Climate Projections for North America over the next 50 years: Uncertainty due to Internal Variability

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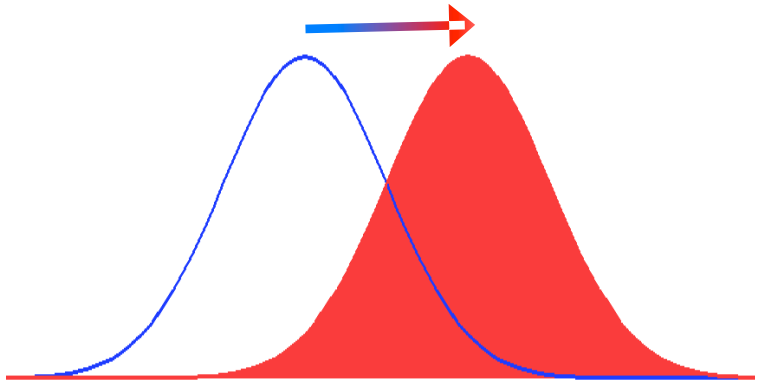
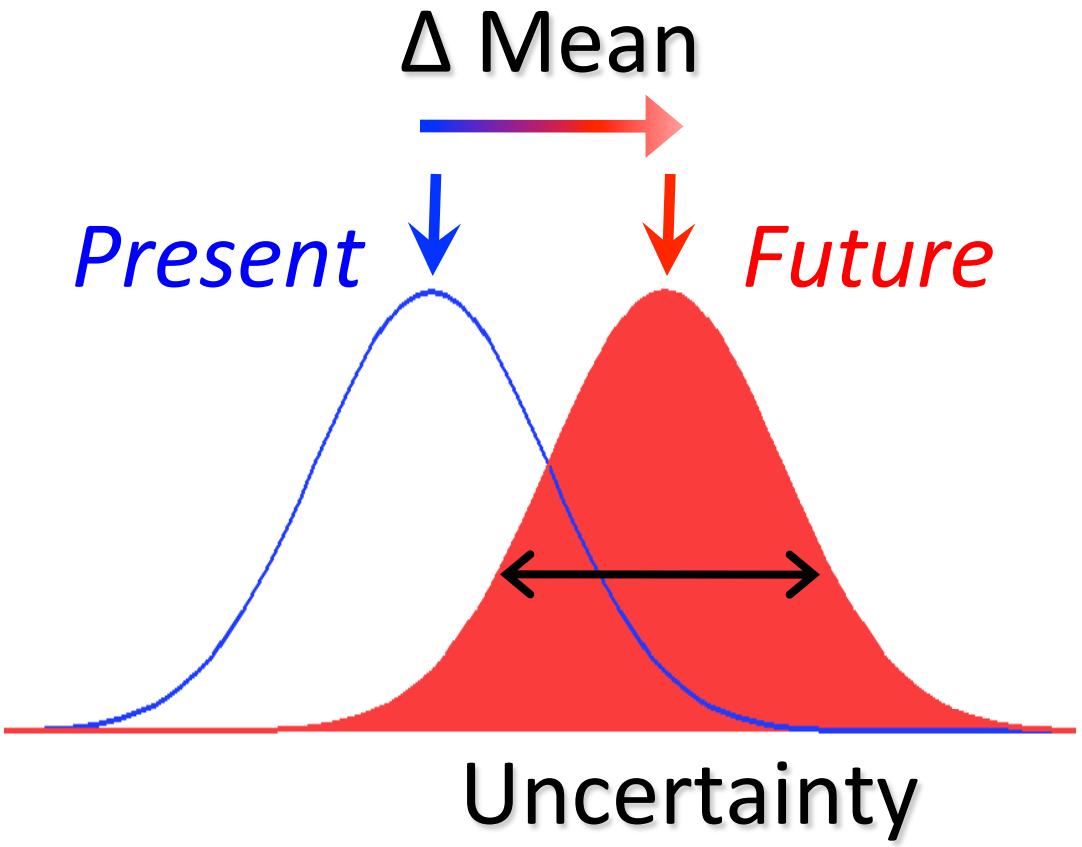
NCAR
NATIONAL CENTER FOR ATMOSPHERIC RESEARCH



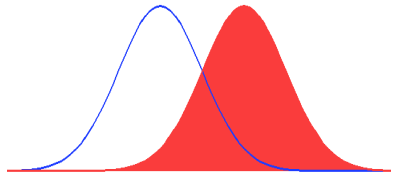
ASP Summer Colloquium
August 6, 2013

Climate Change



Signal: Δ Mean/Uncertainty

Climate Change: Sources of Uncertainty



- **Forcing**

  GHG emissions scenario (e.g., B1, A1B, A2, 4 RCPs)

  ozone, sulfate aerosols, land use, black carbon …

  ✓ IPCC 4th and 5th Assessments (multiple scenarios)

- **Response**

  Model differences

  (different physics, parameterizations, resolution …)

  ✓ IPCC 4th and 5th Assessments: 23 and ~60 models

- **Internal (Unforced) Variability**
  - atmosphere
  - ocean
  - coupled atmosphere-ocean system

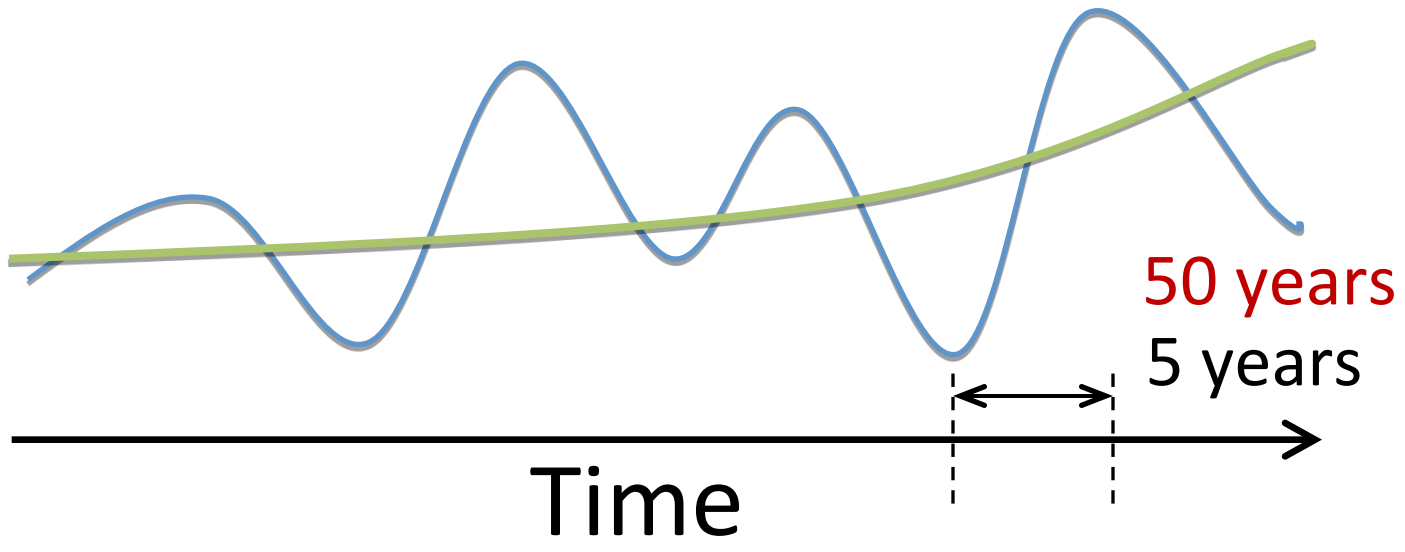
  X IPCC 4th and 5th Assessments: < 3 simulations per model

  multi-decadal variability poorly assessed

Assessing Climate Change in the Presence of Unforced Multi-decadal Variability

Unforced Climate Variability

Forced Climate Change

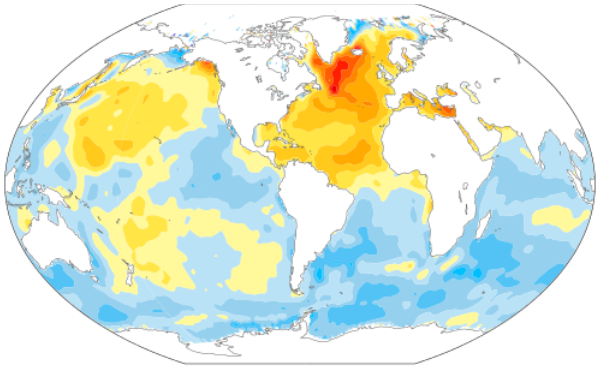


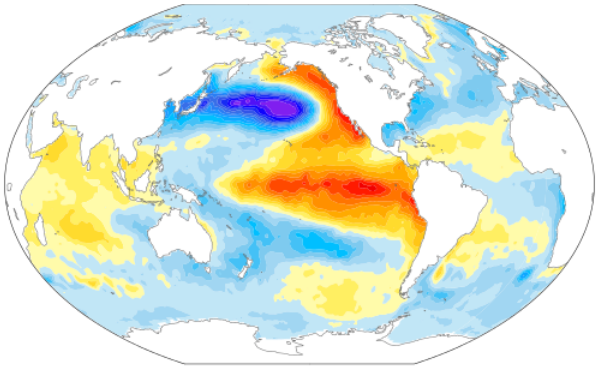
Two Examples of Unforced Multi-Decadal Variability

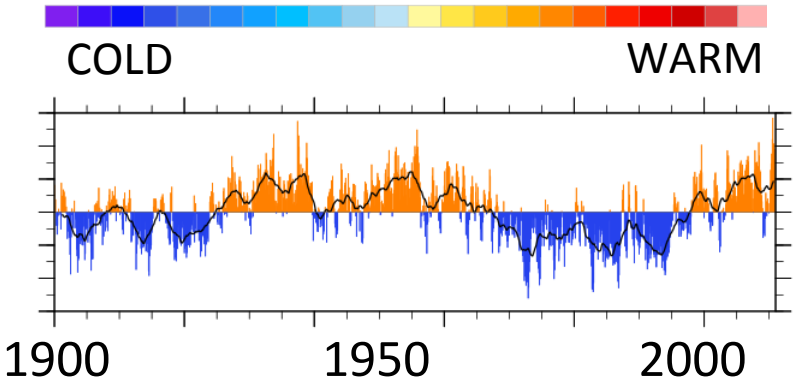
Atlantic Multi-Decadal Oscillation (AMO)

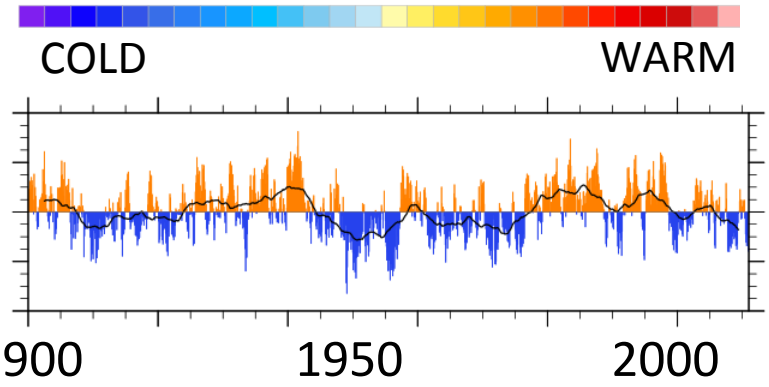
Pacific Decadal Oscillation (PDO)

