Atlantic Decadal Variability:Combining observations and models to investigate predictability

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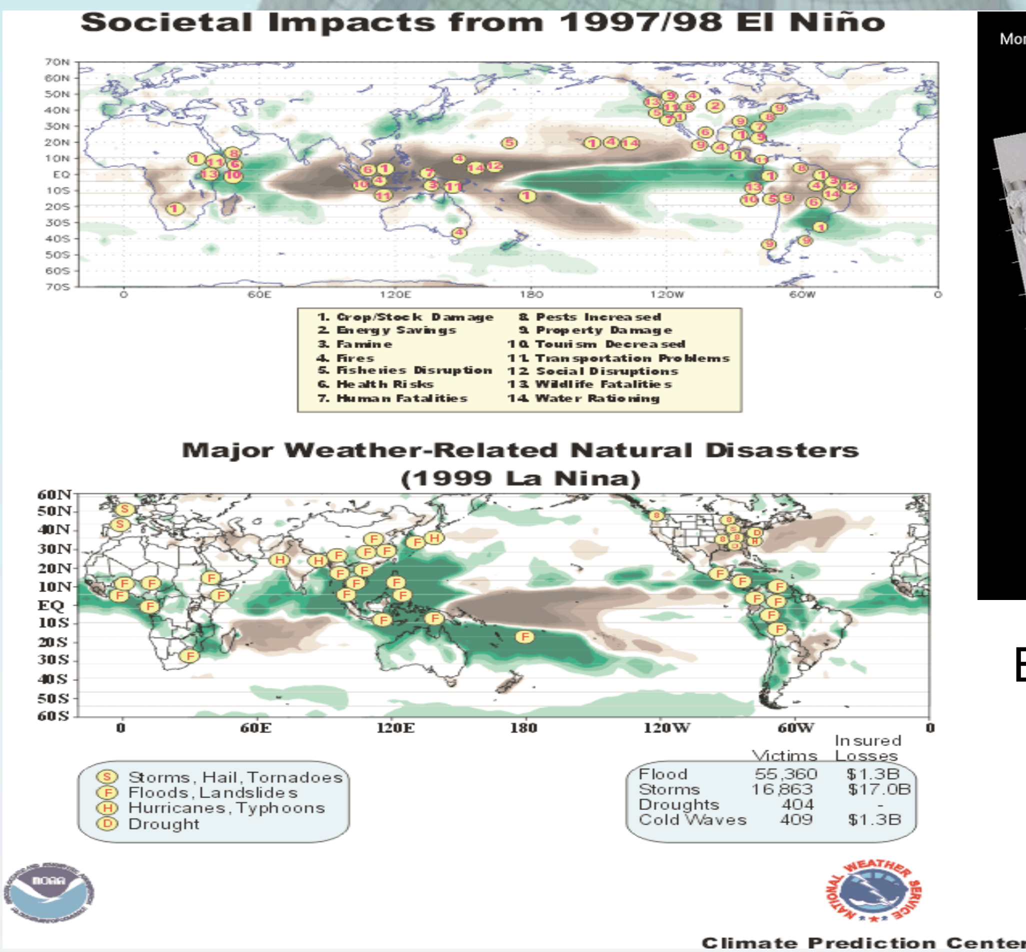
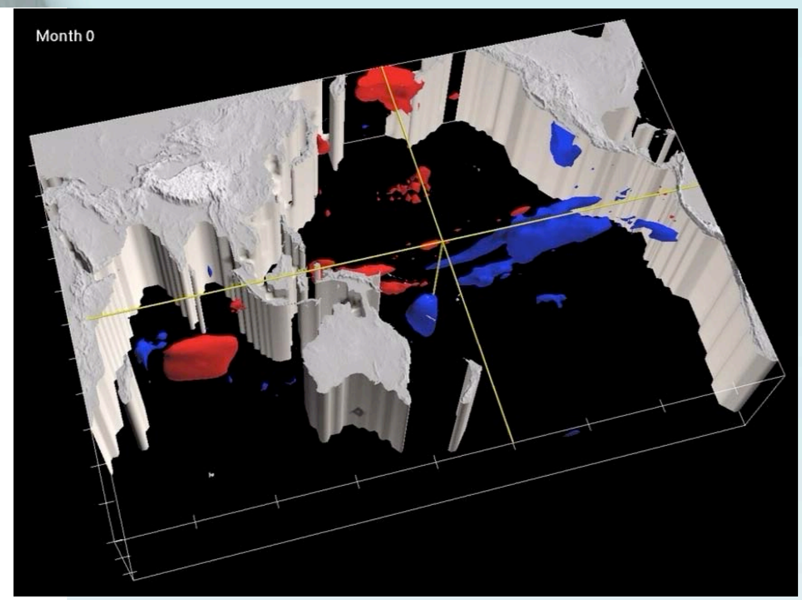
Understanding Ocean-Atmosphere Interactions in the Tropical Pacific has Laid the Foundations for Physics – Based Seasonal Forecasts

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





Evolution of El Nino and La Nina

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

OUTLINE

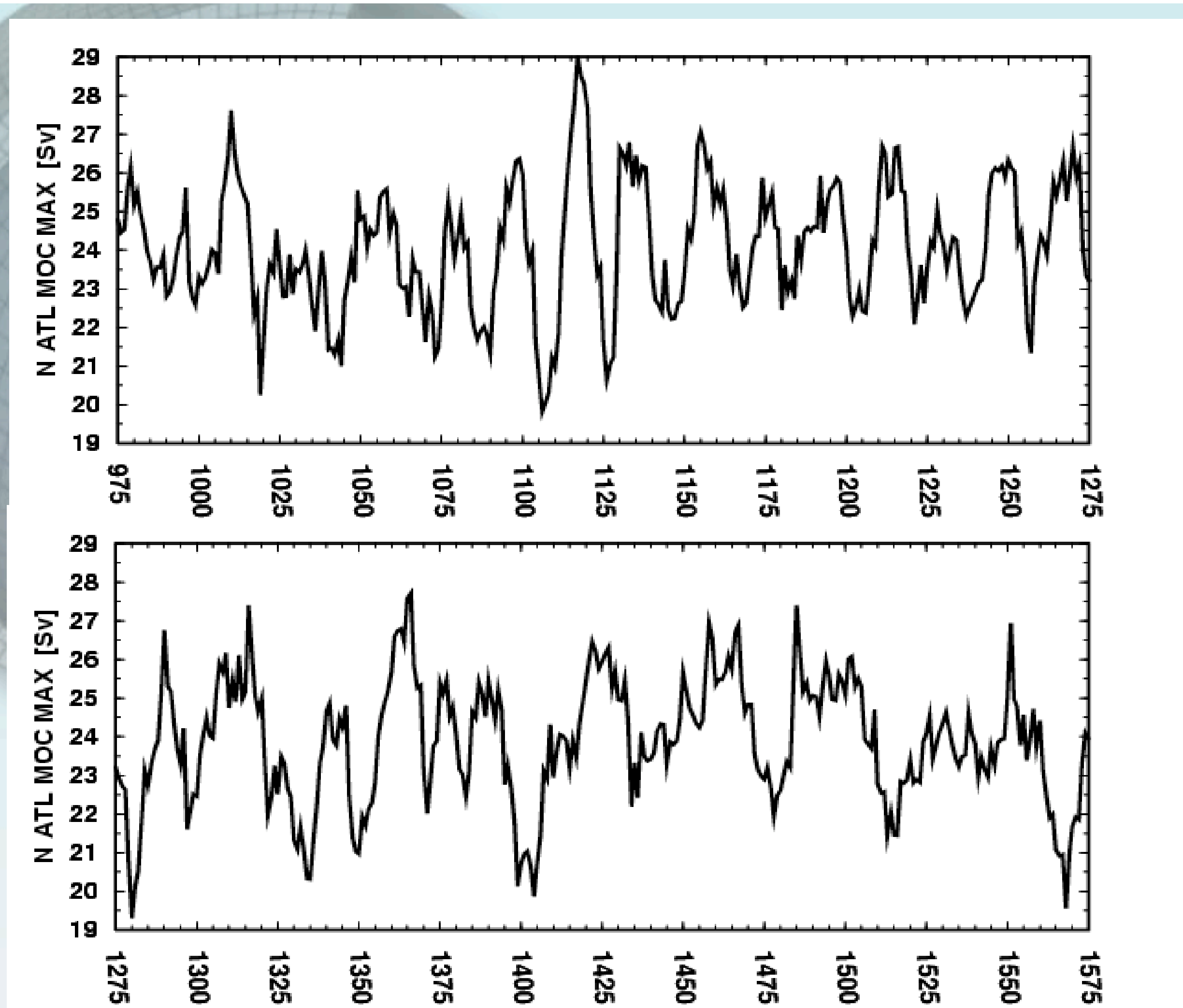
- Predictability Studies
- Introduction to GFDL's Coupled Ensemble Filter Assimilation System (CDA)
- Perfect Model Studies (OSSE) to assess AMOC initialization
- Real Predictions
- Challenges
- Remarks

Decadal Variability and Predictability

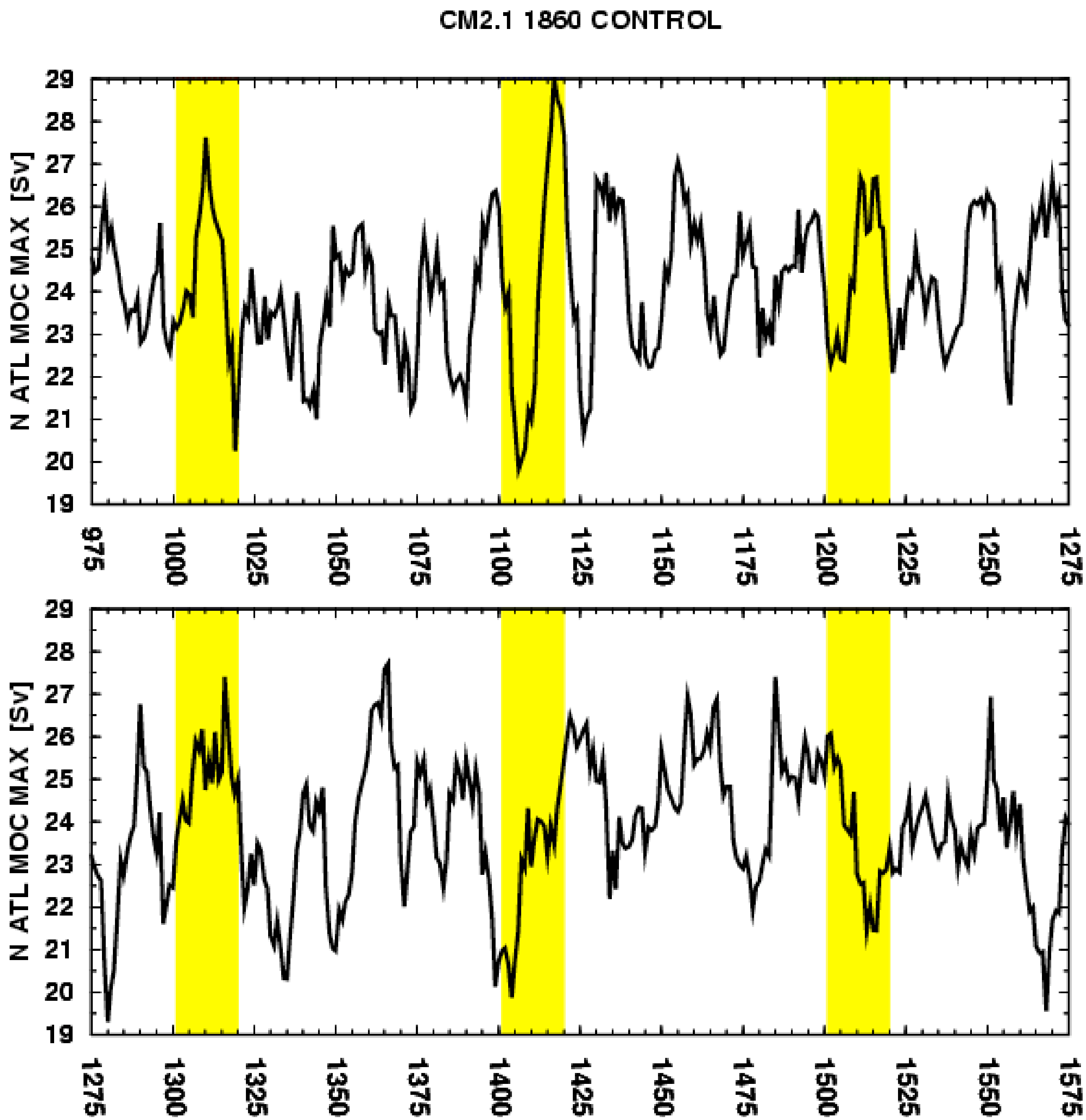
- Processes important in decadal variability
- How do we estimate decadal predictability?
- How well are models simulating decadal variations?
- Observing and detecting changes

