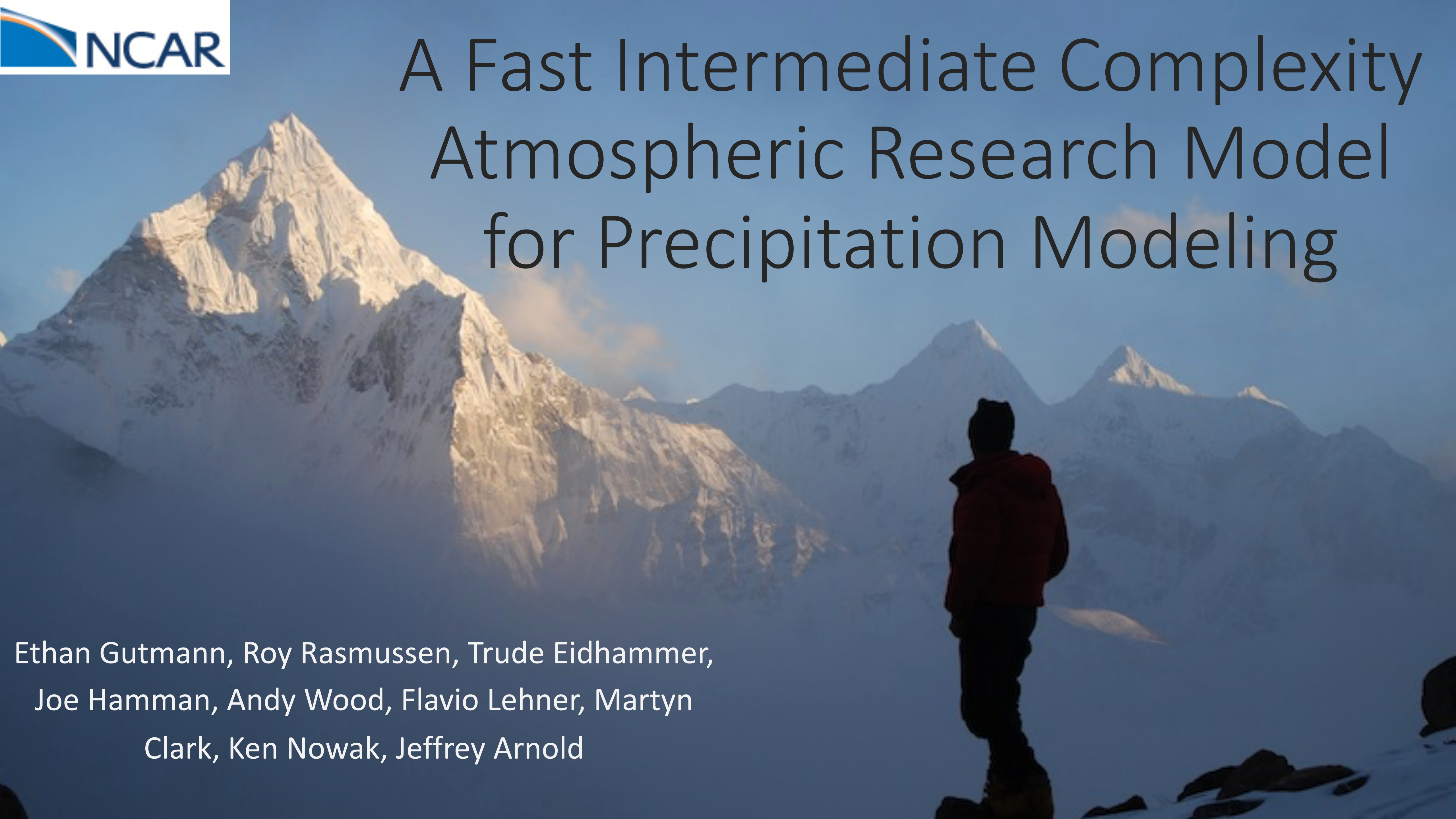
A Fast Intermediate Complexity Atmospheric Research Model for Precipitation Modeling



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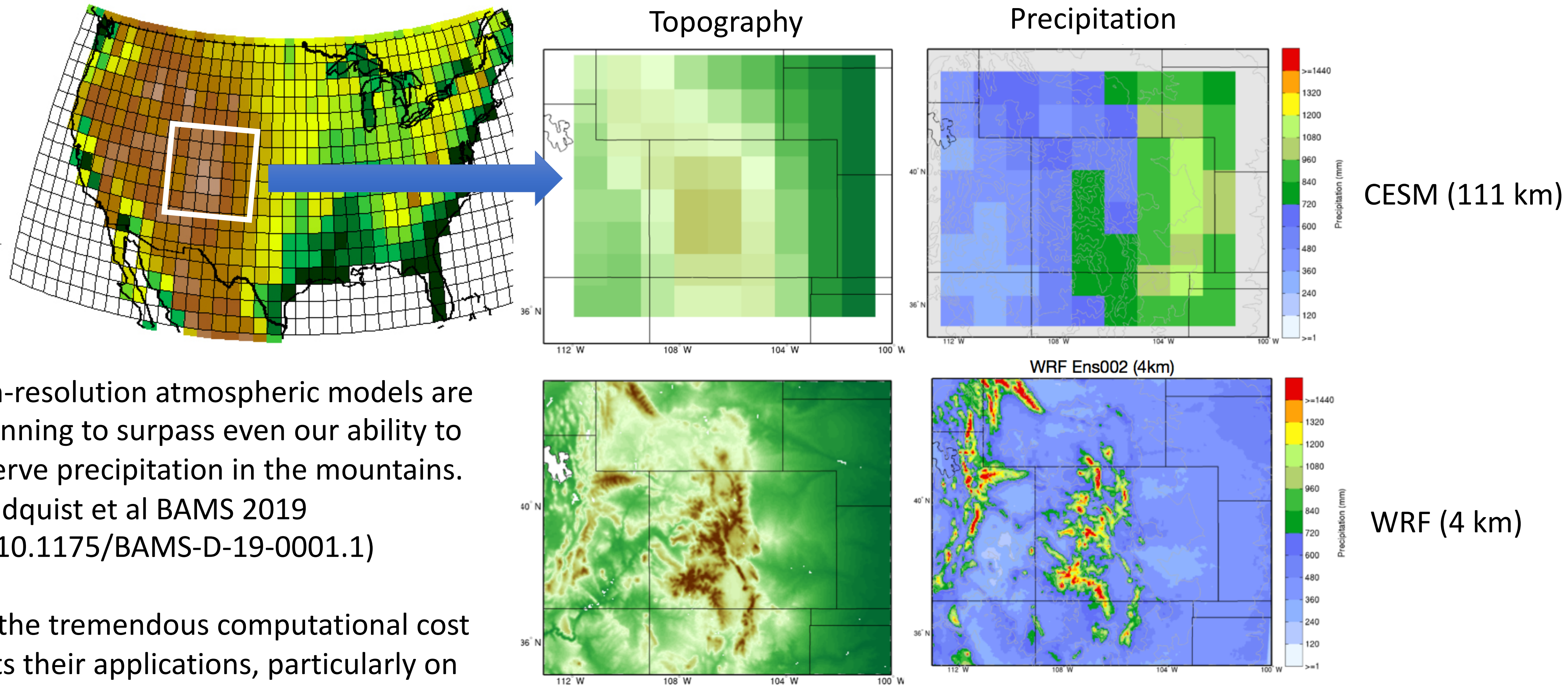
Climate Model Native Resolution and Precipitation



High-resolution atmospheric models are beginning to surpass even our ability to observe precipitation in the mountains. (Lundquist et al BAMS 2019 doi:10.1175/BAMS-D-19-0001.1)

