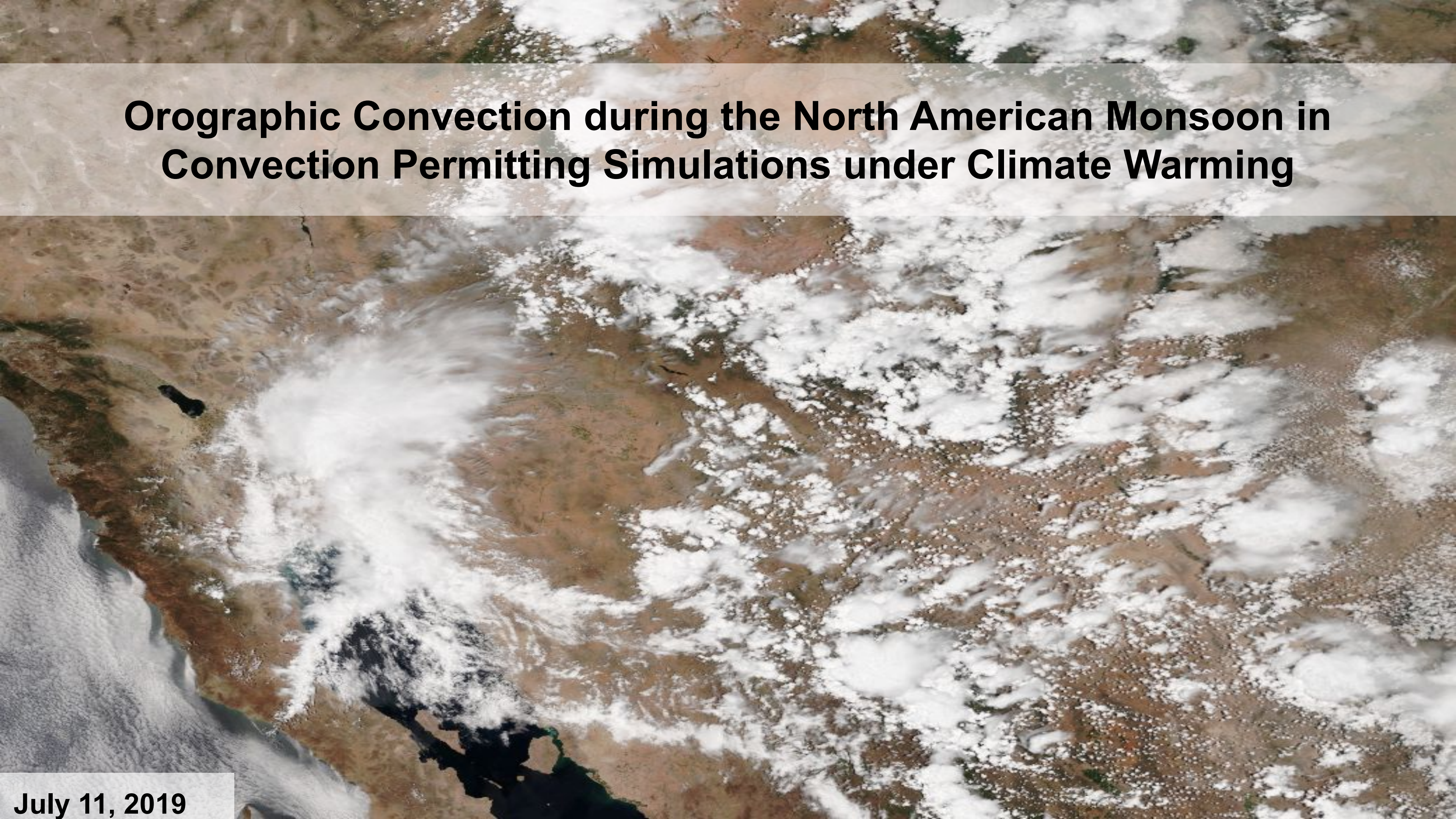
Orographic Convection during the North American Monsoon in Convection Permitting Simulations under Climate Warming

19th Mountain Met Conference

Brendan Wallace and Justin Minder

June 11, 2019

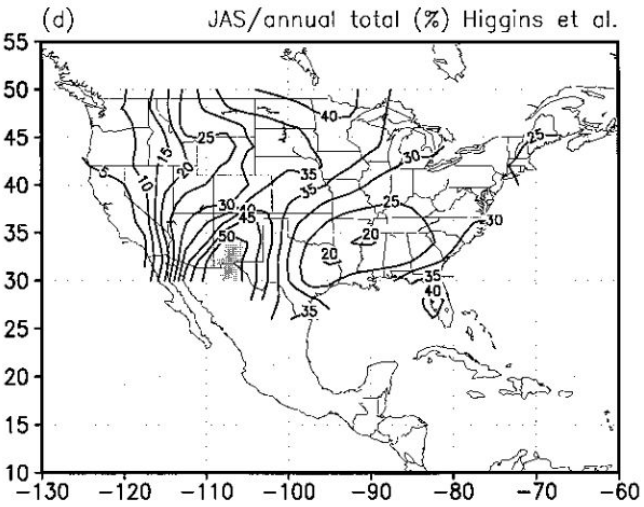
Orographic Convection during the North American Monsoon in Convection Permitting Simulations under Climate Warming

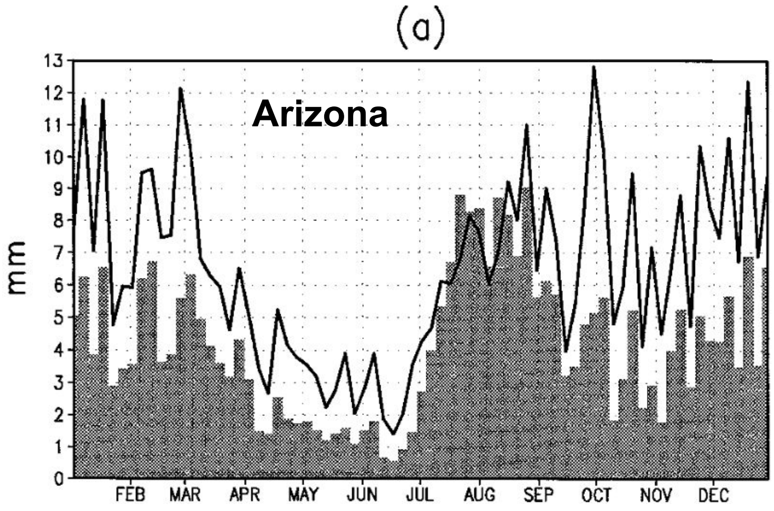


July 11, 2019

The North American Monsoon (NAM)

- Period with pronounced increase in rainfall for southwestern US and western Mexico
  - Typically July-September
- JAS rainfall can make up to 40-50% of total annual rainfall for parts of AZ & NM **(Higgins et al. 1997)**



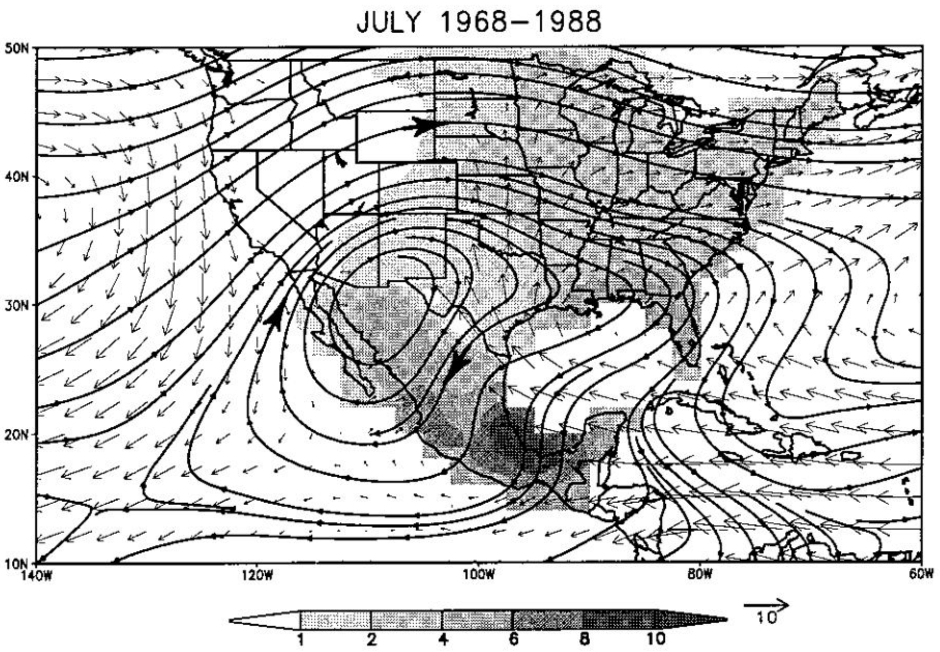


(Higgins et al. 1997)

NAM Synoptic Regime

- Cold season transient synoptic activity migrates northward with jet **(Higgins et al. 1997)**
- Land-sea thermal contrast reverses mean flow over gulf to be light southeasterly
- Weak synoptic forcing and stronger seasonal heating increases amplitude of diurnal orographic convection **(Wallace 1975, Carbone et al. 2008)**

