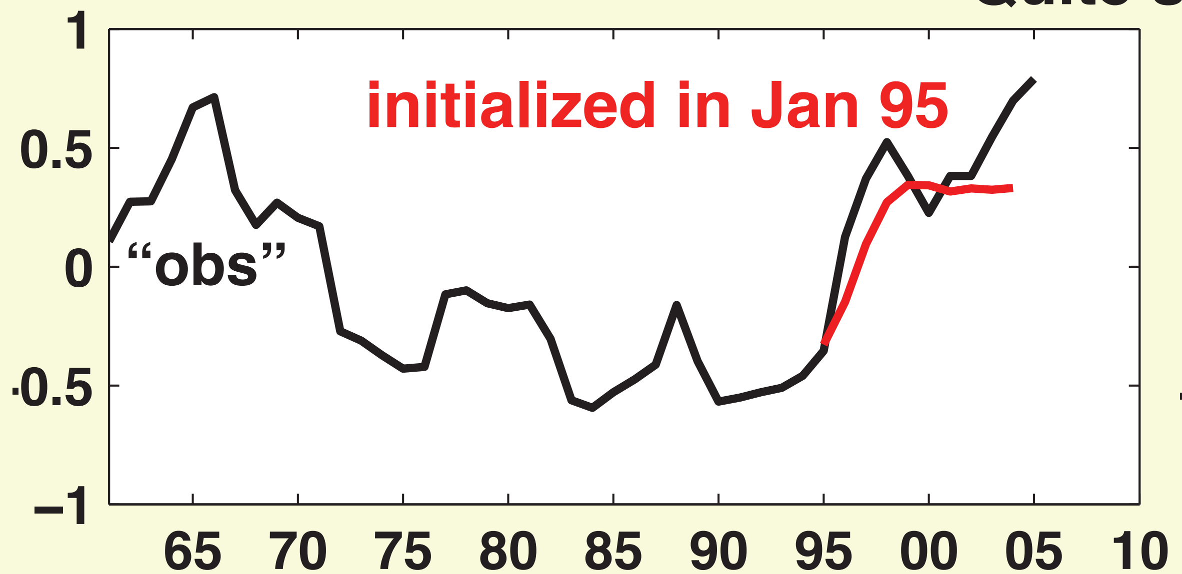
Upper 600m anomalies
(seasonal cycle removed)

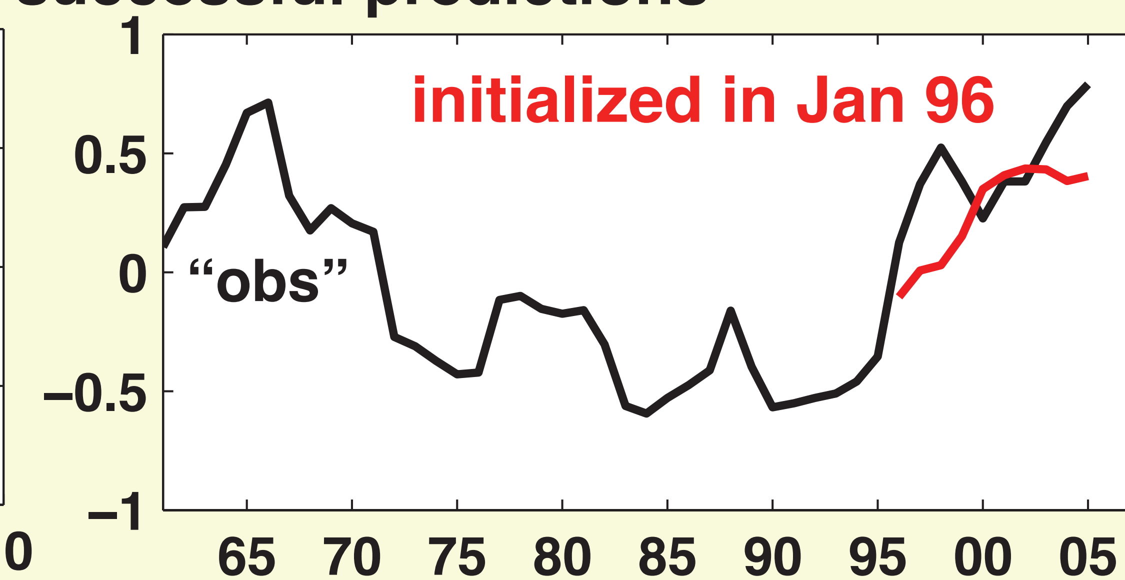
Unsuccessful predictions





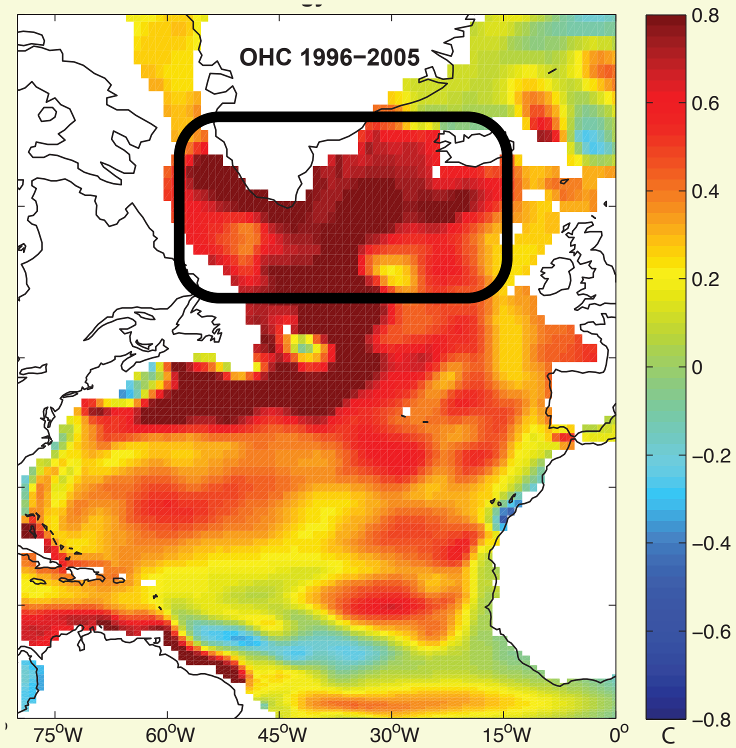
Quite successful predictions



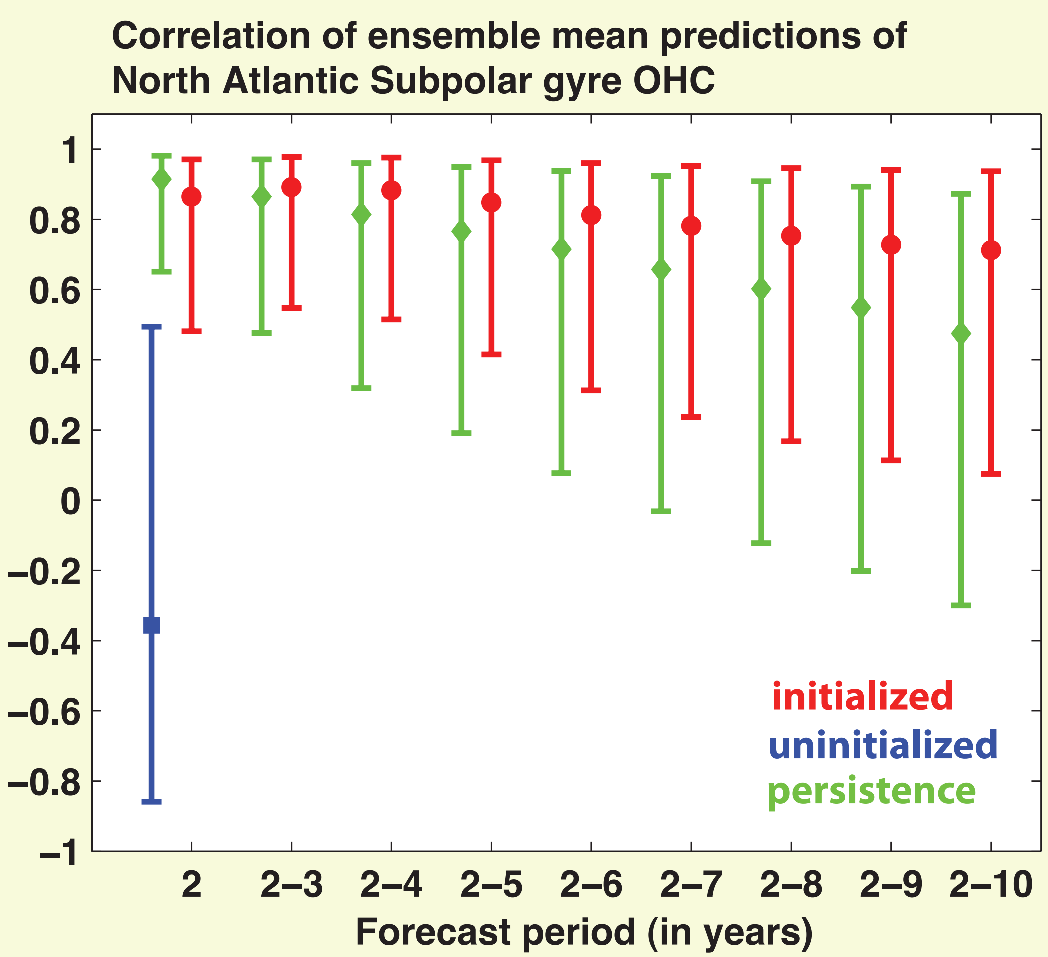


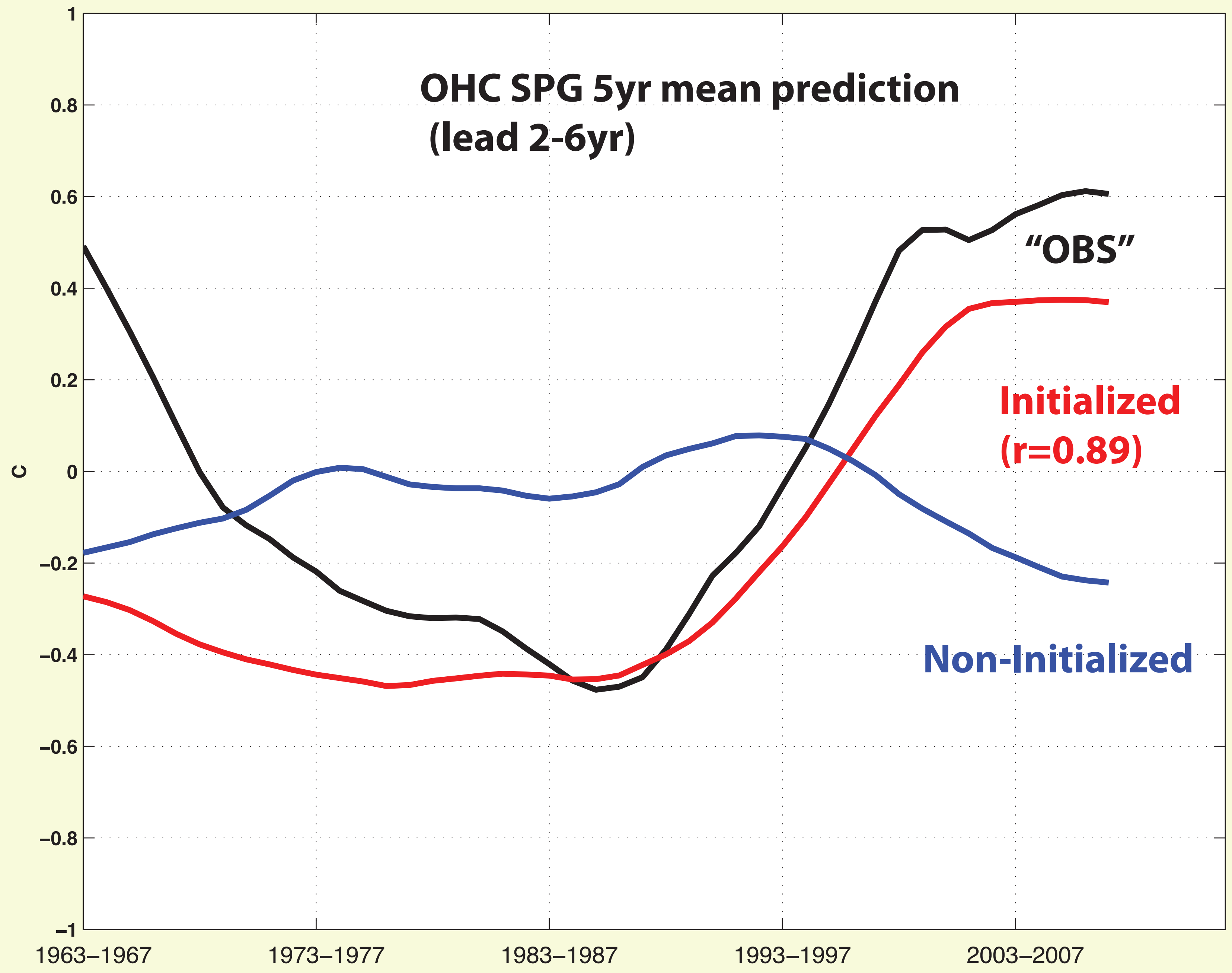
Successful prediction in 1995. Do we get it for the right reasons?
Why aren’t the other predictions successful?