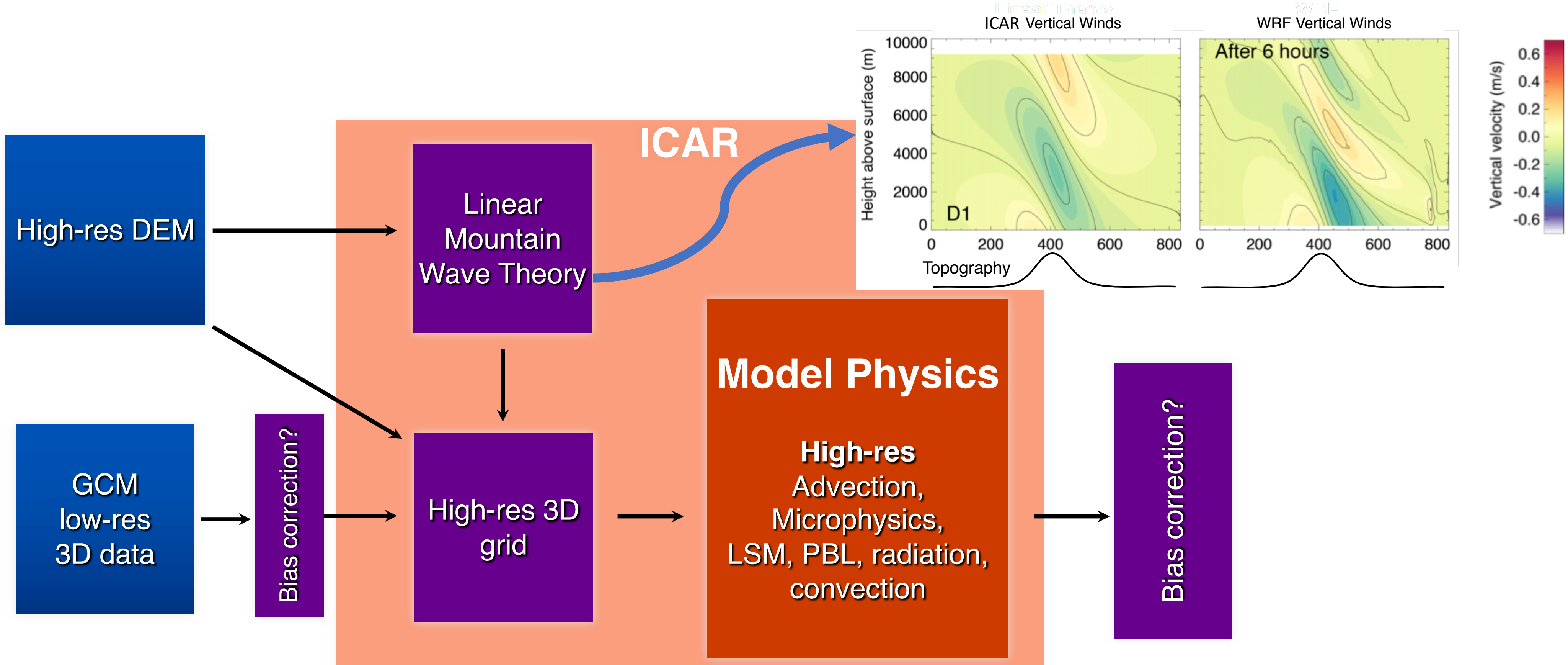
But the tremendous computational cost limits their applications, particularly on climate time scales.

Intermediate Complexity Atmospheric Research model (ICAR)

http://github.com/NCAR/icar

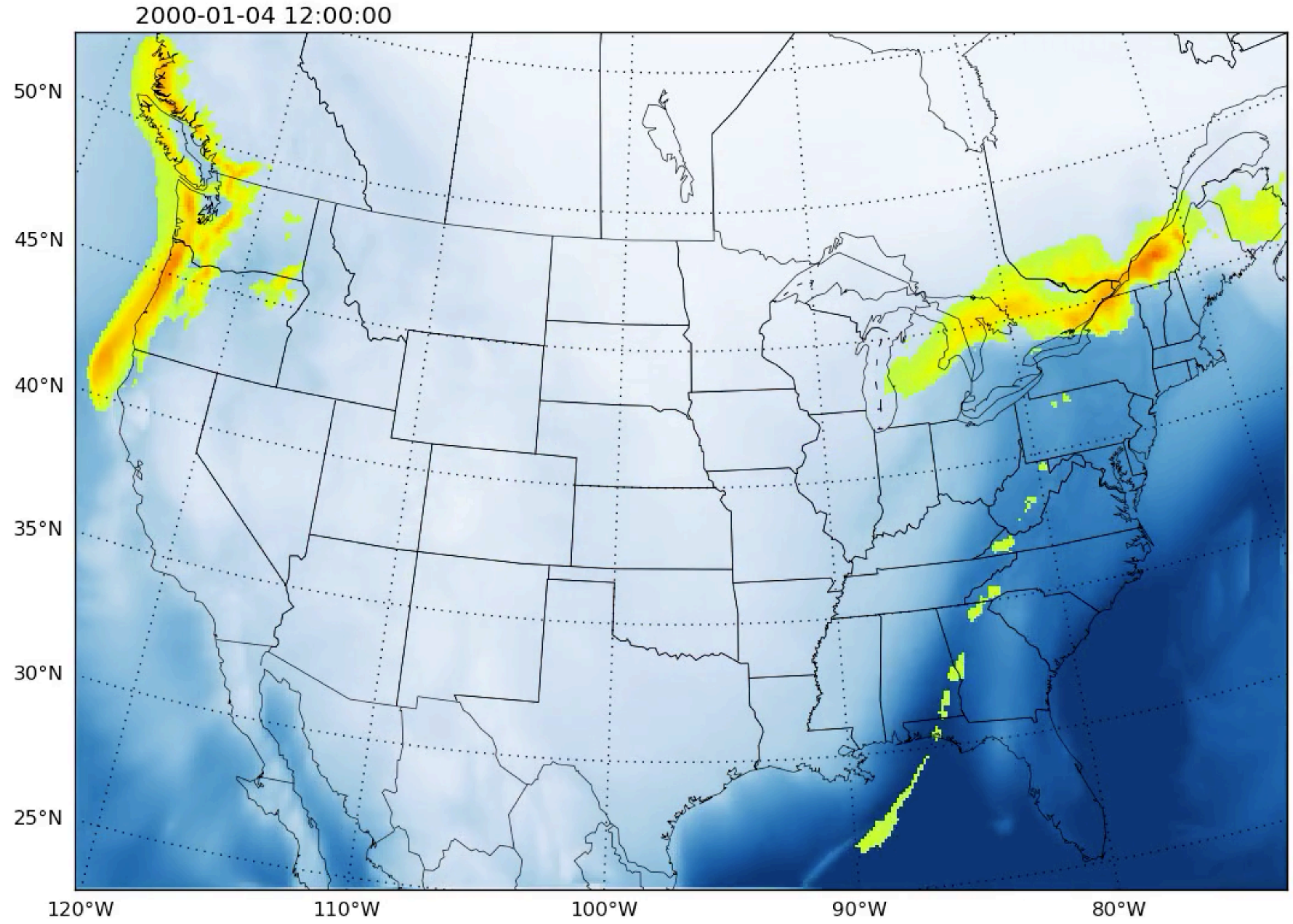
Identify the key physics and develop a simple model

