

The North American Monsoon in a Changing Climate

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Invited Presentation

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Photo credit: L. G. Bailey



UA SCIENCE
**Hydrology &
Atmospheric Sciences**



Presentation Outline

- Information about our department at UA
- North American monsoon climatology, importance
- Observed monsoon trends
- Projected changes
- Summary points



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**Hydrology &
Atmospheric Sciences**



Department of Atmospheric Sciences established in 1957, help oversee the establishment of the National Center for Atmospheric Research.

Department of Hydrology and Water Resources established in 1961, from Geology. The first autonomous department in the U.S. devoted to the study of water.

Departments combined in 2016, allowing us to better consider the integrated water cycle.



Current Climate Change Reports

<https://doi.org/10.1007/s40641-019-00135-w>

MONSOONS AND CLIMATE (Y MING, SECTION EDITOR)



Current and Future Variations of the Monsoons of the Americas in a Warming Climate

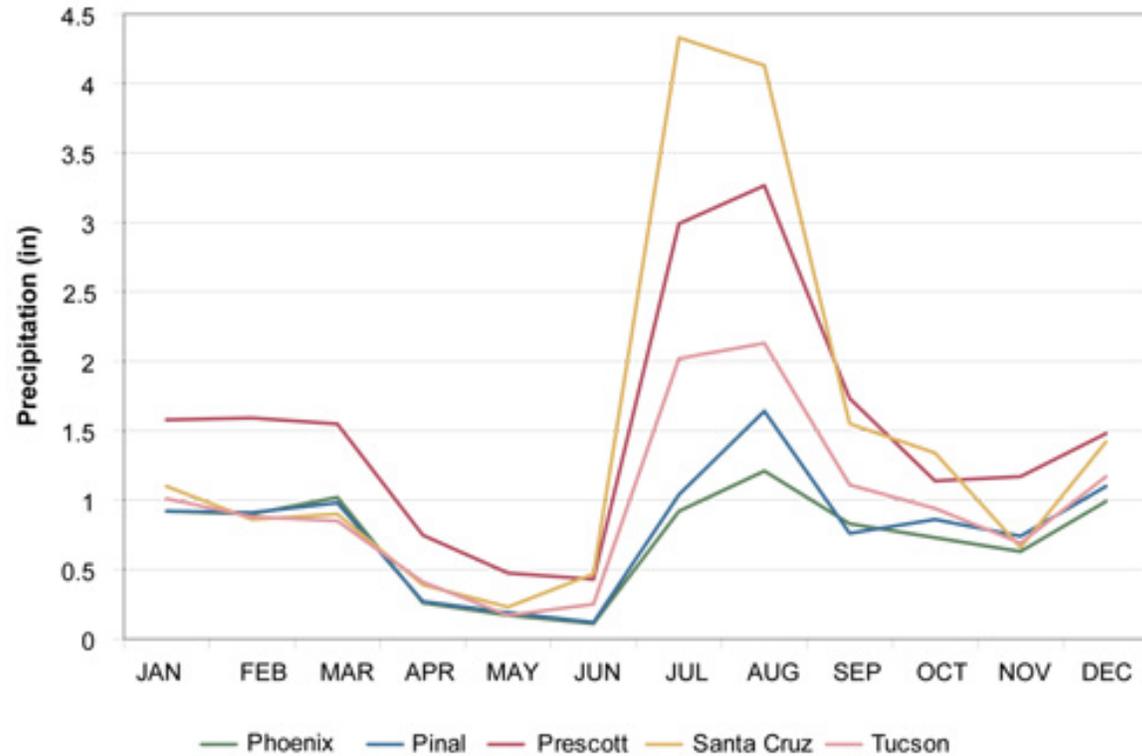
Salvatore Pascale^{1,2}  · Leila M. V. Carvalho³ · David K. Adams⁴ · Christopher L. Castro⁵ · Iracema F. A. Cavalcanti⁶

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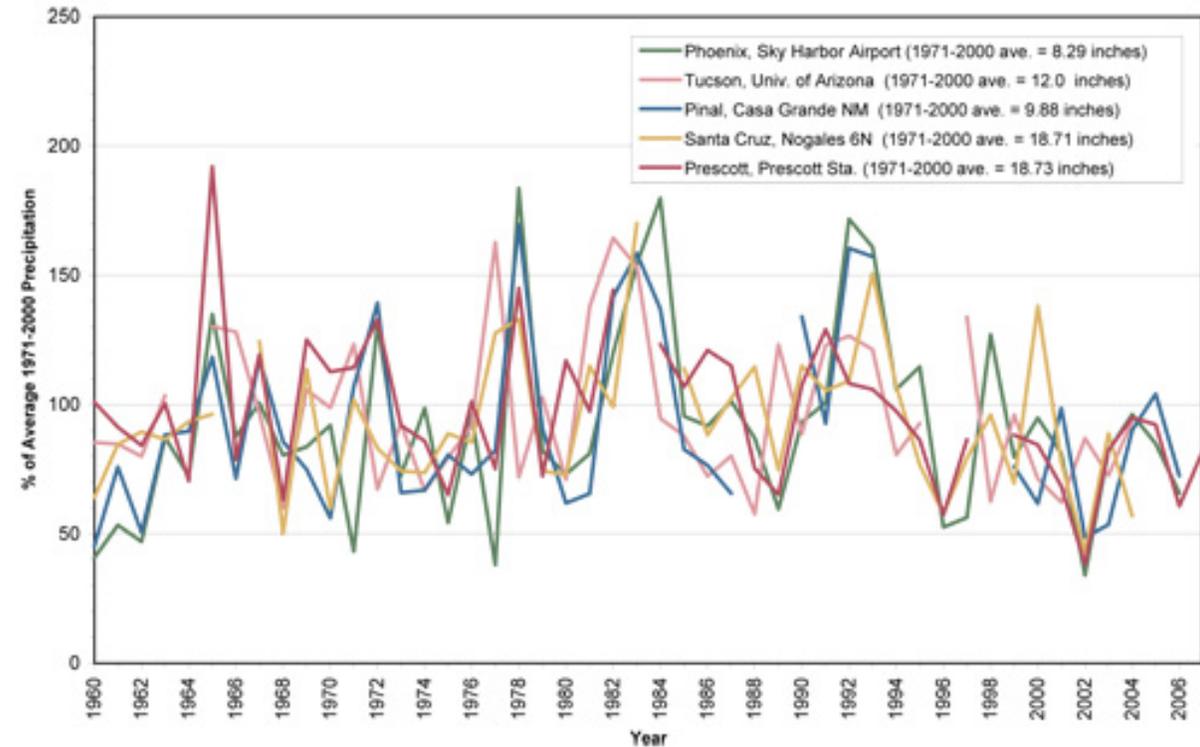


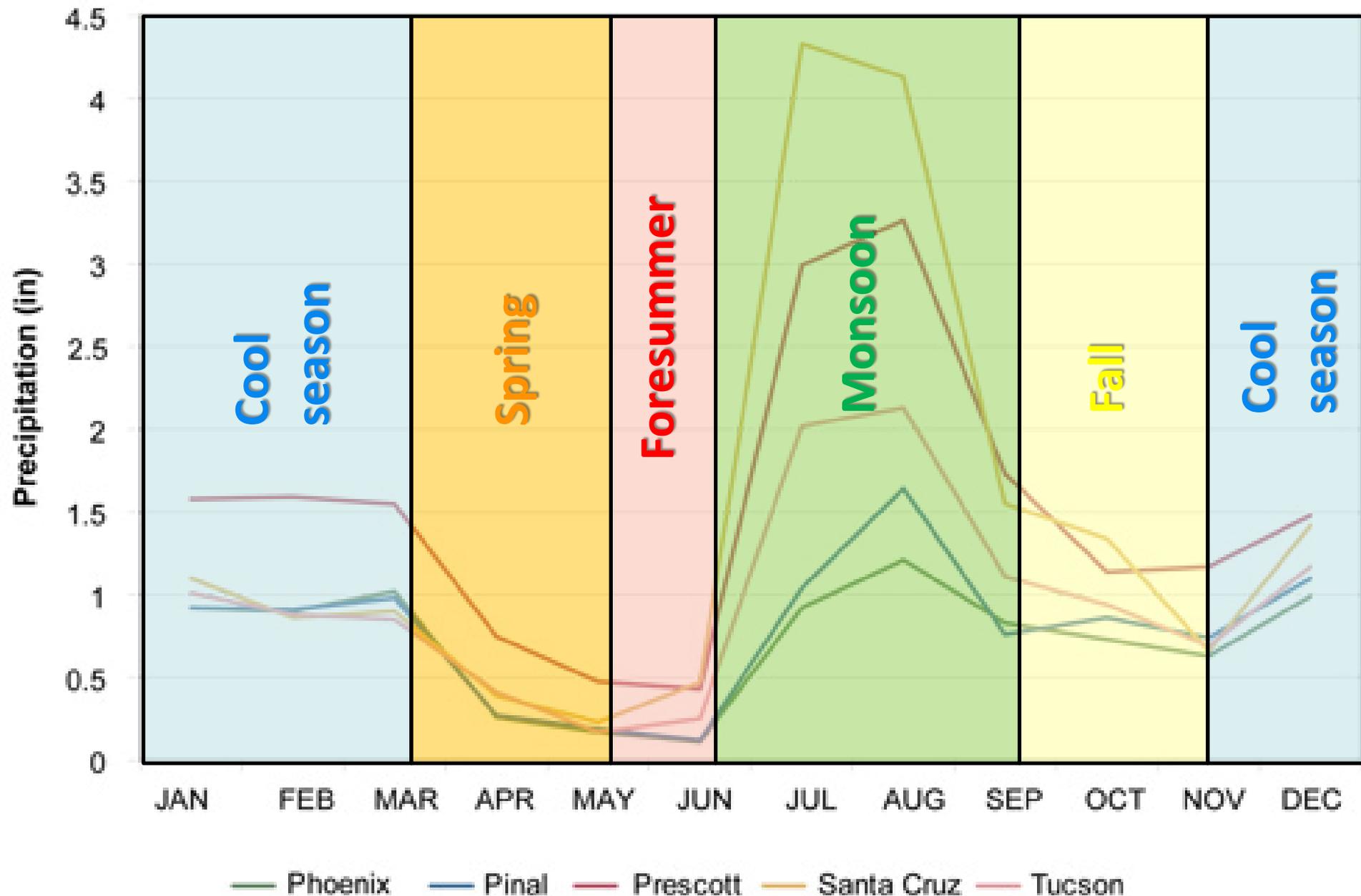
Precipitation across Arizona

Monthly average



Total annual (1990-2007)

