INARCH Model COPEing strategies : Regional Climate and SnowModeling Activities (with bonus sublimation study)

Ethan Gutmann,
Research Applications Laboratory, NCAR
Rachel McCrary, William Ryan Currier, Bert Kruyt, Ross Mower and others
Jessica Lundquist, Glen Liston, Mimi Hughes

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Modeling Links to the Common Observing Period Experiment

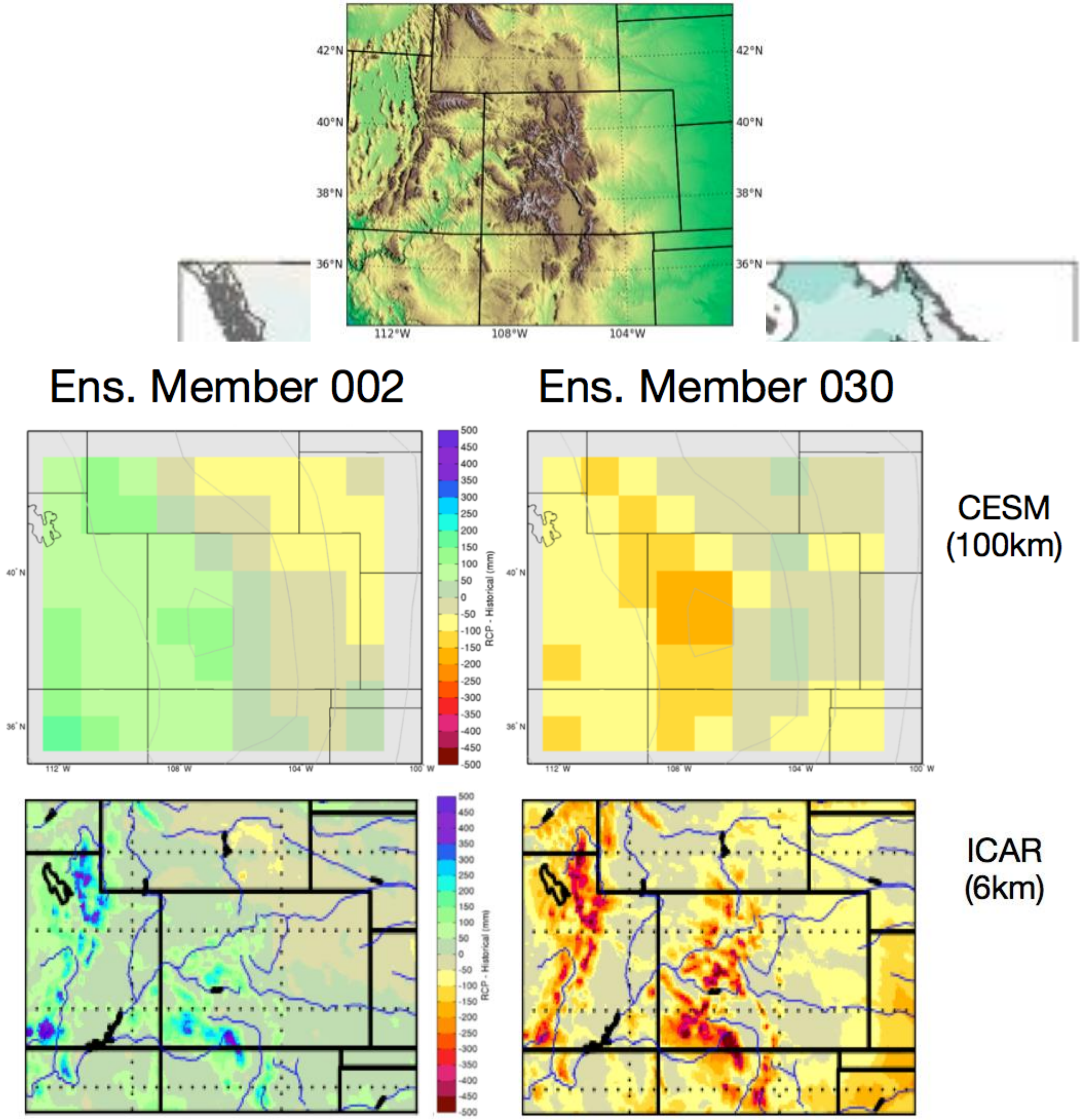
- Observe, **Predict**, Protect
- To protect mountain environments we need to be able to predict (model) them
- We present configuration of relevant models for evaluation
  - Regional Climate Change : ICAR the Intermediate Complexity Atmospheric Research model
    - Historical Reanalysis
    - Future CMIP5/6 simulations
  - Snow : snow drift resolving simulations with SnowModel
    - Initial North America simulations
    - Future: Himalayas, South America, Alps, …
- **Goal**: leveraging observations over alpine research catchments to improve model predictions

