The more extreme nature of North American monsoon precipitation in the Southwestern United States

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Invited Presentation

WRRC Brown Bag

17 April 2018

Outline

- Monsoon weather hazards
- Severe weather monsoon meteorology
- High resolution modeling approach, performance
- Changes in atmospheric environment, extreme weather
- Information translation
- Concluding points

Acknowledgement: Funding from Strategic Environmental Research and Development Program (SERDP), Resource Conservation and Resiliency (Project RC-2205).

Monsoon Severe Weather Hazards
Effects of Anthropogenic Climate Change?

<u>Forecast concerns</u>

- Precipitation amount
- Precipitation intensity
- Wind gusts (outflow boundaries)
- Spatial location
- Timing

Phoenix Dust Storm: 5 July 2011

SERDP
DOD ▪ EPA ▪ DOE

THE HUNTER'S EDGE
25th OPERATIONAL WEATHER SQ

14TH WEATHER SQUADRON

16TH WEATHER SQUADRON

<u>**UA Project Team**</u>: Hsin-I Chang, Tim Lahmers (M.S.), Thang Luong (Ph.D.), Carlos Carrillo (Ph.D.), Megan Jares (M.S.), Jeremy Mazon (M.S.), Jennifer Stutler (M.S.), Bill Cassell (M.S.), Mike Leuthold

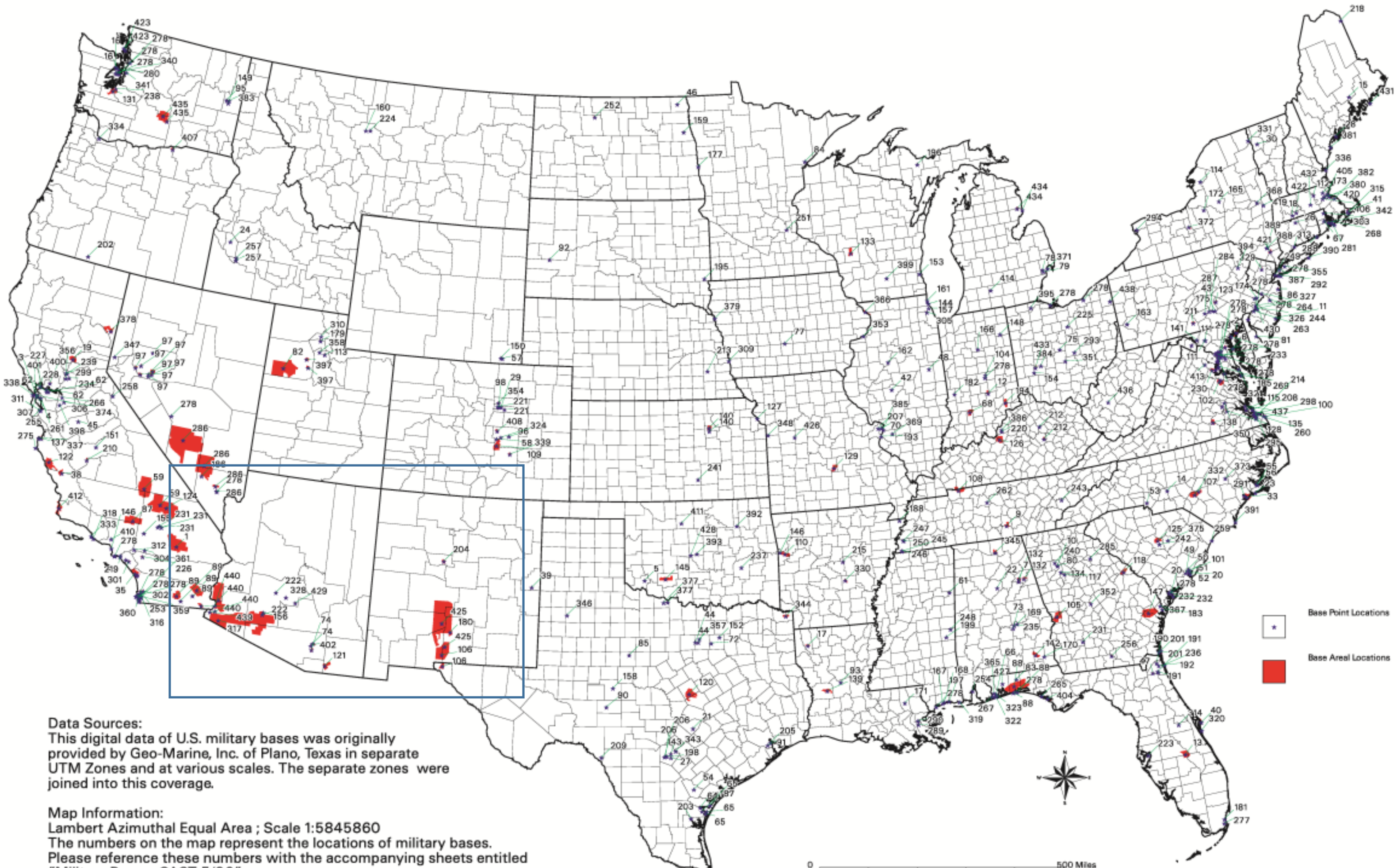
25th OWS Terminal aerodrome forecast (TAF) Weather Watch and Warning Criteria

Weather Watches					
Watch Type	Criteria	Area Affected	Desired Lead Time	Mission Impact (other than those stated in AFMAN 15-129)	Issued By
Tornado	Tornado or Funnel Cloud	Aerodrome (5NM)	As potential warrants		OWS
Damaging Winds	Winds >= 50 kts	Aerodrome (5NM)	As potential warrants		OWS
Hail	>= ¾ inch	Aerodrome (5NM)	As potential warrants		OWS
Freezing Precipitation	Any	Aerodrome (5NM)	As potential warrants		OWS
Heavy Snow	>= 2" in 12 hrs	Aerodrome (5NM)	As potential warrants		OWS
Heavy Rain	>= 2" in 12 hrs	Aerodrome (5NM)	As potential warrants		OWS
Lightning	Potential Within 5 nm	Aerodrome (5NM)	30 minutes		OWS
Lightning	Within 5 nm of Aerospace Maintenance and Regeneration Group (AMARG)	Aerodrome (5NM)	30 minutes		OWS

Weather Warnings					
Warning Type	Criteria	Area Affected	Desired Lead Time	Mission Impact (other than those stated in AFMAN 15-129)	Issued By
**Tornado	Tornado or Funnel Cloud	Aerodrome (5NM)	30 minutes		OWS
**Damaging Winds	Winds >= 50 kts	Aerodrome (5NM)	60 minutes		OWS
**Strong Winds	Winds 35-49 kts	Aerodrome (5NM)	60 minutes		OWS
**Hail	>= ¾ inch	Aerodrome (5NM)	60 minutes		OWS
**Freezing Precipitation	Any	Aerodrome (5NM)	90 minutes		OWS
**Heavy Snow	>= 2" in 12 hrs	Aerodrome (5NM)	90 minutes		OWS
Heavy Rain	>= 2" in 12 hrs	Aerodrome (5NM)	90 minutes		OWS
**Lightning	Within 5 nm of Runway Complex	Aerodrome (5NM)	Observed		WF
Lightning	Within 5 nm of AMARG	Aerodrome (5NM)	Observed		WF
** NOTE: 355 OSS/OSW and/or DMAFB CP will ensure these WWA criteria are sent to the NAOC POC.					

NOTES:
*ALL OBSERVED WEATHER WARNINGS AND ADVISORIES WILL BE ISSUED BY THE WEATHER FLIGHT DURING REGULAR DUTY HOURS. OWS WILL ISSUE OBSERVED WARNINGS/ADVISORIES WHEN THE WF IS NOT ON DUTY

