Sensitivity of AMOC Potential Predictability to Observing Systems

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Coordinated Decadal Prediction for AR5

Basic model runs:

1.1) **10 year integrations** with initial dates towards the end of 1960, 1965, 1970, 1975, 1980, 1985, 1990, 1995 and 2000 and 2005 (see below).

Is the historical ocean observing system up to the task?

- Ensemble size of 3, optionally increased to O(10)
- Ocean initial conditions should be in some way representative of the observed anomalies or full fields for the start date.
- Land, sea-ice and atmosphere initial conditions left to the discretion of each group.

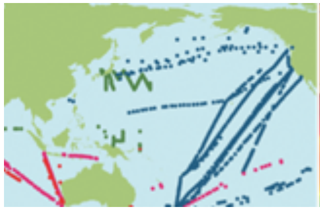
1.2) **Extend integrations** with initial dates near the end of 1960, 1980 and 2005 **to 30 yrs**.

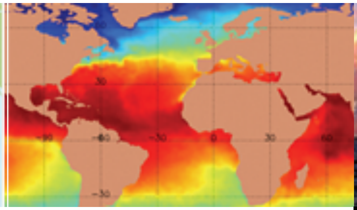
- Each start date to use a 3 member ensemble, optionally increased to O(10)
- Ocean initial conditions represent the observed anomalies or full fields.

