High-resolution regional climate simulations of warm season convection in the U. S.

Kristen Lani Rasmussen

Contributions from Roy Rasmussen, Andreas Prein, Changhai Liu, and Kyoko Ikeda

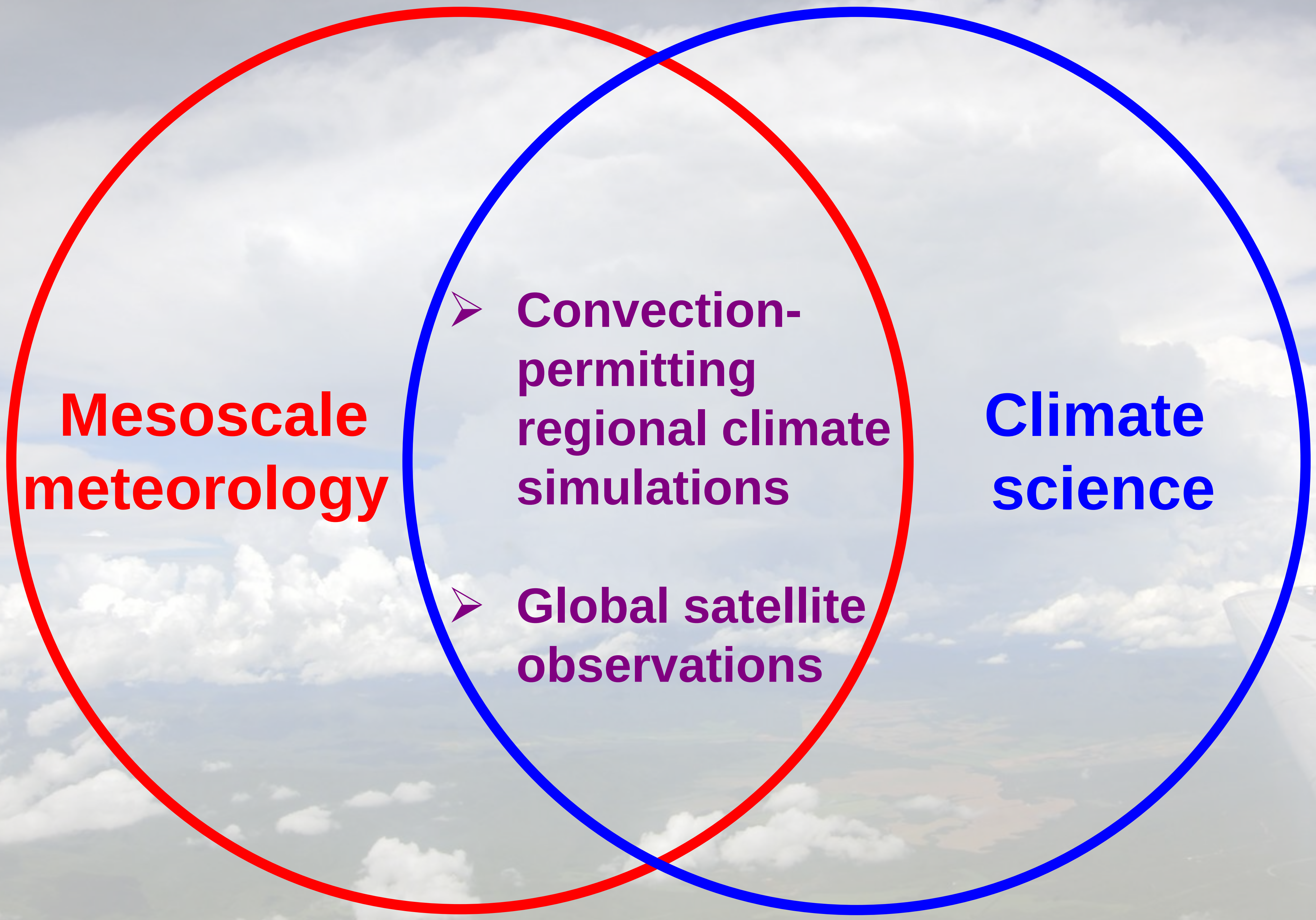
Advanced Study Program
Developing Scientific Leaders of the Future
NCAR
NATIONAL CENTER FOR ATMOSPHERIC RESEARCH

Mesoscale & Microscale Meteorology
MMM
LABORATORY

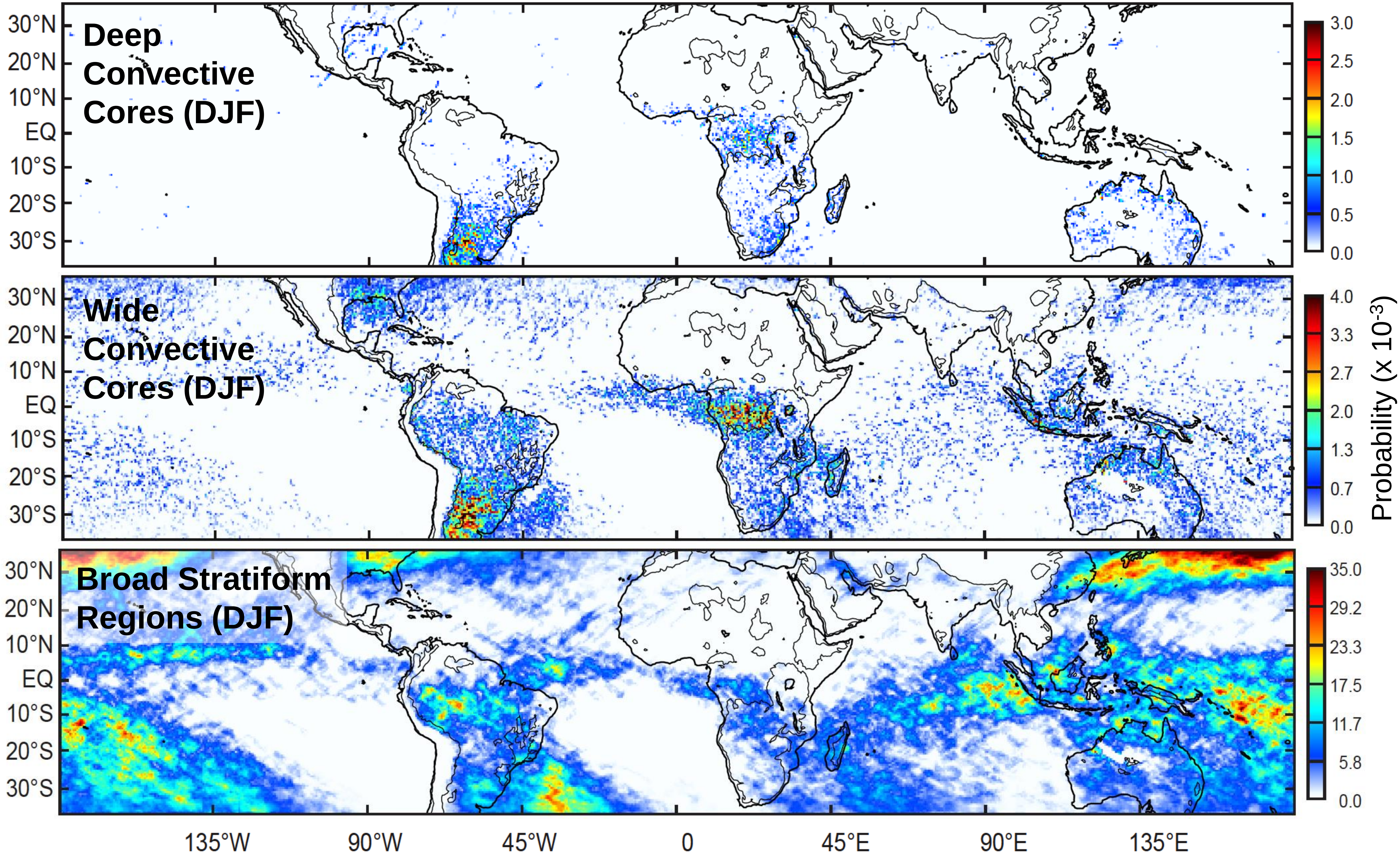
Convection and Climate Motivation

- The ***intersection of weather and climate*** requires improved understanding of clouds and mesoscale processes
- A fundamental understanding of the ***global*** nature of clouds and their ***physical processes*** is imperative for understanding global weather and climate

Convection and Climate Motivation



Nature of global convective systems



Houze, Rasmussen, Zuluaga, and Brodzik (2015), *Reviews of Geophysics*

Accurately representing convection and precipitation in a *future climate* requires high resolution simulations at convection and terrain-resolving scales

- → **Pseudo-Global Warming (PGW) approach**
  (Schar et al. 1996; Sato et al. 2007; Hara et al. 2008; Kawase et al. 2009; Rasmussen et al. 2011; Liu et al. 2016)

- → This approach was used to study the Colorado headwaters region (Rasmussen et al. 2011) and was recently expanded to the entire contiguous United States (Liu et al. 2016) by a large team at NCAR/RAL/MMM

