The best of both worlds: Processed-based and data-driven regional climate.

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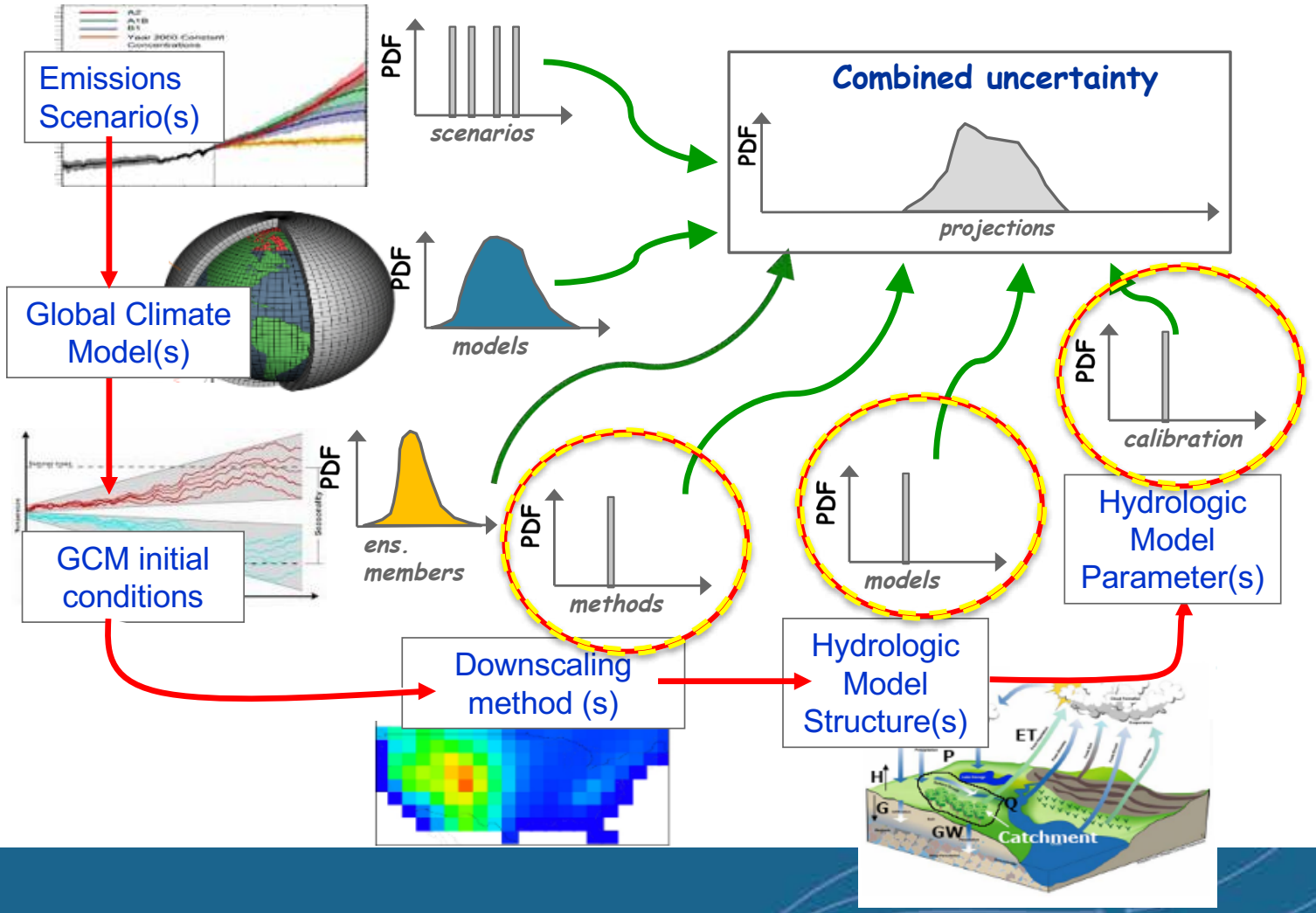
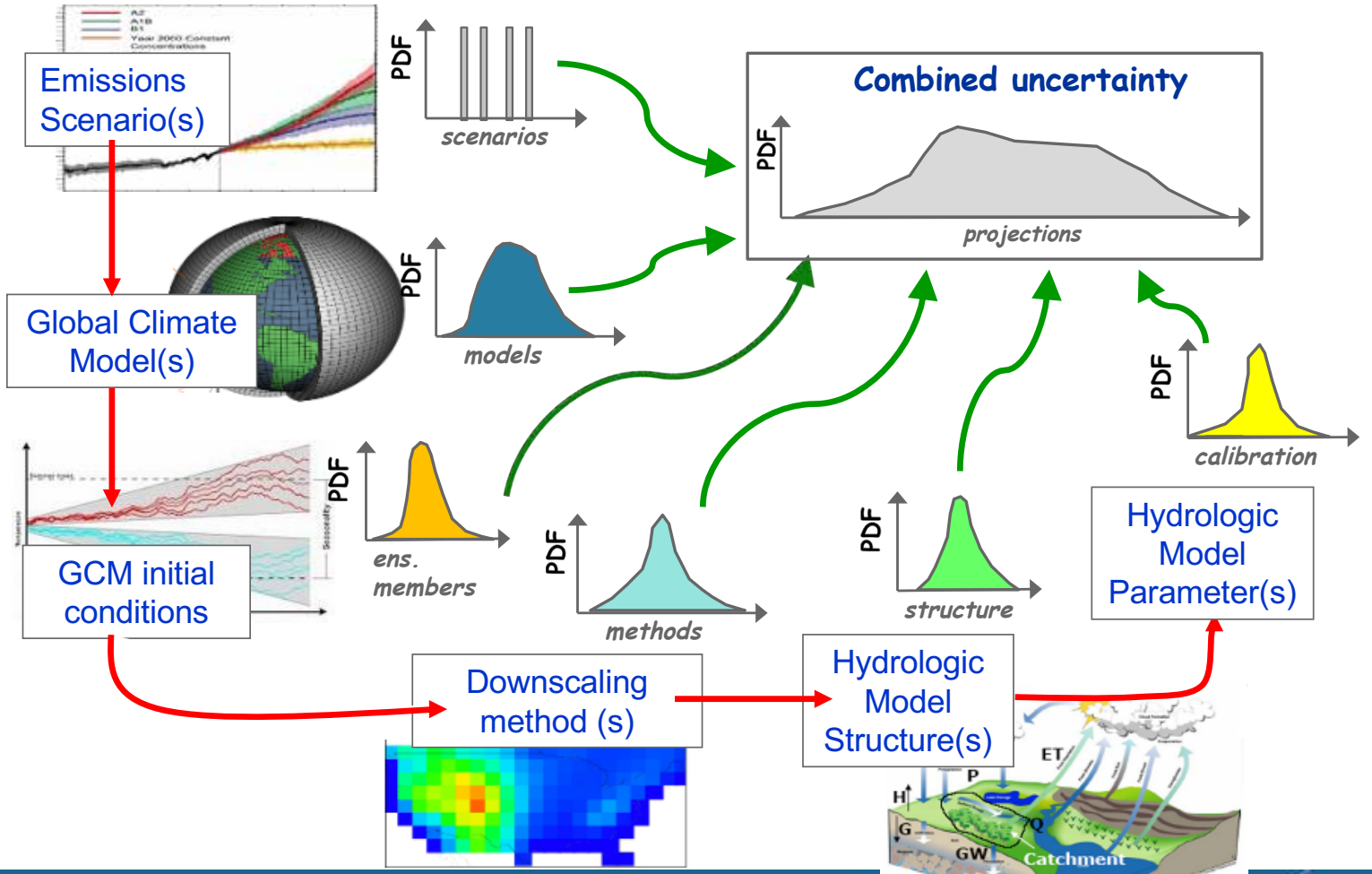
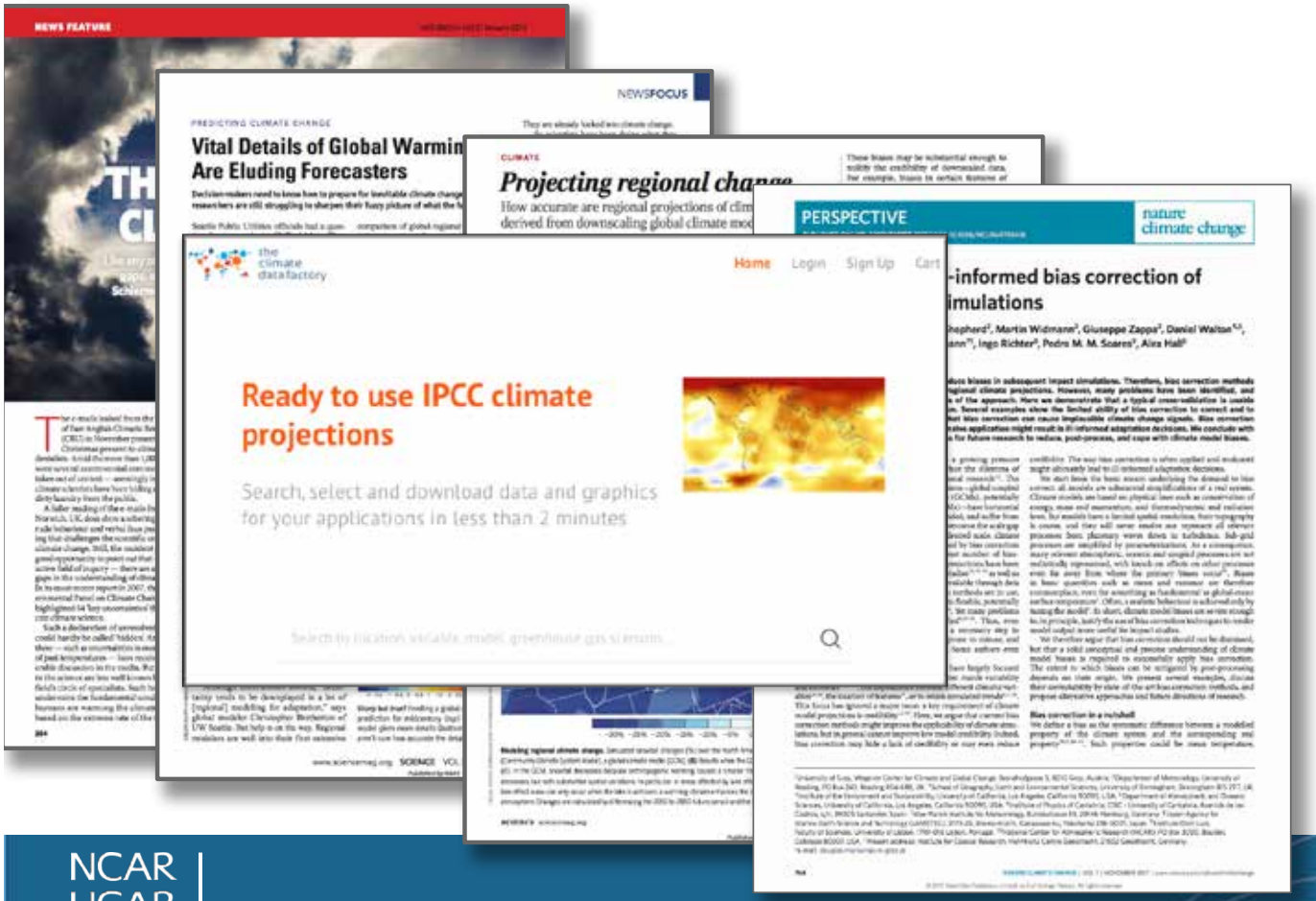
How do water resource managers approach this?