GOAL: >90% of the information for <1% of the cost



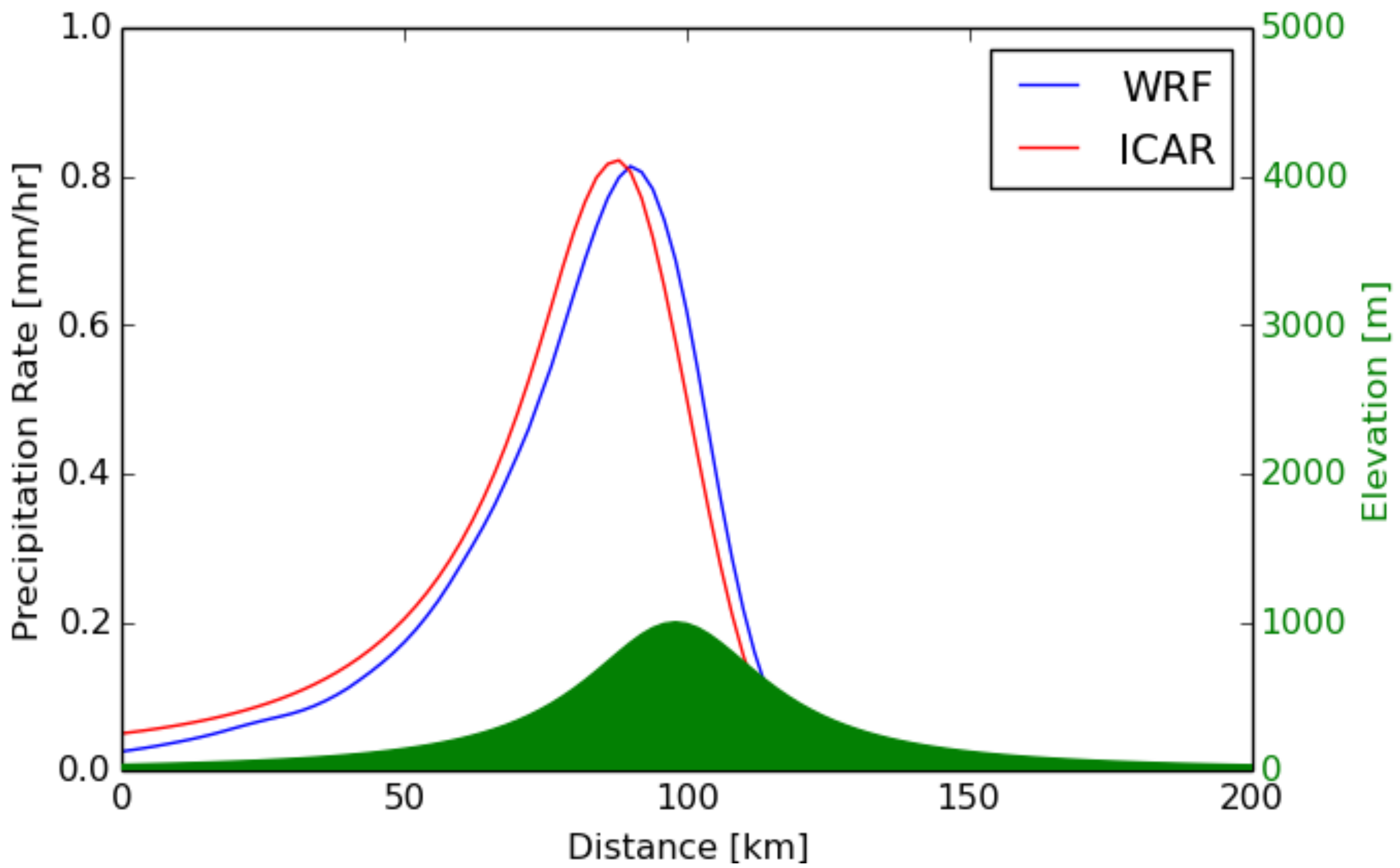
Gutmann et al (2016) *JHM* doi:10.1175/JHM-D-15-0155.1

ICAR simulation

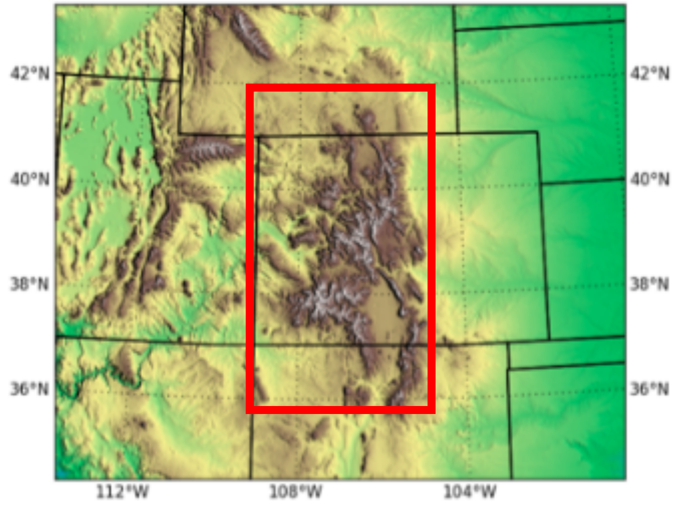


Ideal case: test sensitivity to model parameters

- Idealized orographic precipitation test
- Constant potential temperature profile, constant background wind, relative humidity, atmospheric stability.



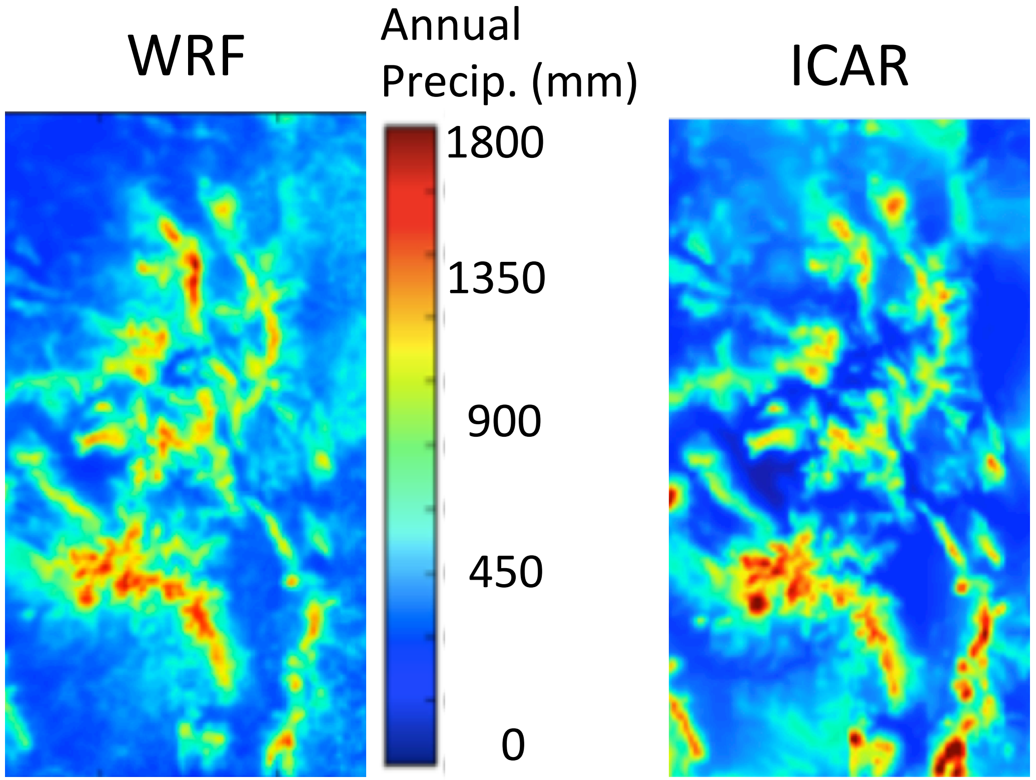
ICAR Precipitation



WRF and ICAR have very similar precipitation distributions.

ICAR requires ~1% of the computational effort of WRF.

