The Future of Predictability: Can Decadal Prediction Be Informative?

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ECMWF Seminar 2010

NESL / NCAR

Disclaimer

- Most of what we know about decadal climate variability has been learned in the past 20-30 years
- Climate system records are not long
- Some of what we think is known is from coupled model simulations
- We should not worry about being completely wrong

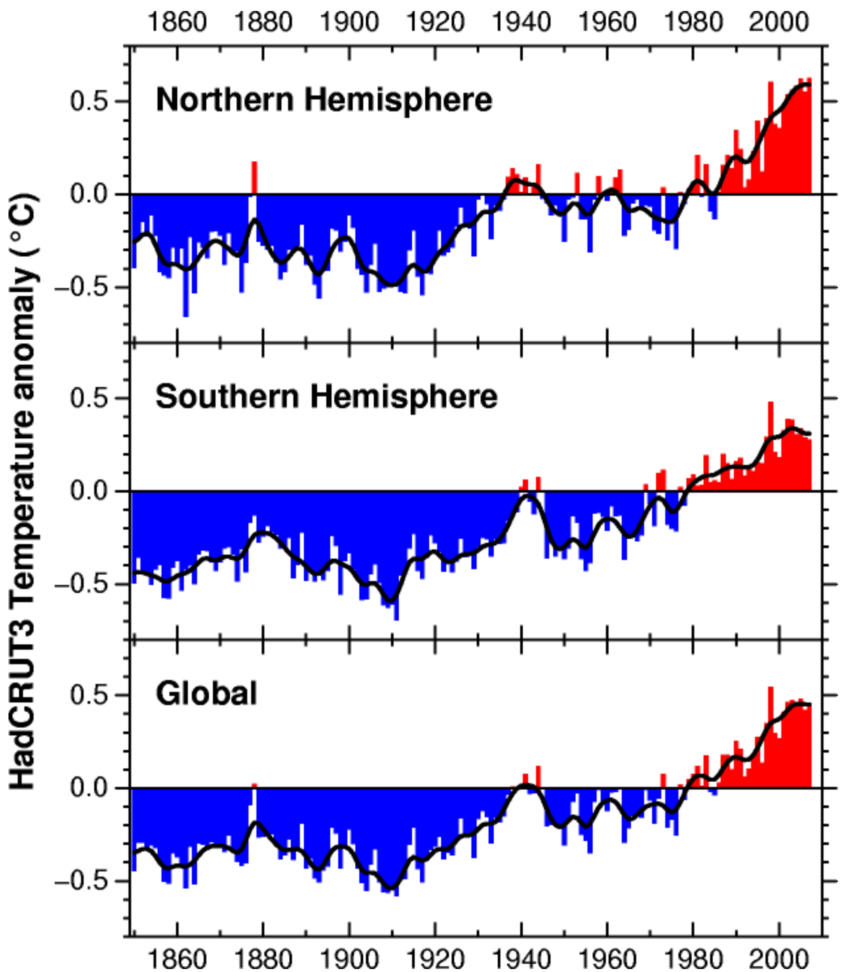
OUTLINE

- *Credit-> G. Branstator, J. Hurrell, G. Danabasoglu, Haiyan Tang and S. Yeager*
- IPCC and scientific rationale
- What is being asked at decadal timescales

  Decadal signals in climate-why bother?
- Evidence of predictability and a scientific basis for decadal prediction
- Newer predictability estimates and the challenges ahead for decadal prediction

A climate ‘prediction’ we can do: The Earth is Warming

Climate Research Unit
East Anglia University, UK



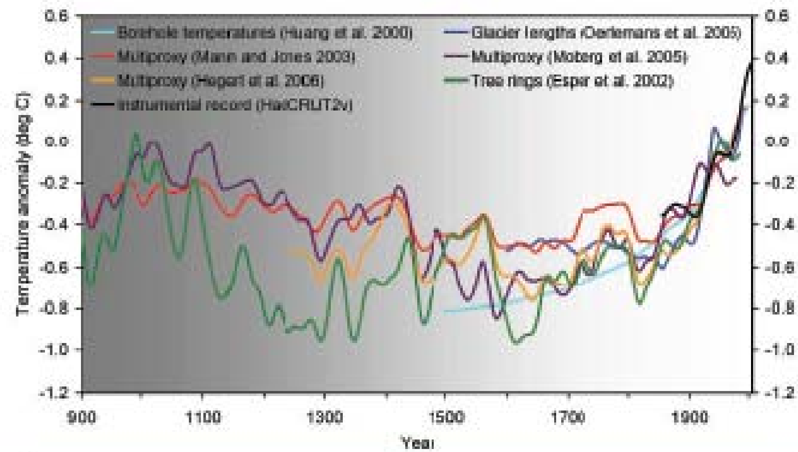
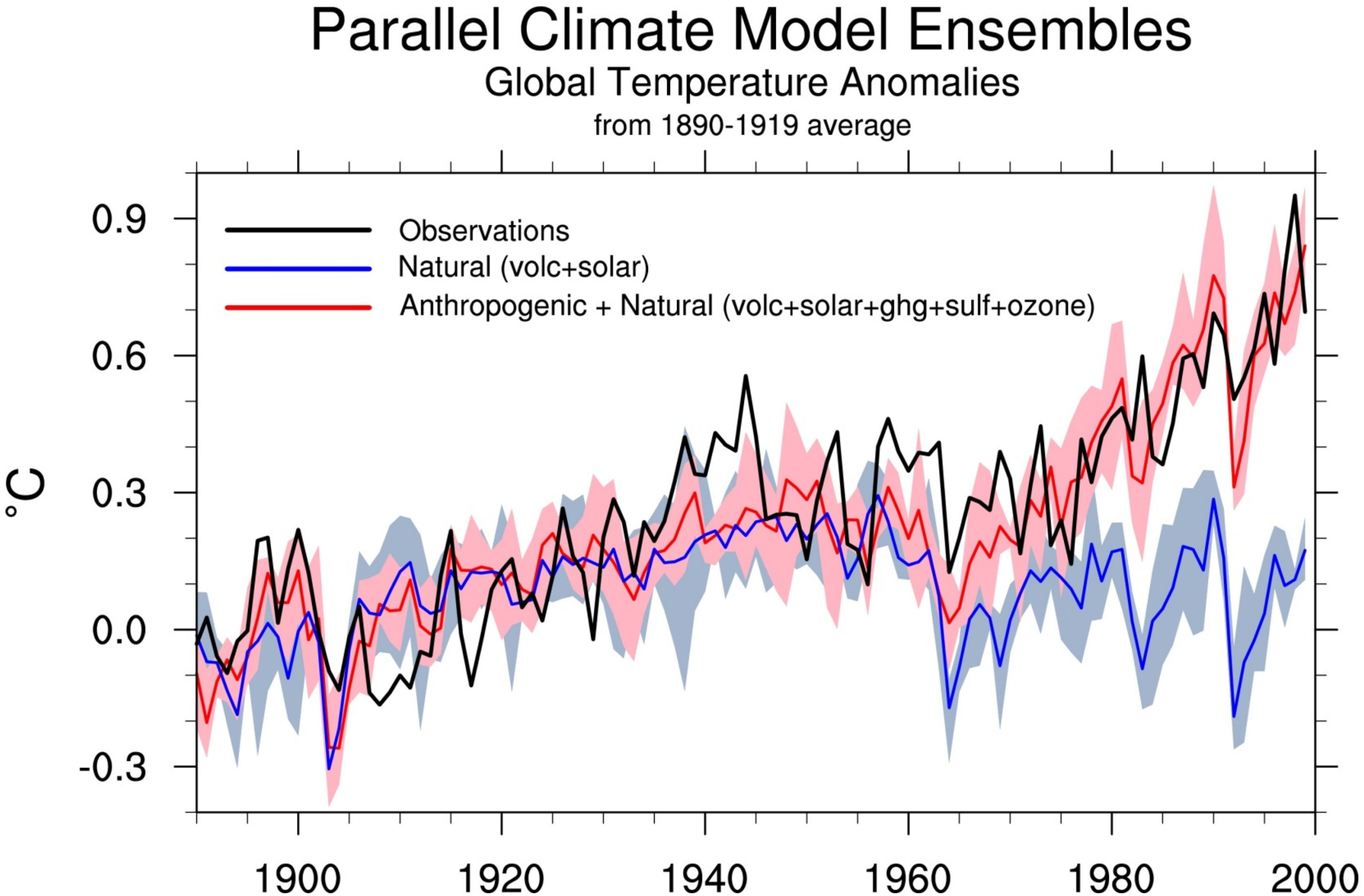


Figure S-1. Smoothed reconstructions of large-scale (Northern Hemisphere mean or global mean) surface temperature variations from six different research teams are shown along with the instrumental record of global mean surface temperature. Each curve portrays a somewhat different history of temperature variations, and is subject to a somewhat different set of uncertainties that generally increase going backward in time (as indicated by the gray shading). This set of reconstructions conveys a qualitatively consistent picture of temperature changes over the last 1,100 years, and especially the last 400.

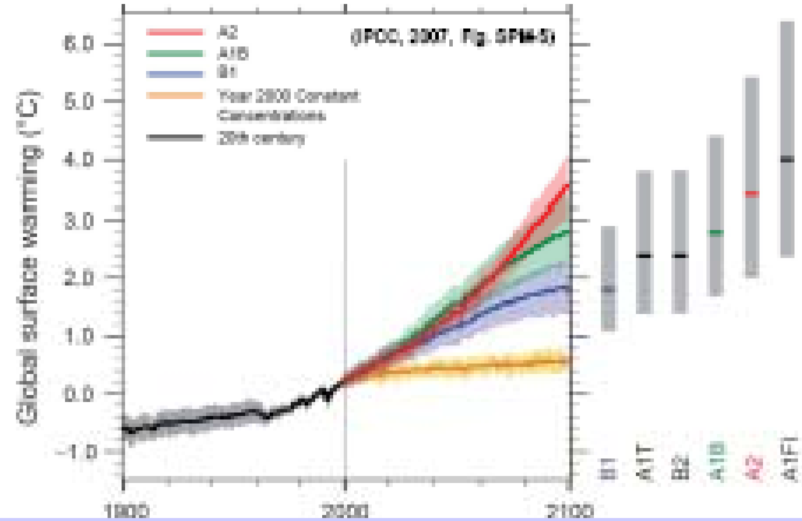
National
Research
Council
Report

Calibrate with 20th century and test attribution hypotheses



Large signal to noise ratio for Global Mean Temperature

Project greenhouse gases and surface temperature into 21st century

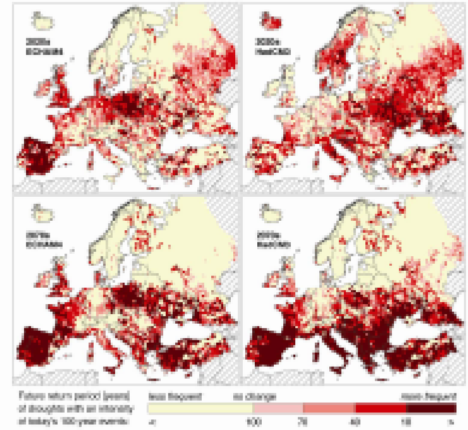


Multi-Model Ensemble

Continued greenhouse gas emissions at or above current rates would cause further warming and induce many changes in the global climate system during the 21st century that would *very likely* be larger than those observed during the 20th century. Warming tends to reduce land and ocean uptake of carbon dioxide, increasing the fraction of anthropogenic emissions that remain in the atmosphere. This leads to greater climate change for a given emissions scenario.

Models: Unless we control emissions things will get worse

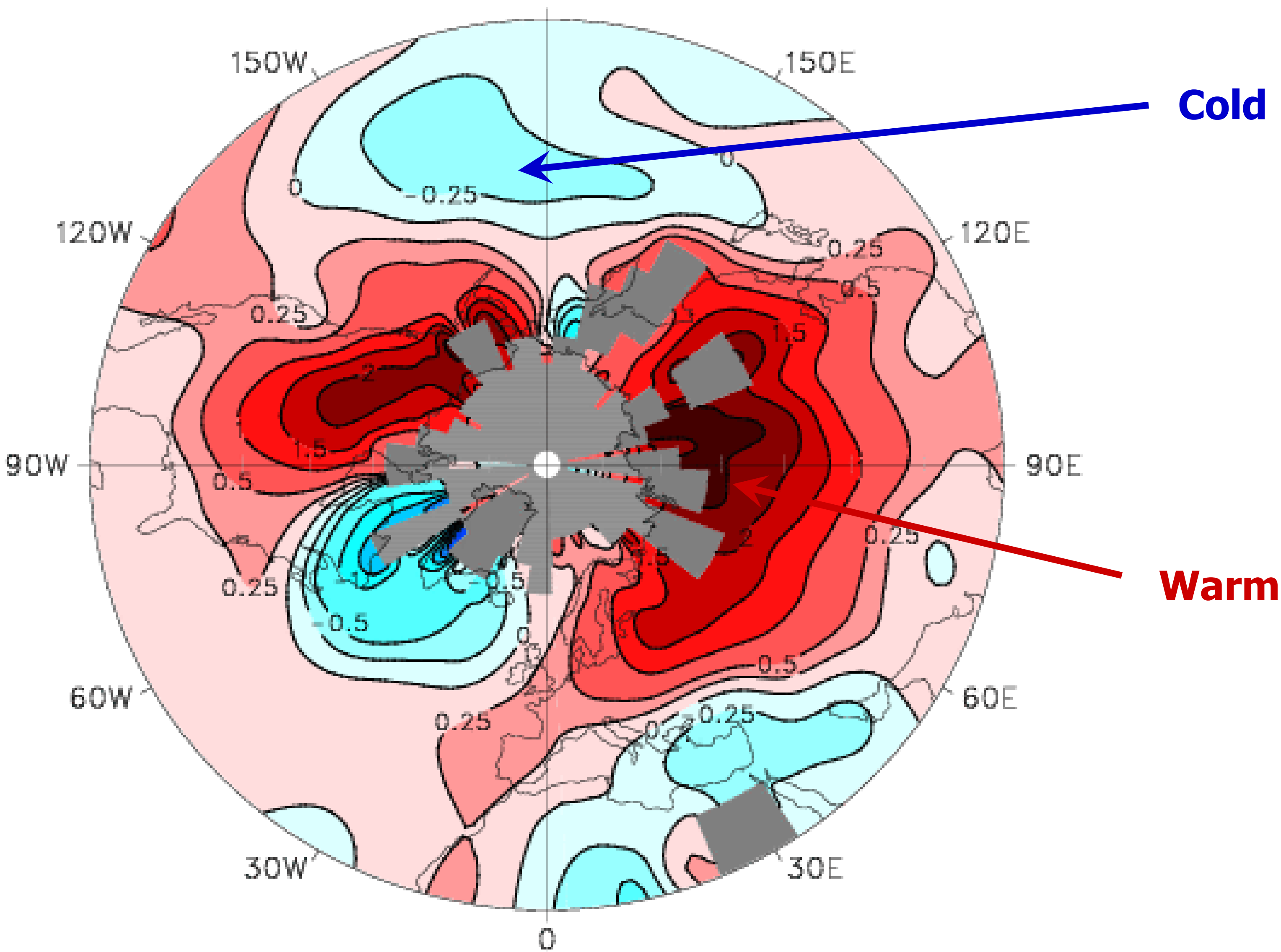
Possible Consequences-AR4



Change in 100-year drought occurrence: 2020s and 2070s compared to 1961-90 (ECHAM4 and HadCM3 GCMs; IS92a emissions; business-as-usual water use). (Lehner et al., 2005).

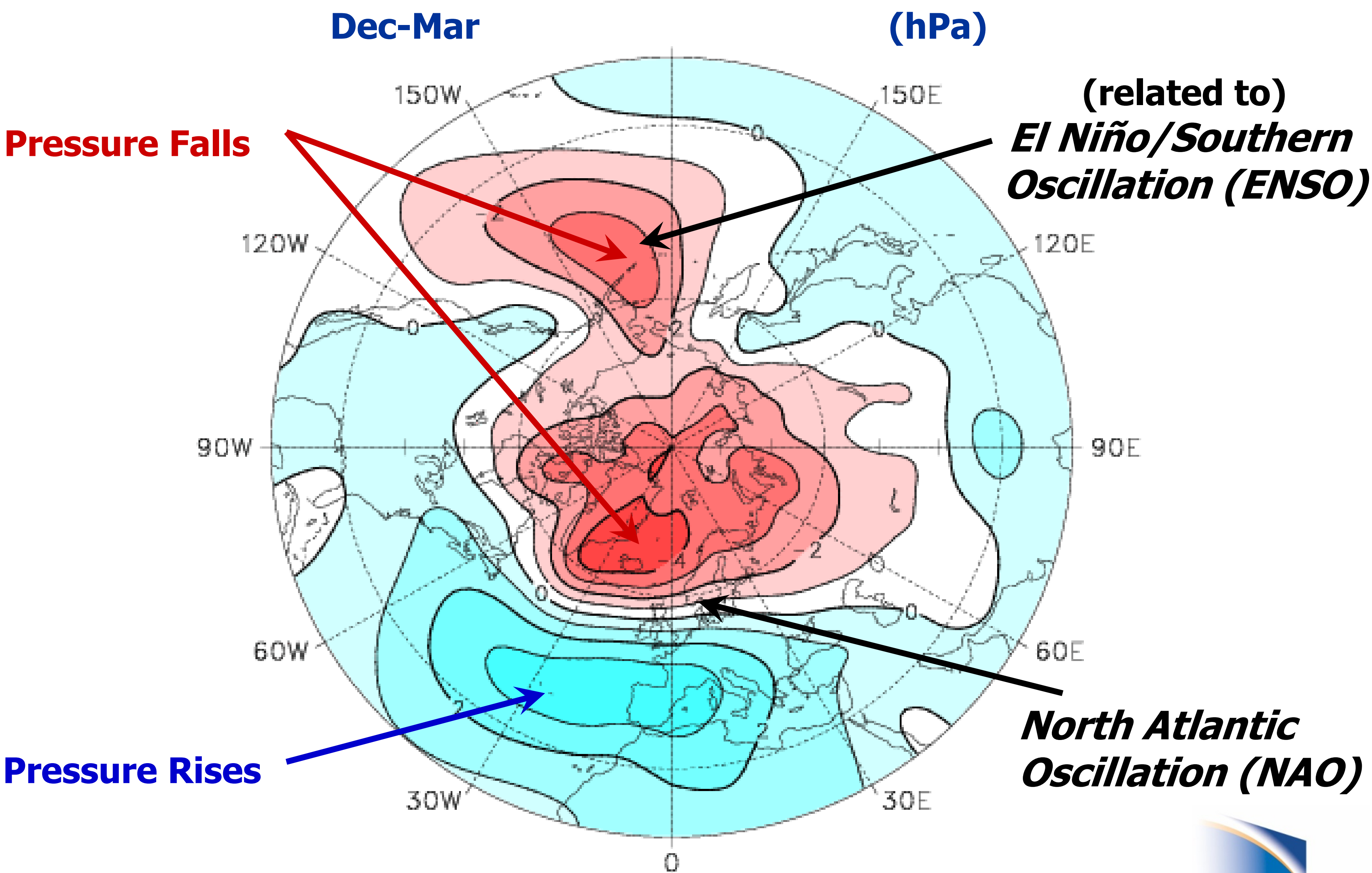
- Arctic ice disappears
- Sea level rise 7”-23”
- Permafrost disappears
- Coral reefs die
- More extreme events- category 5 hurricanes, heat waves, droughts
- All of above uncertain and for the most part regional

Regional Temperature Change (DJFM)



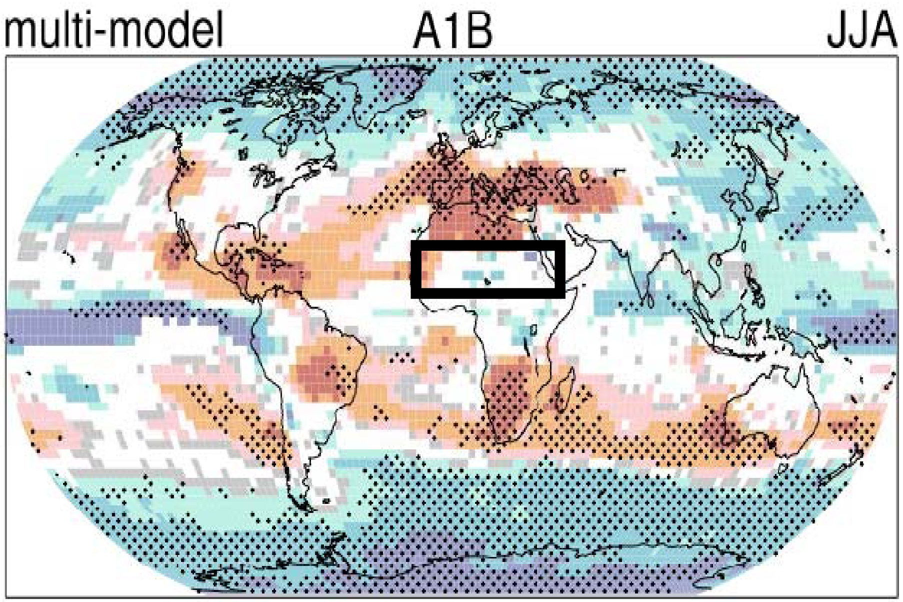
Effects from human activities are superimposed on the background "noise" of natural variability

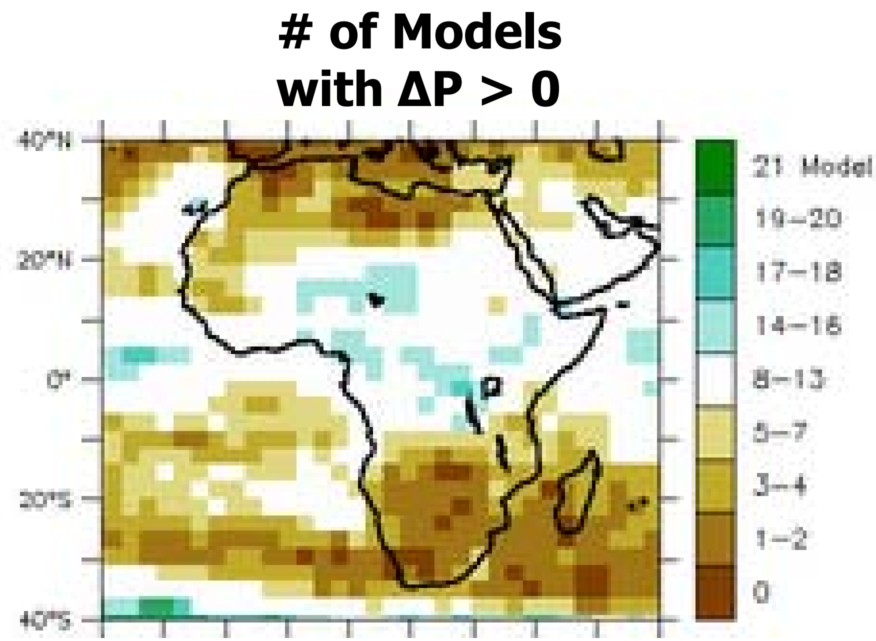
Winter Sea Level Pressure Change



NCAR

Regional Climate Change





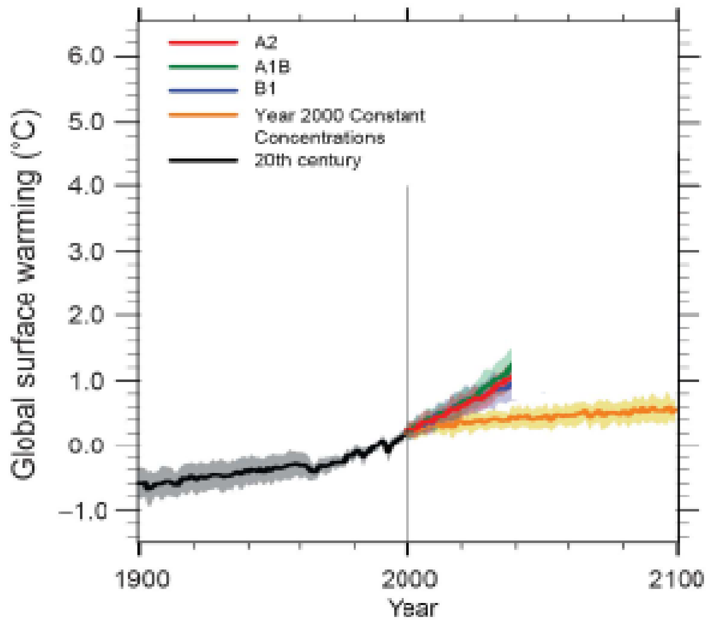
To date: only "what if" scenario –based projections

Future: shorter term climate 'predictions' – the only tractable way to address regional climate change?

Can we reduce uncertainty/increase reliability by decadal projection?

GHG forcing more certain

Short-term climate projections



For the next two decades a warming of about 0.2°C per decade is projected for a range of SRES emission scenarios. Even if the concentrations of all greenhouse gases and aerosols had been kept constant at year 2000 levels, a further warming of about 0.1°C per decade would be expected.

But, signal confounded by Natural Variability: El Nino, Decadal Climate Shifts, etc.