Revealing and reducing uncertainties



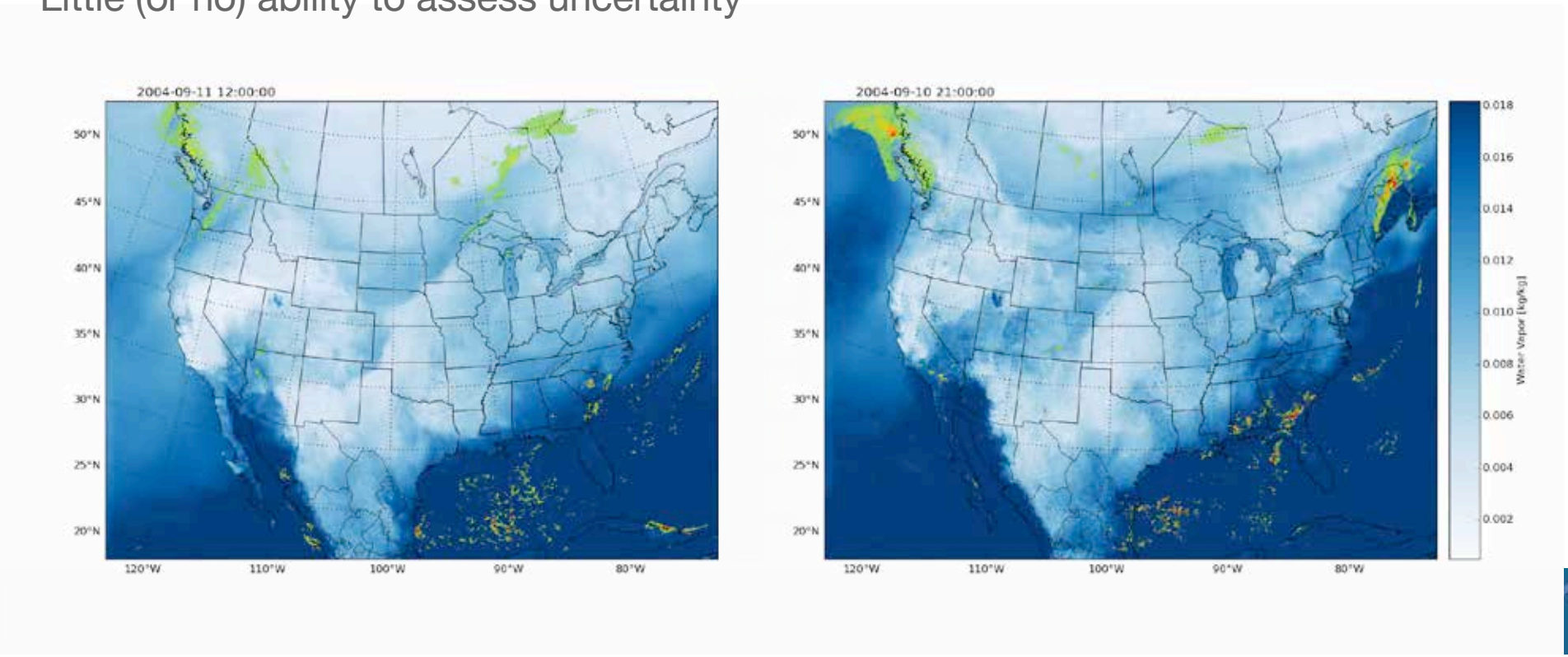
Is Downscaling Legitimate?



