Climate Model Projection Uncertainties: Role of Initial Conditions & Internal Variability

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NCAR
NATIONAL CENTER FOR ATMOSPHERIC RESEARCH

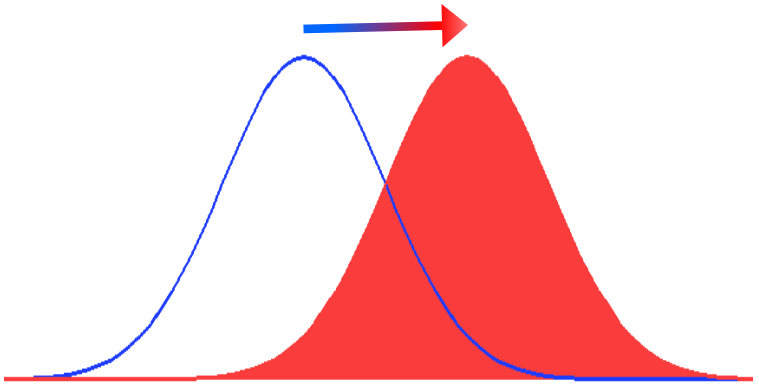
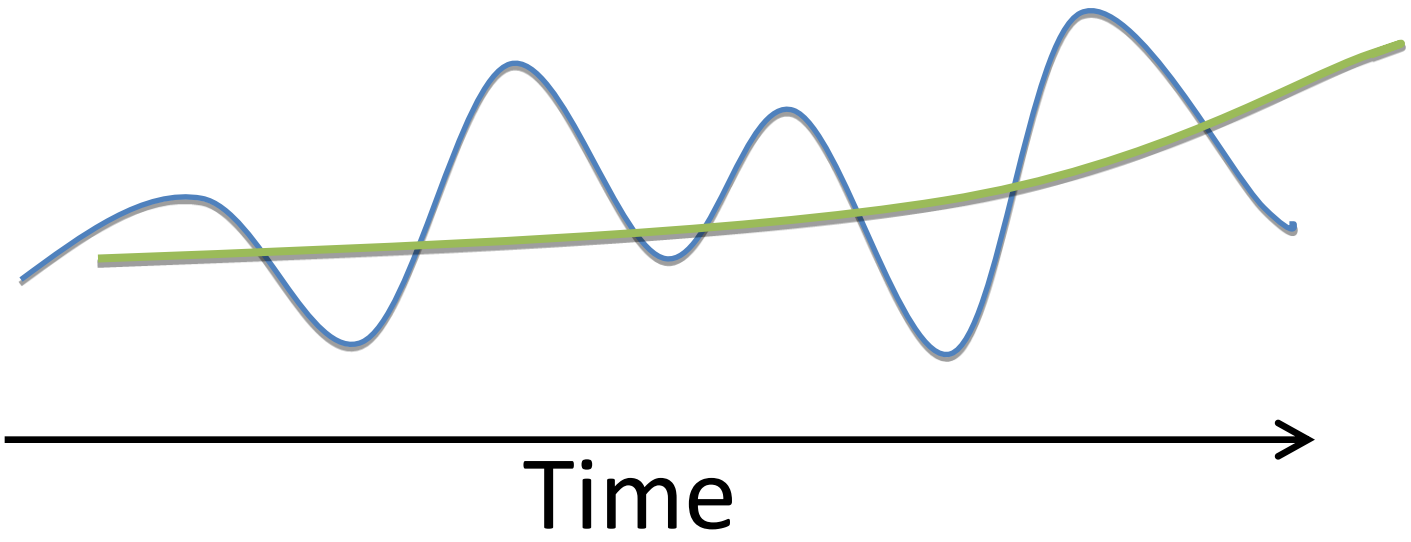


IMAGE Theme-of-the-Year Workshop

August 9, 2012

Climate Variability (unforced)

Climate Change (externally forced)

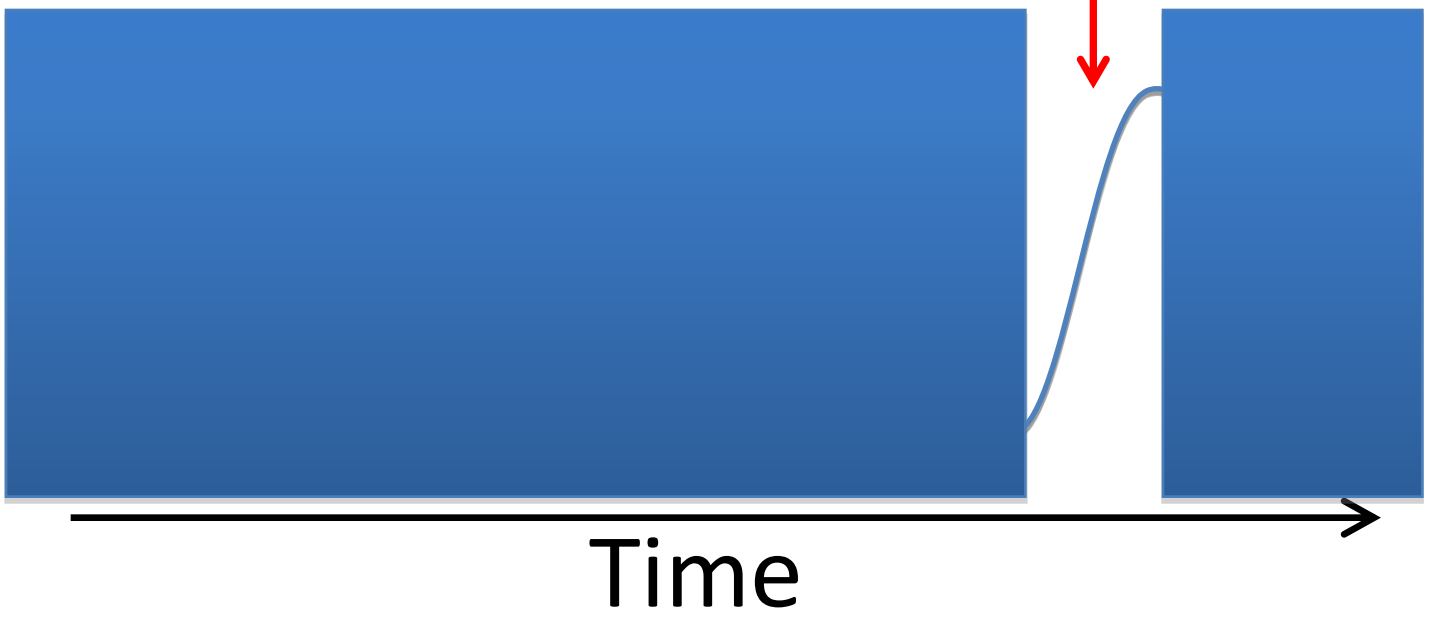


Climate Variability

or

Climate Change

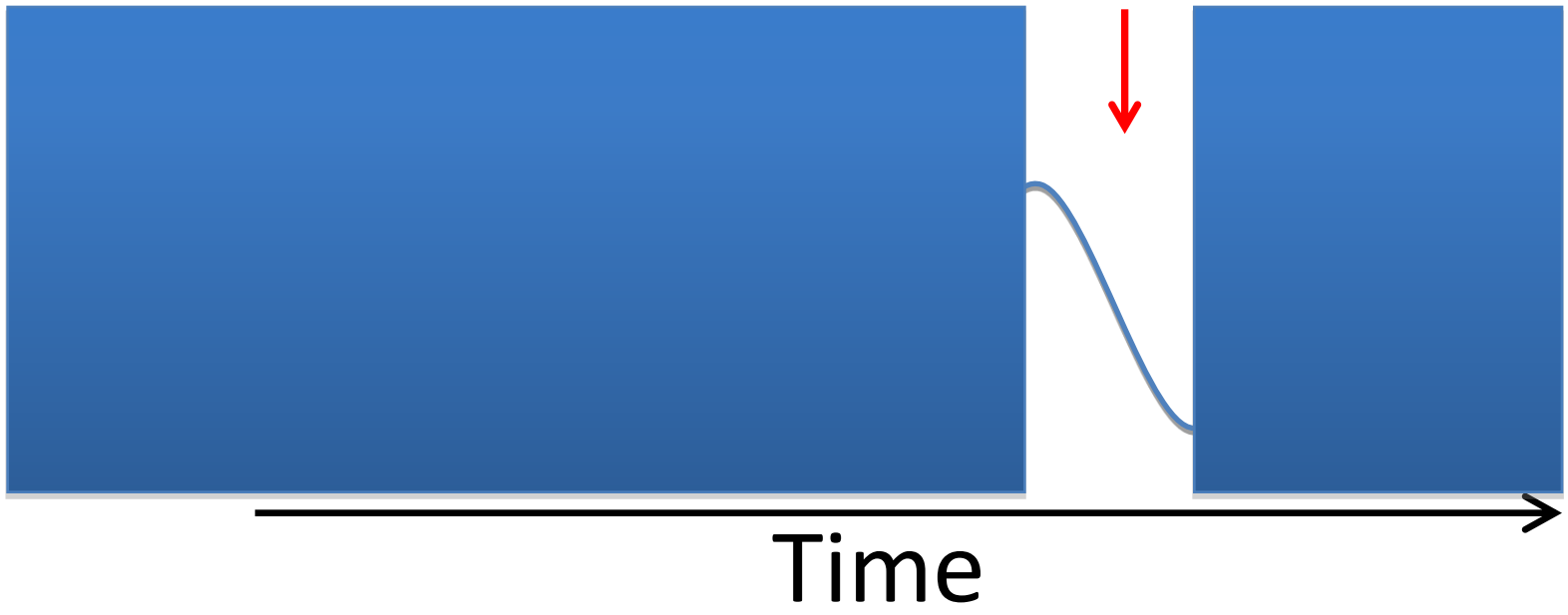
?



Climate Variability

or

Climate Change ?



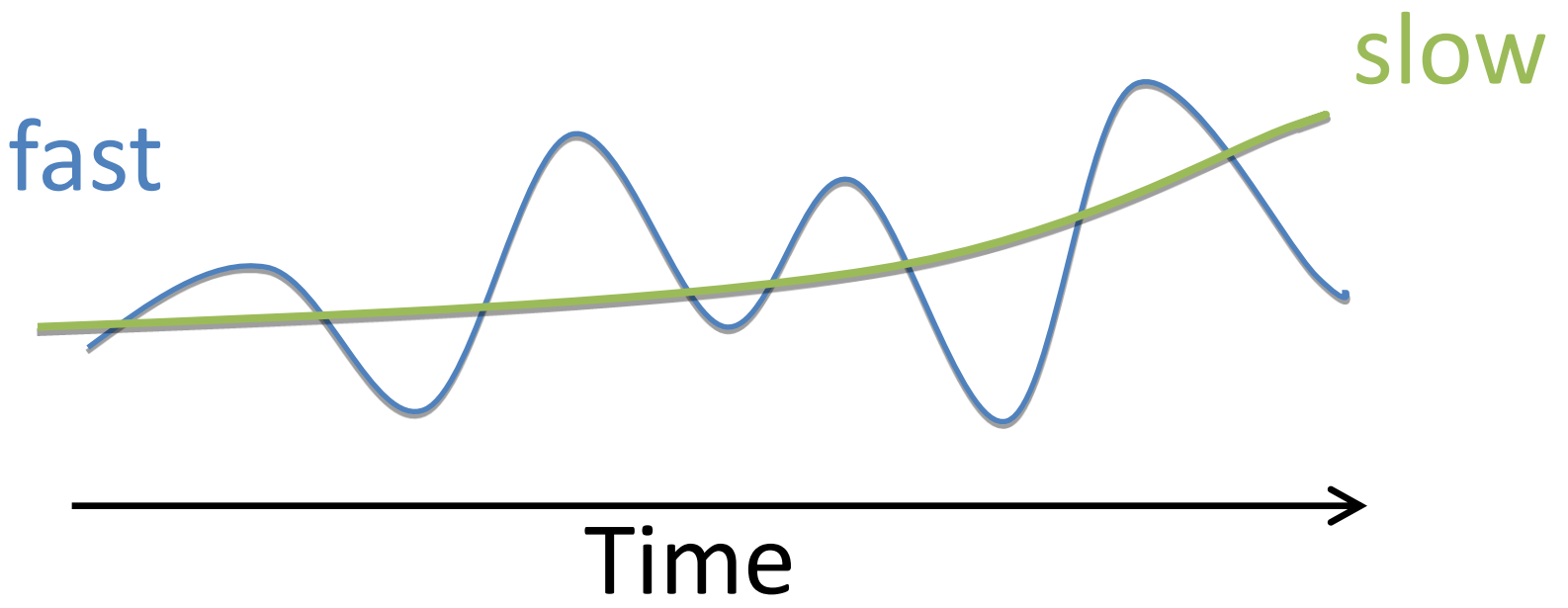
Two Examples of Slow Natural Climate Variations