Mean monthly 925 hPa vector winds, 200 hPa streamlines, shaded precipitation



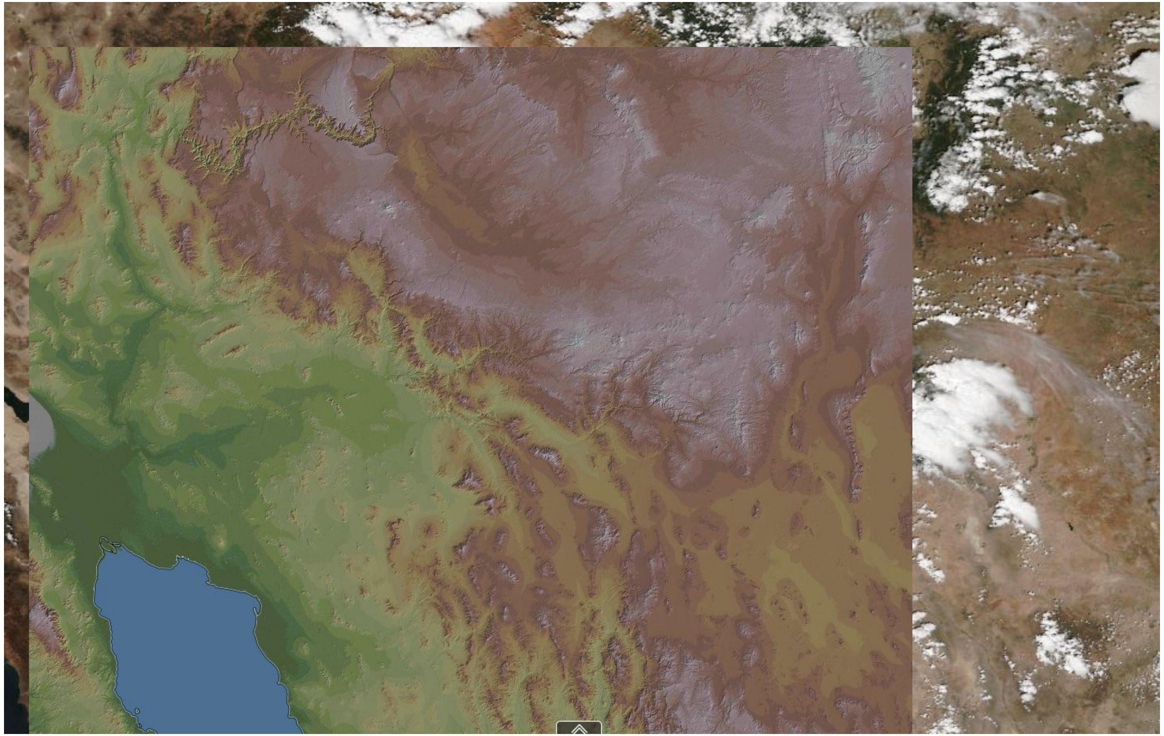
(Higgins et al. 1999)

Orographic Precipitation

- Precipitation phase locked to terrain where low-level convergence and strong heating aid convection **(Damiani et al 2008, Demko & Geerts 2010)**.

Orographic Precipitation

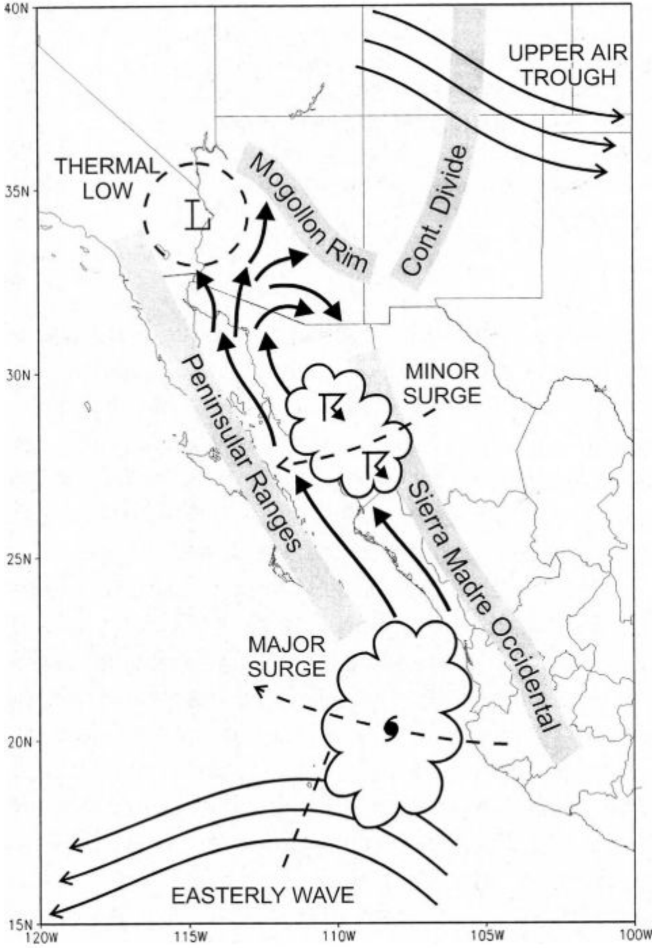
- Precipitation phase locked to terrain where low-level convergence and strong heating aid convection **(Damiani et al 2008, Demko & Geerts 2010)**.



Gulf Surges

- Southeasterly flow over Gulf of California provides enough moisture to allow organization of convection **(Adams & Souza 2009)**

- Precipitation during surge periods can account for 70% of summertime rainfall **(Pascale & Bordoni 2016)**.

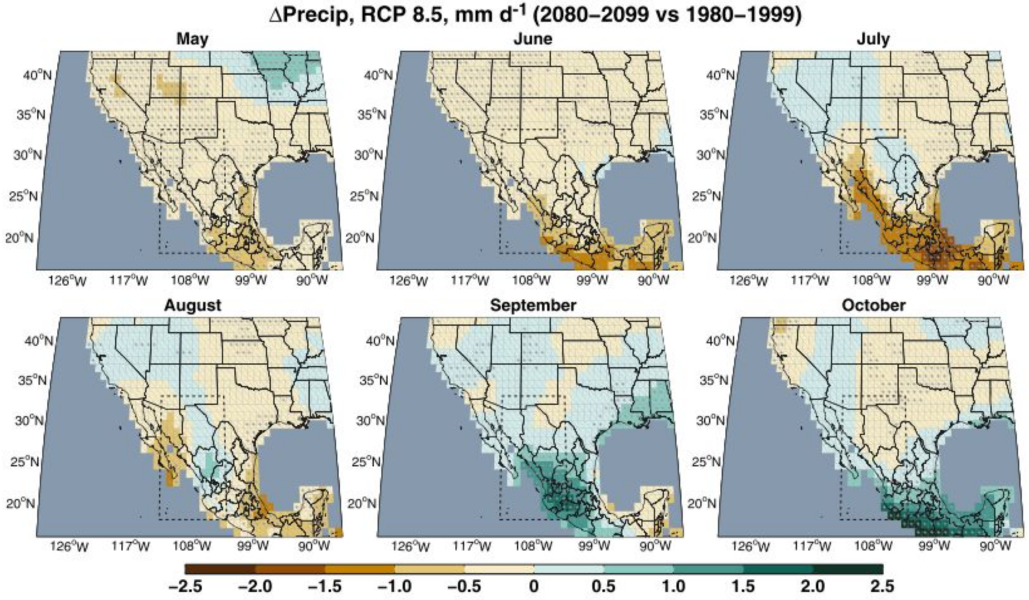


(Adams & Comrie 1997)

How will these aspects of the NAM change under climate warming?

GCM Projections

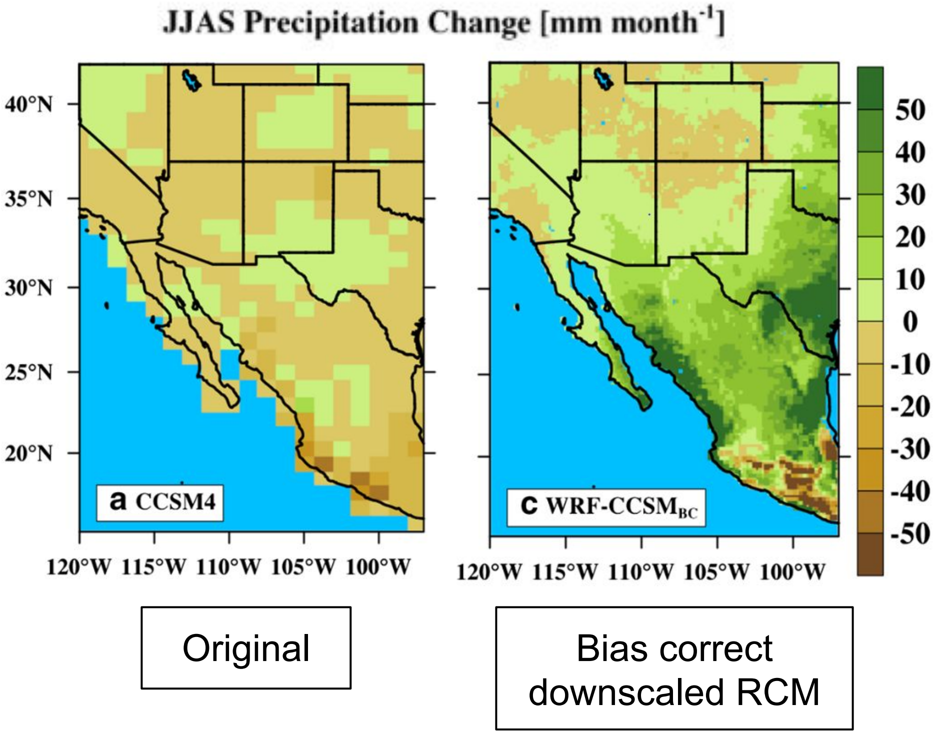
- Global climate models (GCM) project delayed onset of monsoon **(Cook & Seager 2013, Maloney et al. 2014, Torres-Alavez et al. 2014)**
- Late-season surface evaporation overcomes imposed large scale stability from warming



