Decadal Variability:
The newest scientific frontier for understanding & prediction

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OUTLINE

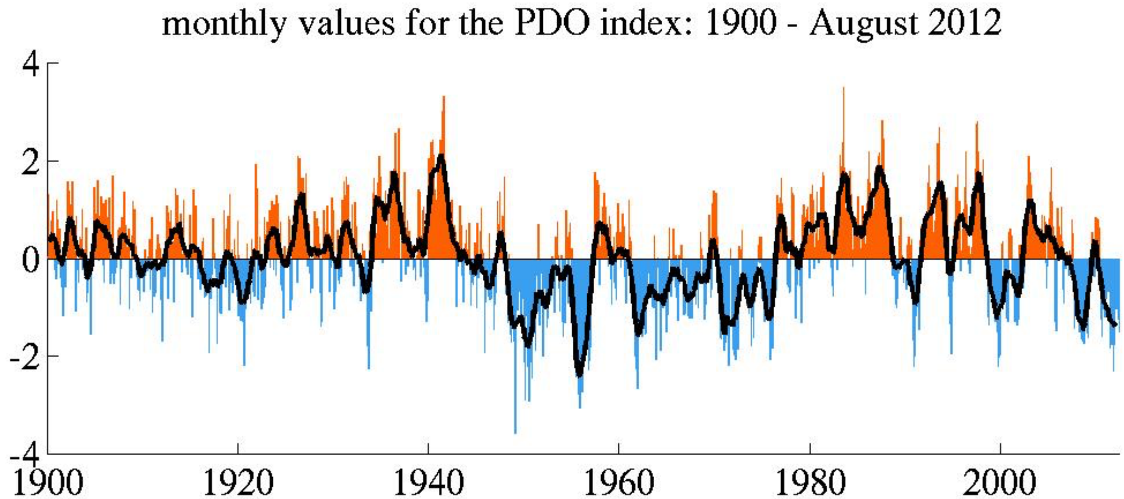
- Background
- Large-scale "Modes" of Variability
- Experimental Decadal Prediction
- Long-lead Predictions of Interannual Variability
- Summary

BACKGROUND

… Decadal Variability

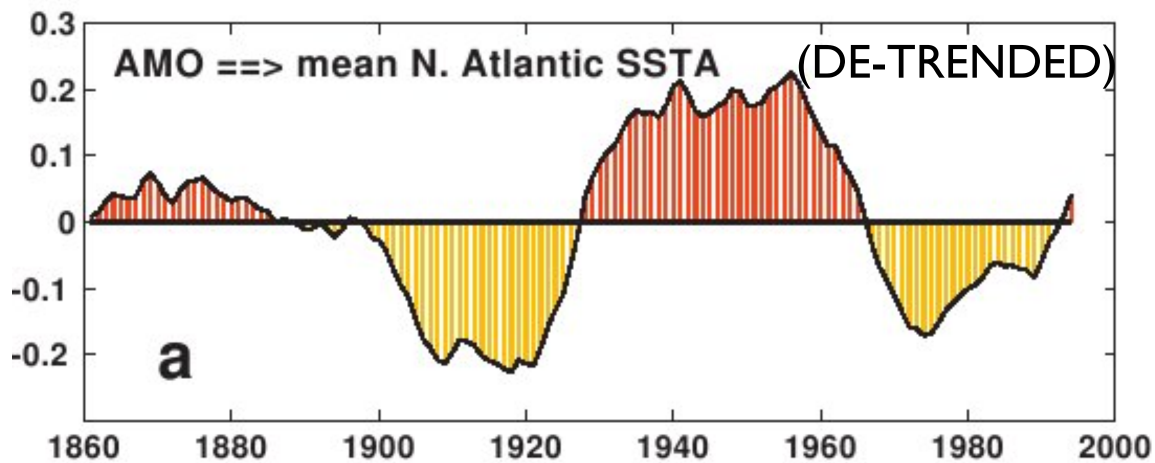
- What is it?
- Why is it important?
- How important is it?

Pacific Decadal Oscillation (PDO)



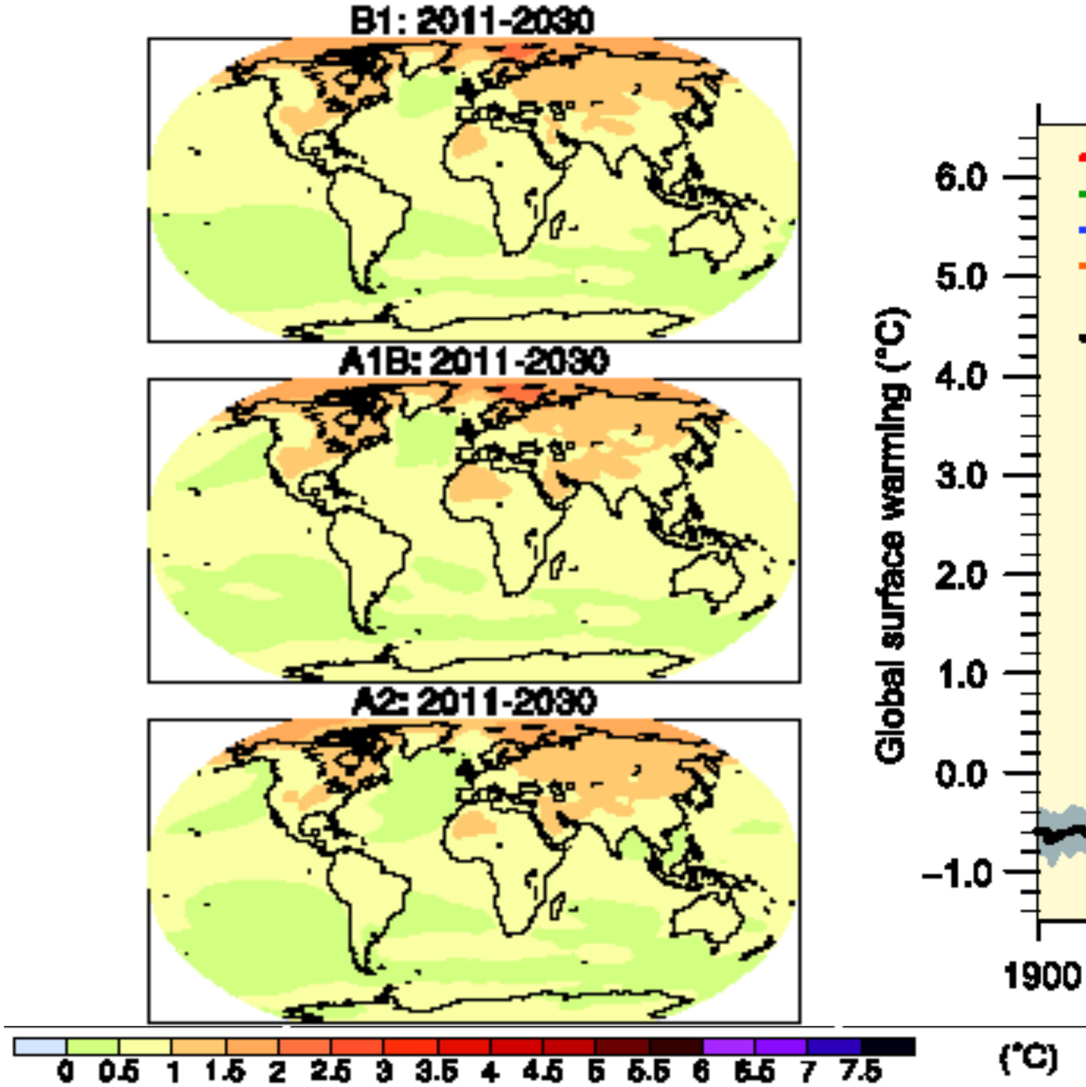
10-40+ year timescale

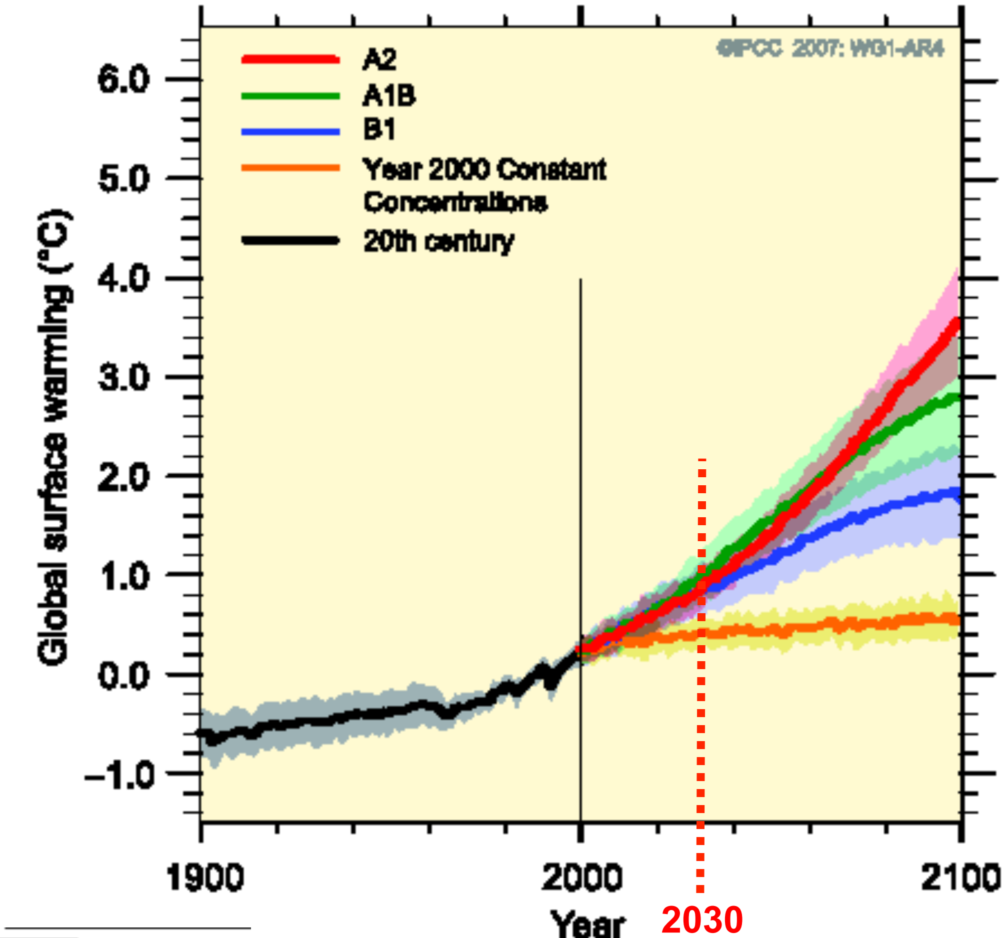
Atlantic Multi-decadal Oscillation (AMO)



50-100 year timescale

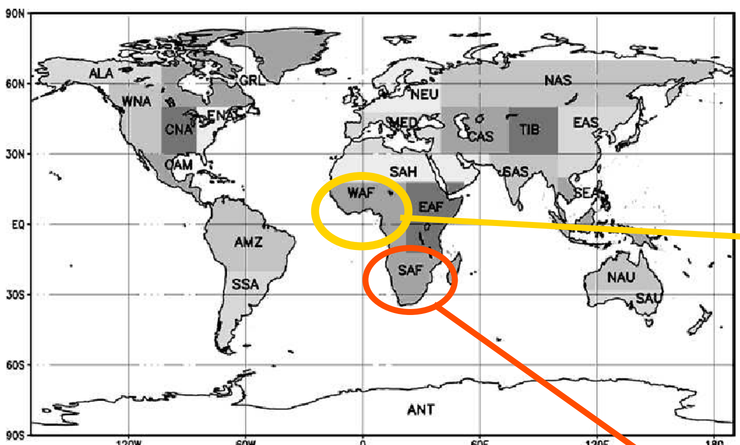
Global Climate Change Projections





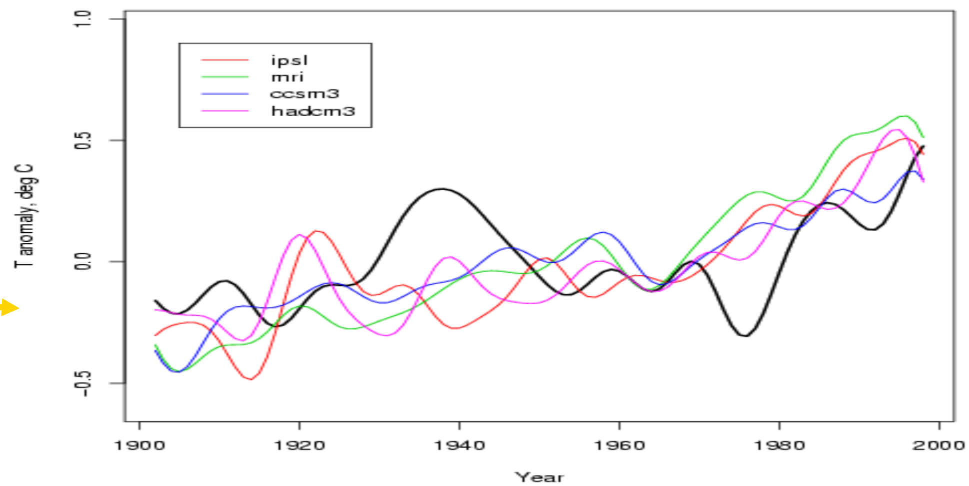
Source: IPCC 4th Assessment Report, Working Group 1

Regional Scale Decadal Predictions?

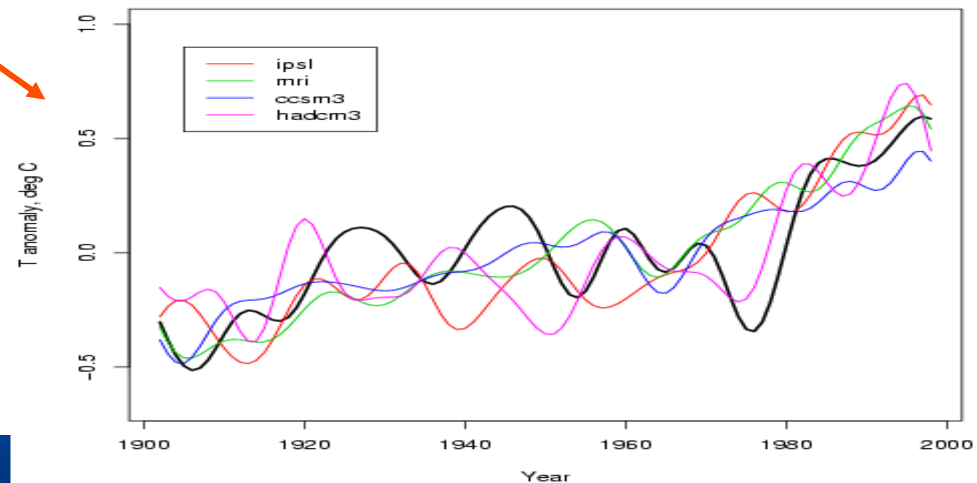


ALA	Alaska	NEU	Northern Europe	NAS	Northern Asia
WNA	Western North America	MED	Mediterranean	TIB	Tibet
CNA	Central North America	CAS	Central Asia	EAS	Eastern Asia
ENA	Eastern North America	SAH	Sahara	SAS	Southern Asia
GRL	Greenland	WAF	West Africa	SEA	South East Asia
CAM	Central America	EAF	East Africa	NAU	Northern Australia
AMZ	Amazonia	SAF	Southern Africa	SAU	Southern Australia
SSA	Southern South America	ANT	Antarctic		