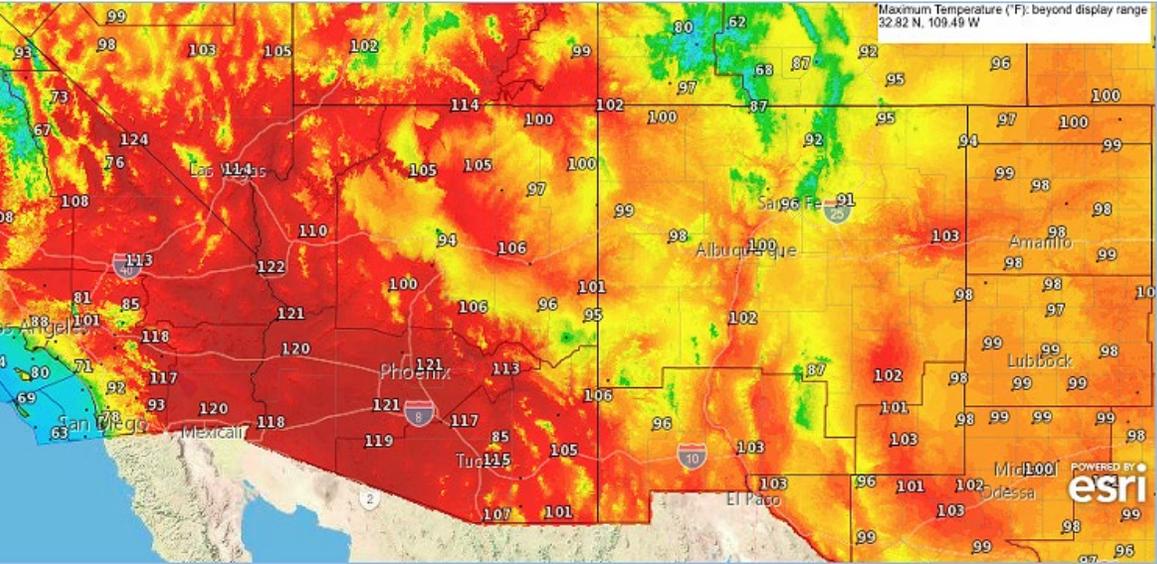




Foresummer or Pre-monsoon: late May - June

Hot, dry time of the year

*Southwest heat wave in June 2017:
Over 120° F in places*



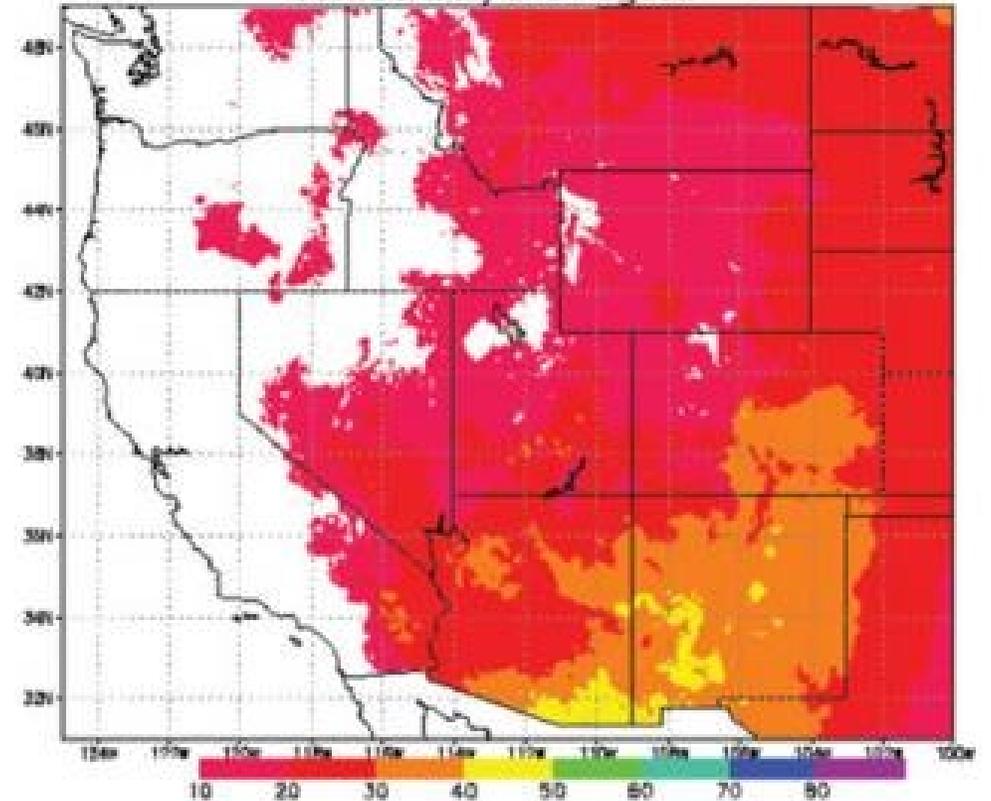
*Phoenix, Arizona: 4 million
One of 10 largest U.S. cities*



North American monsoon: July - September



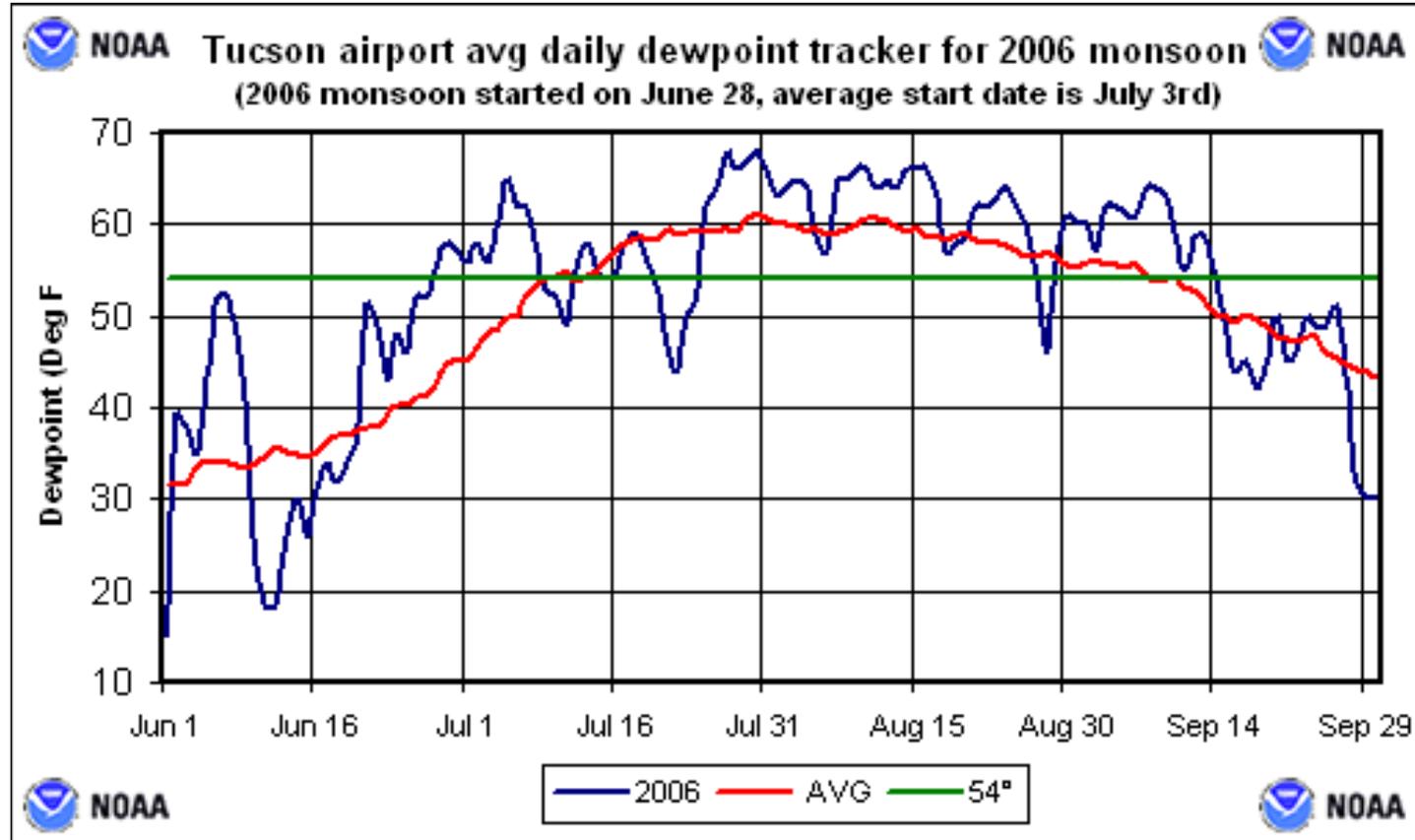
Percent of average annual precipitation that falls between July and August.



