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

Zaitao Pan (Saint Louis Univ.) and
X. Liu, S. Kumar, Z. Gao, J. Kinter, B. Wan

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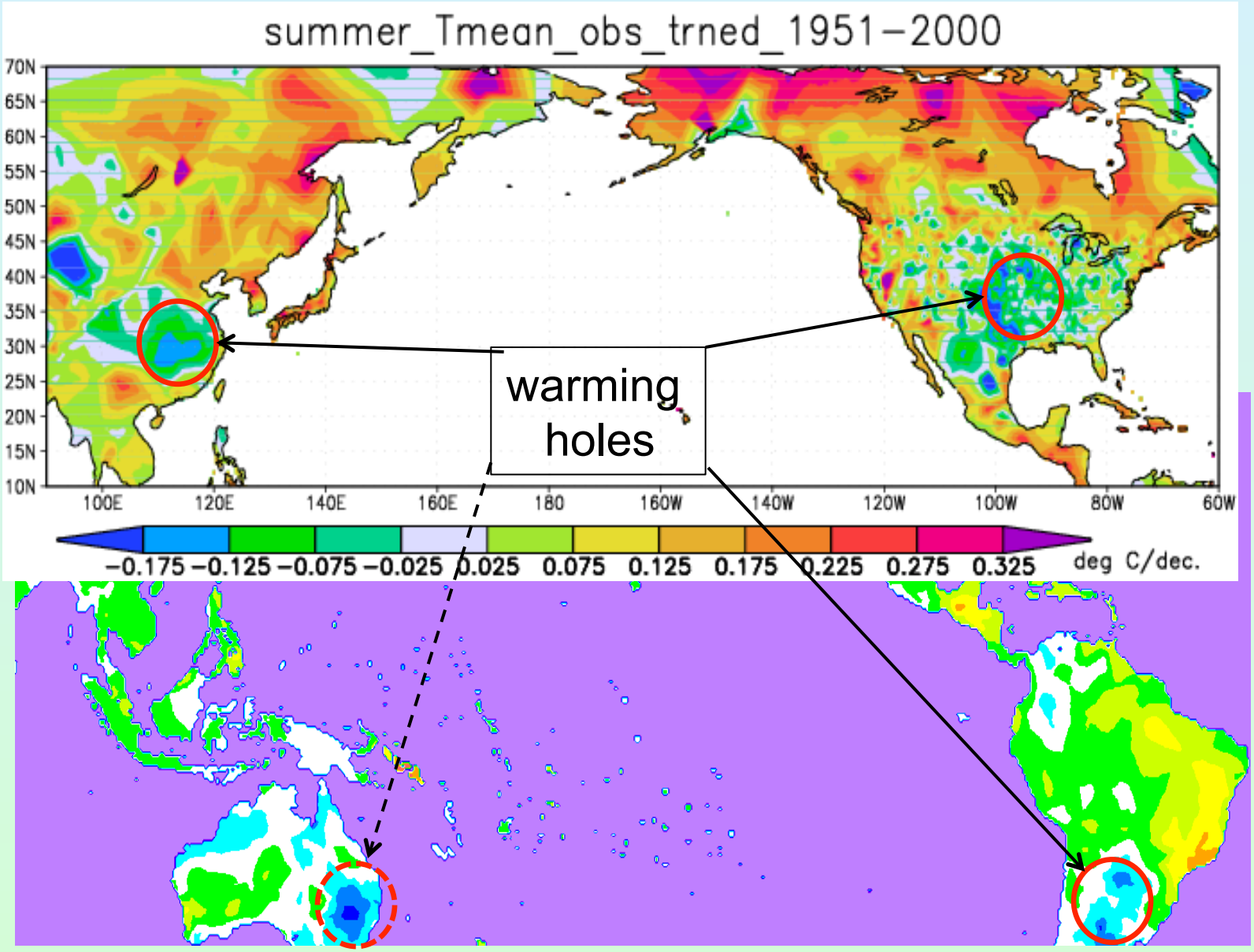
Outline

