Atlantic Decadal Variability:Combining observations and models to investigate predictability

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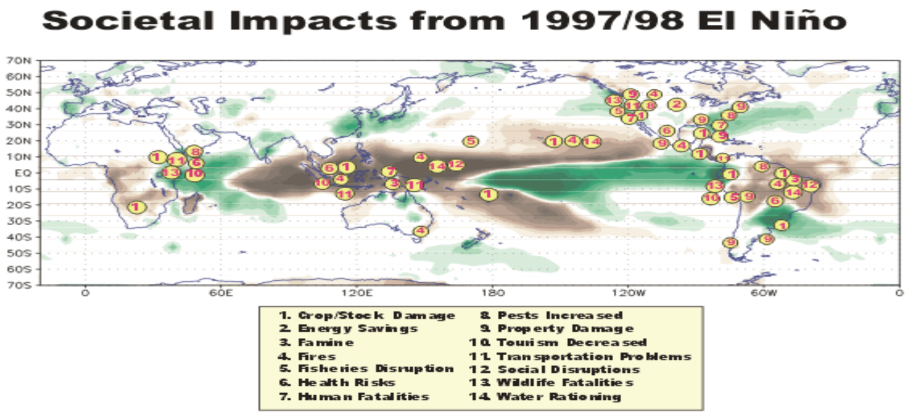
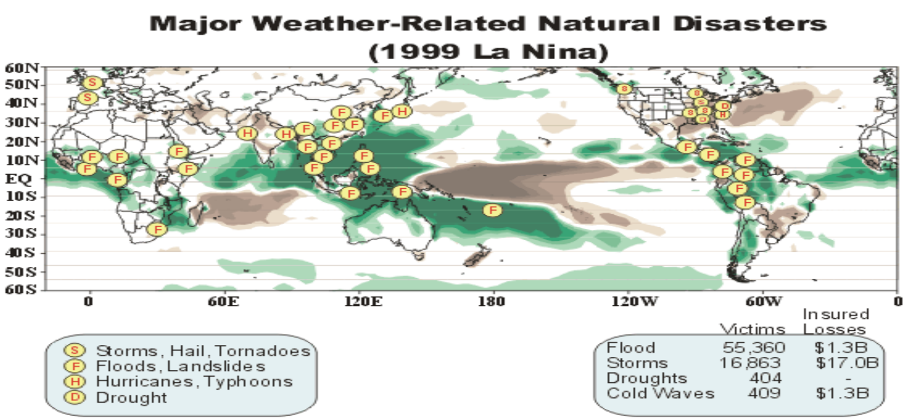
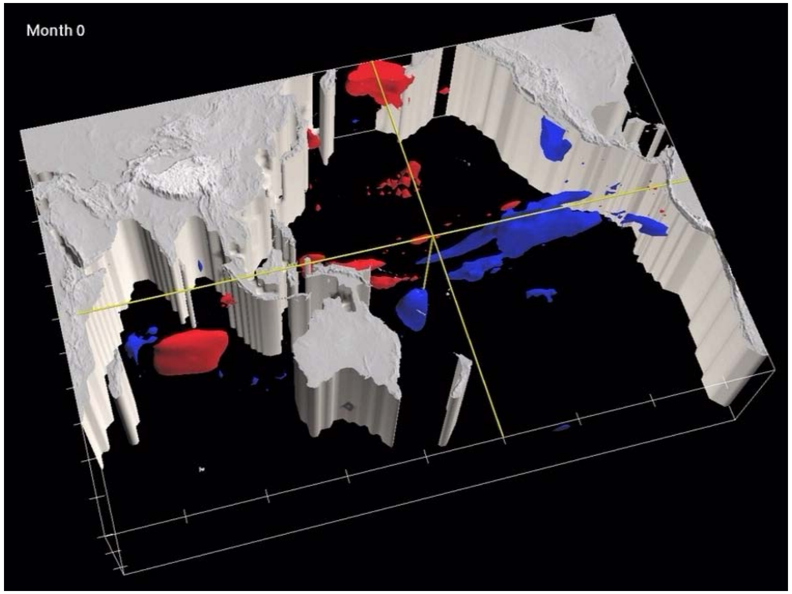
Understanding Ocean-Atmosphere Interactions in the Tropical Pacific has Laid the Foundations for Physics – Based Seasonal Forecasts

The close interplay between hypotheses, successes in confronting theories and observations, and observed (and attributable) impacts were factor in this success.





Climate Prediction Center



Evolution of El Nino and La Nina

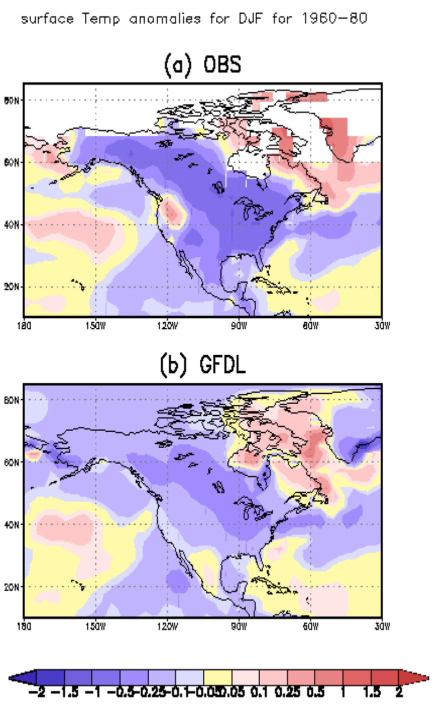
In contrast to S/I forecasting decadal climate predictions are in their infancy.

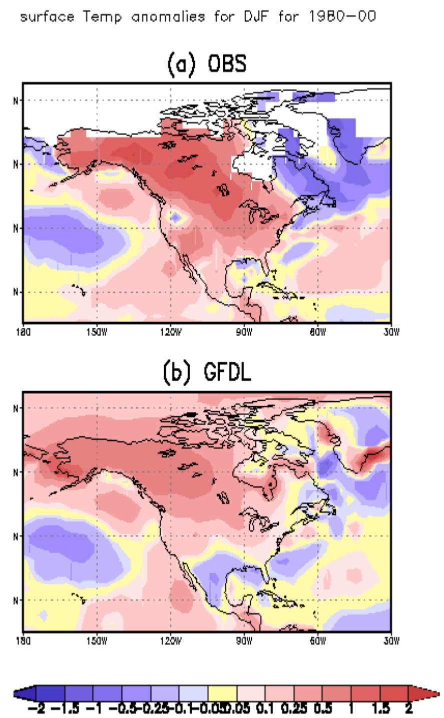
OUTLINE

- Decadal Variability
- Atlantic Multi-decadal Oscillation (AMO)
- Meridional Overturning Circulation (MOC) and AMO
- Predictability of MOC
- Current Status of Ocean Data Assimilation (ODA) from CLIVAR GSOP
- Can we Constrain the MOC with the current ocean observing system? - Perfect Model Assimilation Studies
- Summary of Atlantic Variability Workshops

Some Regional Decadal Predictability is Associated with Global Warming

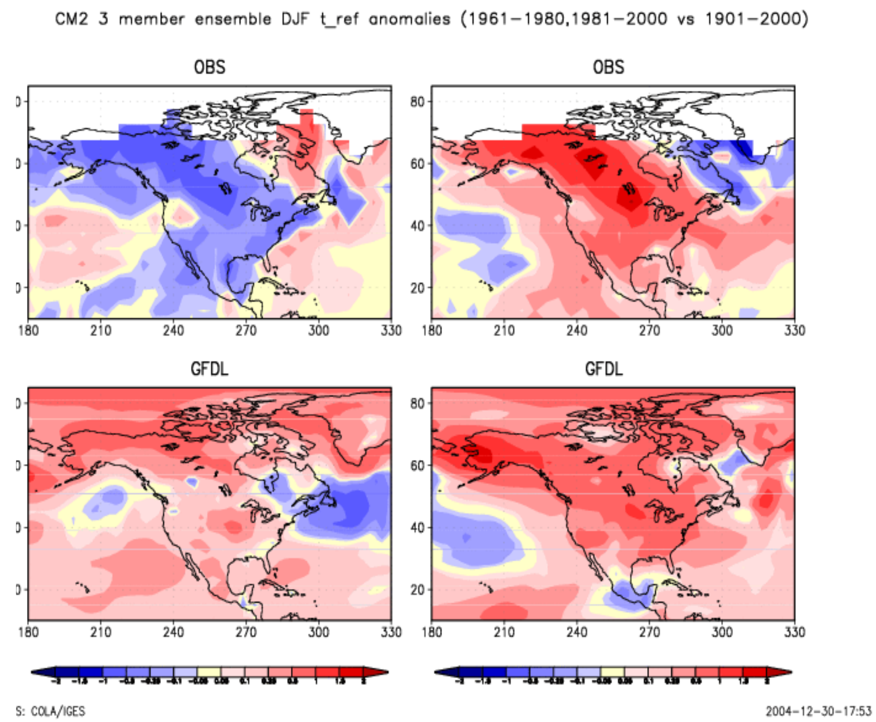
Model forced with observed SSTs





Ocean specified - land predicted

Specified radiative forcing from 1860

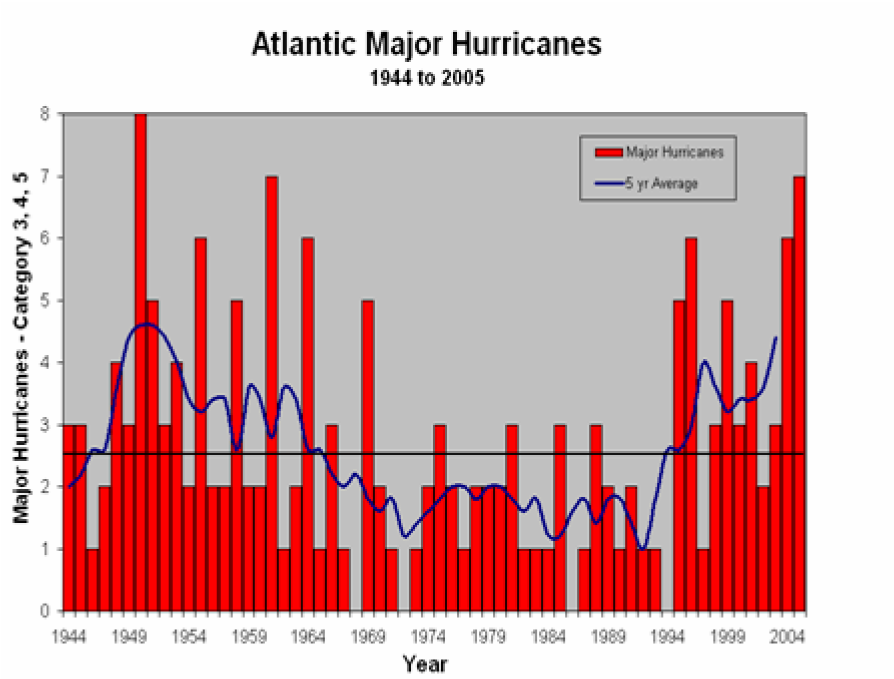


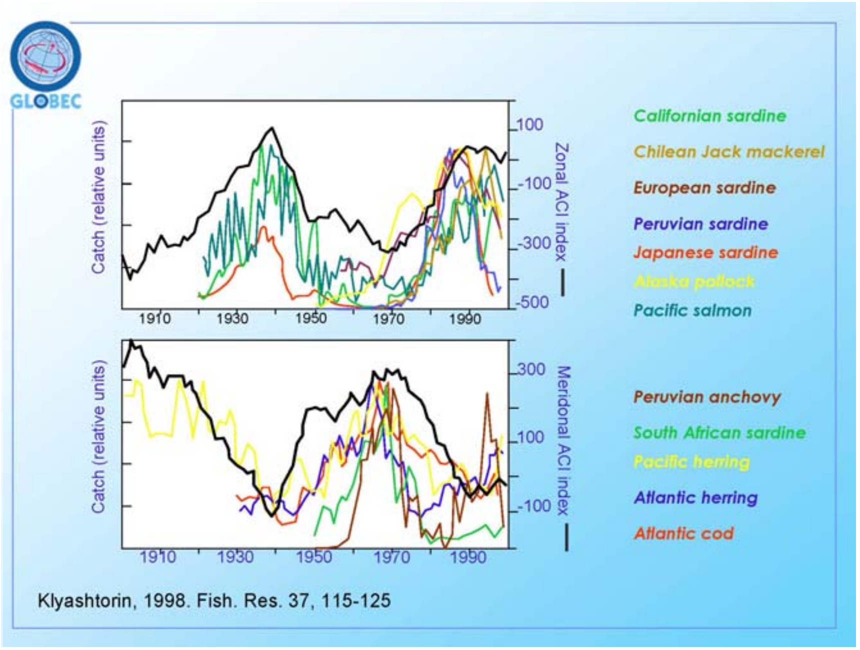
Ocean and Land predicted, but missing impacts of natural decadal variability

Understanding Both Natural Climate Variability and Global Warming is Critical for Attribution Studies

Global decadal climate variability underlies much of these variations

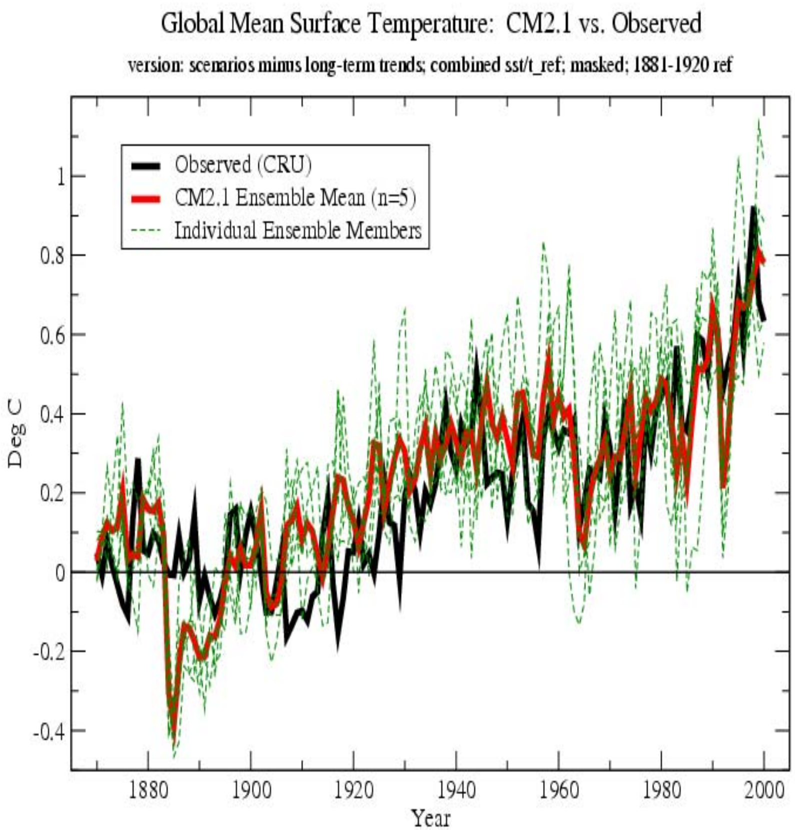
What are the common mechanisms linking droughts, hurricanes, fisheries?



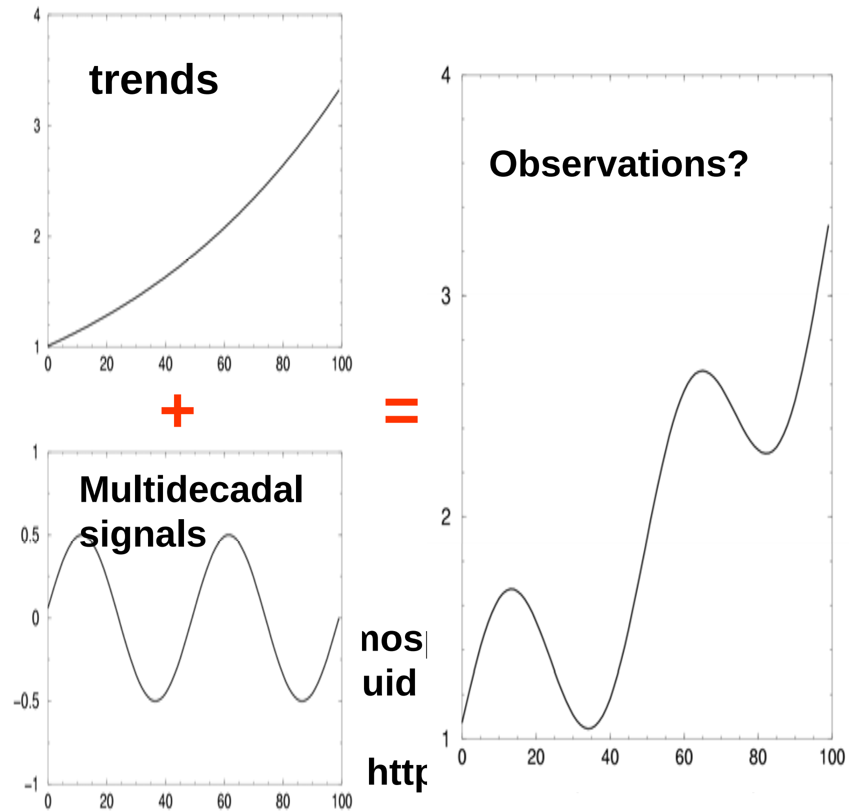


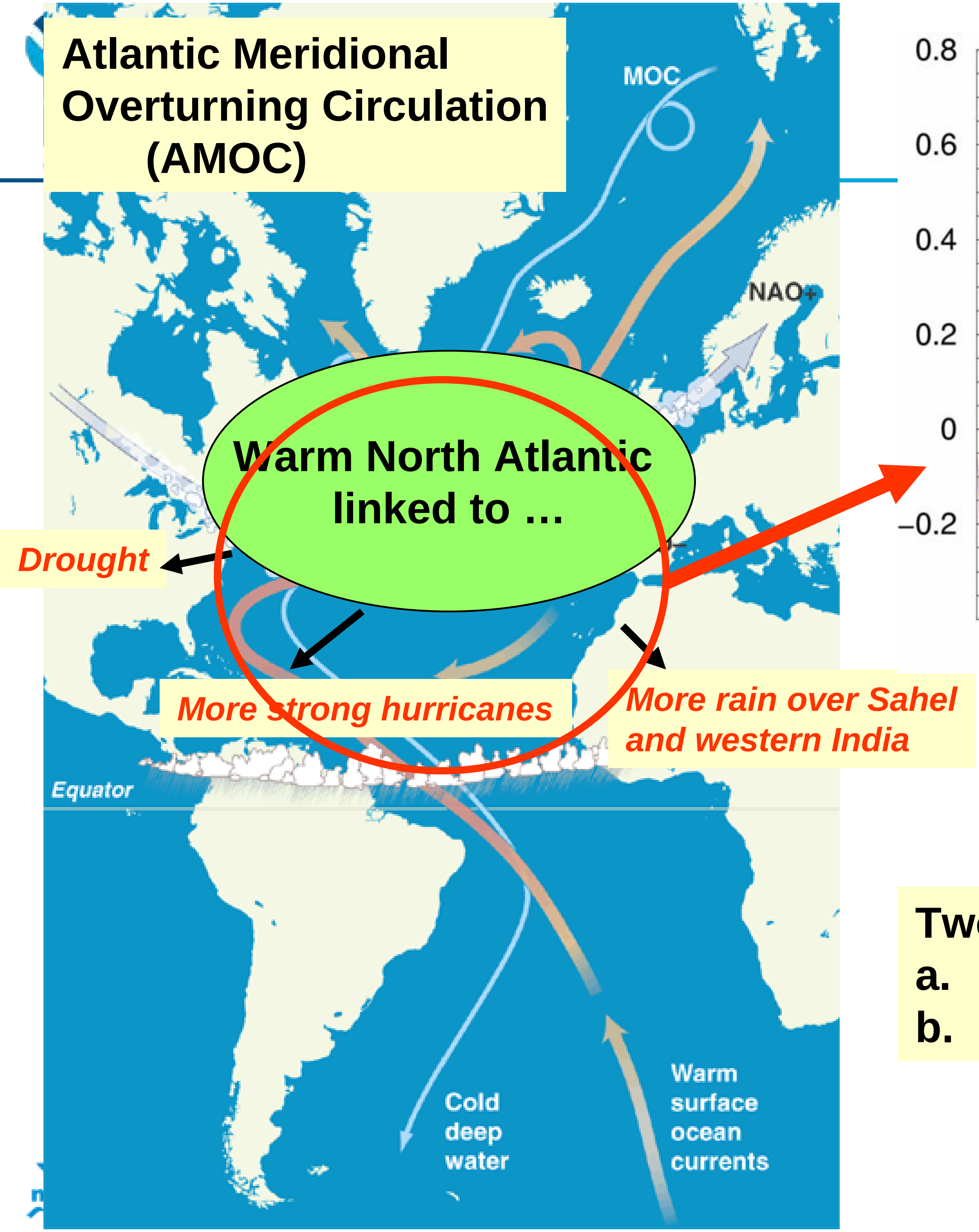
How Well Do We Understand the Climate of the 20th Century?

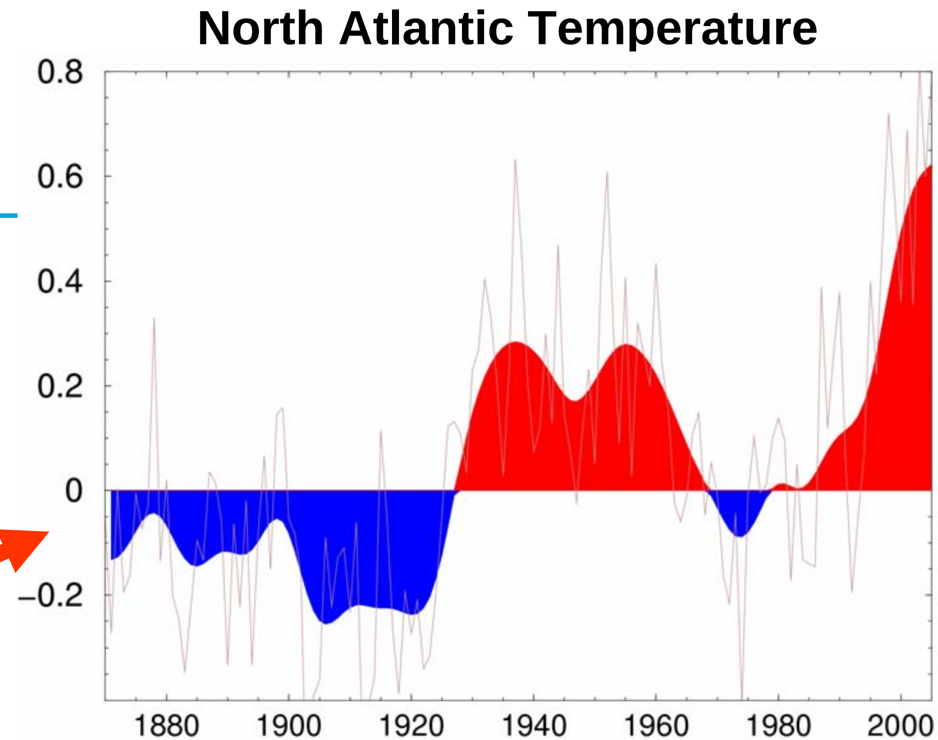
Successful Simulations?



Or is the explanation more complicated?



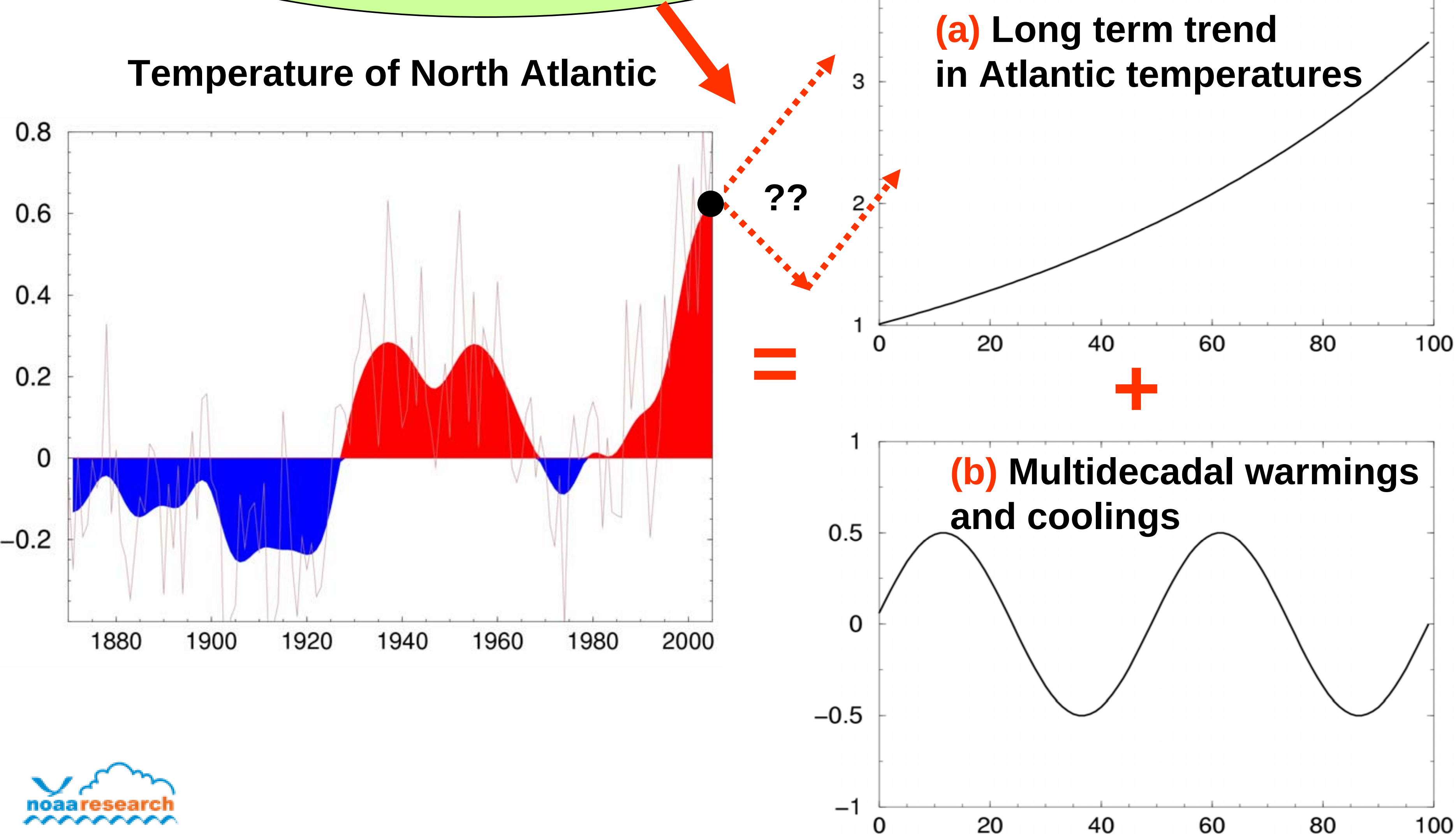


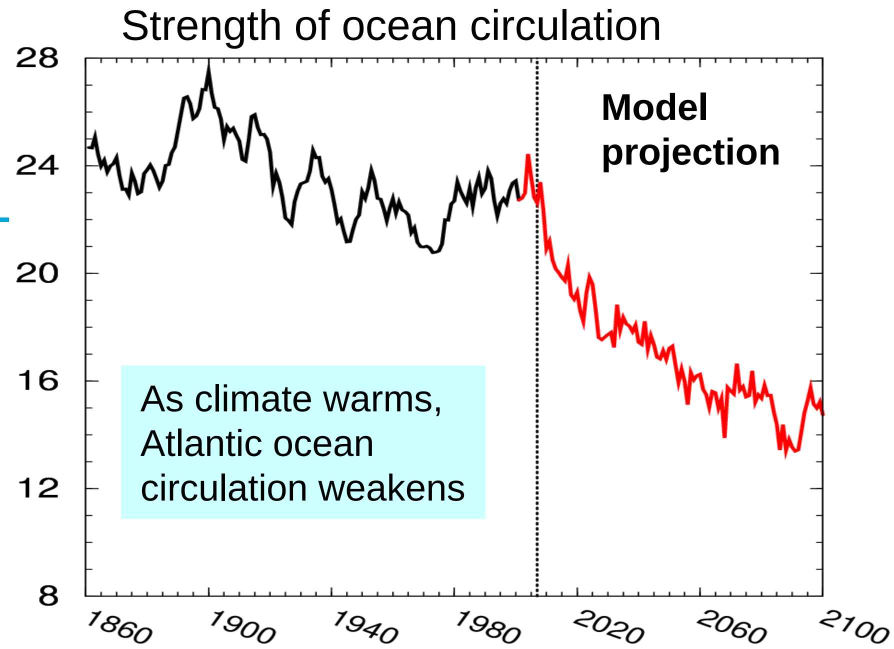


Two important aspects:

a. **Decadal-multidecadal fluctuations**
b. **Long-term trend**

What will the next decade or two bring?