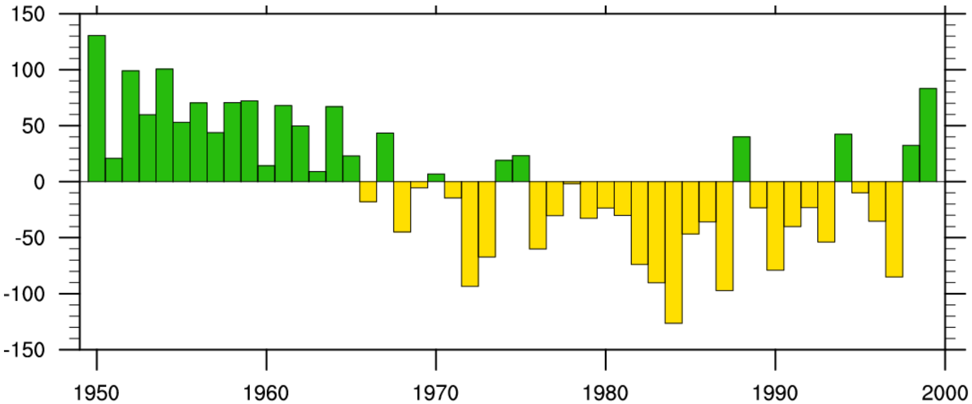
Scientific motivation for Decadal Prediction

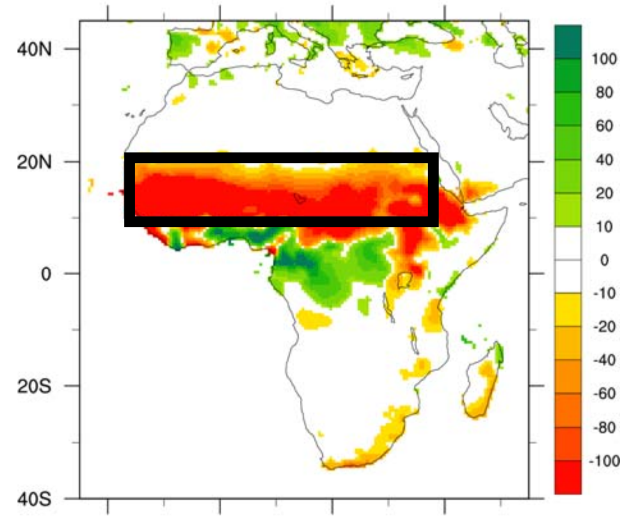
Examples of climate modes of variability on decadal timescales

Rainfall Anomalies (mm)

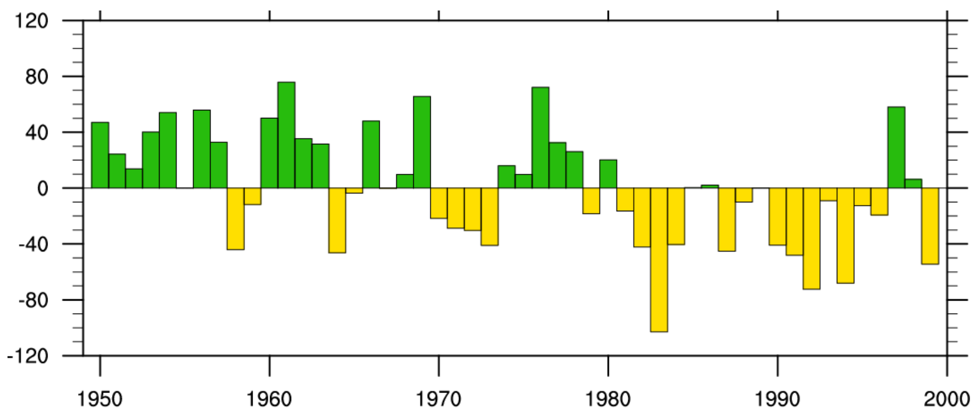
50-year Trend (mm)

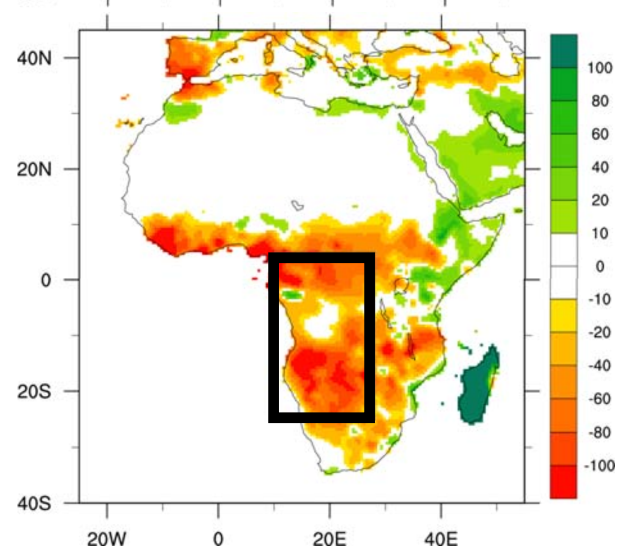
Sahel: JAS



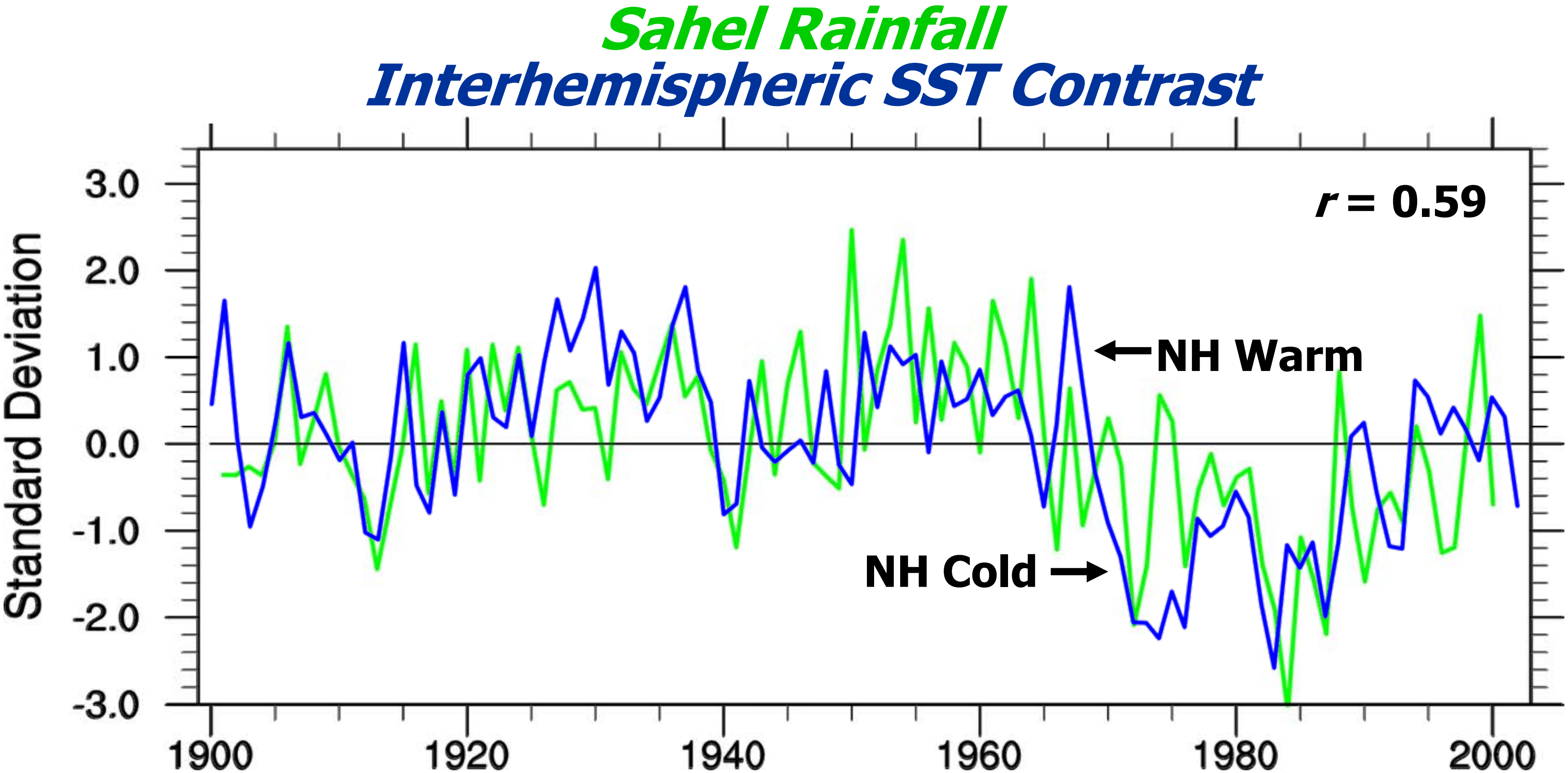


Southern Africa: FMA

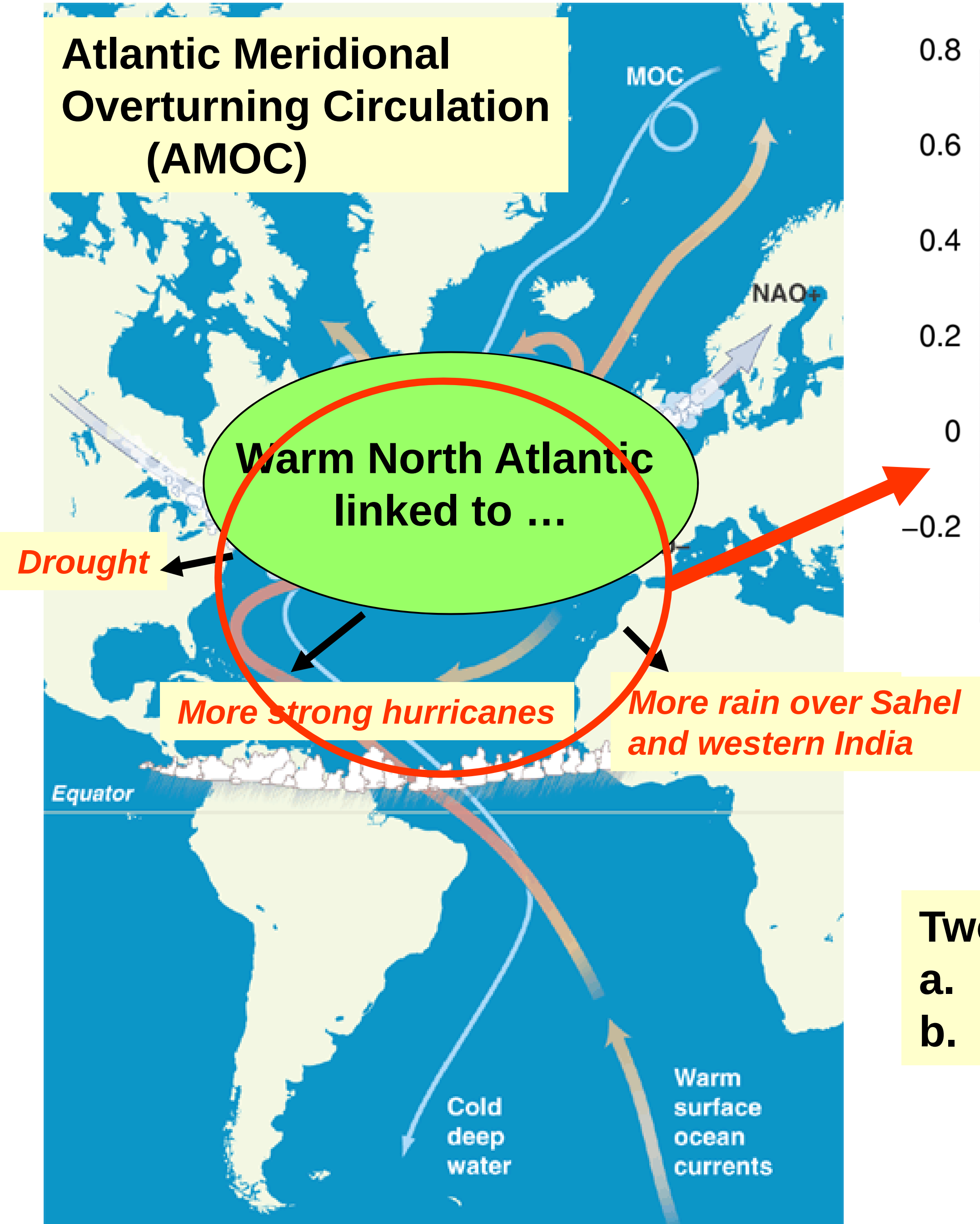


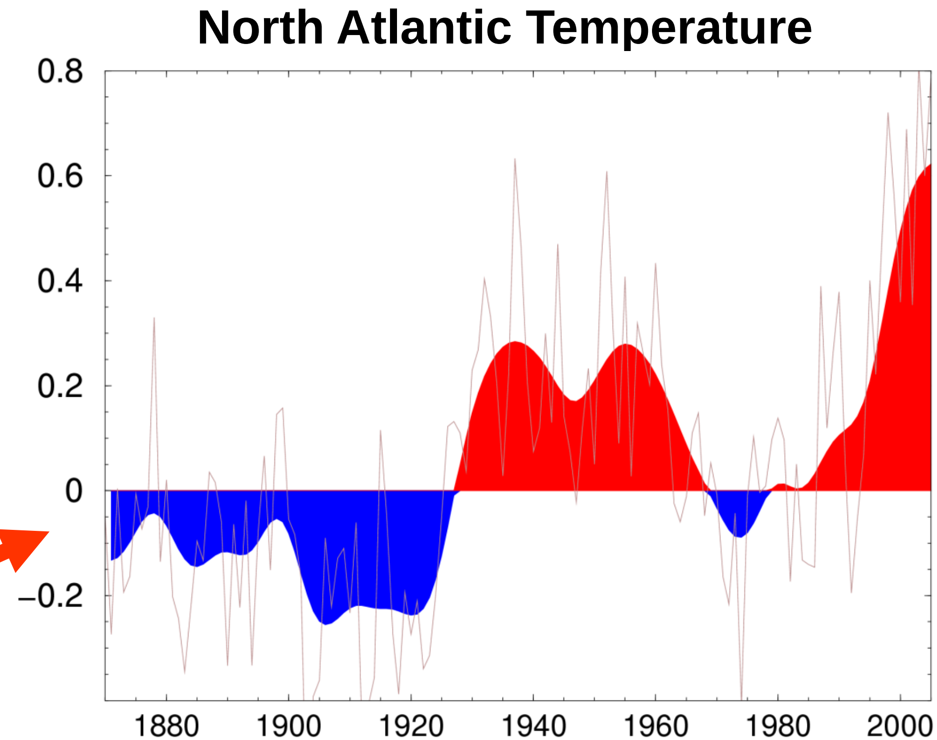


Relationship to Atlantic SST



Hurrell and Folland (2002)





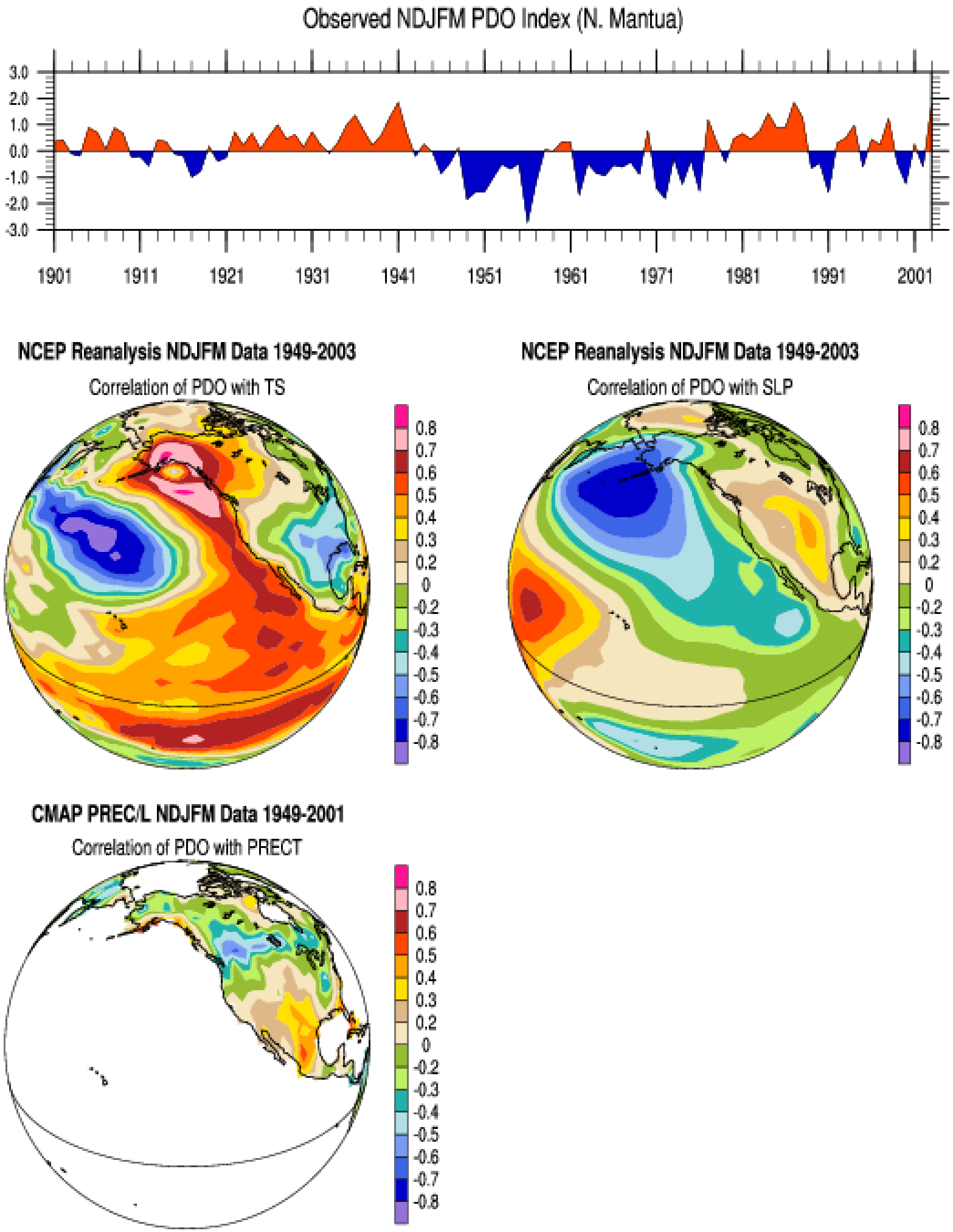
Two important components:

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

PACIFIC DECADAL VARIABILITY (PDV)

Formerly known as

Pacific Decadal Oscillation (PDO)

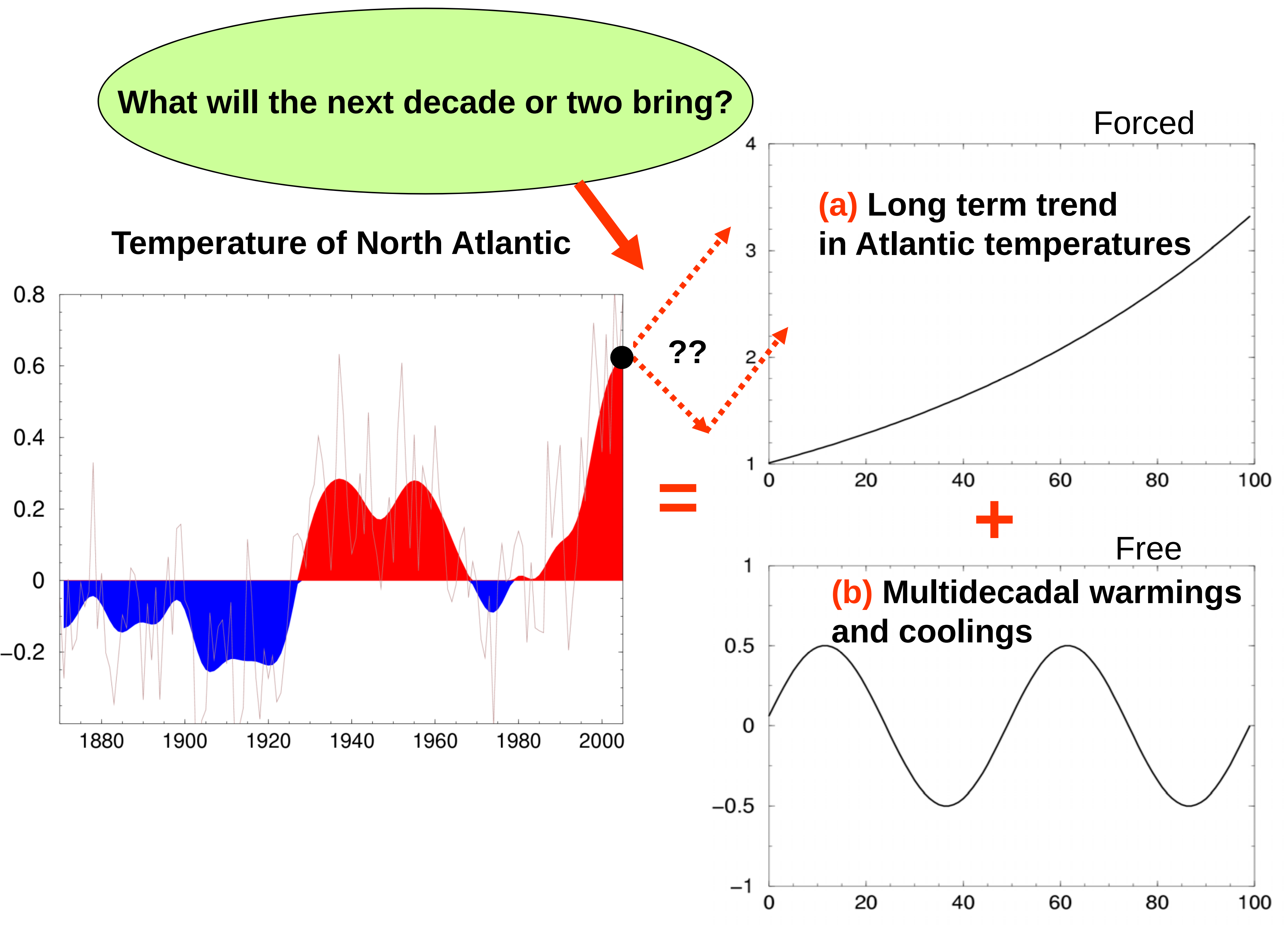


Can we build the Scientific Basis for Decadal Prediction?

1) Existence of decadal predictability needs to be proven

2) Null hypothesis: decadal fluctuations in SST associated with the MOC or PDO arise from low-pass filtering of unpredictable atmospheric noise by the slow components of the climate system such as the oceans

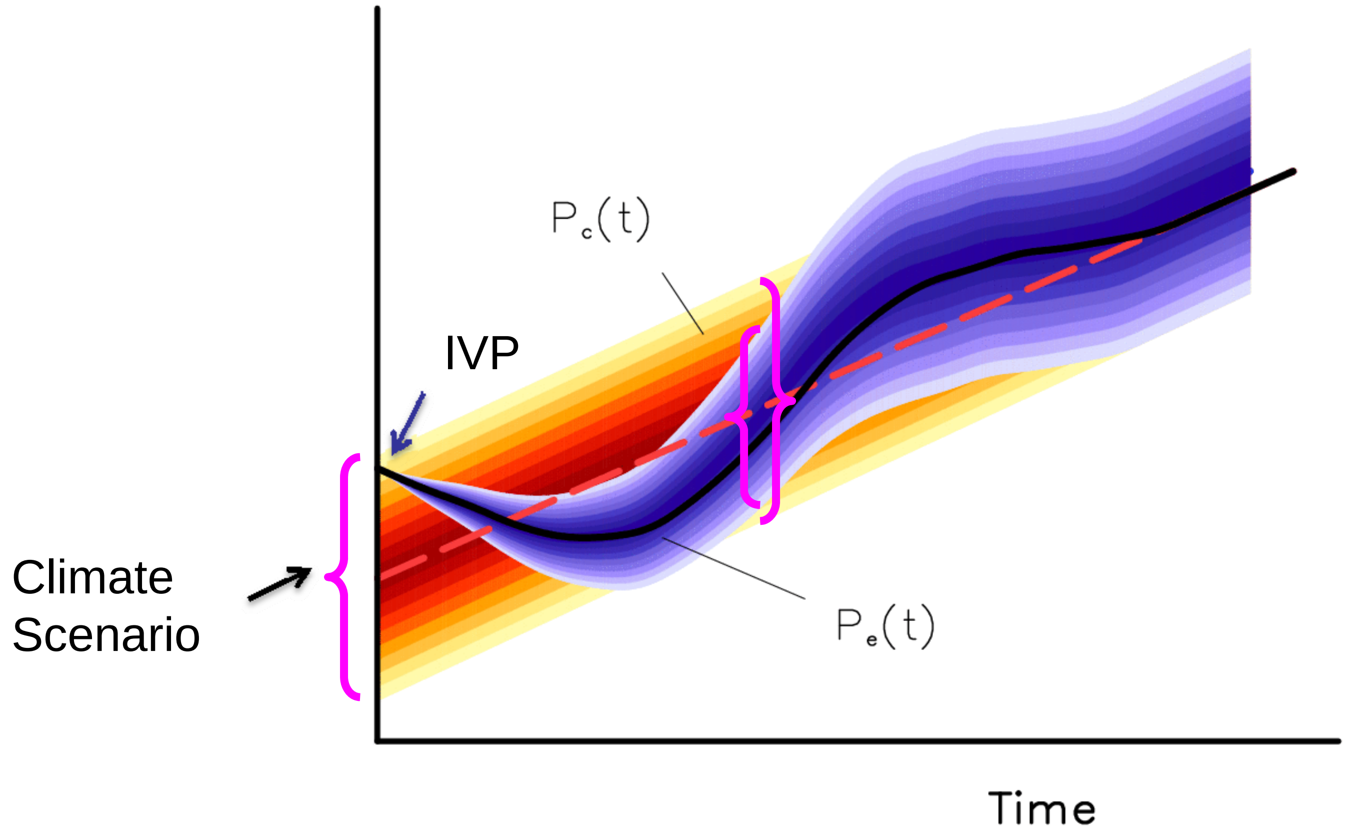
- **But there is some tantalizing evidence from models:**
  - ✓ **PREDICATE → 60% of decadal variance in Europe/ North Atlantic climate potentially predictable**
  - ✓ **GFDL/NCAR → potential predictability of MOC**



What will the next decade or two bring?
Temperature of North Atlantic
??
=
+
Forced
(a) Long term trend
in Atlantic temperatures
Free
(b) Multidecadal warmings
and coolings
0.8
0.6
0.4
0.2
0
−0.2
1880
1900
1920
1940
1960
1980
2000
4
3
2
1
0
20
40
60
80
100
1
0.5
0
−0.5
−1
0
20
40
60
80
100

Schematic Decadal Prediction (absent climate drift):

Initial value, Forced & Total Predictability



Add information from initial state distribution

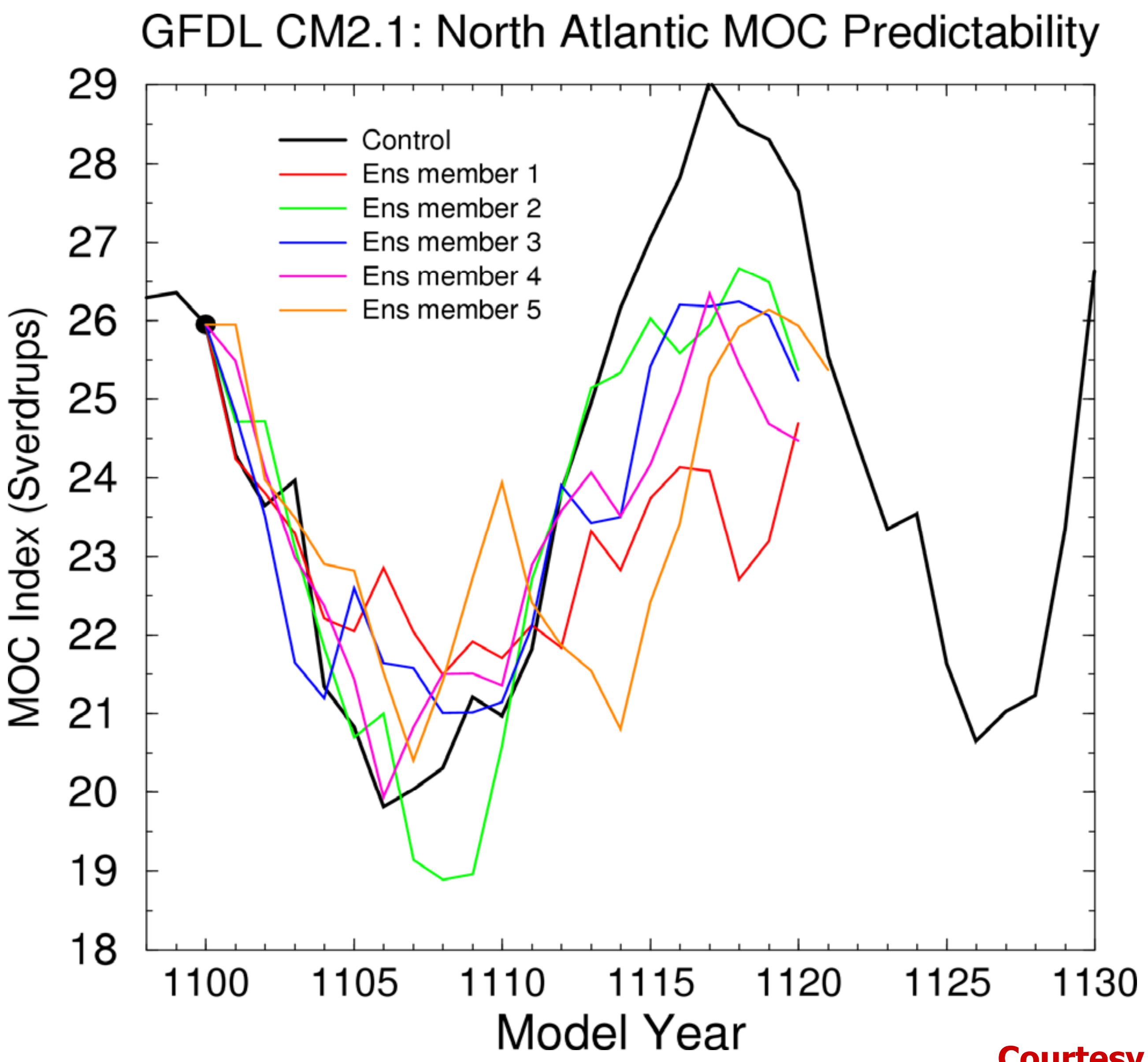
How long is this information retained?

