Convection Permitting Modeling of North American Climate

Changhai Liu and Kyoko Ikeda

Sponsored by NCAR Water System Program

Team members:

Roy Rasmussen, Mike Barlage, Fei Chen, Martyn Clark, Aiguo Dai, Jimy Dudhia, David Gochis, Ethan Gutmann, Kyoko Ikeda, Changhai Liu, Andrew Newman, Andreas Prein, Gregory Thompson, David Yates, and University Collaborators

NCAR Day of Networking & Discovery
April 28 2017

Project Team

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Dynamical Downscaling	Ethan Gutmann	RAL/HAP
Social Impacts	Dave Yates	RAL/HAP

OUTLINE

Overview of the Project

- Motivations & Objectives
- Methodology
- Numerical Experiments

Results of Two Completed Experiments

- 13-year control simulation
- 13-year climate sensitivity simulation

Science Objectives of the Project

- to evaluate WRF's ability to capture orographic precipitation/ snowpack in western US and convective precipitation in eastern US
- to assess future changes of snowfall/snowpack and associated hydrological cycles
- to examine precipitation changes under the CMIP5 projected global warming, including extremes, intensity, frequency, duration and type
- to provide a valuable community dataset for regional climate change and impact studies

Numerical Approach

- 4-km WRF model with ***1360x1016x51*** cells
- Physics parameterizations
  - Microphysics [Thompson & Eidhammer 2014]
  - Noah-MP LSM [Niu et al 2011]
  - YSU PBL [Hong et al 2006]
  - RRTMG radiation [Iacono et al 2008]
- Spectral nudging: U, V, T, and GH

Two Completed Experiments

- **EXP1**: Retrospective/Control simulation
  - **WRF_{input} = ERA-Interim**
  - 13 years: *Oct. 1 2000 – Sep. 30 2013*

- **EXP2**: Pseudo-Global Warming (PGW) simulation
  - **WRF_{input} = ERA-Interim + $\Delta CMIP5_{RCP8.5}$**

    $\Delta CMIP5_{RCP8.5} = CMIP5_{2071\text{-}2100} - CMIP5_{1976\text{-}2005}$
  - 13 years: *Oct. 1 2000 – Sep. 30 2013*

What is PGW approach?

- Compute 19 CMIP5 model ensemble monthly mean
  - Historical period : *1976-2005* Future period (RCP8.5): *2071-2100*
- Compute perturbation from two climates
- Add perturbation to ERA-I data

Monthly mean of **historical** condition **CMIP5 1976-2005**

Monthly mean of **future** condition **CMIP5 2071-2100**

WRF Inputs for Future Climate Simulation

Monthly perturbation of CMIP5 ensemble mean

+

6 hourly ERA-I data

- No storm track change
- What does today's weather look like in a warmer climate?

Ongoing Experiments

- **EXP3**: CESM-based historical period *(2000-2009)* simulation

- **EXP4**: CESM-based future period *(2090-2099)* simulation

(Dai et al 2017)

$$WRF_{input} = CESM' + (\overline{CMIP5} - \overline{CMIP5}_{bias})$$

$$(CESM' = CESM - \overline{CESM})$$

Conventional bias correction (Done et al 2012)

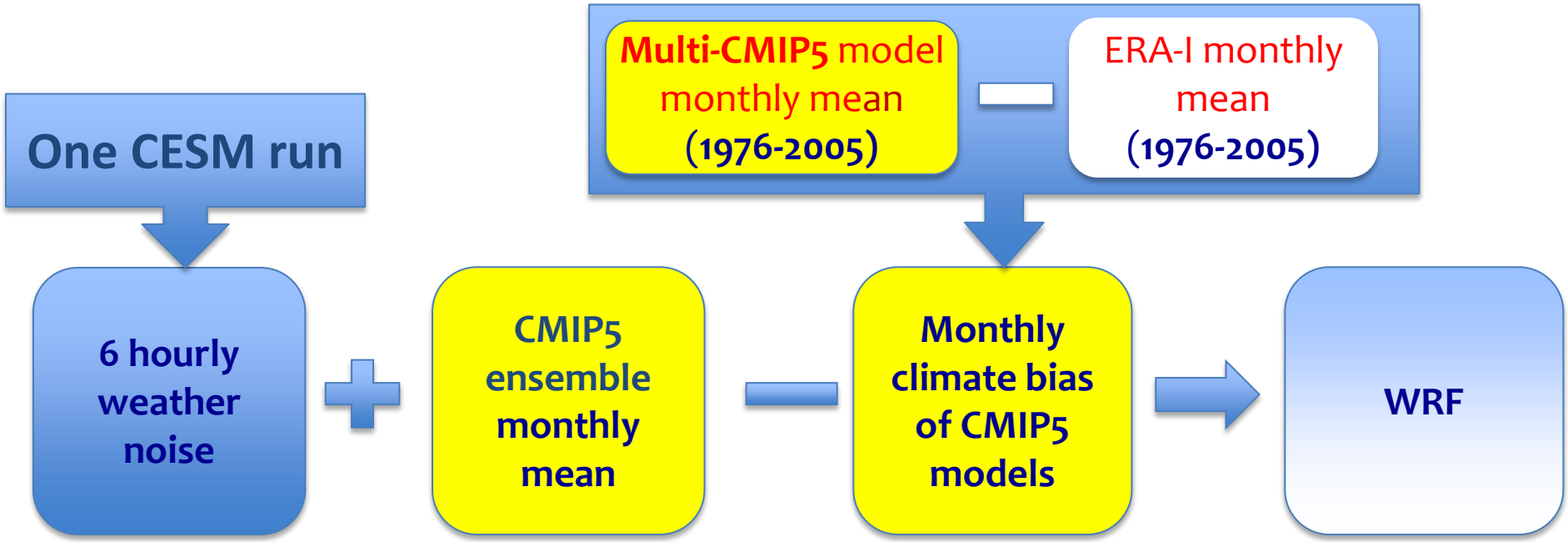
$$WRF_{input} = CESM' + (\overline{CESM} - \overline{CESM}_{bias})$$

$$(CESM' = CESM - \overline{CESM})$$

Forcing Data Construction

$$WRF_{input} = CESM' + \overline{CMIP5} - \overline{CMIP5}_{bias}$$

$$(CESM' = CESM - \overline{CESM})$$



- Permit storm track changes
- Minimize influence of unforced natural variations

Difference between PGW and CESM-based Simulations: Weather Noise

PGW:

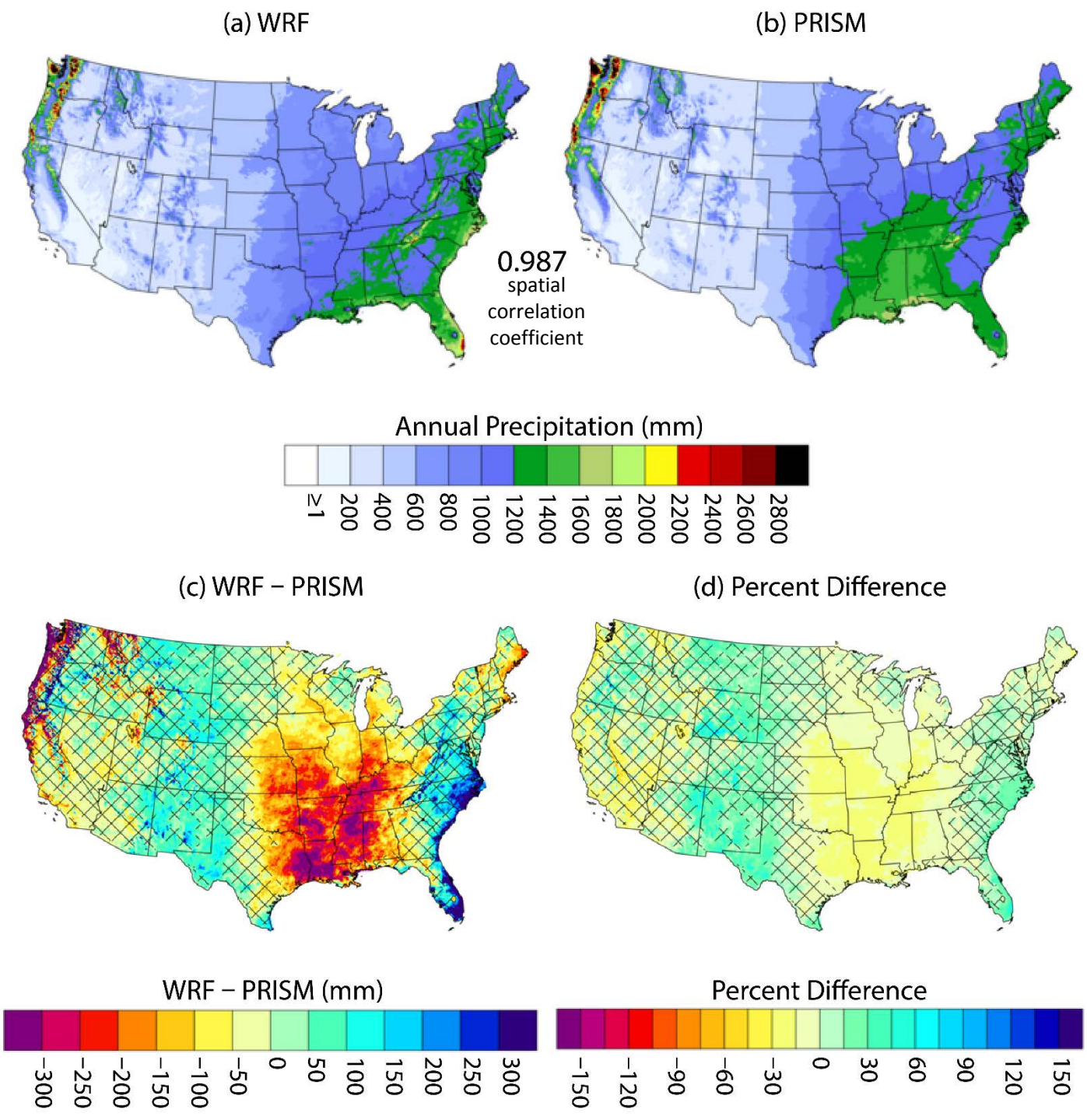
$$WRF_{input} = ERA\text{-}I' + \overline{ERA\text{-}I}_{1976\text{-}2005} + (\overline{CMIP5}_{2071\text{-}2100} - \overline{CMIP5}_{1976\text{-}2005})$$