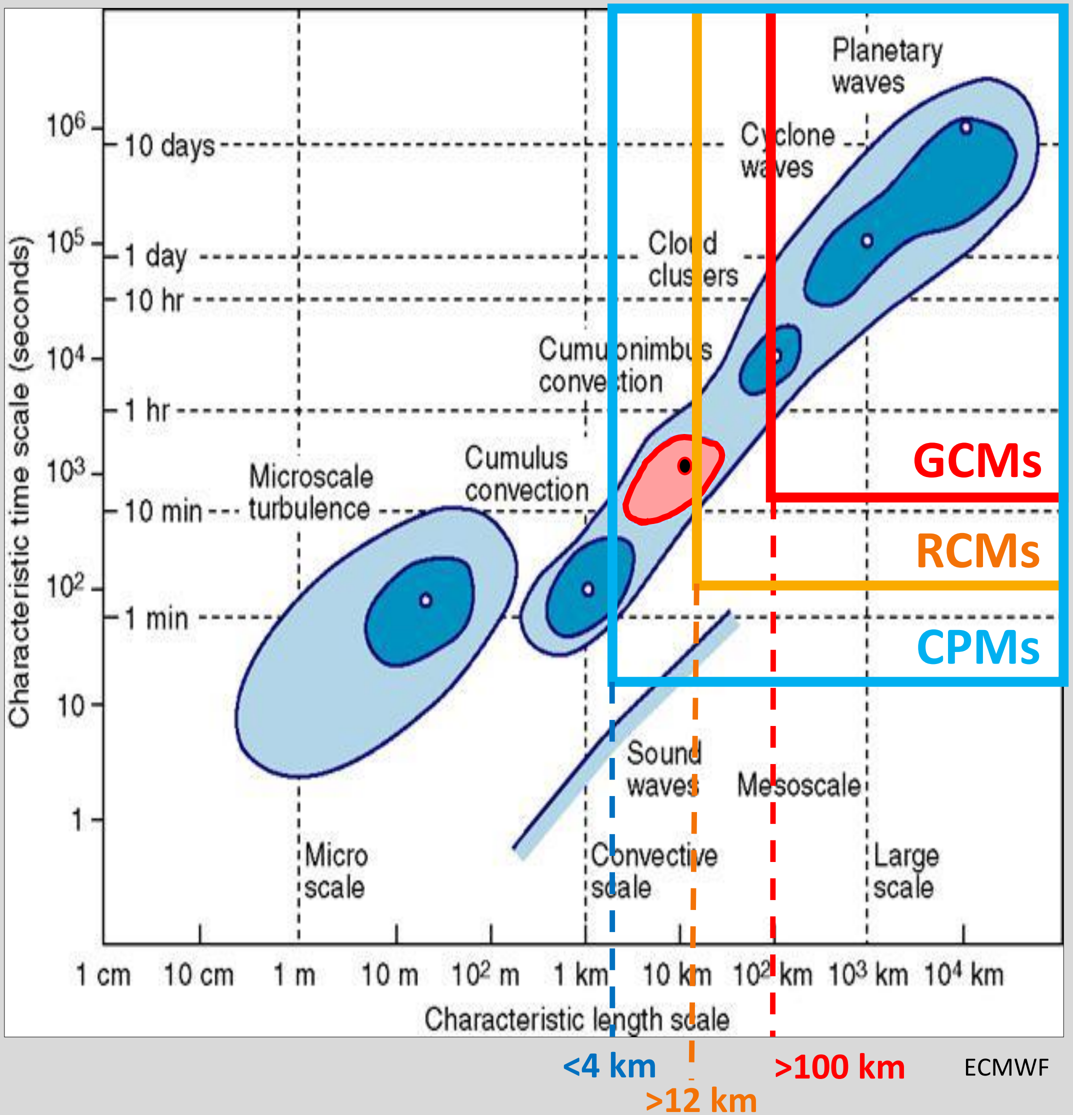
Military Bases in the Continental United States



Data Sources:
This digital data of U.S. military bases was originally provided by Geo-Marine, Inc. of Plano, Texas in separate UTM Zones and at various scales. The separate zones were joined into this coverage.

Map Information:
Lambert Azimuthal Equal Area ; Scale 1:5845860
The numbers on the map represent the locations of military bases.
Please reference these numbers with the accompanying sheets entitled "Military Bases- CAST 5/96".

Convection Permitting Models (CPMs)



CPM grid spacing ≤ 4 km

Weather forecasting

- Weisman et al. 1997
- Done et al. 2004

Climate

- Langhans et al. 2012

Courtesy Andreas Prein

What are the prerequisite meteorological conditions for strong monsoon thunderstorms?

Thermodynamic Criteria: Heat + Moisture

<u>Atmospheric Instability</u>

Cool the atmosphere aloft, warm atmosphere below
Facilitates development of vertically developed, cumuliform clouds

Convective available potential energy (CAPE)

<u>Atmospheric moisture</u>

Upper-level moisture: from easterly flow aloft
Low-level moisture: typically from surges of moisture from Gulf of California

Column integrated precipitable water (PW)

Monsoon Thunderstorms in Arizona

Monsoon thunderstorms at Kitt Peak at mature stage with gust fronts.

Forced by the diurnal mountain valley circulation

Form over the mountains during late morning to early afternoon

Reach mature stage by about mid-afternoon.

(*Photo taken around 3pm)*

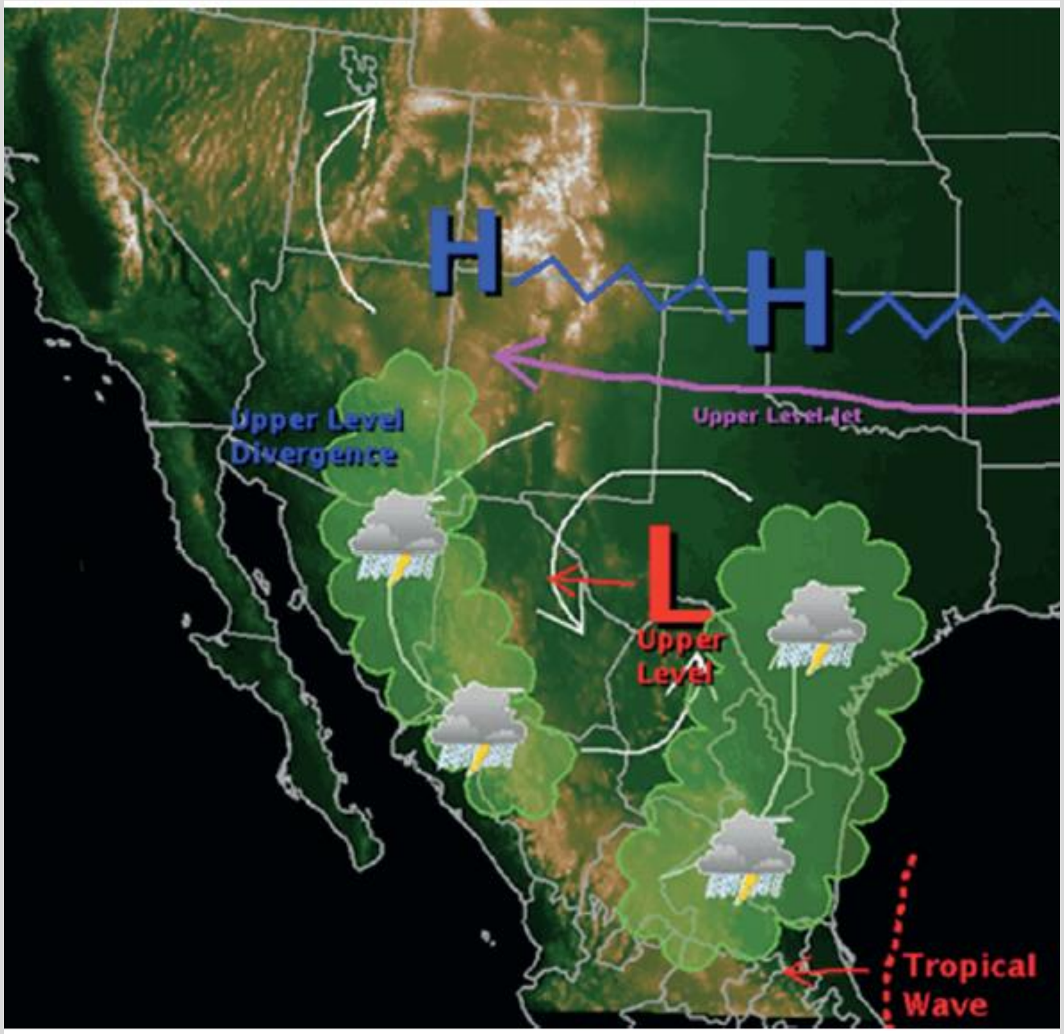
Dynamic criteria

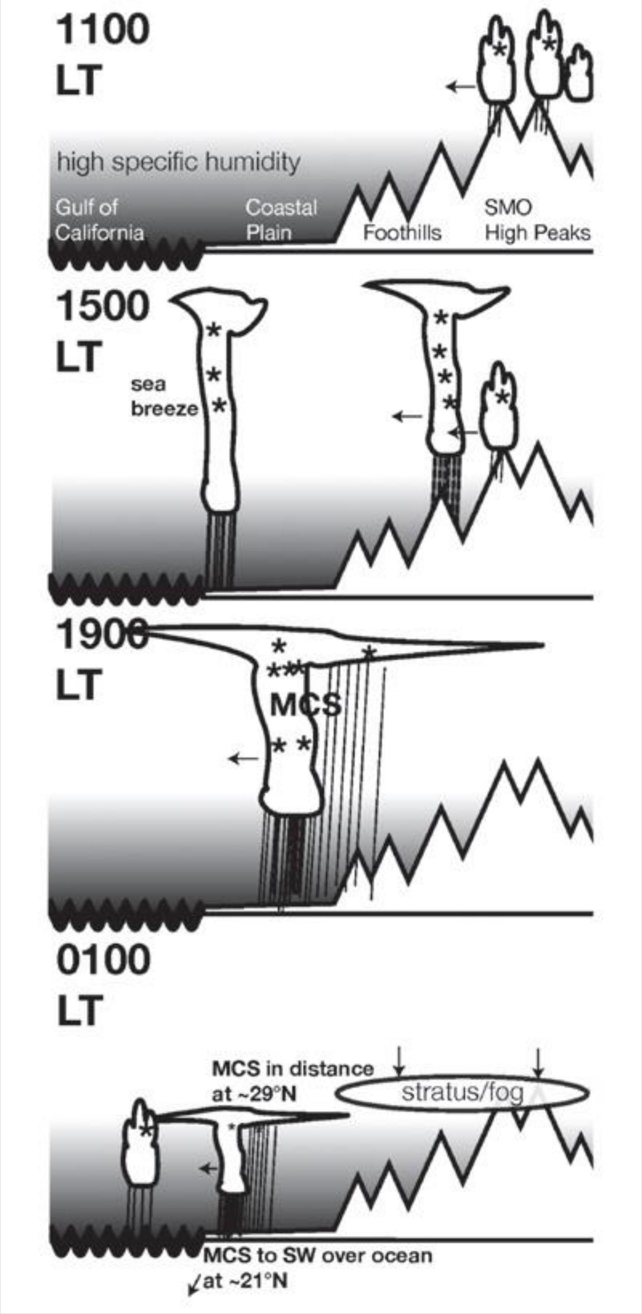
Monsoon ridge positioning
+
Upper-level disturbance (inverted trough)
+
Gulf surge

