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

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Climate Change

Δ Mean

Present → Future

Uncertainty

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
  ✗ 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

Time

5 years

50 years
Two Examples of Unforced Multi-Decadal Variability

Atlantic Multi-Decadal Oscillation (AMO)

Pacific Decadal Oscillation (PDO)

SST

1900  1950  2000

COLD  WARM

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

Community Climate System Model v3 (CCSM3 T42)

Spread is not predictable!

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

Total = Internal + Forced

Run 16

<table>
<thead>
<tr>
<th>Total</th>
<th>Internal</th>
<th>Forced</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.8 °C</td>
<td>-1.3 °C</td>
<td>2.1 °C</td>
</tr>
</tbody>
</table>

Run 22

<table>
<thead>
<tr>
<th>Total</th>
<th>Internal</th>
<th>Forced</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.4 °C</td>
<td>1.3 °C</td>
<td>2.1 °C</td>
</tr>
</tbody>
</table>

• Forced and unforced amplitudes similar over U.S.
• Unforced component has large spatial scales
Summer Precipitation Trends 2010-2060

Total = Internal + Forced

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

# runs with a positive trend

total # runs
Chance of a Positive Trend in the Next 50 Years

Precipitation

Temperature

Winter

CCSM3

High chance of negative trend

ECHAM5

High chance of positive trend

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

High chance of positive trend

Even chances

High chance of negative trend

Precipitation

Temperature
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

SLP Trend contour interval = 1hPa / 51 years

Opposite SLP Trends
CCSM3 DJF Temperature & SLP Trends 2010-2060

Total = Unforced + Forced

Run 29

Run 6

Forced SLP trends small compared to unforced
CCSM3 Large Ensemble SLP Trends 2005-60

Member 10

Member 11

Member 12

Member 13

Member 14

Member 15

Member 16

Member 17

Member 18

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

Cannot directly compare

ECHAM5 Run 3
CCSM3 Run 22

°C / 51 years
Air Temperature Trends (2010-2060)

Internal + Forced Responses in a Single Realization

**ECHAM5 Run 3**

**CCSM3 Run 22**

Cannot directly compare

**Forced Responses**

**ECHAM5**
- 17 member average

**CCSM3**
- 40 member average

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 probabilistic sense, or after “removing” the effect of the atmospheric circulation.
Winter Air Temperature Trends (2010-2060)

Forced Responses

- CCSM3
- ECHAM5

17 member average
40 member average

CCSM3 Run 22
ECHAM5 Run 3

Raw
Circulation Residual

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

°C / 51 years

-6 -5 -4 -3 -2 -1 0 1 2 3 4 5 6
Comparing single model runs with nature (attribution of climate trends)

1970-2005
30-member CCSM4-1°
17-member ECHAM5

C = CCSM4
E = ECHAM5

°C / 36 years
Observations

CCSM4 Run 15

CCSM4 Run 24

H L H

hPa / 36 years

°C / 36 years

1970-2005 Trends
Observations    CCSM4 Run 15    CCSM4 Run 24

Circulation Residuals

°C / 36 years
1970-2005 Trends
Observations

CCSM4 Run 15

CCSM4 Run 24

Circulation Residuals

1970-2005 Trends

CCSM4 Forced Response

°C / 36 years
North Atlantic Sea Surface Temperature Trends 1970-2005
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...)

![Diagram of Earth and probability distribution curves]
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

CCSM3  ECHAM5  OBS

DJF

JJA

std dev 8yr low-pass
Signal-to-Noise for 2010-2060 Trends