Climate Variability

and

Climate Change

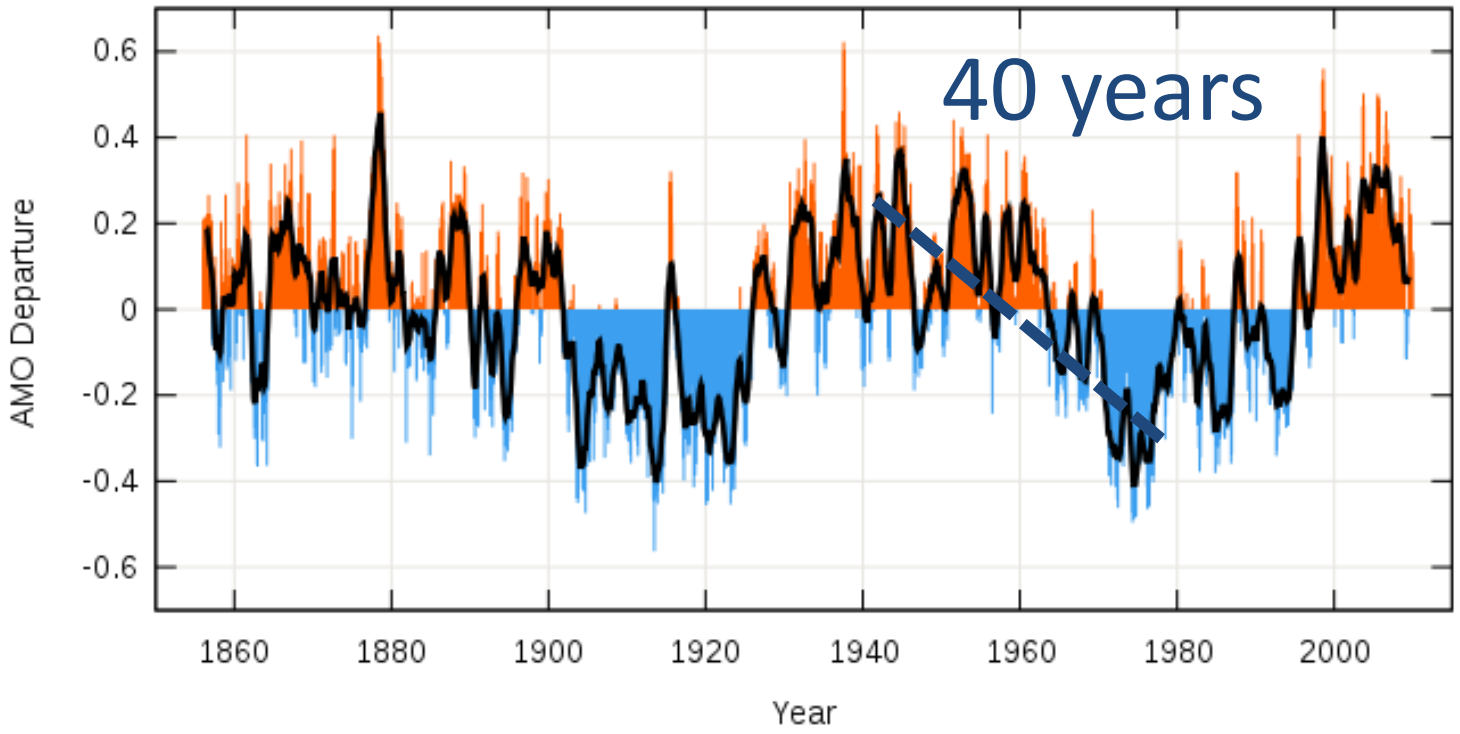
Can be very slow: multiple decades



Atlantic Multidecadal Oscillation (AMO)

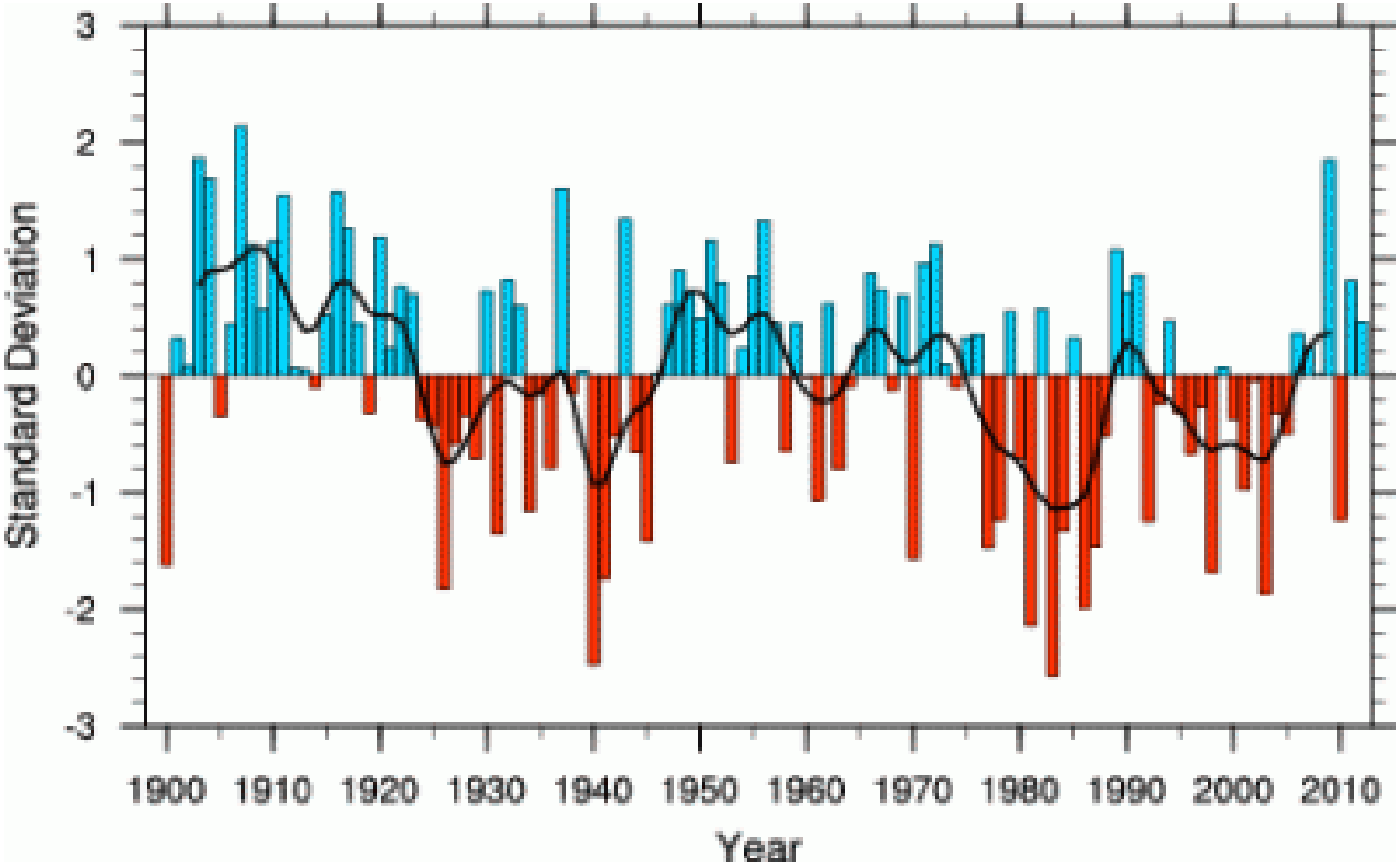
North Atlantic Sea Surface Temperature Anomalies

Ocean

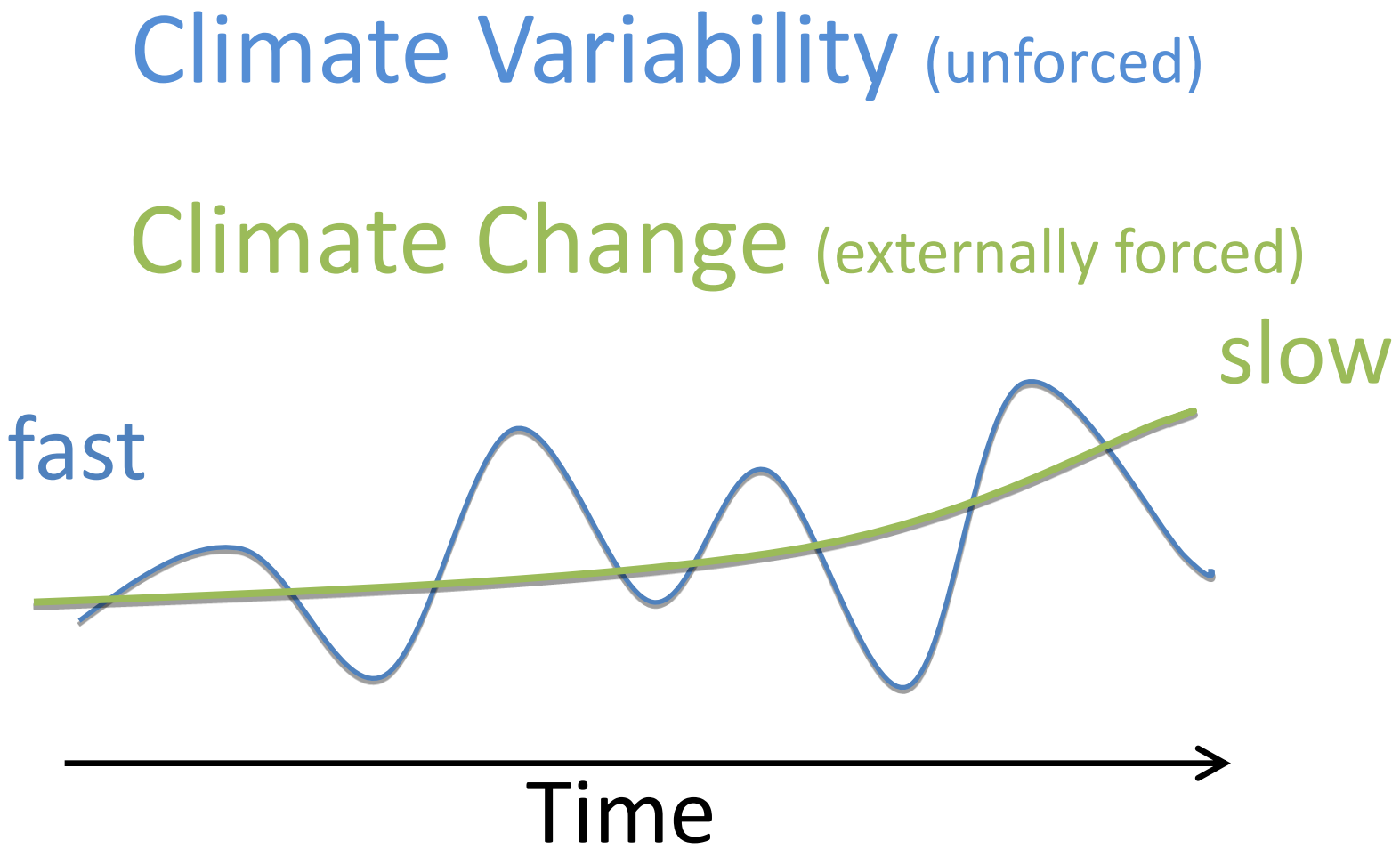


North Pacific Sea Level Pressure Index
"Pacific Decadal Oscillation"

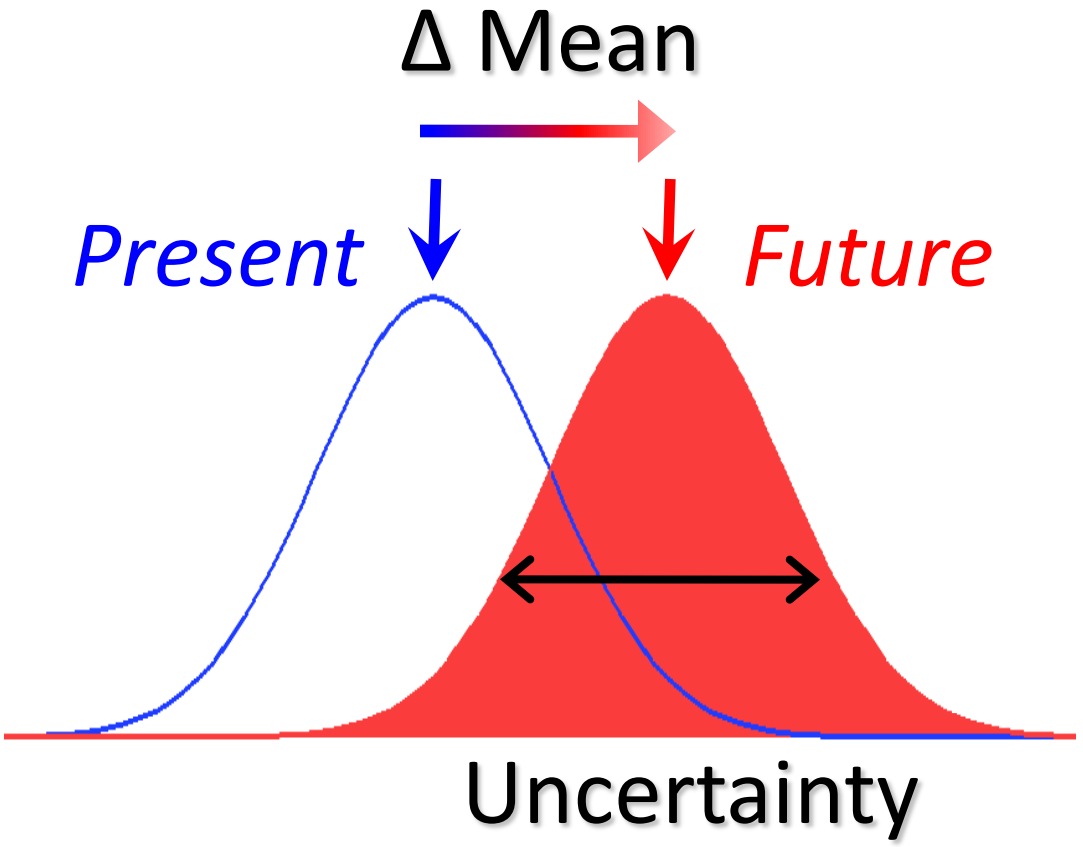
Atmosphere



Can be difficult to distinguish with short records



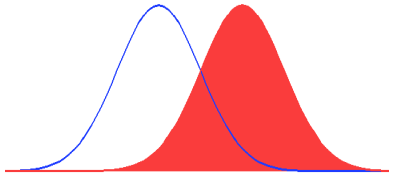
Climate Change



(e.g., due to unforced variability)