- Missing features in climate models (e.g. mountains)
- Disparity between downscaled projections
- Some consistent features arise from physics!
- Movement to include more physics!
- And be aware of how this work may be used…

Physics to the Rescue ?

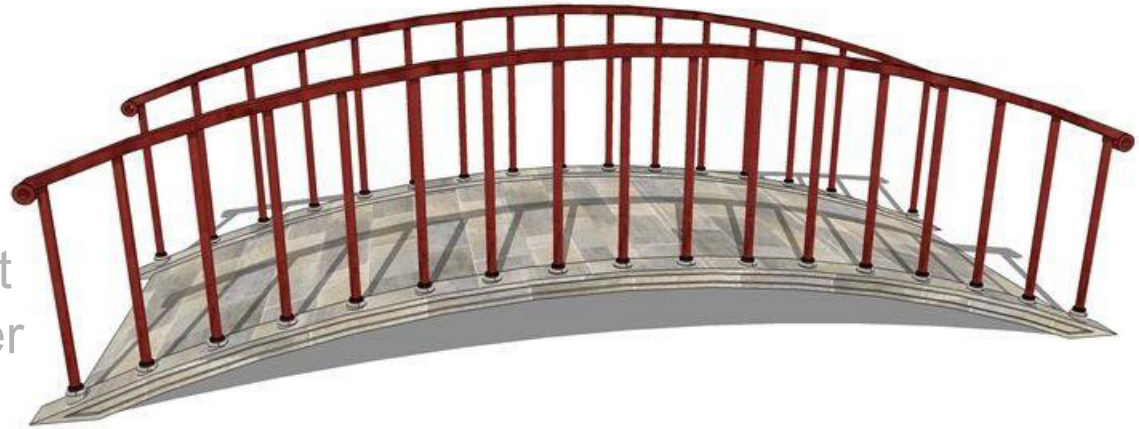
- Convection permitting/resolving regional climate models
- Millions (and millions) of CPU hours
- Little (or no) ability to assess uncertainty



The Conceptual Divide in Downscaling

Physics

The only way to get the "correct" answer

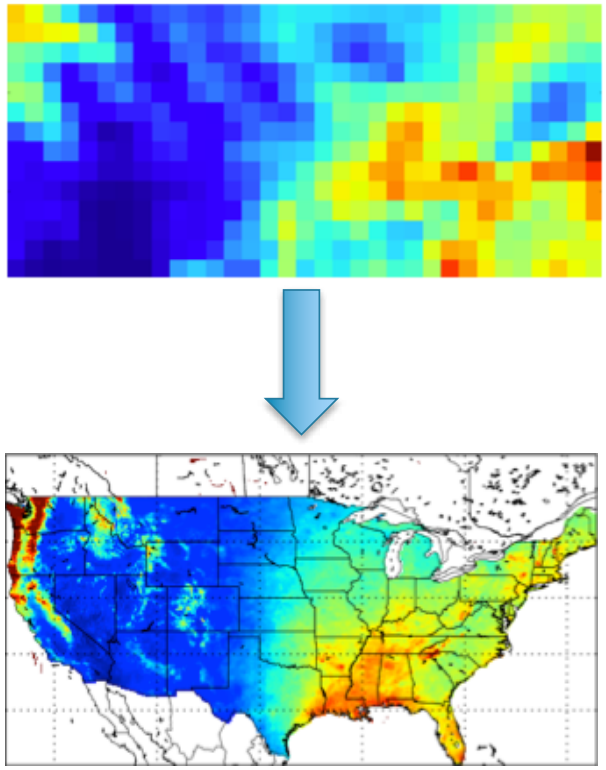


Statistics

The only way to get a relevant answer

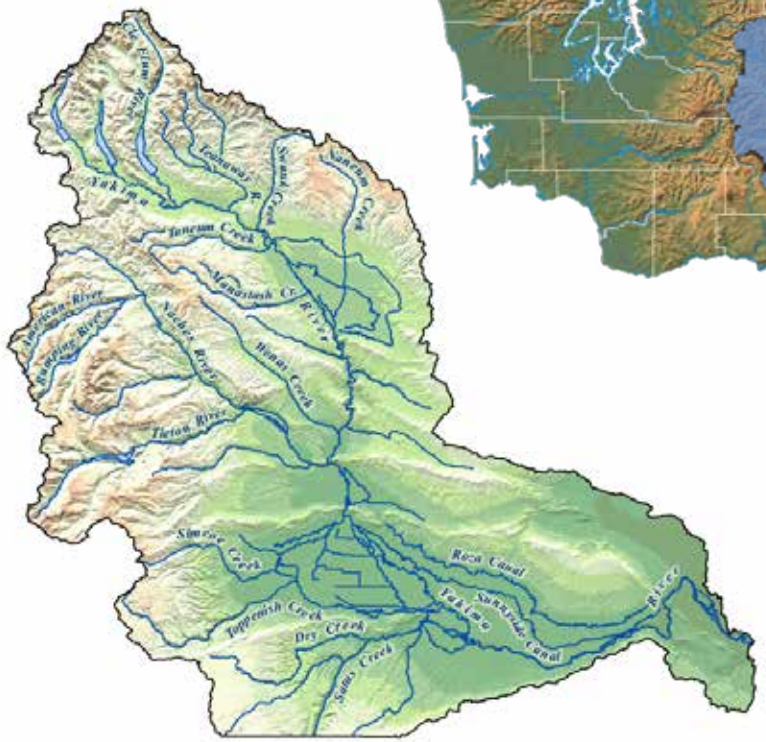
Regional Climate Downscaling Techniques

- Simple Bias Correction Statistical Techniques
  - LOCA, BCSD, QM
- Circulation conditioned statistical techniques
  - GARD (**bringing physics to statistical methods**)
- Simple Atmospheric Model
  - ICAR (**with statistical corrections applied internally)**
- Full Atmospheric Model
  - WRF 4km (only PGW feasible)
  - WRF 50km (or 25 or limited 12km)



Yakima River Basin

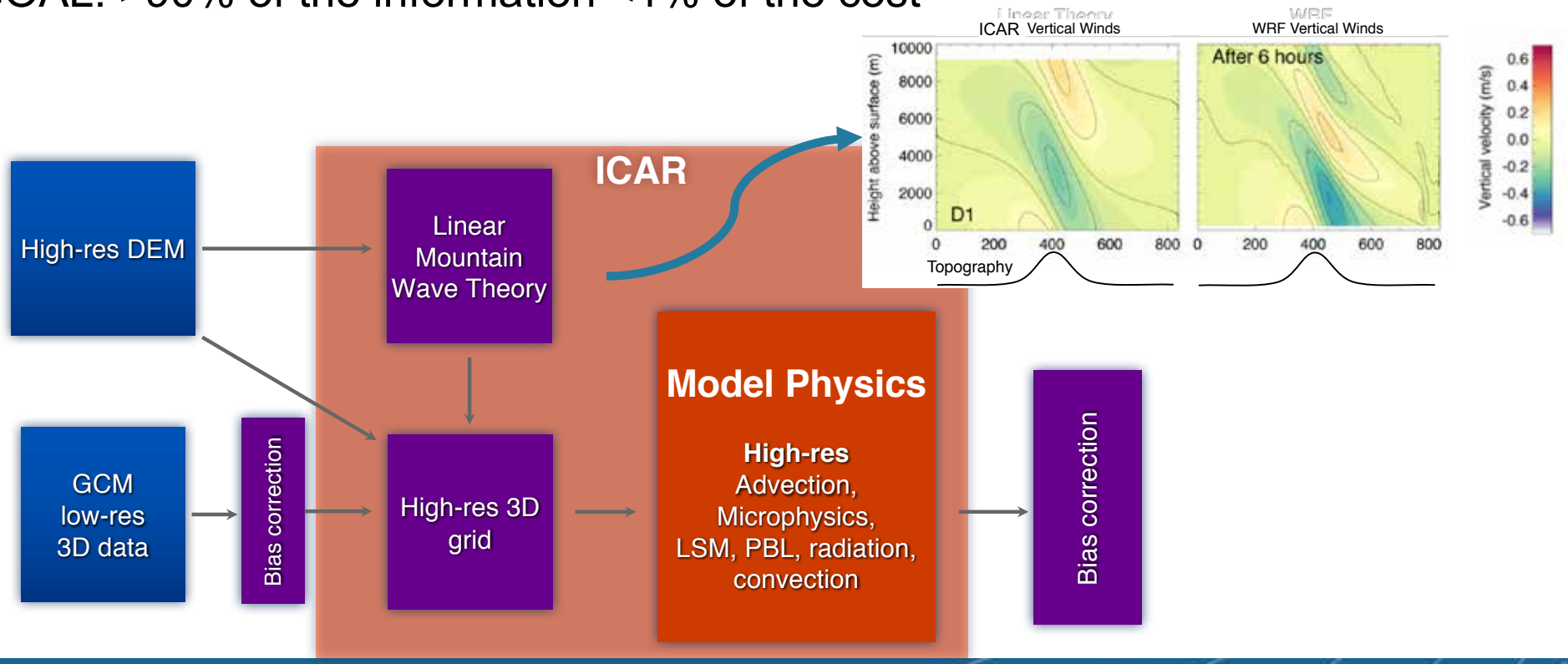
- East side of Cascades
- 6 major reservoirs
- Agriculture dependent on water



