GFDL Activities in Decadal Intialization and Prediction

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Presented by G. Vecchi

1. Coupled Model Assimilation
2. Influence of observing systems on characterizing AMOC
3. Proto-type Decadal predictions
4. CMIP5 activities in support of AR5
5. Summary

Key Questions

- What seasonal-decadal predictability exists in the climate system, and what are the mechanisms responsible for that predictability?

- To what degree is the identified predictability (and associated climatic impacts) dependent on model formulation?

- Are current and planned initialization and observing systems adequate to initialize models for decadal prediction?

- Is the identified decadal predictability of societal relevance?

Crucial points:

• Robust predictions will require **sound theoretical understanding** of decadal-scale climate processes and phenomena.

• Assessment of predictability and its climatic relevance **may have significant model dependence**, and thus may evolve over time (with implications for observing and initialization systems).

But … even if decadal fluctuations are not predictable, it is still important to understand them to better understand and interpret observed climate change.

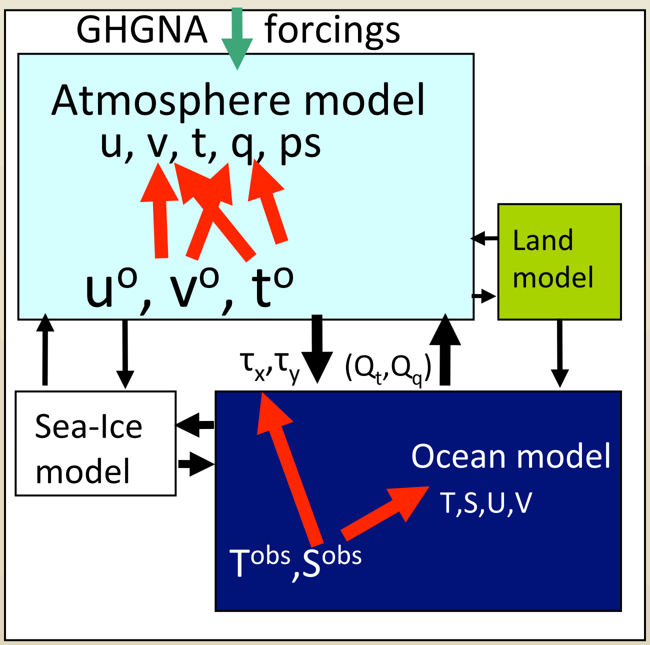
Ensemble Coupled Data Assimilation (ECDA) is at the heart of GFDL prediction efforts

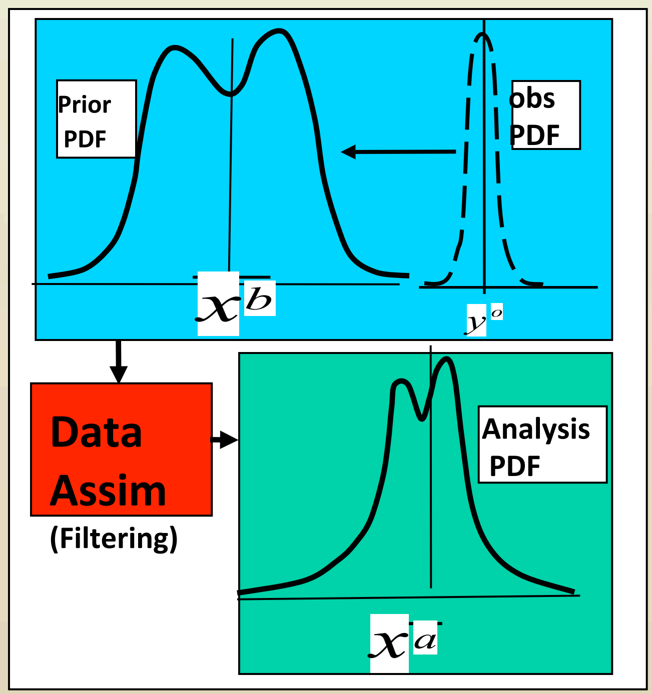
- **Provides initial conditions for Seasonal-Decadal Prediction**
- **Provides validation for predictions and model development**
- **Ocean Analysis kept current and available on GFDL website**

Pioneering development of coupled data assimilation system

Ensemble Coupled Data Assimilation estimates the *temporally-evolving probability distribution* of climate states under observational data constraint:

- Multi-variate analysis maintains physical balances between state variables such as T-S relationship – primarily geostrophic balance
- Ensemble filter maintains the nonlinearity of climate evolution
- All coupled components adjusted by observed data through instantaneously-exchanged fluxes
- Optimal ensemble initialization of coupled model with minimum initialization shocks