Predictability question

"Mean" and "Spread" contributions to predictive 'information'

G. Branstator

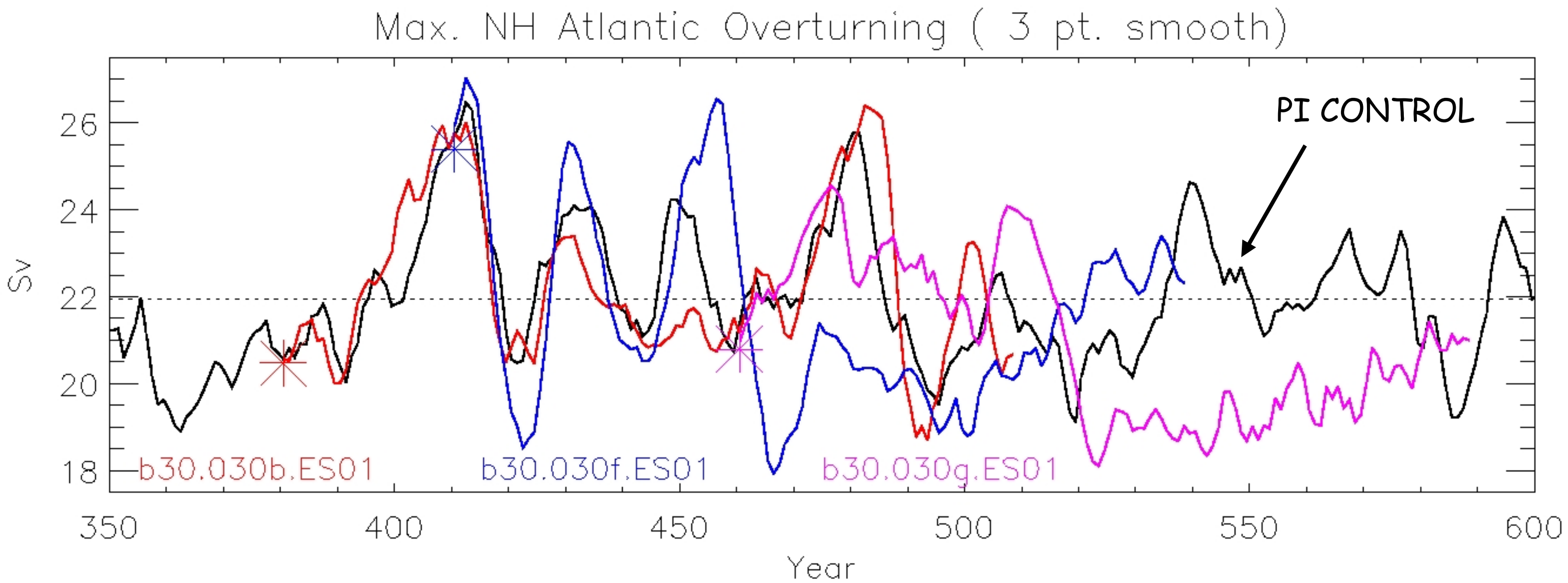
Decadal Predictability circa 2007

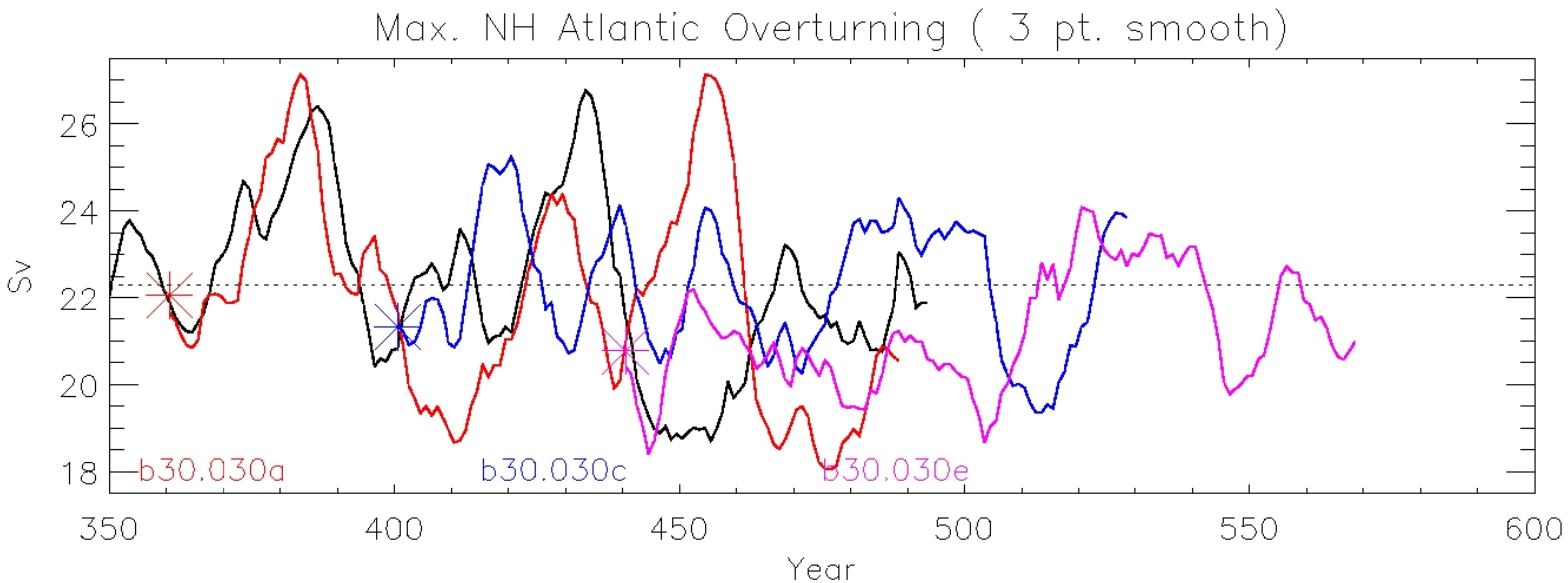


Perturbed ensemble members evolve coherently for two decades

Courtesy of Tom Delworth

MOC in NCAR 20th Century Ensemble Integrations (ca 2007)

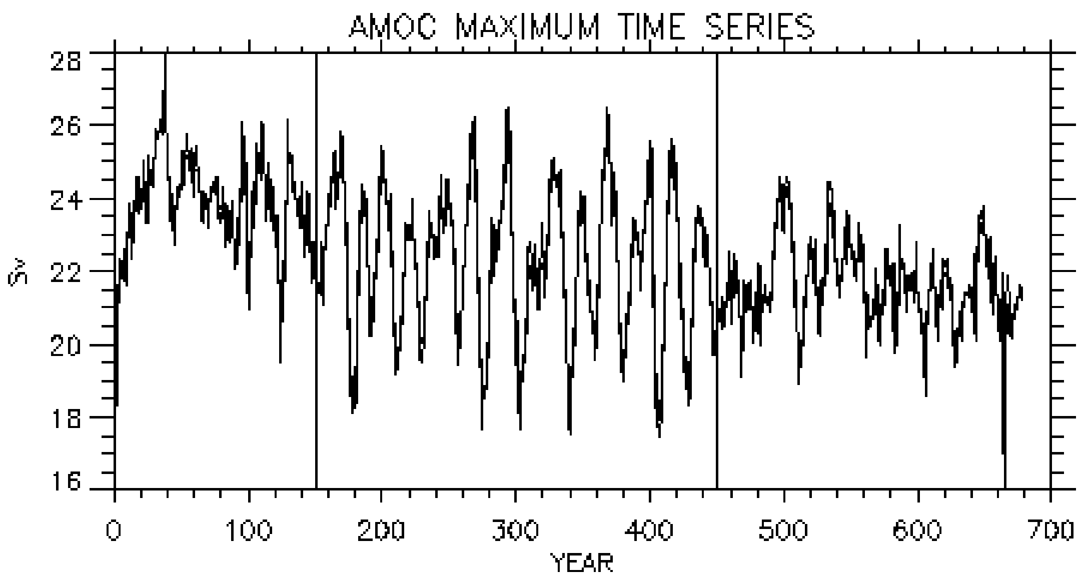




AMOC variations linked to North Atlantic SST anomalies and Atlantic-wide variability (AMO/V)

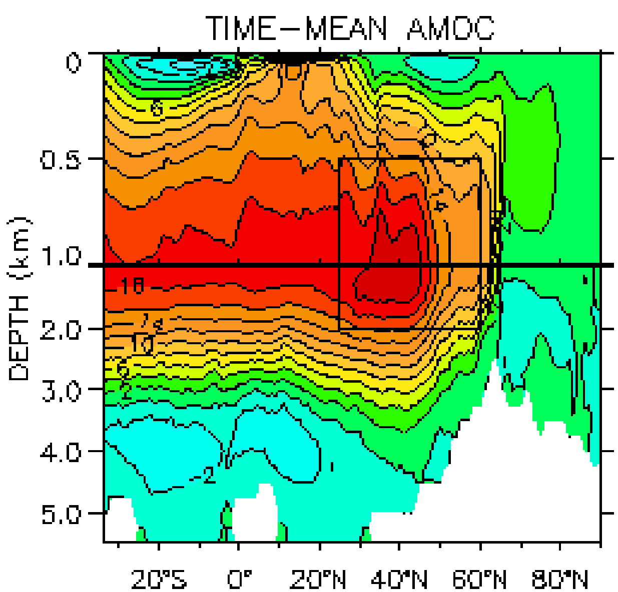
- AMOC predictability means that AMO might be predictable
- Includes decadal variations in Sahel precip
- Includes Atlantic Hurricane frequency and possibly intensity
- Decadal NAO variations?

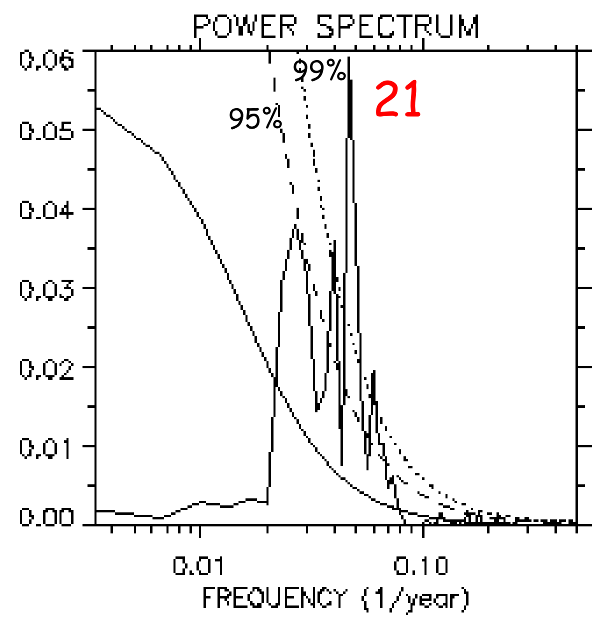
ATLANTIC MERIDIONAL OVERTURNING CIRCULATION (AMOC) IN CCSM3 PRESENT-DAY CONTROL SIMULATION (T85x1)



Reason for AMOC predictability:

AMOC periodicity





Encouraging but

To lay a scientific foundation for decadal prediction a number observed and modeled correlations need to be much better understood . The list on the right is a minimum requirement

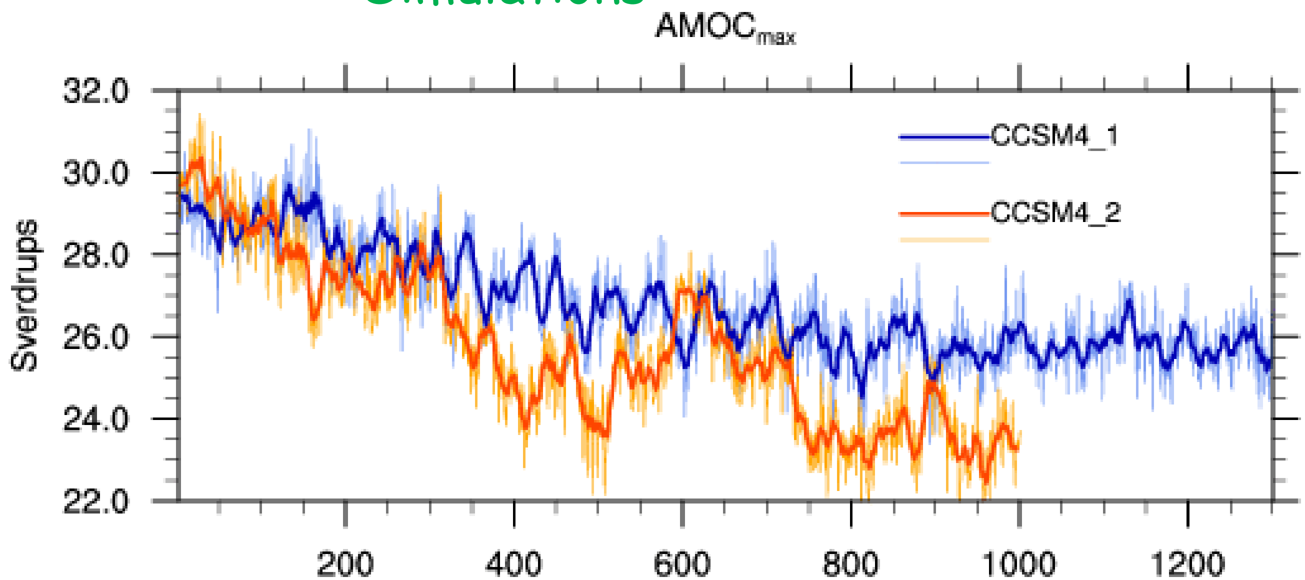
- Need to definitively tie AMO to AMOC
- Need to tie and understand how atmospheric climate links to AMO
- Must compare to trend and residual variability
- Must improve models ability to replicate nature to a ‘trustable’ level

That was then—this is now

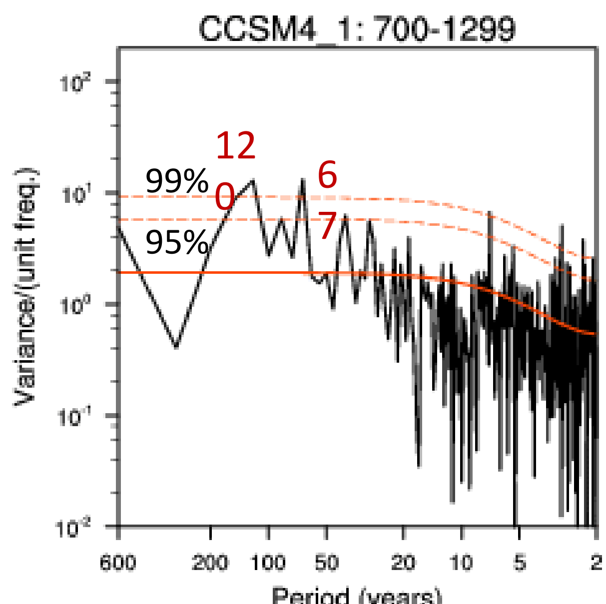
AMOC Maximum Transports in CCSM4 Pre-Industrial Control Simulations

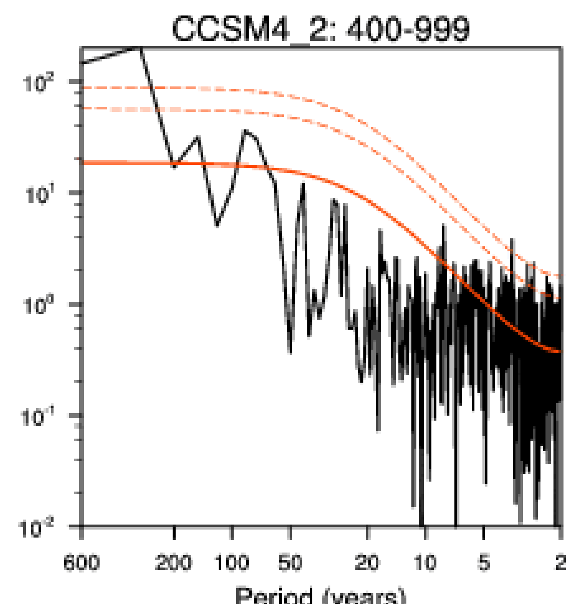
CCSM4_1: 1° FV atmosphere

CCSM4_2: 2° FV atmosphere



NO STRONG SPECTRAL PEAKS in new Model !

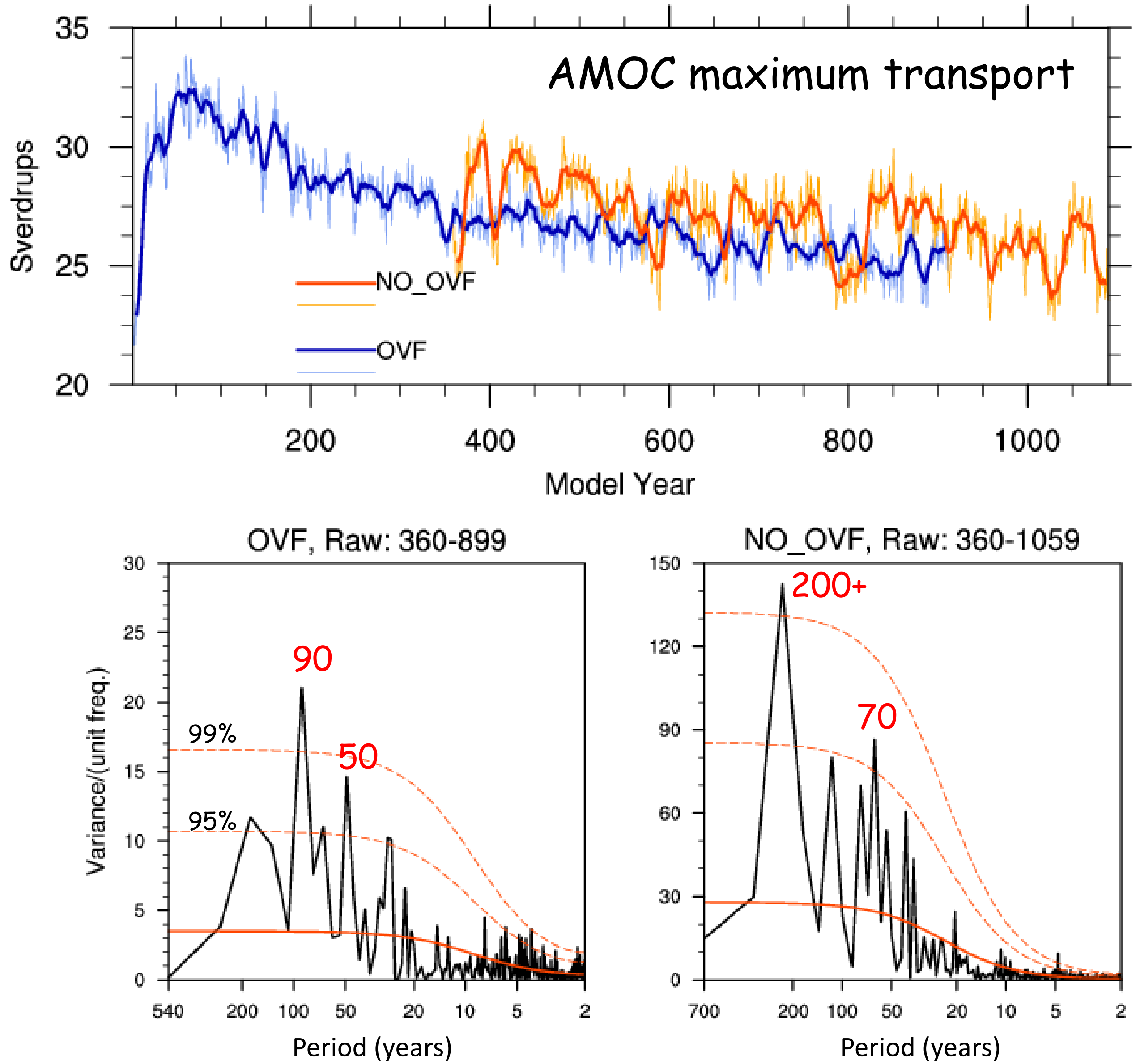




IMPACTS OF PARAMETERIZED NORDIC SEA OVERFLOWS ON AMOC VARIABILITY

Preliminary CCSM4 present-day simulations with 2° atmosphere and 1° ocean resolution

Nonstandard version without overflow parametrisation has spectral peaks



What about Predictability without Spectral peaks e.g. thermal inertia?

Analysis of Grant Branstator

CCSM3 40-member Ensembles

- T42, 1x ocean / perturb only atmosphere
- A1B starting from year 2000 C20C
- Commitment from year 2000 C20C
- A1B (II)
- A1B (III)
- A1B (IV)

} various initial states

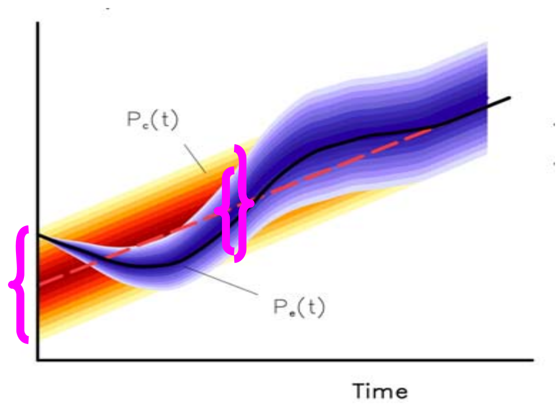
CCSM3 T42, 1x control

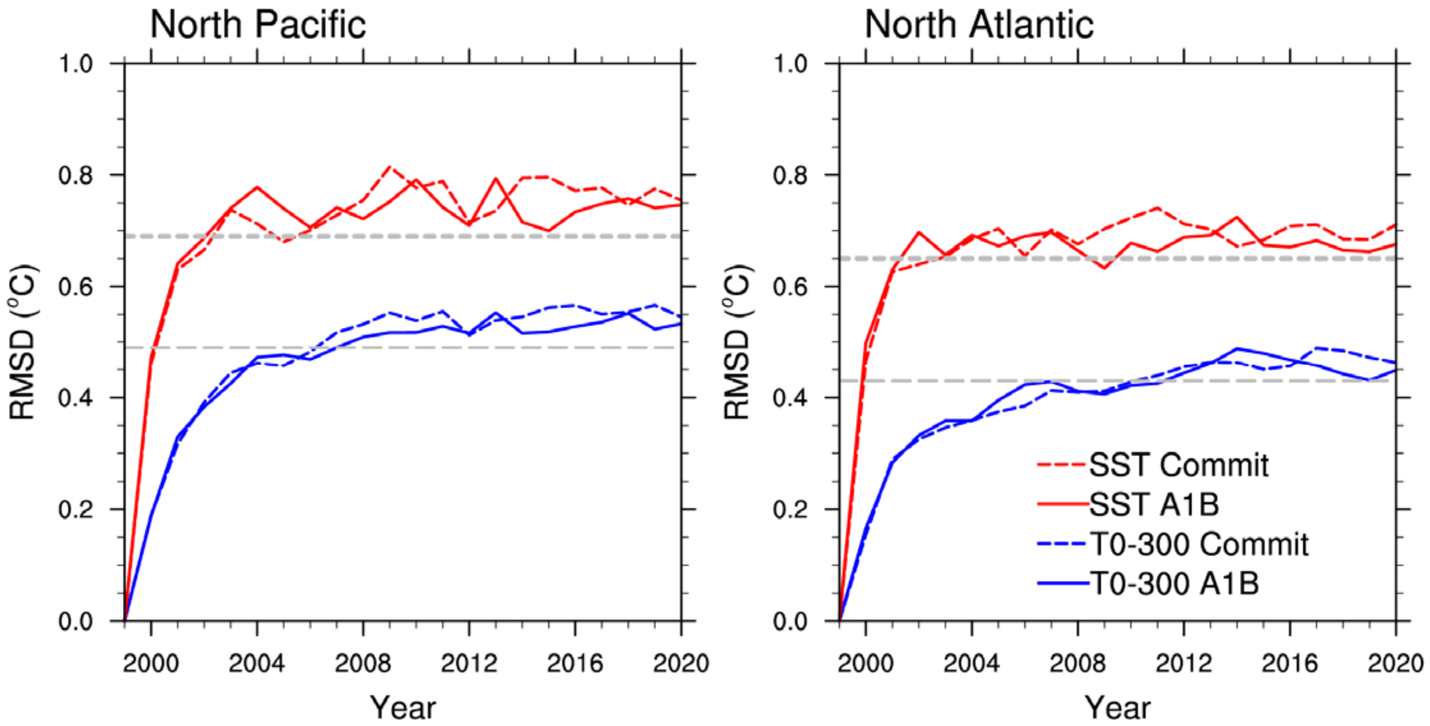
- years 300-999

CCSM4 1°, 1x control

- years 600-1299

CCSM3 Ensemble Spread



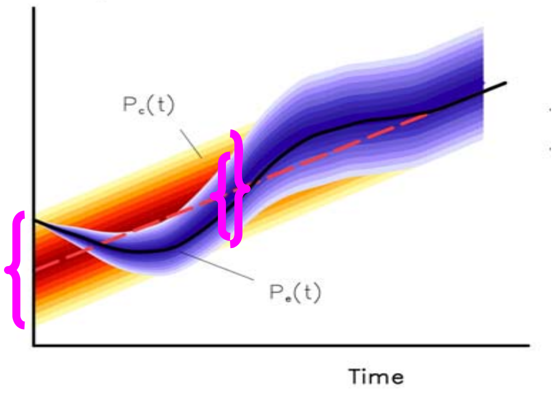


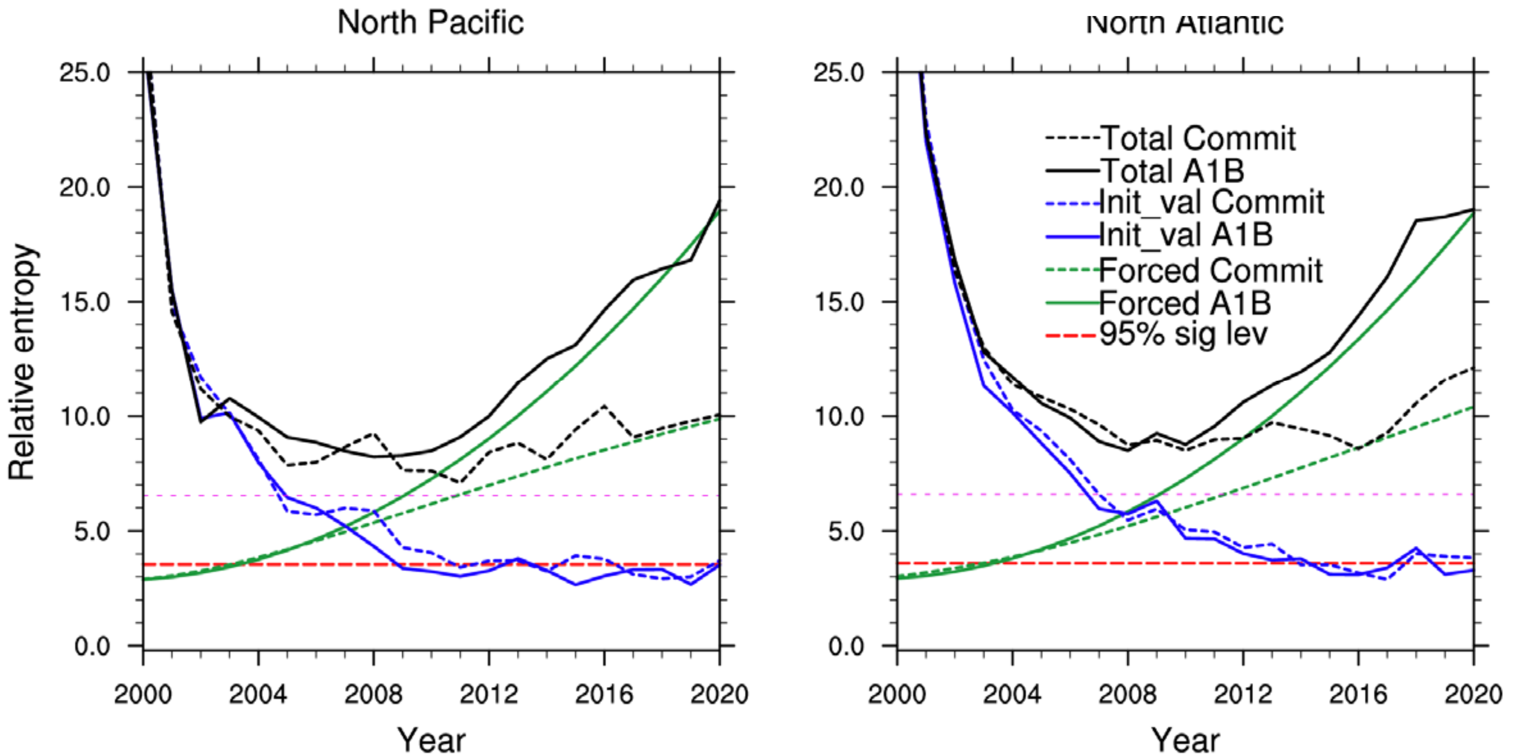
5-7 years of thermal inertia in the upper ocean