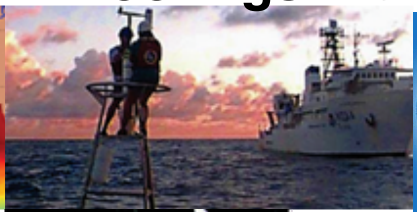
Ocean observations assimilated

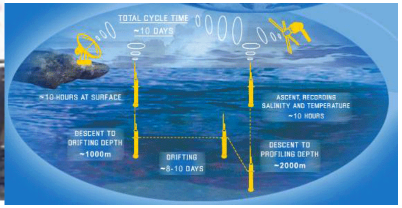
1982 1993 2001

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





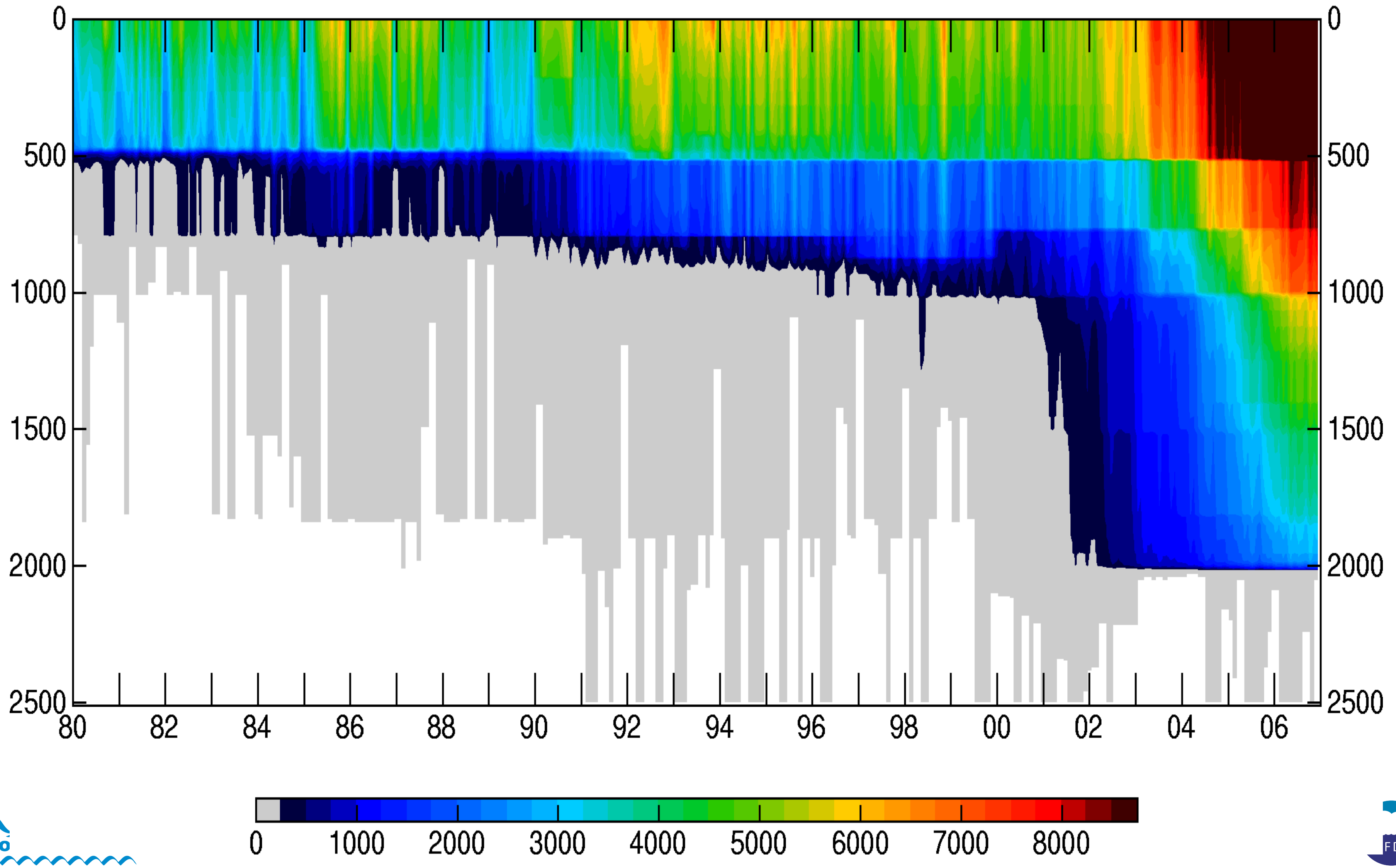




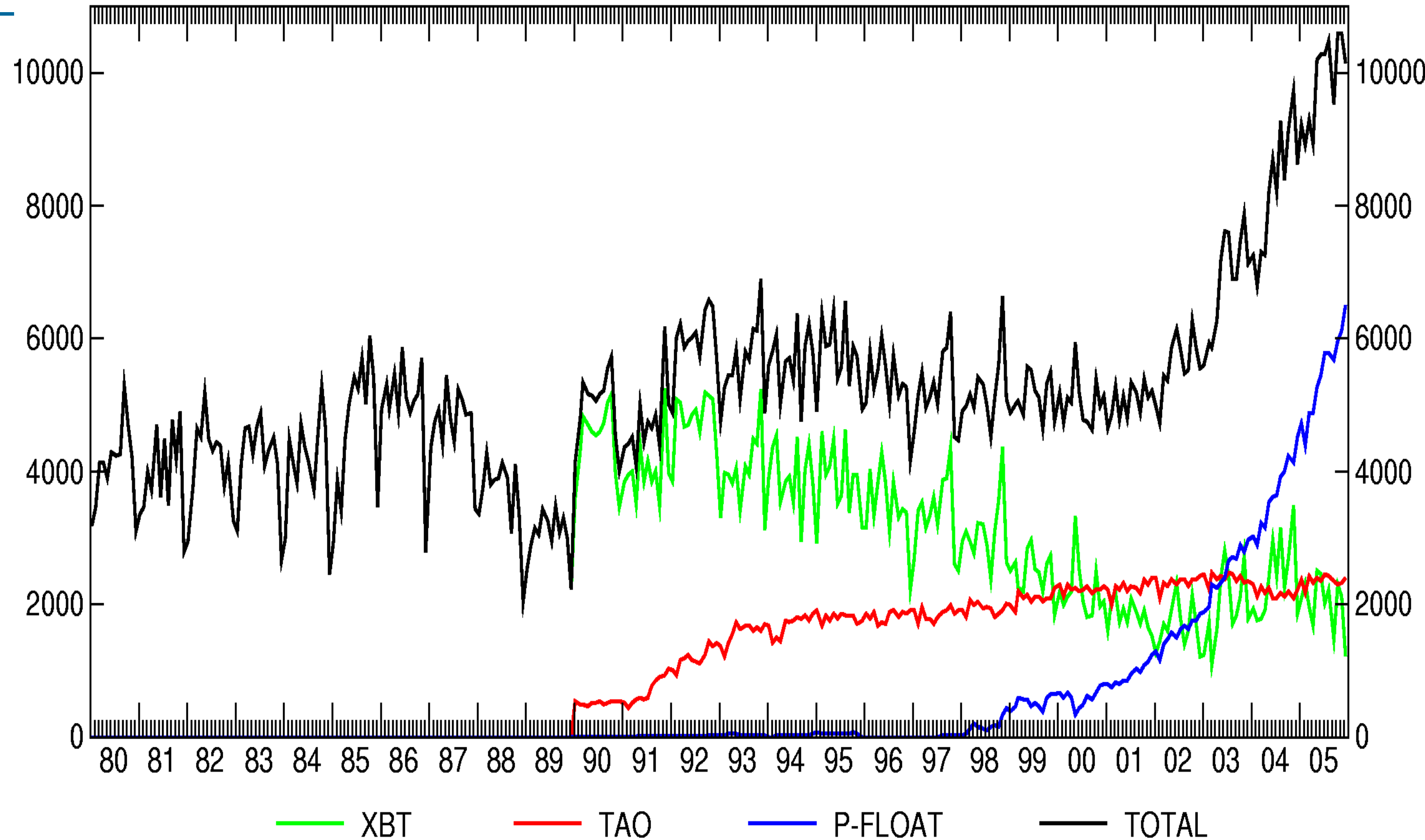
The ocean observing system has slowly been building up…

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

Number of Temperature Observations per Month as a Function of Depth



Number of Temperature Profiles per Month (NODC:1980-89; MEDS:1990-Present)



A Question

Given a coupled model and the climate monitoring system, how much can we predict climate change and/or variation on a decadal time scale ?

- ✓ **Predictability (Griffies and Bryan 97; Collins et al. 06; Latif et al. 06)!**
- ✓ **The climate observing system has representation errors !**
- ✓ **Model is biased !**

The Potential Predictability of AMOC Depending on Observing Systems

OUTLINE

- An Ensemble Coupled Data Assimilation (ECDA) system applied to perfect model 'twin' experiments to conduct coupled initialization and prediction exps.
- Given the reanalyzed atmosphere and the 20th-century XBT & 21st-century Argo ocean observations, how well does the climate observing system monitor AMOC?
- Based on the assessment upon observing systems, what is the sources of the predictability of AMOC**? – Relative contributions of the Labrador Sea Water (LSW), the GIN Sea Water (GSW) and the Atlantic Gyre System (GRS)**

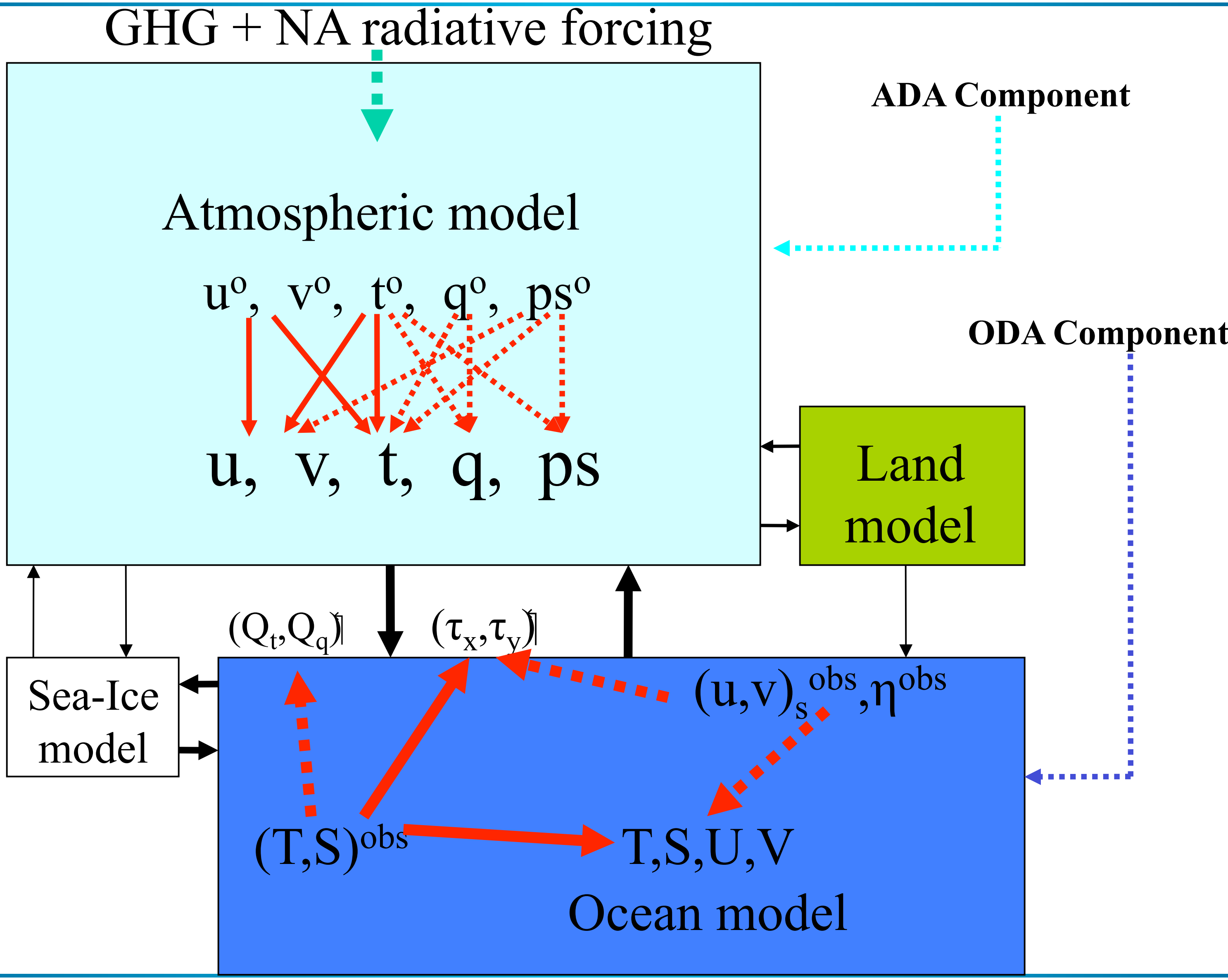
✓ **Intra-decadal to multidecadal AMOC predictability – Ocean Initial Value to Coupled Initial Value Problem:** impact of an atmospheric/oceanic observing system in the AMOC's Predictability?

