Use of Dynamical Downscaling to Improve Regional Climate Change Projections in the Southwest U.S.

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Presentation Outline

Motivation for improved climate change projection in the Southwest

Why use dynamical downscaling for climate change projection with a regional climate model and how does it work?

Dynamical downscaling results for select IPCC AR4 models for the cool and warm season: historical performance in late 20th century and climate change projections.

Use of dynamically downscaled data in a hydrologic model for water resource projection

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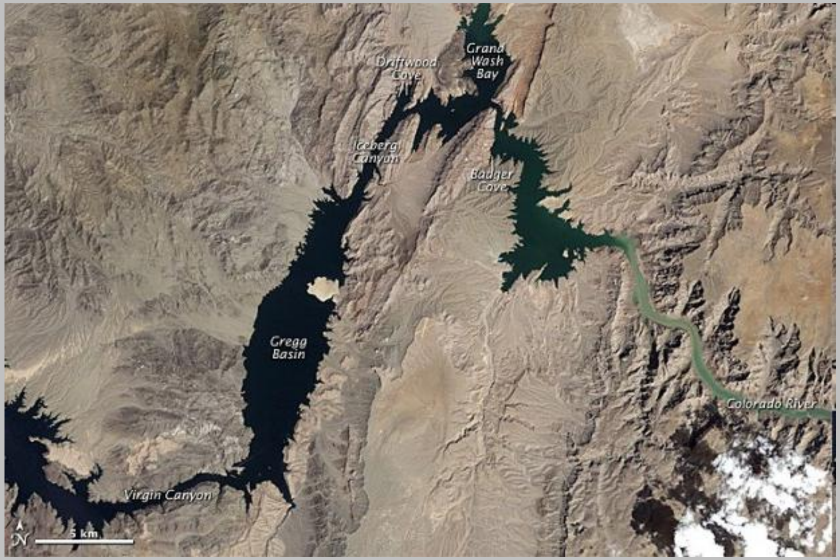
UA Contributors: F. Dominguez, H-I. Chang, C. Carrillo, E. DeMaria, M. Durcek, S. Wi, E. Rivera

What is CURRENTLY HAPPENING to Colorado River reservoirs
This is a primary water source in Arizona!



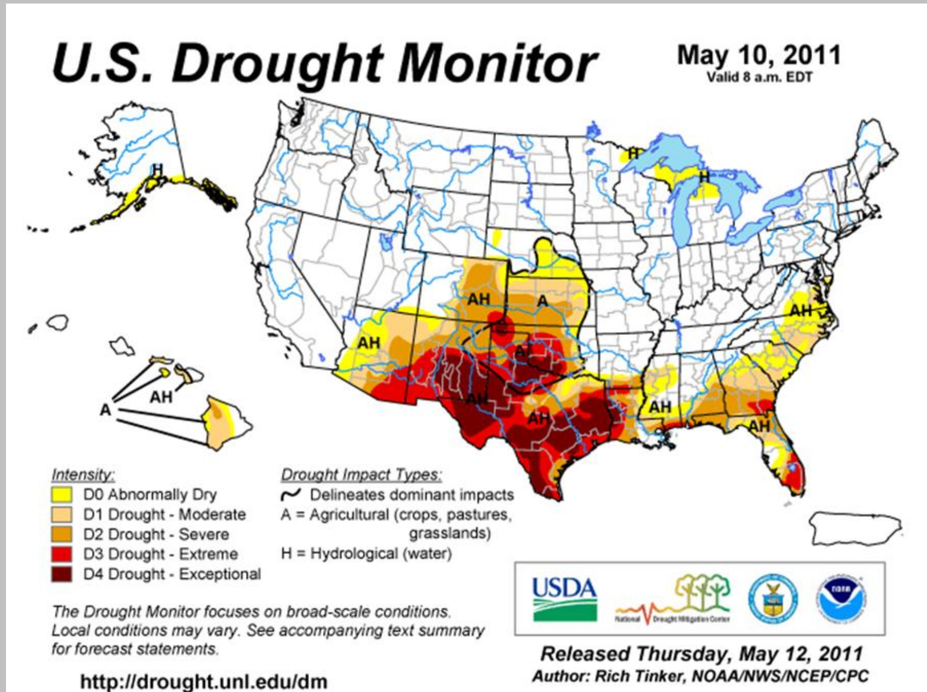
Lake Mead: 1985

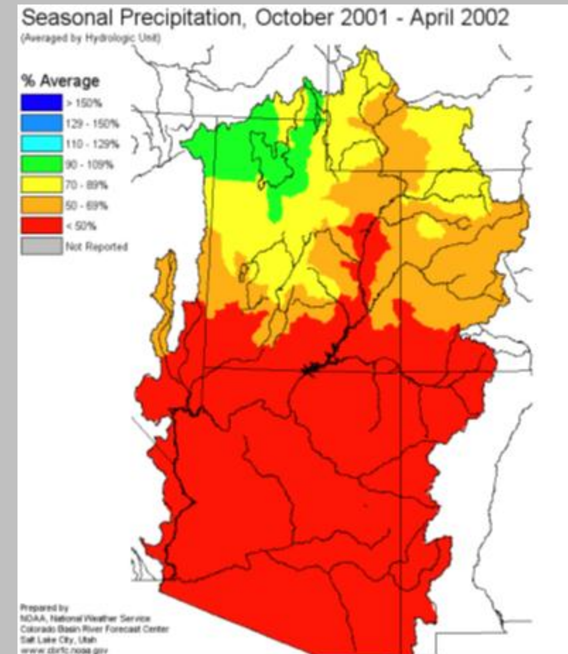
Lake Mead today
At lowest level since 1937

From Arizona Daily Star Article
November 2010

2011 on track to be one of the worst fire seasons in Arizona state history

NASA Imagery of Horseshoe Fire in May 2011



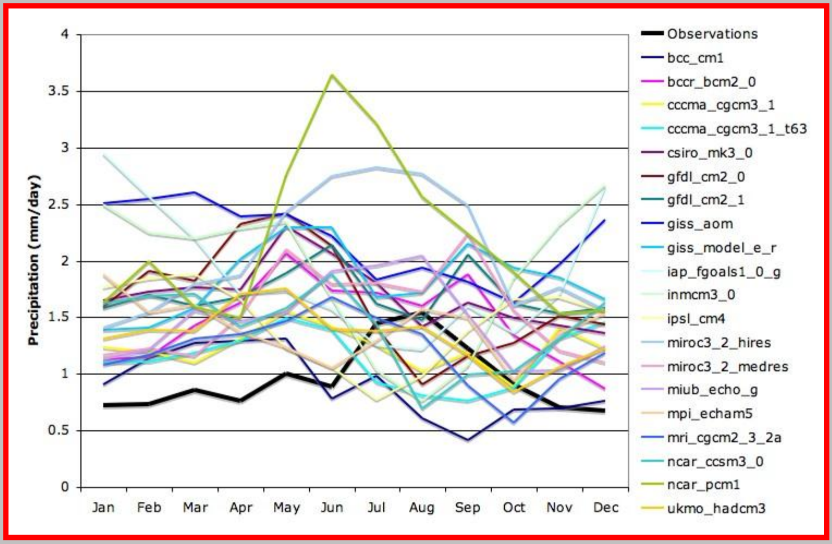


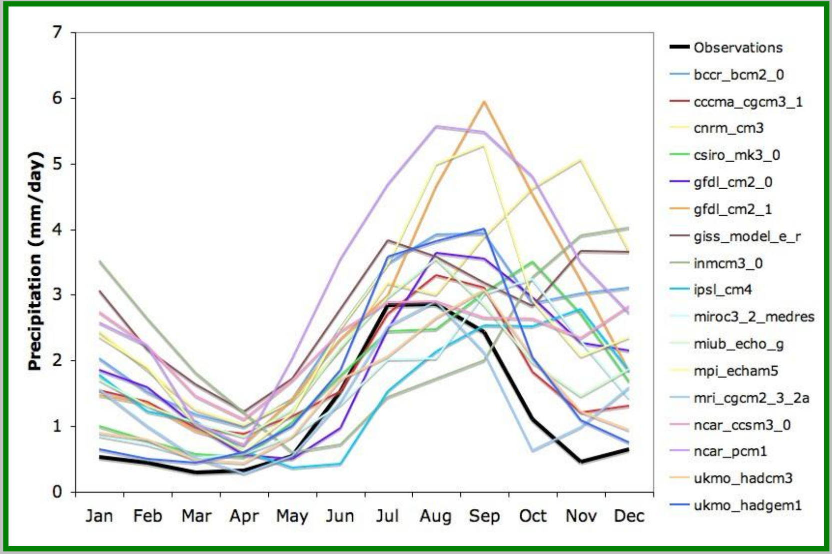
***Dr. John Nielson Gammon, Texas State Climatologist*: 2011 record spring drought in west Texas likely due to the combination of La Niña and climate change (*New York Times* article).**

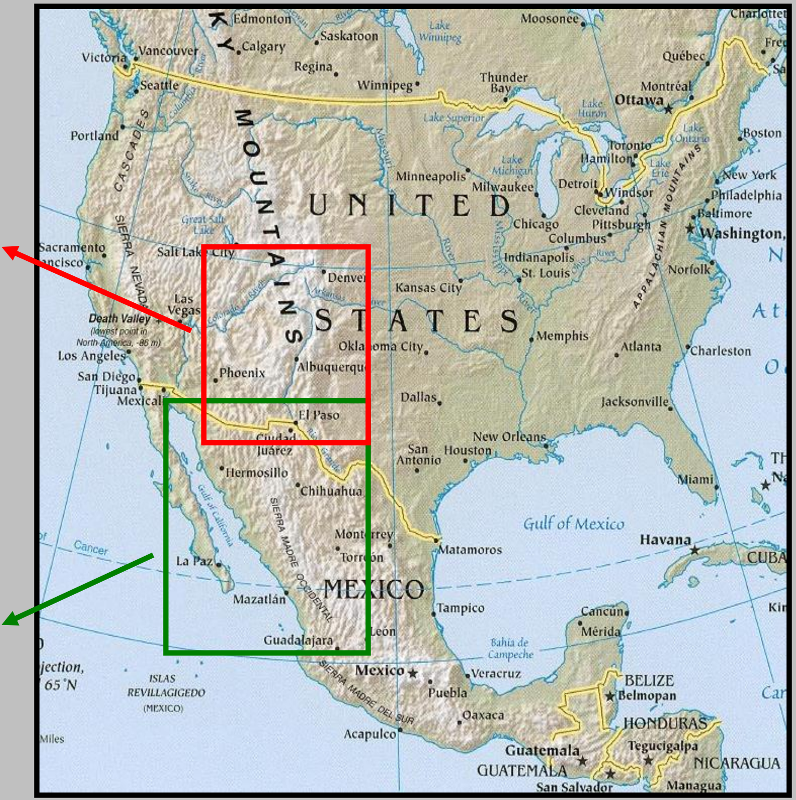
Critical questions therein:

1. **How is natural climate variability interacting with climate change to intensify extremes?**
2. **Can current IPCC-based climate change projections resolve on a regional scale?**

Monthly average historical precipitation from IPCC AR4 models







Historical average of simulations (sres_20c3m) 1970-2000

(Francina Dominguez)

“Downscaling” = Create higher spatial resolution data at regional or local scale

<u>Statistical:</u> Use a statistical transfer function to relate global climate model atmospheric information to regional or local surface characteristics, such as precipitation or temperature. Transfer function must be trained on observed historical data.