CONUS Project Team at NCAR

Project Lead	Roy Rasmussen	NCAR/RAL
Experiment Designing and WRF Modeling	Changhai Liu	NCAR/RAL
	Jimy Dudhia	NCAR/MMM
	Liang Chen, Sopan Kurkute	University of Saskachewan
Data Analysis and Management	Kyoko Ikeda, Changhai Liu, Andreas Prein, Andrew Newman, Aiguo Dai, Kristen Rasmussen	NCAR/RAL, NCAR/MMM
Microphysics	Greg Thompson	NCAR/RAL
Land surface modeling	Fei Chen, Mike Barlage	NCAR/RAL
Hydrology modeling	David Gochis	NCAR/RAL
Snow Physics	Martyn Clark	NCAR/RAL
Dynamical Downscaling	Ethan Gutmann	NCAR/RAL
Social Impacts	Dave Yates	NCAR/RAL

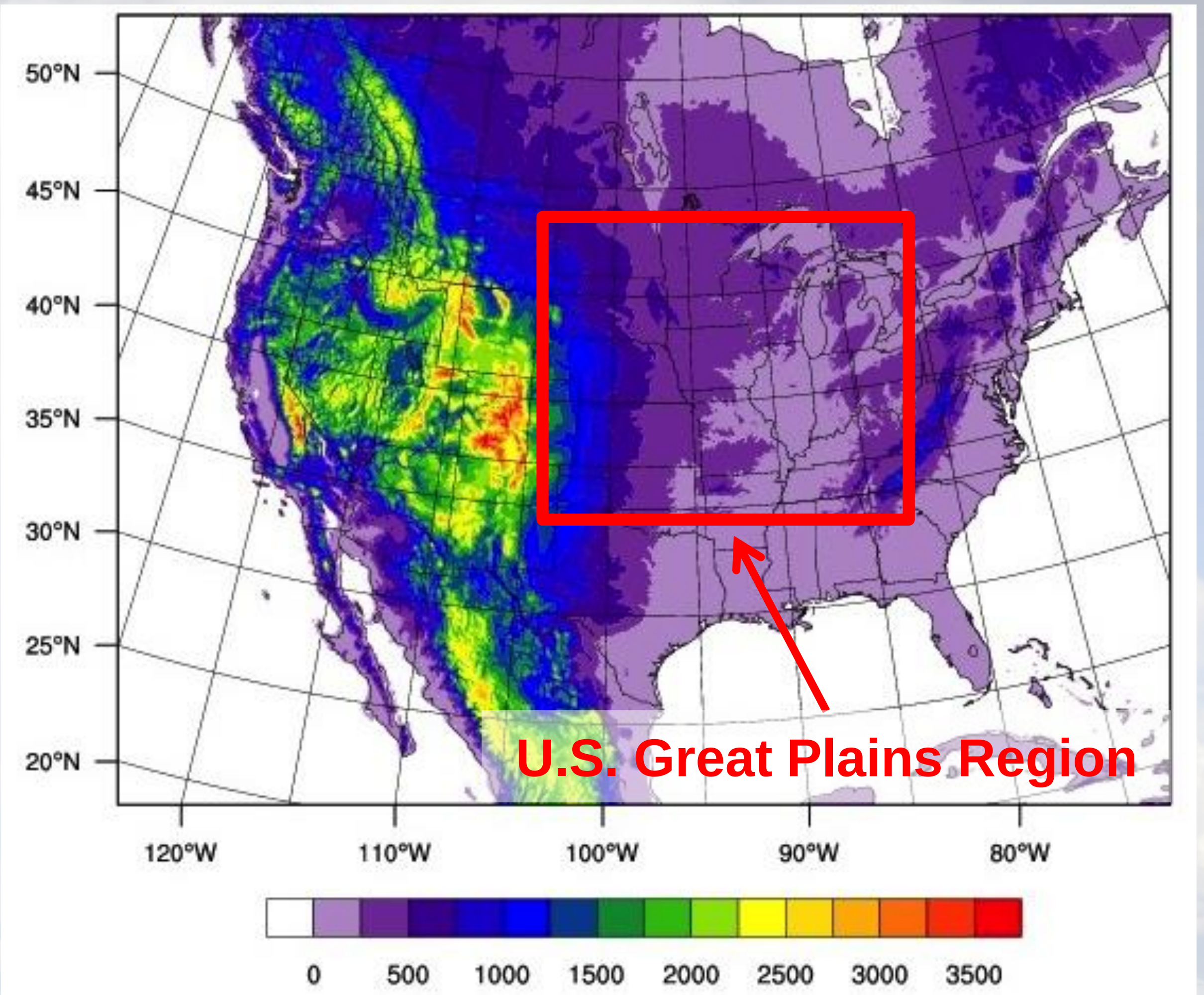
CONUS = Contiguous U.S.

WRF CONUS Experiment Setup

- V3.4.1 WRF model with a 4-km-spacing domain of ***1360****x****1016****x****51*** points
- Physics parameterizations:
  1. Thompson aerosol-aware microphysics
  2. Noah-MP LSM
  3. YSU PBL
  4. RRTMG radiation
- Use of spectral nudging
- Novel methodology for devising forcing from CMIP5 projections

  - CMIP5 19 model ensemble mean climate

WRF Model Domain



Elevation (m)

Pseudo Global Warming (PGW) Approach

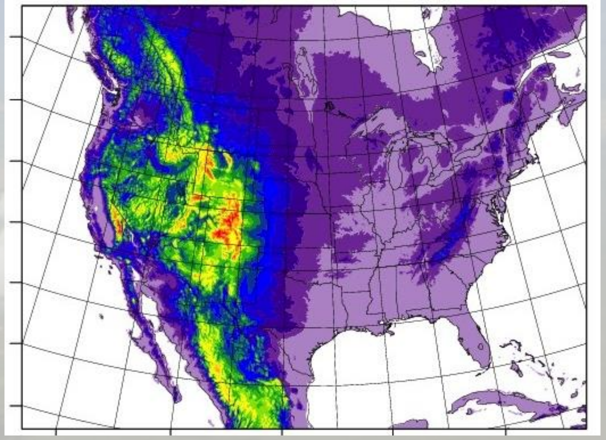
- Compute 30-year CMIP5 19 model ensemble monthly mean
  - Historical period : *1976-2005* Future period (RCP8.5): *2071-2100*
- Compute perturbation – difference between two climates
- Add perturbation to the 6-hourly ERA-I data

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



WRF MODEL

- No change in storm tracks

  Same transient spectra

CONUS Project Numerical Experiments

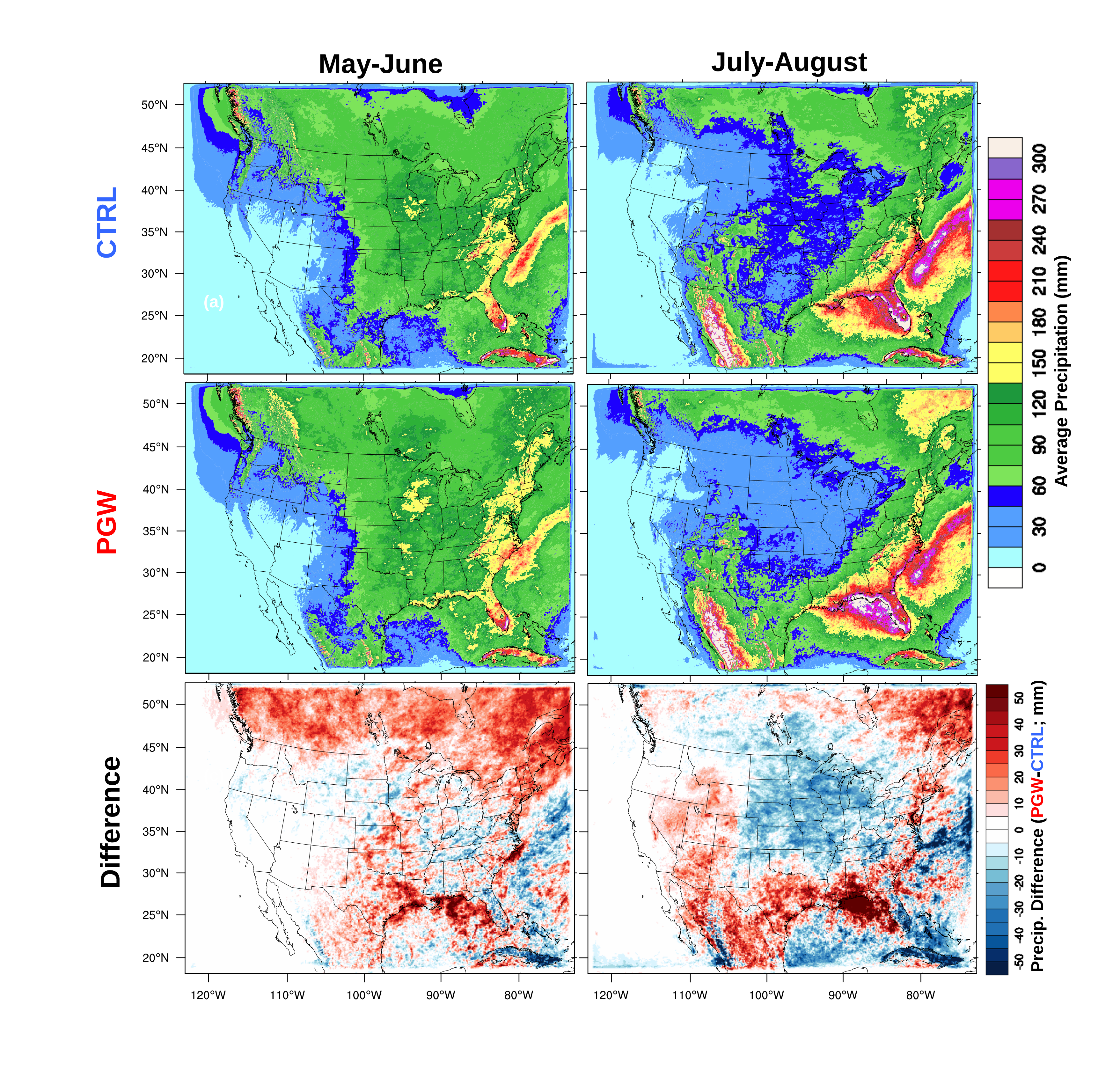
- **EXP1: Retrospective/Control (CTRL) simulation**
  - forced with ERA-I reanalysis
  - 13-year continuous integration:
    Oct. 1 2000 – Oct. 1 2013