Western Africa : Annual-Mean Temperature



Southern Africa : Annual-Mean Temperature



Climate Change **Projections cannot** deliver predictions of decadal variability

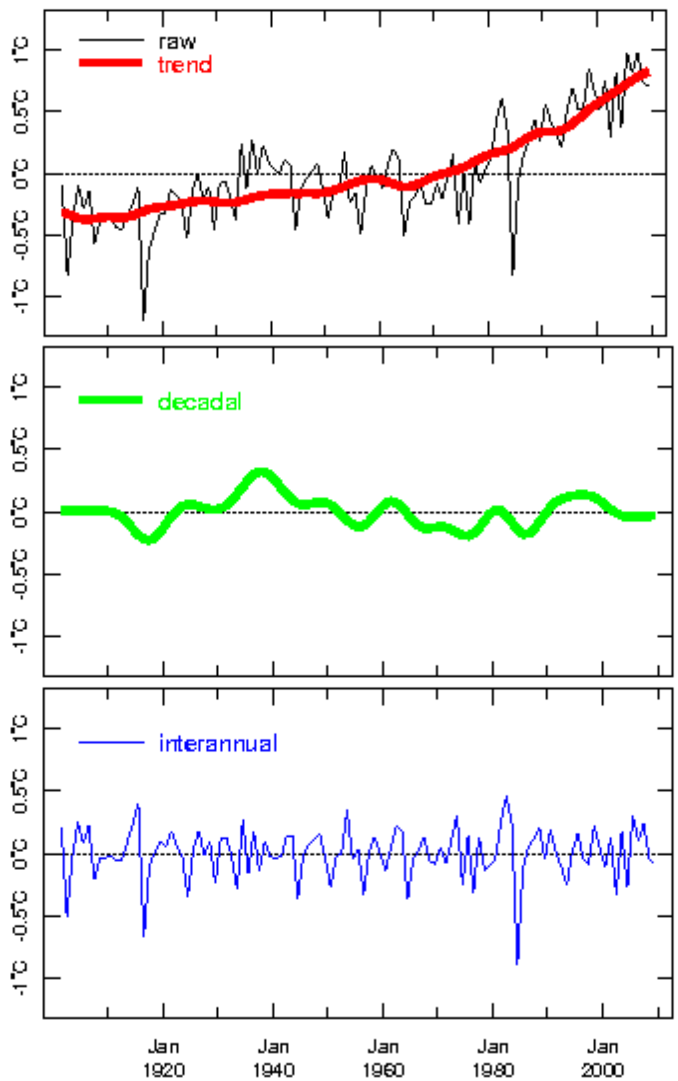
Climate Variability & Change Globally

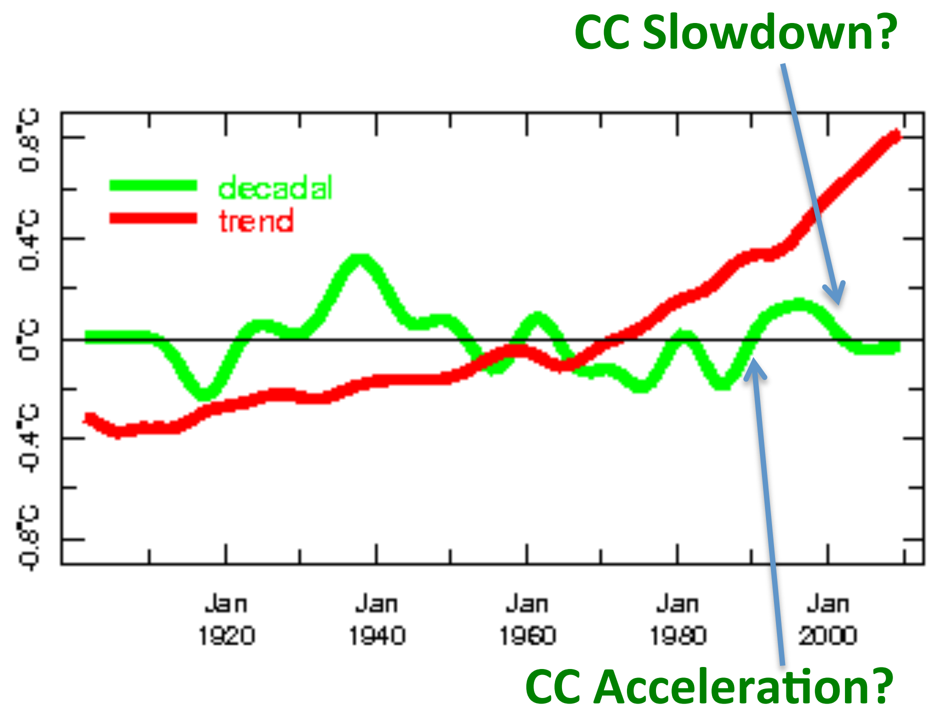
Annual Mean Temperature

63%

9%

27%

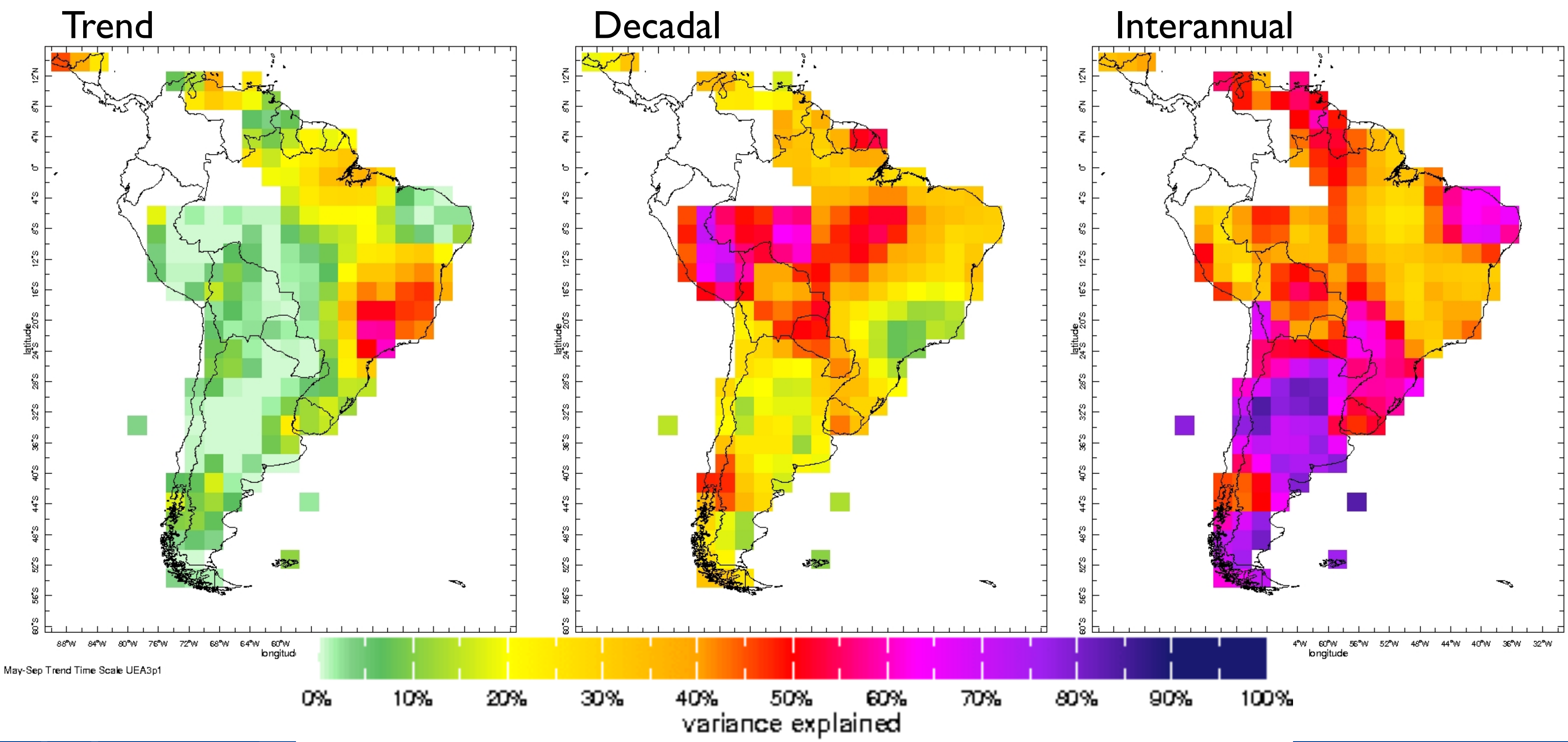




(Greene, Goddard & Cousin, *EOS*, 2010)

Timescale Decomposition for South America

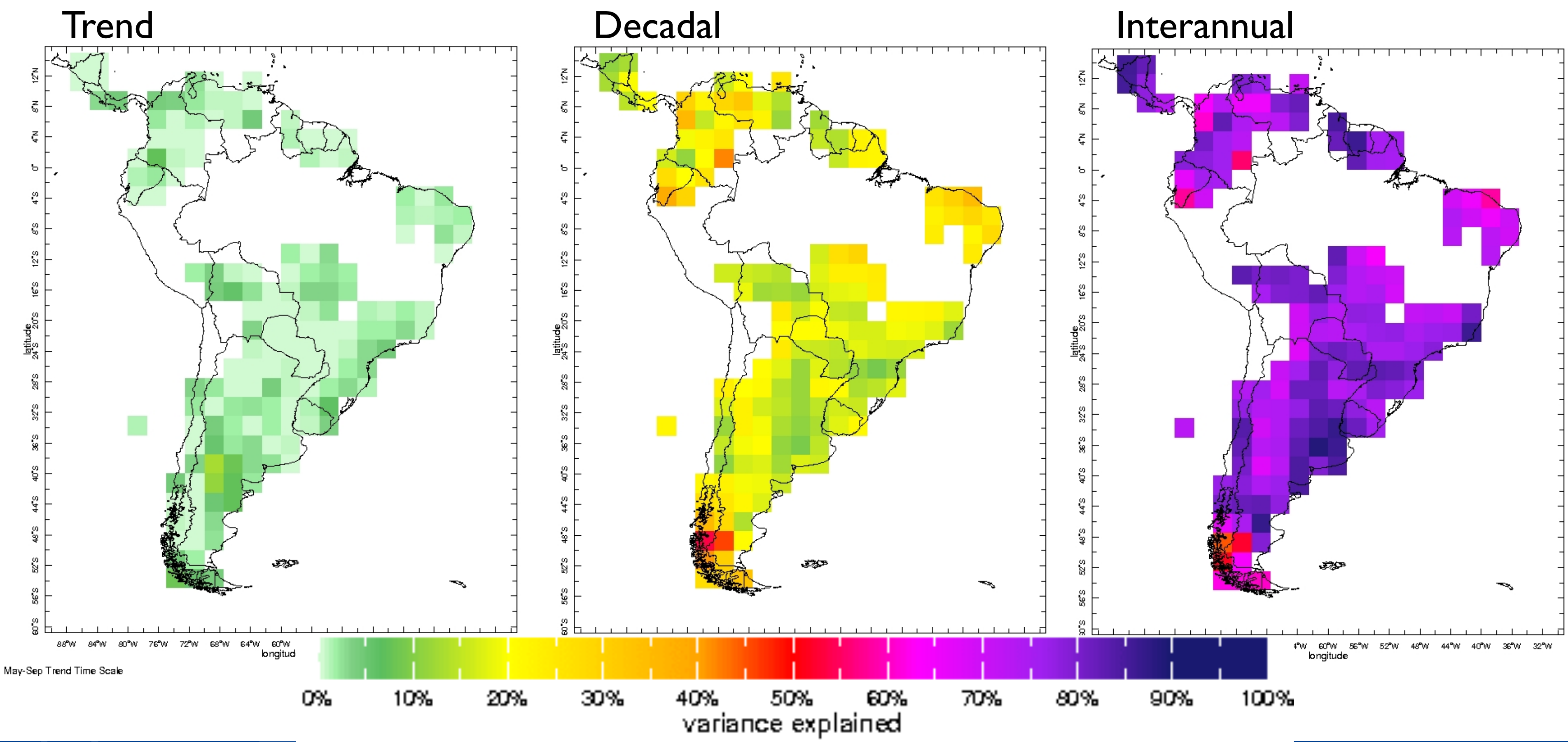
20th Century Observed TEMPERATURE – May-September



http://iridl.ldeo.columbia.edu/maproom/Global/Time_Scales/

Timescale Decomposition for South America

20th Century Observed PRECIPITATION– May-September



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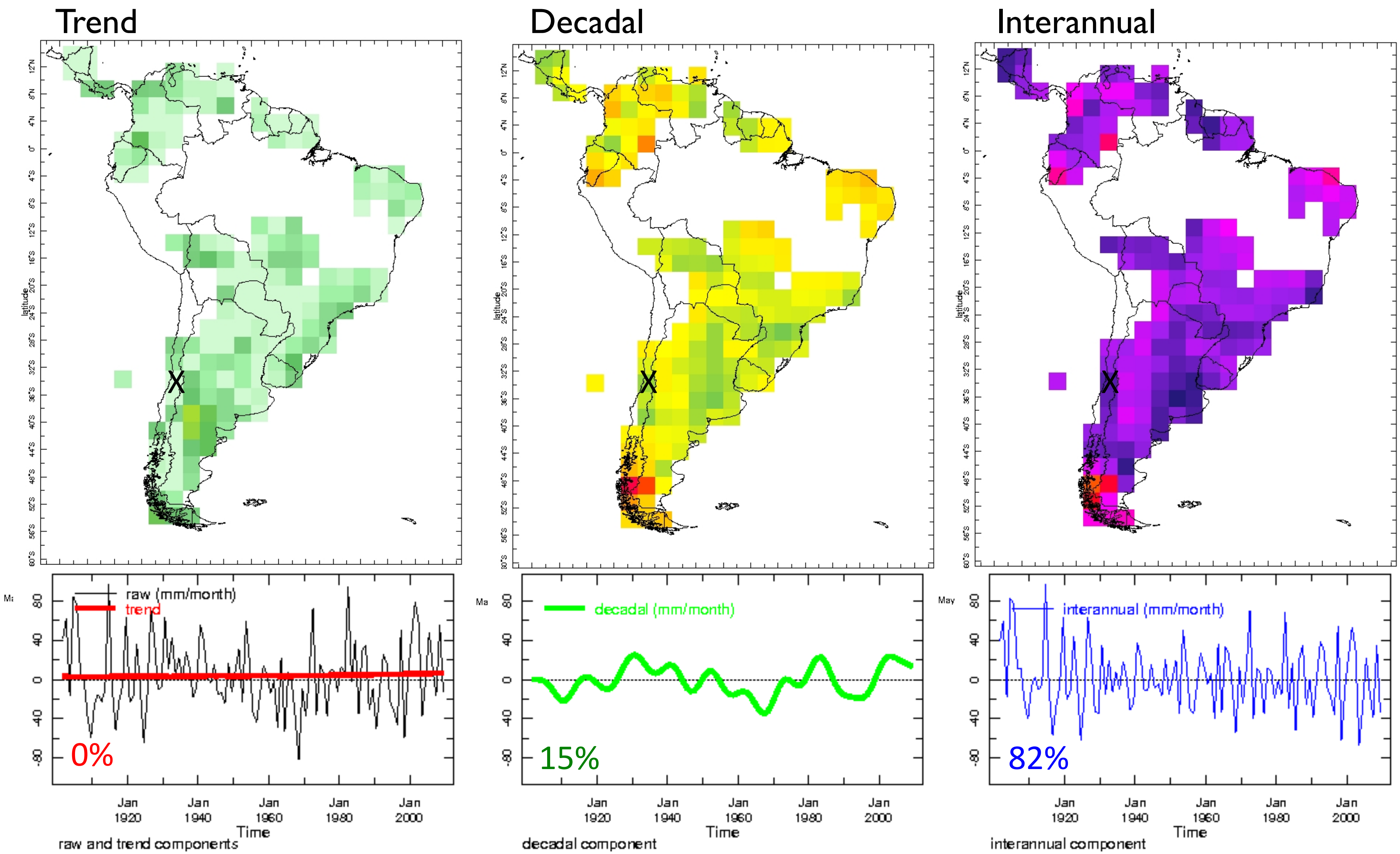
20th Century Observed PRECIPITATION– May-September



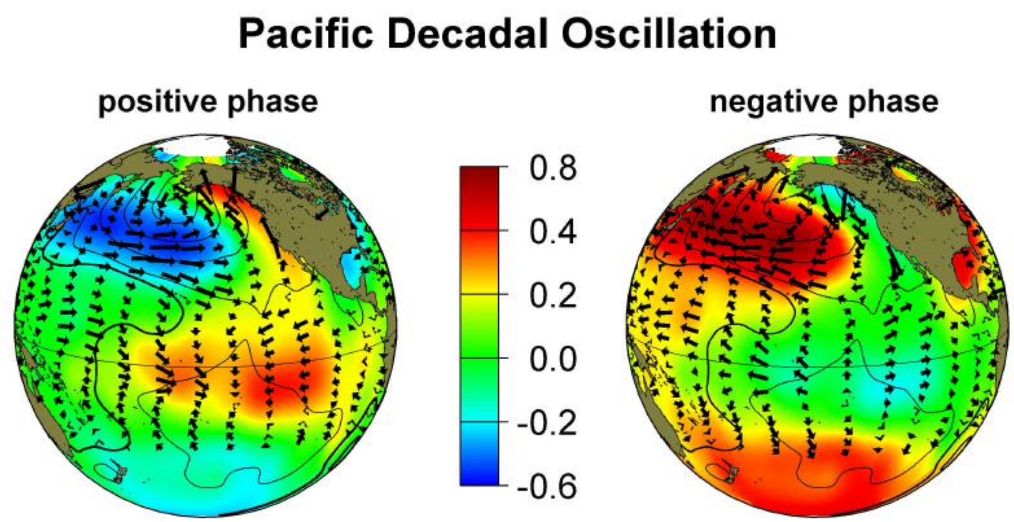
LARGE-SCALE "MODES" OF VARIABILITY

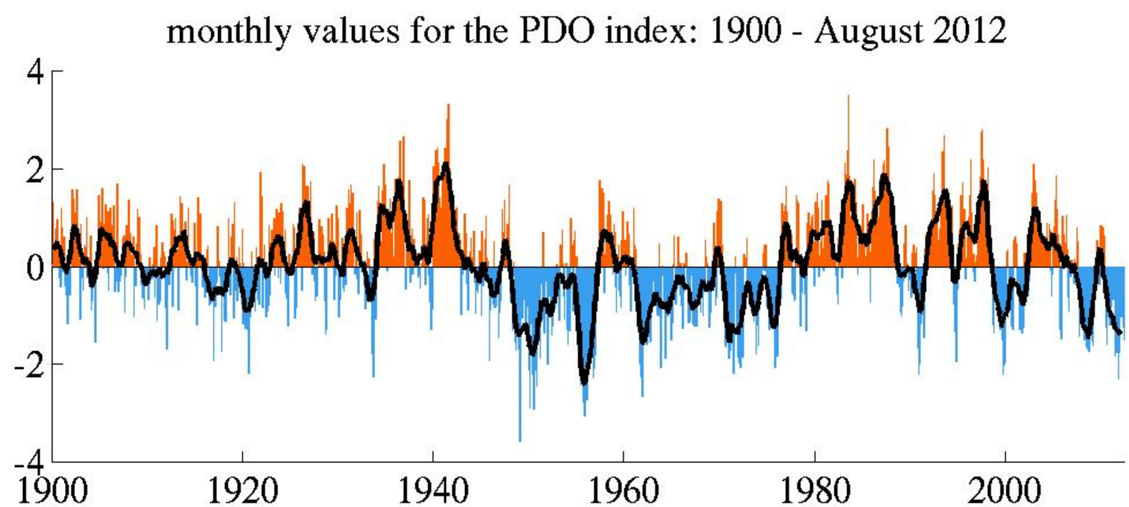
- Atlantic Multi-decadal Variability (AMV or AMO)
- Pacific Decadal Variability (PDV or PDO or IPO)
- Regional Climate Impacts

Decadal Variability

PDO (Pacific Decadal Oscillation) – The principal mode in the Pacific

- PDO refers mainly to N. Pacific sea surface temperatures (SSTs).
- The characteristic *pattern,* shows SST in the tropical Pacific out of phase with that in the higher latitudes.
- IPO (Inter-decadal Pacific Oscillation) considers both hemispheres





(Source: http://jisao.washington.edu/pdo)

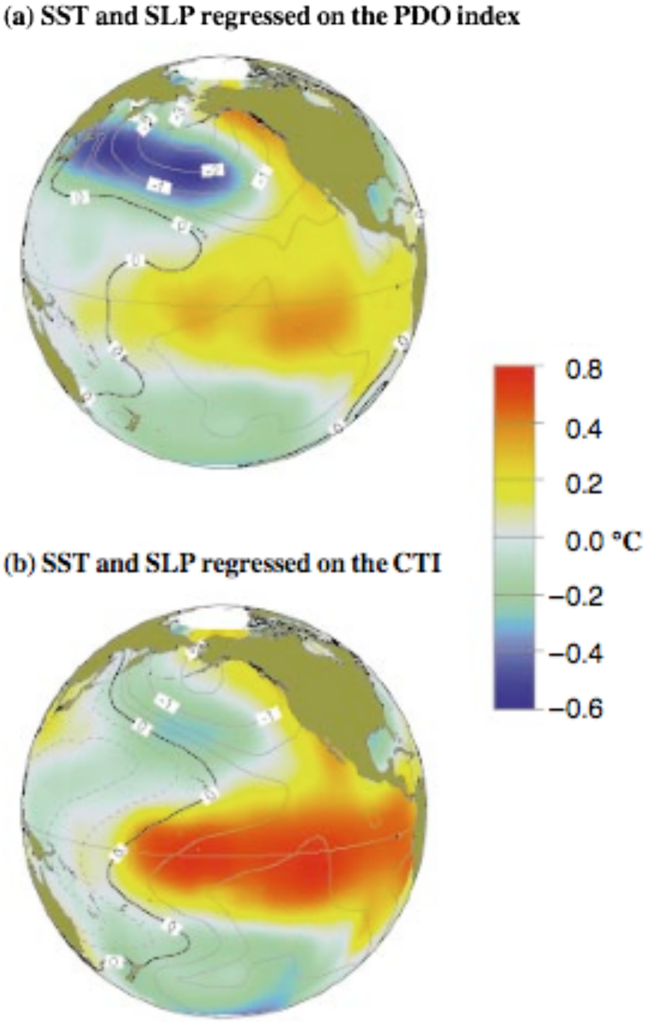


FIG. 2. COADS SST (color shaded) and SLP (contoured) regressed upon (a) the PDO index and (b) the CTI for the period of record 1900–92. Contour interval is 1 mb, with additional contours drawn for +/−0.25 and 0.50 mb. Positive (negative) contours are dashed (solid).

Mantua et al. (1997; *BAMS*)

- the PDO has a similar structure to ENSO, but its amplitude is greatest over the North Pacific
- degree of equatorial symmetry suggests tropical forcing

PDO Mechanism?