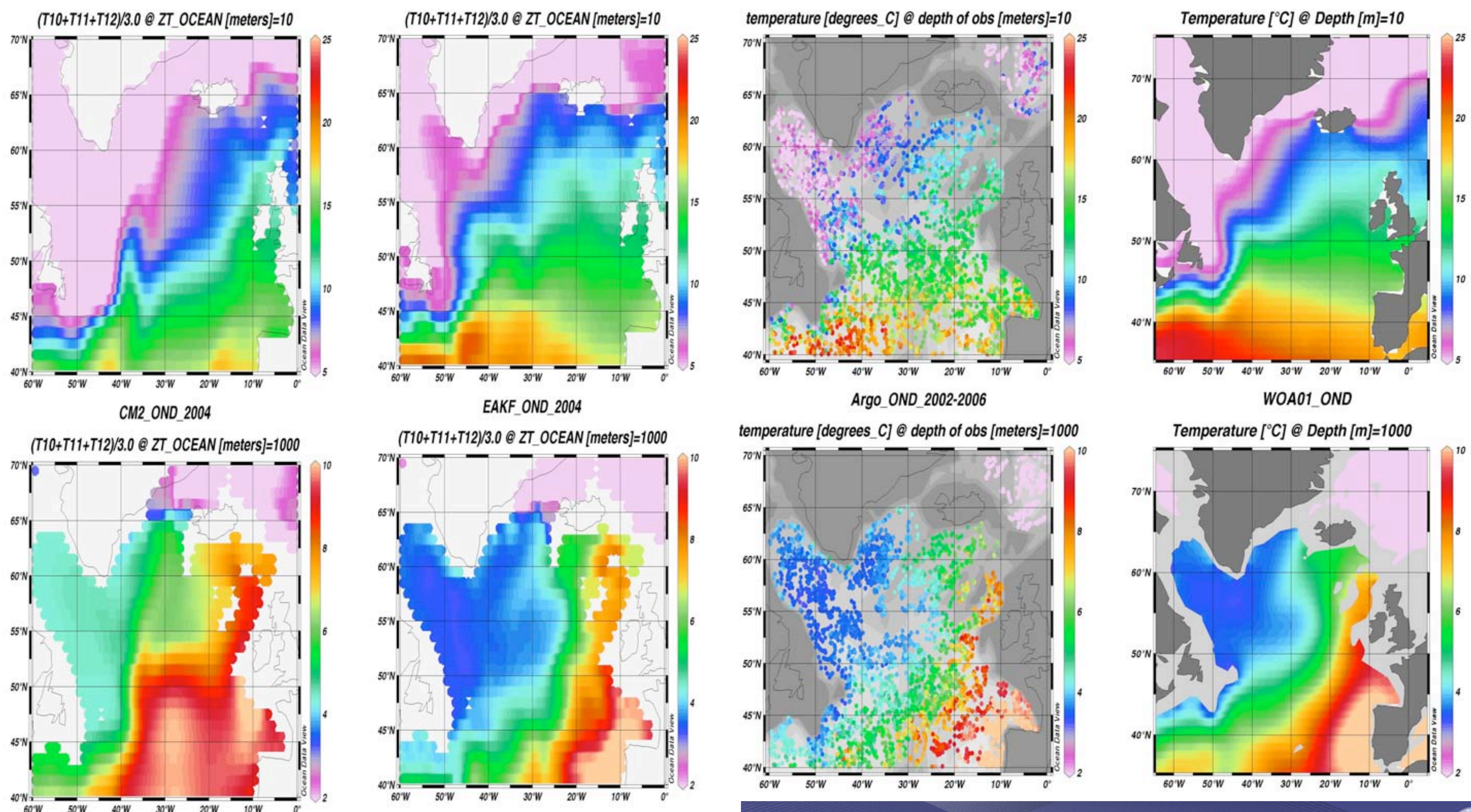




S. Zhang, M. J. Harrison, A. Rosati, and A. Wittenberg MWR 2007

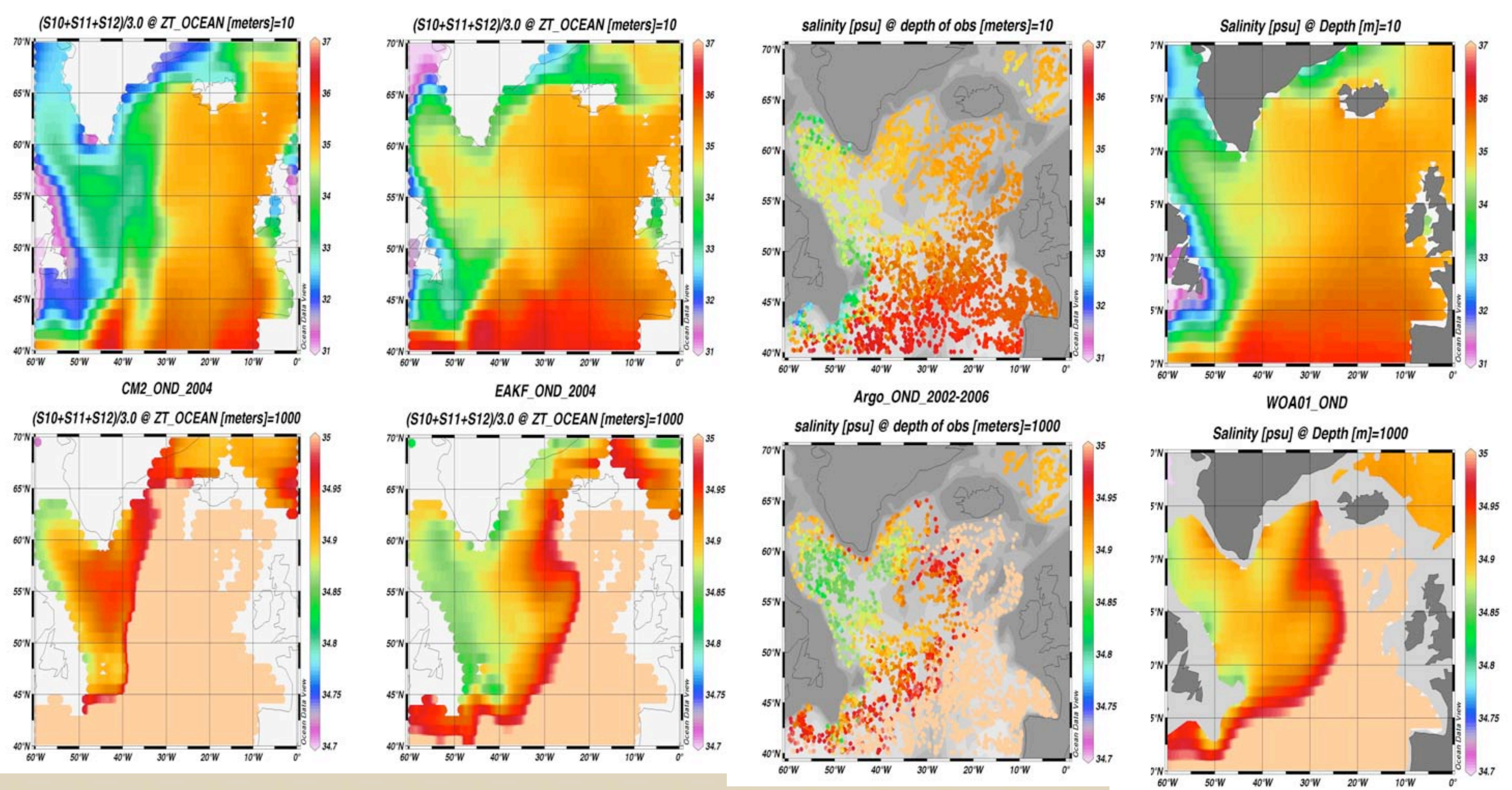
OND N.A. - TEMPERATURE

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



OND N.A. - SALINITY

NO-ASSIM	ASSIM(ECDA)	Argo	WOA01



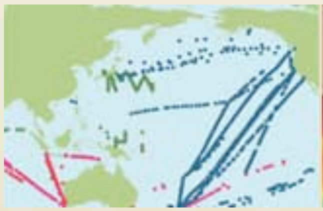
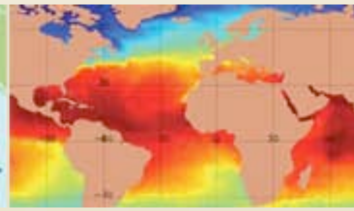
ECDA activities to improve Initialization

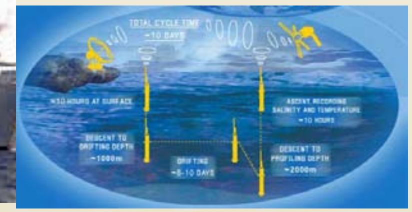
- **Multi-model ECDA to help mitigate bias**
- **Fully coupled model parameter estimation within ECDA**
- **ECDA in high resolution CGCM**
- **Assess additional predictability from full depth ARGO profilers**
- **Produce Pseudo Salinity profile - 1993-2002**

Ocean observations assimilated

1982 1993 2001

XBT's 60's | Satellite SST | Moorings/Altimeter | ARGO

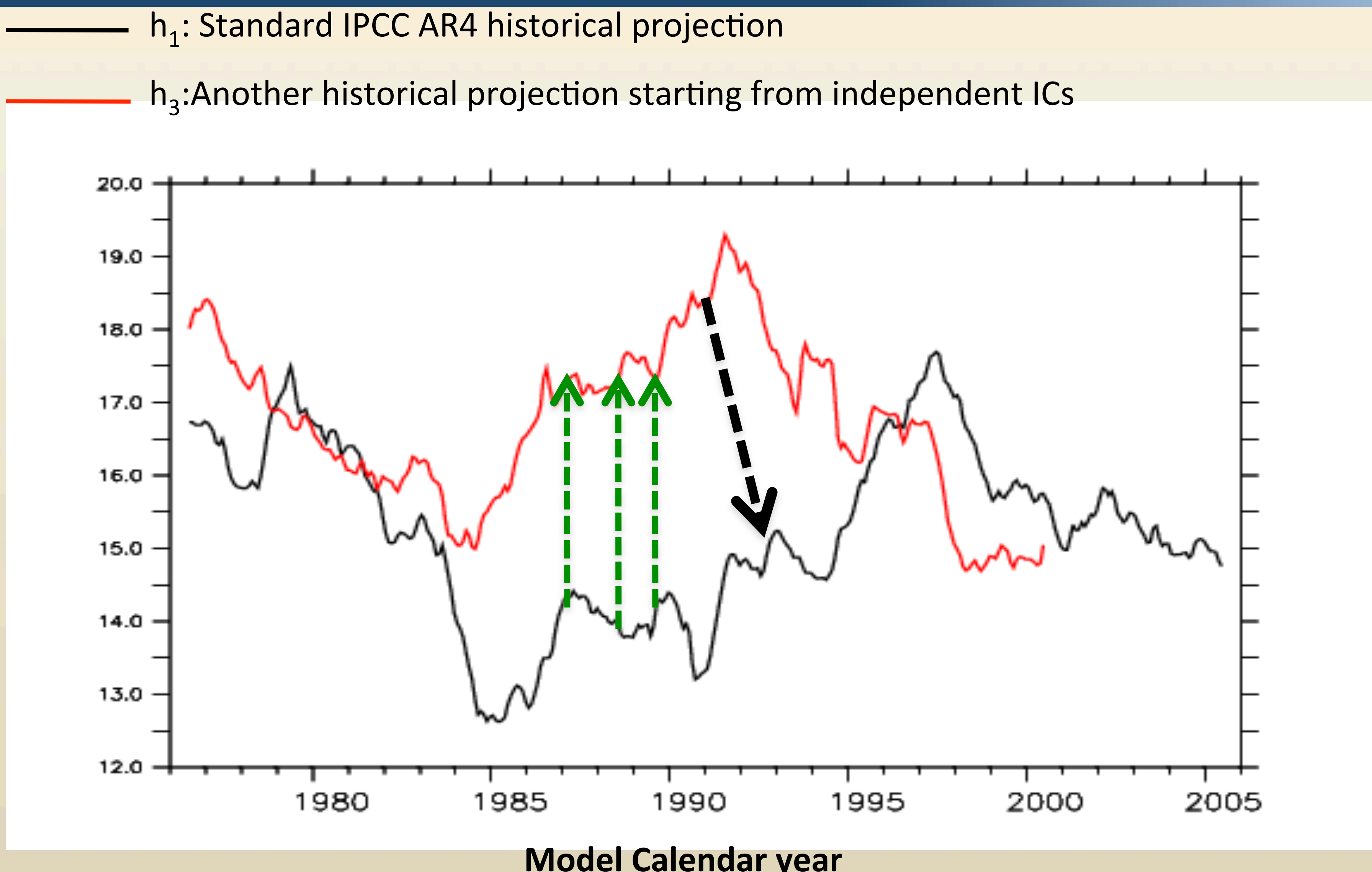






The ocean observing system has slowly been building up…

Its non-stationary nature is a challenge for the estimation of decadal variability

GOAL: Estimate the impact that various observing systems have on our ability to represent the AMOC within models, and to predict the AMOC.