Figures courtesy of Western Regional Climate Center and based on PRISM data produced by the PRISM Climate Group at Oregon State University

From Climate Assessment for the Southwest (CLIMAS)

National Weather Service Monsoon Tracker



Old definition: monsoon onset defined as when dew point exceeds 54°F for three consecutive days.

North American monsoon: climatological evolution

Starts in June along the western slopes of the Sierra Madre Occidental, reaching Southwest U.S. by July. Ends September.

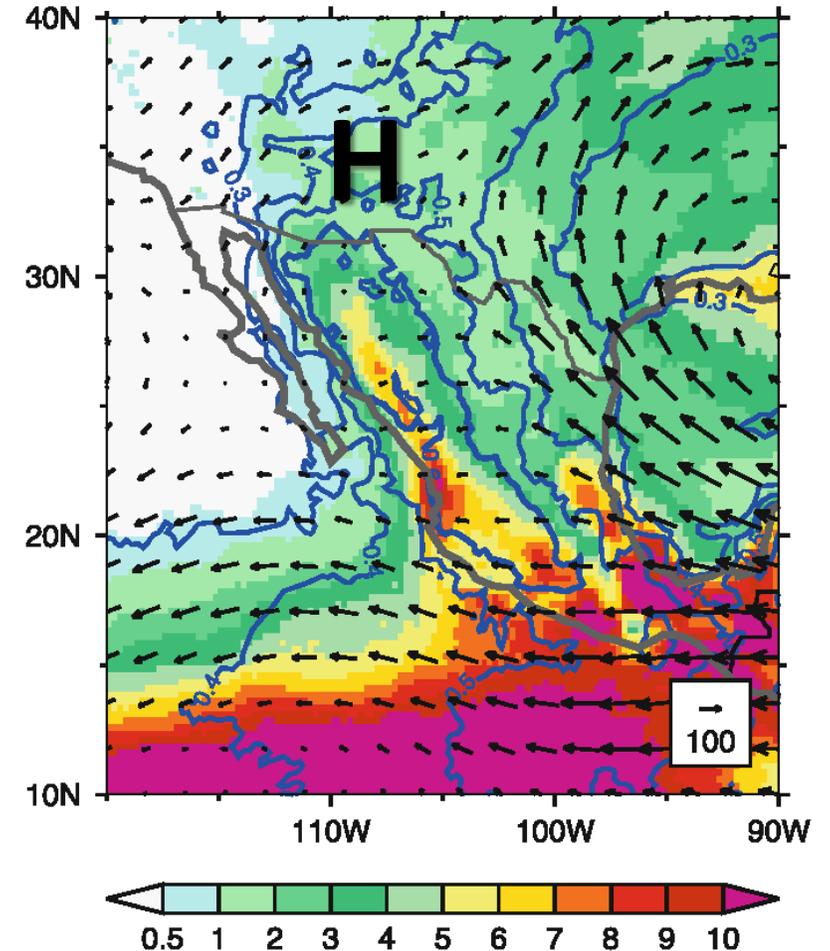
Follows the development and northward advance of subtropical (monsoon) ridge in western North America.

Moisture sources include East Pacific, Gulf of Mexico, and Gulf of California.

Heaviest precipitation occurs in elevated topography. Precipitation at lower elevations more intermittent, tied to 'bursts' of organized convection.

Boreal summer (JJA)

Mean precipitation (mm day^{-1})
Average integrated moisture flux ($\text{kg m}^{-1} \text{s}^{-1}$)



Pascale et al. (2019)

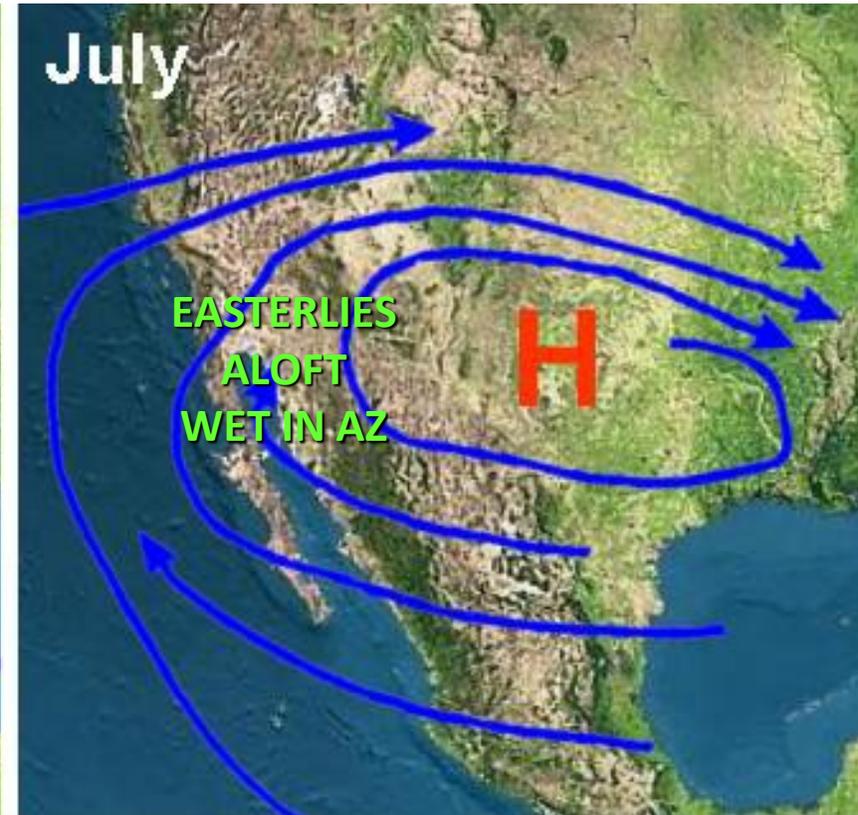
Monsoon ridge in 500-mb geopotential height pattern

Before monsoon



Westerlies aloft.
High pressure ridge to the south.
Little moisture at upper levels.

During Monsoon



Easterlies aloft.
High pressure ridge to north (and east)
Moisture transport from Gulf of Mexico



