Inter-model variability and mechanism attribution of central and southeastern U.S. “warming hole” in the 20th century as simulated by CMIP5 models

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Outline

1. Observed global “warming holes (WH)”
2. Inter- and intra-model variability of skills in capturing WH
3. Attribution of possible WH mechanisms
4. Record-breaking temperature frequency as a metric for climate change
Observed global warming holes
Globally there are 3 major warming holes (WHs). They are all in central section of continents and

• over **eastern slopes** of major mountain ranges, where large pressure gradient exists,
• in intense **agricultural** regions where plenty of soil moisture is available for evaporation, and
• downstream of **low-level jets** where MCSs and convergence are prominent.

(Pan et al., 2009)
U.S. warming hole

U.S. Max. Temperature Change

Summer 1951-1975

Winter 1951-1975

Summer 1976-2000

Winter 1976-2000

1951-75, summer

1951-75, winter

1976-00, summer

1976-00, winter
# Model description

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25 models, 112 ensemble members

Blue colored are also have GHG and NAT runs
1951-2000 Tmax trend simulated by 25 models
Trend of Mean Surface Temperature - 25 model ensemble mean

25-model-mean temperature over various periods

1901-2000

1951-2000

1976-2000
Six high-resolution model simulated temperatures

six models: ACCESS, CanCSM, CCSM4, CNRMS, CSIRO, and MRI-CGCM3, totaling 28 members.
Temp. trends simulated by 15 members of GISS-E2-H

Summer Mean Temperature Change during 1951-2000 (°C/dec.)

5 rows: 5 starting times

3 columns: initialization methods
Linear Trends of Temperature in WH Region

Summer, 1901-2000

winter, 1901-2000

Summer, 1951-2000

Winter, 1951-2000

Mean

Obs

Model ID

Trend (°C)

Trend (°C)

Trend (°C)

Trend (°C)

Maximum T

Minimum T
Temperature trend of *HistoricalNat* simulation

1901-2000, JJA

1901-2000, DJF

1951-2000, DJF
Temperature trend of *Historical*GHG simulation

Trend of Mean Surface Temperature - 6 model ensemble mean

- **Summer 1901-2000**
- **Winter 1901-2000**
- **Summer 1951-2000**
- **Winter 1951-2000**

Different maps show temperature trends in various seasons and decades.
Trend difference between *historical* & *historicalNat* runs

All forcing *historical* run includes dynamic land surface evolution
Temp. trends in warming hole under different forcing

Trends of SE U.S. Mean Temperature

- 1901-2000, JJA
- 1901-2000, DJF
- 1951-2000, JJA
- 1951-2000, DJF

GHG  Nat  His-Nat  His
4. Record-breaking statistics

- **Hot July 2012** (worst drought in recent 5 decades in U.S):
  - 4,420 stations broke/tied daily *high maximum* records
  - 325 stations broke/tied daily *low minimum* records
    - an over 10 to 1 ratio.

- **Cool July 2008:**
  - 500 stations broke/tied high maximum records
  - 667 stations broke/tied low minimum records.

- Thus, the number of record-breaking temperatures can serve as a metric for climate change.

(Source: http://www.ncdc.noaa.gov/oaclim/research/records/)
Theoretical expectation

• If $x$ is an iid variable, probability $p_n$ of $n^{th}$ obs. in a series $x_m = x_1, x_2, \ldots x_n$ has a higher value than all previous obs. can be expressed as:

$$p_n = \frac{1}{n}, \quad n \text{ is length of sequence.}$$

• If $x$ is not an iid variable, but rather has a linear warming trend, it can be shown for a normally distributed $x$ that

$$p_n \approx \frac{1}{n} + \frac{\nu}{\sigma} \frac{2\sqrt{\pi}}{e^2} \sqrt{\ln\left(\frac{n^2}{8\pi}\right)}$$

Here $\nu$ is trend in yr$^{-1}$ and $\sigma$ is the stdev of temperature.

Daily frequency of record-breaking temperature

U.S.
(From Meehl et al., 2009 GRL)

China
(Pan et al. 2012)
Frequency of record-breaking temperature - China

\[ p_n = \frac{1}{n} \]

\[ p_n \approx \frac{1}{n} + \frac{\nu}{\sigma} \frac{2\sqrt{\pi}}{e^2} \sqrt{\frac{n^2}{8\pi}} \]

Observed

CCSM4
Ratio of high/low record temperature - China

**Annual High/Low Ratio**

- **Observed**
- **CCSM4**
Comparison of observed and simulated *monthly* record frequency.
Comparison of observed and simulated monthly record frequency
Observed cooling (WH) occurred over southeastern U.S. in winter during 3rd quarter and over central U.S. in summer during 4th quarter of 20th century.

Great majority of models have difficulty in reproducing the anomalous cooling.

Simulations with GHG only resulted in strong warming in the central U.S. that may have compensated the cooling.

Some models can capture reasonably well the behavior of record-breaking temperatures, including daily frequency decay and Hi/Lo ratio.