CCSM3 Basin Relative Entropy

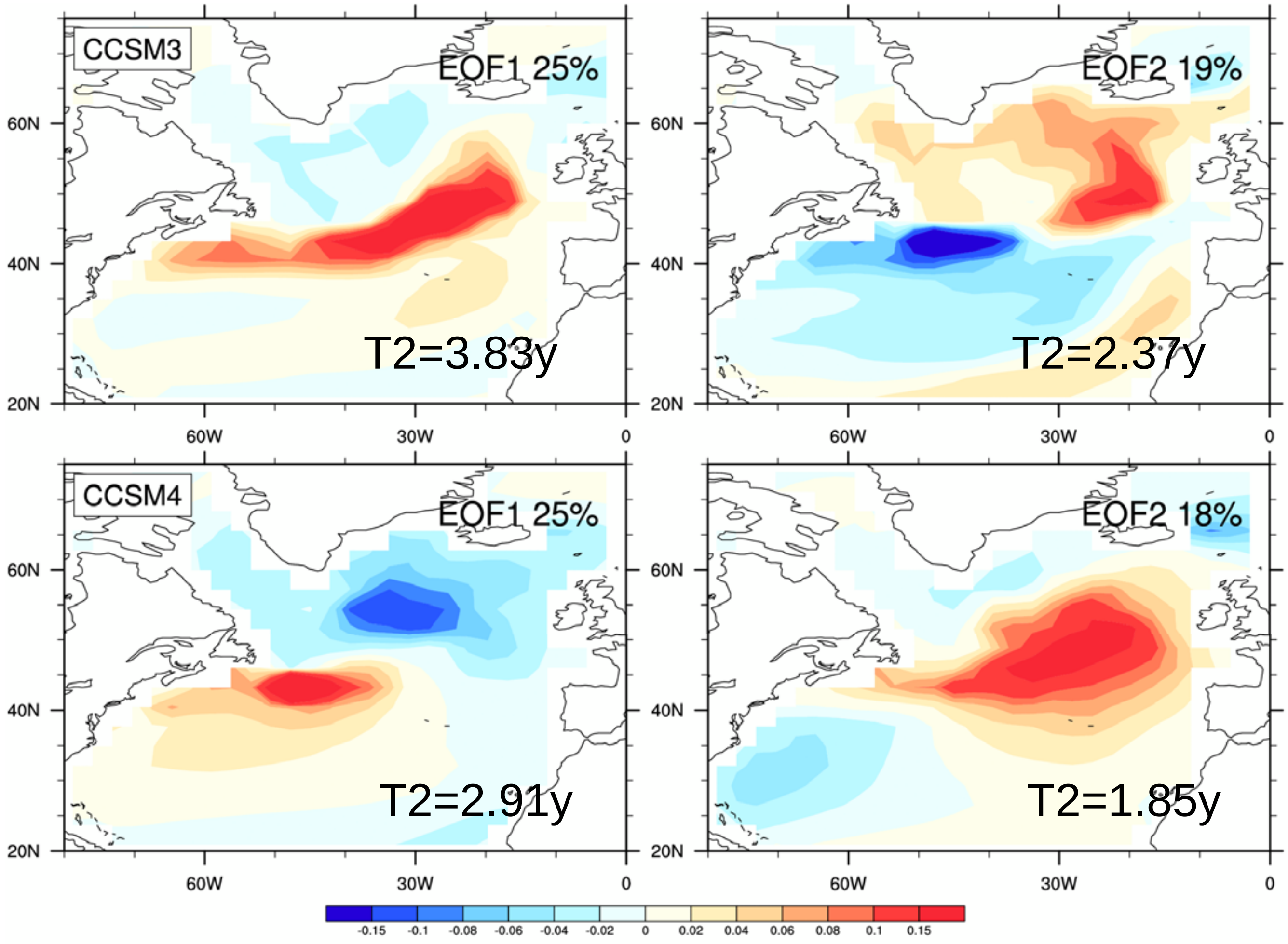
Disentangle forced and free predictability

$$R = \int_S P_e(s) \log_2 \left[\frac{P_e(s)}{P_c(s)} \right] ds$$

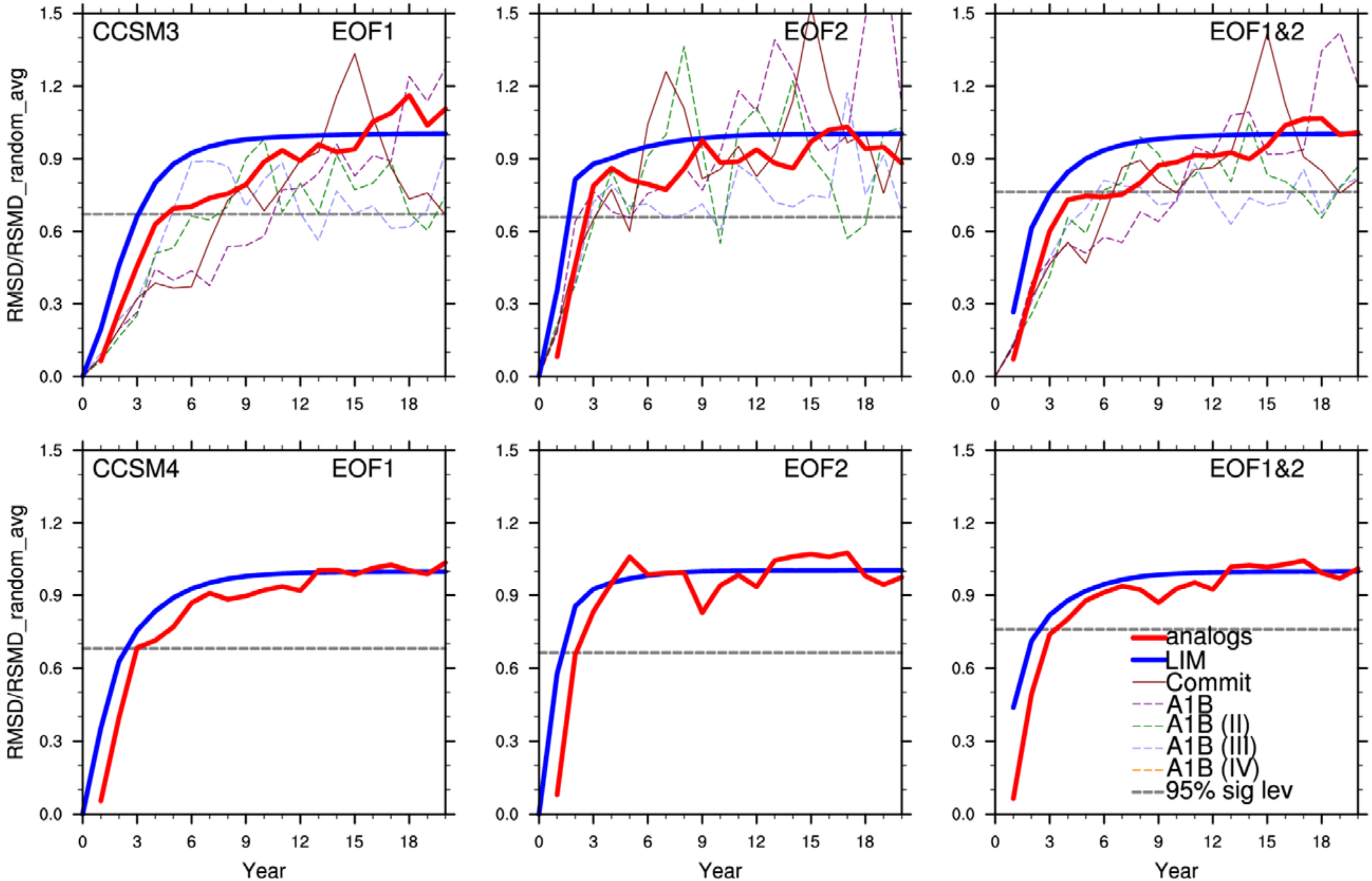




T0-300m Intrinsic Modes
North Atlantic



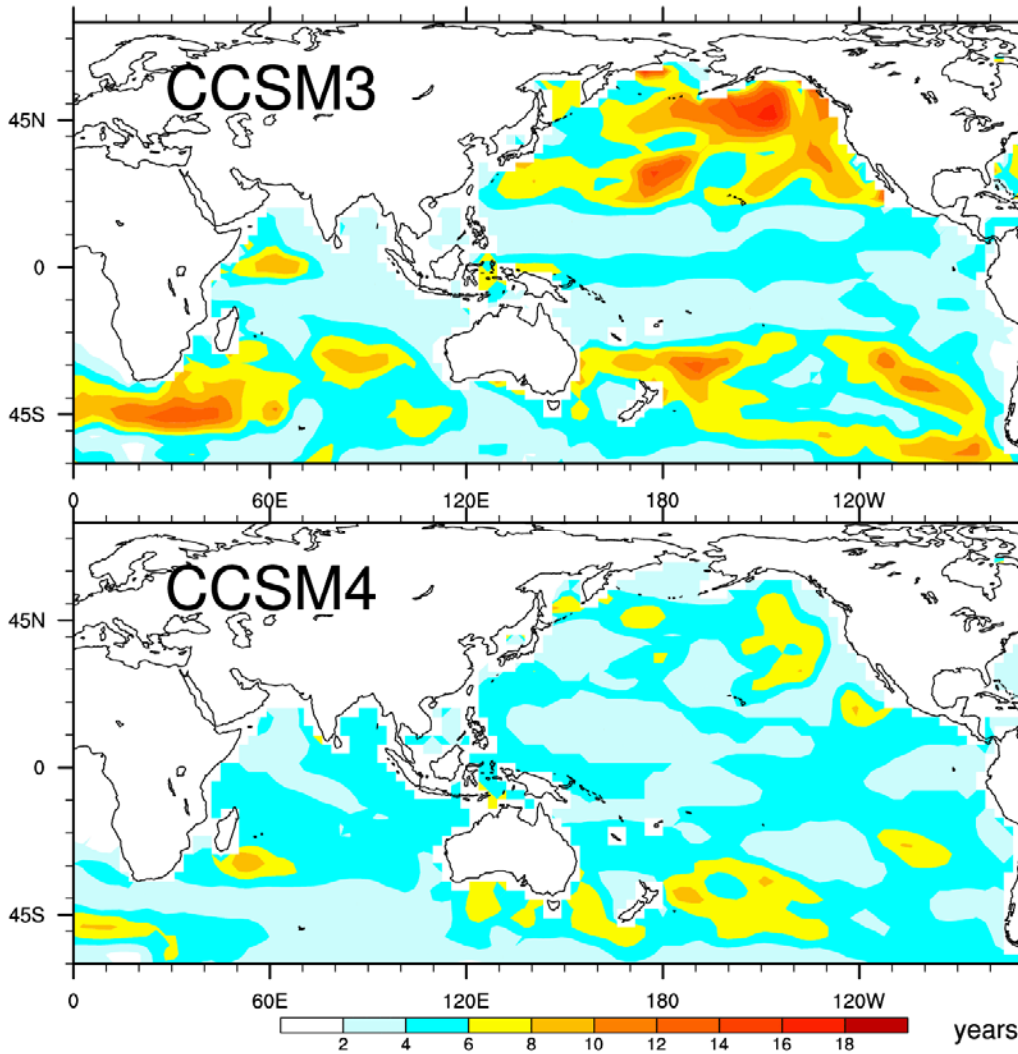
CCSM3 vs CCSM4 Spread
North Atlantic Modes



CCSM3 vs CCSM4

Local Predictability

Year Analog Spread Reaches 95% Saturation



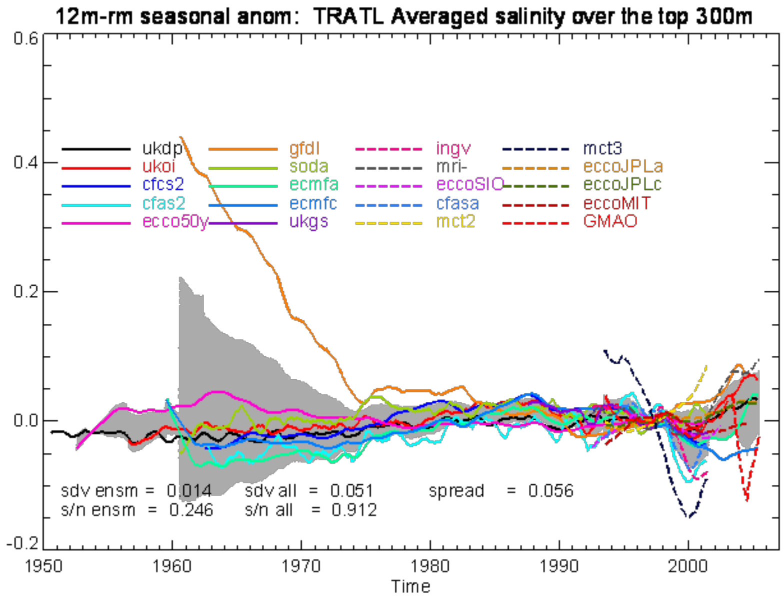
Decadal Predictability

Major challenge :imperfect Ocean ICs

- **Initialization before Argo floats**
  - **Many different global ocean reanalysis products, but significant differences exist**

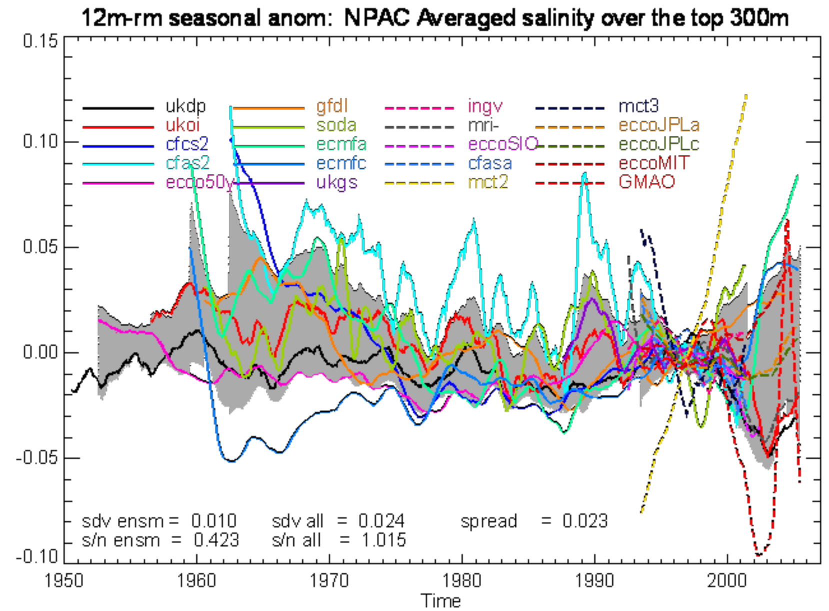
  Large inherent uncertainty in salinity & driving of AMO

Atlantic Salinity Anomalies (upper 300 m)



Tropics ←

Mid-Lat →



For Decadal Prediction

Possible payoff but there are challenges for initialization & calibration …

- **Large uncertainty in climate signals**

  Signal to noise ratio > 1 in the Eastern Pacific for Temperature
  Signal to noise ratio <1 for salinity in most regions and T in some
  What is happening now? There is not consistent picture after 2000

- **Forcing fluxes and analysis methods are largest source of uncertainty**

  Data assimilation does not always collapse the spread

  May require coupled data assimilation

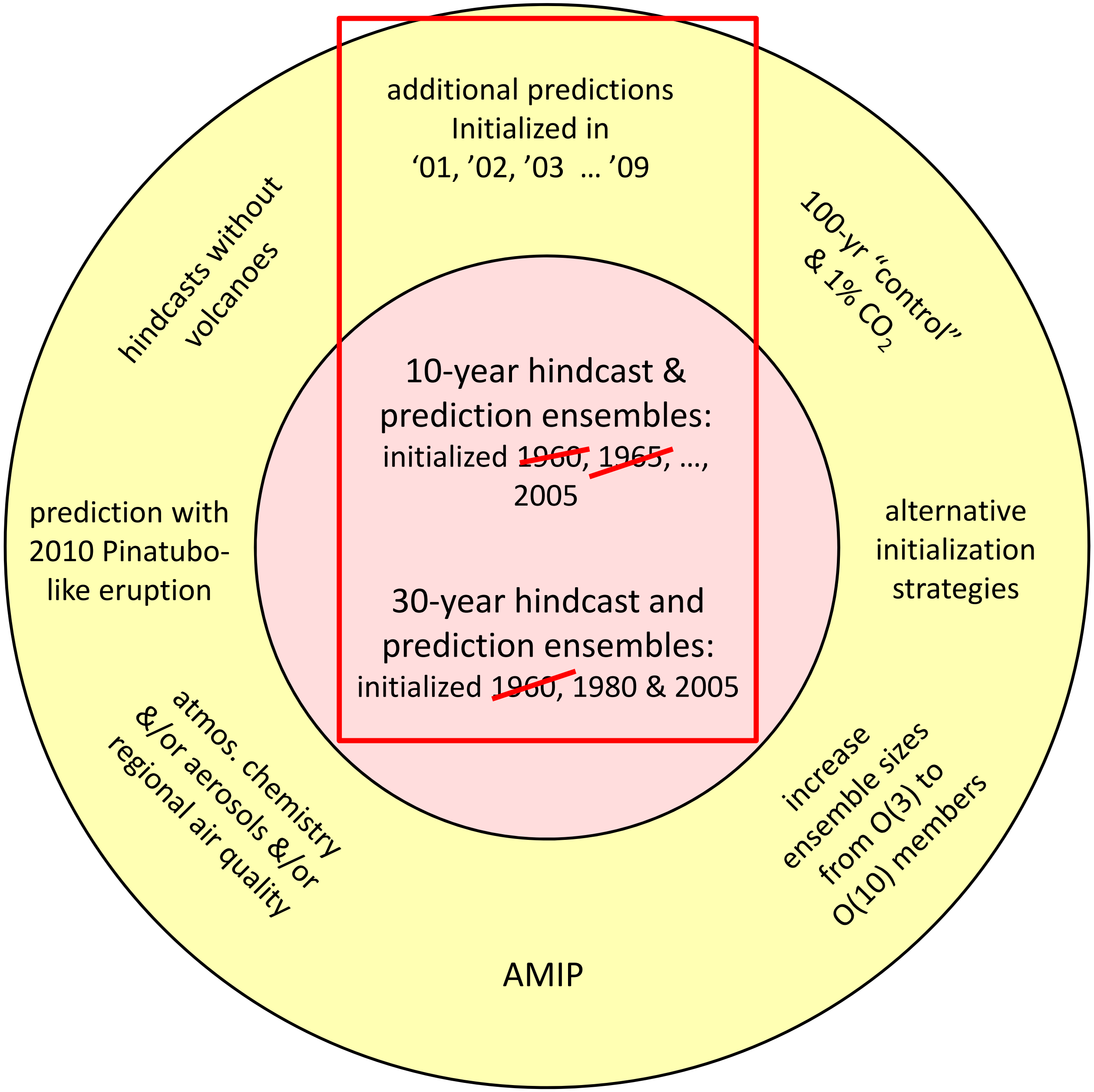
- **At least 20 current analyses: maybe more?**

  Need to initialize with several products

- **What is the best method of smooth initialization**

  Need to minimize initialization shock

CMIP5 Decadal Prediction Experiments

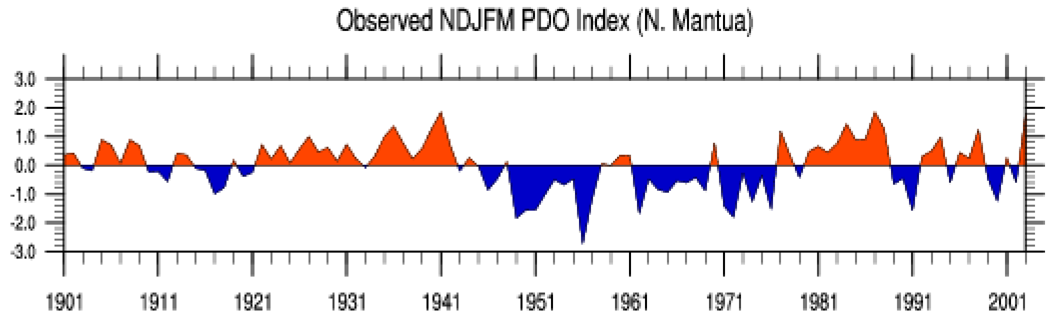


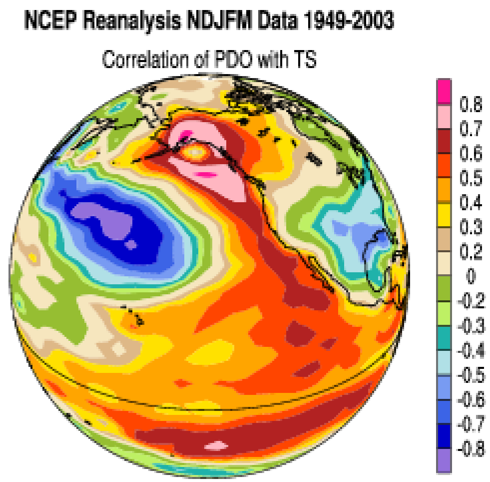
Hindcast Simulations:

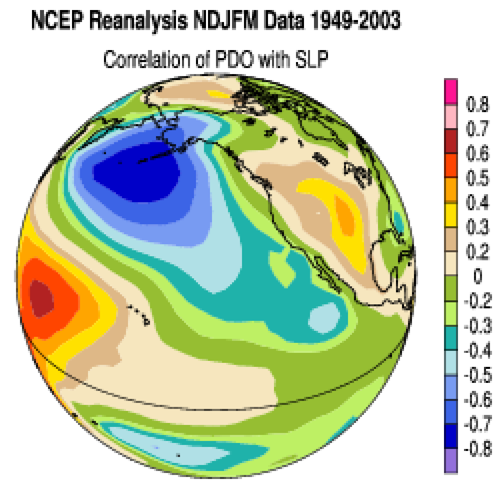
- Forced with the Coordinated Ocean-ice Reference Experiments version 2 (CORE2) data sets for 1948-2007 (Large and Yeager 2004; 2008).

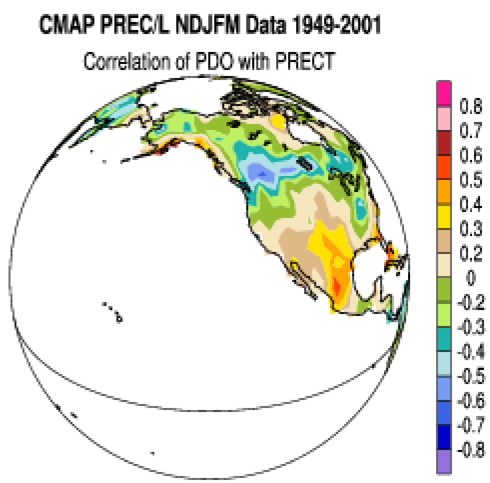
- Repeat the forcing cycle a few times and use the ocean and sea-ice solutions at a given date as initial conditions for prediction experiments.

- Assess the sensitivity of model solutions (particularly AMOC) to surface salinity restoring strength and ocean – sea-ice coupling.