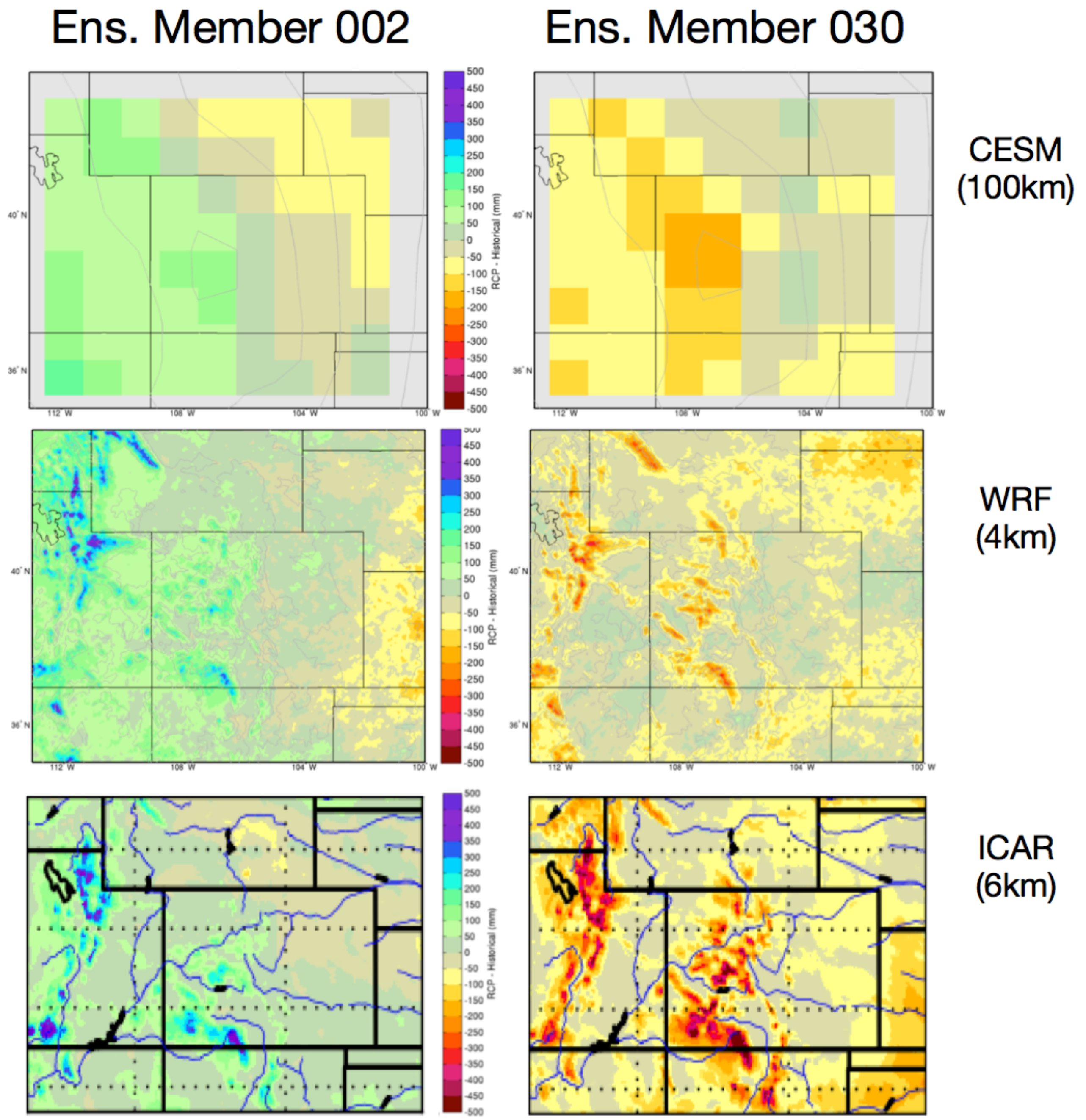
This enables a quasi-dynamical downscaling for a wide variety of GCM / scenario combinations



(pre-bias correction)

Change in Climate

- Can we know which ensemble member climate projection is “correct”?
- Need to understand variability and quantify uncertainty
- Prefer physically based approaches
  - Fewer stationarity assumptions
- ICAR provides a “similar” downscaled projection as WRF (for <1% the cost)