<u>Dynamical:</u> Use a regional atmospheric model to explicitly simulate the dynamic processes of weather and climate. Typical grid spacing of 20 – 50 km.

Two approaches to downscale coupled climate model projections :

Statistical Downscaling

- Pro : Cheap and computationally efficient.
- Can use many different scenarios, model runs.
- Pro : Easily transferable to other regions.
- Con : Requires long and reliable observation data.
- Con : Depends on choice of predictors.
- Con : Assumes stationarity of predictor-predictand relationship.
- Con : Cannot account for feedbacks.

Dynamical Downscaling

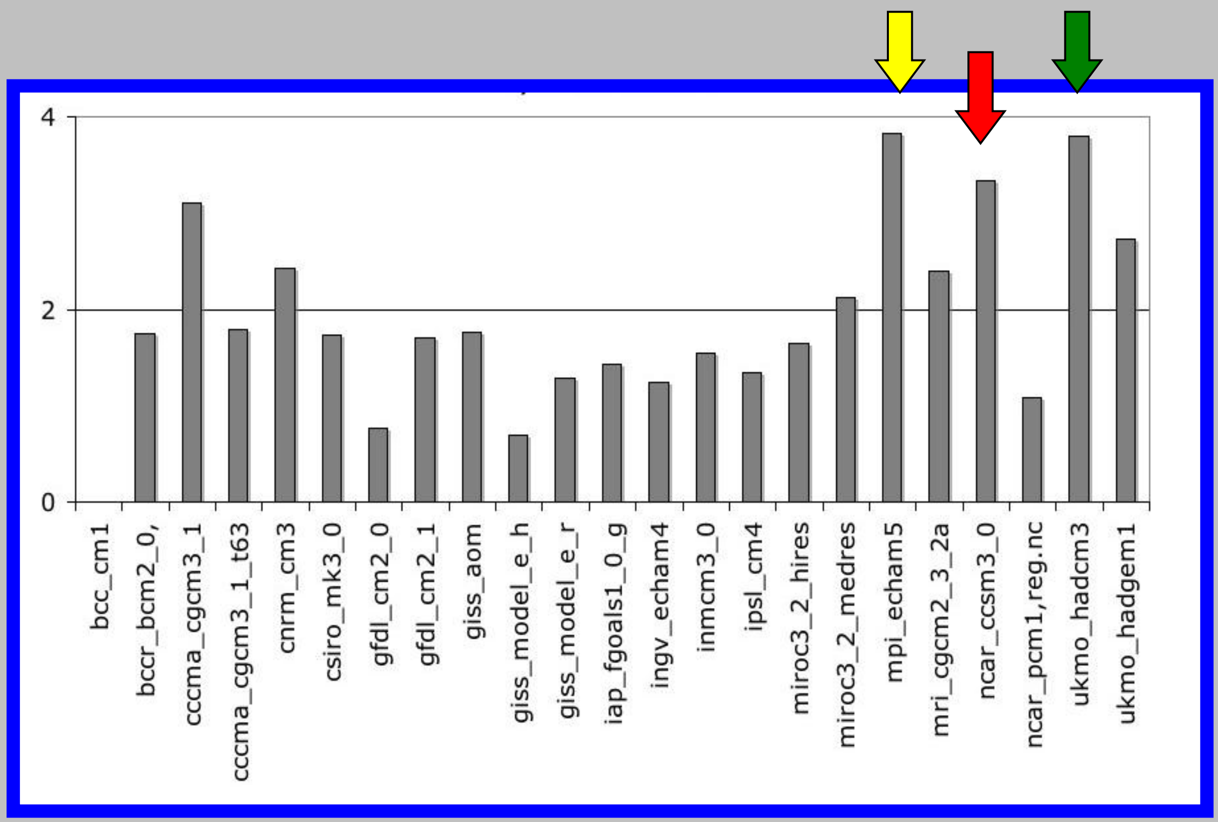
- Pro : Produces responses based on physically consistent processes.
- Pro : Captures feedbacks.
- Pro : Can model changes that have never been observed in historical record.
- Pro : Useful where topographic controls are important.
- Con : Requires significant computational power.
- Con : Yields only a few model realizations.
- Con : Dependent on GCM boundary forcing.

Dynamical downscaling of “well performing” IPCC AR4 models for the Southwest

HadCM3: 1968-2070 (completed)

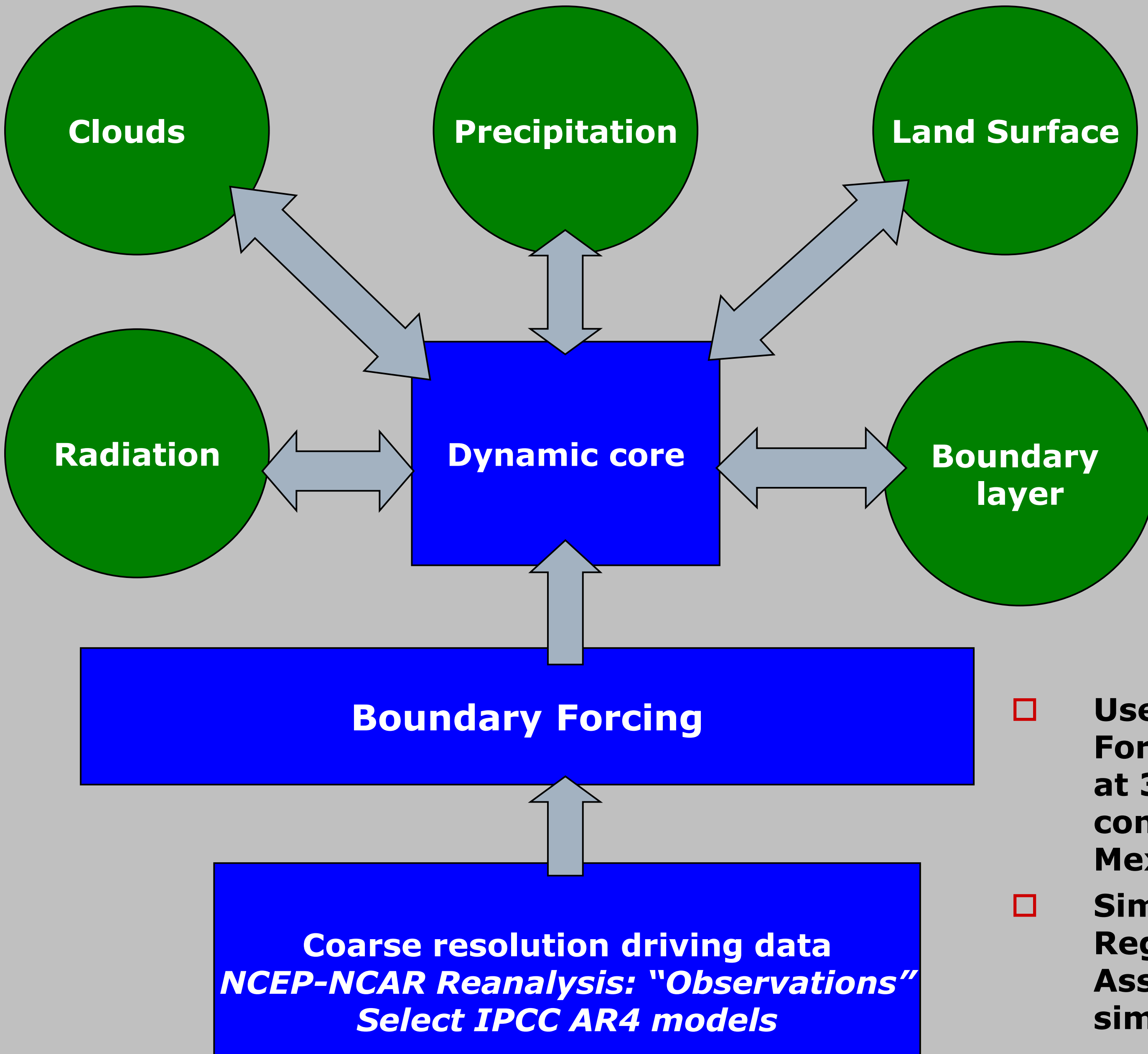
MPI-ECHAM5: 1950-2100 (completed)

CCSM: 1950-2100 (still pending)