SST



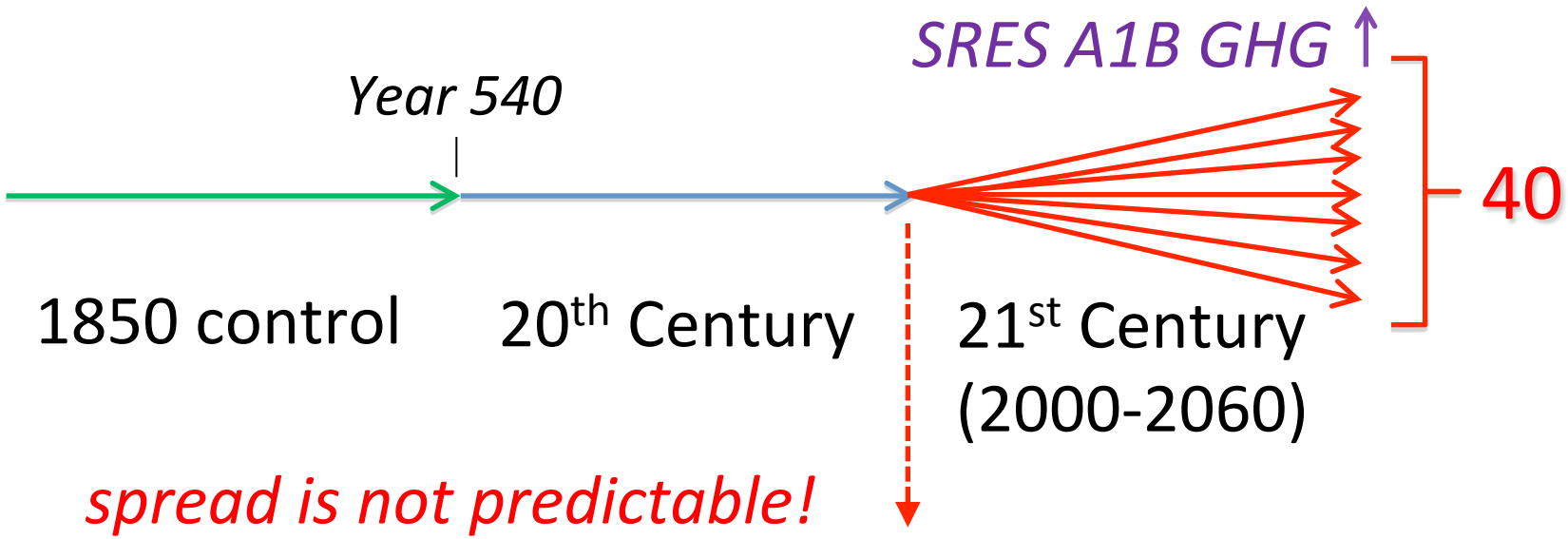






Assessing Climate Change in the Presence of Unforced Multi-decadal Variability: The CCSM Large Ensemble Project

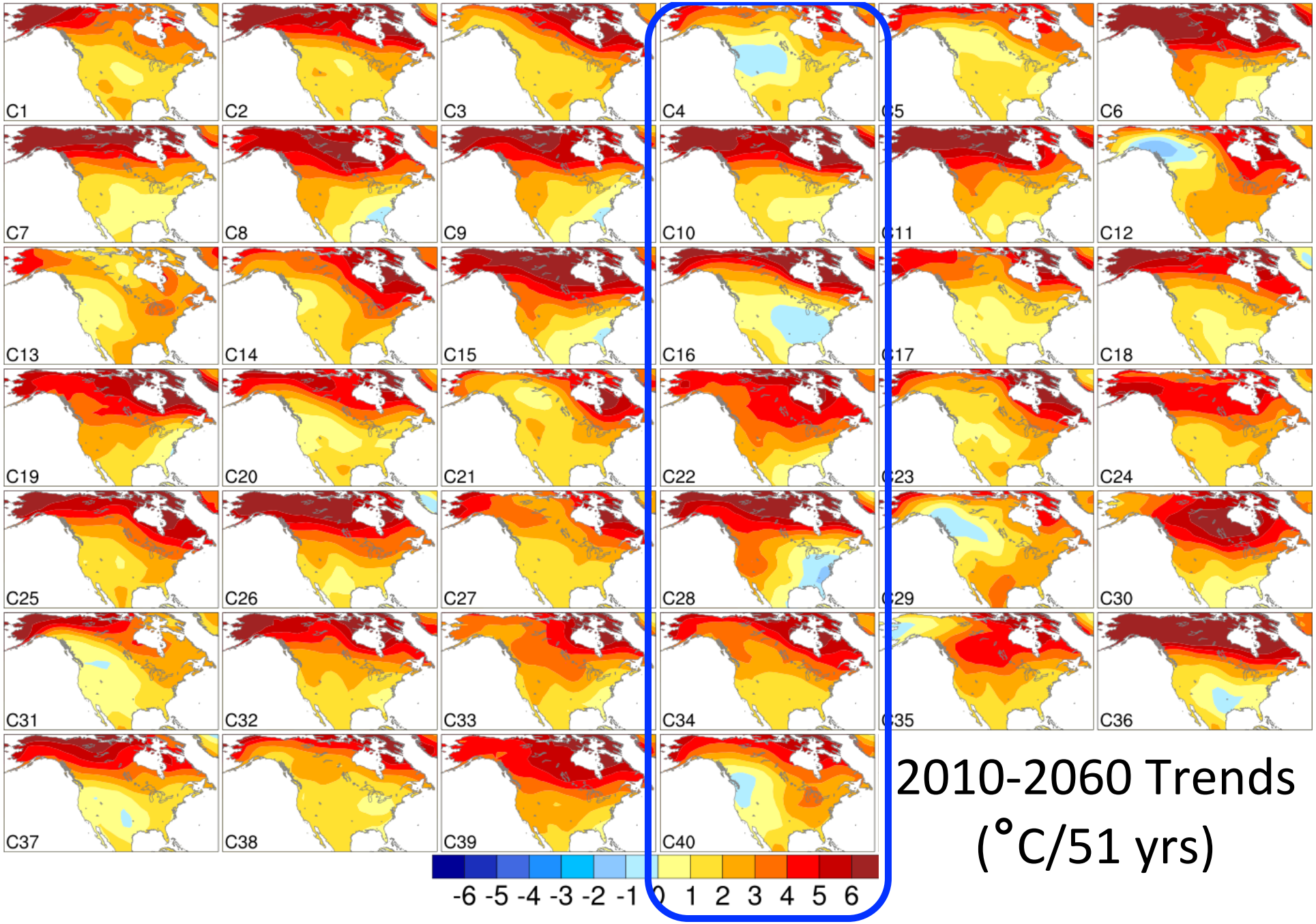
Community Climate System Model v3 (CCSM3 T42)



Different atmospheric initial states (Dec 1999, Jan 2000)
Same ocean, ice, land initial states (Jan 1, 2000)

A First Look

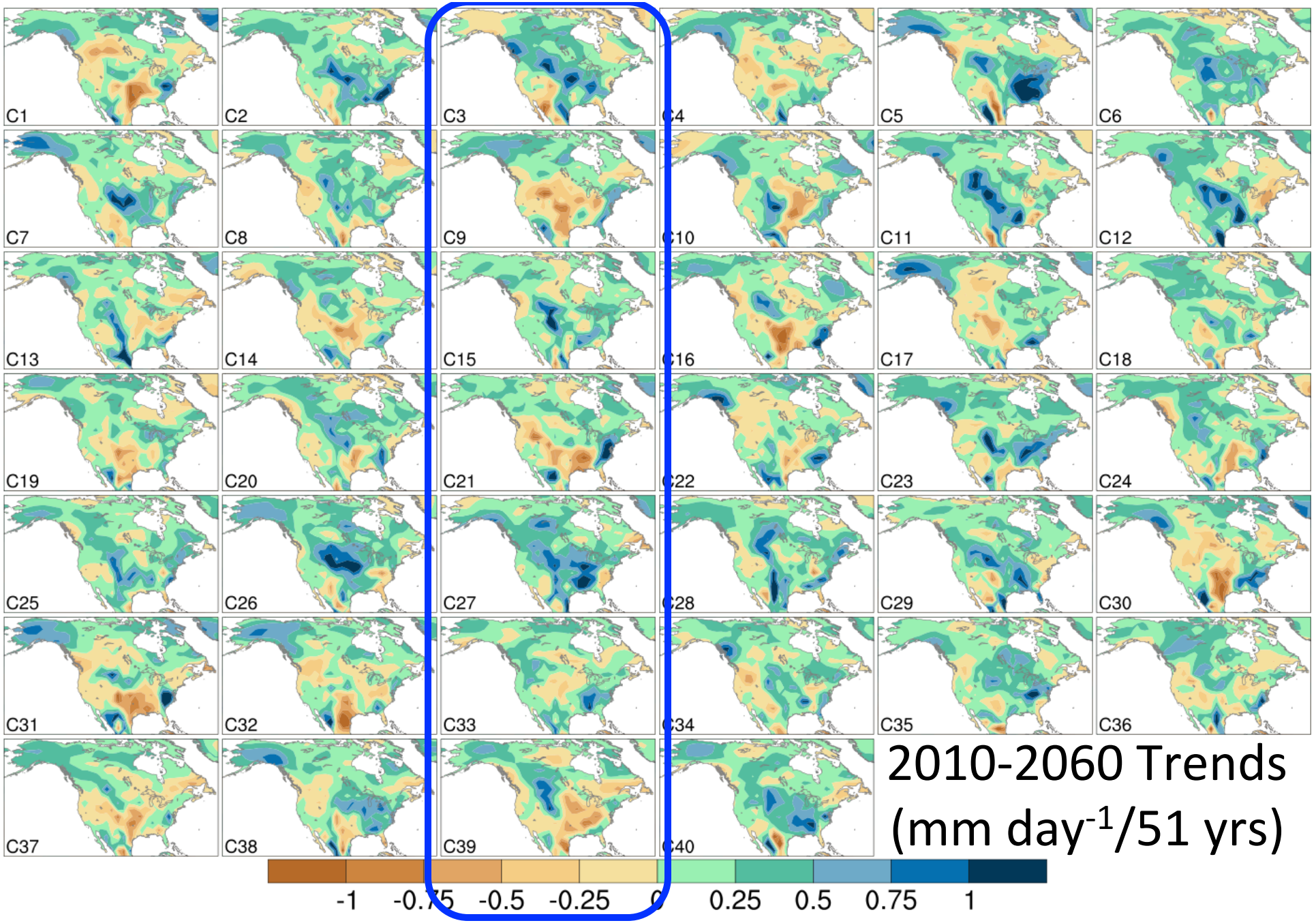
Winter Air Temperature Trends 2010-2060



2010-2060 Trends
(°C/51 yrs)