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



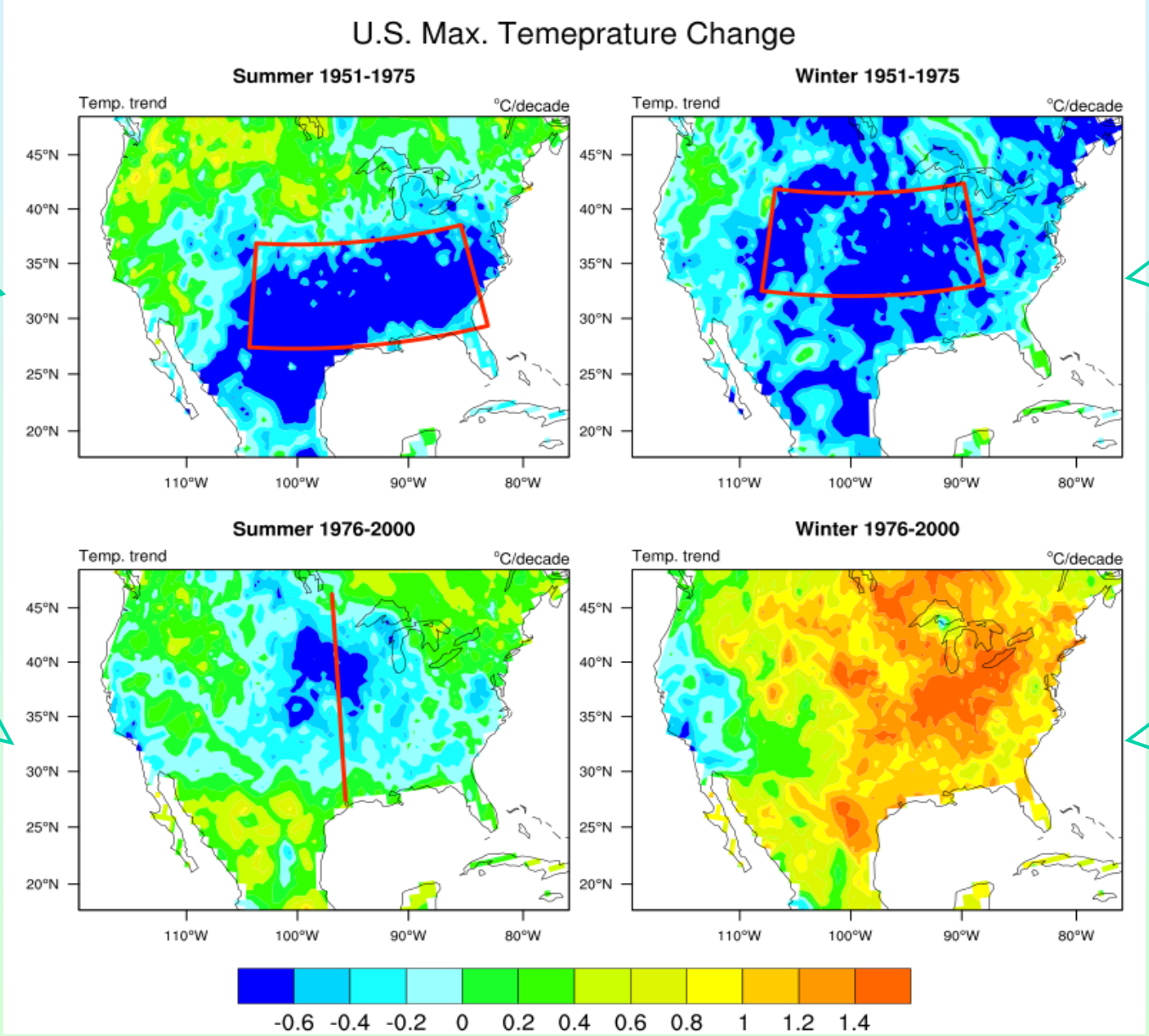
Common features of warming holes

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



1951-75, summer

1951-75, winter

1976-00, summer

1976-00, winter

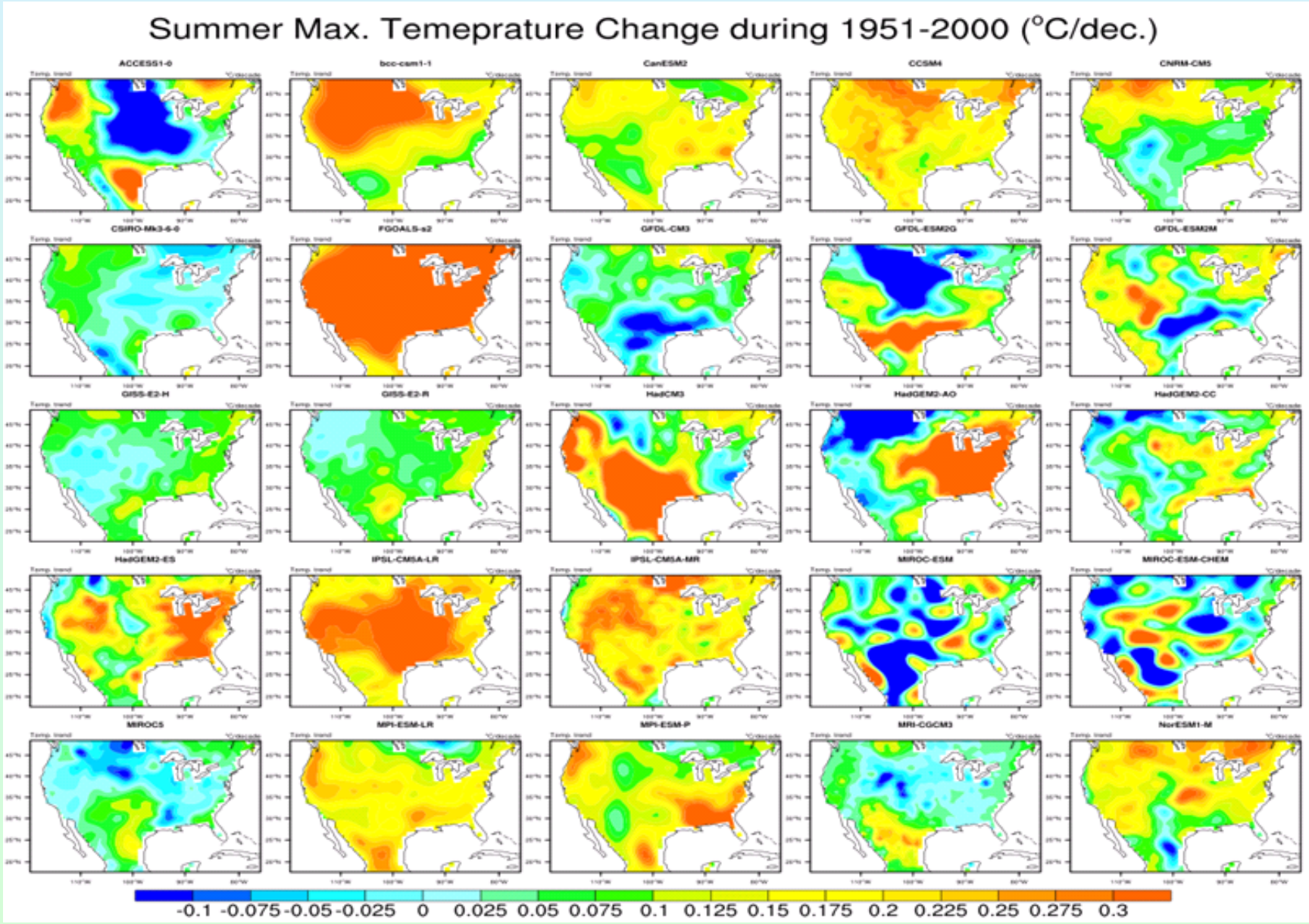
Model description

Model ID	Model symbol	Res. (lon. x lat.)	Members
1	**ACCESS1-0**	1.875 x 1.25	1
2	**BCC-CSM1.1**	2.8 x 2.8	3
3	**CanESM2**	2.8 x 2.8	5
4	**CCSM4**	1.25 x 1.0	6
5	**CNRM-CM5.1**	1.4 x 1.4	8
6	**CSIRO-MK3.6**	1.8 x 1.8	10
7	**FGOALS-S2.0**	2.8 x 1.6	3
8	**GFDL-CM3**	2.5 x 2.0	4
9	**GFDL-ESM2G**	2.5x2.0	1
10	**GFDL-ESM2M**	2.5x2.0	1
11	**GISS-E2-H**	2.5 x 2.0	15
12	**GISS-E2-R**	2.5 x 2.0	16
13	**HADCM3**	2.5x3.75	1
14	**HadGEM2-AO**	1.8 x 1.25	1
15	**HadGEM2-AO**	1.8 x 1.25	1
16	**HadGEM2-ES**	1.8 x 1.25	1
17	**IPSL-CM5A-LR**	3.75 x 1.8	5
18	**IPSL-CM5A-MR**	3.75 x 1.8	2
19	**MIROC5**	1.4 x 1.4	4
20	**MIROC-ESM**	2.8x2.8	1
21	**MIROC-ESM-chem**	1.4 x 1.4	1
22	**MPI-ESM-LR**	1.9 x 1.9	3
23	**MPI-ESM-P**	1.9 x 1.9	2
24	**MRI-CGCM3**	1.1 x 1.1	4
25	**NorESM1-M**	2.5 x 1.9	1