Observing and Prediction System Components Assessed

INPUTS

XBT network of oceanic observations (“*20th century observing system*”)

ARGO network of oceanic observations (“*21st century observing system*”)

Atmospheric winds and temperatures

Estimates of future greenhouse gases and aerosols

OUTPUTS: “Observed” or Predicted Metrics

AMOC

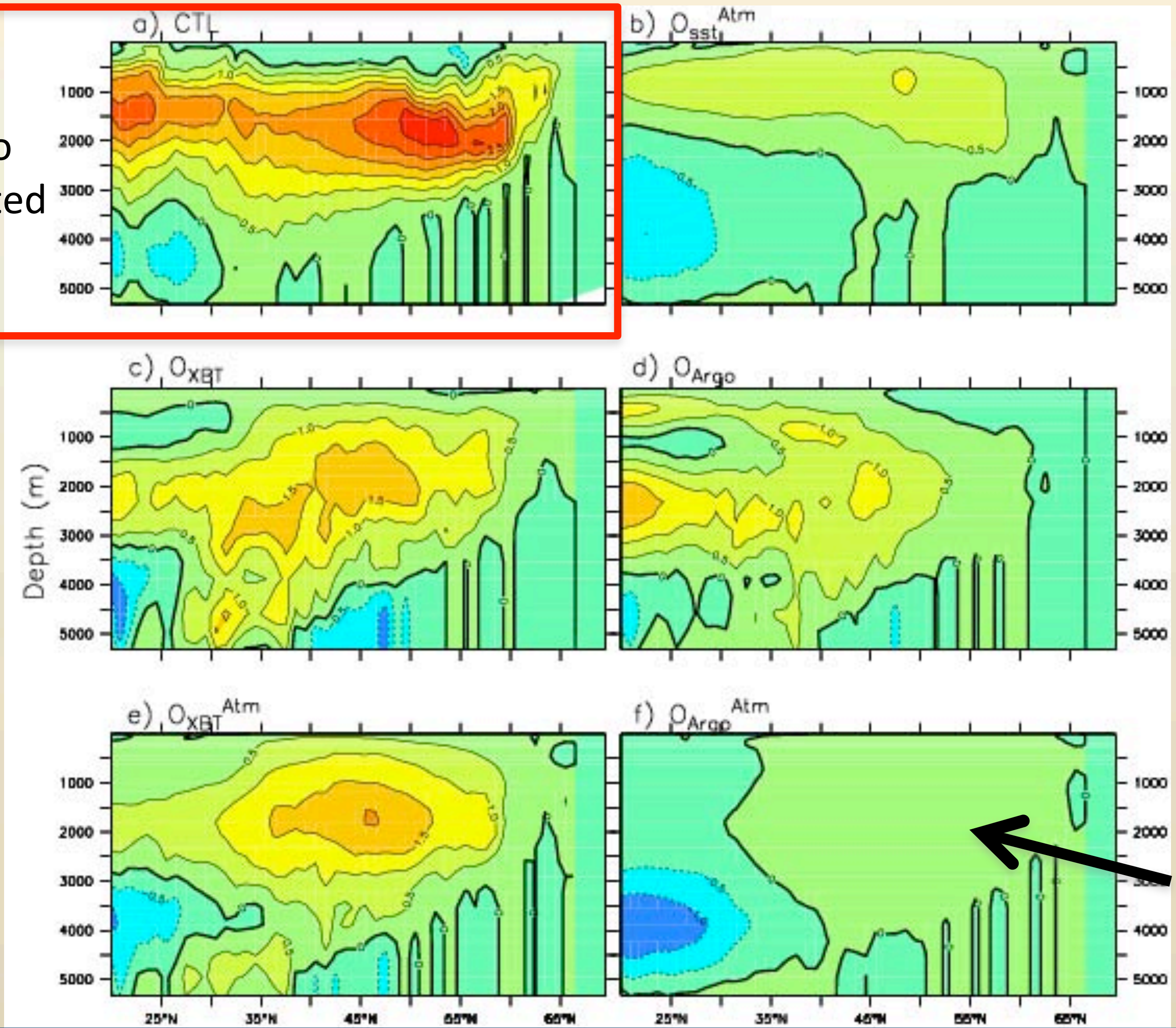
Lab Sea Water

Greenland Sea Water

North Atlantic Oscillation

Recovery of "true" spatial pattern of AMOC as a function of observing system

" Worst case" (no assimilated data)



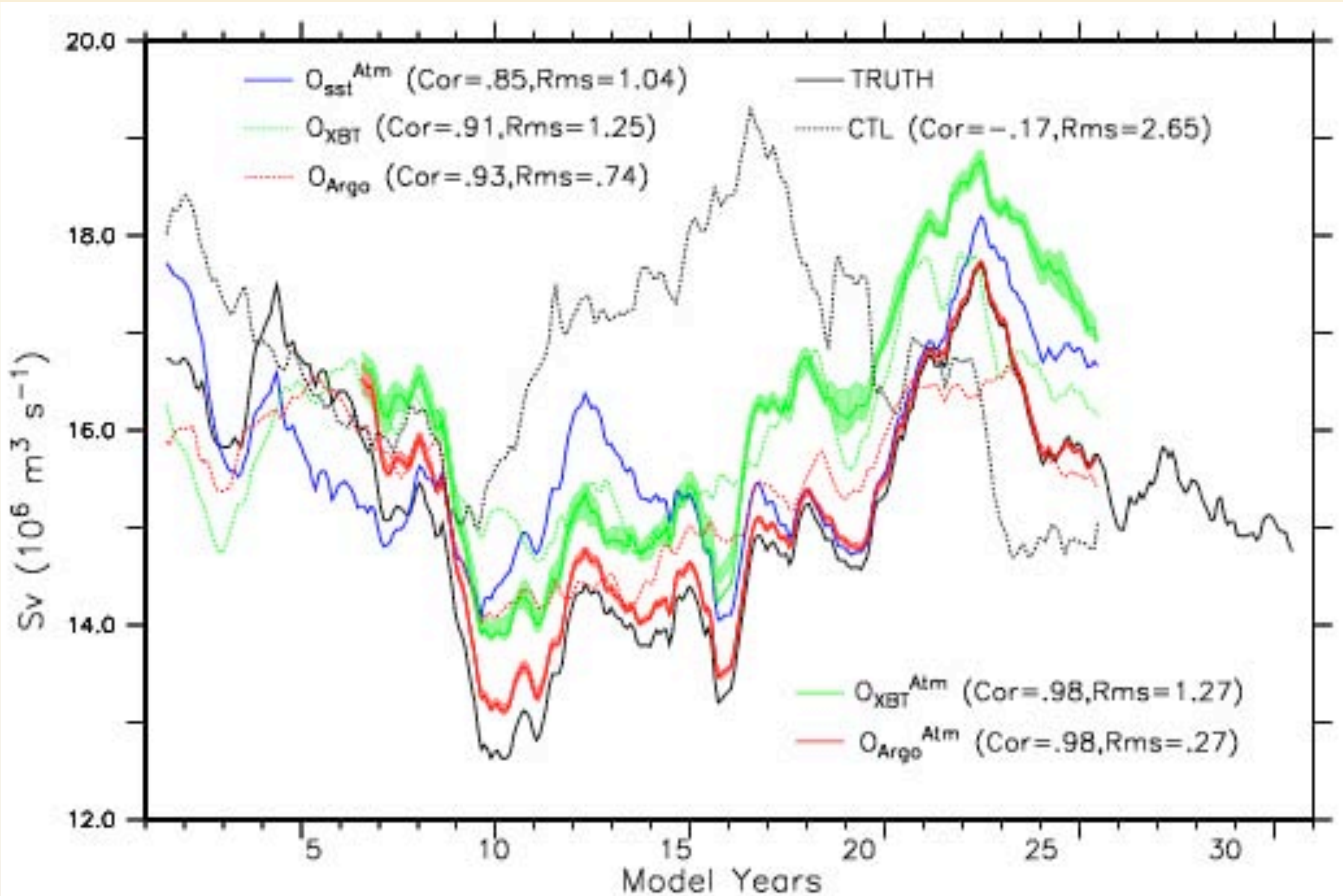
Other panels show difference between assimilated AMOC and "truth" as a function of observing system