- **EXP2: Pseudo-Global Warming (PGW) simulation**
  - forced with ERA-I plus climate perturbation
  - $D_{RCP8.5} = CMIP5_{2071-2100} – CMIP5_{1976-2005}$
  - 13-year continuous integration

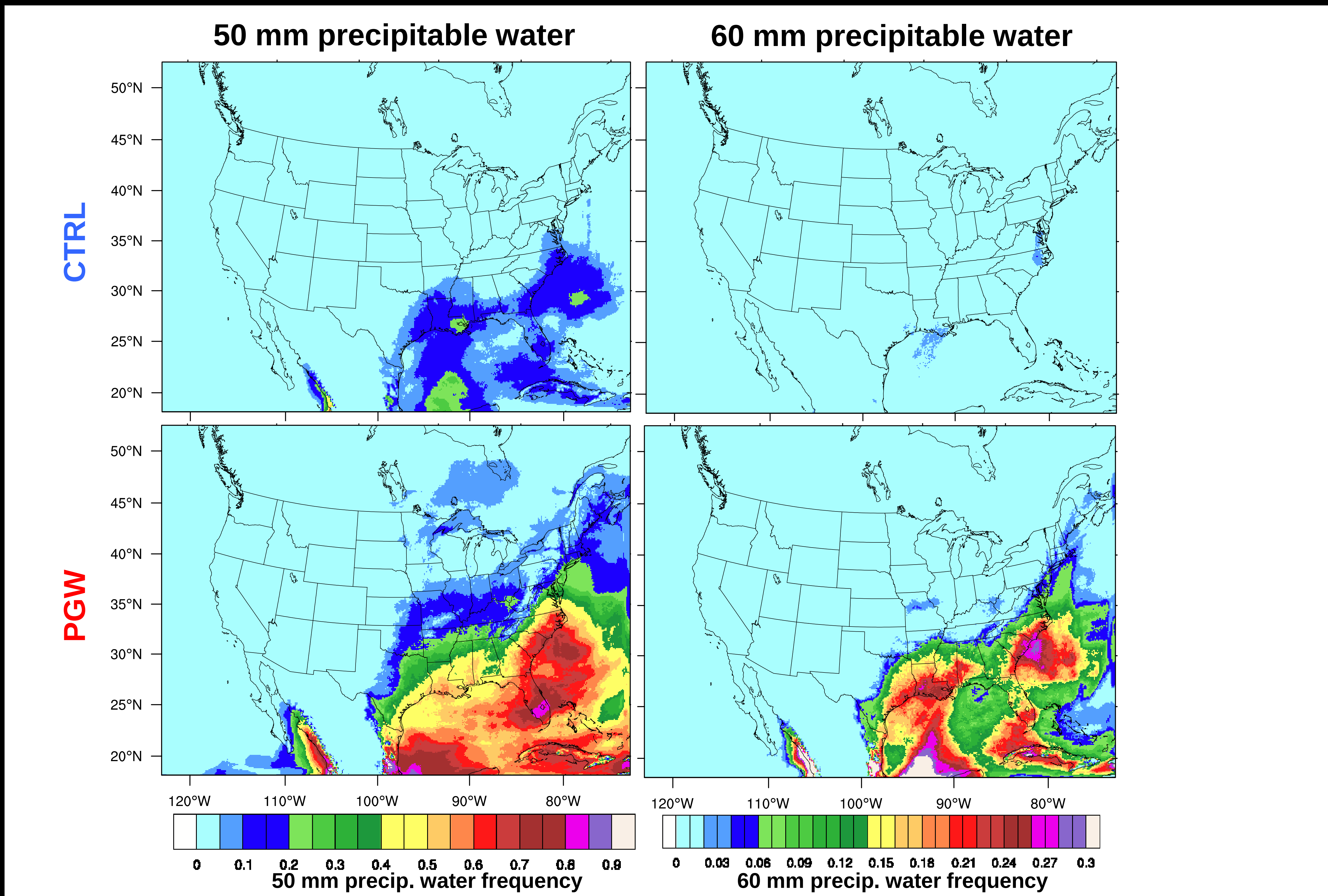
Liu et al. (2016)

How does precipitation and atmospheric moisture change in a future climate?

Average precipitation



Precipitable water frequency



How does the convective population change in a future climate?

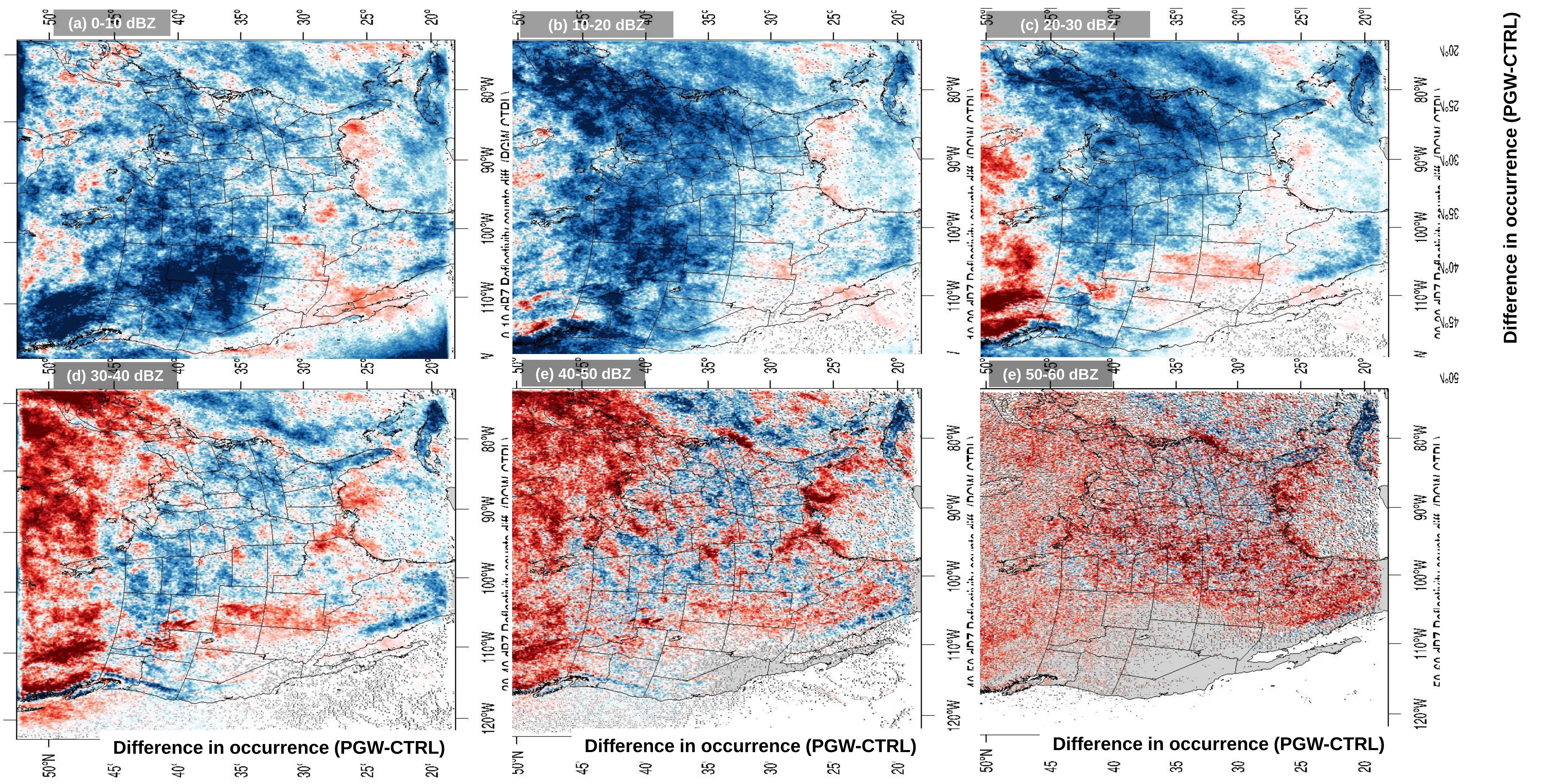
Changes in the convective population

Methodology:

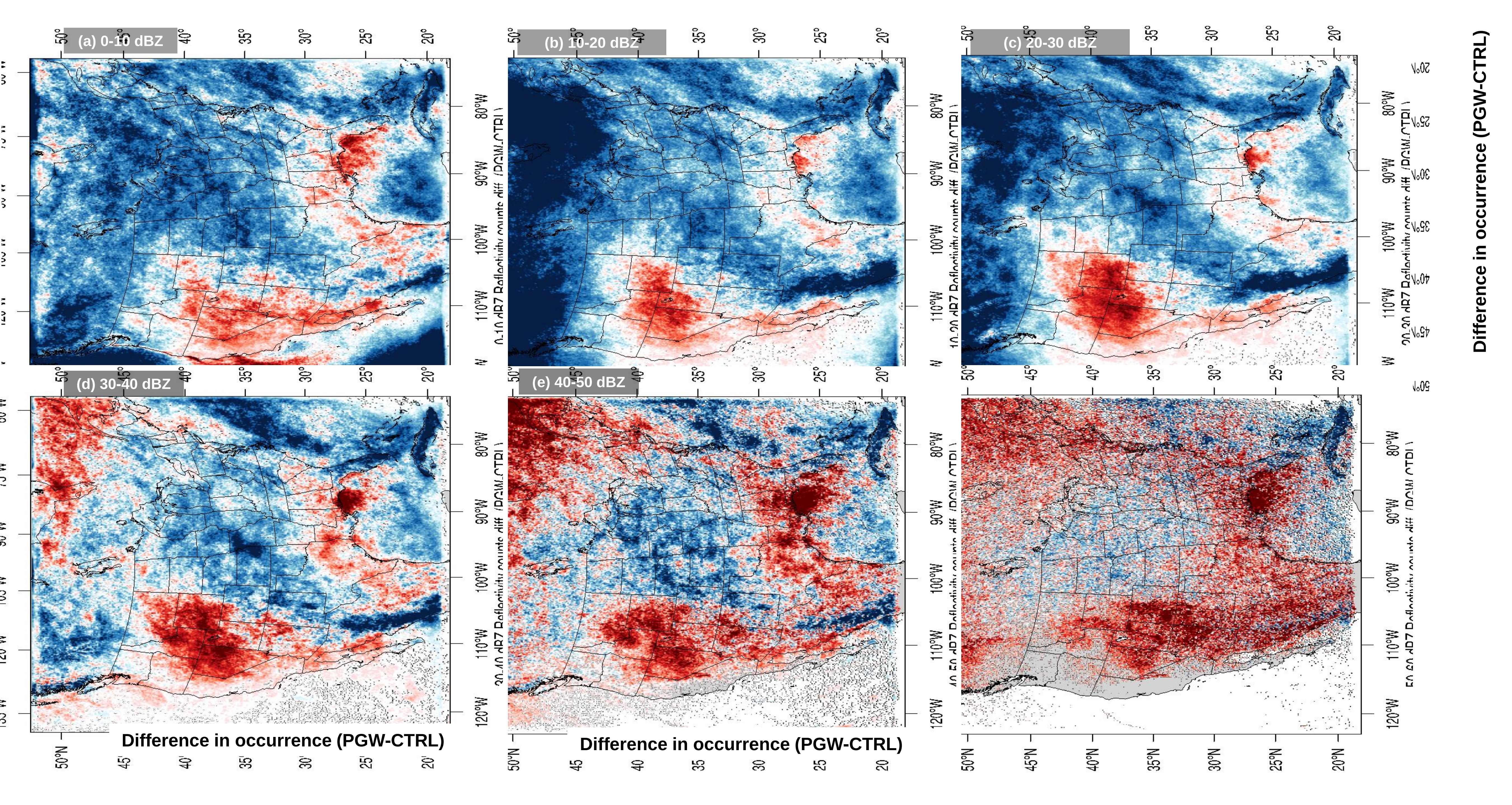
- Use the WRF PGW experiment hourly output (CTRL and PGW runs) to calculate the frequency of occurrence within six reflectivity ranges

- Compare the convective populations by taking the difference (PGW-CTRL)

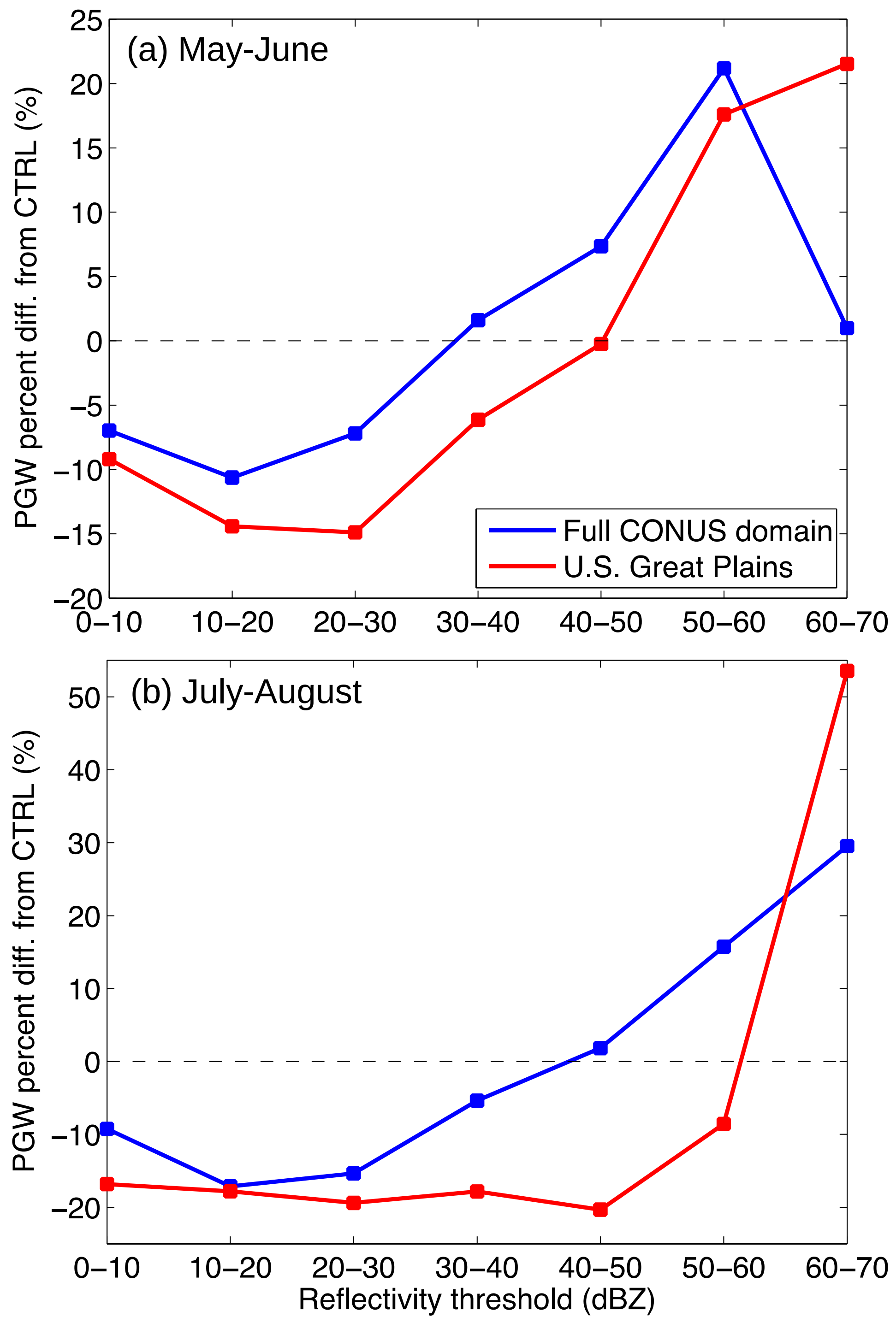
Changes in the convective population (MJ)