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

The N. Atl. MOC in the 1860 Control



The N. Atl. MOC in the 1860 Control



Preliminary Experimental Design

Building some small ensembles:

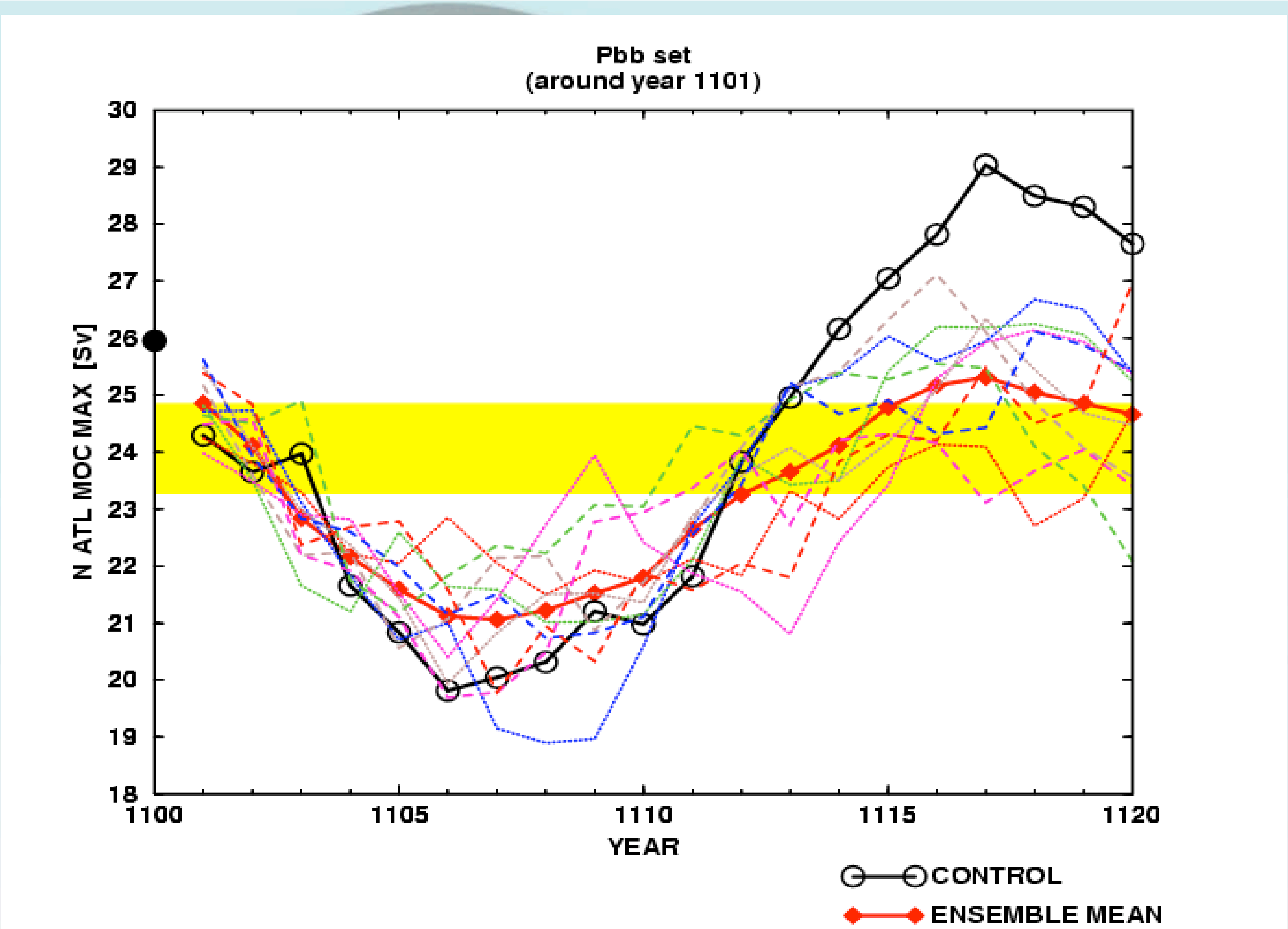
The CM2.1 model produces a separate restart file for each of its 4 main subcomponents.

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. For example…

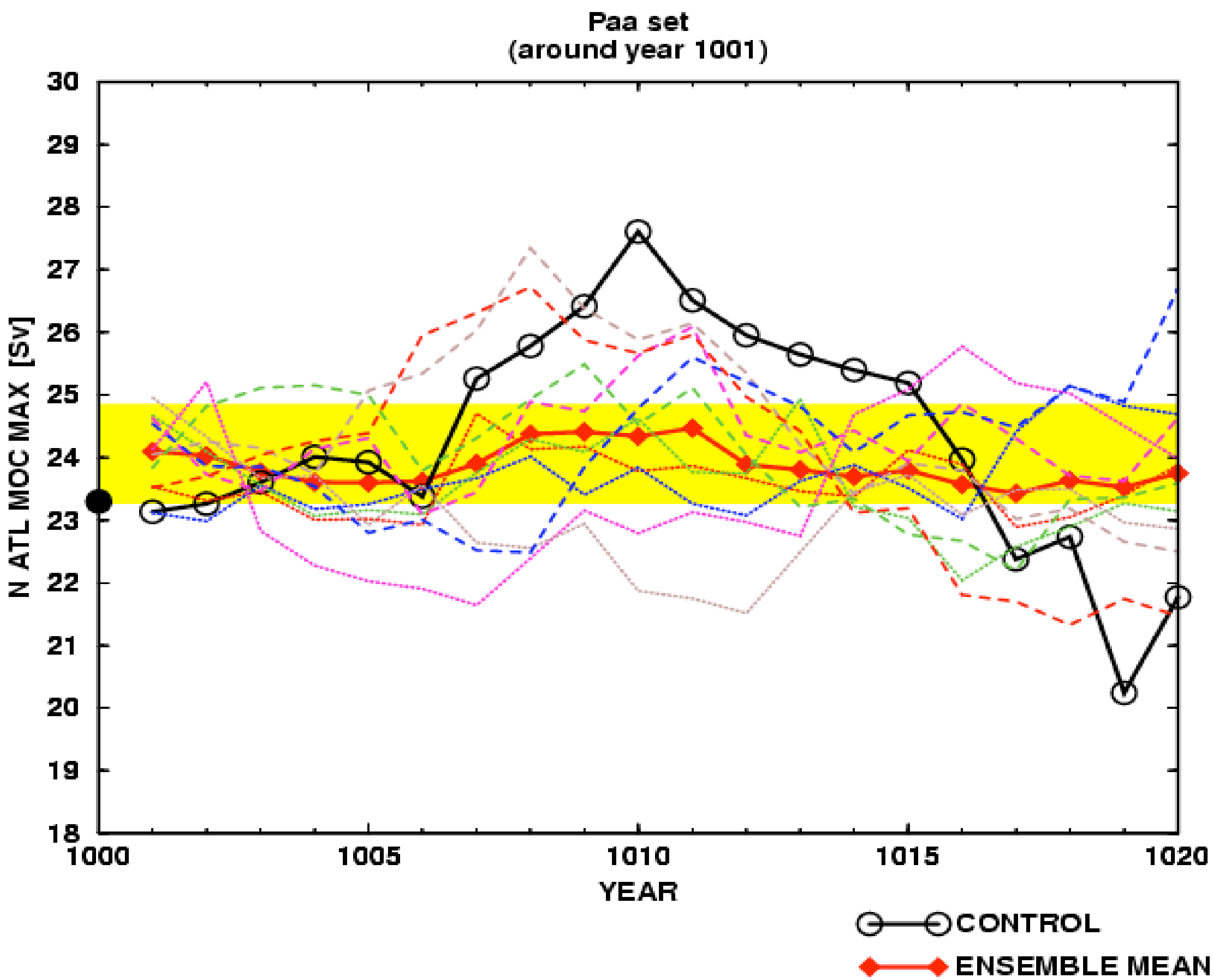
ocean	land	sea ice	atmos	
	➢1 Jan 1001		**➢07 Dec 1000**	**➢06 Jan 1001**
			➢12 Dec 1000	**➢11 Jan 1001**
			➢17 Dec 1000	**➢16 Jan 1001**
			➢22 Dec 1000	**➢21 Jan 1001**
			➢27 Dec 1000	**➢26 Jan 1001**

generating a ten member ensemble

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



…or not? And why?

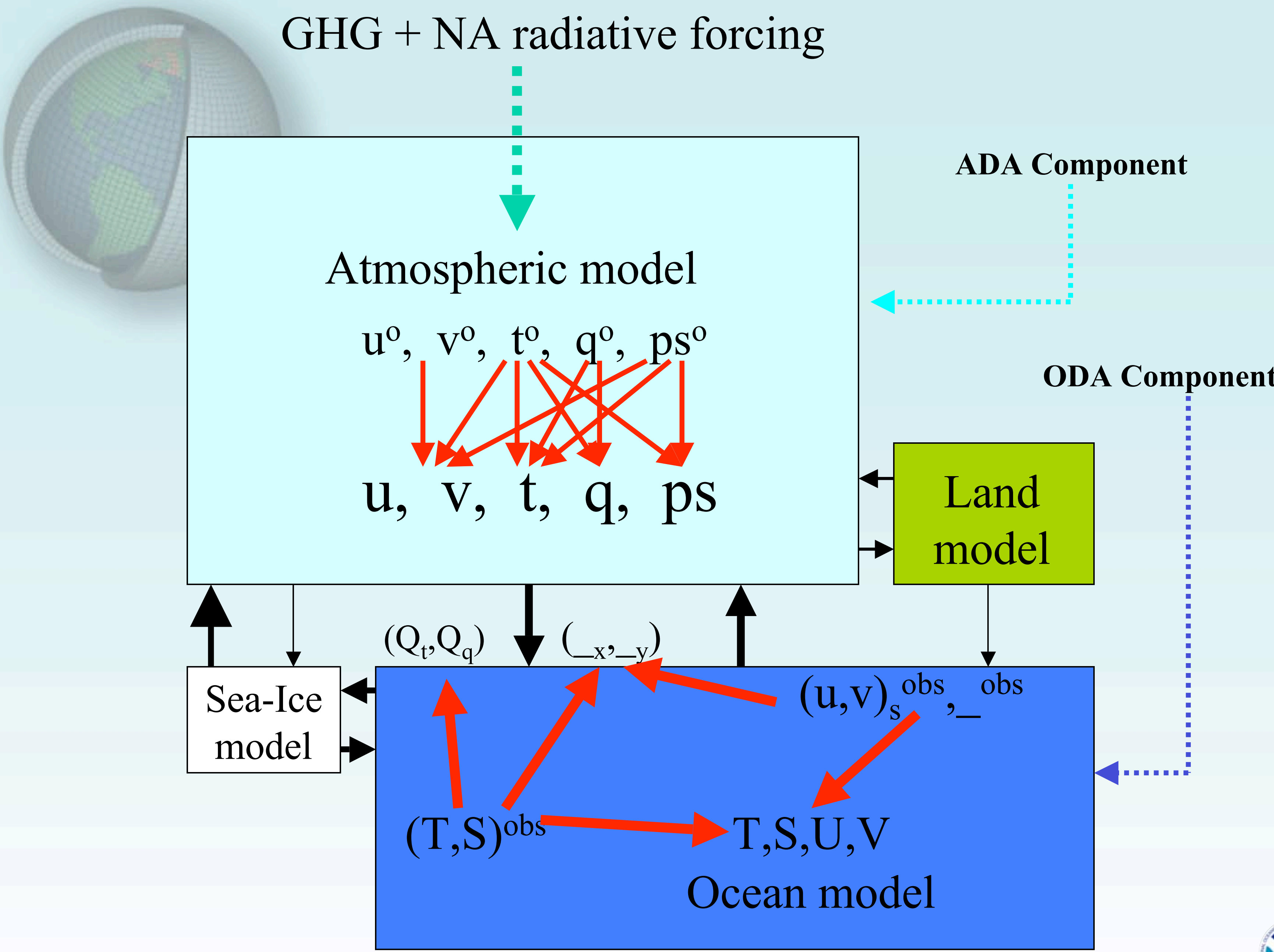


Atlantic decadal predictions

Two complementary pathways are being pursued at GFDL using our CDA system :