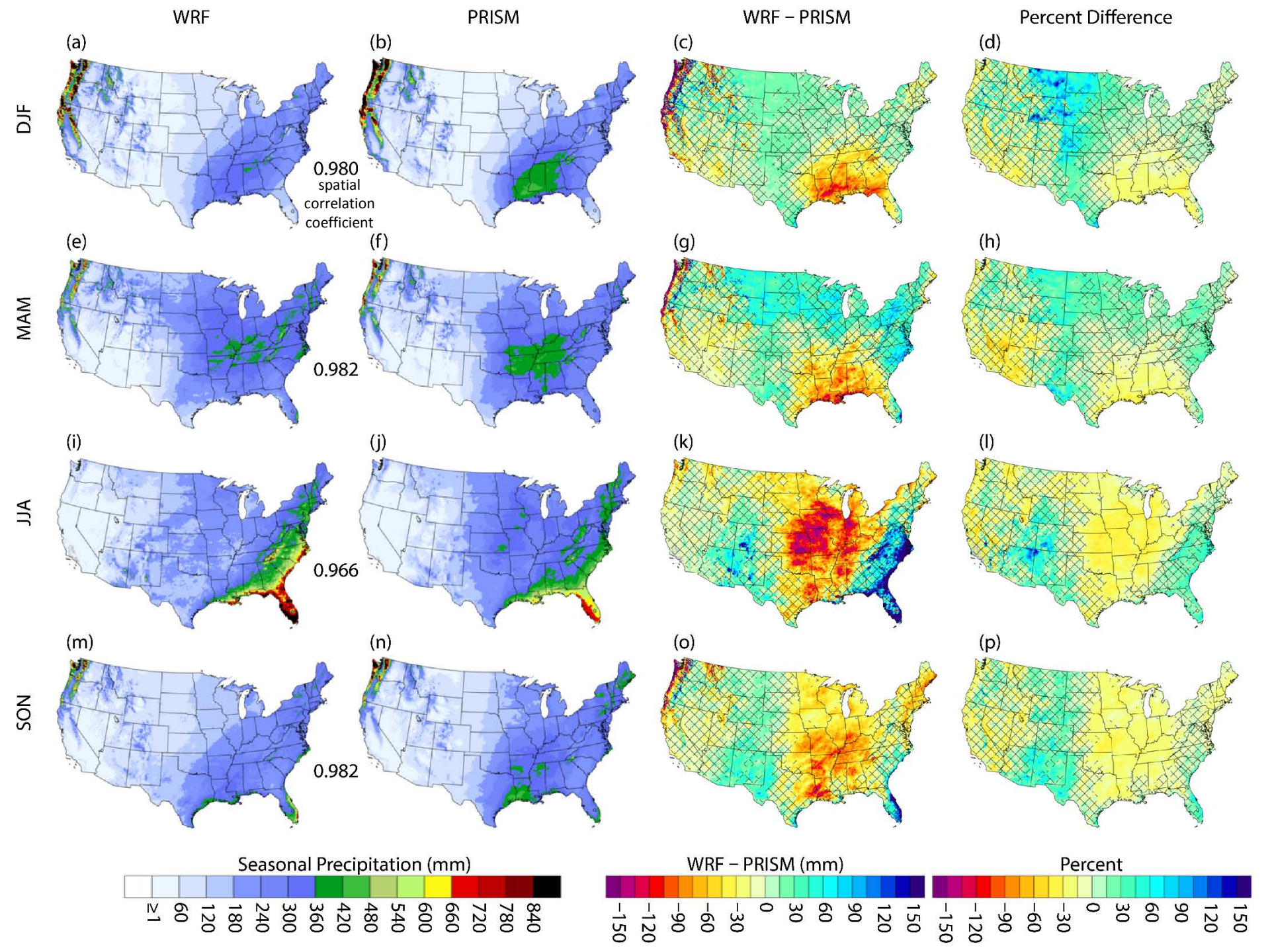
CESM-based:

$$WRF_{input} = CESM' + \overline{ERA\text{-}I}_{1976\text{-}2005} + (\overline{CMIP5}_{2071\text{-}2100} - \overline{CMIP5}_{1976\text{-}2005})$$

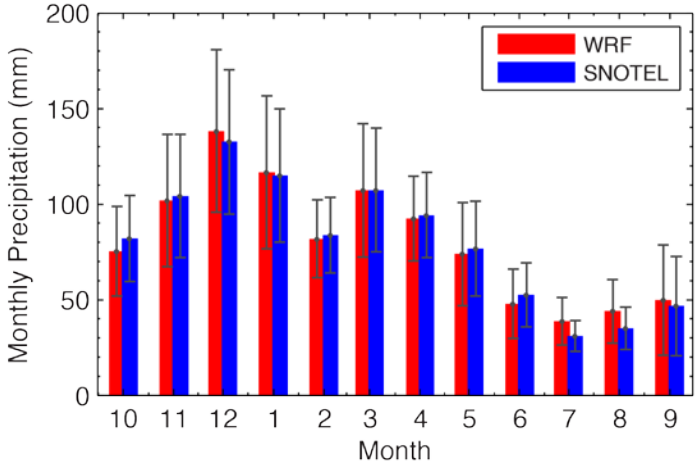
$$CESM' = CESM - \overline{CESM}_{2071\text{-}2100}$$

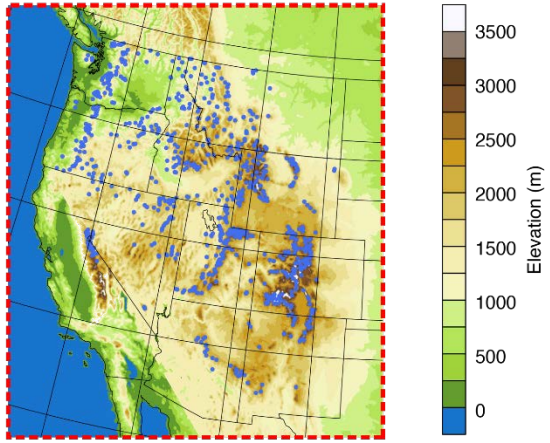
Validation of Retrospective Experiment (Liu et al 2016)


(a) WRF
(b) PRISM
0.987
spatial
correlation
coefficient
Annual Precipitation (mm)
≥1
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
2600
2800
(c) WRF − PRISM
(d) Percent Difference
WRF − PRISM (mm)
−300
−250
−200
−150
−100
−50
0
50
100
150
200
250
300
Percent Difference
−150
−120
−90
−60
−30
0
30
60
90
120
150

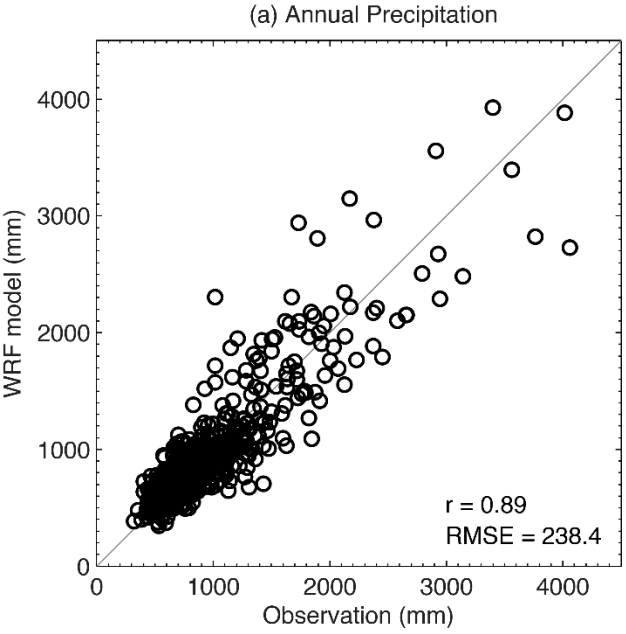

WRF
PRISM
WRF − PRISM
Percent Difference
(a)
(b)
(c)
(d)
DJF
0.980
spatial
correlation
coefficient
(e)
(f)
(g)
(h)
MAM
0.982
(i)
(j)
(k)
(l)
JJA
0.966
(m)
(n)
(o)
(p)
SON
0.982
Seasonal Precipitation (mm)
≥1
60
120
180
240
300
360
420
480
540
600
660
720
780
840
WRF − PRISM (mm)
−150
−120
−90
−60
−30
0
30
60
90
120
150
Percent
−150
−120
−90
−60
−30
0
30
60
90
120
150

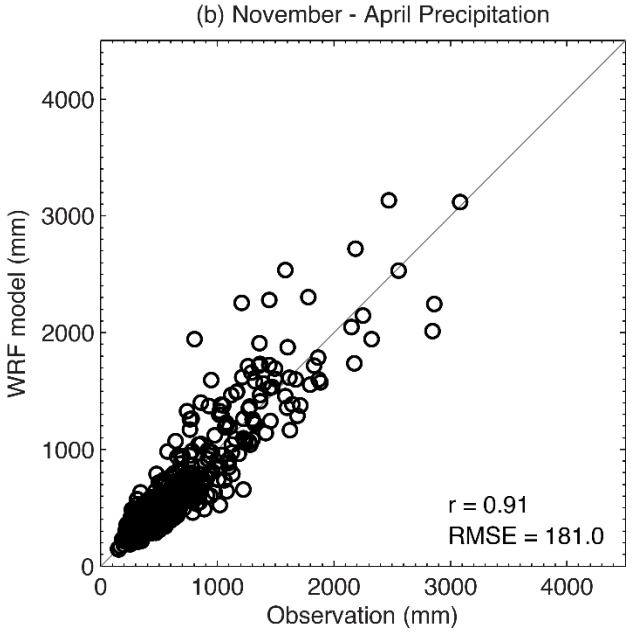
13-year Average Monthly Precipitation at SNOTEL sites