ICAR: the Intermediate Complexity Atmospheric Research model

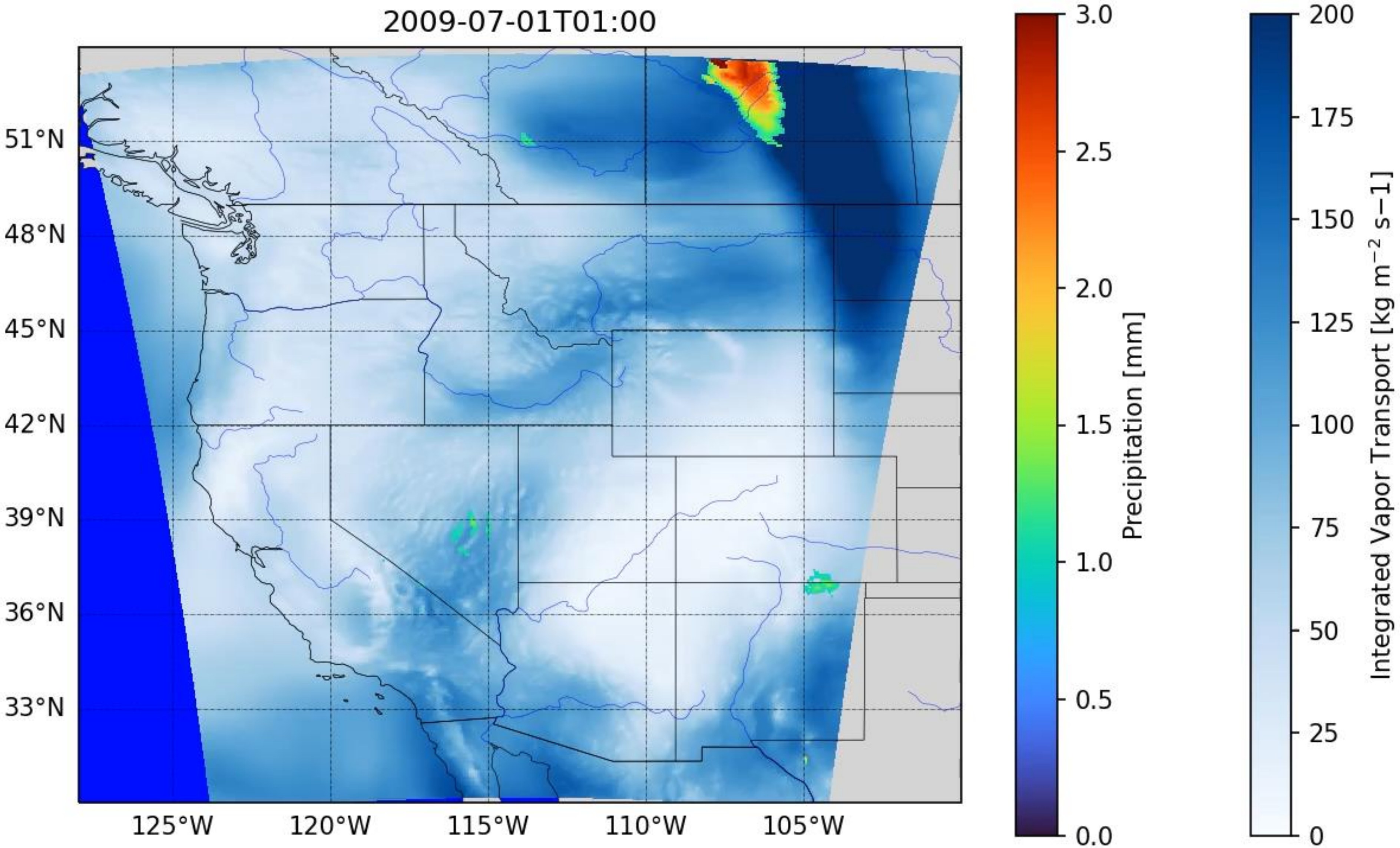
- Regional climate simulations with 90% of the information for 1% of the computational cost
  - Perhaps the only practical way to explicitly resolve alpine research catchments across 100s of climate projections, makes evaluation and improvements an important INARCH task

- Linear mountain wave theory for for flow over mountains

- Recent improvements:
  - NoahMP: improved snow physics
  - RRTMG radiation code to simulate GHGs
  - Lake model: lake effect snow etc.
  - BMJ convection scheme
  - iterative wind solver to remove top boundary artifacts