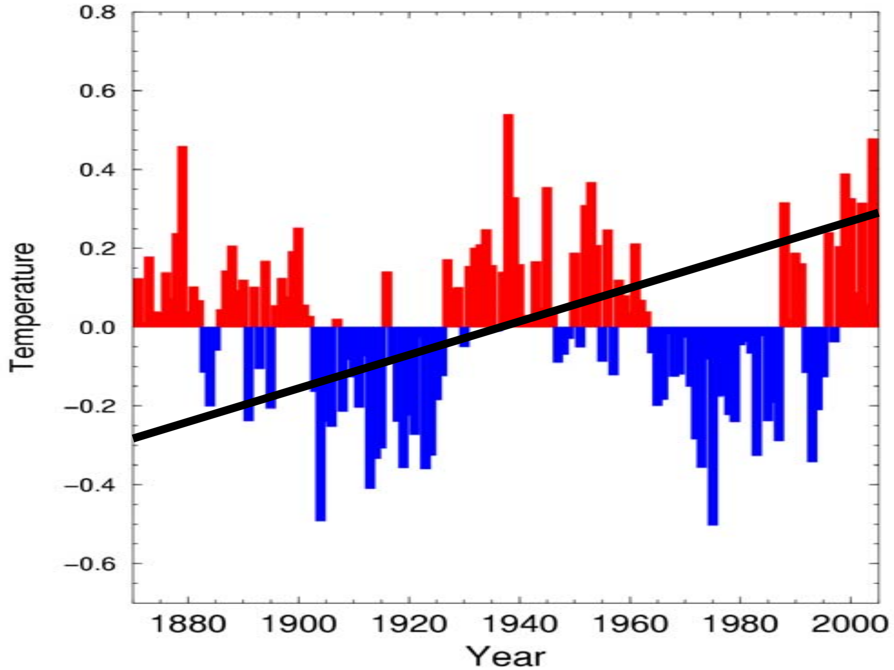
Putting the pieces together …

1. **Decadal-multidecadal fluctuations**
   a. **Natural variability**
   b. **Forced change**
2. **Long-term weakening trend of circulation**

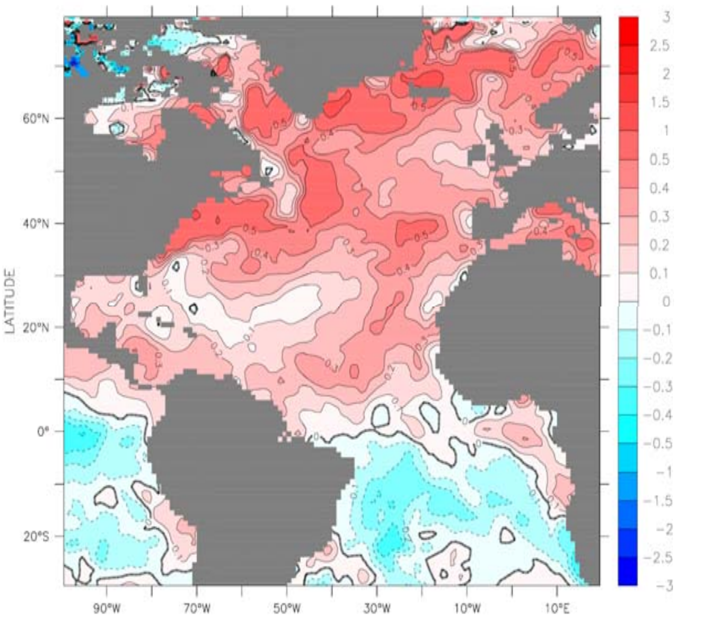
<u>GOAL:</u> Predict decadal scale evolution of the Atlantic in response to multiple factors

Decadal Variability is a Major Factor in Atlantic During the 20th Century

Average North Atlantic Temperatures
with trend removed



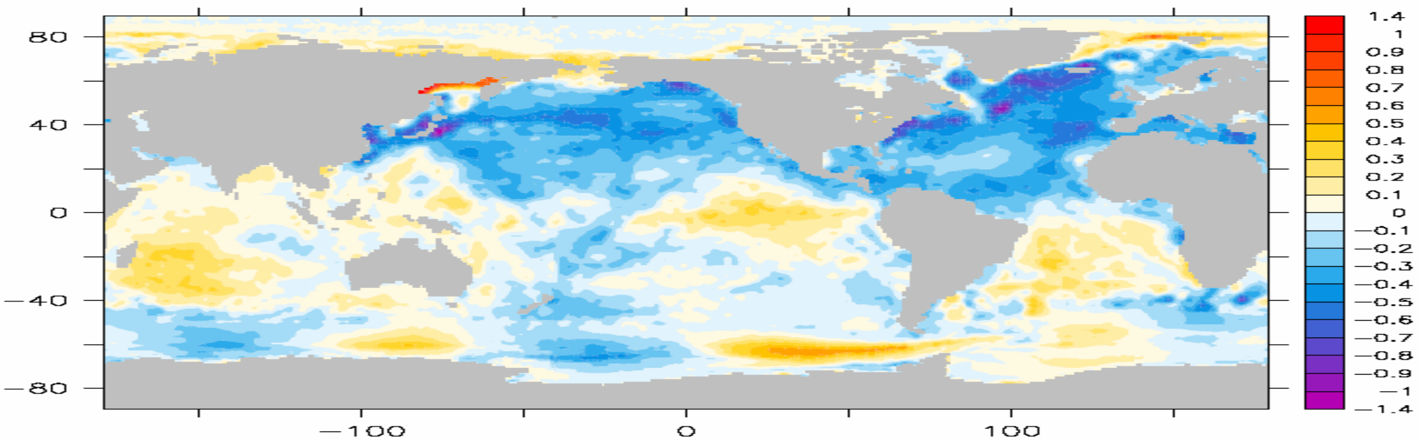
Sea Surface Temperature (SST) Differences
1941-1960 minus 1965-1984



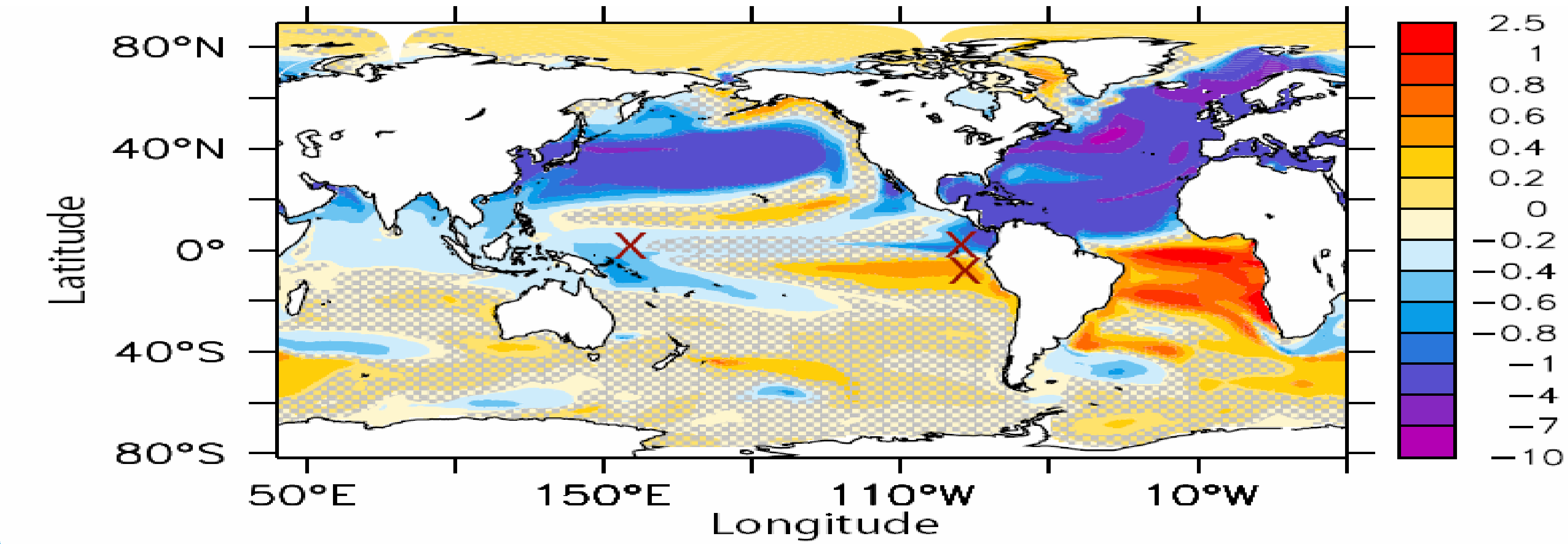
This variation is termed the Atlantic Multi-Decadal Oscillation (AMO)

Atlantic Changes (Decadal and Longer) Have Global Impacts

Observed SST Difference (1971-1990) – (1941-1960) (HadISST, detrended)

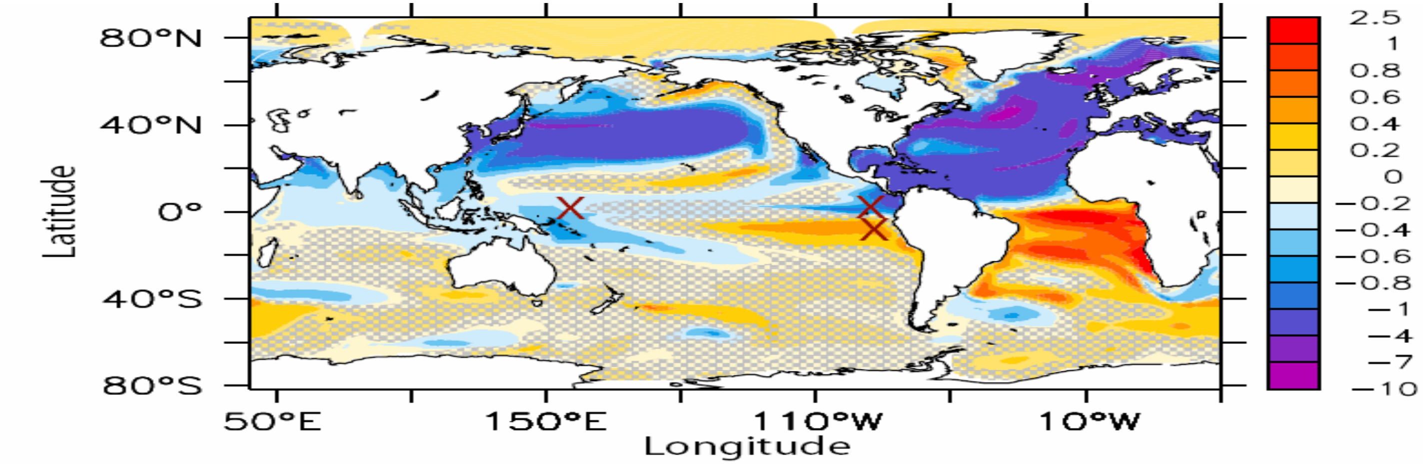


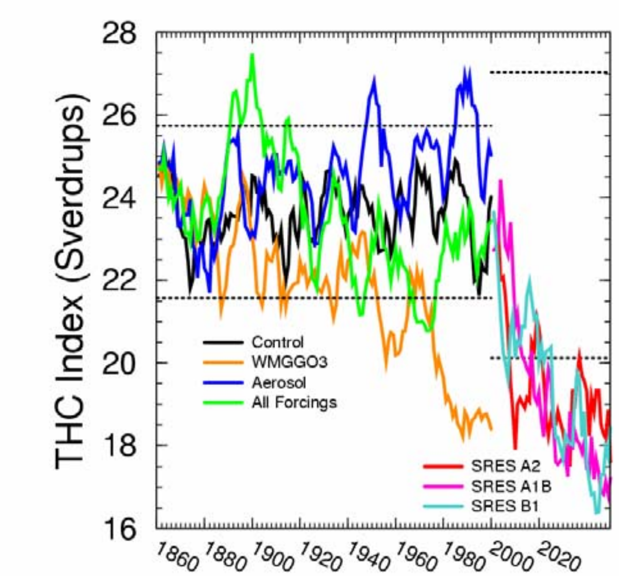
Simulated SST anomaly from the water-hosing experiment (Zhang and Delworth 2005)



What is the Potential for Abrupt Changes in the Near Future?

Global temperature changes resulting from an Atlantic THC shut down



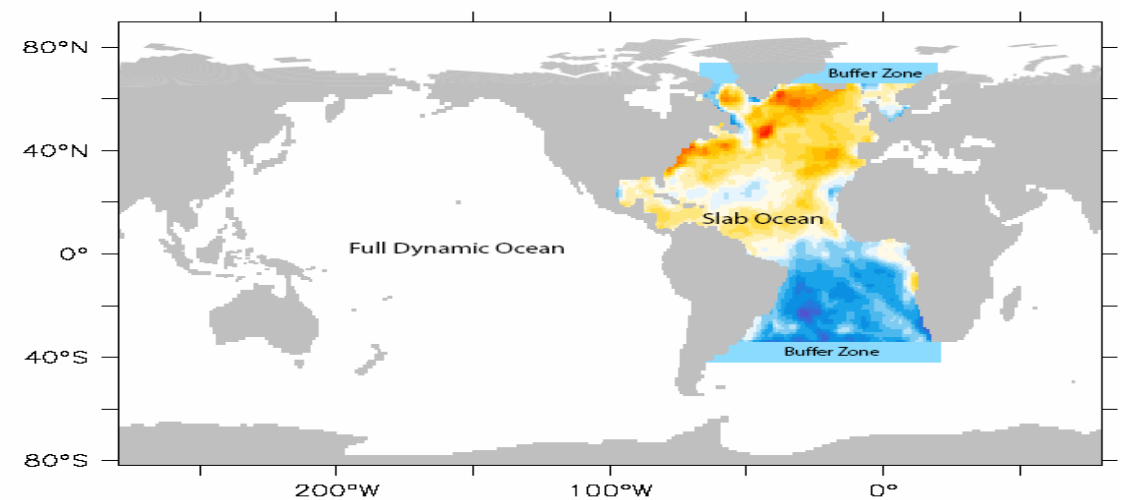


Models suggest a slow down of the Atlantic thermohaline circulation (THC) in the 21st C

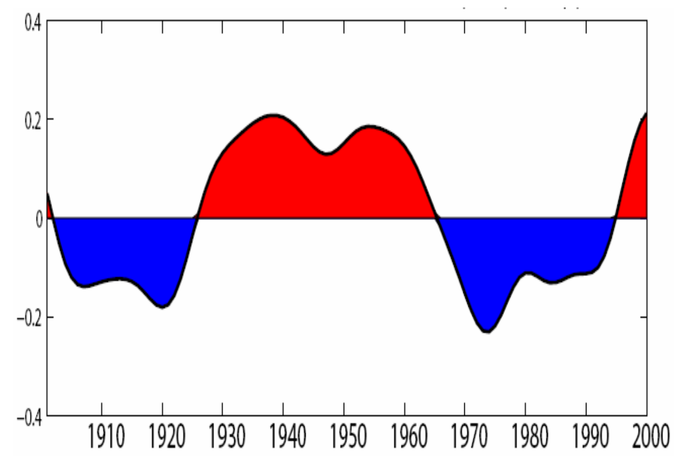
Note: the aerosol effects have delayed the onset of this

Impact of the Atlantic Multidecadal Oscillation on the 20th Century Climate Variability

Rong Zhang
Tom Delworth



Schematic diagram of the hybrid coupled model



Observed AMO Index (HadISST)

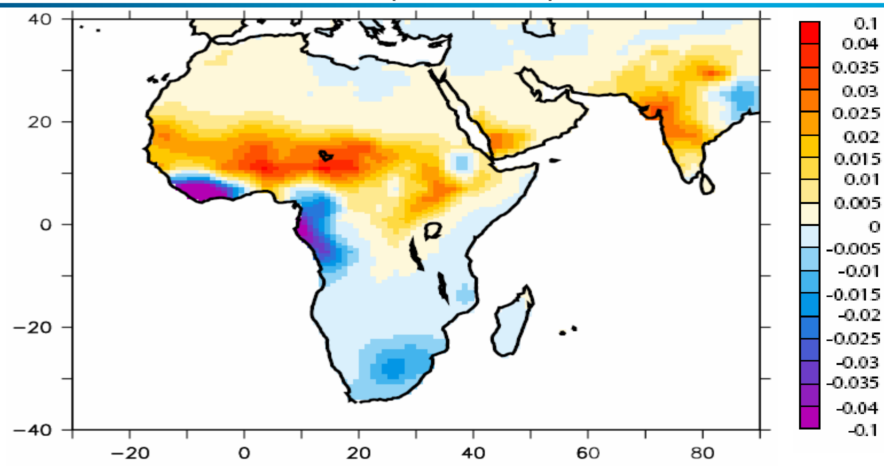
Model Description: GFDL CM2.1 - Latest developed fully coupled GCM (Delworth et al., 2005)

To simulate the impact of AMO, we modified CM2.1 into a hybrid coupled model: the Atlantic basin is modified to a slab ocean, all other are the same as CM2.1 (Zhang and Delworth 2006)

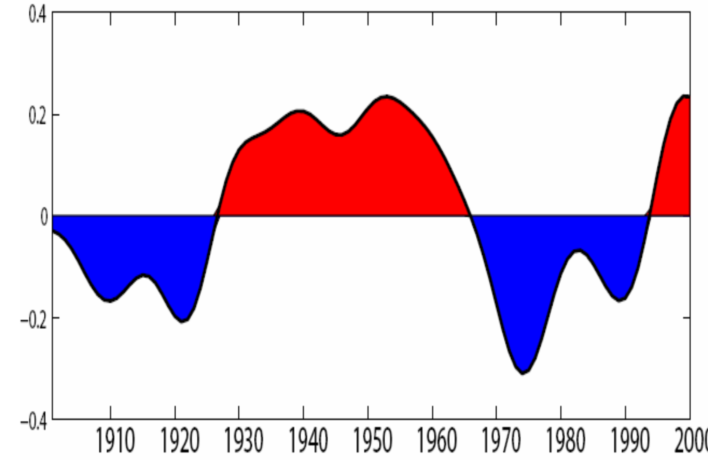
10-member ensemble experiments: forced by the same anomalous qflux in the Atlantic modulated by observed AMO Index (1901-2000)

The AMO is Linked to Regional Rainfall Anomalies

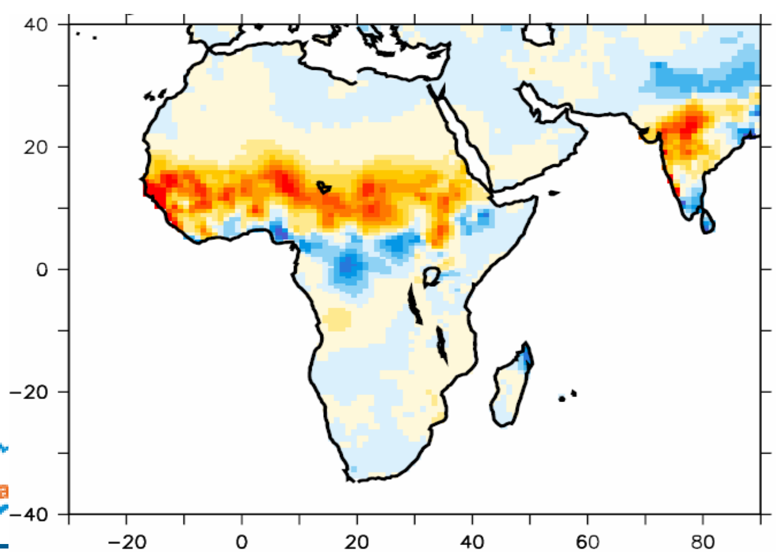
Regression of modeled LF JJAS Rainfall Anomaly on modeled AMO Index (1901-2000)



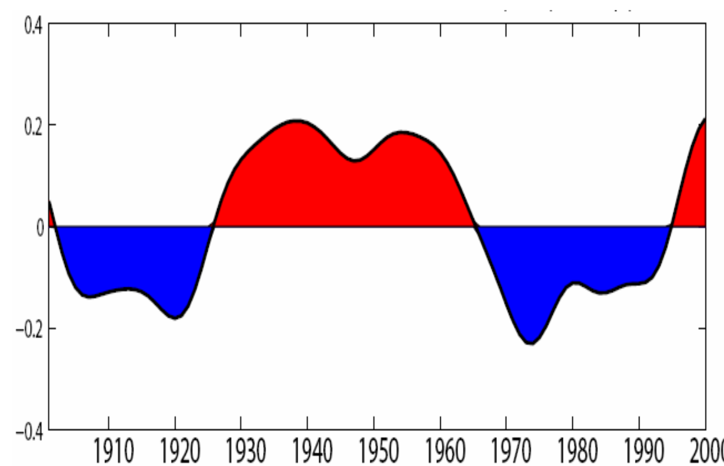
Modeled AMO Index



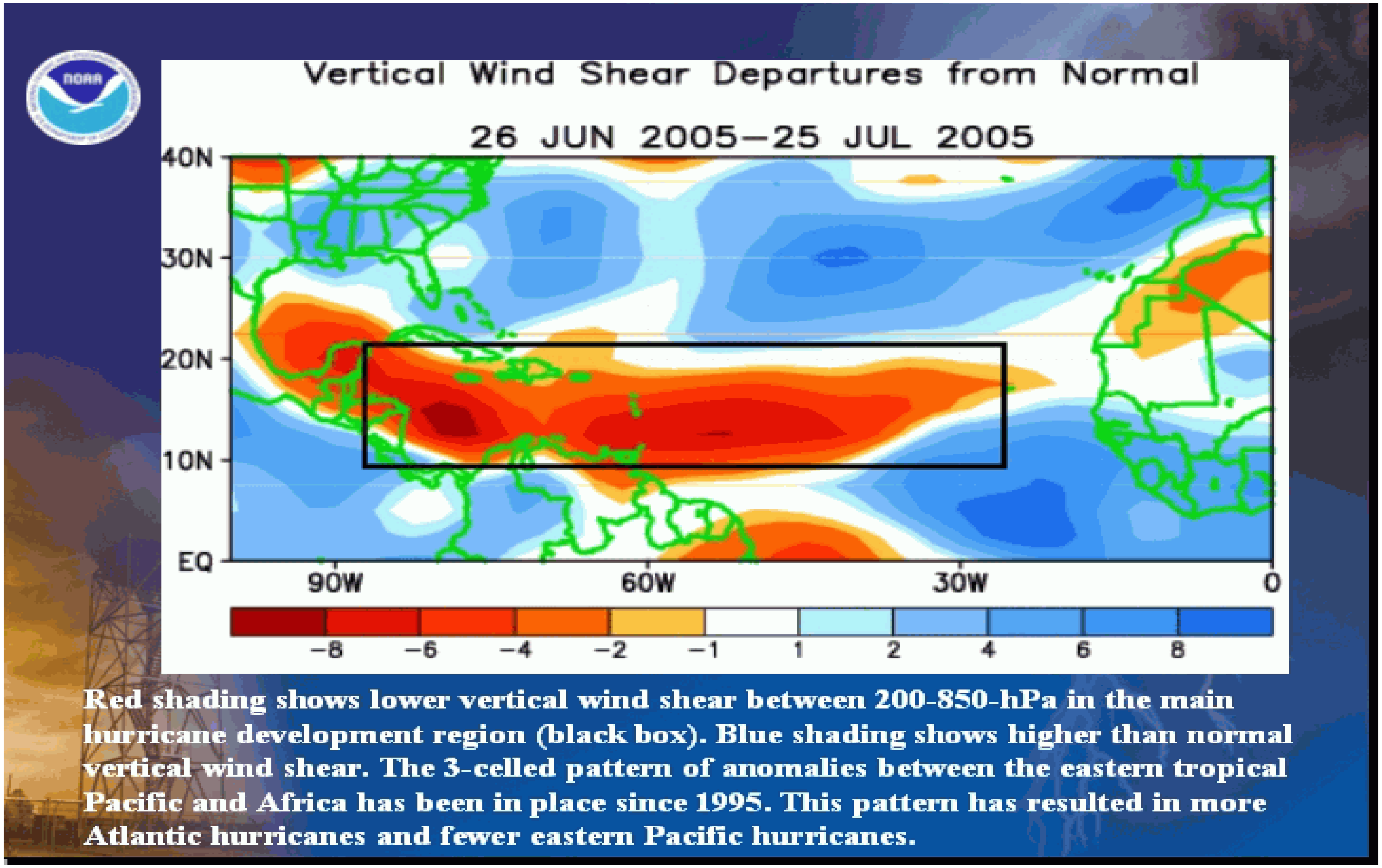
Regression of observed LF JJAS Rainfall Anomaly (CRU data) on observed AMO Index



Observed AMO Index



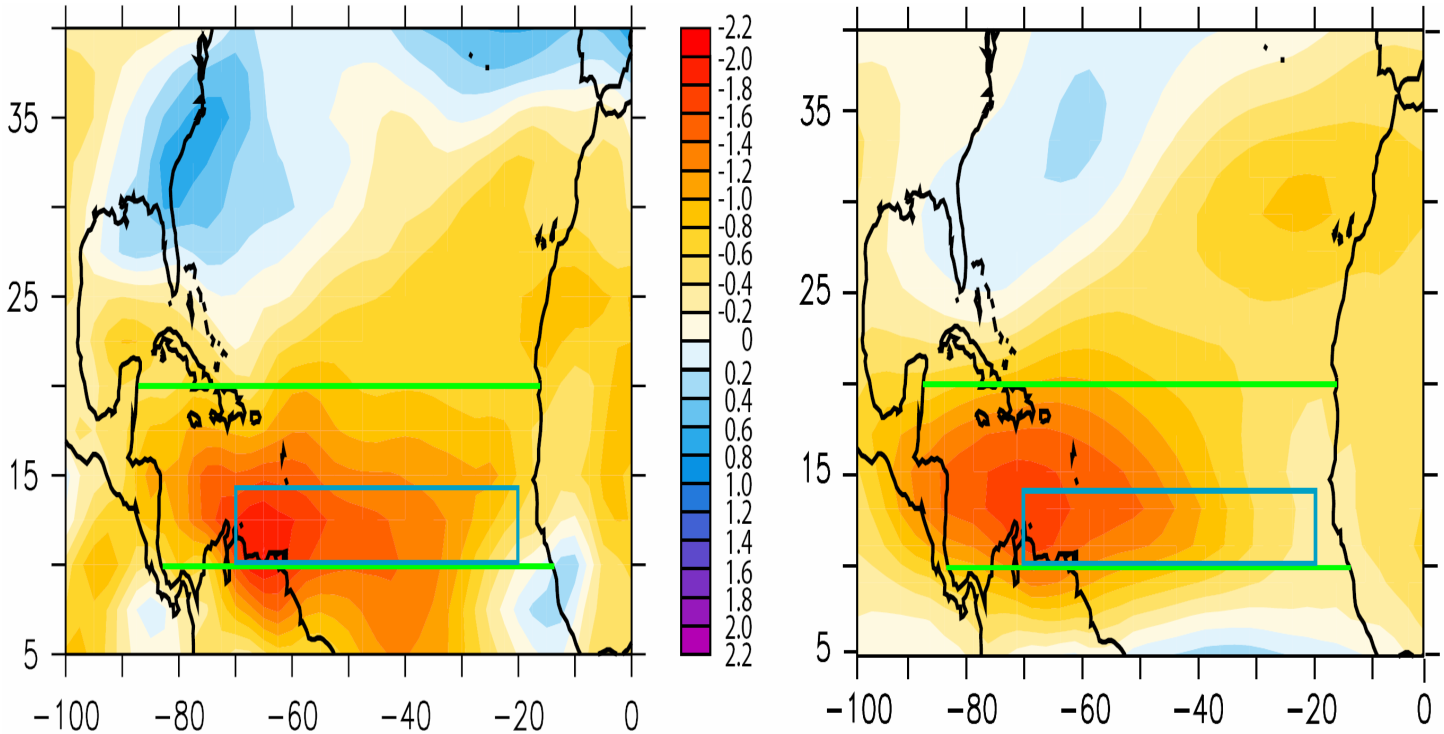
Impact of AMO on Atlantic Hurricane Activity



NOAA 2005 Atlantic Hurricane Outlook

The AMO Has Played an Important Role During the 20th Century in Decadal Modulation of Hurricane Activity

Regression of LF ASO vertical shear of zonal wind (m/s) on AMO index (1958-2000)



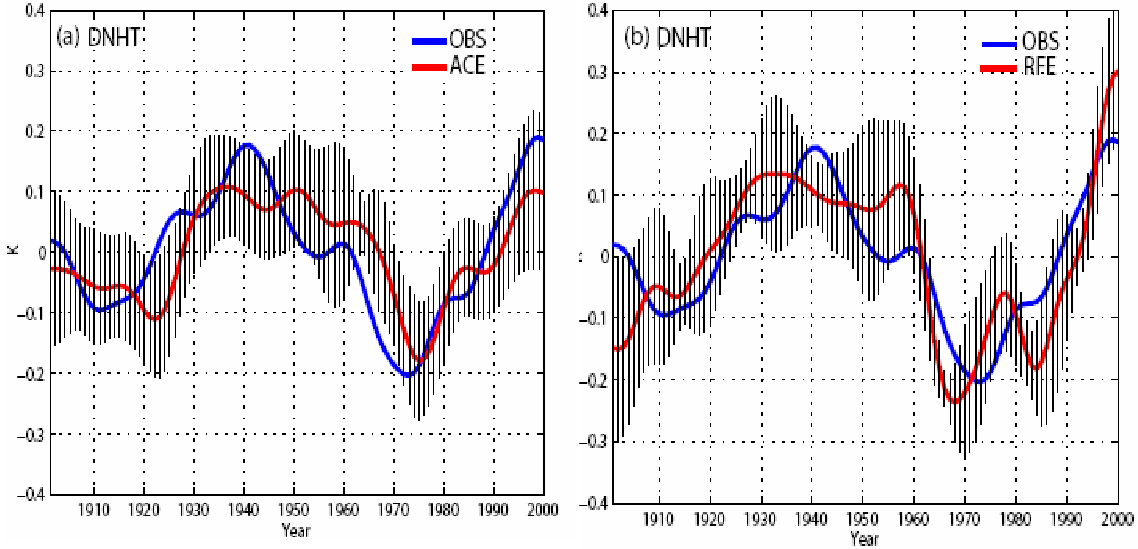
ECMWF 40-yr Reanalysis

MODEL (10-member ensemble mean)

Studies, which are currently under way to study the decadal predictability of the AMO, show some promise

What is the Origin of the Decadal Variability in Northern Hemisphere Temperatures?