Each simulation is forced with the identical GHG increase

Summer Precipitation Trends 2010-2060



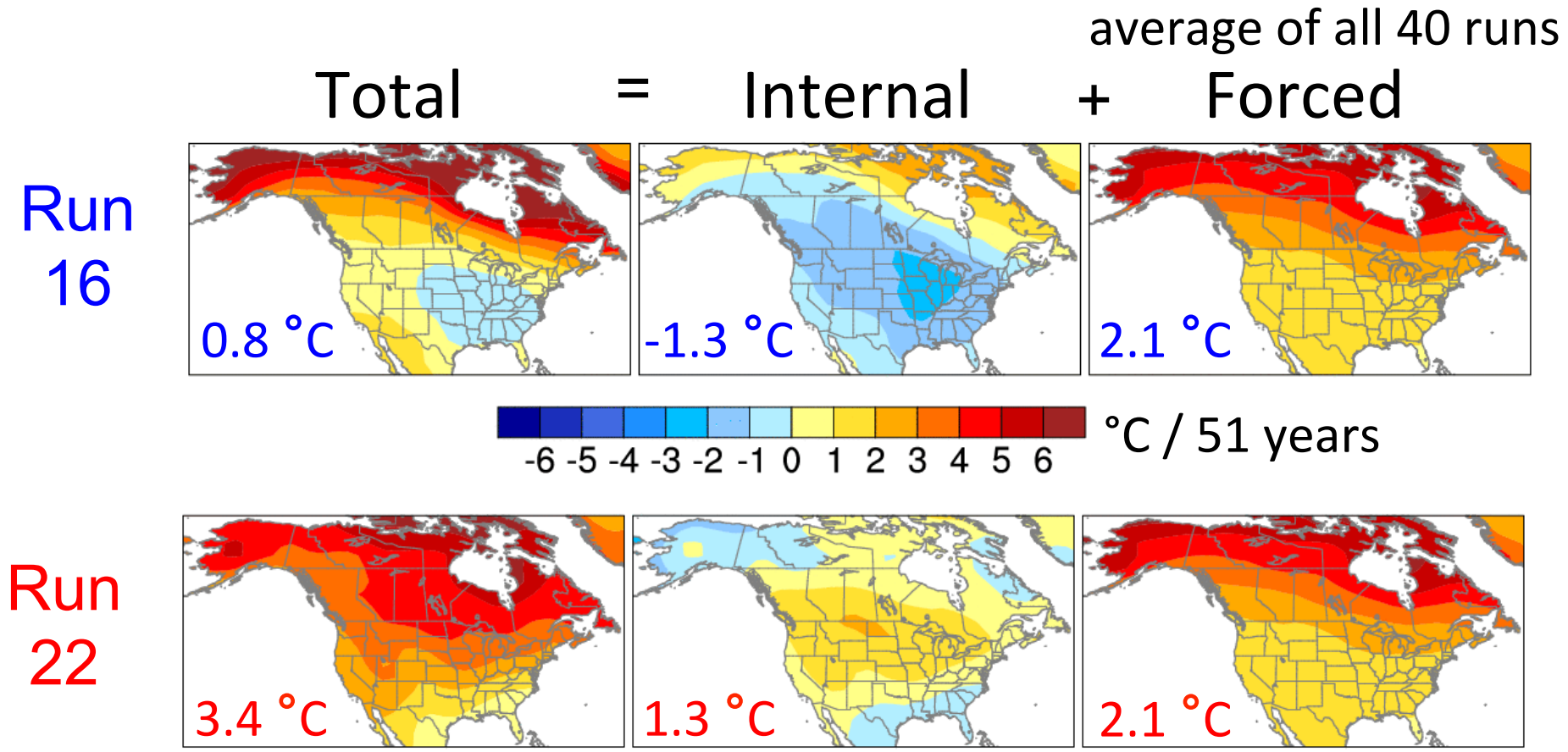
Each simulation is forced with the identical GHG increase

Superposition of Internally-generated and GHG-forced Trends in any Single Realization

Forced Trend: Average of all 40 Runs

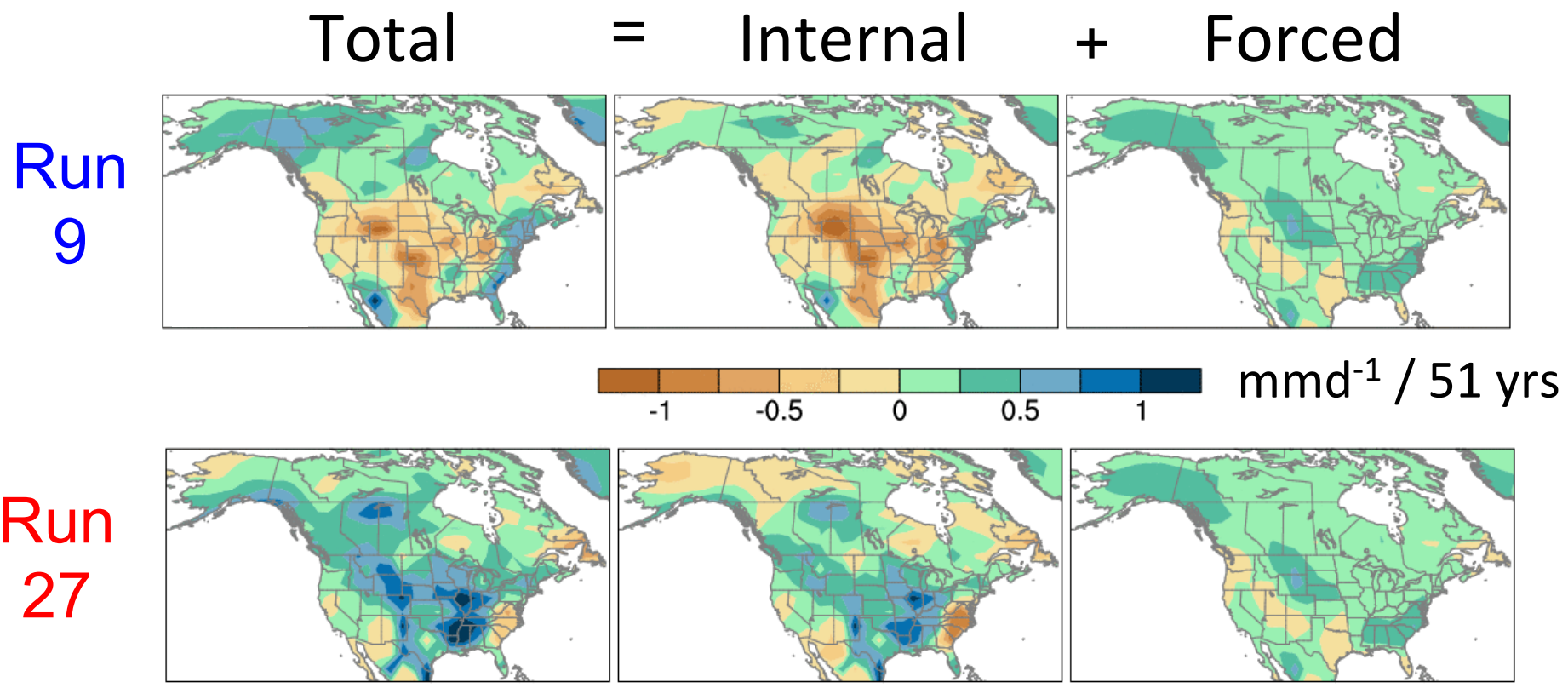
Internal Trend: Total - Forced

Winter Air Temperature Trends 2010-2060



- Forced and unforced amplitudes similar over U.S.
- Unforced component has large spatial scales

Summer Precipitation Trends 2010-2060



- Unforced component can be larger than forced
- Unforced component has large spatial scales

Traditional Signal-to-Noise Analysis

Signal: Forced (ensemble mean) Trend

Noise: Standard Deviation of Trends across the ensemble

40-member CCSM3 *vs*. 17-member ECHAM5

2010-60 Trends

CCSM3 ECHAM5

Air Temperature

DJF

JJA

1-5

Signal-to-Noise Ratio

1 2 3 4

Precipitation

DJF

JJA

< 1-2

Chance of a positive trend *(warmer, wetter)* in the next 50 years

$$\frac{\text{\# runs with a positive trend}}{\text{total \# runs}}$$

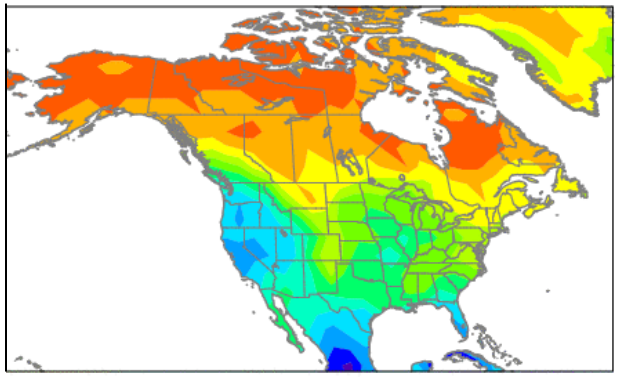
Chance of a Positive Trend in the Next 50 Years