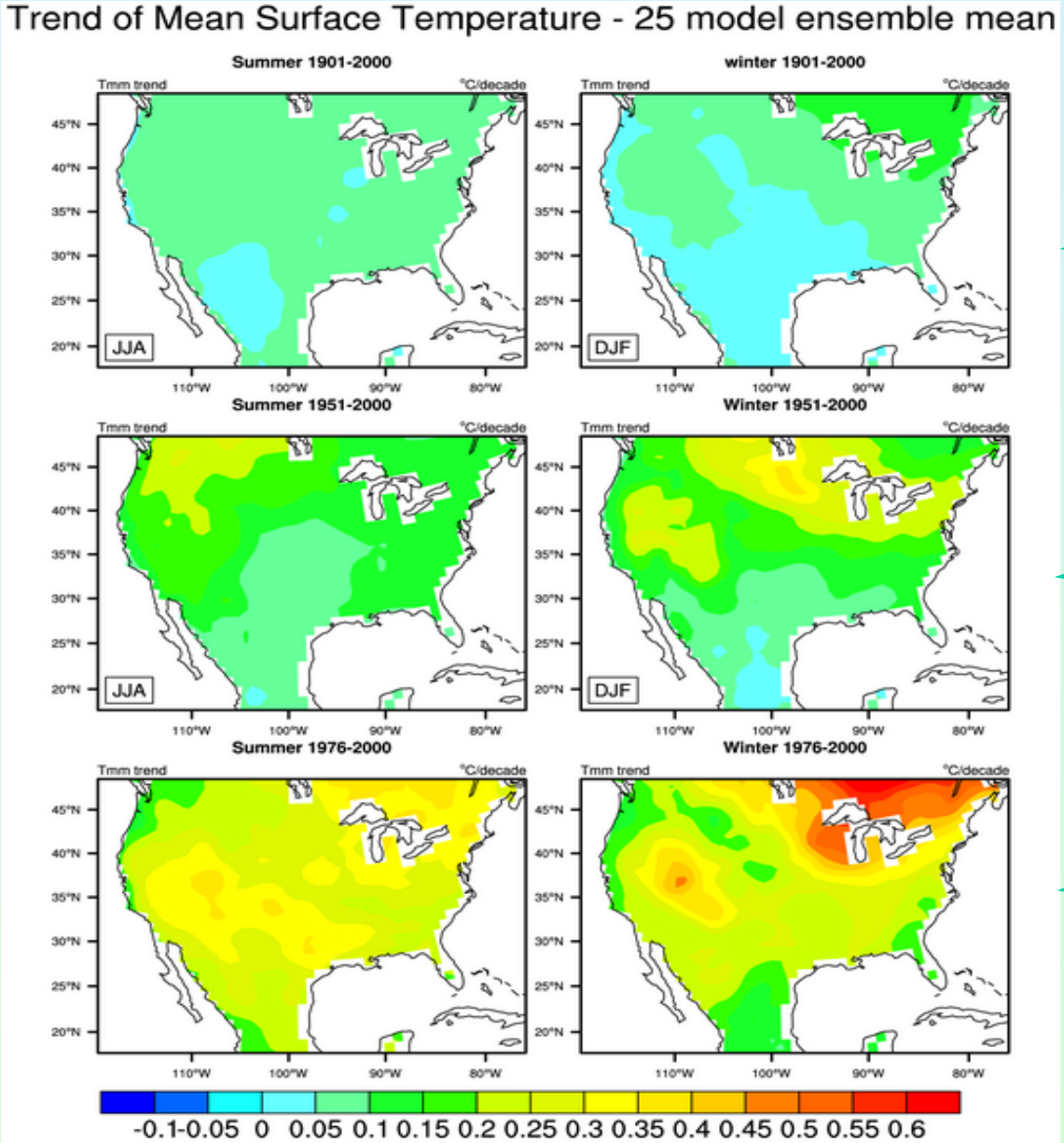
25 models, 112 ensemble members

Blue colored are also have GHG and NAT runs

1951-2000 Tmax trend simulated by 25 models



25-model-mean temperature over various periods



1901-2000

1951-2000

1976-2000

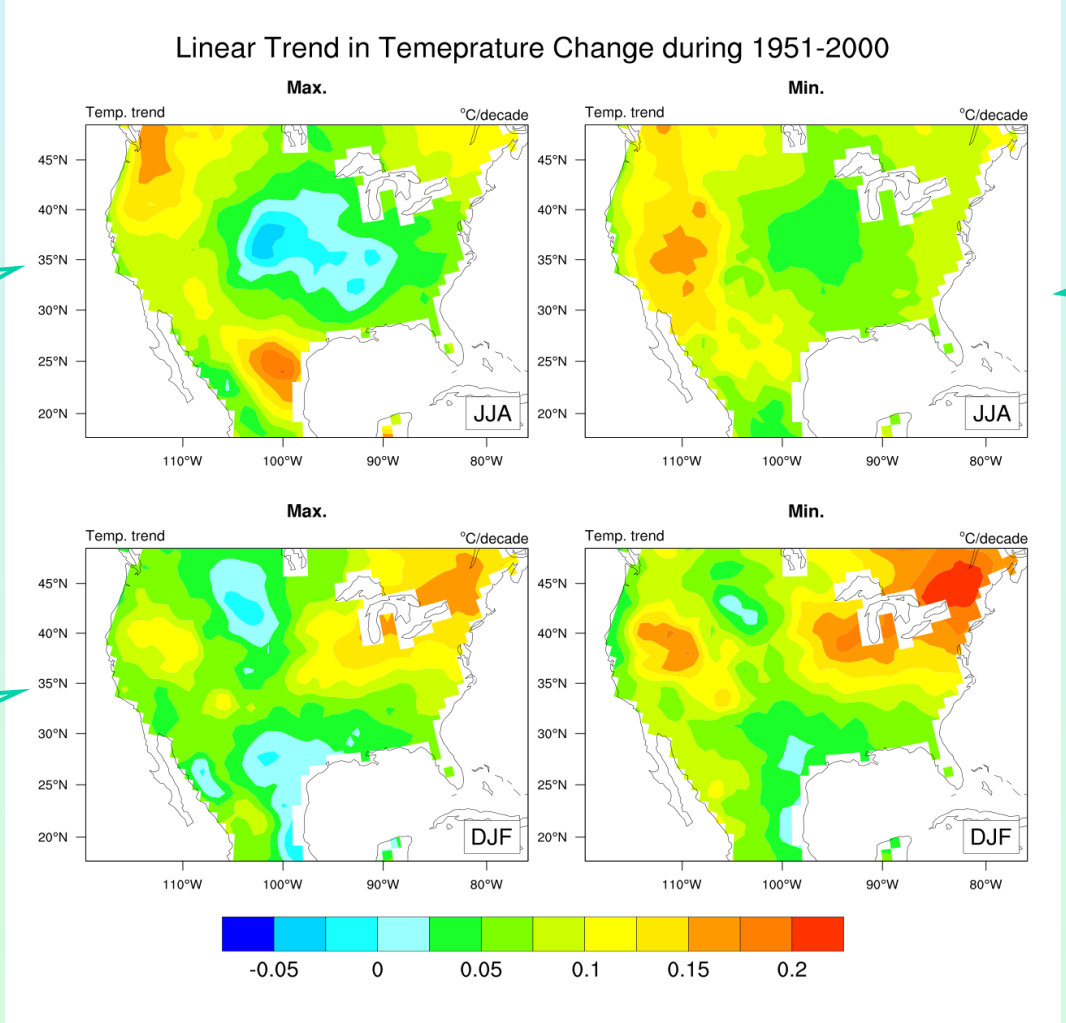
Six high-resolution model simulated temperatures