"BEST"

(Argo plus atmosphere temp and winds)

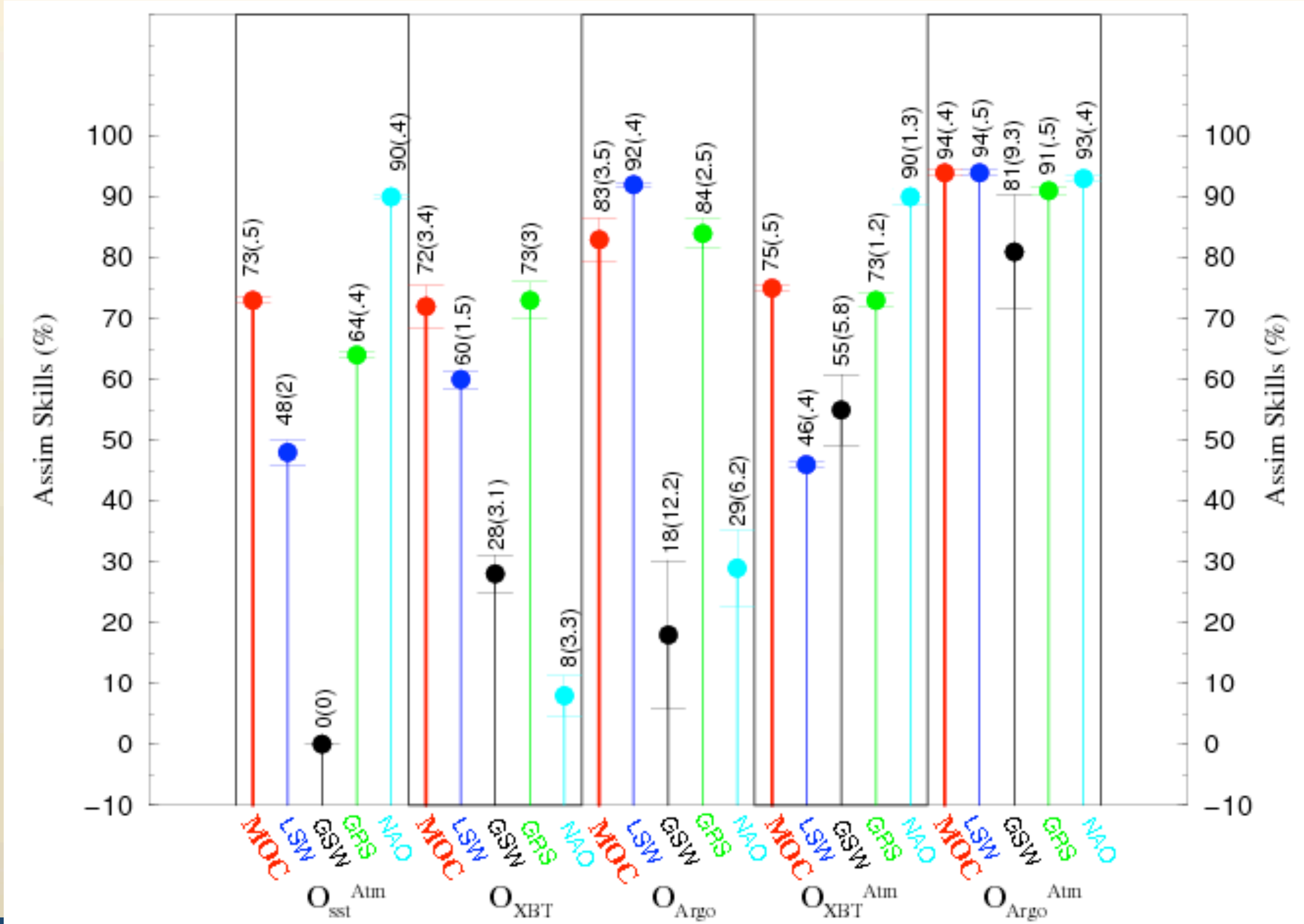
Ability to represent AMOC in models is a function of observing system

- Use of ARGO plus atmospheric temperature and winds performs best

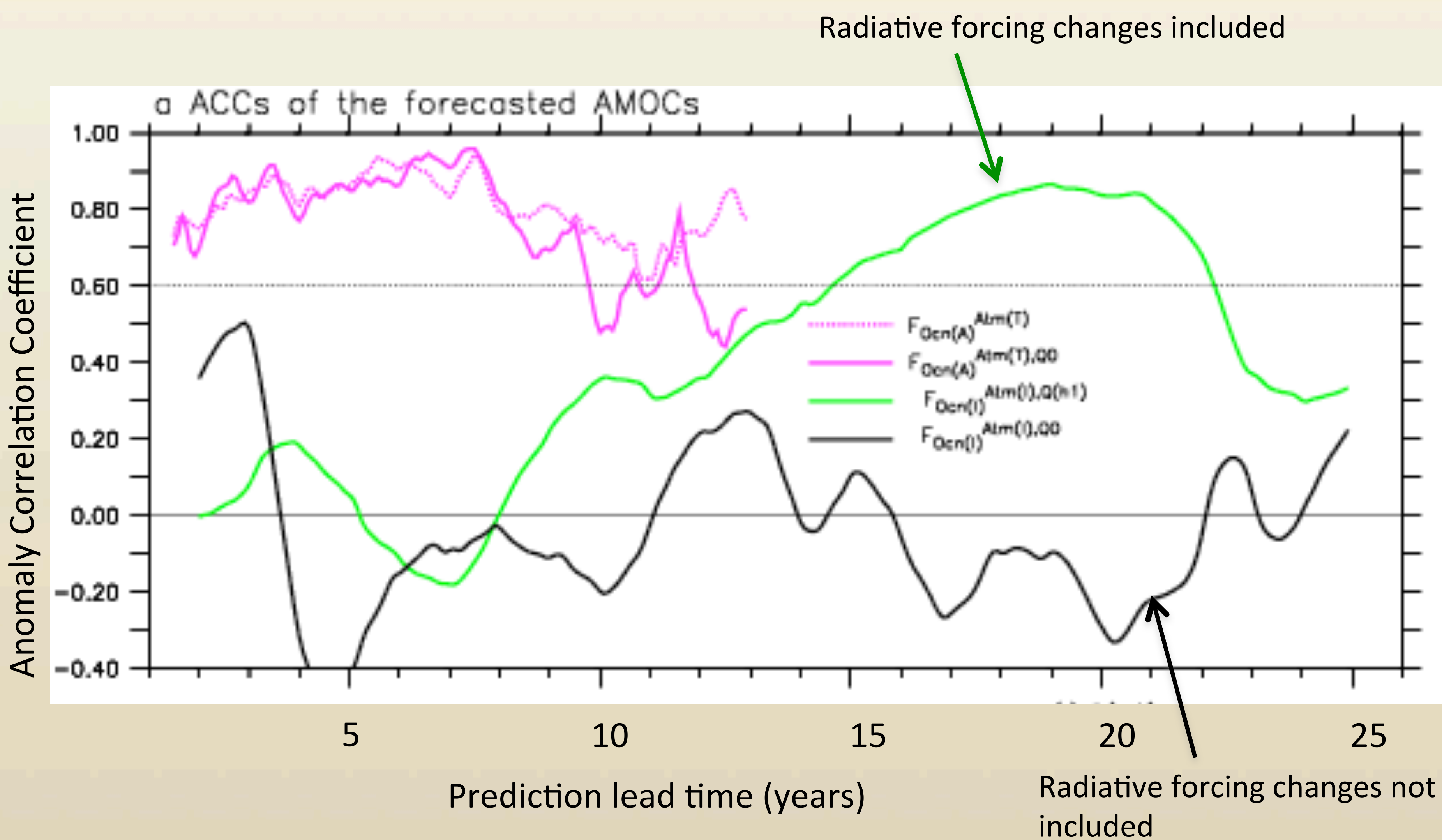


Zhang et al, accepted

Ability to capture various North Atlantic climate features as a function of observing system



Inclusion of changing radiative forcing impacts predictive skill



Summary and Discussion

1. Atlantic SST variability has a rich spectrum with clear climatic impacts. This motivates attempts to understand the relationship of the AMOC to that variability, and to predict AMOC variations.

2. The use of ideal twin experiments, in concert with coupled assimilation system, allows an assessment of the potential of various observing systems to observe and predict the AMOC.