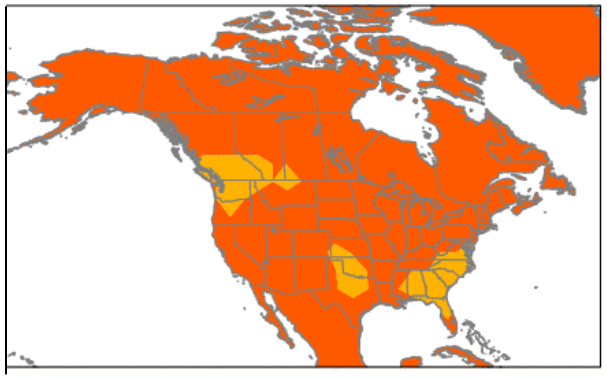
Precipitation

Temperature

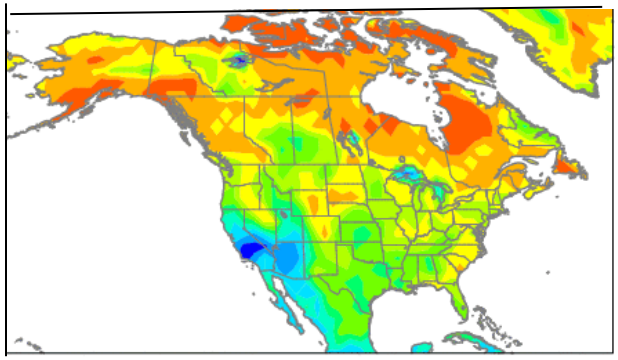
Winter

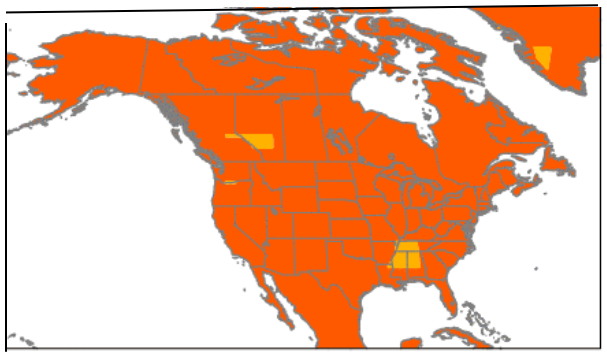
CCSM3



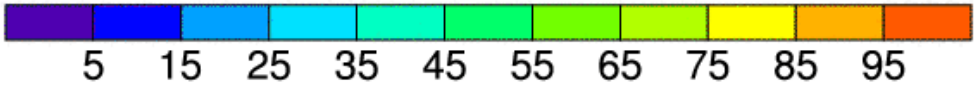


ECHAM5





Even chances



High chance of negative trend

High chance of positive trend

Chance of a Positive Trend in the Next 25 Years

2010-2035

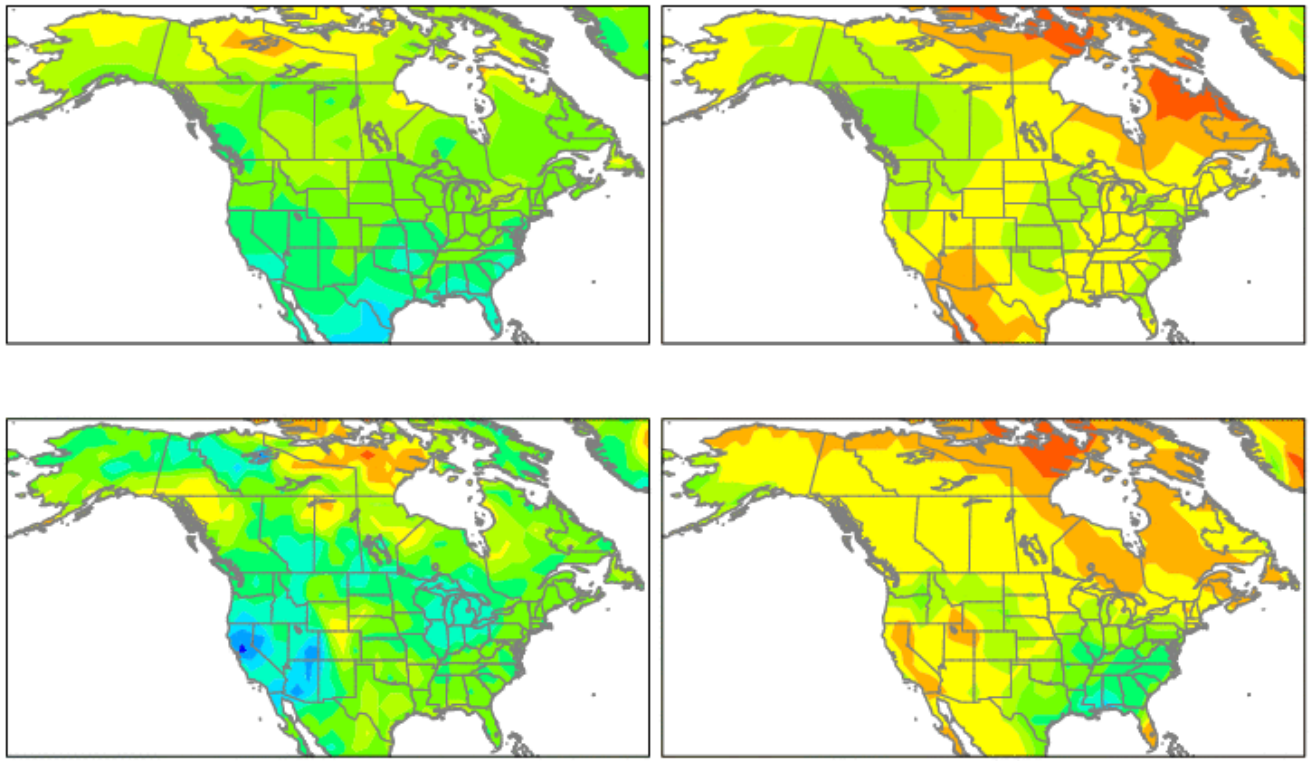
Winter

Precipitation

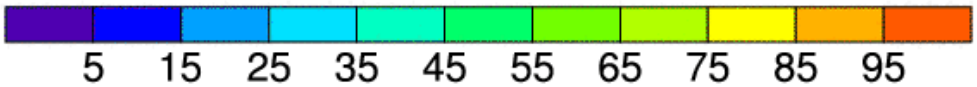
Temperature

CCSM3

ECHAM5



Even chances



High chance of negative trend

High chance of positive trend

What causes internal variations in
50-year climate trends?
(where does the "noise" come from?)

Thermodynamics

(Clouds/water vapor, Snow cover, Soil Moisture, SST, Sea Ice)

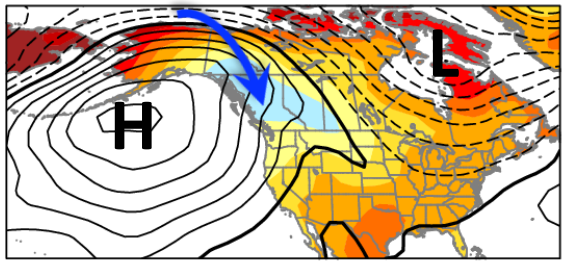
Dynamics

(Atmospheric Circulation)

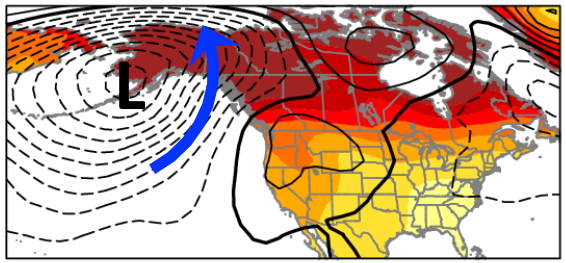
CCSM3 DJF Temperature & SLP Trends 2010-2060