✓ **Decadal to multidecadal AMOC predictability – a Joint Coupled Initial/ Boundary Value Problem: Impact of GHGNA obs and estimation on the AMOC's predictability**

Why ECDA for climate studies?

- ✓ A Ensemble Coupled Data Assimilation system estimates a temporally-evolving ***joint-distribution*** (***Joint-PDF***) of climate states under observational data constraint, with:
  - Multi-variate analysis scheme maintaining physical balances among state variables mostly
    - – T-S relationship in ODA
    - – Geostrophic balance in ADA
  - Ensemble filter maintaining properties of high order moments of error statistics (nonlinear evolution of errors) mostly
- ✓ Optimal ensemble initialization given data and model dynamics:
  - All coupled components are adjusted by data through exchanged fluxes
  - Minimized initial shocks for numerical climate forecasts

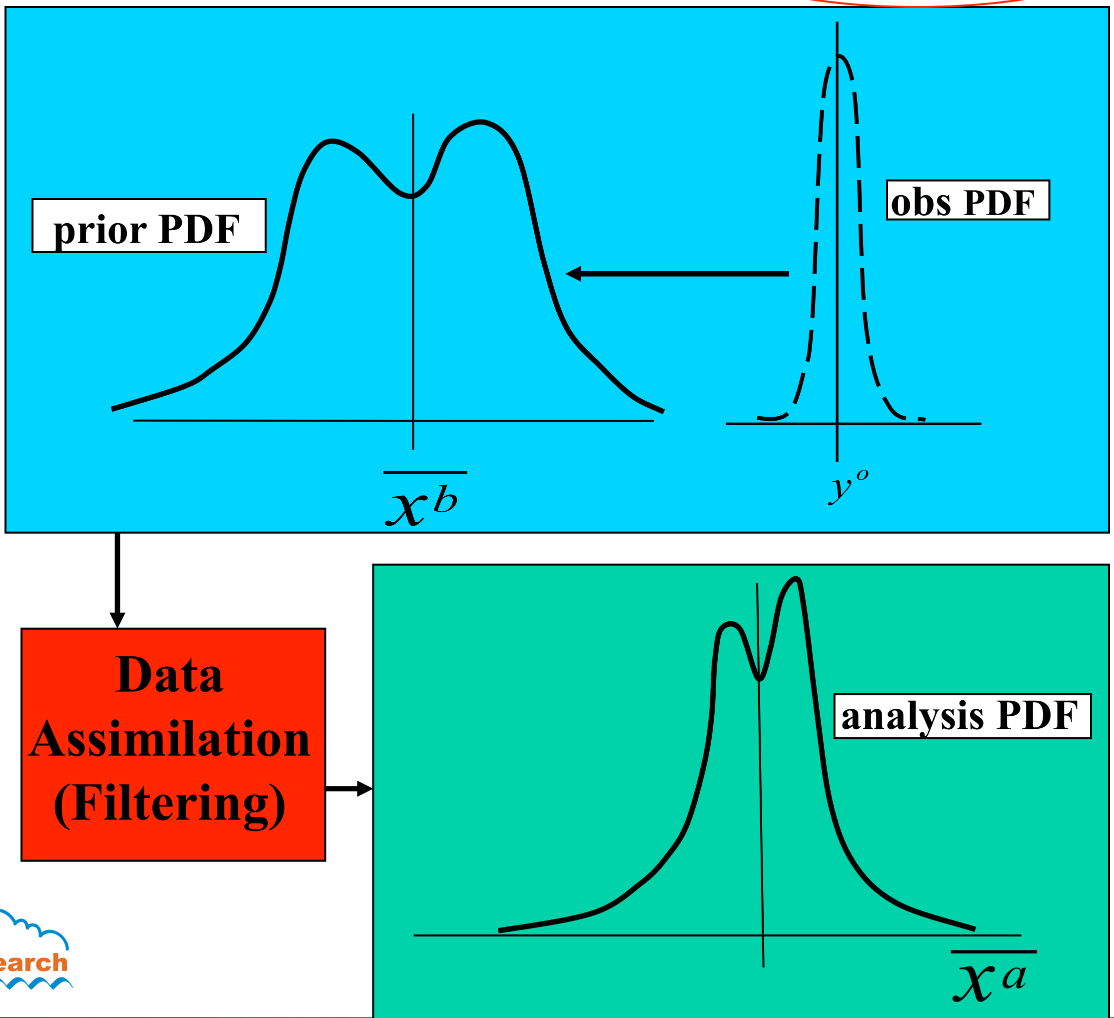
Multi-variate coupled analysis Scheme



CDA System: Ensemble Kalman Filtering Algorithm

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

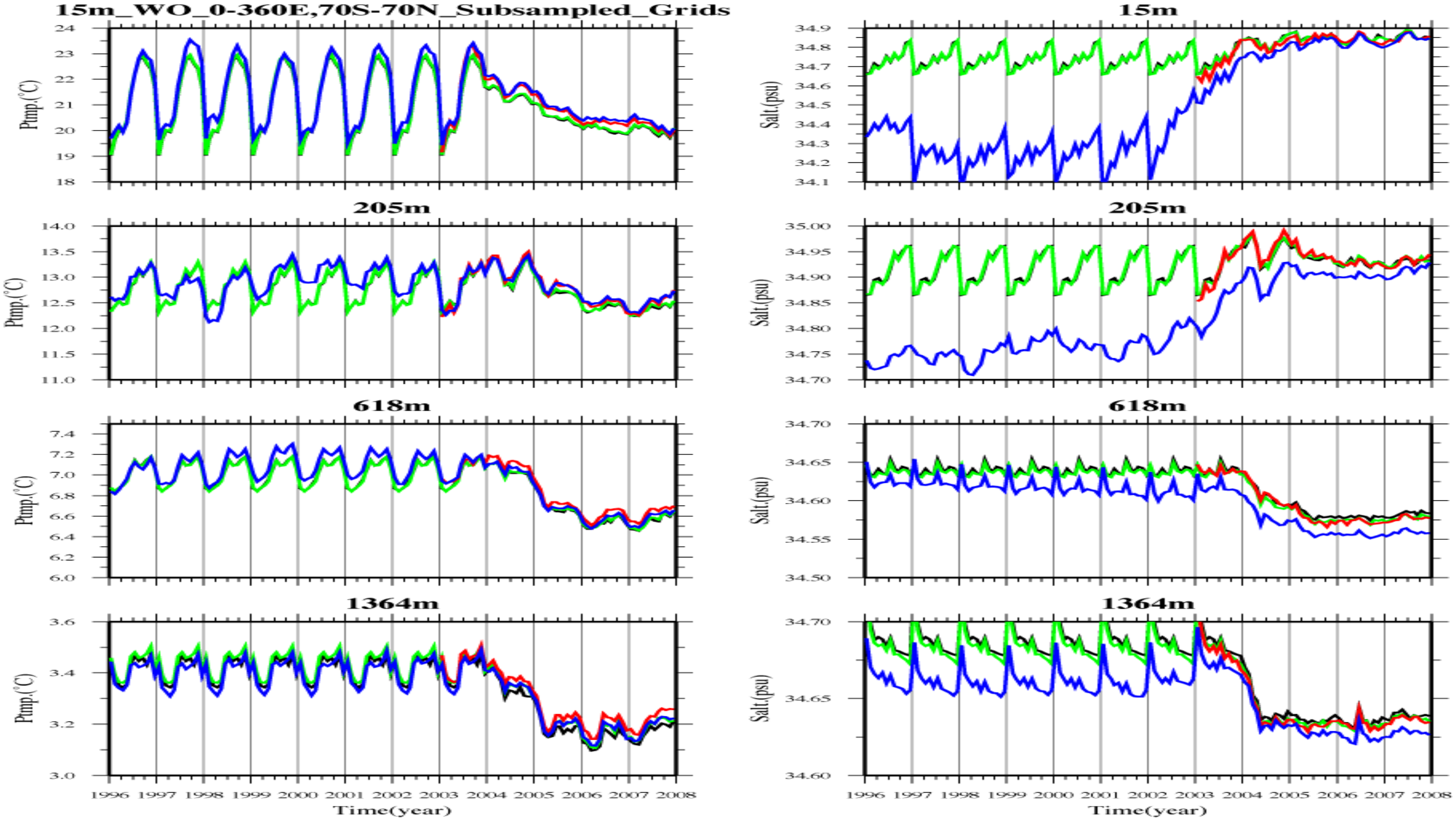
- ✓ Atmospheric internal variability
- ✓ Ocean internal variability (model does not resolve)



WOA1(black), WOA5(green), ECDA(blue), ARGO(red)