3. Model results suggest that the ARGO network is crucial to most faithful representation of AMOC in model analysis.

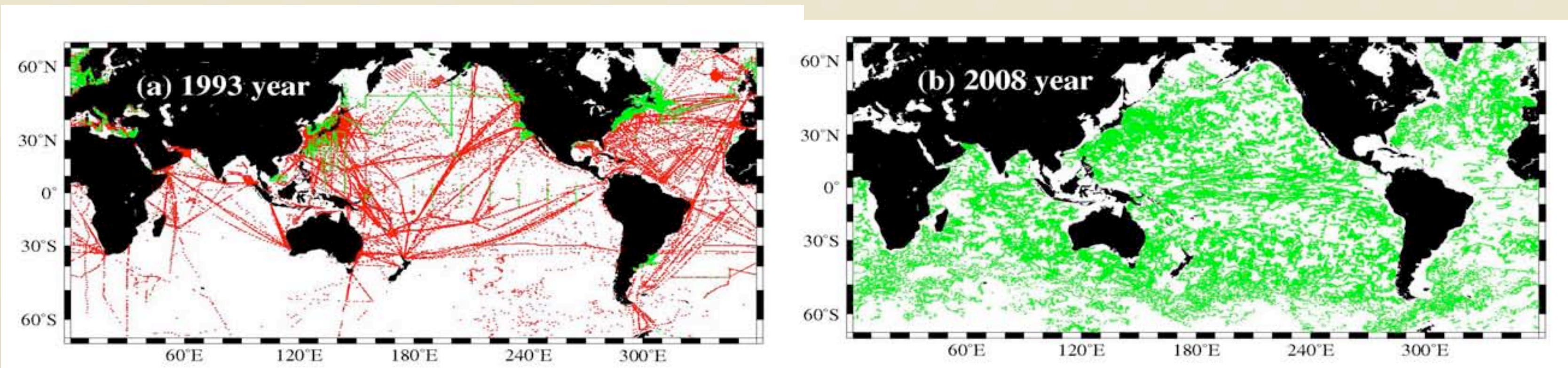
4. Predictability experiments show use of ARGO network plus atmospheric analysis provides the most skillful AMOC prediction (skill for AMOC is 78% with ARGO versus 60% without). Inclusion of changing radiative forcing tends to increase skill on longer time scale.

5. These experiments DO NOT take into account model bias, which is a formidable challenge.

6. GFDL decadal prediction efforts using observed data are ongoing using ensemble coupled assimilation system and GFDL CM2.1 model.

Pseudo-Salinity INTRODUCTION

Previous studies mostly used vertical coupled T-S EOF modes and showed that EOF modes effectively represented the coupled variability of T-S fields, and the salinity profiles were reconstructed from in situ temperature and sea level observations as well. However, their studies have been limited to the specified area where proxy data were sufficient for the predetermined T-S EOF modes and evaluation of their studies. In the 21st century, we can obtain more than 100,000 temperature and salinity profiles worldwide each year, thanks to the successful international Argo project. This high-density T-S profile array without seasonal and spatial bias upper 2000 m of the ice-free oceans, makes it possible to apply the previous studies to the global ocean.

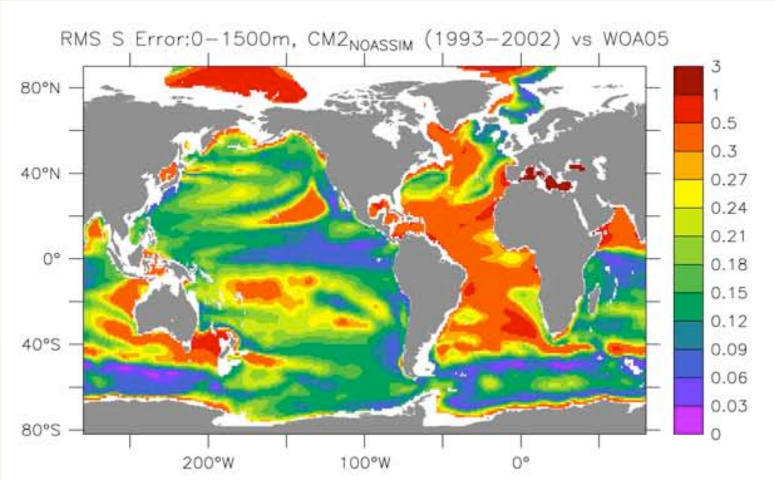


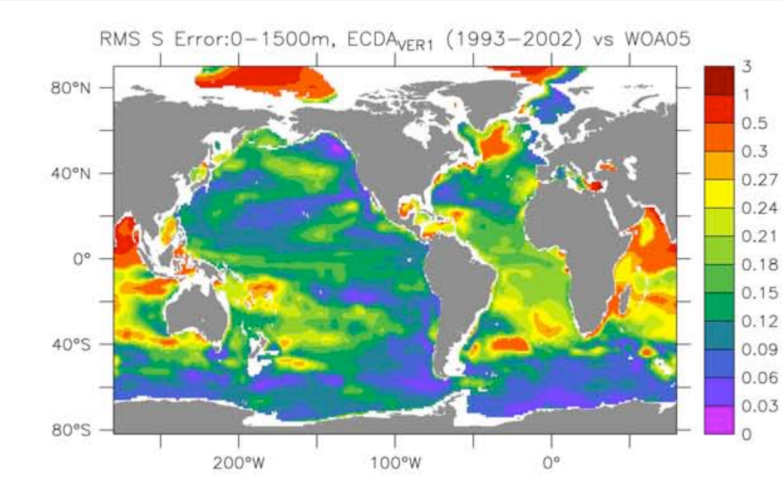
Green: T-S data location, Red: T only data location