Results: OHC predictions



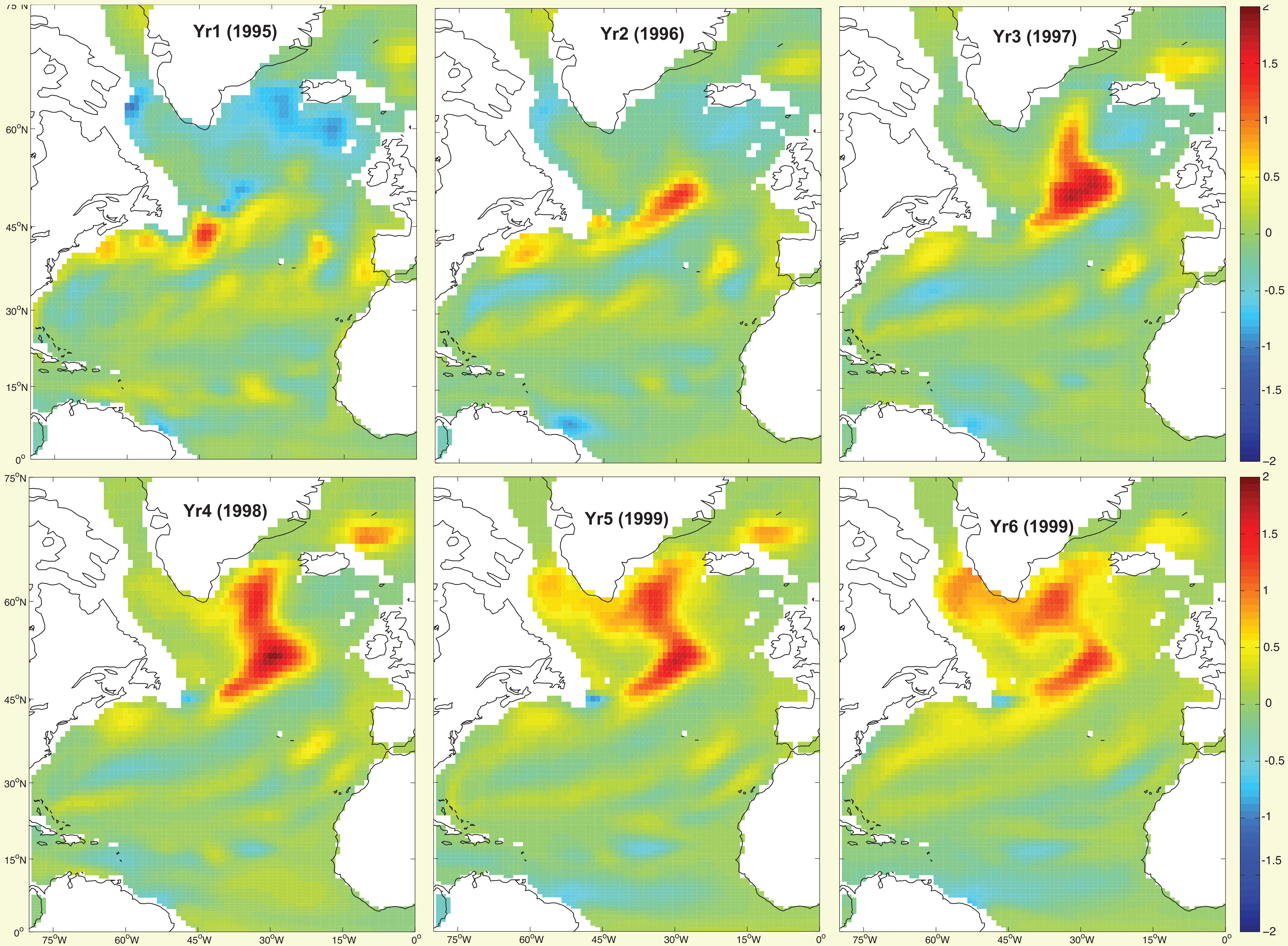
SPG box





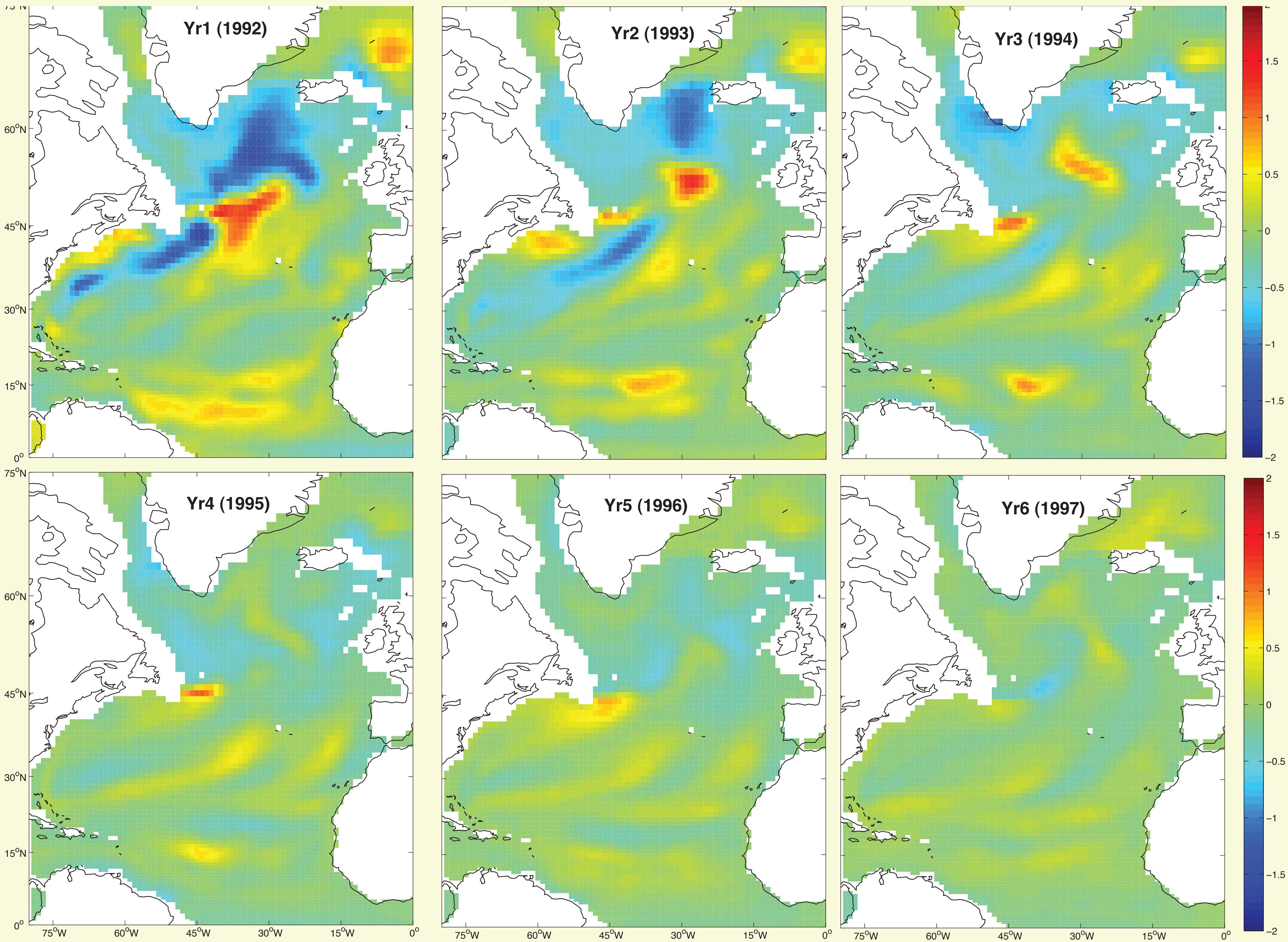
Not predicted by the non-initialized experiments.
Suggests internally driven mechanism rather than radiatively forced

Predicted OHC after 1995 initialization



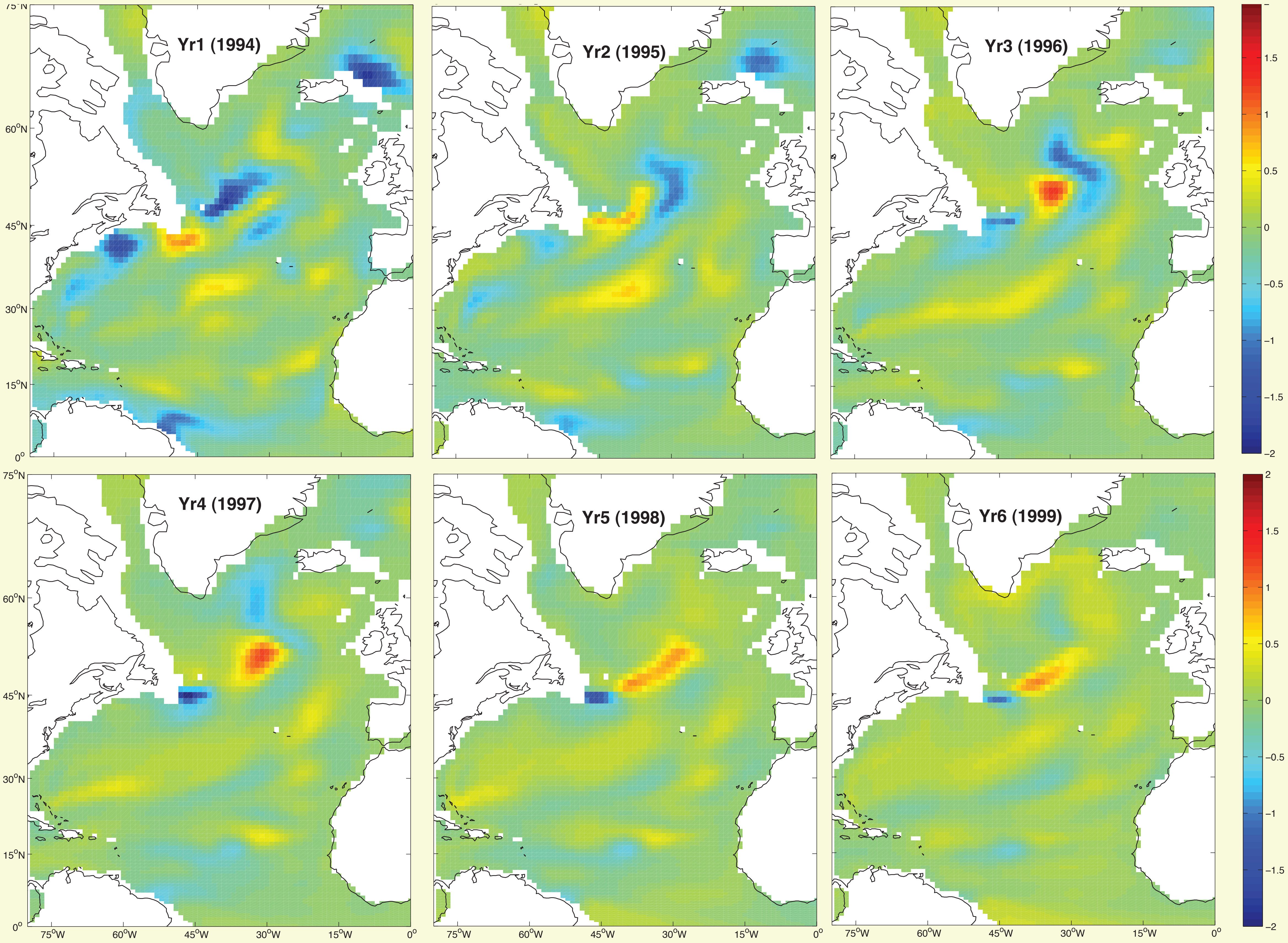
OHC evolution suggests advection from subtropics. AMOC-driven?