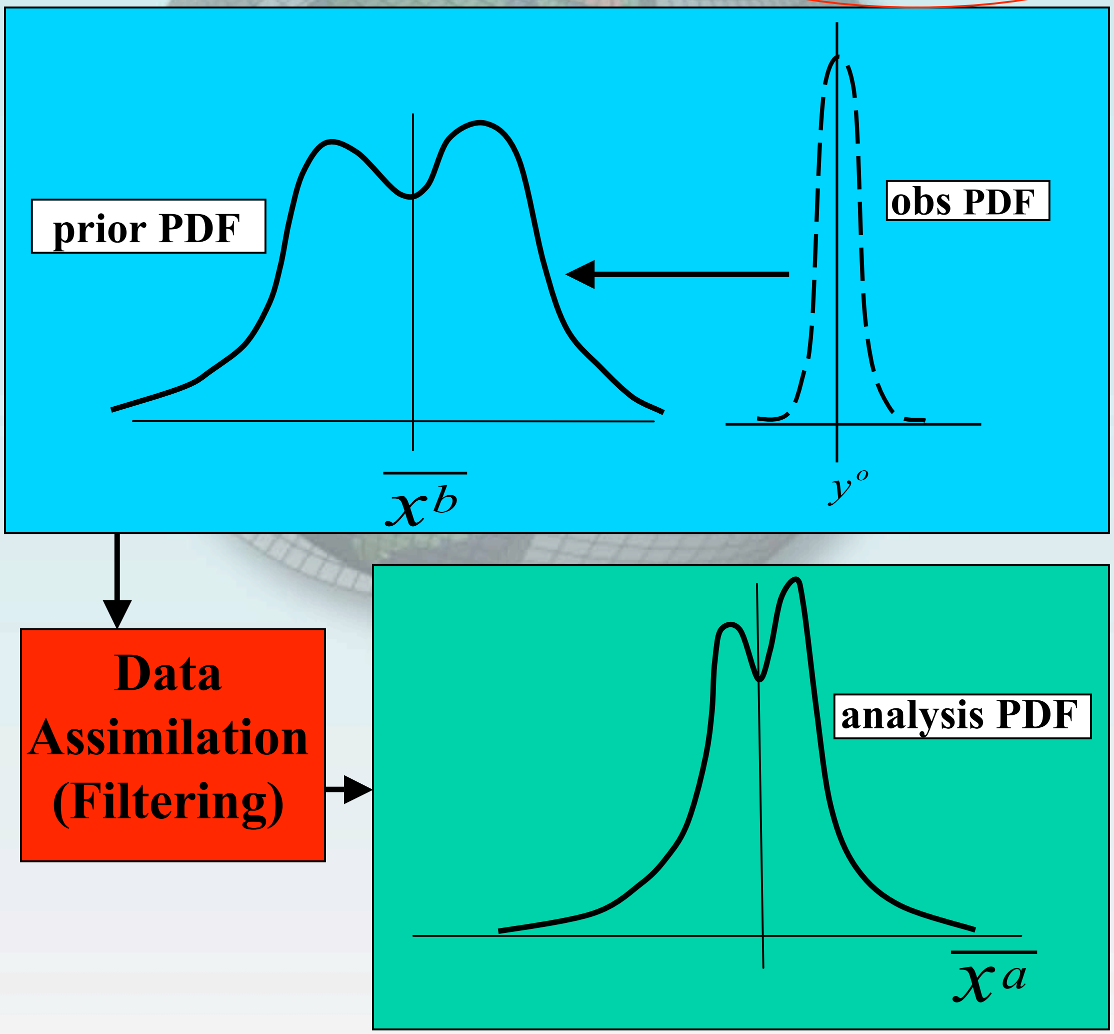
1. Use "perfect model" experiments to characterize the ability of the CDA methodology and observing system to constrain the AMOC.

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


GHG + NA radiative forcing
ADA Component
Atmospheric model
uº, vº, tº, qº, psº
u, v, t, q, ps
ODA Component
Land model
Sea-Ice model
(Qt,Qq)
(_x,_y)
(u,v)s obs, _ obs
(T,S)obs
T,S,U,V
Ocean model

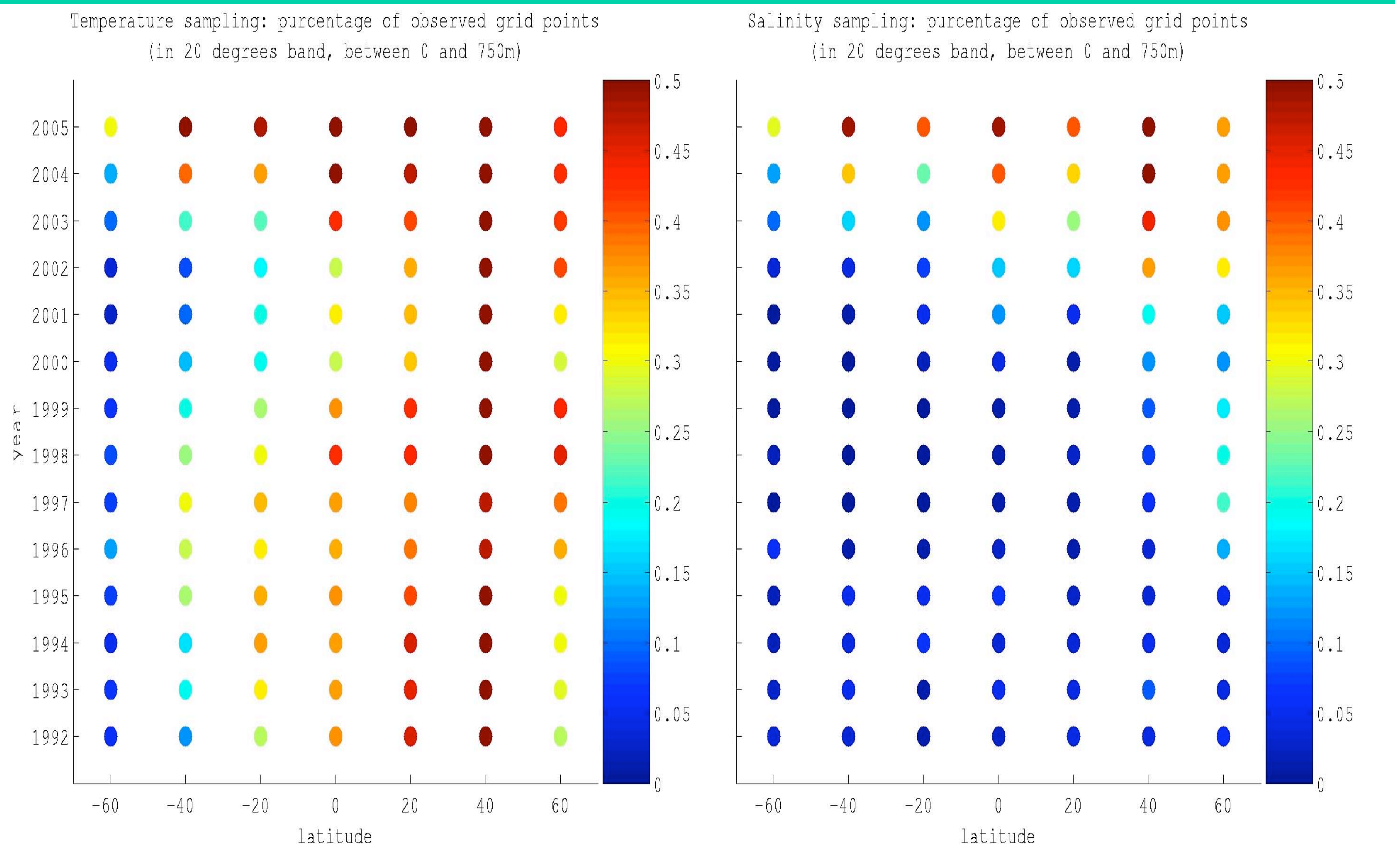
CDA System: Ensemble Kalman Filtering Algorithm

$$\overbrace{d\mathbf{x}_t / dt = f(\mathbf{x}_t, t)}^{\text{Deterministic (being modeled)}} + \overbrace{\mathbf{G}(\mathbf{x}_t, t)\mathbf{w}_t}^{\text{Uncertain (stochastic)}}$$