Signal: Δ Mean/Uncertainty

Climate Change: Sources of Uncertainty



- **Forcing**

  GHG emissions scenario (e.g., B1, A1B, A2, RCPs)
  ozone, sulfate aerosols, land use, black carbon …

- **Response**

  Model sensitivity
  (different physics, parameterizations, resolution …)

- **Internal (Natural) Variability**
  - atmosphere ← *Unpredictable beyond a few weeks*
  - ocean ← *Some predictability (up to 5-10 years)*
  - coupled atmosphere-ocean system

(see Branstator and Teng, 2010, 2012)

IPCC Fourth Assessment Report
Climate Change 2007: The Physical Science Basis

- Forcing

  3 Scenarios for 21st Century (B1, A1B, A2)

- Model Sensitivity

  23 Coupled General Circulation Models

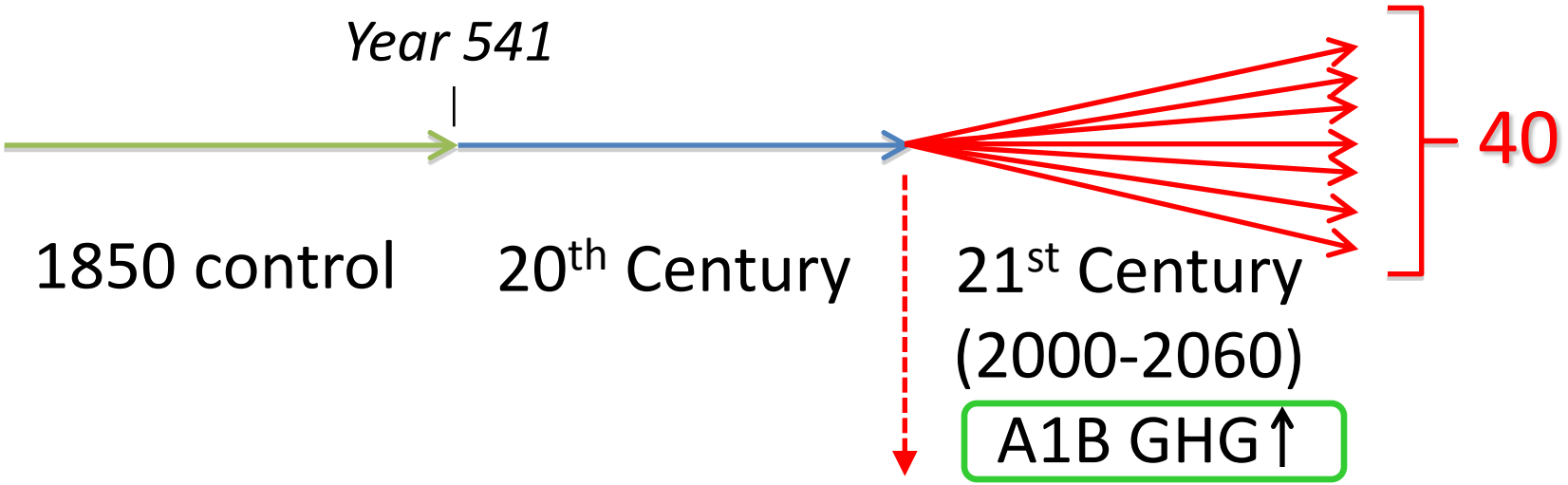
- Internal (Natural) Variability

  Multi-Decadal Time Scales Poorly Assessed

  too few (< 3) simulations per model

The NCAR Large Ensemble Project:
Uncertainty Due to Natural Variability

40 CCSM3 Integrations



e.g., spread is not predictable!

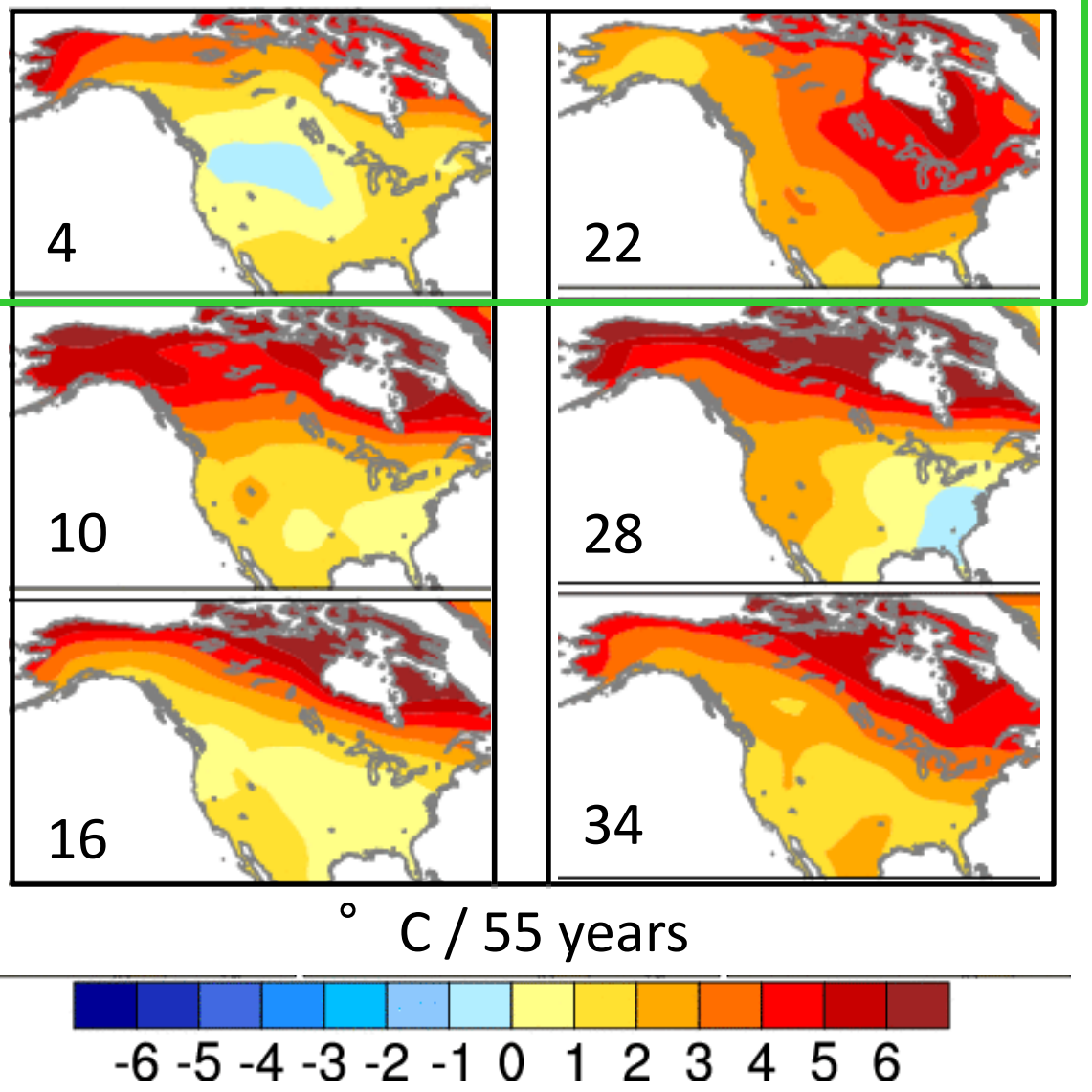
different atmospheric initial states
same ocean, ice, land initial states