(Blue: Observed temperatures with the linear 100 yr trend removed)



Red: ensemble mean temperature where the Atlantic is forced with anomalous heat flux that approximates AMO

Red: ensemble mean when model forced with radiative forcing with linear trend removed

Is there a link between radiative forcings and Atlantic decadal variability??

Mechanisms of AMO

The AMO is thought to be driven by multidecadal variability of the Atlantic thermohaline circulation (THC)

(Bjerknes 1964; Folland 1984; Delworth et al., 1993; Delworth and Mann 2000; Latif et al 2004)

Enhanced THC strength enhances the poleward transport of heat in the North Atlantic, driving the large-scale positive SST anomalies.

Changes in vertical and horizontal density gradients in the North Atlantic alter the THC (enhanced density gradients strengthen the THC)

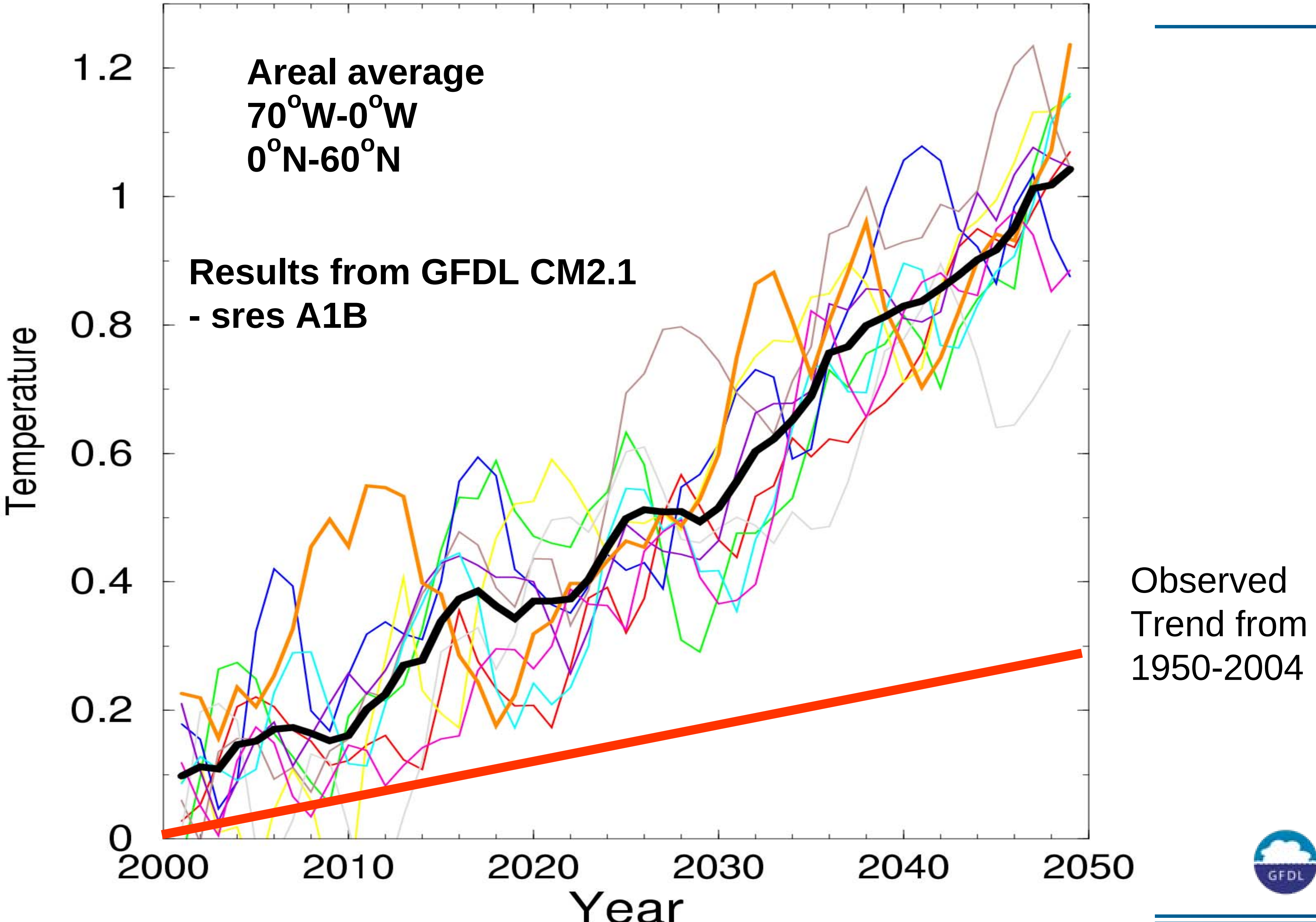
How will the Atlantic change in the future?

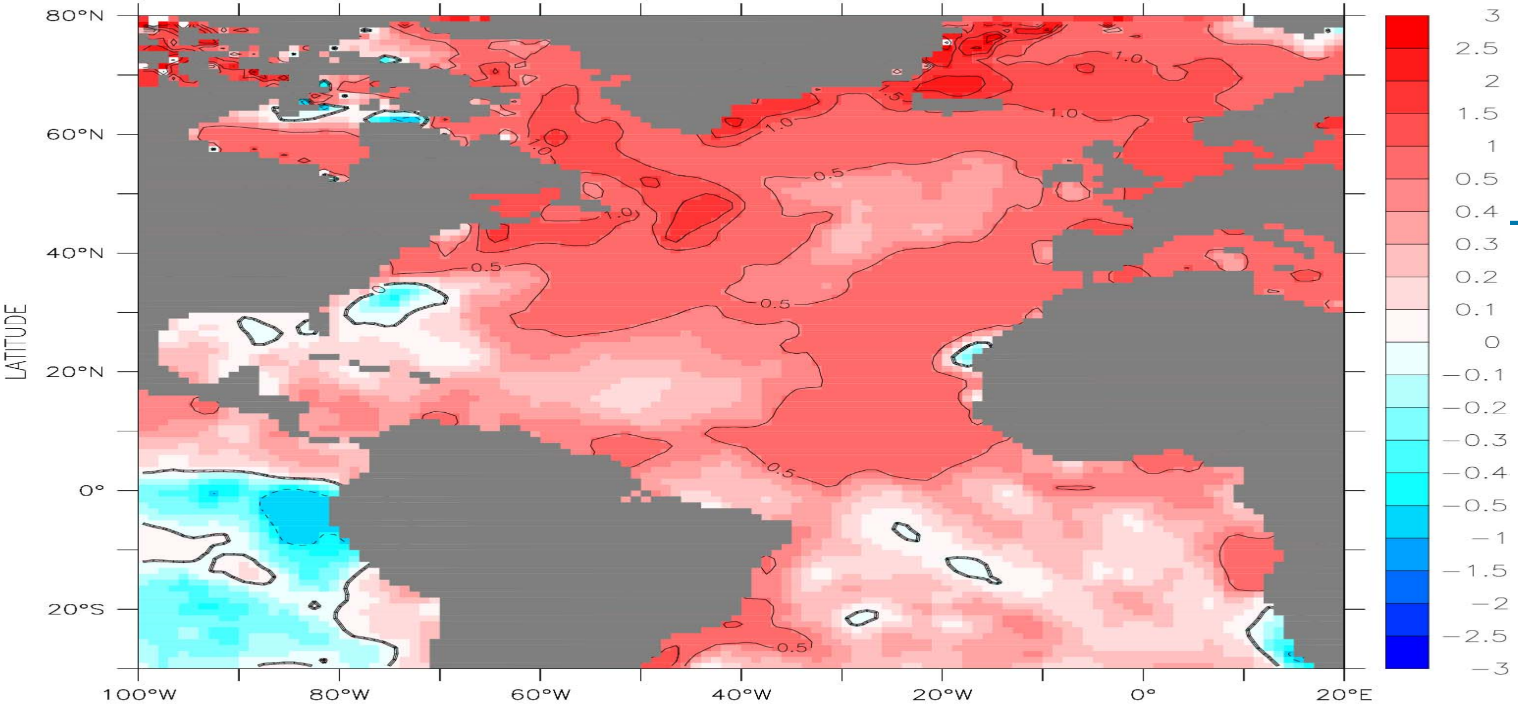
Two primary influences:

1. **<u>Natural variability of the Atlantic (AMO)</u>**
   From known initial state, use models
   to predict the decadal-scale evolution of the system.

2. **<u>Response to anthropogenic forcing</u>**
   a. Direct thermal response
   b. Ocean circulation response (thermohaline circulation)
   c. Other factors (Atmospheric circulation changes;
   Greenland ice sheet; etc.)

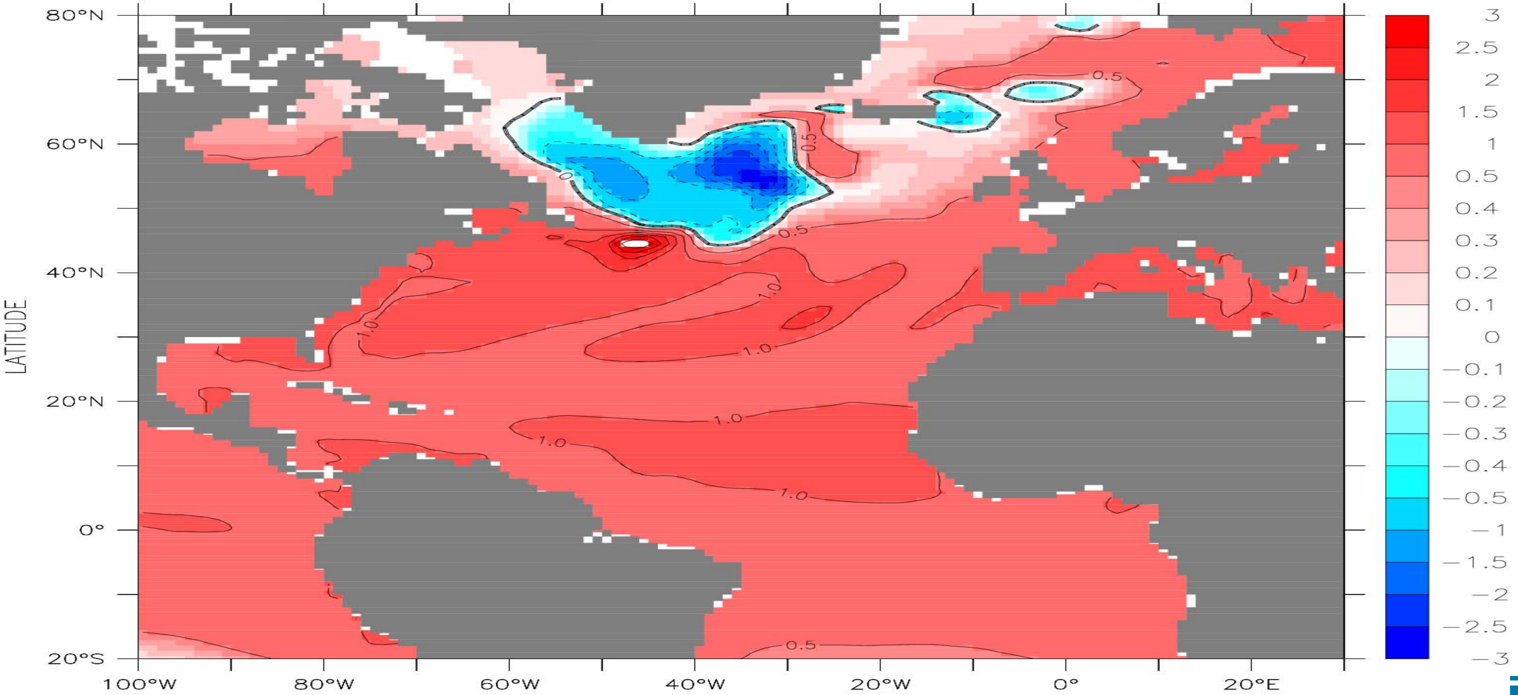
Projected Atlantic Sea Surface Temperature Change (relative to 1991-2004 mean)





Observed Change

2001-2004
Minus
1965-1984



Projected Change

2041-2050
Minus
2001-2005

Summary

1. **The Atlantic Multidecadal Oscillation (AMO) is a prominent mode of Atlantic variability with significant climate links (hurricanes, rainfall, temperature)**

2. **Observed Atlantic behavior is a combination of the AMO and a long term warming trend, with the trend likely a response to increasing greenhouse gases.**

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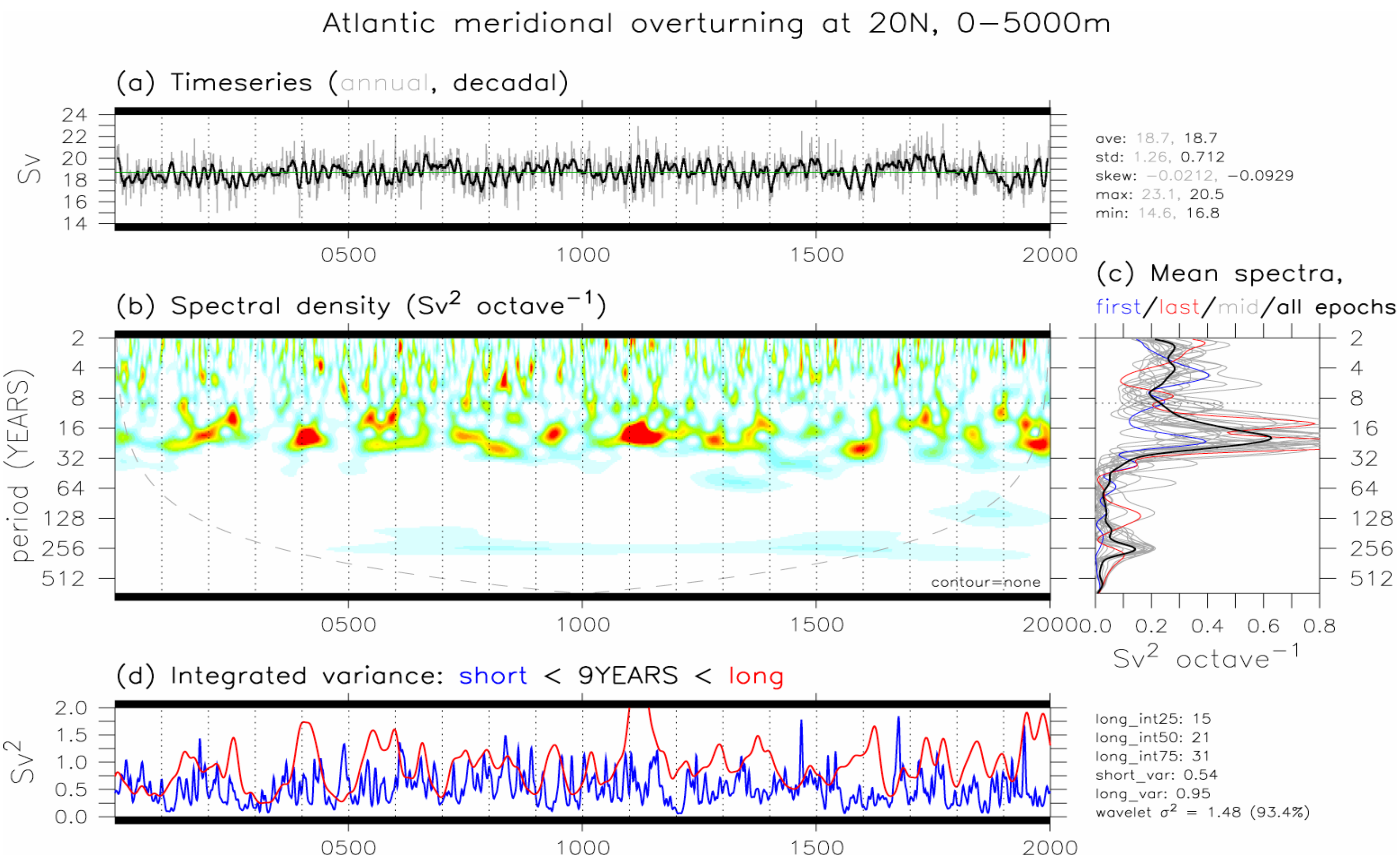
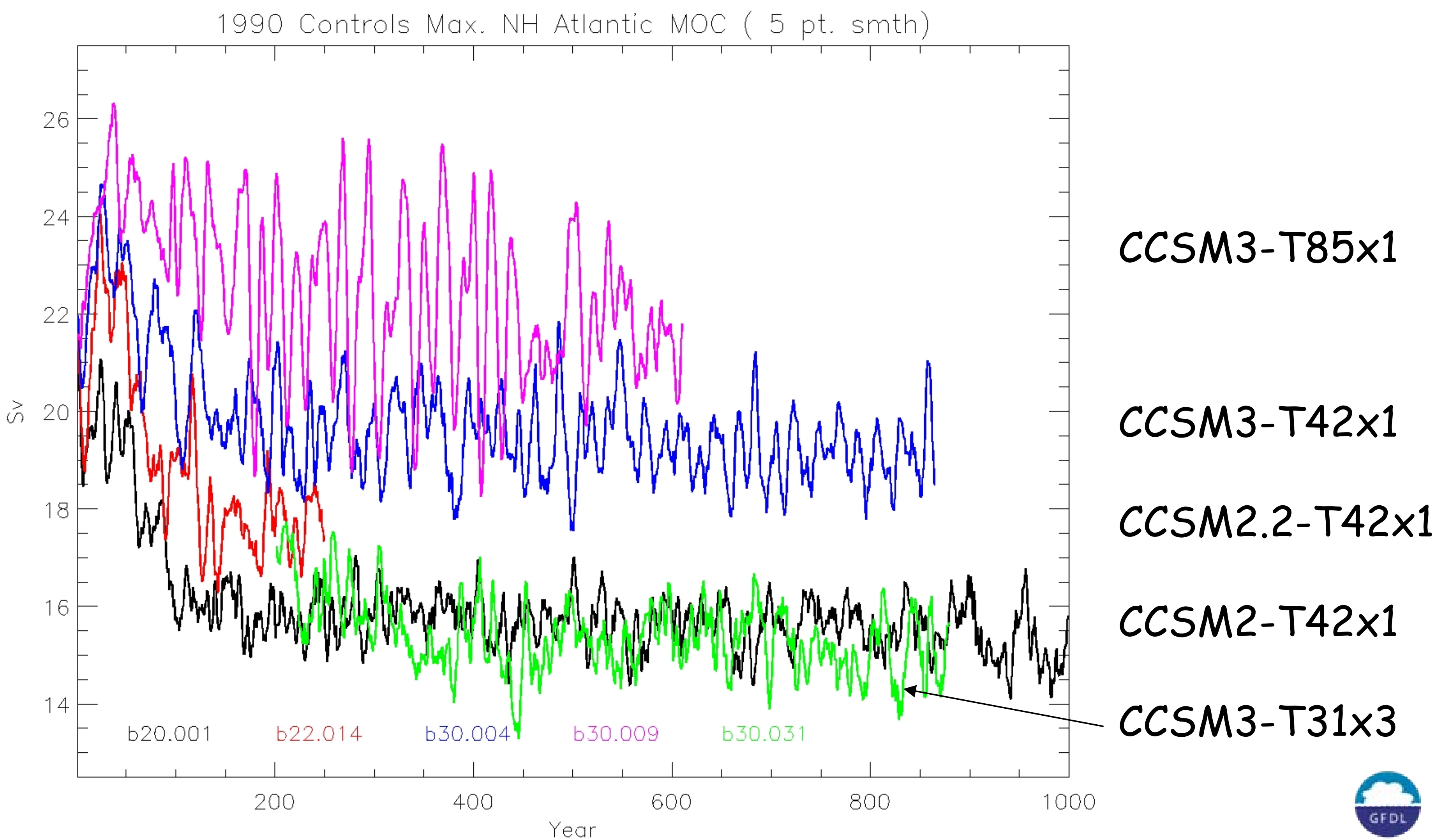
CM2.1 MOC wavelet analysis



From A. Wittenberg

MOC in Present-Day Control Experiments from G. Danabasoglu,NCAR



QUESTIONS: Atlantic Decadal Variability Workshop
G. Danabasoglu,NCAR

- What are the dynamical mechanisms of the decadal oscillations of the MOC?
- How does this oscillation affect our assessment of 20th century, future scenario, etc. climates?
- What are the effects on predictability?
- How do we initialize our ensemble integrations with this oscillation present?

"What are the pros and cons of initial ocean states for climate change scenario ensemble integrations with the same vs. different phases of the MOC or other oceanic oscillatory phenomena, and how would that relate to the number of ensemble members required for analysis?"

A discussion topic at the 11th Annual CCSM Workshop

- Why does it appear to depend on model resolution?
- Does the amplitude of the oscillation depend on the mean state?
- What are the regional and global impacts of the variability?

Atlantic decadal predictability

Two complementary pathways are being pursued at GFDL using our CM2.1 global coupled model:

1. Use “perfect predictability” experiments to characterize potential predictability in the system, and its physical basis.