ICAR: Intermediate Complexity Atmospheric Research model

Identify the key physics for a simple model
GOAL: >90% of the information <1% of the cost

http://github.com/NCAR/icar



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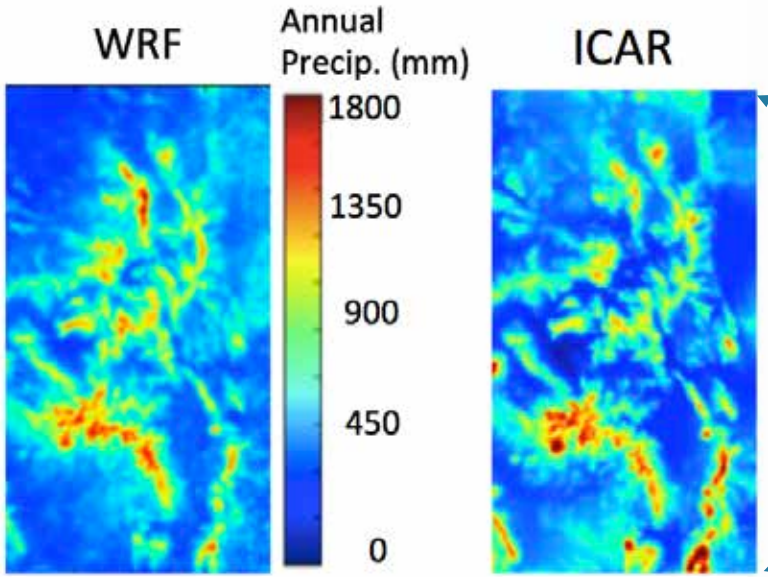
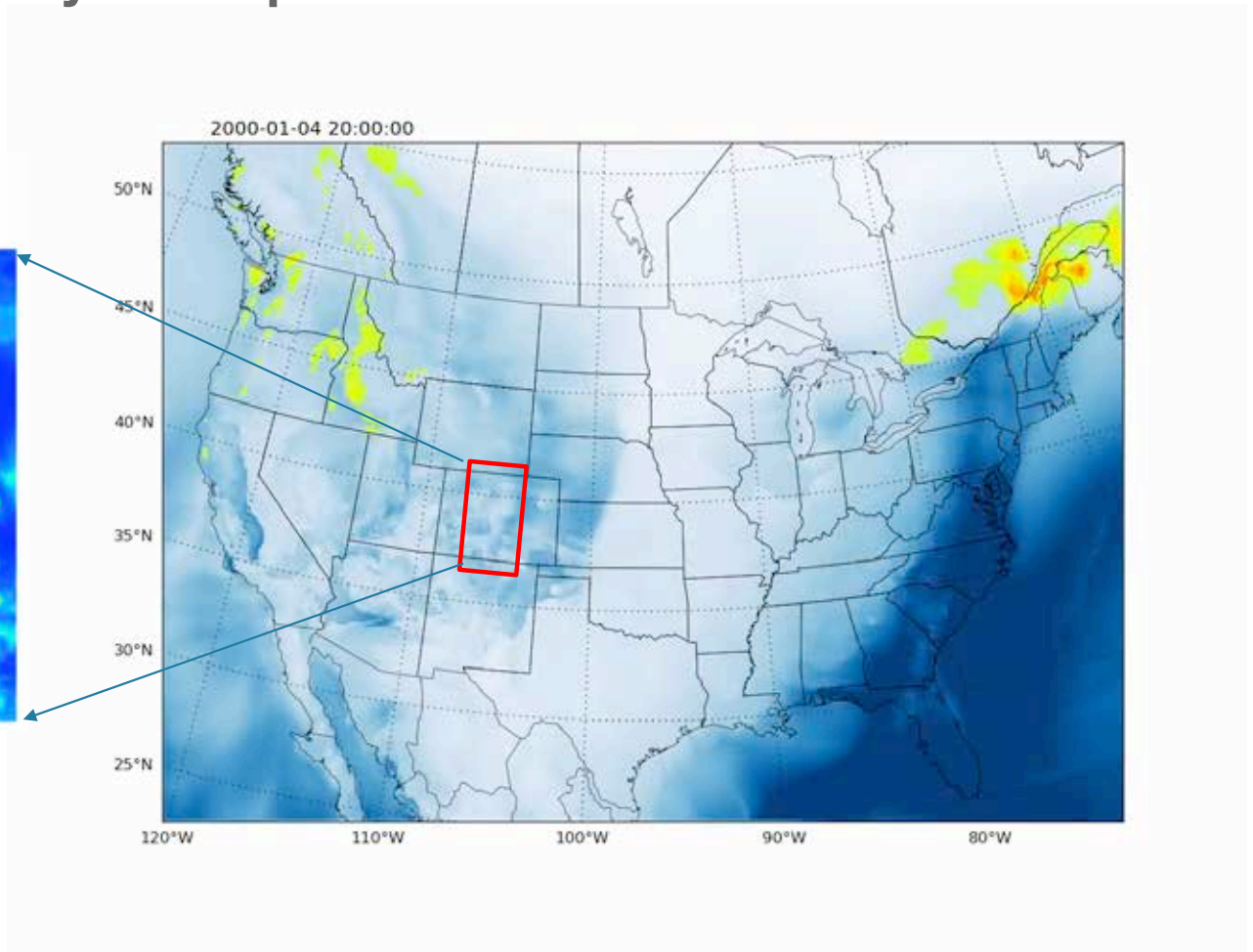
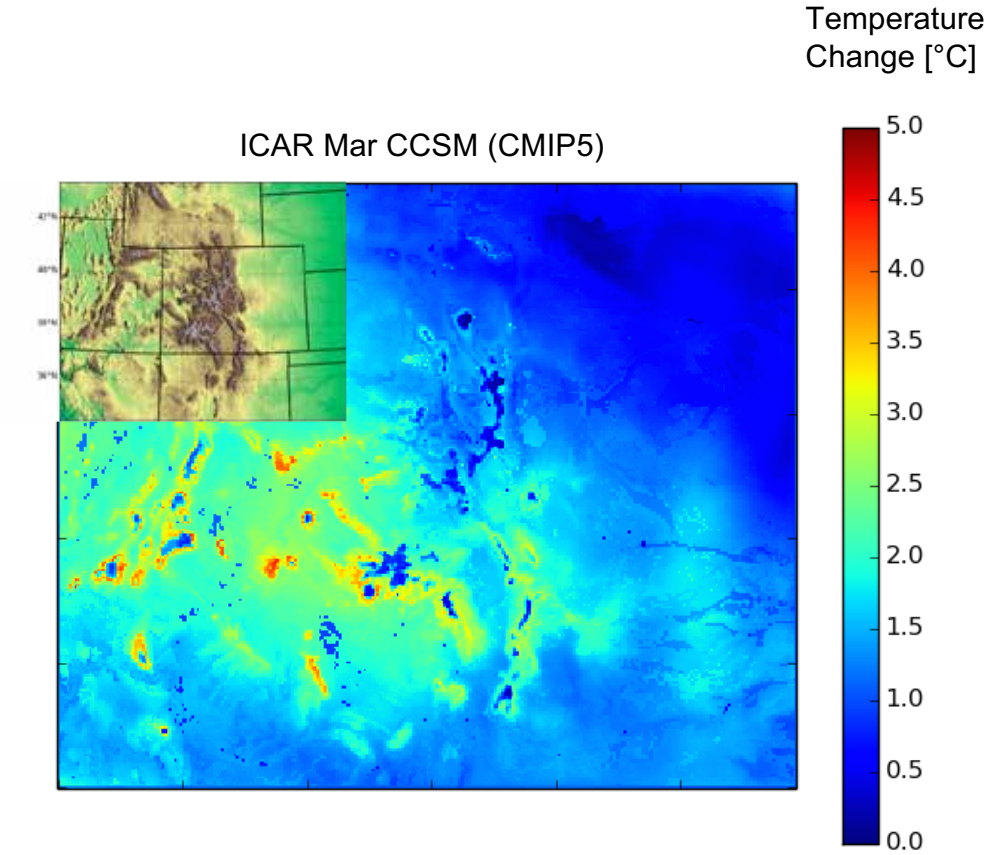