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

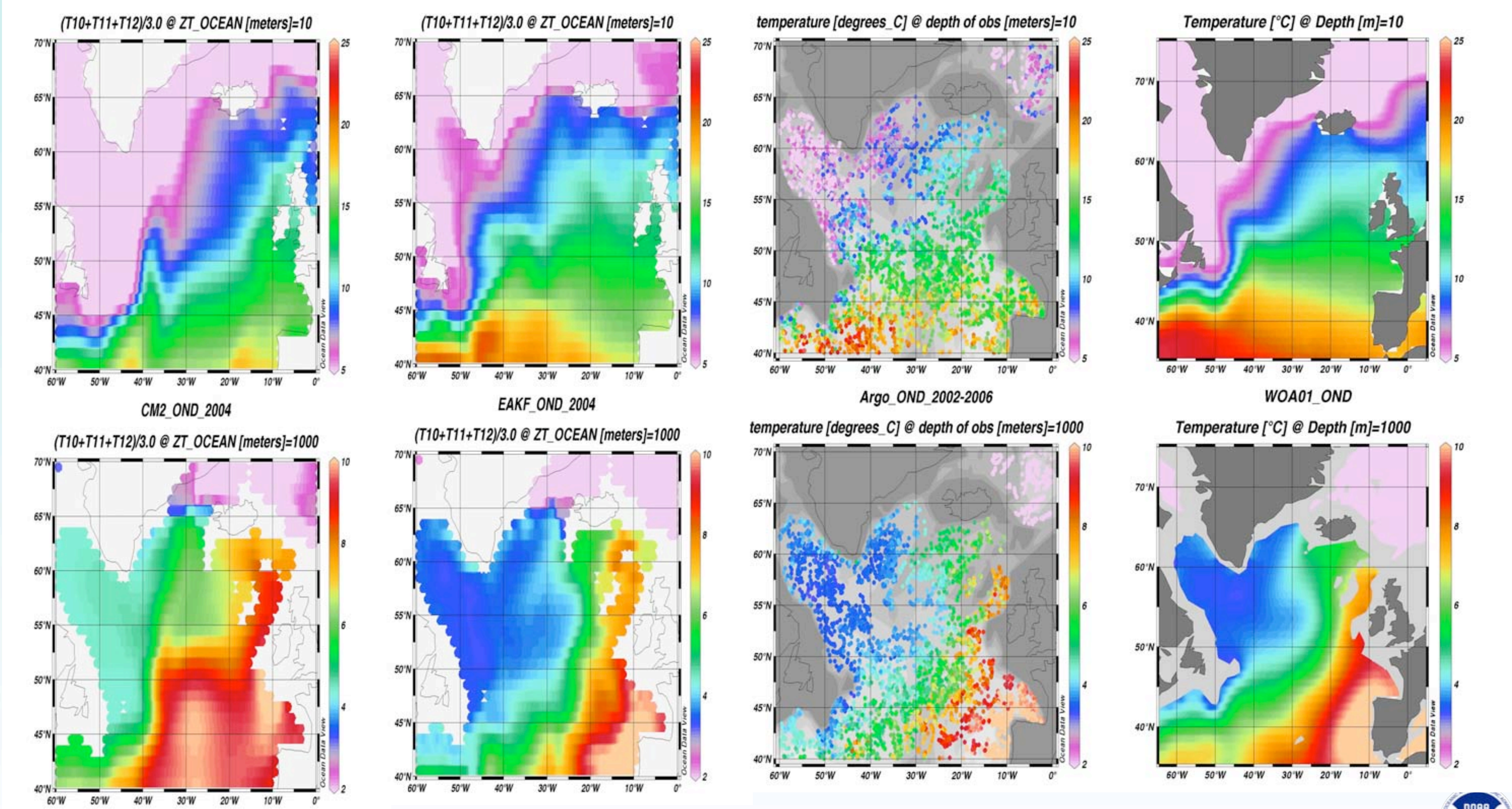
Sampling



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

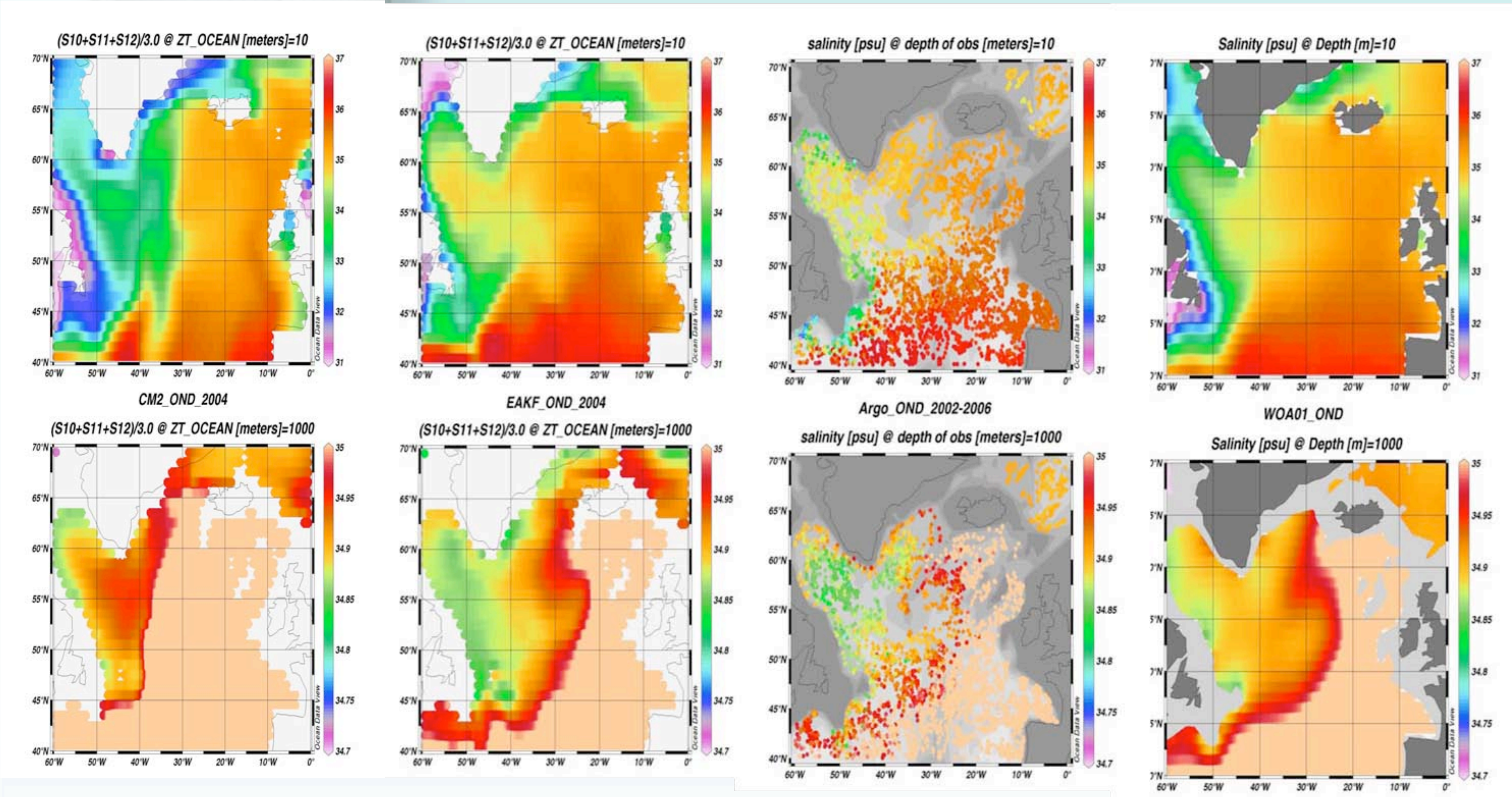
OND N.A. - TEMPERATURE

NO-ASSIM ASSIM(EAKF) Argo WOA01



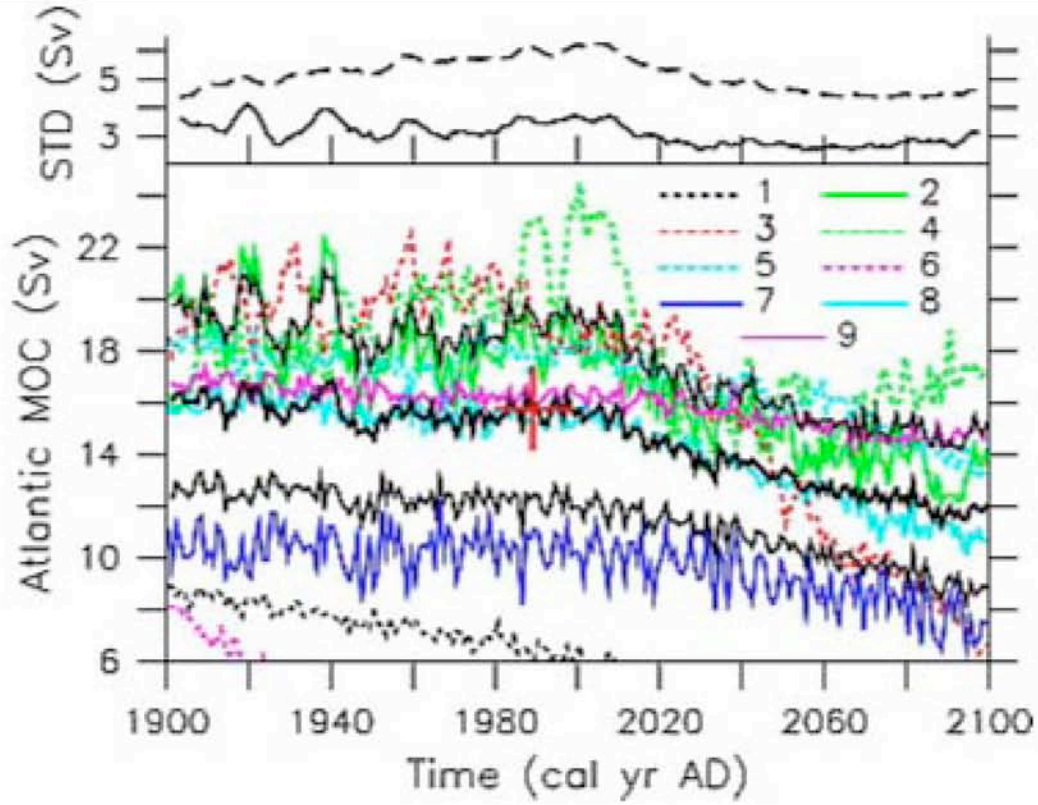
OND N.A. - SALINITY

NO-ASSIM | ASSIM(EAKF) | Argo | WOA01



Uncertainty in MOC projections

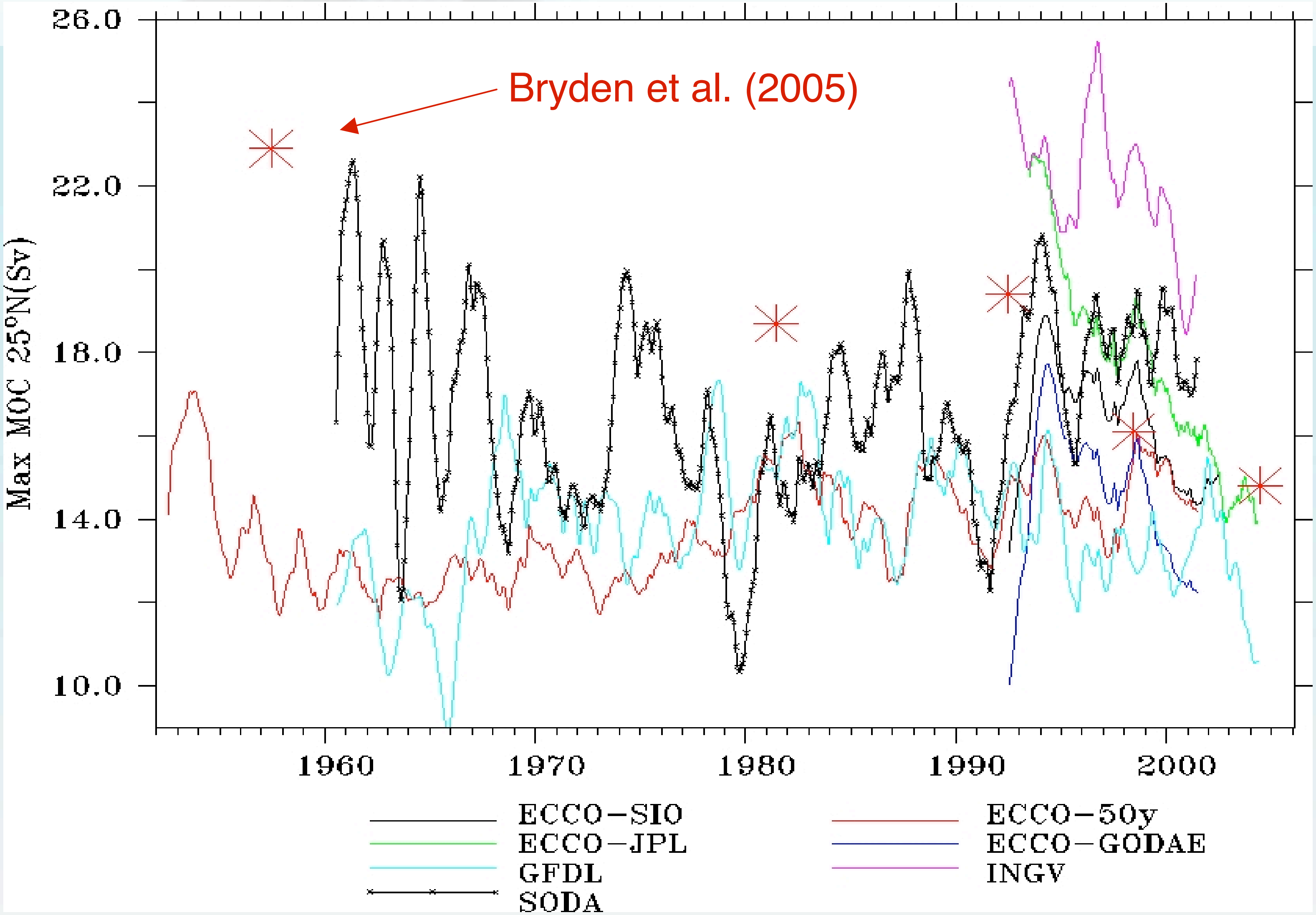
Increased realism from more realistic initial conditions?