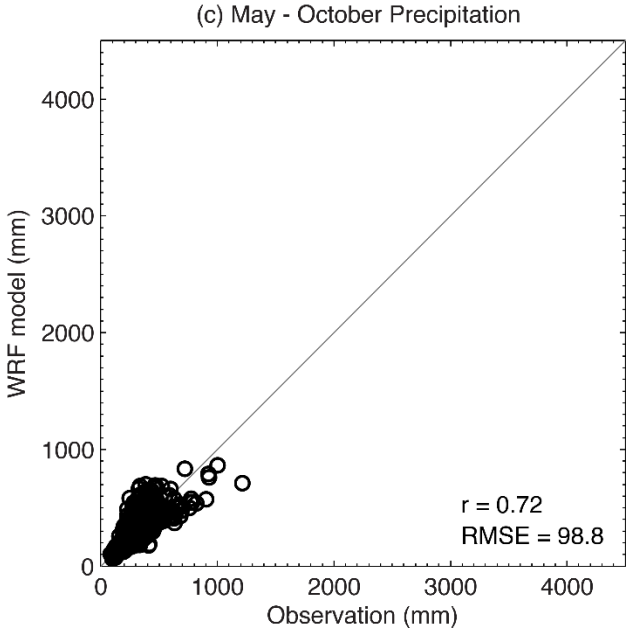


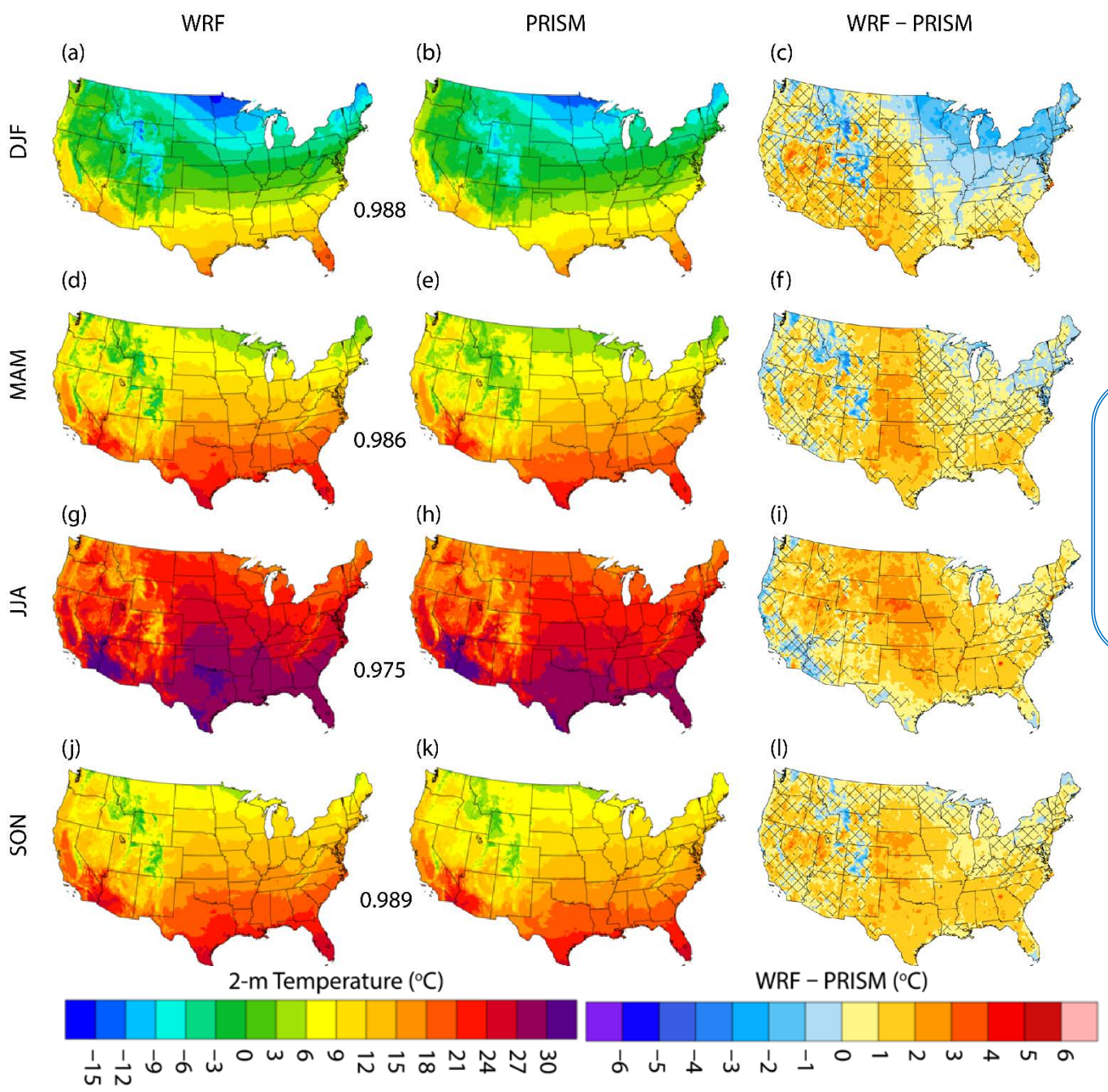


13-year Average Annual and Seasonal Precipitation at SNOTEL Sites









13-year Average Seasonal 2-m T: Comparison between WRF and PRISM

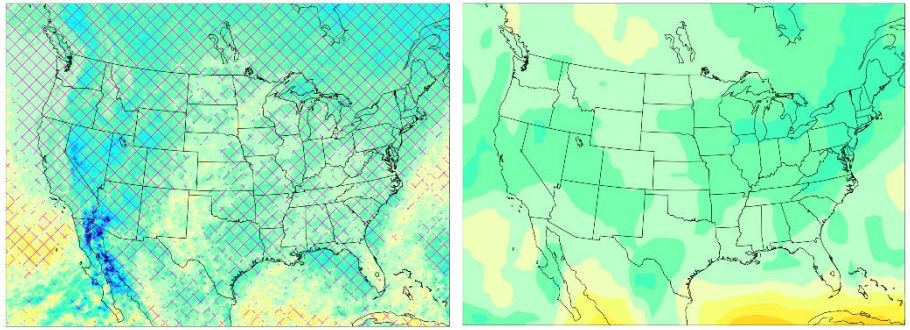
Highlights of Pseudo-global Warming Experiment Results

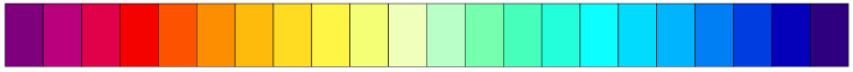
(Liu et al 2016; Musselman et al 2017; Rasmussen et al 2017; Prein et al 2017)

Annual and Seasonal Precipitation Change from the 19 CMIP5 Model Ensemble and WRF Runs

WRF ANN Percent Change

CMIP5 ANN Percent Change





(Future – Current)/Current x 100 (%)