2. Use assimilated ocean state for decadal scale projections

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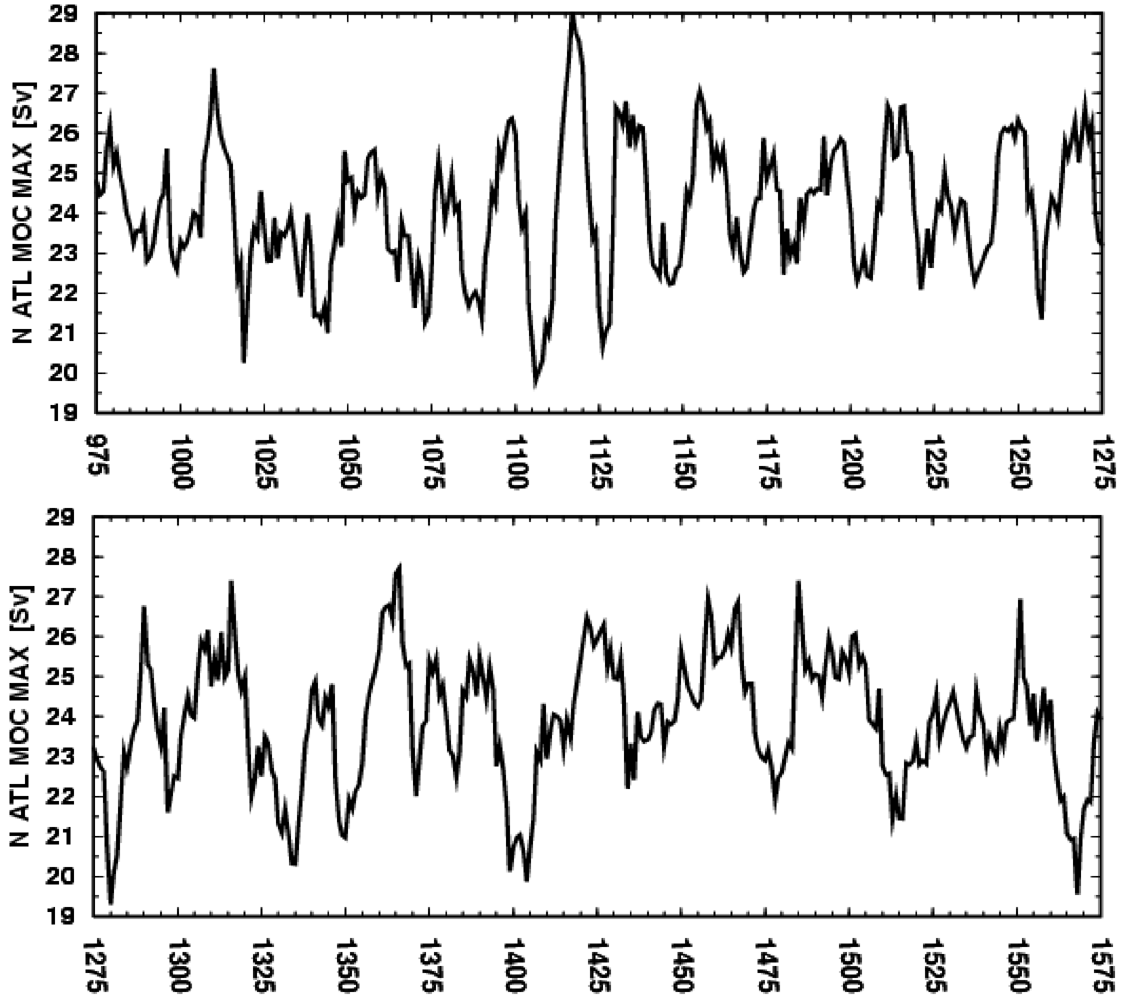
Decadal Variability is Present in GFDL's Models – This Enables Decadal Predictability Studies

The N. Atl. MOC in the 1860 Control



Decadal Predictability Experimental Design

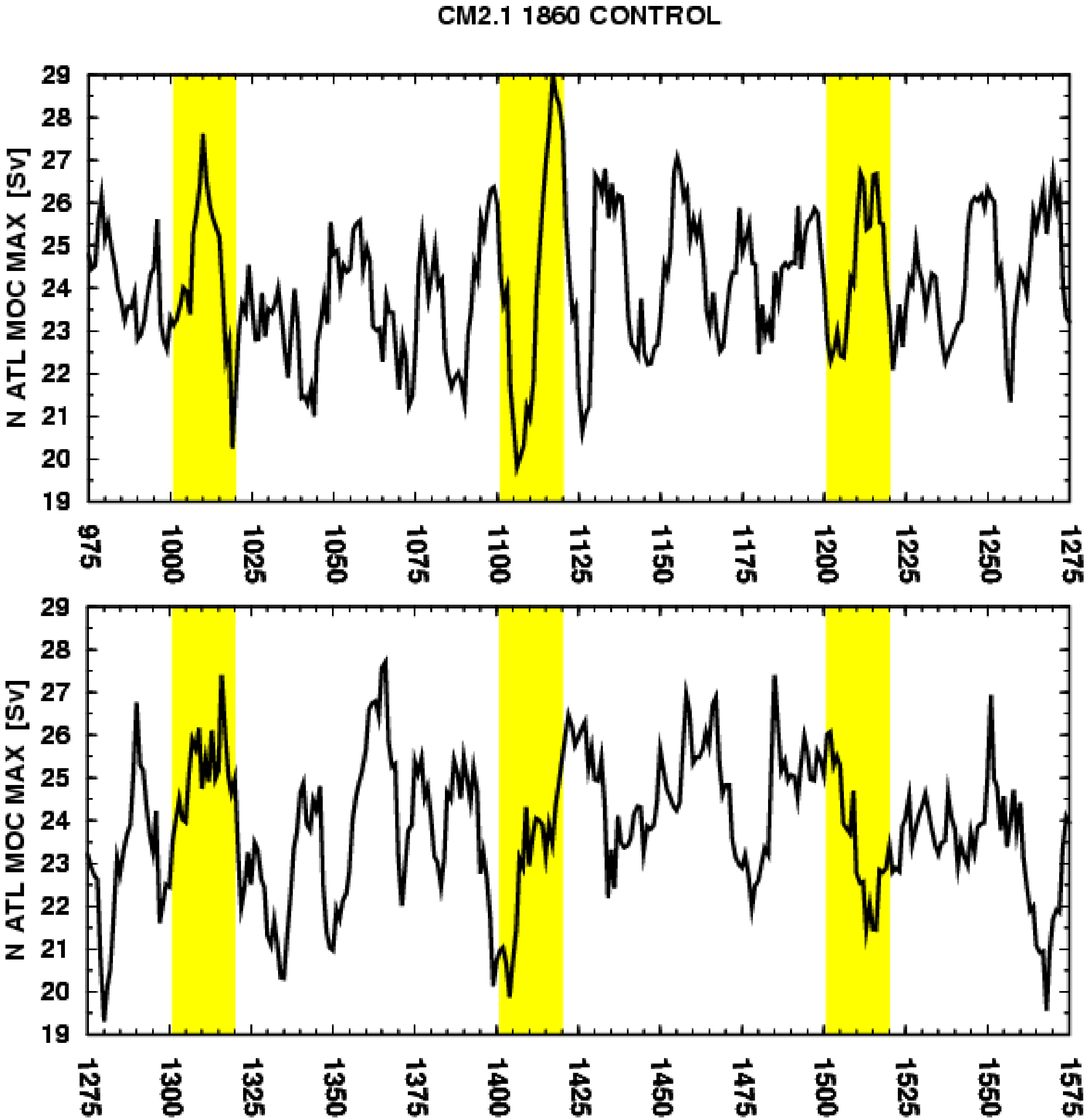
Our investigation begins by arbitrarily selecting 6 points in time from the long control experiment.

The 6 "initialization points" are separated by 100 years. (1 Jan 1001, 1101, 1201, 1301, 1401 & 1501)

We first focus on the annual mean N. Atlantic MOC strength for the 20 year periods beginning at each of the 6 initialization points. So, they are…

1001-1020	**1301-1320**
1101-1120	**1401-1420**
1201-1220	**1501-1520**

The N. Atl. MOC in the 1860 Control



Preliminary Experimental Design

Building some small ensembles:

The CM2.1 model produces a separate restart file for each of its 4 main subcomponents.

In our first line of inquiry, we generated ensembles of 20 year long runs by mixing atmospheric restarts drawn from days >5 days and < 1 month from the 1 Jan initialization used for the ocean, land & sea ice restarts.

Preliminary Experimental Design

<u>Building some small ensembles:</u>

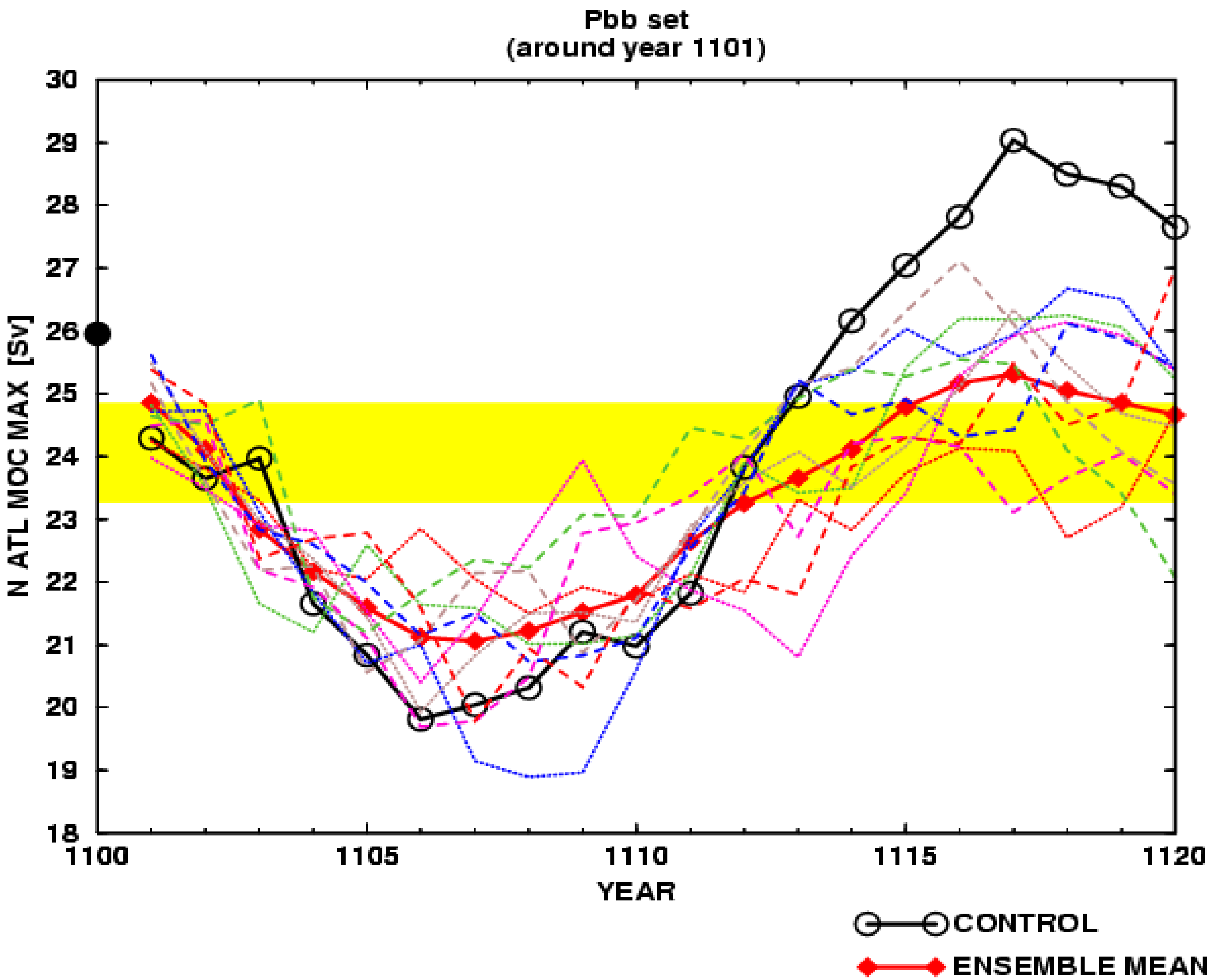
The CM2.1 model produces a separate restart file for each of its 4 main subcomponents.

In our first line of inquiry, we generated ensembles of 20 year long runs by mixing <u>atmospheric</u> restarts drawn from days >5 days and < 1 month from the 1 Jan initialization used for the <u>ocean, land & sea ice</u> restarts. For example…

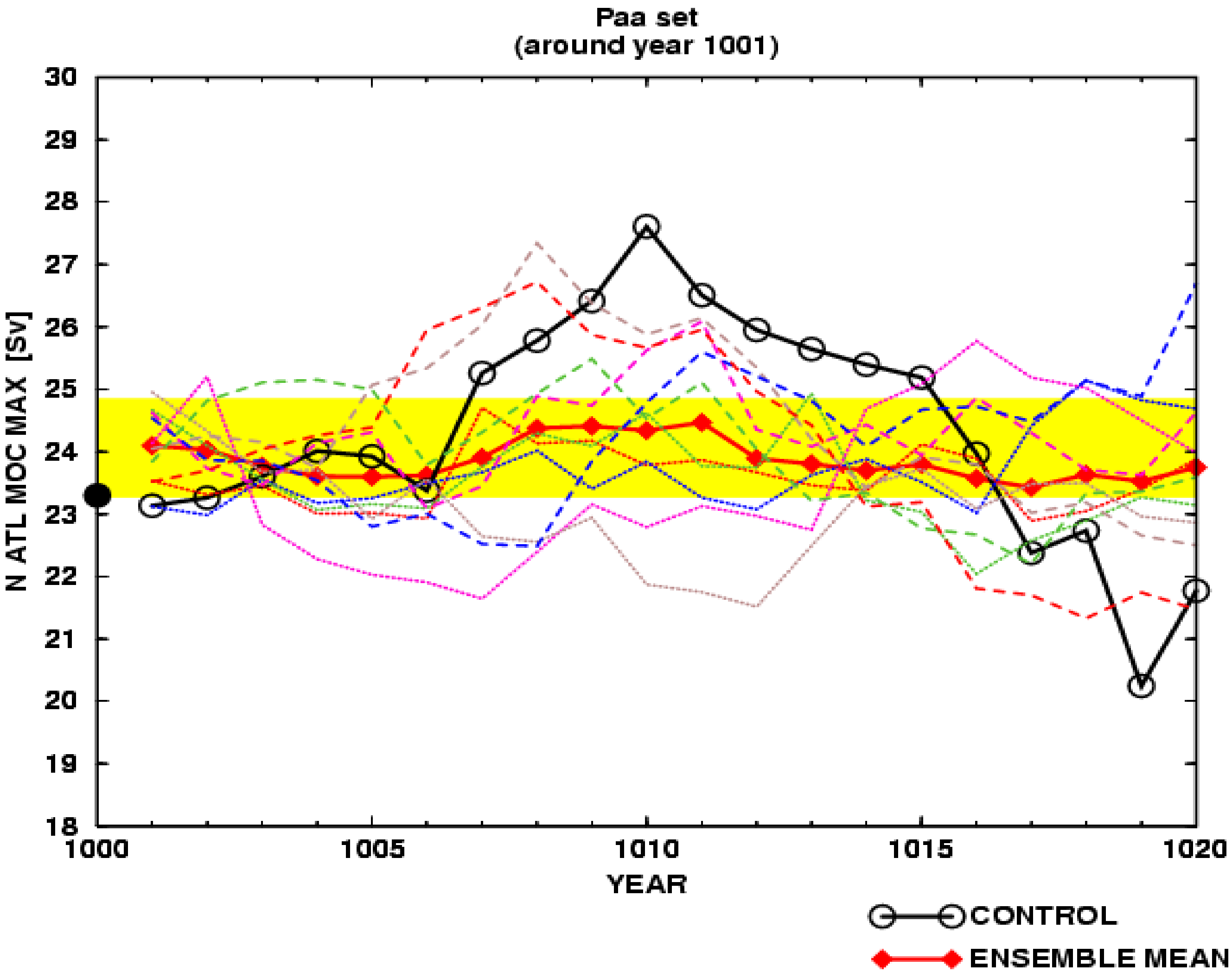
ocean	land	sea ice	atmos	
➢1 Jan 1001			➢07 Dec 1000	➢06 Jan 1001
			➢12 Dec 1000	➢11 Jan 1001
			➢17 Dec 1000	➢16 Jan 1001
			➢22 Dec 1000	➢21 Jan 1001
			➢27 Dec 1000	➢26 Jan 1001

generating a ten member ensemble

?? Will the ensemble members suggest Atl. MOC exists over periods of a decade or longer…



…or not? And why?



"The MM ensemble indicates considerable predictability in the N.A. MOC variations on dacadal time scales." (Collins et al. 2006)

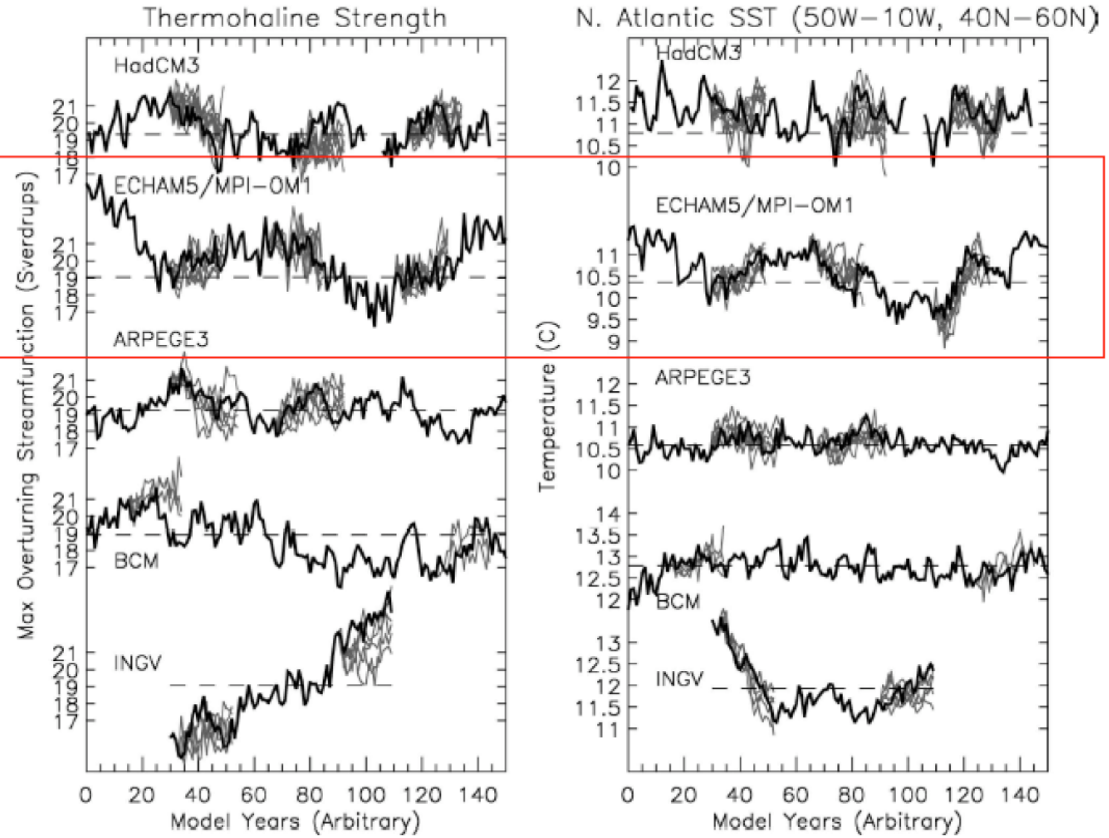


FIG. 9. Classical predictability experiments with five different European coupled ocean–atmosphere GCMs: (left) prediction of thermohaline strength and (right) prediction of North Atlantic SST. The ensemble experiments (thin gray) were initialized from control experiments (thick black) by only perturbing atmospheric initial conditions. The ensemble experiments indicate considerable predictability in the North Atlantic on decadal time scales. From Collins et al. (2006).

From Collins et al. 2006

ECHAM5-OM1: good correspondence between MOC and SST

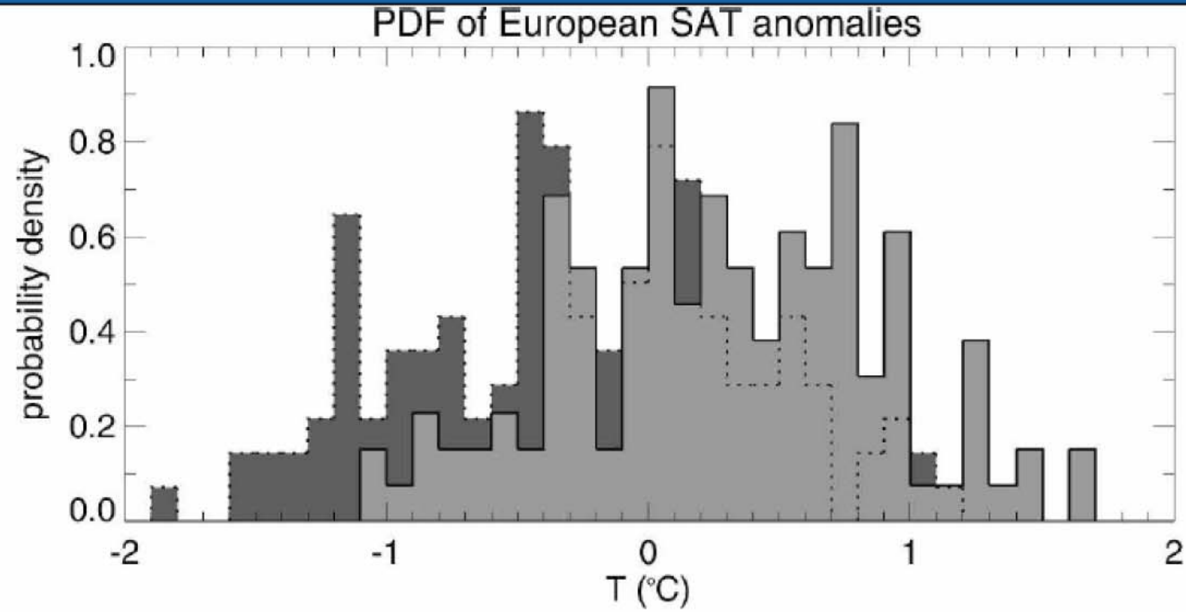
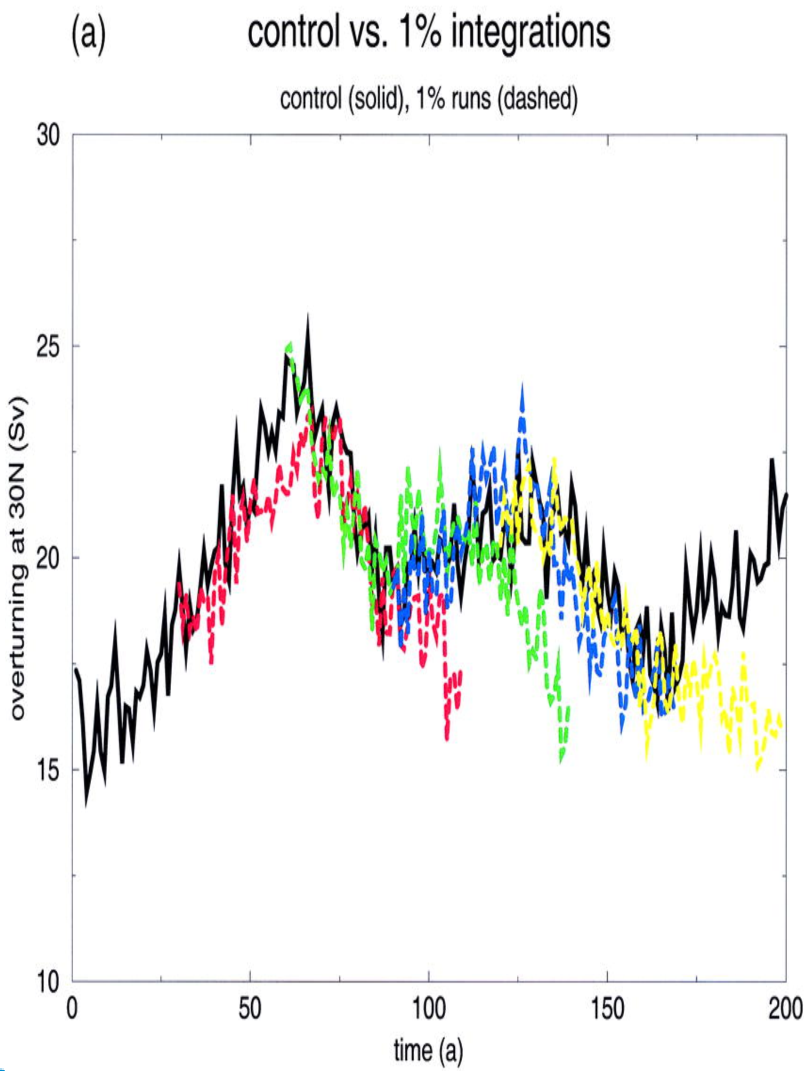


FIG. 2. PDFs of the European SAT anomalies for years with strong (light gray/solid) and weak (dark gray/dotted) anomalies of the North Atlantic MOC, defined as exceeding ±0.44 standard deviations, respectively.

Pohlmann et al. 2006

Latif et al. (2004)



- Decadal prediction is not only an initial value problem but also a boundary value problem.
- Anthropogenic effects need to be taken into account for longterm forecasts.
- Much of the prediction results depend on a proper initialization. ODA still not mature.

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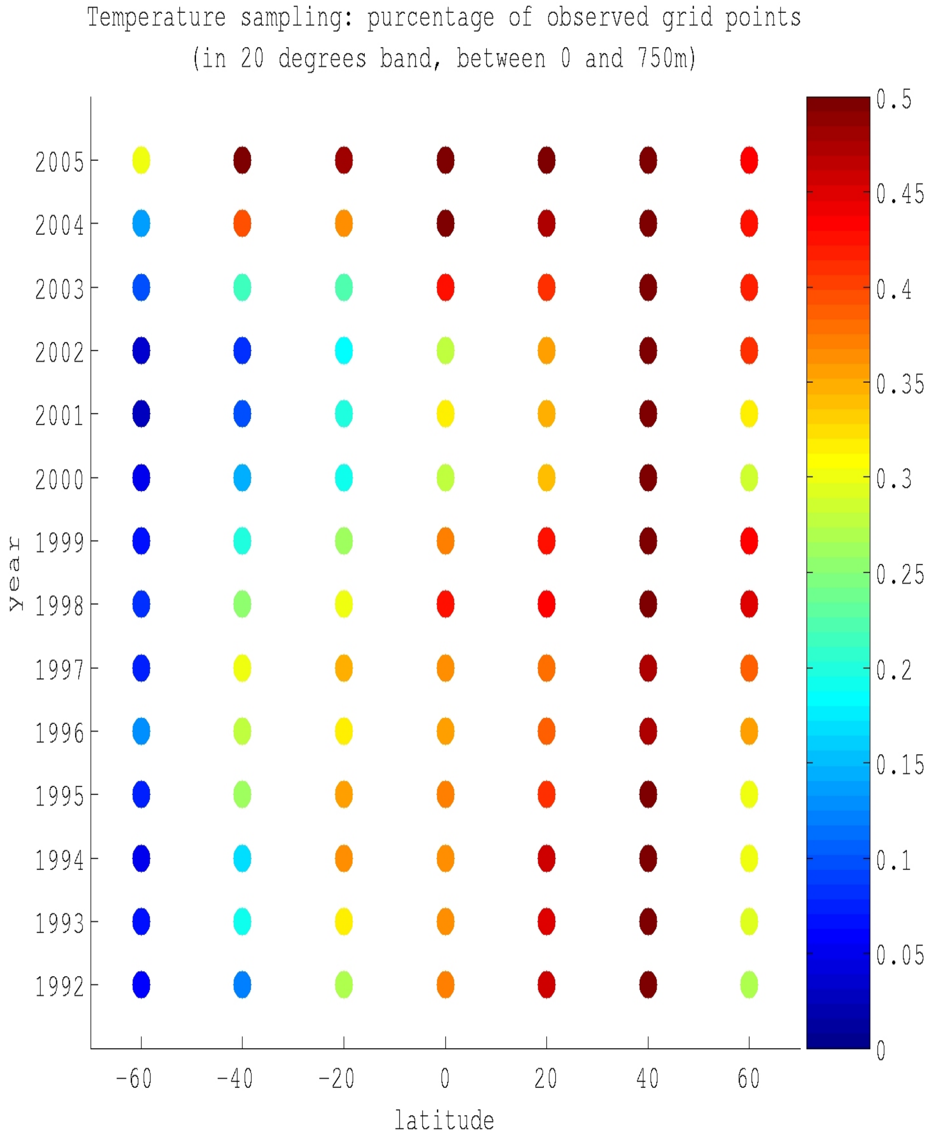
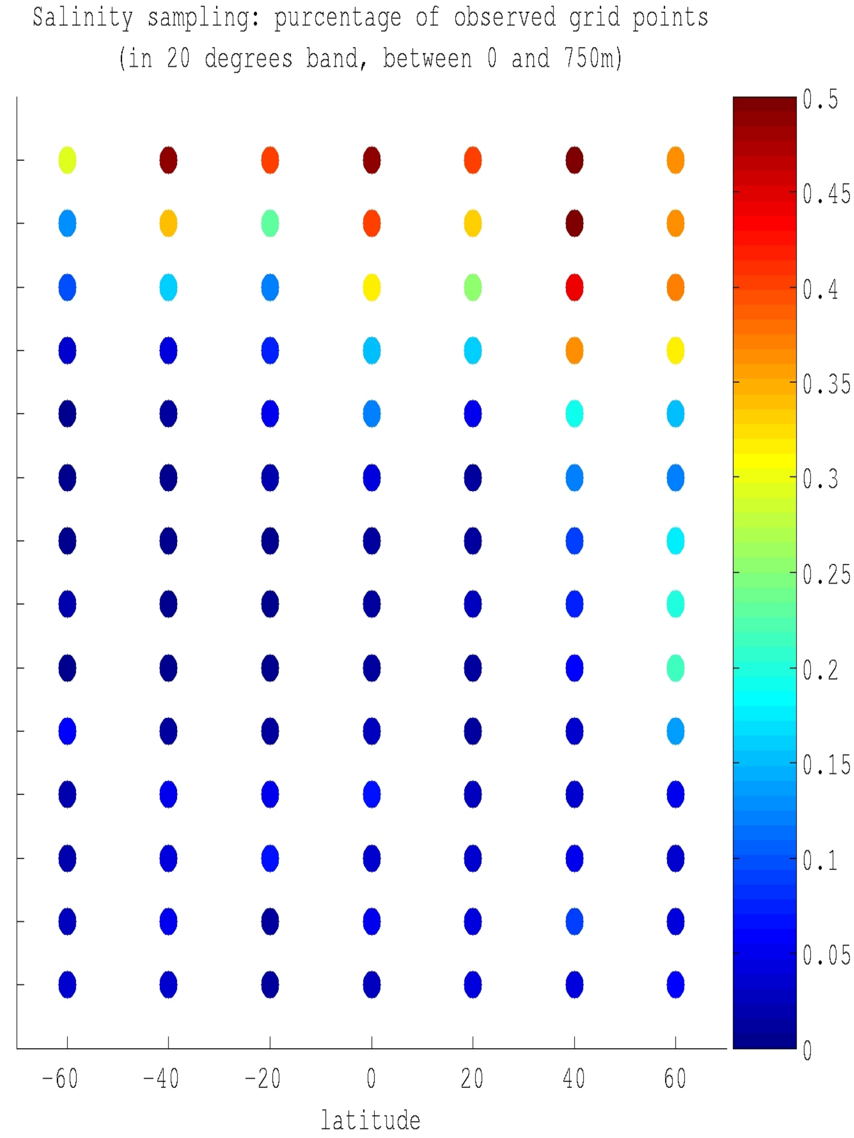
Sampling