MOC projections using some more recent AOGCMs
(20th Century forcings followed by SRES A1B 2000-2100)

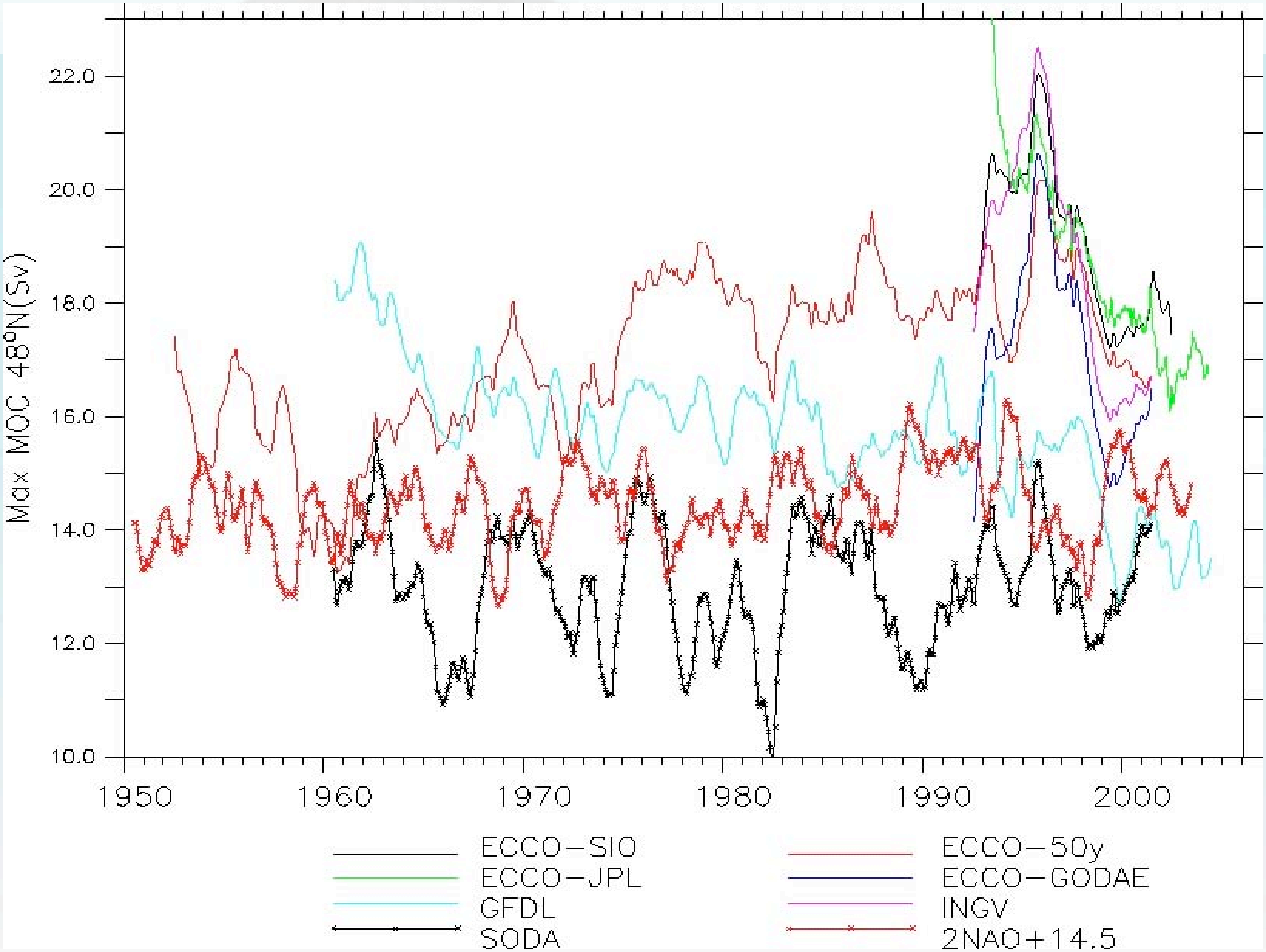
(Schmittner et al GRL 2006)

Max. MOC 25ºN



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

Max. MOC 48°N



Max MOC 48°N(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

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.

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

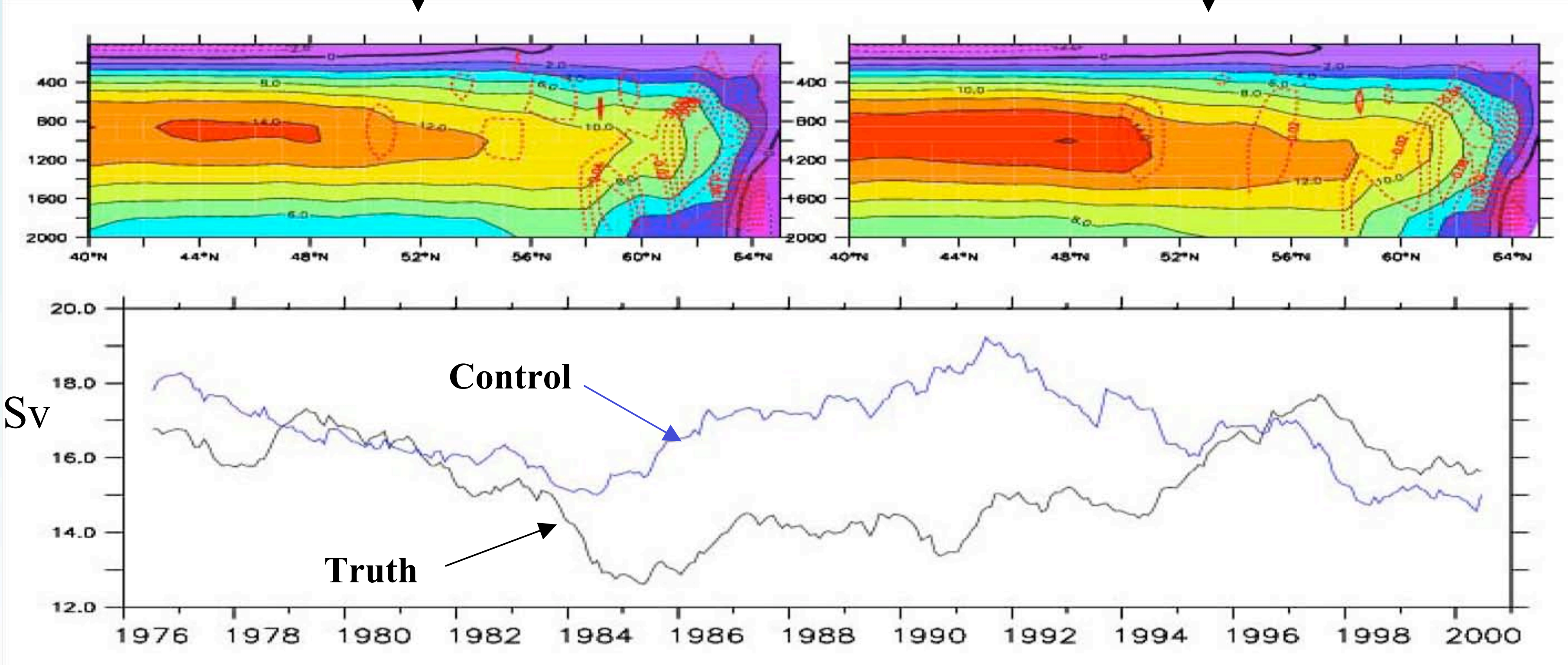
- Idealized Twin Experiments: Can we reconstruct Atlantic MOC from the XBT/Argo network? What are issues?
  - Only using top 500 m ocean temperature measurements
  - Only using top 500 m ocean temperature and salinity measurements
  - Using Argo measurements (down to 2000 m deep for temperature and salinity)

Are the ocean observing systems adequate to constrain the AMOC?

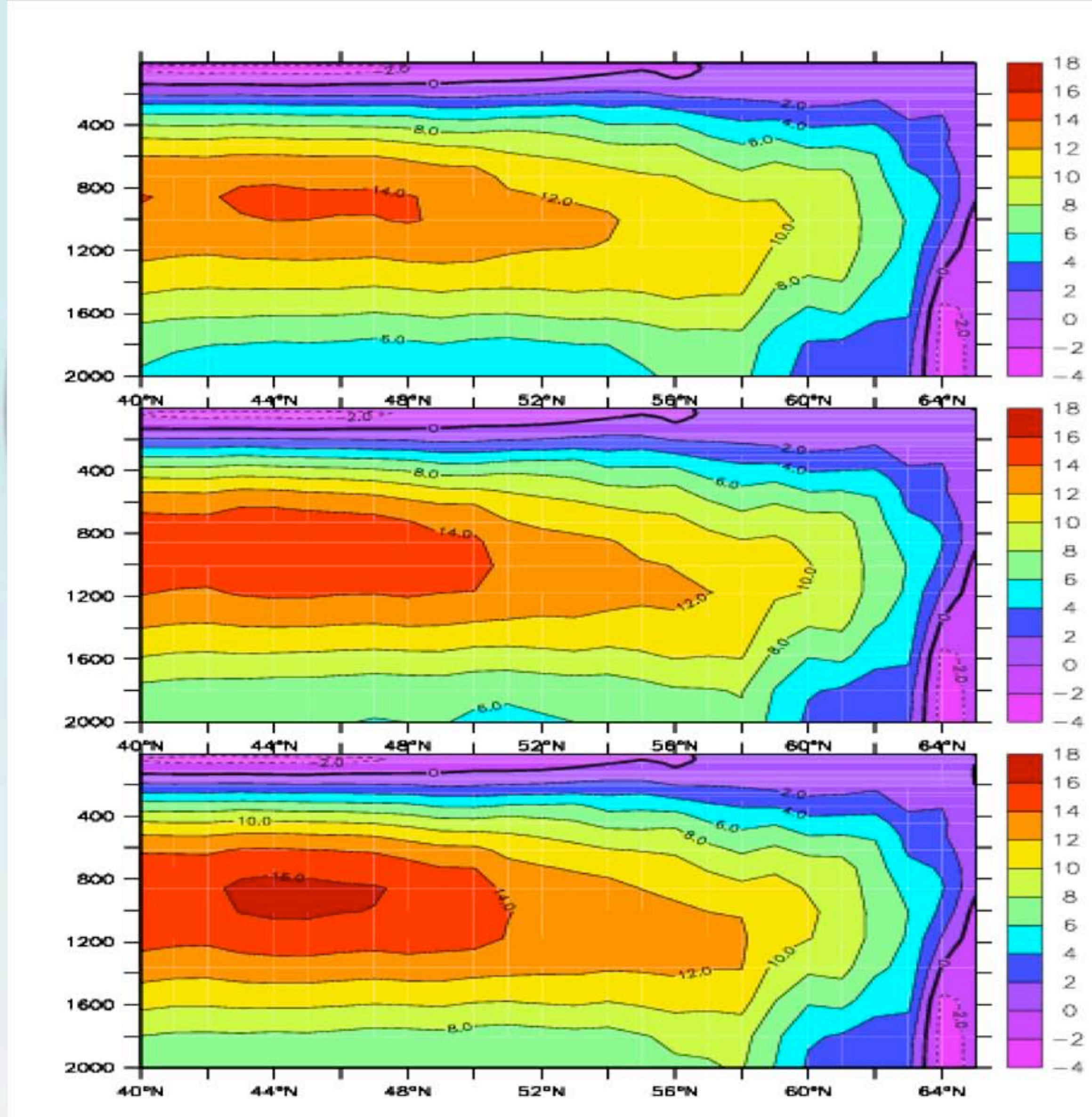
Truth: Historical radiative forcing run from 1861-2000, initializing the model from 300-yr spinup using 1860 radiative forcing