Predicted OHC after 1992 initialization



No sign of large-scale warming in the other predictions initialized before 1995

Predicted OHC after 1994 initialization

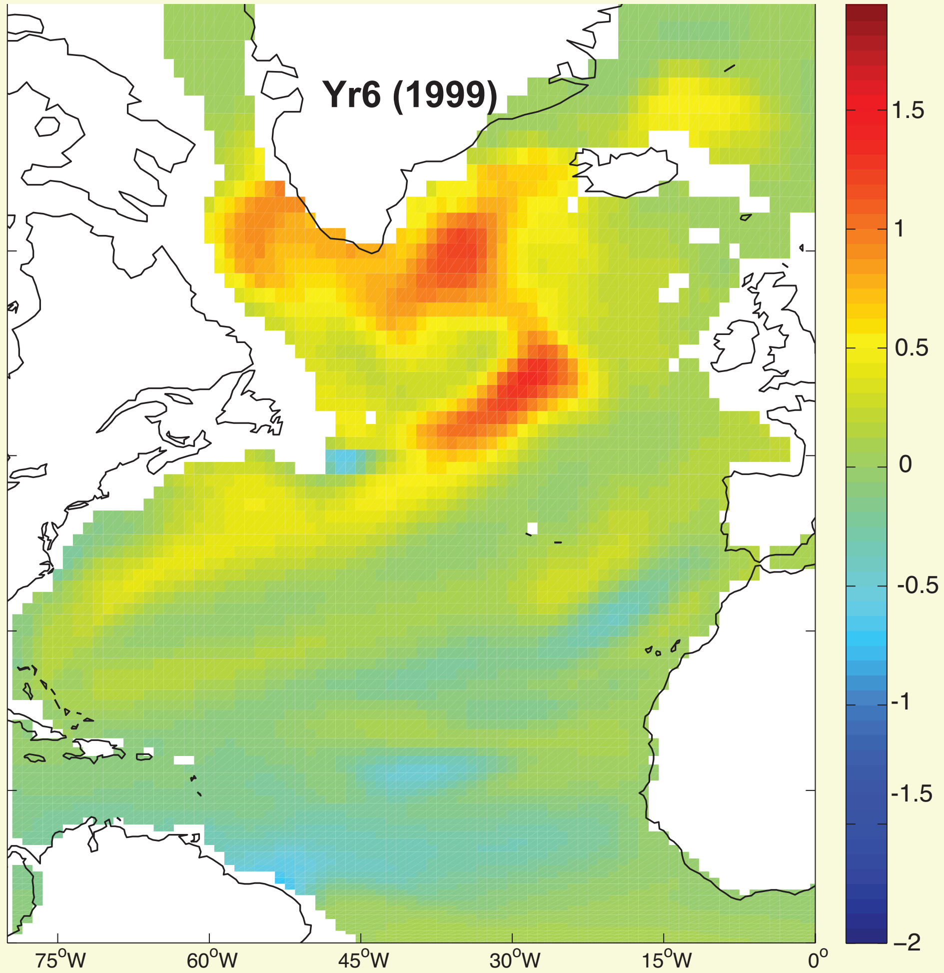


No sign of large-scale warming in the other predictions initialized before 1995

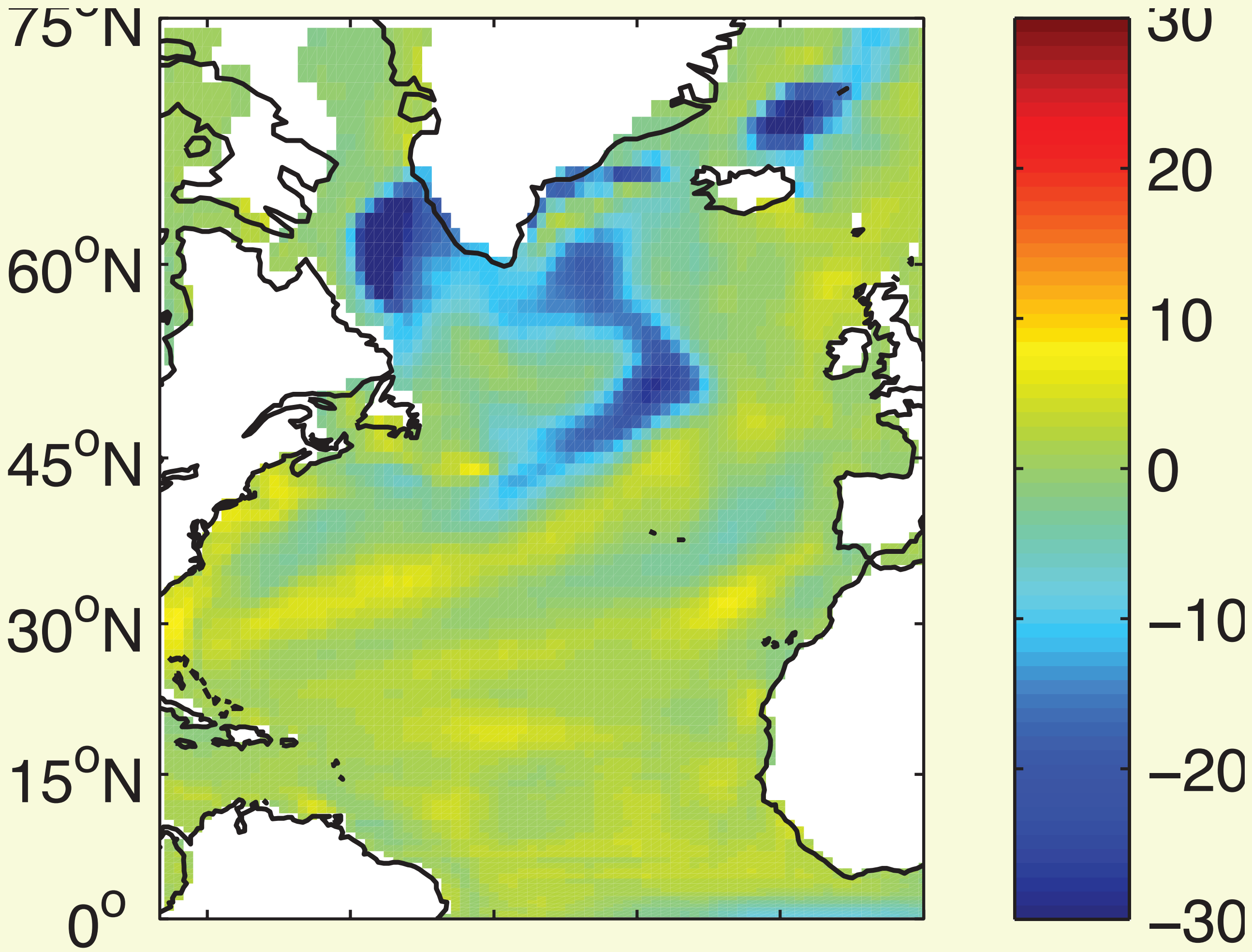
Can it be because the NAO switched sign in 1995 and the warming is just the response to NAO-Qfluxes?

No

OHC predicted 6 yrs after 1995 initialization



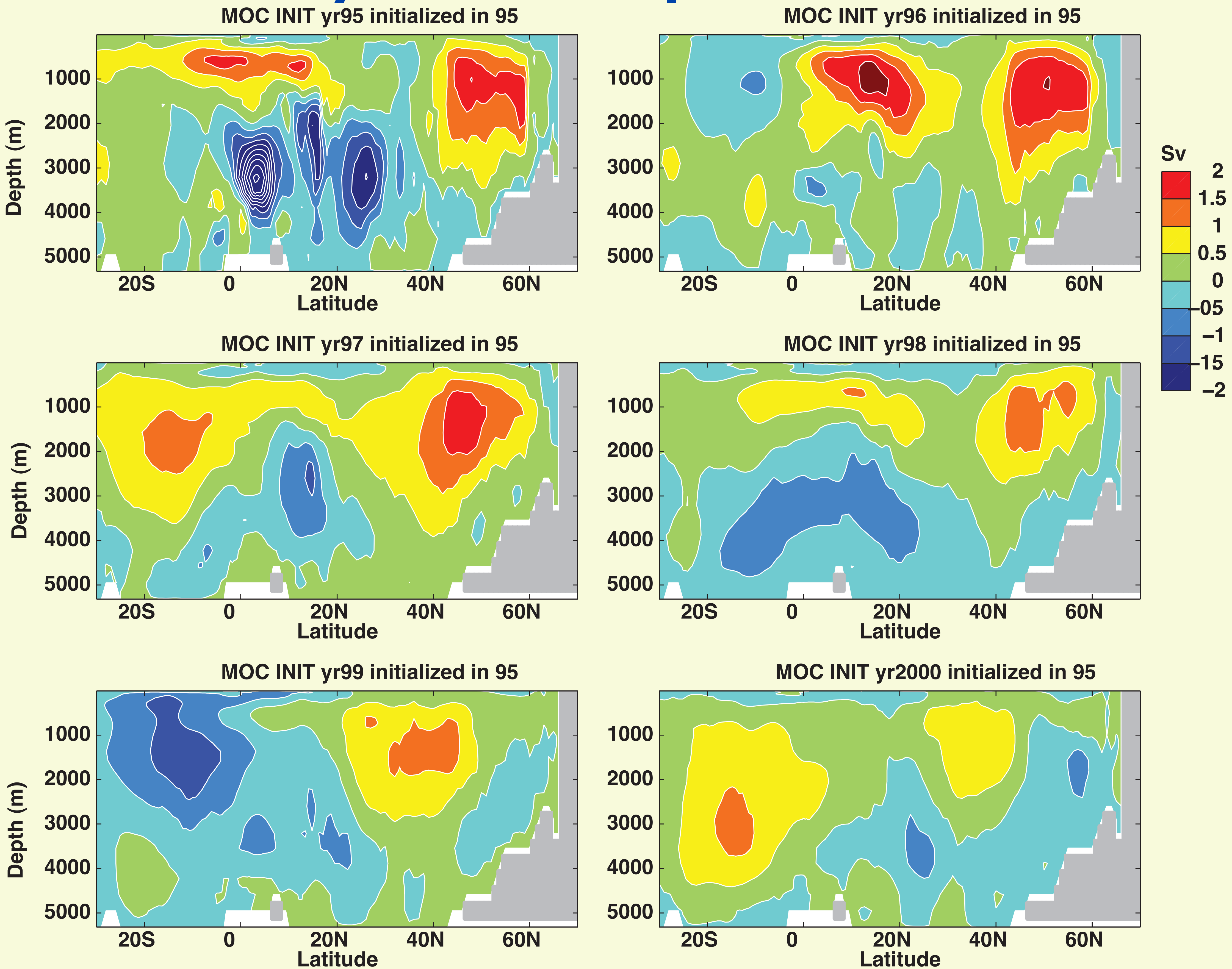
Qflux predicted 6 yrs after 1995 initialization