Future Winter Temperature Trends 2005-2060
6 of the 40 CCSM3 Integrations

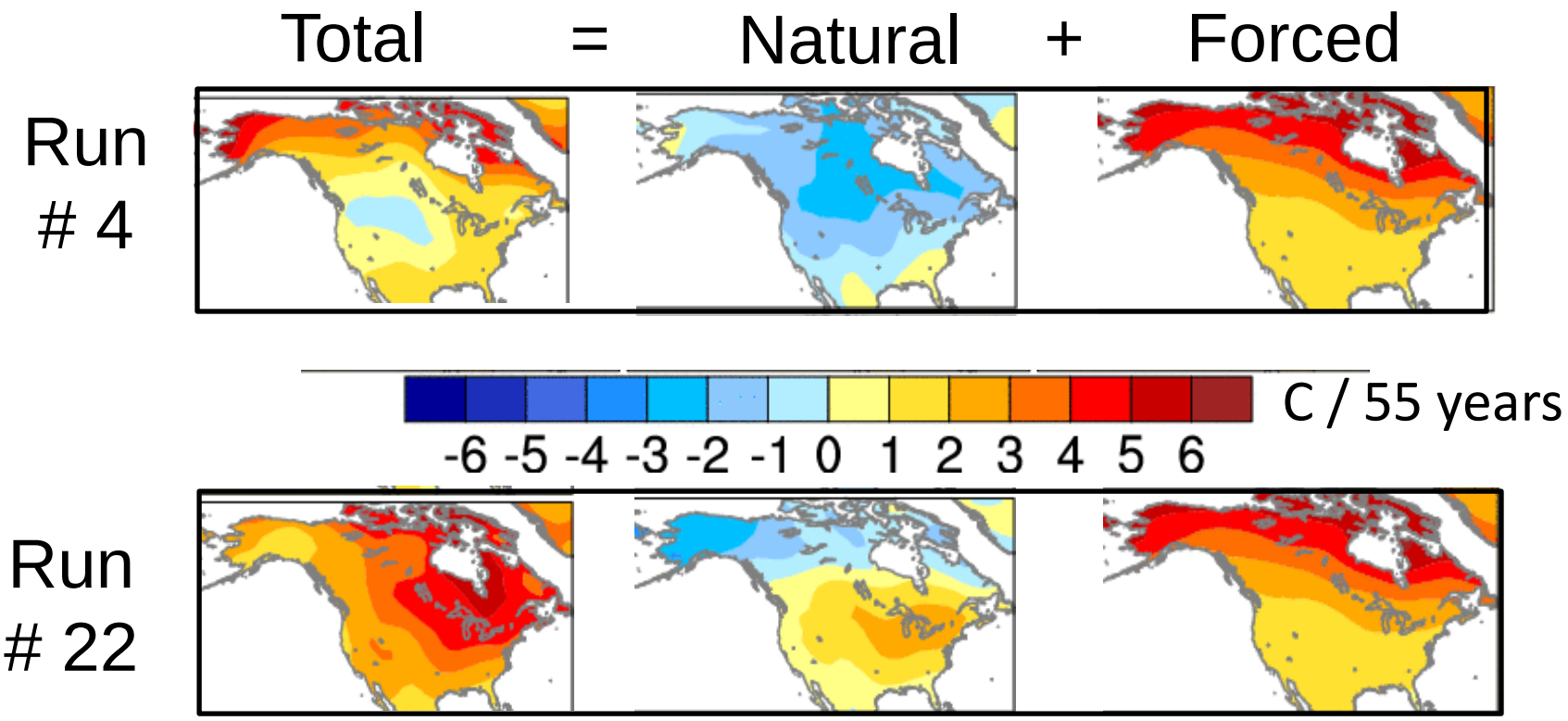
Natural Variability

+

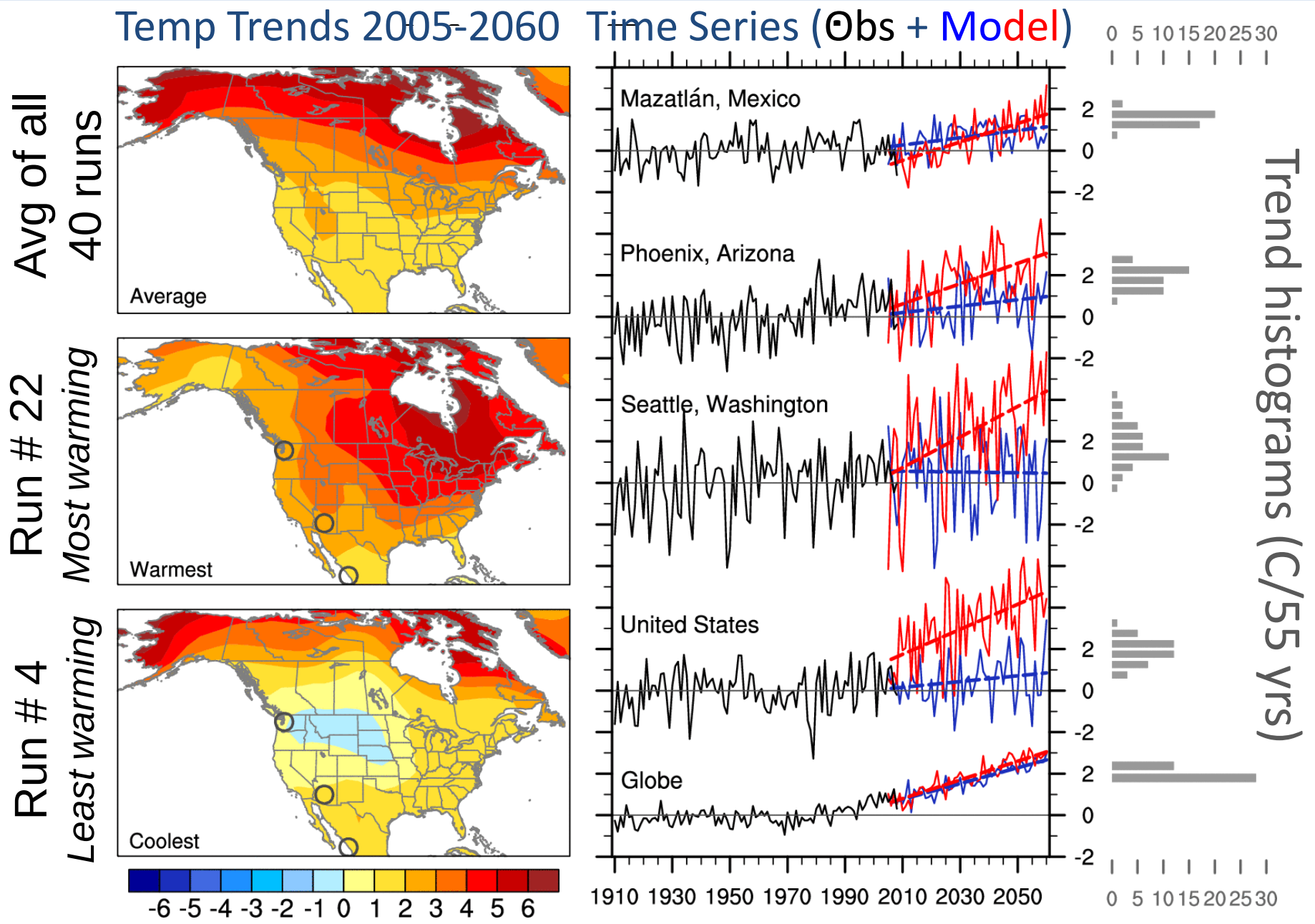
Climate Change



Future Winter Temperature Trends 2005-2060

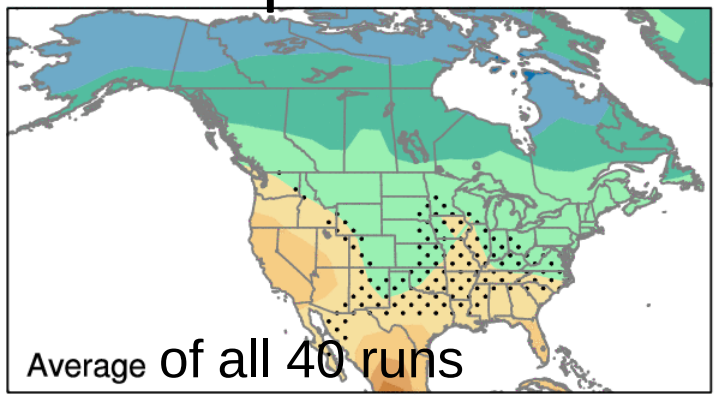


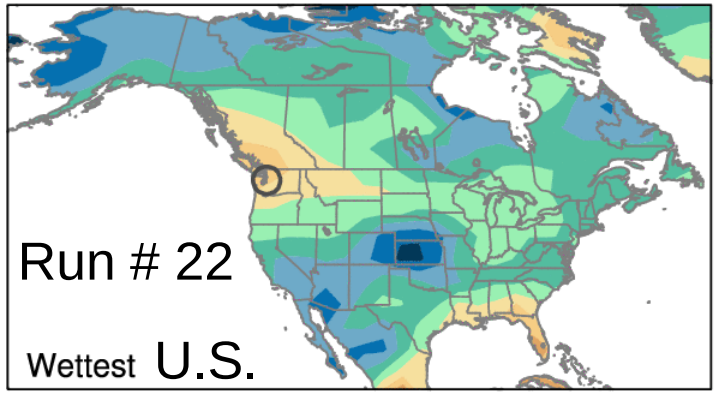
Deser, Knutti, Solomon, Phillips: *Nature Climate Change, 2012*

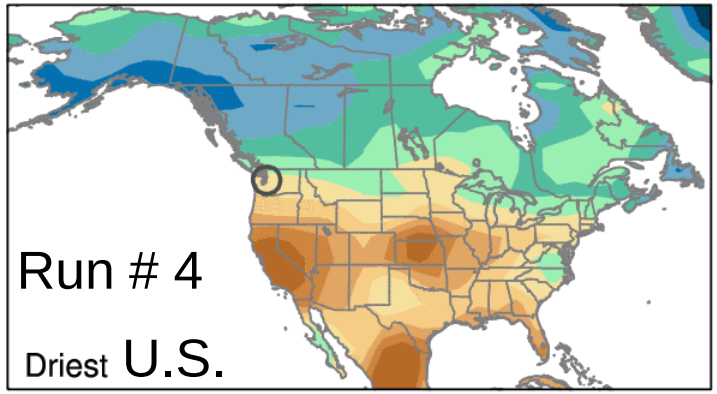


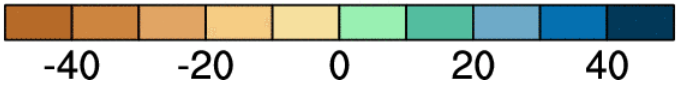
Precipitation

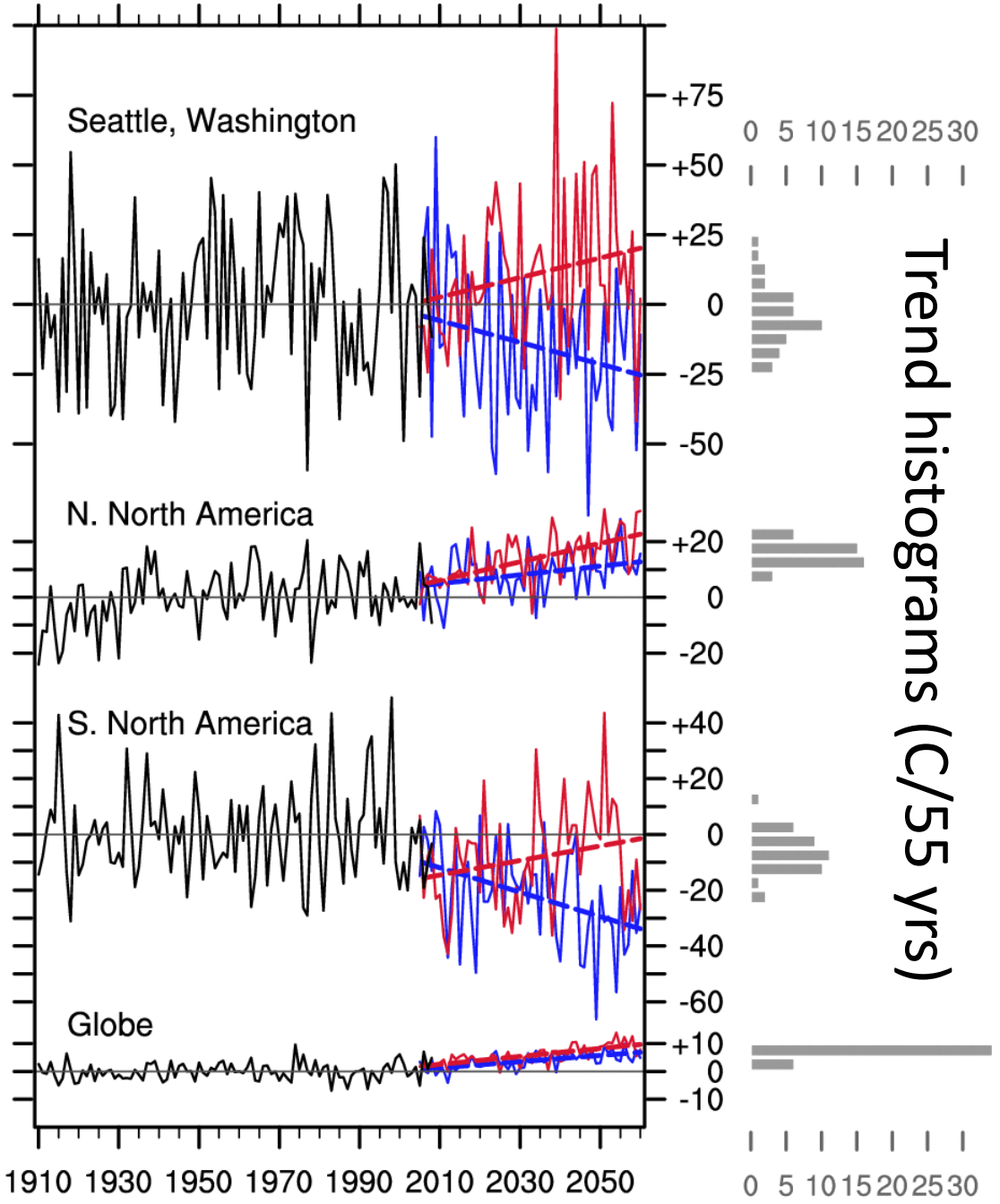
Deser, Knutti, Solomon, Phillips: *Nature Climate Change, 2012*



