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
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

- Mesoscale meteorology
  - Convection-permitting regional climate simulations
  - Global satellite observations

- Climate science
Nature of global convective systems

Deep Convective Cores (DJF)

Wide Convective Cores (DJF)

Broad Stratiform Regions (DJF)

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

→ 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

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**CONUS** = Contiguous U.S.
WRF CONUS Experiment Setup

- V3.4.1 WRF model with a 4-km-spacing domain of \(1360 \times 1016 \times 51\) 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
Pseudo Global Warming (PGW) Approach

- Compute 30-year CMIP5 19 model ensemble monthly mean
- Compute perturbation – difference between two climates
- Add perturbation to the 6-hourly ERA-I data

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:
    \[ \text{Oct. 1 2000 – Oct. 1 2013} \]

• **EXP2: Pseudo-Global Warming (PGW) simulation**
  - forced with ERA-I plus climate perturbation
  - \( D_{RCP8.5} = \text{CMIP5}_{2071-2100} - \text{CMIP5}_{1976-2005} \)
  - 13-year continuous integration

Liu et al. (2016)
How does precipitation and atmospheric moisture change in a future climate?
Average precipitation

CTRL

PGW

Difference

(a)

(b)

(c)

May-June

July-August

Average Precipitation (mm)

Precip. Difference (PGW-CTRL; mm)
Precipitable water frequency

CTRL

PGW

50 mm precipitable water

60 mm precipitable water

50 mm precip. water frequency

60 mm precip. 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)

(a) 0-10 dBZ
(b) 10-20 dBZ
(c) 20-30 dBZ
(d) 30-40 dBZ
(e) 40-50 dBZ
(f) 50-60 dBZ

Difference in occurrence (PGW-CTRL)

Changes in the convective population (MJ)
Changes in the convective population (JA)

- (a) 0-10 dBZ
- (b) 10-20 dBZ
- (c) 20-30 dBZ
- (d) 30-40 dBZ
- (e) 40-50 dBZ

Difference in occurrence (PGW-CTRL)
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?
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
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)

CAPE (J kg\(^{-1}\))

CIN (J kg\(^{-1}\))

CAPE Difference (PGW - CTRL; J kg\(^{-1}\))

CIN Difference (PGW - CTRL; J kg\(^{-1}\))
Thermodynamic environment (JA)

CAPE (J kg$^{-1}$)

CIN (J kg$^{-1}$)

Average CAPE (J kg$^{-1}$)

Average CIN (J kg$^{-1}$)

CAPE Difference (PGW – CTRL; J kg$^{-1}$)

CIN Difference (PGW – CTRL; J kg$^{-1}$)
CAPE and CIN Comparison

May-June

July-August

CTRL CIN (J/kg)

PGW CIN (J/kg)

CAPE (J/kg)

Number of points
CAPE expected to increase in future climate

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

- Sounding comparison from Corpus Christi, Texas
Thermodynamics sounding comparison

- Sounding comparison from Corpus Christi, Texas
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?