Subsampled grids indicate the matching points with monthly Argo distribution every year

Subsampled grids from ‘97-’03 used the Argo distribution of 2003



WOA01(black), WOA05(green), GFDL_CDA(blue), and Argo(Red).
All time series have been averaged around the subsampled grids of box area.
* Subsampled grids indicate the matching points with the monthly Argo distribution for every year.
* Subsampled grids from 1997 to 2003 year used the Argo distribution of 2003 year.

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5 obs systems to simulate the evolution of climate obs from pre-industrial to present

Obs system	Atmosphere		Ocean		Historical period	Data Constraint
	Data	Format	Data	Format		
O_{SSTt}^{Atm}	U, v, T	Gridded reanalysis	Tropical SST (SSTt)	Gridded	ML 19C 20-21C	Surface forcings only
O_{XBT}	-	-	SSTt, **XBT** (CDT,MBT, OSD,MRB)	Gridded In situ	ML 20C	20C ocean-only
O_{XBT}^{Atm}	U, v, T	Gridded reanalysis	SSTt, **XBT**	Gridded In situ	ML 20C	20C atmosphere and ocean obs
O_{Argo}	-	-	SSTt, Argo	Gridded In situ	21C	21C ocean-only
O_{Argo}^{Atm}	U, v, T	Gridded reanalysis	SSTt, Argo	Gridded In situ	21C	21C atmosphere and ocean obs

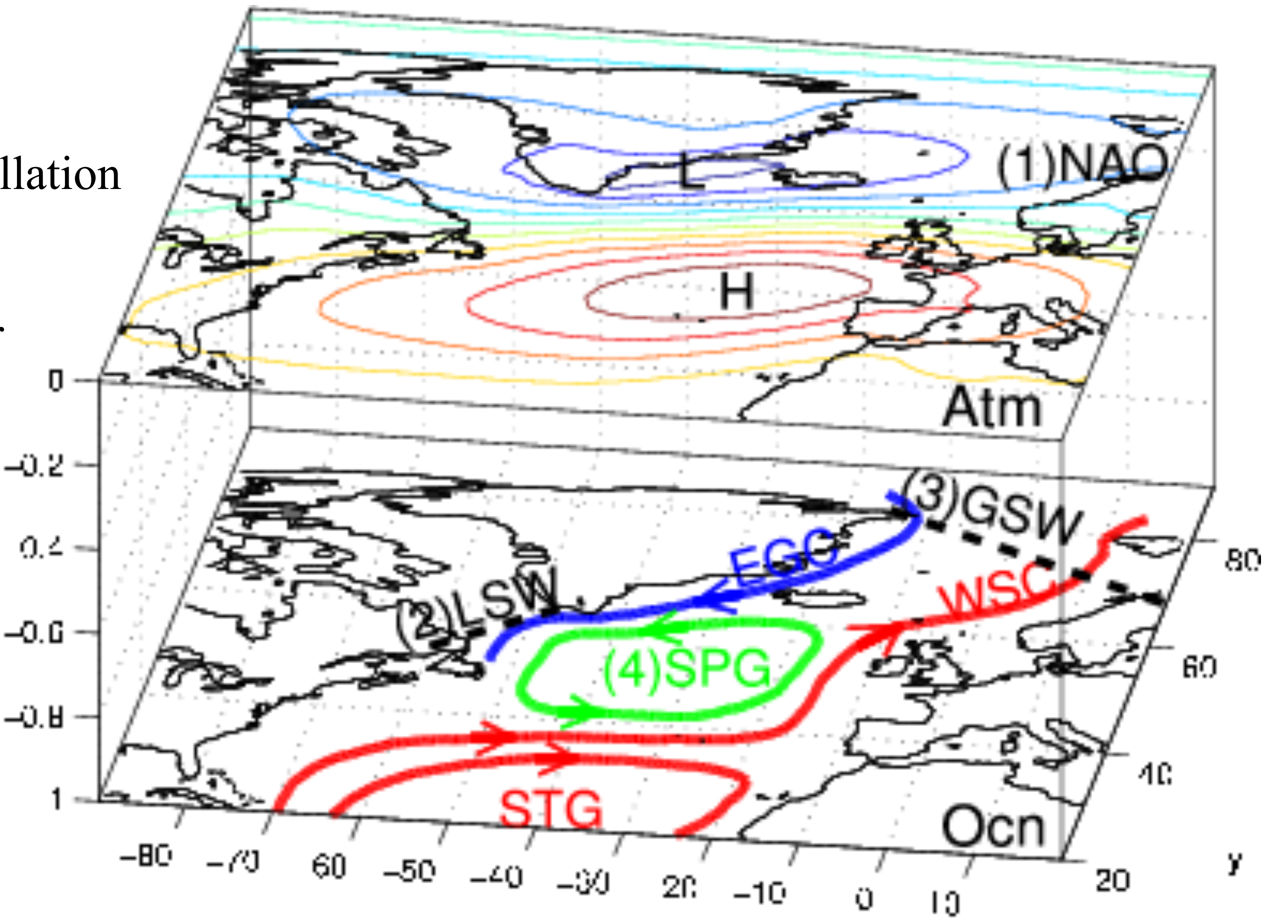
The atmospheric and oceanic circulations coupled in the NA region, influencing AMOC