Climatological Importance of North American monsoon

Ecosystems, Biodiversity



Water resources, Agriculture



North American monsoon as driver of weather and climate extremes

Wildfire



Intense rainfall, Flash flooding



High winds, dust storms

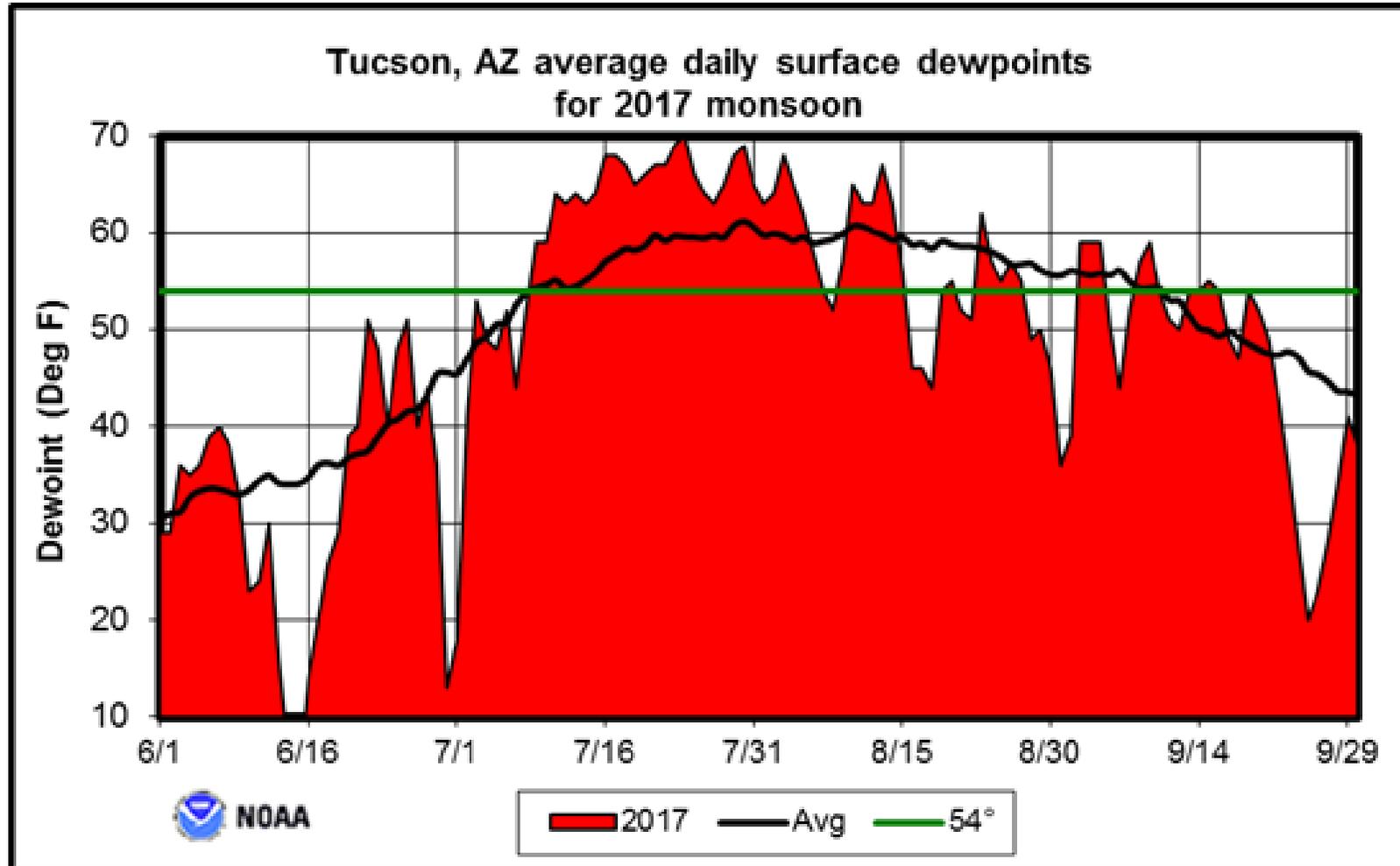


Lightning



Monsoon whiplash?

2017: **Hottest June** to **Wettest July!**



Here in Tucson...

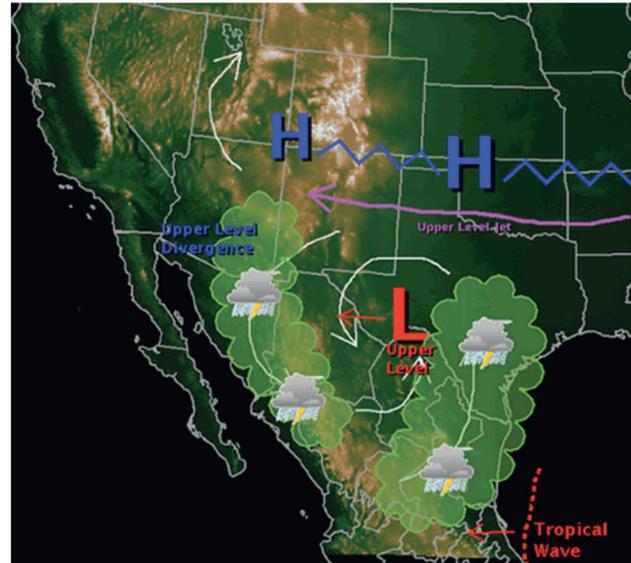
**No rain in June, reached
117° F**

Nearly 7 inches rain in July

More dramatic monsoon transitions also seem to be happening globally in last few years (e.g. India, South America).

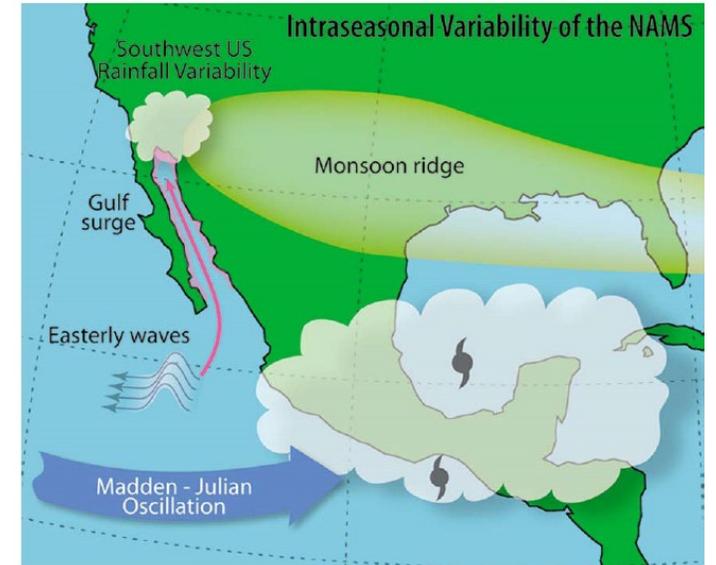
North American monsoon variability

Transient Inverted Troughs



Pytlak et al. (2005)

Gulf surges, MJO, easterly waves, tropical cyclones

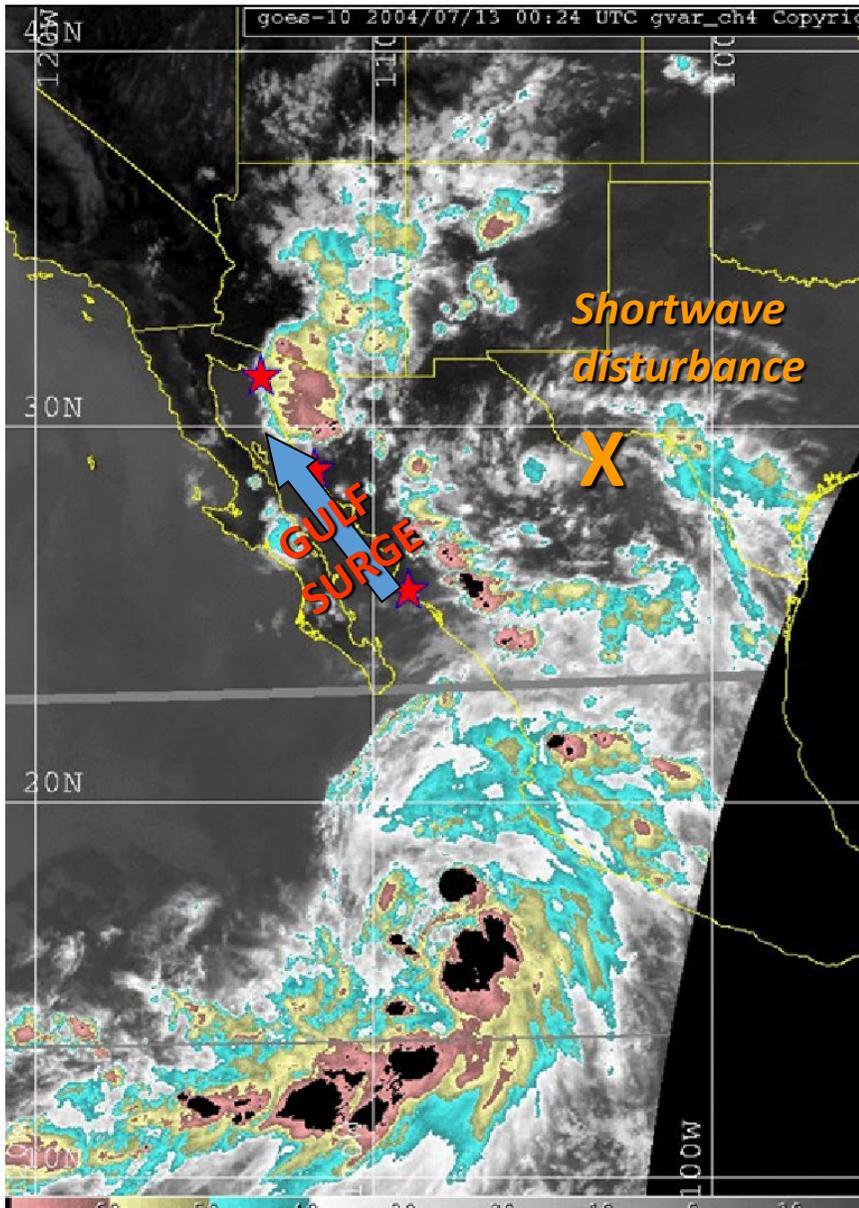


Maloney et al. (2008)

Atmospheric teleconnection responses



Ciancarelli et al. (2013)



Conditions for enhanced monsoon thunderstorms

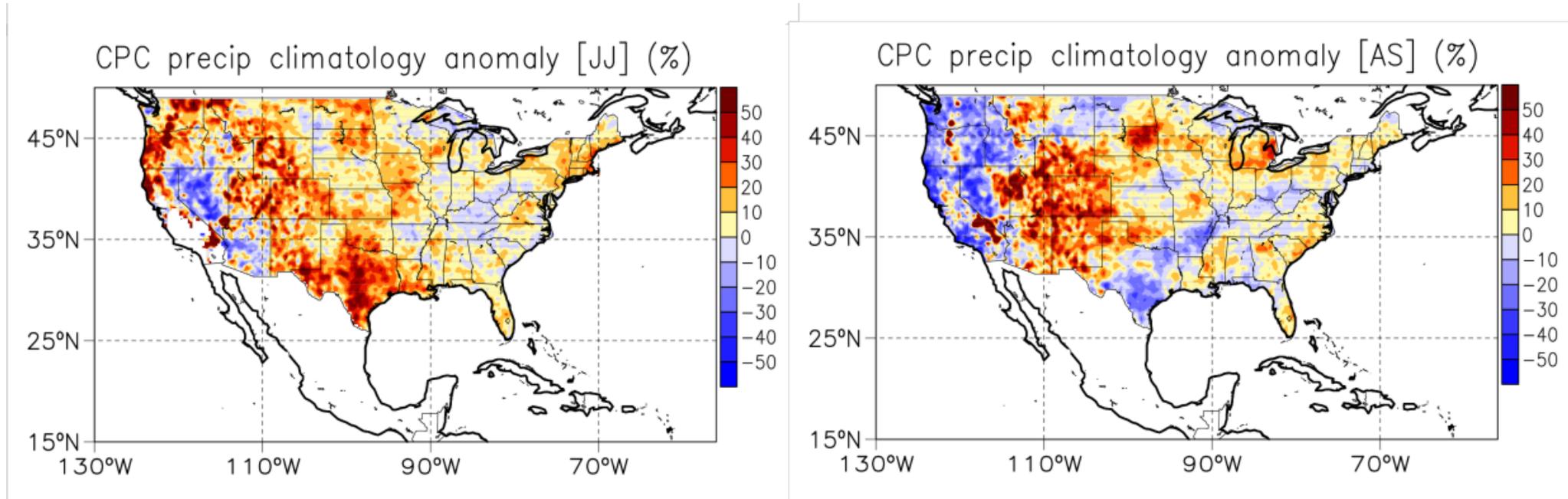
An upper-level disturbance (X) traveling around the monsoon ridge.