=

Large-scale upward motion
+
Vertical wind shear
+
Influx of low level moisture

Inverted trough: Favors upward motion and vertical wind shear





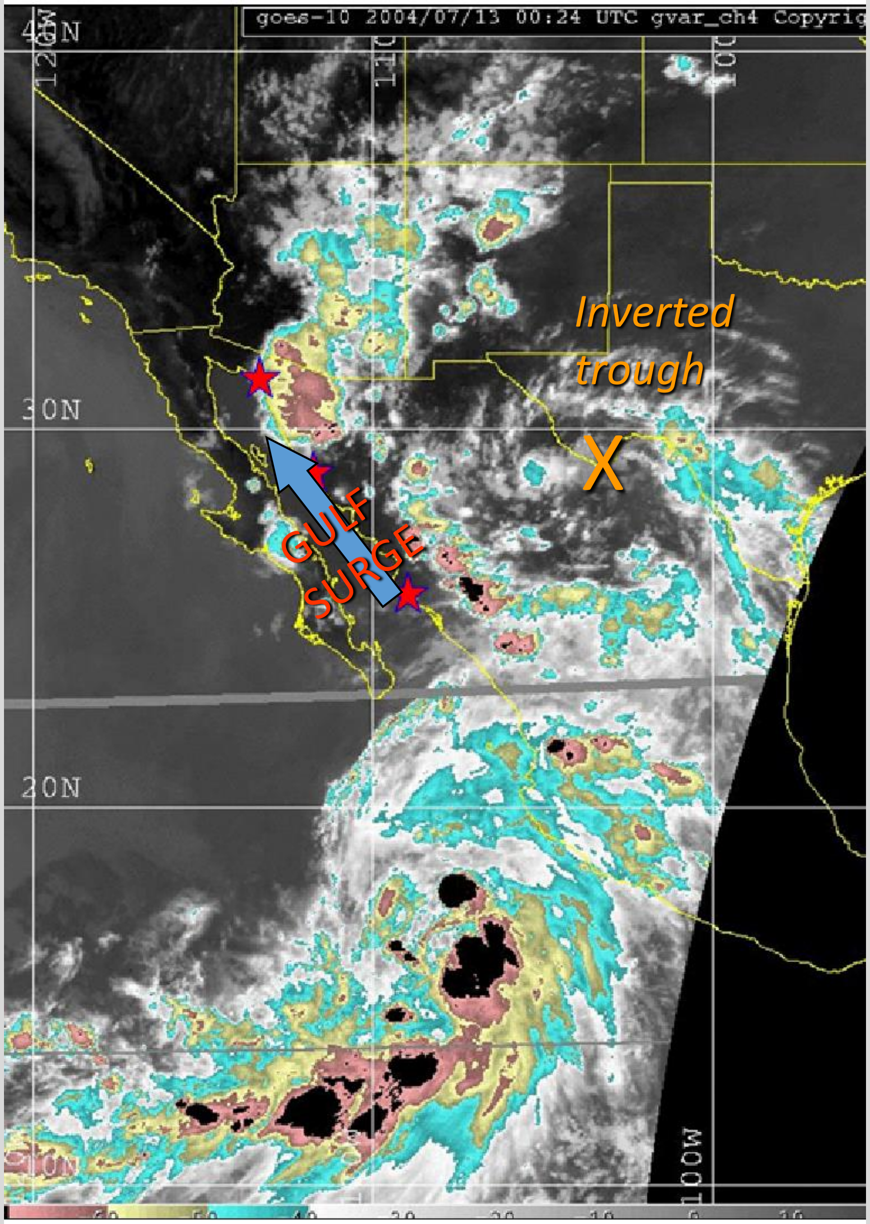
Nesbitt et al. (2008)

Convective organization and propagation

Convective clouds form over the mountains in the morning.

By afternoon and evening storms propagate to the west towards the Gulf of California where they can organize into mesoscale convective systems if there is sufficient moisture and instability.

It's likely that a resolution less than 5 km is necessary to represent this process correctly in regional models. Global models pretty much fail.



Conditions for enhanced monsoon thunderstorms NAME IOP 2: July 2004

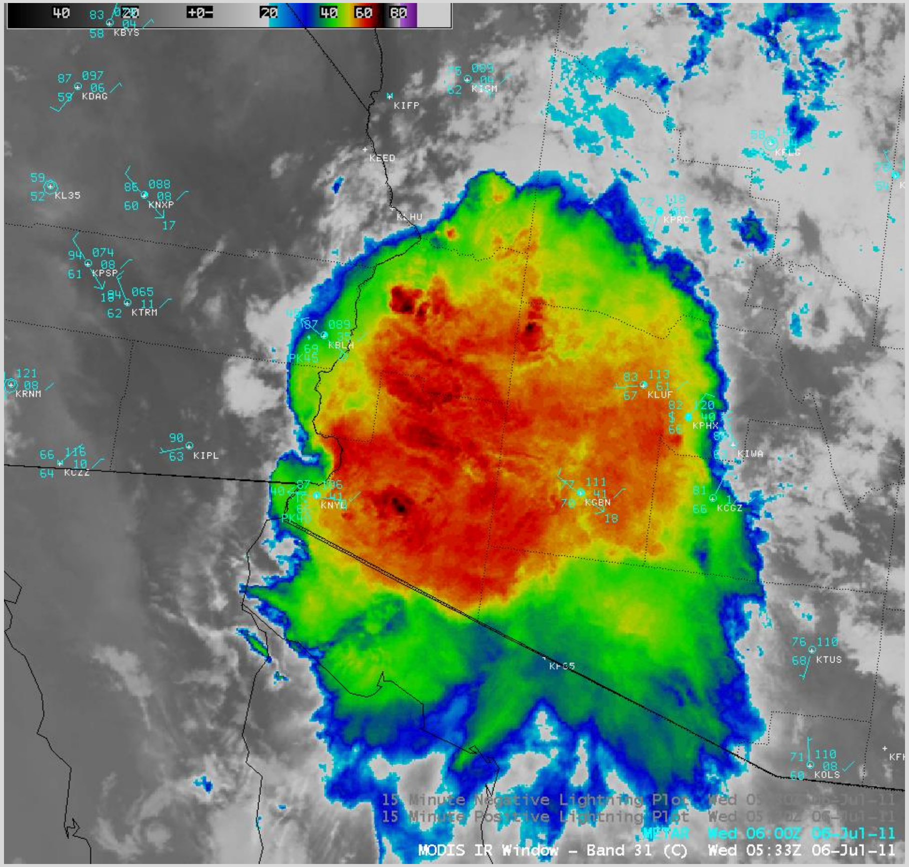
An inverted trough (X) traveling around the monsoon ridge.