Observed ENSO Teleconnections

Take average SST anomaly averaged over box shown below, then correlate that time series with SST anomalies in the rest of the world ocean

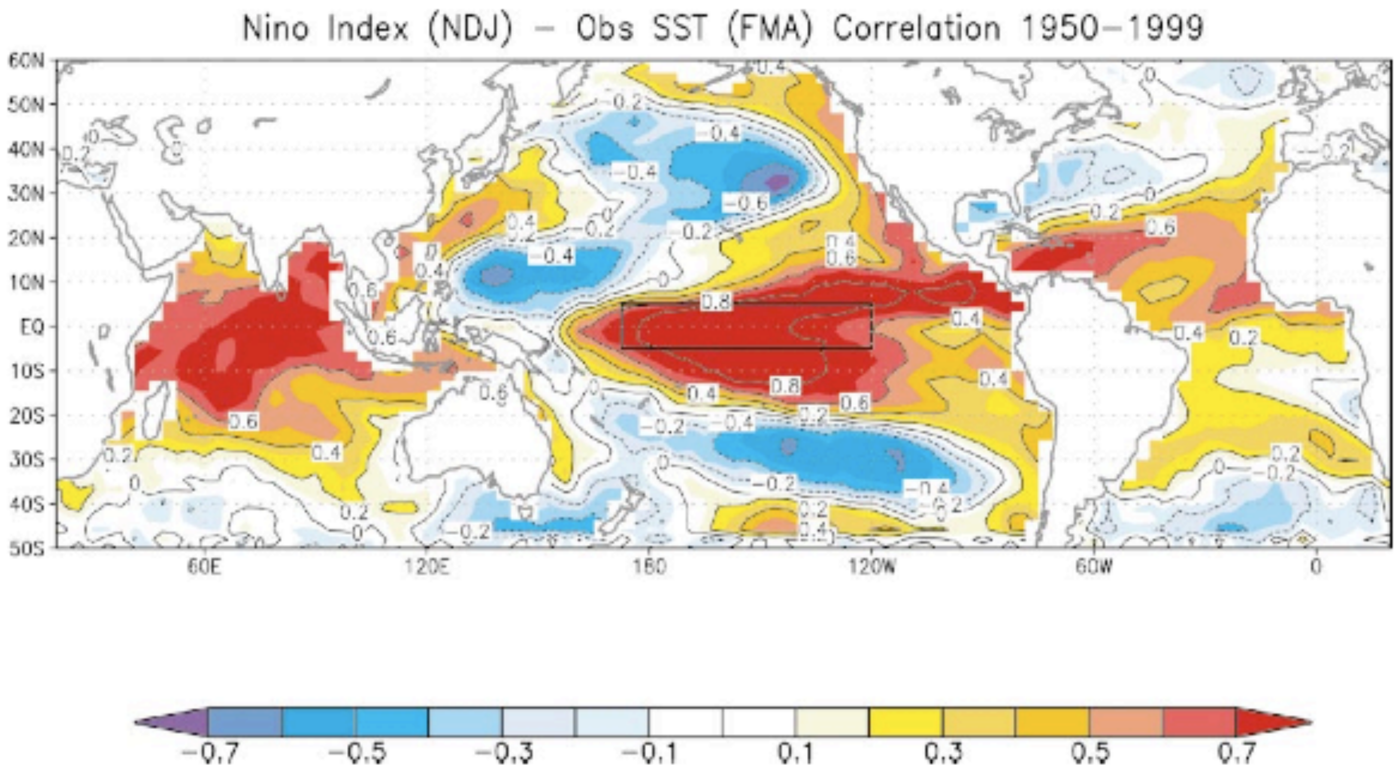
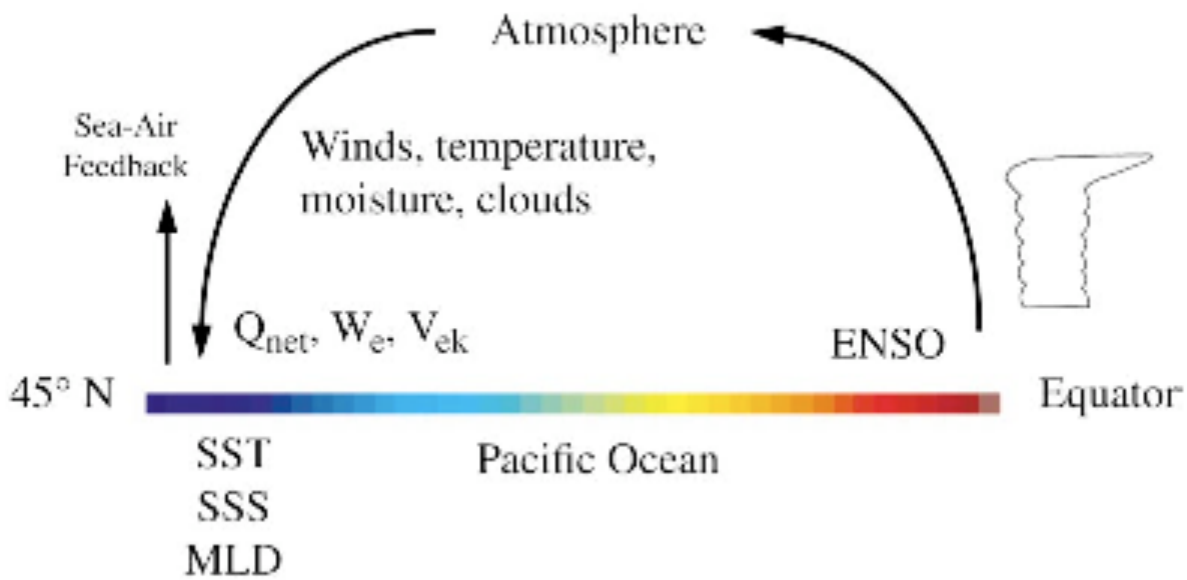


FIG. 2. Correlation between SST anomalies in the ENSO region (indicated by the box in the equatorial Pacific) in NDJ with global SST anomalies in the subsequent FMA for the period 1950–99 [shading (contour) interval is 0.1 (0.2)]. The gridded SST fields were constructed from EOFs (Smith et al. 1996) prior to 1982 and optimum interpolation of surface and satellite data (Reynolds and Smith 1994) for 1982–99.

Alexander et al. (2002; *J. Climate*)

PDO Mechanism?

Atmospheric Bridge

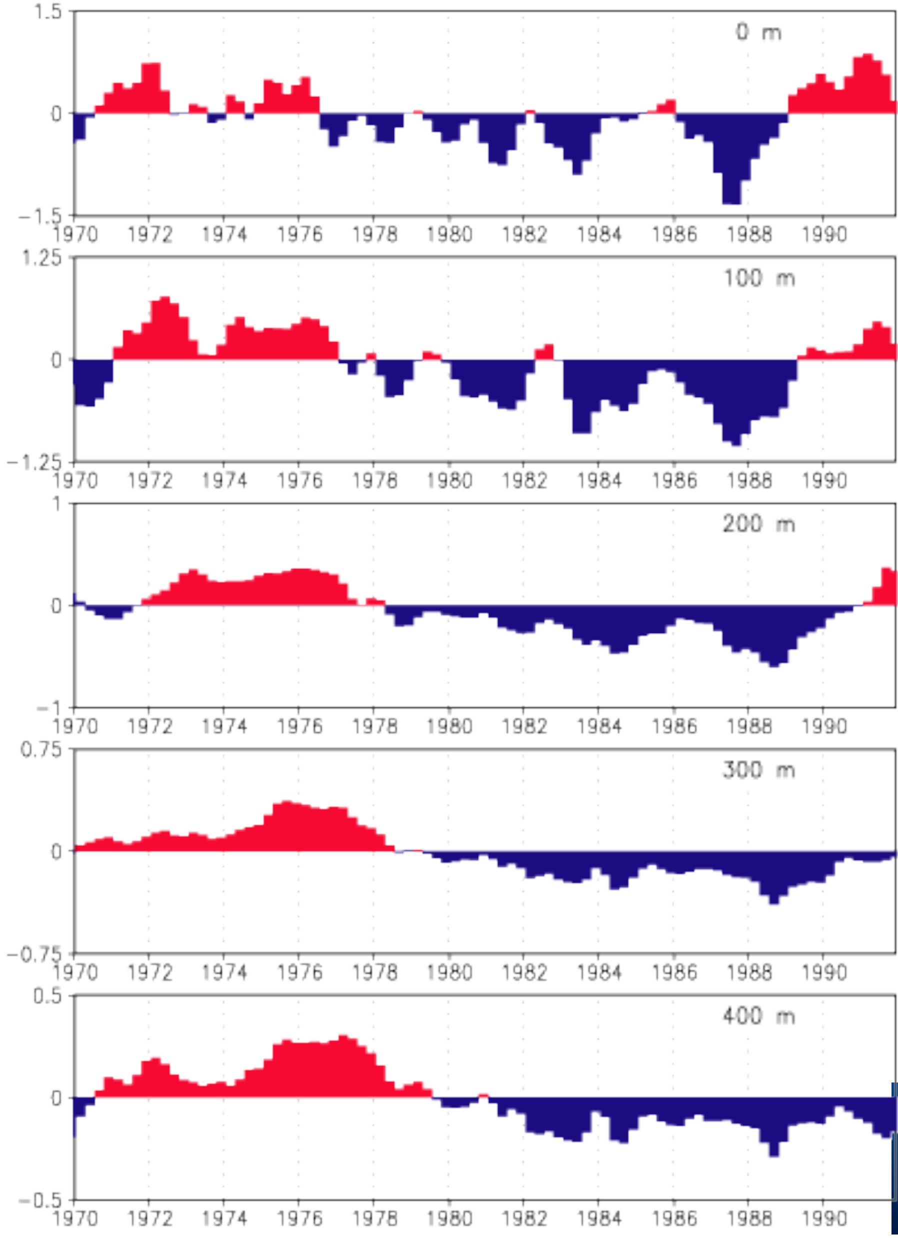


- tropical forcing generates atmospheric Rossby waves that propagate poleward
- surface wind changes in North Pacific create SST anomaly

Alexander et al. (2002; *J. Climate*)

PDO Mechanism?

Mechanism for Mid-Latitude SSTa Persistence: "Re-emergence"

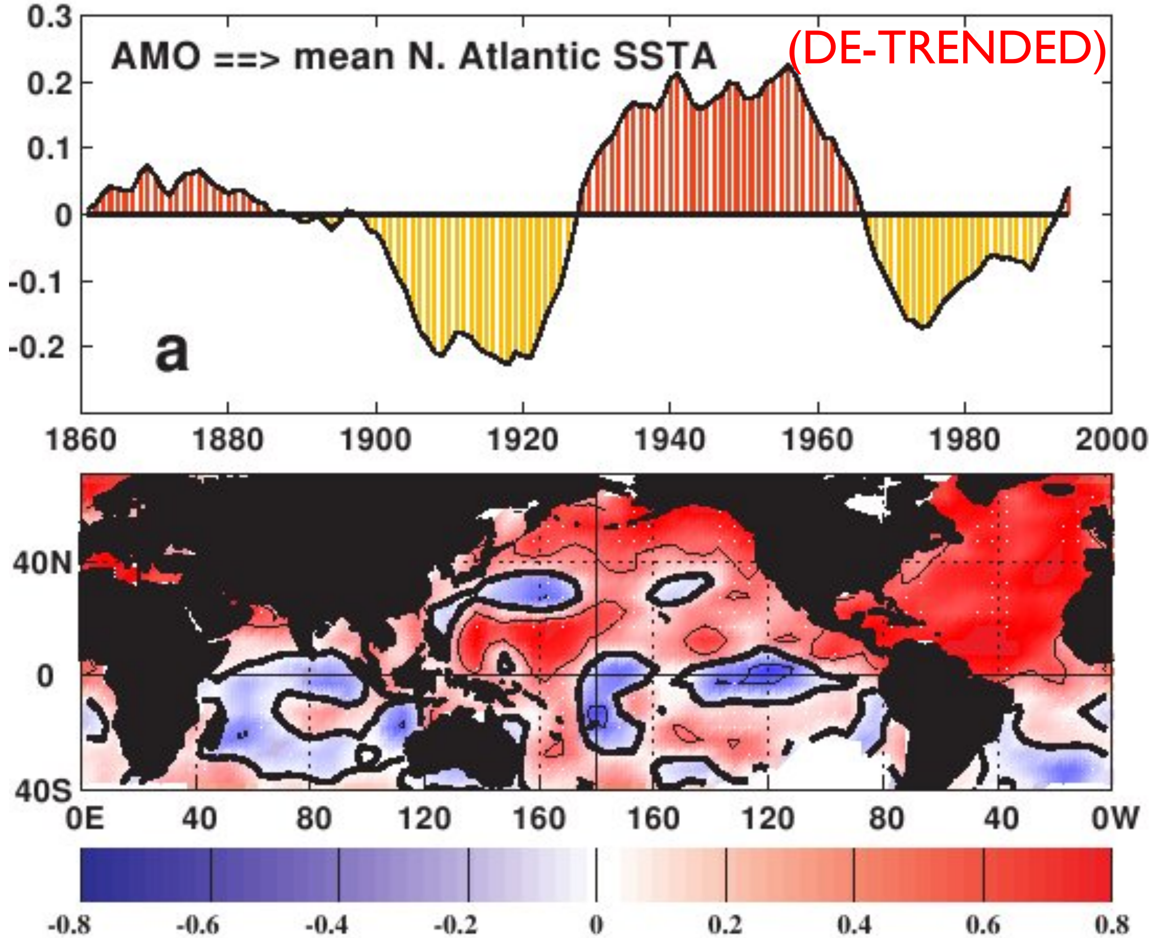


- ocean temperature anomalies at different depths (in N. Pacific)
- note how the anomalies penetrate the ocean, but become weaker

(Deser et al. 1996, J. Climate)

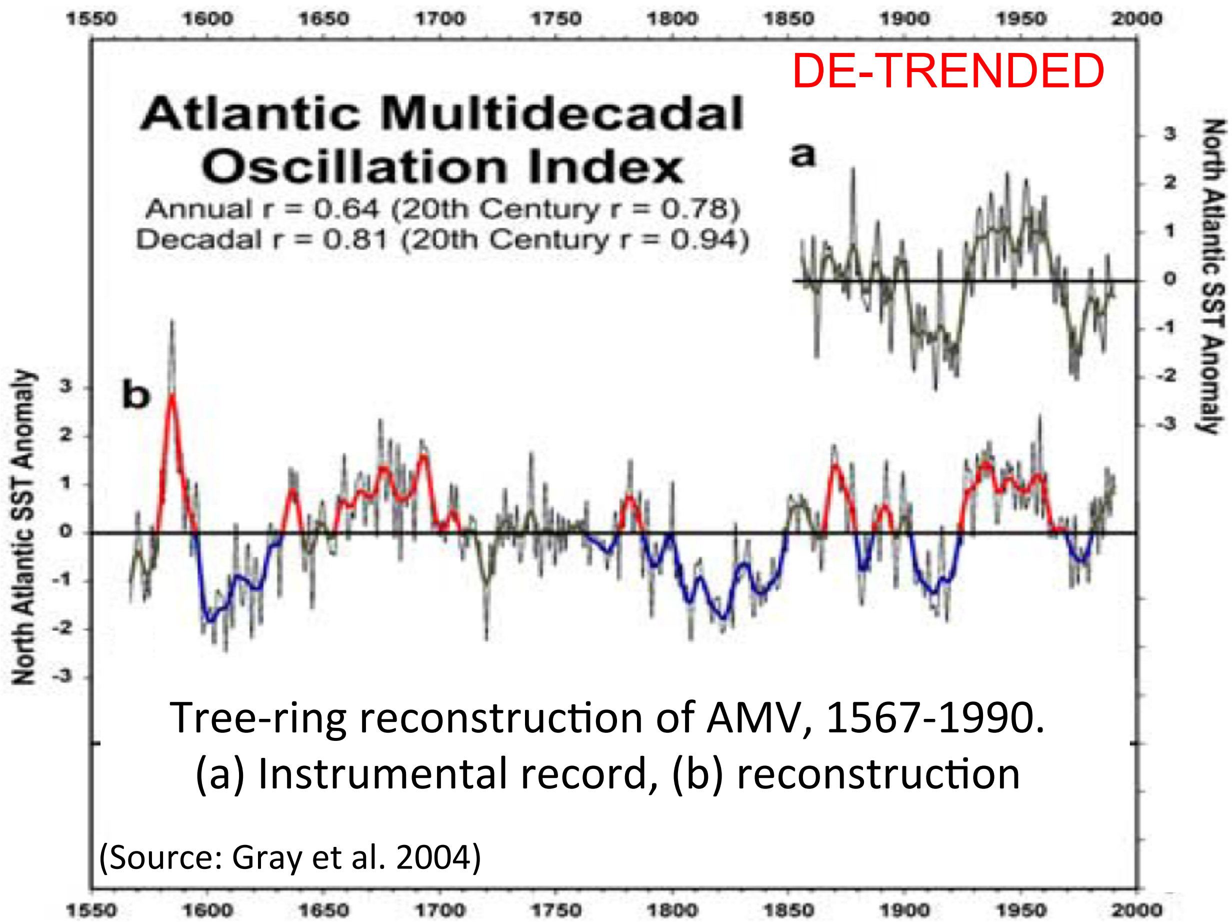
Decadal Variability

AMO (Atlantic Multi-Decadal Oscillation) – The principal mode in the Atlantic



Atlantic Multi-decadal Oscillation (AMO)

Has Existed for Centuries… at least



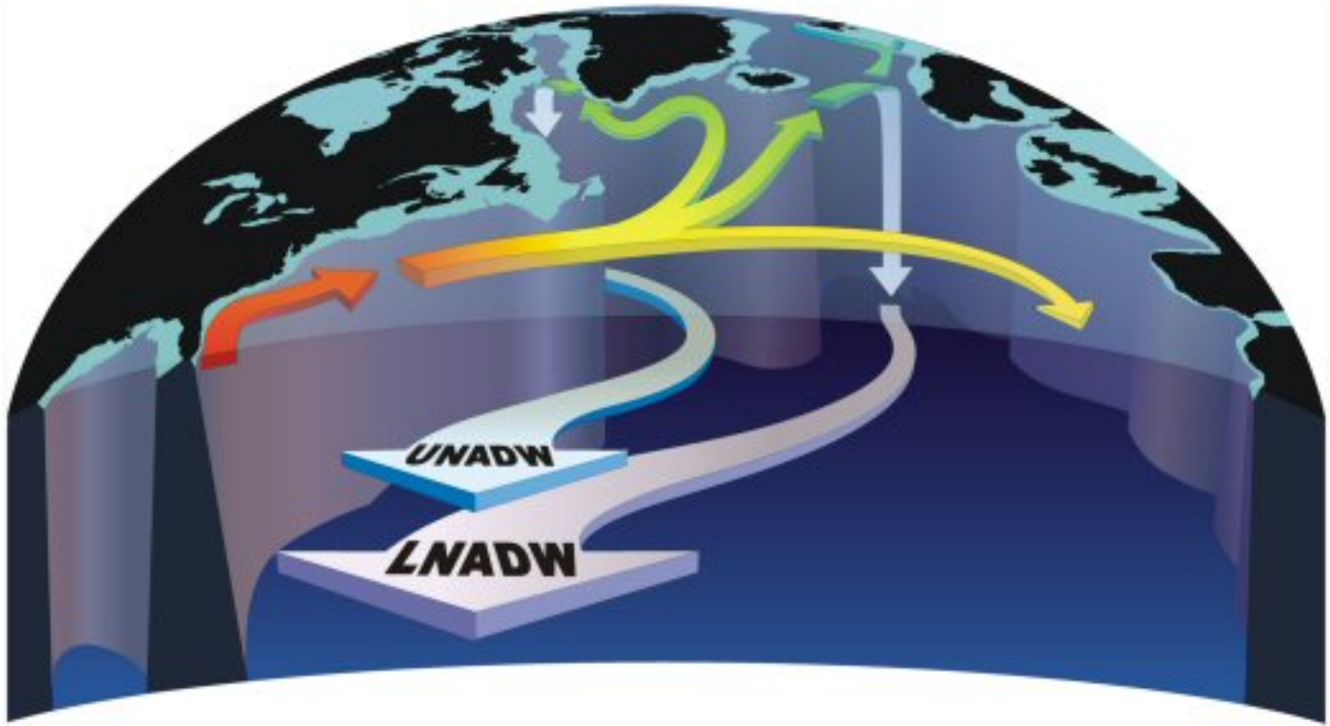
Tree-ring reconstruction of AMV, 1567-1990.
(a) Instrumental record, (b) reconstruction

(Source: Gray et al. 2004)

Thermohaline Circulation in Atlantic Ocean

(Atlantic part of Ocean Conveyor Belt Circulation)

Density driven "Overturning" circulation



Thermal part: Cold (more dense) in high latitudes vs warm (less dense) in low latitudes

→ **Drives THC** *(refers to mean air-sea fluxes)*

Haline (salt) part: More precipitation (fresher, less dense) in high latitudes v more evaporation (saltier, more dense) in low latitudes