Western North America (US+) Simulations



NC
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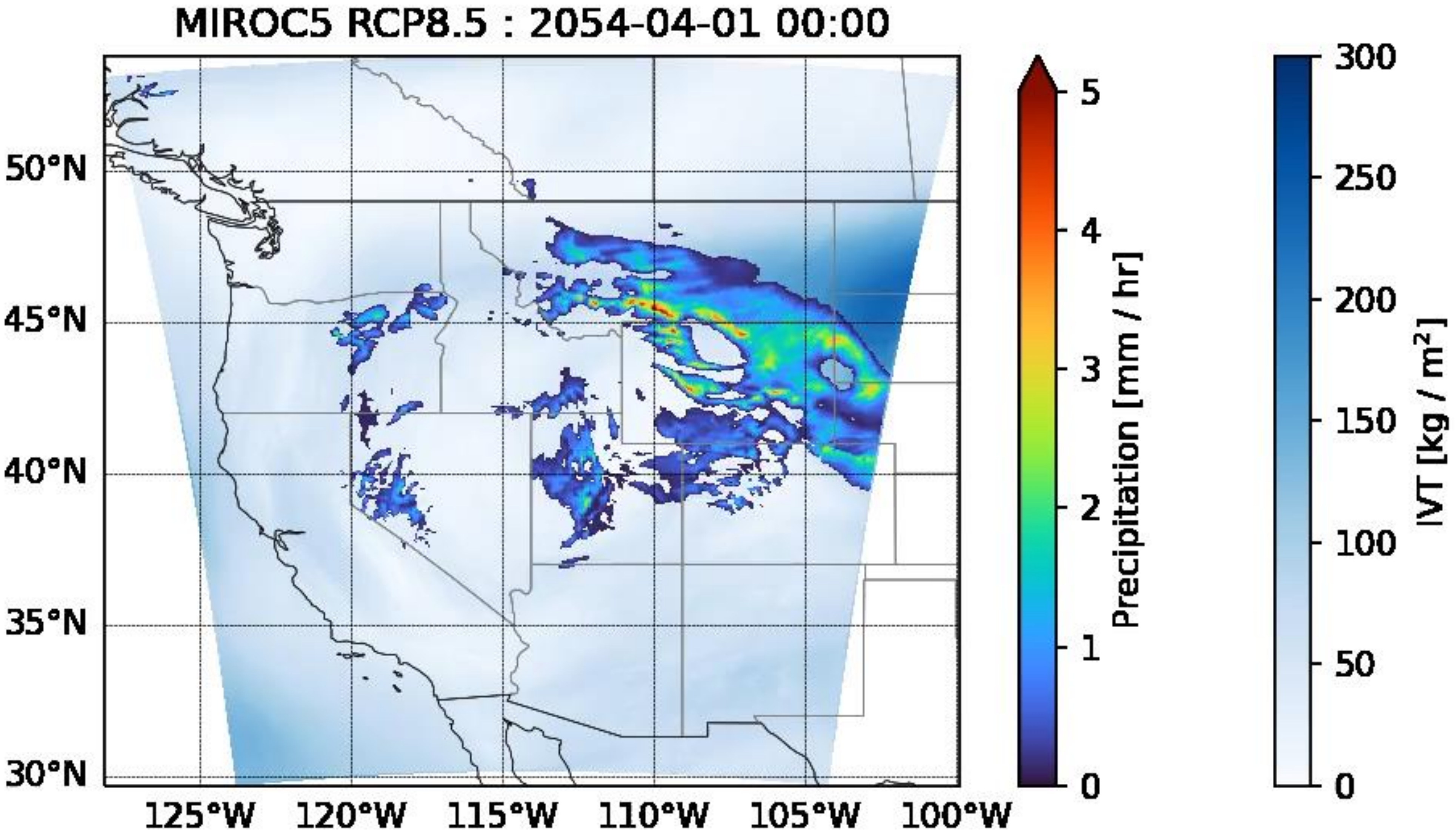
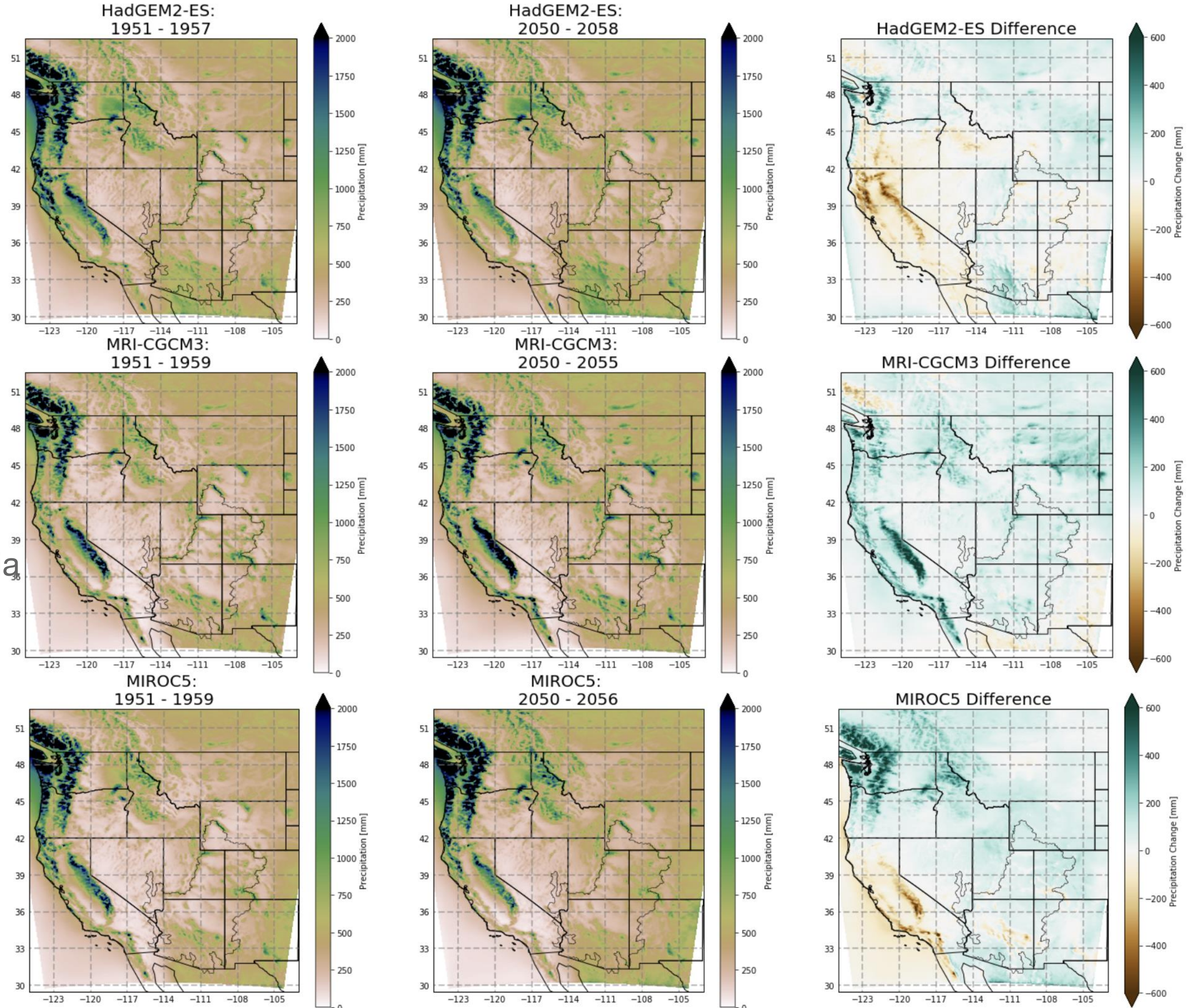
ICAR CMIP forced simulations



ICAR Climate Projections

- CMIP5 and CMIP6
  - ~20 models
  - RCPs : 4.5 & 8.5
  - SSPs : 2-4.5, 3-7.0, & 5-8.5
- Western N.America (US+) domain
  - 6km grid spacing
  - S. America, High Mountain Asia
- One physics suite…
  - Thompson microphysics
  - BMJ convection
  - Lake model
  - NoahMP LSM
  - RRTMG radiation