JJA, Tmax

JJA, Tmin

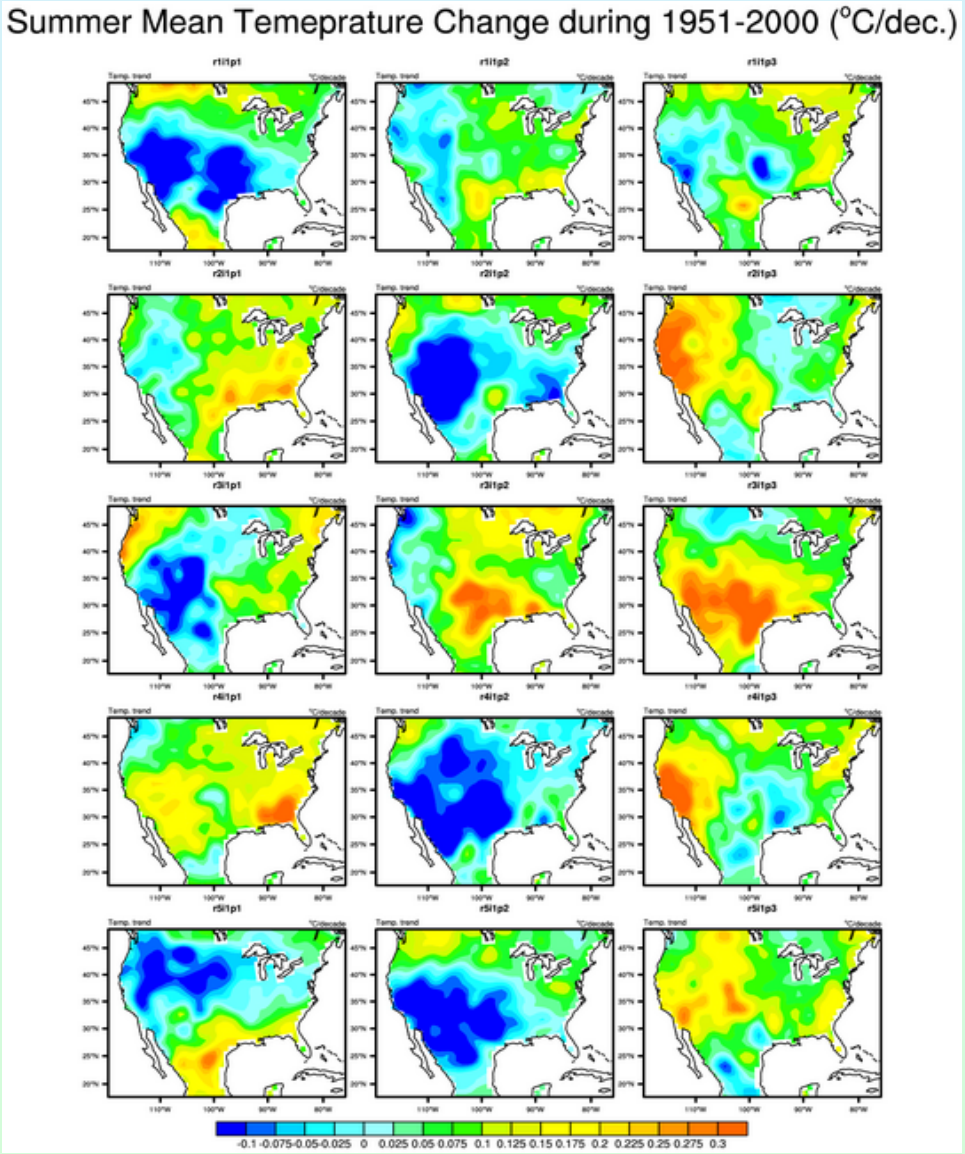
DJF, Tmax

DJF, Tmin



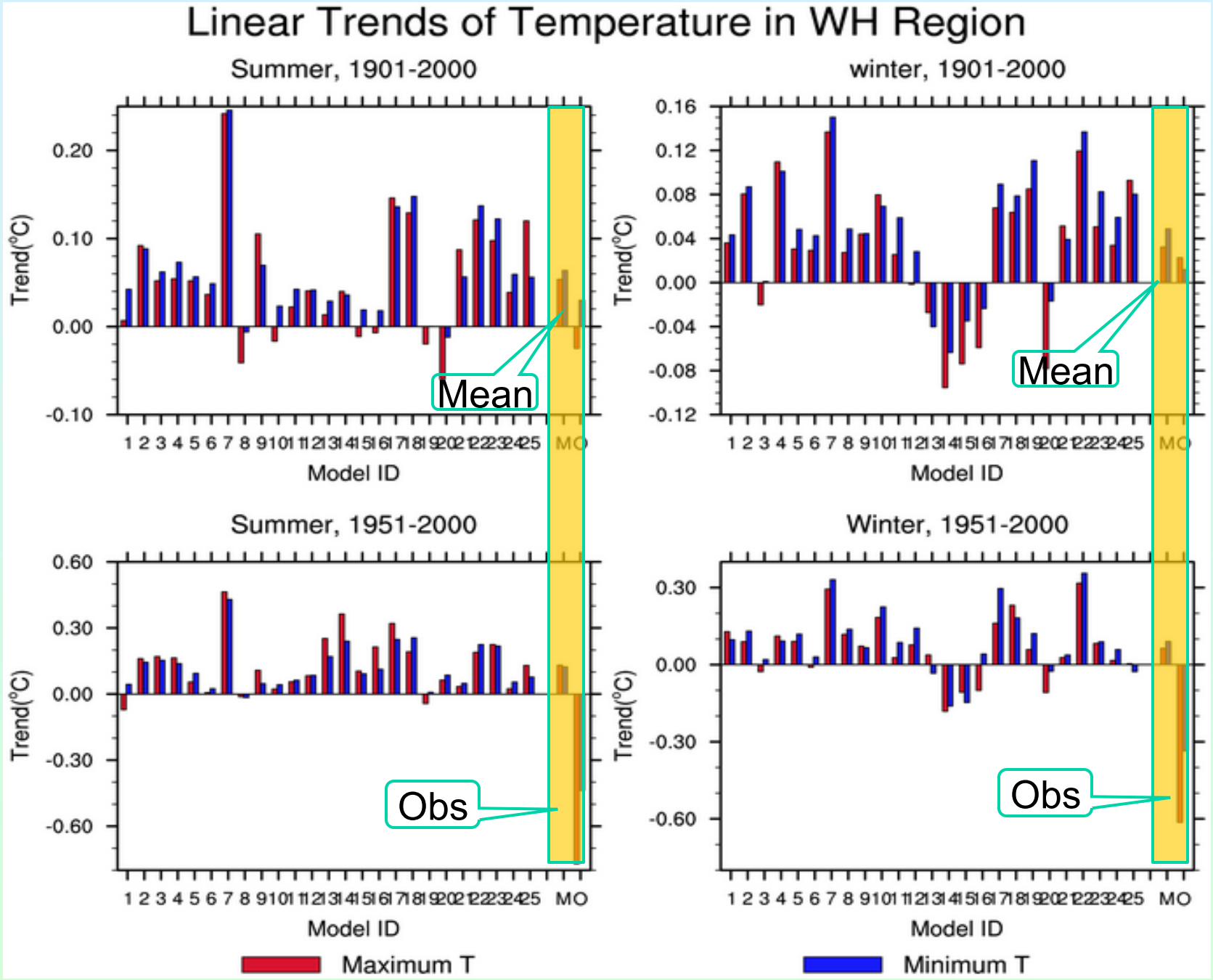
six models: ACCESS, CanCSM, CCSM4, CNRMS, CSIRO, and MRI-CGCM3, totaling 28 members.

Temp. trends simulated by 15 members of GISS-E2-H



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
Trend(°C)
Model ID
Mean
Obs
Maximum T
Minimum T

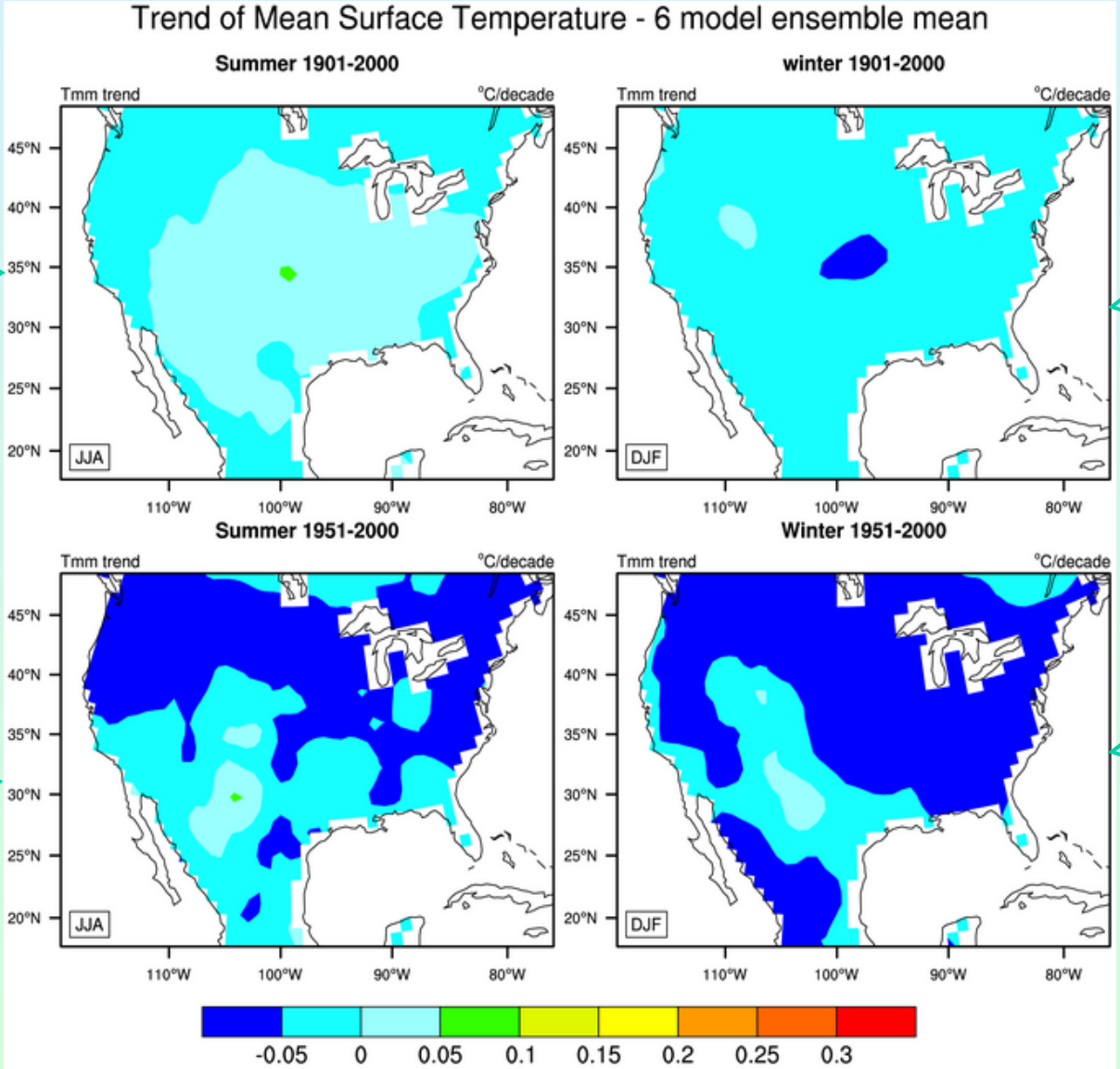
Temperature trend of *HistoricalNat* simulation