Low level-moisture surging up the Gulf of California

<u>*RESULT*</u>

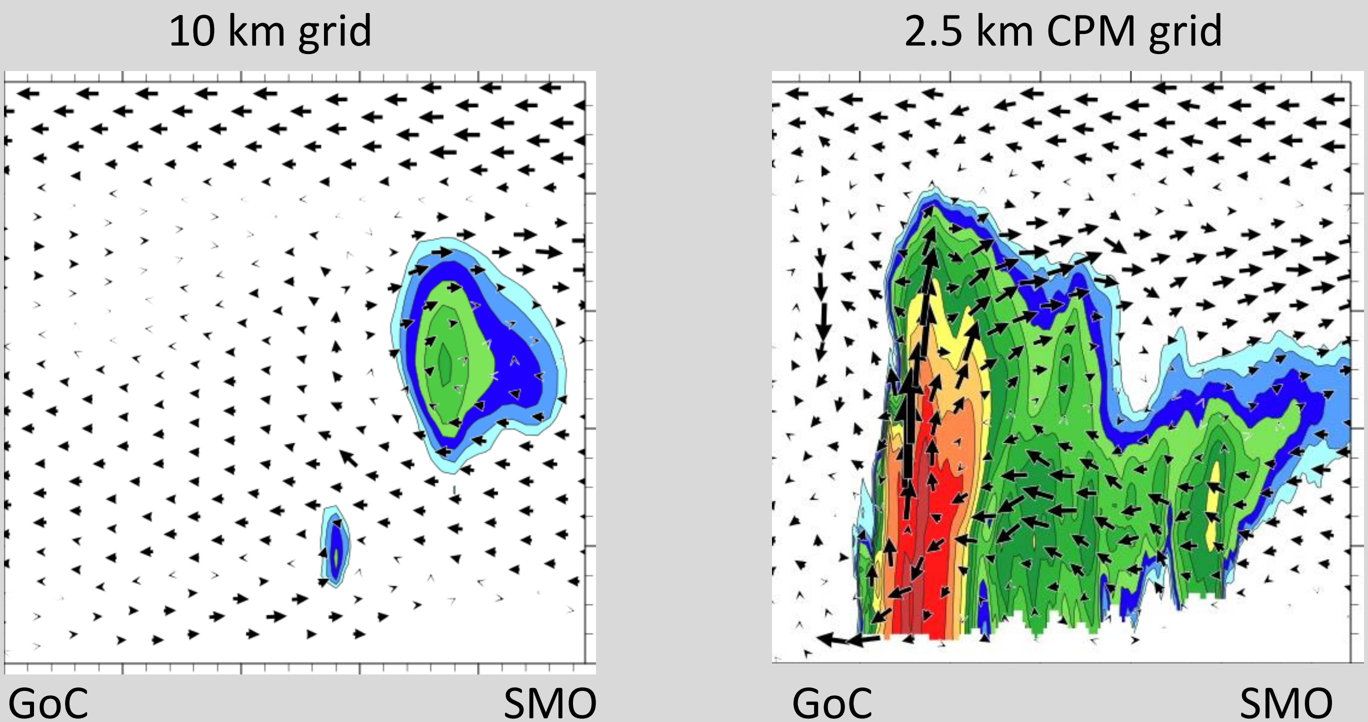
Thunderstorms which originate on the Mogollon Rim intensify and move westward toward low deserts and the Colorado River Valley.

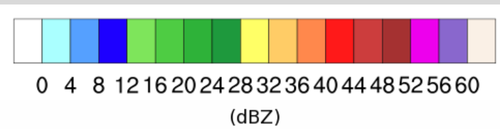
Mesoscale convective system associated with 5 July 2011 Phoenix dust storm



http://cimss.ssec.wisc.edu/goes/blog/archives/8409

Difference in WRF model simulated radar reflectivity for NAME IOP2 case: 3 UTC 14 July 2004 Vertical cross section through model depth from Sierra Madre Occidental to Gulf of California at 29.5°N

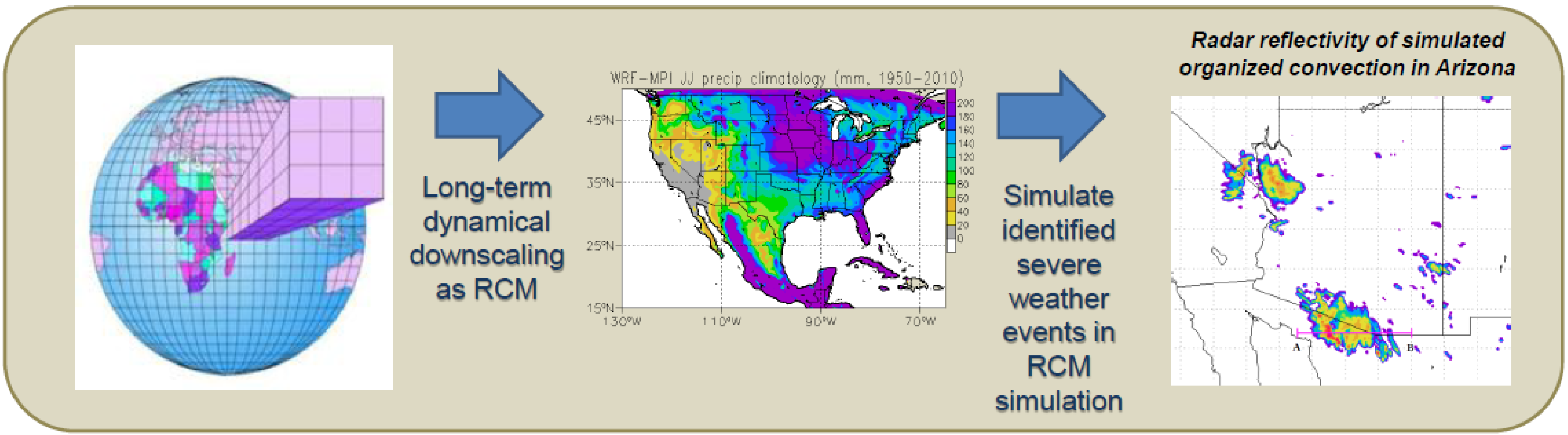




Cassell et al. (in revision)

Wind vectors scale with ratio of 10:1 in horizontal to vertical.

Methodological approach using regional convective-permitting modeling

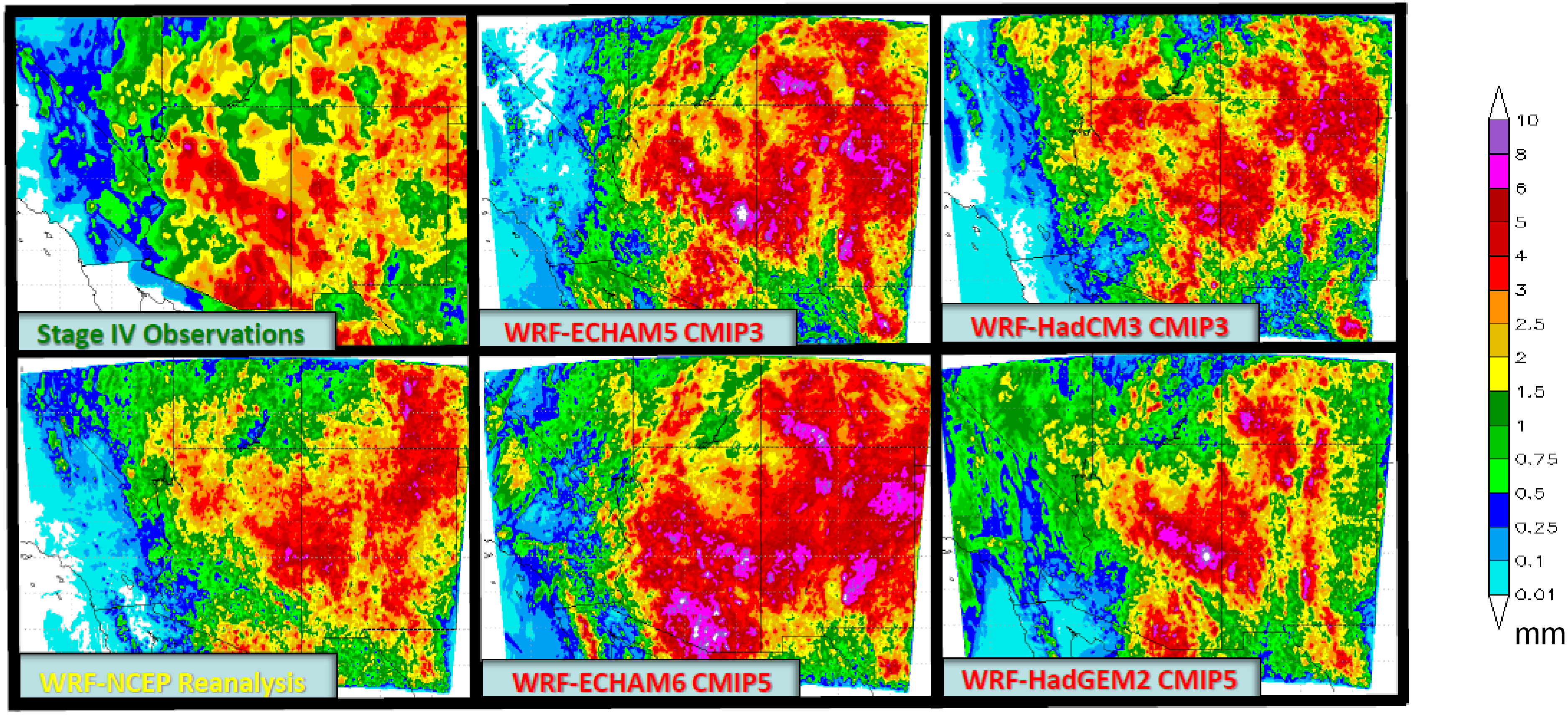


Select CMIP3 and 5 models & global reanalysis
1-2.5° resolution

Baseline WRF long term regional climate model simulations for historical and future periods
35-50 km resolution