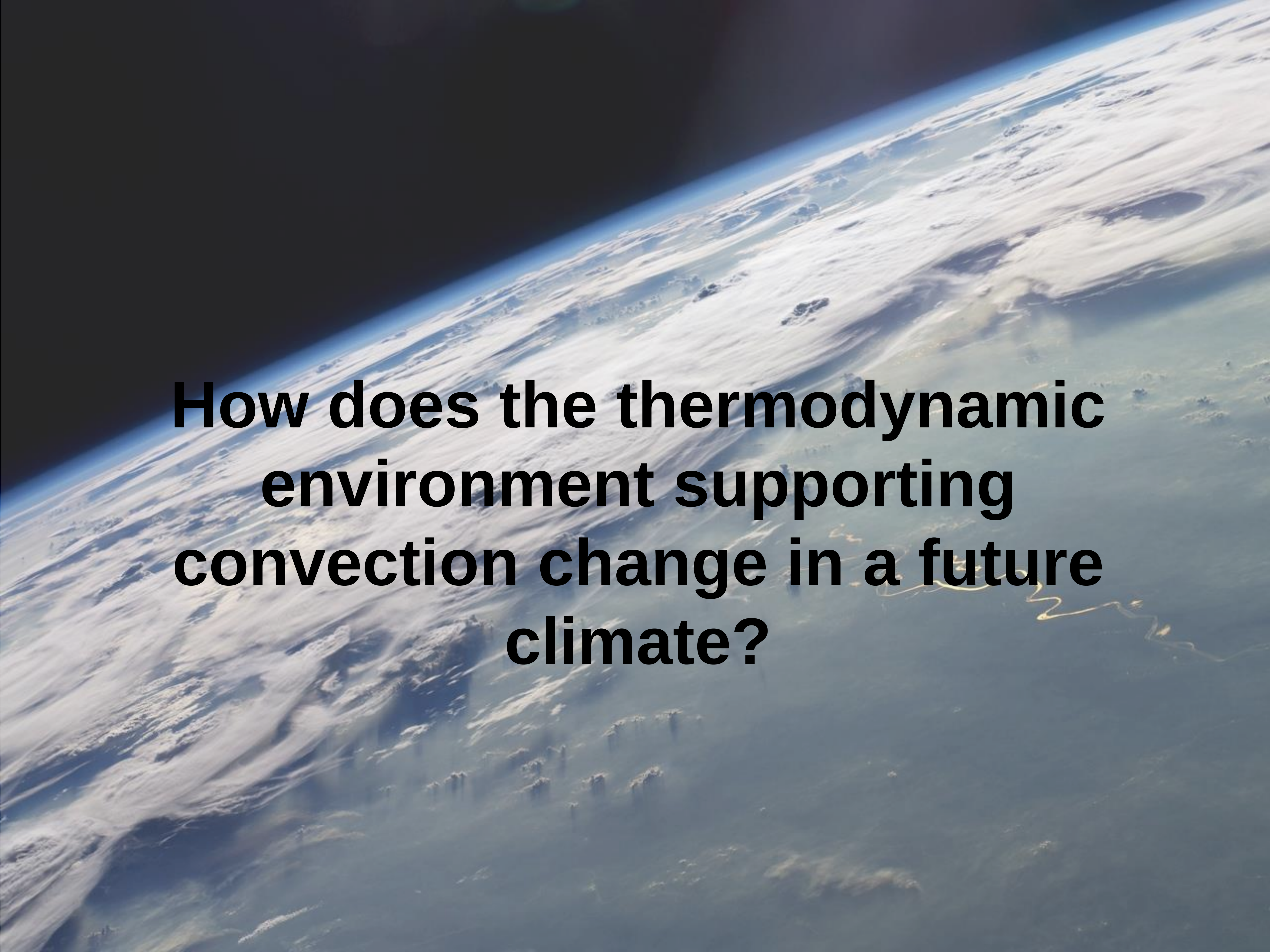
Changes in the convective population (JA)



Changes in the convective population

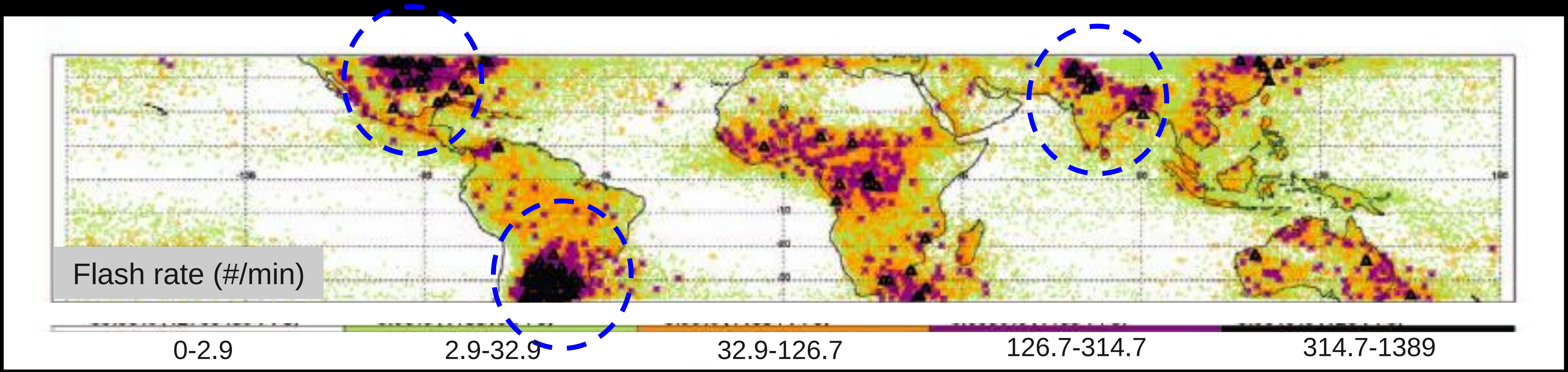


- **Reduced frequency of low reflectivity ranges**
- **Increased frequency of high reflectivity ranges**
- **Indicates changes in the convective population in a future climate**



How does the thermodynamic environment supporting convection change in a future climate?

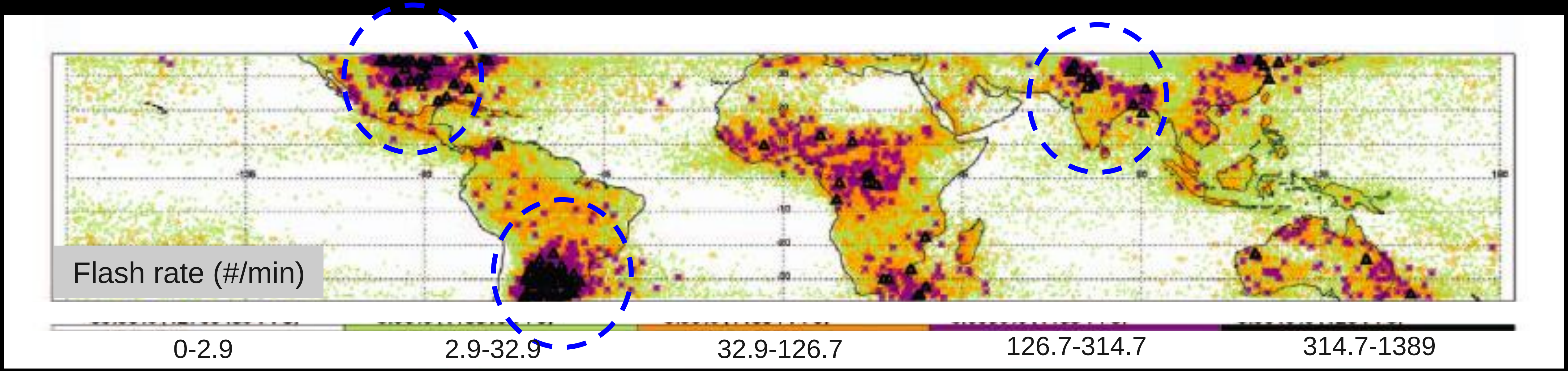
Most Intense Thunderstorms on Earth



The deepest convective storms on Earth occur near major mountain ranges (Zipser et al. 2006; Houze et al. 2015)

→ Combination of low level moisture advection and an upper level capping inversion inhibiting convection