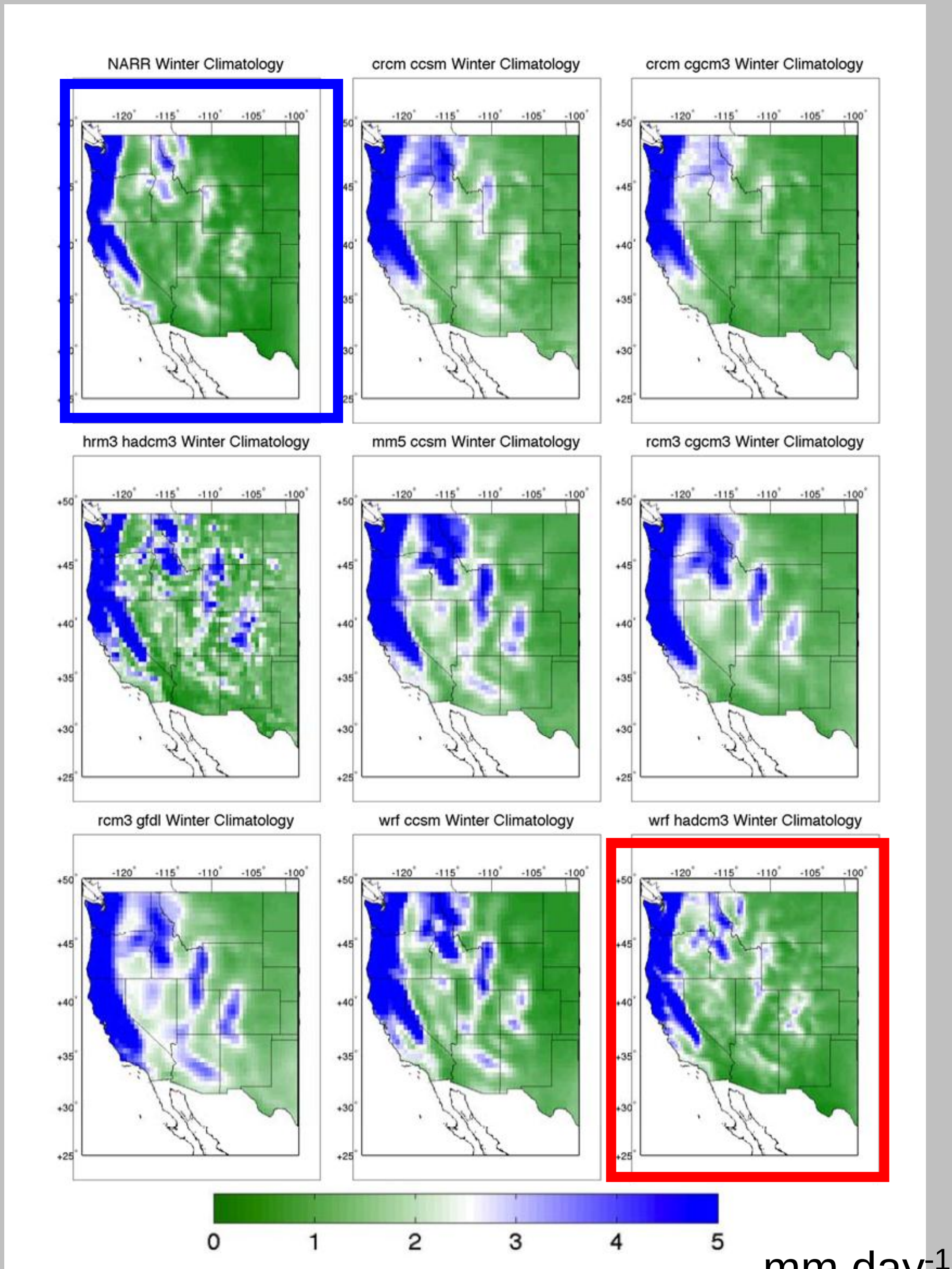
Dominguez et al (2009)

Regional Climate Model Structure



- **Use Weather Research and Forecasting (WRF) Model at 32 km grid spacing over contiguous U.S. and Mexico**
- **Similar to North American Regional Climate Change Assessment (NARCCAP) simulations**

Winter season analysis



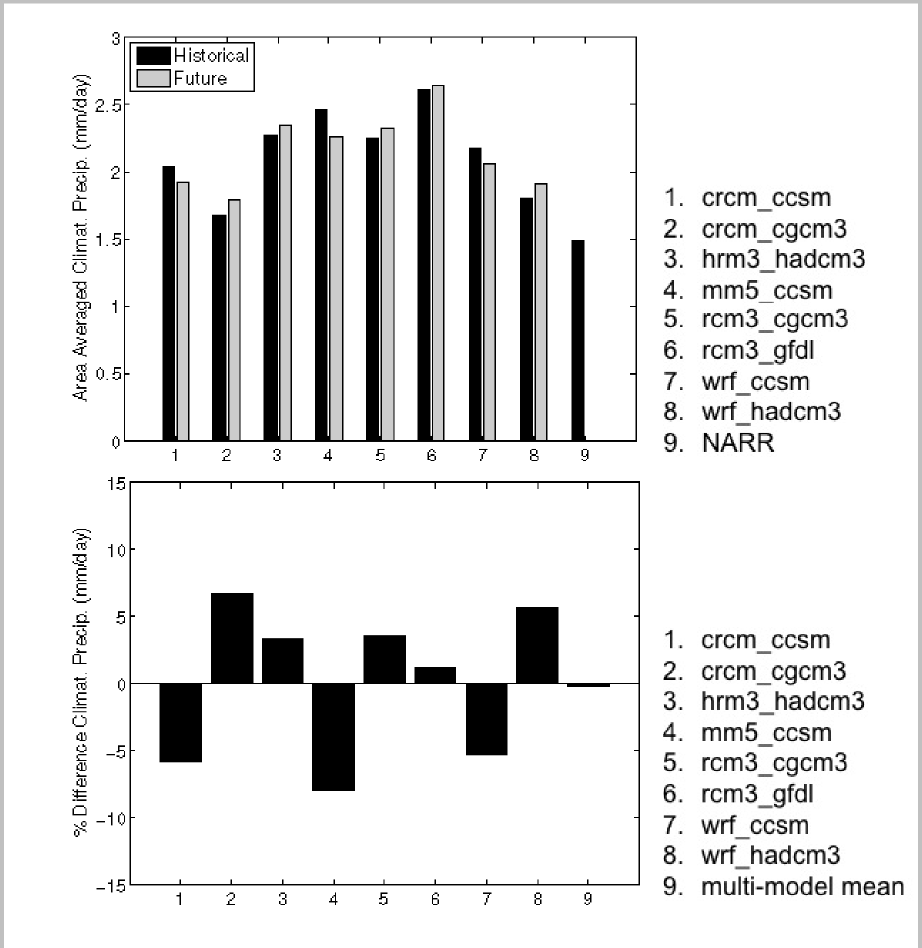
Monthly historical (1968-2000) average precipitation in winter (DJF)

- NARR Observed
- NARCCAP models
- WRF-HadCM3

Extreme event precipitation pattern is very similar

Dominguez et al. (2011), submitted

Historical (1968-2000) and future precipitation (2038-2070) in western U.S.



No coherent trend in mean winter precipitation considering all the NARCCAP models, with most in the range of 10% of historical average.

Not surprising, as mean changes dependent on large-scale circulation changes and western U.S. is the transition zone between drying subtropics and moistening high latitudes.

Dominguez et al. (2011), submitted

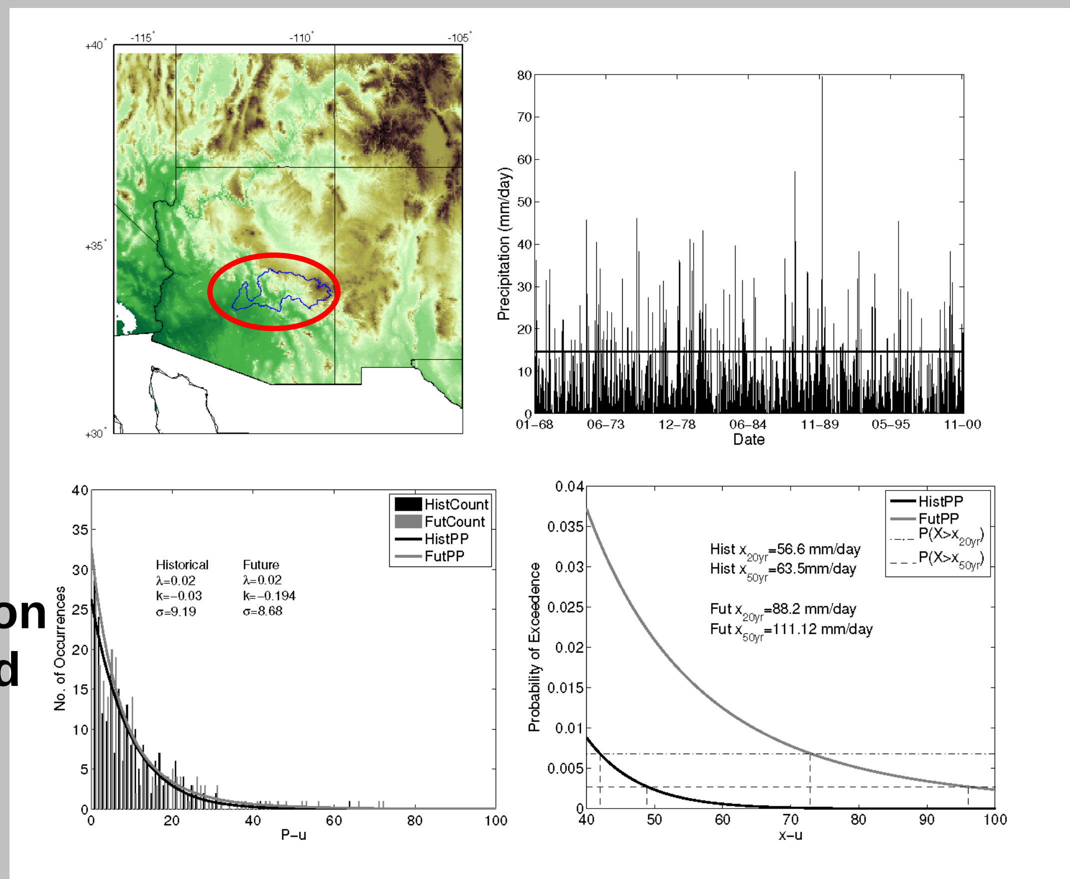
Computation of precipitation distribution from WRF-HadCM3: Salt River Basin