Temperature sampling: purcentage of observed grid points
(in 20 degrees band, between 0 and 750m)
year
2005
2004
2003
2002
2001
2000
1999
1998
1997
1996
1995
1994
1993
1992
-60 -40 -20 0 20 40 60
latitude
0.5 0.45 0.4 0.35 0.3 0.25 0.2 0.15 0.1 0.05 0


Salinity sampling: purcentage of observed grid points
(in 20 degrees band, between 0 and 750m)
-60 -40 -20 0 20 40 60
latitude
0.5 0.45 0.4 0.35 0.3 0.25 0.2 0.15 0.1 0.05 0

Forcing fluxes and analysis methods are largest source of uncertainty

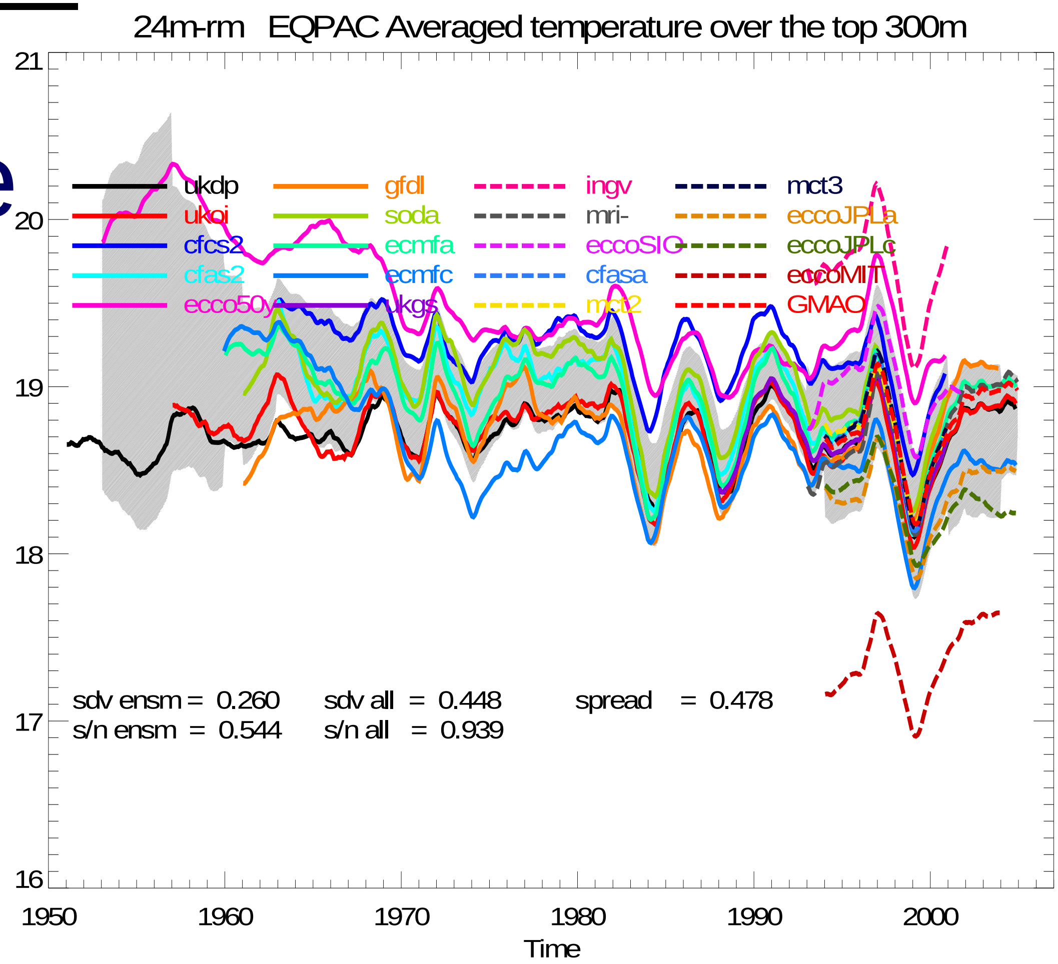
Data Assimilation does not always collapse the spread: <u>We need to pay more attention to the assimilation methods.</u>

Uncertainty in the Mean

- Ambiguity in the definition

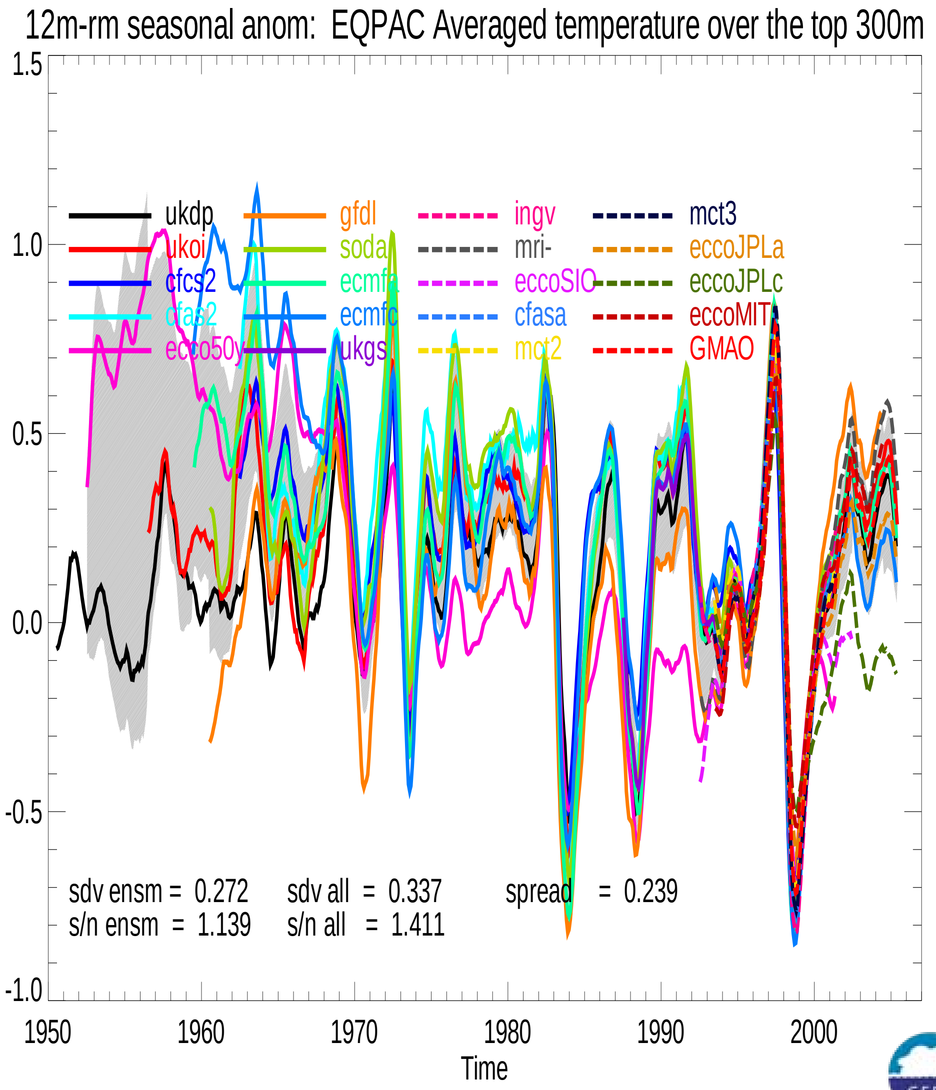
  closest level, interpolated values…?

- Real Uncertainty?



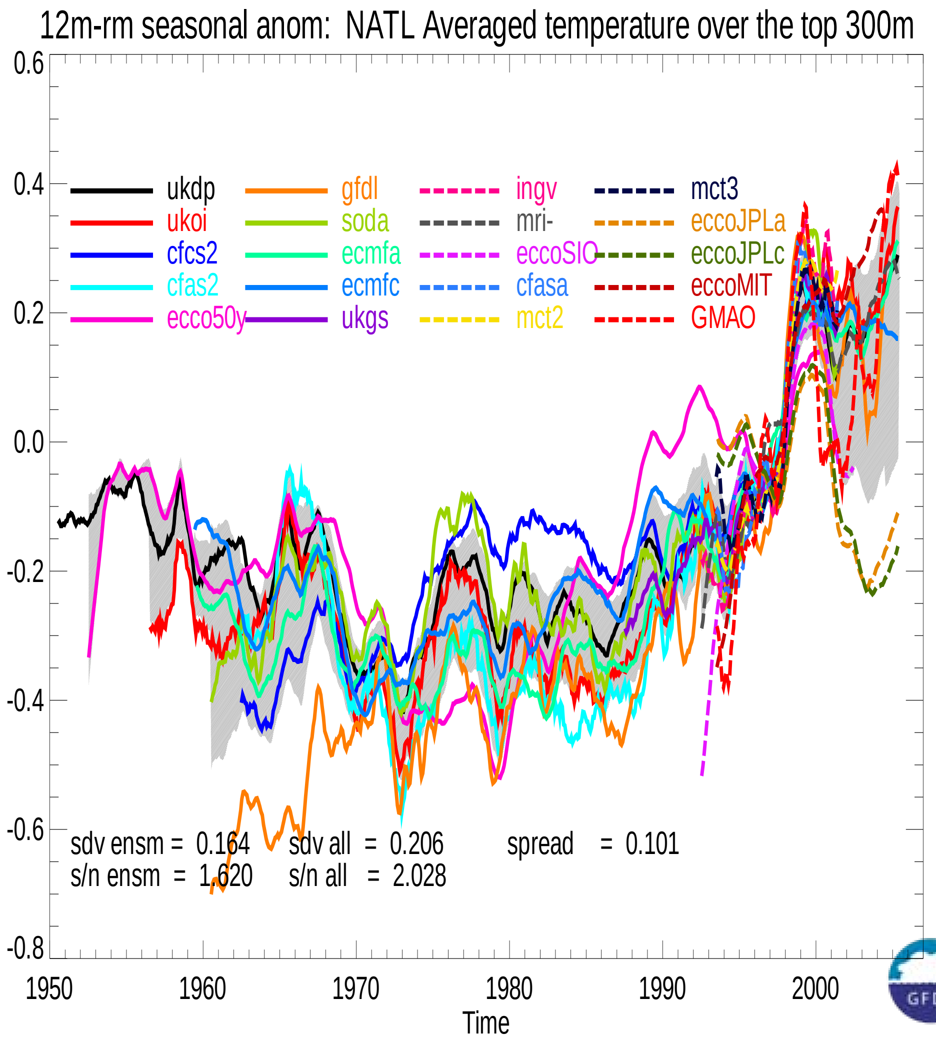
T300: Equatorial regions

- **Eq Pac: Uncertainty decreases with time.**
- **Relatively robust interannual variability.**
- **Increased uncertainty after 2000. Why?**



T300: Mid latitudes (northern)

- The North Atlantic is dominated by a warming trend, especially post 1997
- Large uncertainty after 2000.
- Phase/amplitude of decadal variability is poorly resolved.



Summary

sampling issues (even for the 90's period)

- significant differences between data fits (normalized)

- most probably room for better model-data fit (without over-fitting)

Transport Measures

Meridional overturning, MOC:

$$\psi(y,z,t) = \int_z^0 \int_{xw}^{xe} V(x,y,z,t)\,dxdz$$

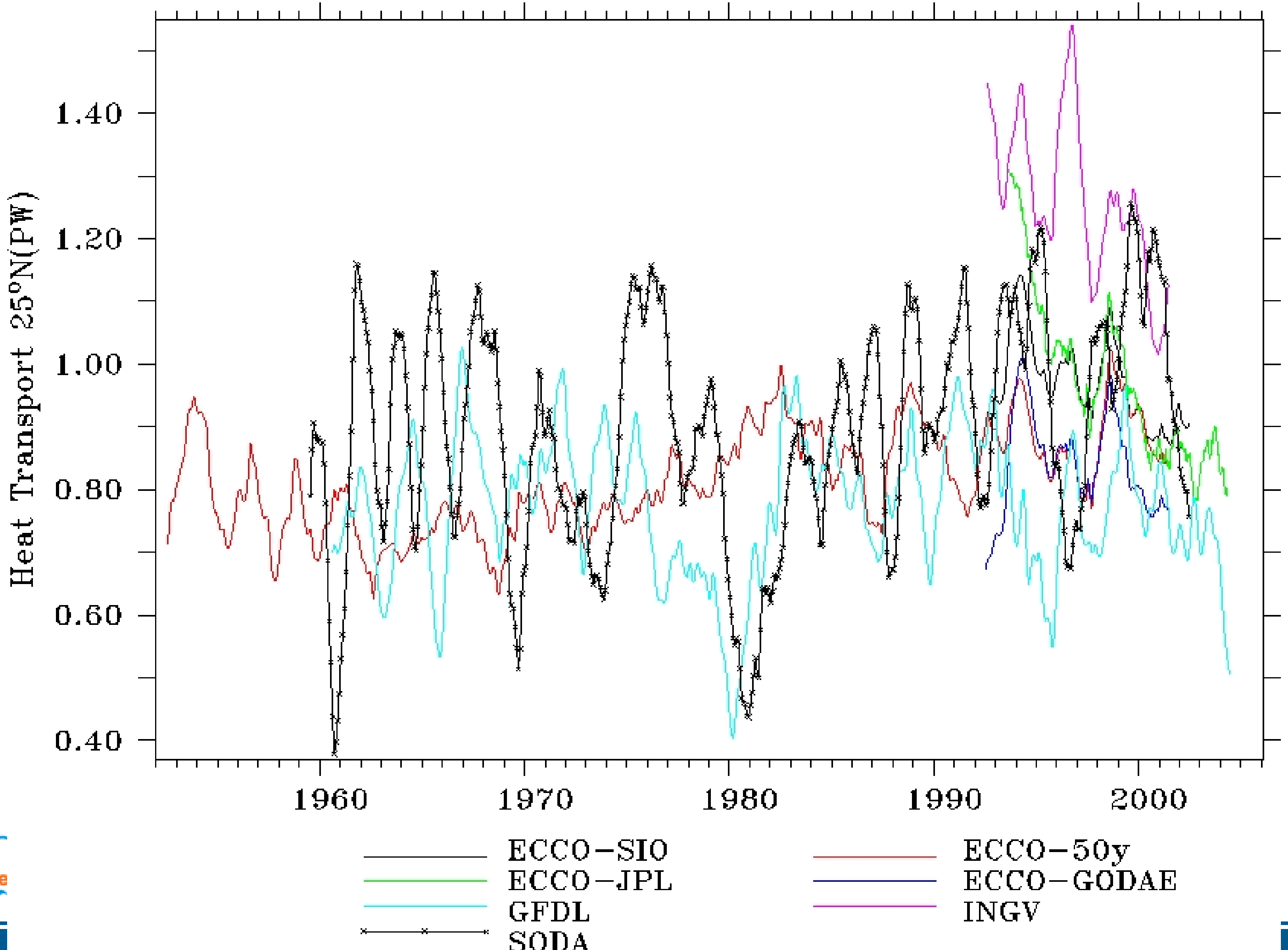
Heat transport (rel. 0^oC):

$$HT(y,t) = \int_{-H}^0 \int_{xw}^{xe} V(x,y,z,t) \cdot T(x,y,z,t)\,dxdz$$

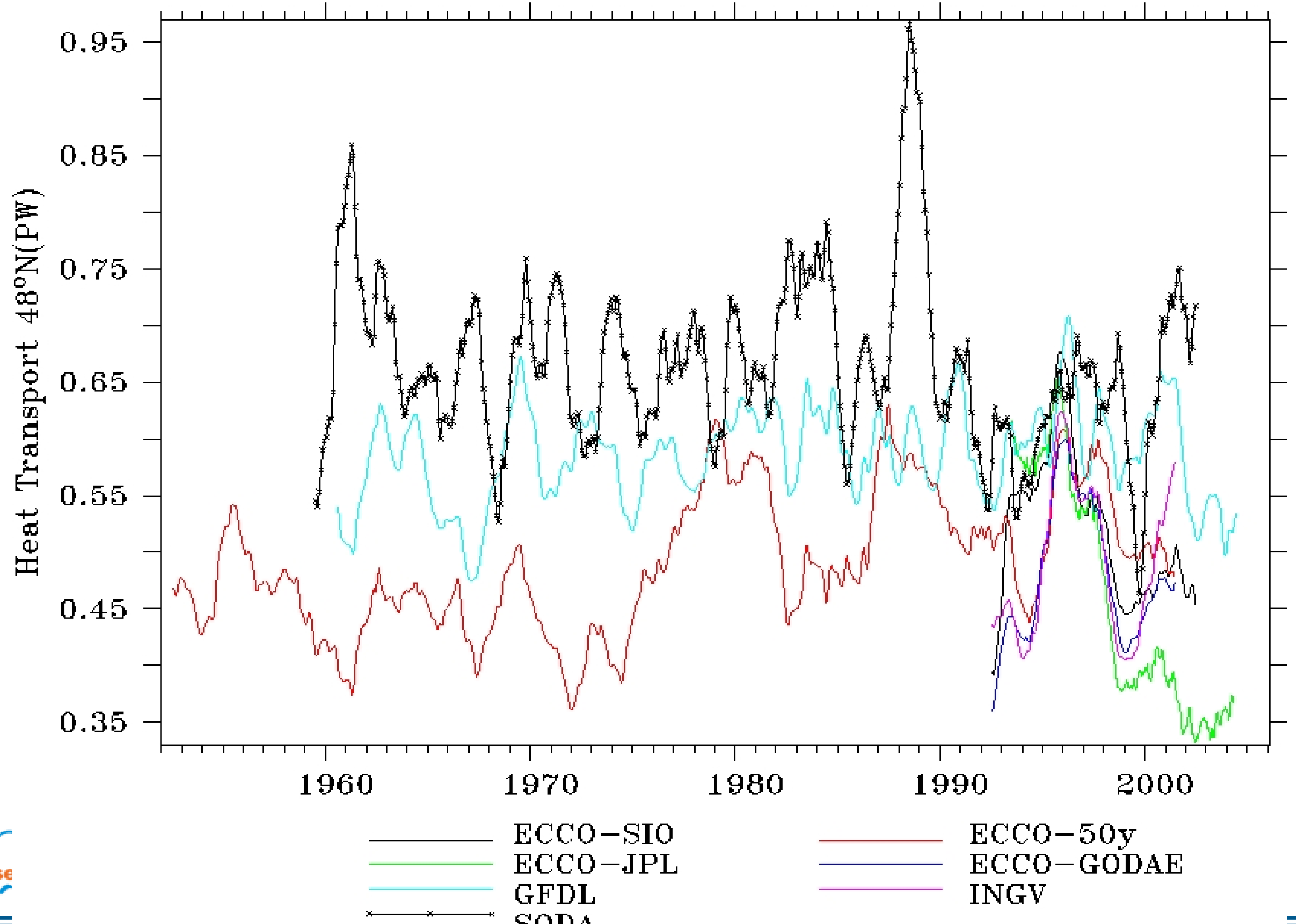
Freshwater transport (rel. 35 psu):

$$ST(y,t) = \int_{-H}^0 \int_{xw}^{xe} V(x,y,z,t) \cdot (1 - S(x,y,z,t)/S_o)\,dxdz\,, \quad S_o = 35$$

Heat transport 25ºN

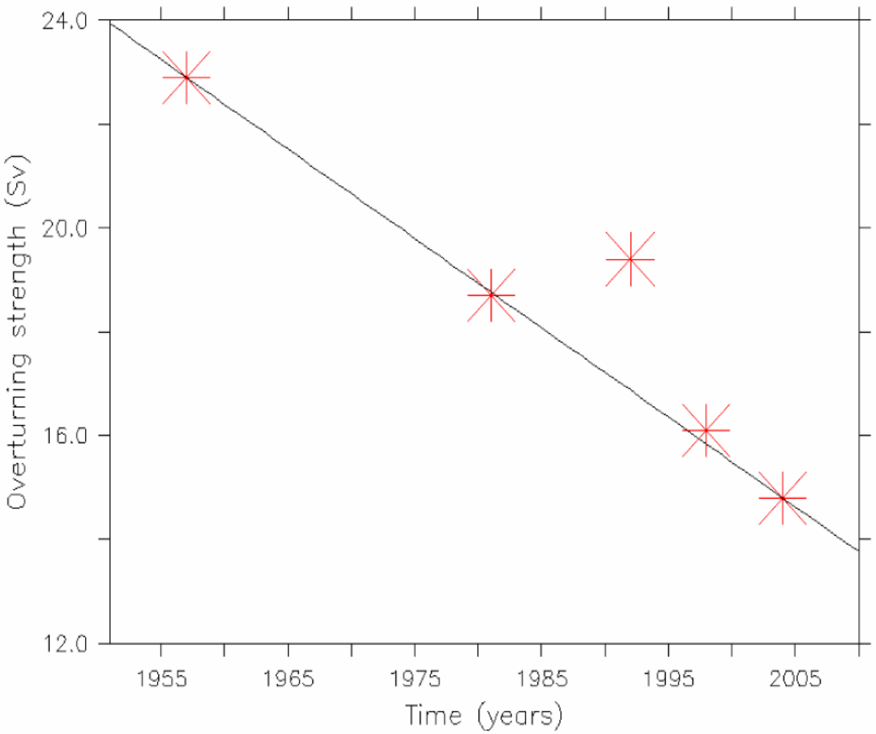


Heat transport 48ºN



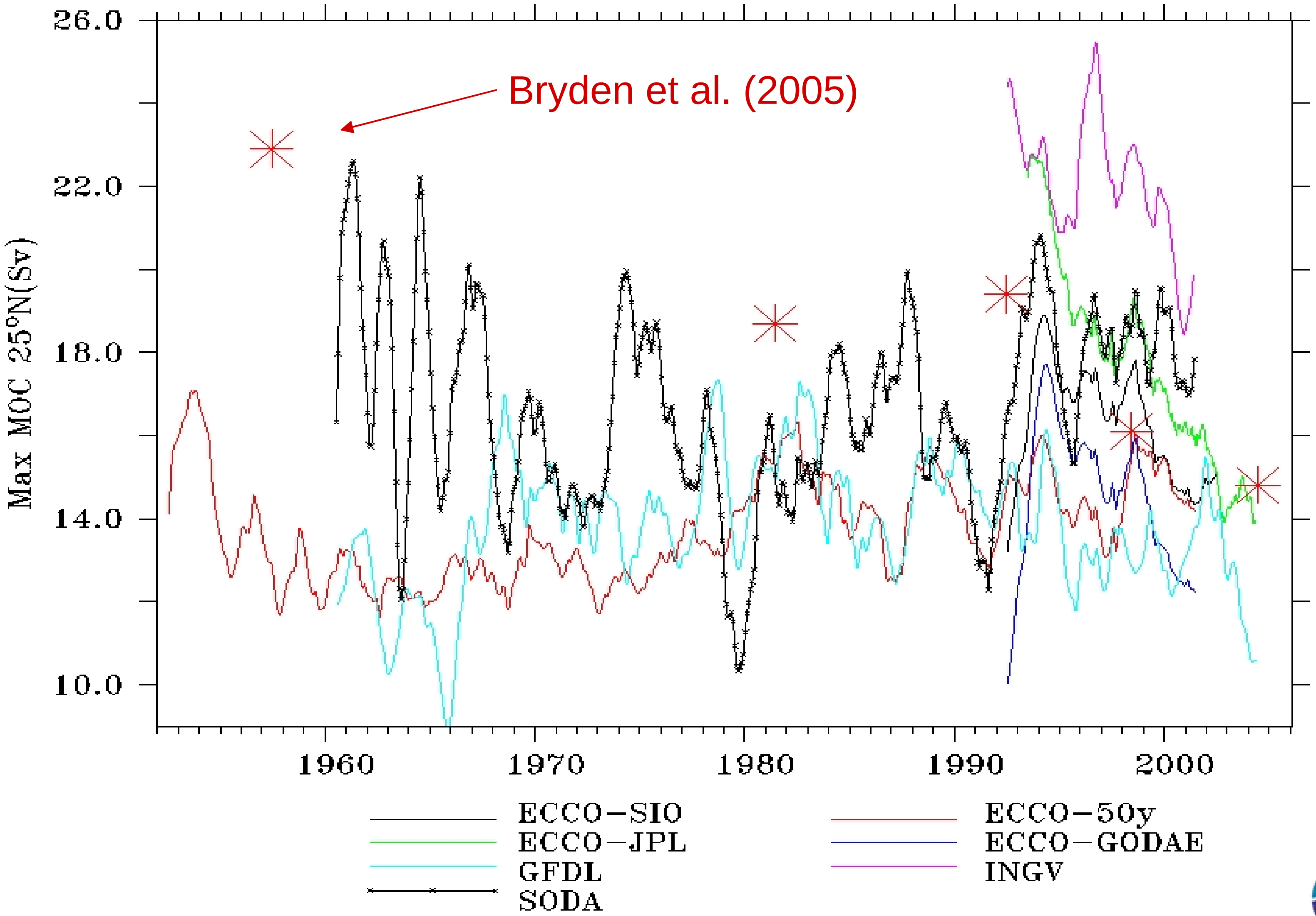
Slowing of the Atlantic meridional overturning circulation at 25N

Bryden, Longworth and Cunningham, Nature 438, 655-657, 2005

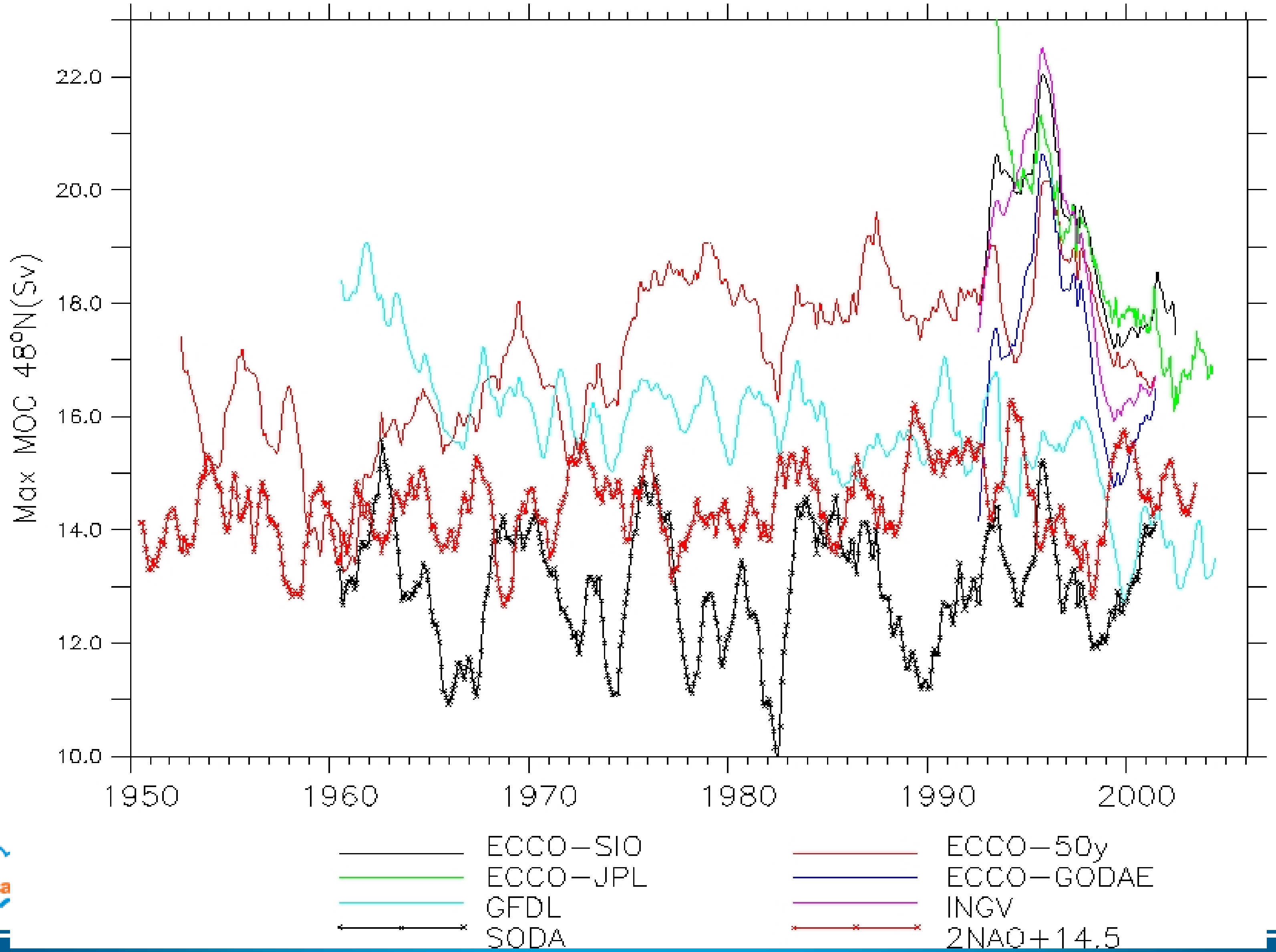


Trend or Noise?