Cook & Seager (2013)

RCM Projections

- Regional climate models better match observations **(Castro et al. 2012)**
- Recent attempts at addressing GCM drying trend using 20-km RCM show increased precipitation **(Meyer & Jin 2017)**
- Still susceptible to errors in parameterized convection **(Gao et al. 2017)**

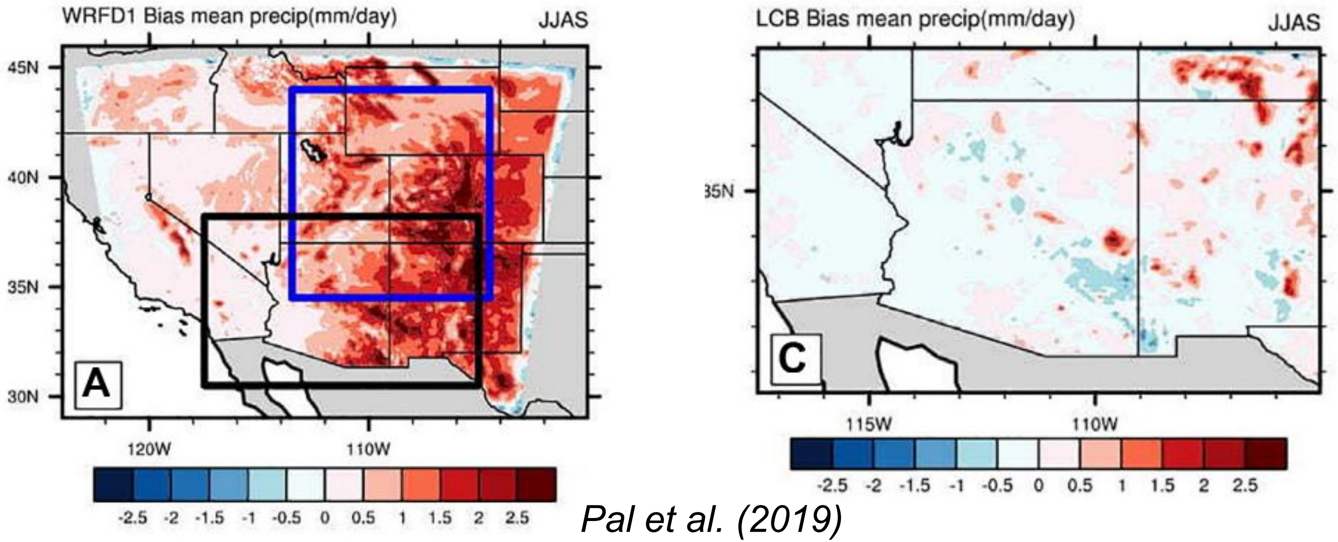


Meyer & Jin (2017)

Utility of Convection-Permitting Models

- Seasonal CPM simulations show improvement at capturing subdaily precip extremes and reducing mean precip biases **(Ban et al. 2015, Prein et al. 2017, Pal et al. 2019)**

12 km ***Mean JJAS Precipitation Biases*** **4 km**



Pal et al. (2019)

Research Question

What is the NAM precipitation response to climate warming?

Hypothesis

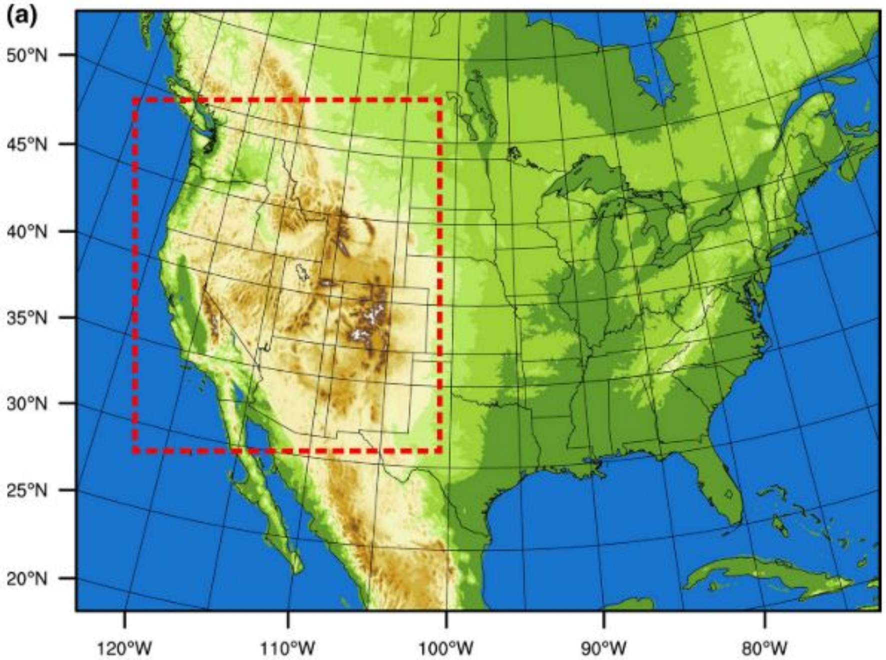
- ***Precipitation will increase***
- ***Enhanced moisture fluxes from Gulf of California will intensify domain-wide precipitation and overcome warming induced stability***
- ***Local orographic circulations will converge moisture and enhance highest accumulations over topography***

Model Setup

- Utilize a set of completed continental-scale convection permitting regional climate simulations from Liu et al. (2017) (hereafter CONUS)

- October 2000 - September 2013
- 4 km grid spacing at 1360 x 1016 grid points
- 51 vertical levels up to 50 hPa
- Spectral nudging employed to reduce drift

- Thompson microphysics
- YSU PBL
- RRTMG
- Noah-MP
- No convective parameterization



Liu et al. (2017)

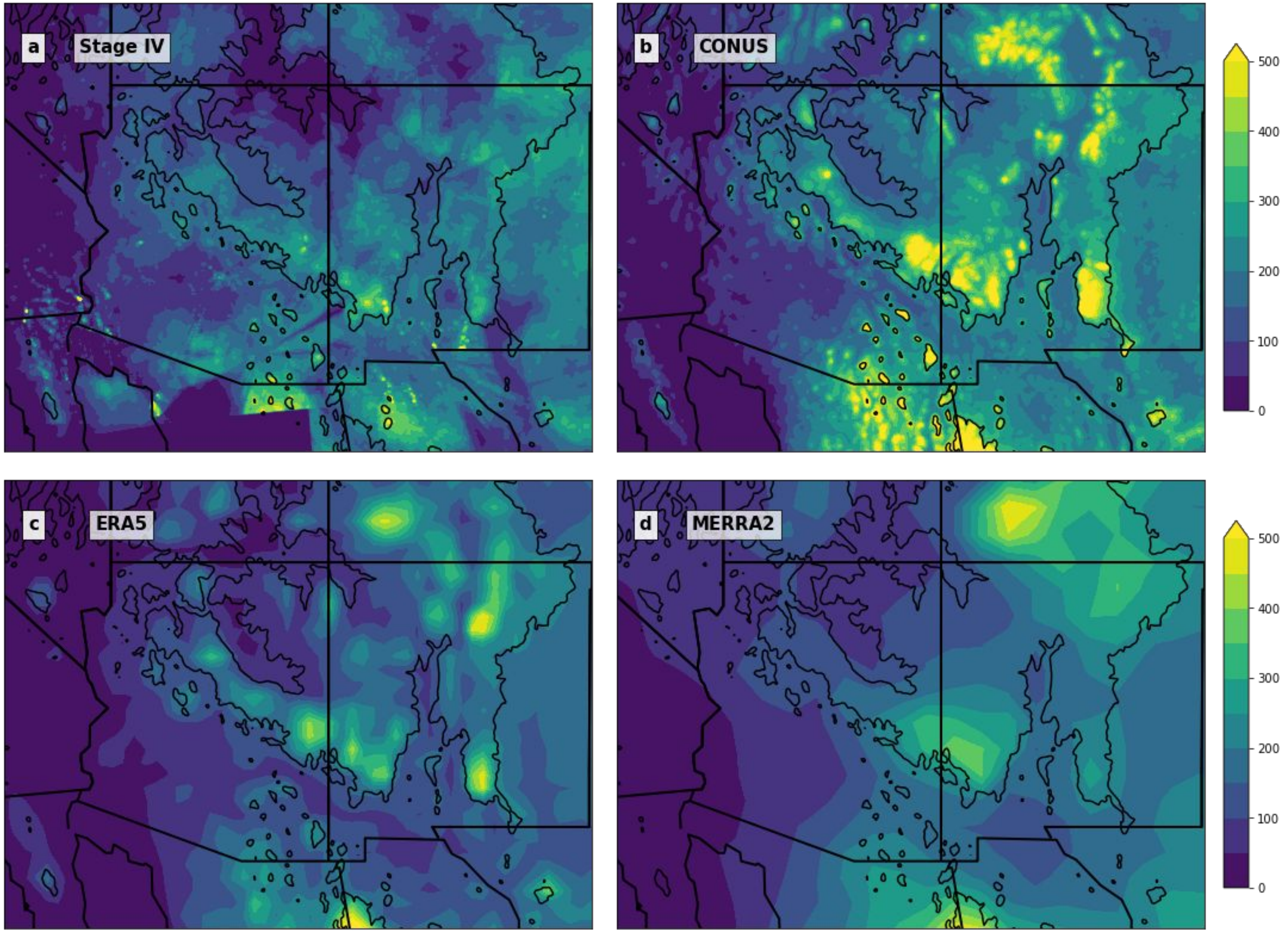
- Two simulations are performed:

1. **Control**
    a. Forced by 6-hourly ERA-Interim reanalysis at 0.7 degree resolution

2. **Pseudo-global warming (PGW)**
    a. ERA-Interim data perturbed by 19 member CMIP5 ensemble under RCP8.5 average [(2071-2100) - (1976-2005)]
    b. Warming varies spatially and is updated on a monthly basis
    c. Perturb horizontal wind, geopotential, temperature, specific humidity, soil temperature, soil moisture, sea surface temperature, sea level pressure, and sea ice
    d. PGW approach allows a climate response without need to downscale GCM ensemble
    e. No internal climate variability between control and future climate state

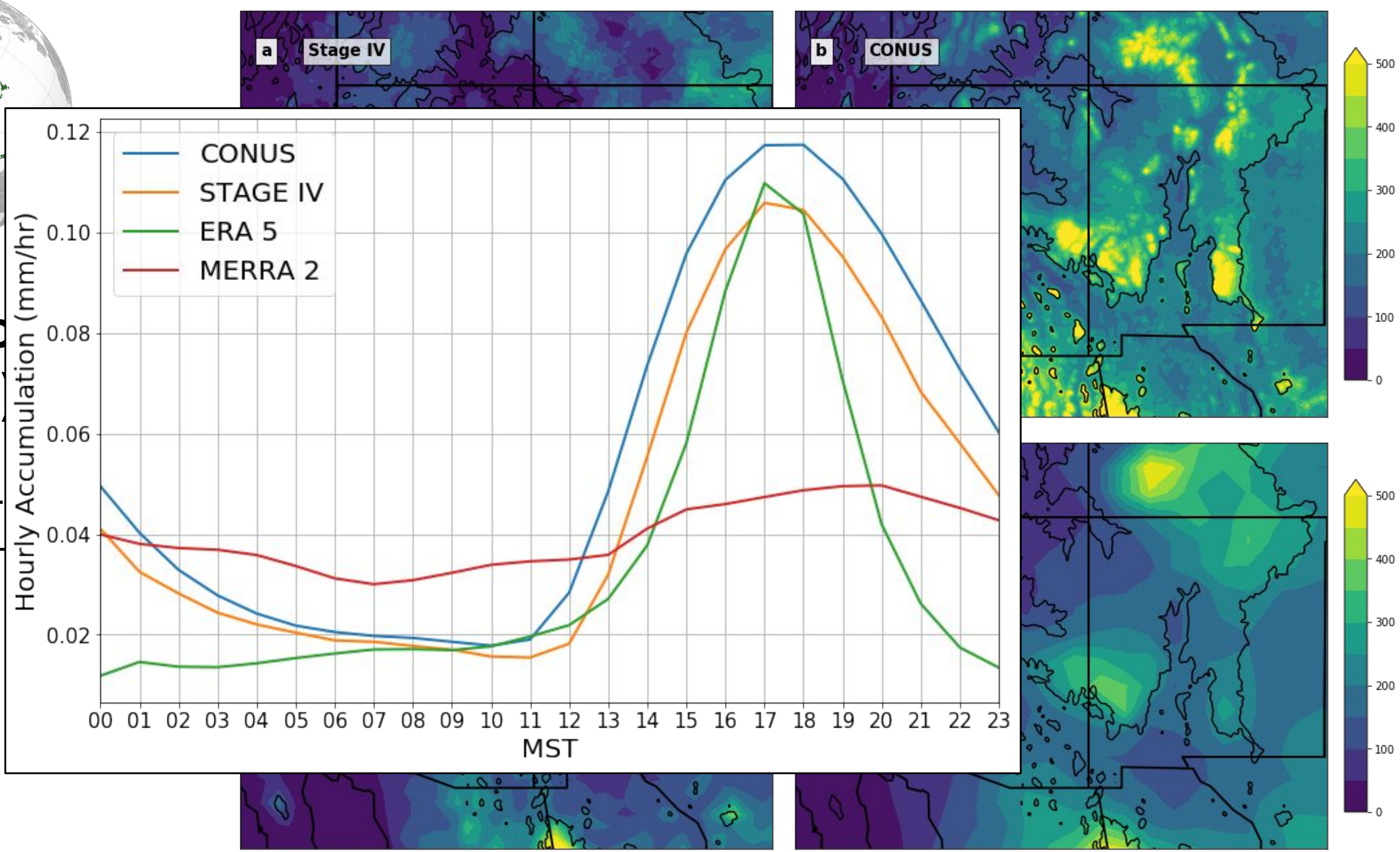
Averaged JJAS Precipitation Sum (2001-2013) [mm]

Black contour - 1700m Elevation Line



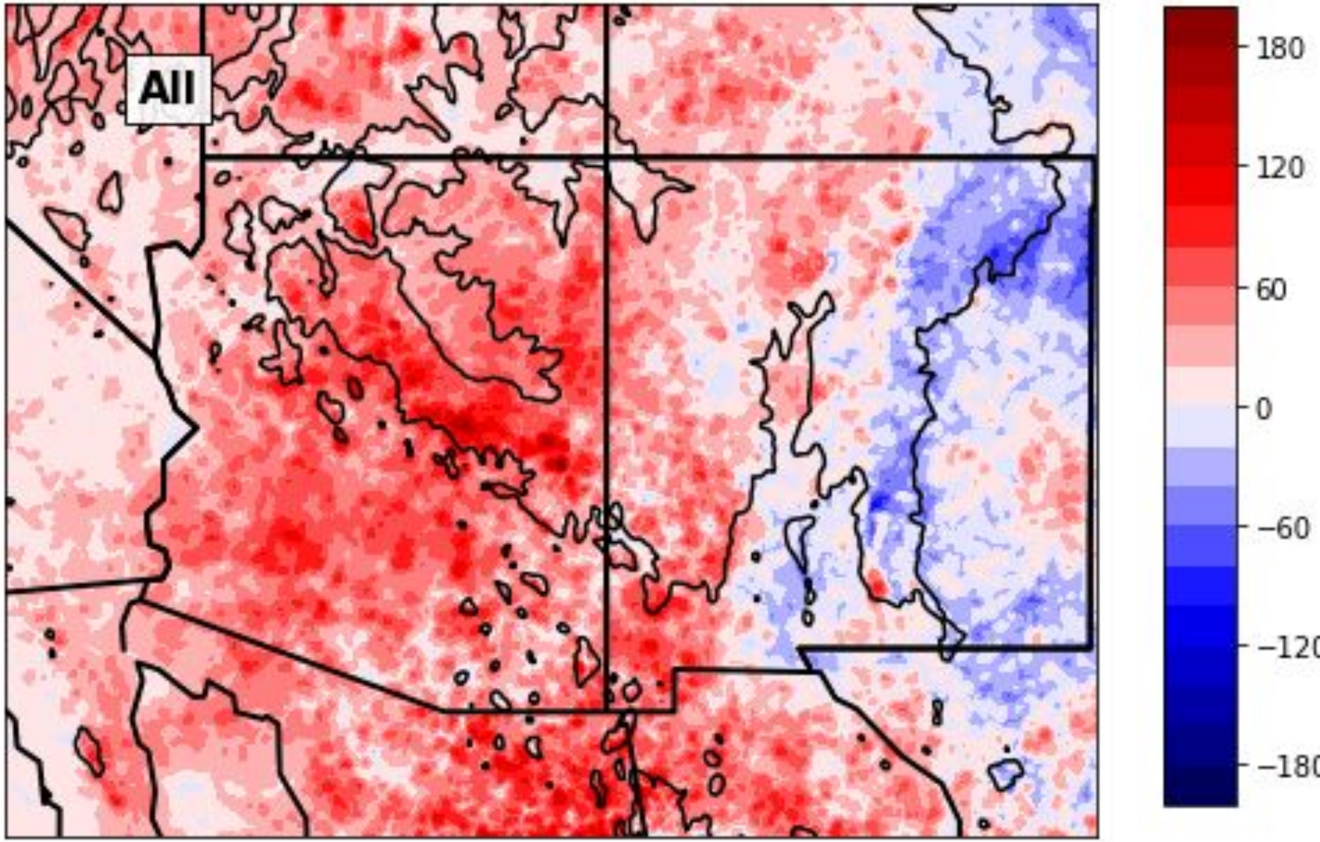
Averaged Precipitatio (2001-2013)