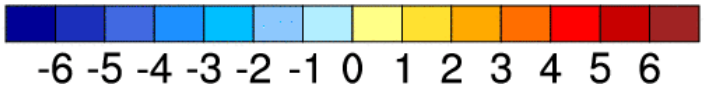
Total

Run 29



Run 6



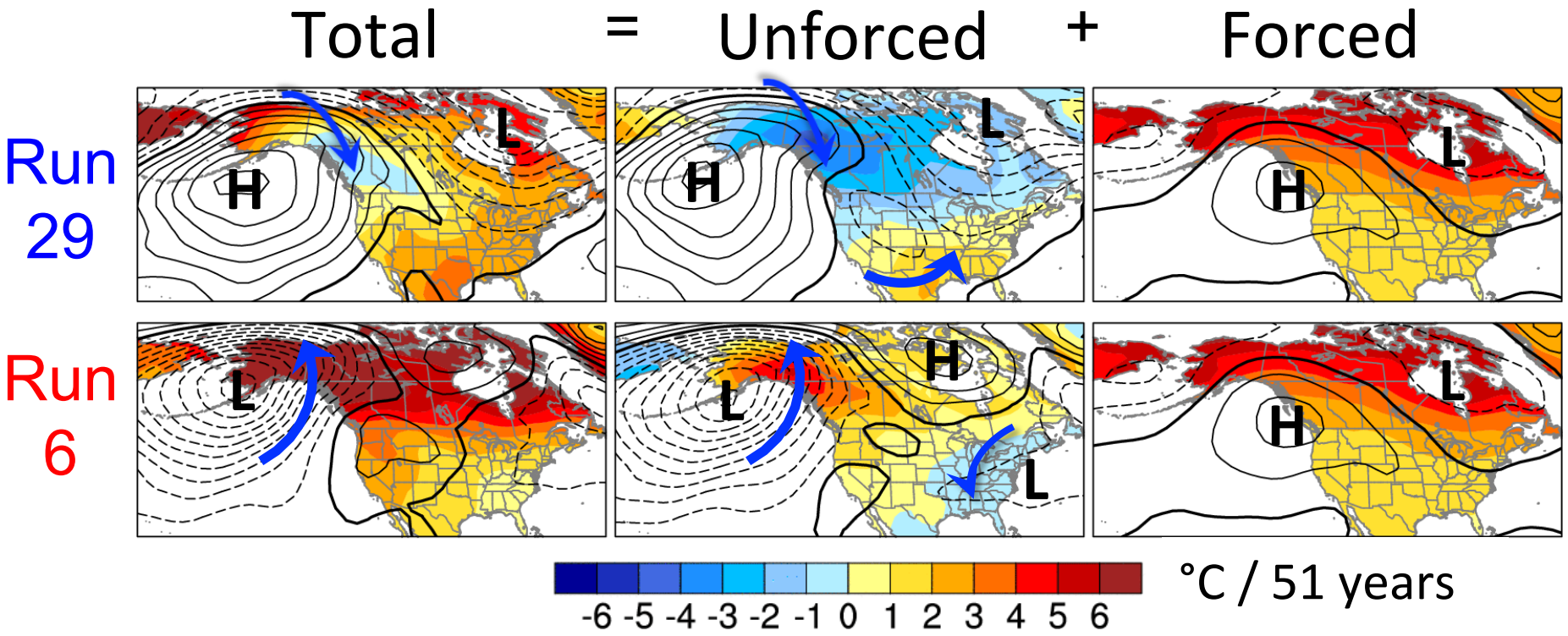


°C / 51 years

SLP Trend contour interval = 1hPa / 51 years

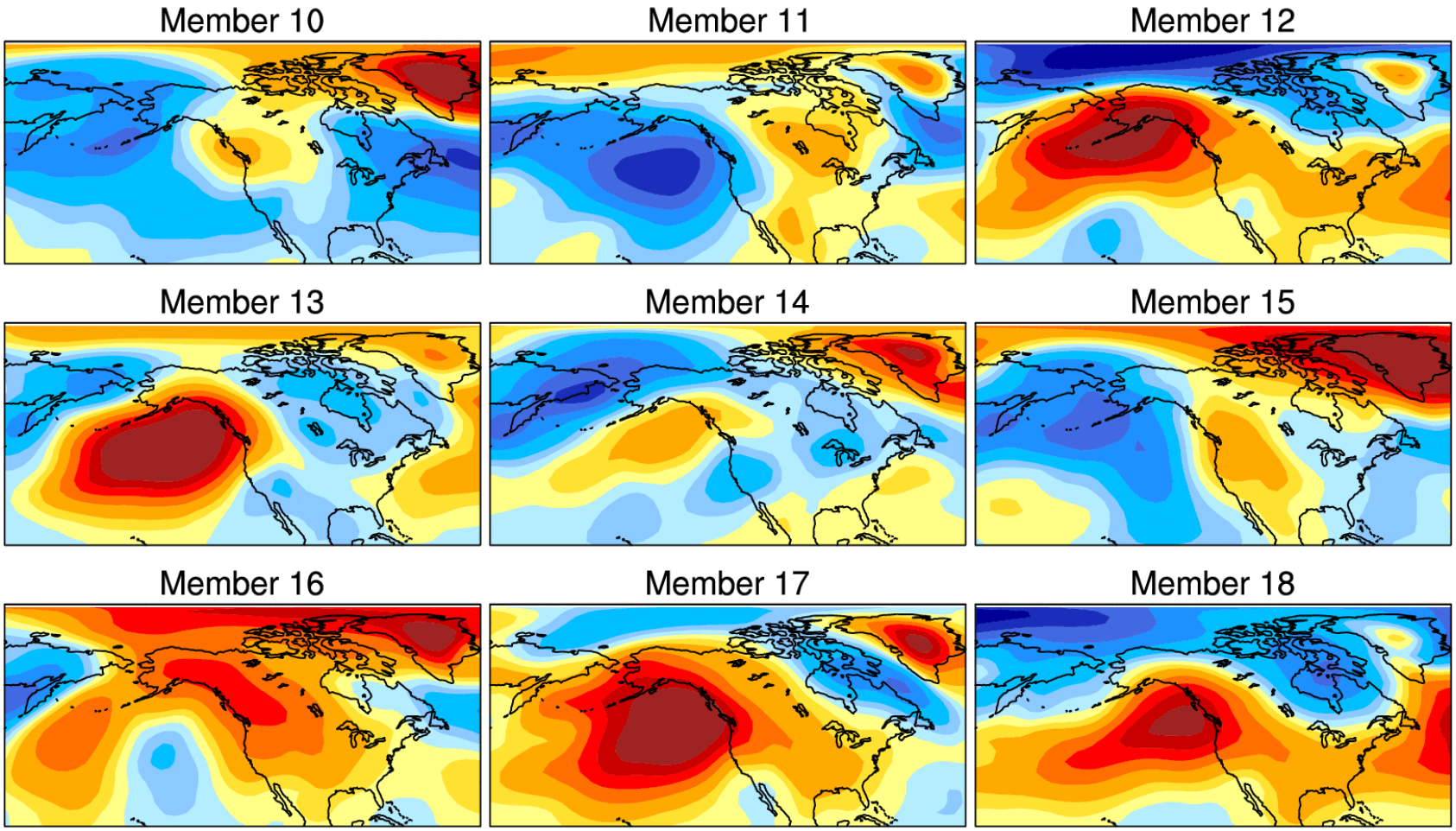
Opposite SLP Trends

CCSM3 DJF Temperature & SLP Trends 2010-2060



Forced SLP trends small compared to unforced

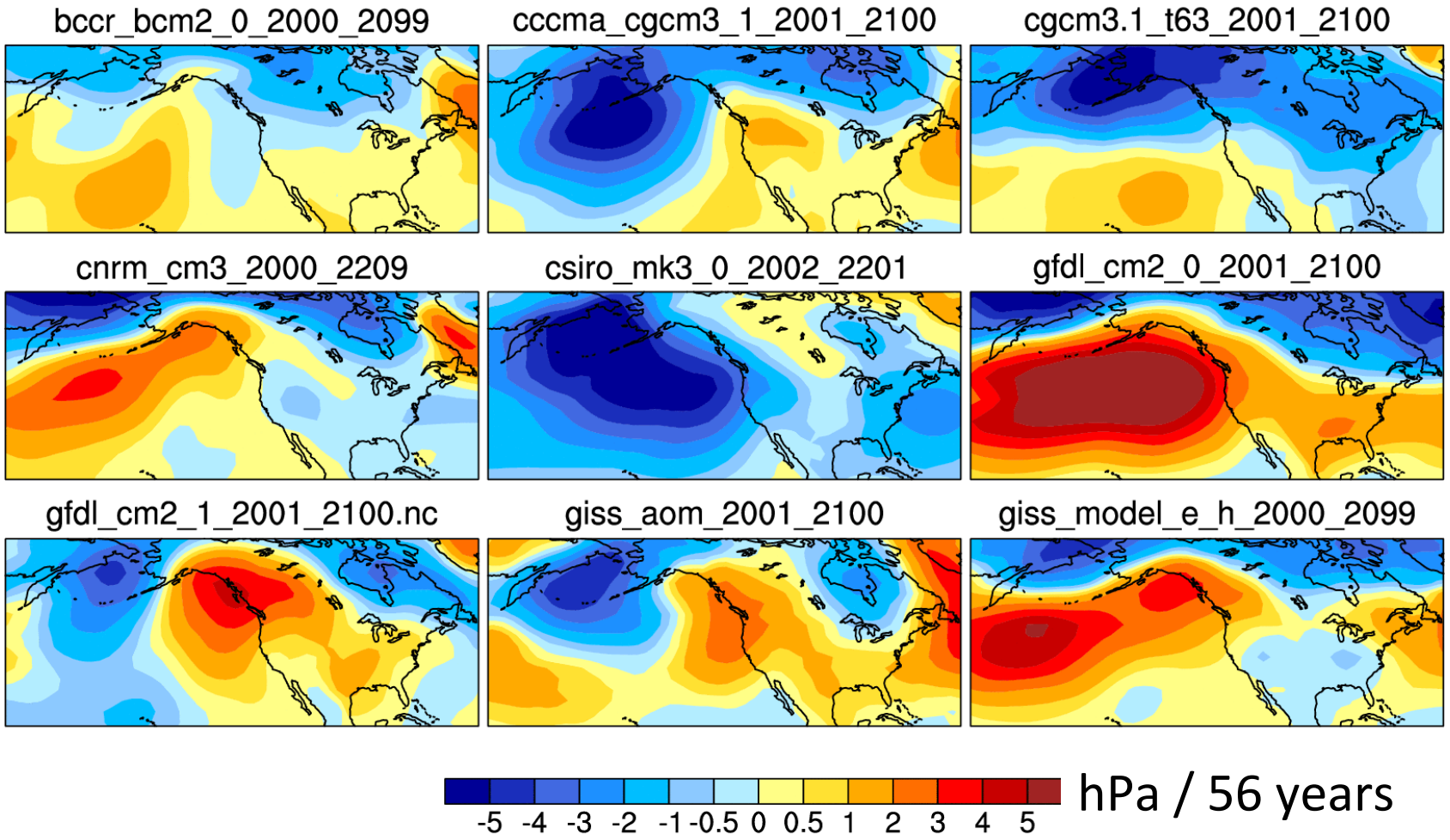
CCSM3 Large Ensemble SLP Trends 2005-60



Internal Variability

IPCC AR4 (CMIP3) Model Archive

SLP Trends 2005-2060



Model Sensitivity or Internal Variability?

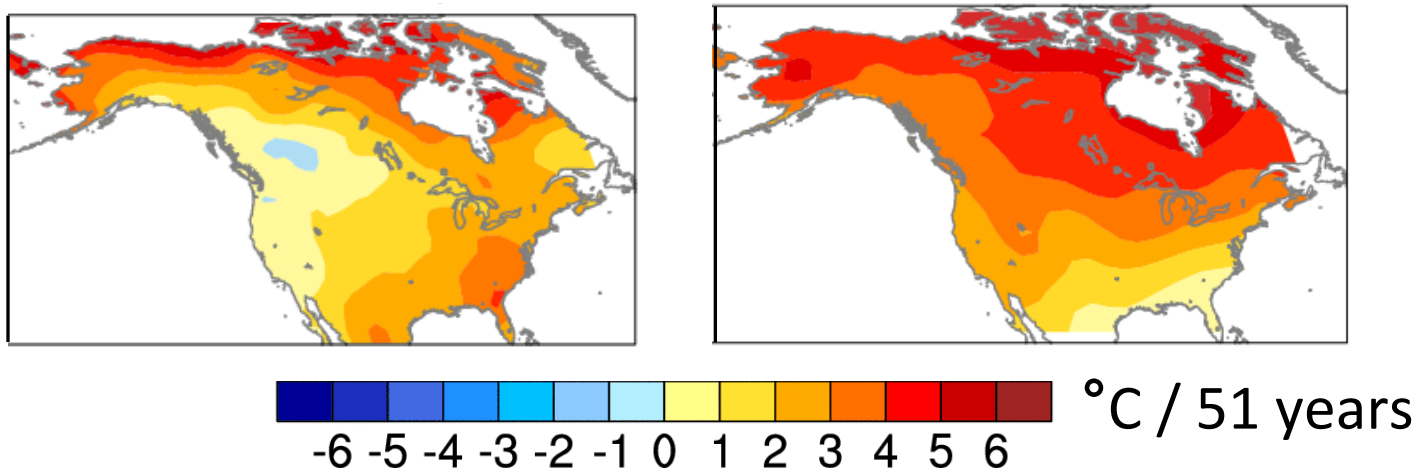
How should we compare single realizations from different models?

Air Temperature Trends (2010-2060)

Internal + Forced Responses in a Single Realization

ECHAM5 Run 3 CCSM3 Run 22

Cannot directly compare

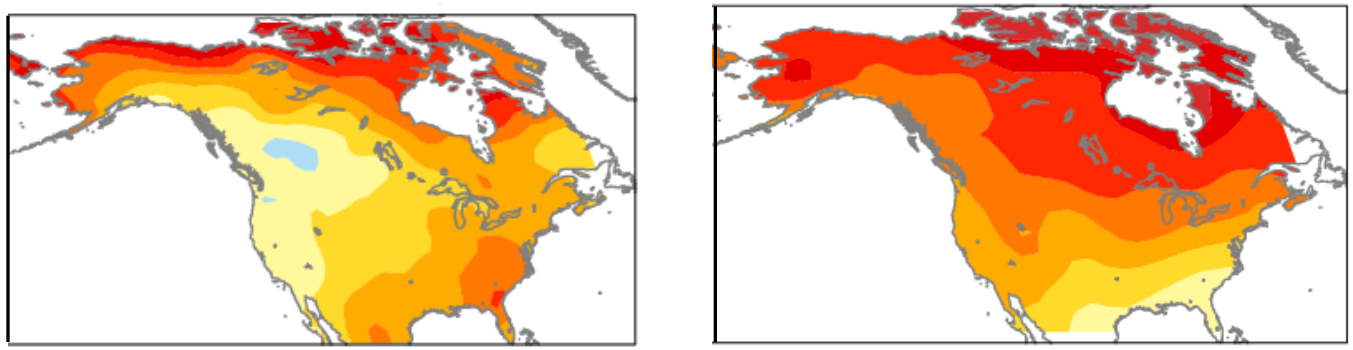


Air Temperature Trends (2010-2060)