Low level-moisture surging up the Gulf of California

RESULT

Thunderstorms which originate on the Mogollon Rim intensify and move westward toward low deserts and the Colorado River Valley.

Observed Change in Early and Late Warm Season Precipitation Climatology: 1980-2010 minus 1950-1980



Recent observational record seems to comport with “wet gets wetter, dry gets drier idea”

Precipitation more ‘phased locked’ to terrain.

Chang et al. (2015)

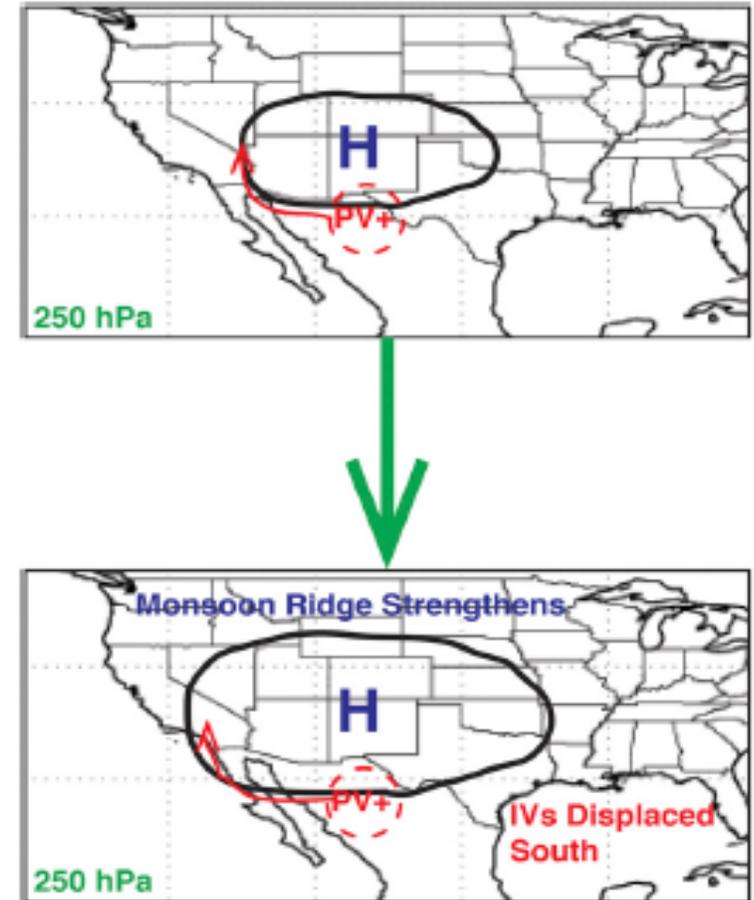
Observed Trends: North American monsoon

Observations suggest **small negative or no trends in mean monsoon precipitation** over the Southwest United States, **but greater spatial contrast in relation to terrain.**

Limited knowledge of what is happening in Mexico, the few studies suggest no significant changes in monsoon precipitation.

Expansion of the monsoon high, and shift to the northwest, is displacing transient inverted troughs further south.

Fewer but more intense precipitation events over the Southwestern United States.



Atmospheric Thermodynamic Conditions

Changes During the Last 30 Years

Long-term modeled and observed increases in instability, atmospheric moisture.

Changes consistent with radiosonde record.

Changes can be attributed to (anthropogenic) climate change

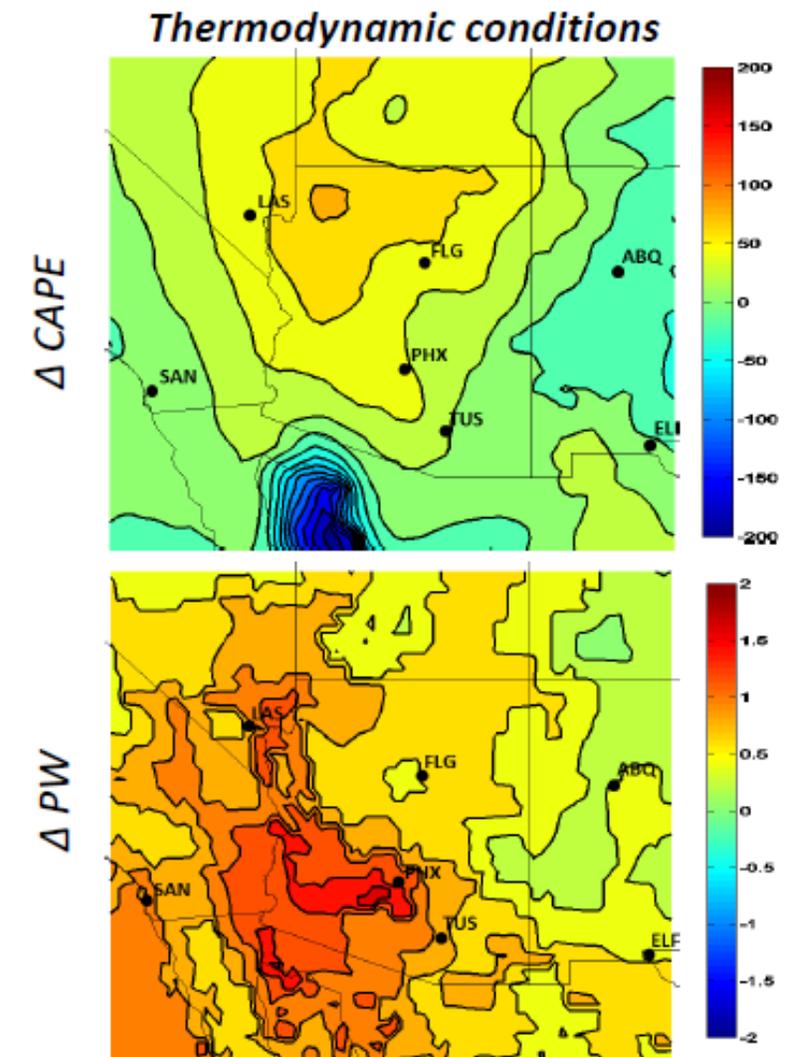
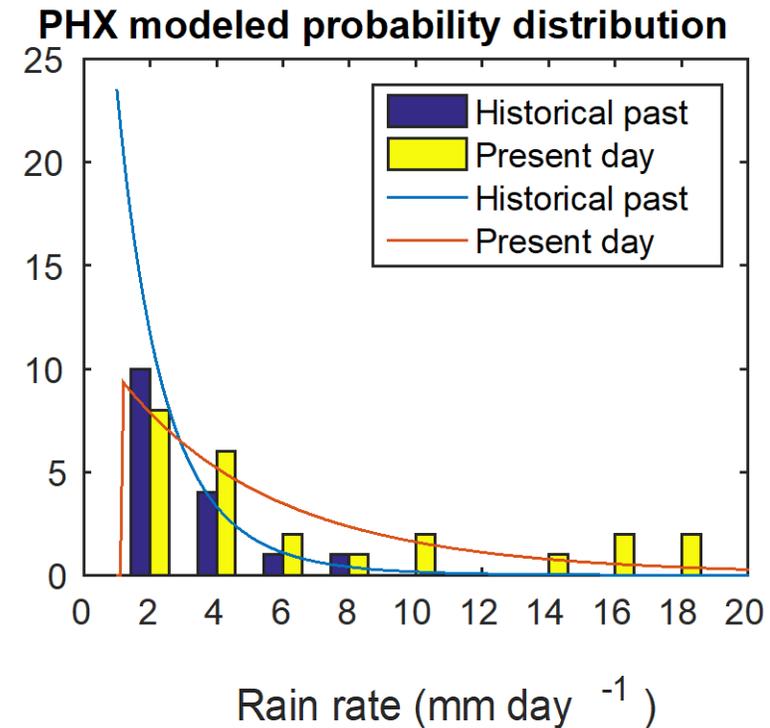
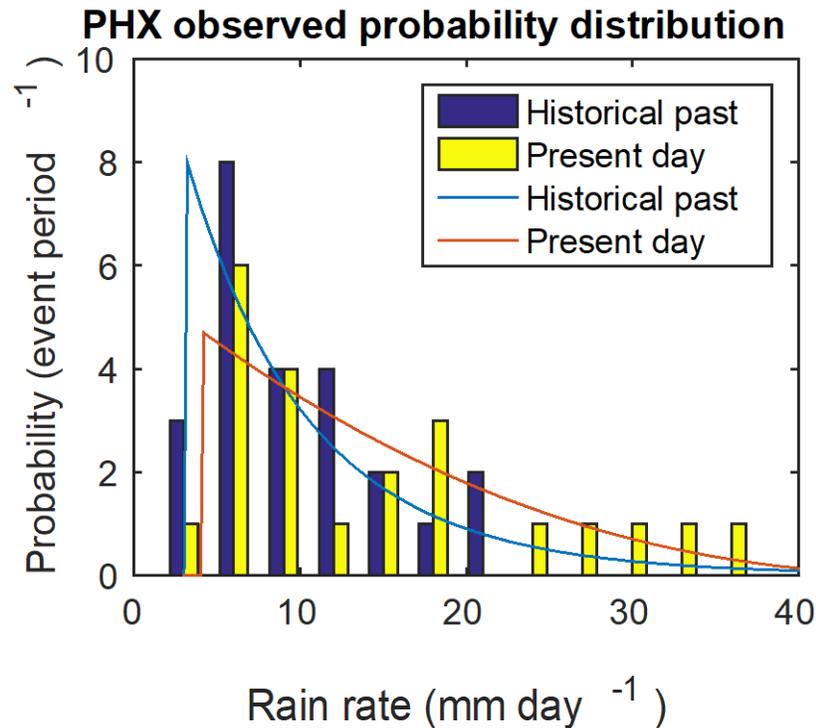