→ **Inhibits THC** *(refers to mean air-sea fluxes)*

Creation of sea ice in leaves salt behind (more dense) → **Drives THC**

Mechanism for Multi-decadal Atlantic variability in one coupled GCM

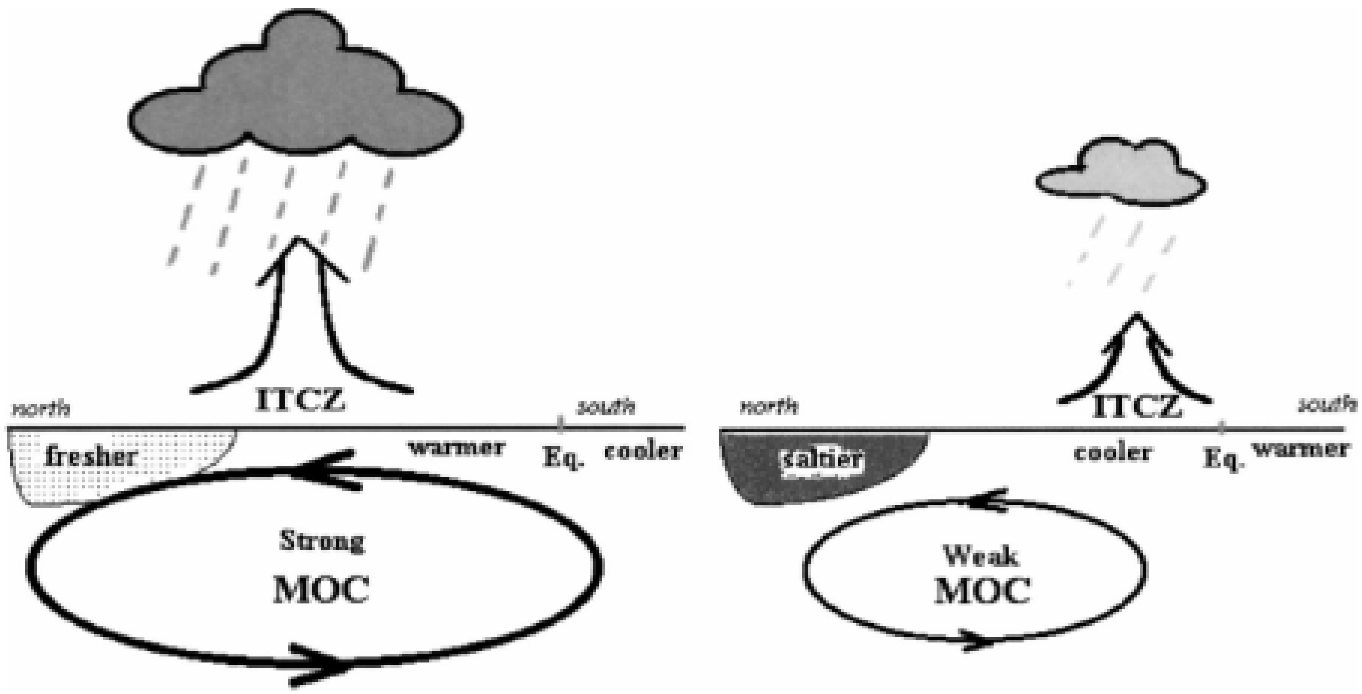
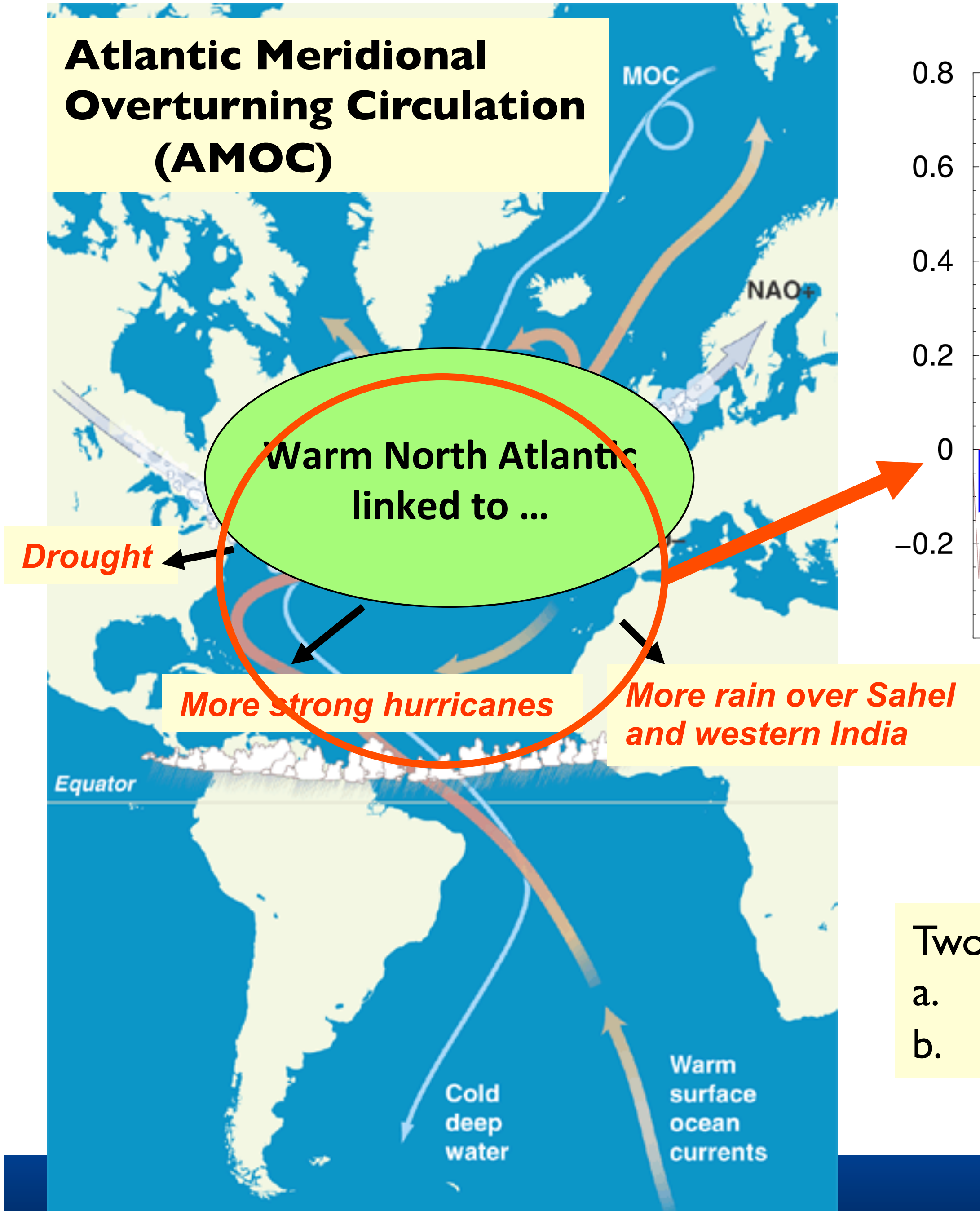
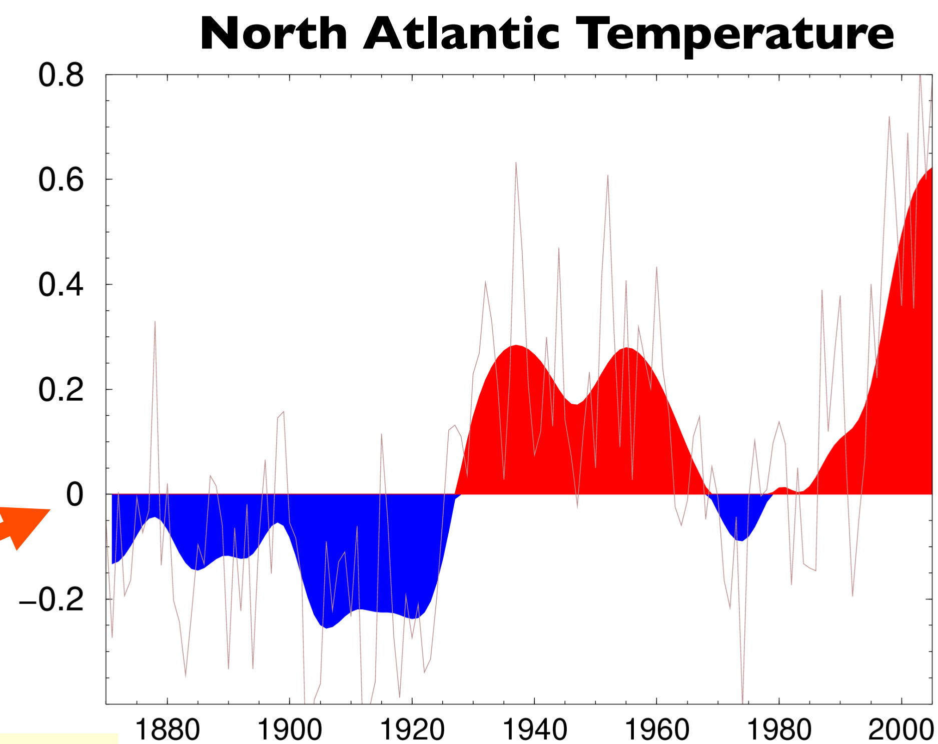


FIG. 16. Schematic of mechanism responsible for centennial THC fluctuation in HadCM3. When the THC is (left) strong ITCZ shifts northward, in response to enhanced SST gradient across equator. Fresh anomalies in the upper-ocean propagate northward and weaken the overturning. This results in the (right) weak phase.

This mechanism still involves the overturning circulation, but relies on tropical rainfall anomalies to create the high-latitude salinity anomalies





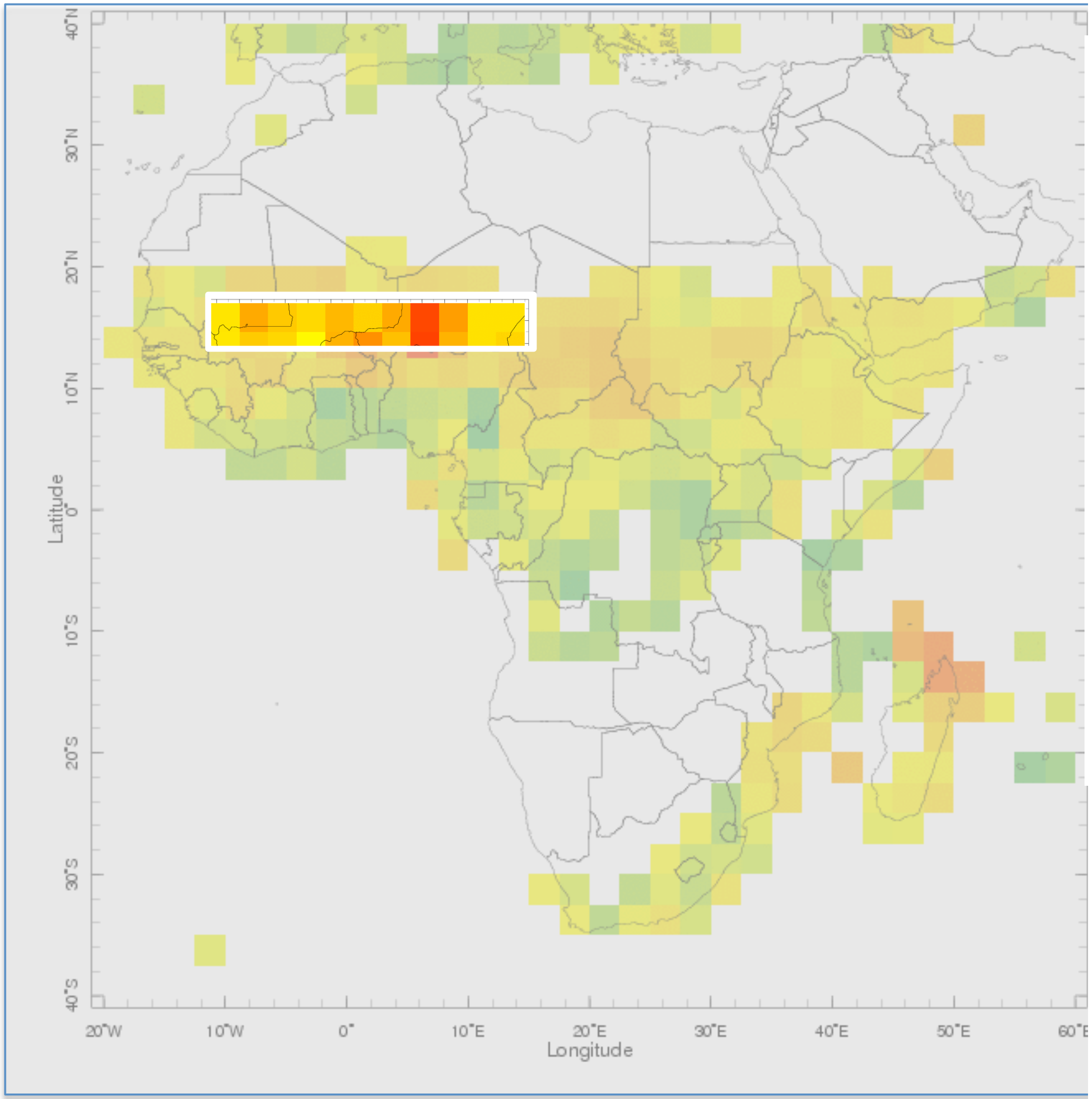
Two important aspects:

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

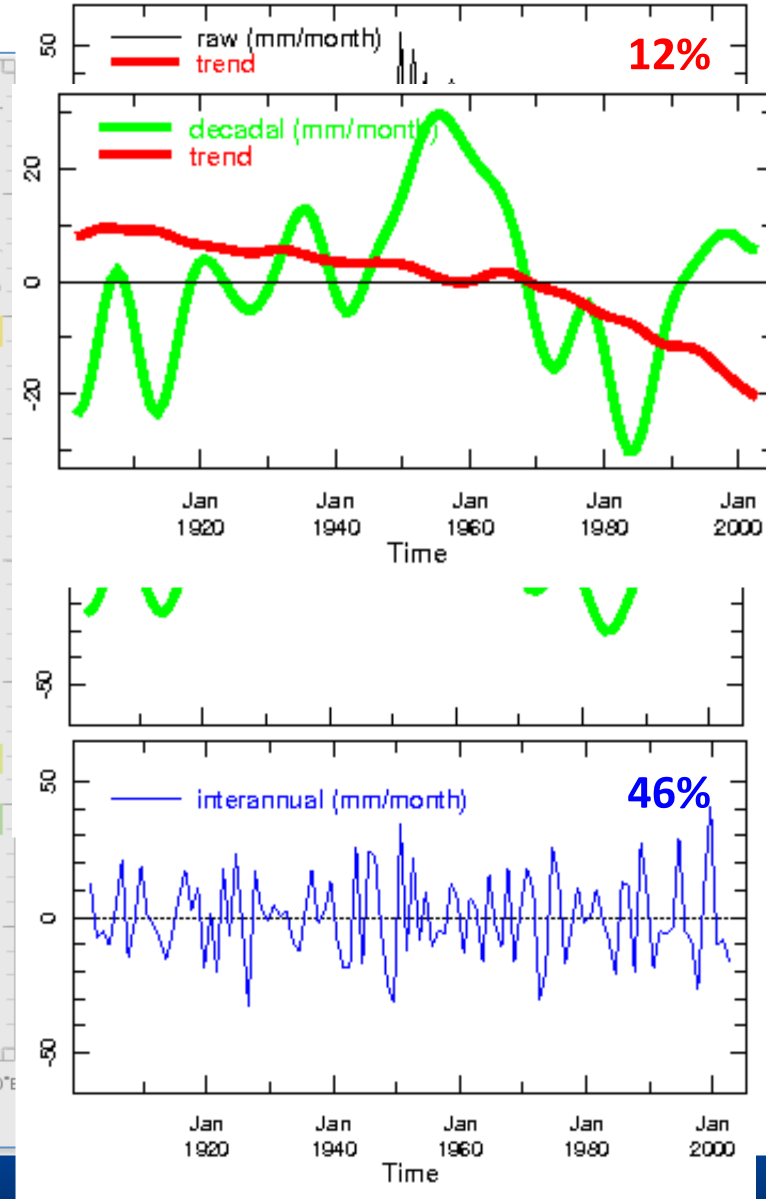
(Courtesy: Joe Tribbia, NCAR)

Precipitation Decadal Variability: % of variance

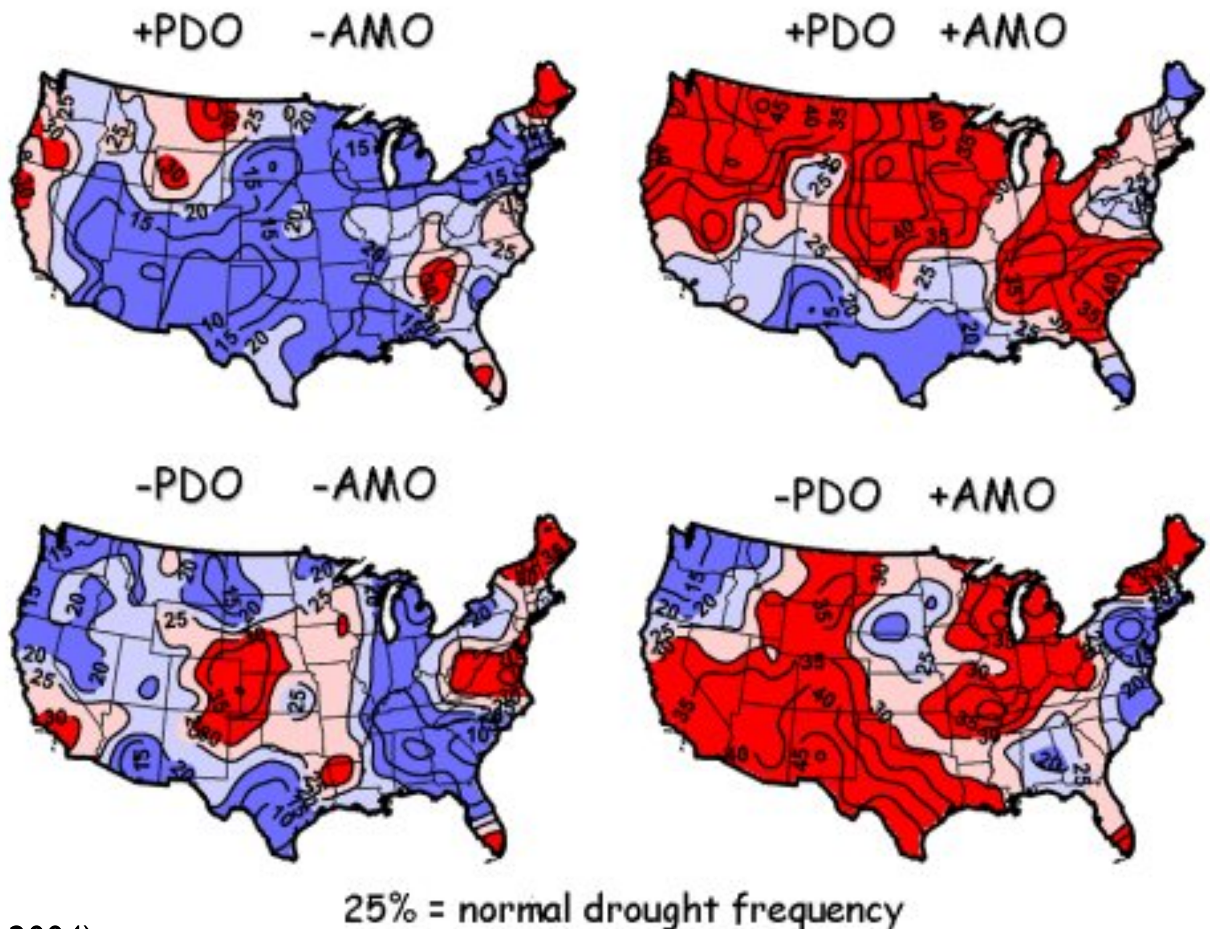
20th Century Gridded Observations – Jul-Aug-Sep Seasonal Means



DECOMPOSITION

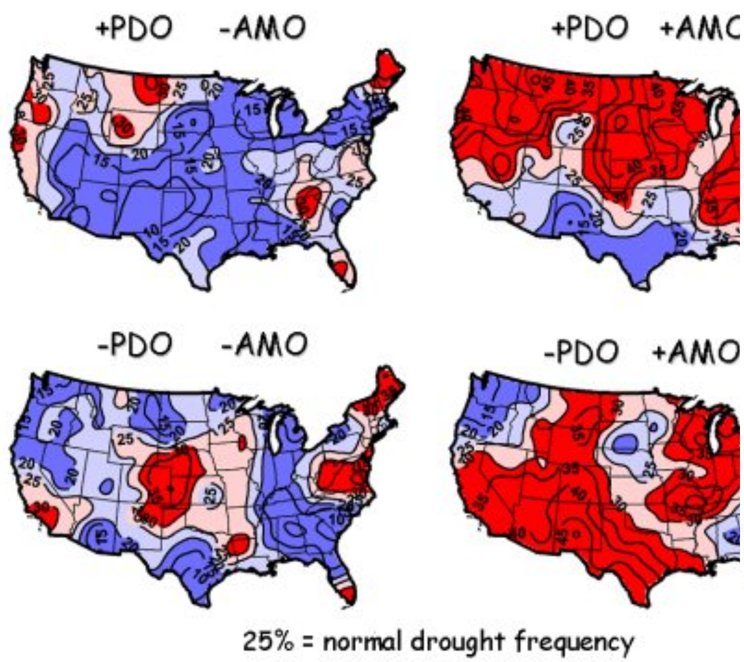


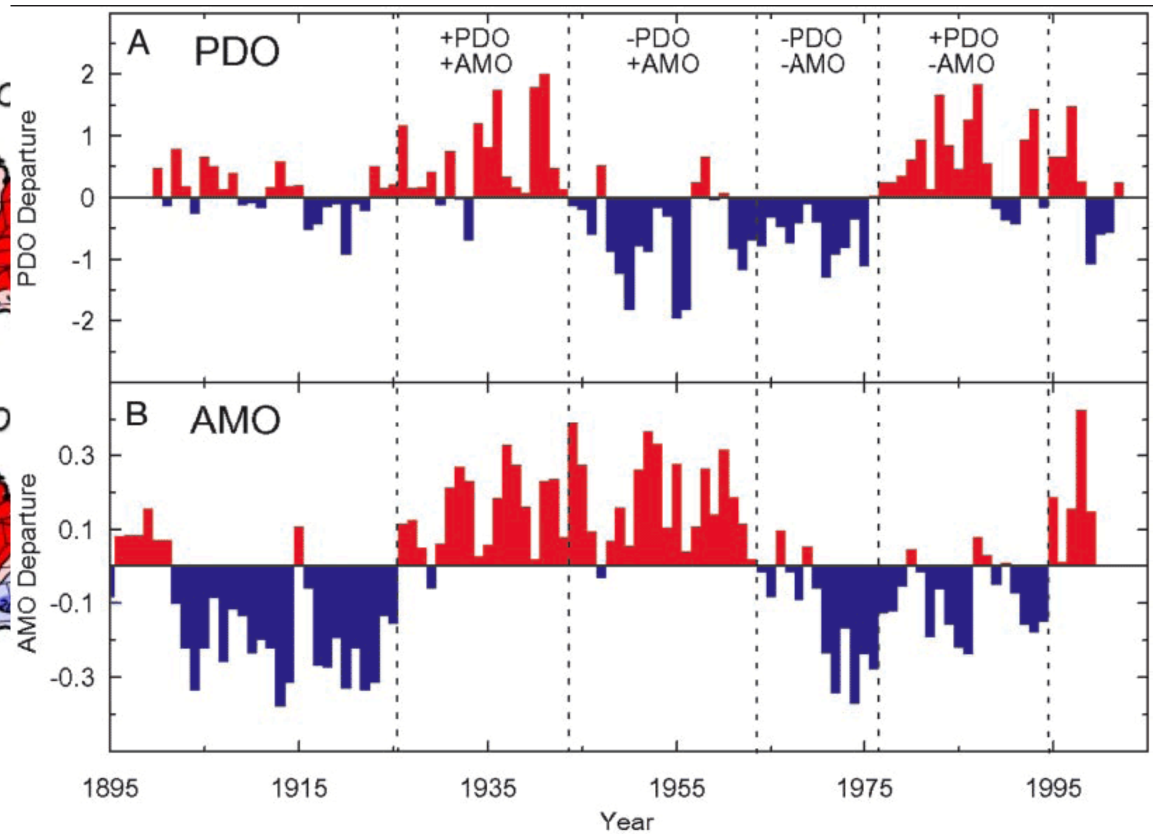
Pacific & Atlantic Impacts on U.S. Drought Frequency