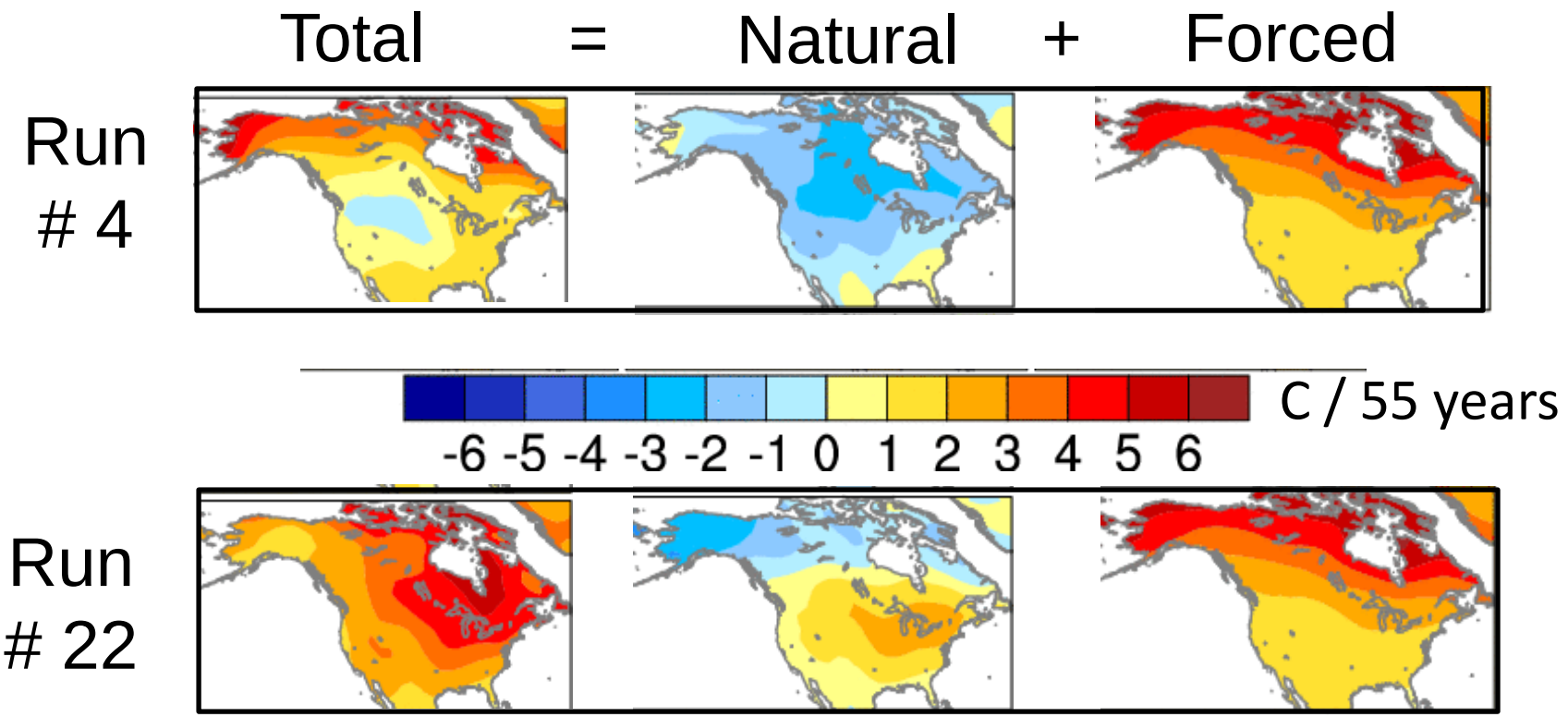








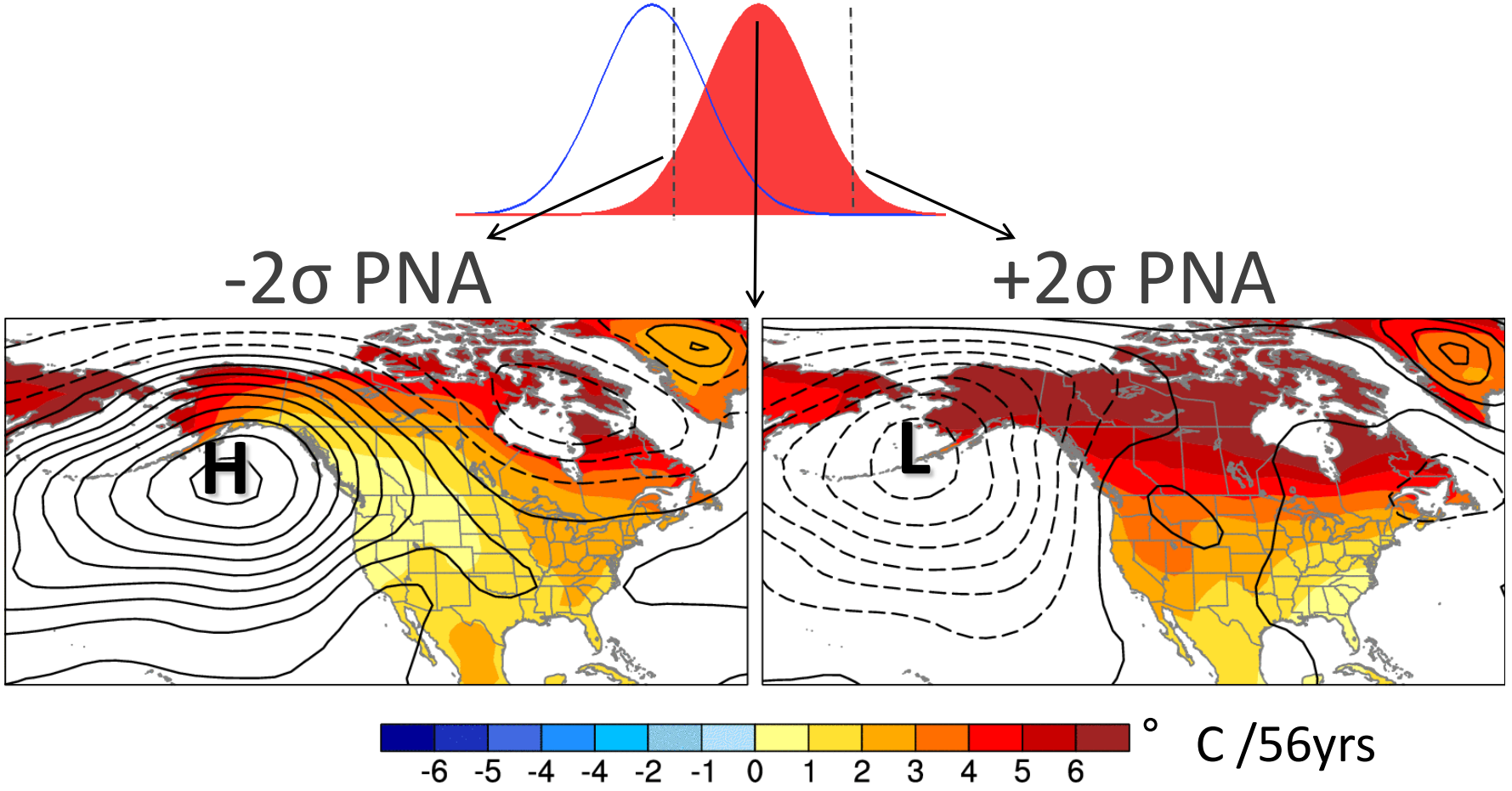
Future Winter Temperature Trends 2005-2060



Where does the natural component come from?

Variability in large-scale atmospheric circulation patterns such as the “Pacific North American (PNA)” pattern

Future Air T and SLP Trends 2005-2060

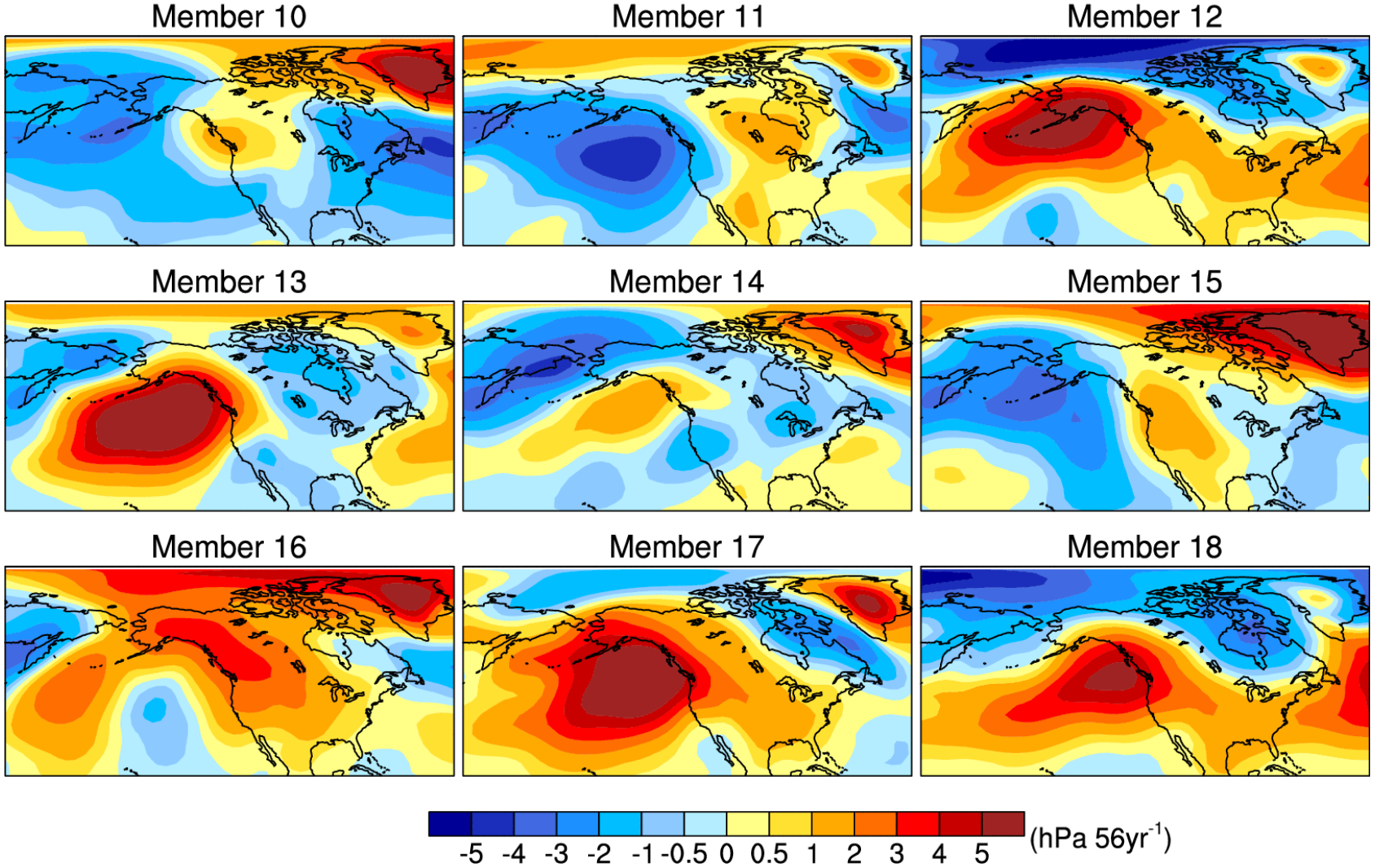


A Range of Future Outcomes Due to Natural Atmospheric Circulation Variability

(Deser et al., in preparation)

CCSM3 Large Ensemble

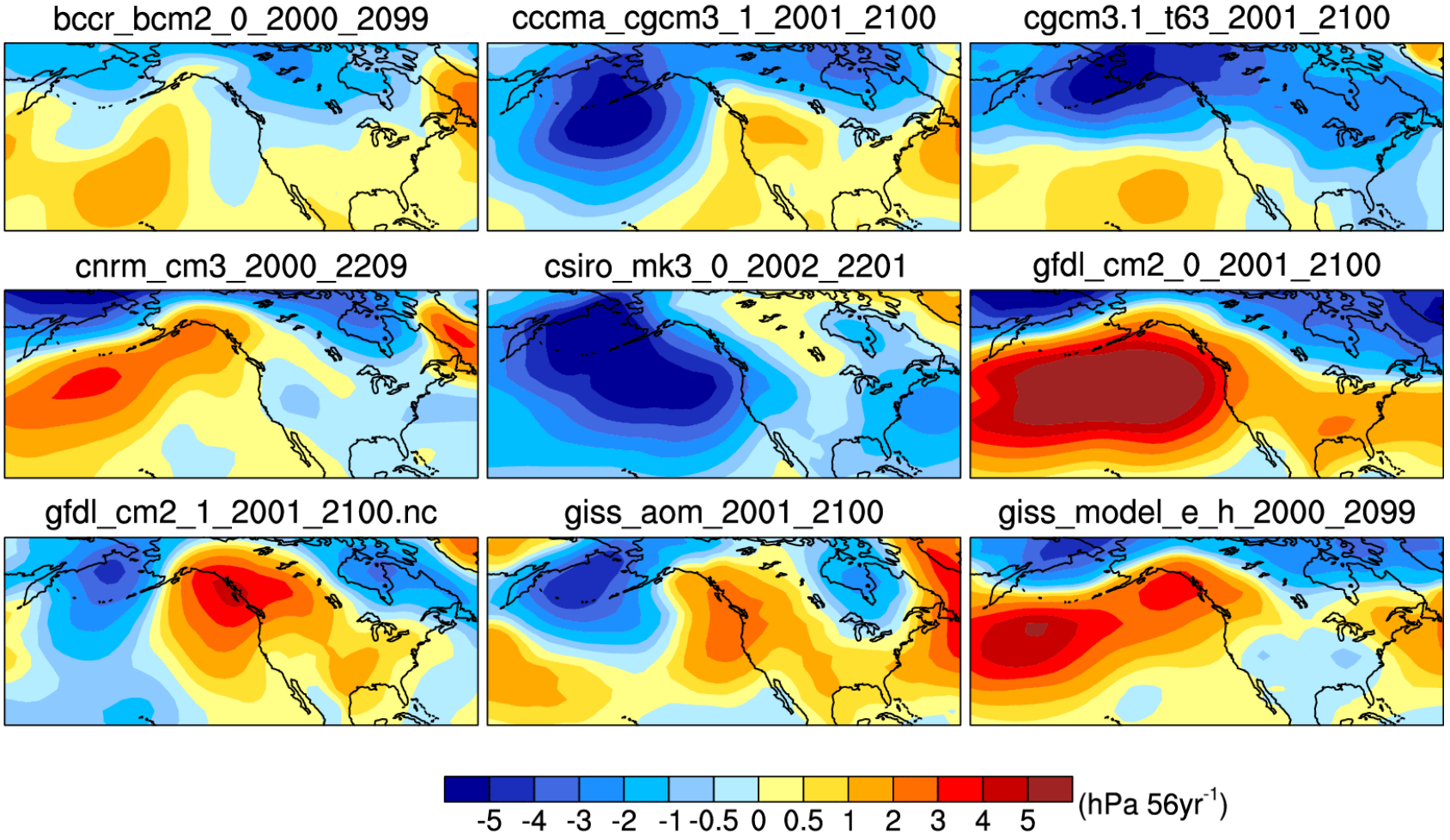
Atmospheric Circulation (DJF SLP) Trends 2005-2060



Natural Variability (in one model)

IPCC AR4 (CMIP3) Model Archive

Atmospheric Circulation (DJF SLP) Trends 2005-2060



Model Sensitivity or Natural Variability?

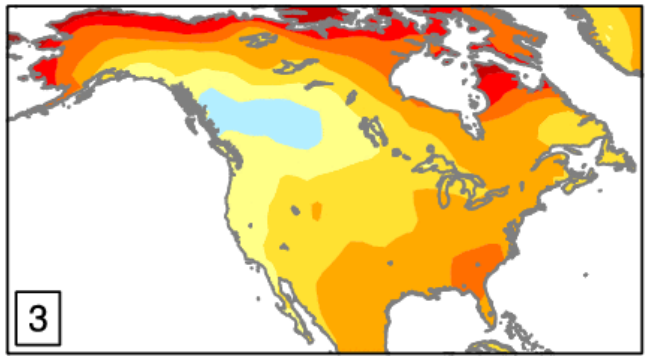
How should we compare single realizations from different models?

We should only compare the forced component; the natural component can only be compared in a probabalistic sense.

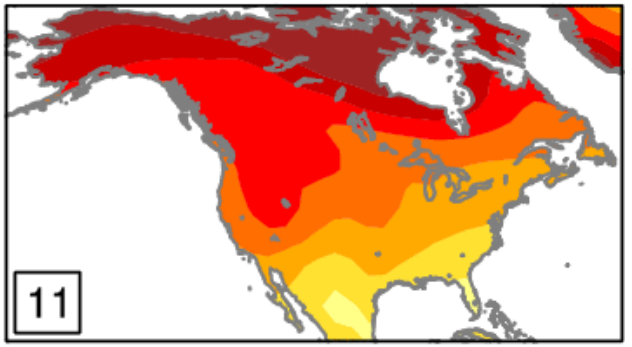
Air Temperature Trends (2005-2060)

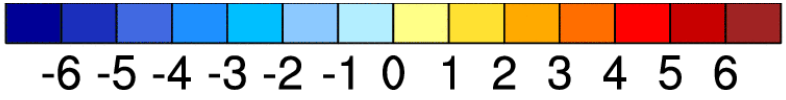
Natural + Forced Responses in a Single Realization

ECHAM5



CCSM3

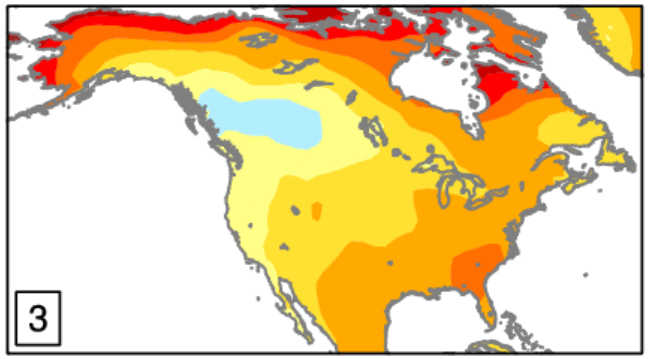




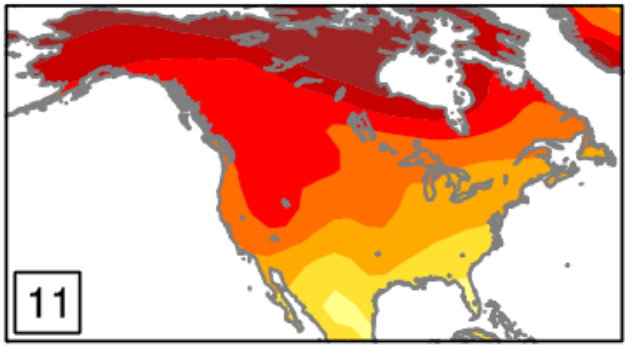
Air Temperature Trends (2005-2060)