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

25-yr (76-00) mean



25-yr Time Mean of the Atlantic MOC

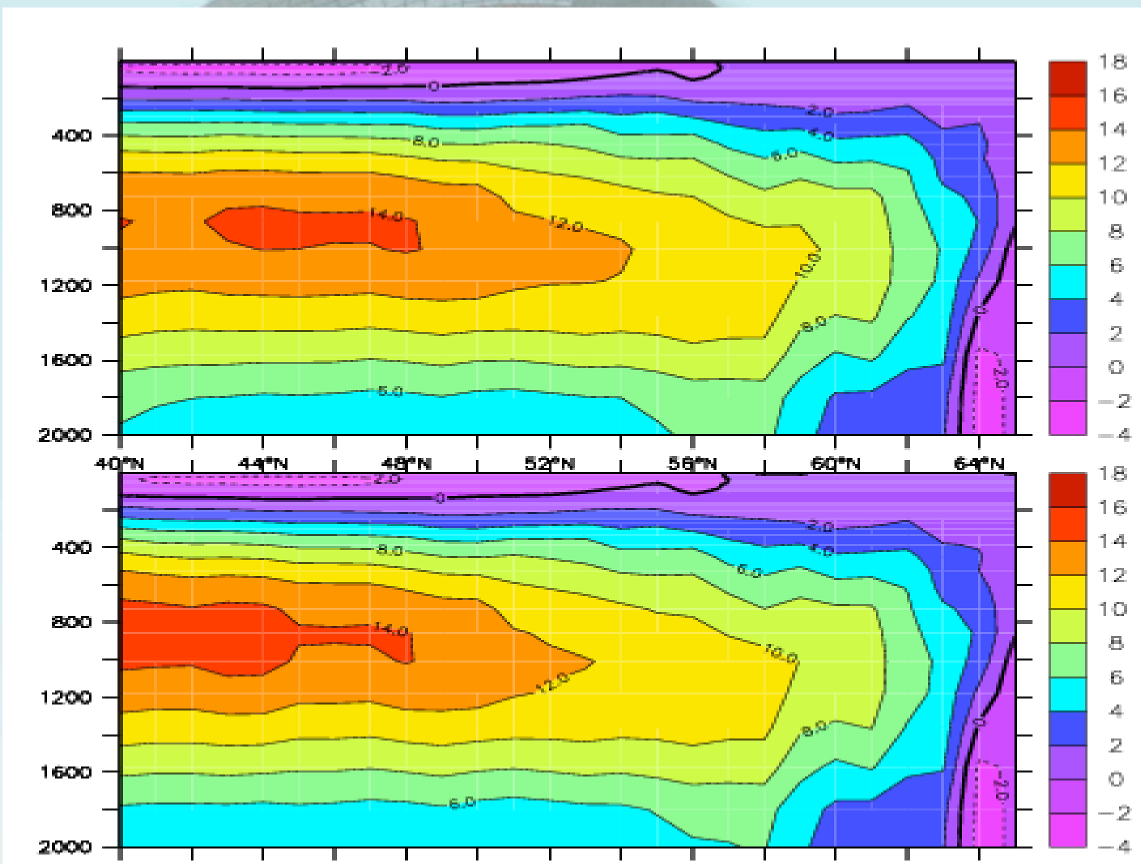


Truth

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

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

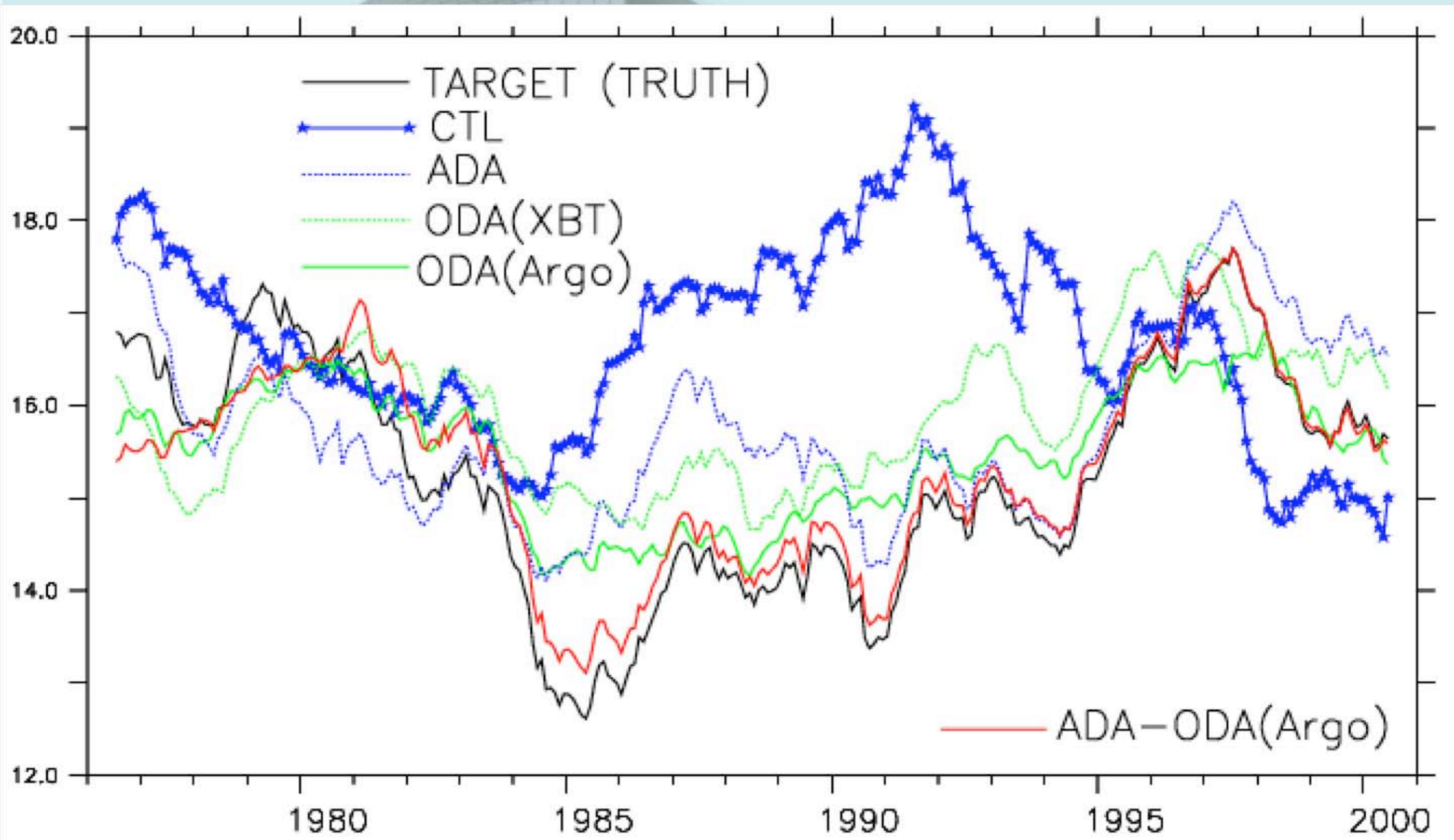
25-yr Time Mean of the Atlantic MOC



Truth

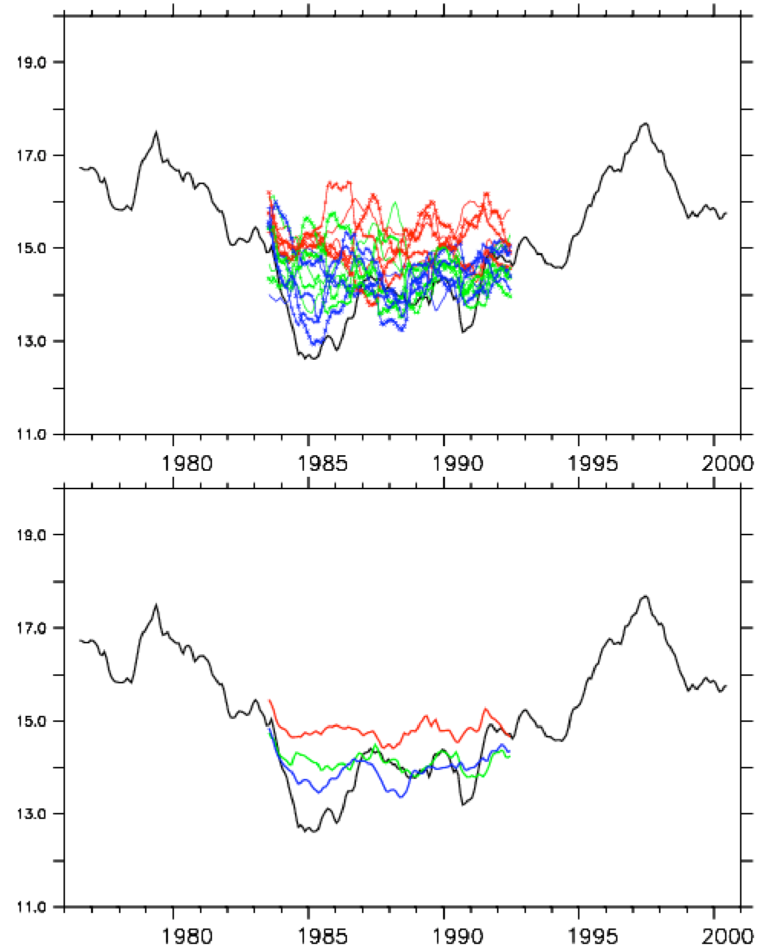
ODA (2000m)
T,S + Cov(T,S)