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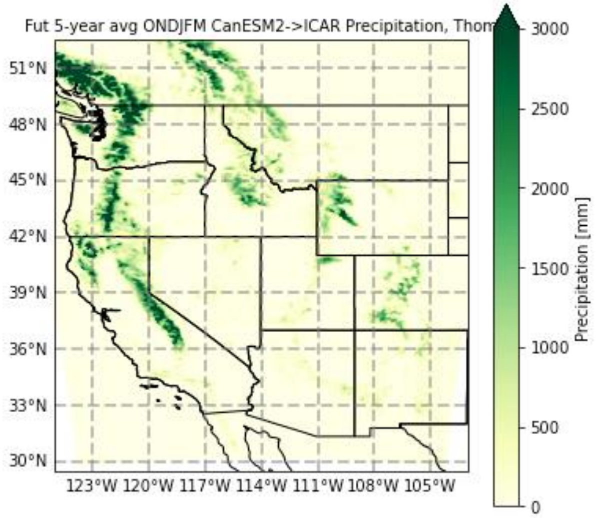
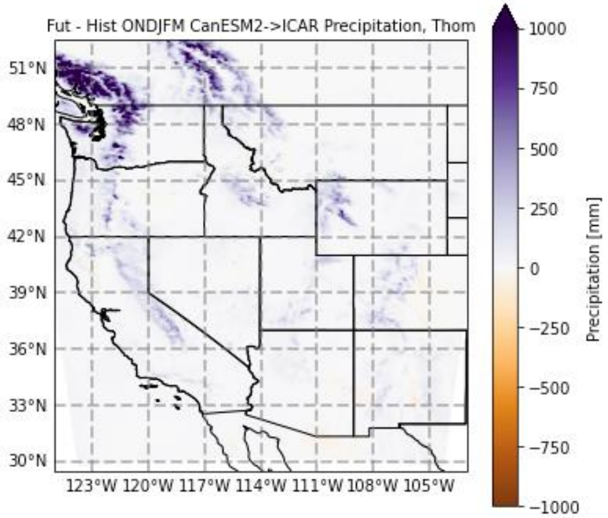
Basin Specific Regional Climate Sensitivities