Internal + Forced Responses in a Single Realization

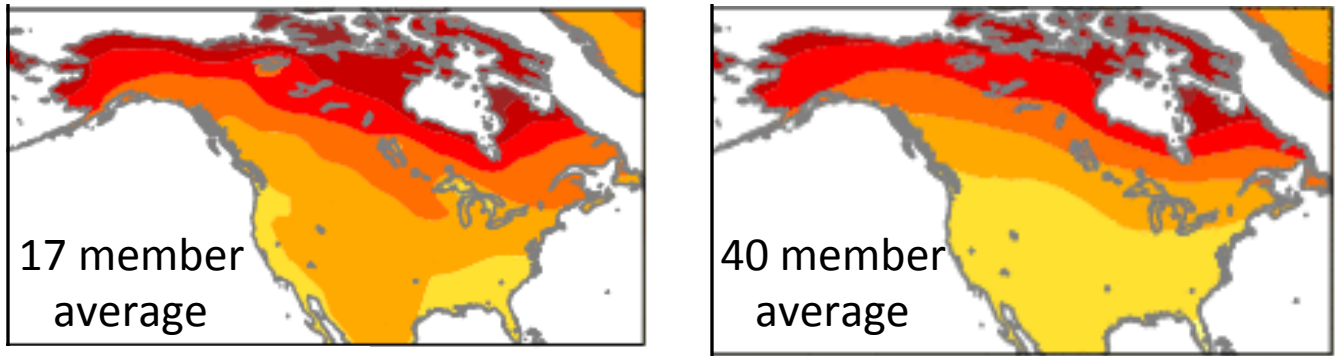
ECHAM5 Run 3 | CCSM3 Run 22

Cannot directly compare



Forced Responses

ECHAM5 | CCSM3

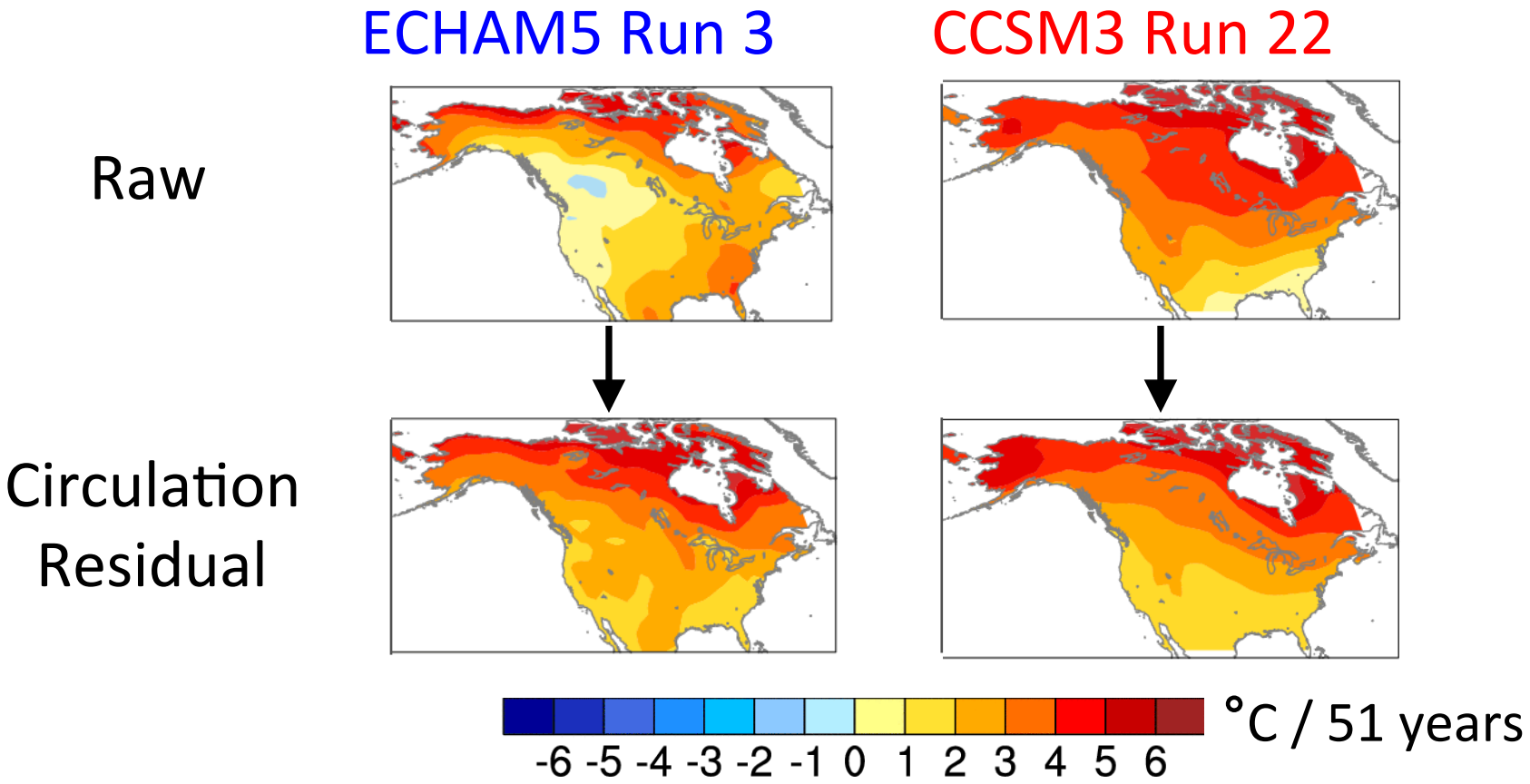


Can compare, but need enough ensemble members to define

How should we compare single realizations from different models?

Can only directly compare the *forced* component;
the *internal* component can only be compared
in a probabalistic sense, or after
"removing" the effect of the atmospheric circulation.

Winter Air Temperature Trends (2010-2060)



3 orthogonal SLP trend predictor patterns
for each air temperature grid box

Comparing single model runs with nature (attribution of climate trends)

1970-2005

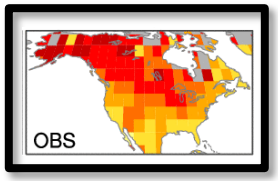
30-member CCSM4-1°

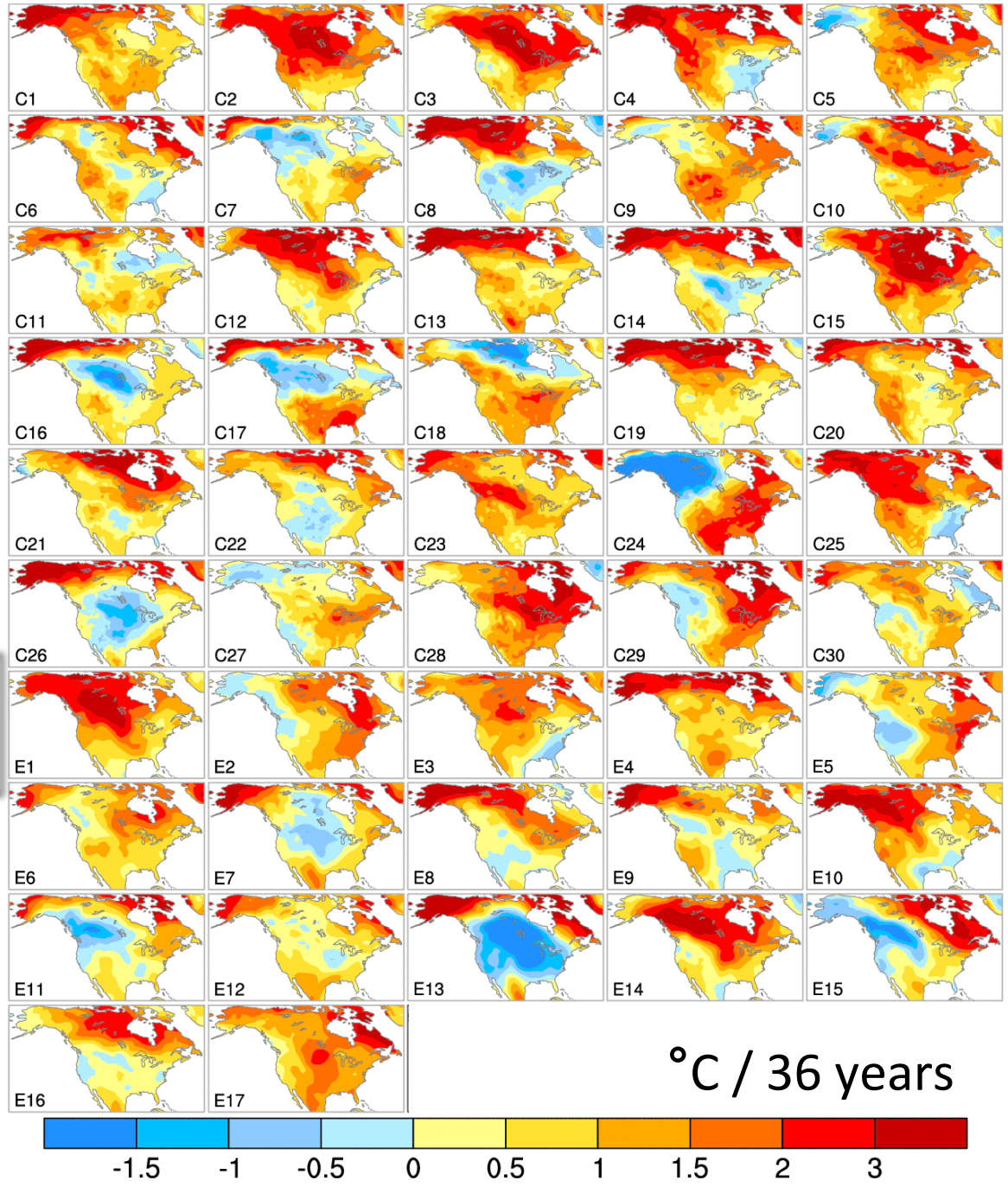
17-member ECHAM5

Winter Air Temp. Trends (1970-2005)