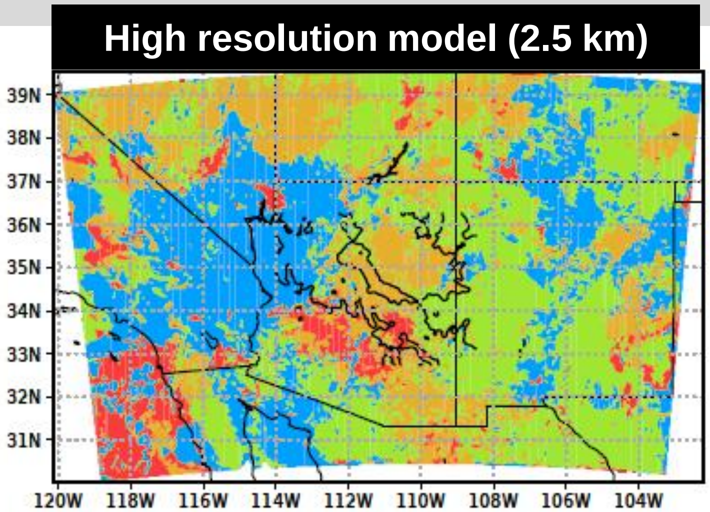
High resolution numerical weather prediction type simulations
2.5 km resolution

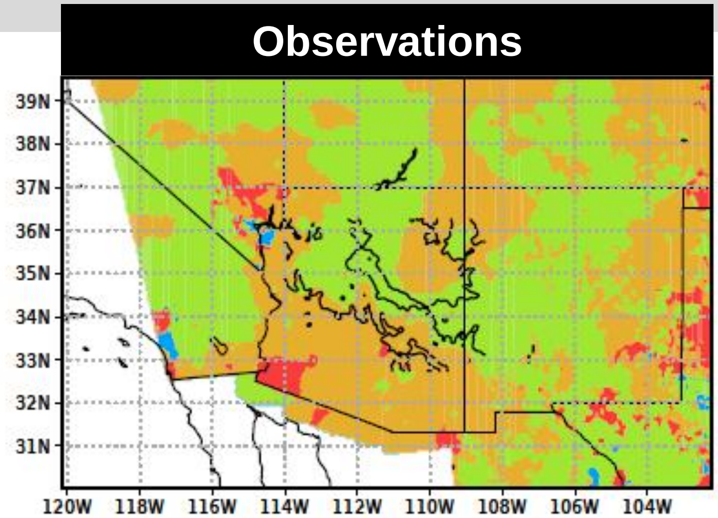
Daily Average Precipitation
Modeled vs. Observations

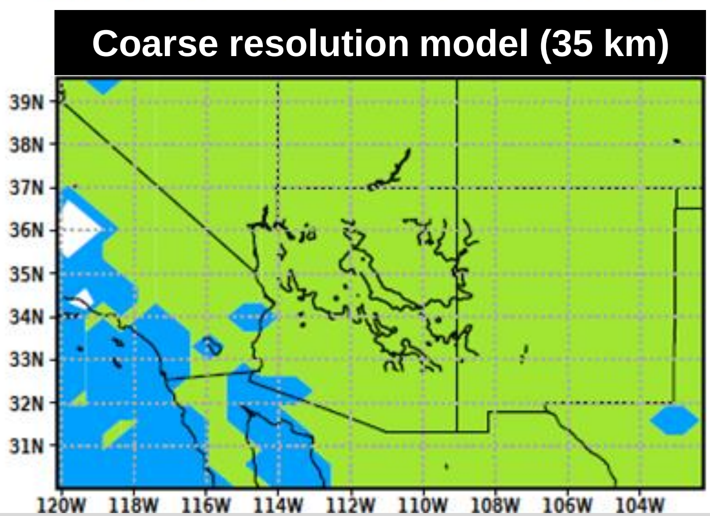


Luong et al. (2017, J. Appl. Meteor. Climatol.)

Timing of Peak Convective Rainfall
Model versus Observations







Peak Rainfall (LT)

5 am – 11 am

11 am – 5 pm

5 pm – 11 pm

11 pm – 5 am

Luong et al. (2017, J. Appl. Meteor. Climatol.)

Atmospheric Thermodynamic Conditions

Changes During the Last 30 Years

- Long-term modeled and observed increases in instability, precipitable water
- Changes can be attributed to (anthropogenic) climate change

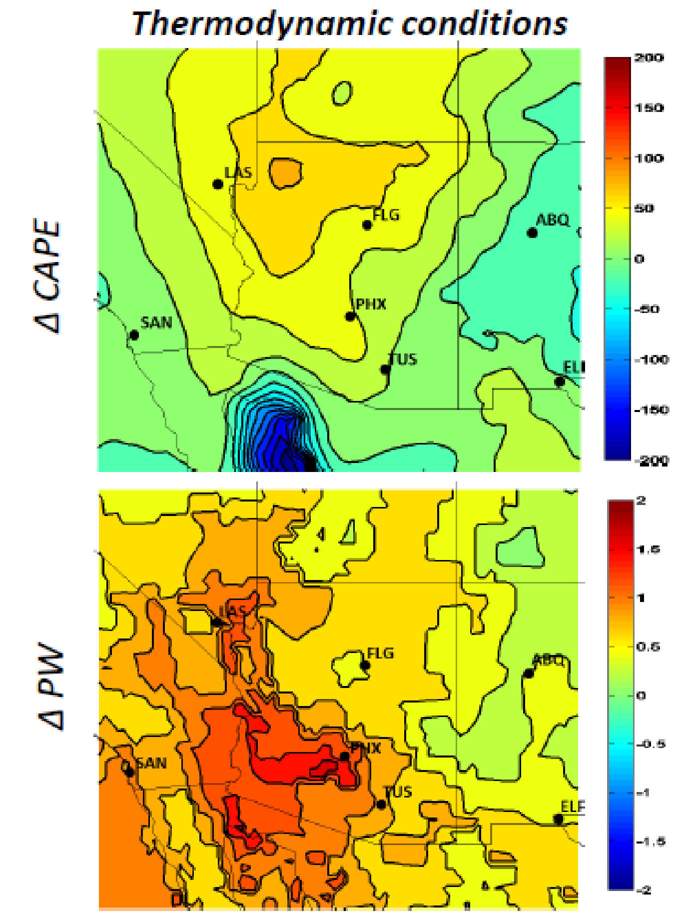
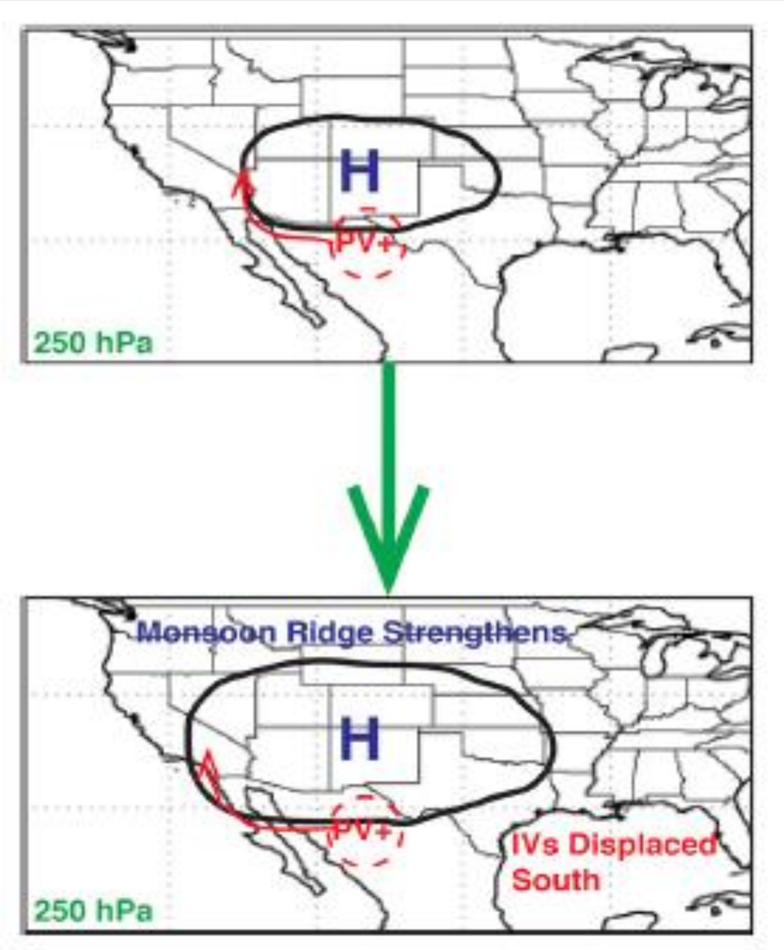


Figure 2: JA differences in downscaled reanalysis (1980-2010 minus 1950-1979) for convective available potential energy (CAPE, J kg^{-1}) and precipitable water (PW, mm). Operational radiosonde sites indicated. (Jares et al., in preparation)