Thompson Microphysics

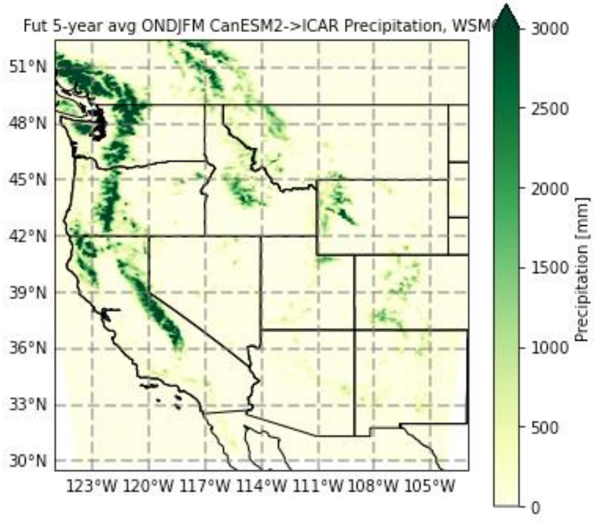


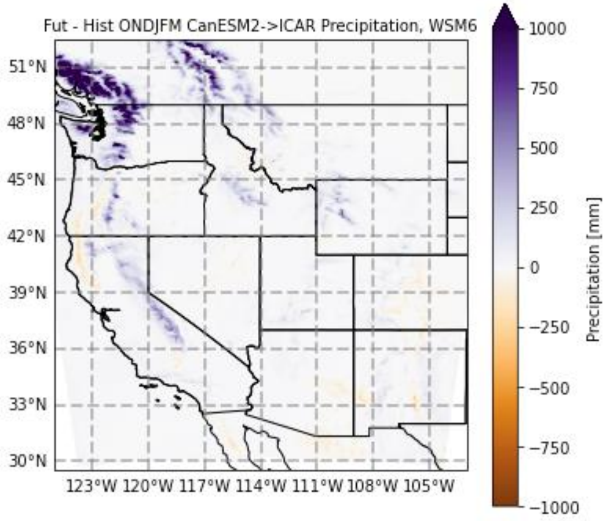


Future Precipitation

Precipitation Change

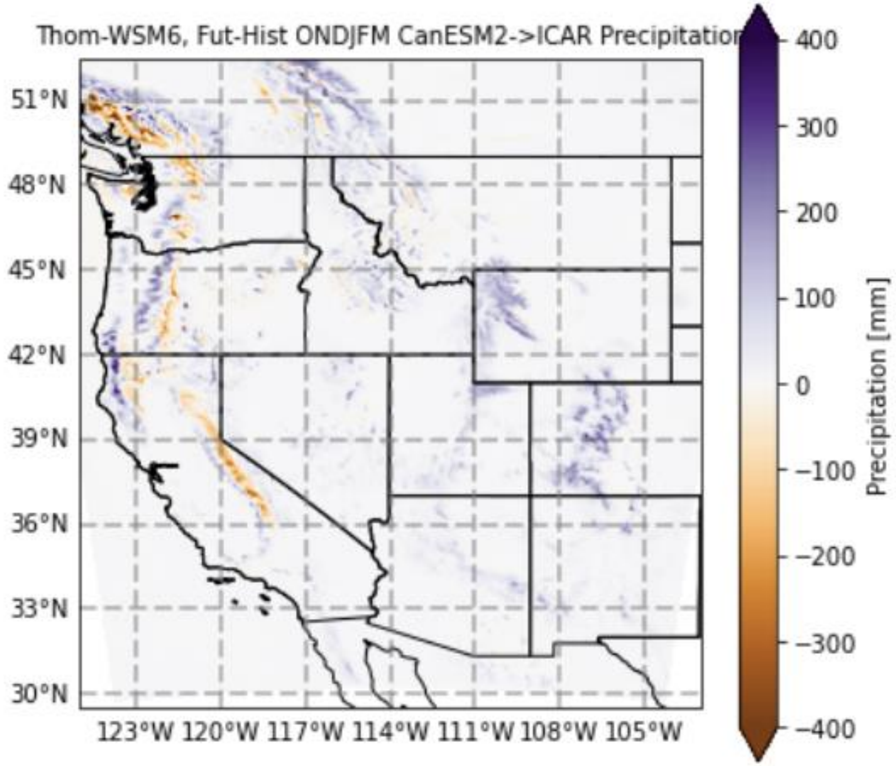
WSM6 Microphysics





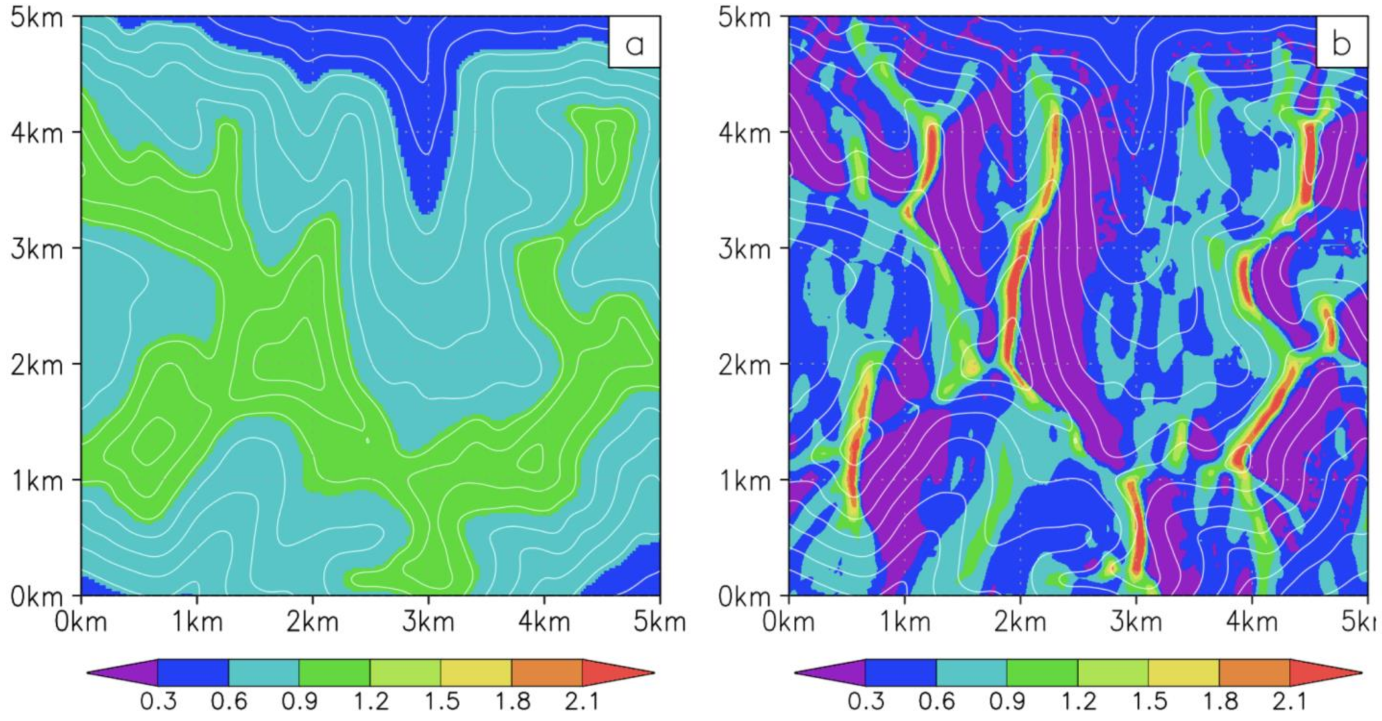
- Microphysical Assumptions can have large effects in mountain basins

Thompson – WSM6 changes



SnowModel: a spatially explicit parallel model

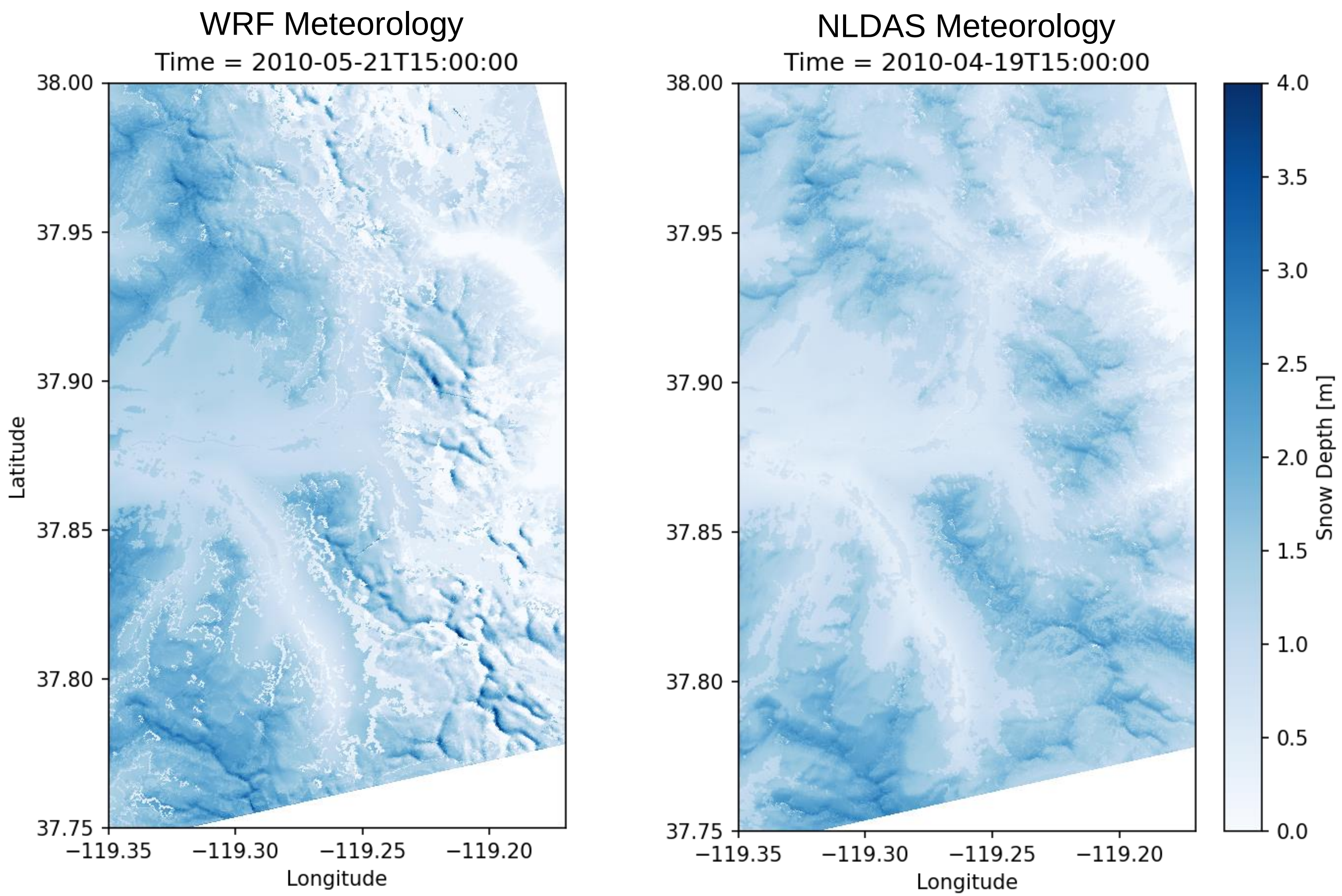
- SnowModel (Liston et al 2002?) has a long history of use and evaluation
  - Wide usage makes evaluation and improvements an important INARCH task
- One of the early “snow-drift resolving” snow modeling systems
- Parallel optimization enables O(100m) grid continental domain simulations
- Added microphysics rain-snow partitioning