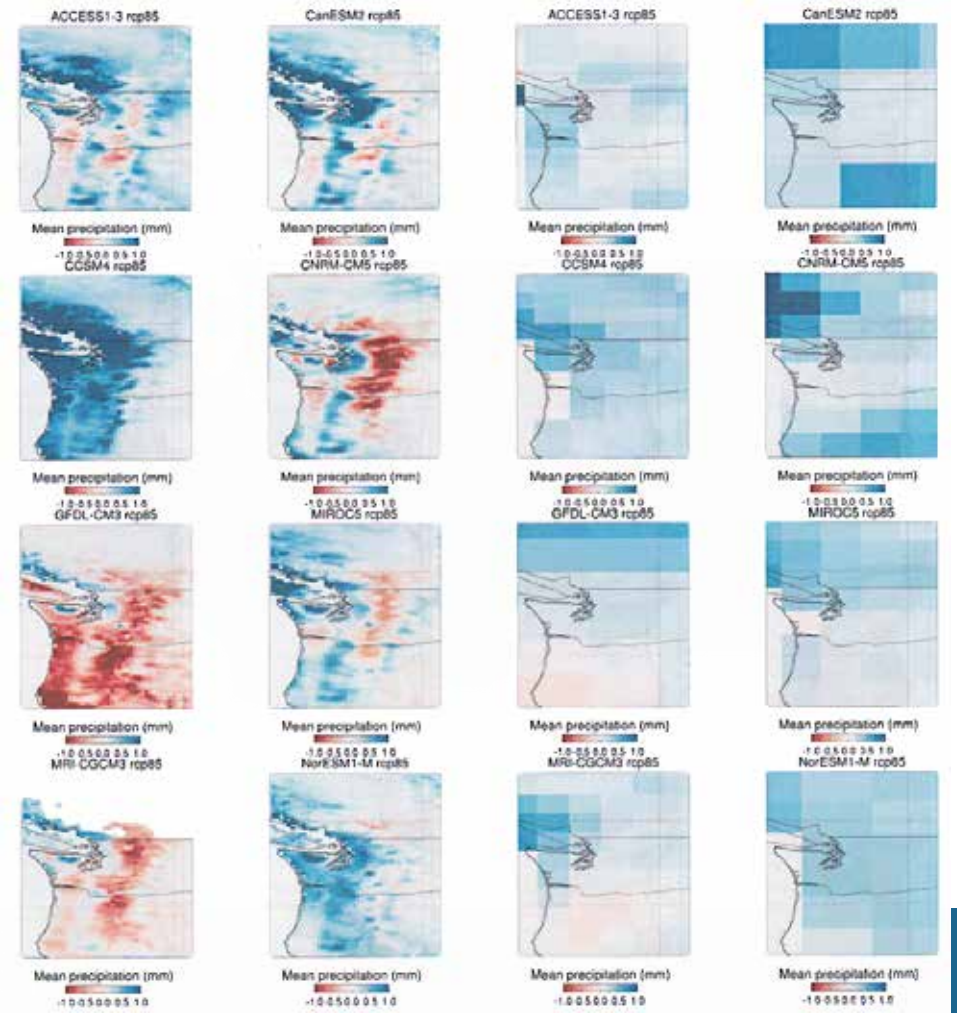


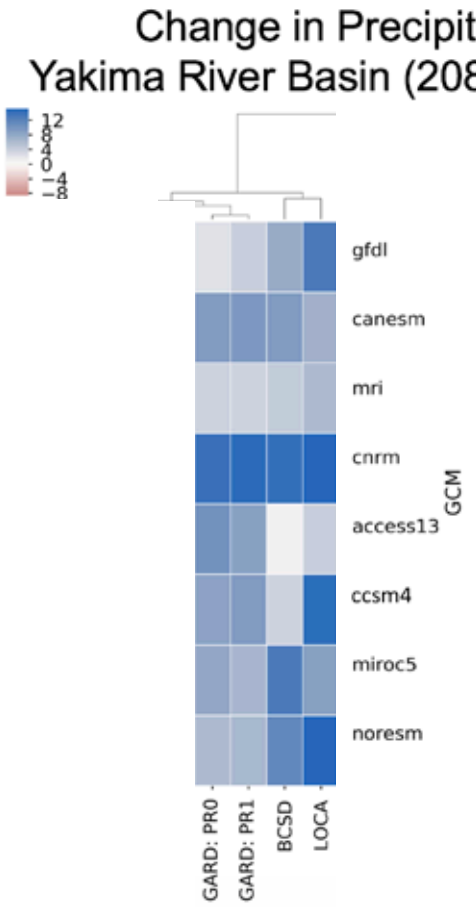
Core physics with online corrections

- ICAR represents 90% of the physics, but the remaining 10% can be problematic.
- ICAR has biases, e.g. too much precipitation on mountain peaks, too little in the valleys
- Known biases can be corrected to keep the rest of the physics consistent.
- Apply a climatological bias correction to precipitation
- Improves LSM snowpack, and thus snow-albedo feedback representation