Max. MOC 25ºN


Bryden et al. (2005)
Max MOC 25ºN(Sv)
26.0
22.0
18.0
14.0
10.0
1960
1970
1980
1990
2000
ECCO−SIO
ECCO−JPL
GFDL
SODA
ECCO−50y
ECCO−GODAE
INGV

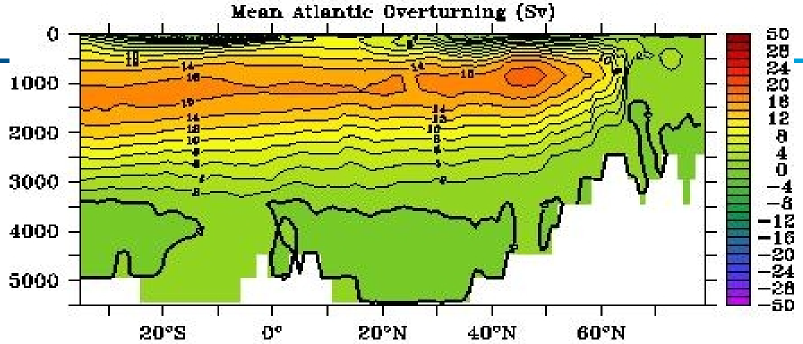
Max. MOC 48ºN



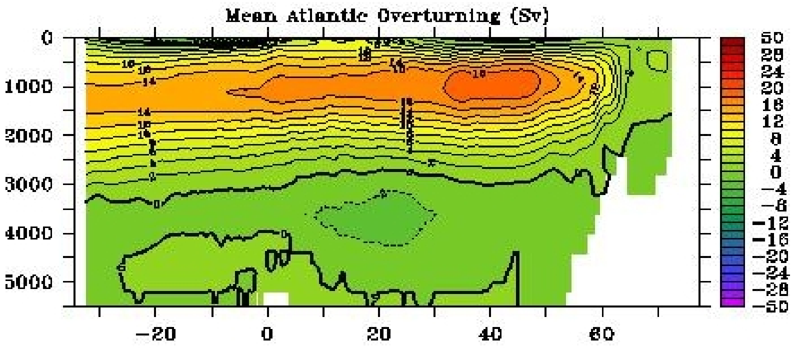
Max MOC 48ºN(Sv)
22.0
20.0
18.0
16.0
14.0
12.0
10.0
1950
1960
1970
1980
1990
2000
ECCO−SIO
ECCO−JPL
GFDL
SODA
ECCO−50y
ECCO−GODAE
INGV
2NAO+14.5

Atlantic MOC

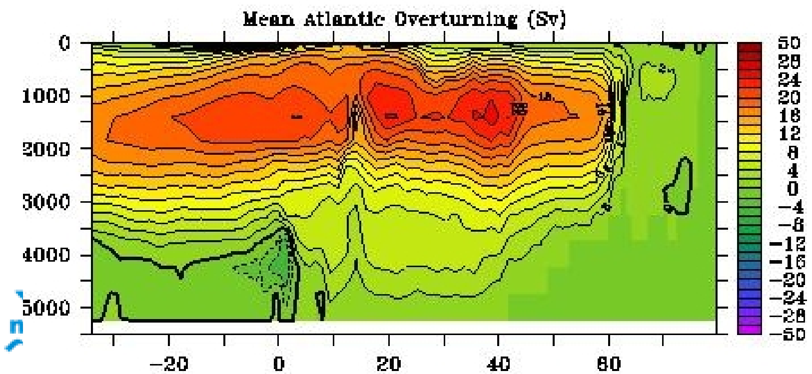
ECCO-SIO



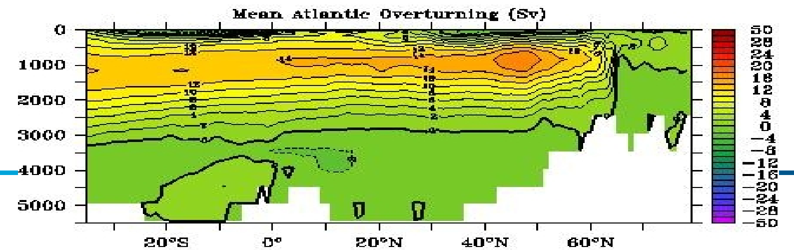
ECCO-JPL



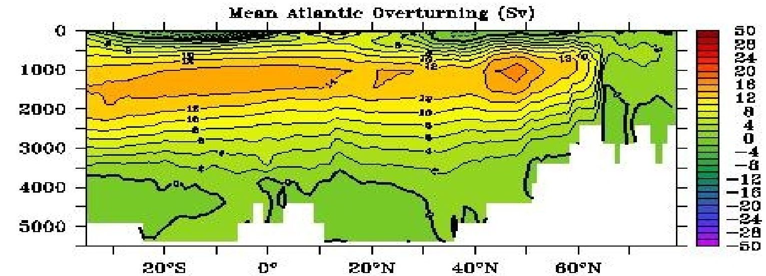
INGV



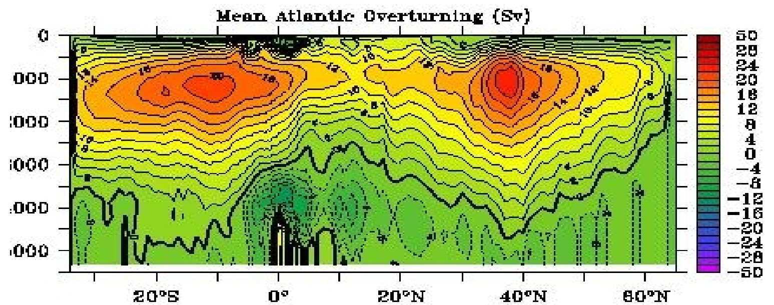
ECCO-50y



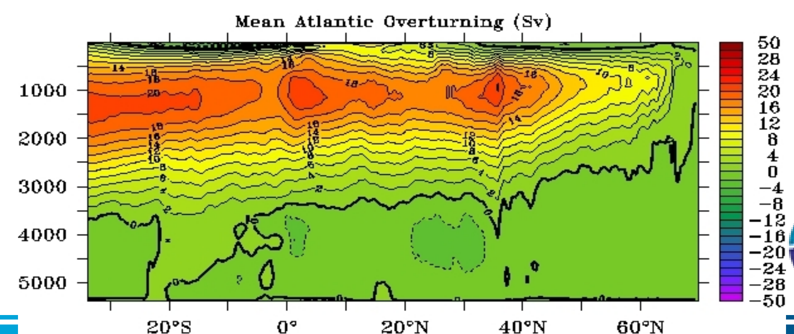
ECCO-GODAE



GFDL



SODA



Heat/FW transport

Heat/FW transport	Global Mean 25N (PW)	Global Mean 20S (PW)	Ind.-Pac. Mean 25N (PW)	Atl. Mean 25N (PW)	Atl. STD 25N (PW)	Atl. Seasonal 25N (PW)	Atl. Drift 25N (PW/10yr)	Global Mean FW 30S (Sv)	Global Mean FW 25N (Sv)	Model Details	Method Details
Ganachaud& Wunsch (2000)	1.80	-0.80	0.50	1.30		Macdonald (1998)		0.72	-0.3		
ECCO-JPL	1.45	-1.30	0.44	1.01	0.30		-0.37	0.50	-0.35	MIT 1-1/3º, Lev KPP, GM	partition Kalman
ECCO-SIO	1.40	-0.44	0.45	0.96	0.21	0.13	-0.08	0.35	-0.31	MIT 1º, Lev, KPP, GM	adjoint
ECCO-50yr	1.26	-0.63	0.38	0.88	0.21	0.14	0.034	0.33	-0.31	MIT 1º,Lev, KPP, GM	adjoint
ECCO-GODAE	1.15	-0.78	0.33	0.82	0.21	0.13	0.033	0.55	-0.31	MIT 1º,Lev	adjoint
GFDL	1.01	0.22	0.20	0.77	0.31	0.11	-0.018			MOM	3D-var
INGV	2.2	-1.1	0.7	1.45	0.25	0.11	-0.27	0.82	-0.45	OPA 2-1/2º,Lev, TKE, eddy vel	multivar. OI
SODA				0.99	0.16		-0.08			MOM 1-1/3º Lev KPP,GM	OI

Questions

- Why is the spread so large between reanalysis?

- relationships between observed and unobserved quantities.

- quality/uncertainties of climatological means.

- impact on the fit to observations of:
  - a) model constraints (strong? weak?), assimilation window length
  - b) weighting
  - c) methodology in general

- data sets used for comparison.
- instrument types and associated errors.
- lack of past observations.

OUTLINE

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- Summary of Atlantic Variability Workshops

Ocean Data Assimilation

GFDL ODA systems :

1. Use "perfect model" experiments to characterize the ability of the ODA methodology and observing system to constrain the MOC.

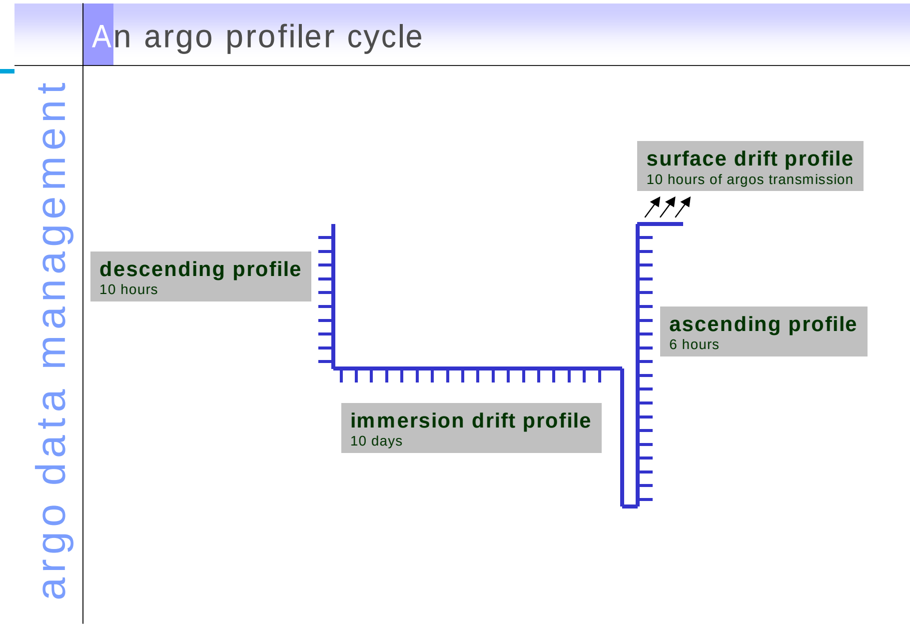
2. Use real data assimilated ocean state for decadal scale projections

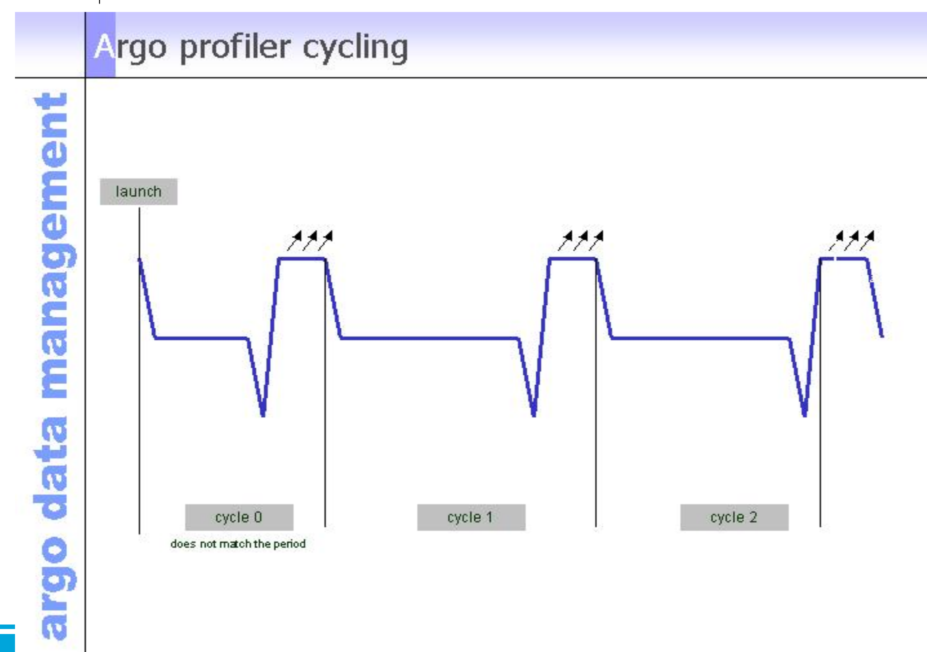
ARGO: Array for Real-time Geostrophic Oceanography

JASON: A hero in Greek mythology

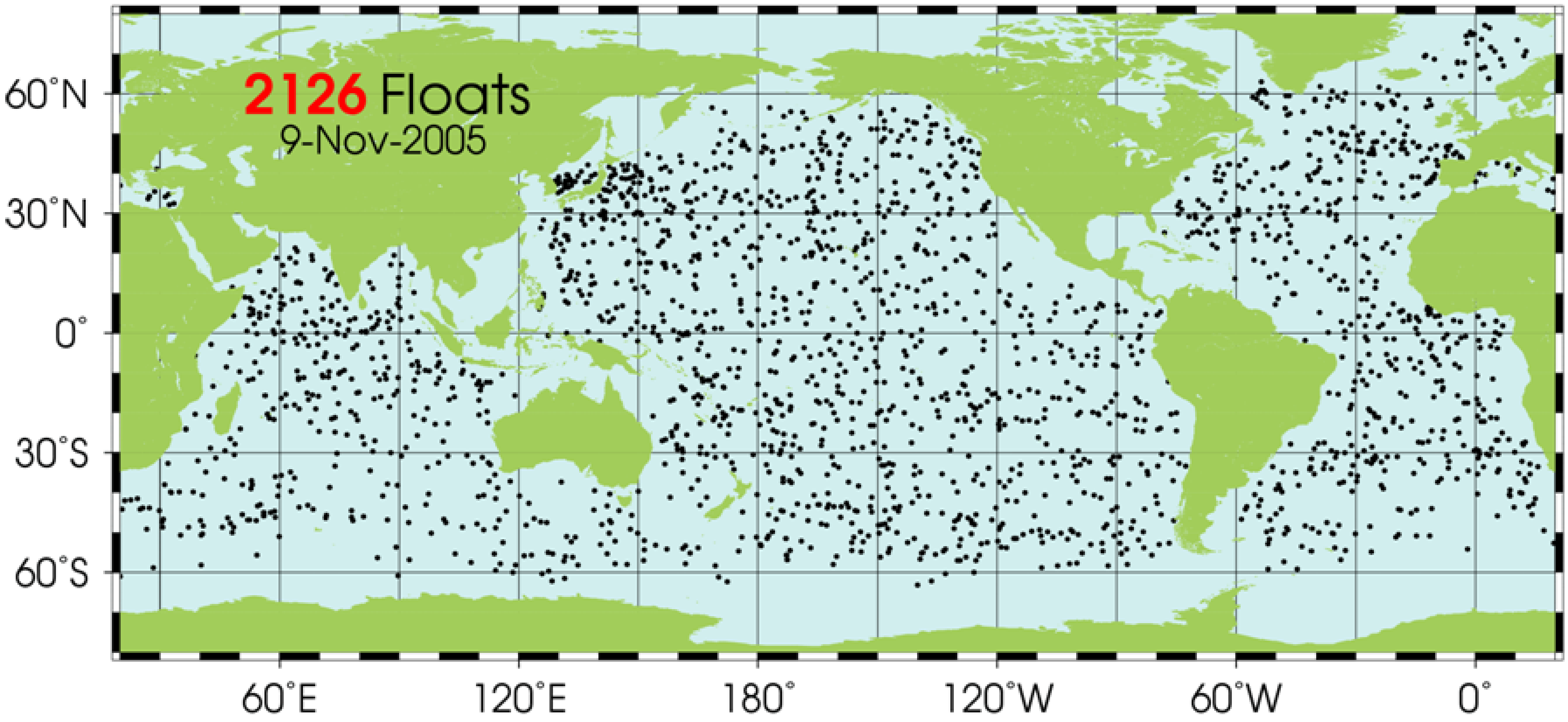
ARGO: JASON's ship

Apex





ARGO deploy: 3000 autonomous profiling floats

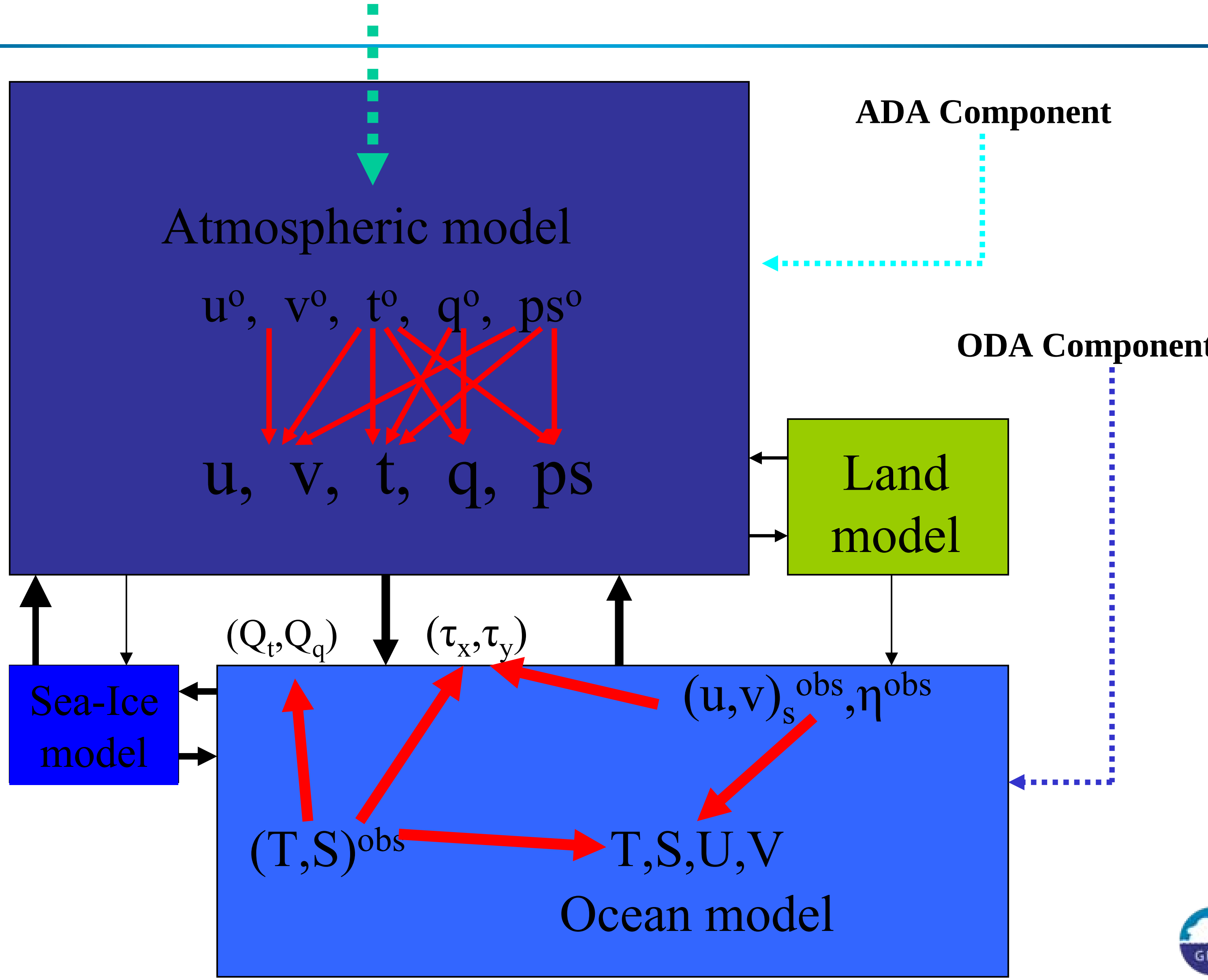


Estimation and Initialization of Atlantic MOC Using GFDL's CDA System Based onPerfect Model Simulations

- Brief Introduction of GFDL's Coupled Data Assimilation System

- Idealized Twin Experiments: Can we reconstruct Atlantic MOC from the XBT/Argo network? What are issues?
  - Only using top 500 m ocean temperature measurements
  - Only using top 500 m ocean temperature and salinity measurements
  - Using Argo measurements (down to 2000 m deep for temperature and salinity)

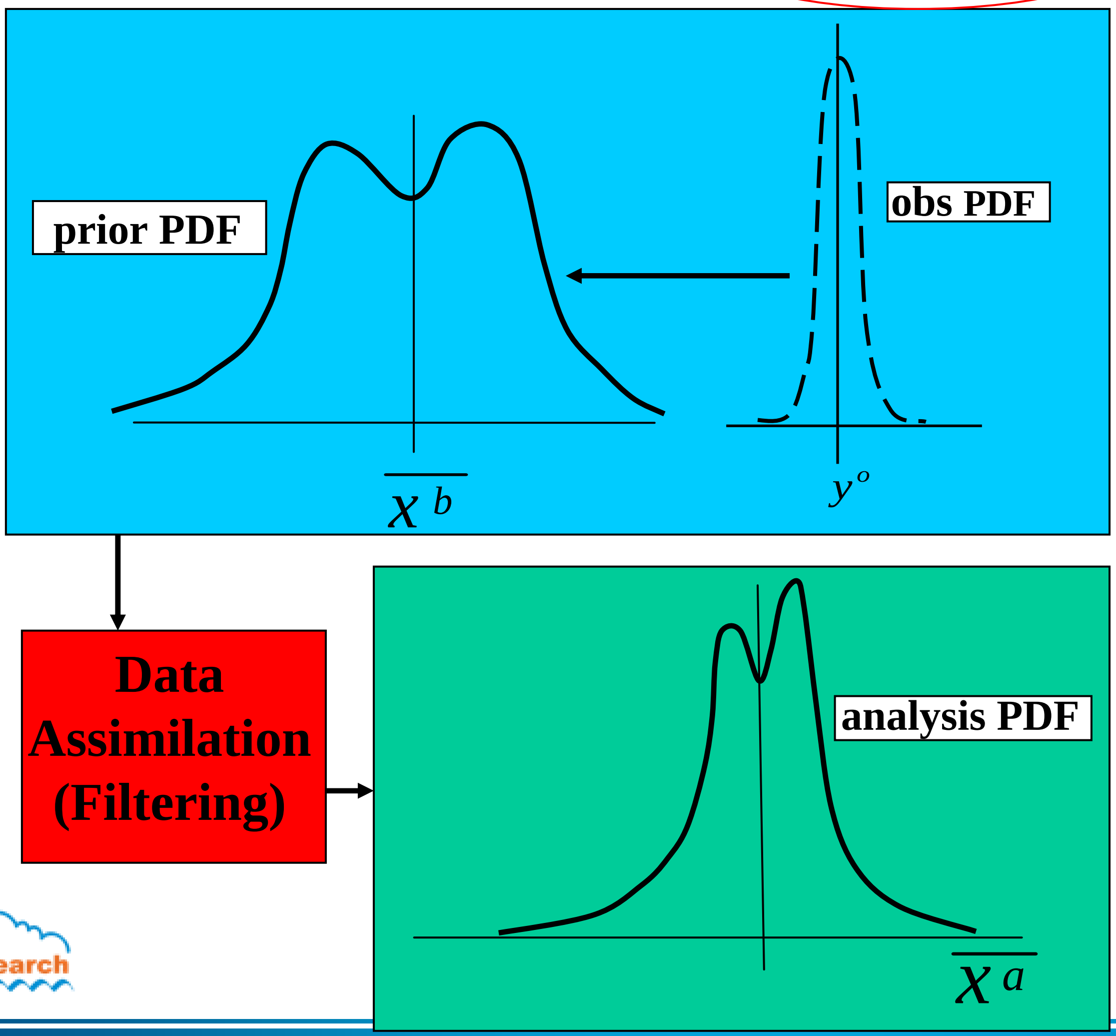
GHG + NA radiative forcing



CDA System: Ensemble Kalman Filtering Algorithm

Deterministic (being modeled) **Uncertain (stochastic)**

$$\overbrace{d\mathbf{x}_t / dt = f(\mathbf{x}_t, t)} + \overbrace{\mathbf{G}(\mathbf{x}_t, t)\mathbf{w}_t}$$

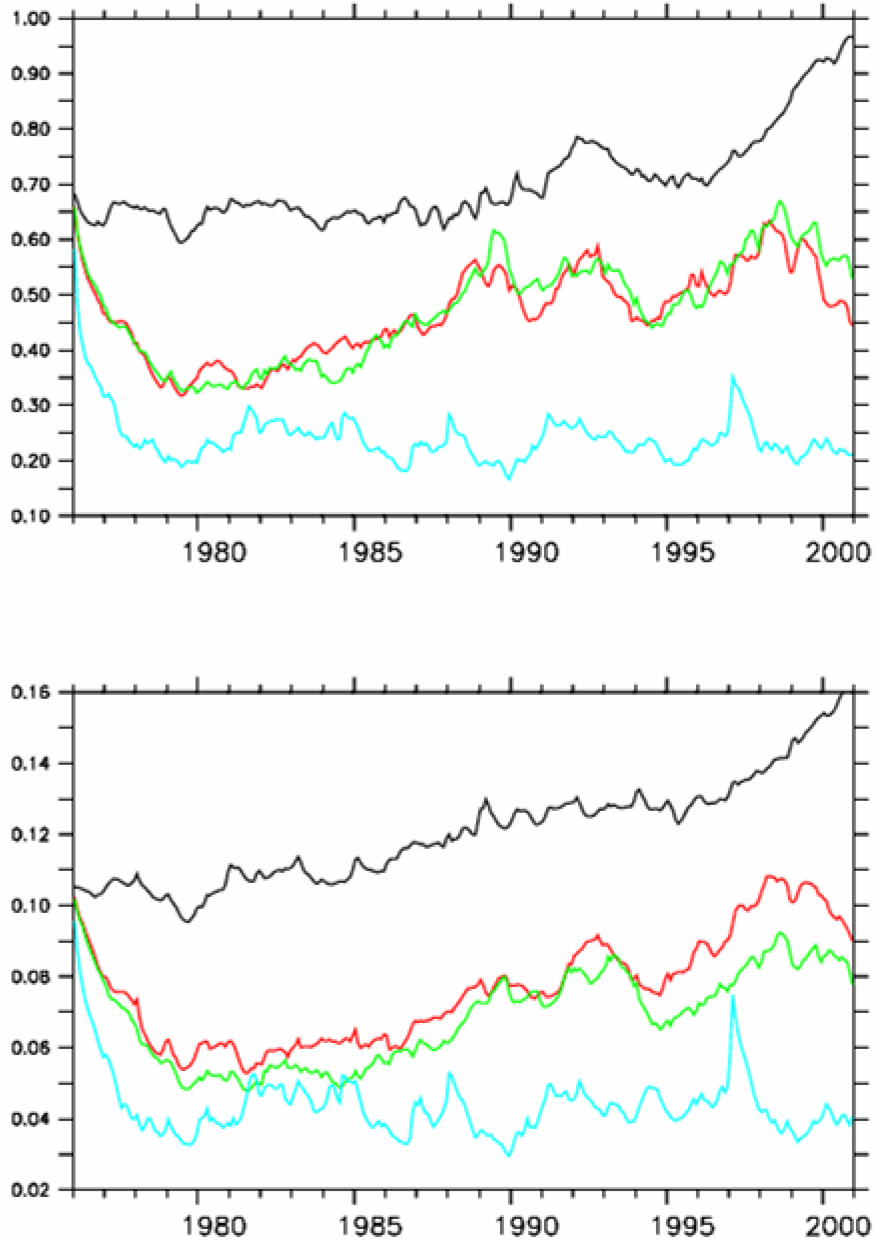


- ✓ Atmospheric internal variability
- ✓ Ocean internal variability (model does not resolve)