Y. Chang, JGR 2010

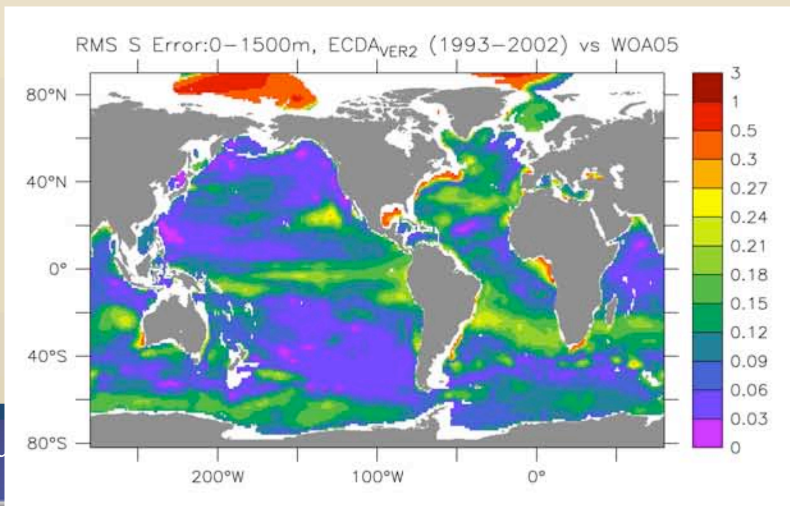
APPLICATION TO THE ASSIMILATION

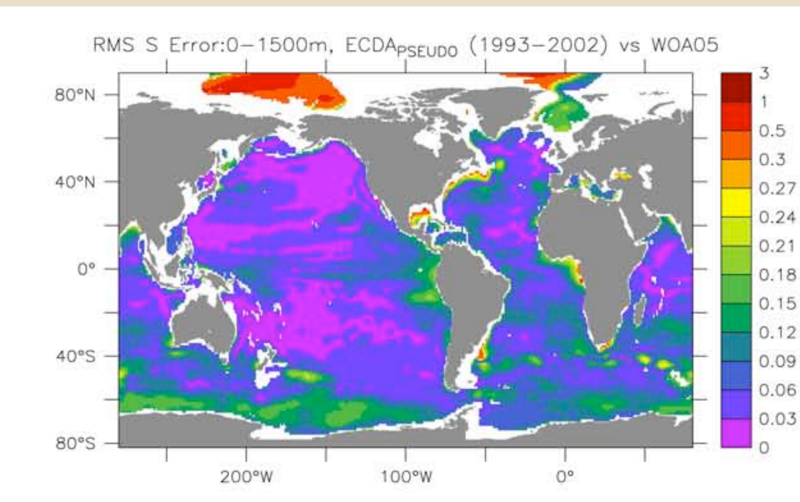
CM2.1 No assim. → GFDL_ECDA ver.1





→ GFDL_ECDA ver.2 → GFDL_ECDA with pseudo salinity

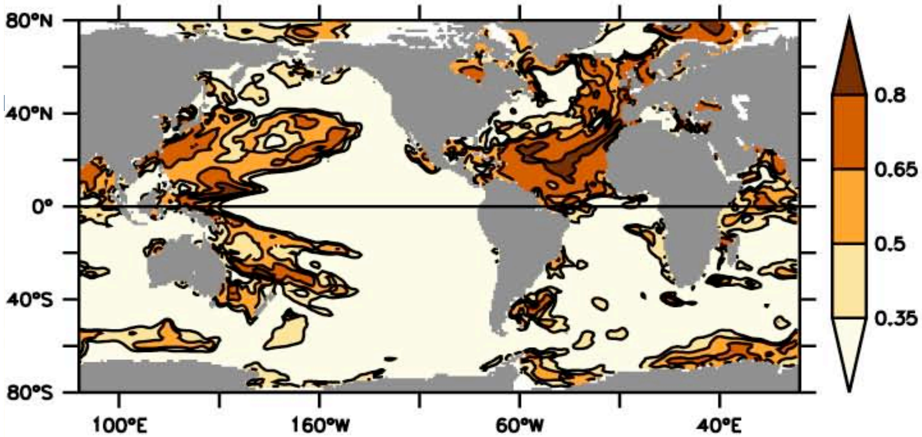




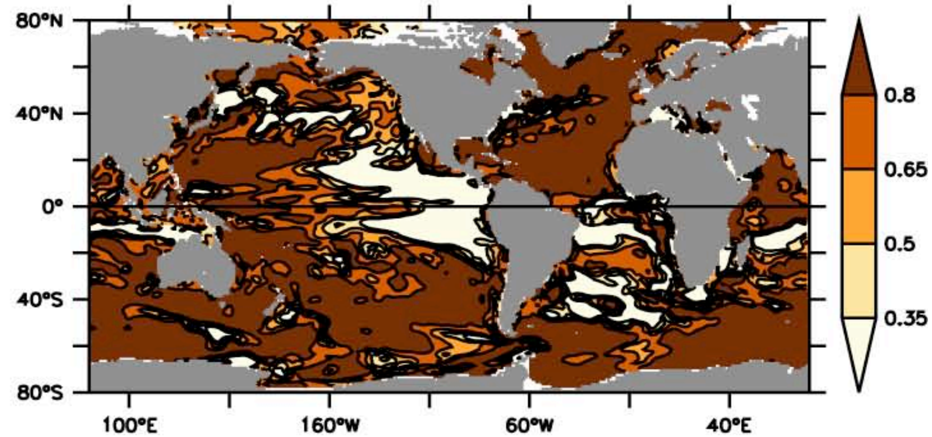
CMIP5 PROTOTYPE EXPERIMENTAL DESIGN

- Initialization- from Ensemble Coupled Data Assimilation (ECDA_ver2.0) Reanalysis
  - Atmosphere - NCEP Reanalysis2 (T,u,v,ps)
  - Ocean - xbt,mbt,ctd,sst,ssh,ARGO
  - Radiative Forcing - GHG, Solar, Volcano, Aerosol
- Hindcasts - 10 member ensembles, starting Jan every year from 1971-2009 for 10 years (total of 4k years)
- Predictions - A1B scenario