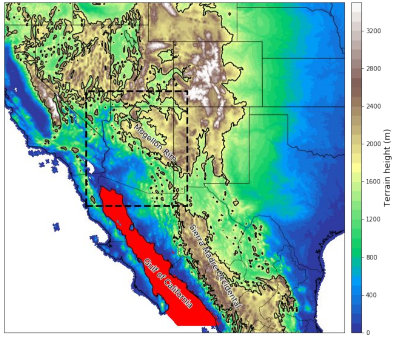
Black contour - Elevation L

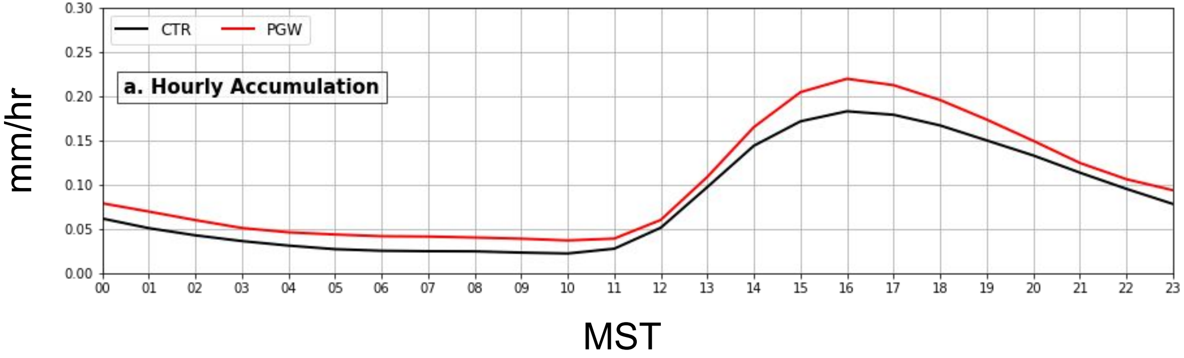


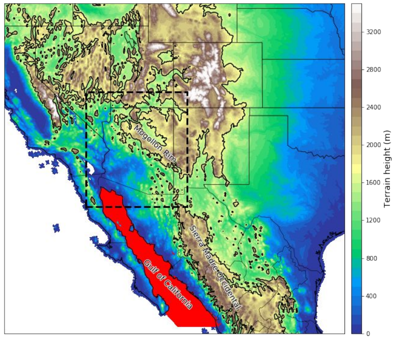
PGW-CTR JJAS Precipitation Difference (2001-2013) [mm]

Black contour - 1700m Elevation Line

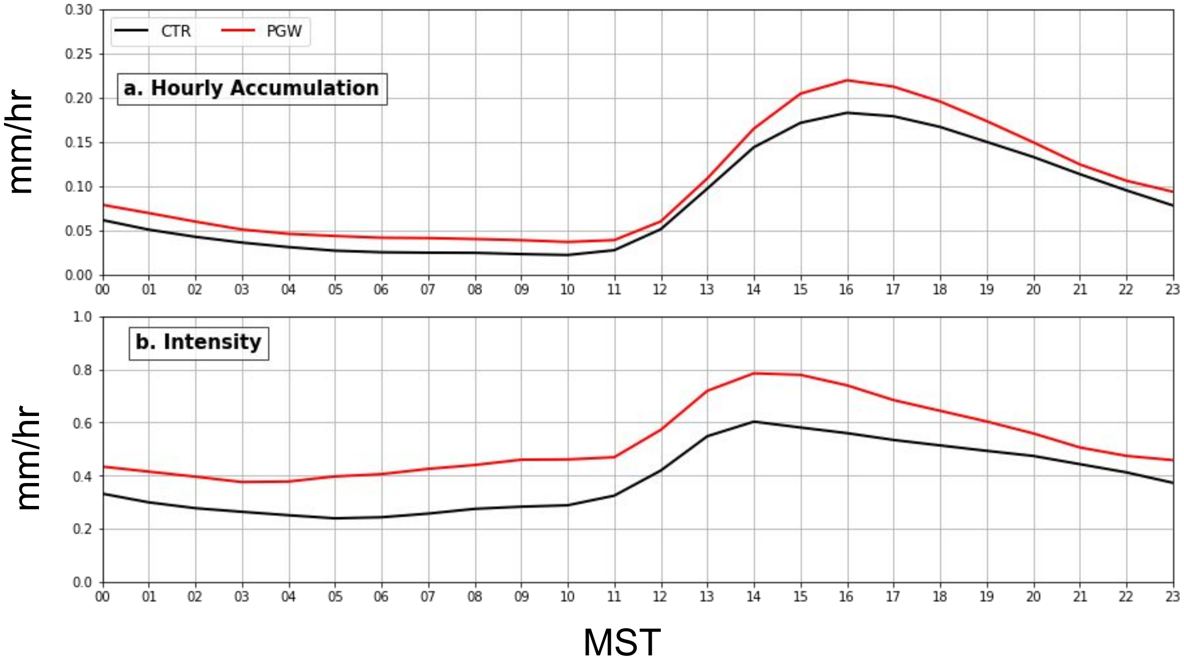


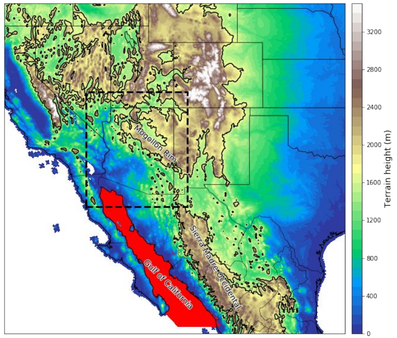

Mogollon Rim
Sierra Madre Occidental
Gulf of California
Terrain height (m)
3200
2800
2400
2000
1600
1200
800
400
0

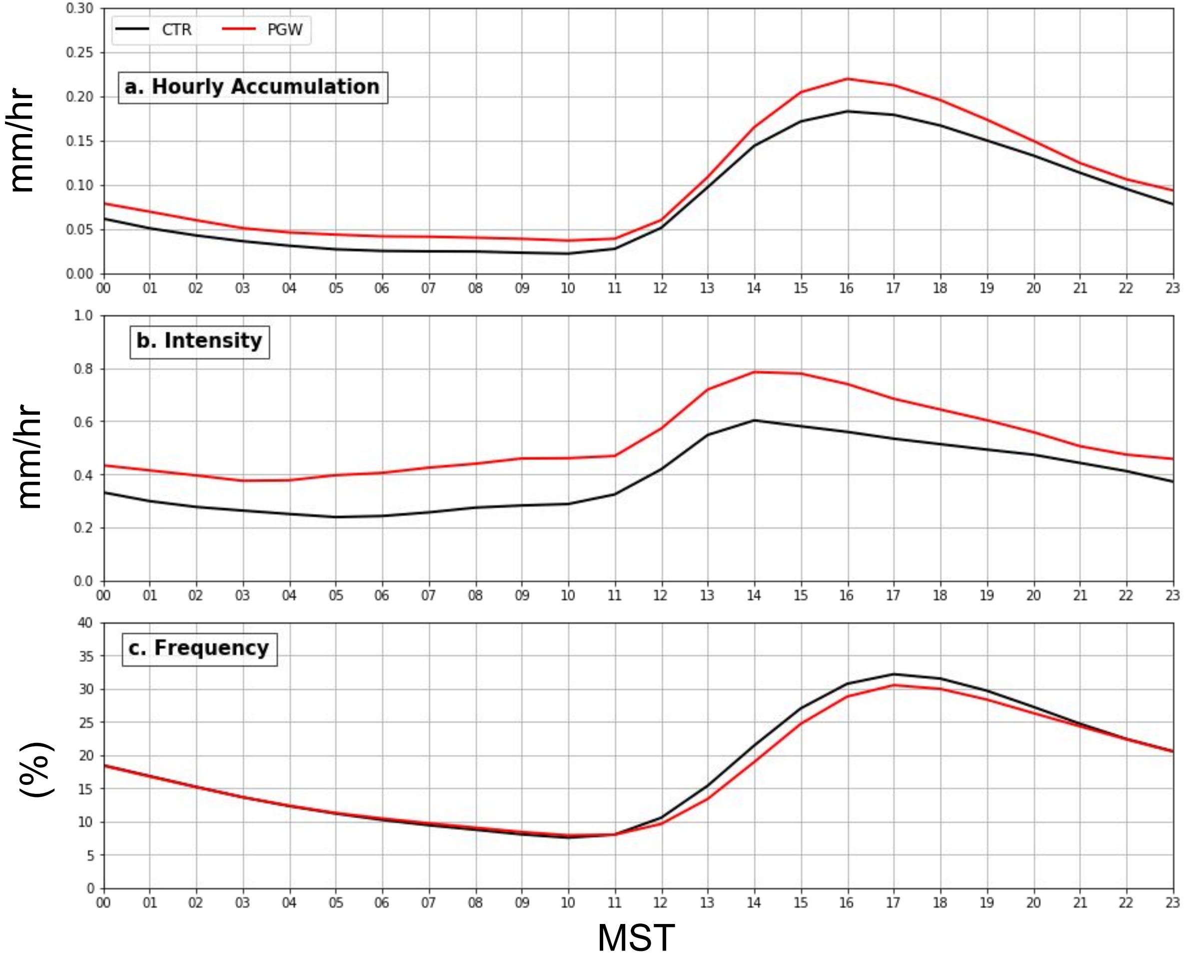

CTR
PGW
a. Hourly Accumulation
mm/hr
0.30
0.25
0.20
0.15
0.10
0.05
0.00
00 01 02 03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23
MST