Atmospheric Dynamic Conditions

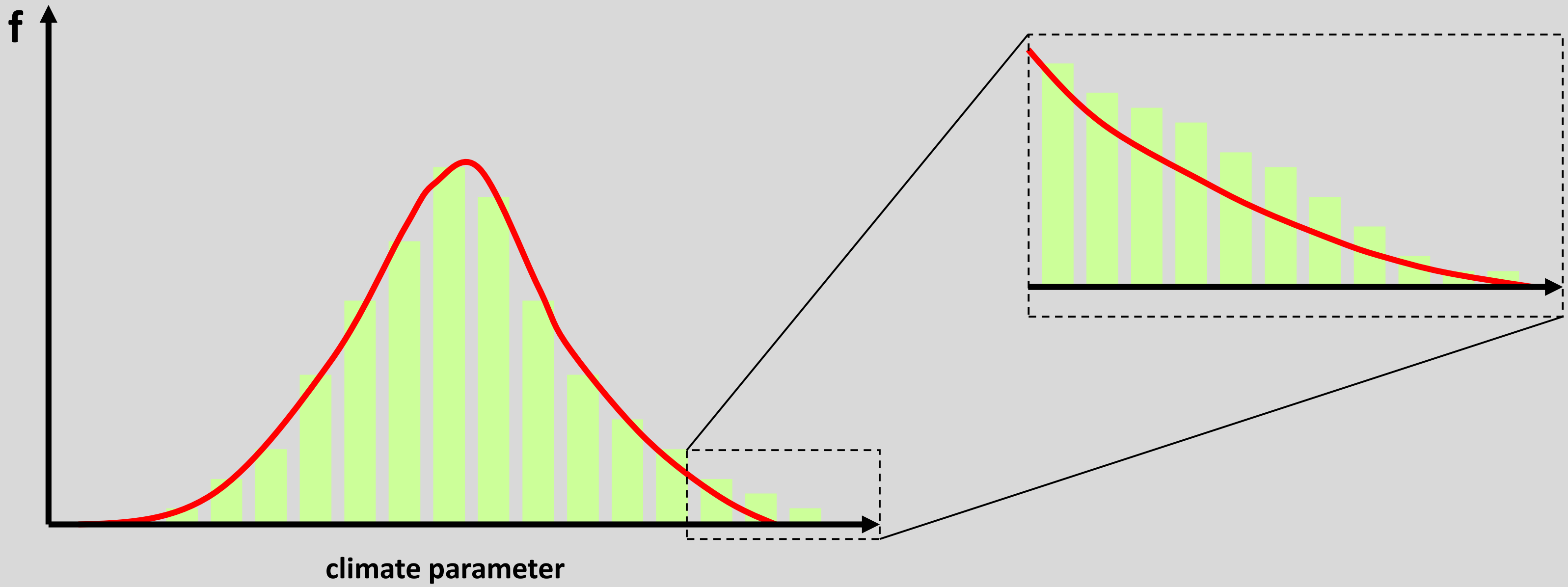
Changes over late 20th century



- The monsoon ridge has expanded
- Upper level disturbance displaced further south of the Southwest U.S.
- Less frequency of organized convective events in Arizona, but these events will be more intense

Lahmers et al. (2016, J. Climate)

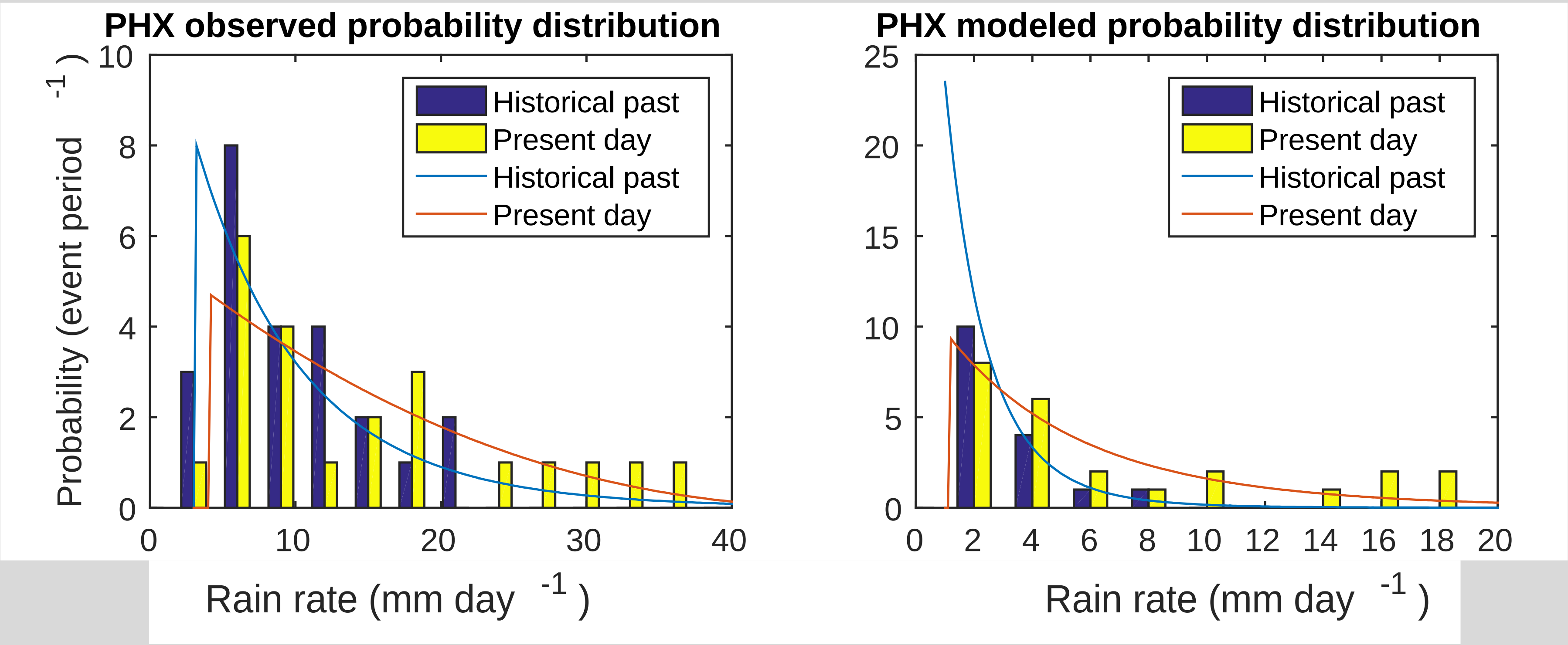
Statistical evaluation of precipitation extremes using Generalized Extreme Value Theory - GEV



- Conceptual idea is that extreme climate values (e.g. for precipitation or wind speed) in the tail of the distribution may not necessarily fit well to a theoretical PDF that applies to the whole lot of data.
- Solution is to fit generalized Pareto distribution, a peak-over-thereshold method, to better describe the behavior in the tail (Rivera et al. 2014)
- Addess statistical uncertainty by boostrap resampling of the distribution.