North Atlantic Max MOC from various ideal assimilation experiments

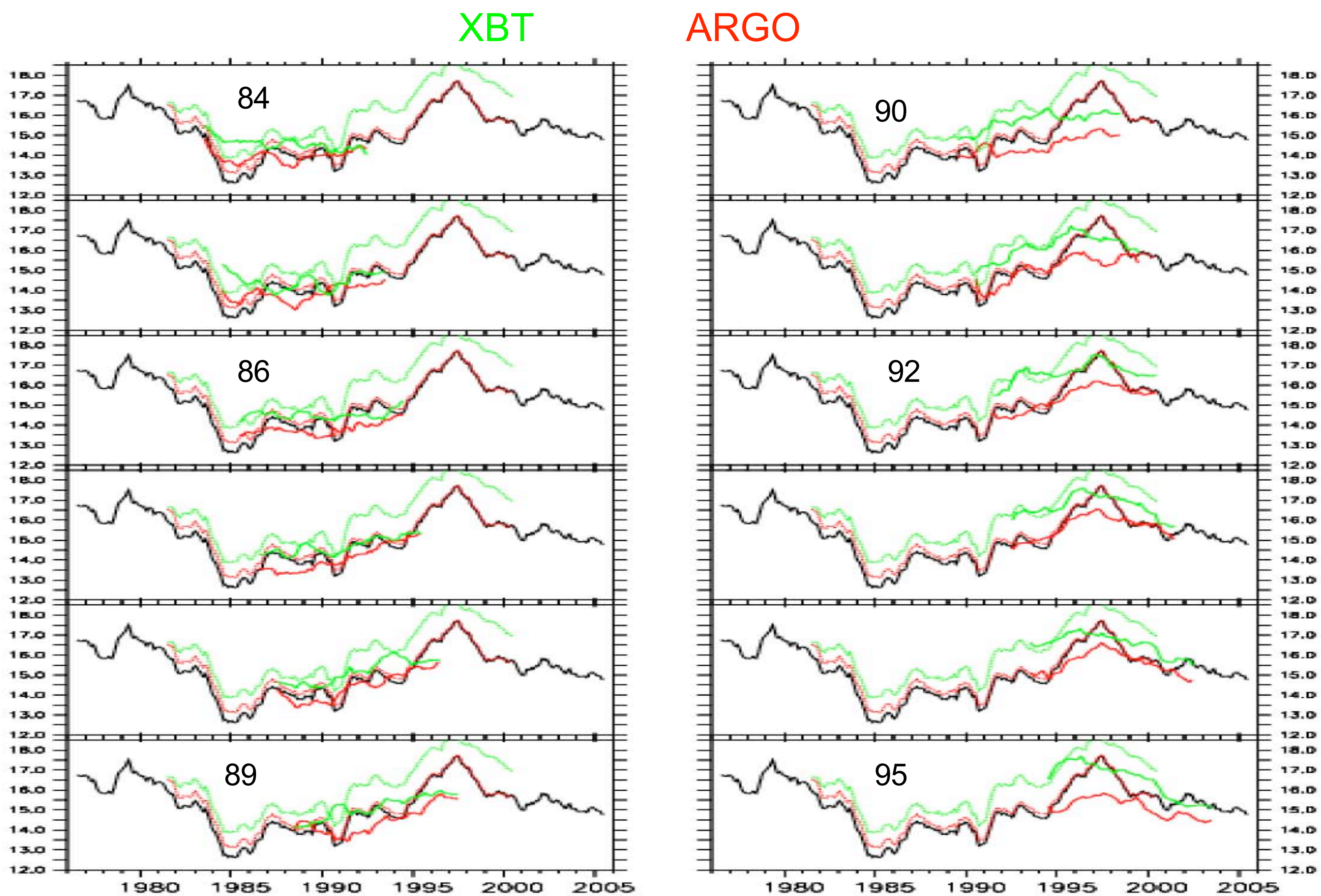


AMOC predictability OSSE

- Black - max AMOC
- Red - oda-xbt
- Green - oda-argo
- Blue - oda-argo+ada



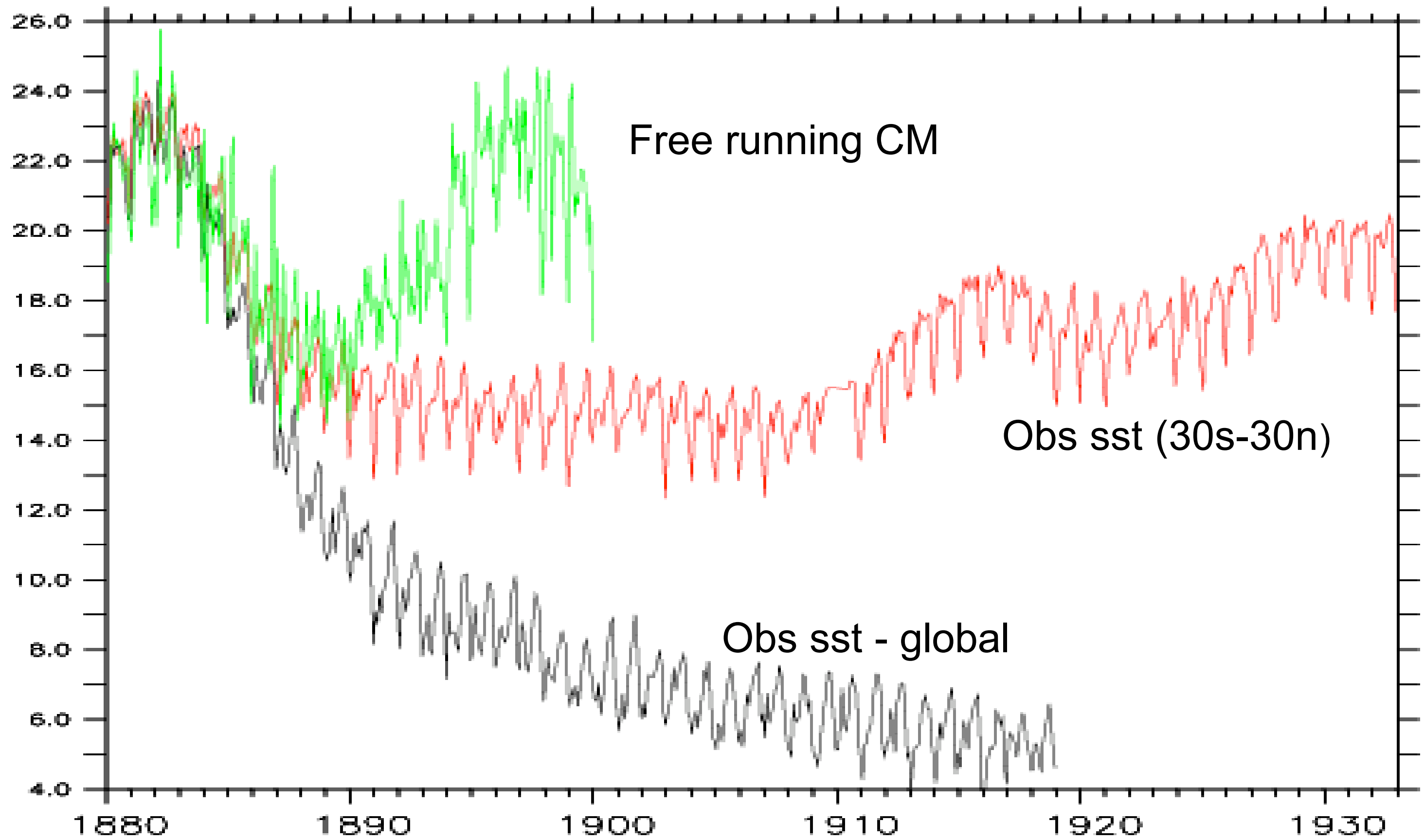
Predictability from OSSE



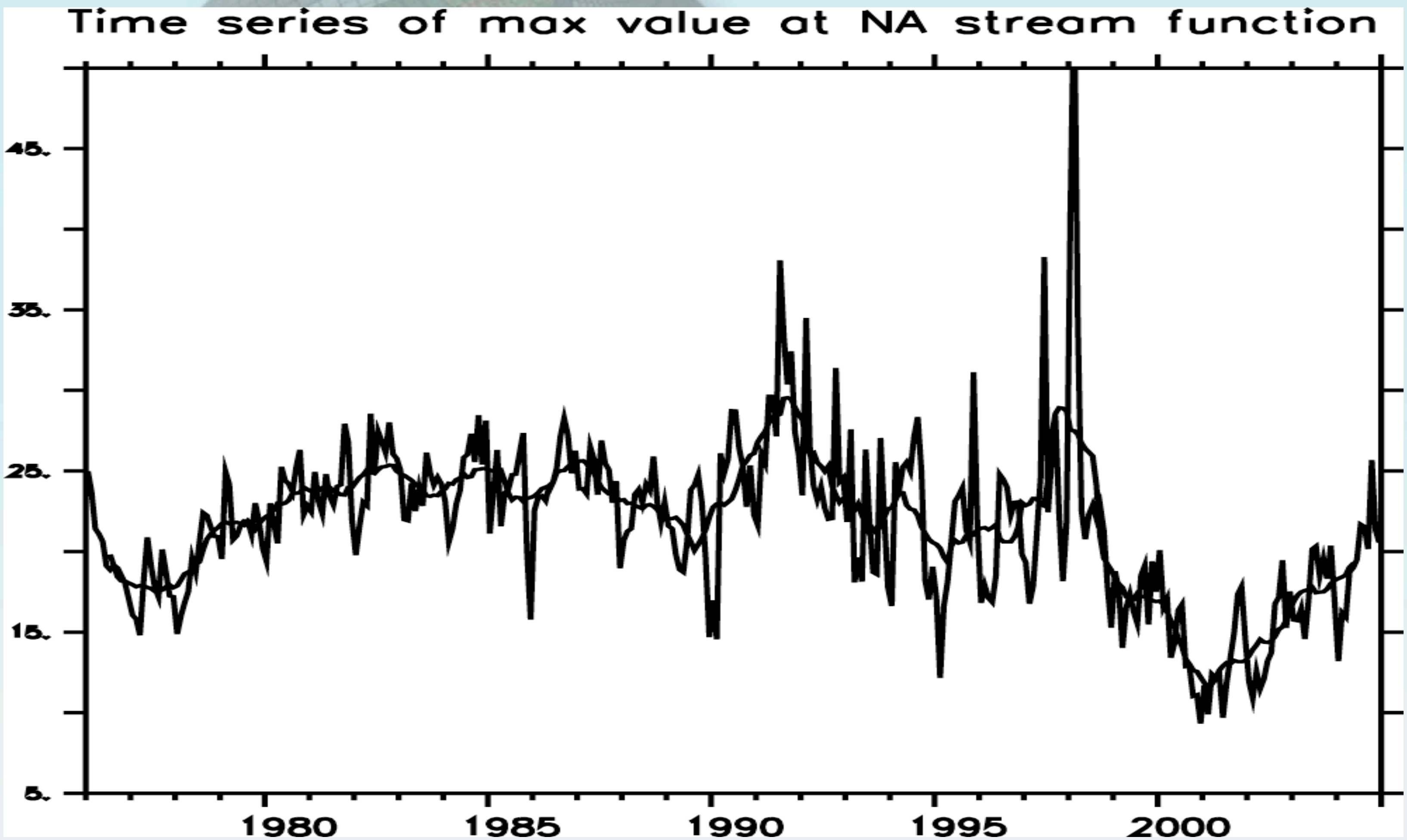
Summary on Impact of Ocean Observation Networks

- 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 AMOC.