A Large Ensemble





WRF Annual Climate Change signal PGW – Control

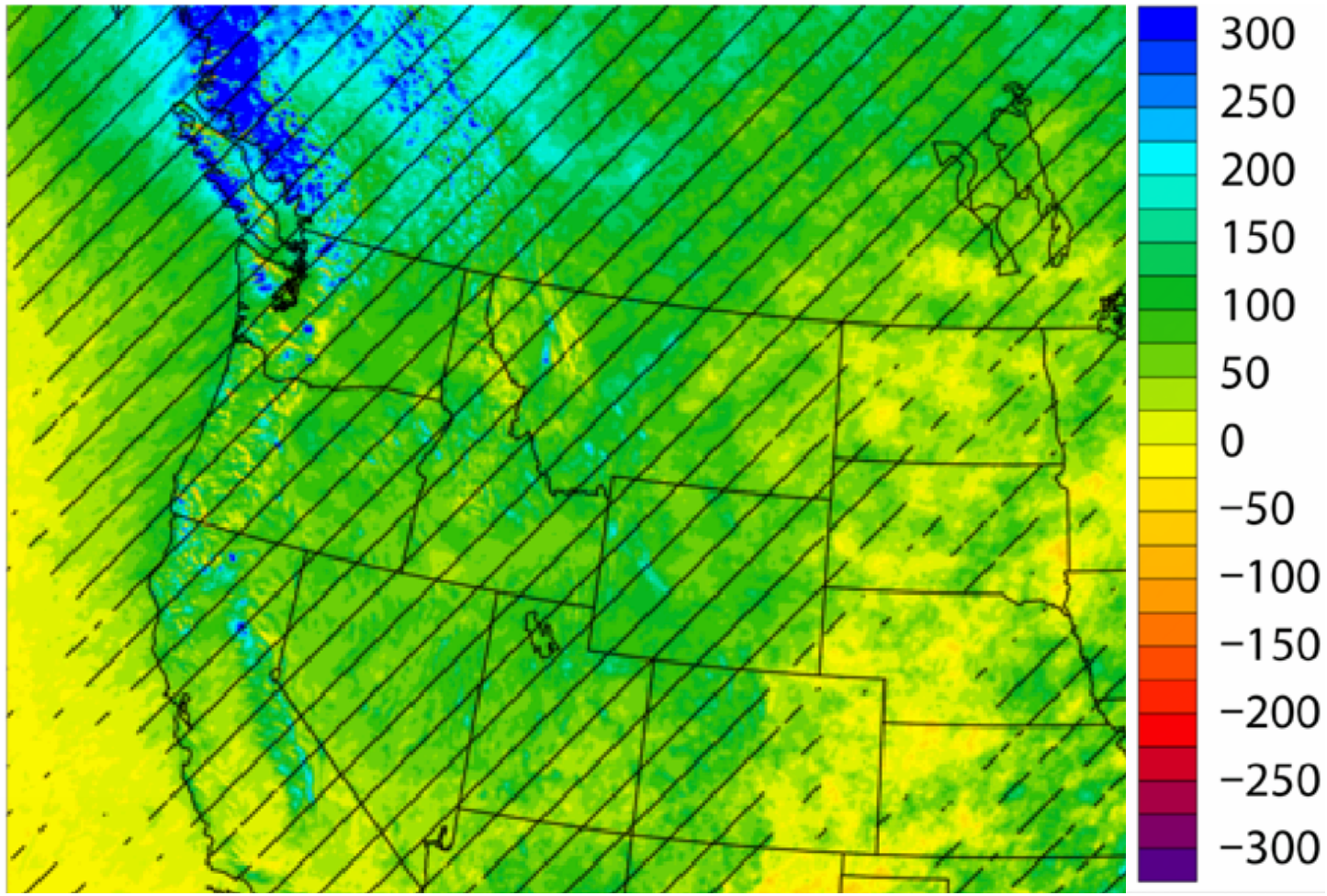
Pseudo Global Warming change signal (PGW)

30-yr mean change in water vapor, temperature, sea level pressure, U and V averaged across 19 GCMs

13 year 4km CONUS WRF simulation

ERA-I (current 13 years)
+PGW (future 13 years)

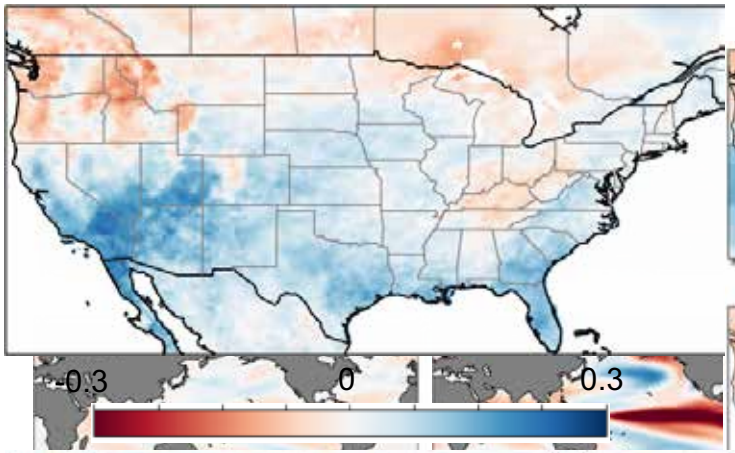
WRF 3.7.1
Convection permitting, RRTMG, Thompson, YSU, Noah-MP