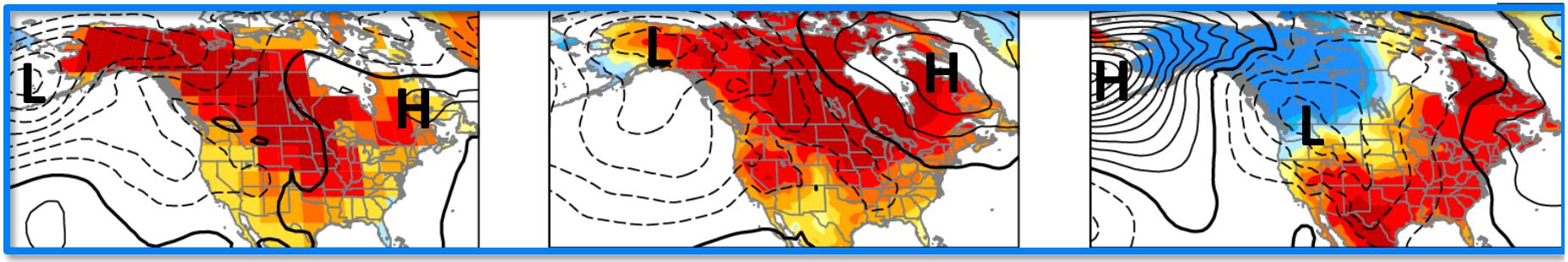
C = CCSM4

E = ECHAM5



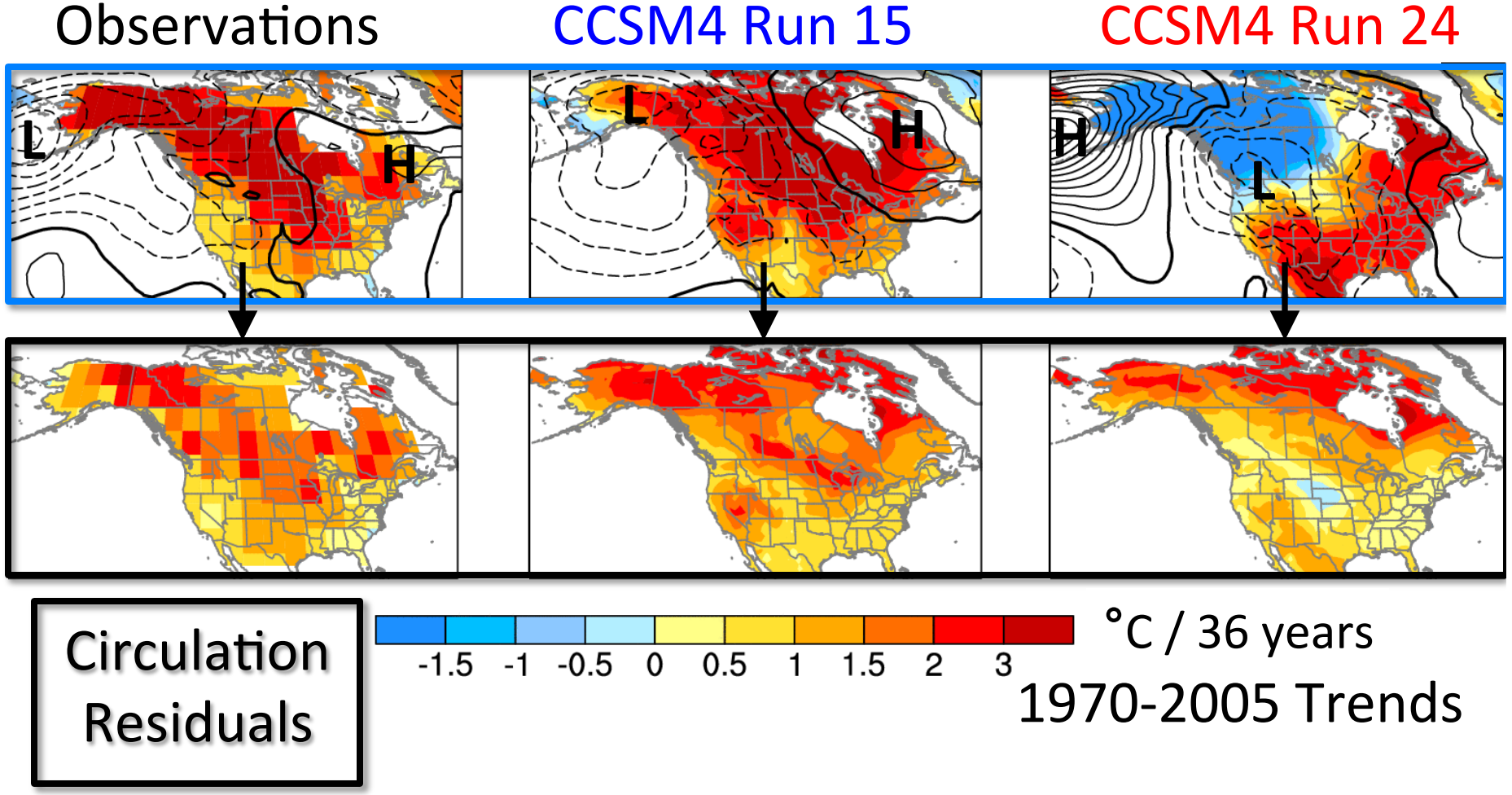


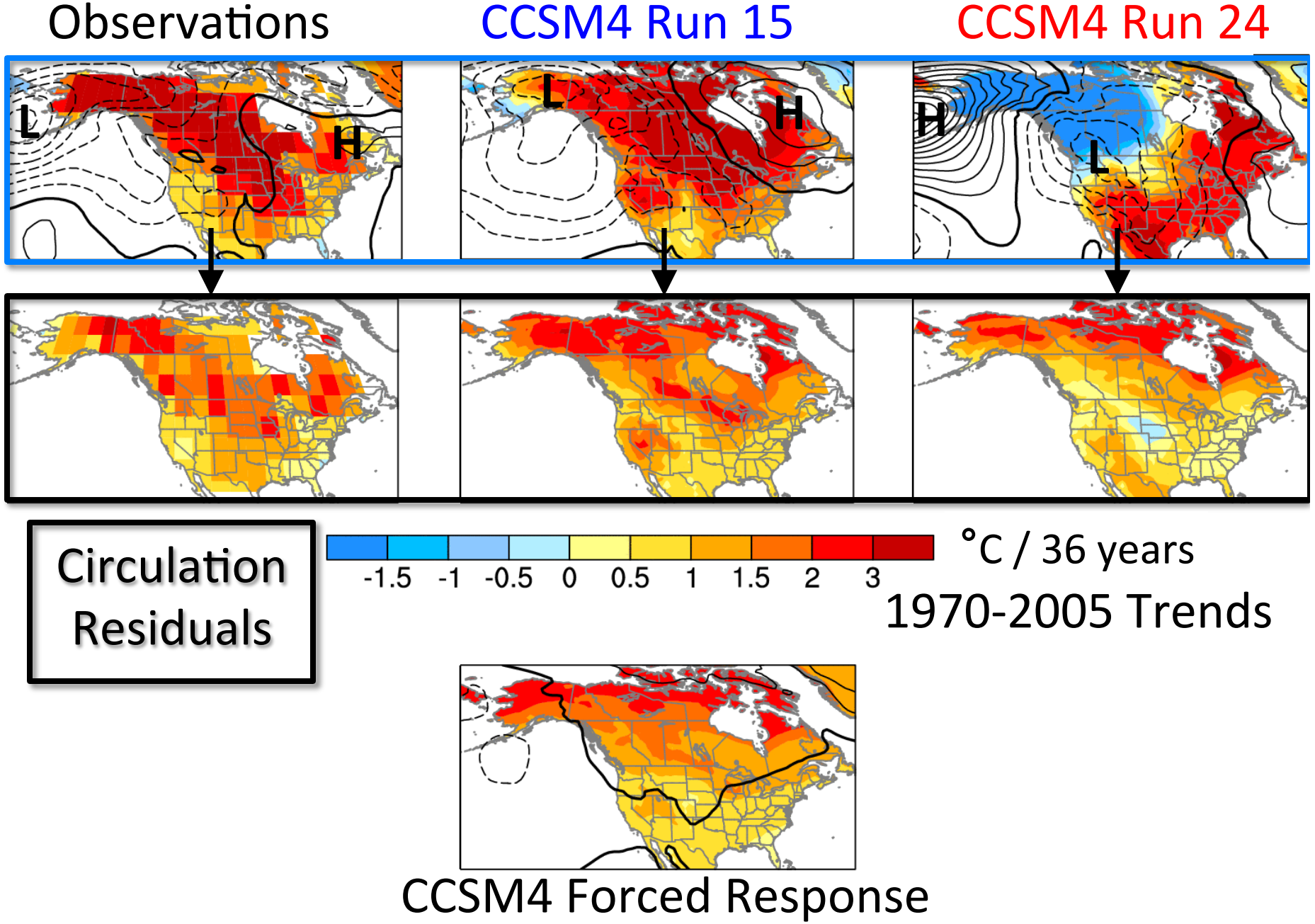
Observations CCSM4 Run 15 CCSM4 Run 24



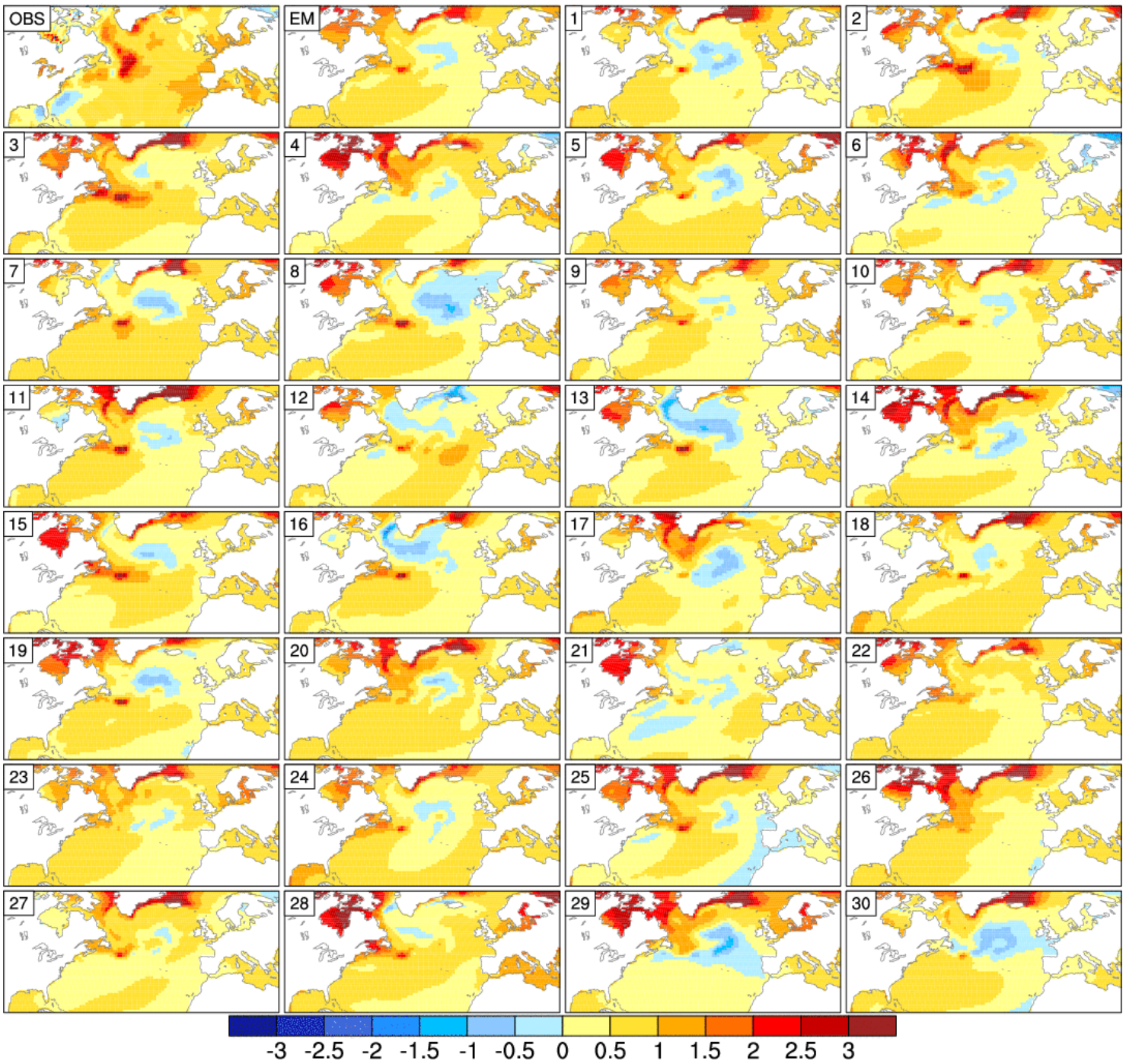
hPa / 36 years -1.5 -1 -0.5 0 0.5 1 1.5 2 3 °C / 36 years

1970-2005 Trends


Observations
CCSM4 Run 15
CCSM4 Run 24
L
H
L
H
H
L
Circulation Residuals
-1.5
-1
-0.5
0
0.5
1
1.5
2
3
°C / 36 years
1970-2005 Trends

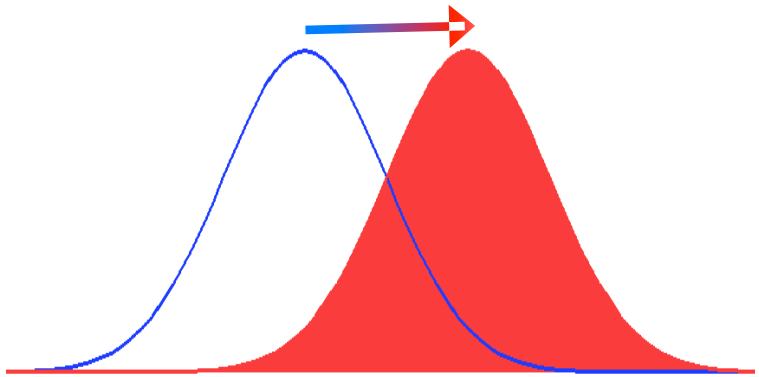

Observations
CCSM4 Run 15
CCSM4 Run 24
L
H
L
H
H
L
Circulation Residuals
-1.5 -1 -0.5 0 0.5 1 1.5 2 3
°C / 36 years
1970-2005 Trends
CCSM4 Forced Response

North Atlantic Sea Surface Temperature Trends 1970-2005

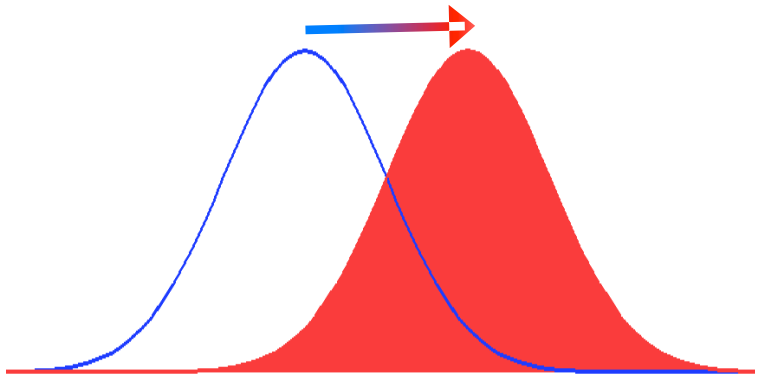

ANN CCSM4 TS Trend 1970-2005 (K 36yr-1)
OBS
EM
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
-3 -2.5 -2 -1.5 -1 -0.5 0 0.5 1 1.5 2 2.5 3

Summary and Outlook

1) We should expect a range of climate trends on local and regional scales over the next 50 years due to superposition of the GHG-forced response and internal variability.