N. American SnowModel simulations

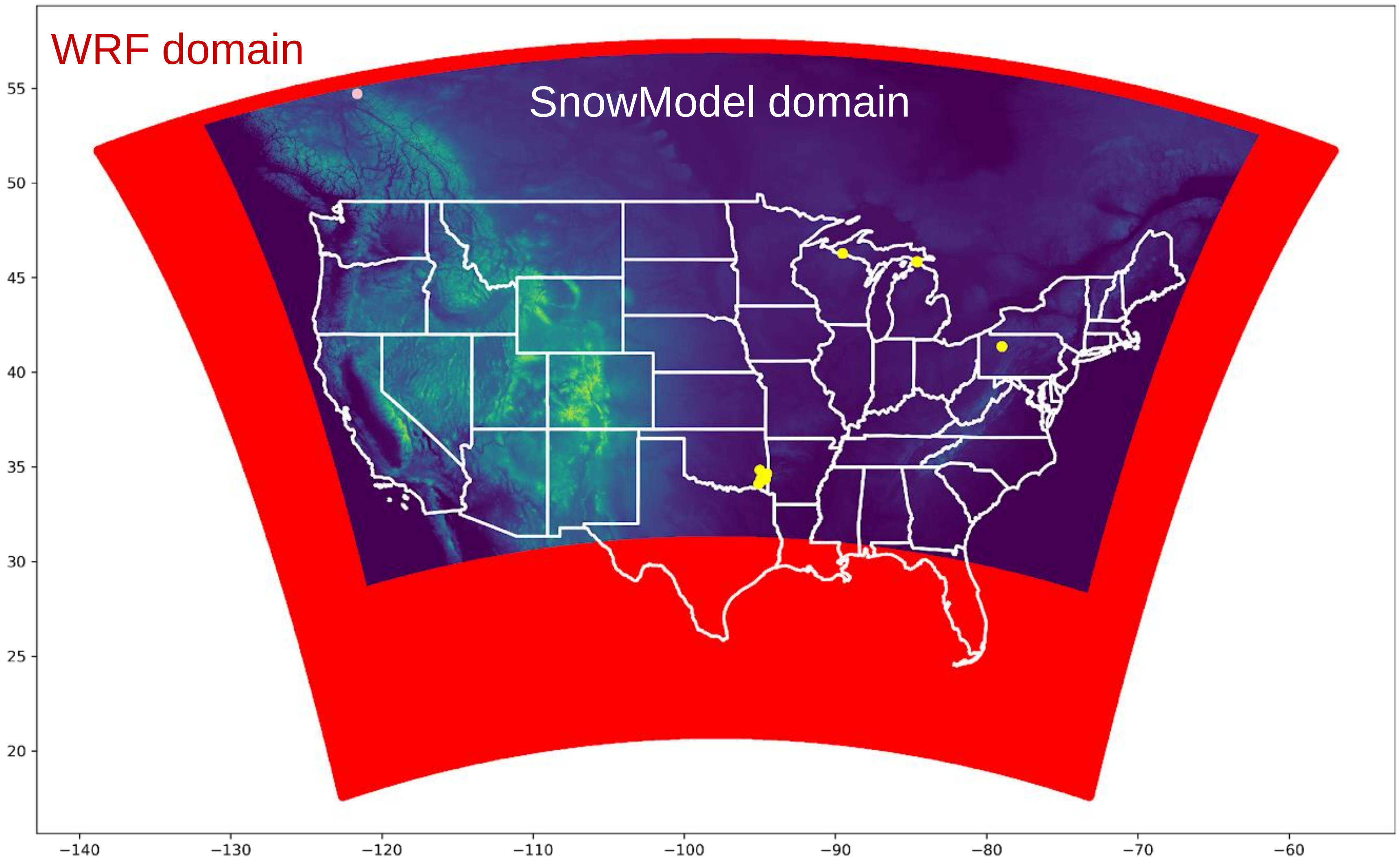
- Tuolumne basin example

- 100 m grid
- WRF 4km forcing
  - High-res winds, rain shadow
  - could use a DL wind model!
- NLDAS forcing
  - wind (from 32km NARR model)
  - Insufficient snow transport (compared to ASO)
  - See Reynolds et al 2020



Large domain SnowModel simulations spanning COPE sites

- 100 m grid
- 25-years of simulation available (1995-2020)
  - 2021-22 may be coming
- Good quality forcing data is a limiting factor
  - S.America coming
  - COSMO over Alps?
- Storing data is a major challenge (100s of TB)