Intensity = Average of all nonzero accumulations







Intensity = Average of all nonzero accumulations

Frequency = Fraction of domain with nonzero accumulations

Frequency reductions

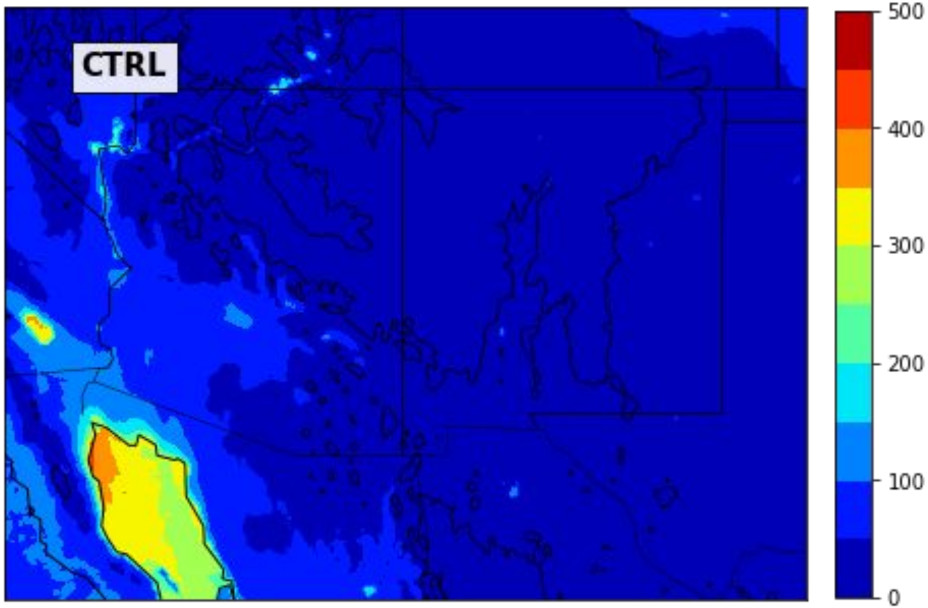
Greater warming aloft stabilizing atmosphere

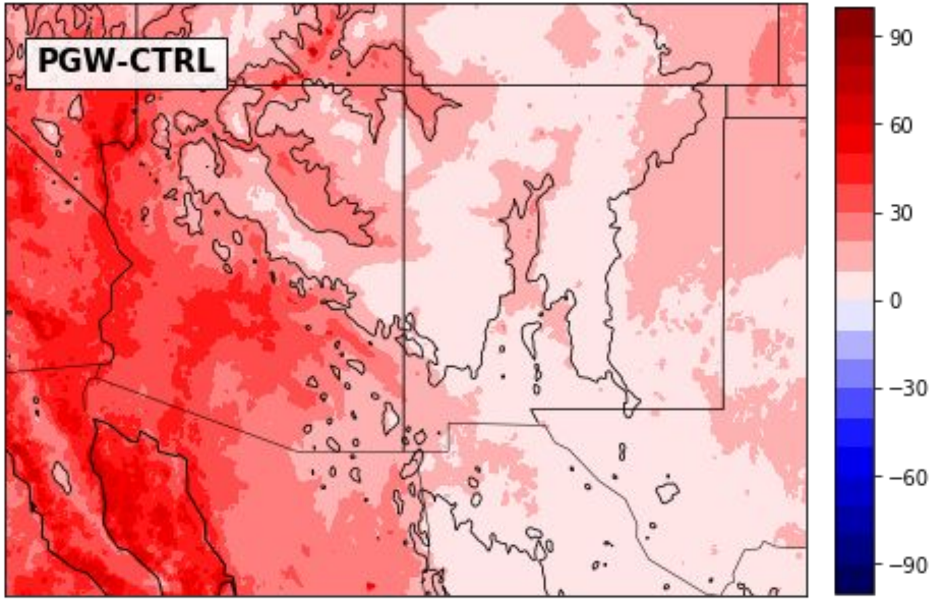
Intensity increases

Enhanced moisture transport

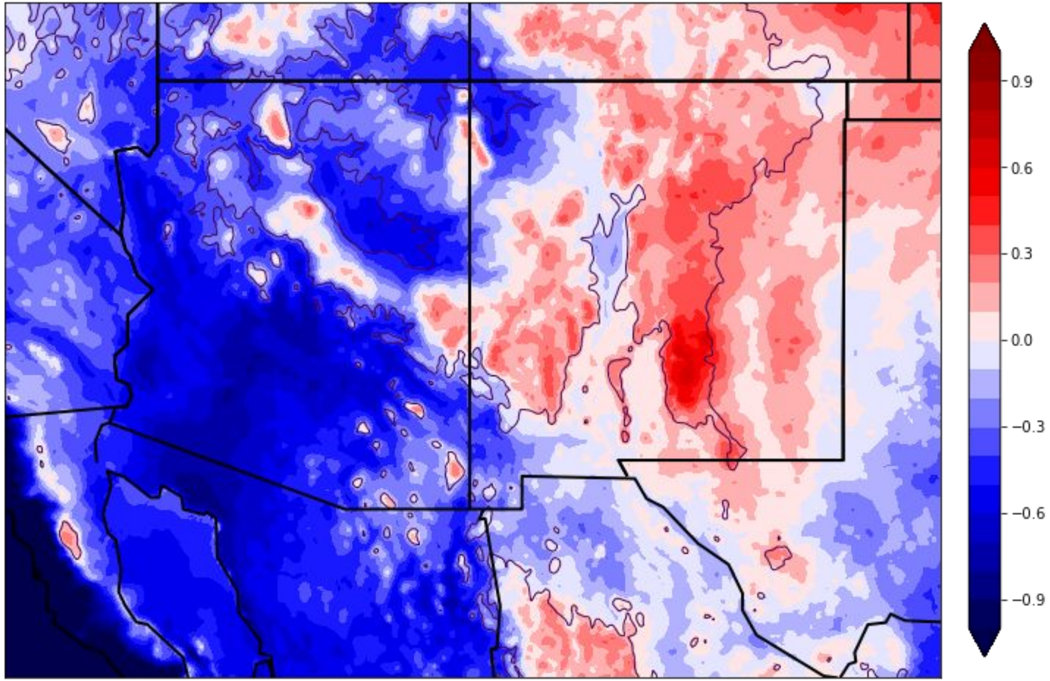
JJAS Most Unstable Convective Inhibition (MUCIN) (2001-2013) at 1200 MST [J kg^{-1}]