Figure 2: JA differences in downscaled reanalysis (1980-2010 minus 1950-1979) for convective available potential energy (CAPE, J kg^{-1}) and precipitable water (PW, mm). Operational radiosonde sites indicated. (Jares et al., in preparation)

Distribution of Extreme Daily Precipitation in Phoenix, Arizona

Lower Frequency, More Intense Events



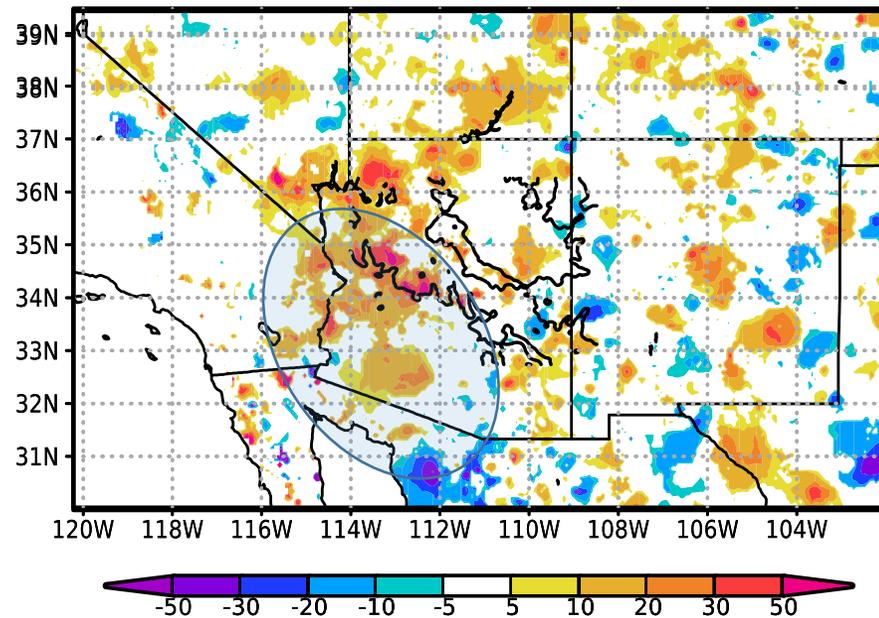
Notes: Historical past = 1950-1970; present day = 1990-2010
Results shown are for Phoenix, Arizona (PHX)

More Significant Changes in Extreme Precipitation

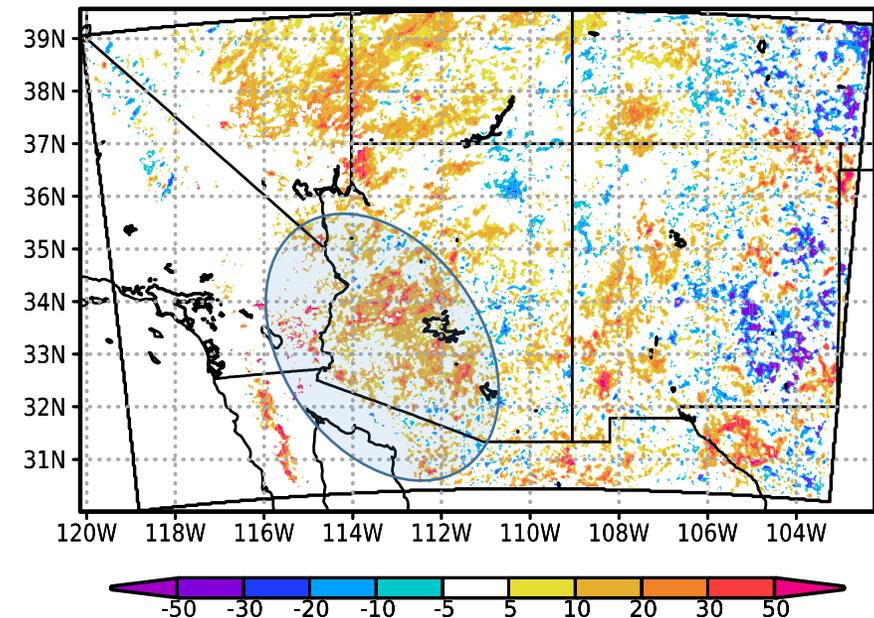
Due to more favorable thermodynamic environment with largest increases in areas most subject to MCS-driven precipitation

Note: *No explicit climate change attribution...*

Station observations



WRF model: $\Delta x = 2.5$ km (CPM)



Note: 1950-1970 vs. 1990-2010,
values in mm

Luong et al. (2017)

Projected changes: North American monsoon

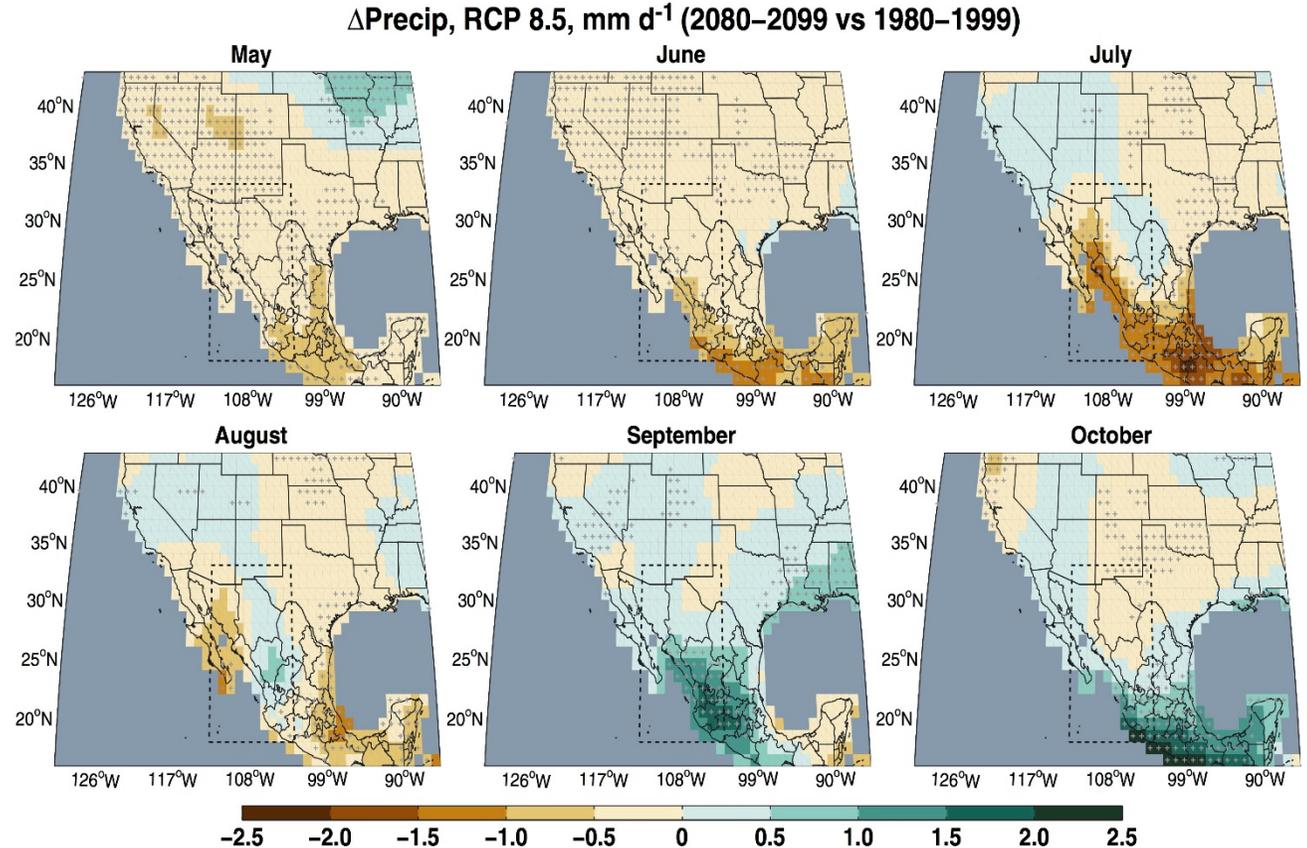
General agreement in CMIP5 models as to **drier monsoon and delayed onset**, shift to wetter conditions during Fall.