Natural + Forced Responses in a Single Realization

ECHAM5

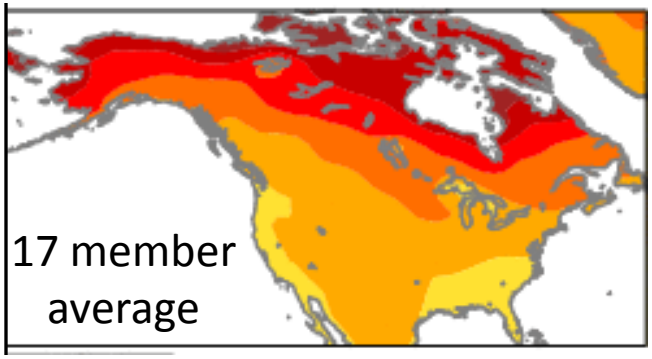


CCSM3

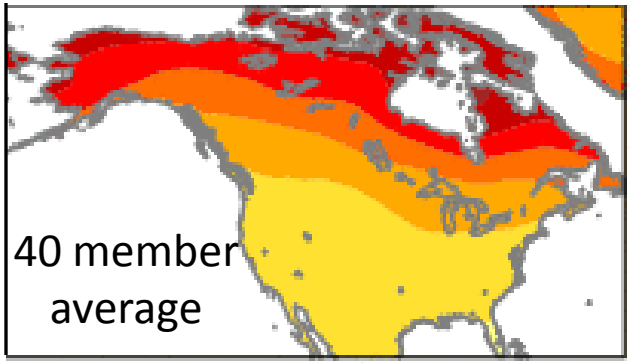


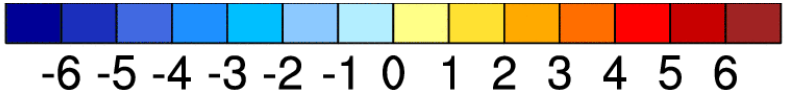
Forced Responses

ECHAM5



CCSM3





How should we compare single realizations from different models?

What if we only have 1 realization?
How do we obtain the forced response
(and separate it from the natural variability)?

Use technique of "Dynamical Adjustment" to reduce the influence of natural circulation variability

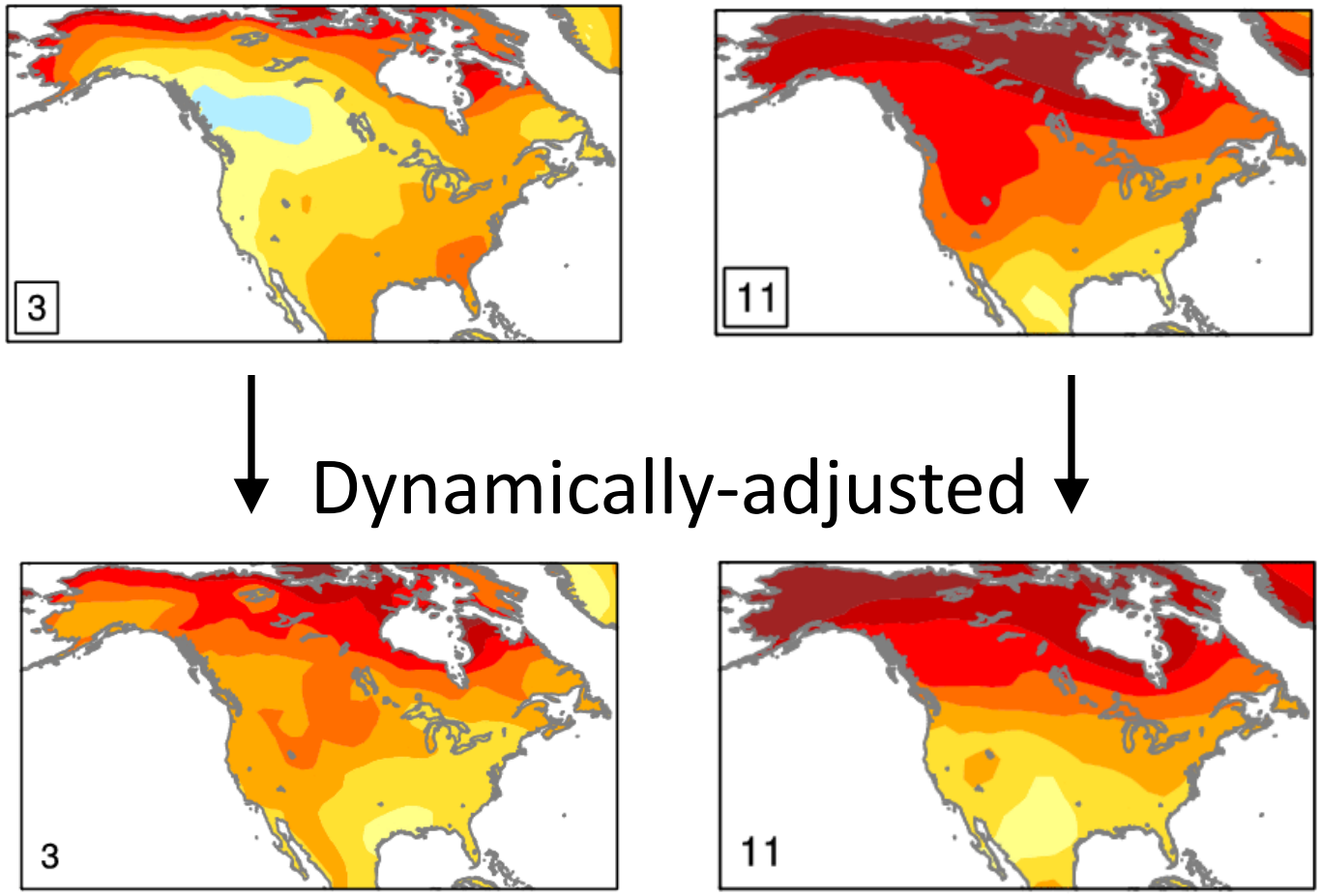
(still under exploration; Wallace et al., PNAS)

Air Temperature Trends (2005-2060)

ECHAM5

Raw

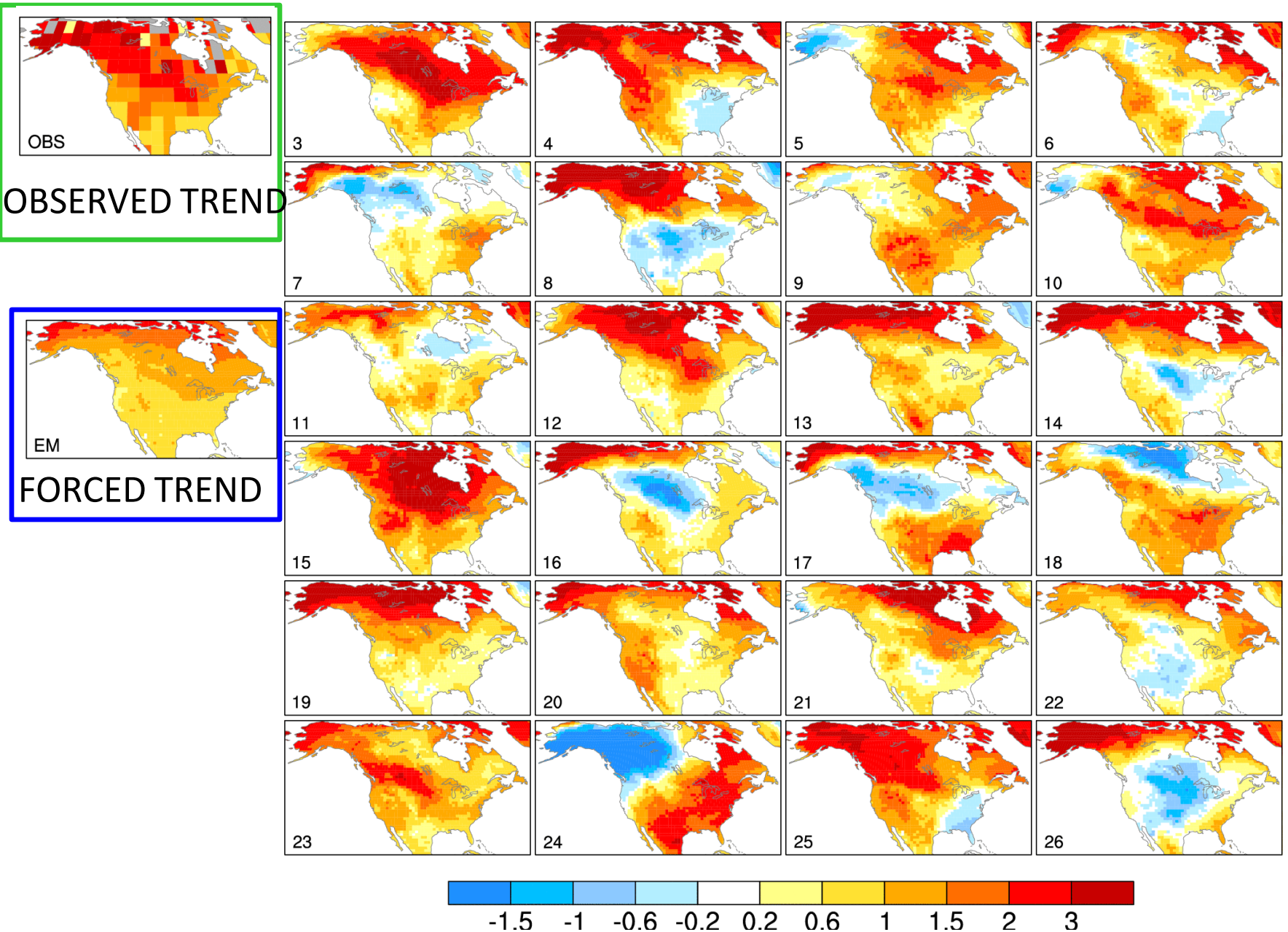
CCSM3



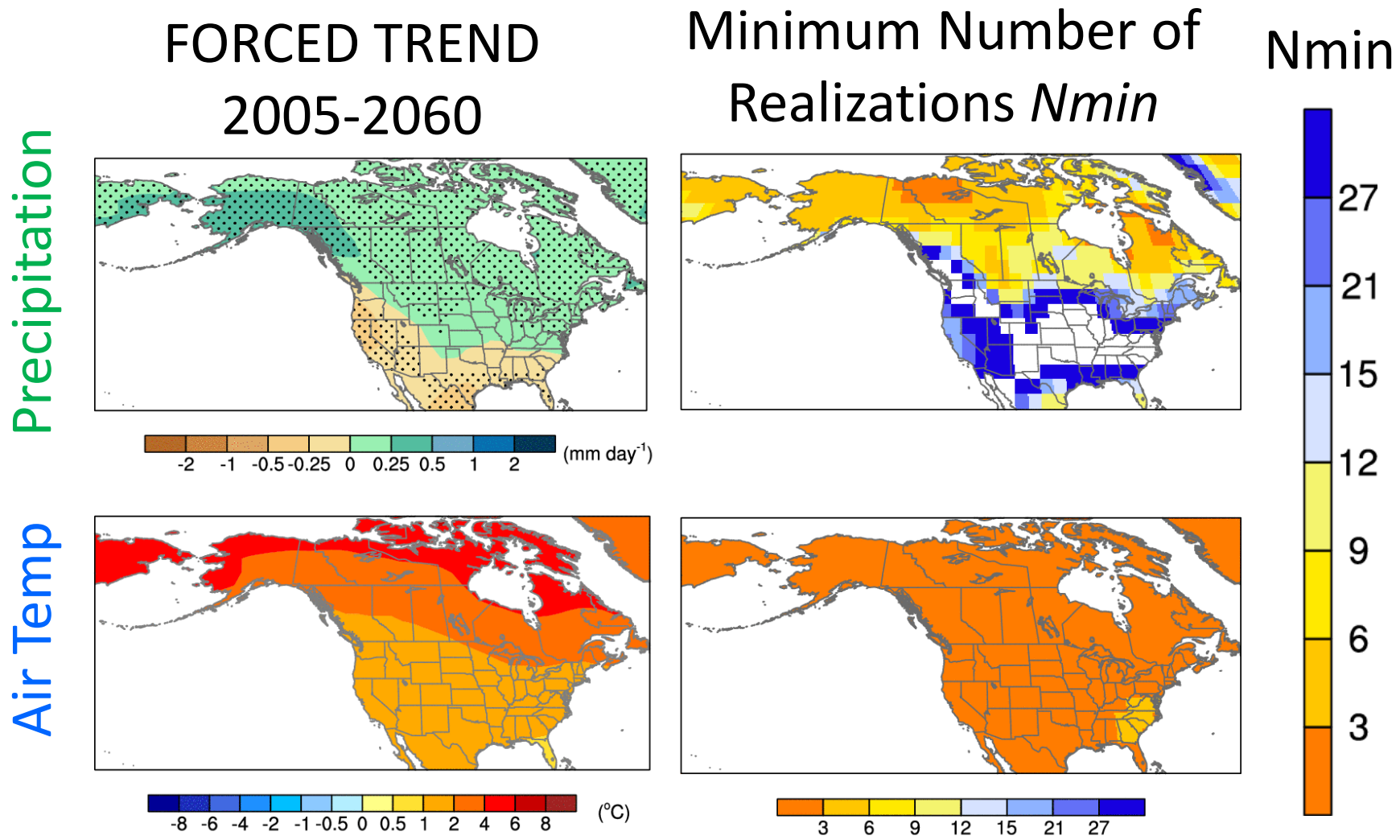
How should we compare the single realization in nature with the single realizations in different models?