(Source: McCabe et al, 2004)

Pacific & Atlantic Impacts on U.S. Drought Frequency



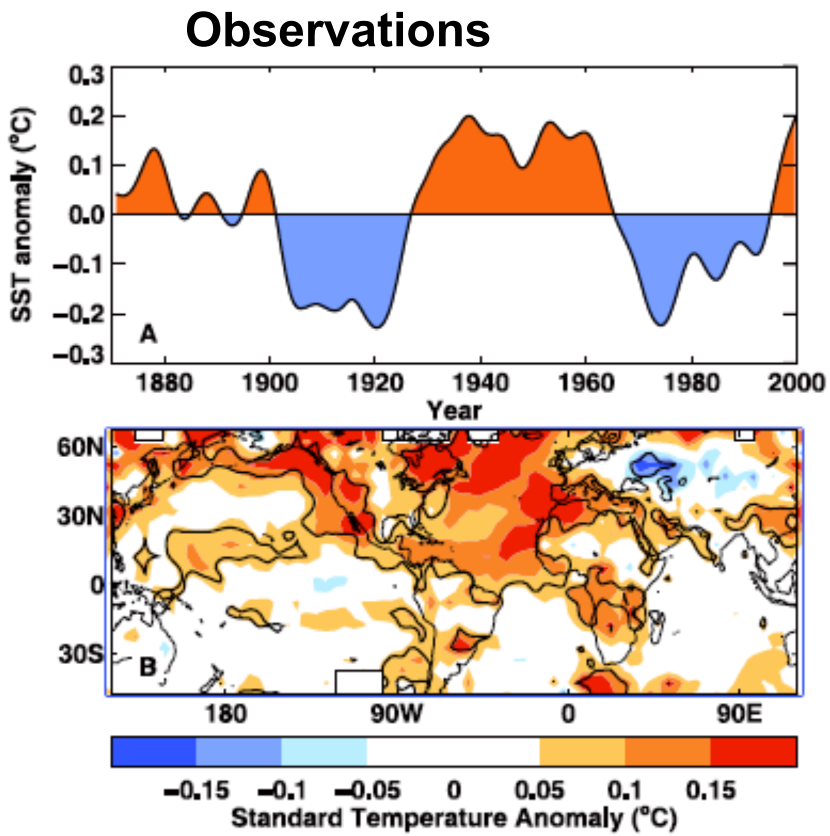


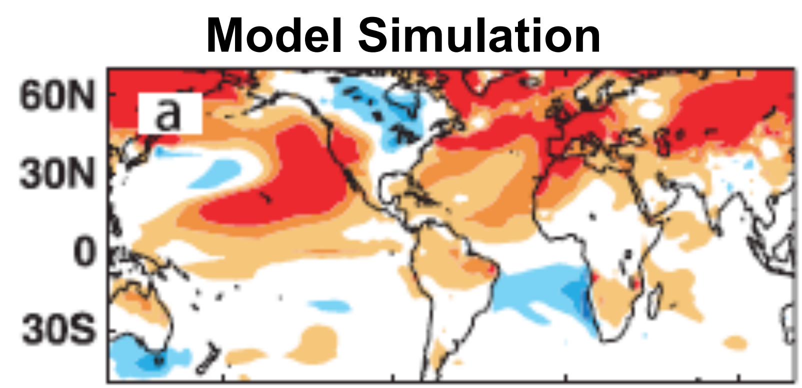
(Source: McCabe et al, 2004)

EXPERIMENTAL DECADAL PREDICTION

- Design
- How to represent the predictions?
- How to represent skill?

Motivation for Prediction: Feasibility

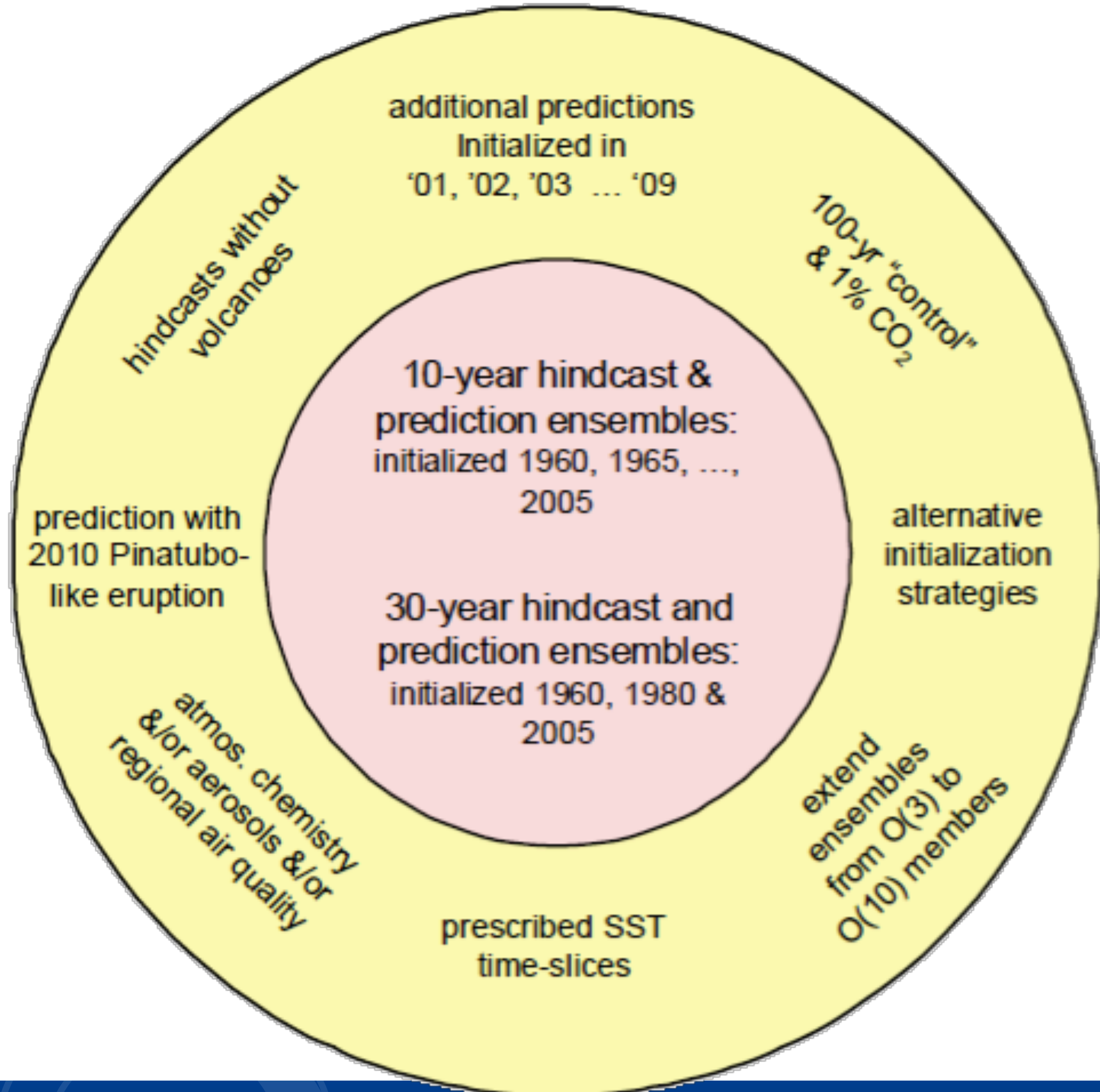




(Knight et al. 2005, GRL)

Model variability, associated with AMOC variations, closely resembles observed variability associated with detrended and decadally-filtered AMV index.

CMIP5 Experimental Prediction Design

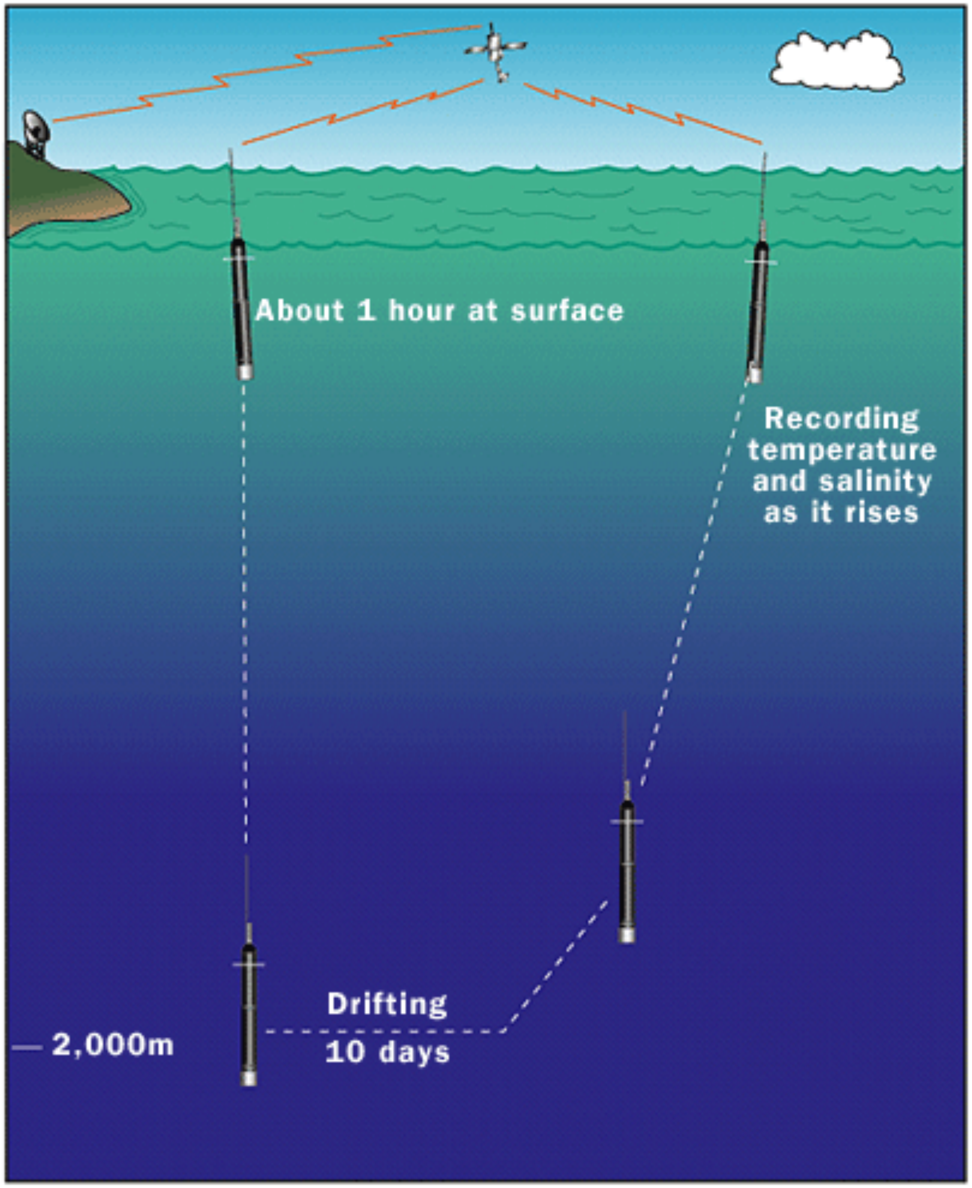


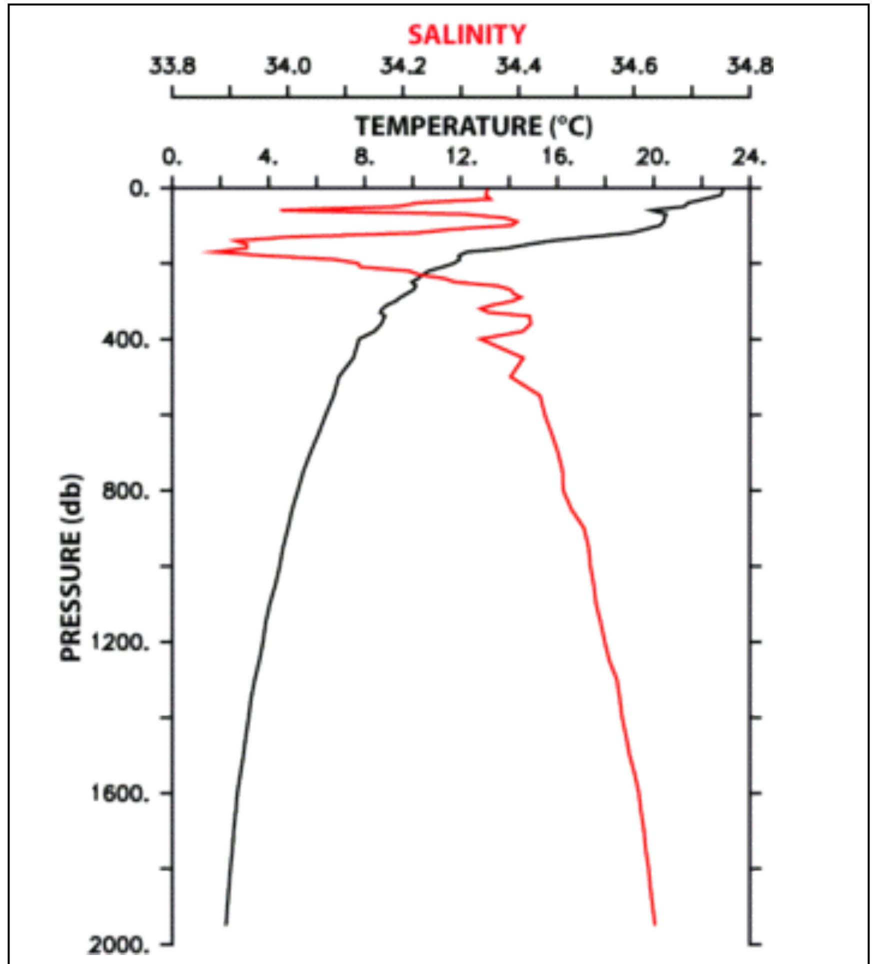
Same models used for IPCC Climate Change Projections

Same scenarios of GHG increases

BUT, ocean state is initialized

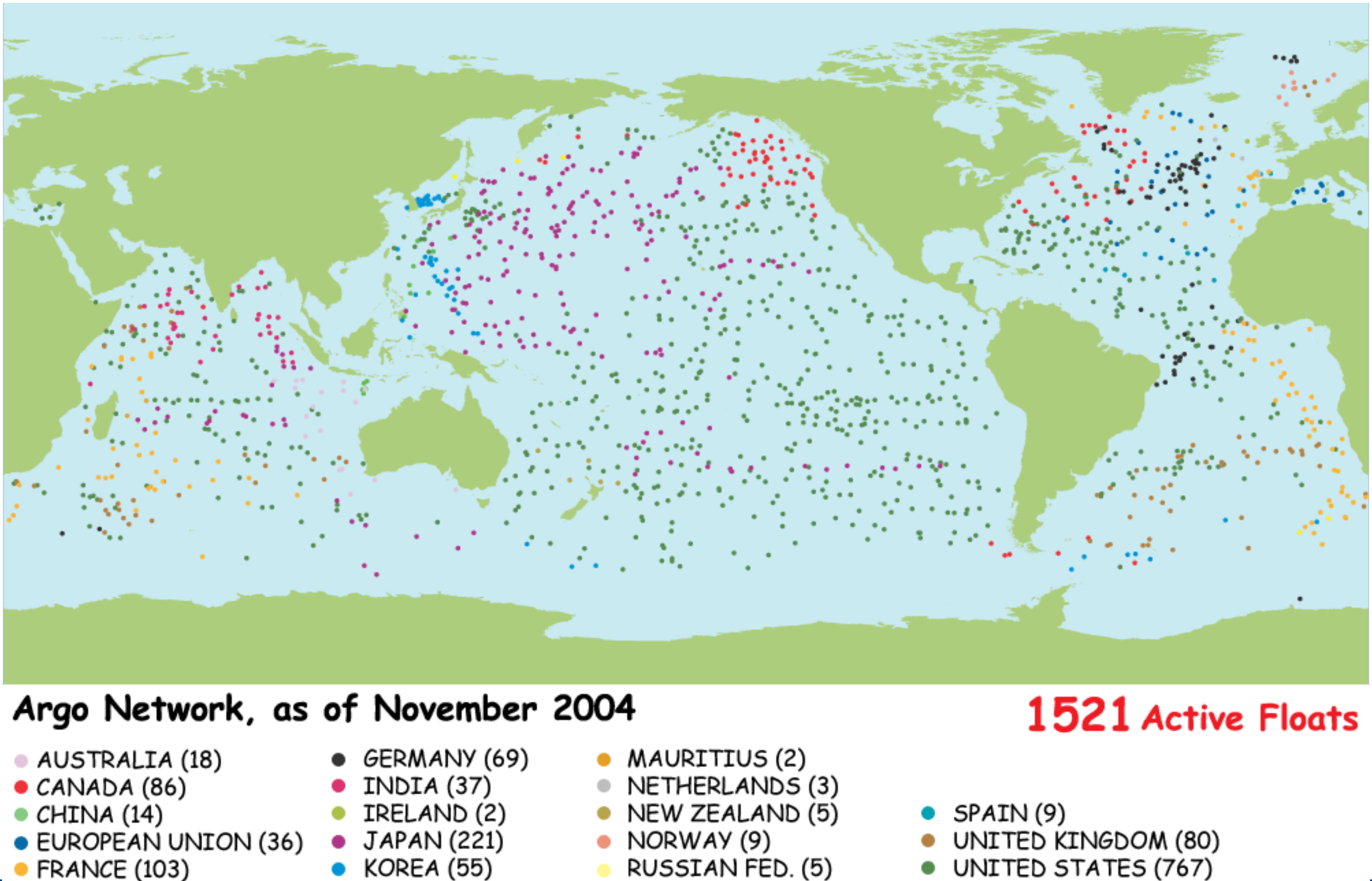
Ocean Observations: Argo Profiling Floats