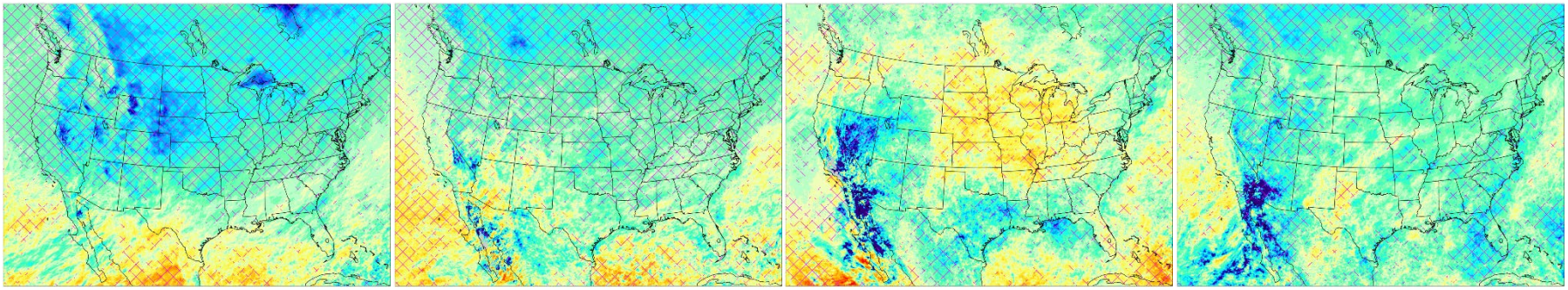
DJF

MAM

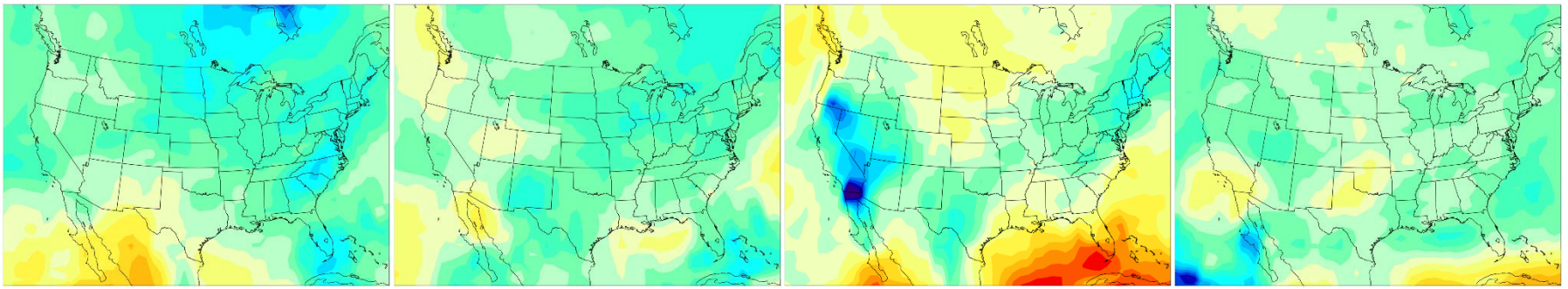
JJA

SON

WRF

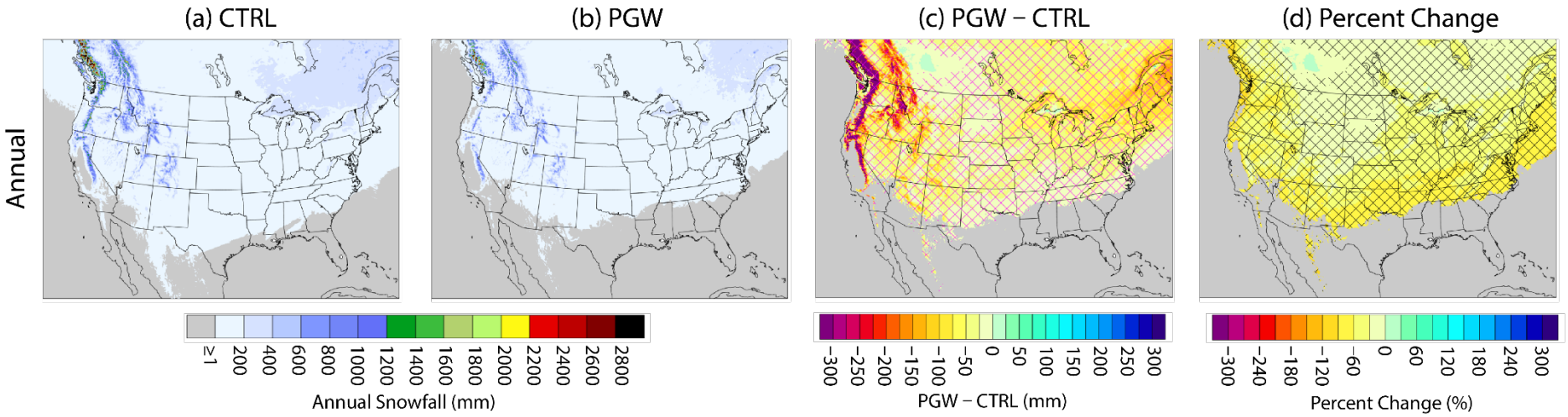


CMIP5

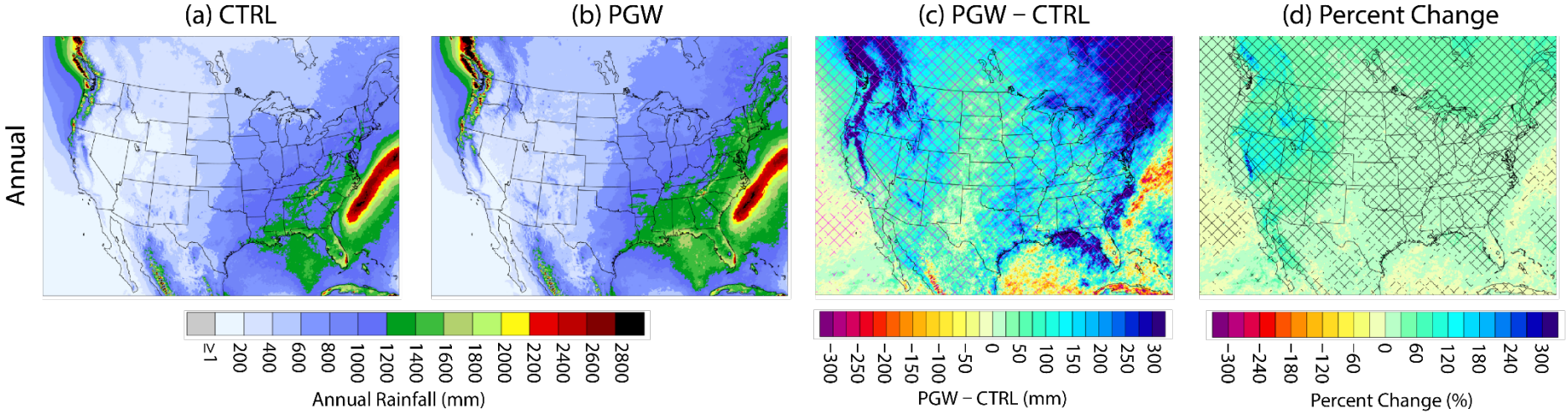


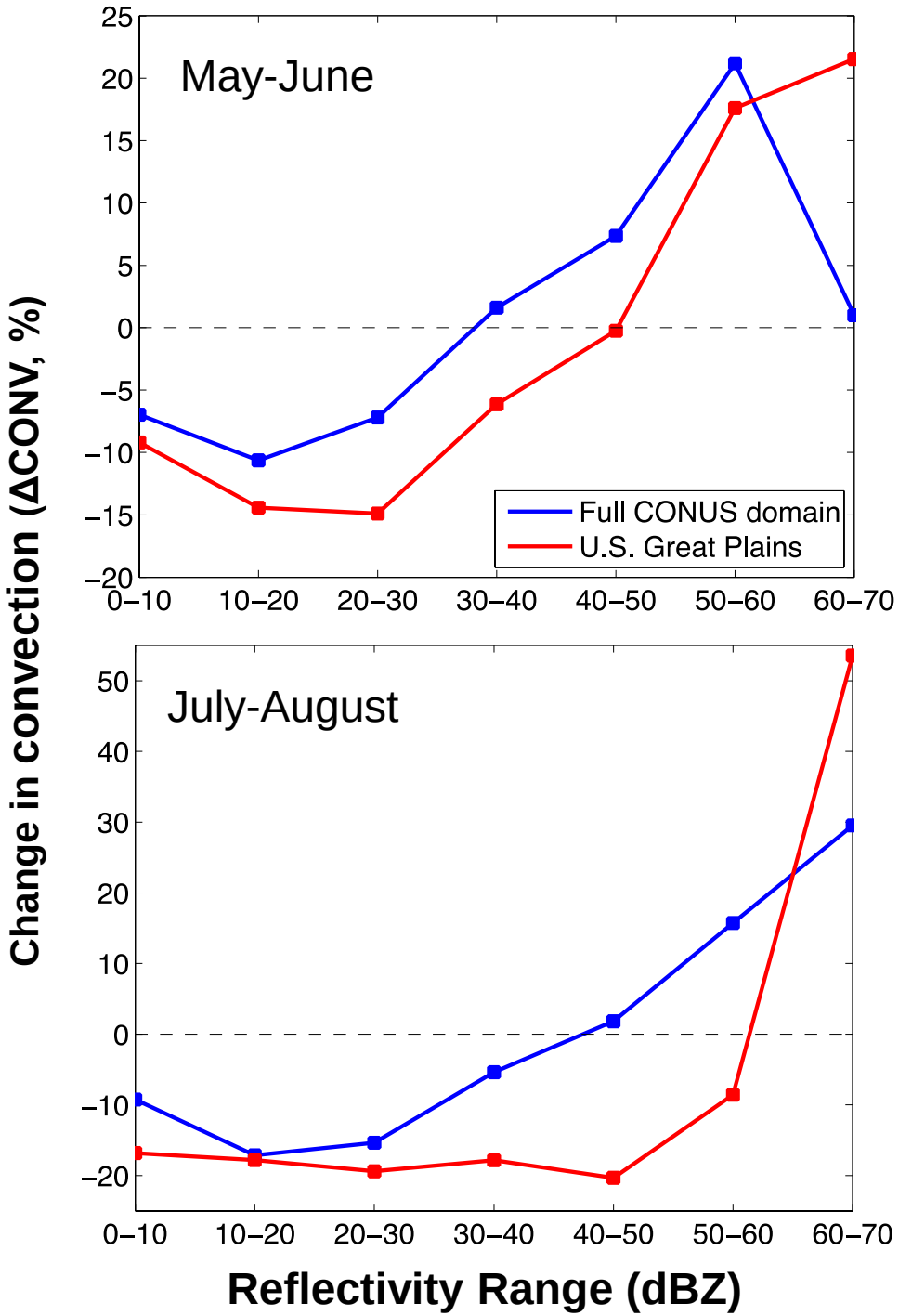
** hatched areas in the WRF results represent statistically significant change at the 0.95 confidence level from the t-test.*

13-year average annual snow



13-year average annual rain





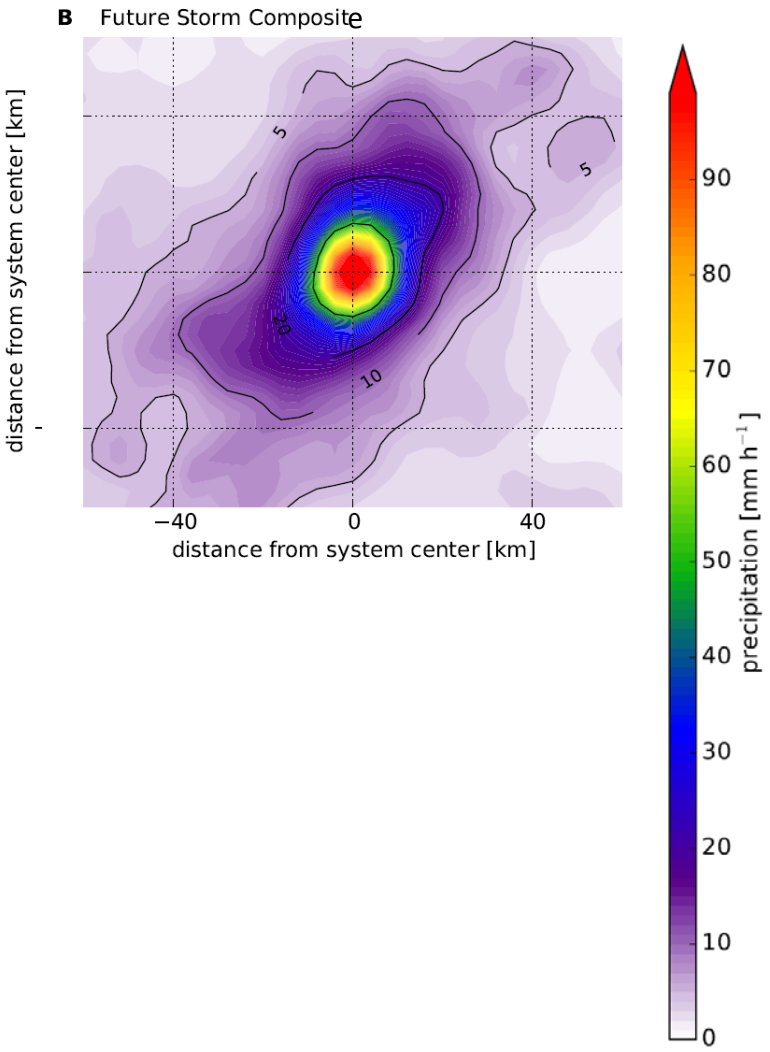
Changes in Convective Population (PGW-CTRL)

- **weak to moderate convection decreases**
- **strong convection increases**

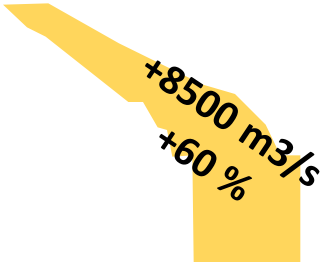
K. Rasmussen et al (2017): Changes in the convective population and thermodynamic environments in convection-permitting regional climate simulations over the United States. *Climate Dynamics* (in revision).

Storm total precipitation – Mid Atlantic

Prein et al (2017): Increasing rainfall volume from future severe convective storms. *Nature* (in review).



MCSs are larger and more intense, raising flood potential to unexpected level



Snowpack percentage difference (PGW-CTRL)