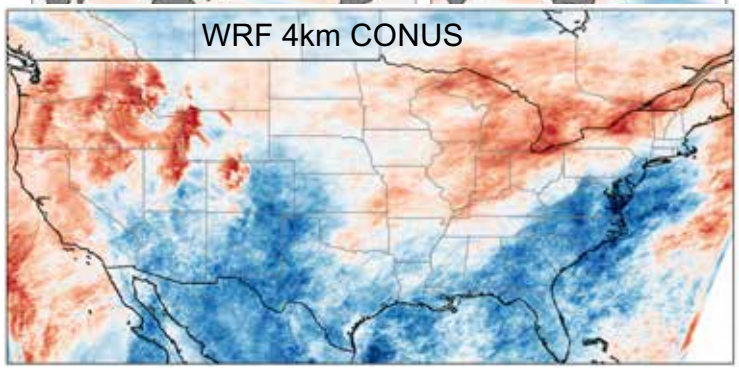


NCAR
UCAR

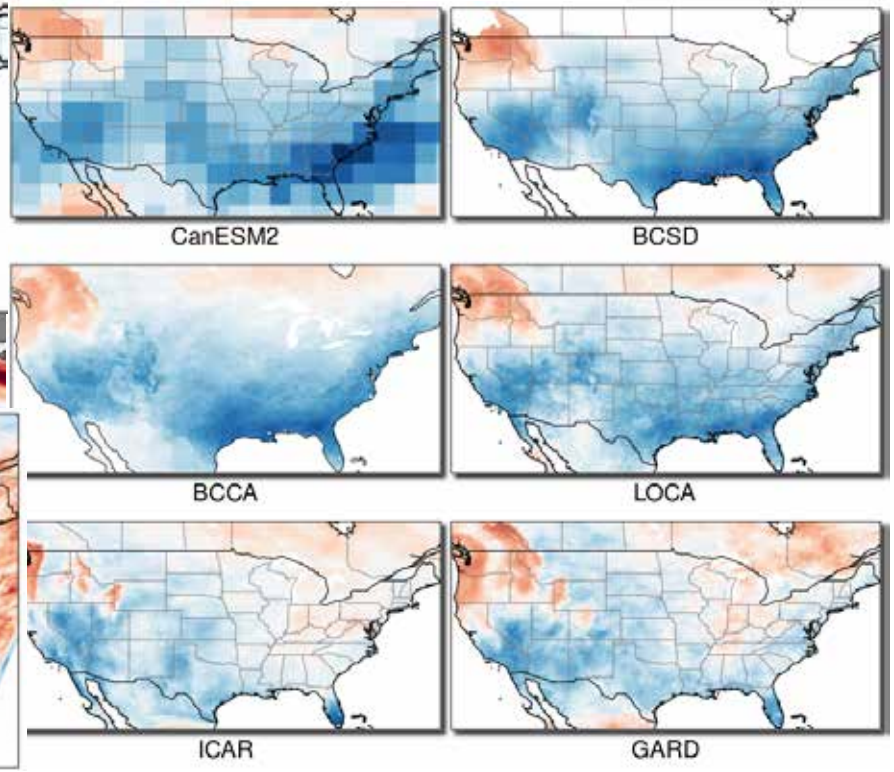
Evaluation - ENSO

Observed
ENSO - Precipitation



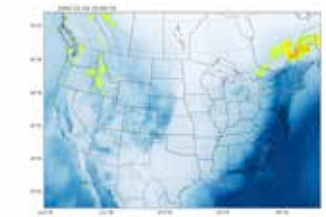


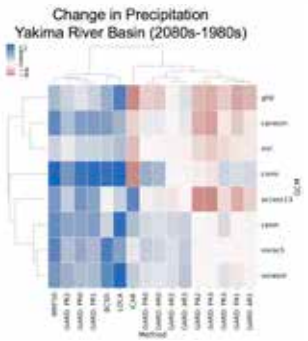
CanESM2

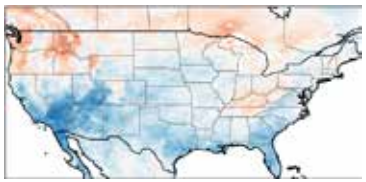


Summary

- Working with water managers to create and understand possible climate projections.
- Combining statistical corrections with simplified physics may provide a more robust climate change representation.
- Methods connected to atmospheric circulation provide different answers than more traditional approaches.
- Teleconnections may provide a useful historical test for climate applications.