1) **NAO**: North Atlantic Oscillation

2) **LSW**: Labrador Sea Water
(deep convection)

3) **GSW**: GIN Sea Water
(deep convection)

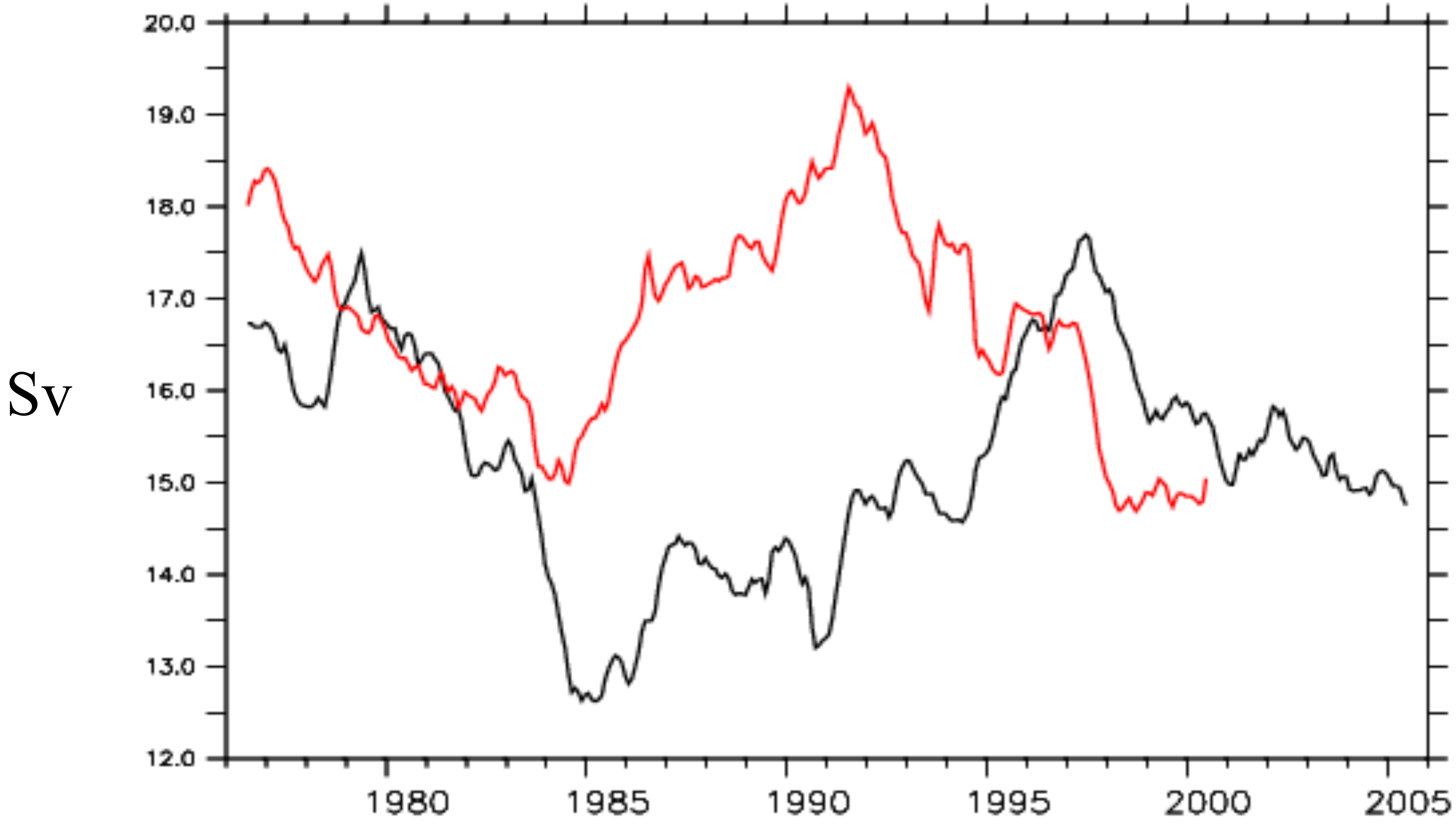
4) **GRS**: Gyre System



2 sets of IPCC AR4 Historical Model Projections: CM2.0

h_1: Standard IPCC AR4 historical projection

h_3:Another historical projection starting from independent ICs



Model Calendar year

Assim skill (1):
Time series of NAO, LSW, GSW & GRS

Truth (h_1)