Surface heat flux damps the warm anomalies, does not create them

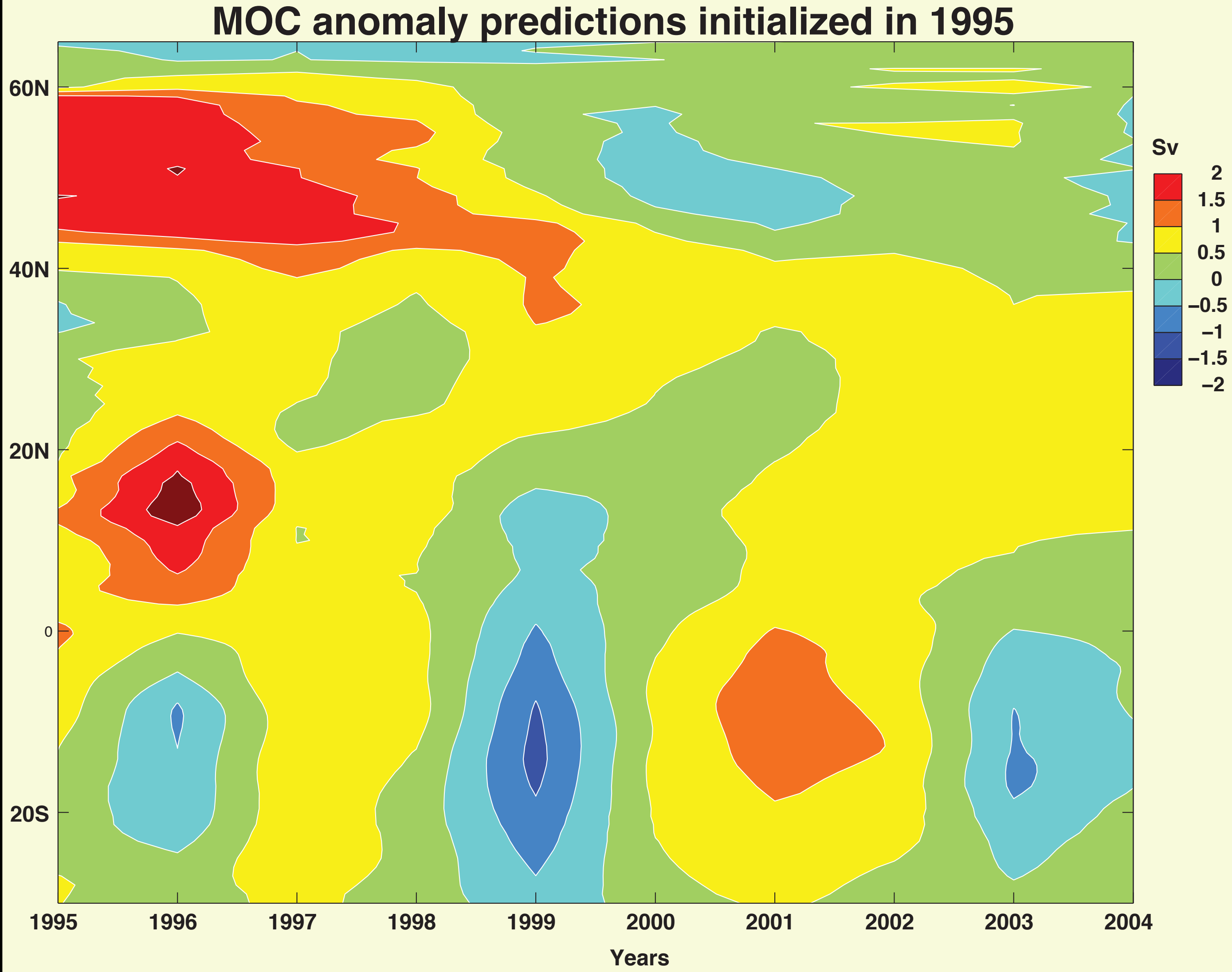
Same at all lead times following 1995 initialization

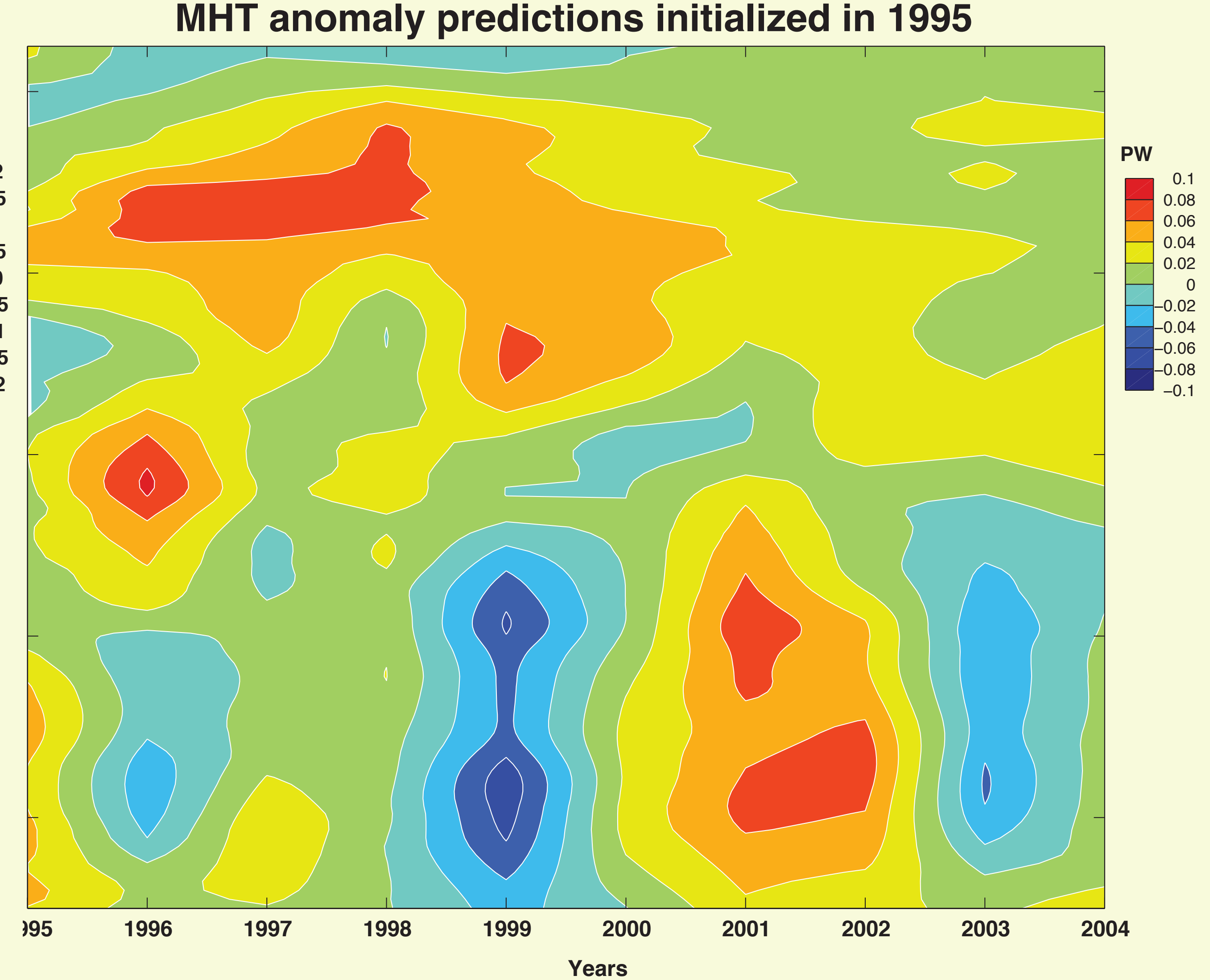
Dynamical response to AMOC?

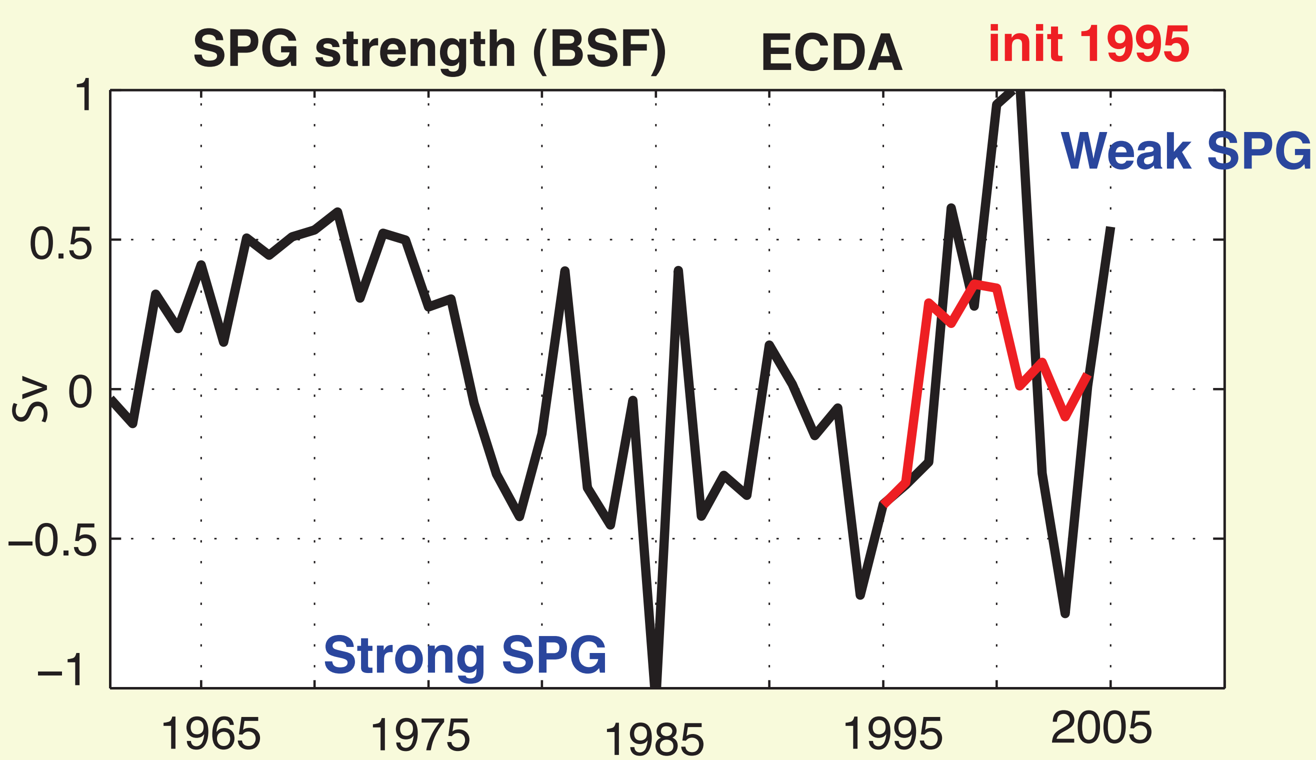


Anomalously high AMOC predicted at high latitudes after 1995 initialization: persists many years and propagates southward

Dynamical response to the 1995 initialization





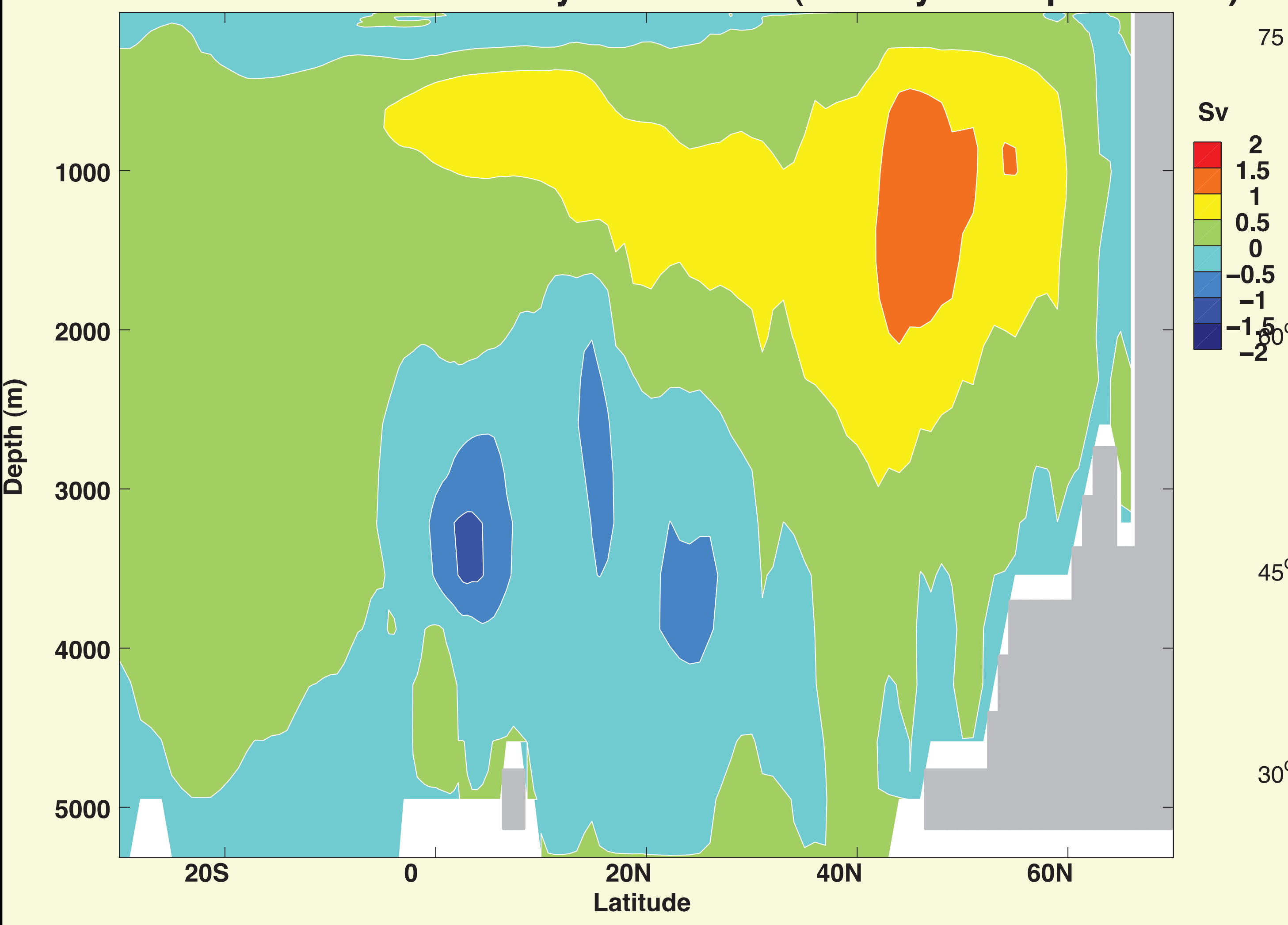


AMOC anomalies associated with enhanced northward transport of heat (and salt)