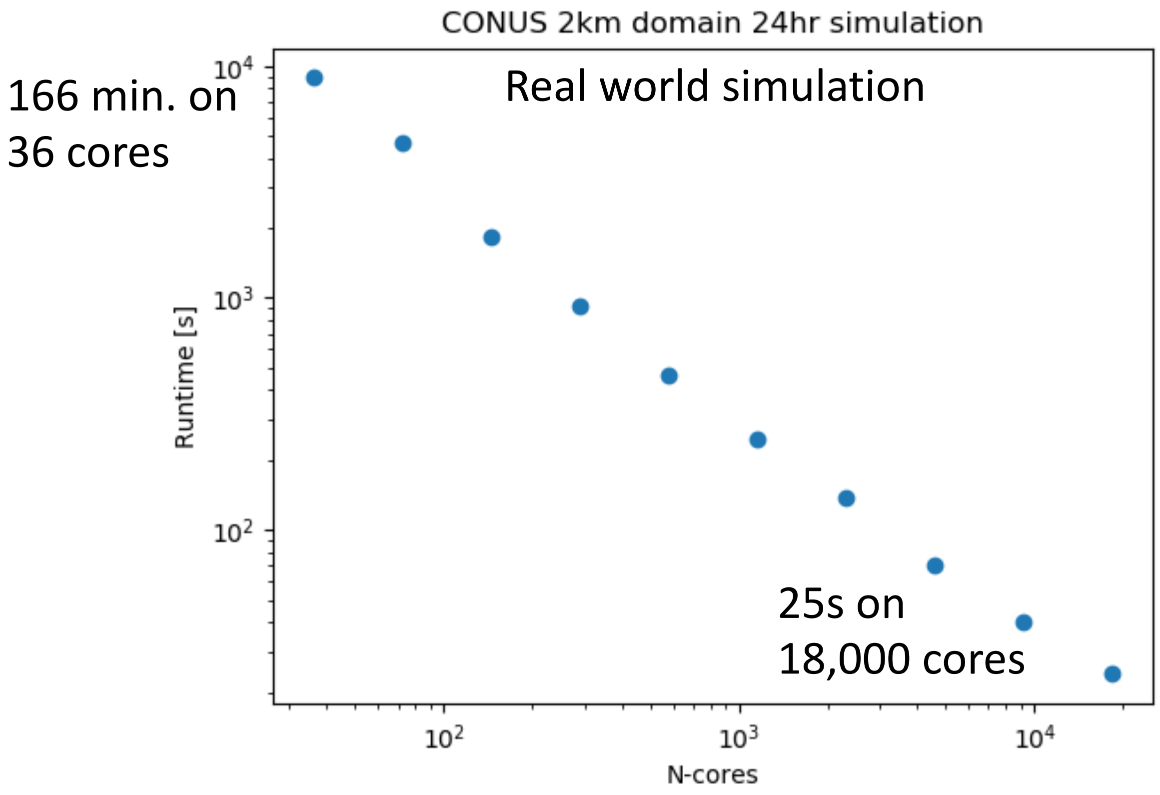


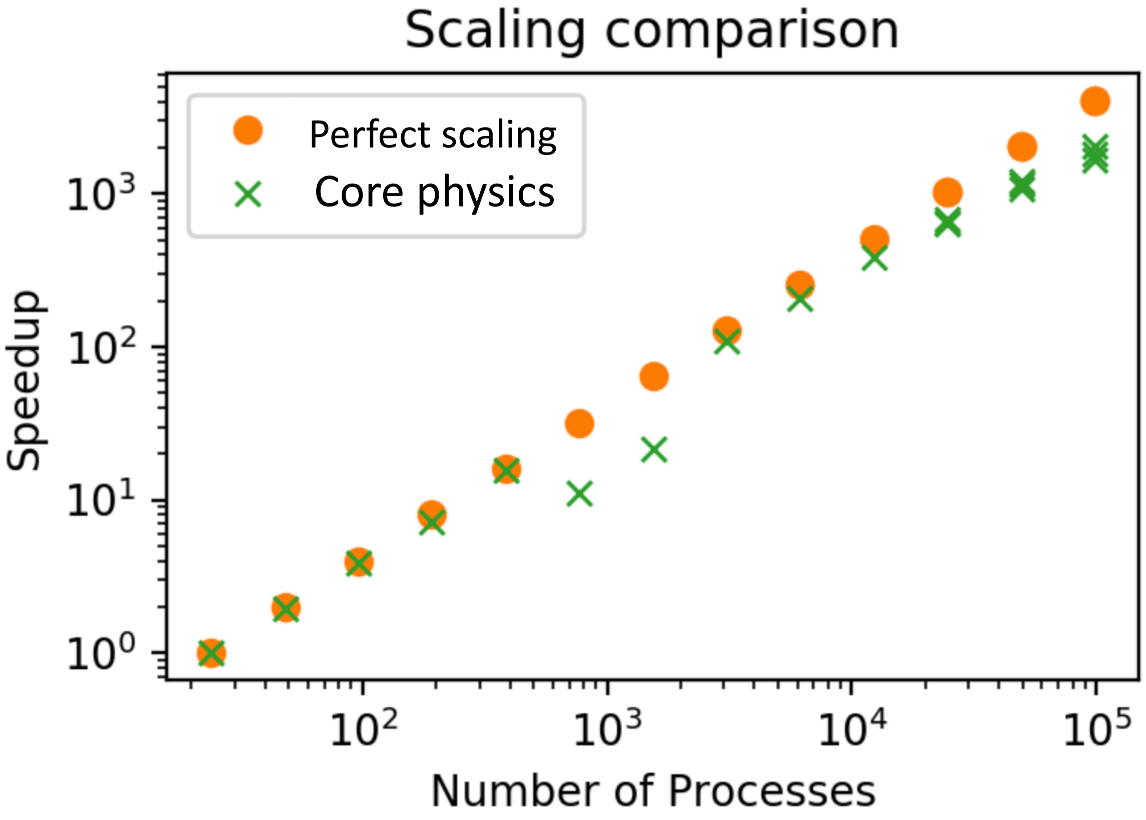
Computational Scalability

New advancements in computational infrastructure in ICAR enable extremely fast simulations.

Parallelization enables simulations to run ~1000x faster (wallclock).

Even file IO parallelization now keeps pace in real world simulations.

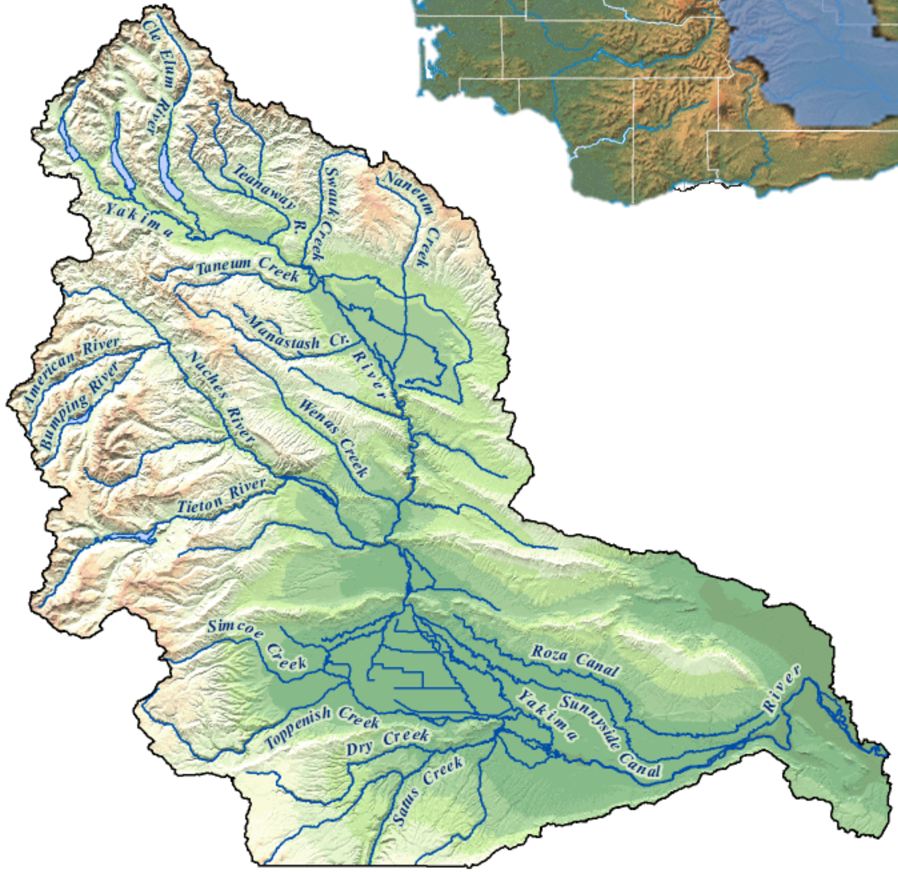




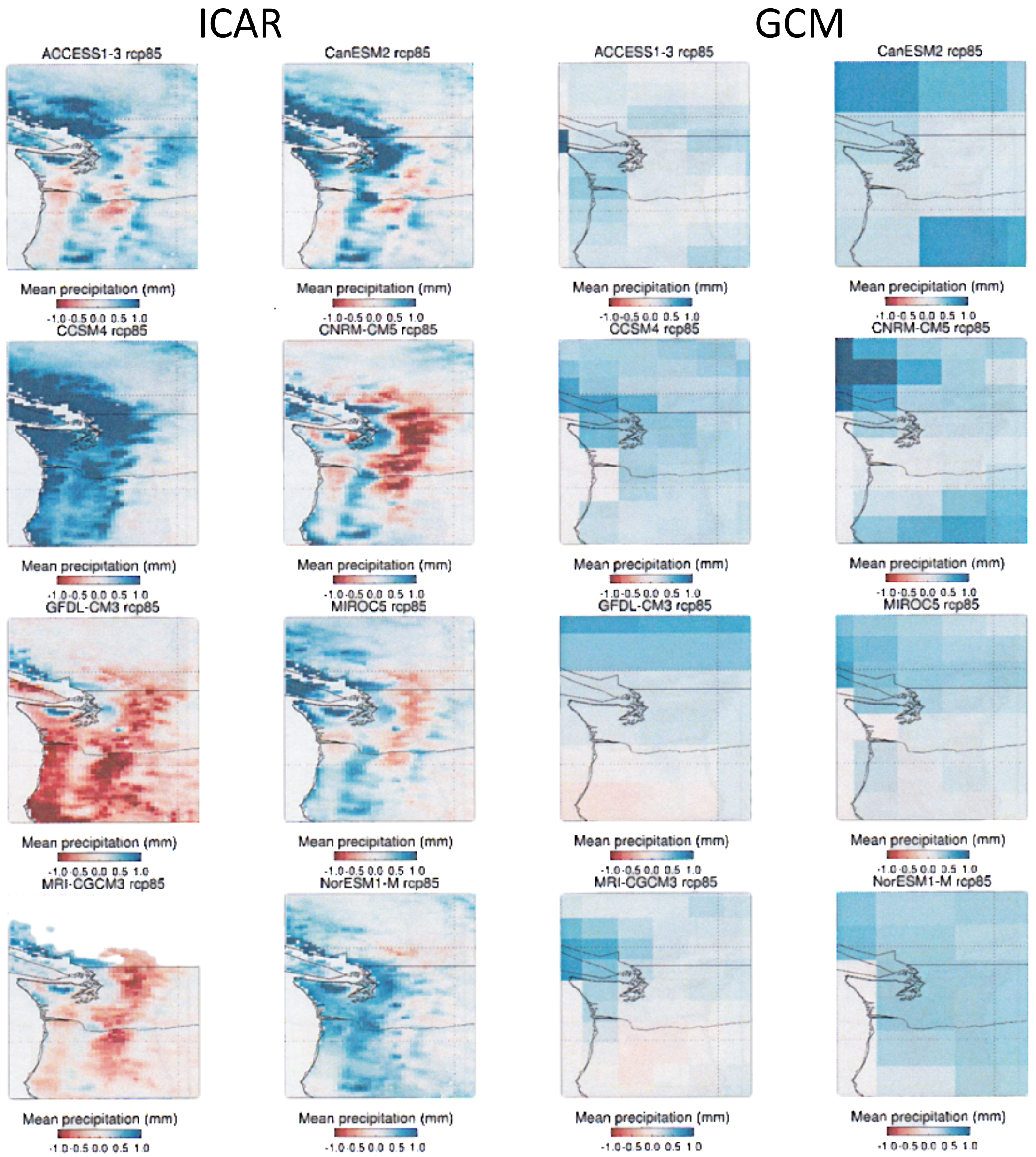
See Rouson et al (2017) doi: 10.1145/3144779.3169104 for core physics implementation