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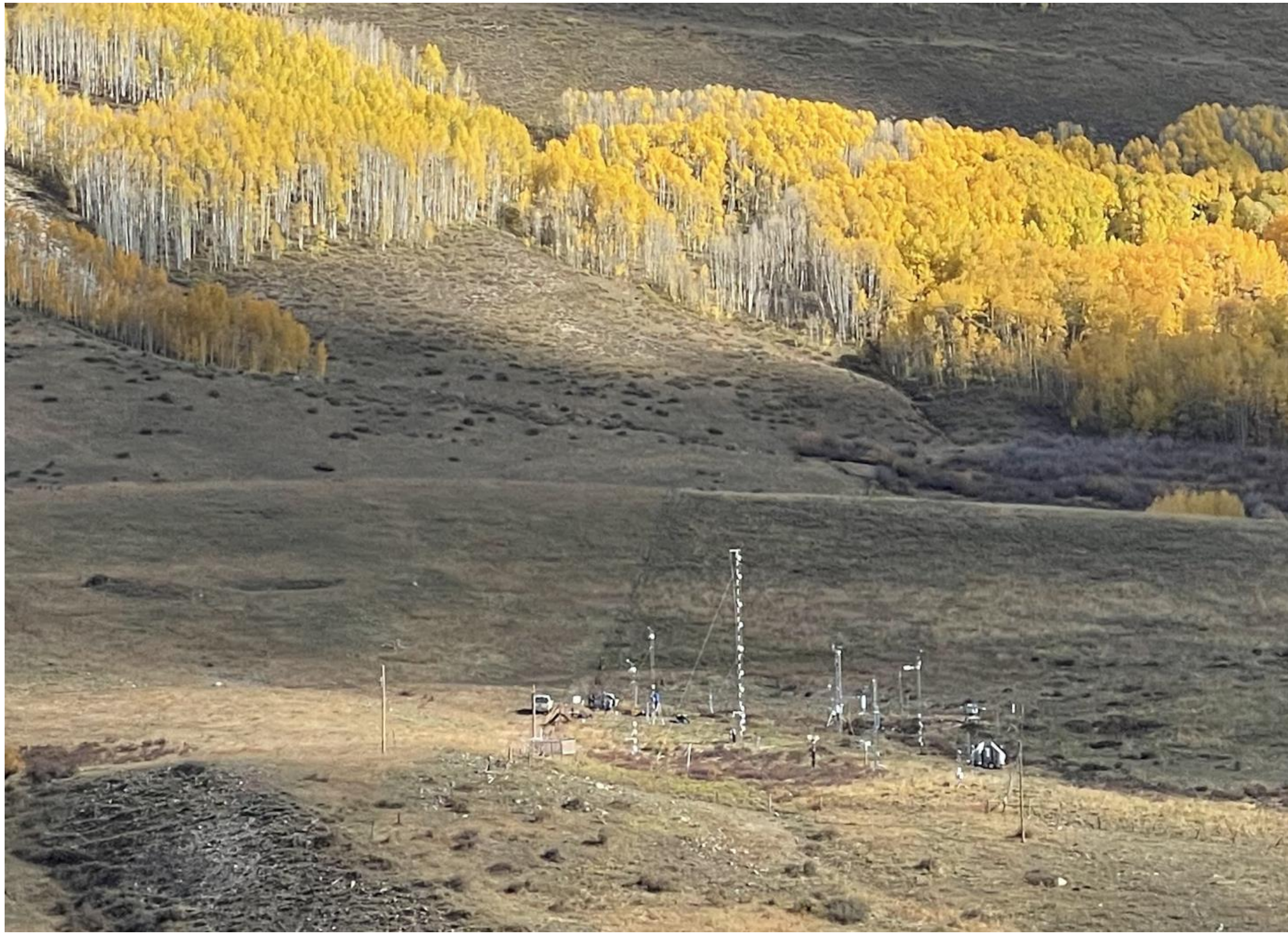
Sublimation of Snow (SOS) - PI Jessica Lundquist