Root mean squared errors of top 2000 m at north Atlantic (30n:70N)

Temperature (°C)

Salinity (psu)



Control

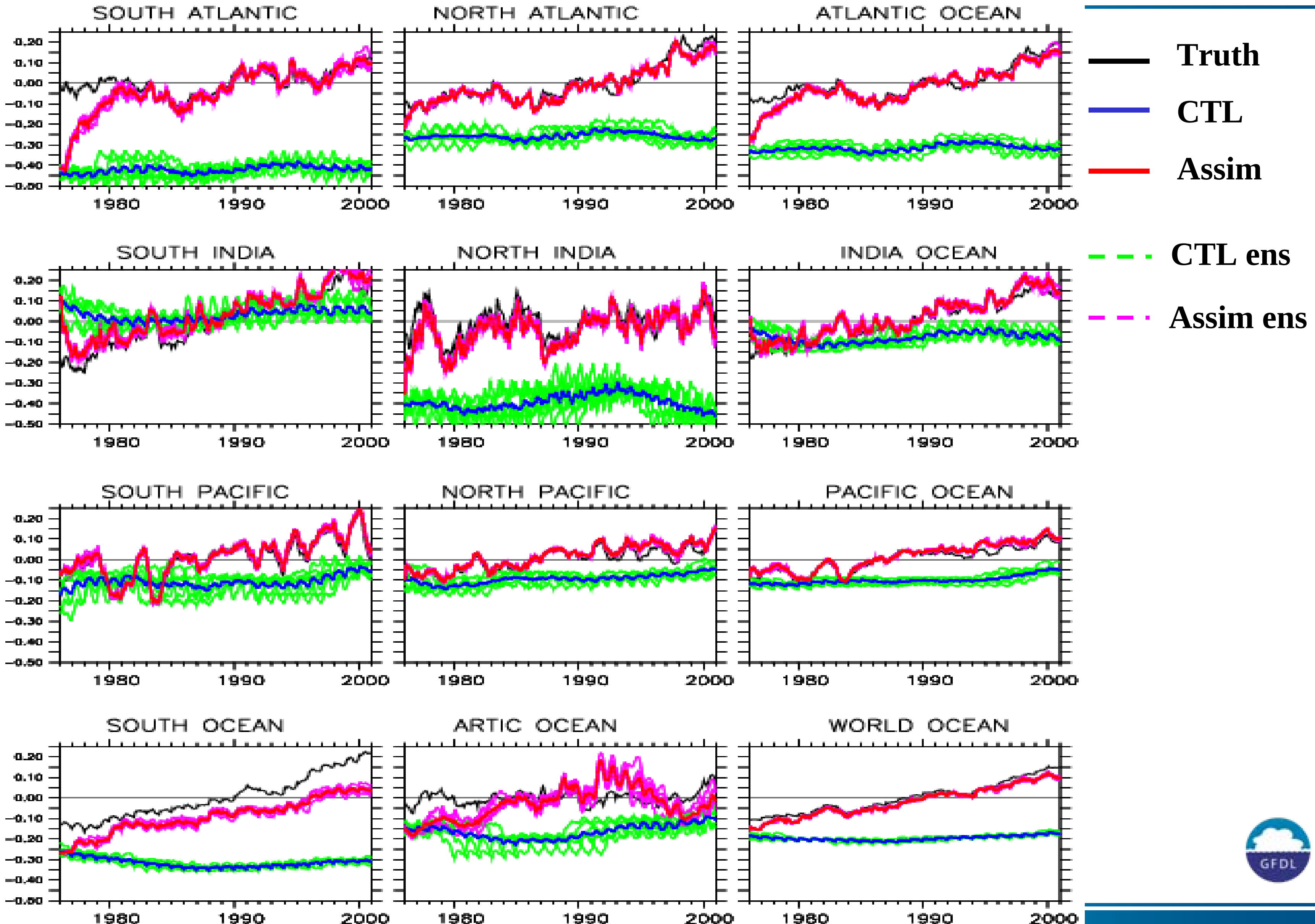
ODA (500m) T+Cov(T,S)

ODA (500m) T,S + Cov(T,S)

ODA (2000m) T,S + Cov(T,S)

How much can we retrieve the trend of climate change?

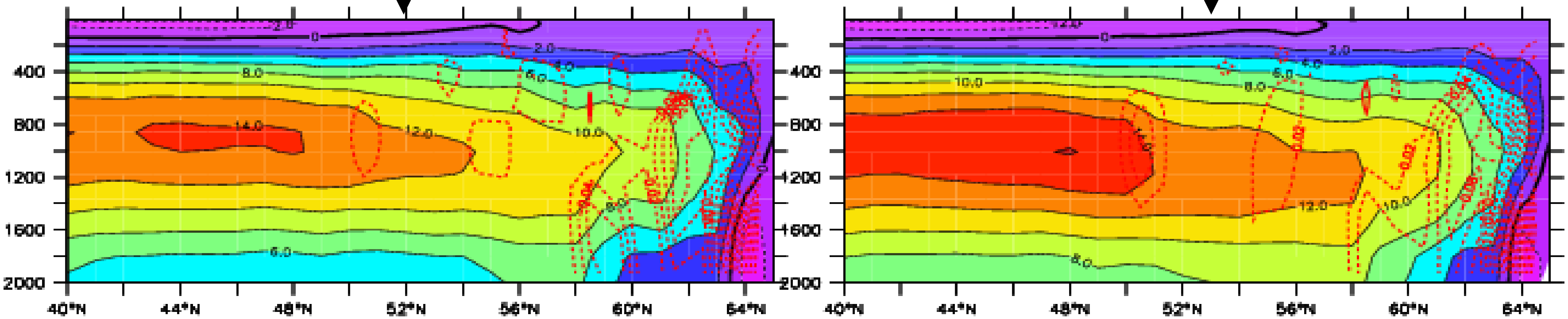
1) Top 500 m Ocean Heat Content (Averaged Temperature) Anomalies

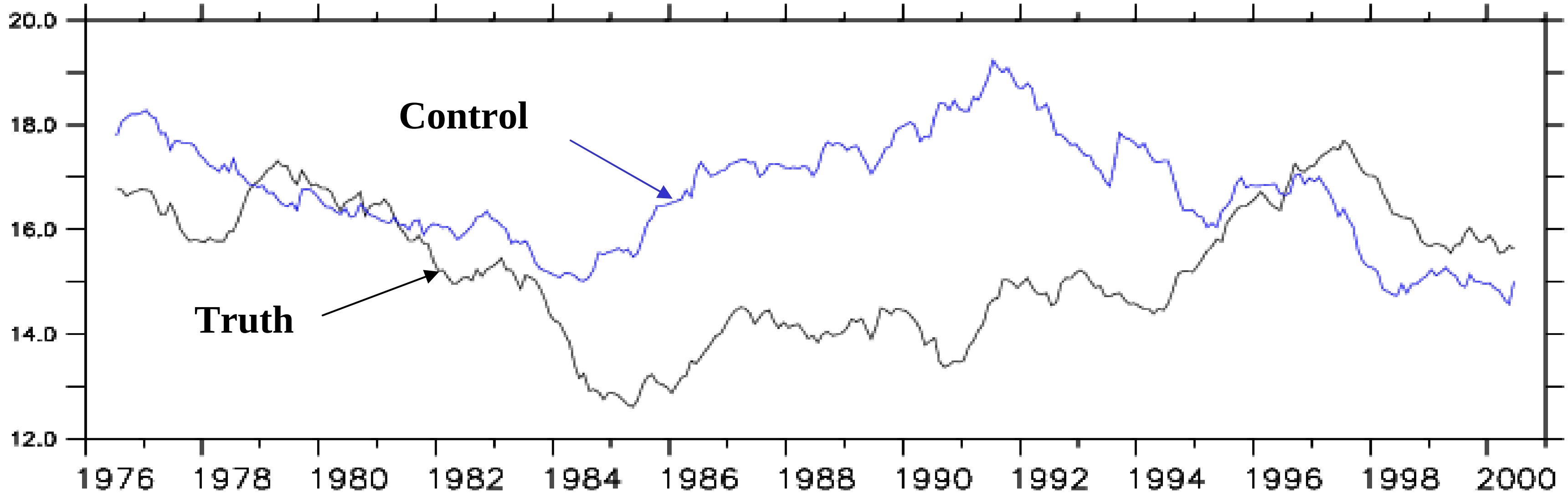


Truth: Historical radiative forcings run from 1861-2000, initializing the model from 300-yr spinup using 1860 radiative forcings

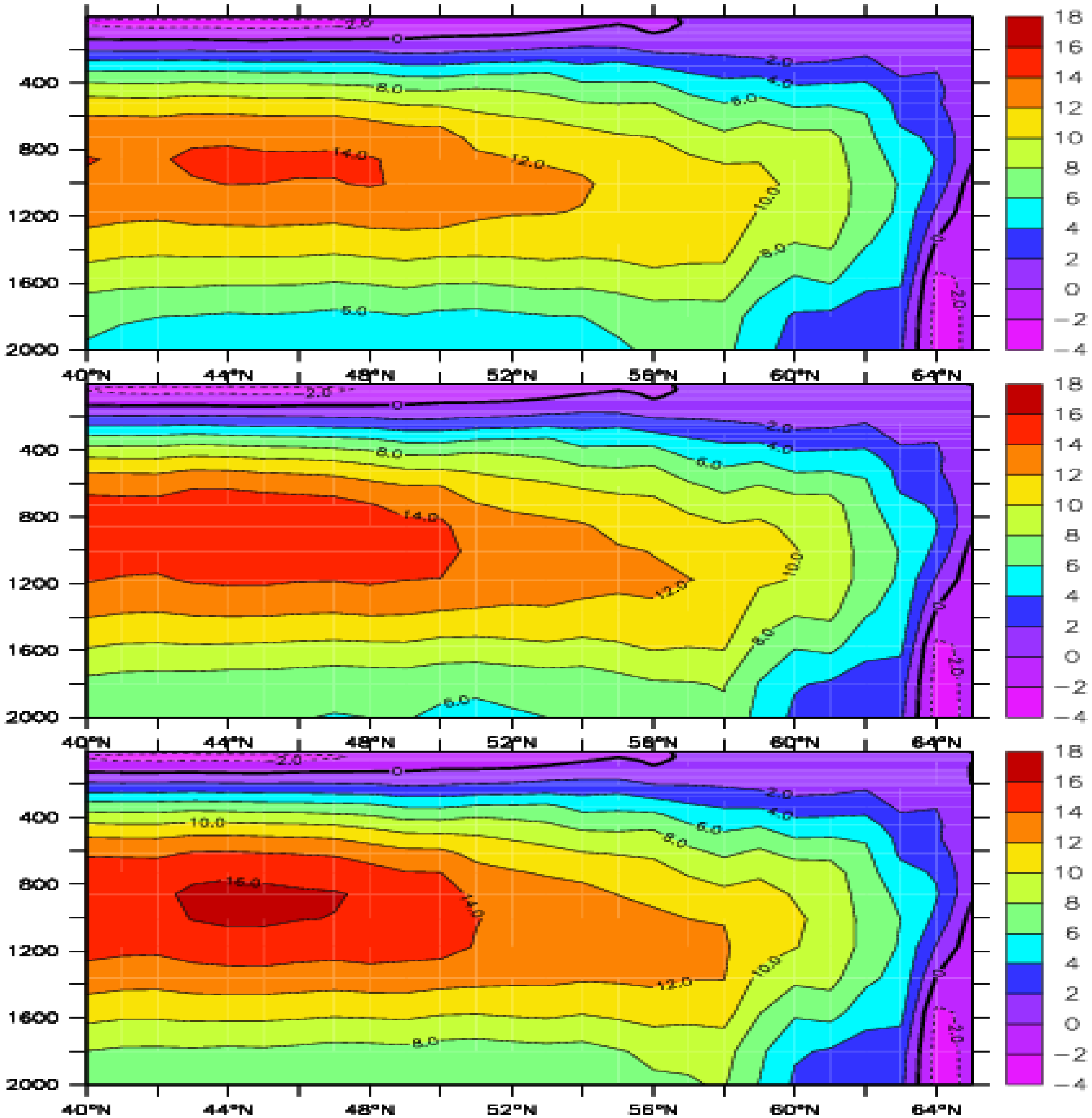
Control: Historical radiative forcings run from 1861-2000, initializing the model from 380-yr spinup using 1860 radiative forcings

25-yr (76-00) mean





25-yr Time Mean of the Atlantic MOC

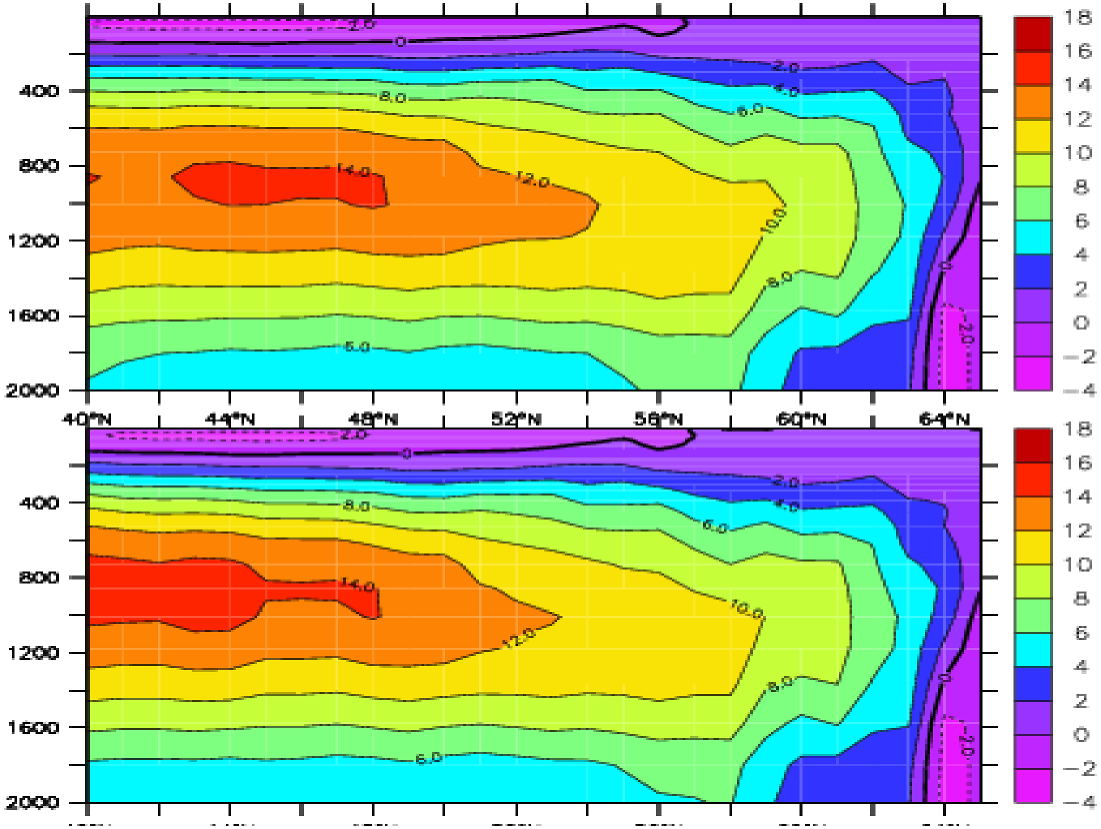


Truth

ODA (500m)
T,S + Cov(T,S)

ODA (500m)
T + Cov(T,S)

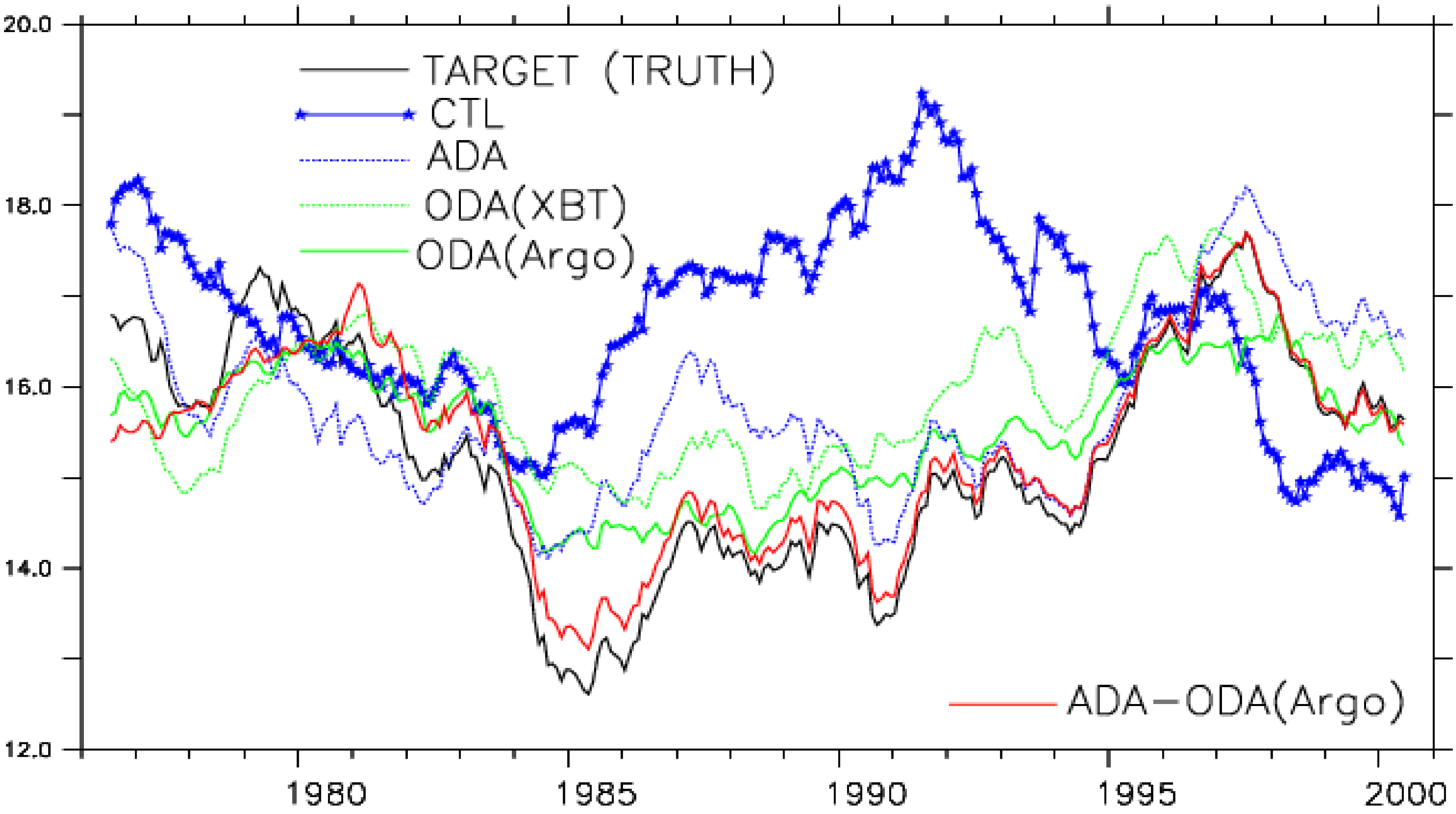
25-yr Time Mean of the Atlantic MOC



Truth

ODA (2000m)
T,S + Cov(T,S)

North Atlantic Max MOC from various ideal assimilation experiments



S. Zhang, personal communication

Remarks

- Based on 2005 Argo network and perfect model framework, the GFDL's ensemble CDA system is able to reproduce the large time scale (decadal) trend of the Atlantic MOC by assimilating both ocean temperature and salinity.

- These results are likely overly optimistic compared to real data assimilation

- The variability of the Atlantic MOC is associated with large-scale THC's heat/salt transport, sea surface forcing from atmosphere, fresh water forcing from ice and runoff and their interaction with the NA topography. Thus, atmospheric data constraint seems to improve the estimate of interannual timescale variability of the Atlantic MOC.

Questions

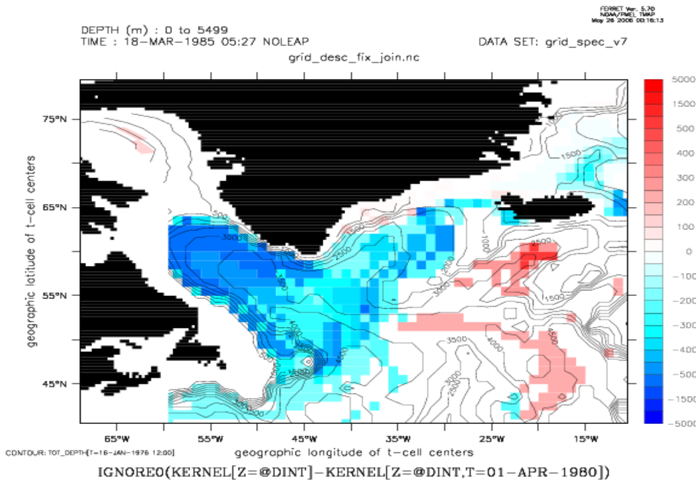
Are we able to reproduce the hydrography and transport in the Labrador basin in an idealized framework?

20th century in-situ network is mainly comprised of XBT and relatively sparse scientific transects. Is this network adequate?

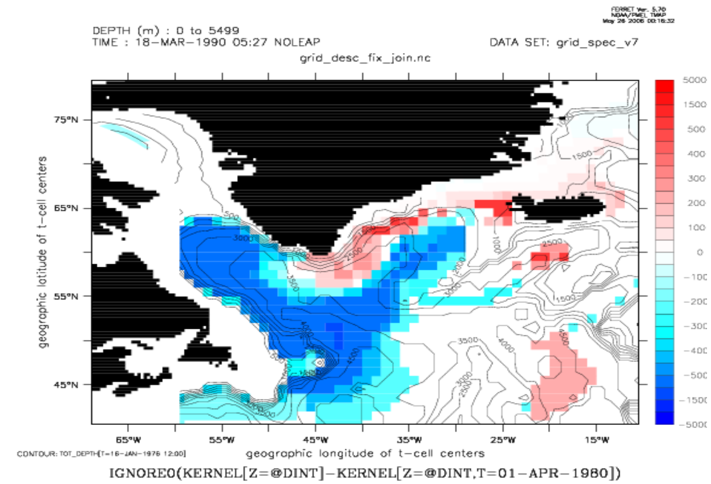
What can we expect from the ARGO network now that is is almost fully deployed?

CM2.0 Variability

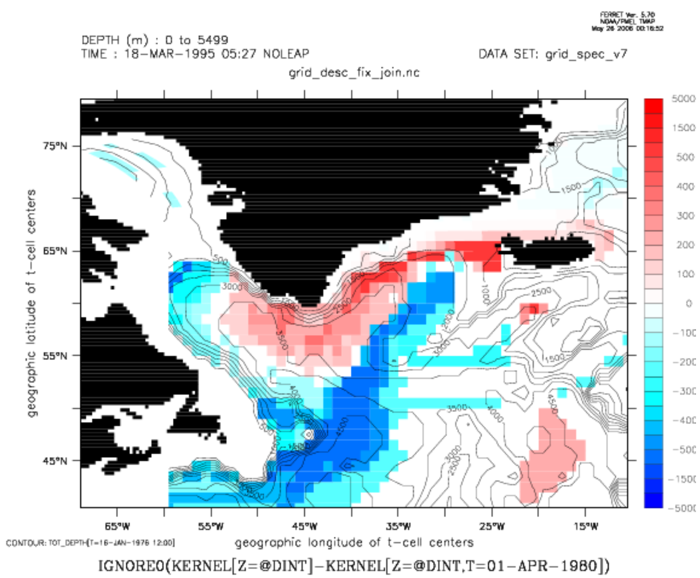
85-80



90-85



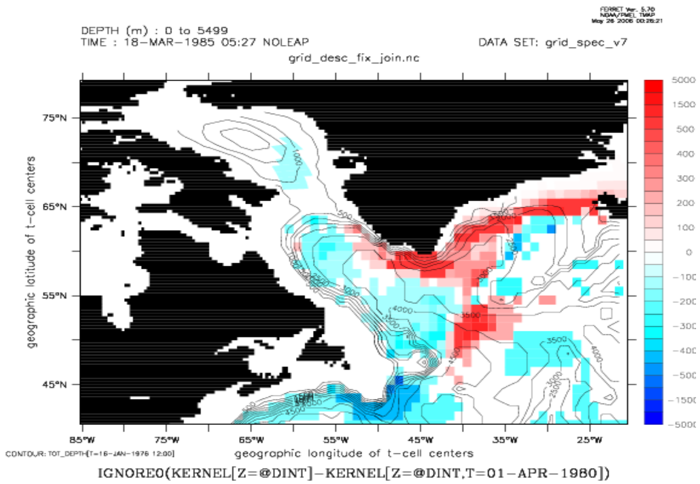
95-90



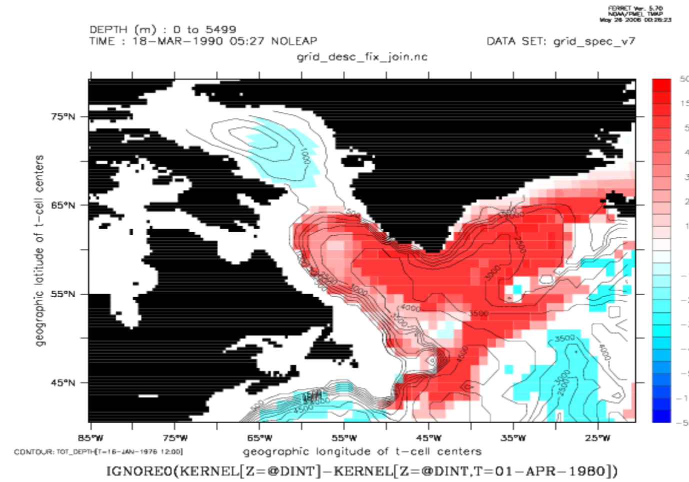
decadal variations in water mass volume (>= sigma2 = 36.8) in CM2. 5 year intervals.