Distribution of Extreme Daily Precipitation

Lower Frequency, More Intense Events

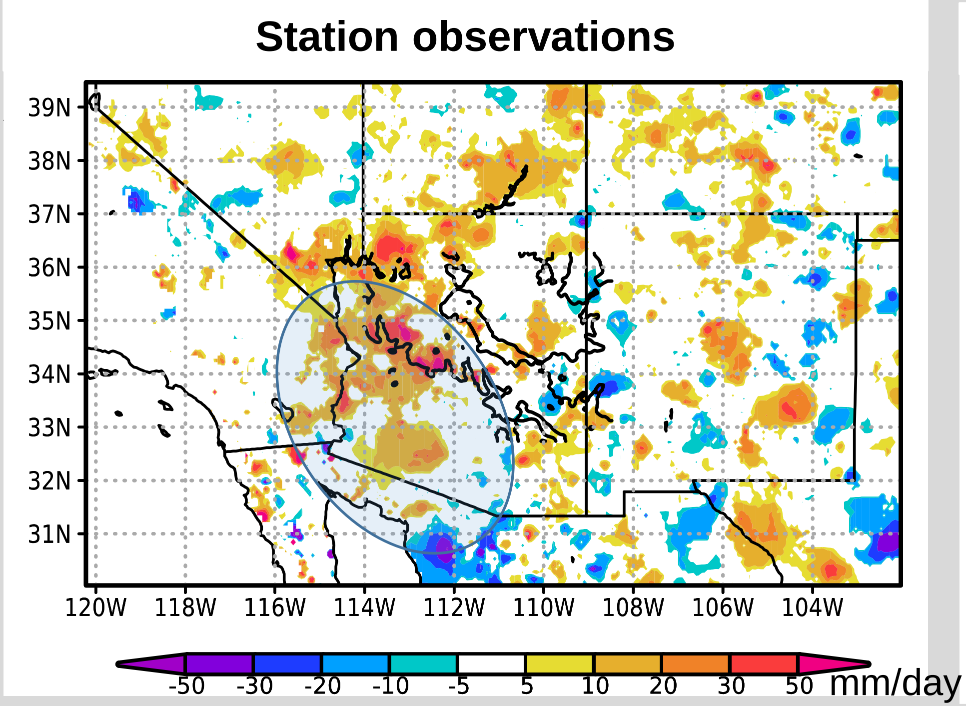


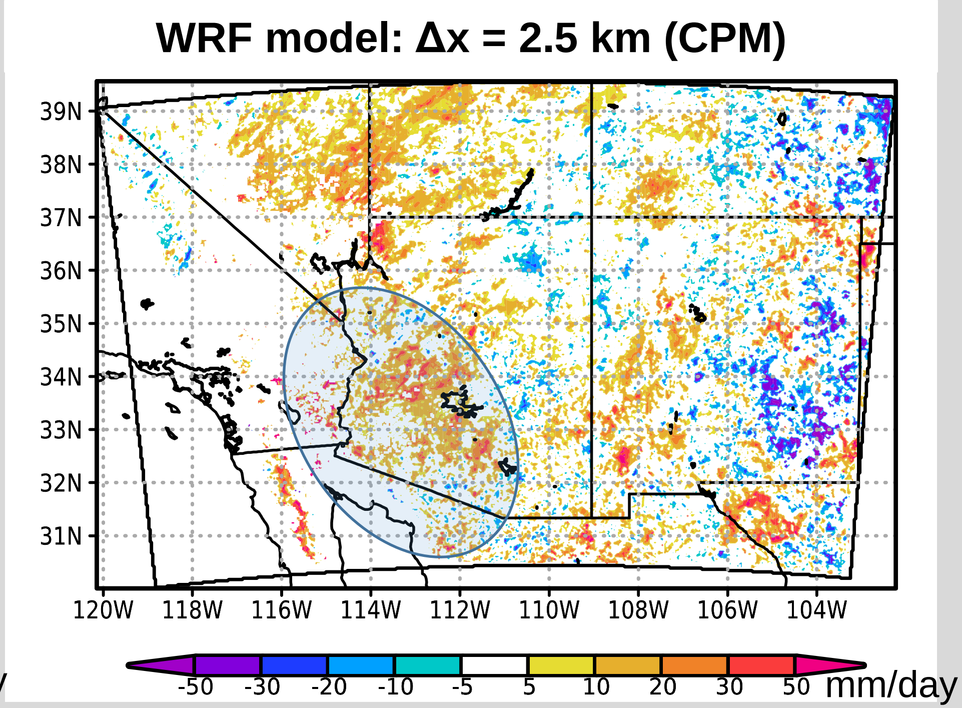
Notes: Historical past = 1950-1970; present day = 1990-2010
Results shown are for Phoenix, Arizona (PHX)

Luong et al. (2017, J. Appl. Meteor. and Climatol.)

Significant Changes: Extreme Precipitation

Largest Increase in Southwest Arizona





Note: 1950-1970 vs. 1990-2010

Luong et al. (2017, J. Appl. Meteor. and Climatol.)

Quantitative estimation of downdraft CAPE on Skew-T, log-P diagram (WAF class notes…)

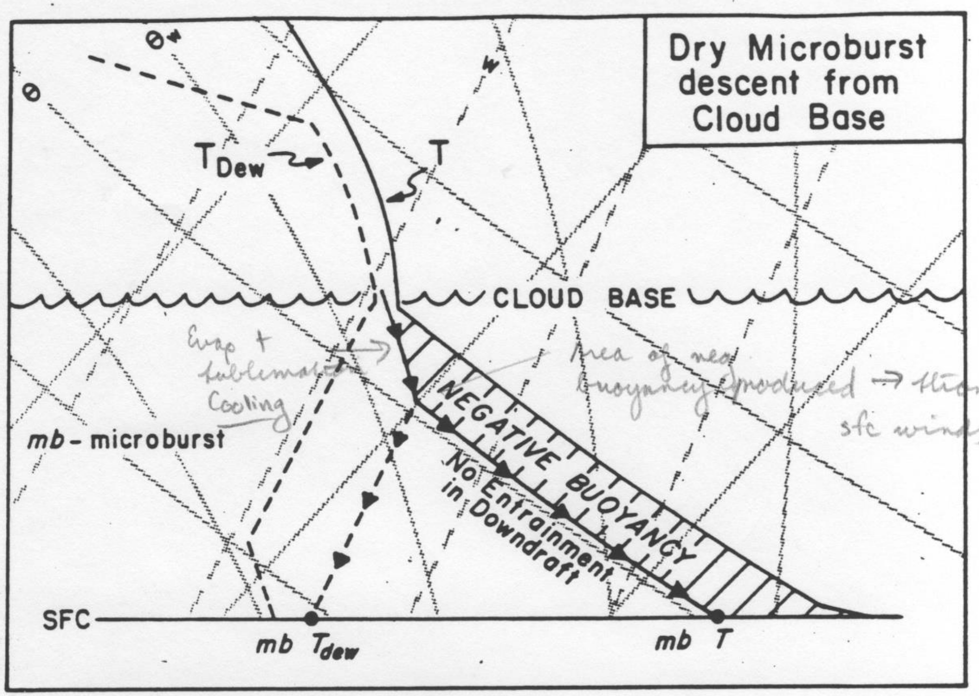


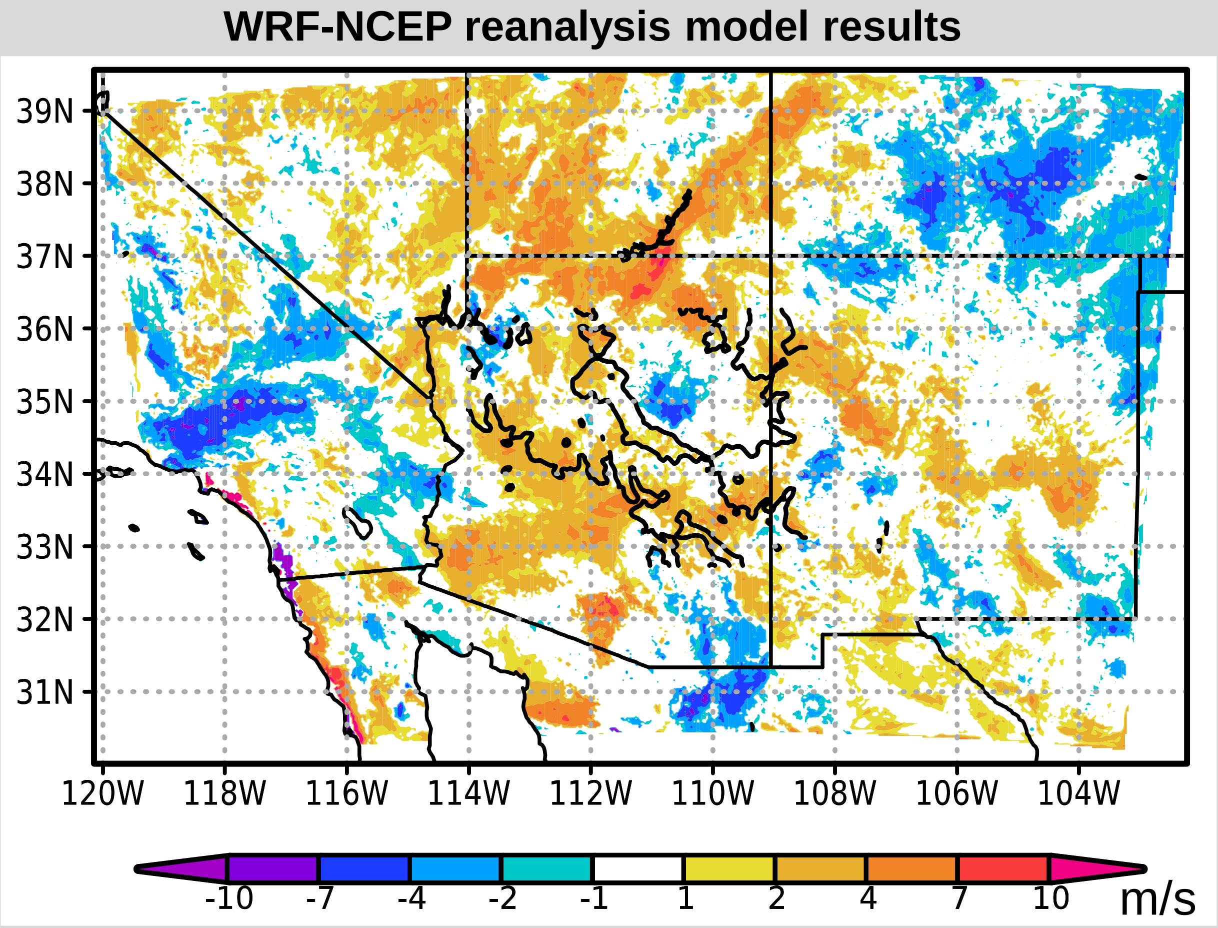
FIG. 10. Model of the thermodynamic descent of a dry microburst from cloud base. Surface temperature and dew-point temperature within the microburst are determined from PAM data. No entrainment into the downdraft is assumed.