Most Intense Thunderstorms on Earth

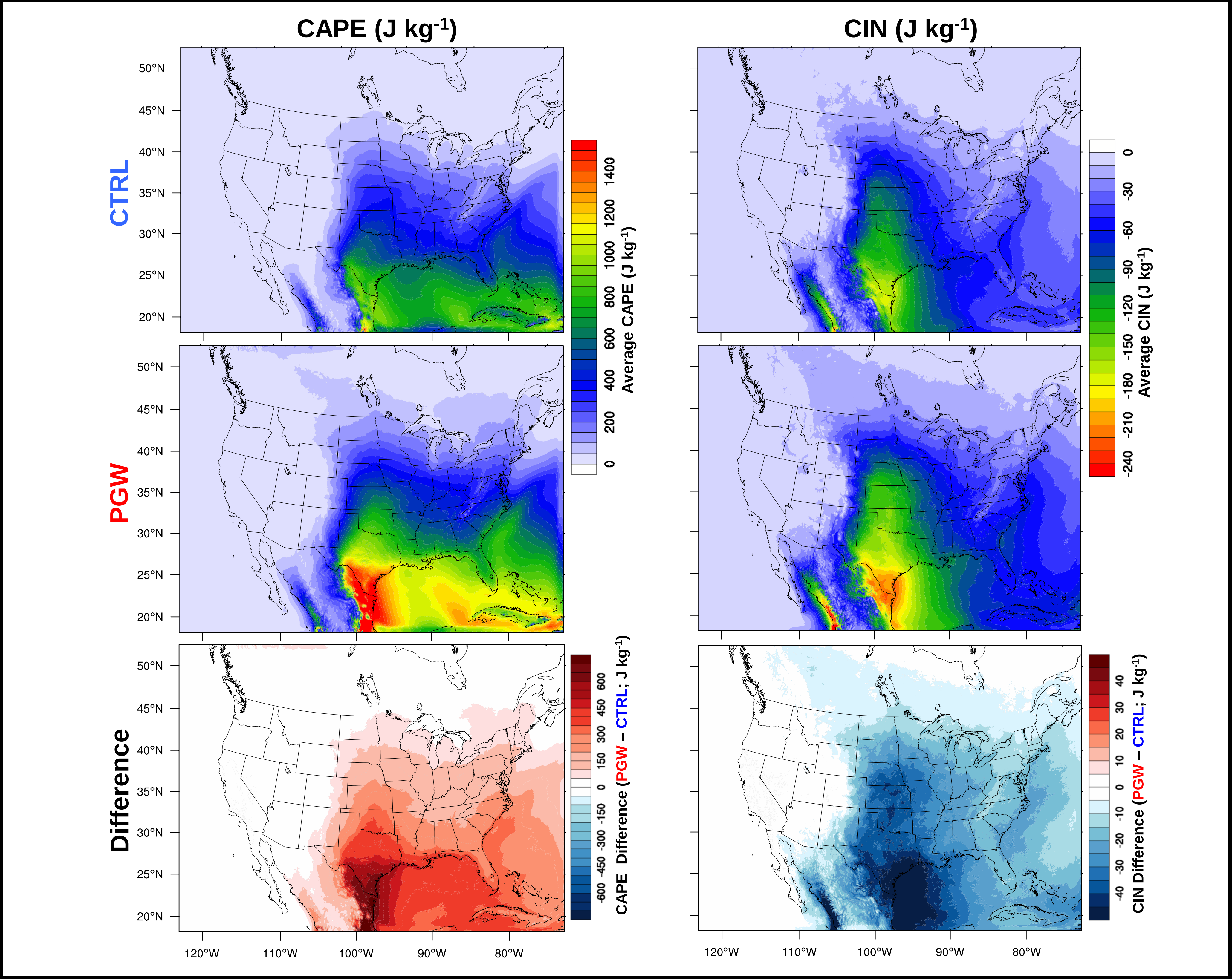


Environments supporting the deepest convection on Earth have ***both*** convective instability ***and*** convective inhibition

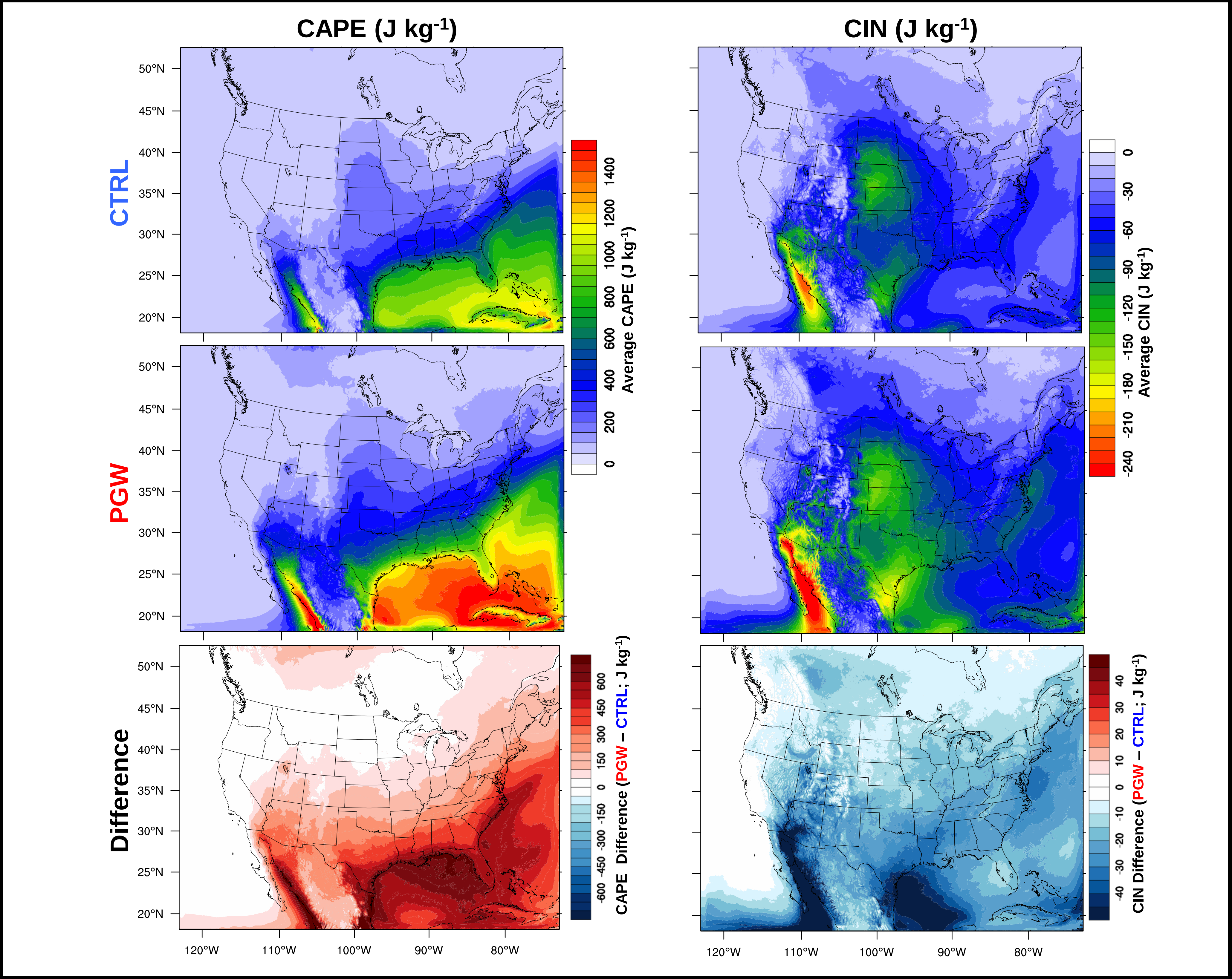
→ Allows for the build-up of convective energy that is critical for generating deep intense convection