1. Salt River Basin (blue outline)

2. Daily precipitation

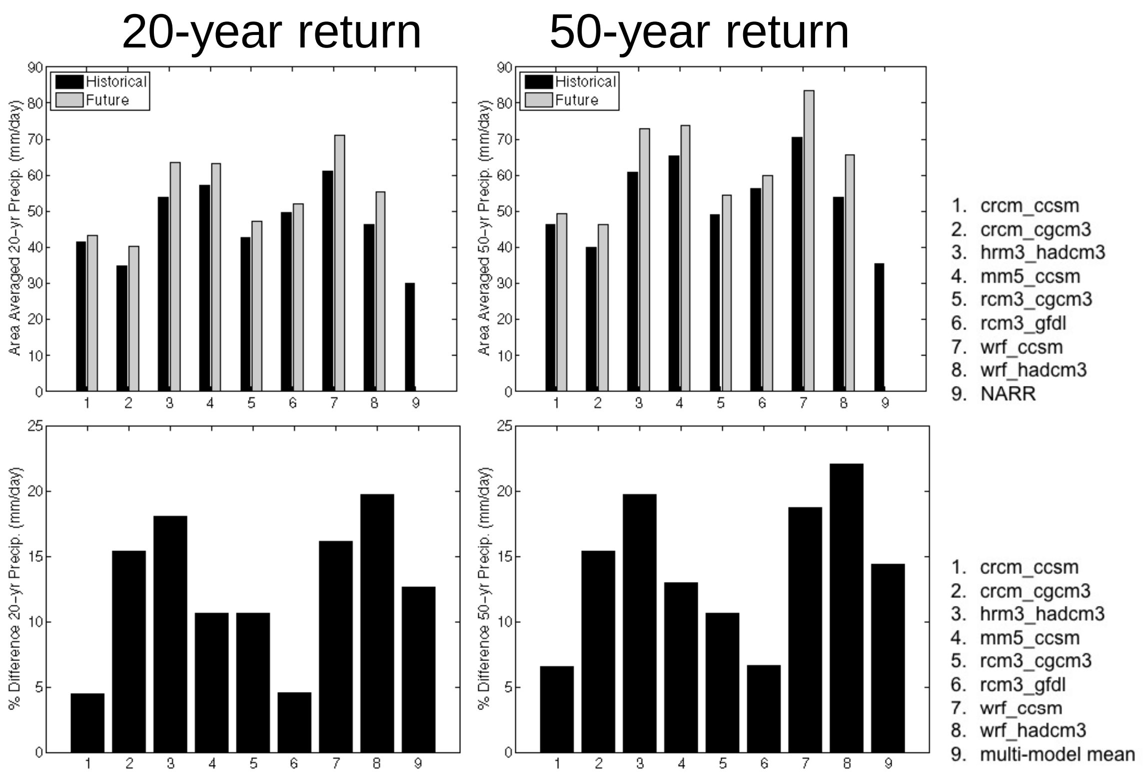
3. Winter distribution of daily precipitation from generalized extreme value theory

4. Exceedence probability with 20 and 50-yr return periods



Dominguez et al. (2011), submitted

Western U.S. winter extreme event precipitation: historical vs. future



An increase in the precipitation associated with extreme event precipitation is a much more robust result.

In agreement with observations of the recent historical record.

Still LARGE spatial differences among the individual models!

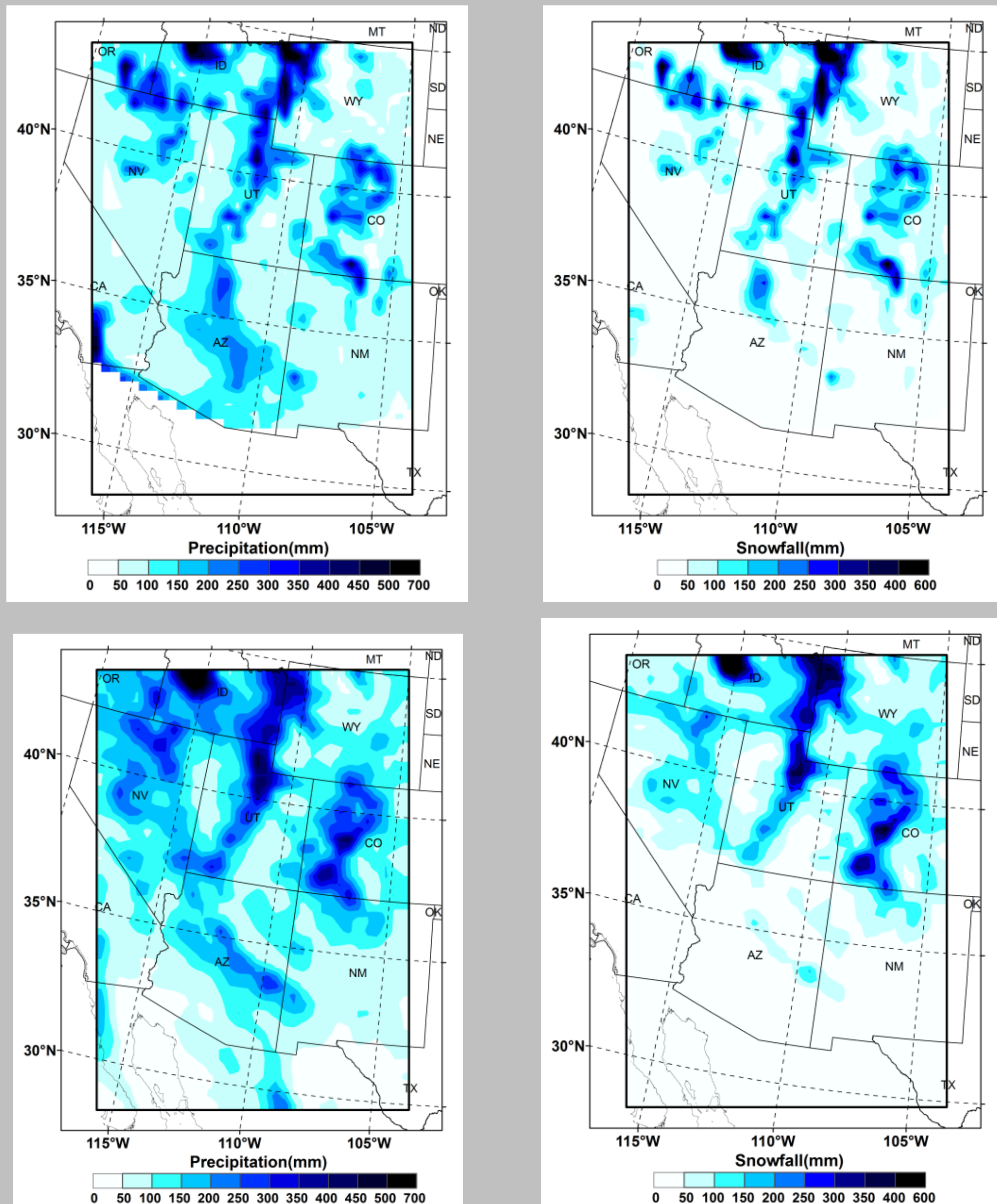
Dominguez et al. (2011), submitted

Observed and WRF-HadCM3 winter precipitation and snowfall in historical period.

Precipitation | *Snowfall*

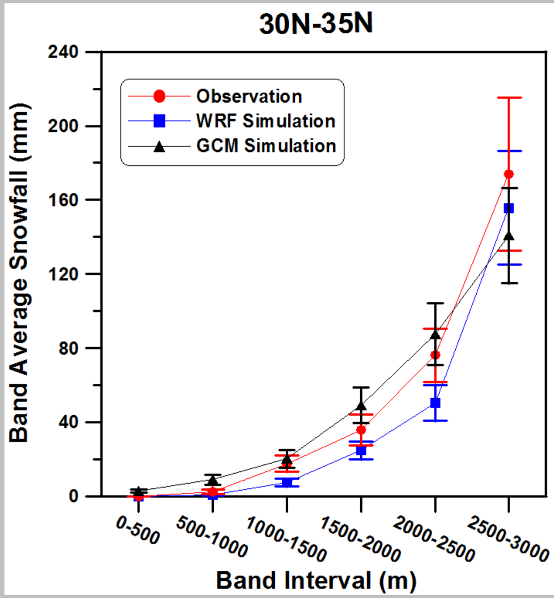
Observed (NARR)