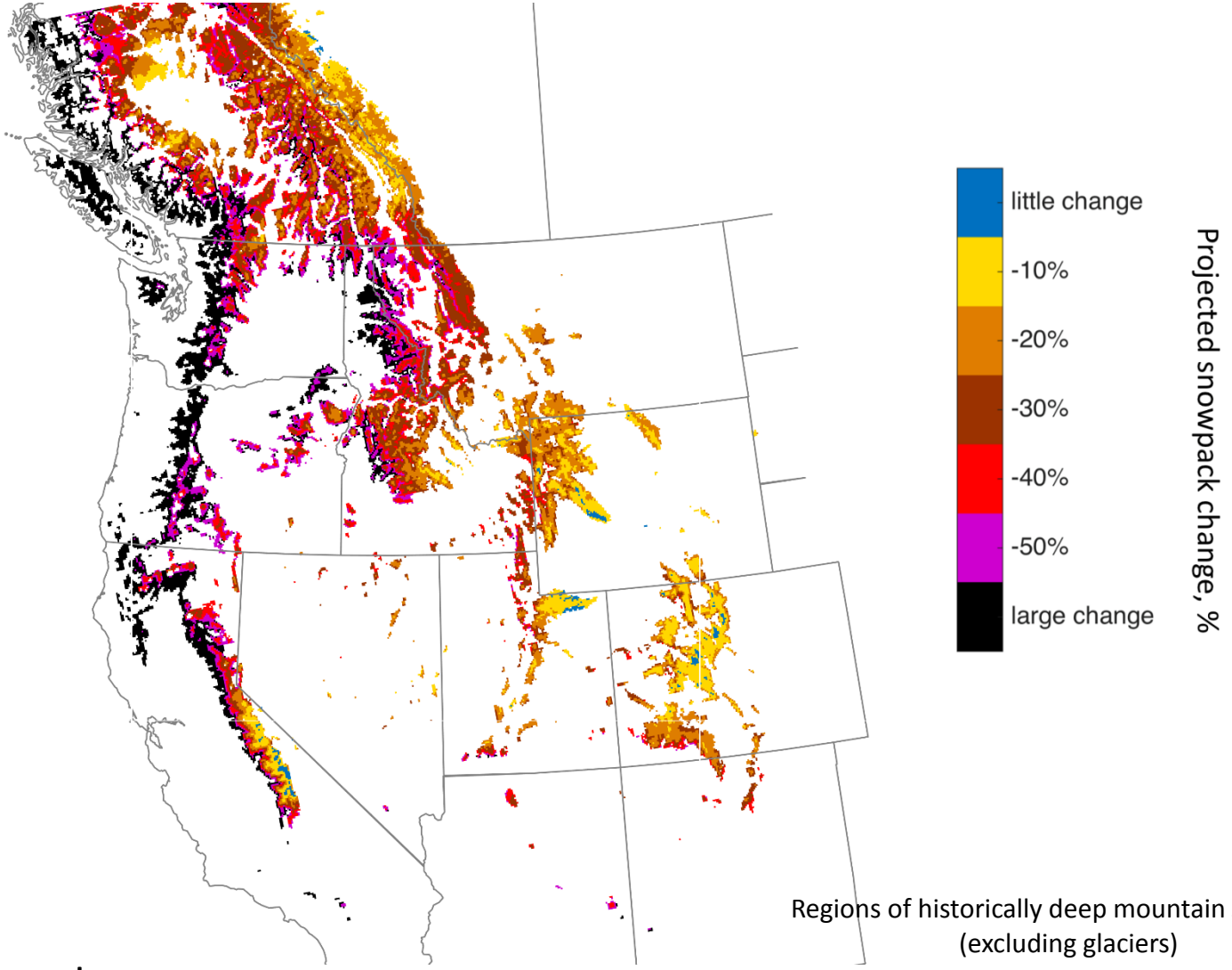
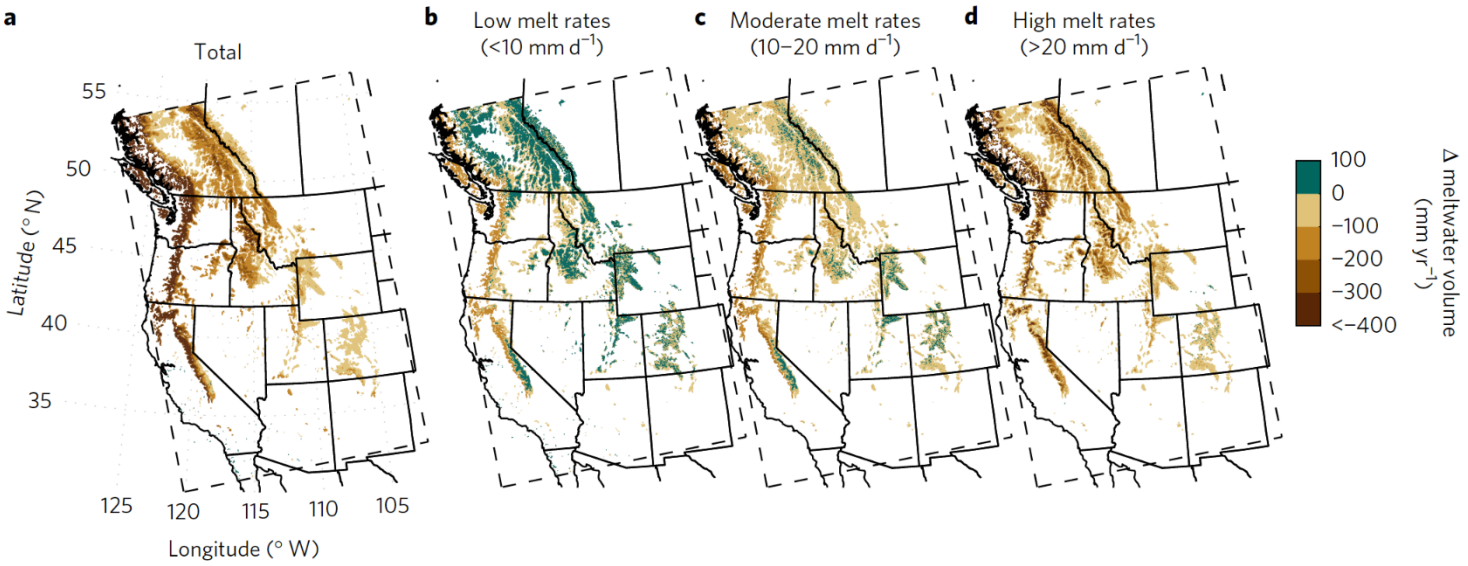


Figure by K.N. Musselman
(unpublished)

Snow meltwater difference (PGW-CTRL)

K. Musselman et al (2017) Slower snowmelt in a warmer world. *Nature Climate Change*.



- Widespread reduction of annual snow meltwater
  - Small regional increases in low snowmelt rates
  - Large reduction in high snowmelt rates
- A tendency for slower snowmelt in a warmer world
  - Contraction of the melt season to a time of lower available energy

Summary (1)

- Retrospective simulation
  - Captured seasonal/annual precipitation and temperature well.
  - Produced a summer dry/warm bias in central U.S.
  - Under-predicted winter-spring precipitation in Deep South.
- Pseudo-global warming simulation
  - Seasonal precipitation increases, except for the drier summer in the Midwest.
  - Convection and MCSs are more intense, raising future flood risk.
  - Snowpack becomes shallower and melts at lower rates.

Summary (2)

- Ongoing simulations
  - A novel approach for constructing WRF forcing data.
  - Useful for assessing the impact of storm track changes.
- On going studies
  - A number of journal papers are in print/preparation using the retrospective and PGW simulation results.
  - Collaborative studies with universities and other research institutions (national and international) are currently being carried out.
- Data management
  - Retrospective and PGW simulation data will be available online via NCAR's Research Data Archive website @ https://rda.ucar.edu/ in June 2017.
  - Contact rasmus@ucar.edu or kyoko@ucar.edu for more information.

Acknowledgments

This work was made possible by NCAR Computational and Information Systems Laboratory's support on Yellowstone and their NCAR Strategic Capability allocation, sponsored by the National Science Foundation.

Ongoing Experiments

- **EXP3**: CESM-based historical period *(2000-2009)* simulation

$$\mathbf{WRF_{input} = CESM' + \overline{ERA\text{-}I}_{1976\text{-}2005}}$$

$$\mathbf{(CCSM' = CCSM - \overline{CCSM}_{1976\text{-}2005})}$$

- **EXP4**: CESM-based future period *(2090-2099*) simulation

$$\mathbf{WRF_{input} = CESM' + \overline{ERA\text{-}I}_{1976\text{-}2005} + (\overline{CMIP5}_{2071\text{-}2100} - \overline{CMIP5}_{1976\text{-}2005})}$$

$$\mathbf{(CESM' = CESM - \overline{CESM}_{2071\text{-}2100})}$$

Difference between New and Traditional Method: Climate Change Estimate

Traditional Method:

$$WRF_{input} = CESM' + \overline{ERA\text{-}I}_{1976\text{-}2005} + (\overline{CESM}_{2071\text{-}2100} - \overline{CESM}_{1976\text{-}2005})$$

New Method:

$$WRF_{input} = CESM' + \overline{ERA\text{-}I}_{1976\text{-}2005} + (\overline{CMIP5}_{2071\text{-}2100} - \overline{CMIP5}_{1976\text{-}2005})$$

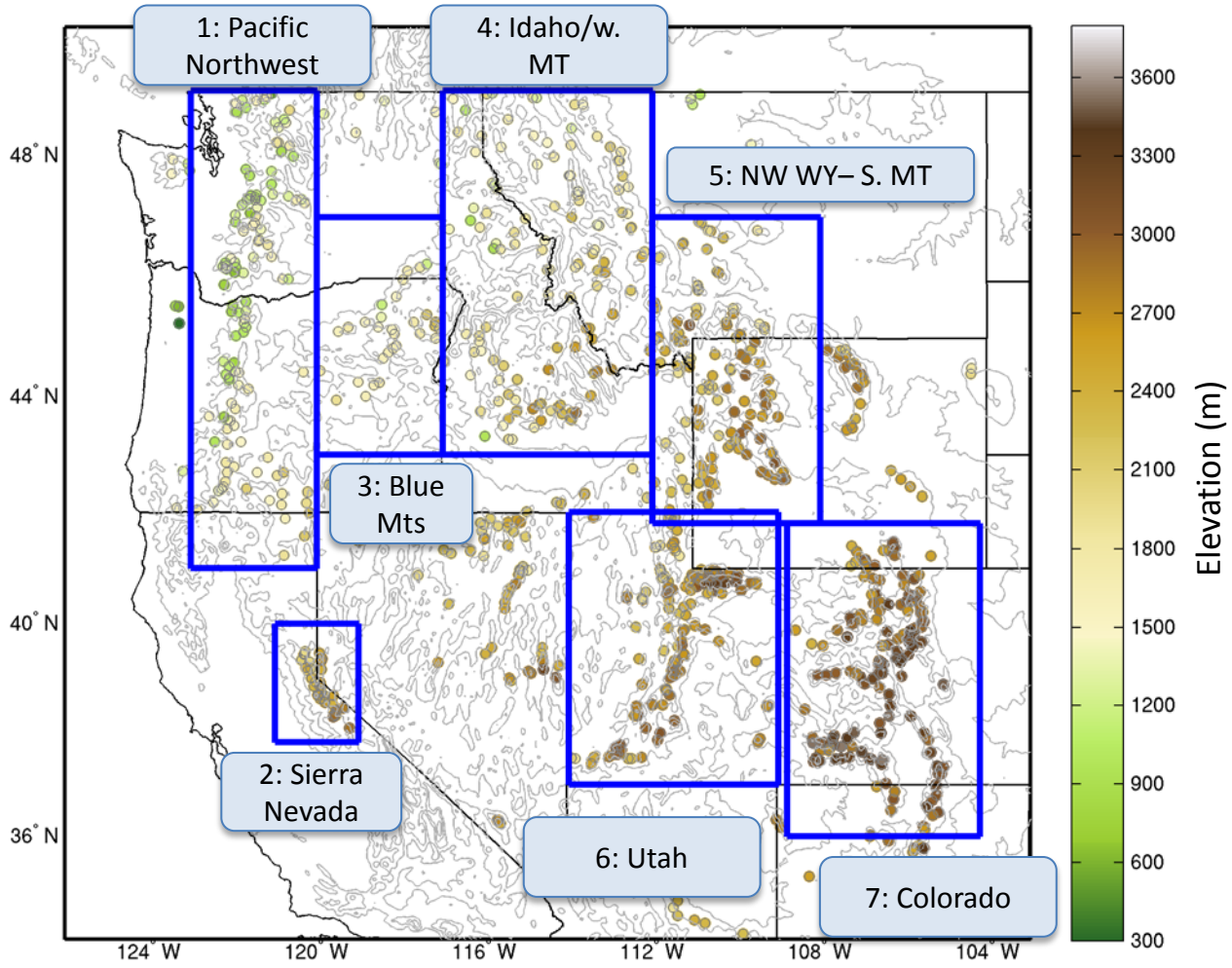
$$CESM' = CESM - \overline{CESM}_{2071\text{-}2100}$$