Weakening of the SPG predicted by the 1995 forecast

Dynamical response to the 1995 initialization

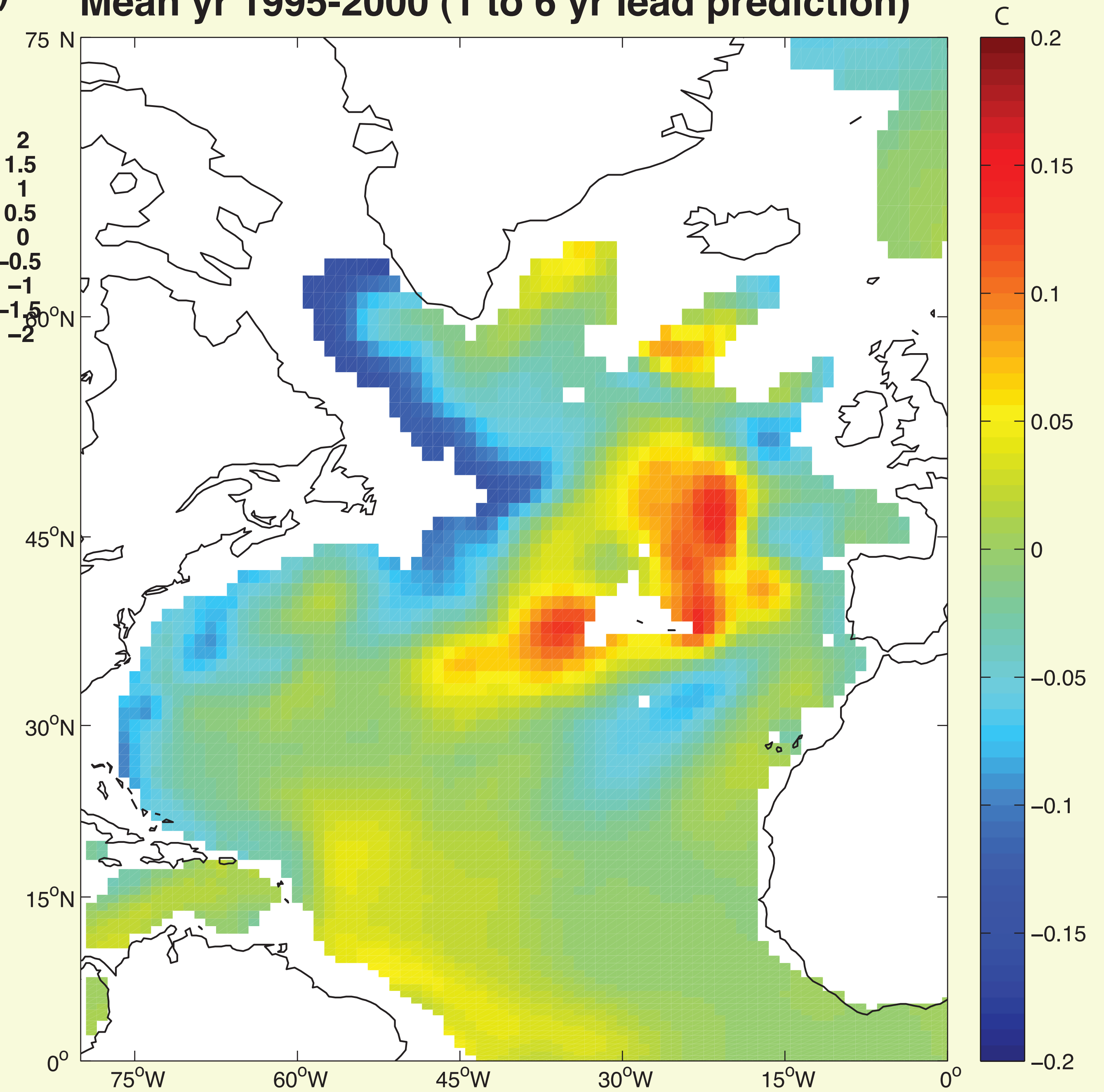
MOC initialized in 1995. Mean yr 1995-2000 (1 to 6 yr lead prediction)



Anomalous AMOC predicted after 1995 initialization and southward propagation of AMOC anomalies

Only for 1995 start

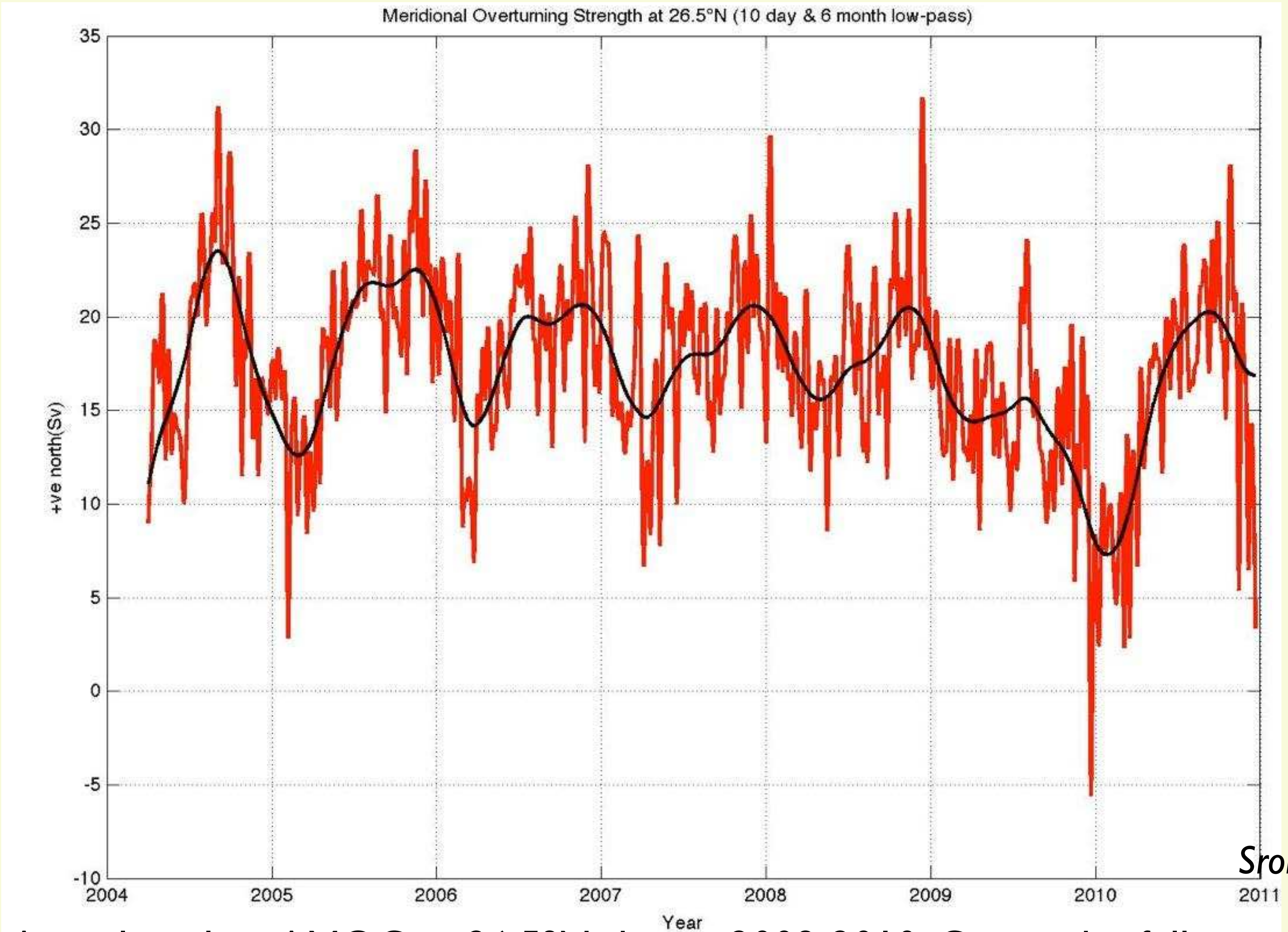
Deep temperature (1000-2500m) initialized in 1995
Mean yr 1995-2000 (1 to 6 yr lead prediction)



The predictions show cold anomalies at depth propagating along the DWBC: enhanced Labrador Sea water formation

Does it mean we can predict the AMOC?

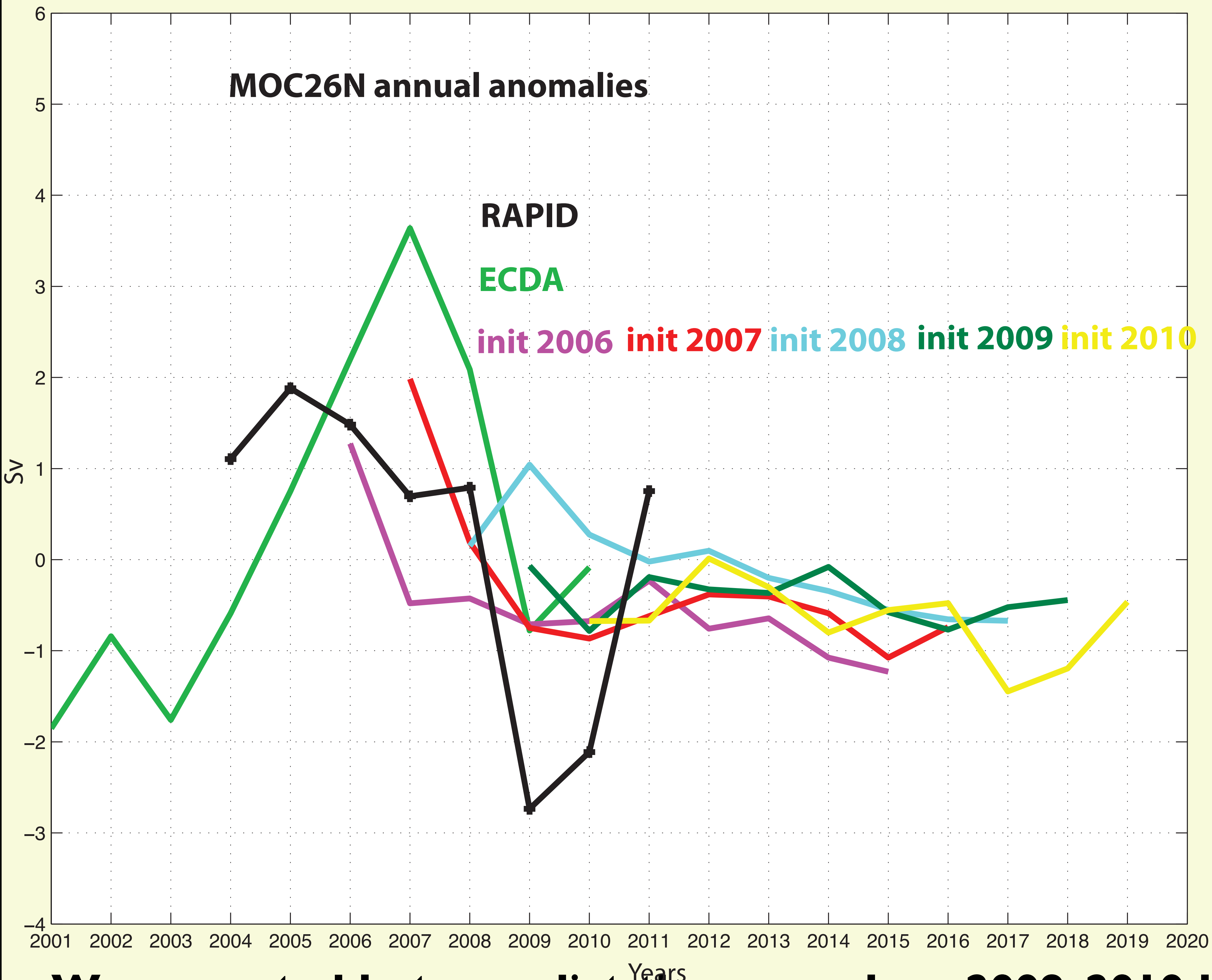
Another case study:AMOC decline in 2009-2010