2) The spread in 50-year climate projections within a single model is mainly due to unforced (and unpredictable) atmospheric circulation variability.

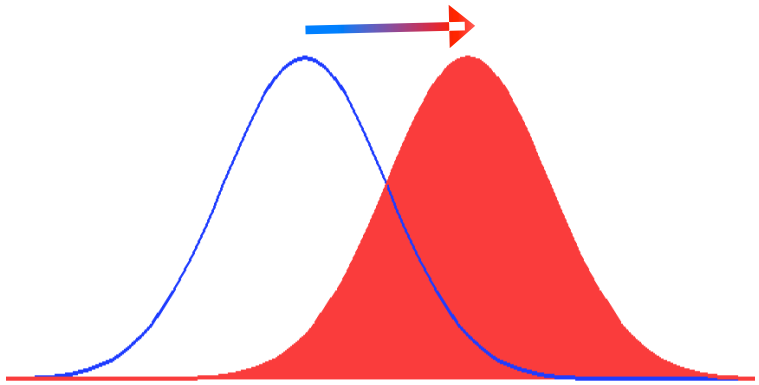


3) Large (10-40 member) ensembles are needed to:

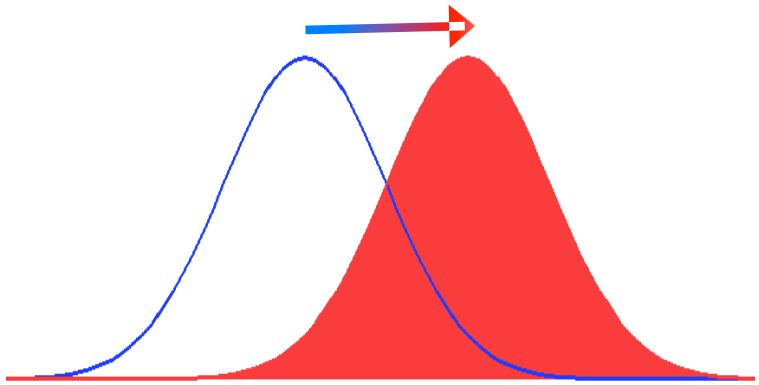
a) define the forced climate signal on regional and local scales,

b) compare models,

c) compare models with nature.



4) Other regions may exhibit higher signal-to-noise ratios (i.e., the tropics) as well as some decadal predictability (recent work by Meehl, Branstator, Teng, Newman…)



Thank You

Large Ensemble output available from the CESM Climate Change and Variability Working Group

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

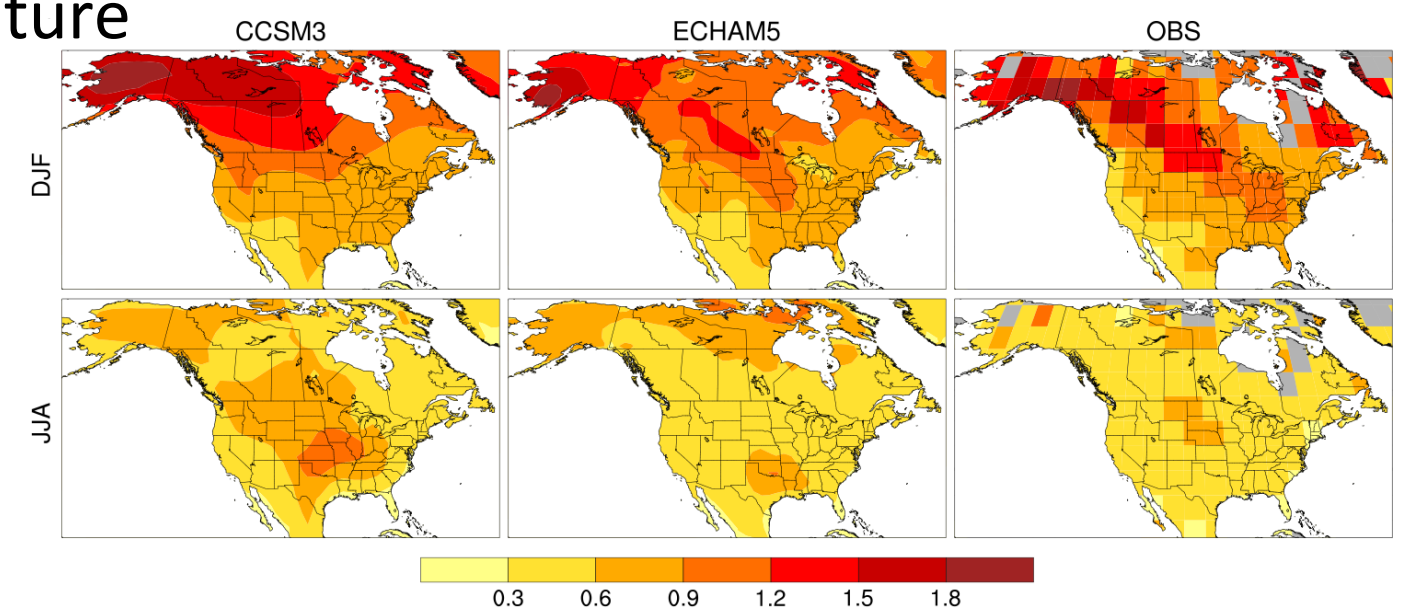
New CESM/CAM5-1° 30+ member ensemble for 1920-2080 is now underway

Deser et al., 2012: *Climate Dynamics*
Deser et al., 2012: *Nature Climate Change*
Deser et al., 2013, *J. Climate, submitted*

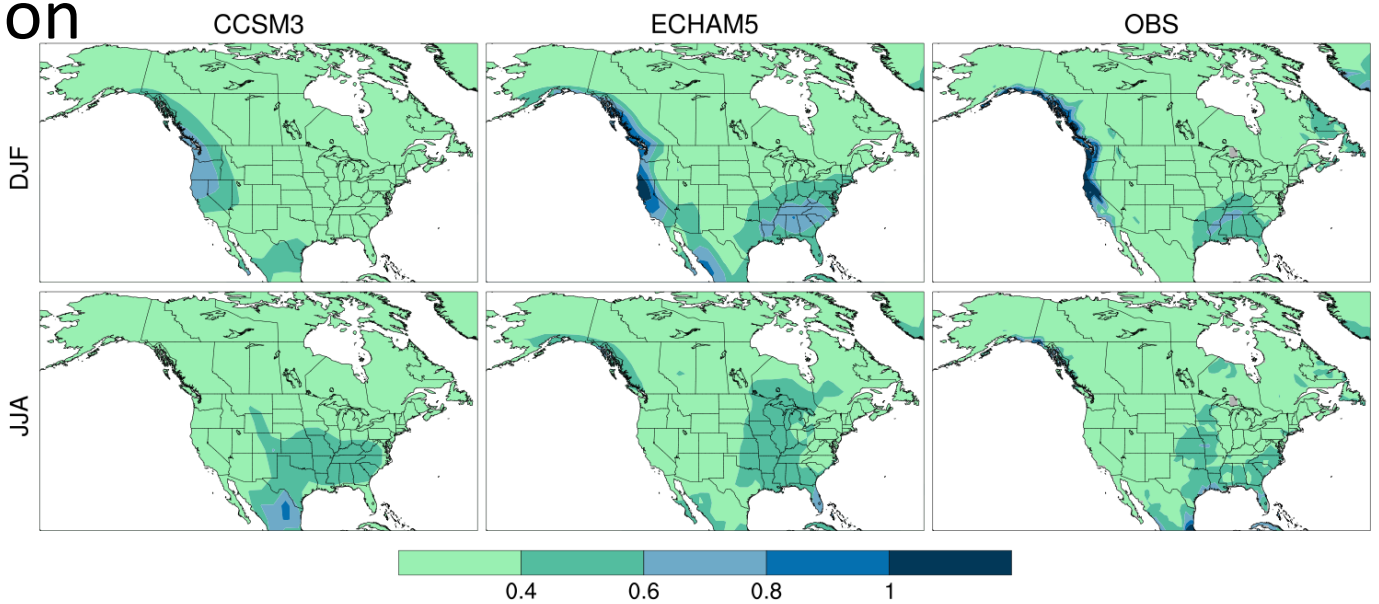
EXTRA

Amplitude of Decadal Variability (std dev 8yr low-pass)

Temperature

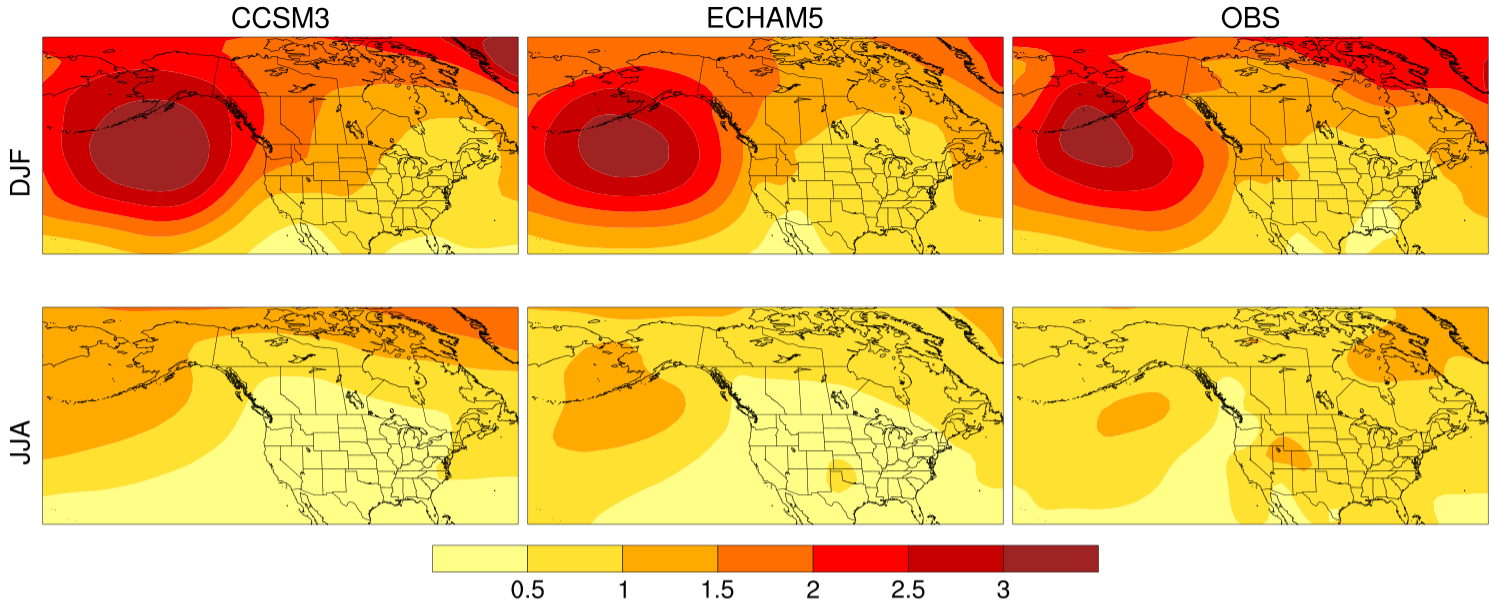


Precipitation



Amplitude of Decadal Variability

Sea Level Pressure



std dev 8yr low-pass

Signal-to-Noise for 2010-2060 Trends