Delayed onset related to **overcoming larger stability barrier to convection**, due to stronger monsoon ridge.

Less agreement among regional models as to the sign of mean precipitation change.

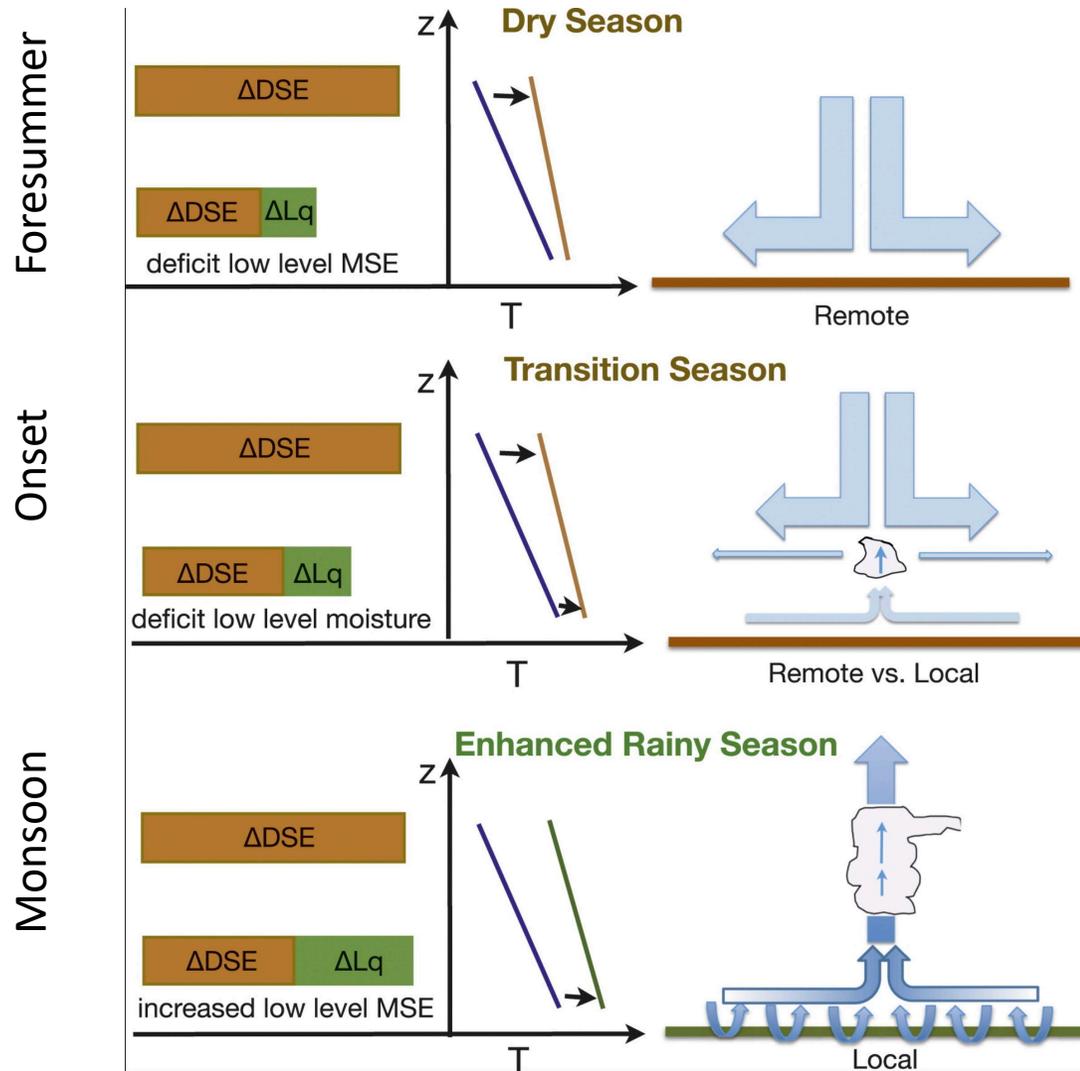
Emerging convective permitting modeling shows **increasing precipitation extremes, with greater confidence**.

Projected mean precipitation changes from CMIP5 Models



Cook & Seager (2014)

Local vs. remote mechanism: Which one dominates?



Insufficient surface sensible and latent heat flux to overcome upper-level stability barrier

Increased surface sensible heat flux. Decrease in upper-level stability barrier that allows convection to develop. *First bout deep convection in Arizona typically associated with an transient inverted trough.*

Increased surface sensible and latent heat flux, that is able to overcome the upper-level stability barrier the majority of the time and generate deep convection.

(Seth et al. 2013)

Limitations of global models in CMIP-type climate projections

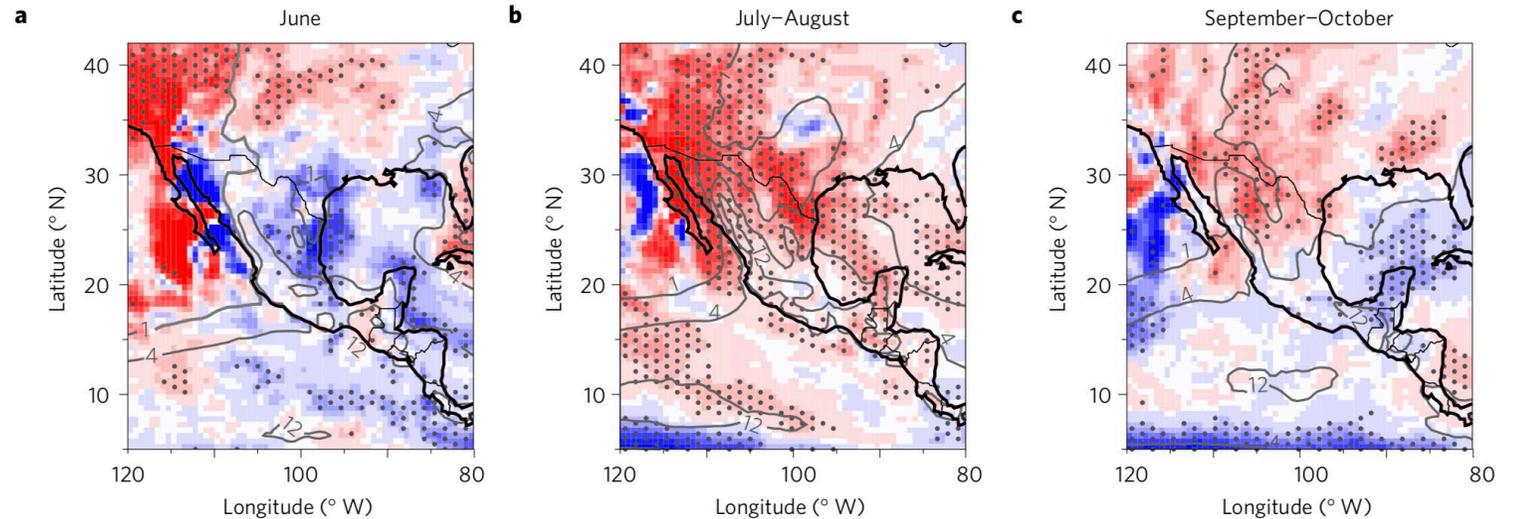
Resolution, precipitation physics

Large-scale dynamics, natural variability, and SST biases

Land-atmosphere coupling

Especially bears on relative lack of confidence in projections for North American monsoon