Srokosz et al. (BAMS, 2012)

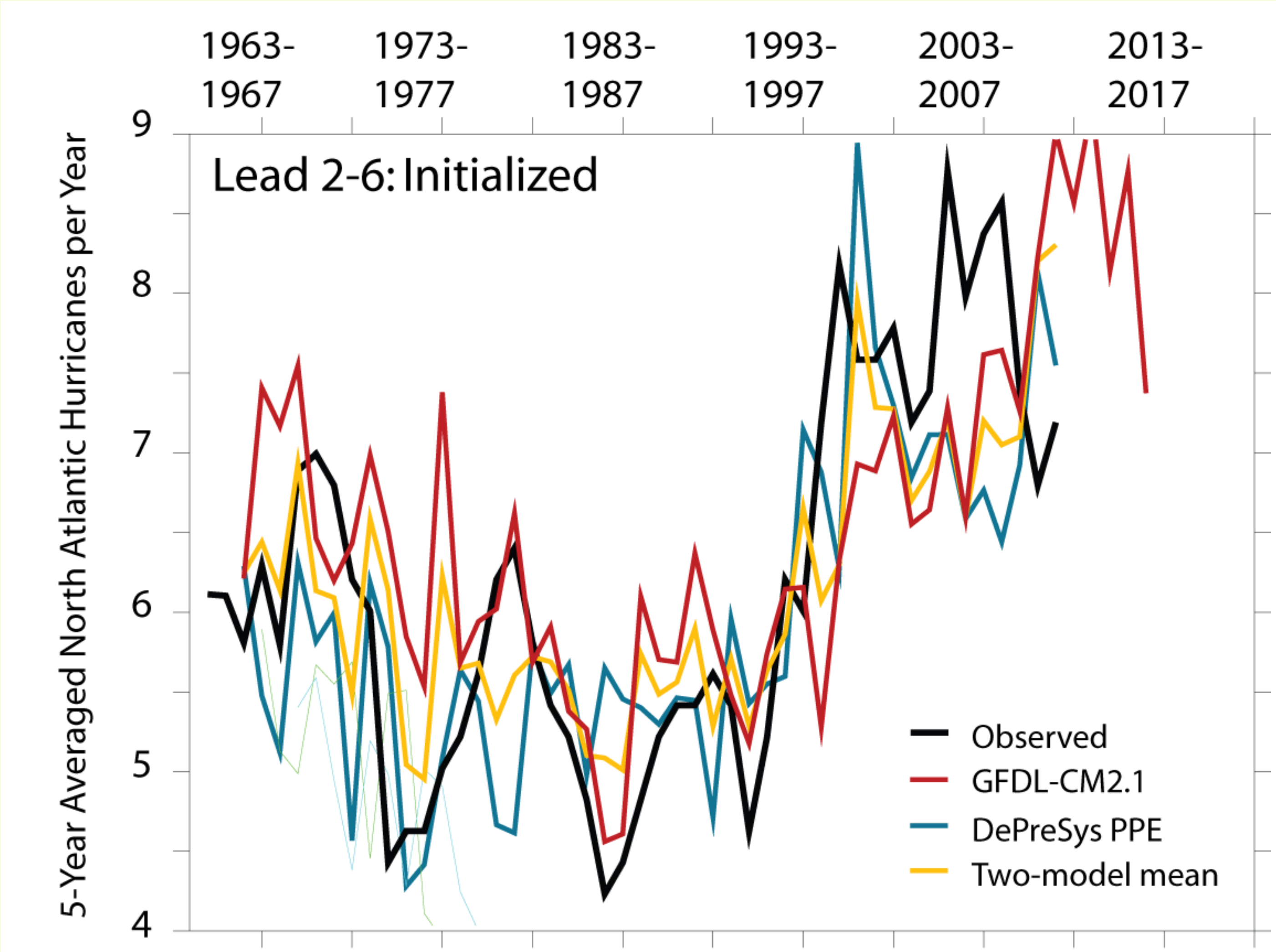
Anomlous low AMOC at 26.5°N during 2009-2010. Cannot be fully explained by changes in wind (Ekman). It has a geostrophic component in observational analysis (Johns US AMOC meeting 2012, McCarthy et al. GRL 2012 submitted). Predictable?

So far not much skill in predicting the AMOC...

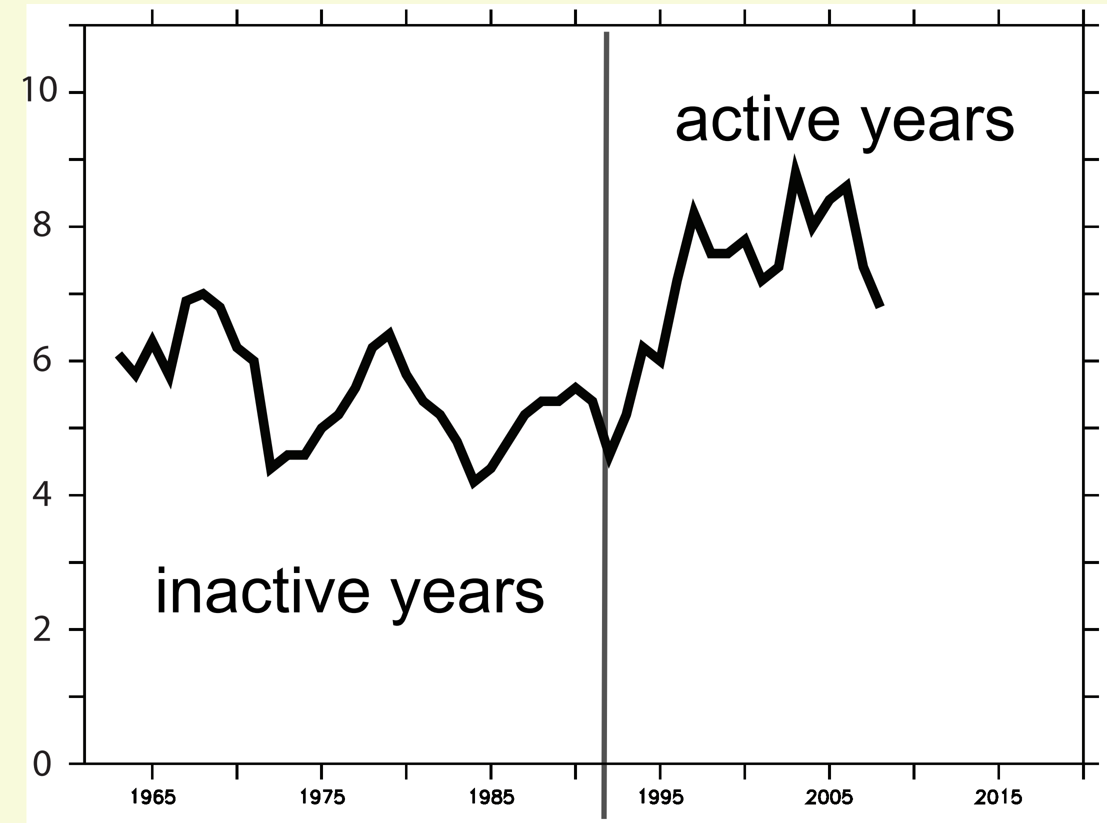


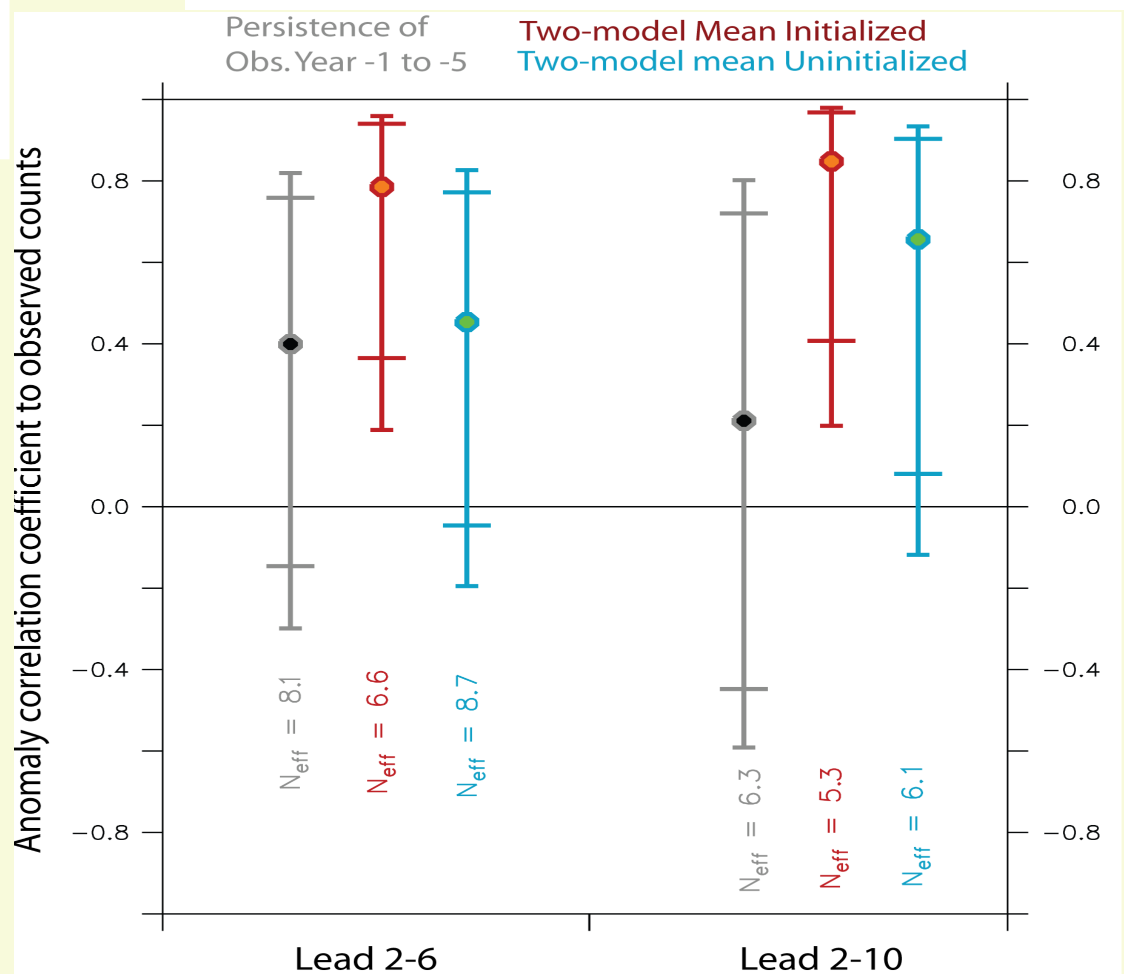
We are not able to predict the anomalous 2009-2010 low MOC measured by RAPID. Is it limited by its representation in ECDA used for the initialization? By the lack of geostrophic variability in CM2.1 (Msadek et al. 2012)?

Any predictive skill in the tropical Atlantic?



Observed hurricane counts





Encouraging results although we can't predict the shift in advance and few degrees of freedom to assess the signifcance of the results

Vecchi, Msadek and coauthors (2012, submitted)

Summary

-The GFDL initialized predictions are able to capture the 1995 shift in the North Atlantic, although weaker than observed.

-Key mechanism: prediction of anomalously high MOC driving a northward transport of heat anomalies

-Preconditioning of the ocean essential. Only 1995 start successful.

-Results consistent with other models despite different initialization and different prediction systems (Robson et al. 2012, Yeager et al. 2012)

Challenges

-Initializing the MOC is difficult (no deep data even with Argo)

-Assessing skill requires observational record for verification. Drift relative to ECDA: good for OHC, can be compared with RAPID for MOC26N. What about higher latitudes that are key for shifts like 1995 ?