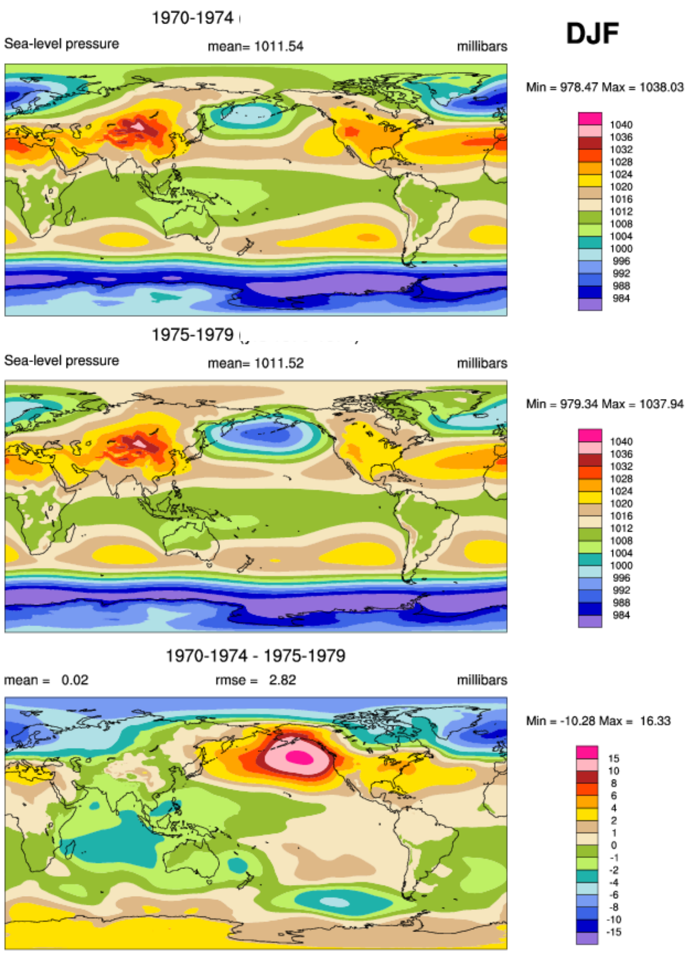


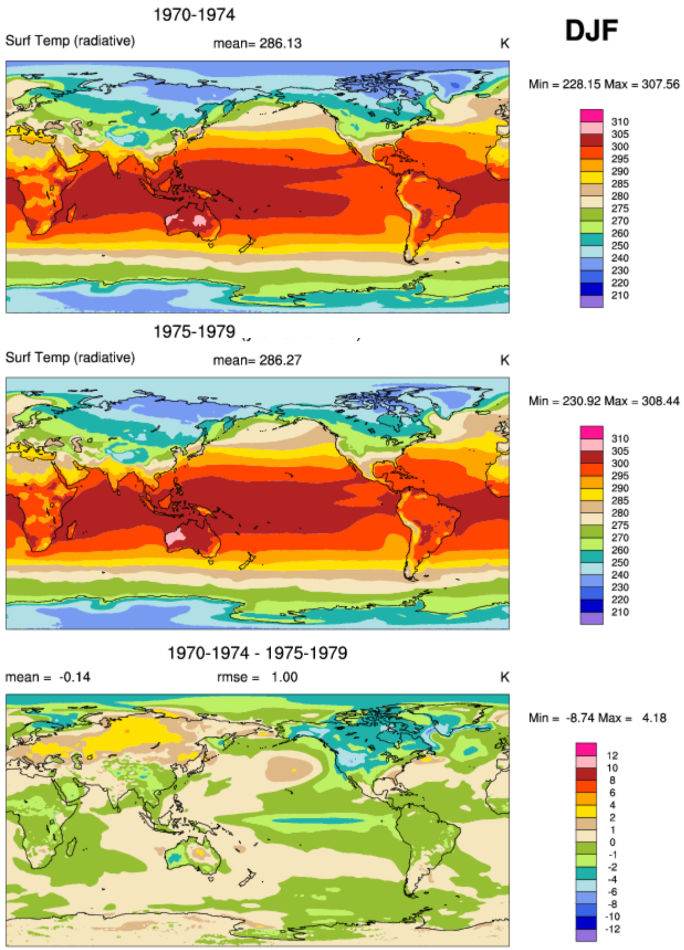




PDO =‘fuzzy’ El Nino
Examine hindcast initialization
For 1976 regime shift

An interesting first result



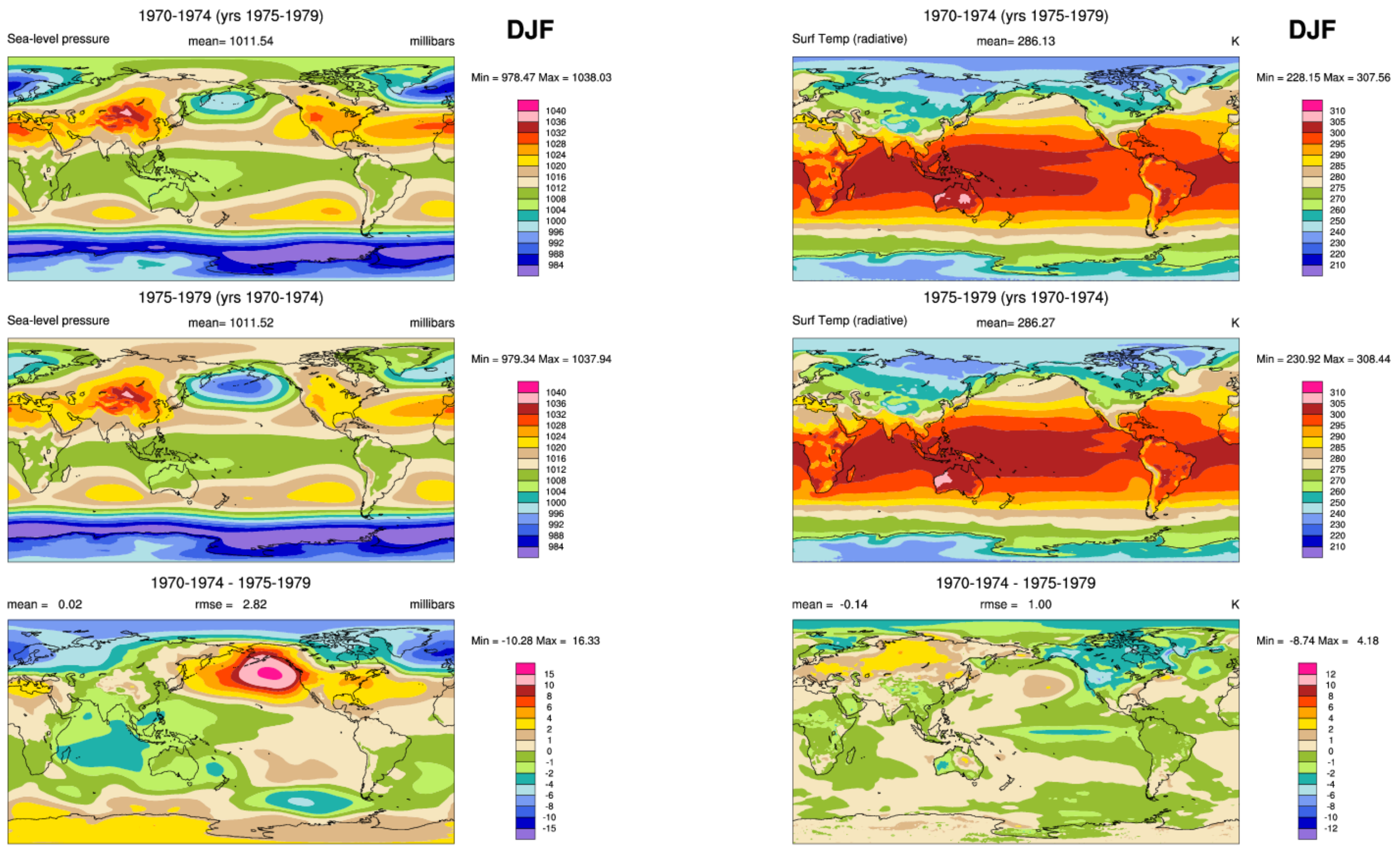


Of course this is due to

- Single case-blind luck or ENSO
- Uncalibrated
- May be only due to climate drift
- Nevertheless – interesting because a dramatic change in PDO occurs
- I assure you I agree 100% with these caveats, BECAUSE…..

An interesting result

almost very interesting



But actually worse than ‘pitiful’ as a forecast

Because there is no operational decadal prediction in US, NSF is willing to let NCAR explore these challenges
For experiments after 2000 we are using
"WEAKLY" COUPLED EnKF DATA ASSIMILATION

Force each ocean ensemble member with a different member from an atmospheric ensemble reanalysis:

- Run an 80-member ensemble of CAM assimilation with 6-hourly coupler output files from each member,
- Run a 46-member ensemble of POP assimilation forced with output from 46 of the CAM assimilation runs.

This technique is already operational (starting from 1 January 1998) and preliminary analyses indicates much increased ensemble spread.

Conclusions

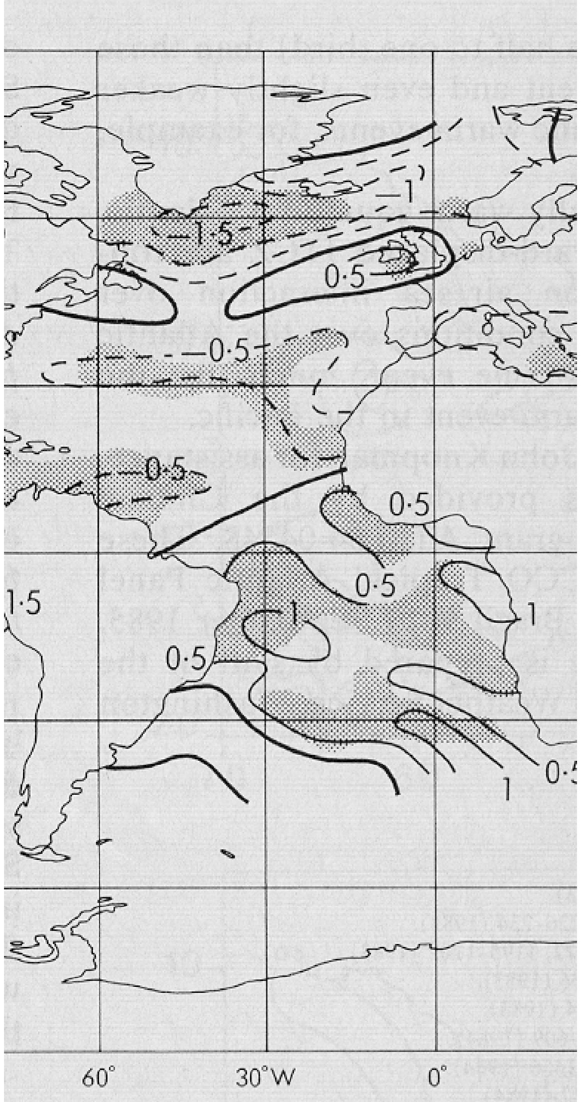
- Great interest in decadal variations in climate for policy, society and science
- Predictability estimates in a state of flux as modeling studies give radically differing results
- How are predictability estimates contaminated by current models?
- Regions of oceanic memory in heat content- what is the time scale?
- Temper expectations and seek scientific understanding-assist SI prediction

Thank-you
and
Questions?

Relationship to Atlantic SST

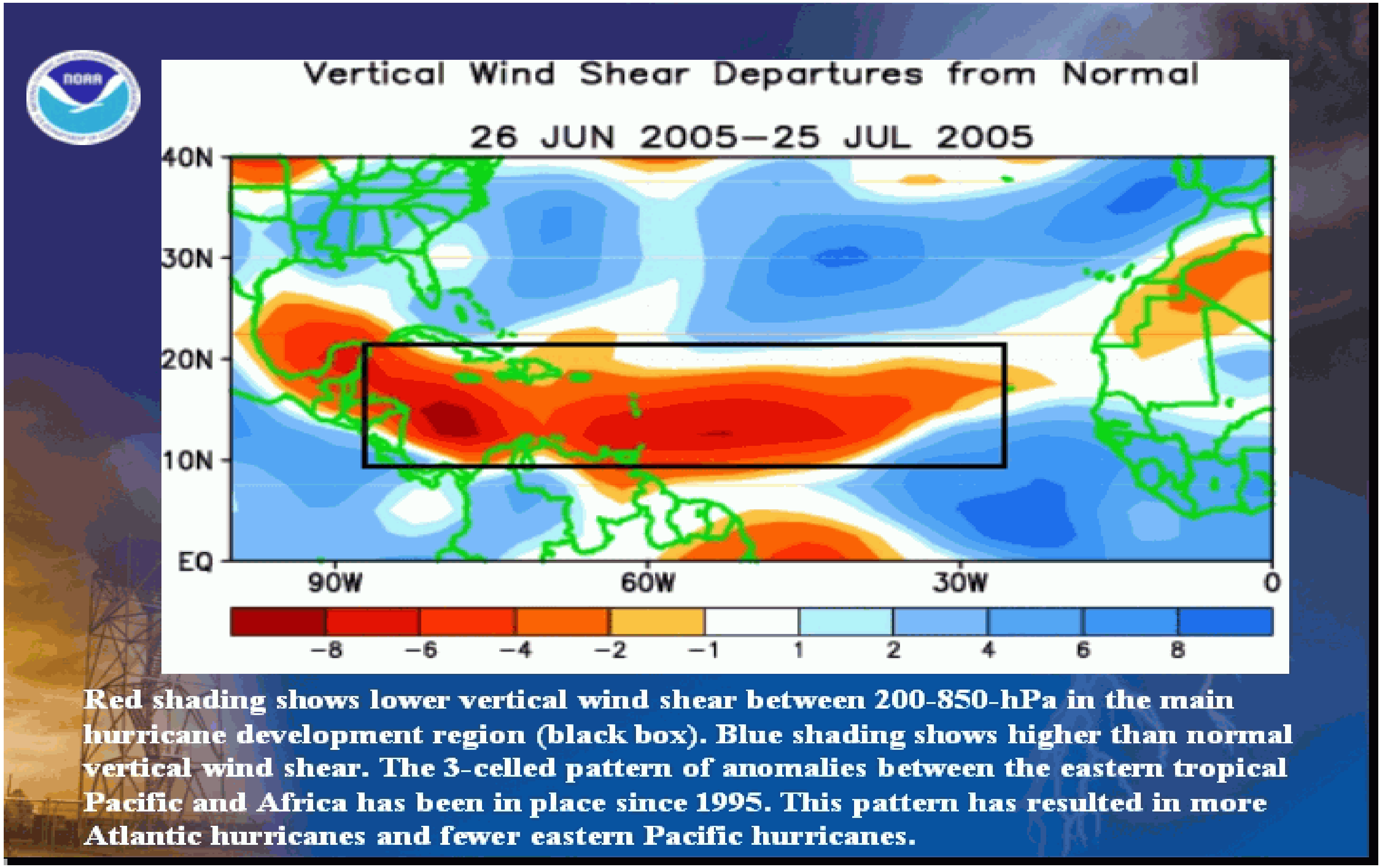
(Dry – Wet) Sahel Summers

Correlation of
Atlantic SST
Anomalies
With Sahelian Rainfall
Anomalies



Lamb (1978); Folland et al. (1986)

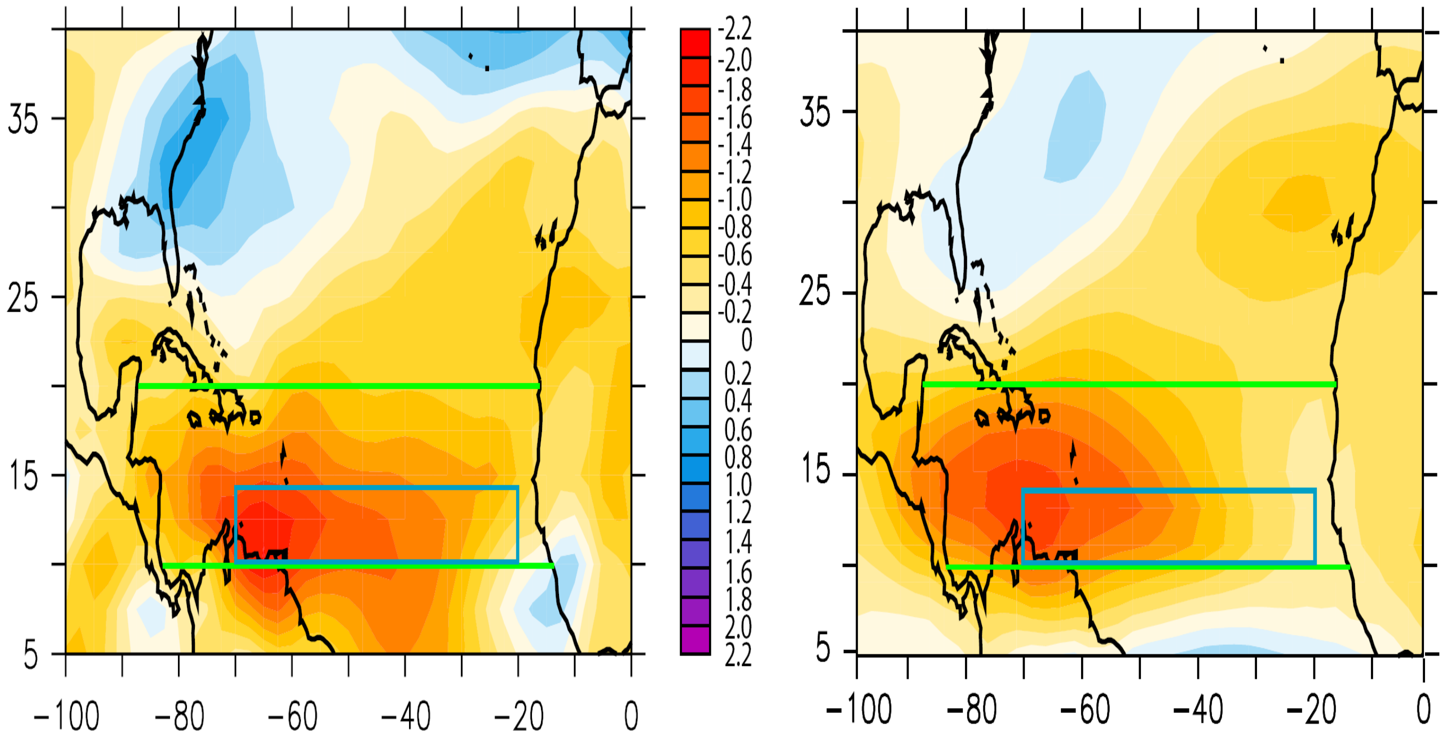
Impact of AMO on Atlantic Hurricane Activity



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)



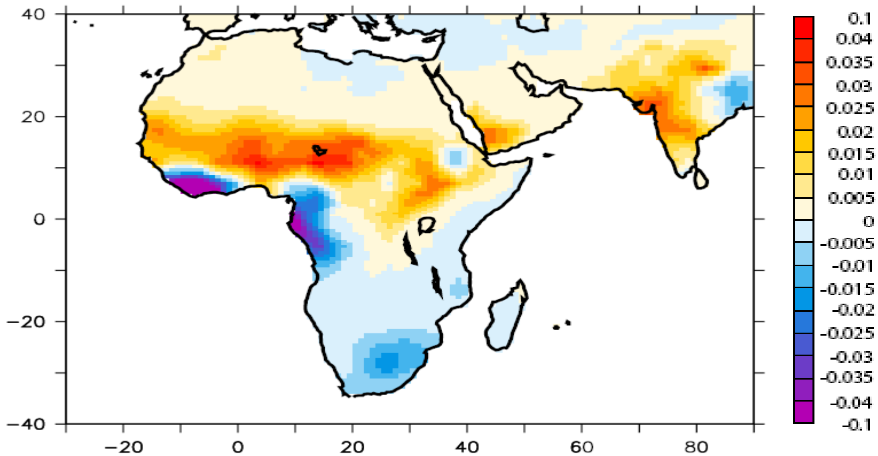
ECMWF 40-yr Reanalysis

MODEL (10-member ensemble mean)

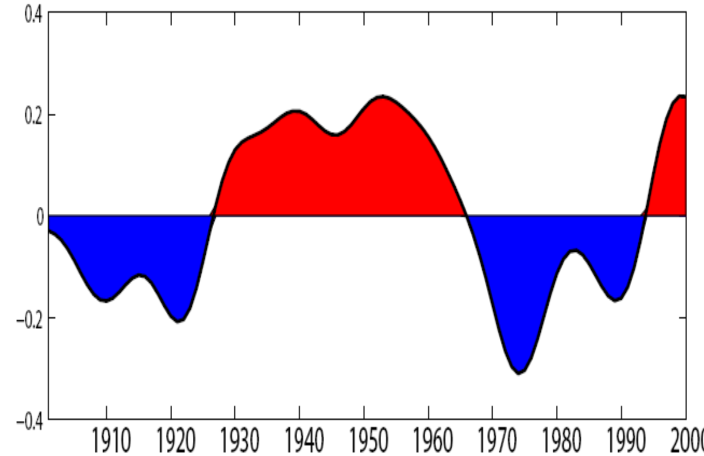
Studies, which are currently under way to study the decadal predictability of the AMO, show some promise

The AMO is Linked to Regional Rainfall Anomalies

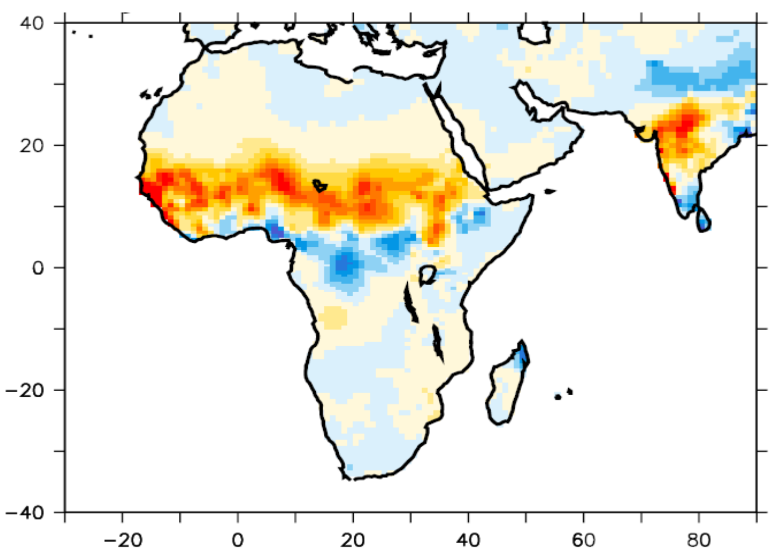
Regression of modeled LF JJAS Rainfall Anomaly on modeled AMO Index (1901-2000)



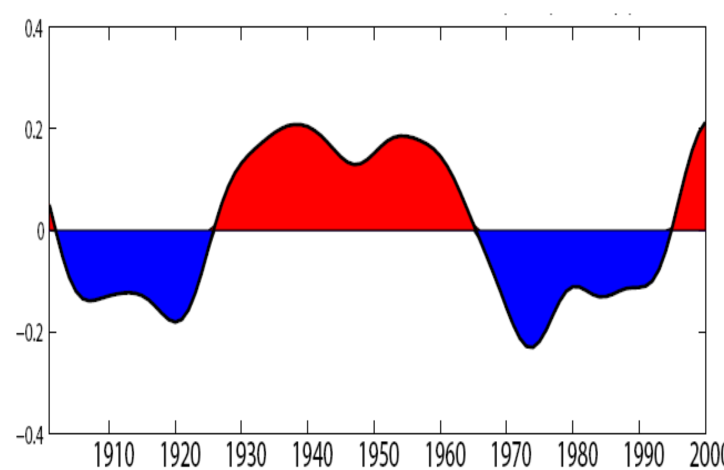
Modeled AMO Index



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



Observed AMO Index



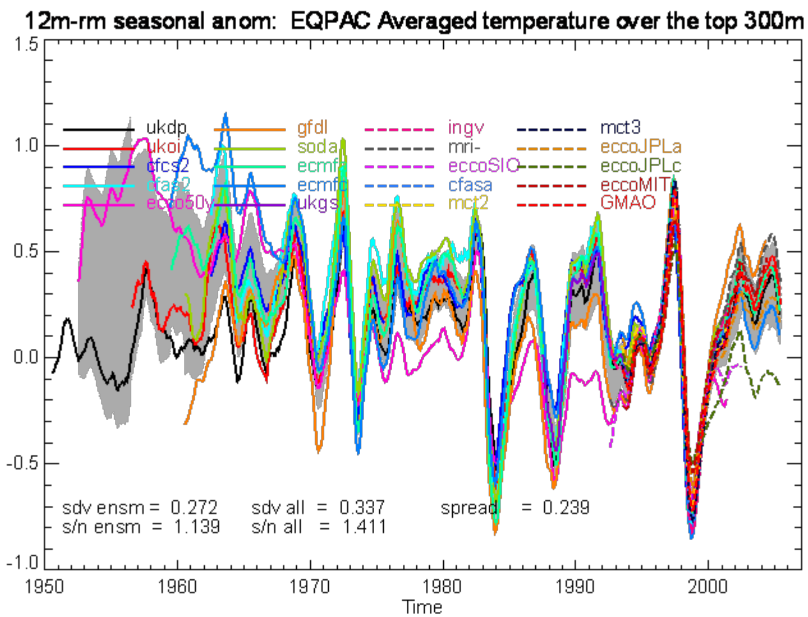
Decadal Prediction

But there are challenges …

- **Initialization**
  - **Many different global reanalysis products, but significant differences exist**

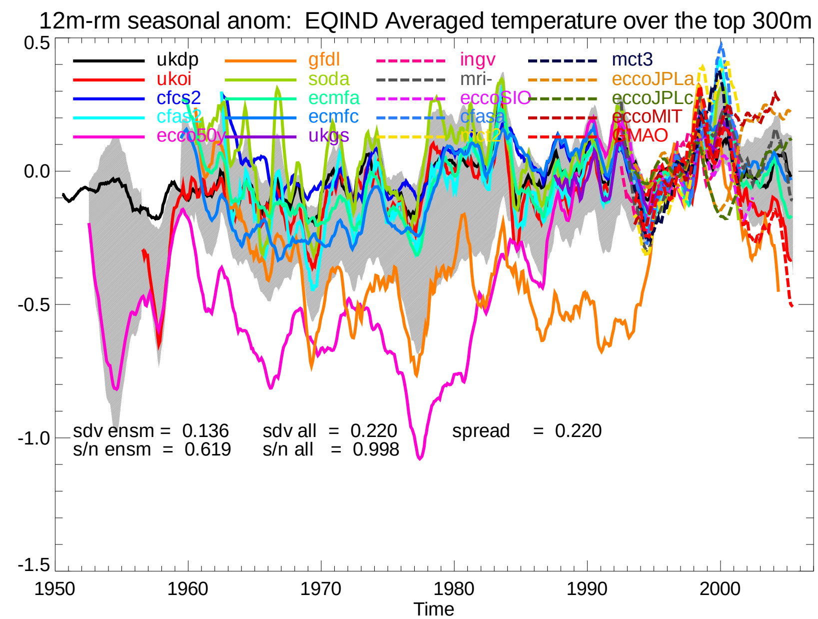
  Ocean observing net not global or comprehensive

Tropical Upper Ocean T Anomalies (Upper 300 m)



Pacific ←

Indian →

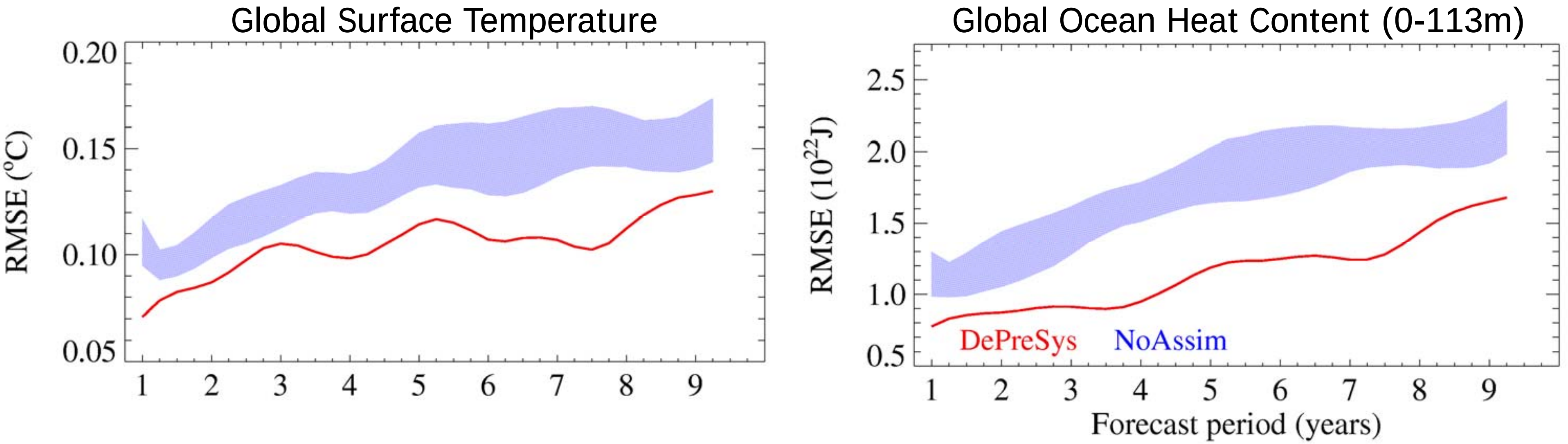


Decadal Prediction

But there are challenges ...