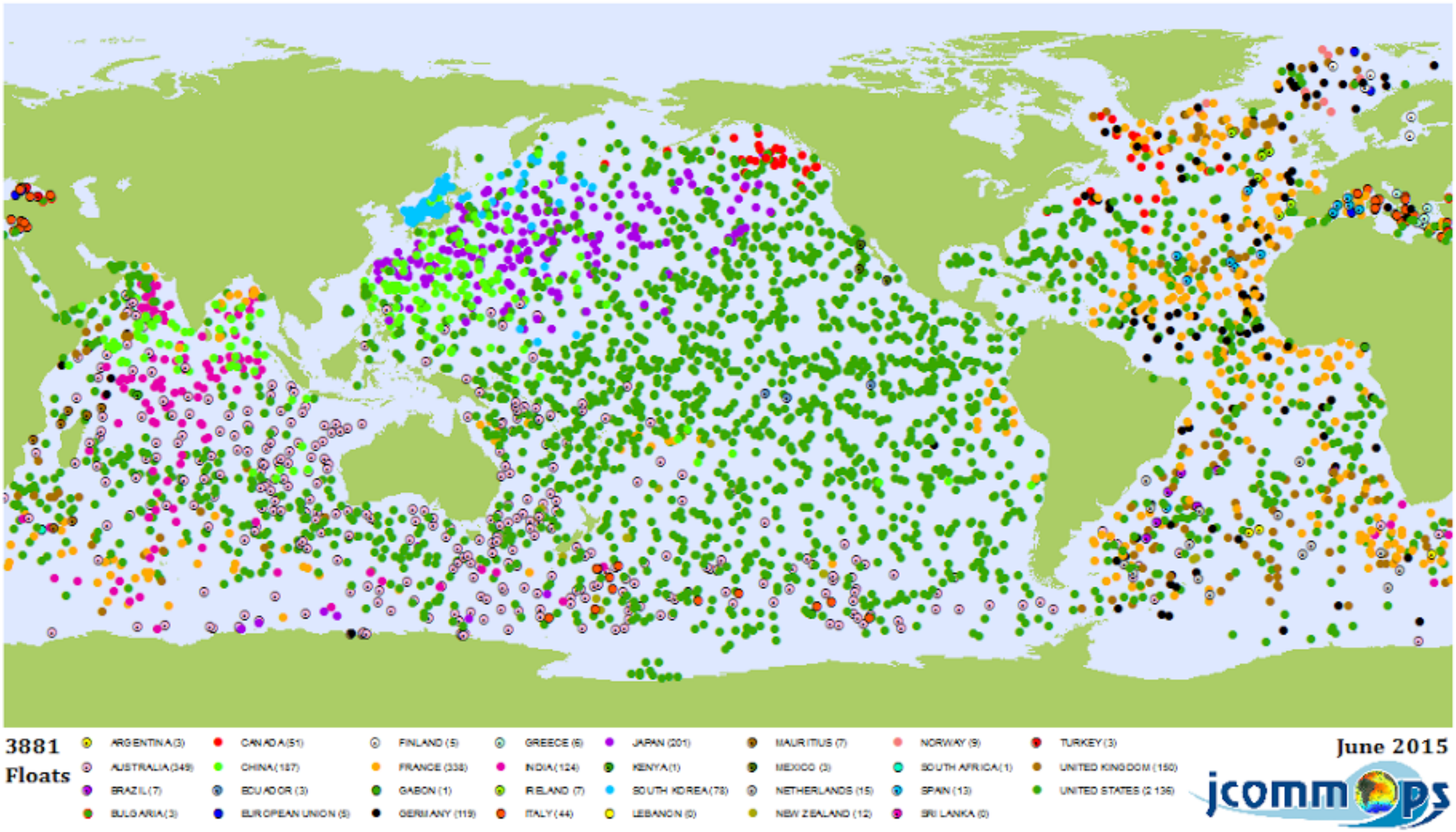


Argo profile from the subtropical North Pacific (20.25N 121.4W, May 15 2004).
This shows interleaving in the salinity data.

Ocean Observations: Network of Argo Floats



Ocean Observations: Network of Argo Floats



(Source: http://w4.jcommops.org/website/Argo)

Predictions? / Projections?

Science AAAS

DOI: 10.1126/science.1139540
, 796 (2007); **317** *Science*

Improved Surface Temperature Prediction for the Coming Decade from a Global Climate Model

Doug M. Smith,* Stephen Cusack, Andrew W. Colman, Chris K. Folland, Glen R. Harris, James M. Murphy

nature Vol 453 | 1 May 2008 | **doi:10.1038/nature06921**

LETTERS

Advancing decadal-scale climate prediction in the North Atlantic sector

N. S. Keenlyside[1], M. Latif[1], J. Jungclaus[2], L. Kornblueh[2] & E. Roeckner[2]

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"… new modeling system that **predicts both internal variability and externally forced changes** and hence forecasts surface temperature with substantially improved skill throughout a decade, both globally and in many regions."

nature Vol 453 | 1 May 2008 | **doi:10.1038/nature06921**

LETTERS

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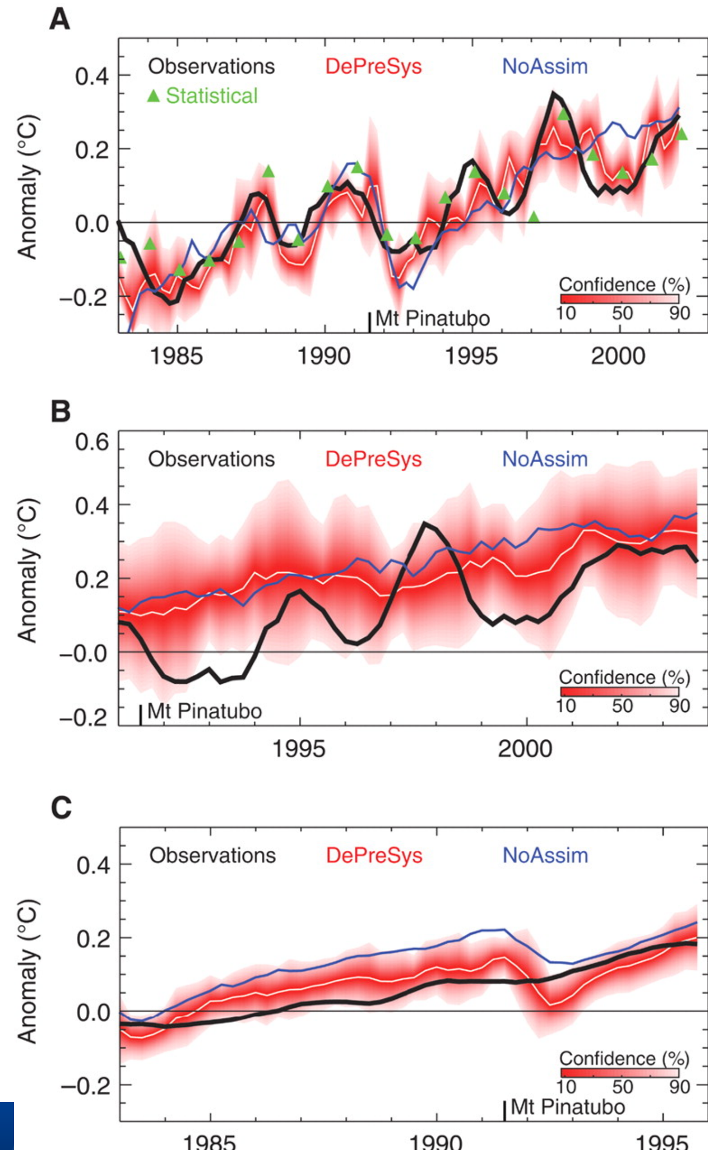
N. S. Keenlyside[1], M. Latif[1], J. Jungclaus[2], L. Kornblueh[2] & E. Roeckner[2]

"…over the next decade, the current Atlantic **meridional overturning circulation will weaken to its long-term mean**… Our results suggest that global surface temperature may not increase over the next decade, as **natural climate variations … temporarily offset the projected anthropogenic warming**."

Smith et al (2007)



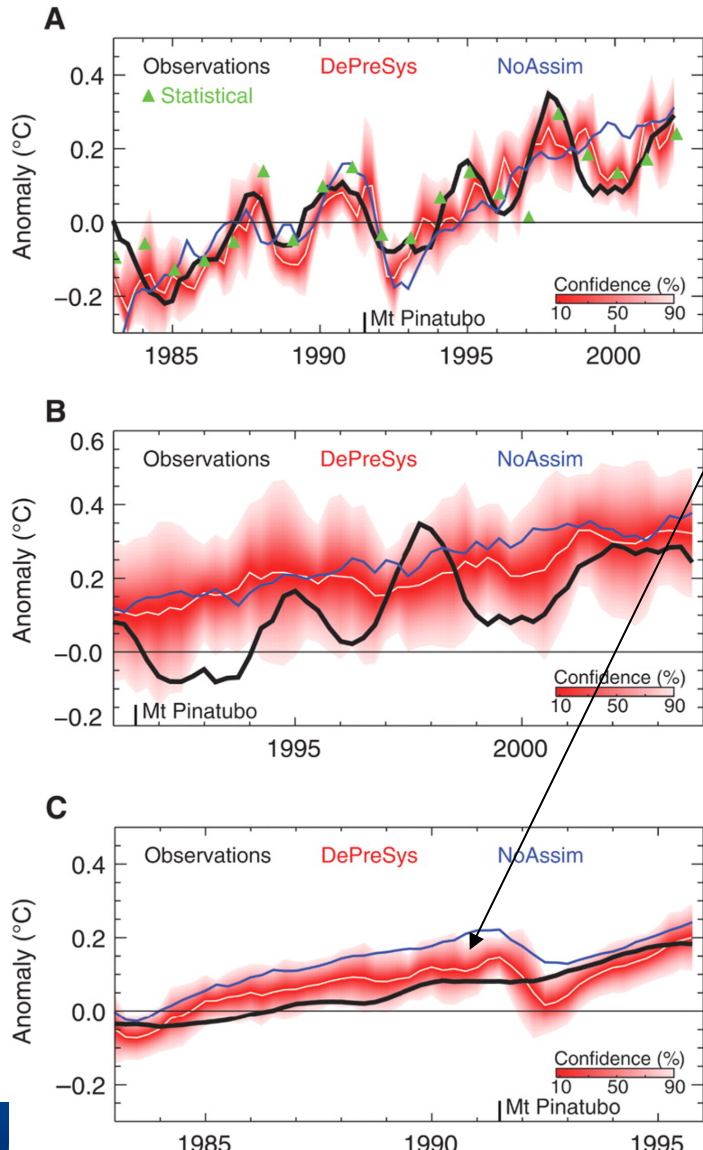
PROs

- View of increasing uncertainty at longer time horizons, as well as over long-time average
- Improved projections relative to original system

CONs

- Global average
- Little to no evidence of [predictable] low-frequency climate *variability* at long lead
- Only 4 ensemble members

Smith et al (2007)



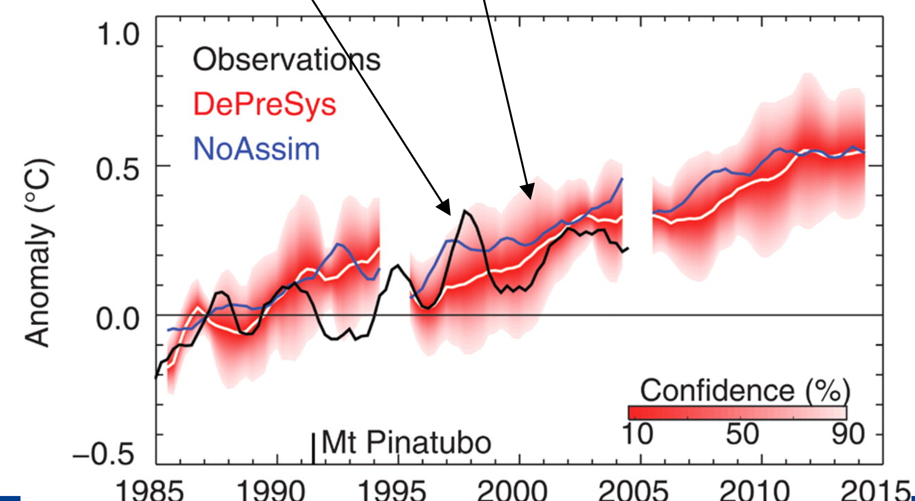
<u>Added PRO:</u>

View of **change in uncertainty with time scale**

1) Uncertainty in decadal-average

2) Uncertainty through a decade due to interannual variability

3) Realization of natural variability through decade



Keenlyside et al (2008)

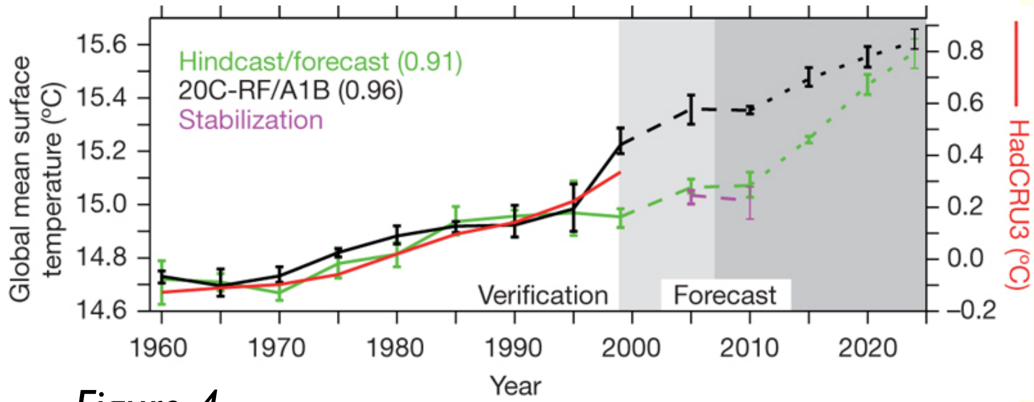


Figure 4

"… the initialized prediction indicates a slight cooling relative to 1994-2004 levels, while the anthropogenic-forcing-only simulation suggests a near 0.3 K rise."

PRO:

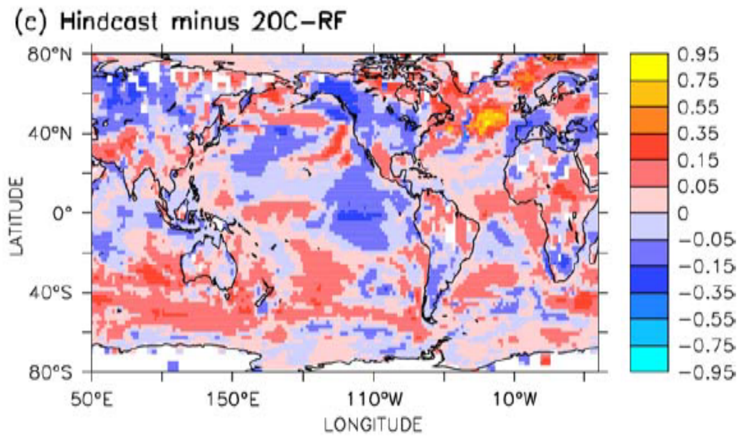
- Focus on mode(s) of natural climate variability

CONs:

- Statements/conclusions seem at odds with evidence (ie. fcst evolution)
- Uncertainty given by spread of 3 ensemble members
- Demonstration of natural climate variability (AMOC) not obvious

Keenlyside et al (2008)

Difference in RMSE (deg. K)



Supp. Figure 2c

Maximum MOC Strength

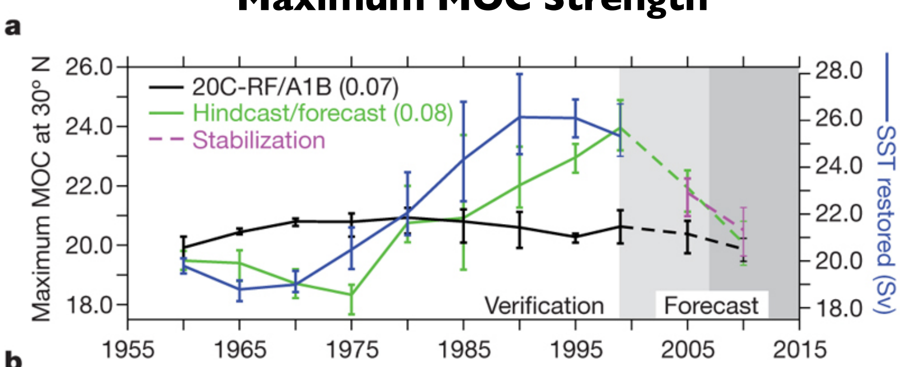


Figure 3a

<u>Regionality?</u>

- New method seems to have greater errors in most places, especially the N. Atlantic
- What does improved performance in eastern Pacific suggest for ENSO variability?

<u>Climate variability?</u>

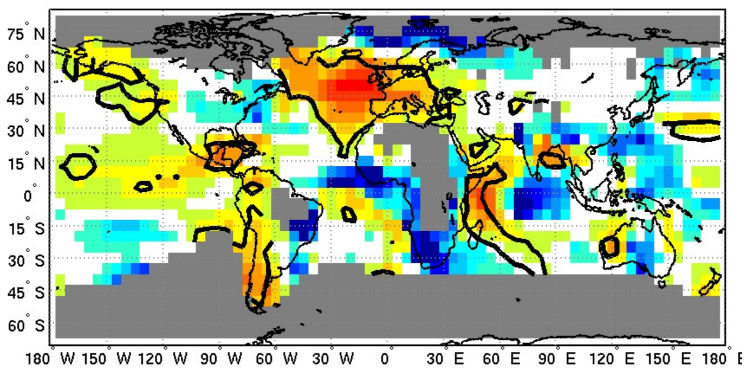
- Lack of verifying observations, so don't really know truth
- But – according to available truth, hindcast has no skill

Decadal Predictions: *Skill still to be demonstrated*

Multi-model Ensemble (12 models: Equal Weighting)

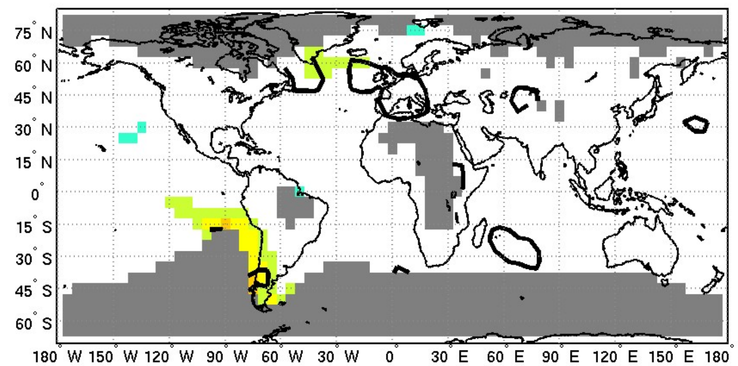
Mean Squared Skill Score

MME temp MSSS: year 2-9 ann
Initialized - Uninitialized

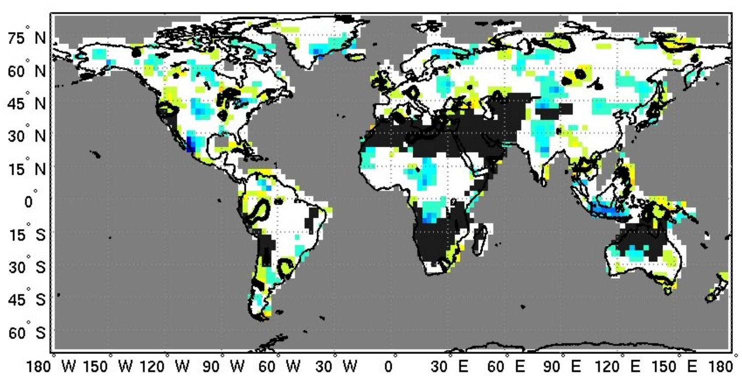


Correlation

MME temp Correlation: year 2-9 ann
Initialized - Uninitialized



MME prcp MSSS: year 2-9 JAS
Initialized - Uninitialized



MME prcp Correlation: year 2-9 JAS
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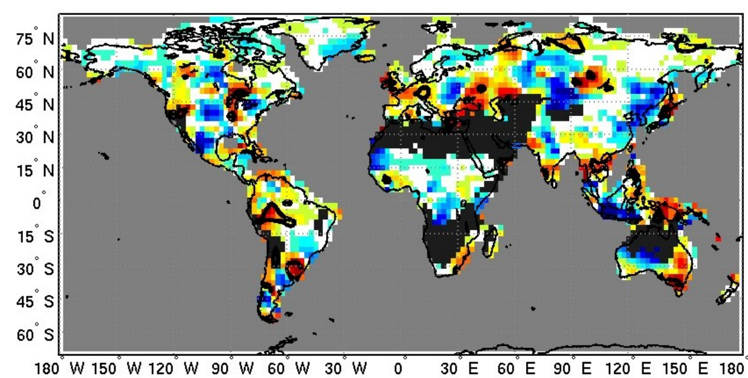


(based on Goddard et al. 2012, Climate Dynamics; See also http://clivar-dpwg.iri.columbia.edu)

US CLIVAR Working Group on Decadal Predictability:

Proposed FRAMEWORK for Verification:

1. Feasibility (of particular model/fcst system)

- Realistic, and relevant, variability?
- Translation of ICs to realistic and relevant variability?