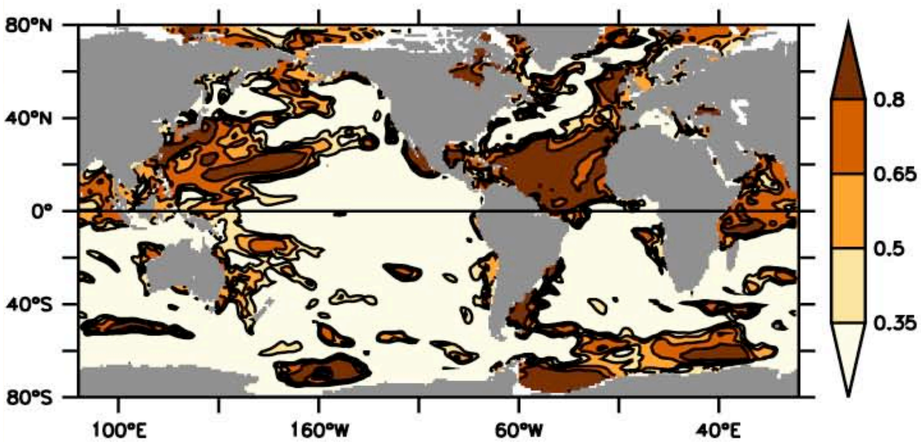
SST CORR between OBS and Hindcasts



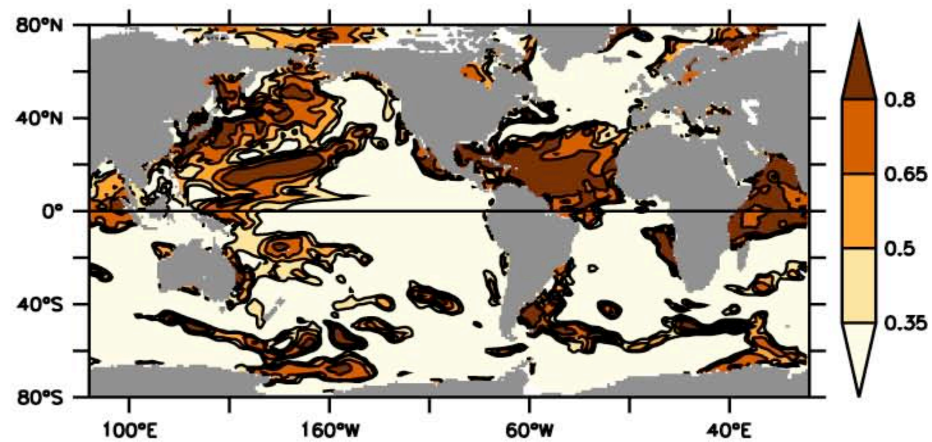
NOASSIM



YR1

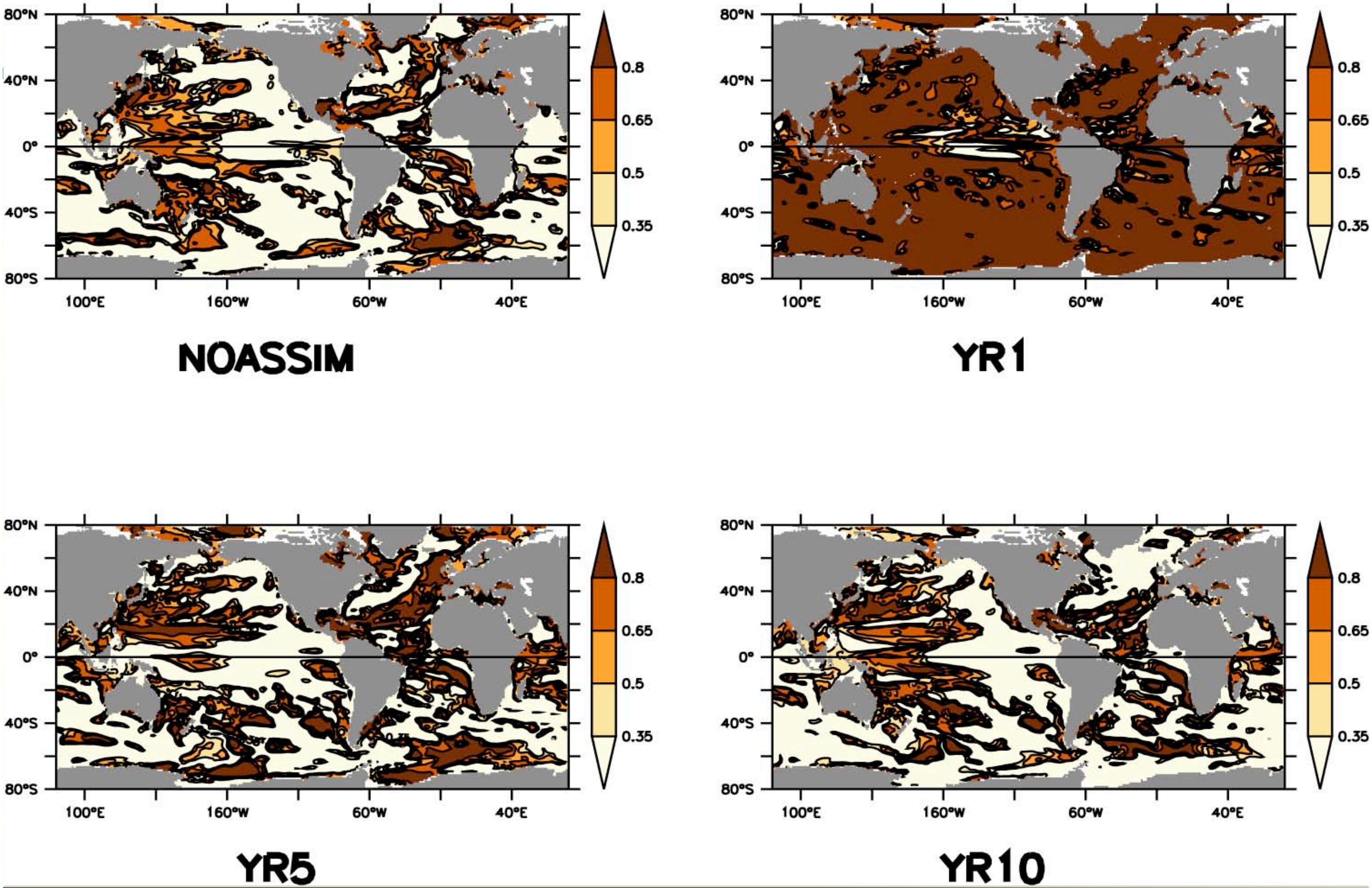


YR5



YR10

Tav300 CORR between OBS and Hindcasts

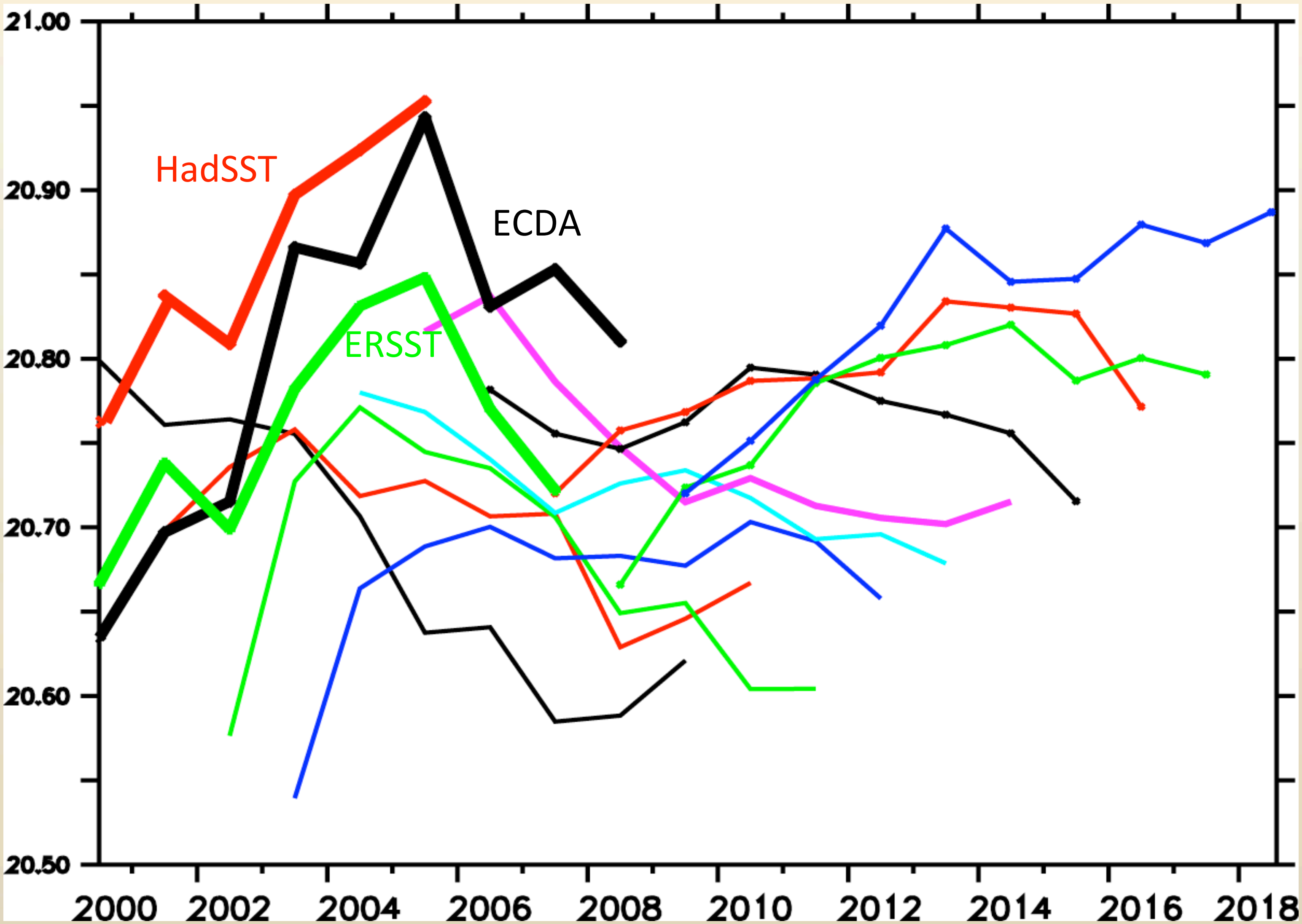


GFDL Decadal Prediction Research in support of IPCC AR5

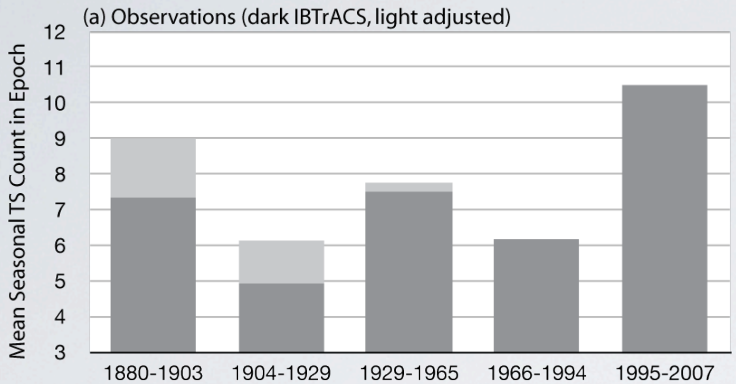
Key goal: assess whether climate projections for the next several decades can be enhanced when the models are initialized from observed state of the climate system.

- **Use ECDA_ver3.0 for initial conditions from "observed state"**
  - **Produce ocean reanalysis 1970-2010**
- **Use "workhorse" CM2.1 model from IPCC AR4 [2010]- RCP forcing**
  - **Decadal hindcasts from 1970 - 2009 every year starting in JAN**
  - **Decadal predictions starting from 2001 onwards**
- **Use experimental high resolution model CM2.5 [2011]**
  - **Decadal predictions starting from 2003 onwards**
- **Use CM3 model [2011, tentative]- indirect effect, atmospheric chemistry**
  - **Decadal predictions starting from 2001 onwards**