Yakima River Basin

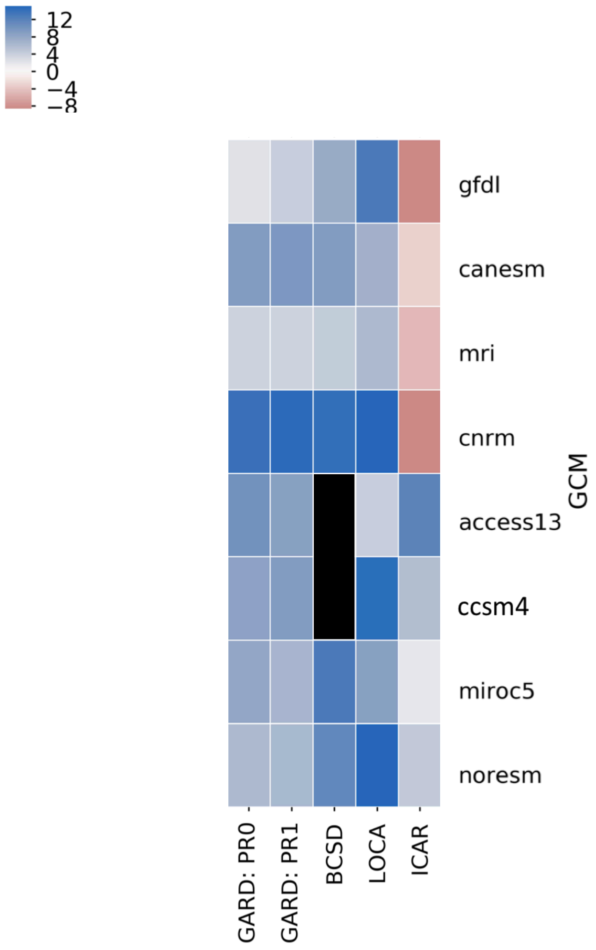
- East side of Cascades
- 6 major reservoirs
- Agriculture dependent on water



A More Robust Ensemble?



Change in Precipitation
Yakima River Basin (2080s-1980s)

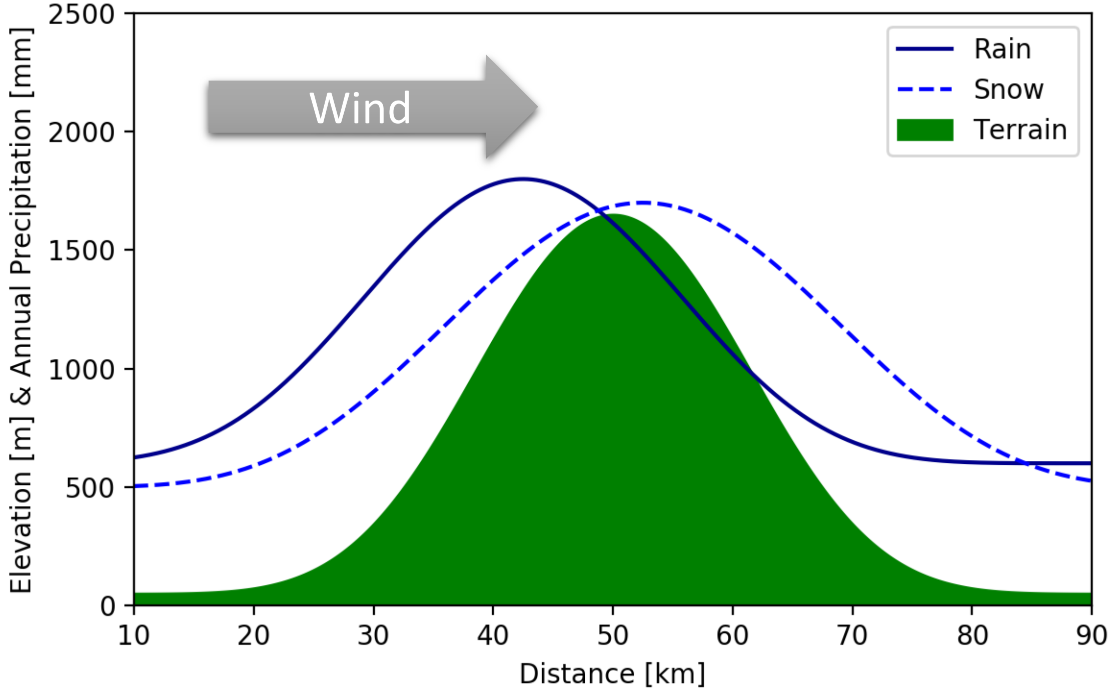


Common statistical downscaling methods all mimic the GCM change (increases in precipitation over the Yakima basin. ICAR projects decreases with some ensemble members downwind of the mountains. This is consistent with limited duration high-resolution WRF simulations.

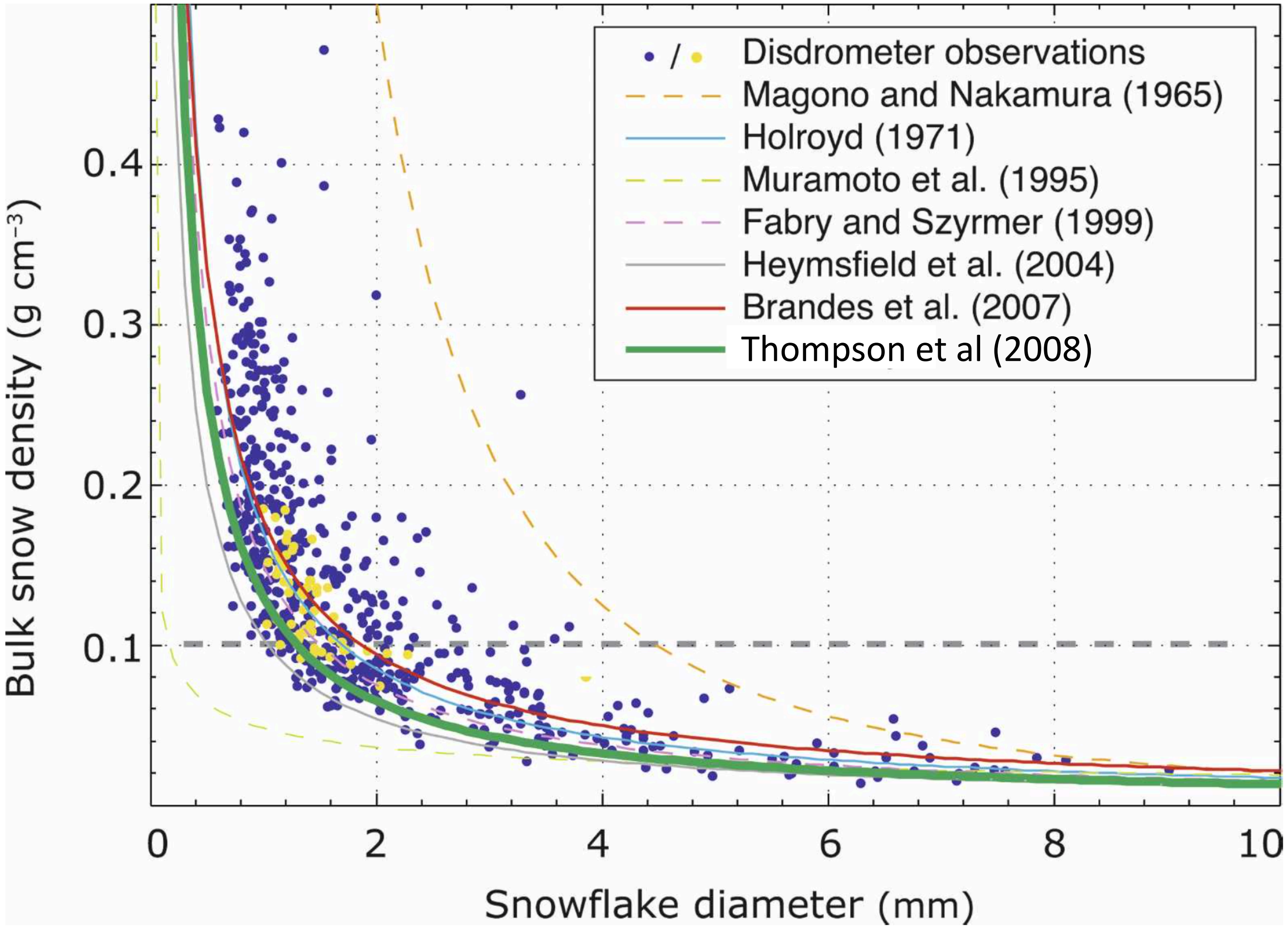
Hamman et al (2020) Gutmann et al (2020) Eidhammer et al (2020)