2. Prediction skill – Quality of system; quality of information

- Where? What space & time scales?
- Actual anomalies & 'decadal scale trends'
- Conditional skill?
- Values of ICs: higher correlations, lower RMSEs

http://clivar-dpwg.iri.columbia.edu/

3. Issues – for research, for concern

i.e. limited ability to quantify uncertainty;
limited understanding of processes, etc.

Asking Questions of the Initialized Hindcasts

Question 1: Do the initial conditions in the hindcasts lead to more accurate predictions of the climate?

→ Mean Squared Skill Score and its decomposition

$$MSSS = 1 - \frac{MSE_{fcst}}{MSE_{ref}}; \quad \text{if ref} = \text{climatological avg.}$$

$$MSSS(f,\bar{x},x) = r_{fx}^2 - [r_{fx} - \left({s_f}/{s_x} \right)]^2 = Correlation^2 - Cond.Bias^2$$

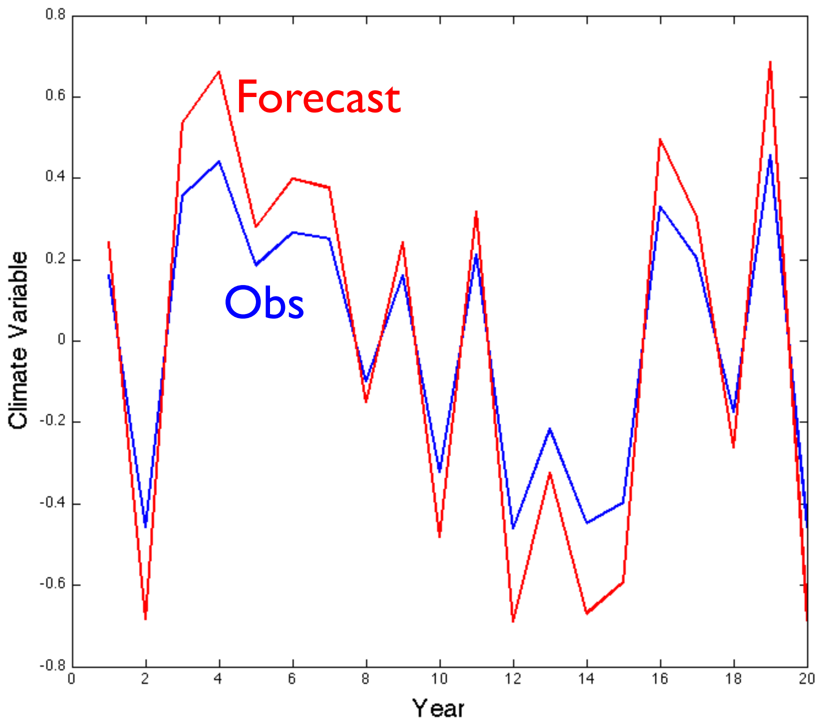
$$MSSS = 1 - \frac{MSE_{init}}{MSE_{uninit}}; \quad \text{here ref} = \text{uninitialized hindcasts}$$

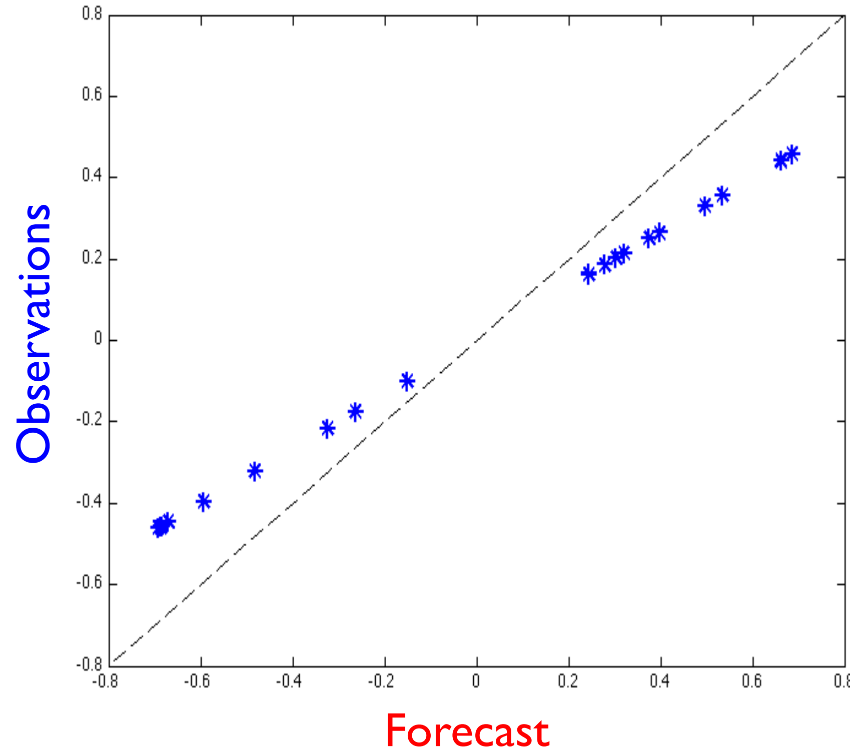
$$MSSS(f,r,x) = \frac{MSSS(f,\bar{x},x) - MSSS(r,\bar{x},x)}{1 - MSSS(r,\bar{x},x)}$$

(from Murphy, Mon Wea Rev, 1988)

Elaboration on “Conditional Bias”

$$\text{Conditional Bias} = [r_{fx} - \left(s_f / s_x \right)]$$

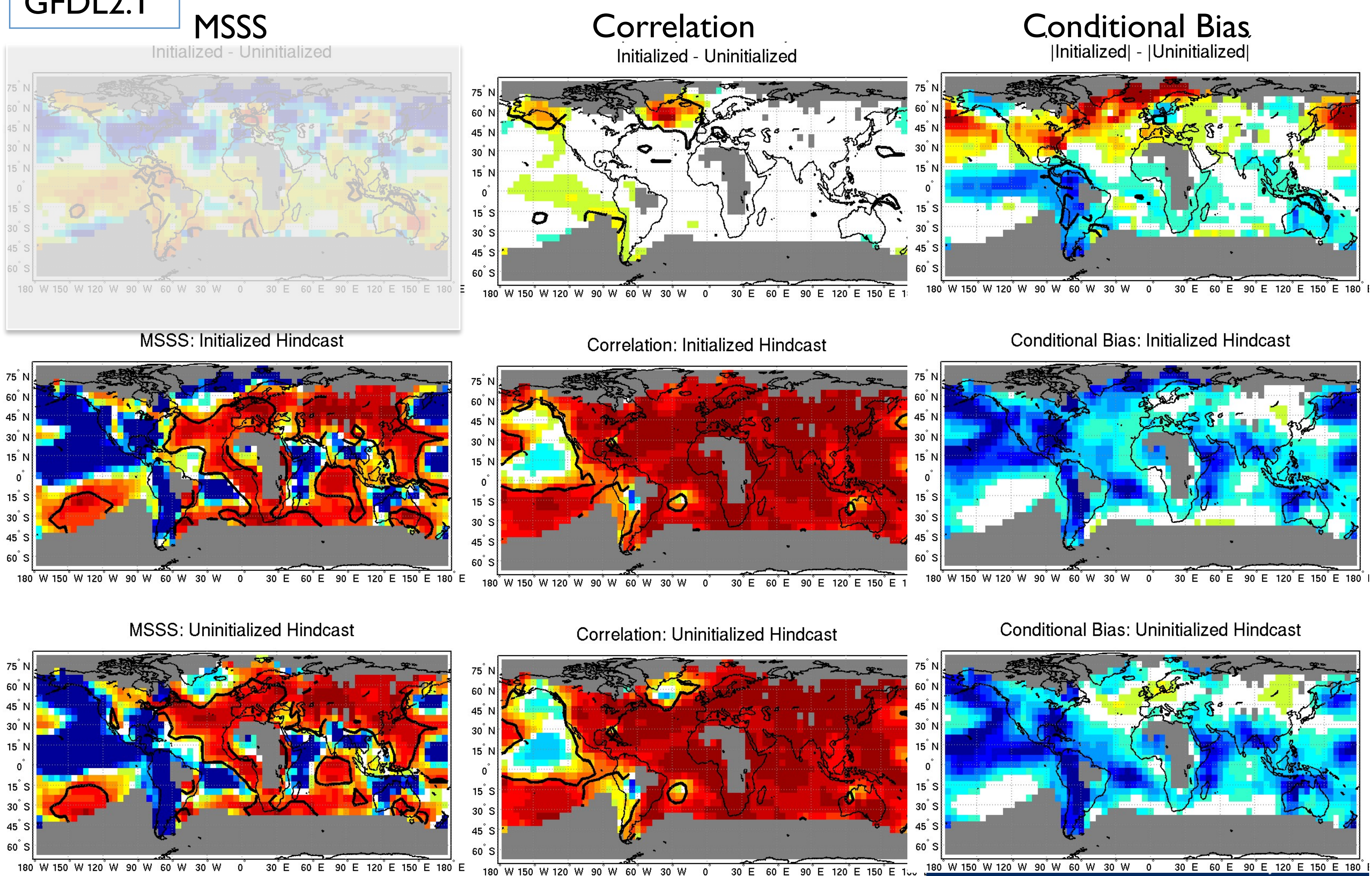




Perfect Correlation, but Conditional Bias because $s_f > s_x$

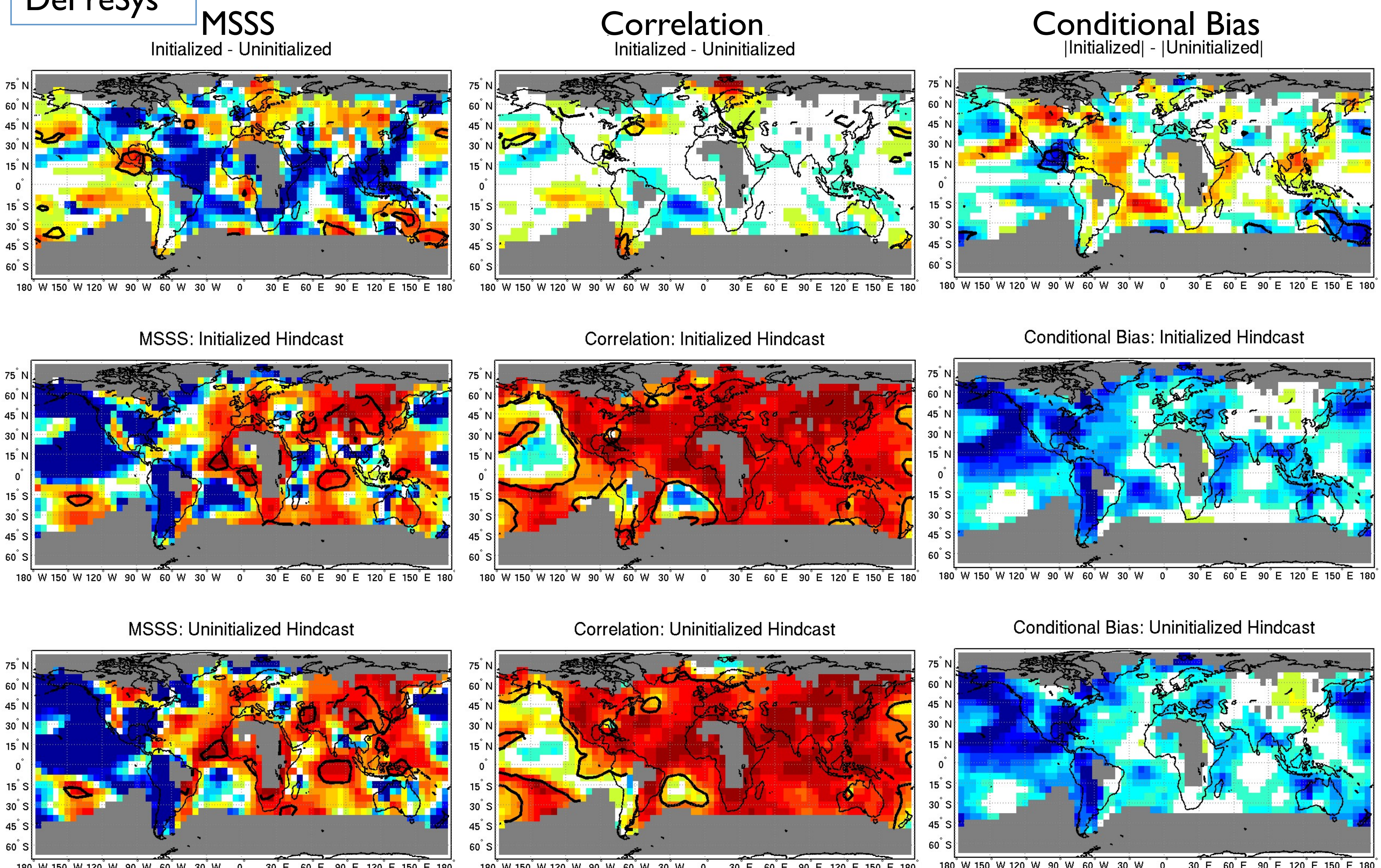
Deterministic Metrics: Mean Squared Skill Score (MSSS)

GFDL2.1



Deterministic Metrics: Mean Squared Skill Score (MSSS)

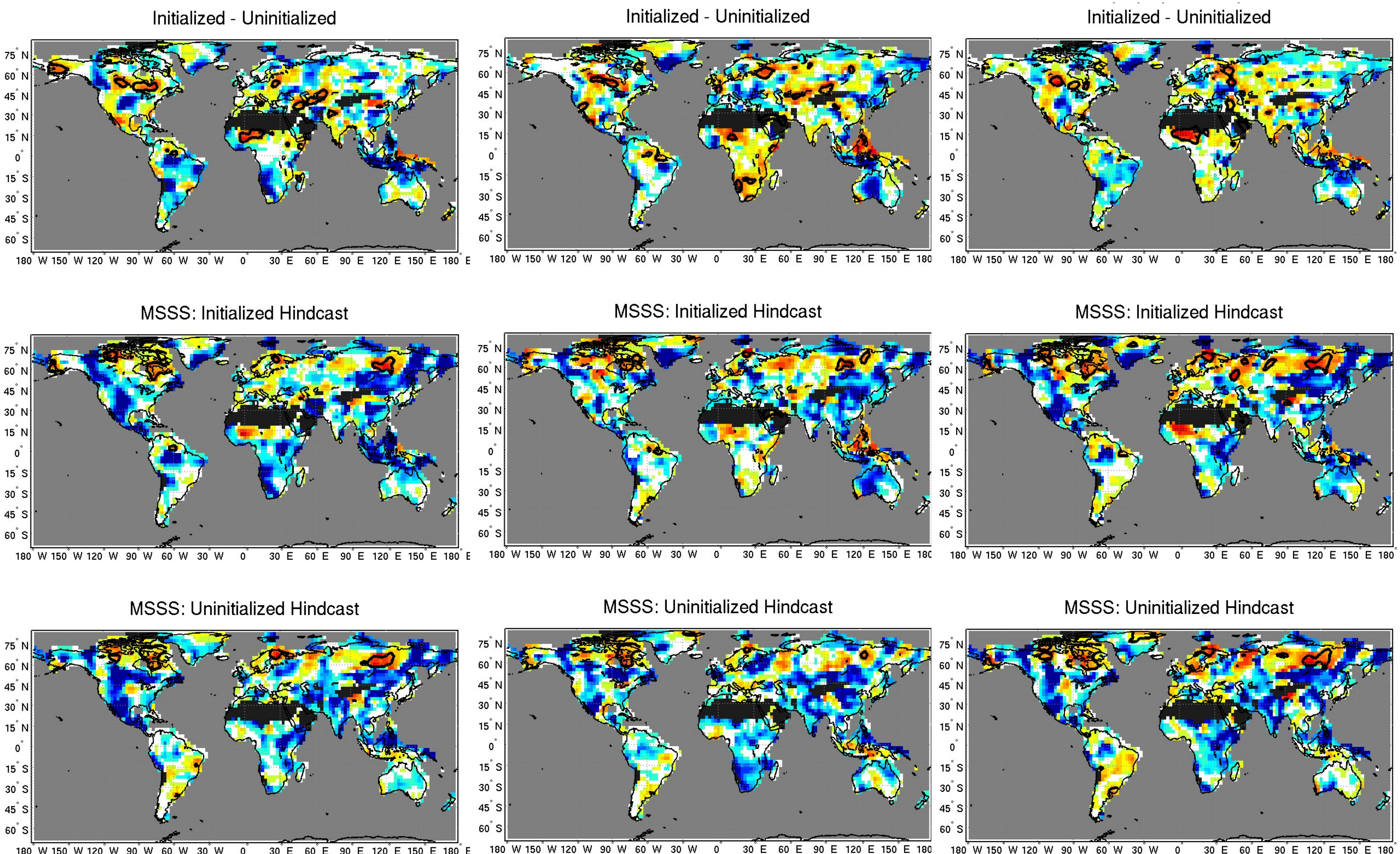
DePreSys



Deterministic Metrics: Mean Squared Skill Score (MSSS)