Perform a similar “dynamical adjustment” but need to think about how to define “natural variability” in observations

Air Temperature Trends (1970-2005) CCSM4



How many realizations are needed to obtain the forced response (with 95% confidence) ?



Global maps in:

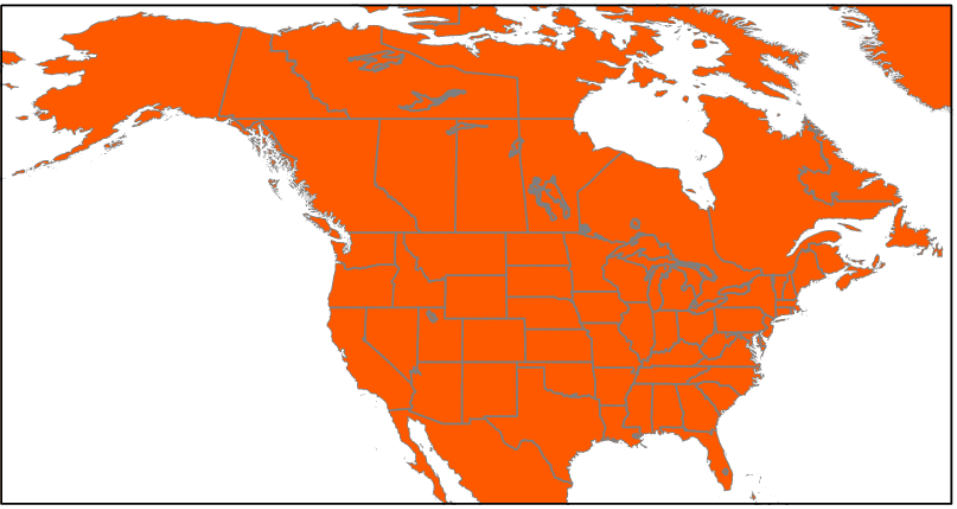
Deser et al., *Climate Dynamics*, 2012

What is the chance that temperatures will warm?

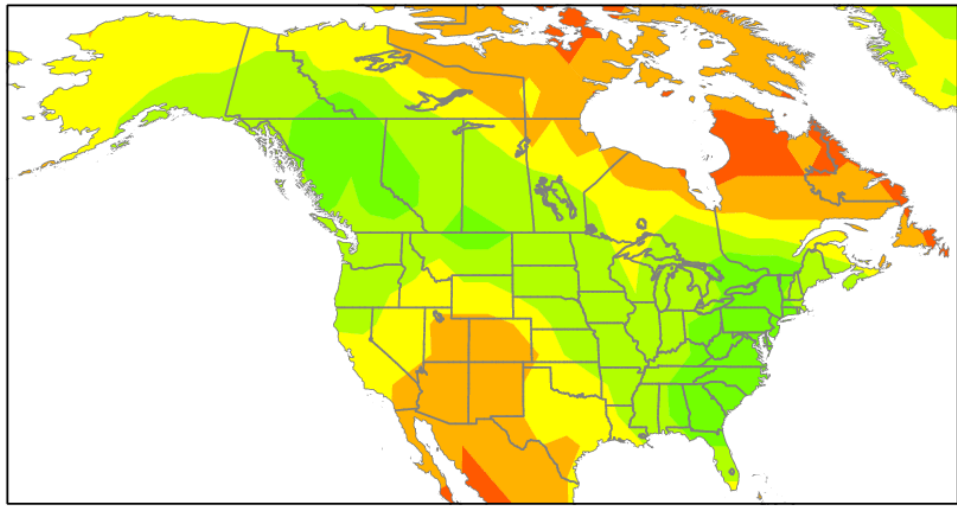
What is the chance that precipitation will decrease?

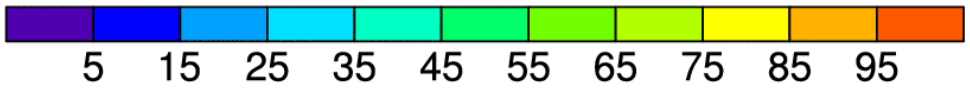
Winter Air Temperature Trends

2005-2060



2005-2032



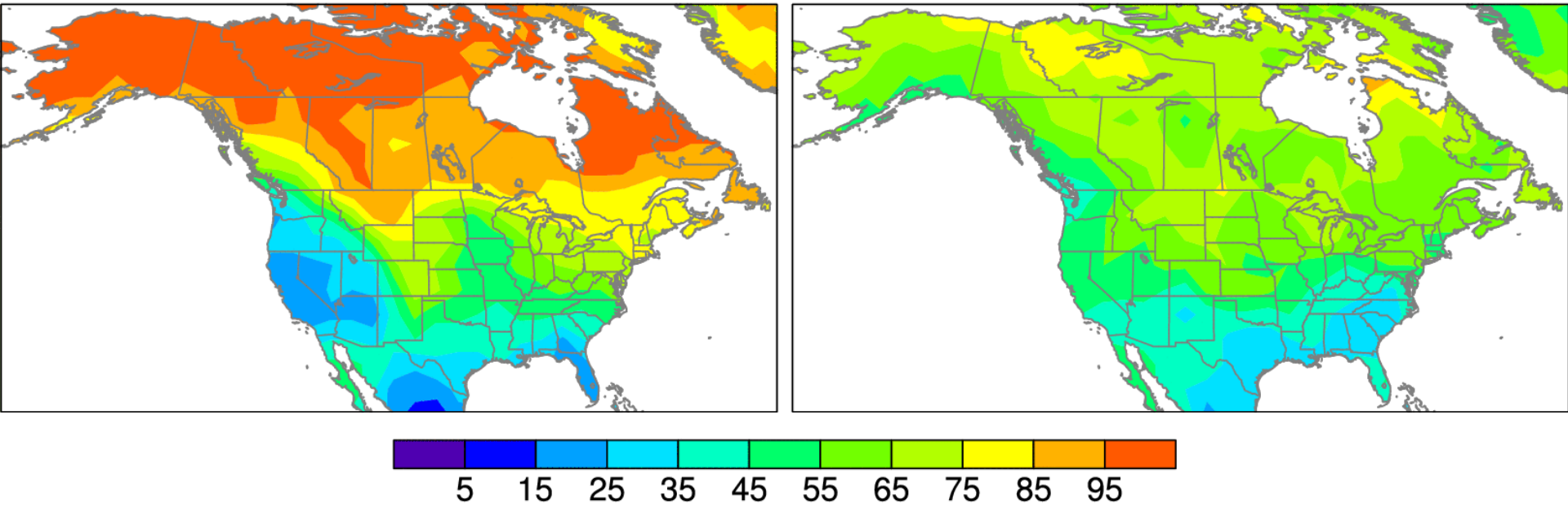


% chance warming

Winter Precipitation Trends

2005-2060

2005-2032



% chance increase

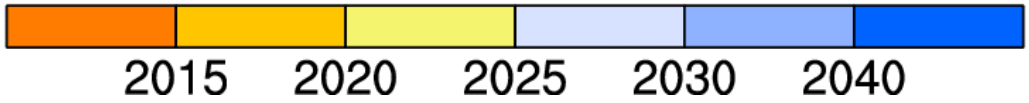
When can the forced climate change signal be detected with 40 realizations? (5 realizations?)

10-year running means
relative to 2010

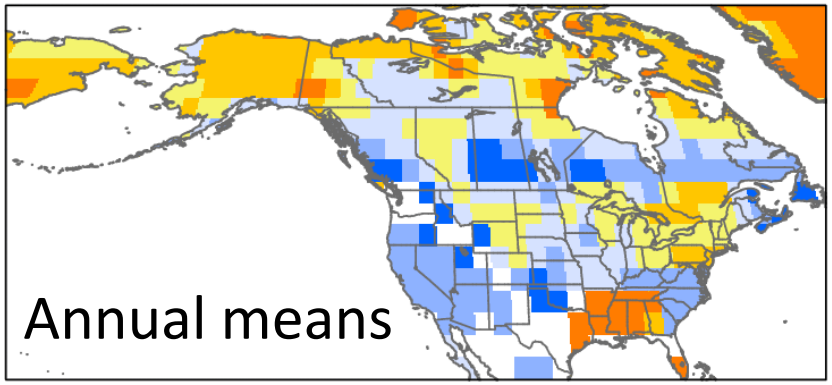
Global maps in:
Deser et al., *Climate Dynamics*, 2012

Decade of Emergence of Forced Signal
(compared to 2010)

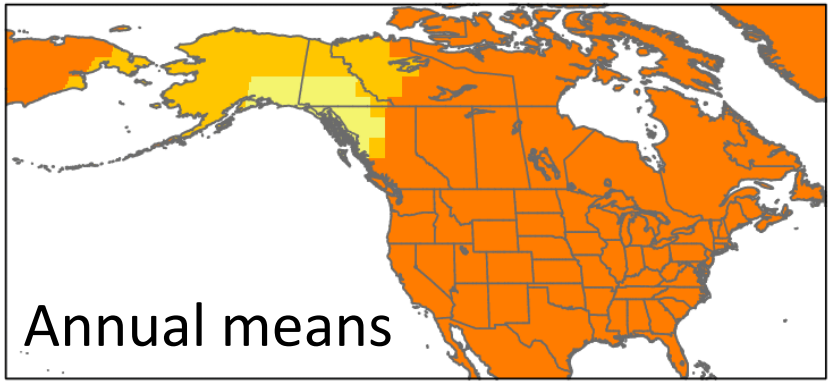
N=40



Precipitation



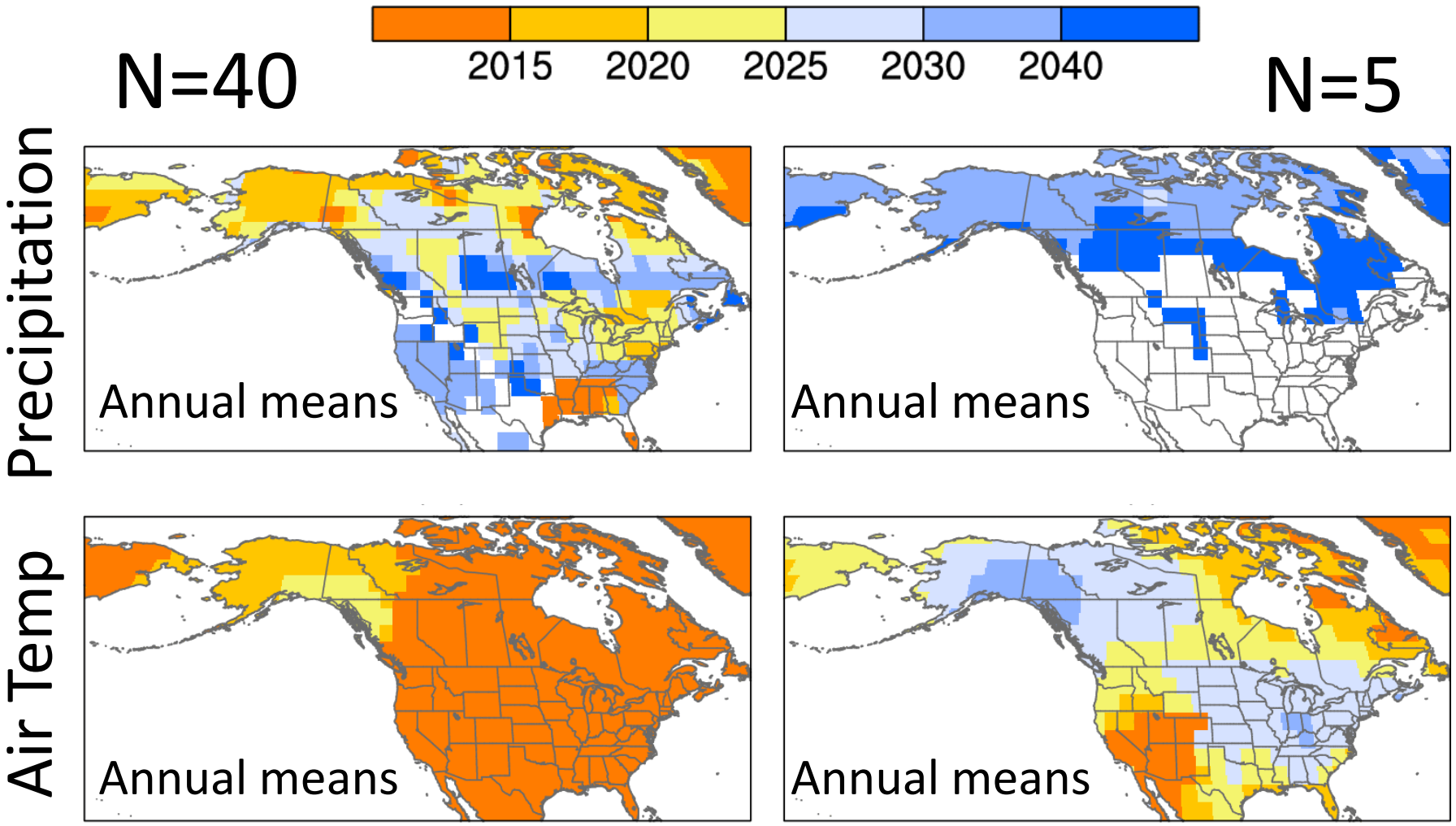
Air Temp



White areas indicate no detectable climate change

Decade of Emergence of Forced Signal

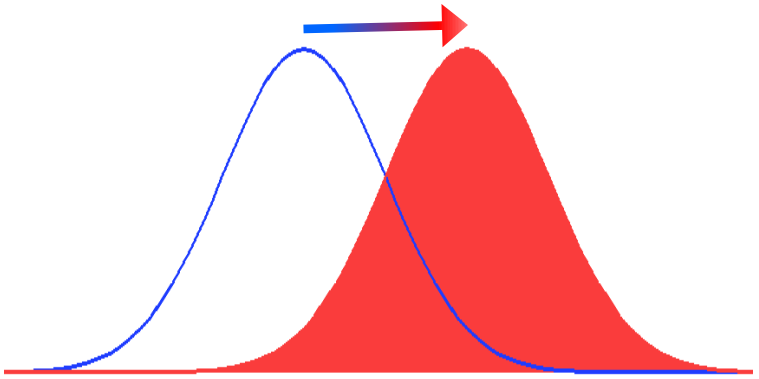
(compared to 2010)