Black contour - 1700m Elevation Line

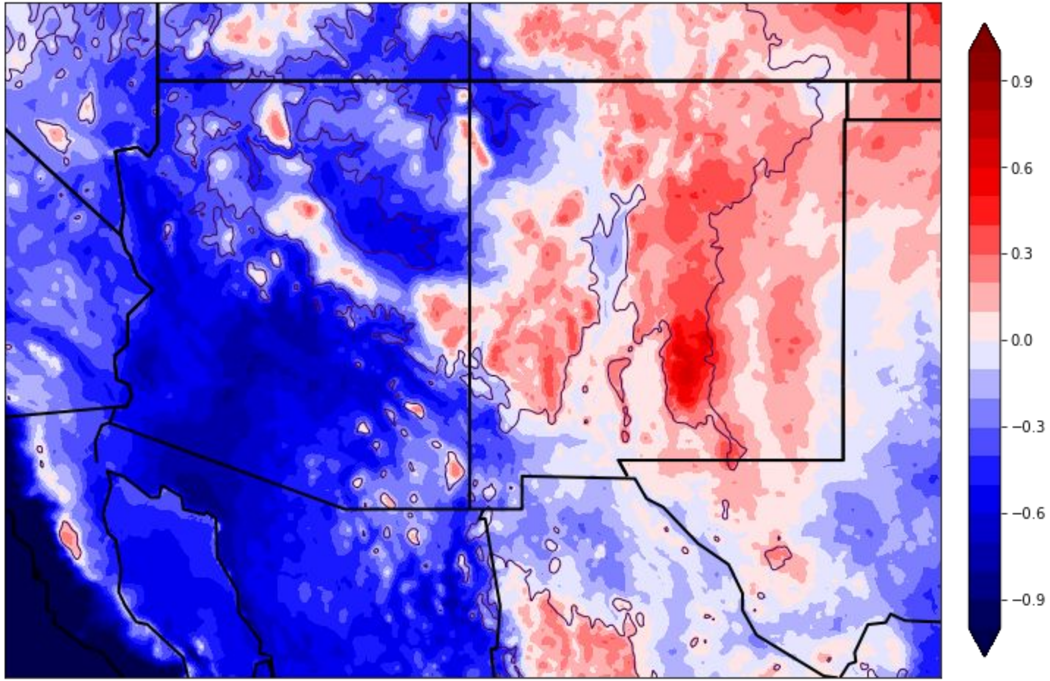




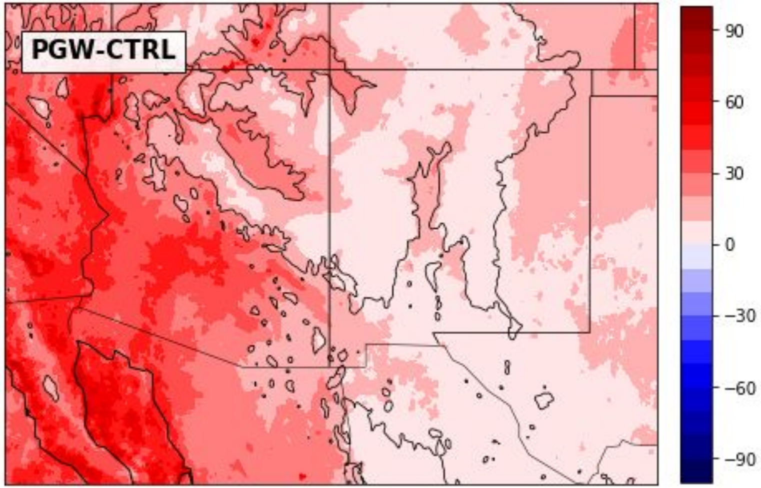
JJAS 0-3km Lapse Rate (2001-2013) at 1200 MST



JJAS 0-3km Lapse Rate PGW-CTR Difference (2001-2013) at 1200 MST



JJAS MUCIN 1200 MST



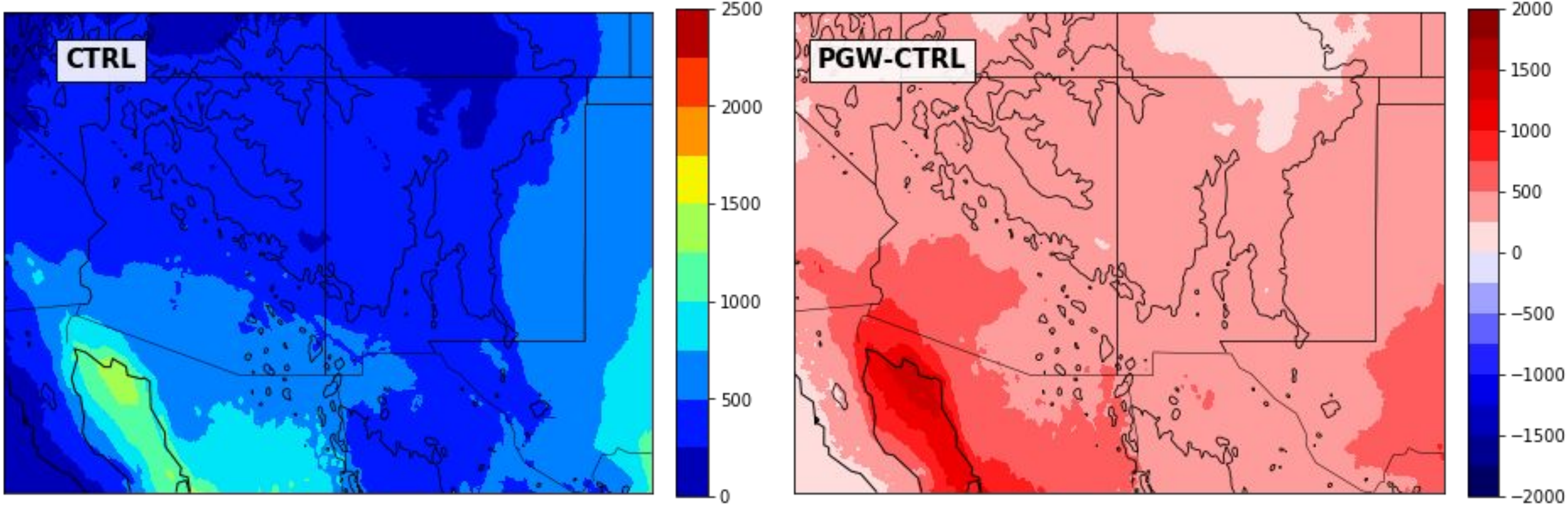
Intensity increases

↓

Enhanced moisture transport

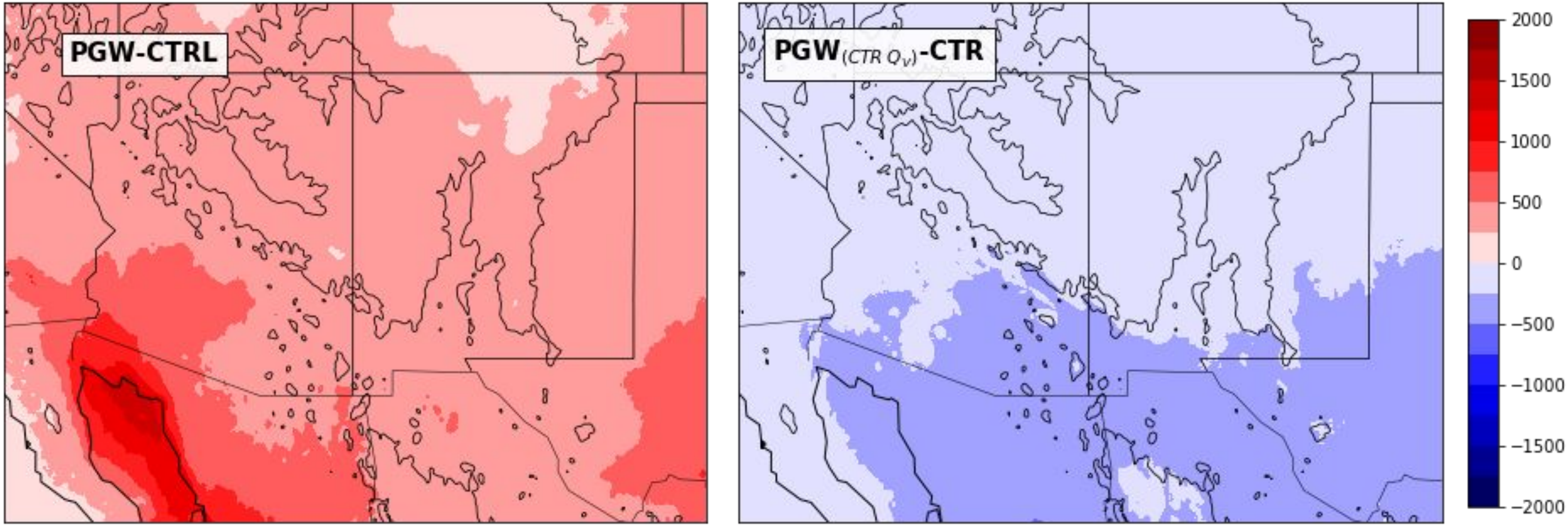
JJAS Most Unstable CAPE (MUCAPE) (2001-2013) at 1200 MST [J kg^{-1}]

Black contour - 1700m Elevation Line



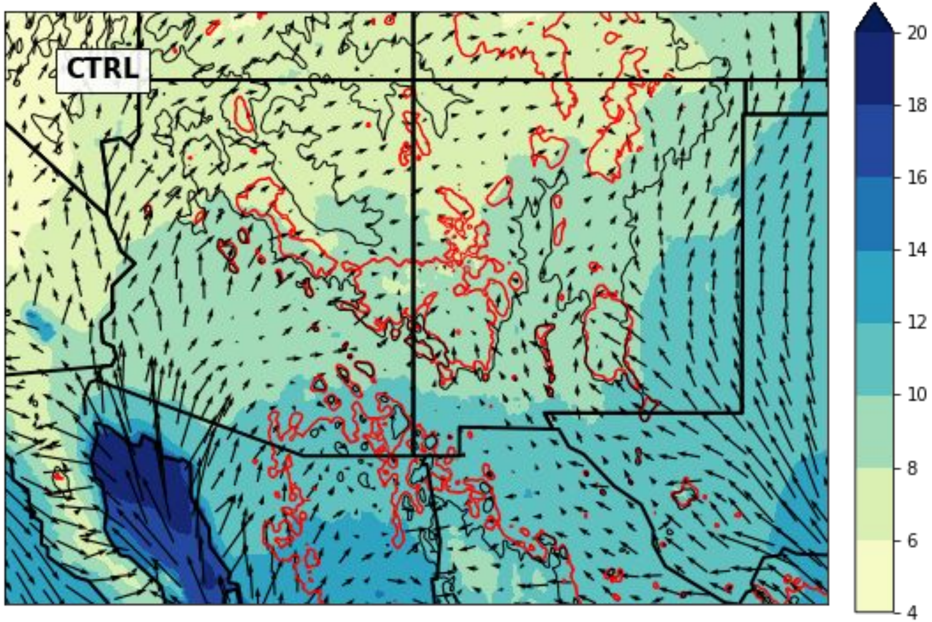
JJAS Most Unstable CAPE (MUCAPE) (2001-2013) at 1200 MST [J kg^{-1}]