Rain and Snow and Water Resources

- Terminal velocity of:
  - snow ~1-2 m/s
  - rain ~10 m/s
- Warmer air will lead to less snow (relatively more rain)
- More precipitation upwind, less downwind
- Assuming constant wind speeds / humidity (and ignoring microphysics conversion rates)

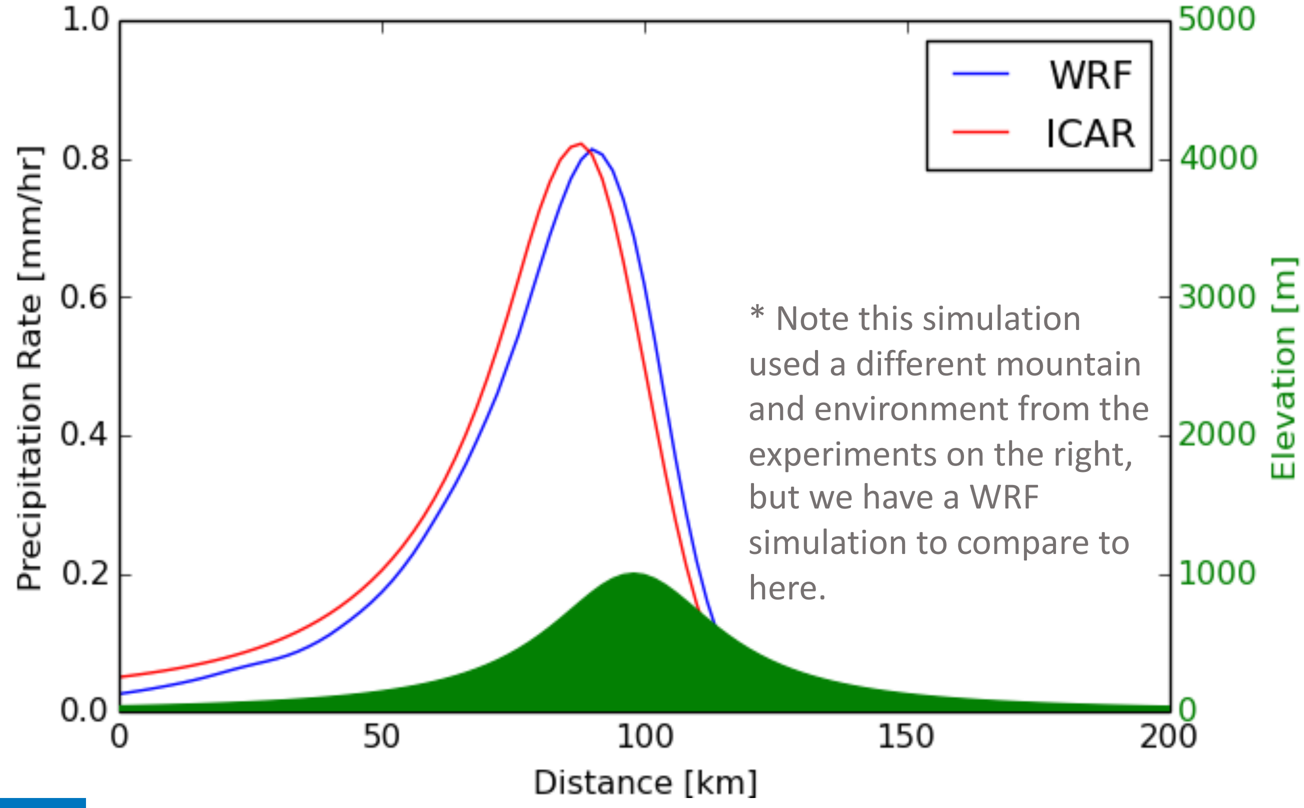


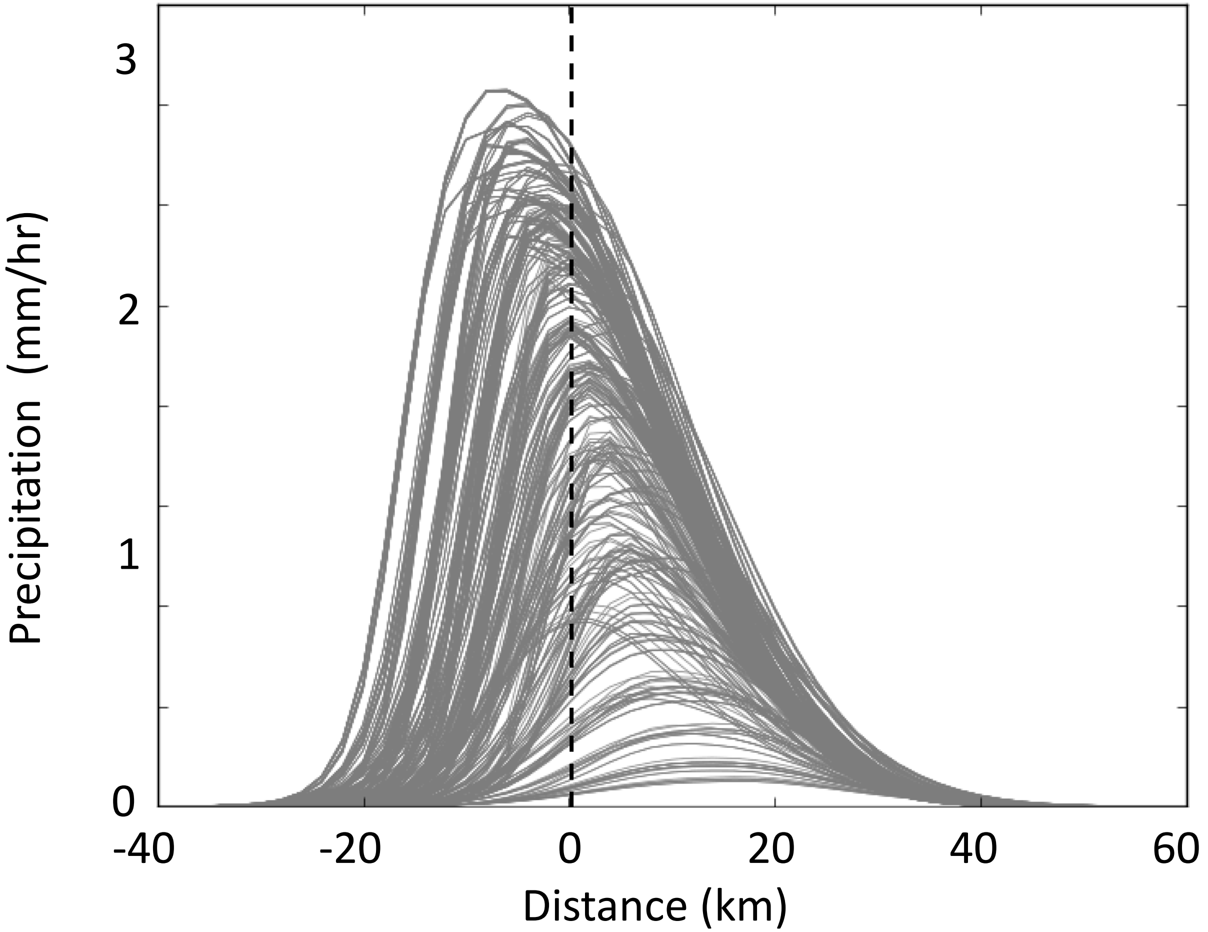
Uncertainty within microphysics parameterizations