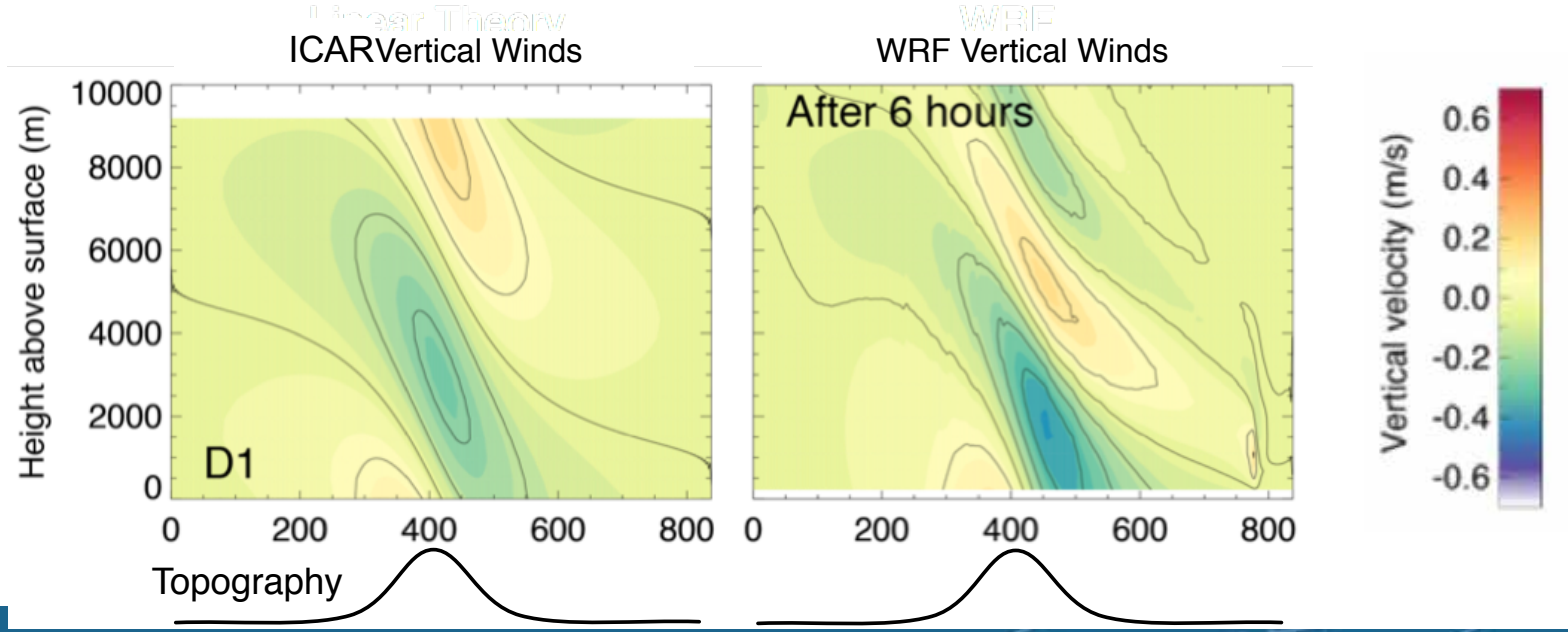




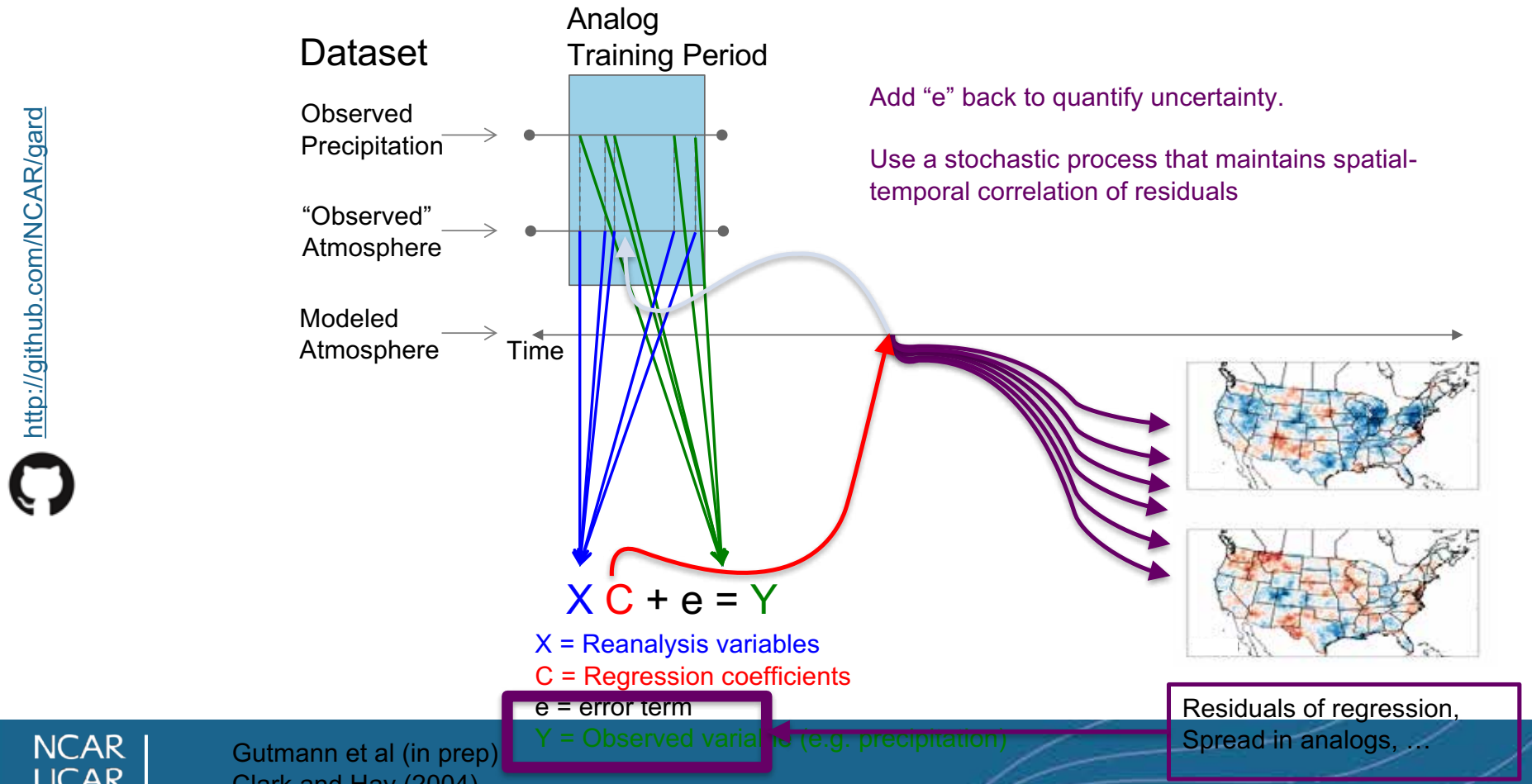
ICAR Dynamics

$$\hat{u}(k,l) = \frac{-m\,(\sigma k - ilf)\,i\hat{\eta}}{k^2 + l^2} \qquad \hat{v}(k,l) = \frac{-m(\sigma l + ikf)i\hat{\eta}}{k^2 + l^2}, \qquad \hat{w}(k,l) = i\sigma\,\hat{\eta}$$

$$\hat{\eta}(k,l) = \hat{h}e^{imz}, \qquad m^2 = \frac{N^2 - \sigma^2}{\sigma^2 - f^2}(k^2 + l^2), \qquad \sigma = Uk + Vl$$



En-GARD: Ensemble Generalized Analog Regression Downscaling



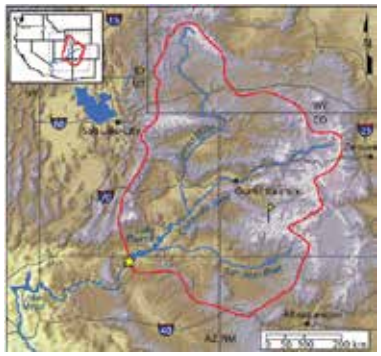
http://github.com/NCAR/gard

NCAR | UCAR

Gutmann et al (in prep)
Clark and Hay (2004)

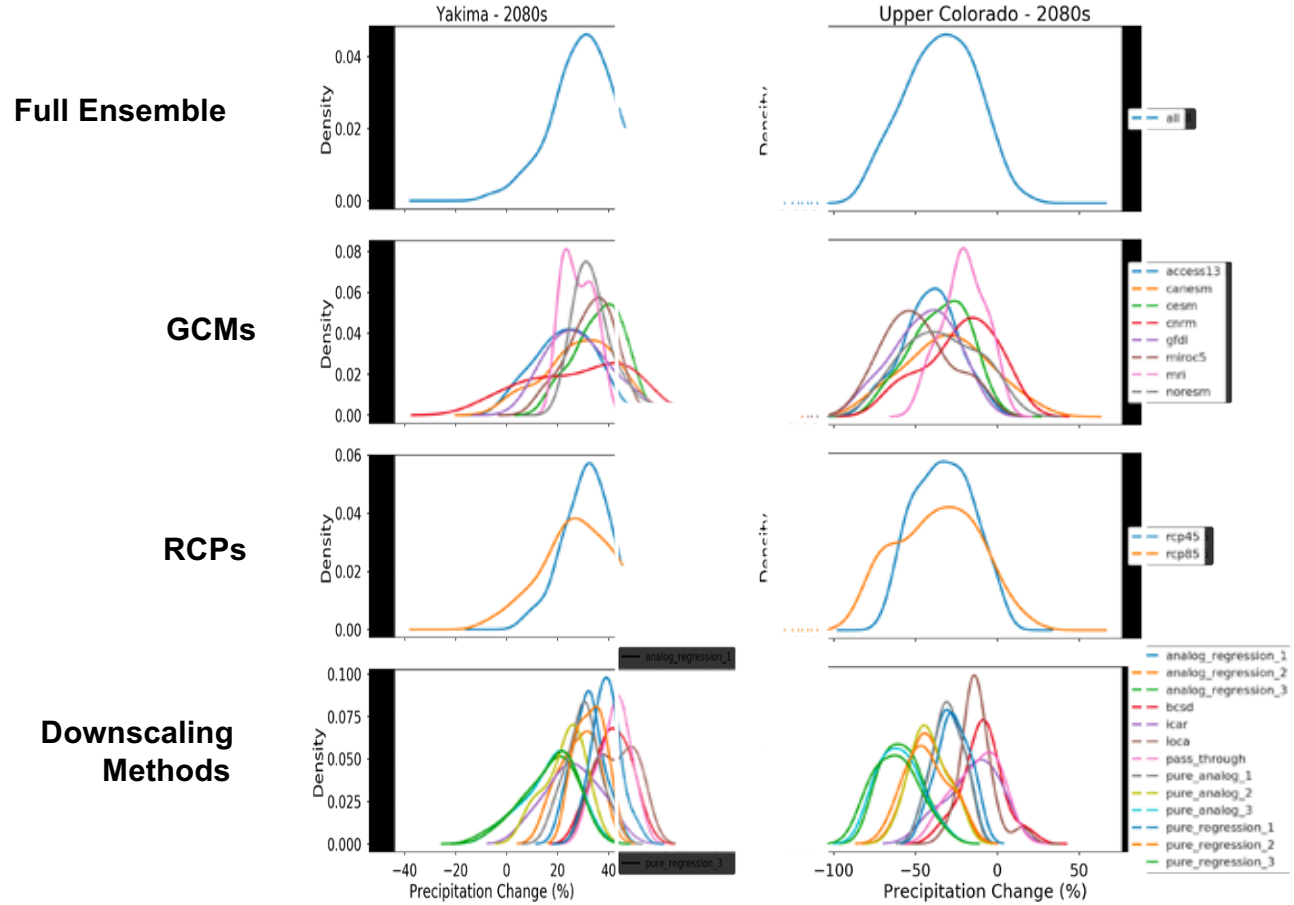
Washington State

Colorado River Basin

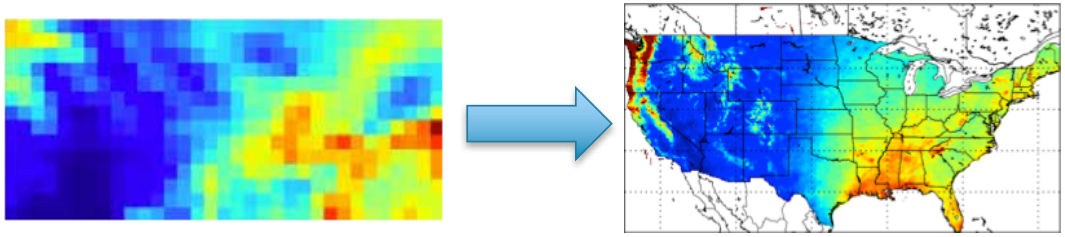


Spread in Mean Annual Precipitation Change (2080s – 1980s) for the Yakima (WA) and Upper Colorado (CO) basins.

- Variations between GCMS are similar to variations between downscaling methods



Simple Statistical Downscaling



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