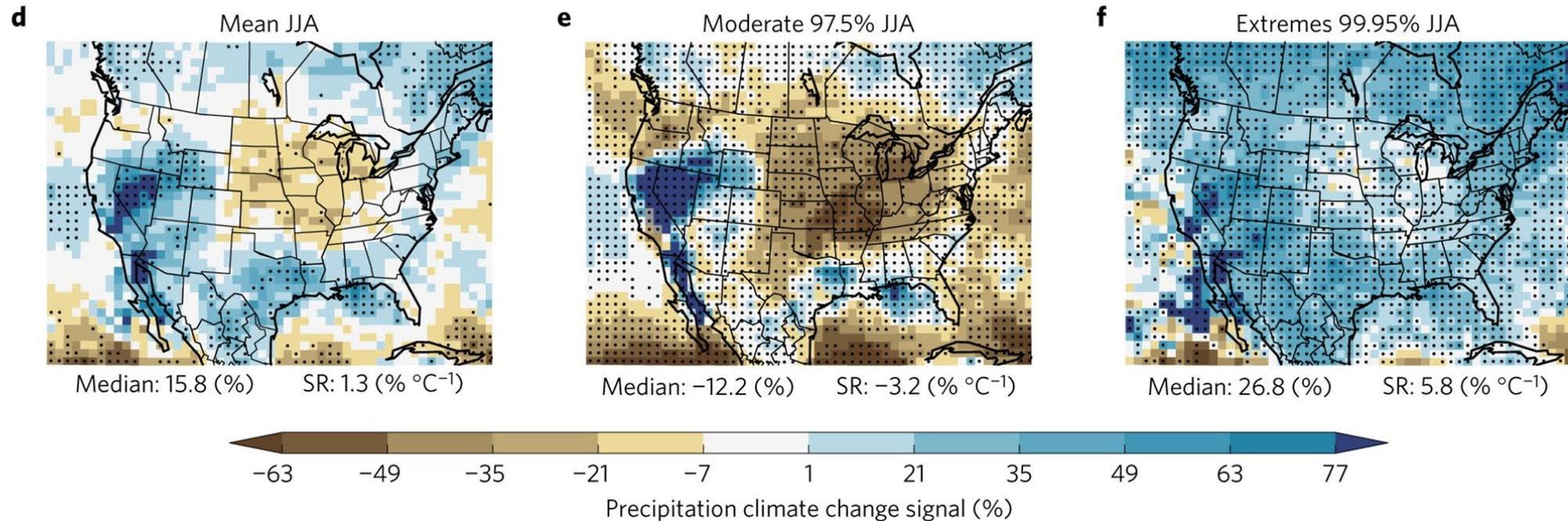
Impact of $2\times\text{CO}_2$ and SST biases on NAM precipitation change



Pascale et al. (2017)

Bias correction of global model SSTs results in greater projected drying of the monsoon, and no increase in monsoon precipitation in fall.

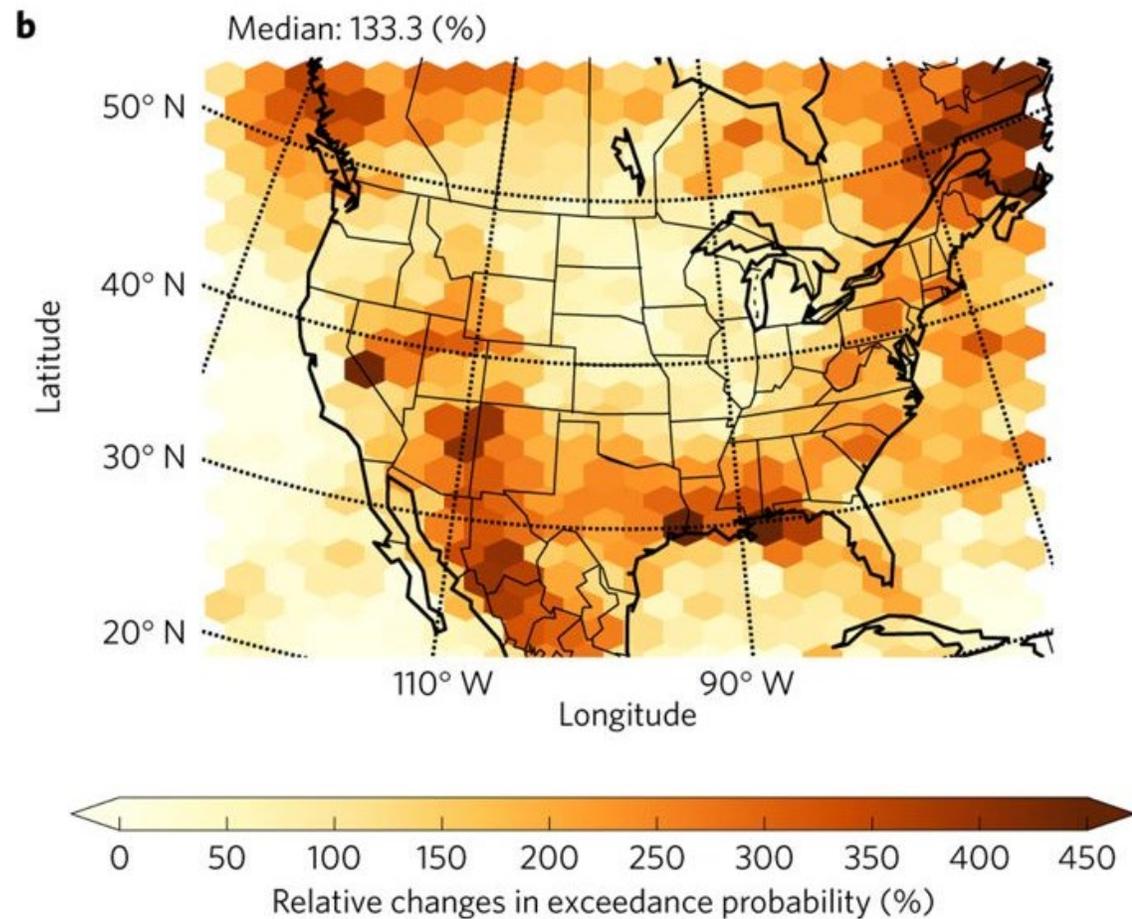
Results from convective-permitting pseudoglobal warming experiment over CONUS



Caveat: This type of climate projection accounts only for the thermodynamic change, but not changes in large-scale atmospheric dynamics

(Prein et al. 2016)

Changes in JJA precipitation exceedance probability keys in on NAM region as a 'hot spot'

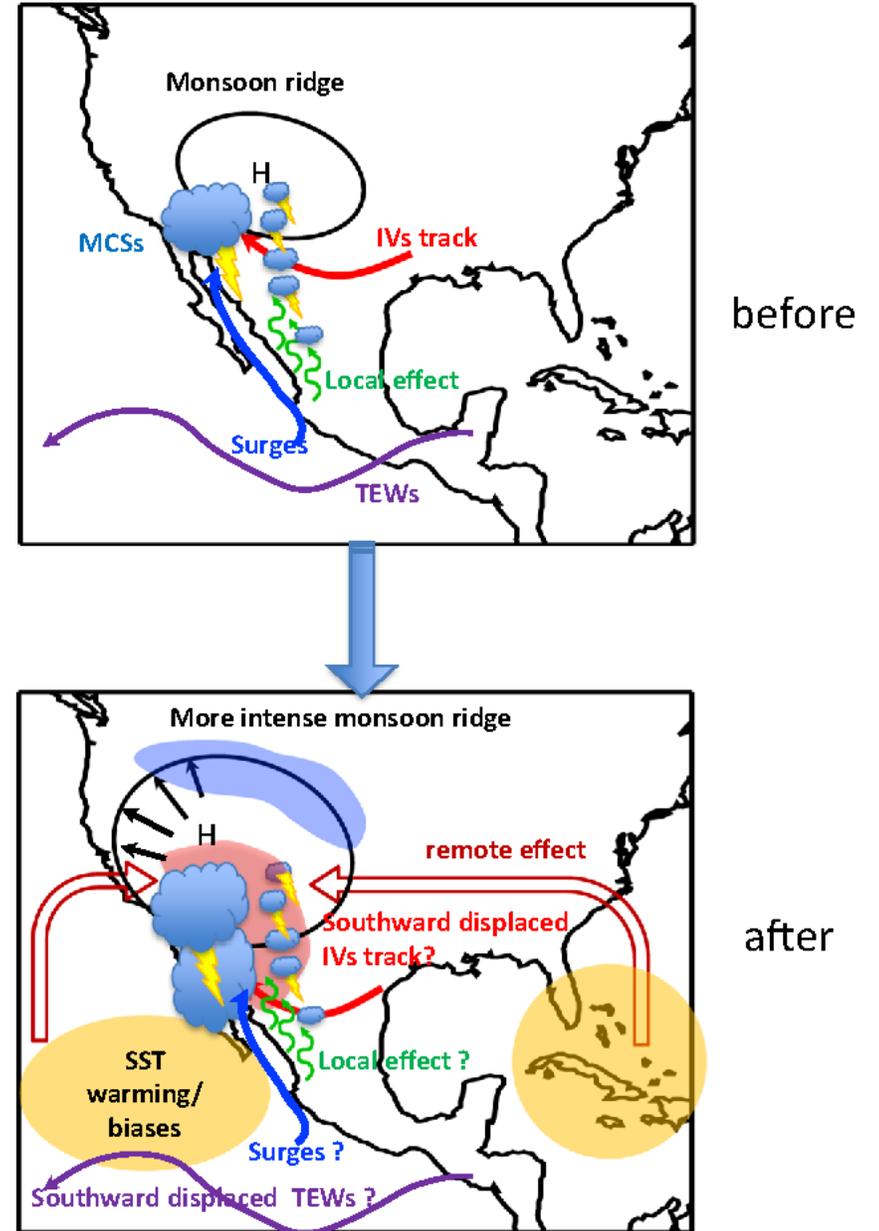


(Prein et al. 2016)

Summary: How is monsoon changing?

1. **Negative or null mean precipitation trends** in the last decades. No long-term delay trend yet.
2. **Monsoon ridge expanding and changing shape**, with implications for transient weather systems.
3. **Remote vs. local effect:** Stronger monsoon ridge acts to suppress convection over land, but counteracted by accelerated evapotranspiration. Which one dominates at what time during the summer?
4. **More intense organized convection** in a more favorable thermodynamic environment, realized by convective-permitting modeling.

And we need to investigate idea of monsoon whiplash...



(Pascale et al. 2019)