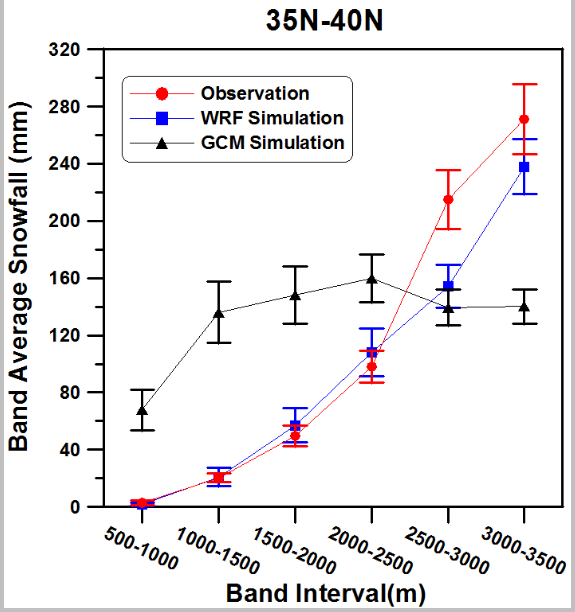
WRF-HadCM3

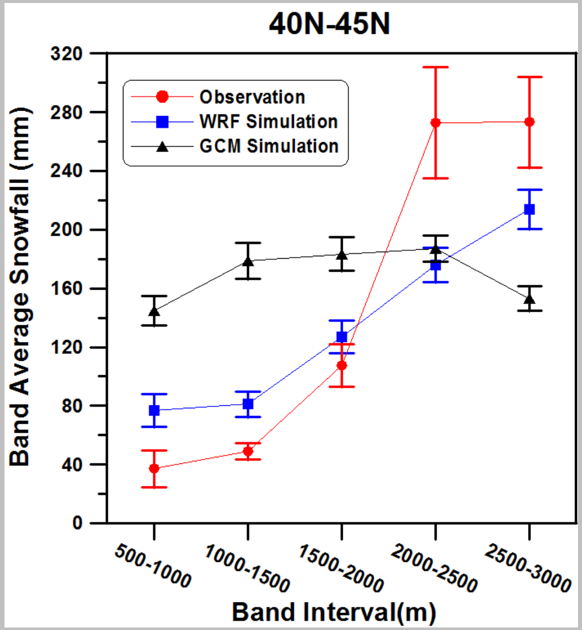


Wi et al. (2011), submitted

Latitudinally-averaged snowfall vs. elevation for historical period

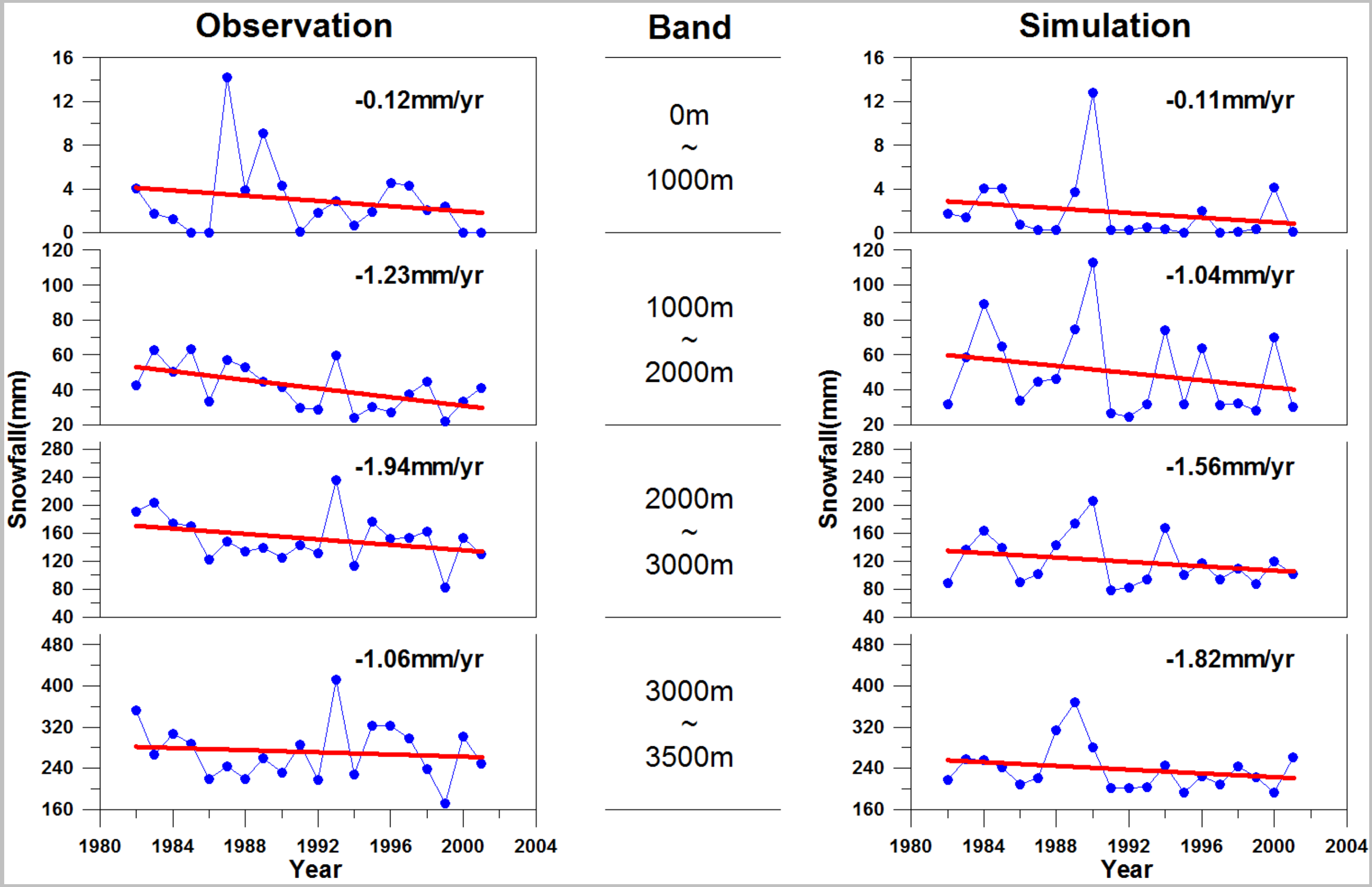






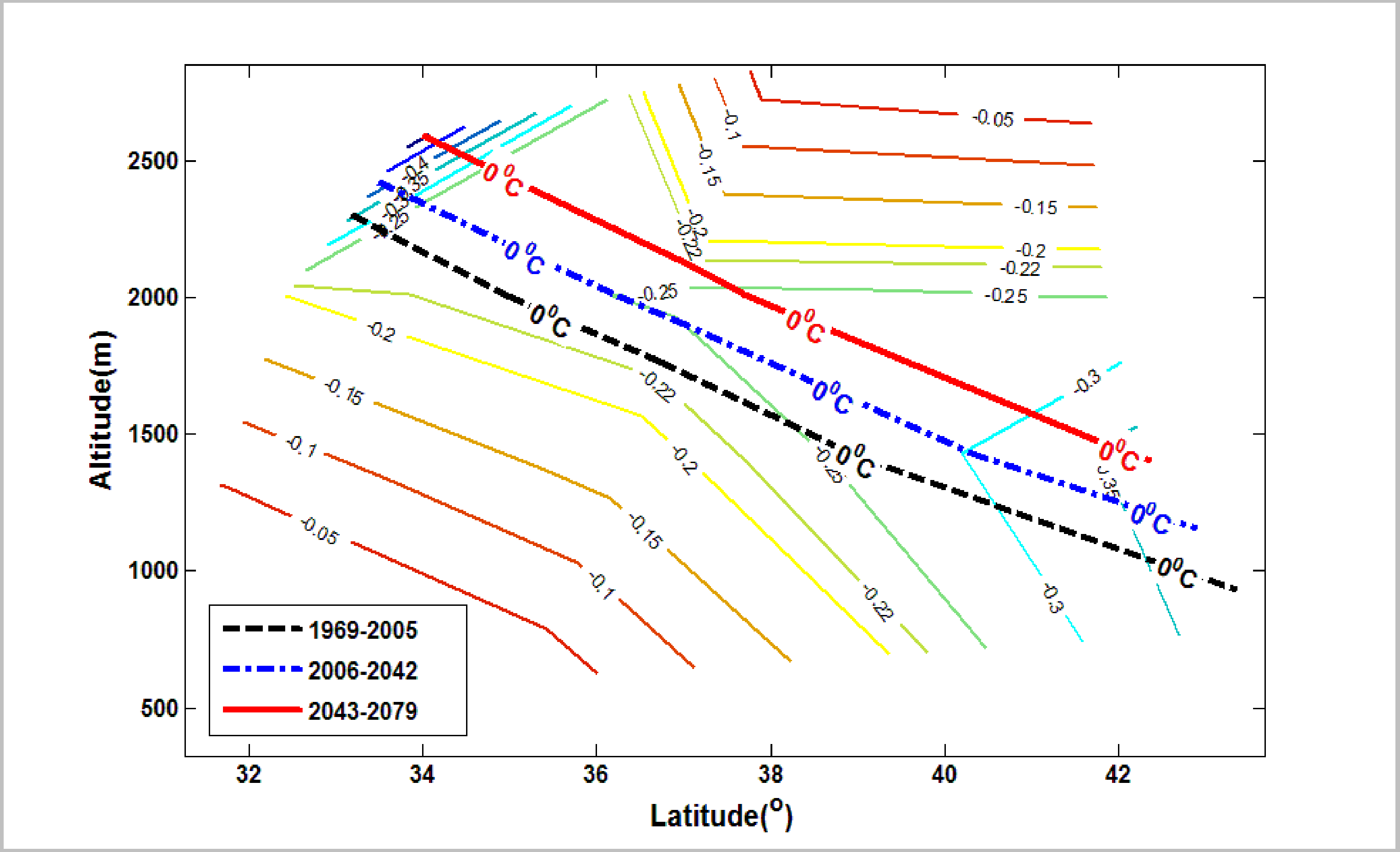
Wi et al. (2011), submitted

Latitudinally-averaged snowfall during historical period as a function of elevation: SNOTEL observations vs. WRF-HadCM3



Wi et al. (2011), submitted

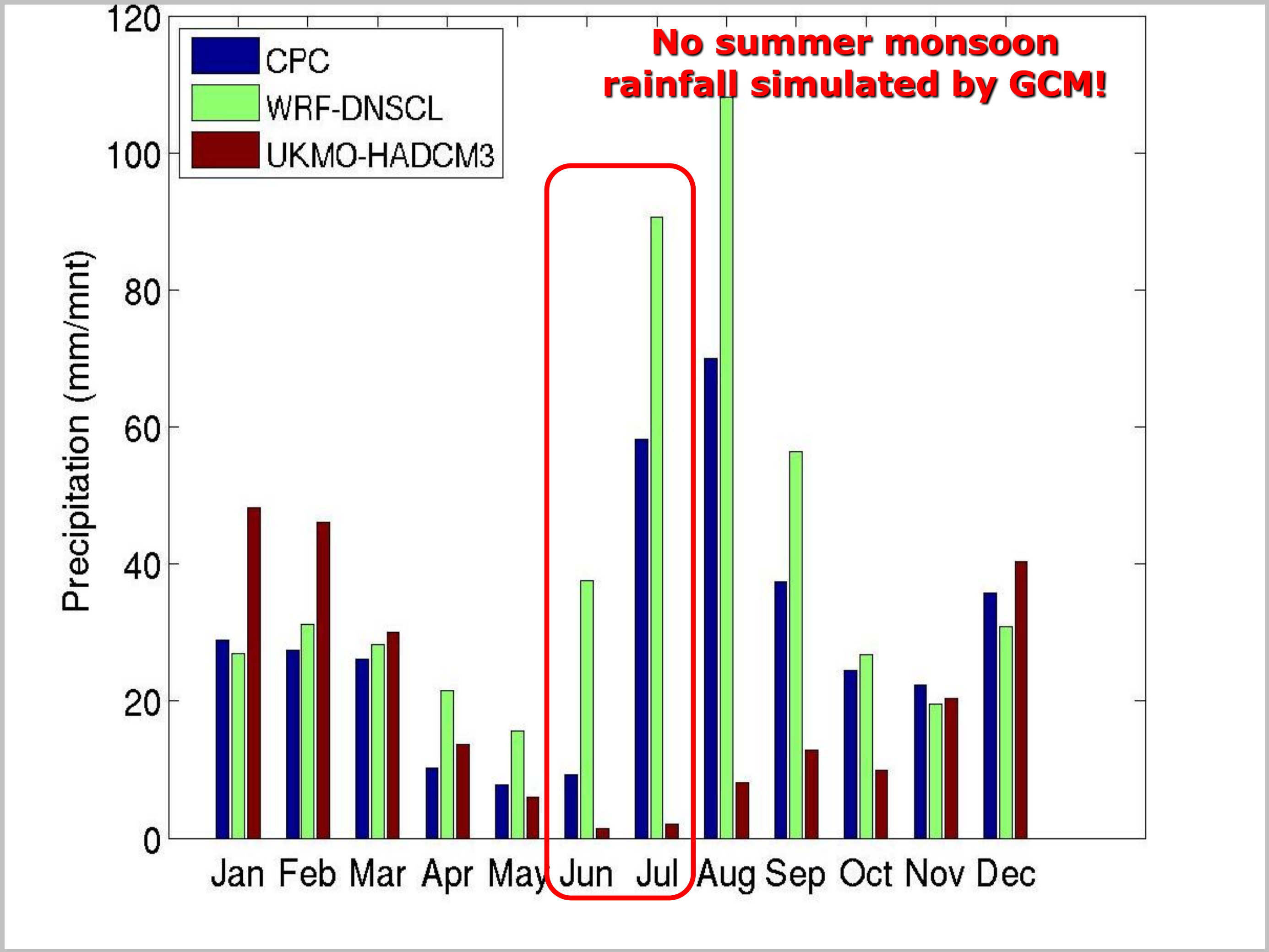
WRF-HadCM3-simulated trends in snowfall and changes in the freezing line as a function of latitude and elevation