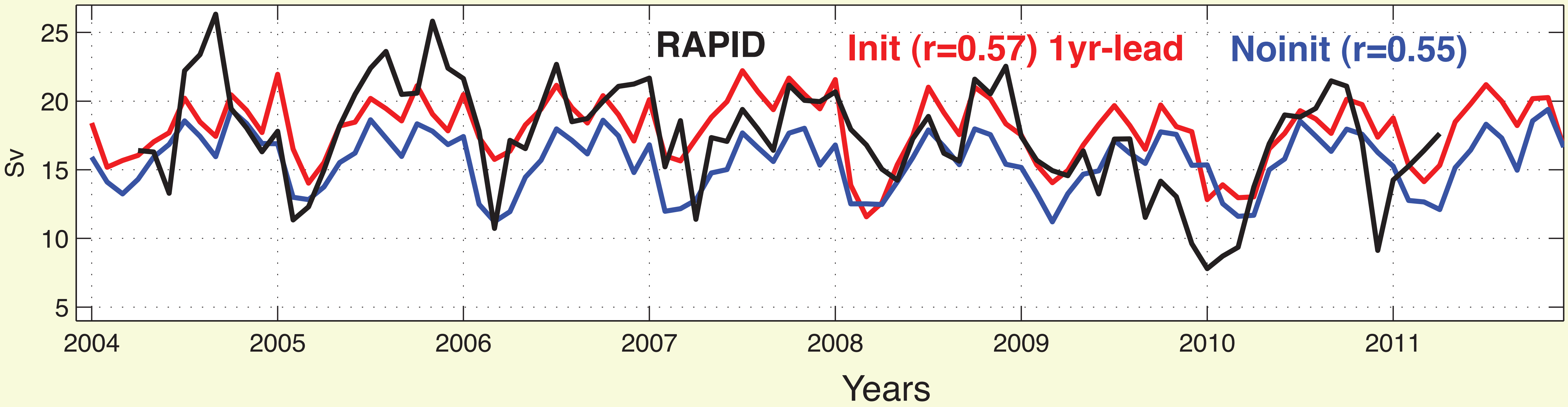
-Challenge to define a climatology with a non-stationary observational system The introduction of Argo after 2000 may have changed the character of the drift

-There is also a 1995 shift in hurricanes frequency captured with our predictions (*Vecchi et al. submitted*): linked to MOC?

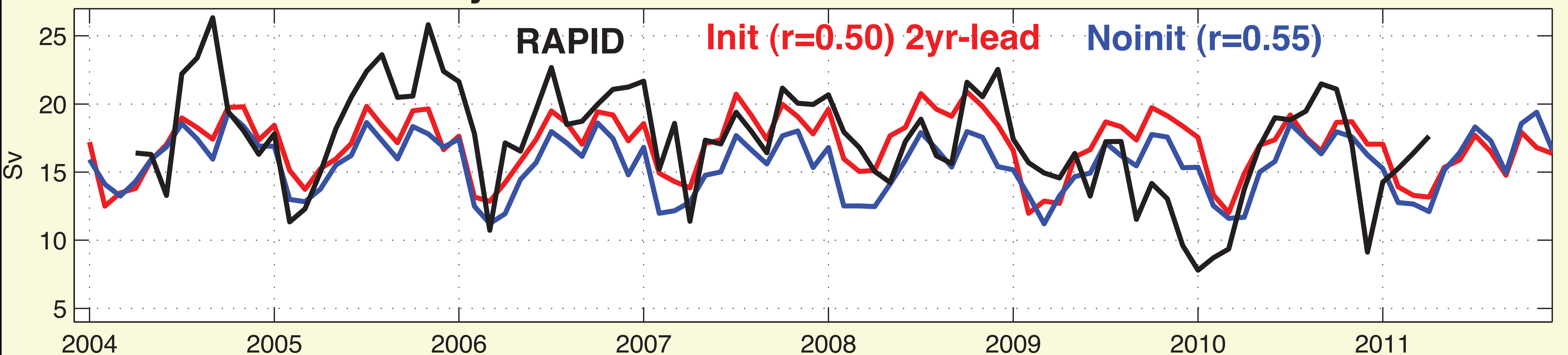
=> Decadal predictions provide a valuable opportunity to test and improve climate models and initialization systems.

Does that mean we can successfully predict the MOC?

MOC 26N seasonal cycle not removed. Drift corrected with RAPID as the “truth”

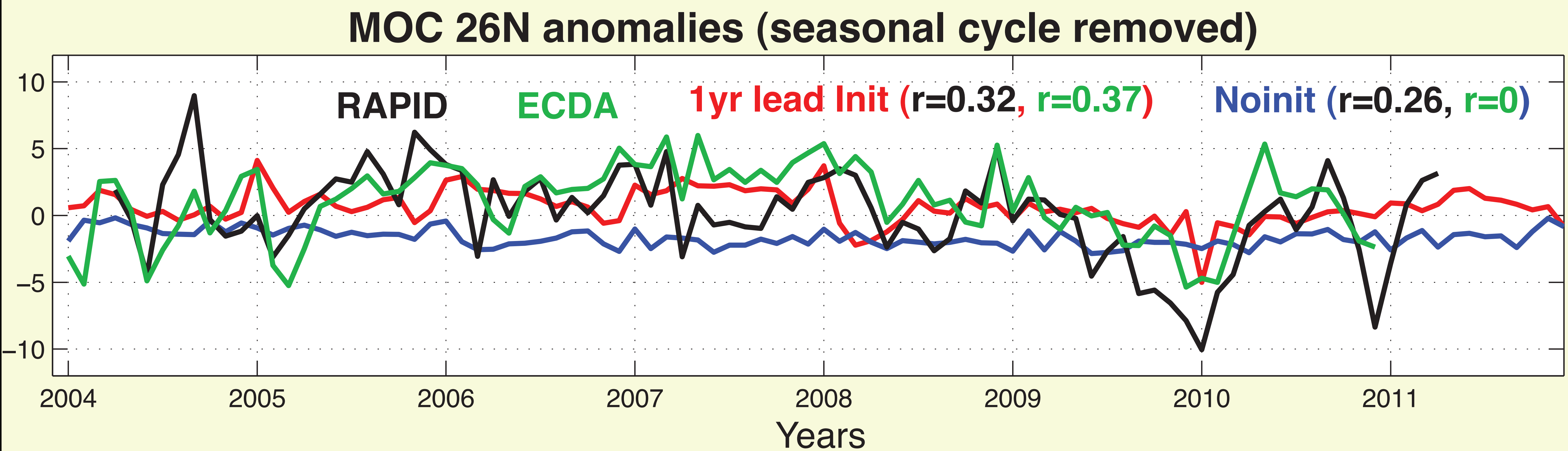


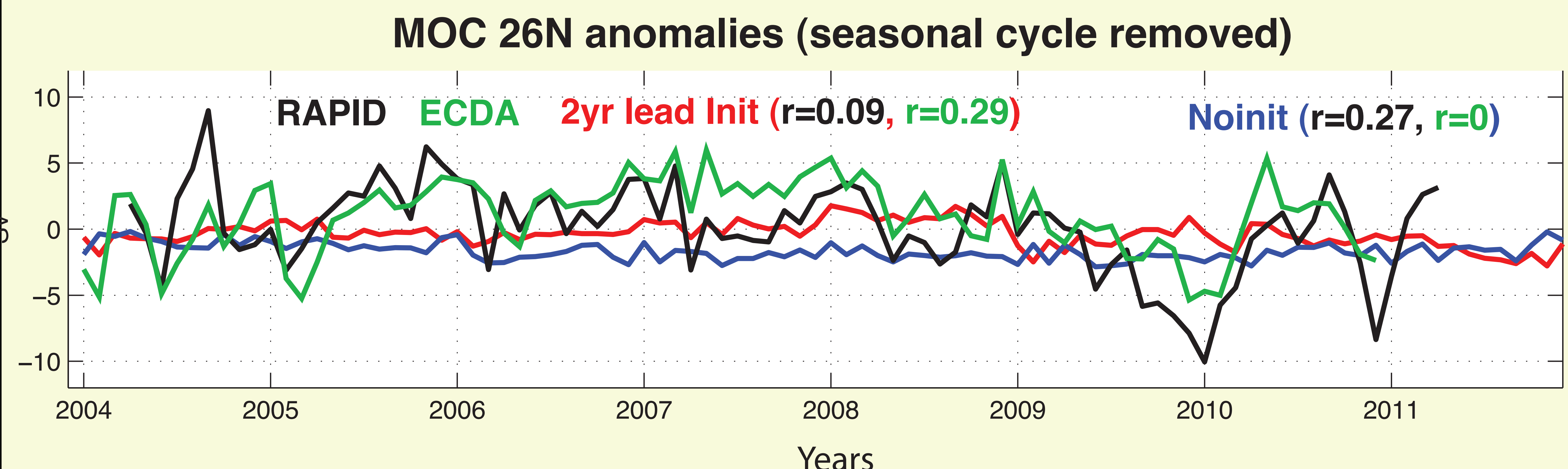
MOC 26N seasonal cycle not removed. Drift corrected with RAPID as the “truth”



Looks good if we don’t remove the seasonal cycle, but...THIS IS NOT SKILL

Does that mean we can successfully predict the MOC?