→ Look at thermodynamic environments in the PGW experiments

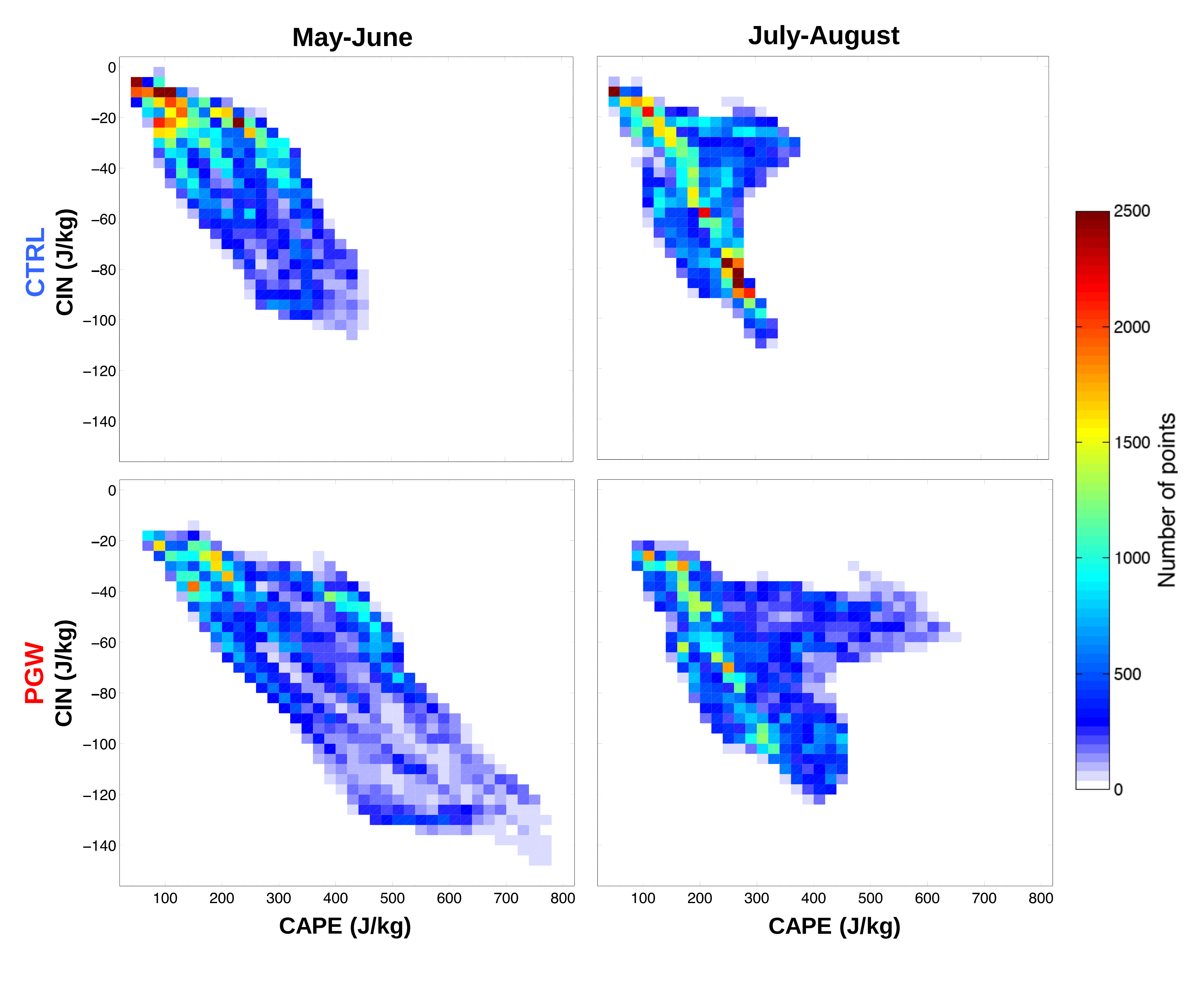
Thermodynamic environment (MJ)



Thermodynamic environment (JA)

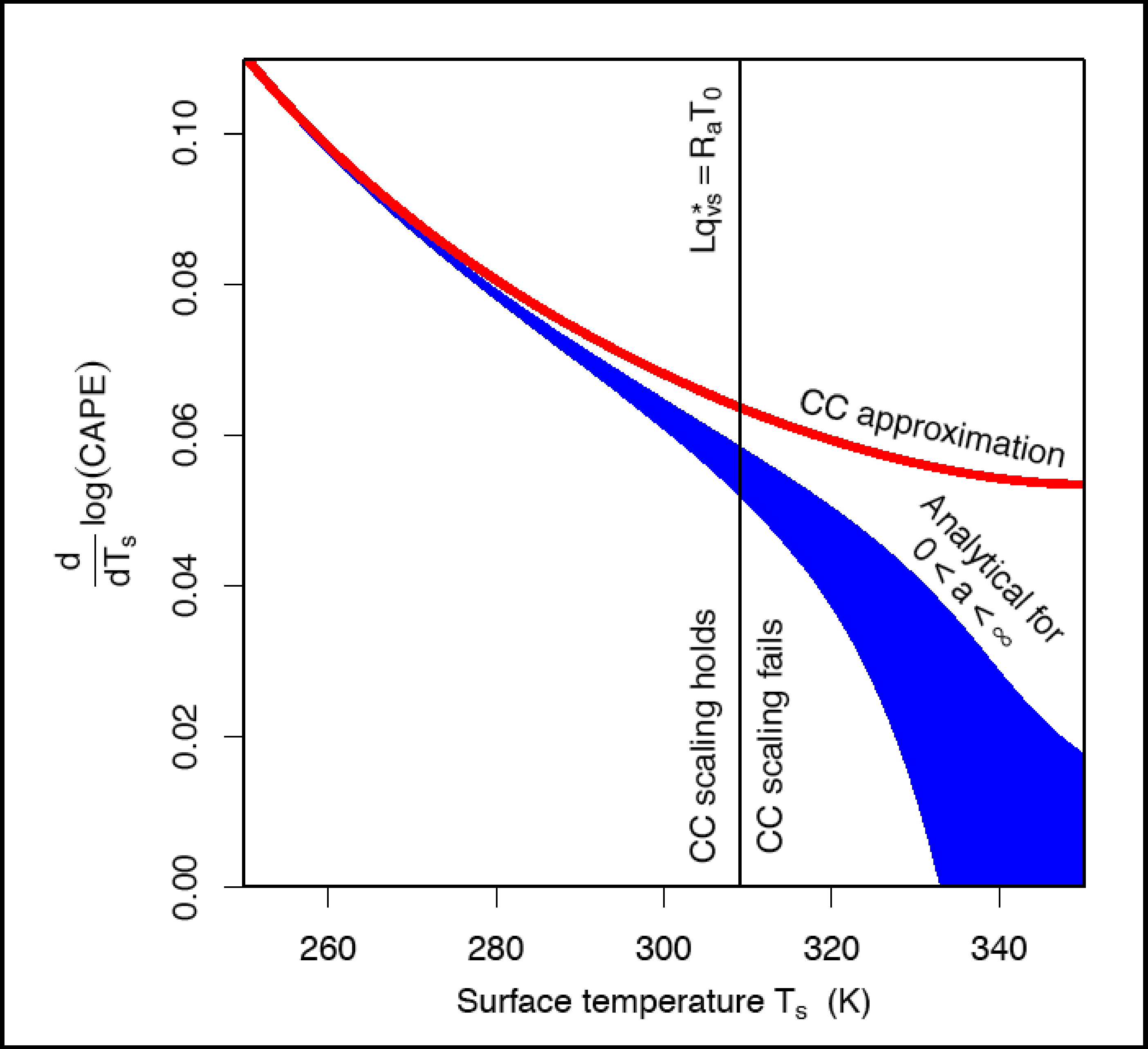


CAPE and CIN Comparison



CAPE expected to increase in future climate

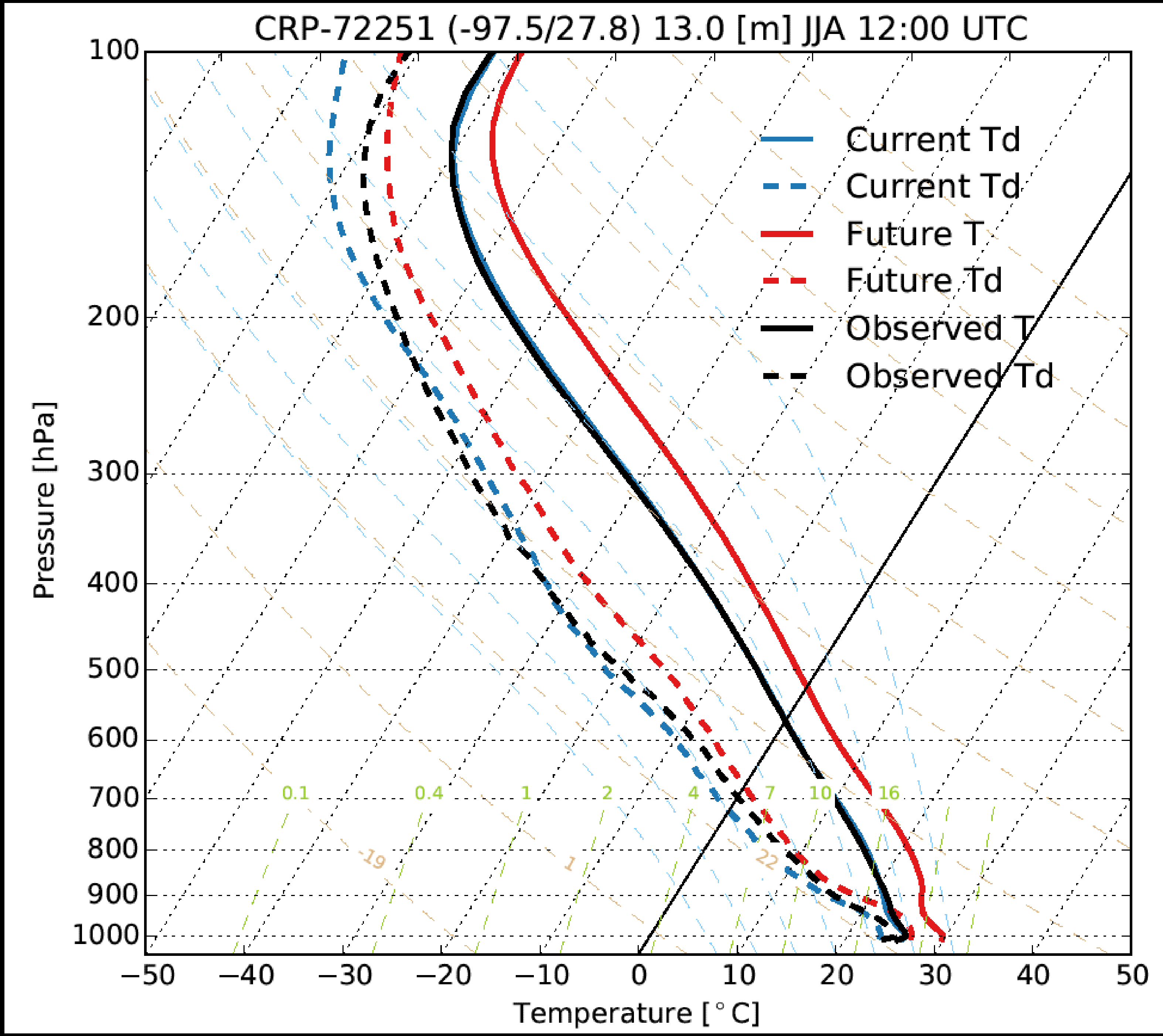
- CAPE results from the PGW CONUS runs are consistent with Romps (2015)