- **Is a decadal prediction societally useful?**
    - o **Improved skill beyond ENSO?**

Decadal Climate Predictions at the Hadley Centre



Doug Smith, James Murphy, Stephen Cusack

Mechanisms of AMO

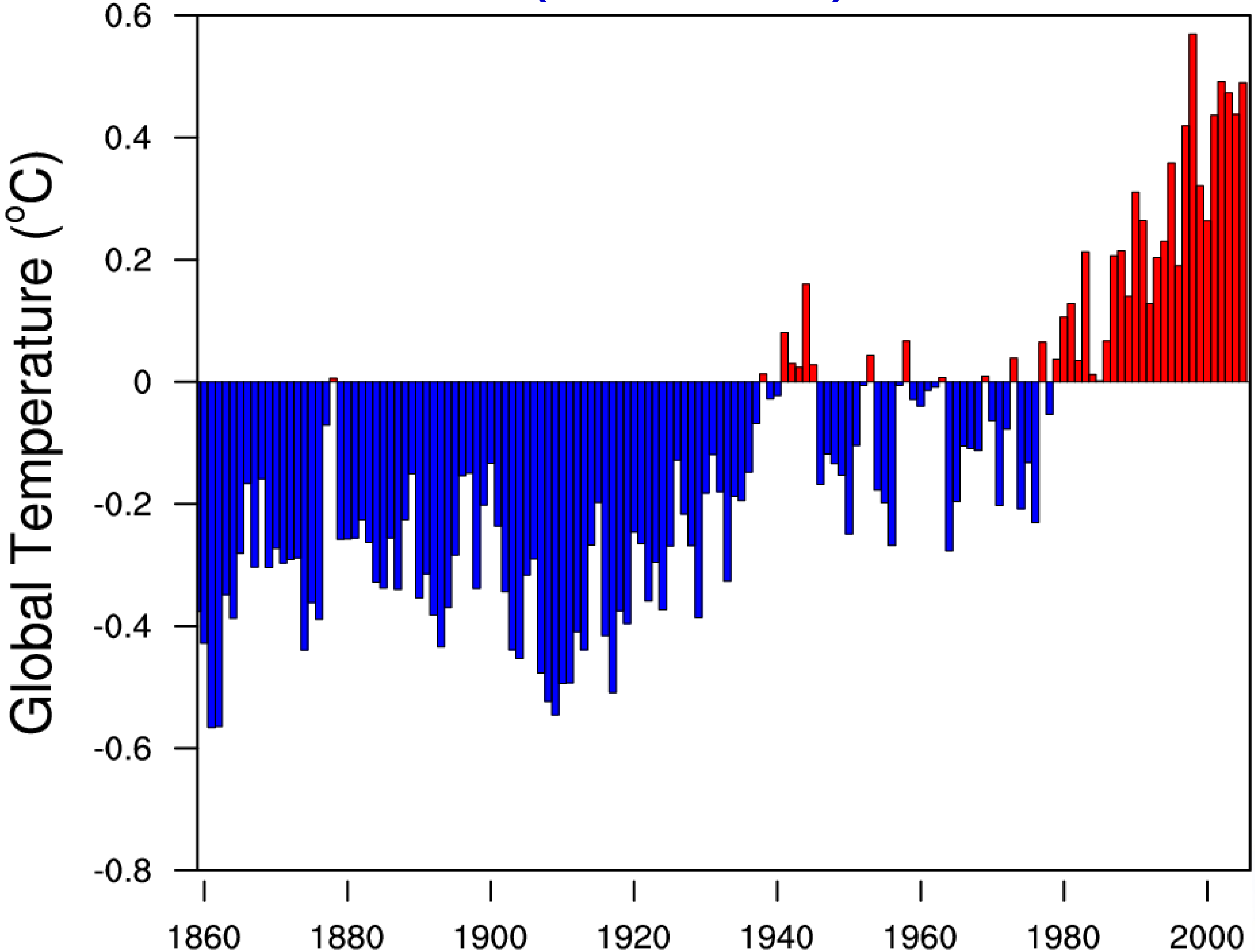
The AMO is thought to be driven by multidecadal variability of the Atlantic thermohaline circulation (THC) *(Bjerknes 1964; Folland 1984; Delworth et al., 1993; Delworth and Mann 2000; Latif et al 2004)*

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)

Annual Global Mean Surface Temperature

(1860-2005)



Typical Scientific Global Change Info/Fcst

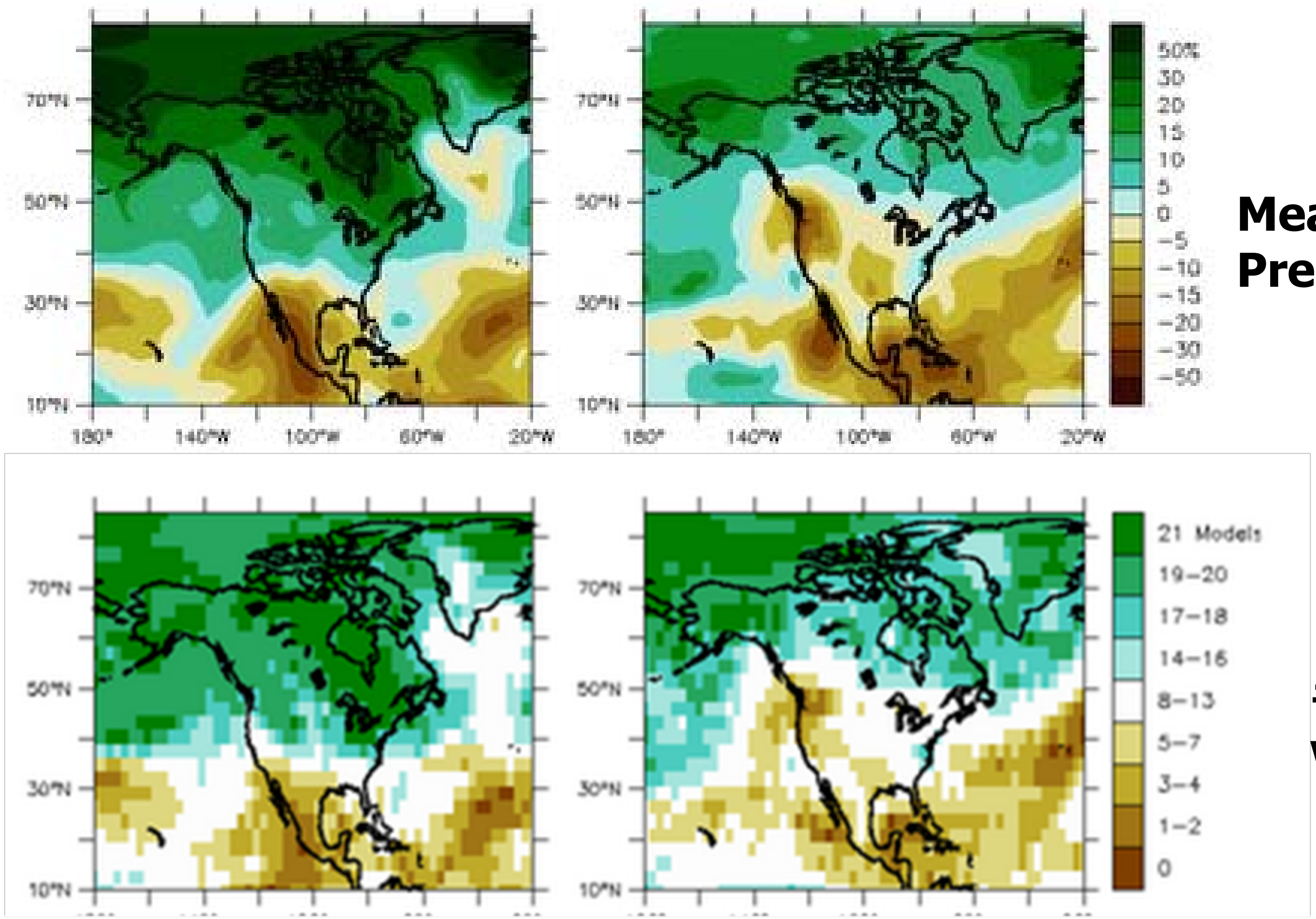
Society Needs Regional Info

NCAR

Using this method we can't reliably predict Regional Climate Change

2080-2099 (A1B) - 1980-1999

DJF **JJA**



Mean Δ Precipitation (%)

# of Models with ΔP > 0

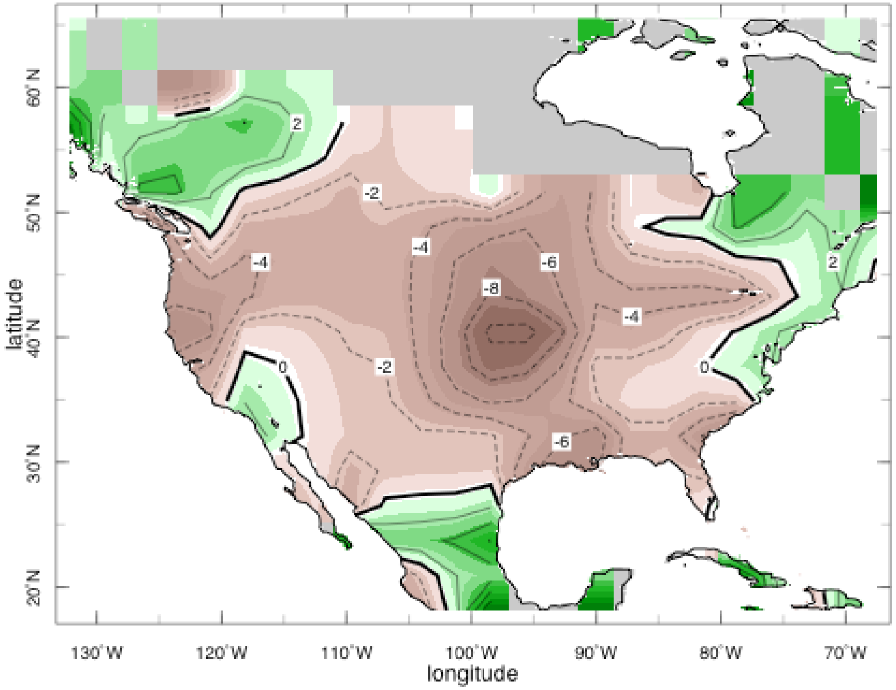
As pointed out by A. Giannini

Is there a dustbowl in our near future?

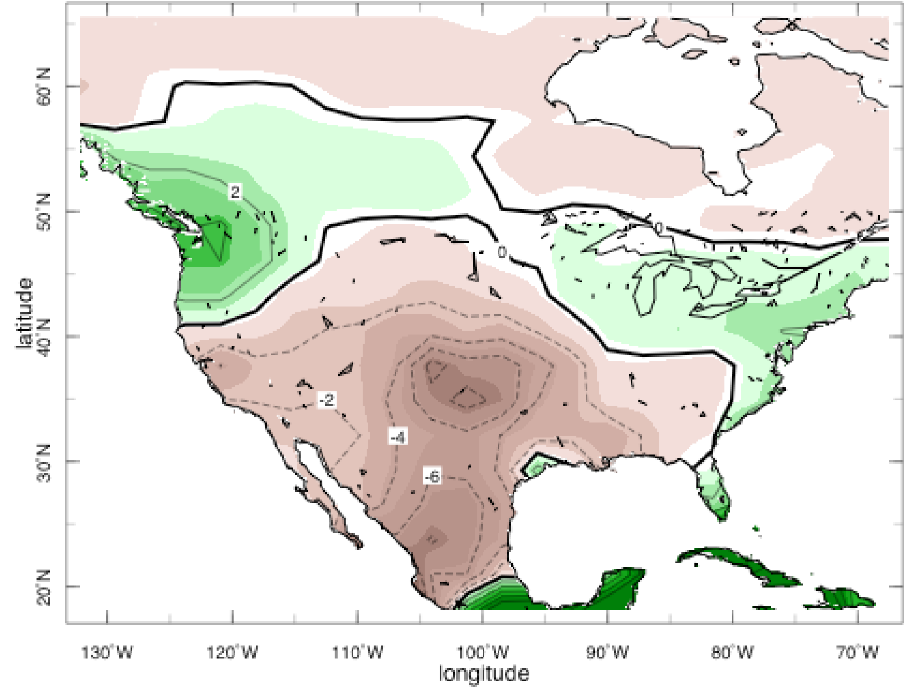
Oceanic Forcing of US Climate

Precipitation Anomaly 1932-1939

OBSERVED



GOGA MODEL



Seager et al. (2005)

GOGA MODEL = Global Sea Surface Temperature Specified

Pacific Interdecadal Variability

Epoch Differences: High – Low N Pac SLP Index

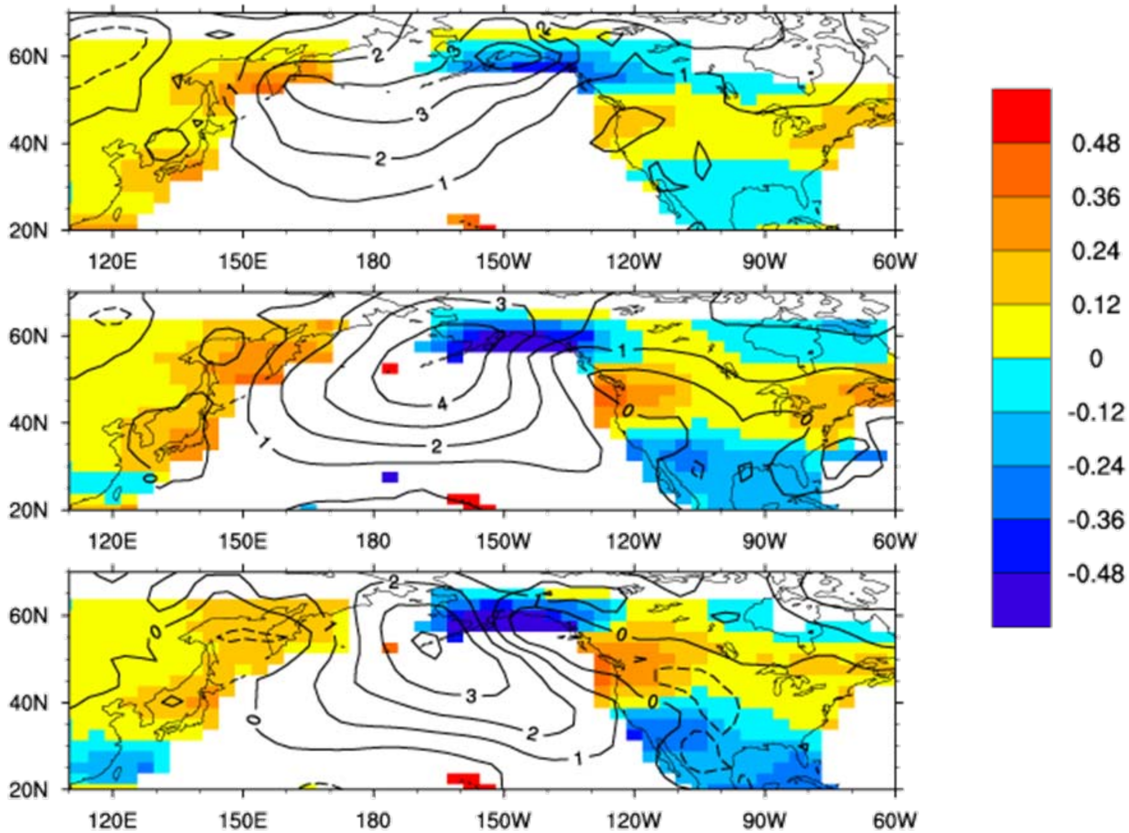
Precipitation (shading) and Sea Level Pressure (contours)

1900-1924 minus 1925-1946

1947-1976 minus 1925-1946

Sign reversed

1947-1976 minus 1977-1997



➢***The above highlights the regimes of North Pacific Interdecadal Variability in atmospheric circulation and precipitation in Pacific rim countries.***

Deser et al. (2004)

June 30, 2010

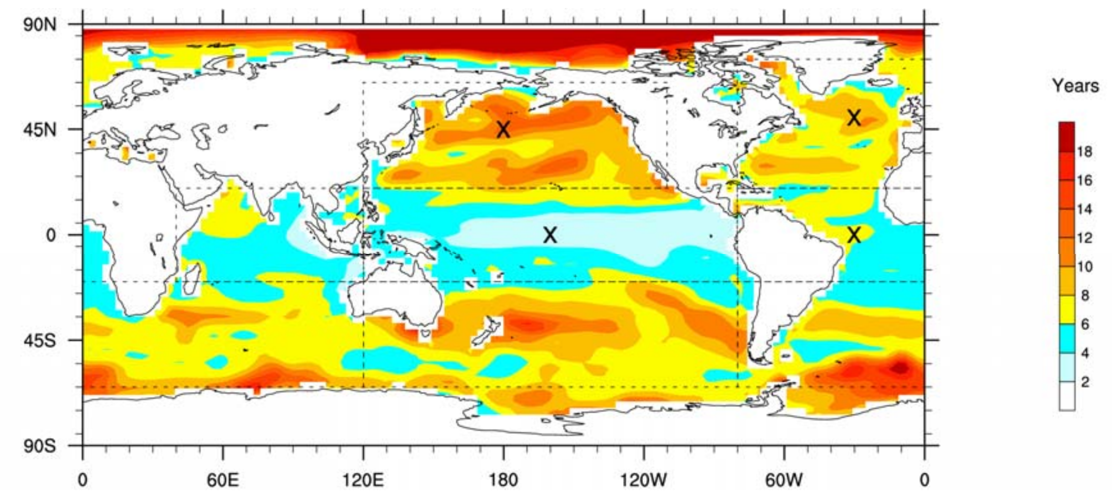
Decadal Predictability Limits for CCSM3 and CCSM4