1901-2000, JJA

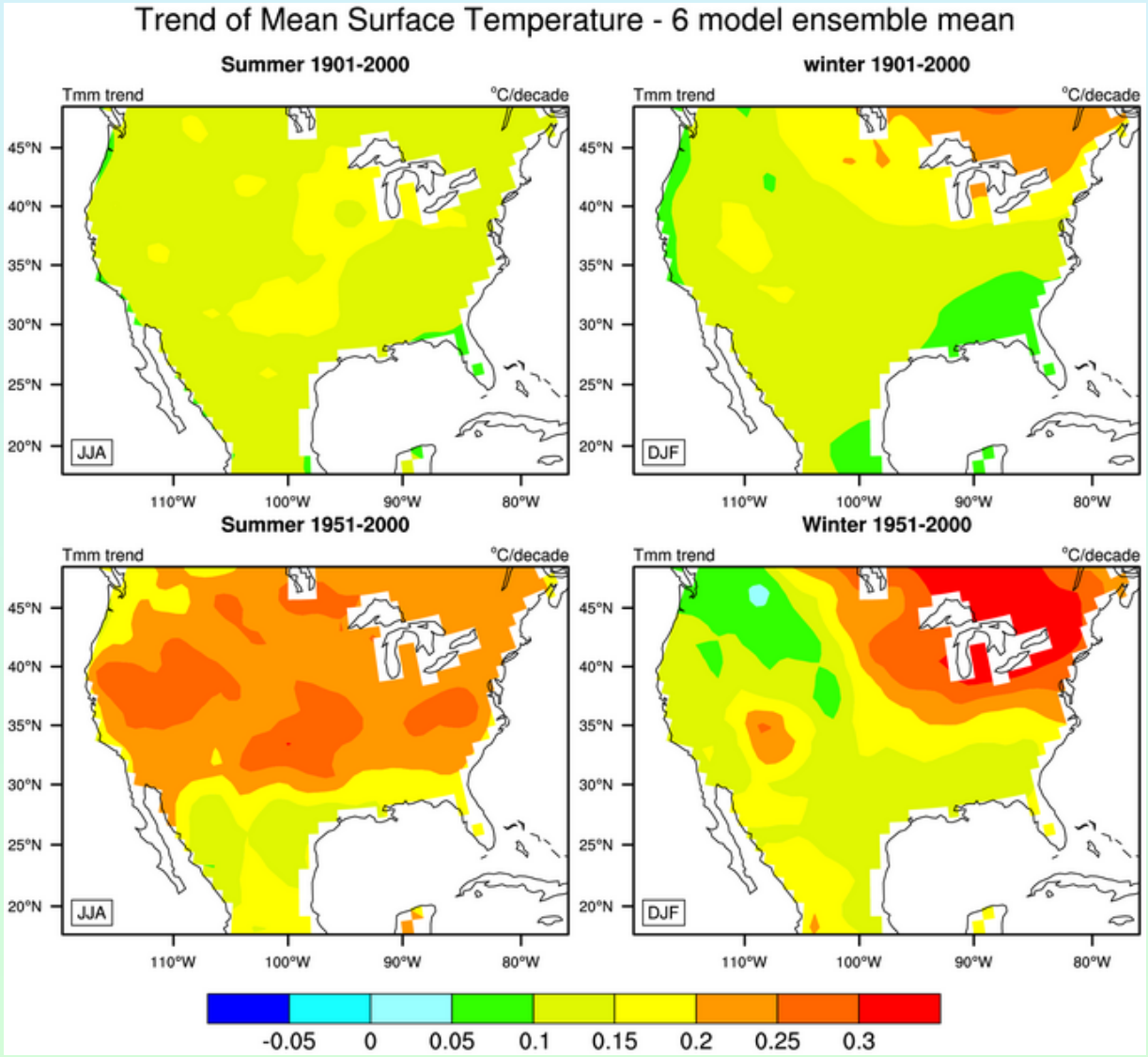
1901-2000, DJF

1951-2000, DJF

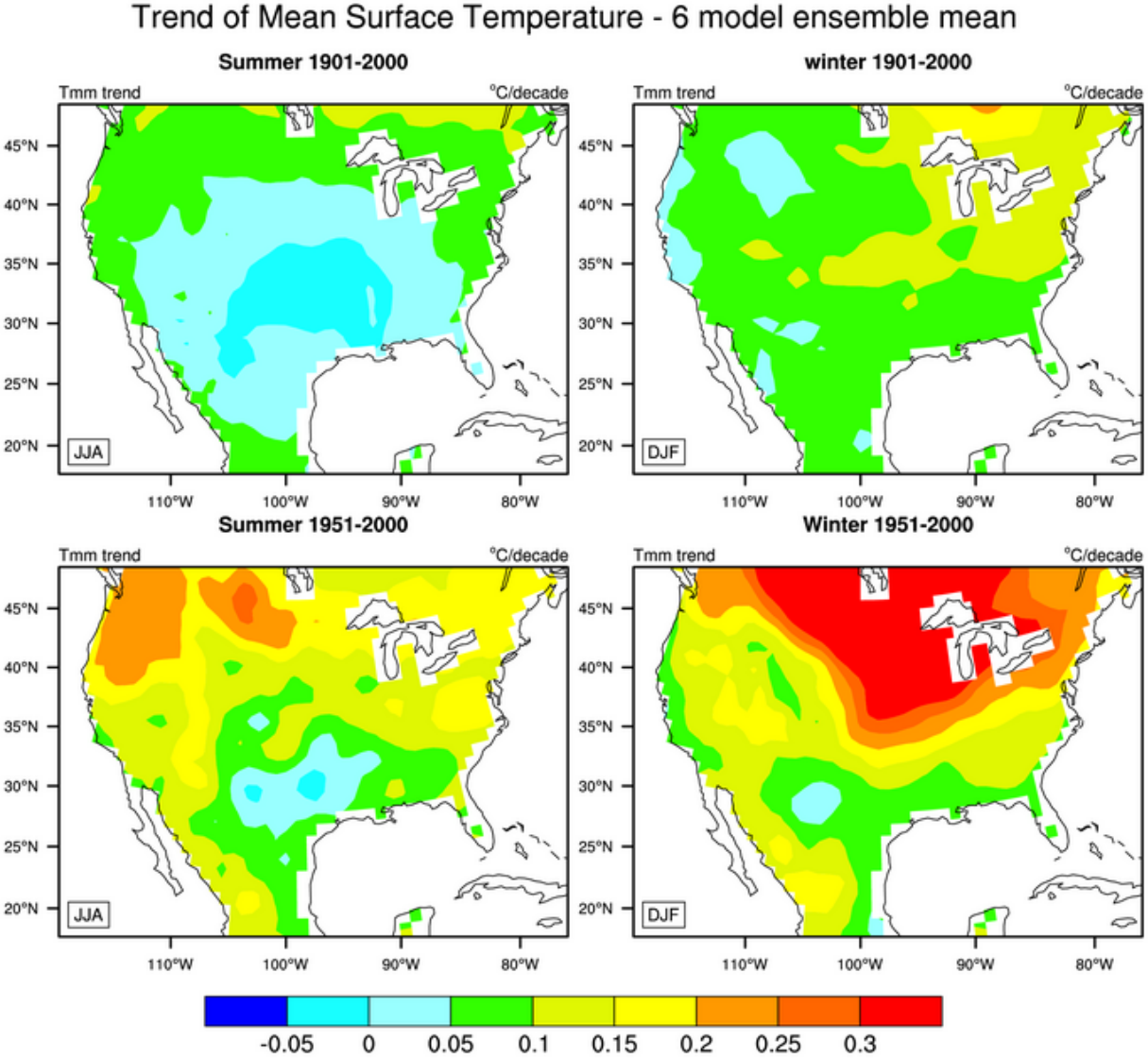
1951-2000, DJF



Temperature trend of *HistoricalGHG* simulation

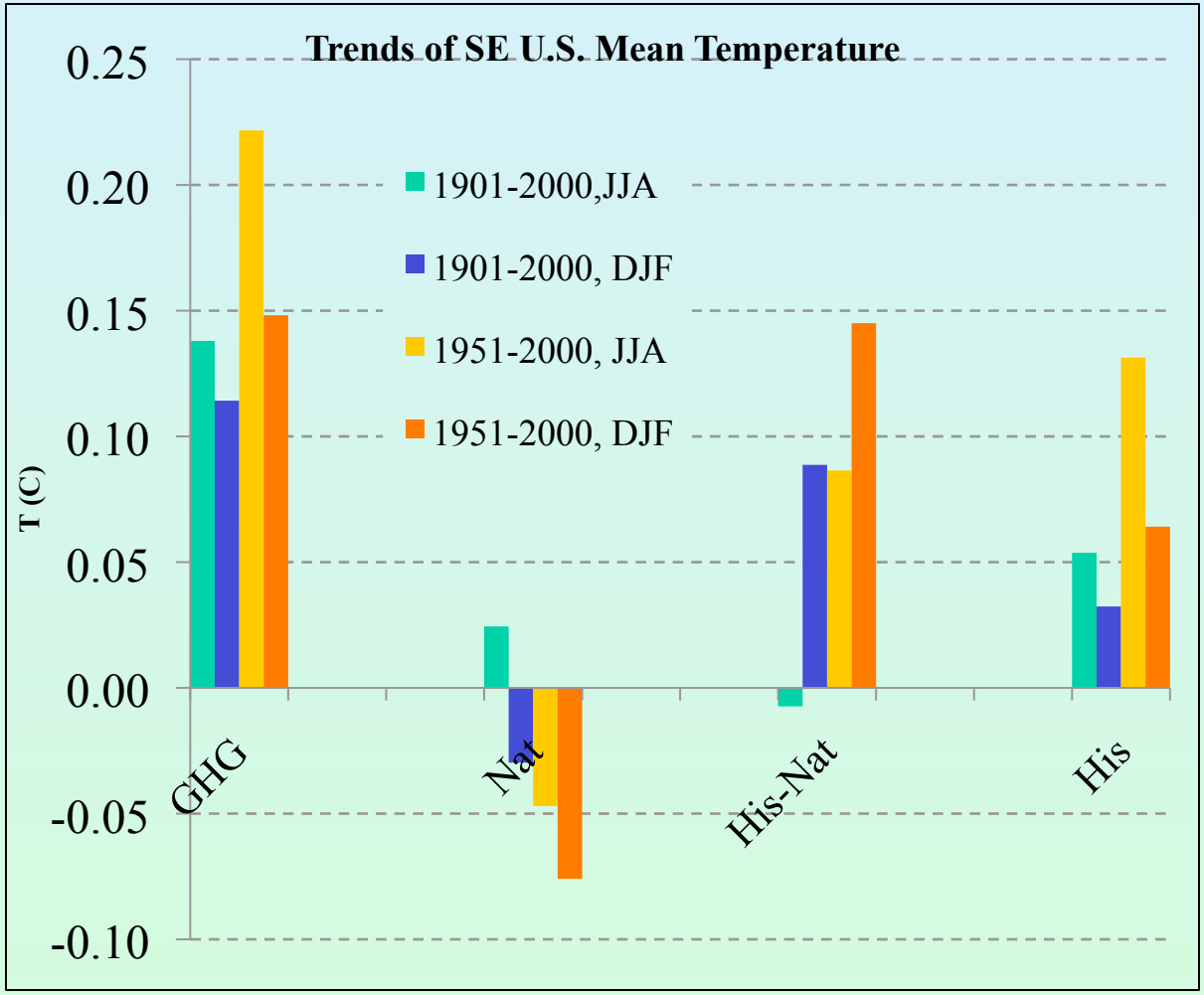


Trend difference between *historical* & *historicalNat* runs



All forcing *historical* run includes dynamic land surface evolution

Temp. trends in warming hole under different forcing



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/oa/climate/research/records/)

Theoretical expectation

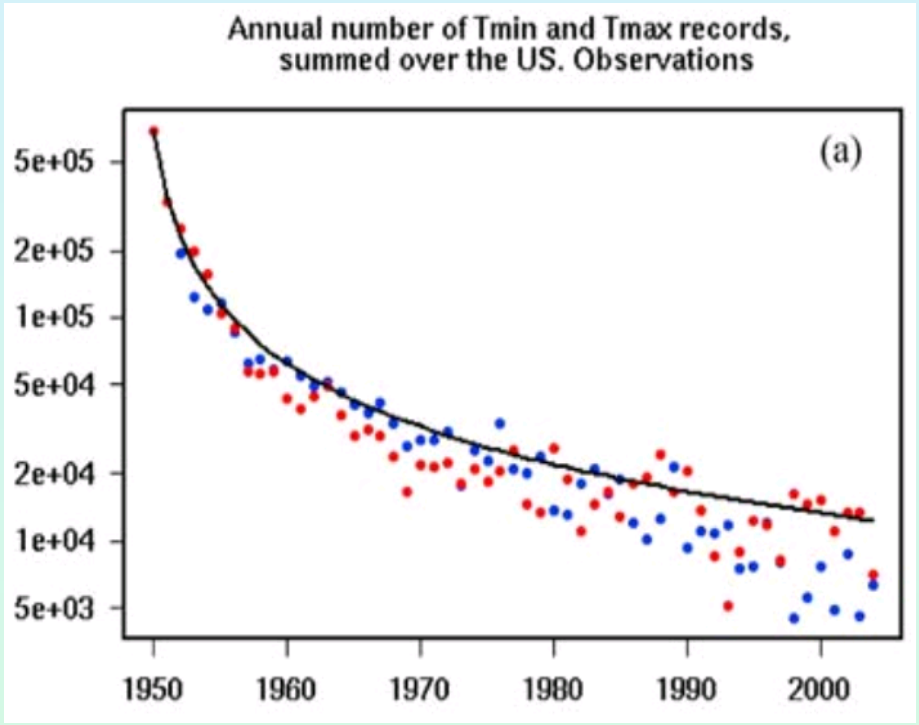