Model Evaluation at SNOTEL Sites

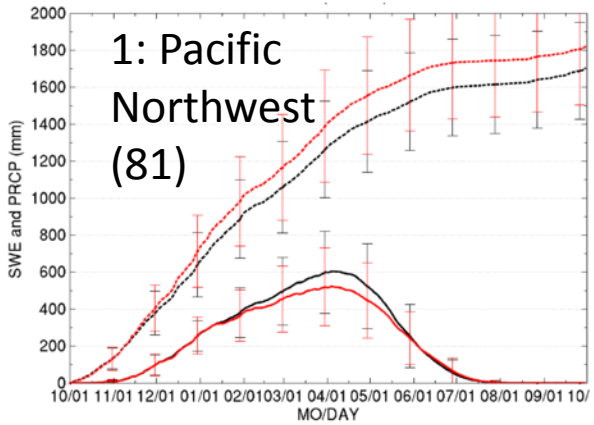
SNOTEL site at Brooklyn Lake, WY

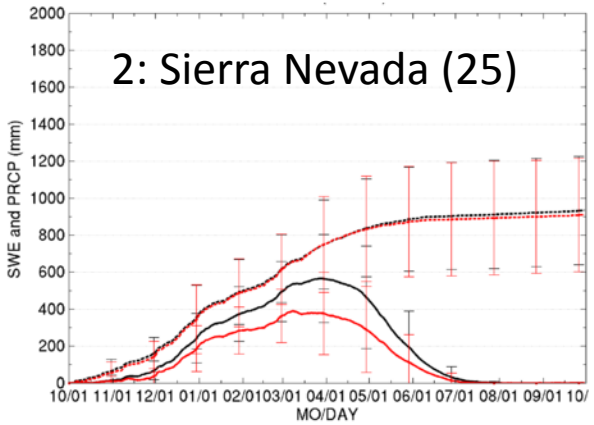
Snow gauge

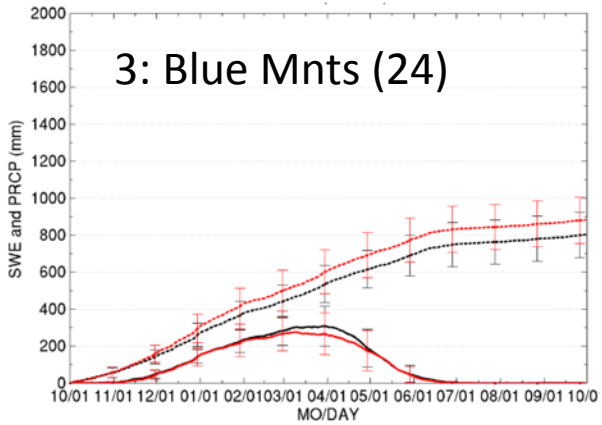
Snow pillow

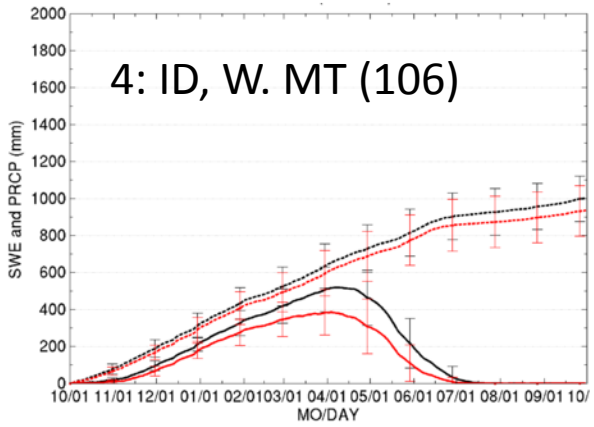


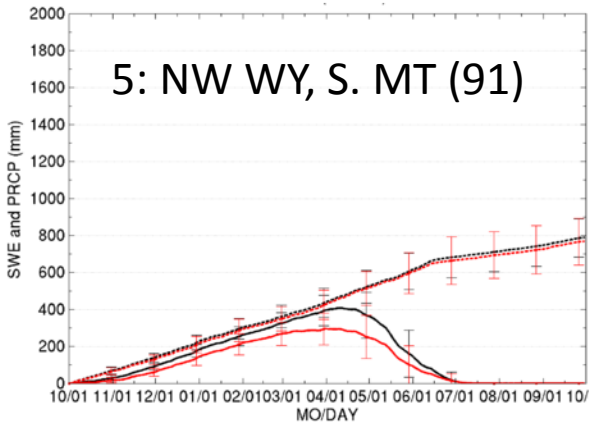
SNOTEL vs WRF at SNOTEL sites: 13-year climatology