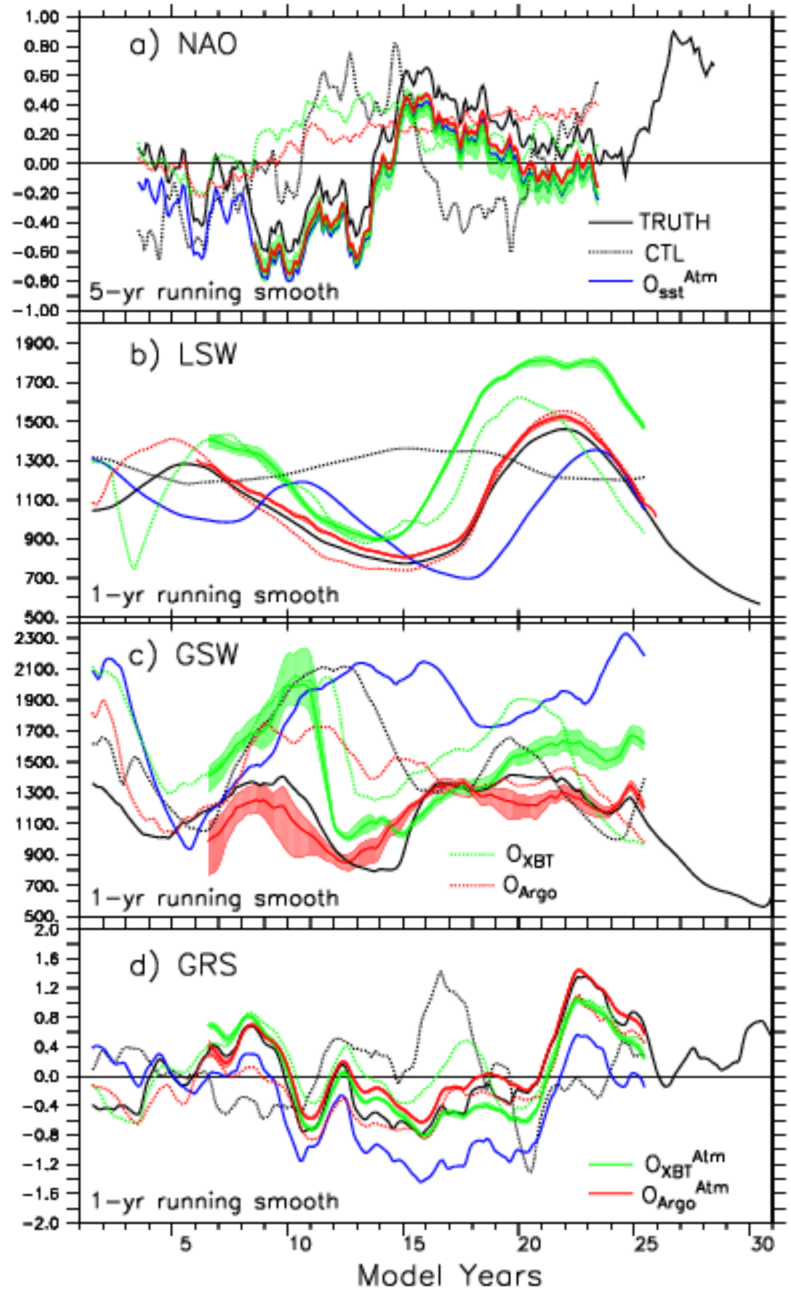
Assim using O_{SSTt}^{Atm}

Assim using O_{XBT}

Assim using O_{Argo}

Assim using O_{XBT}^{Atm}

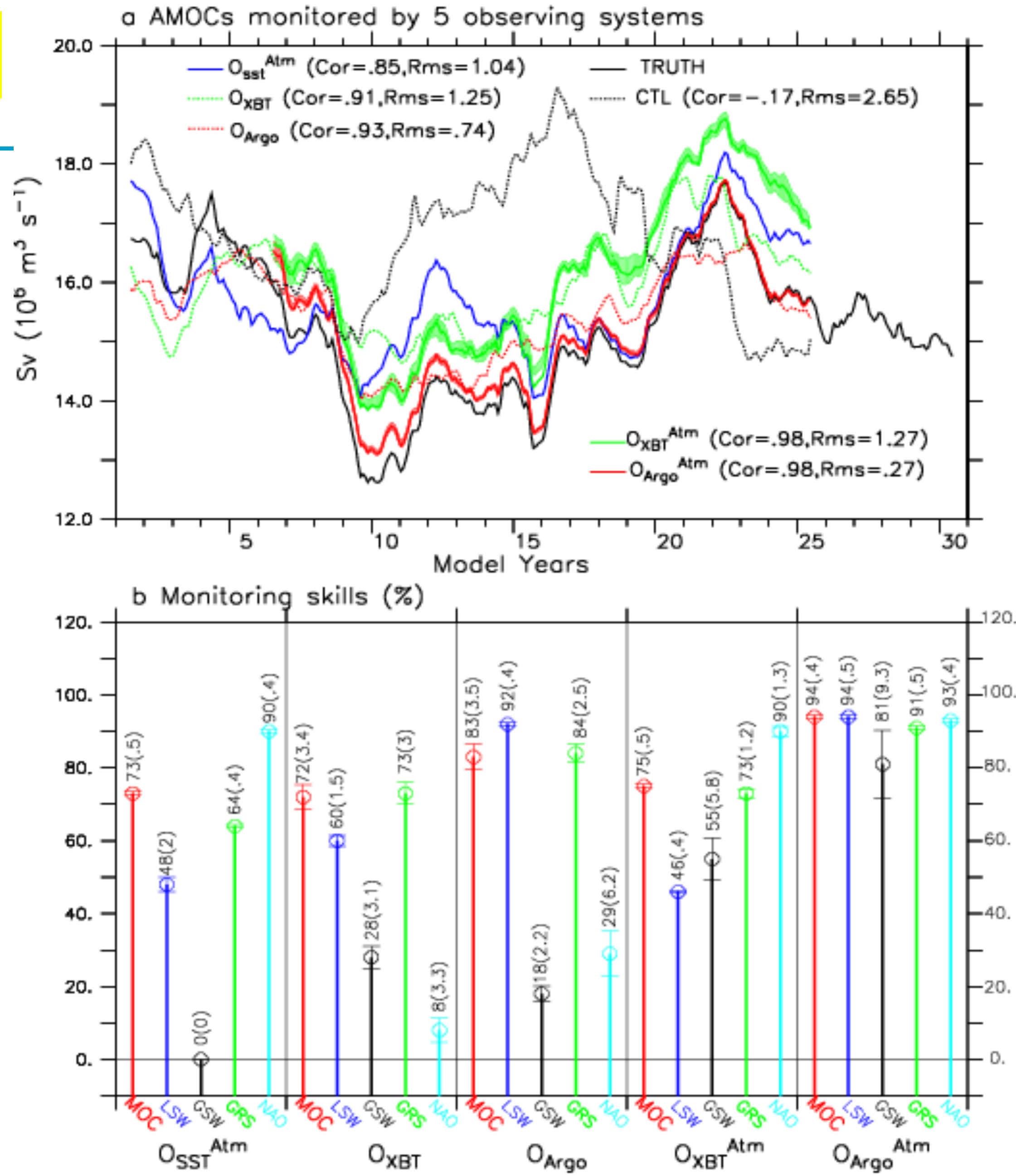
Fcst based on O_{Argo}^{Atm}



Assim skill (2):

a) Time series of the reconstructed AMOC

b) The accuracy of the reconstructed AMOC, NAO, LSW, GSW,GRS



Assim skill (3): Summary

- ✓ Surface forcings only (O_{SSTt}^{Atm}) resolve NAO signals 90%, LSW 48%, GRS 64%, no skill for GSW, AMOC 73%.

- ✓ Sub-surface Argo (XBT) observations only, O_{Argo} (O_{XBT}), resolve LSW signals 92% (84%), GRS 84% (73%), AMOC 83% (72%), almost no skill for GSW and NAO.

- ✓ The 21st-(20th-)century climate (including the atmosphere and ocean) observing system, O_{Argo}^{Atm} (O_{XBT}^{Atm}), resolves NAO signals 93% (90%), LSW 94% (46%), GSW 81% (55%), GRS 91% (73%) and AMOC 94% (75%).

- ✓ The LSW variation produced by O_{SSTt}^{Atm} has a 5~10-yr lag time scale compared to low frequency (5-yr running smooth) NAO signals.