Grant Branstator
Haiyan Teng

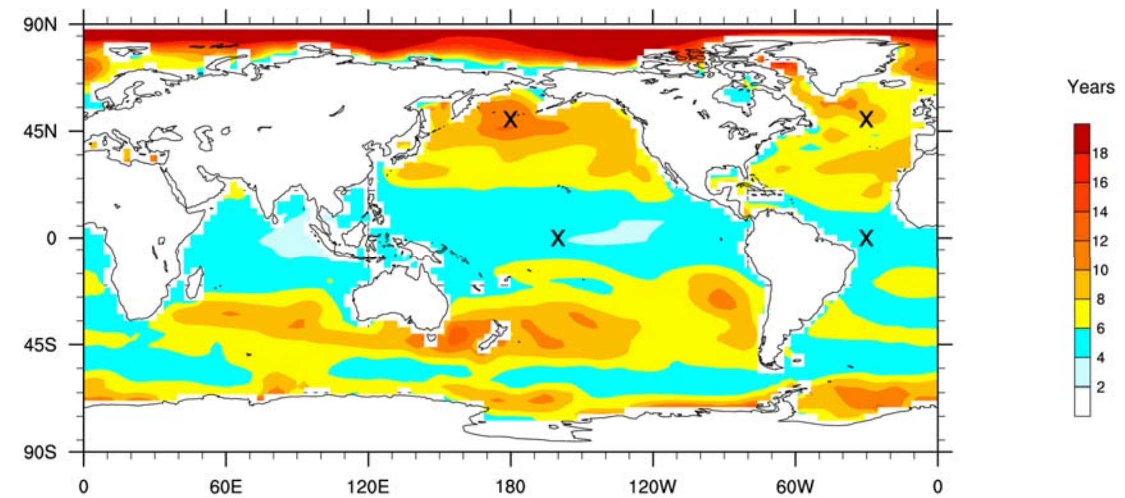
NCAR/CGD

T0-300m Characteristic Period

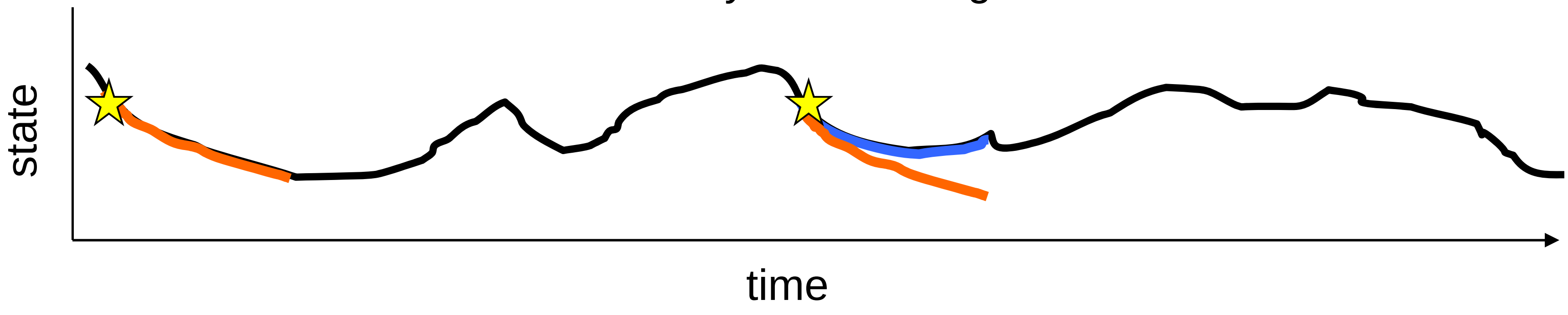
CCSM3

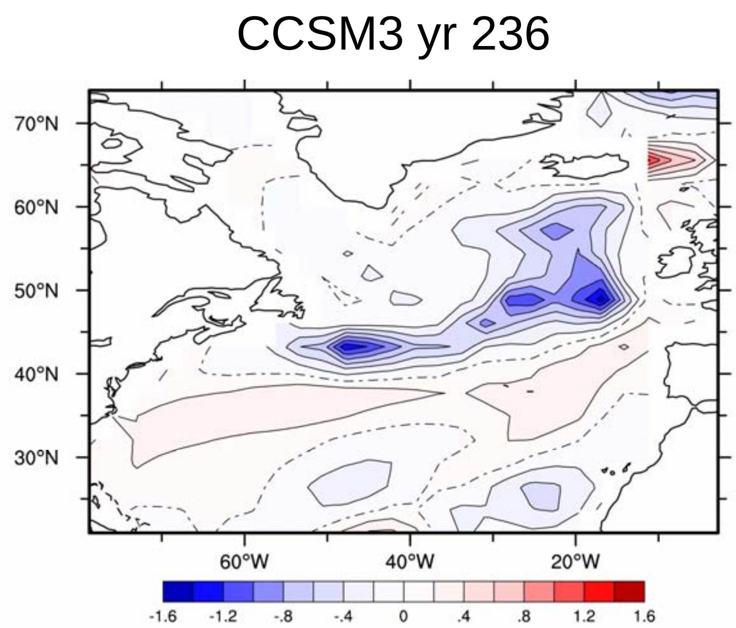


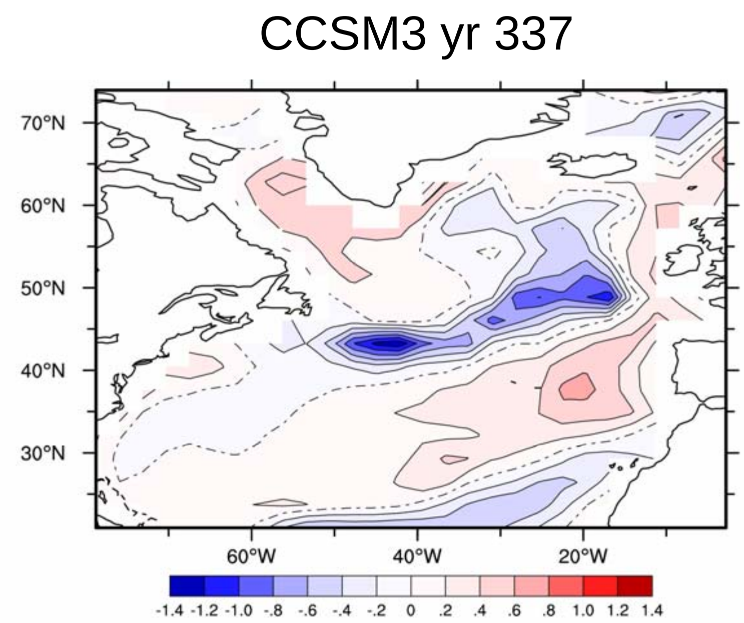
CCSM4

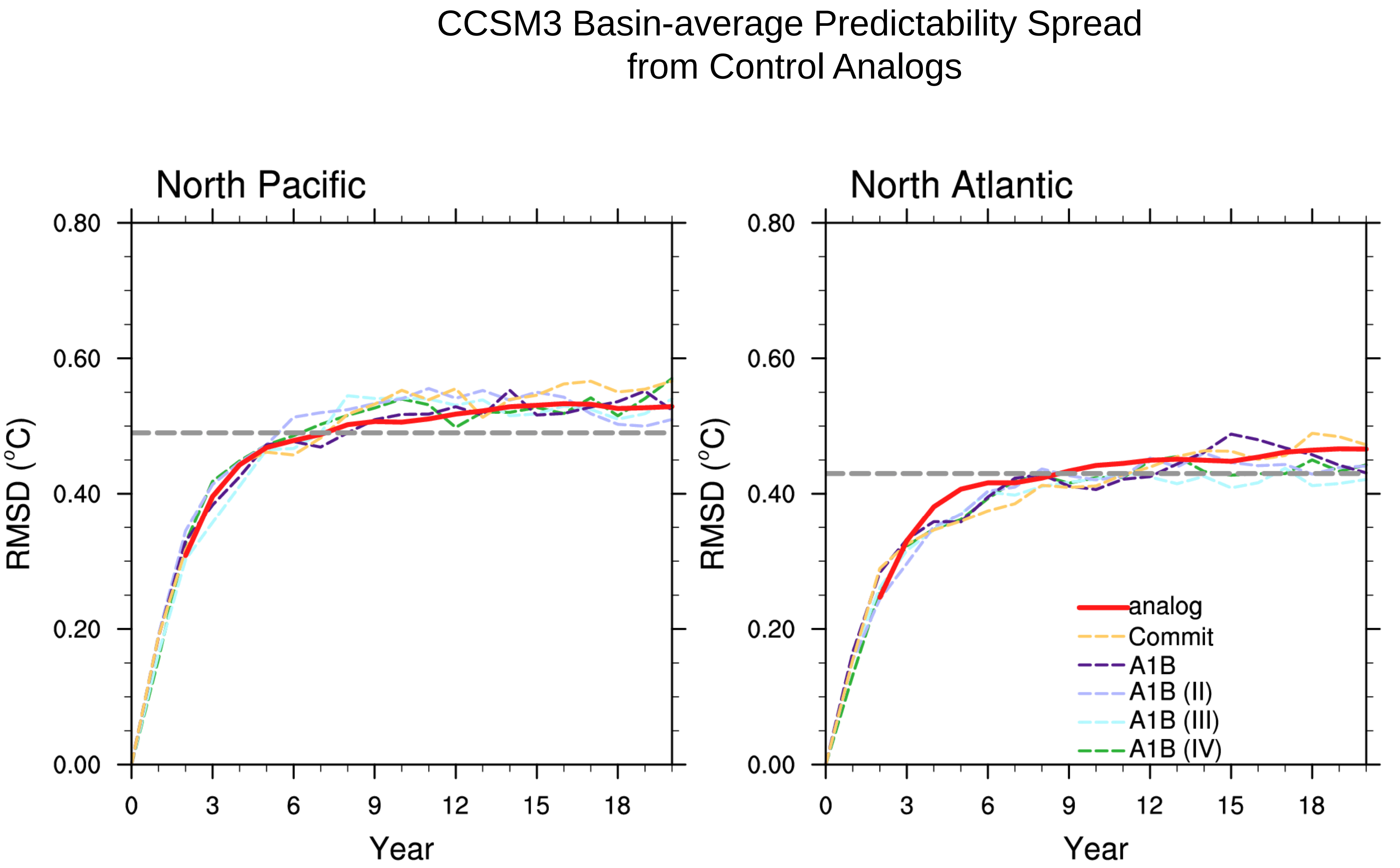


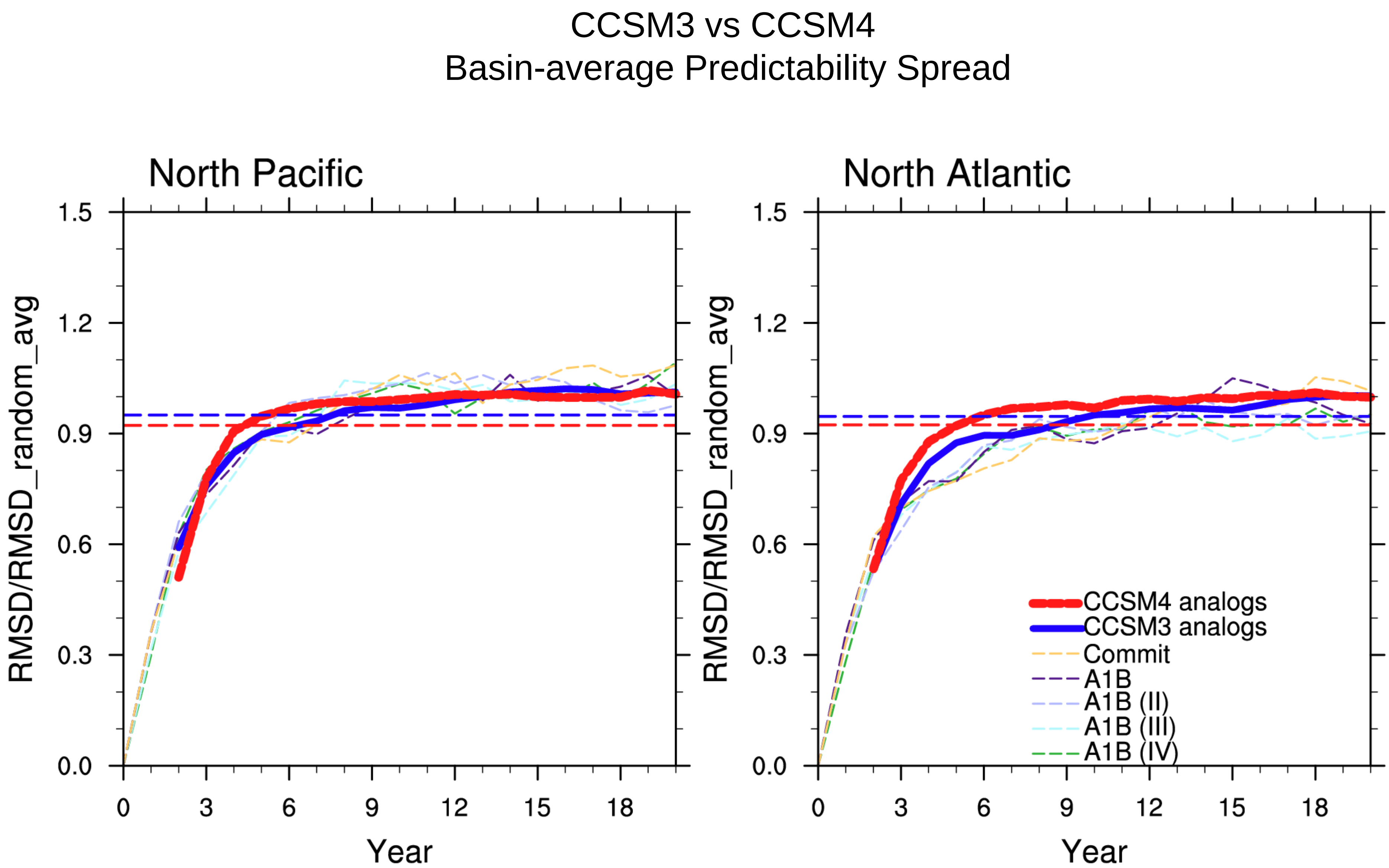
Predictability from Analogs



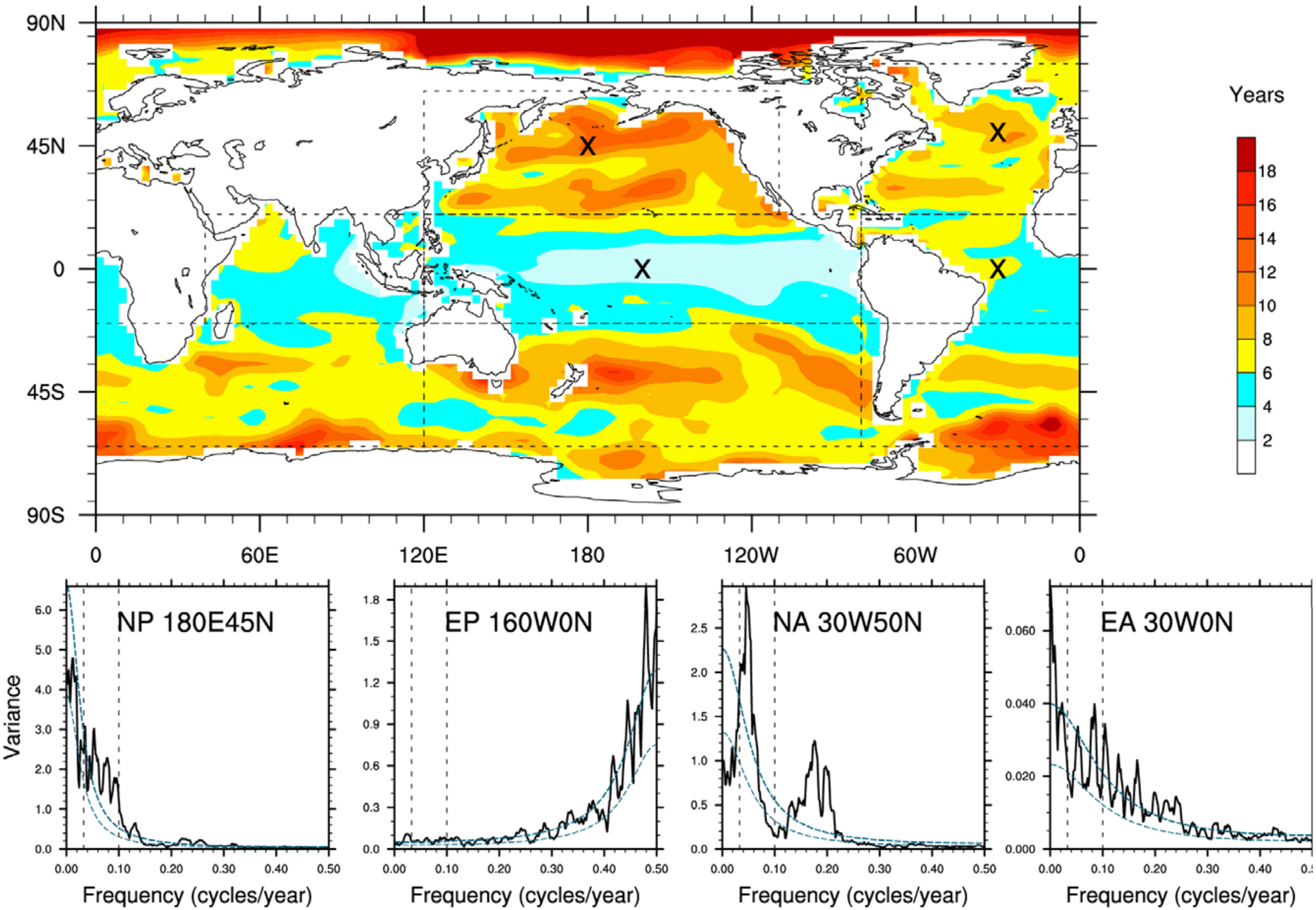





CCSM3 Basin-average Predictability Spread
from Control Analogs
North Pacific
North Atlantic
RMSD (^{o}C)
0.00
0.20
0.40
0.60
0.80
0
3
6
9
12
15
18
Year
analog
Commit
A1B
A1B (II)
A1B (III)
A1B (IV)

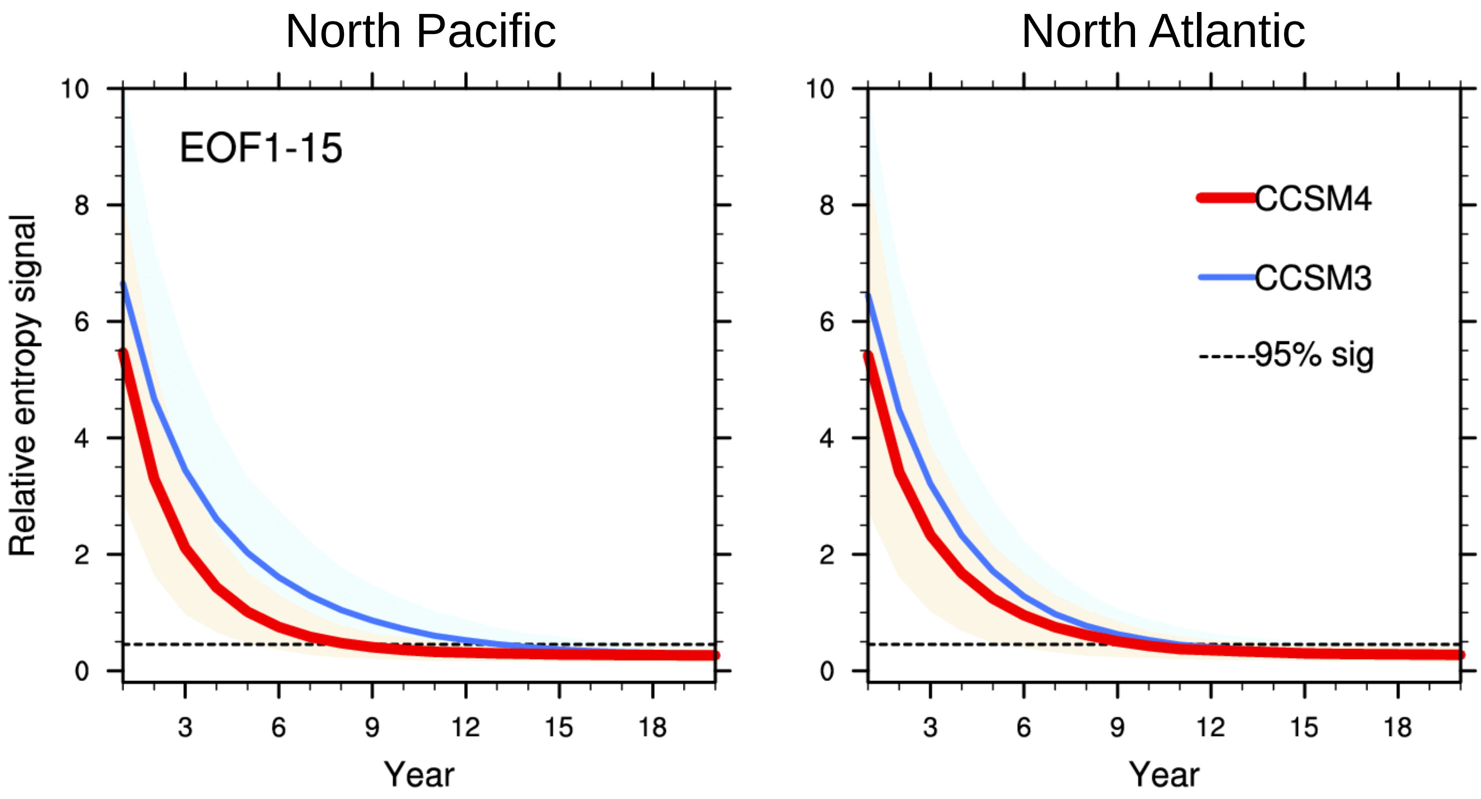

CCSM3 vs CCSM4
Basin-average Predictability Spread
North Pacific
North Atlantic
RMSD/RMSD_random_avg
Year
1.5
1.2
0.9
0.6
0.3
0.0
0
3
6
9
12
15
18
CCSM4 analogs
CCSM3 analogs
Commit
A1B
A1B (II)
A1B (III)
A1B (IV)

CCSM3 T0-300m Characteristic Period

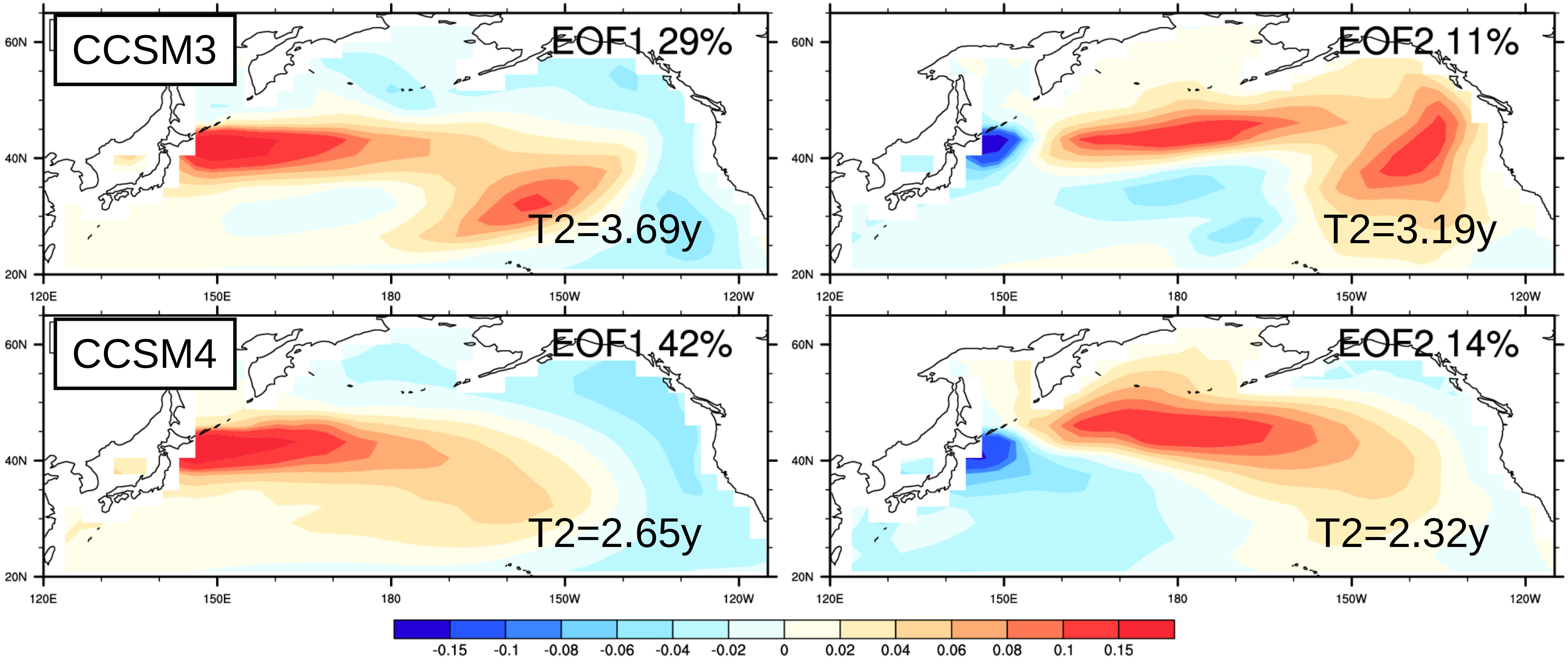


Predictability of Basin-wide, Ensemble Mean Anomalies
CCSM3 vs CCSM4
700 Case Average Using LIM

$$s_{t+1} = Ls_t \ , \ L = \mathrm{cov}(s_{t+1}, s_t)[\mathrm{cov}(s_t, s_t)]^{-1}$$

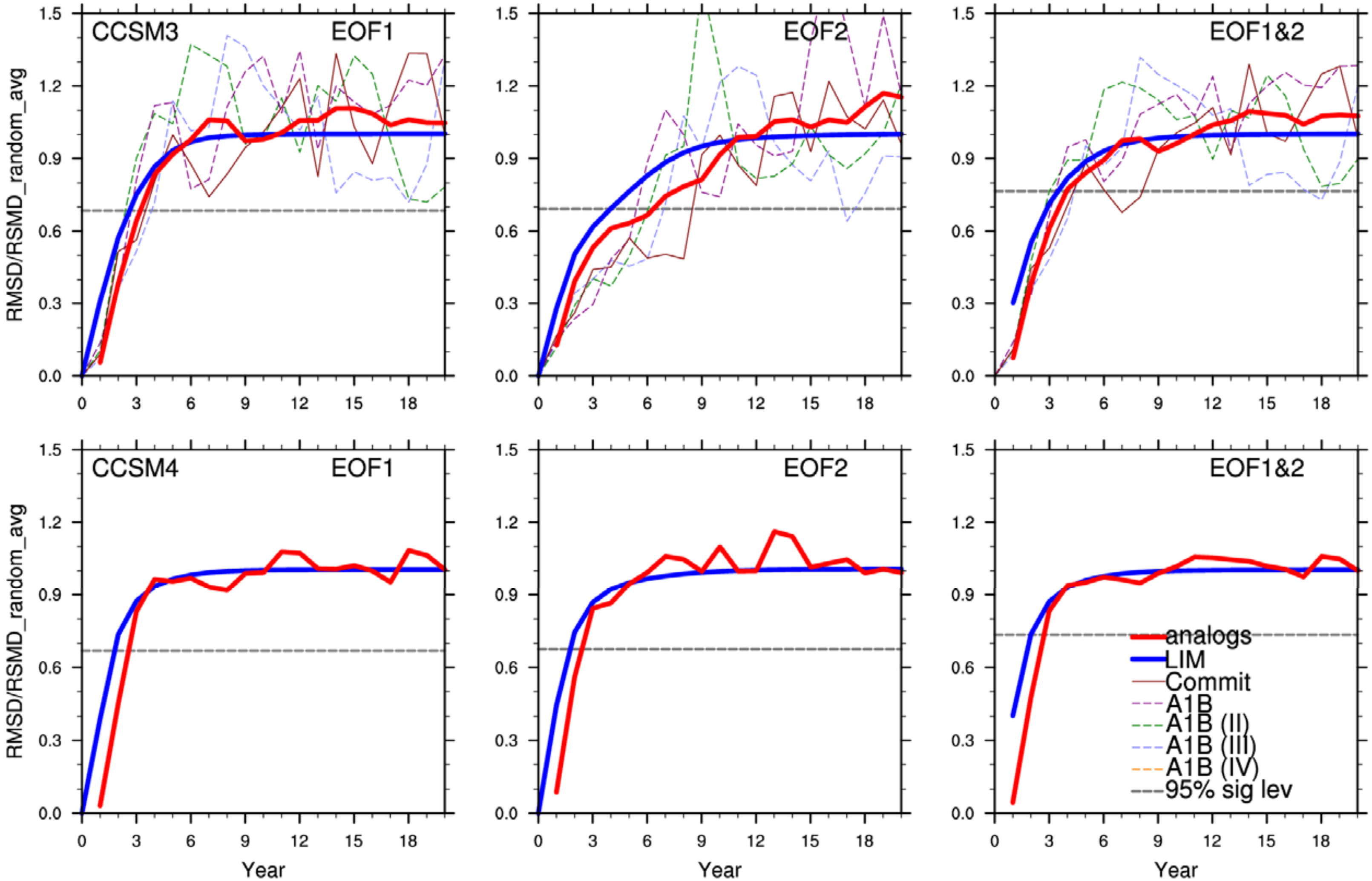


T0-300m Intrinsic Modes
North Pacific

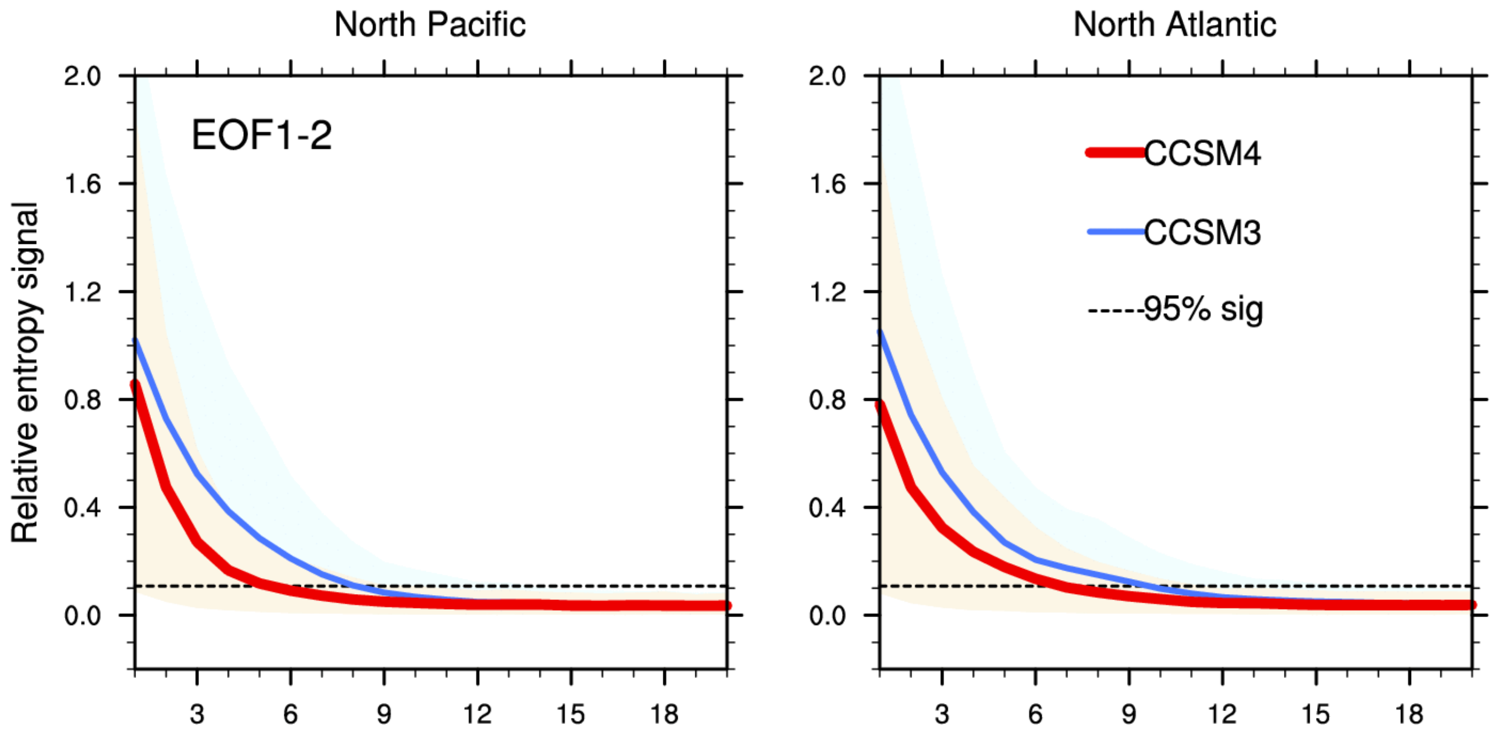


CCSM3 vs CCSM4 Spread

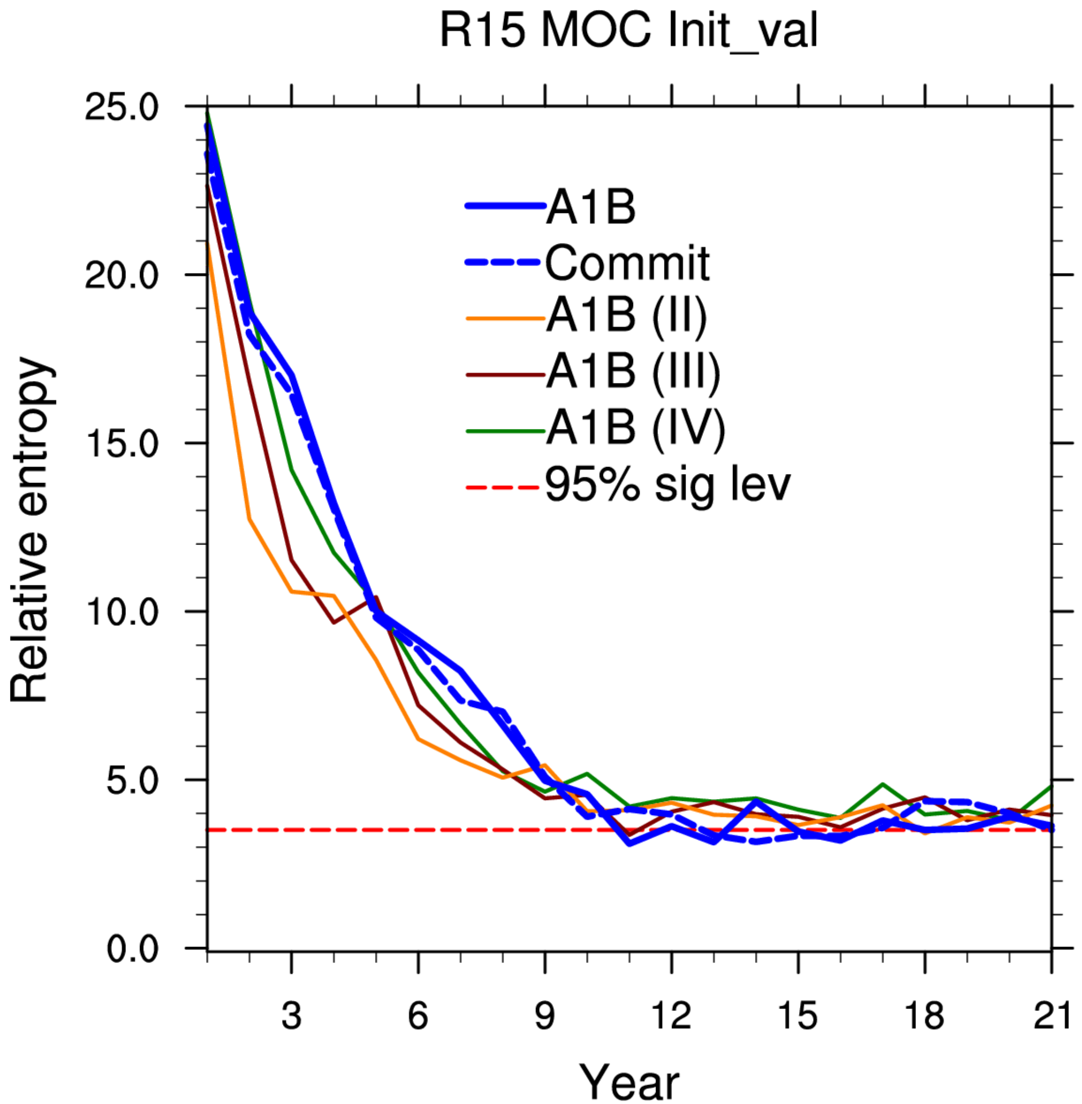
North Pacific Modes



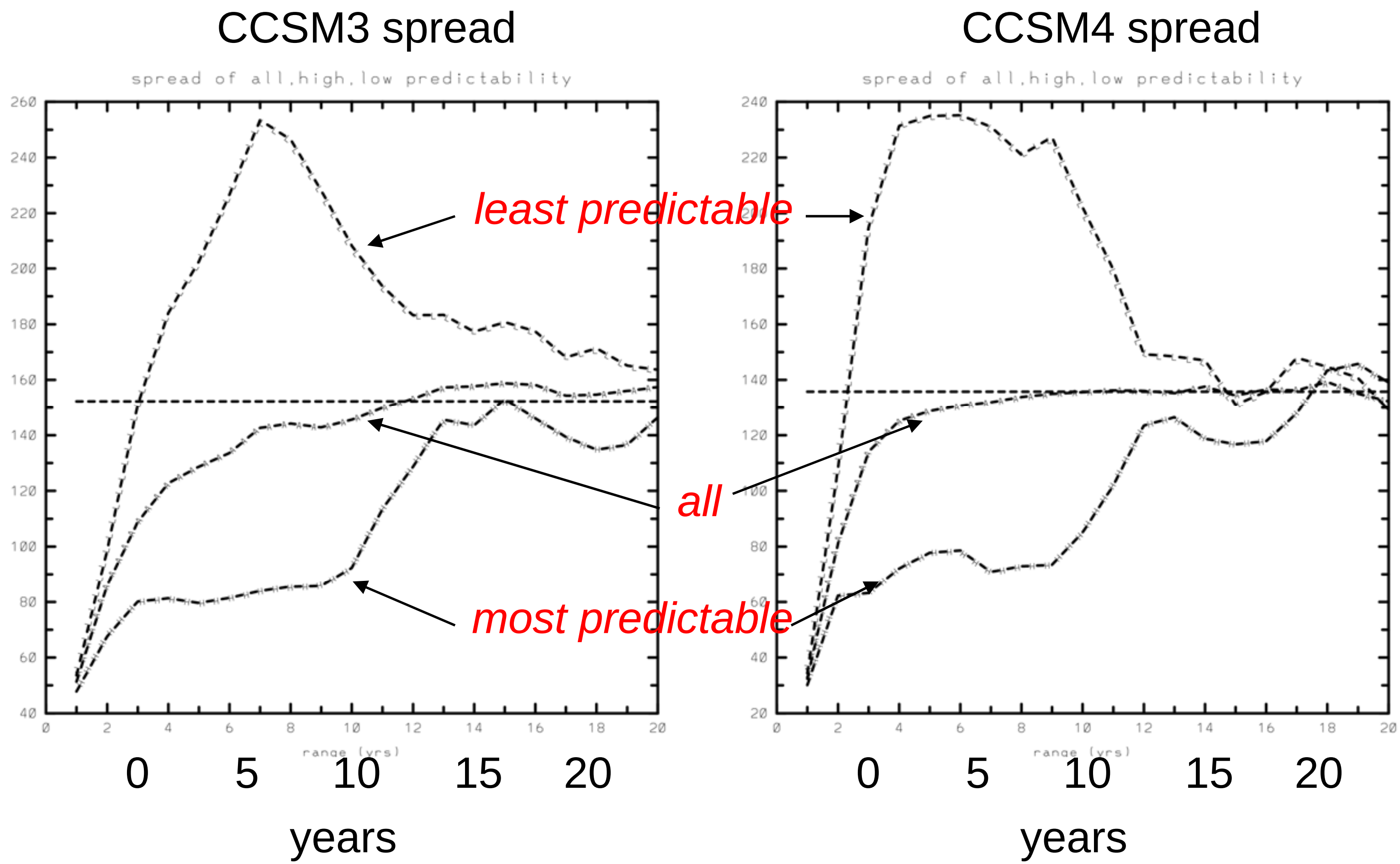
Predictability of PC1 + PC2 Ensemble Means
CCSM3 vs CCSM4
700 Case Average Using LIM