Wi et al. (2011), submitted

Summer monsoon analysis

Annual precipitation climatology for Arizona (1968-2000)



Monsoon Interannual Variability
Remotely forced teleconnections and land surface feedback

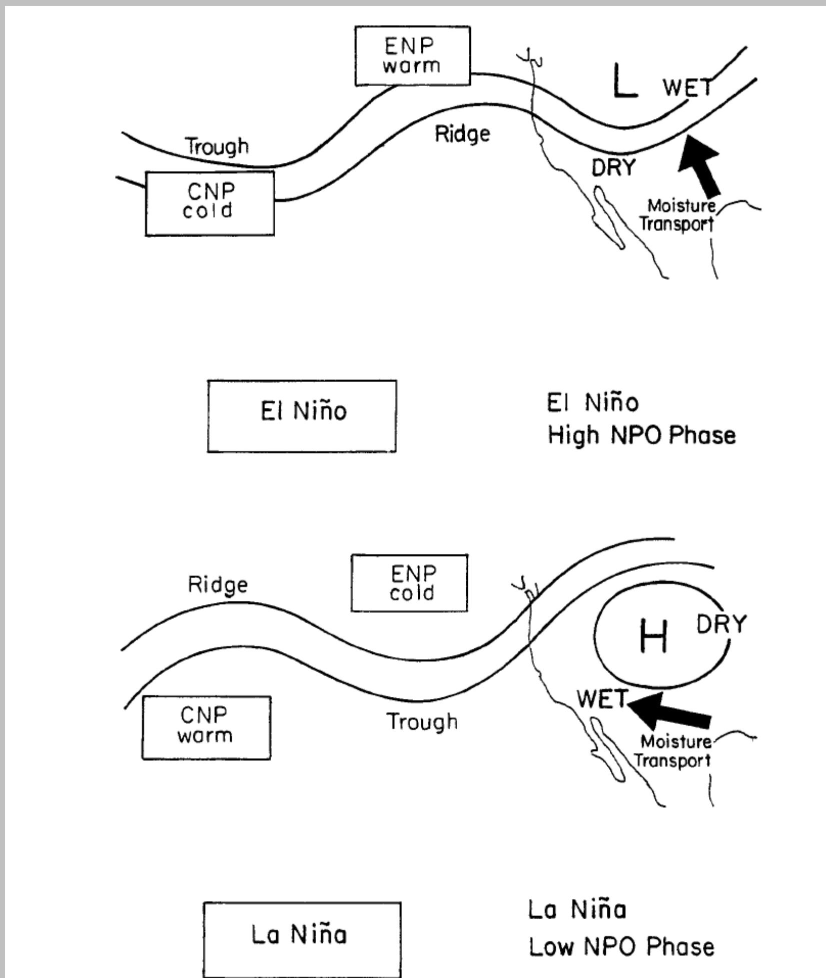


FIG. 14. Idealized relationship of monsoon ridge position and midlevel moisture transport to Pacific SSTs at monsoon onset.

Climatology delayed

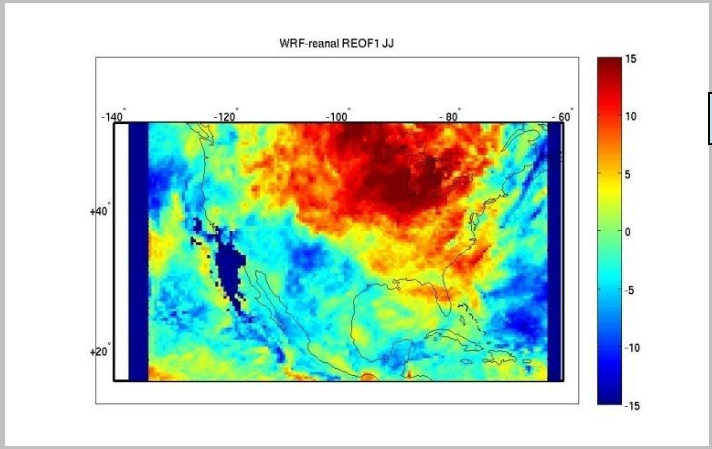
Climatology accelerated

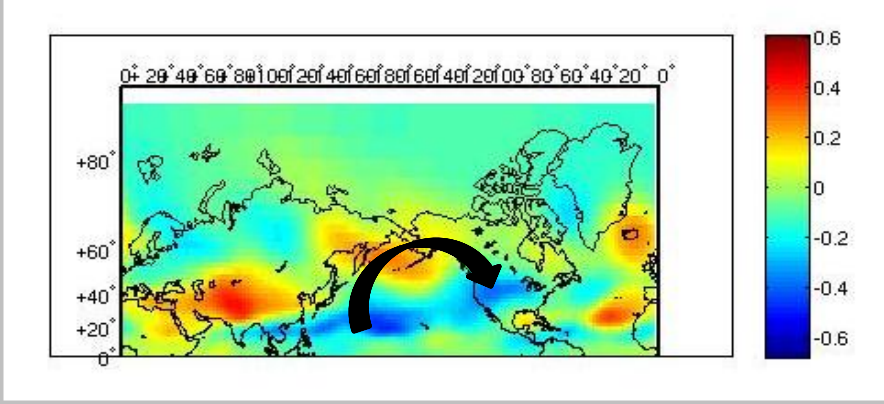
(Castro et al. 2001)