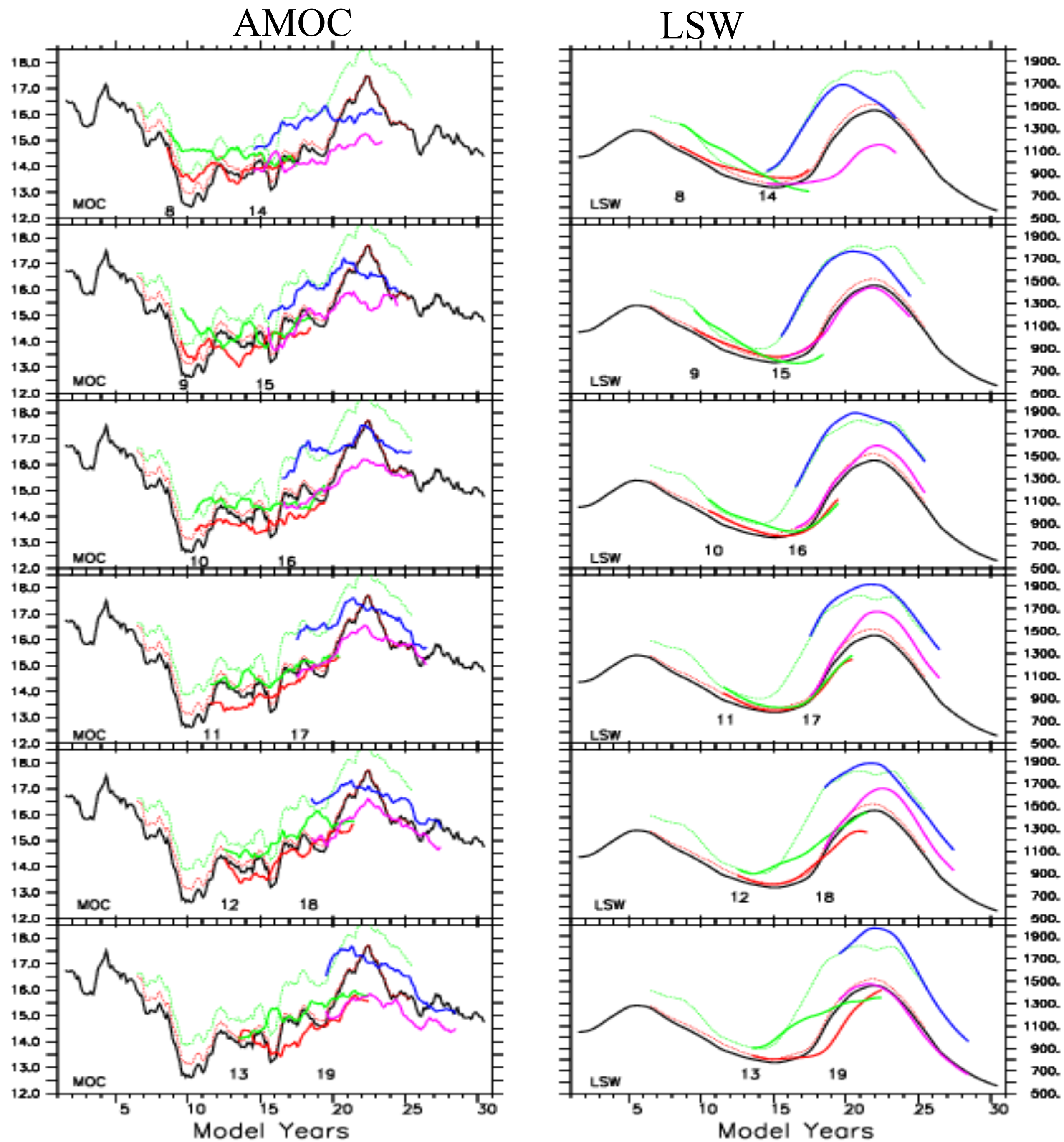
The Potential Predictability of AMOC Depending on Observing Systems

OUTLINE

- ✓ ..
- ✓ ..

- ✓ Based on the assessment upon observing systems, what is the sources of the predictability of AMOC**? – Relative contributions of the Labrador Sea Water (LSW), the GIN Sea Water (GSW) and the Atlantic Gyre System (GRS)**

Relative contributions of LSW, GSW, GRS to the AMOC's predictability



h_1 (truth)

Assim using O_{XBT}^{Atm}

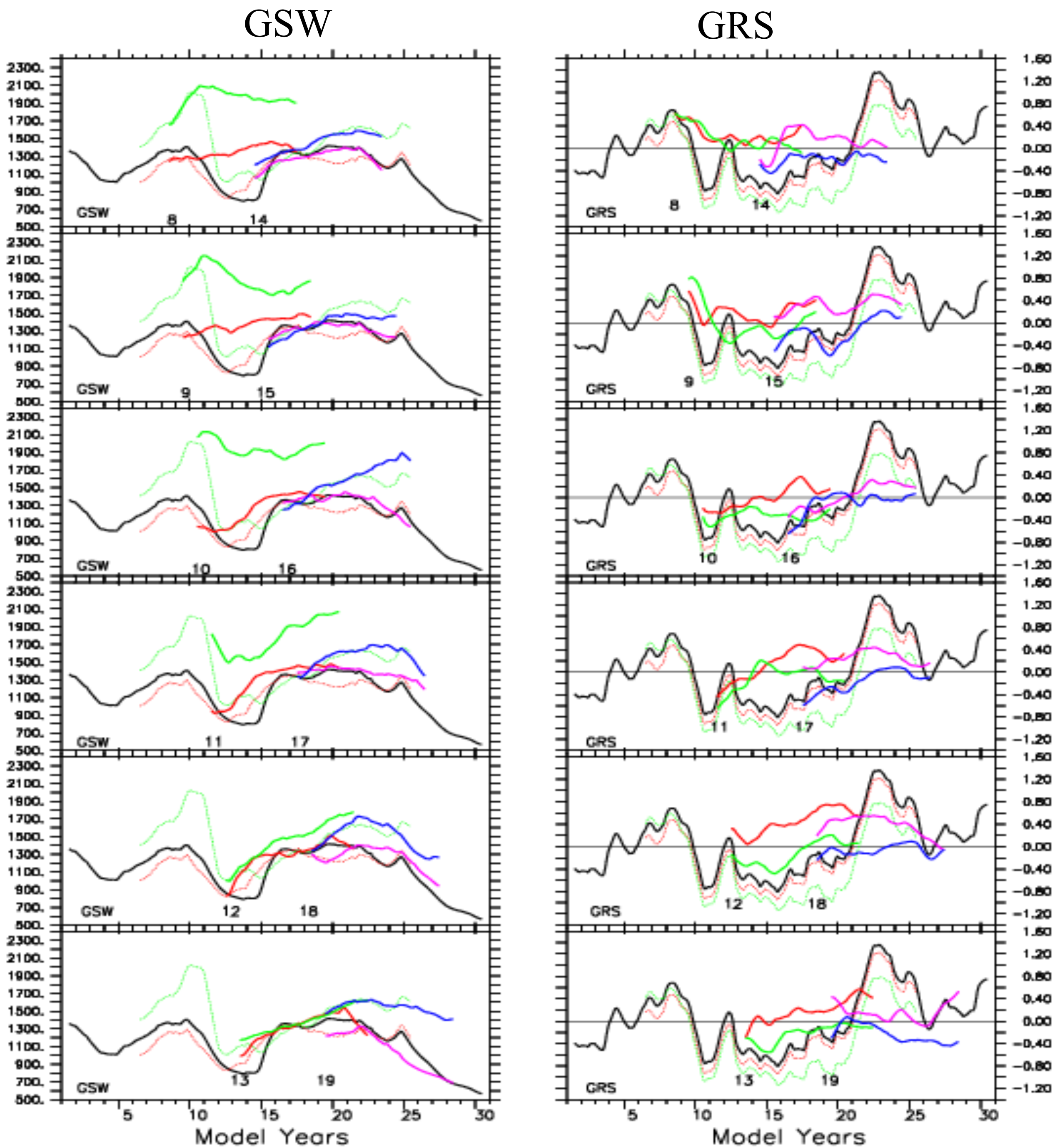
Assim using O_{Argo}^{Atm}

Fcst based on O_{XBT}^{Atm}

Fcst based on O_{Argo}^{Atm}

Fcsts- 10 member ensembles for 12 years

Relative contributions of LSW, GSW, GRS to the AMOC's predictability



h_1 (truth)