White areas indicate no detectable climate change

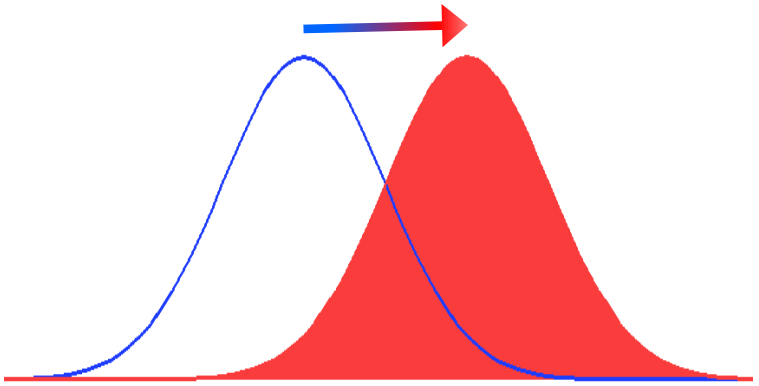
Summary and Outlook

1) We should expect a range of climate change outcomes on local and regional scales due to natural variability of the atmospheric circulation, even over the next 50 years.



Summary and Outlook

2) Large (~ 30 member) ensembles are needed to properly compare climate change signals between different models, and between models and nature.



Thank You

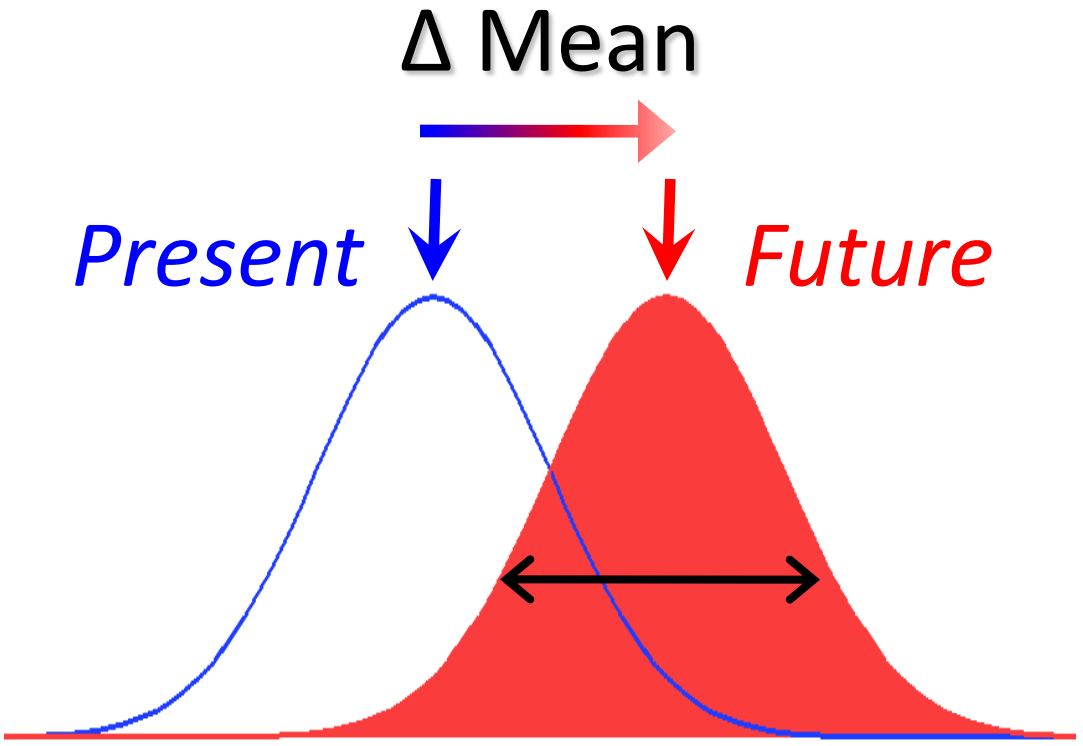
CCSM3 Large Ensemble output available from the CESM Climate Change and Variability Working Group (C. Deser, co-chair)

http://www.cesm.ucar.edu/working_groups/Climate/

Deser et al., *Climate Dynamics*, 2012
Deser et al., *Nature Climate Change*, in press

Extra

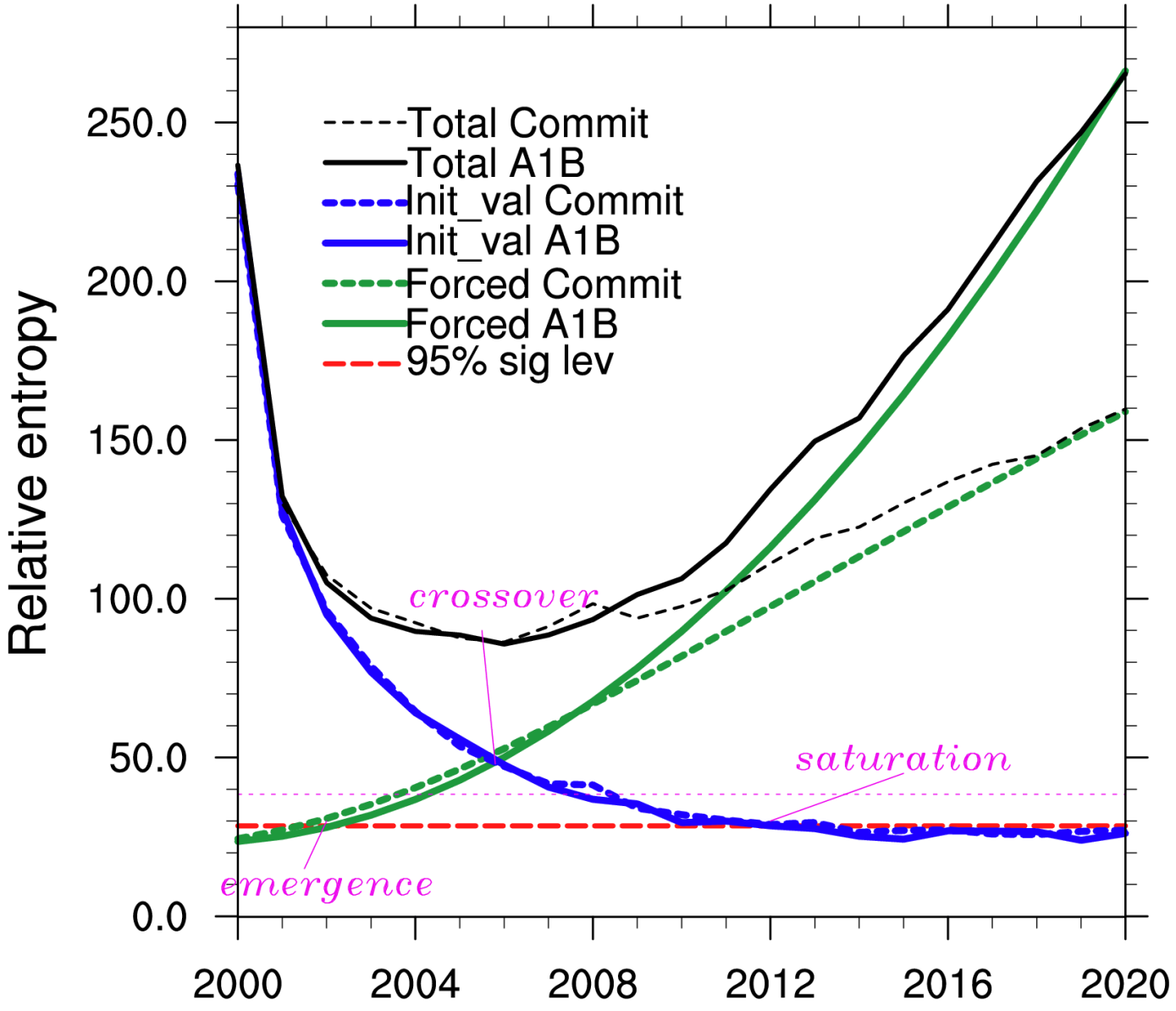
Climate Change



(e.g., due to unforced variability)

1) Can we predict the unforced variability?

1) How well can we predict the unforced variability?



Branstator and Teng, 2010

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Climate Change 2007: The Physical Science Basis

- Forcing

  3 Scenarios for 21st Century (B1, A1B, A2)

- Model Sensitivity

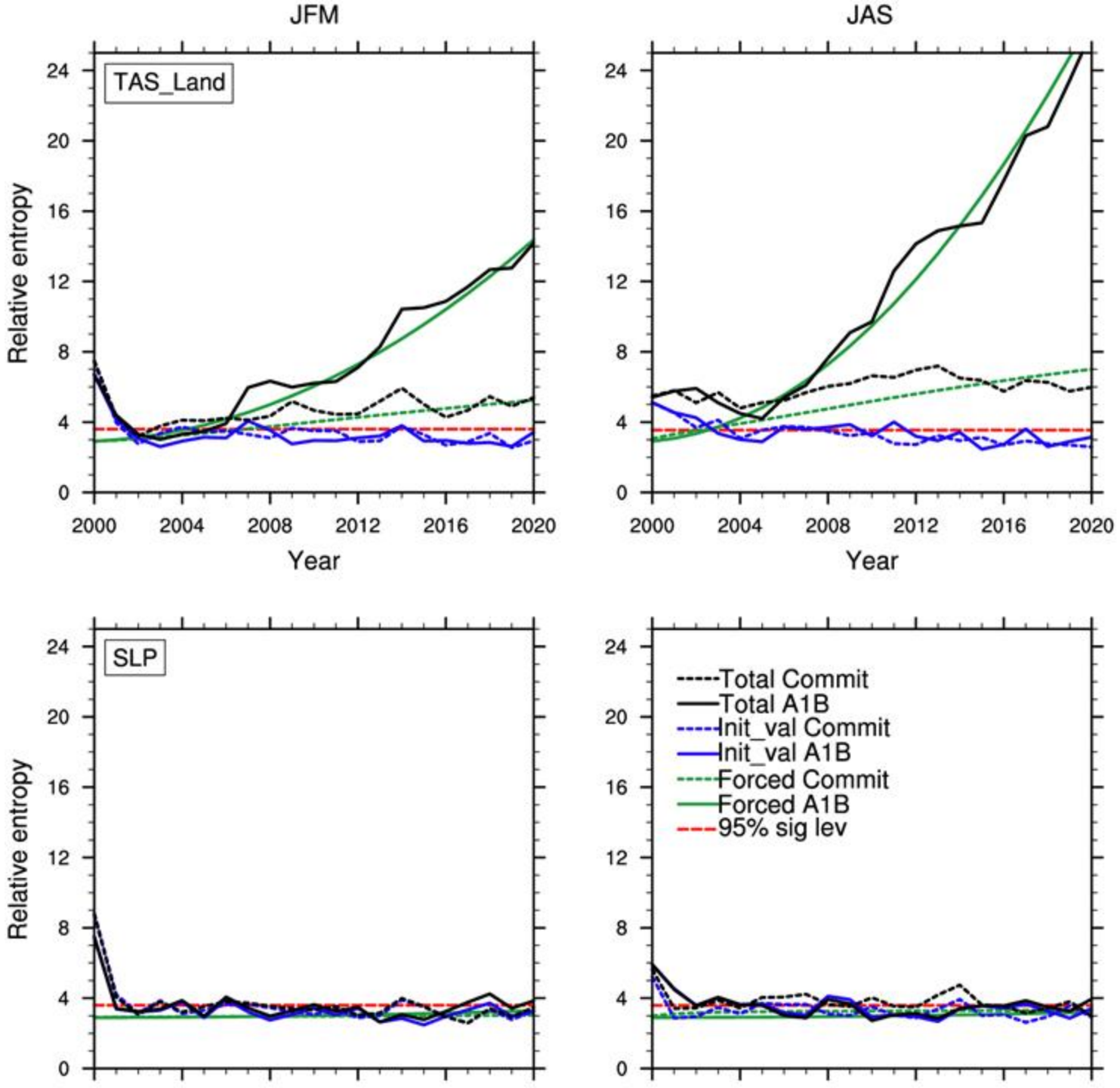
  23 Coupled General Circulation Models

- Internal (Natural) Variability

  Poorly Assessed : Need Many Simulations per Model

# Simulations	1	2	3	4	5	6	7
# Models	10	1	3	2	3	0	1

CMIP3; CMIP5 expected to be similar


JFM
JAS
TAS_Land
SLP
Relative entropy
Year
0
4
8
12
16
20
24
2000
2004
2008
2012
2016
2020
Total Commit
Total A1B
Init_val Commit
Init_val A1B
Forced Commit
Forced A1B
95% sig lev