Dominant Mode of JJ downscaled SPI and relationship to 500-mb height anomalies

Dominant Precipitation Mode ***500-mb Height Anomaly***

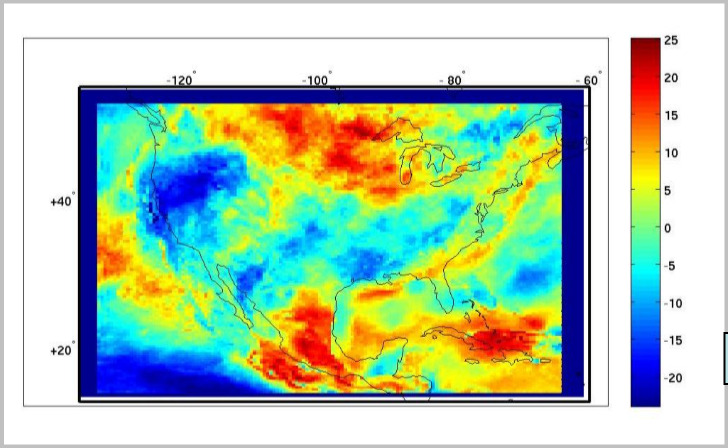
WRF-Reanalysis

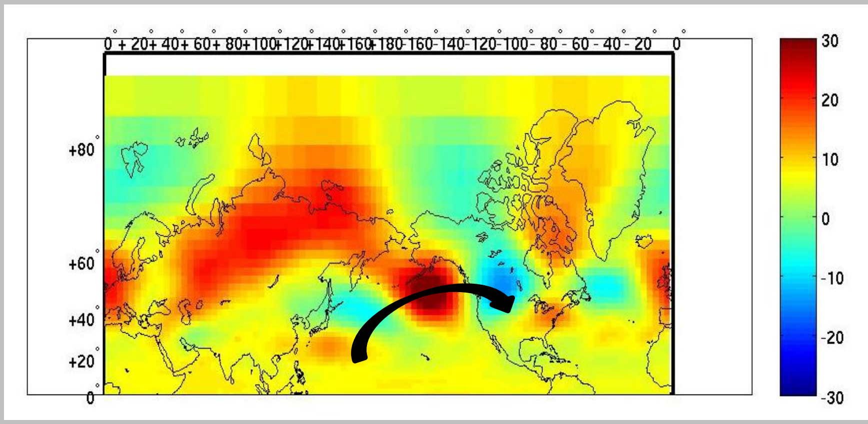




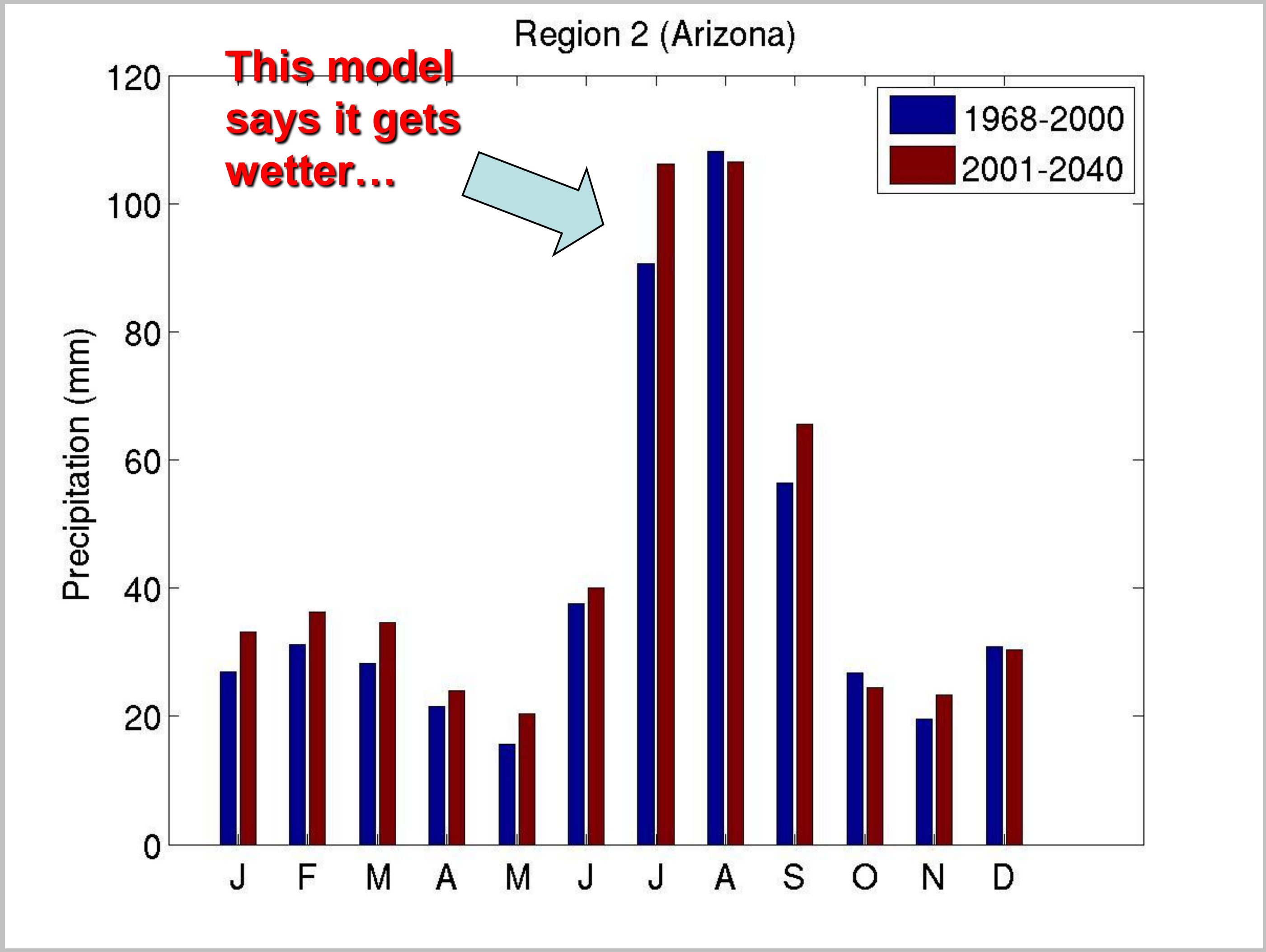
Principal Component Regression

WRF-HadCM3

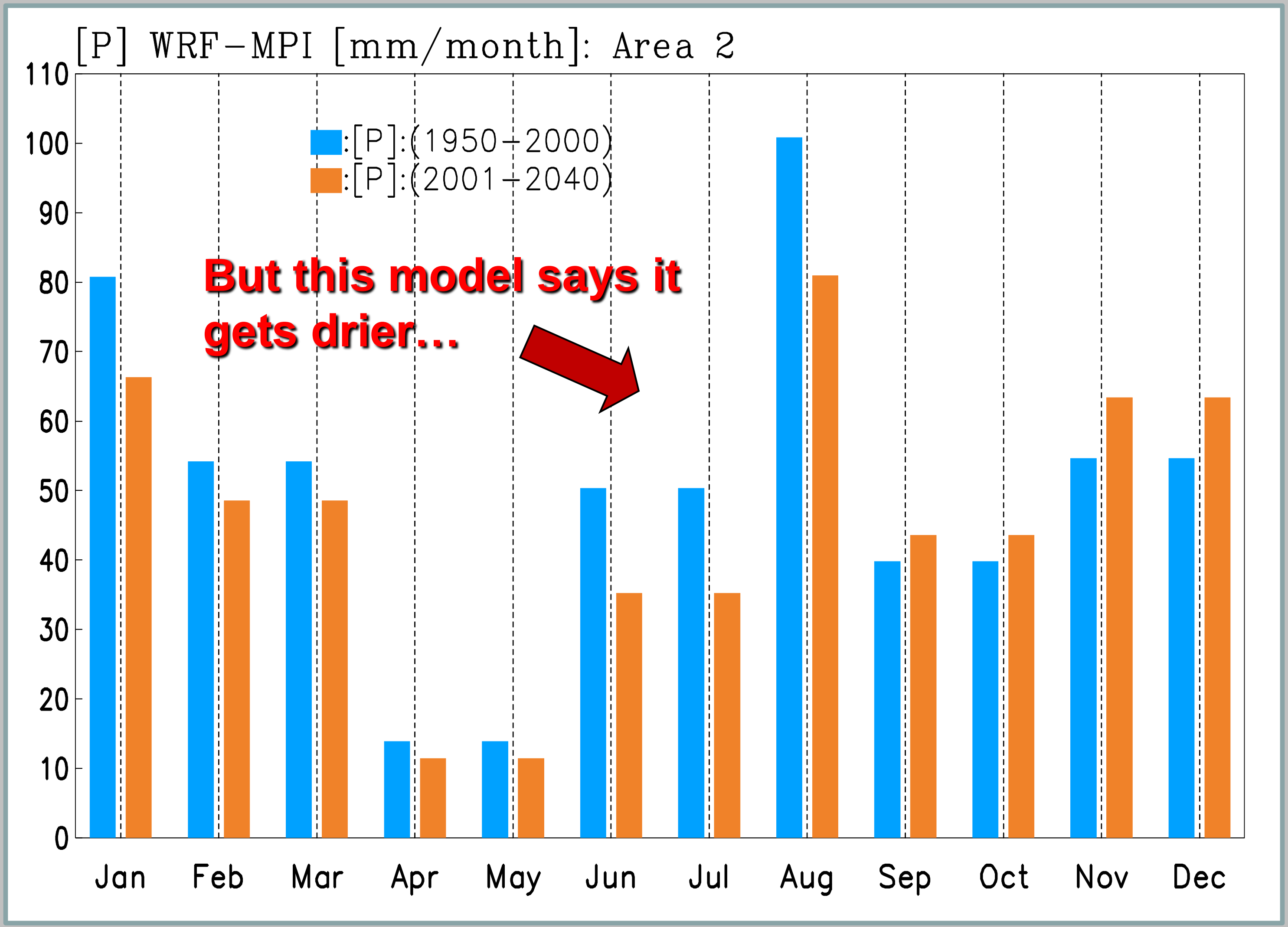




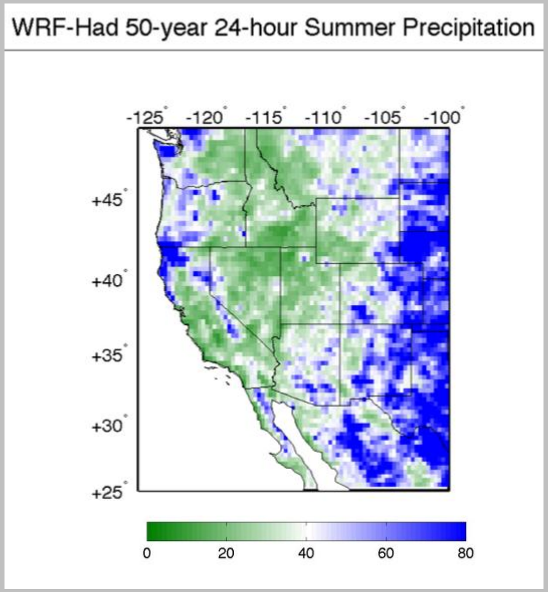
Change in WRF-HadCM3 dynamically downscaled precipitation in Arizona



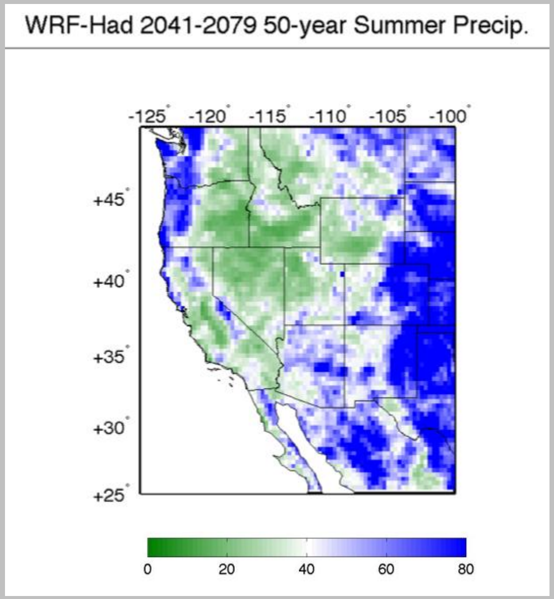
Change in WRF-MPI dynamically downscaled precipitation in Arizona



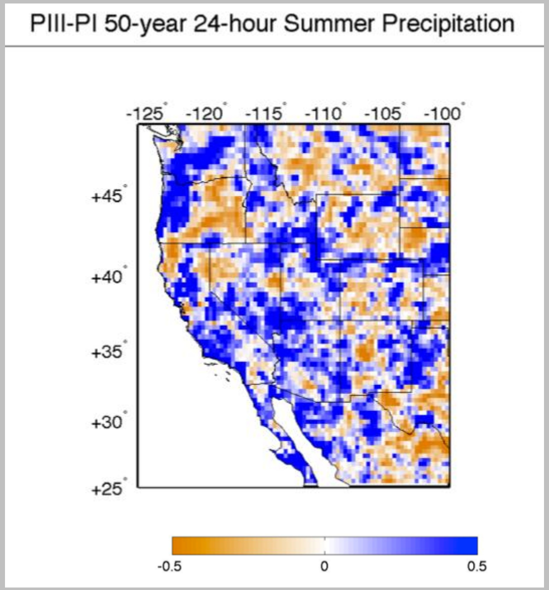
50-year WRF-HadCM3 summer precipitation events: historical vs. future



mm day^{-1}



mm day^{-1}



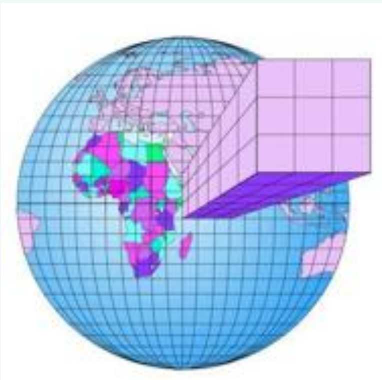
% change

Generally, an increase in warm season precipitation intensity tied to the terrain forced thunderstorms.

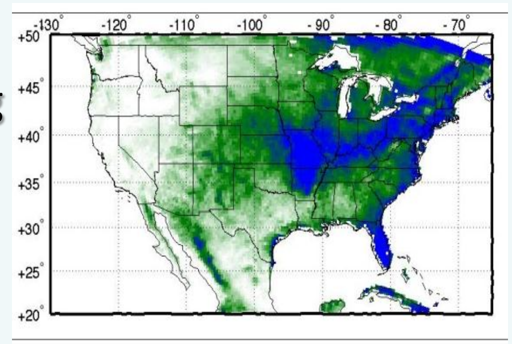
<u>My opinion:</u> Hotter and drier before monsoon onset, the wetter and more severe weather once monsoon arrives. Arrival modulated by natural variability (ENSO,PDO). We're actively working on this….