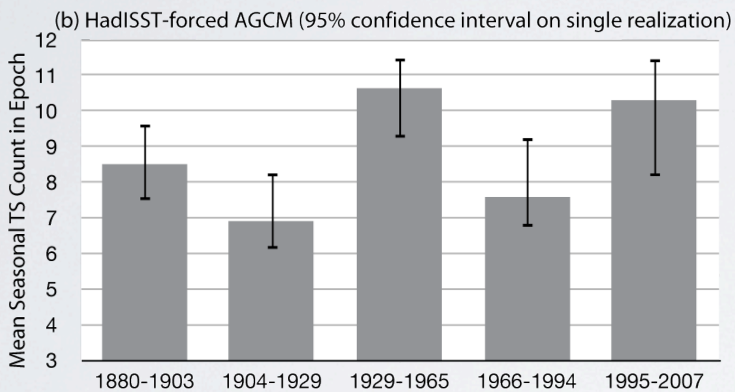
N.H. SST Predictions



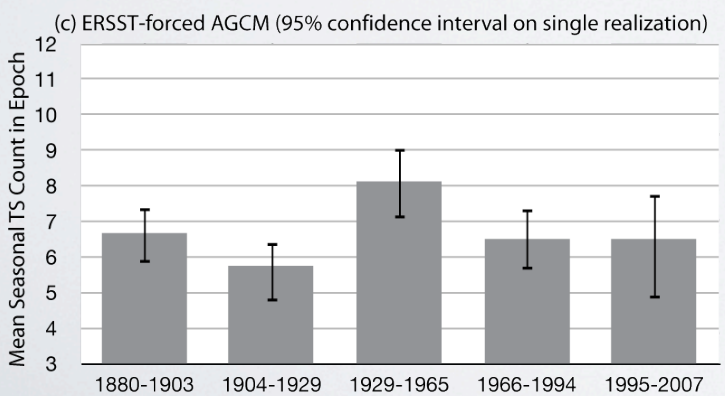
ABILITY OF AGCM TO RECOVER MULTI-DECADAL TS VARIABILITY DEPENDS ON SST FORCING



Observed

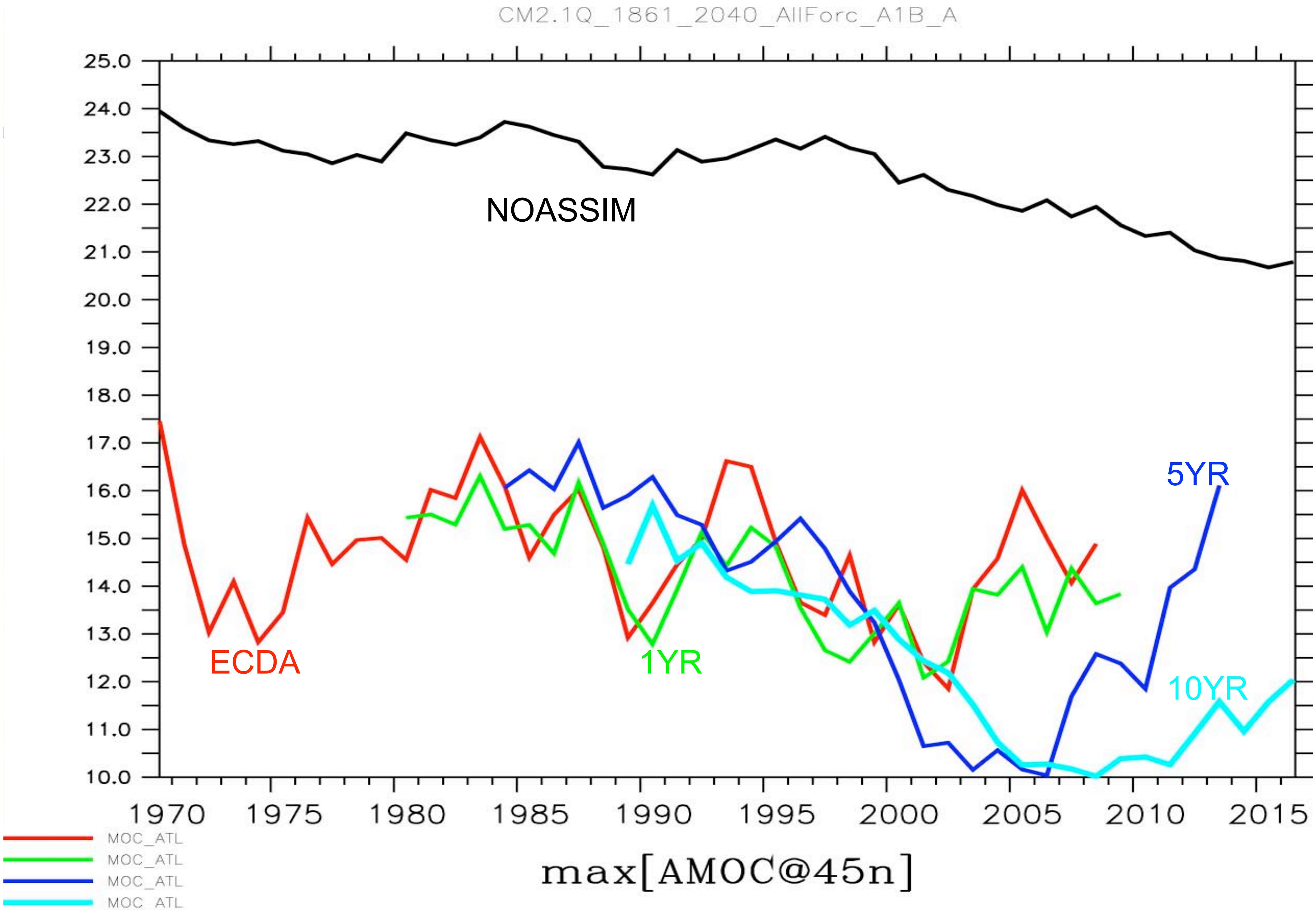


HadISST-Forced AGCM



ERSST-Forced AGCM

Vecchi, Zhao and Held (2010, in prep.)


CM2.1Q_1861_2040_AllForc_A1B_A
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2015
NOASSIM
ECDA
1YR
5YR
10YR
MOC_ATL
MOC_ATL
MOC_ATL
MOC_ATL
max[AMOC@45n]

Policy Relevance of the Predictions in the Presence of:

- **Model Error**
- **Prediction Uncertainty**
- **Projection Uncertainty**
- **Observational Uncertainty**

Concluding Remarks

- **Decadal climate variability:**
  - *Crucial piece – predictability may come from both*
    - *forced component*
    - *internal variability component*
  - *… and their interactions.*
- **Decadal predictions will require:**
  - *Better characterization and mechanistic understanding (determines level of predictability)*
  - *Sustained, global observations*
  - *Advanced assimilation and initialization systems*
  - *Advanced models (resolution, physics)*
  - *Estimates of future changes in radiative forcing*
- **Decadal prediction is a major scientific challenge**
- **An equally large challenge is evaluating their utility**

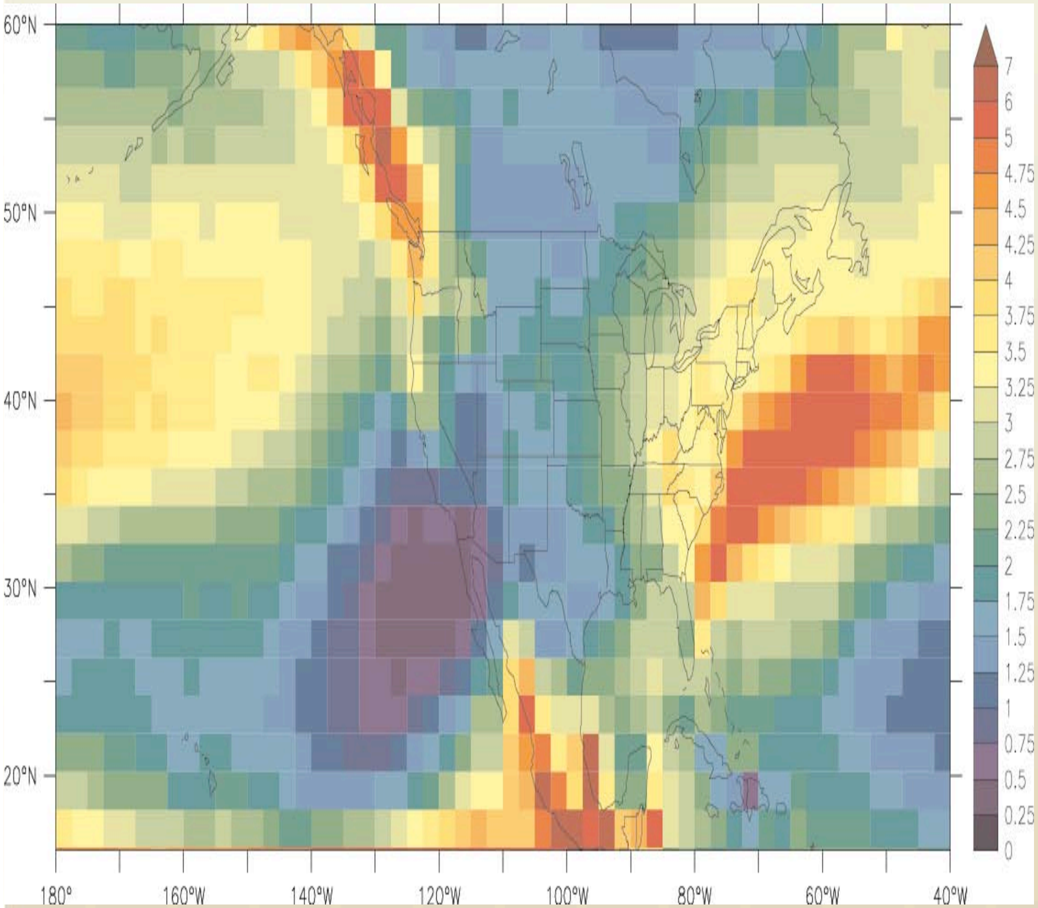
Hi-Resolution Model development

- **Simulated variability and predictability is likely a function of the model**
- **Developing improved models (higher resolution, improved physics, reduced bias) is crucial for studies of variability and predictability**
- **New global coupled models: CM2.4, CM2.5, CM2.6**

	Ocean	Atmos	Computer	Status
CM2.1	100 Km	250 Km	GFDL	Running
CM2.3	100 Km	100 Km	GFDL	Running
CM2.4	10-25 Km	100 Km	GFDL	Running
CM2.5	10-25 Km	50 Km	GFDL	Running
CM2.6	4-10 Km	25 Km	DOE	In development

PRECIPITATION (mm/day)

CM2.1



PRECIPITATION (mm/day)

CM2.1 CM2.5