Black contour - 1700m Elevation Line



JJAS Daily Averaged [2001-2013]

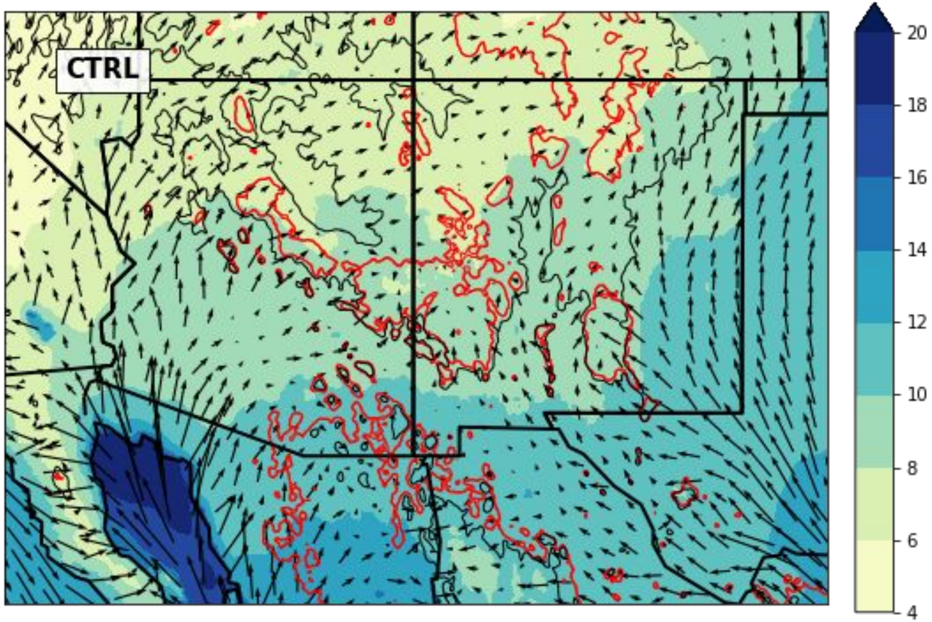
Vectors - CTR 1 km Integrated water vapor flux
Shading - CTR 10-m specific humidity
Contour - Averaged Daily CTR Precipitation Accumulation >3 mm/day
Contour - 1700m Elevation

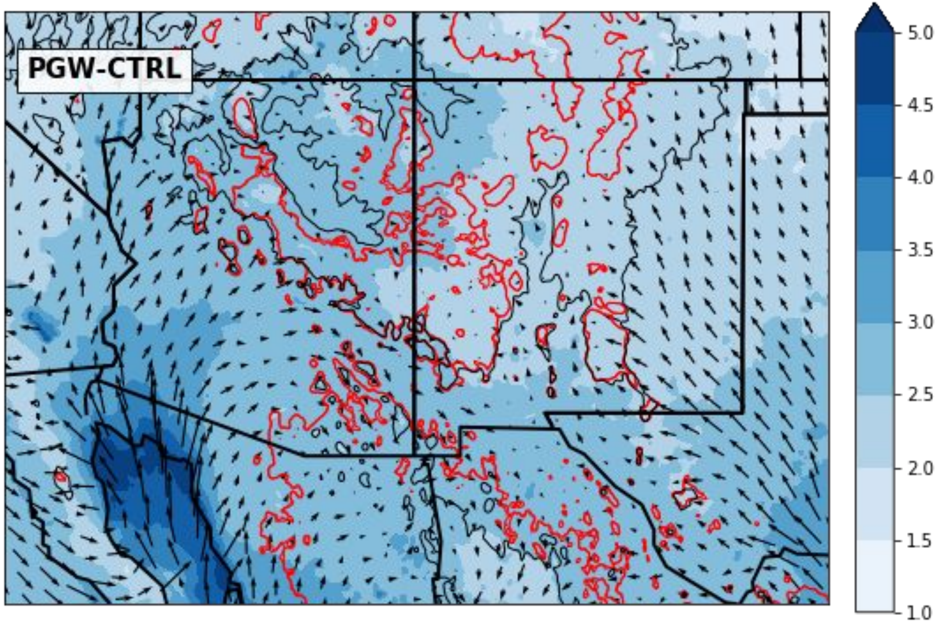


JJAS Daily Averaged [2001-2013]

Vectors - CTR 1 km Integrated water vapor flux
Shading - CTR 10-m specific humidity
Contour - Averaged Daily CTR Precipitation Accumulation >3 mm/day
Contour - 1700m Elevation

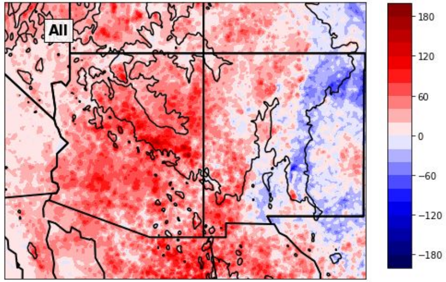
Vectors - Δ(1 km Integrated water vapor flux)
Shading - Δ(10-m specific humidity)
Contour - Averaged Daily PGW Precipitation Accumulation >3 mm/day
Contour - 1700m Elevation





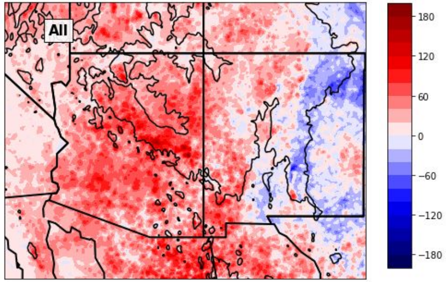
Conclusions

- Increase in seasonal NAM precipitation primarily composed of increases in intensity

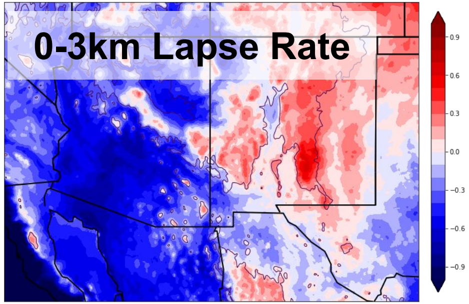


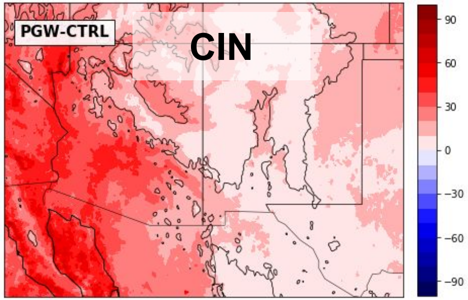
Conclusions

- Increase in seasonal NAM precipitation primarily composed of increases in intensity



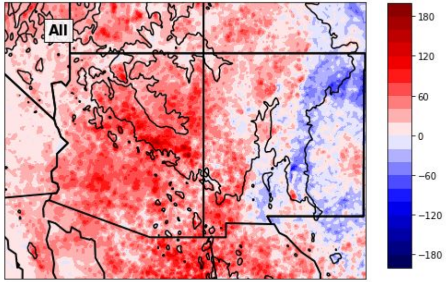
- Vertical warming acts to increase stability
    - Over regions of high terrain, surface warming and moistening overcomes this



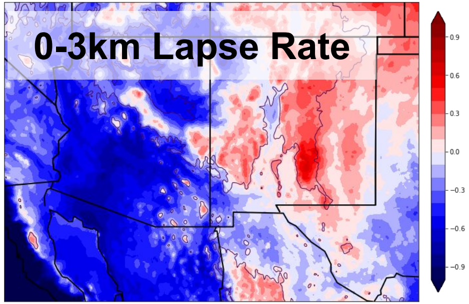


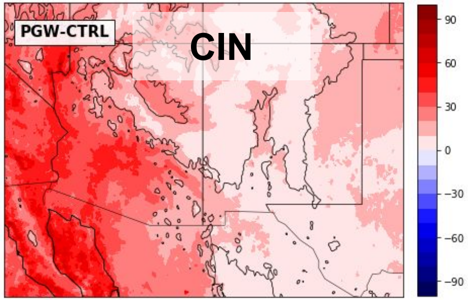
Conclusions

- Increase in seasonal NAM precipitation primarily composed of increases in intensity



- Vertical warming acts to increase stability
    - Over regions of high terrain, surface warming and moistening overcomes this





- Larger moisture concentrations make existing rainfall more intense