- If x is an iid variable, probability p_n of n^{th} obs. in a series $x_m = x_1, x_2, \ldots x_n$ has a higher value than all previous obs. can be expressed as: $p_n = \frac{1}{n}$, n is length of sequence.
- If x is not an iid variable, but rather has a linear warming trend , it can be shown for a normally distributed x that

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

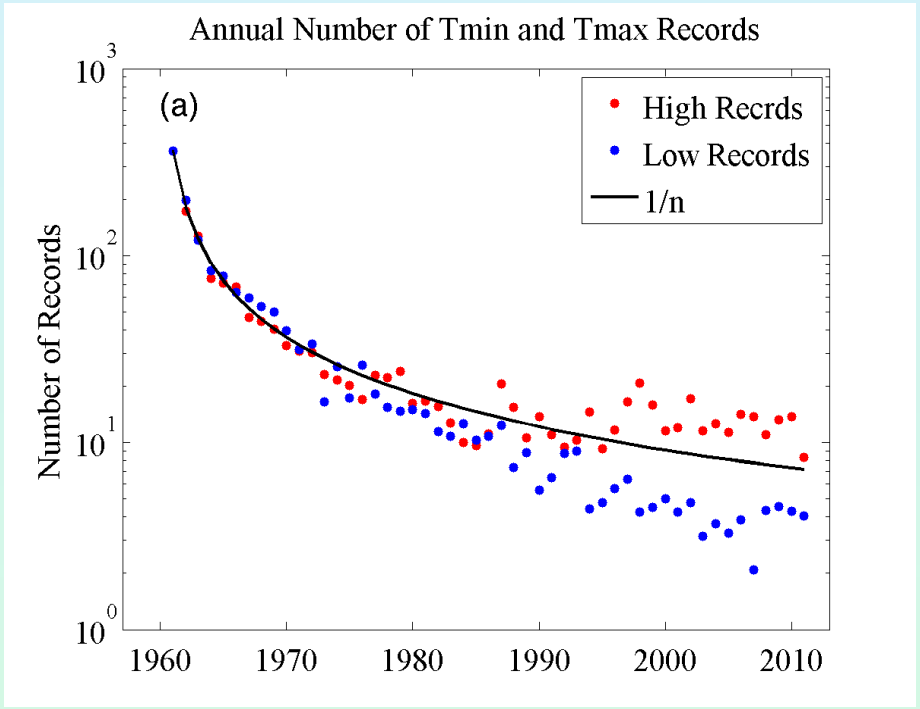
Here v is trend in yr^{-1} and σ is the stdev of temperature.

Wergen, Q, and J. Krug (2010): Record-breaking temperatures reveal a warming climate. Europhysics Letters, 92(3), 30008.

Daily frequency of record-breaking temperature

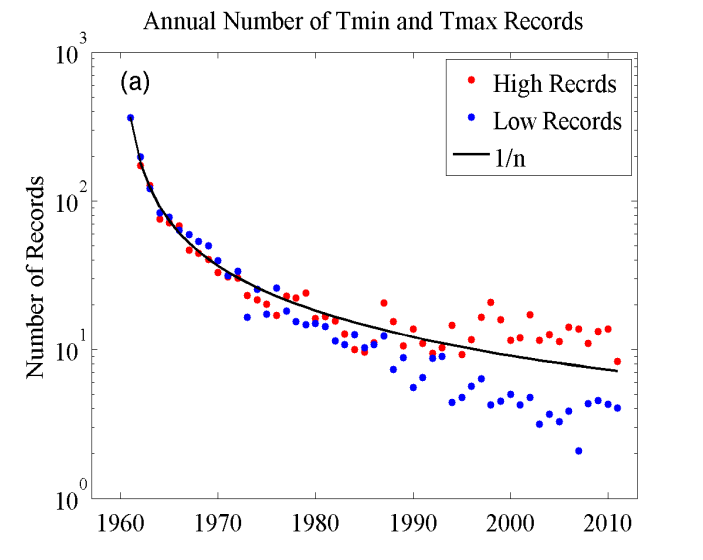


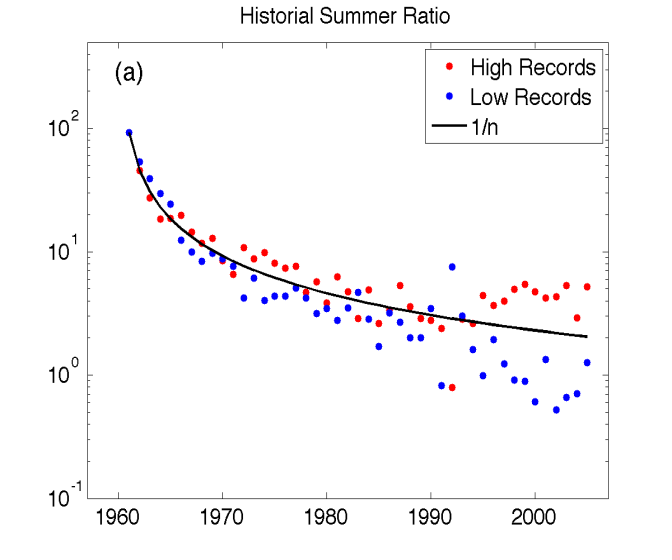
U.S.
(From Meehl et al., 2009 GRL)