Multi-model schematic:

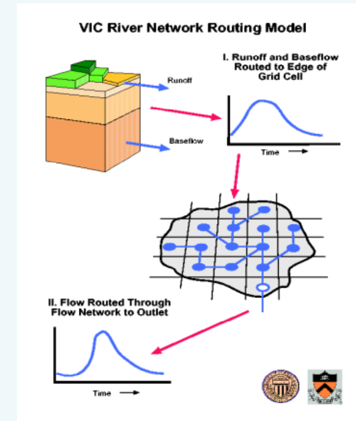
not a straight forward process!



Dynamical downscaling



Bias correction



1. Global Climate Models (GCMs) (2.5° resolution)

2. Regional climate model (RCM) simulations (35km resolution

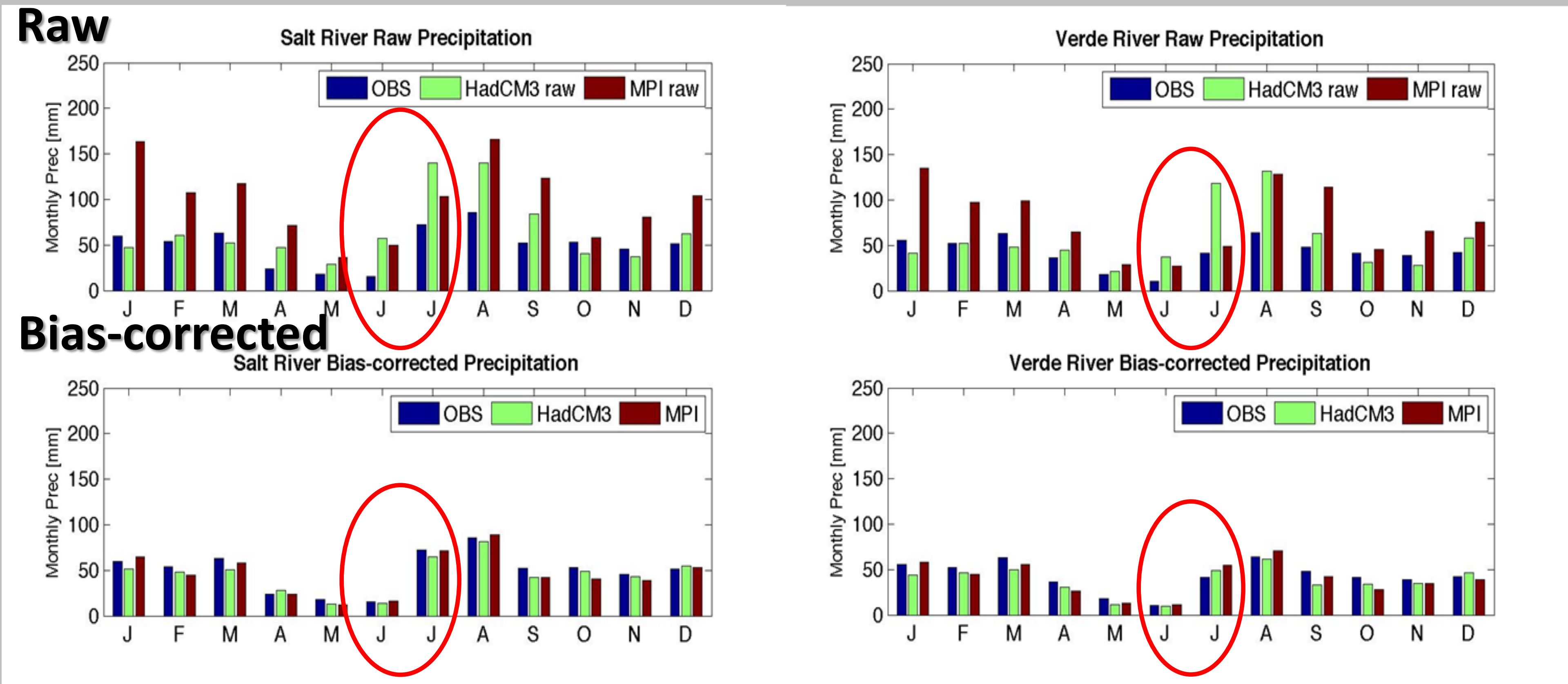
3. VIC hydrologic model watershed simulations (1/8 degree resolution)

Ultimate goal: long-term reliable future water management data for drought planning for water resource management, agriculture and natural hazards, i.e. floods, severe weather, wildfire

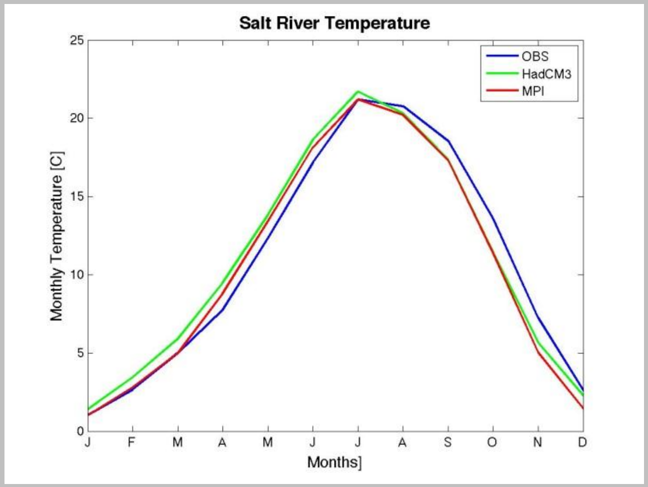
Preparing RCM data for VIC

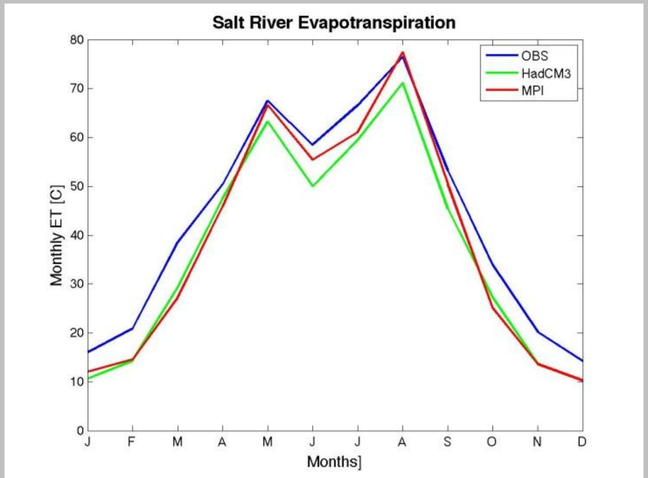
RCM precipitation and temperatures were:

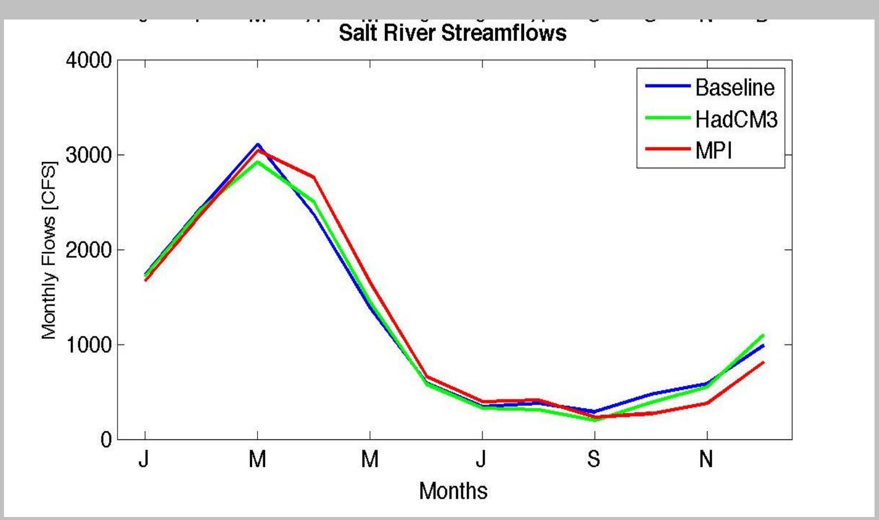
- rescaled to a 1/8 degree grid using an area weighted average
- Bias-Corrected using a Quantile method*

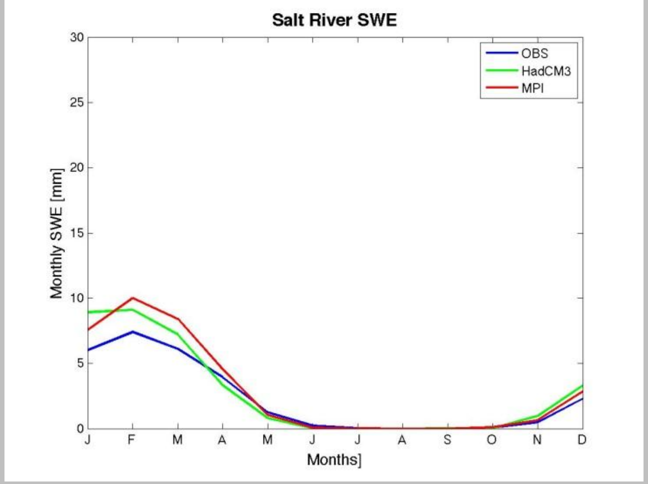


Hydrology model result: Salt River Basin (50 year climatology, monthly average)









Concluding points

Current global model climate models are spatially inadequate and misrepresent important physical processes—therefore their projections may be wrong.

Dynamical downscaling adds value because a regional model can better represent the land surface influences on precipitation processes: orgraphically forced snowfall in winter, monsoon thunderstorms in summer.

What do dynamically downscaled projections suggest so far?

> **<u>Winter:</u> Precipitation does not change, but is more intense. Less snowfall, especially in the Southwest. Greatest changes occur with the shift of the freezing line with elevation.**
>
> **<u>Summer:</u> Inconclusive whether monsoon gets drier or wetter from two IPCC AR4 models considered, but likely greater severity of thunderstorms either way.**

Regional climate model data are near a spatial scale adequate for water resource projection with a hydrologic model, appropriately accounting for individual model bias.