Romps (2015)

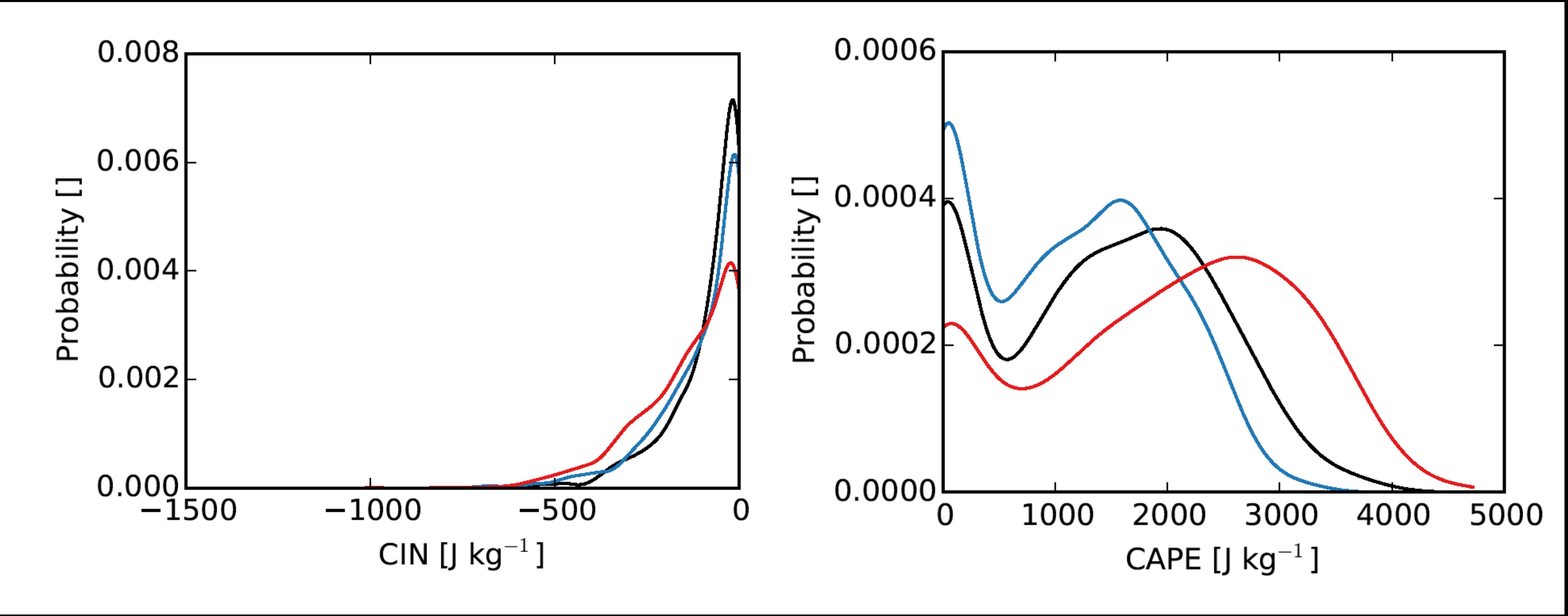
Thermodynamics sounding comparison

- Sounding comparison from Corpus Christi, Texas

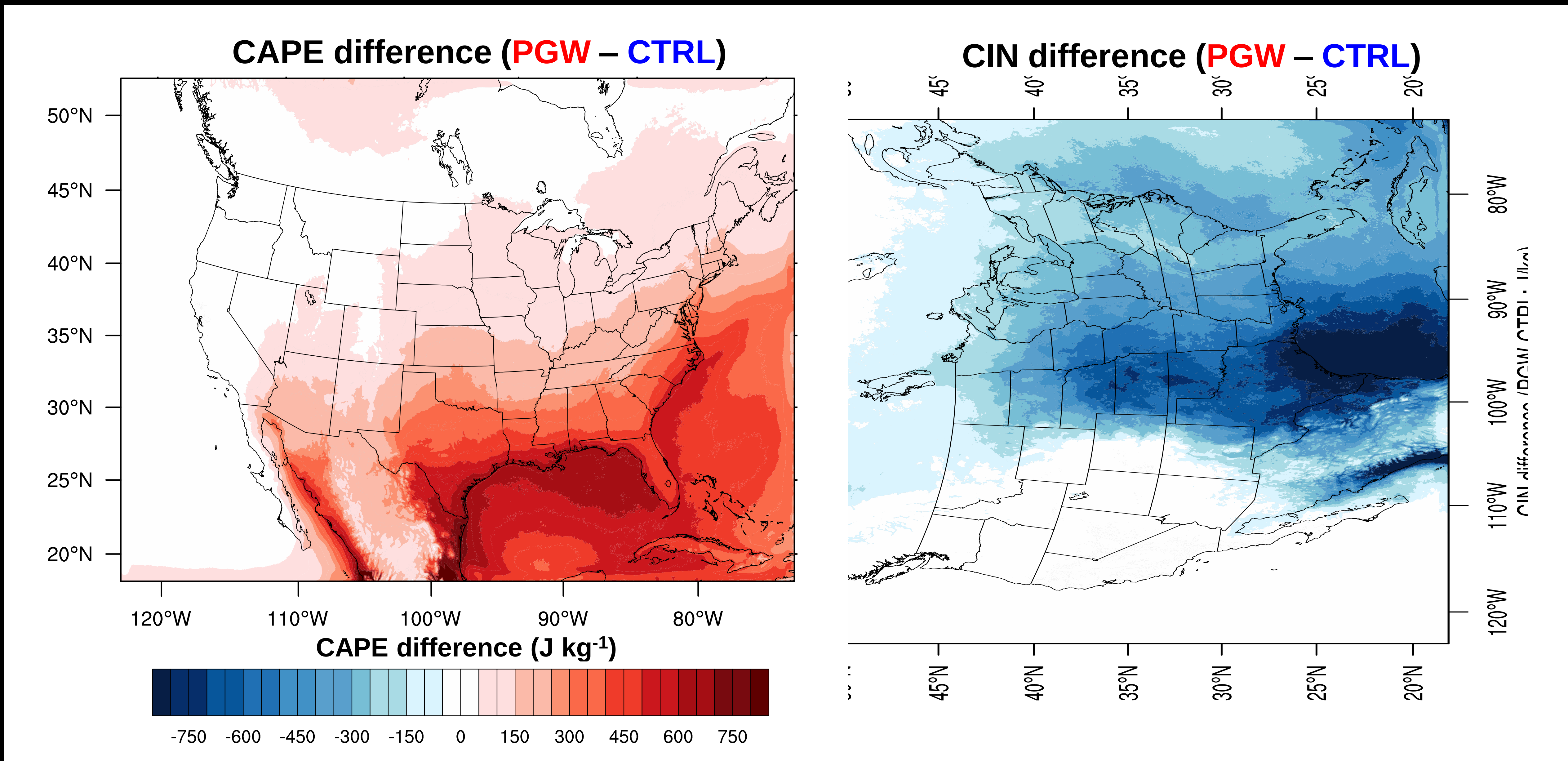


Thermodynamics sounding comparison

- Sounding comparison from Corpus Christi, Texas



Thermodynamic response



CAPE and CIN are increasing across the continental U.S. → Could explain changes in the convective population

Conclusions

- **Changes in the convective population**
  - Decreases in low to mid reflectivity ranges, increases in high reflectivity ranges
  - Fewer weak storms, more extreme storms
  - Large changes in the convective population over the U.S. Great Plains

- **Thermodynamic environment changes**
  - **CAPE increases everywhere** – More energy available for convection
  - **CIN increases everywhere** – More energy inhibiting convection, stronger capping inversion to break through
  - Increases in both CAPE and CIN support a changing convective population in a future climate → *fewer weak storms and more extreme storms*

Questions?

Advanced Study Program
Developing Scientific Leaders of the Future
NCAR
NATIONAL CENTER FOR ATMOSPHERIC RESEARCH

Mesoscale & Microscale Meteorology
MMM
LABORATORY