EnKF estimation (idealized) using XBT network (500m)
T+cov(t,s)

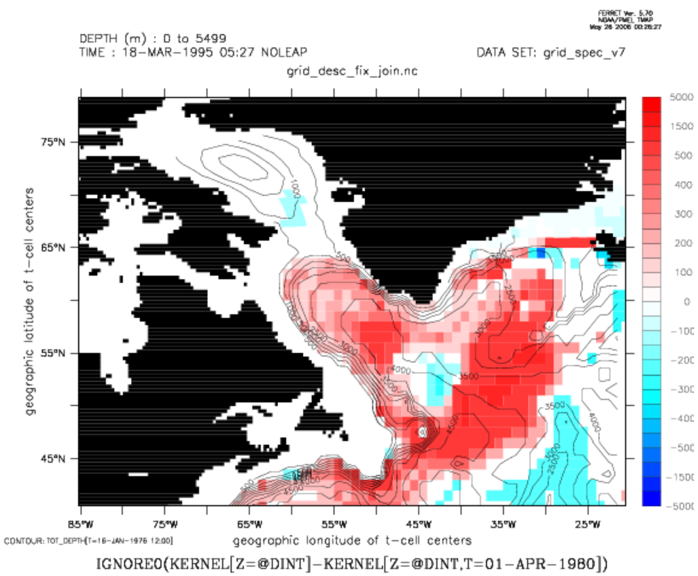
85-80

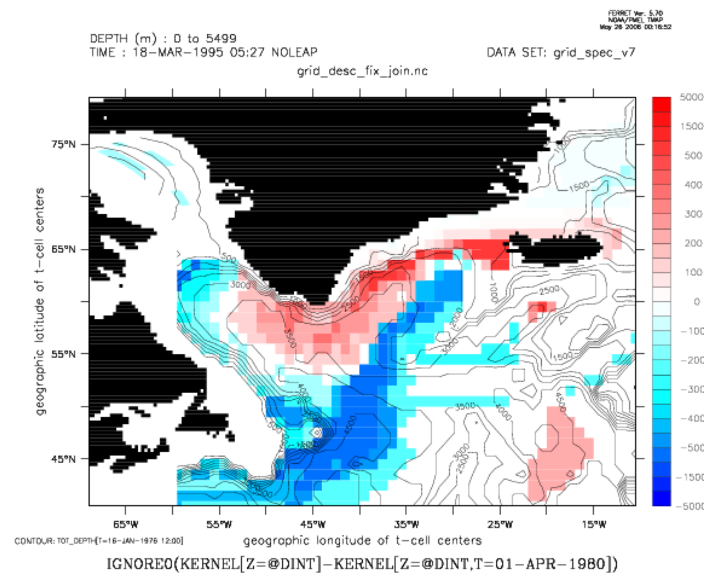


90-85



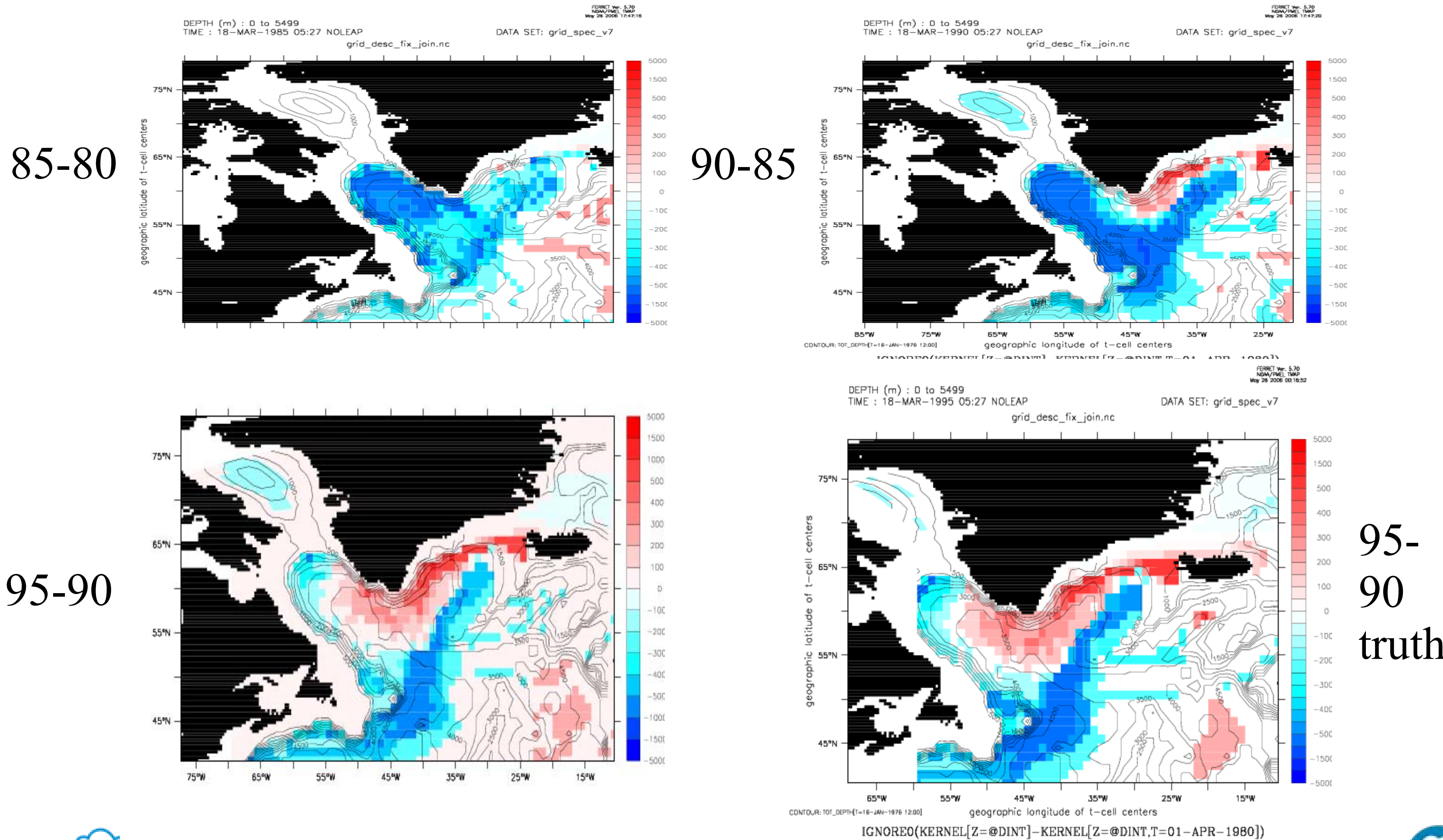
95-90





95-90 truth

EnKF estimation using ARGO network T and S to 2000m



Summary

- Idealized experiments indicate that proper initialization of N Atlantic requires temperature and salinity observations (using ocean in-situ constraint only)
- ARGO data to 2000m helps to recover changes in dense water volume in the Lab Sea

Gael Forget (MIT) has assessed the impact of ARGO profiles on ocean state estimates using the ECCO modeling infrastructure: MITgcm and its adjoint

Both

(i) ideal twin experiments and

(ii) 'realistic' calculations with real ARGO profiles and realistic model configurations

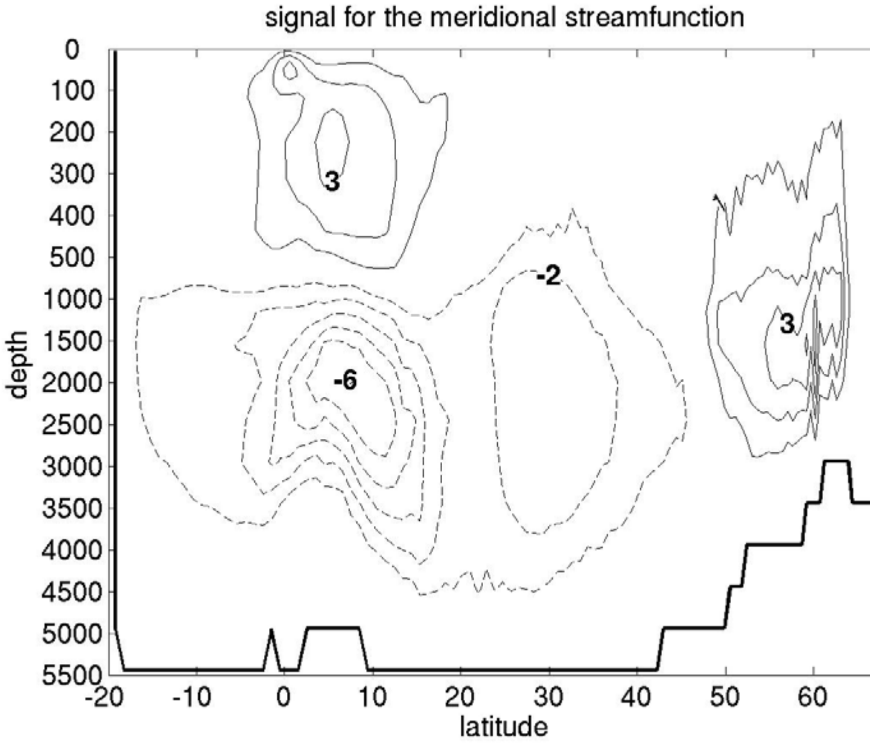
have been carried out.

Impact on the MOC of the Atlantic has been a particular focus

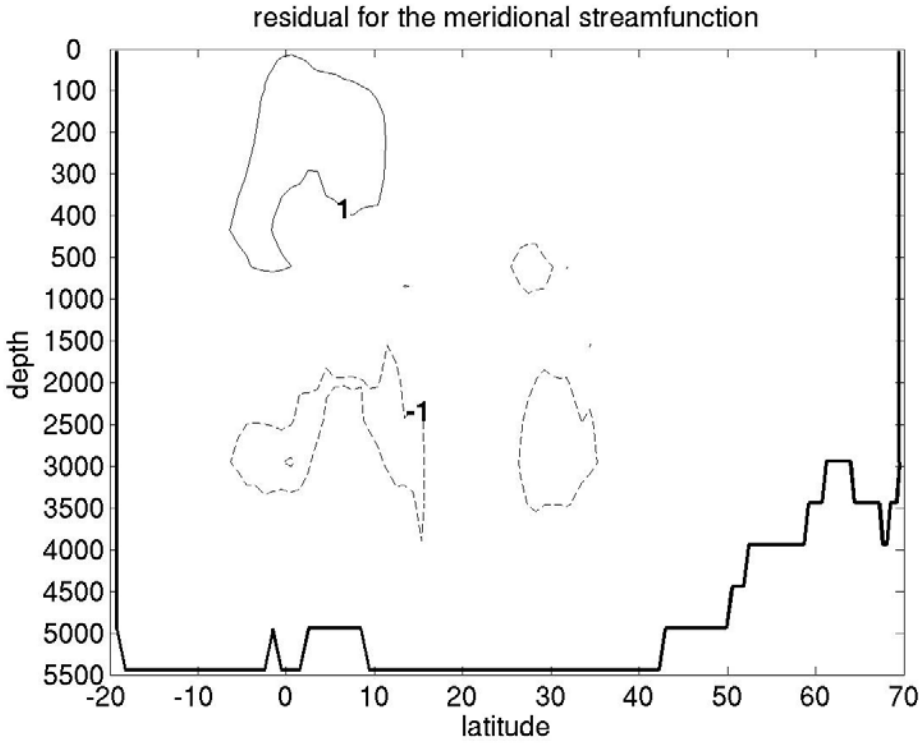
Assimilation of ARGO profiles dramatically improves the ability of the model to simulate the MOC and its heat transport.

Idealized experiments

(simulated ARGO profiles / 1 year-long / Initial State control)



Error in MOC before assimilation

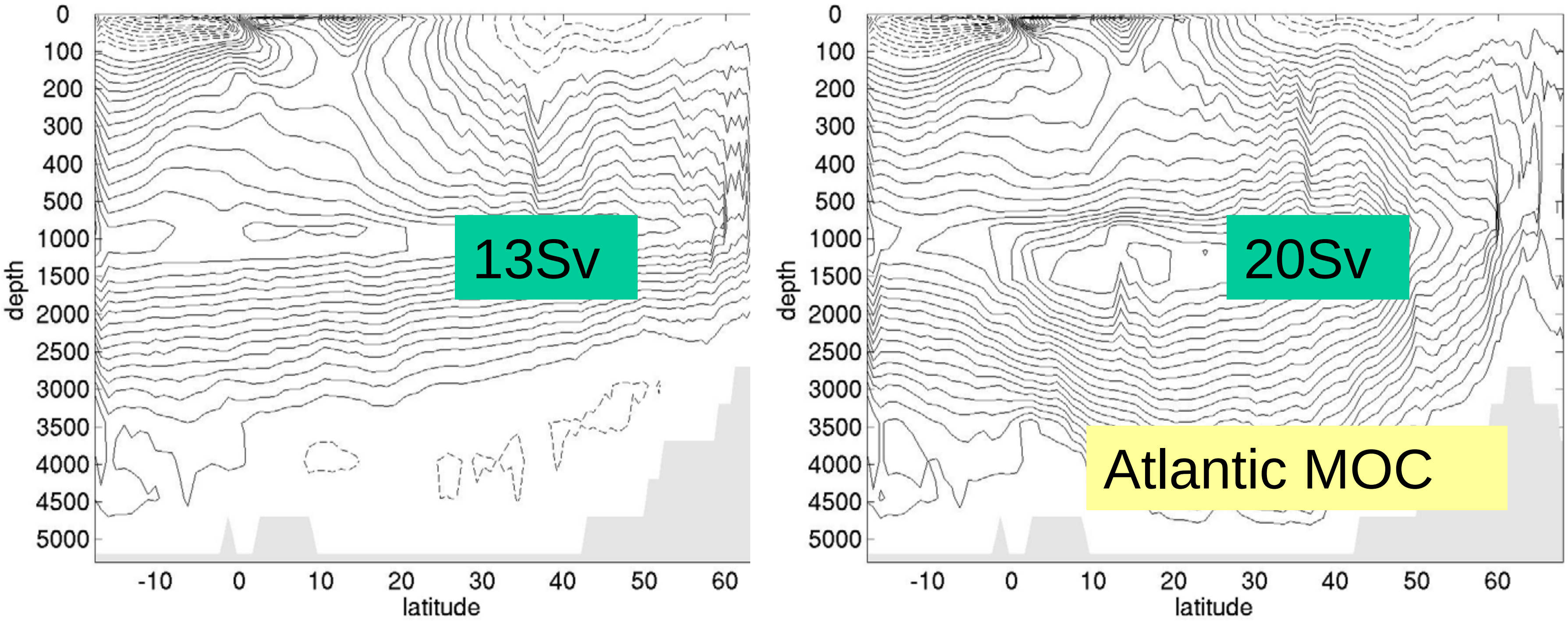


Error after assimilation

Forget et al, a,b 2007, Ocean Modeling

Real ARGO profiles, May 2002-Apr 2003

(+climatology south of 30N & below 2000m)



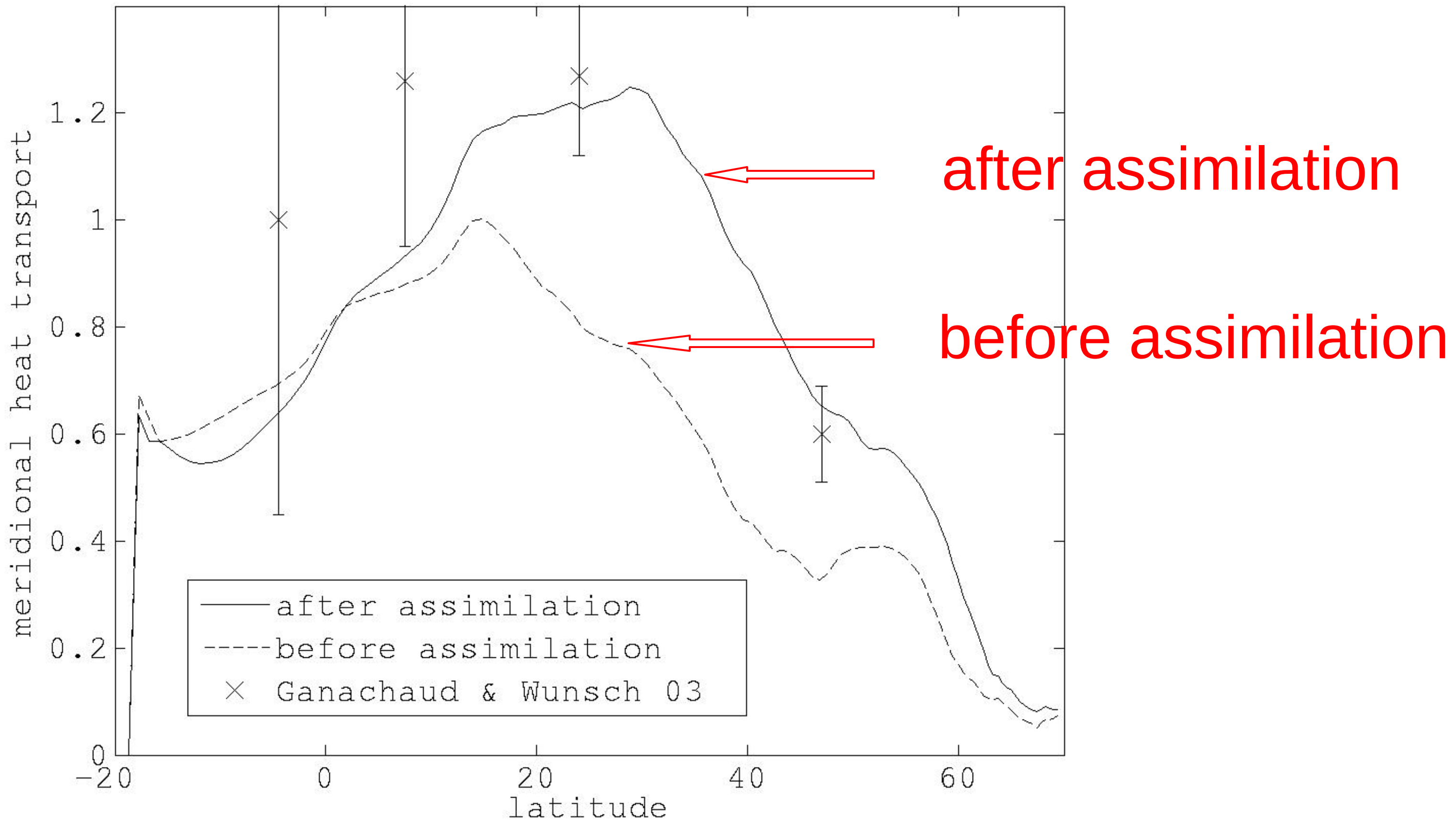
before assimilation

after assimilation

Forget et al, a,b 2007, Ocean Modeling

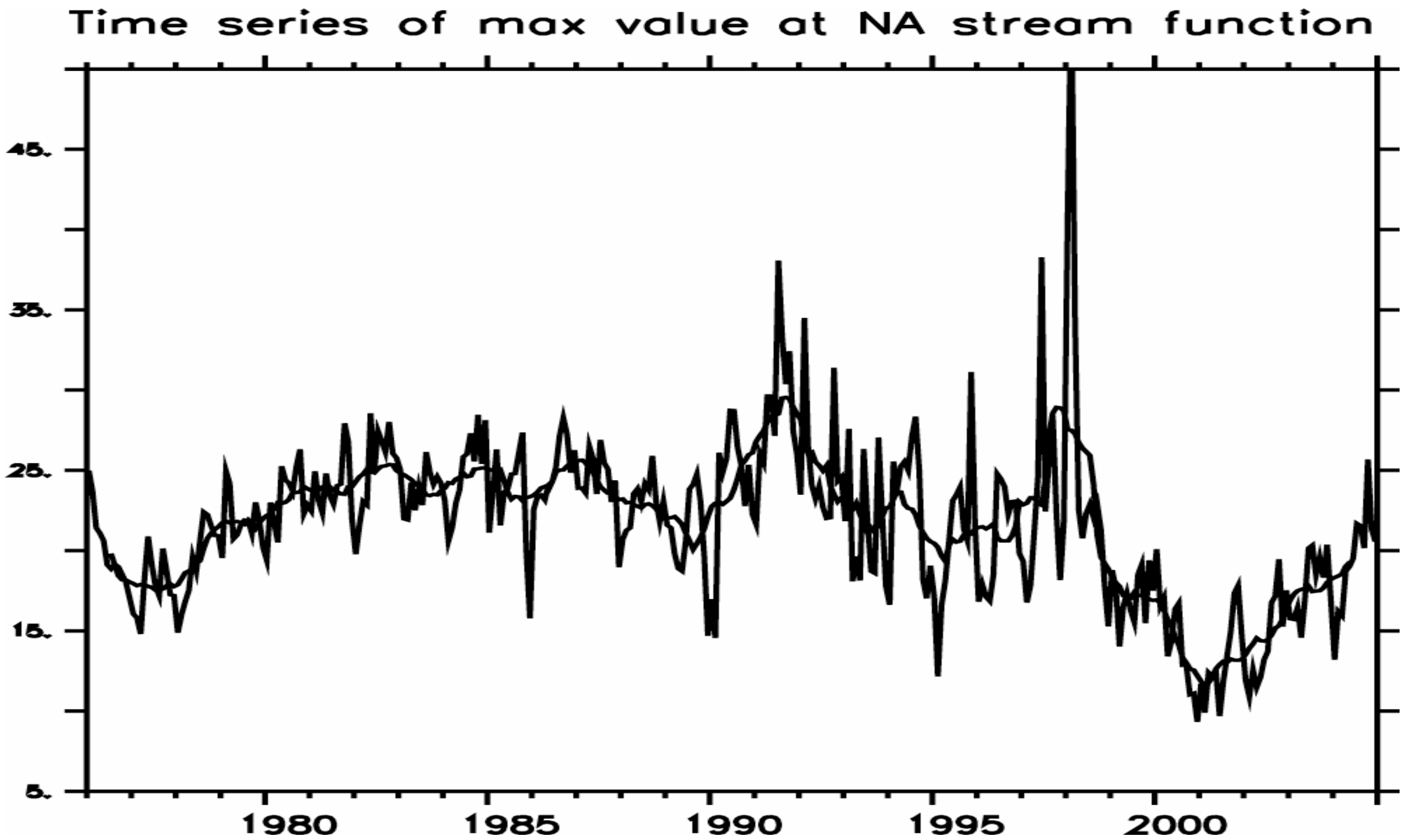
Real ARGO profiles, May 2002-Apr 2003

(+climatology south of 30N & below 2000m)



Courtesy J. Marshall

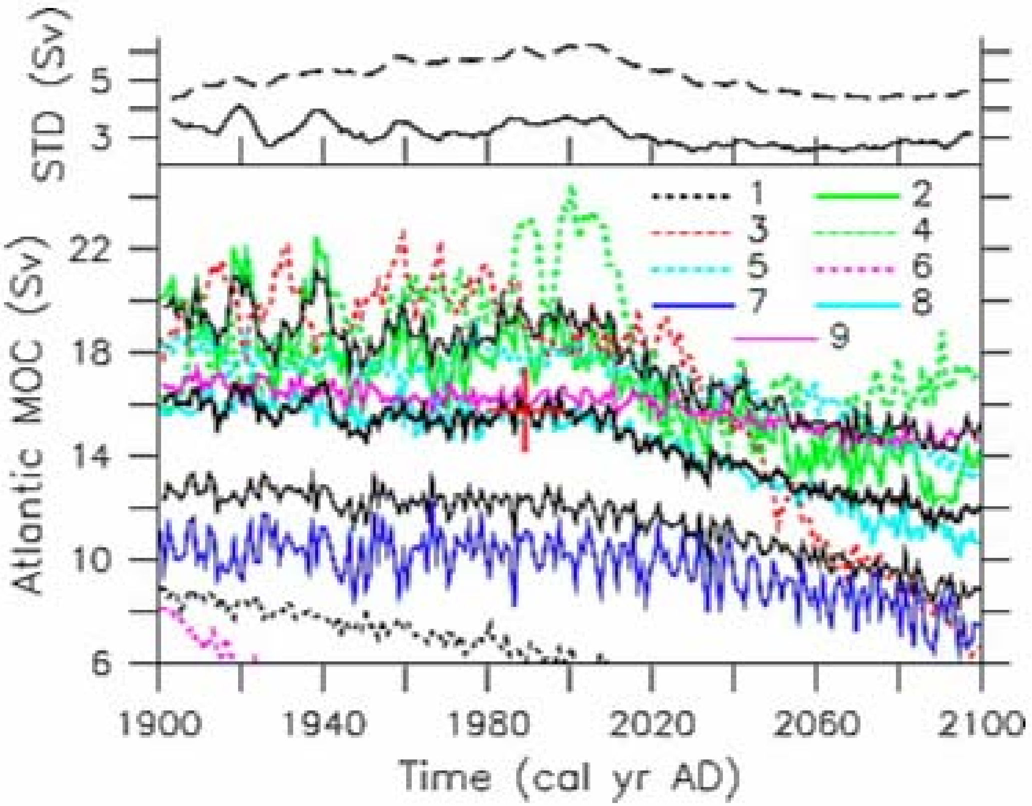
Max Value of Atlantic MOC from 30 yr Reanalysis using EnKF ODA



ARGO begins

Uncertainty in MOC projections

Increased realism from more realistic initial conditions?



MOC projections using some more recent AOGCMs

(20th Century forcings followed by SRES A1B 2000-2100)

(Schmittner et al GRL 2006)

OUTLINE

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noaaresearch

GFDL

Synthesis of two recent workshops on Atlantic climate change, variability, and predictability

- Workshop 1: GFDL (Princeton), June 1-2, 2006
- Workshop 2: AOML (Miami), January 10-12, 2007

Overall purpose of pair of workshops was to develop a framework for coordinated activities to

(a) nowcast the state of the Atlantic
(b) assess decadal predictability of the Atlantic and possible atmospheric impacts
(c) develop a prototype decadal prediction system, if warranted by (a) and (b)

Workshop Goals

- Summarize aspects of what is known about decadal Atlantic variability, both in terms of observational analyses and physical mechanisms
- Discuss and assess what might potentially be predictable
- Discuss strategies for initializing models for decadal prediction
- Initiate efforts to catalyze US research on Atlantic predictability and predictions

noaaresearch

GFDL

GFDL/AOML Workshop 1 Presentations

- Impact of Atlantic variability on climate, including North American drought (Pacific dominant, but role for Atlantic)
- Predictability, both from statistical methods and dynamical models
- GFDL and CCSM models exhibit pronounced interdecadal variability in the Atlantic
- Initialization of models / nowcasting state of the Atlantic

GFDL/AOML Workshop 2 Presentations

- Summary of aspects of observational analyses of Atlantic decadal variability (surface and subsurface)

    Phenomena of three time scales are of importance:

    decadal-scale fluctuations

    multi-decadal changes (AMO)

    trend

    All need to be understood in order to describe Atlantic variability and change.

- Presentations on current observing systems in the Atlantic. This included a statement that with RAPID/MOC array in place, "… we estimate that the year-long average overturning can be defined with a standard error of 1 about Sv."

- Presentation on paleo reconstructions for the Atlantic and their utility.

- Analysis of forced and internal variability components of Atlantic changes – suggestion that Atlantic multidecadal variability has a significant internal variability component

Key underlying questions

- Does Atlantic ocean decadal variability impact larger-scale climate?
- Is there multi-annual to decadal predictability of the state of the Atlantic ocean?
- Does oceanic predictability (if any) have atmospheric relevance, either locally for the Atlantic or over adjacent continents?
- Do we have the proper tools to realize any potential predictability?
  - *ability to adequately observe the climate system*
  - *assimilation systems to initialize models*
  - *models that are "good enough" to make skillful predictions*
- More generally, does it "matter" if we initialize IPCC-type climate change projections from the observed state of the climate system?

Workshop Recommendations

- Diagnostics Program – physical mechanisms of variability
- Predictability studies – which components have decadal predictability?
- Development of Improved Tools for Decadal Prediction and Analyses
  - Models
  - Observational/Assimilation systems
- Experimental Decadal Predictions (statistical, dynamical, multiple models)

Final points

- Initial focus on Atlantic, but systems are global
- Possible emphasis for IPCC AR5 on decadal scale projections initialized from observed state of the climate system
- Crucial piece – predictability may come from both
  - forced component
  - internal variability component

  … and their interactions.

Real possibility that there will be little "meaningful" predictability that comes from the initial state of the ocean beyond the seasonal time scale … but we need to find out.