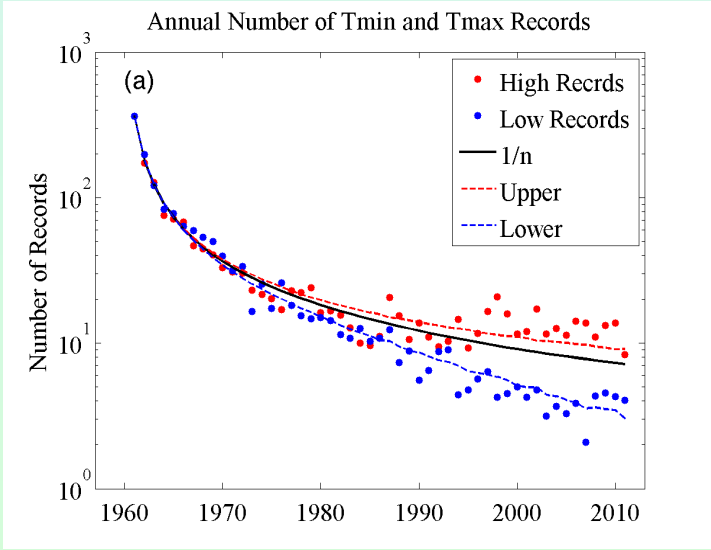
China
(Pan et al. 2012)

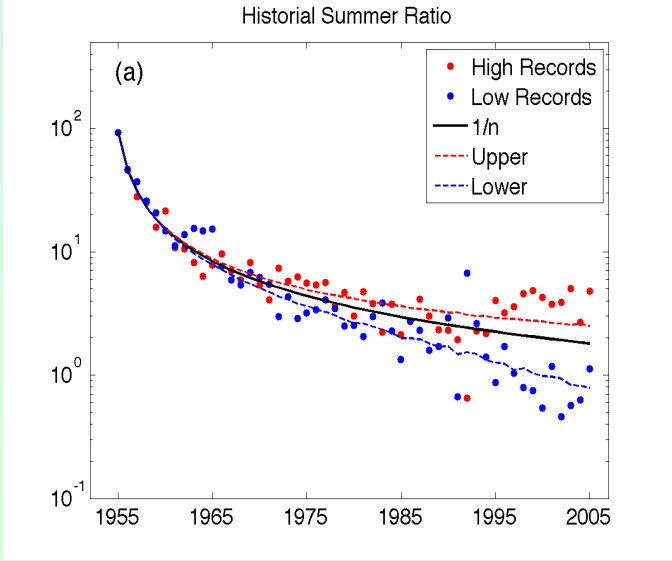
Frequency of record-breaking temperature - China





$$p_n = \frac{1}{n}$$



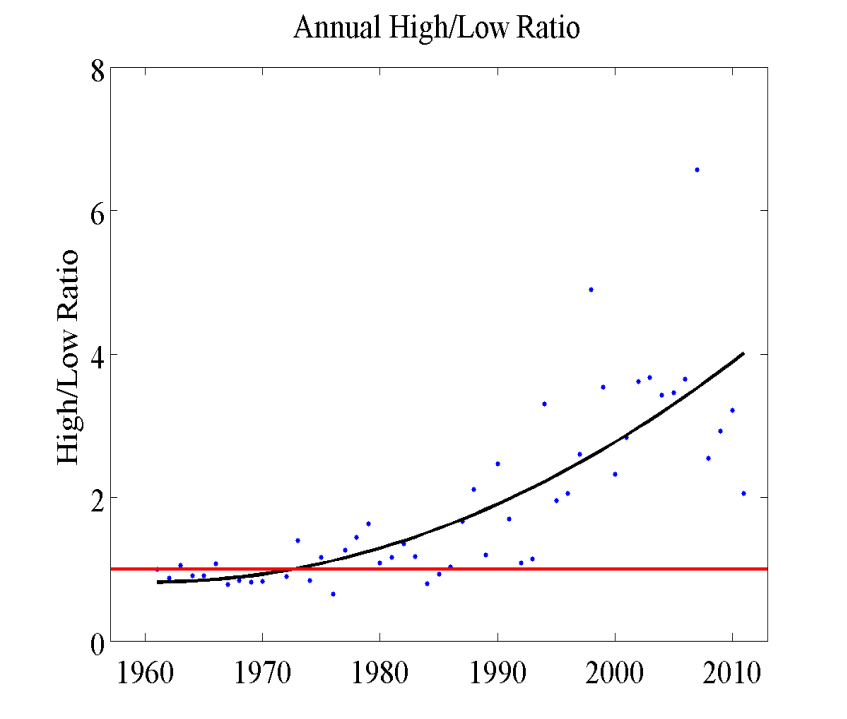


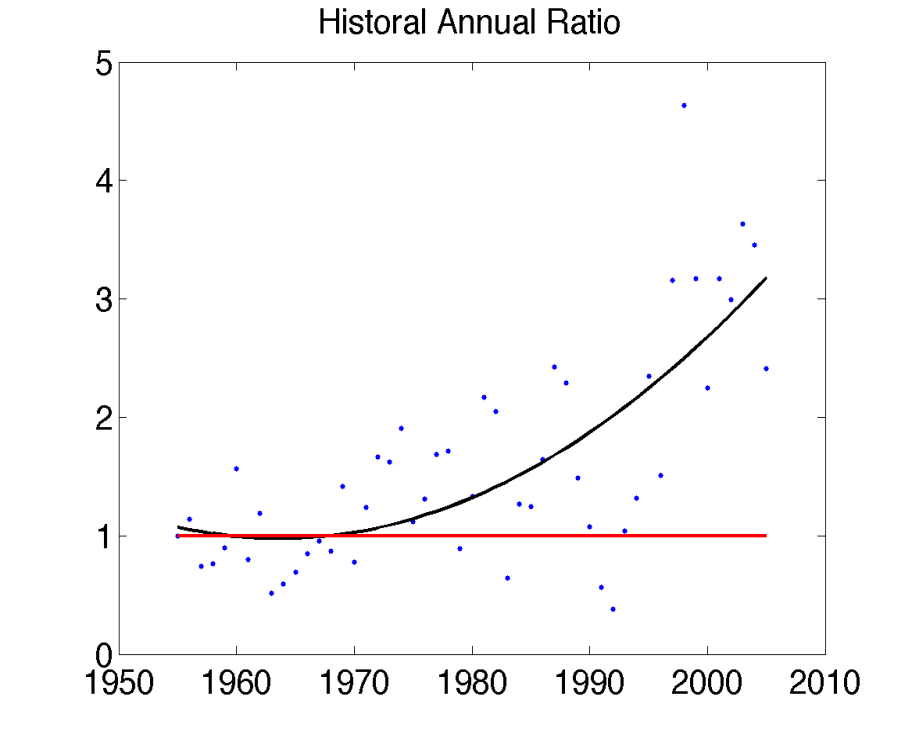
$$p_n \cong \frac{1}{n} + \frac{v}{\sigma}\frac{2\sqrt{\pi}}{e^2}\sqrt{\ln\left(\frac{n^2}{8\pi}\right)}$$