Assim using O_{XBT}^{Atm}

Assim using O_{Argo}^{Atm}

Fcst based on O_{XBT}^{Atm}

Fcst based on O_{Argo}^{Atm}

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Summary

- ✓ The LSW convection governs the low frequency AMOC variability throughout the 12 lead years for this model.
- ✓ The ARGO network has increased AMOC predictability over the XBT network. This raises questions about using the historic data to validate predictions.
- ✓ Based on these studies the AMOC predictability using the ARGO network is encouraging to expect that there may be skill in AMOC decadal predictions
- ✓ Perfect model scenario gives a most optimistic case. In the real data case salinity plays an important role in density.
- ✓ Impact of model bias is a serious challenge

Coordinated Decadal Prediction for AR5

Additional model runs:

1.3) **10 year integrations** each year in Argo era from near end of 2001, 2002, 2003, 2004, 2006, 2007 (2008, ..)

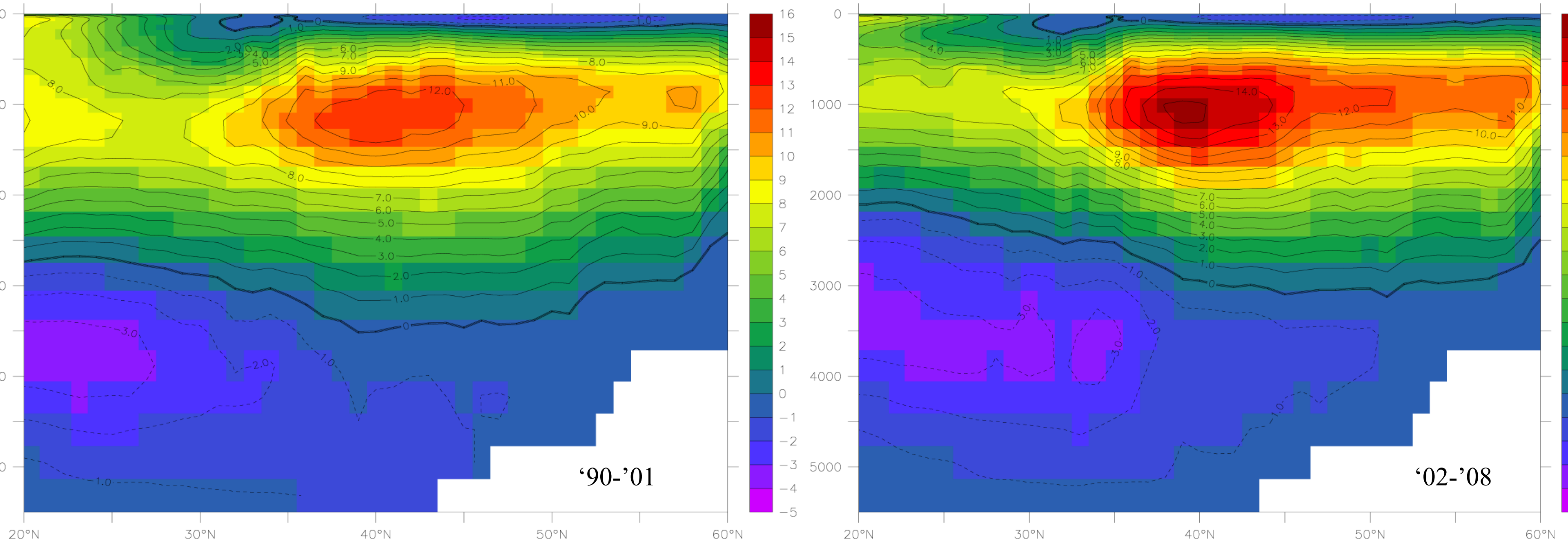
1.4) For models w/ 20th century runs, run additional ensemble members that extend to 2035. These runs form a "control" against which the value of initializing short-term climate and decadal forecasts can be measured.

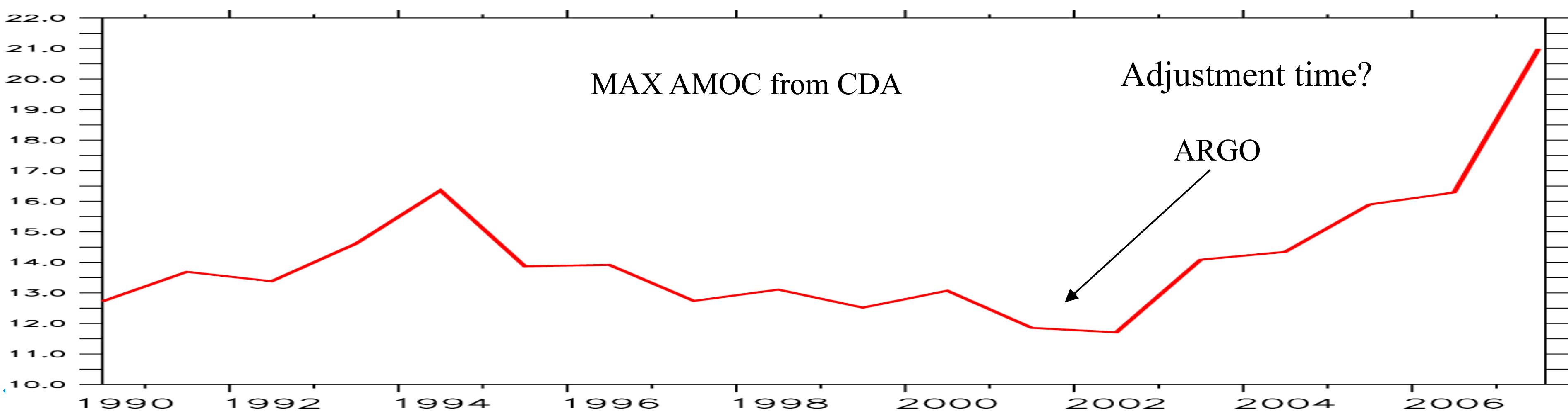
1.5) For models which do not have 20th century and other standard runs, suggest making a 100 year control integration, and a 70 year run with a 1% per year increase in CO_2. These integrations will allow an evaluation of model drift, climate sensitivity and ocean heat uptake, and give some idea of the natural modes of variability of the model.

2) Further studies which would be of interest

- Comparison of initialization strategies
- Repeat of the 1.1 2005 forecast with a high and/or low anthropogenic aerosol scenario
- Repeat of the 1.1 2005 forecast with an imposed "Pinatubo" eruption in 2010
- Impact of Interactive Ozone chemistry
- Air quality

Is the increase in overturning real or is it due to the onset of ARGO data in the assimilation ?





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**