Estimate downdraft strength by square root of 2 x DCAPE

Extract DCAPE from convective-permitting model simulations, analyze in a similar way to precipitation…

Extreme Downdraft Wind Speed

Significant Change



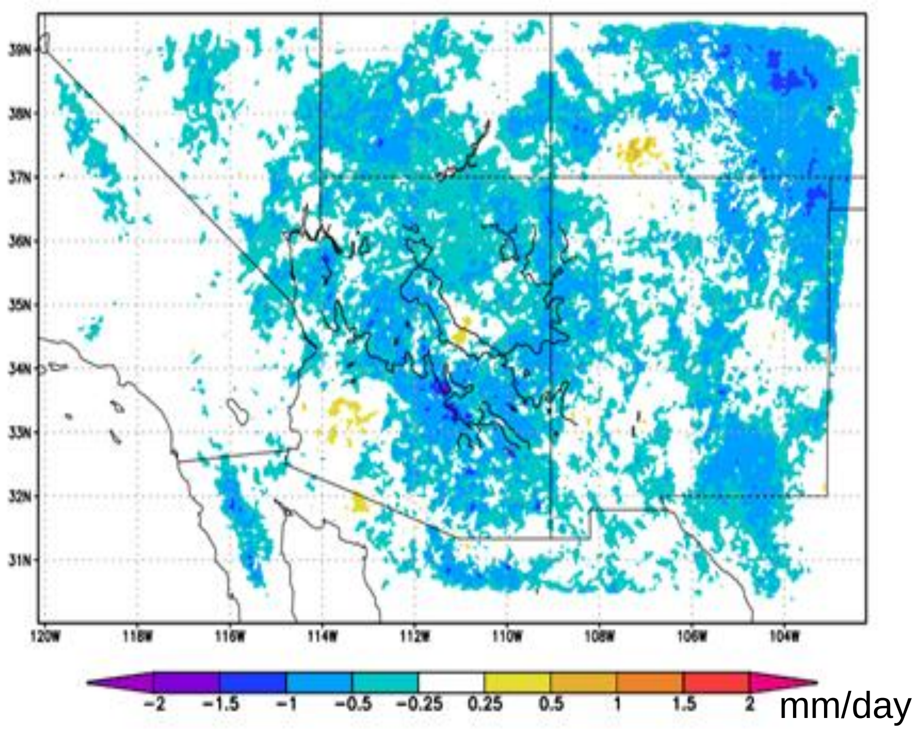
Note: Timeframes 1950-1970 vs. 1990-2010

Luong et al. (2017, J. Appl. Meteor. and Climatol.)

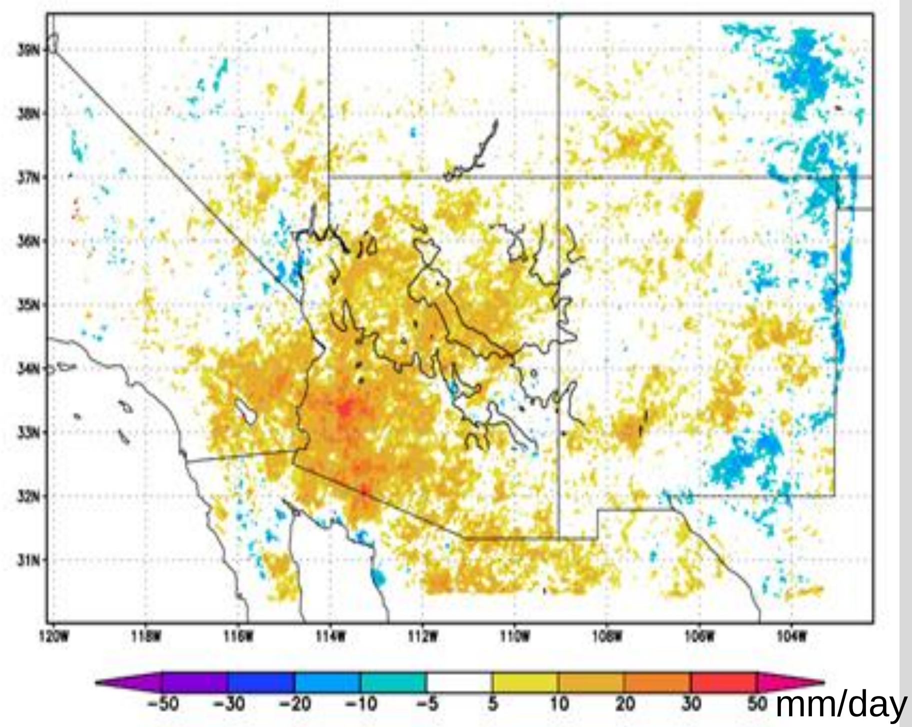
Precipitation

Significant Change, Ensemble of Four CMIP3 and CMIP5 Global Climate Models

Mean trend from model ensemble



Extreme trend from model ensemble



Note: Time period is 2021-2040 minus 1991-2010

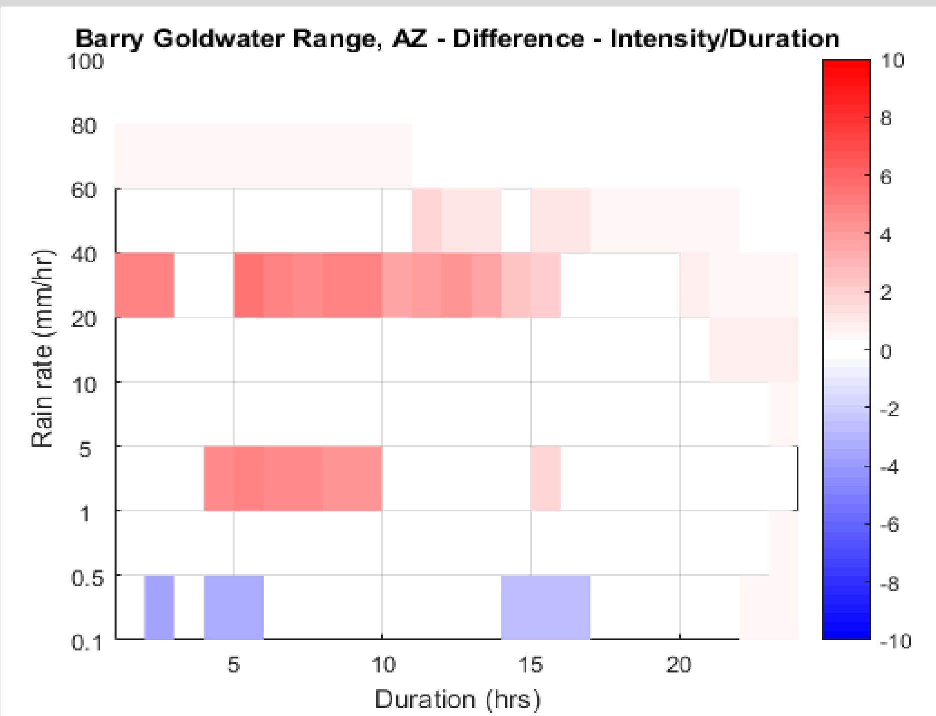
Castro et al. (in prep)

Precipitation Intensity and Duration

Significant Percentage Changes

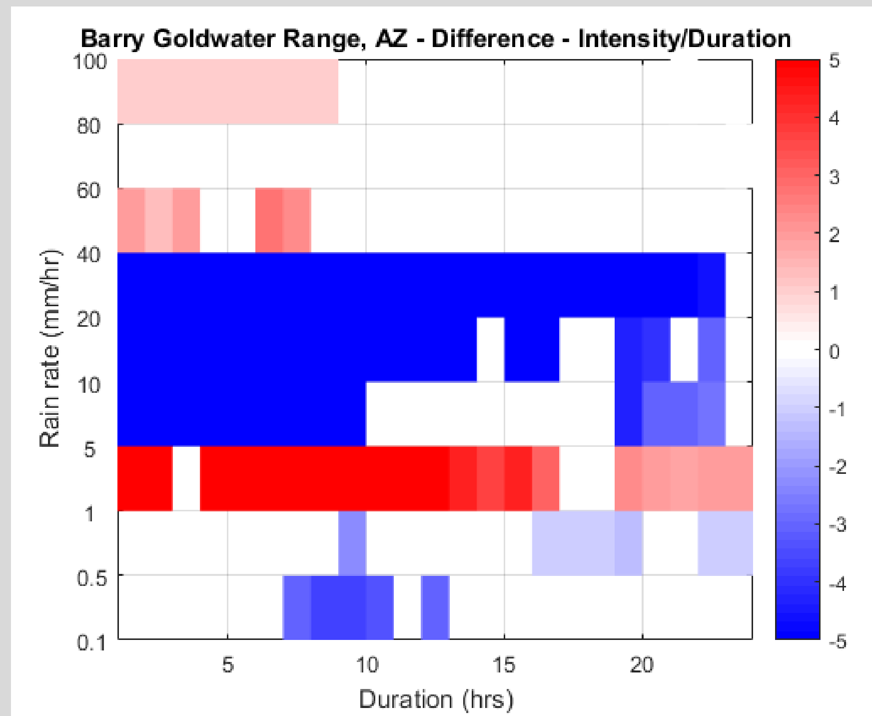
WRF NCEP

1990-2010 minus 1950-1970



WRF CMIP Ensemble Average

2021-2040 minus 1990-2010



Concluding Points

- There has been a long term increase in atmospheric moisture and instability in recent decades, due to anthropogenic climate change
- The more favorable thermodynamic environment is causing monsoon thunderstorms to be more extreme, though they are becoming less frequent
- High resolution atmospheric modeling is able to pinpoint southwestern Arizona as a local ‘hot spot’ where monsoon storms are now more intense, and this trend is projected to continue
- The model information generated by this work is at a spatial scale that is informative for decision making and conforms to weather watch and warning criteria