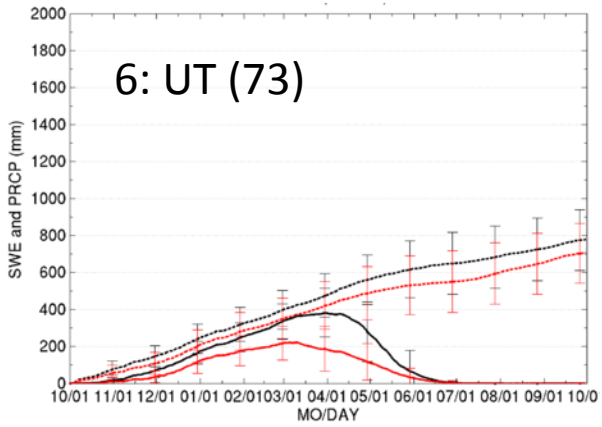


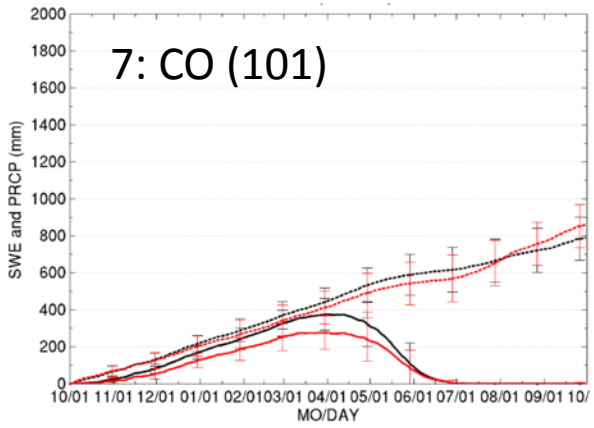


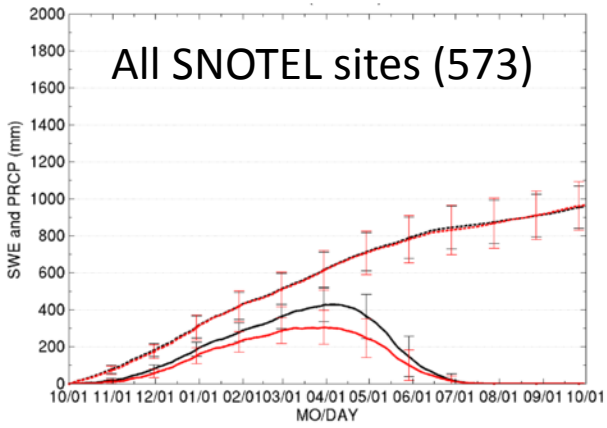


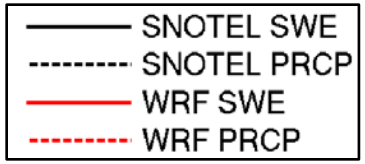






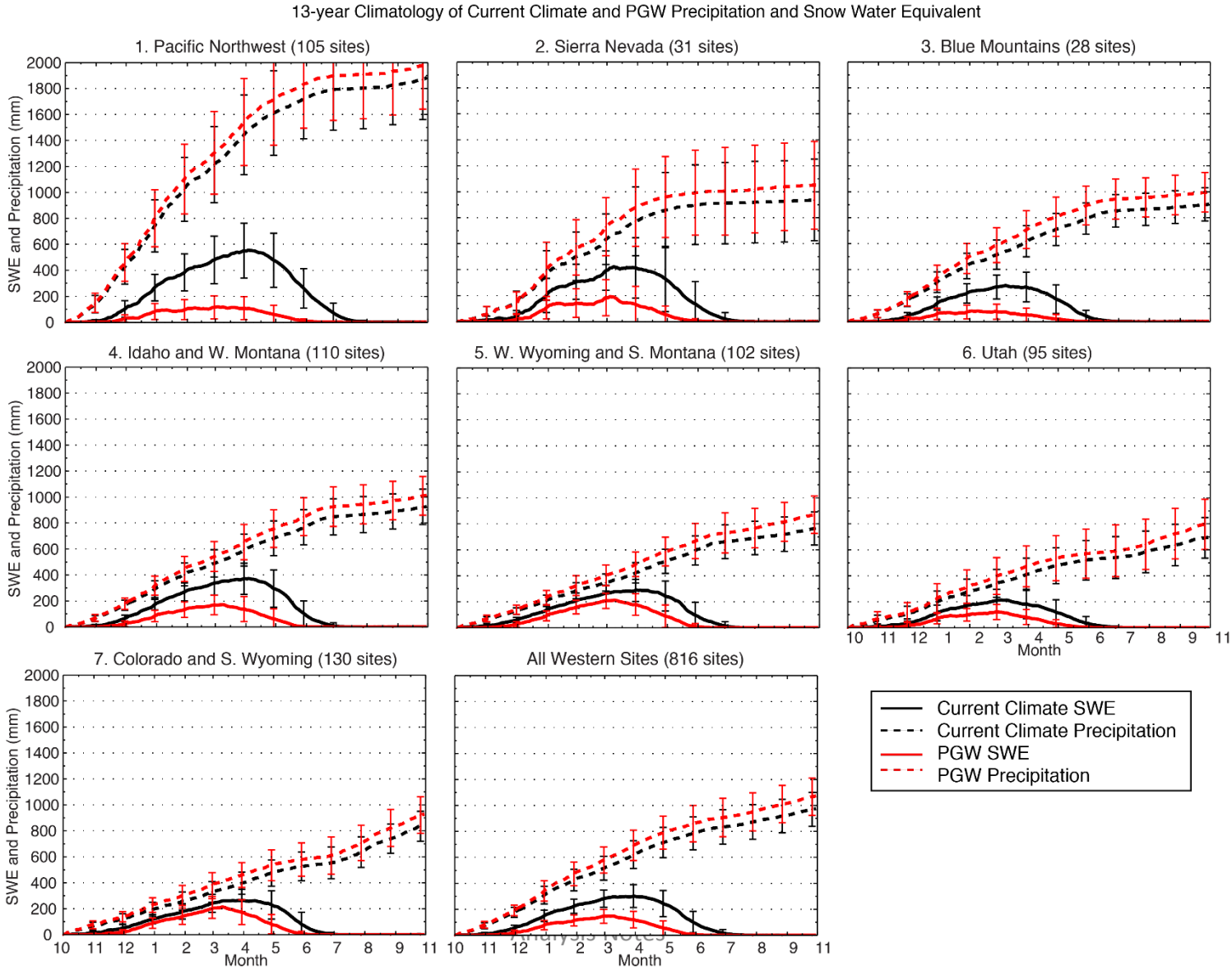




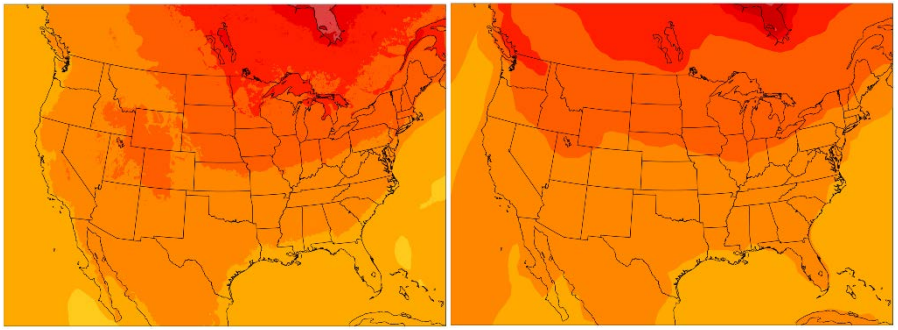


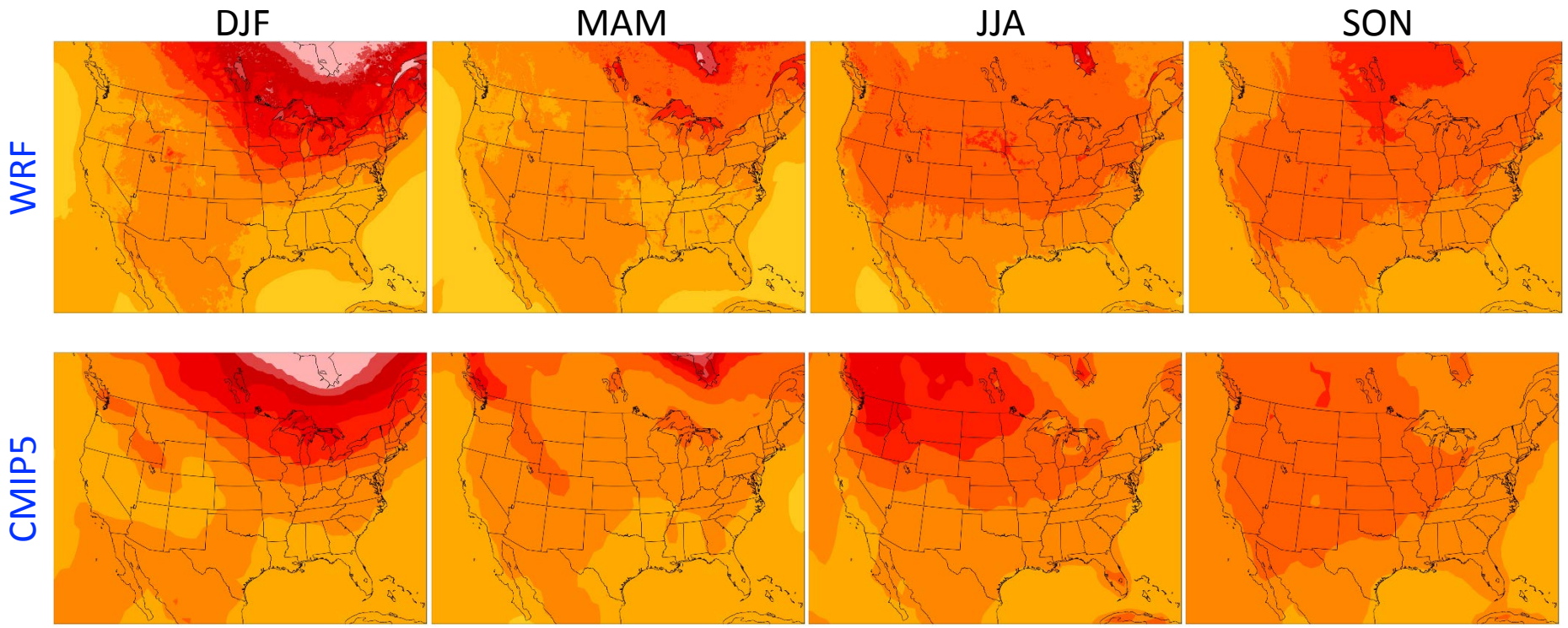
PRCP: -9% – +10%
SWE : -43% – -11%

Precipitation and SWE at SNOTEL sites over sub-regions

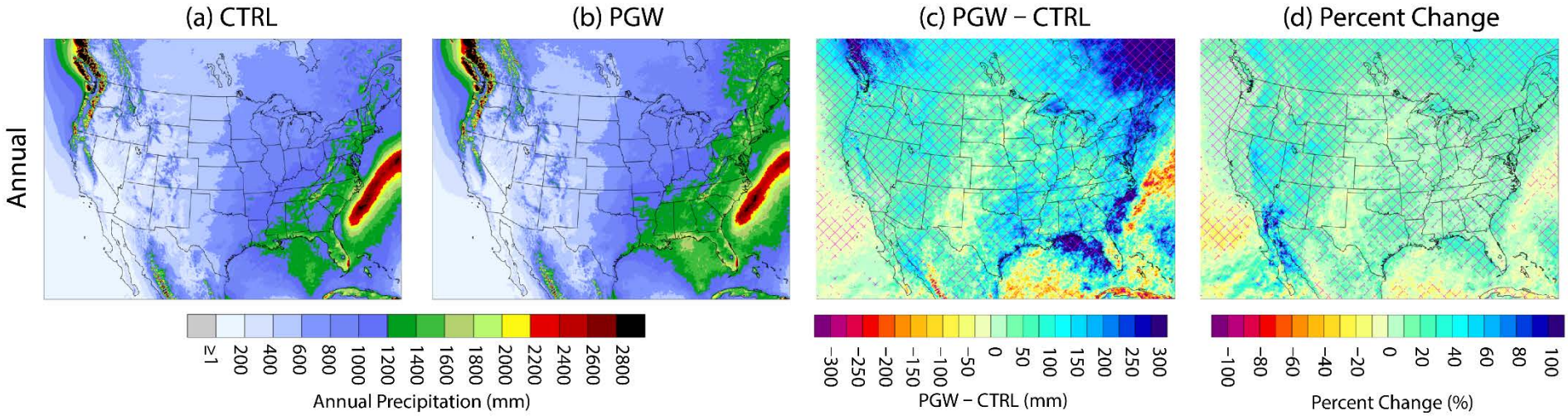


Average Annual and Seasonal 2-m T Change from 19 CMIP5 Model Ensemble and WRF Runs