Observed

CCSM4

Ratio of high/low record temperature - China

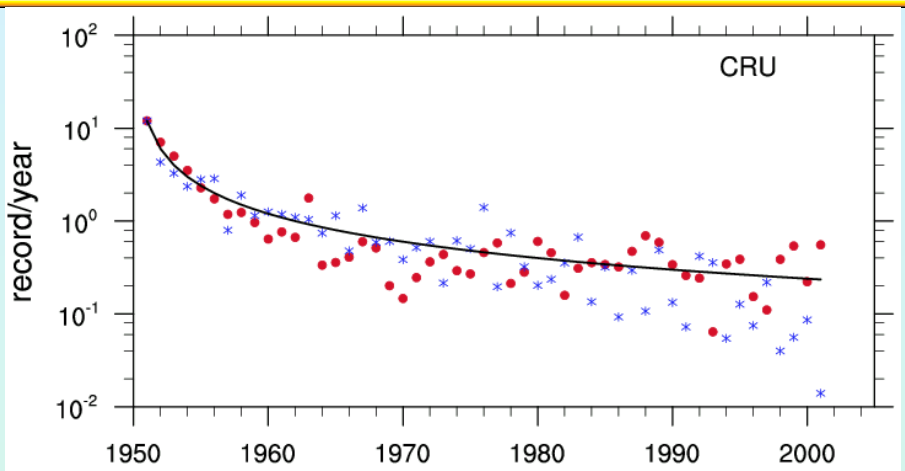


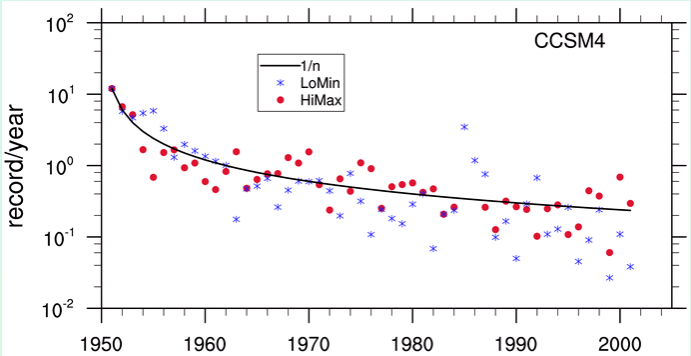


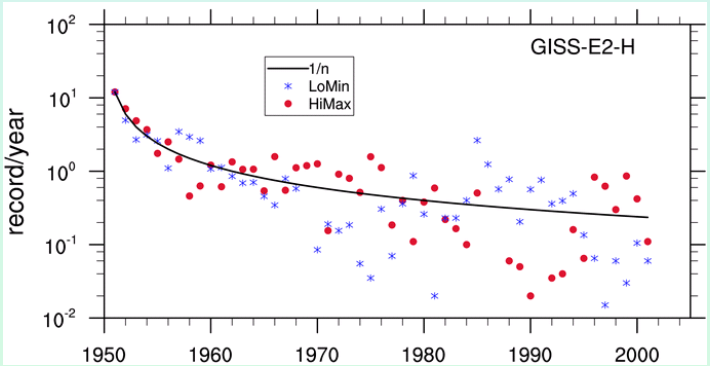
Observed

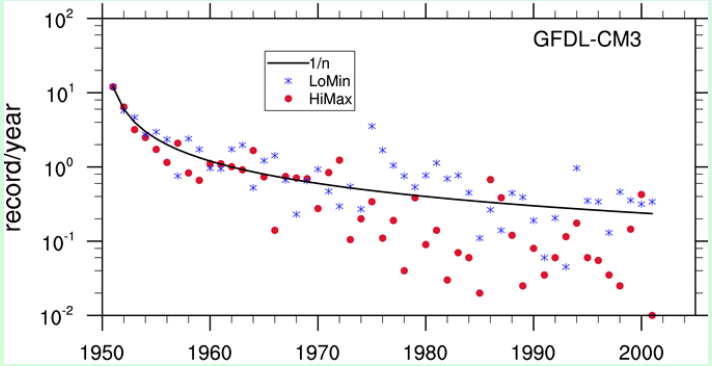
CCSM4

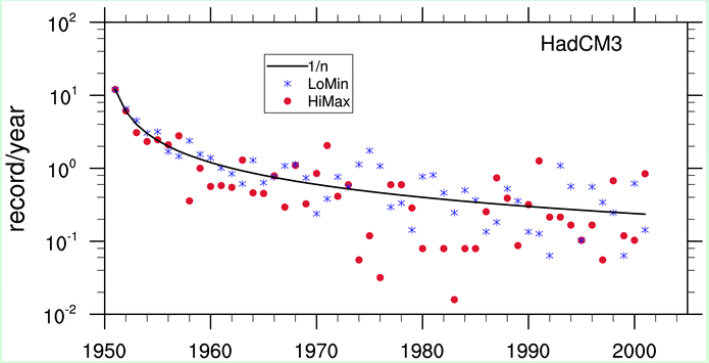
Comparison of observed and simulated *monthly* record frequency



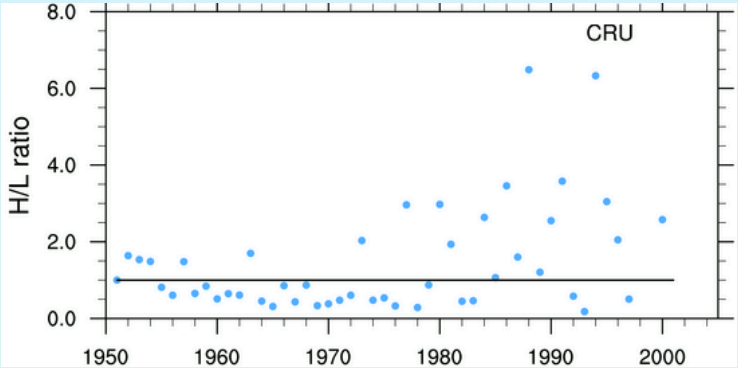


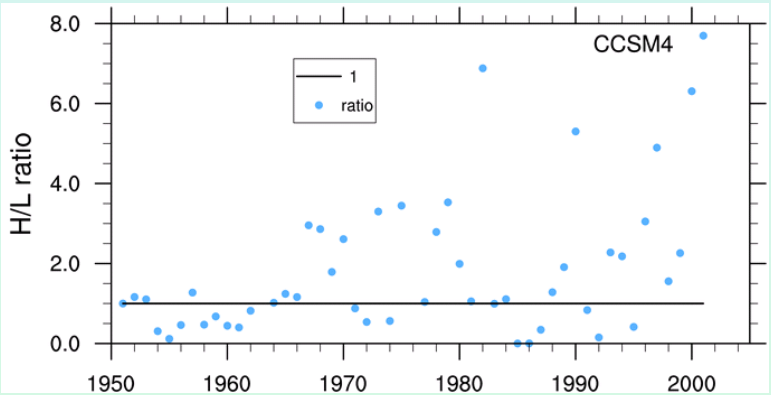


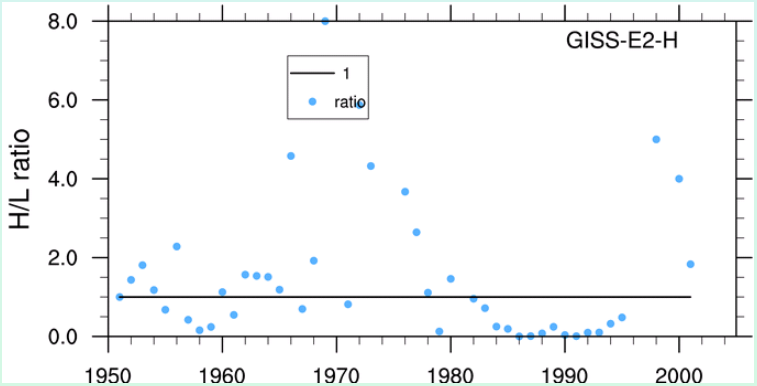


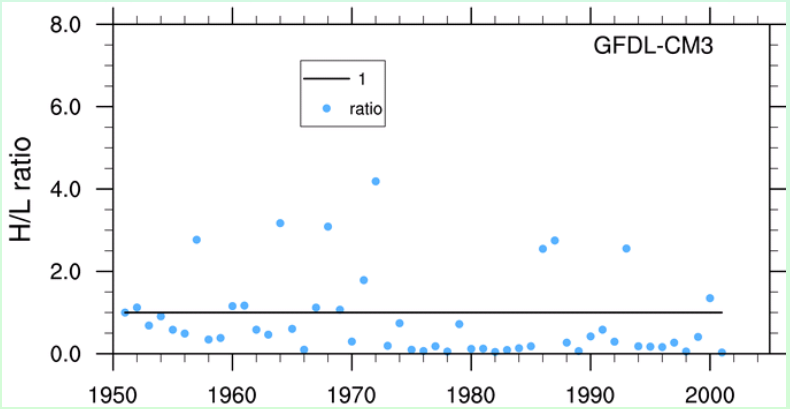


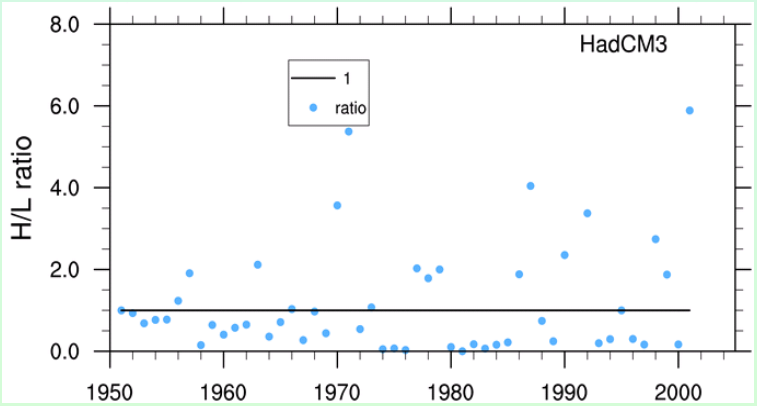
Comparison of observed and simulated monthly record frequency











Summary and Conclusions

- 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.