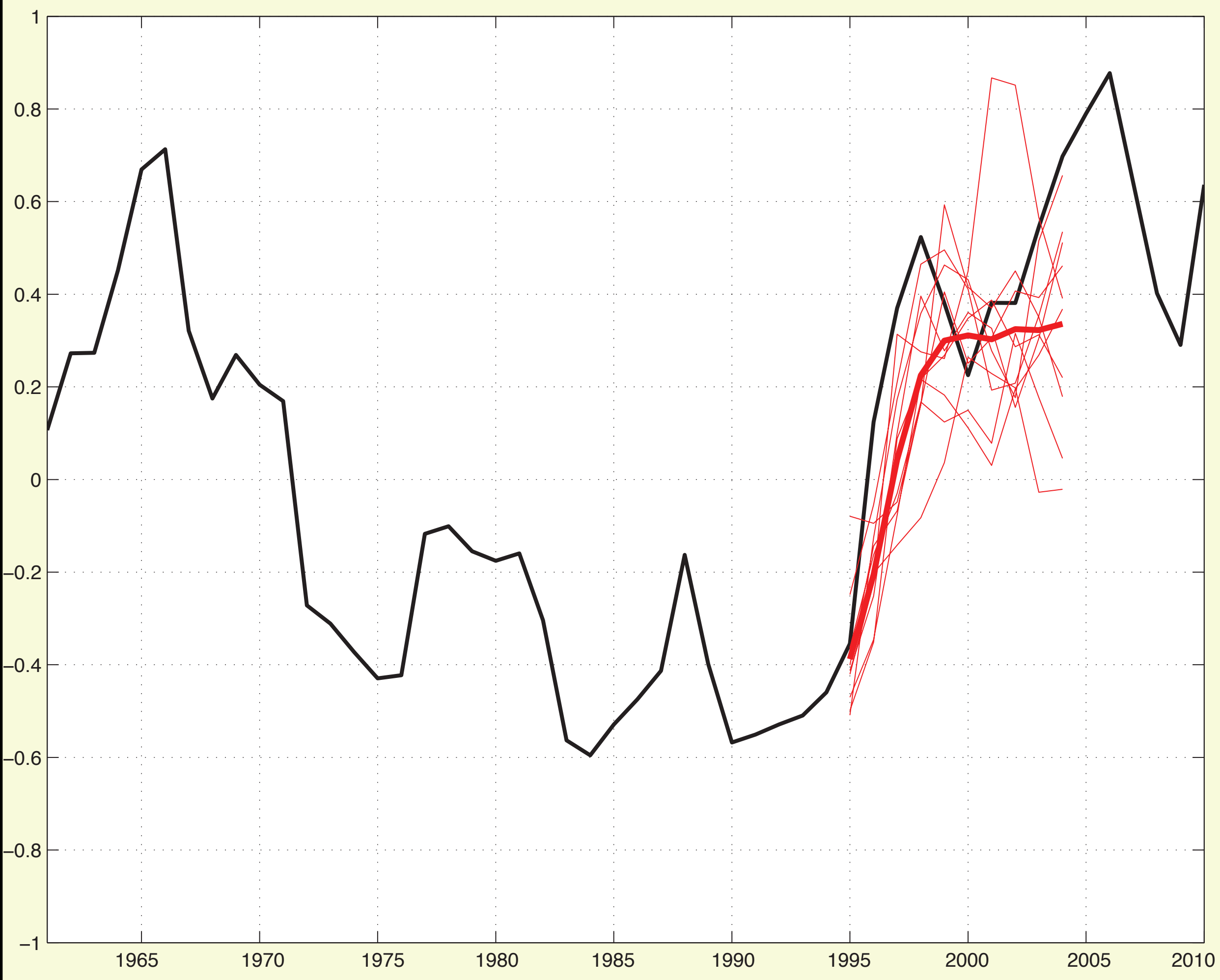




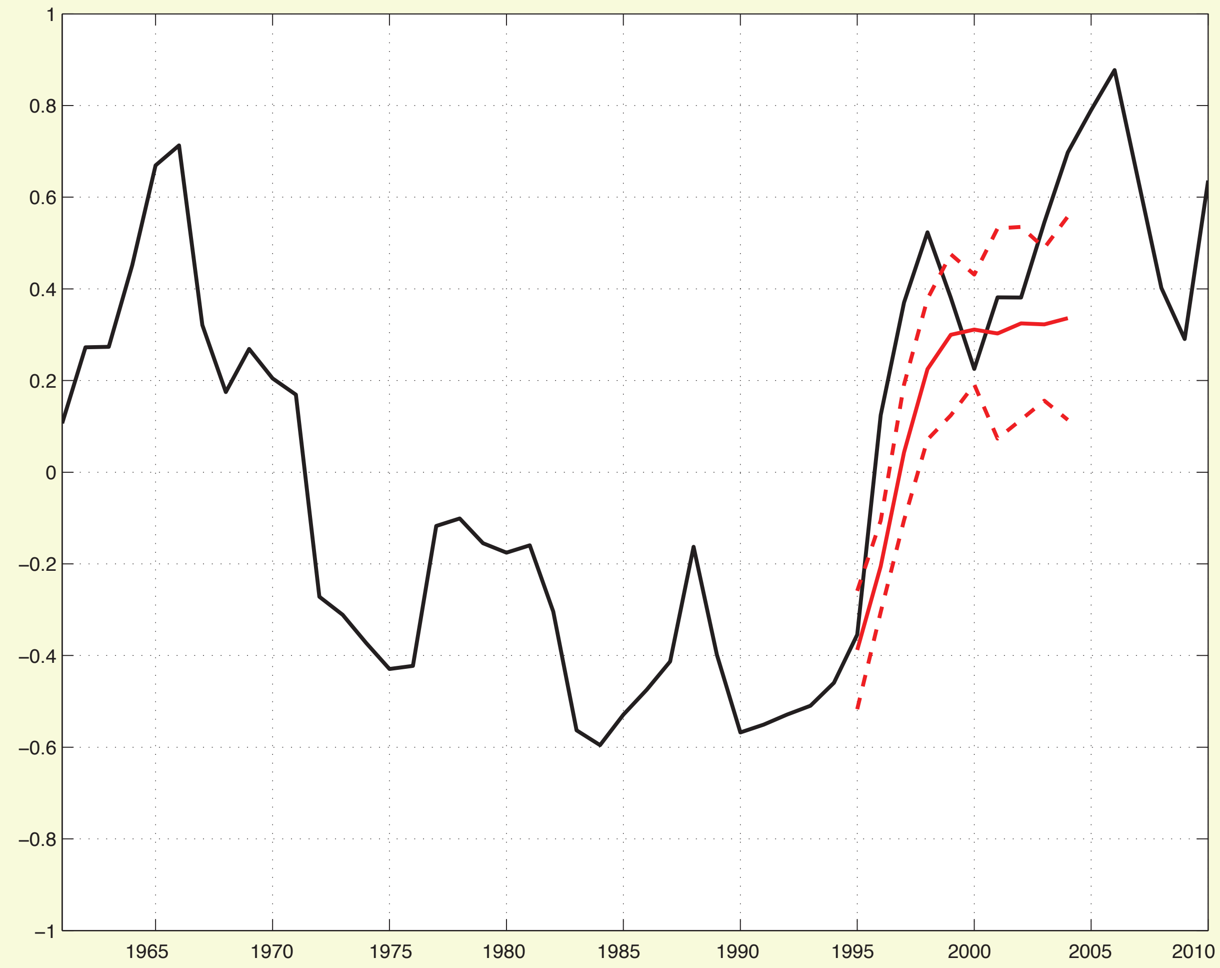
No significant skill at 26N

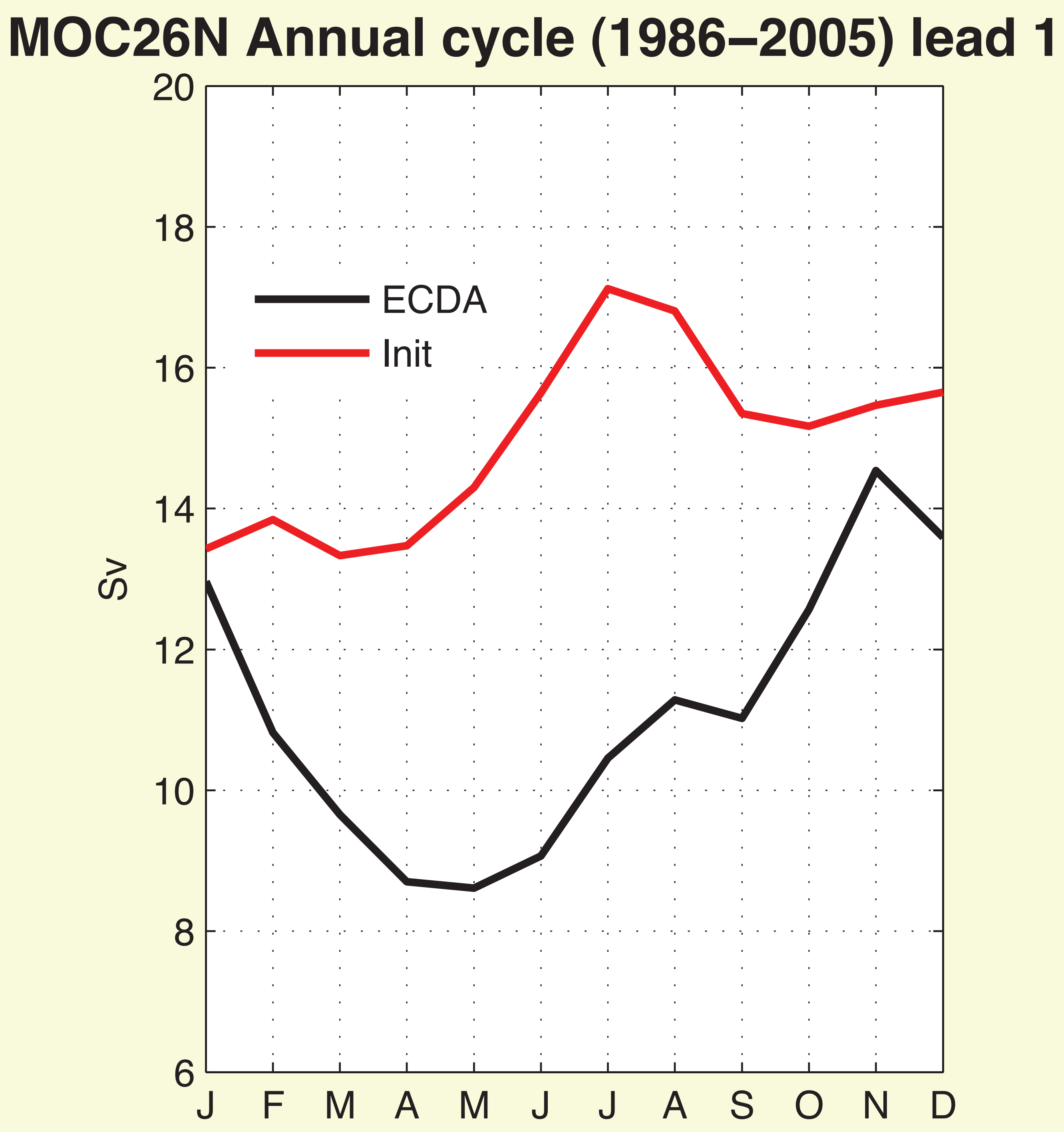
Reliability: Do the observations lie between the predictions spread?

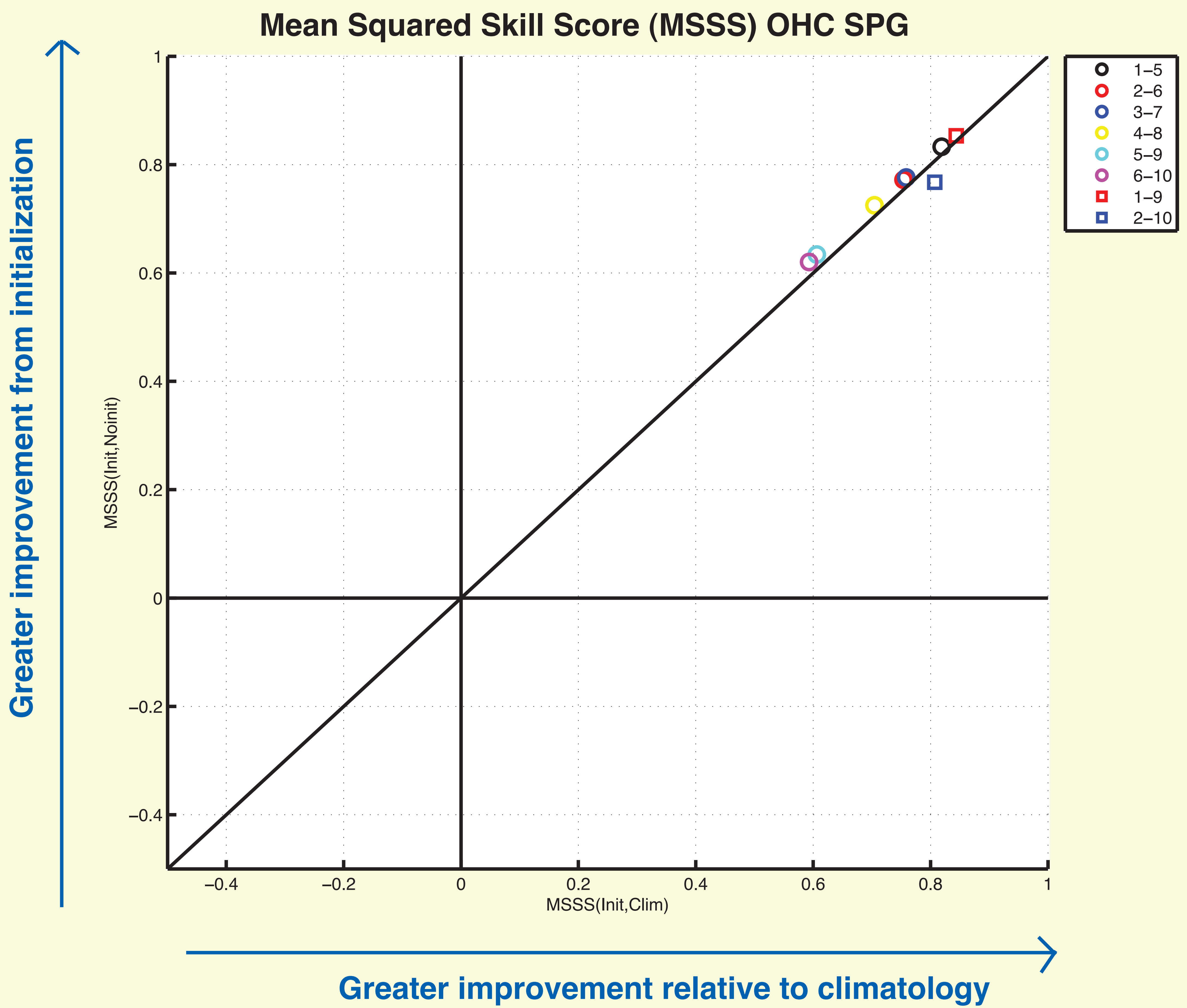
Spread of 95 OHC predictions



Std




MOC26N Annual cycle (1986–2005) lead 1
20
18
16
14
12
10
8
6
Sv
ECDA
Init
J
F
M
A
M
J
J
A
S
O
N
D


Mean Squared Skill Score (MSSS) OHC SPG
Greater improvement from initialization
MSSS(Init,Noinit)
1
0.8
0.6
0.4
0.2
0
−0.2
−0.4
−0.4
−0.2
0
0.2
0.4
0.6
0.8
1
MSSS(Init,Clim)
1–5
2–6
3–7
4–8
5–9
6–10
1–9
2–10
Greater improvement relative to climatology