AMOC assimilating SST

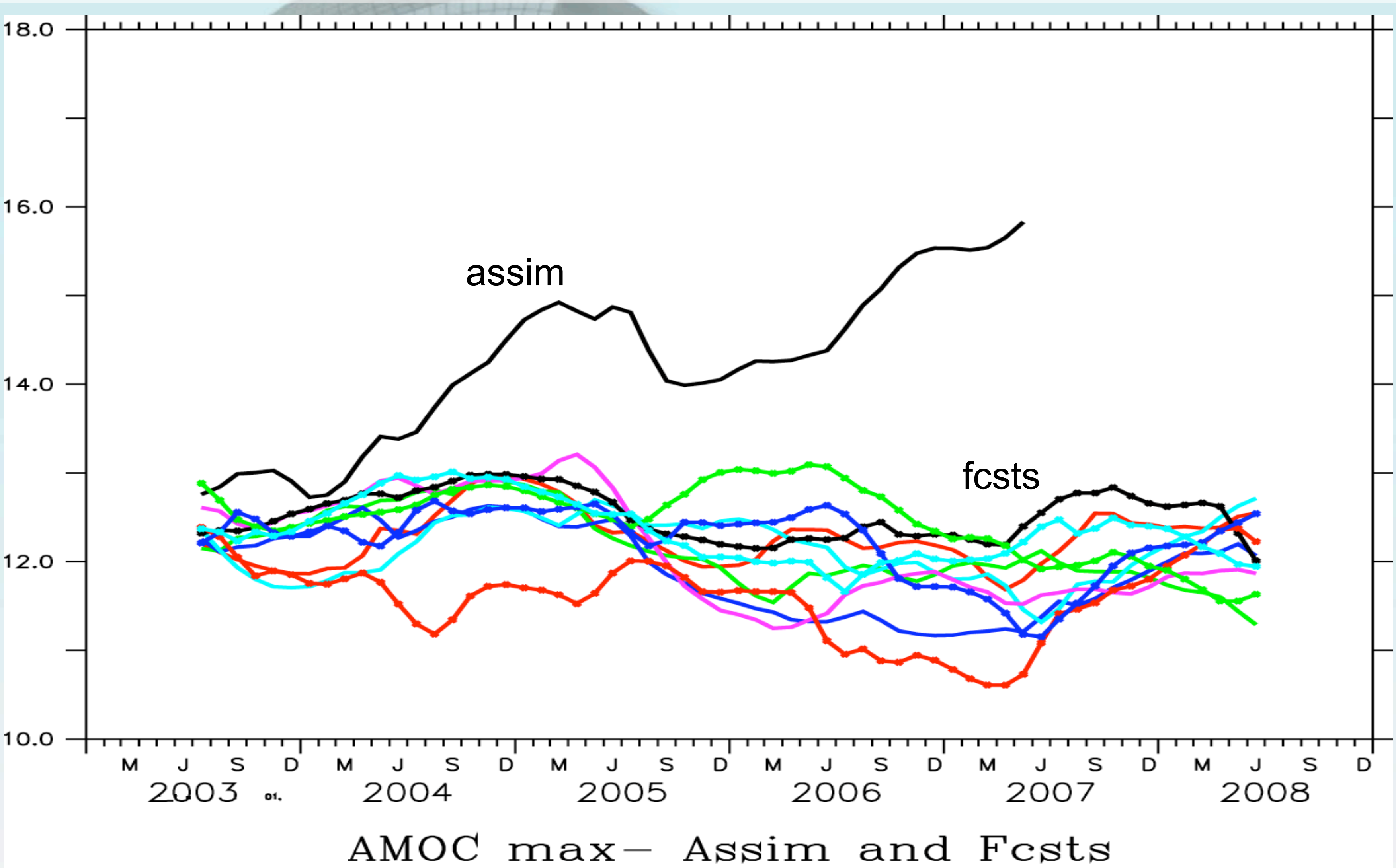


Max Value of Atlantic MOC from 30 yr Reanalysis using EnKF ODA

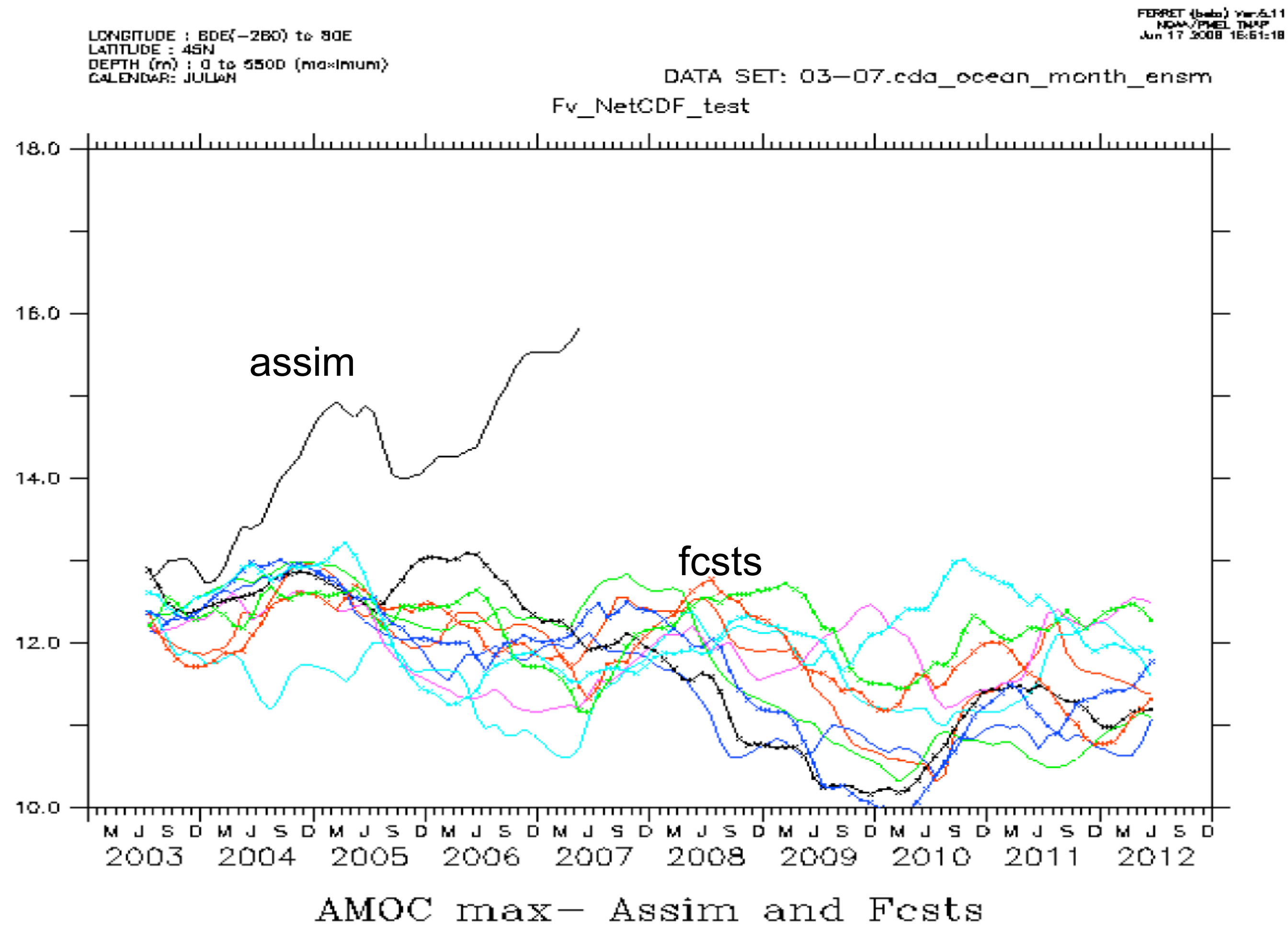


ARGO begins

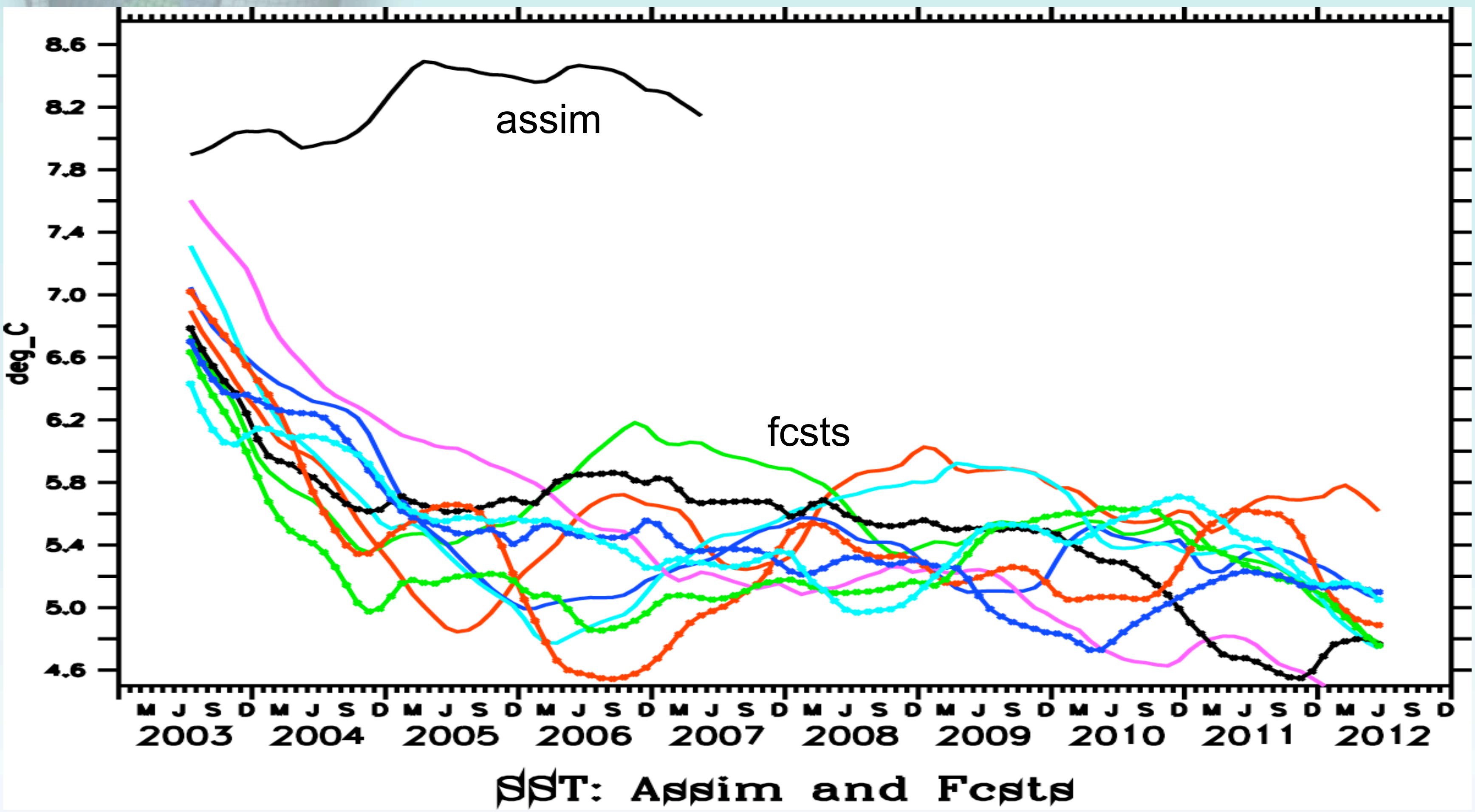
AMOC fcsts initialized from CDA



AMOC fcsts initialized from CDA



N.A. SST

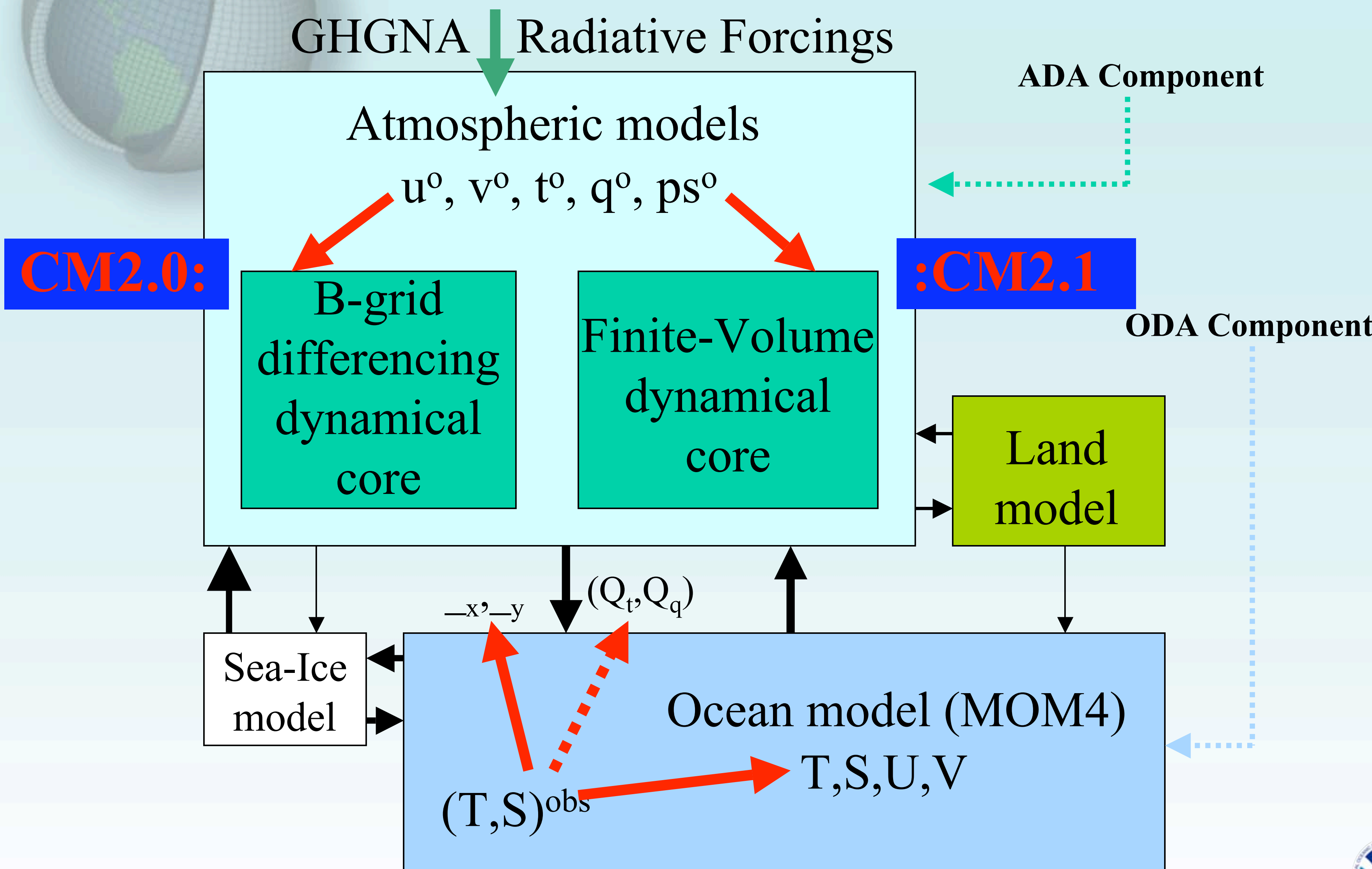


8.6
8.2
7.8
7.4
7.0
6.6
6.2
5.8
5.4
5.0
4.6
deg_C
assim
fcsts
M J S D M J S D M J S D M J S D M J S D M J S D M J S D M J S D M J S D M J S D
2003 2004 2005 2006 2007 2008 2009 2010 2011 2012
SST: Assim and Fcsts

CHALLENGES

- Demonstrate skill in decadal predictions of AMOC and climate
- For Decadal predictions how do we handle model drift?
- Long term observations
- Observing system to constrain the deep ocean
- How can we improve our model prior, bias?
- High Resolution CDA! Grand Challenge!

A Multi-Model Ensemble Data Assimilation System at GFDL



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?

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.