Predictability of the AMOC (15 EOFs)



Case Dependence of NPac Predictability



Bottom Line

1. *For T0-300 initial value predictability limit is 10-12 yrs in CCSM3 northern extratropical basins*

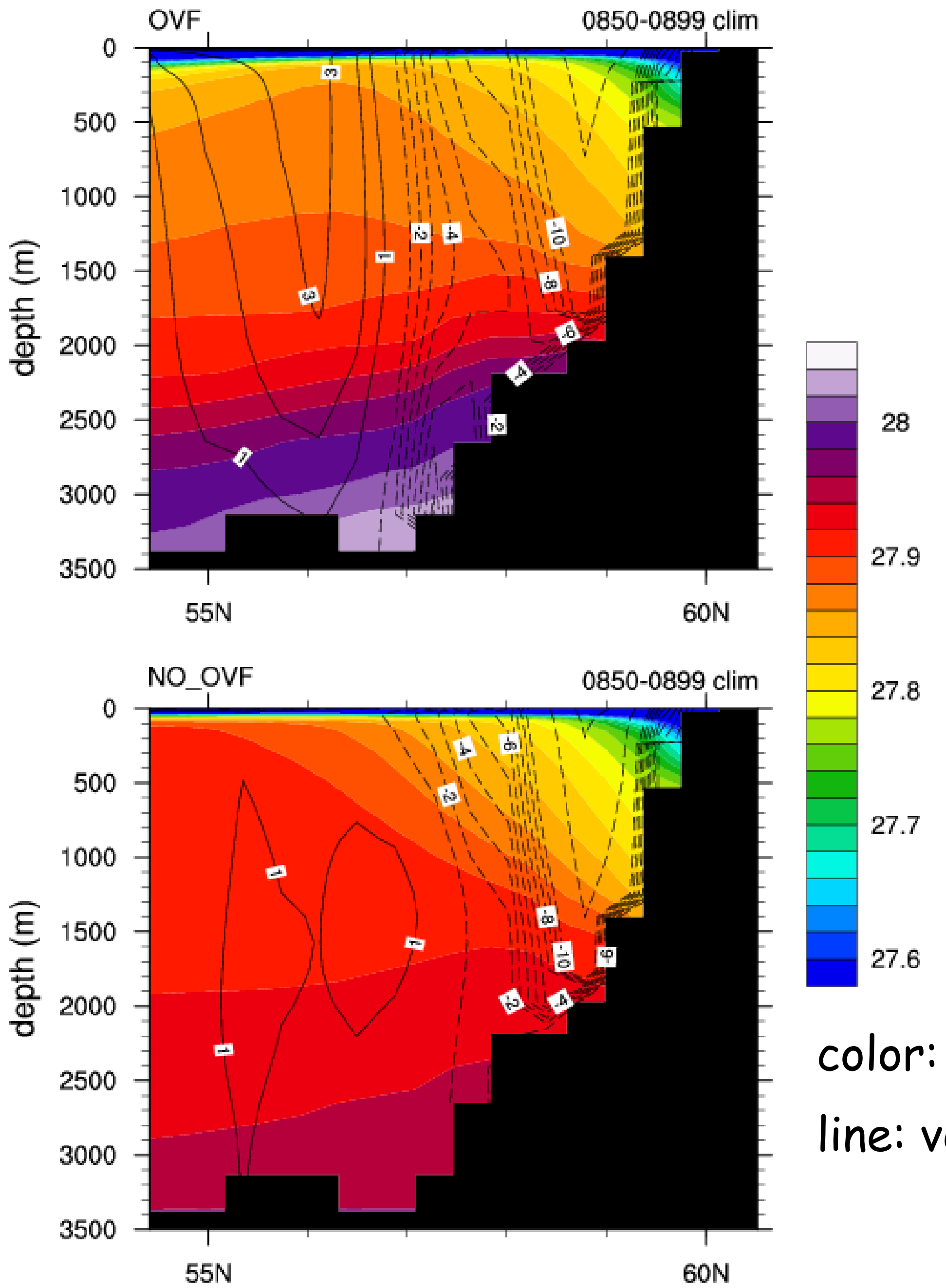
2. *Initial value predictability limit is even shorter in CCSM4 than CCSM3*

3. *Prominent modes do not have above average predictability in either model*

4. *Compared to CCSM3, prominent modes in CCSM4 have*

   - *different structure*
   - *shorter intrinsic time-scales*
   - *less predictability*

Density and section-normal velocity at 45°W



color: density (kg m^{-3})

line: velocity (cm s^{-1})

SOME STARTING DECISIONS….

- We use 1^o resolution versions of both the atmosphere and ocean models.
- We use full fields instead of the anomaly assimilation / initialization approaches, e.g., DePreSys of U.K. Met Office.
- Our first prediction experiments start from 1 January 2000.

Initialization Options for the Ocean Model

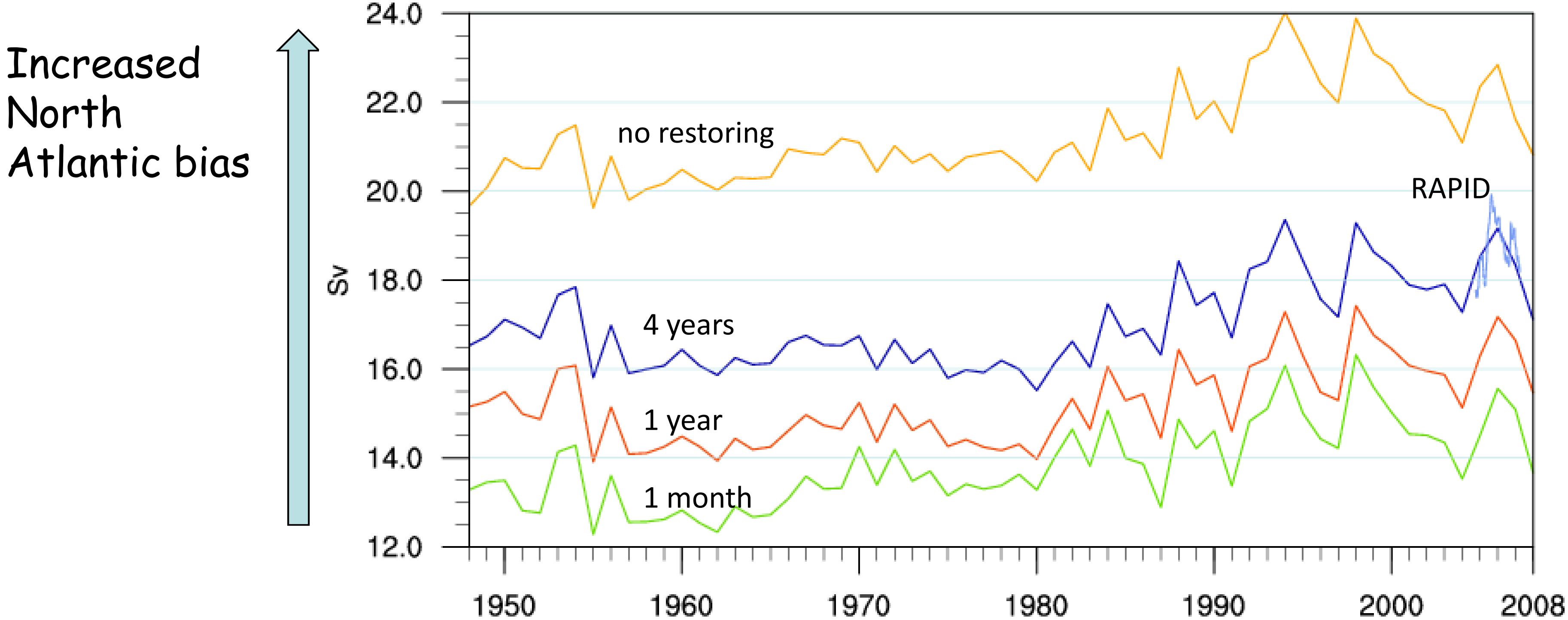
- Use 'hindcast' solutions from ocean-only or ocean-ice coupled simulations.

- Embark on our own ocean data assimilation using Data Assimilation Research Testbed (DART).

Sea ice, atmosphere, and land initial conditions ?????

AMOC Maximum Transports at 26.5°N in Ocean – Ice Hindcast Simulations with CORE2 Forcing

Impacts of surface salinity restoring



Strong salinity restoring reduces model error in the subpolar seas, but it

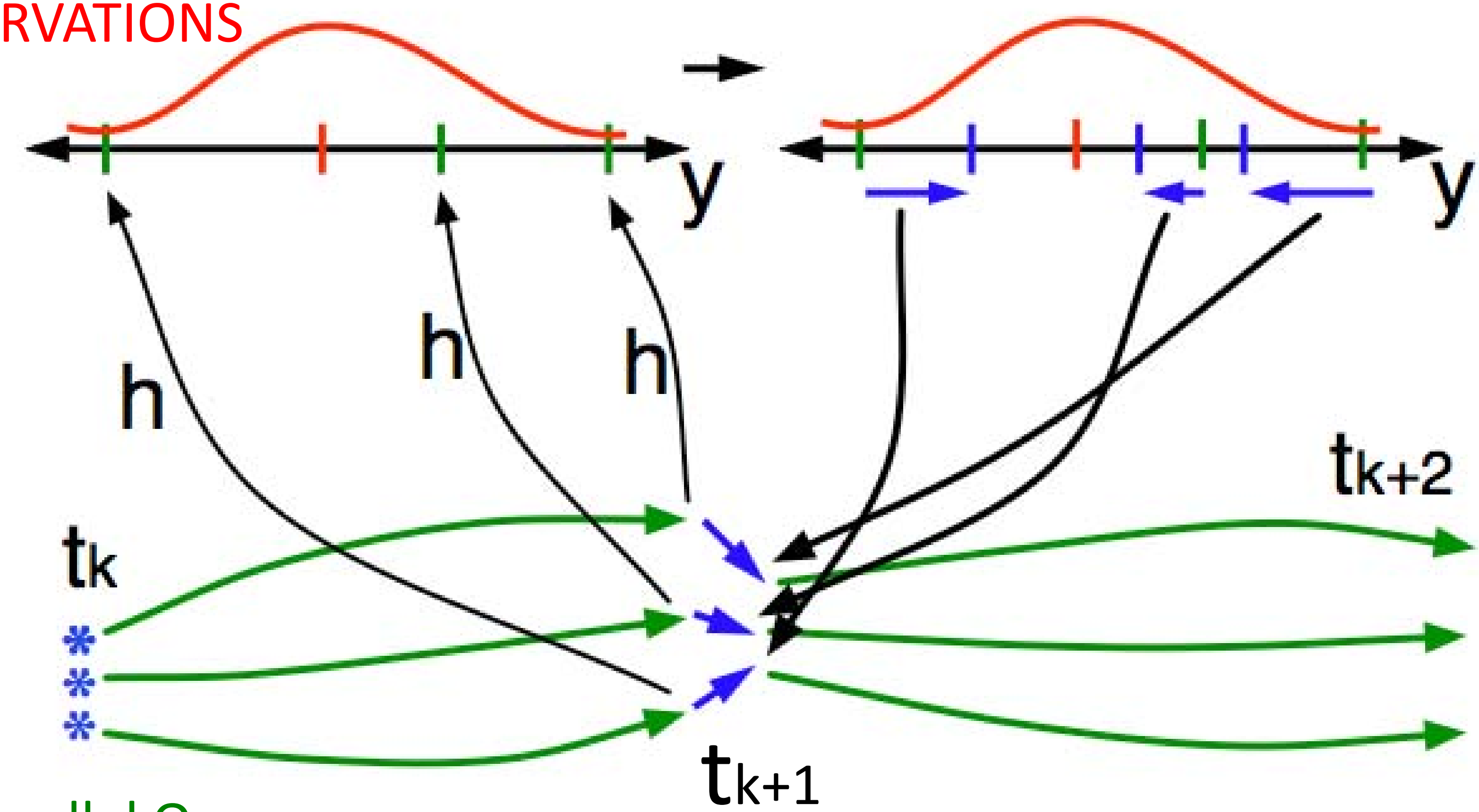
- weakens AMOC
- significantly damps AMOC variability north of 30°N
- reduces max Atlantic northward heat transport to below 1 PW

Ensemble Filter for Large Geophysical Models

To work with POP, DART just needs:

1. A way to make model forecasts;
2. Forward operators, h, interpolation.

OBSERVATIONS

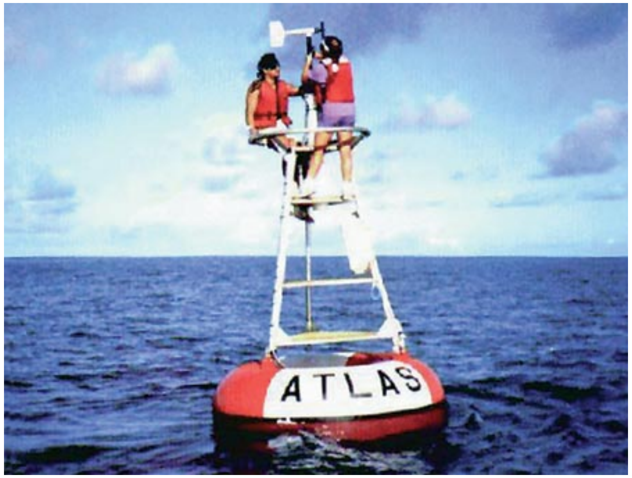


Parallel Ocean Program (POP)

Observations for 1998-1999

Temperature and salinity from World Ocean Database 2005.

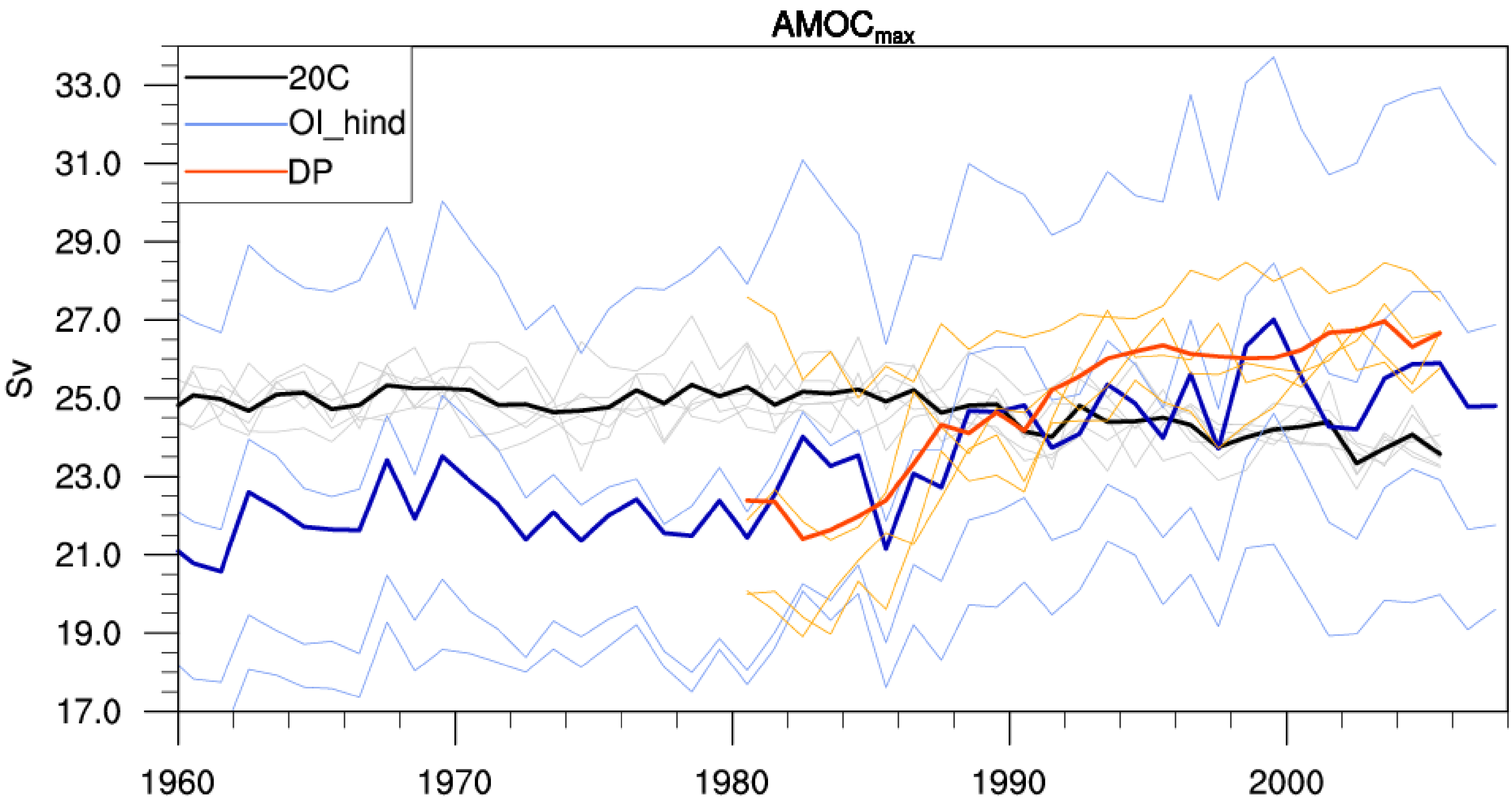
FLOAT_SALINITY	68200
FLOAT_TEMPERATURE	395032
DRIFTER_TEMPERATURE	33963
MOORING_SALINITY	27476
MOORING_TEMPERATURE	623967
BOTTLE_SALINITY	79855
BOTTLE_TEMPERATURE	81488
CTD_SALINITY	328812
CTD_TEMPERATURE	368715
STD_SALINITY	674
STD_TEMPERATURE	677
XCTD_SALINITY	3328
XCTD_TEMPERATURE	5790
MBT_TEMPERATURE	58206
XBT_TEMPERATURE	1093330
APB_TEMPERATURE	580111



Assume observational error SD of 0.5°C and 0.5 psu for T and S, respectively.
System is also ready to assimilate currents and sea surface height.

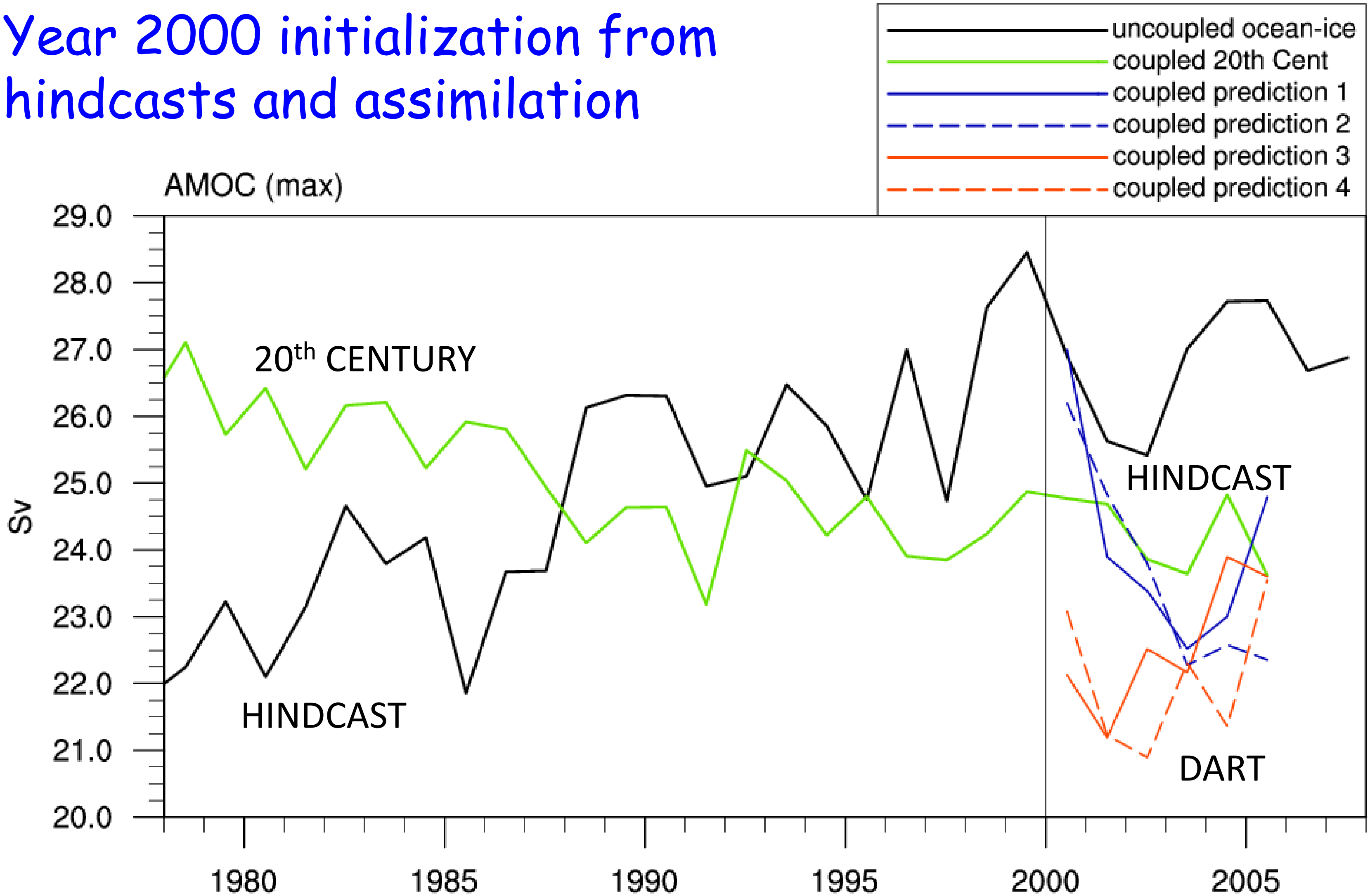
CCSM4 DECADAL PREDICTION SIMULATIONS

Year 1980 initialization from ocean-ice hindcasts

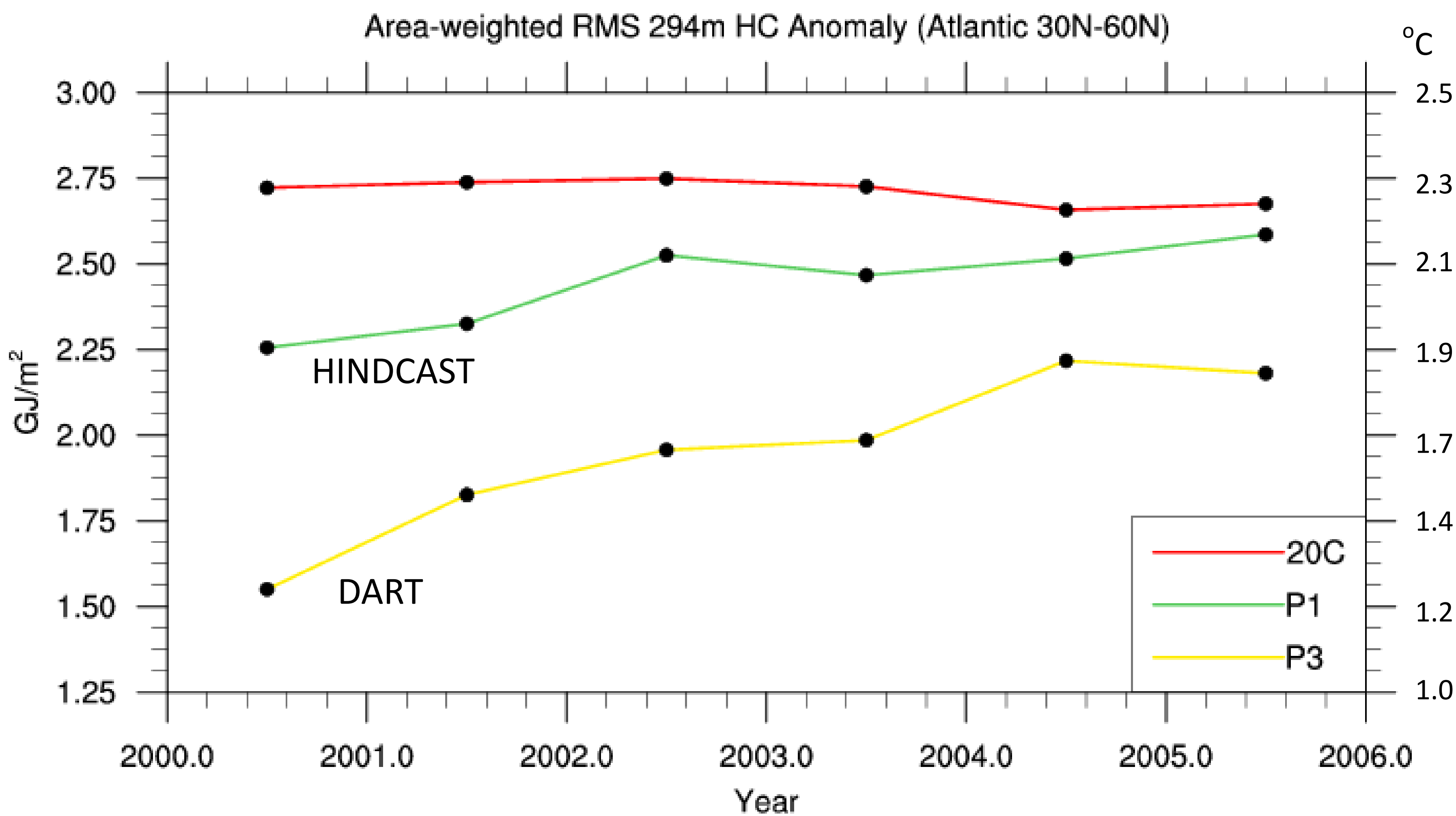


CCSM4 DECADAL PREDICTION SIMULATIONS

Year 2000 initialization from hindcasts and assimilation



Upper ocean (0-300 m) heat content anomaly in the North Atlantic



NEXT STEPS (Continued)

Extend the weakly coupled assimilation approach to cover first the 1 January 1998 – 31 December 2009 period (and than obtain 1970, 1975, … states).

Complete the assimilation initialized decadal prediction experiments.

Assess predictability of AMOC, upper-ocean heat content, etc. in the decadal prediction simulations.

Move towards fully coupled data assimilation.

Move towards high resolution data assimilation (0.1° in ocean and 0.25° in atmosphere).

Explore impacts of using currents and SSH in assimilation.

Open Questions and Challenges

- What are the mechanisms for decadal variability?
- To what extent is decadal variability predictable?
- What is the optimal initialization for the components?
- Does oceanic variability have atmospheric relevance?

- Length of assimilation integrations prior to the start of prediction simulations
- Coupling shock and model drift issues