Ideal case: test sensitivity to model parameters

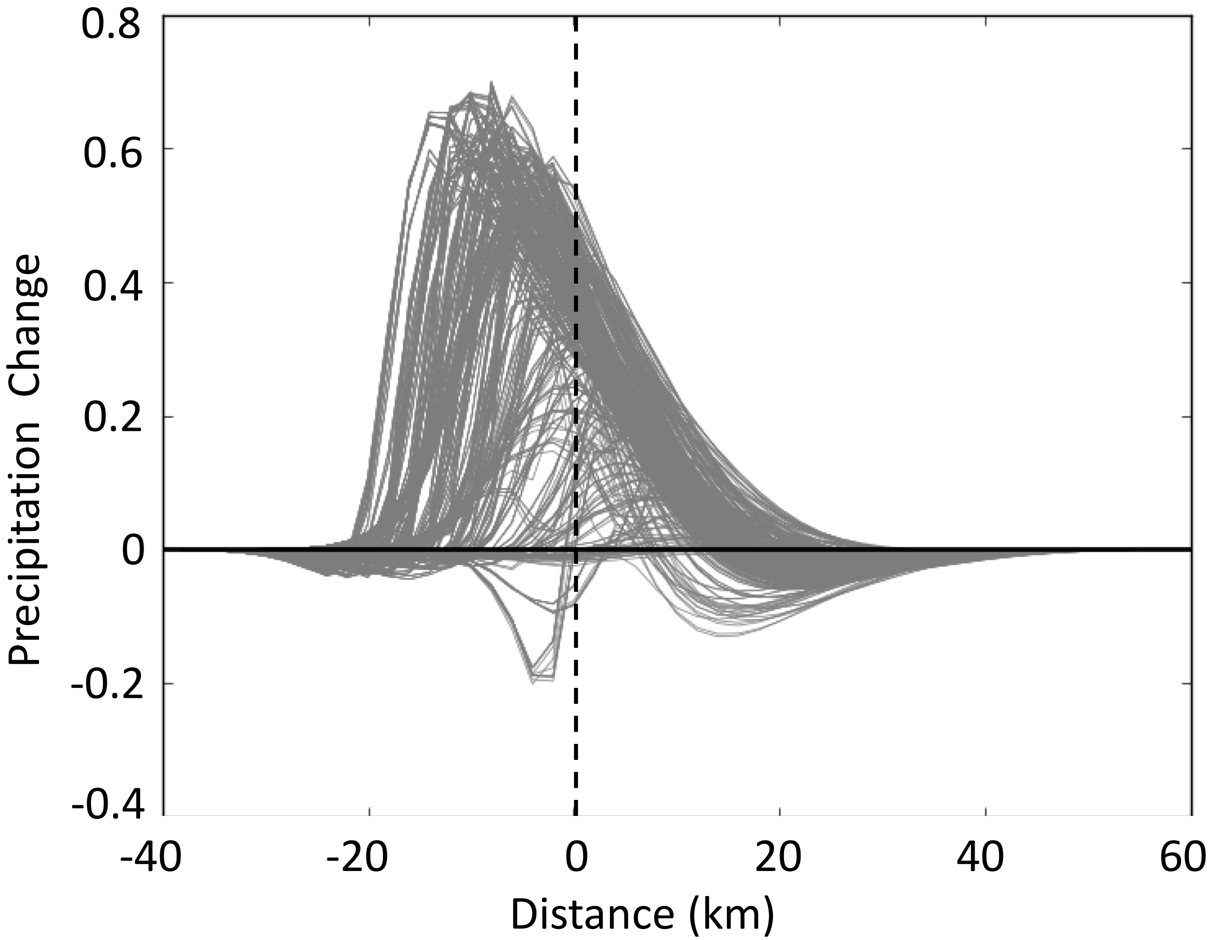
- Varying all microphysical parameters results in large changes in precipitation
- (Some of these may be unrealistic…)





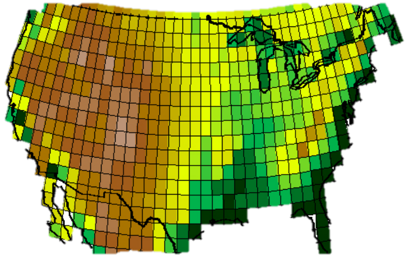
Ideal Change Signal

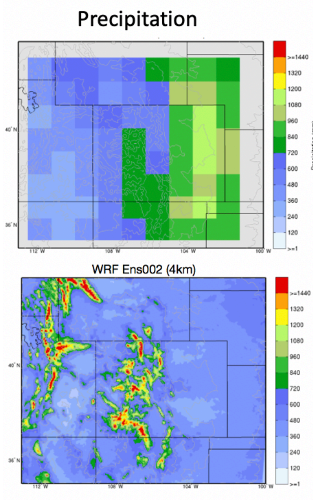
- These changes affect a climate change signal strongly as well (2°C warming)



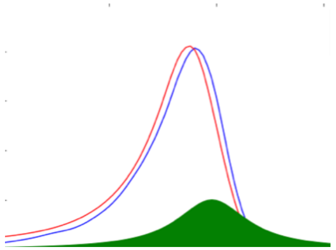
Summary

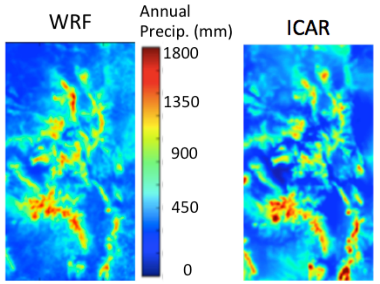
- Water managers need to understand what will happen in their basin; mountains are important



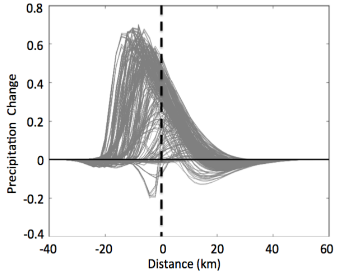


- Simplifying physical assumptions can yield ~90% of the information for 1% of the "cost" (ICAR)





- Uncertainty in physical parameters can create large uncertainties in climate projections



Acknowledgements

- The National Science Foundation supports NCAR
- The development of ICAR has been funded by the US Army Corps of Engineers Climate Preparedness and Resilience Program, the Bureau of Reclamation's Science and Technology program, and NASA's AIST program with support from NCAR's Water System Program.
- Thanks to many for conversations both motivational and technical.
- Damian Rouson (Sourcery Institute) helped with the parallelization
- Idar Barstad was involved in the initial conceptual development