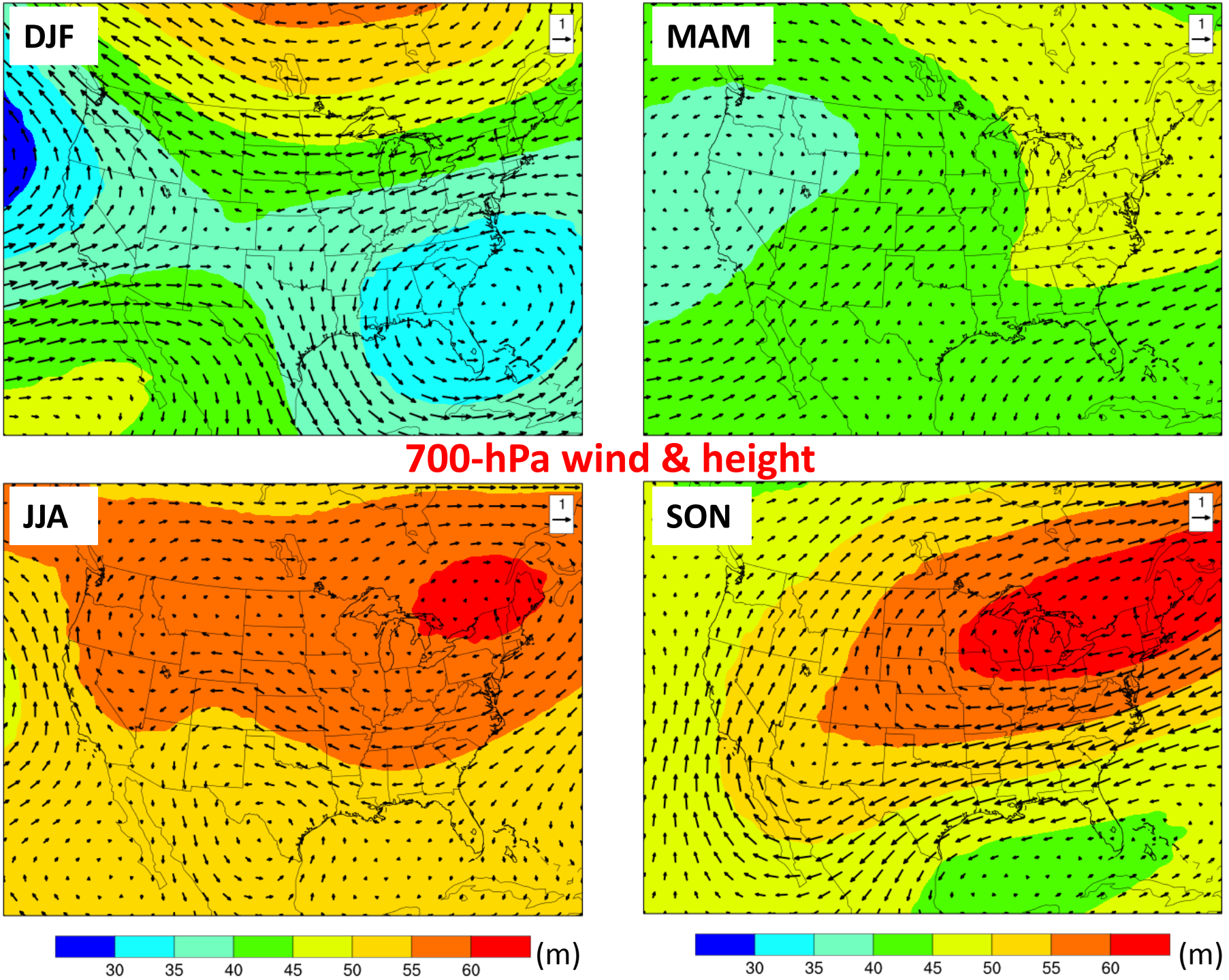


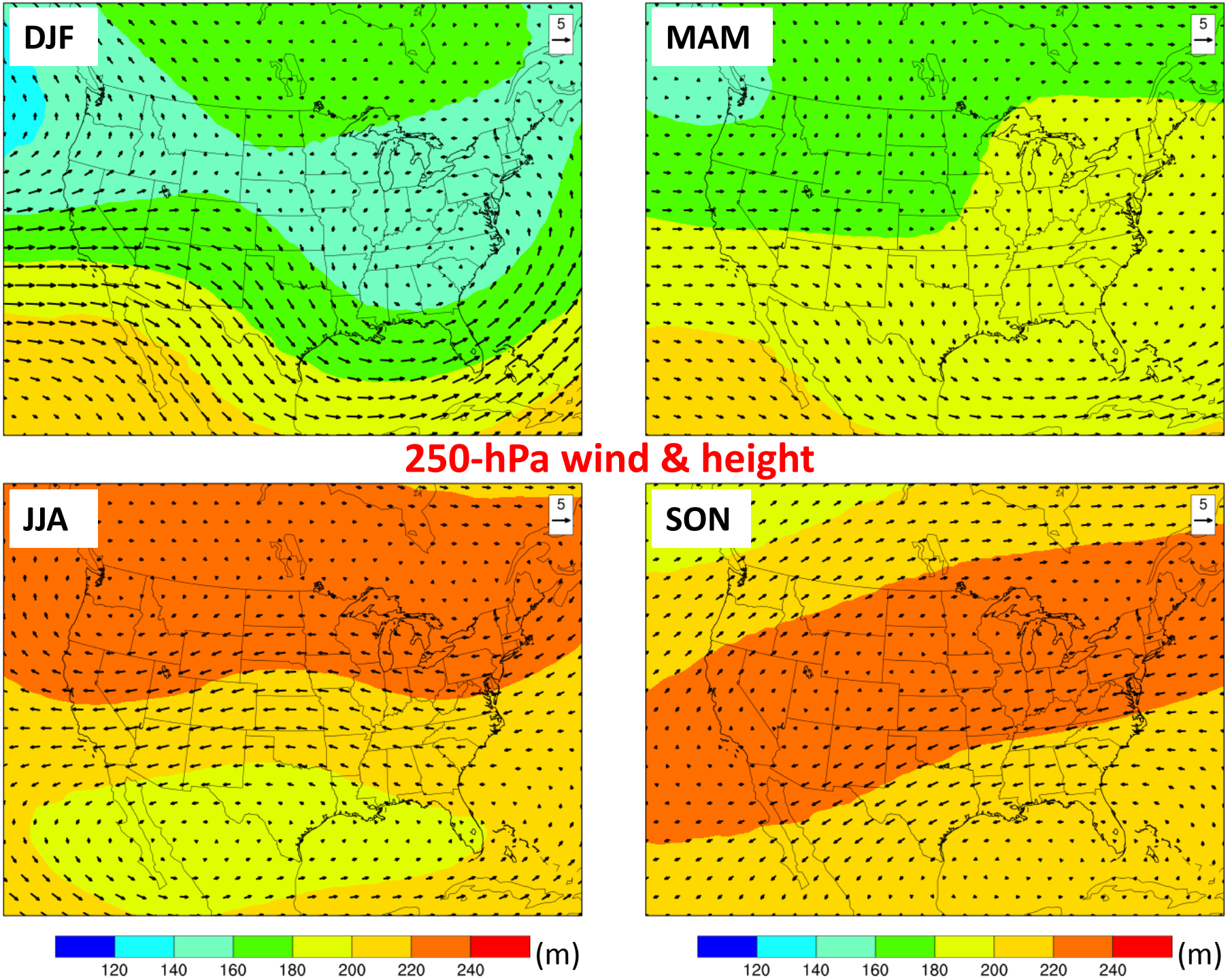


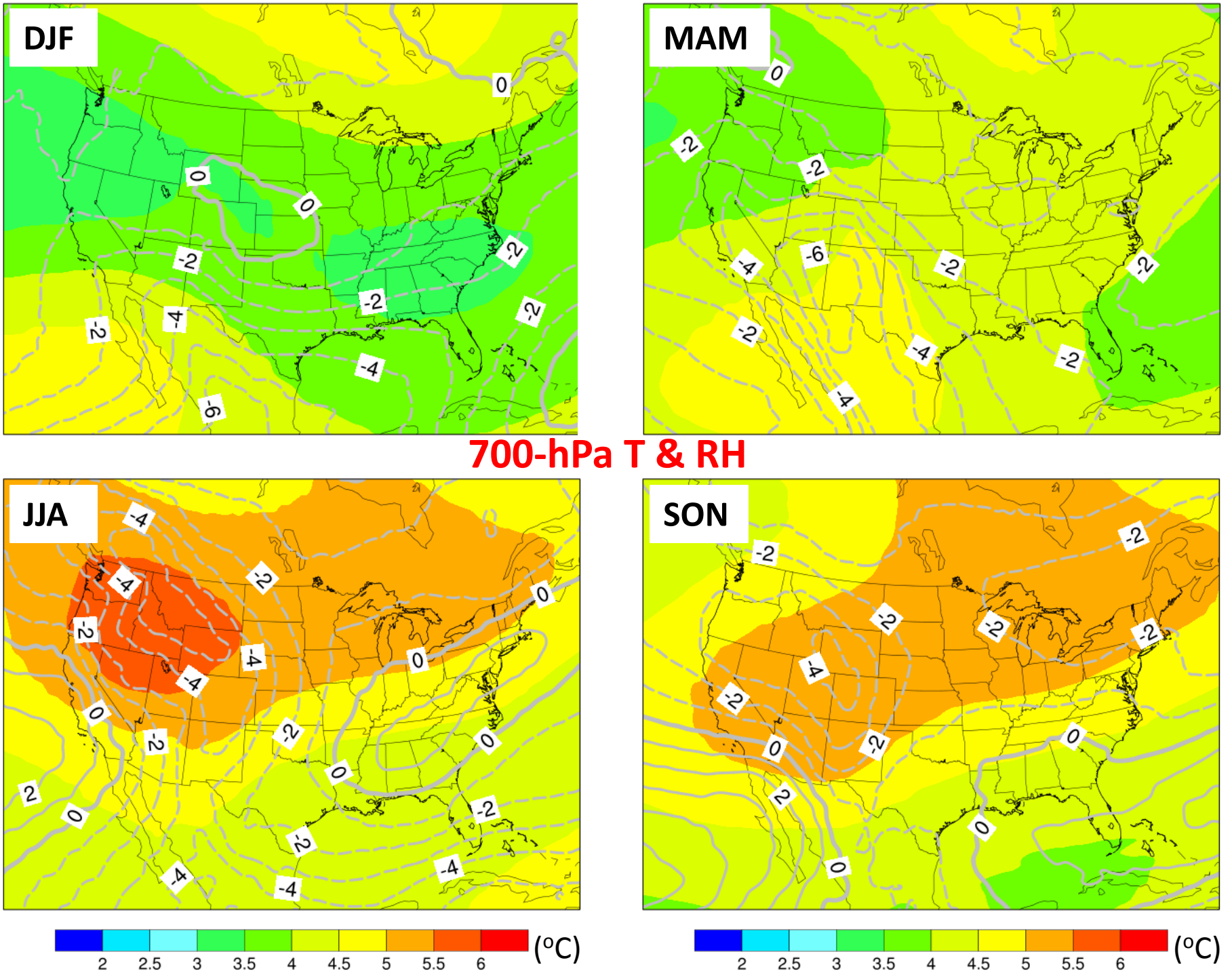
13-year Average Annual Precipitation : CTRL vs PGW

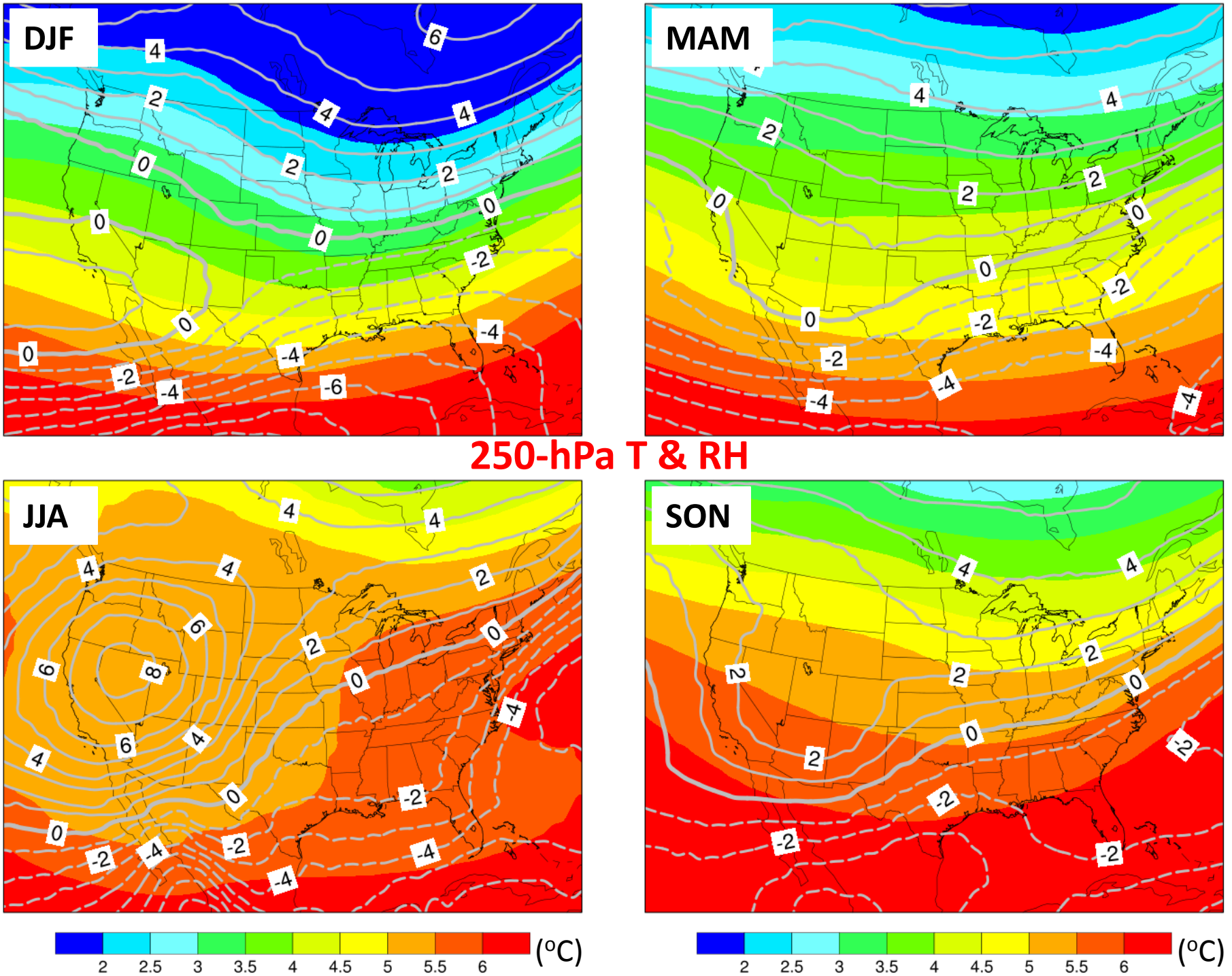


hatched areas represents statistically significant change at the 0.95 confidence level from the t-test.


DJF
MAM
700-hPa wind & height
JJA
SON
30
35
40
45
50
55
60
(m)


DJF
MAM
JJA
SON
5
250-hPa wind & height
120 140 160 180 200 220 240 (m)
120 140 160 180 200 220 240 (m)


DJF
MAM
700-hPa T & RH
JJA
SON
2
2.5
3
3.5
4
4.5
5
5.5
6
(°C)
2
2.5
3
3.5
4
4.5
5
5.5
6
(°C)


DJF
MAM
250-hPa T & RH
JJA
SON
2 2.5 3 3.5 4 4.5 5 5.5 6 (°C)
2 2.5 3 3.5 4 4.5 5 5.5 6 (°C)