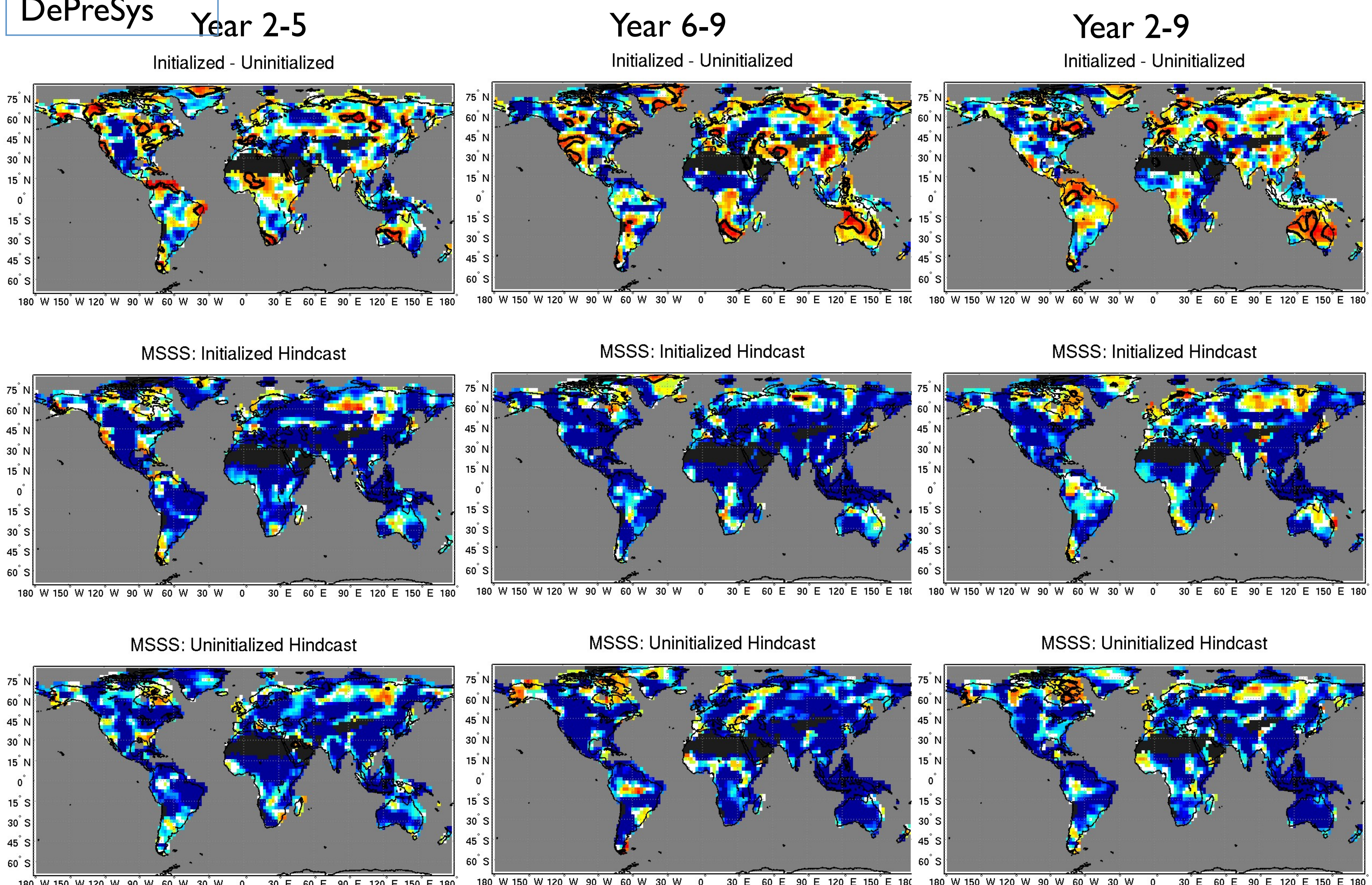
GFDL2.1

Year 2-5 | Year 6-9 | Year 2-9

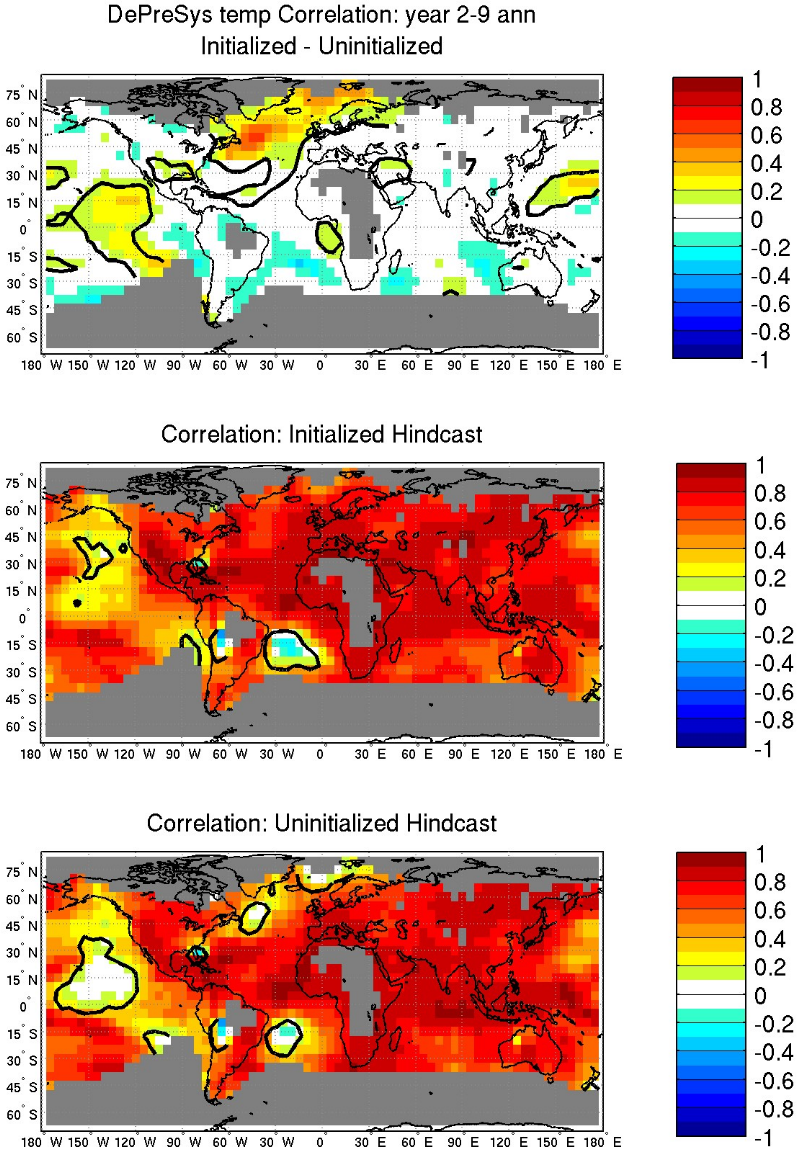


Deterministic Metrics: Mean Squared Skill Score (MSSS)

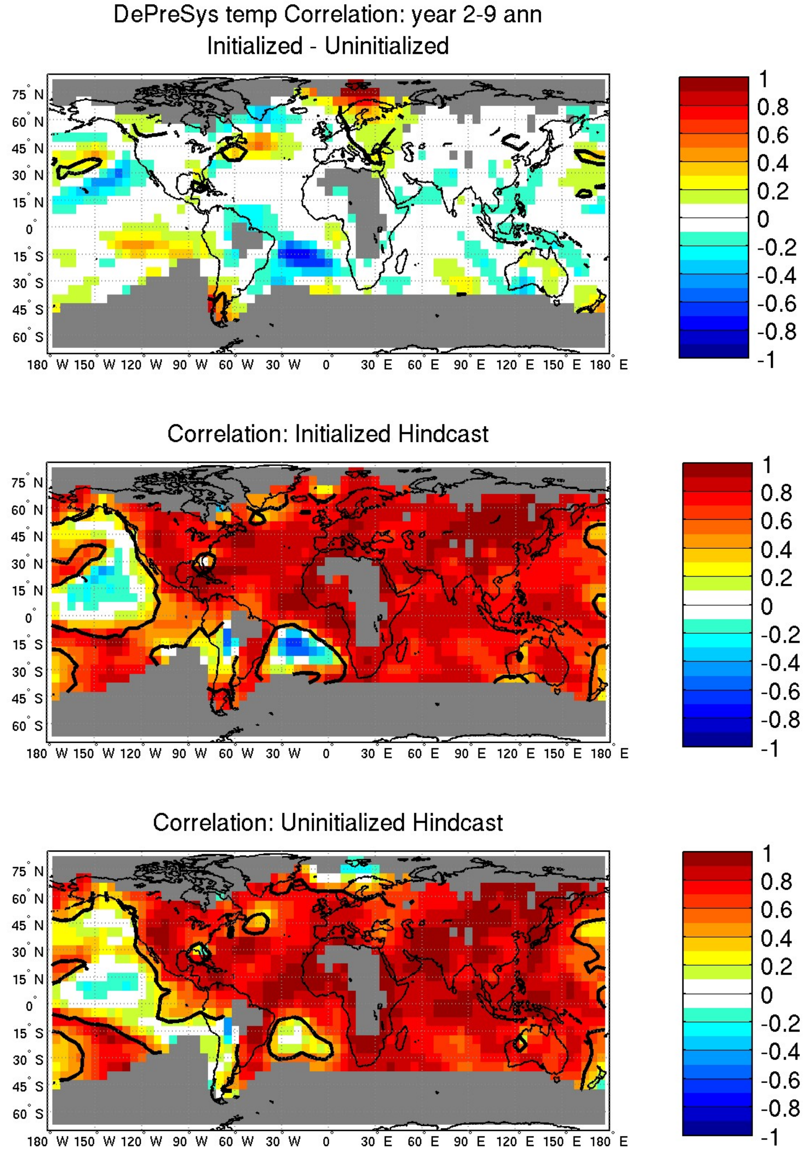
DePreSys



Using ALL start years

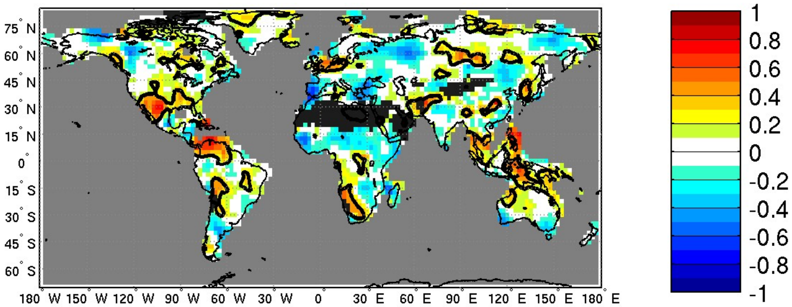


Using Every-5-year starts

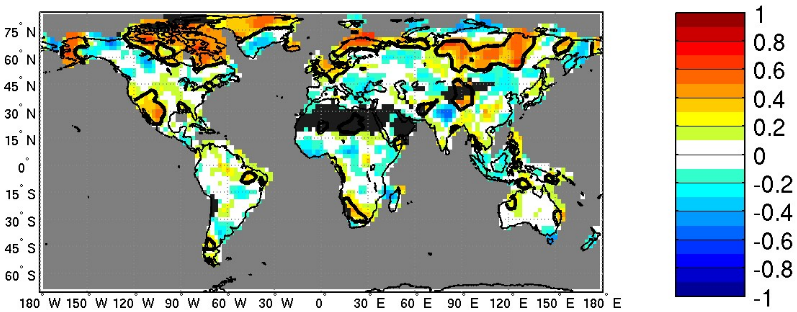


Using ALL start years

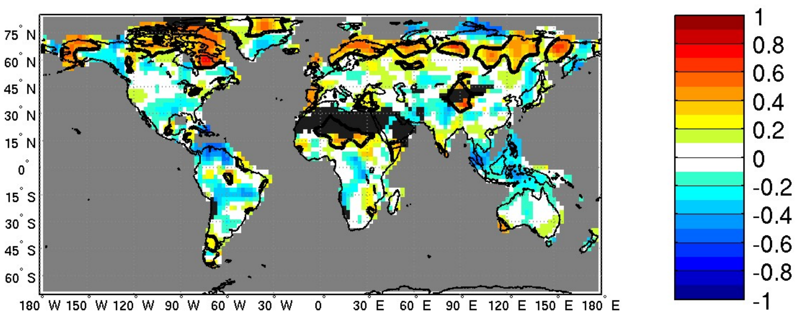
DePreSys prcp Correlation: year 2-9 ann
Initialized - Uninitialized



Correlation: Initialized Hindcast

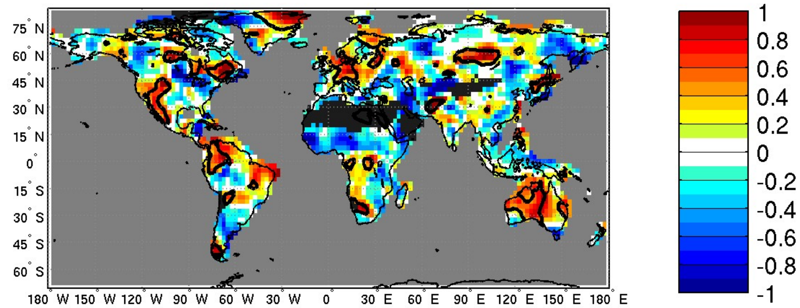


Correlation: Uninitialized Hindcast

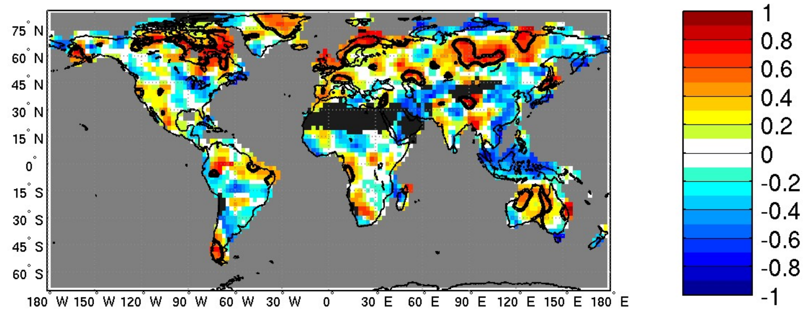


Using Every-5-year starts

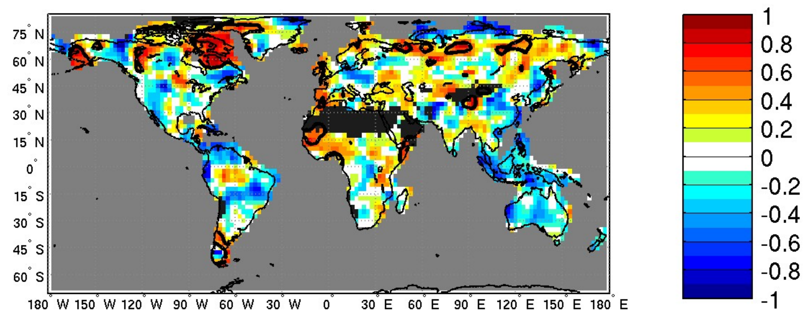
DePreSys prcp Correlation: year 2-9 ann
Initialized - Uninitialized



Correlation: Initialized Hindcast



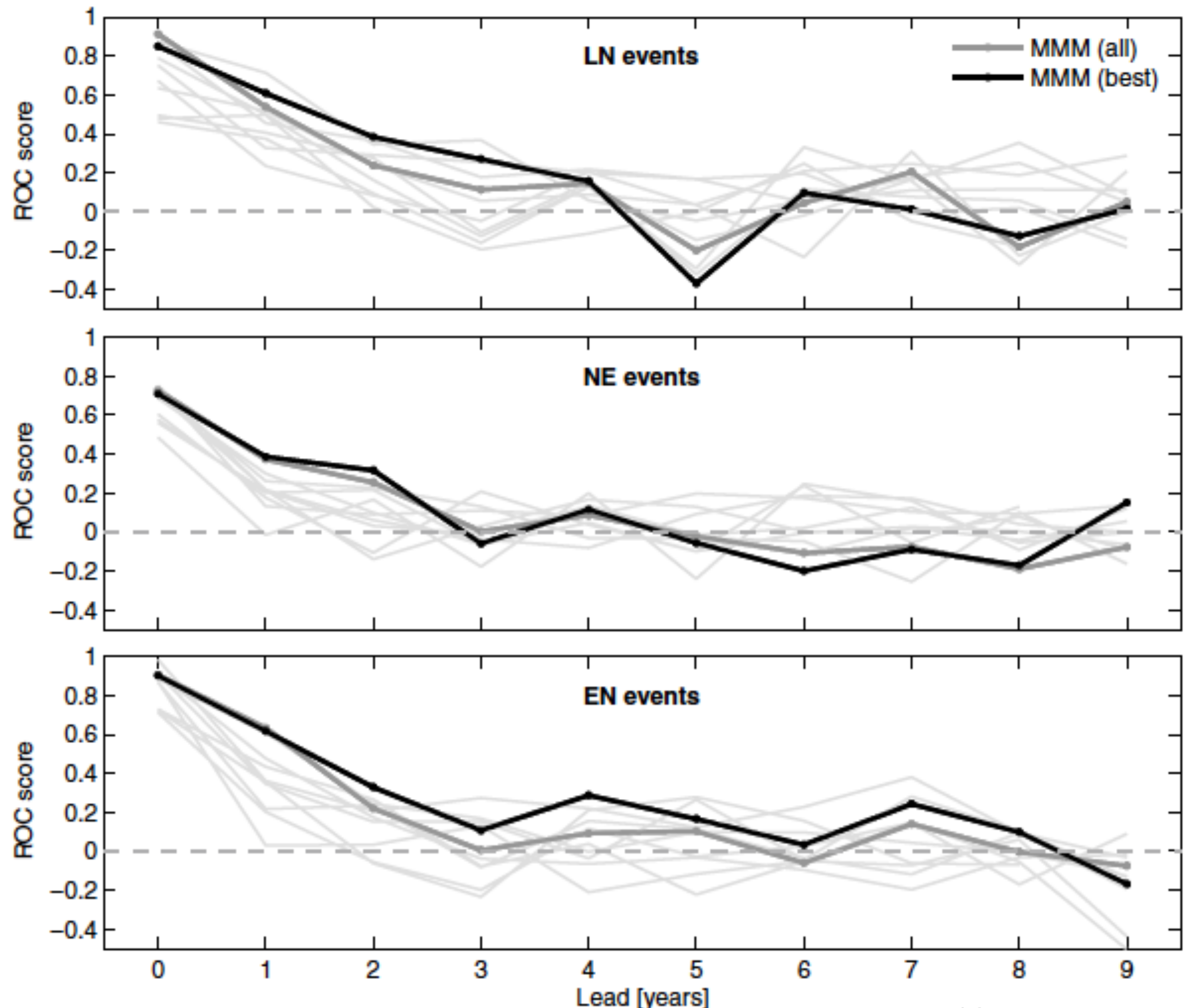
Correlation: Uninitialized Hindcast



LONG-LEAD PREDICTIONS OF INTERANNUAL VARIABILITY

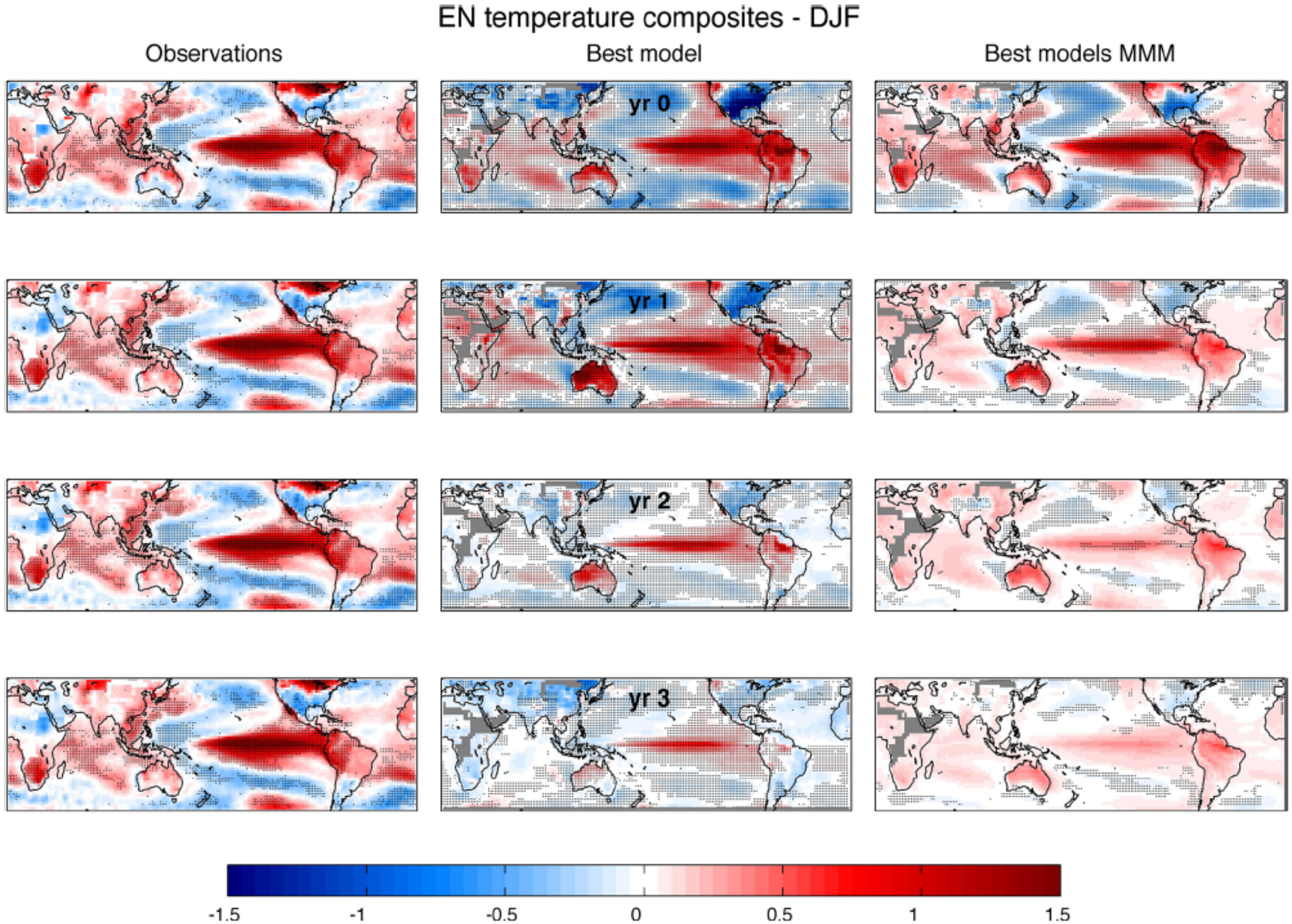
- El Niño in decadal predictions

Potential Long-lead ENSO Forecasts
using Decadal Hindcasts



(Gonzalez and Goddard 2016, Clim. Dyn.)

Potential Long-lead ENSO Forecasts



(Gonzalez and Goddard 2016, Clim. Dyn.)

Fig. 14 Comparison of the composites of near-surface temperature anomalies for EN events. The *left column* presents the near surface temperature composites for the observational CAMS dataset. The *central column* corresponds to the best system (CanCM4) and the *right column* to the multi-model ensemble mean of the subset of systems identified as the 'best' models (BMM, see text). From *top* to *bottom*, *rows* correspond to lead years 0, 1, 2 and 3. The *grey hatching* indicates statistical significance. In the case of the observations, a hypergeometric test with 95 % confidence level was applied. In the case of the models, the hatching indicates sign agreement among ensemble members of at least 60 %

SUMMARY

- Decadal variability = Manmade Climate Change + Natural Var.
  - Natural Decadal Variability driven by slow changes in Pacific and Atlantic SSTs

- Decadal prediction is EXPERIMENTAL
  - Predictions, "Forecasts", Evaluation, Use – all have many questions
  - It seems possible to provide better estimates of near-term climate change (at least T), due largely to correcting biases in Initial Conditions of models
  - Only slight evidence of real experimental predictability; very little available at regional scales (and nothing yet demonstrated for precipitation).

- Skill: Accuracy is an important consideration in use
  - Correlation & Bias are involved

Thank You

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