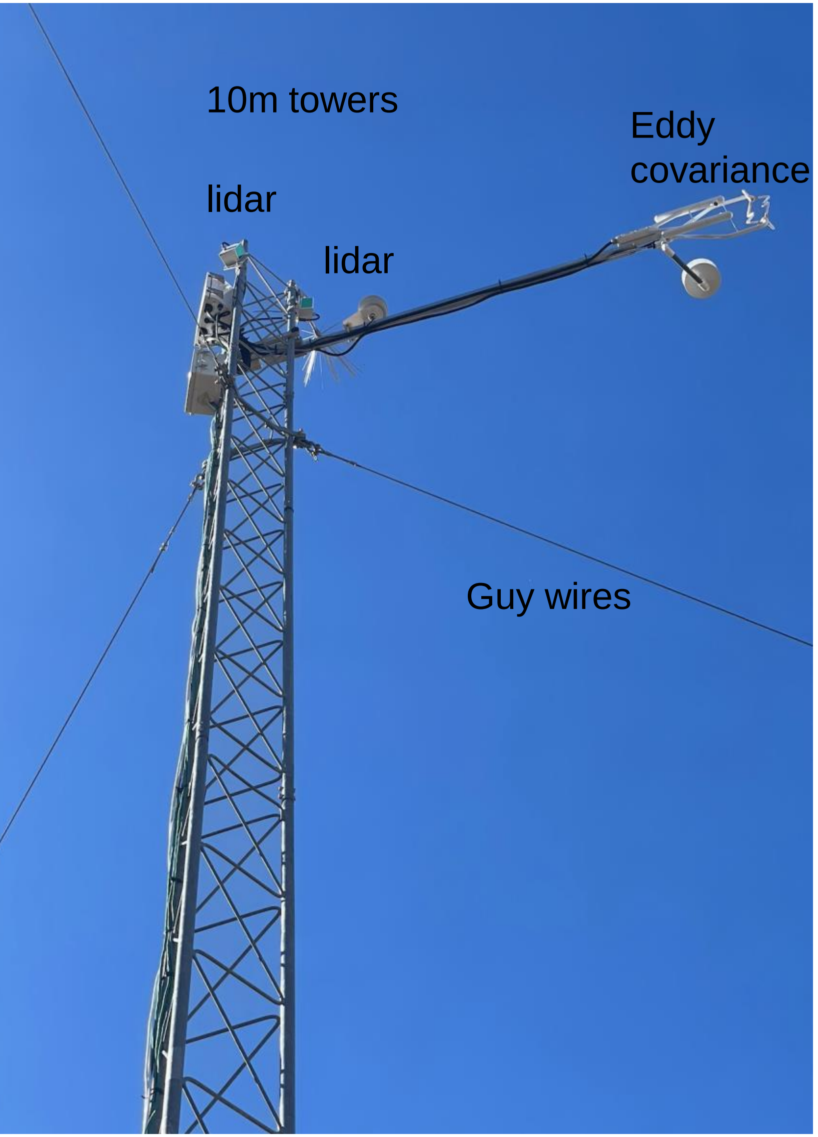
East River basin, Crested Butte, CO

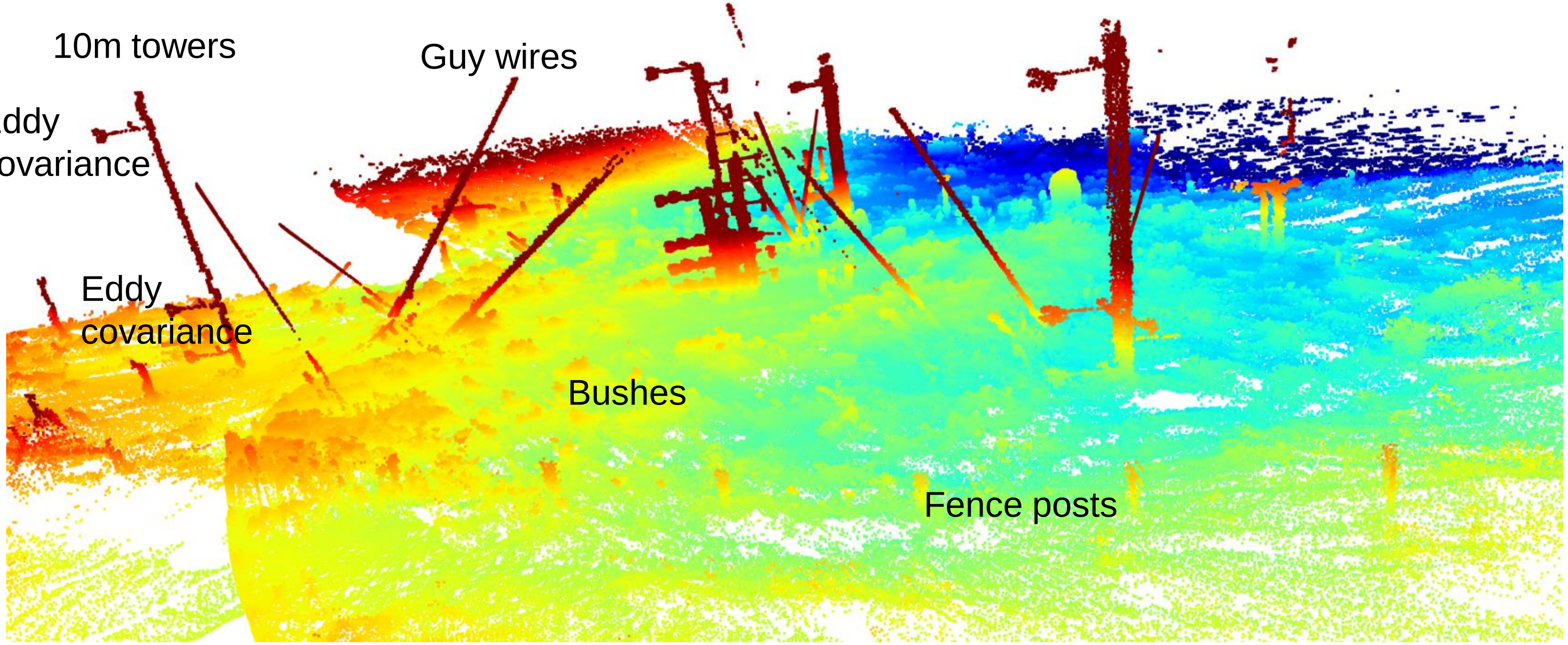
- 3 10m towers, EC@ 1, 3, 10m
- 1 20m tower, EC@ 1, 3, 10, 15, 20m
  - T,RH every meter
- Flowcap blowing snow sensors
- Heated 4way radiation
- Continuous Lidar snow depth and blowing snow mapping
- IR skin temperature, snow and soil thermistors
- Solid state snow pillows
- Air pressure sensors (in snow and outside for pressure pumping)
- Snow pits and weighing “buckets”
- And more with SAIL radars, lidars, soundings



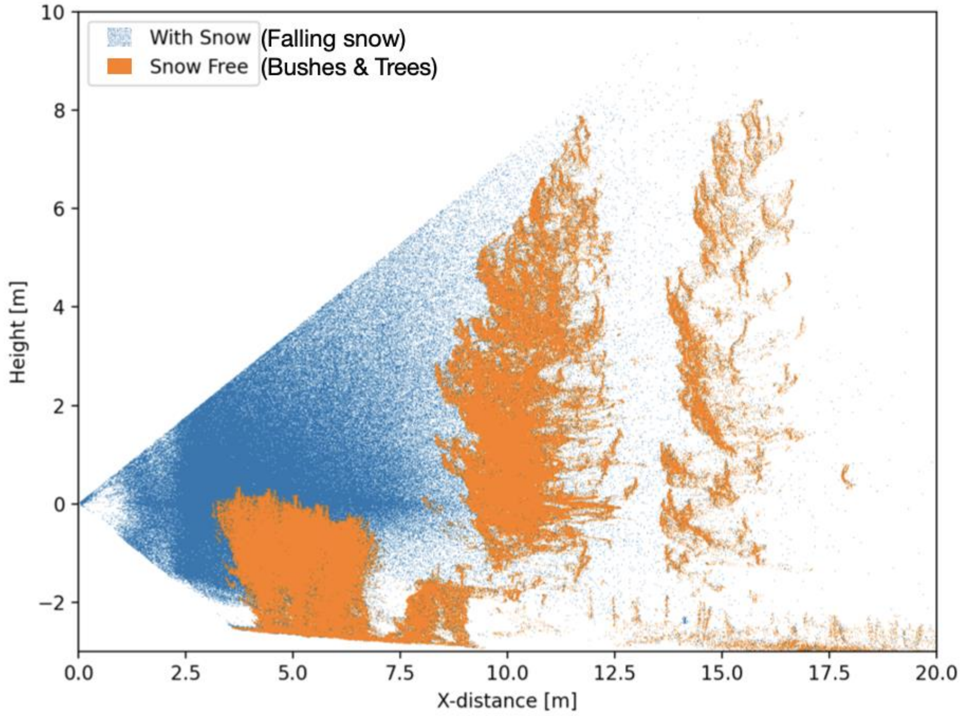
Lidar snow measurements

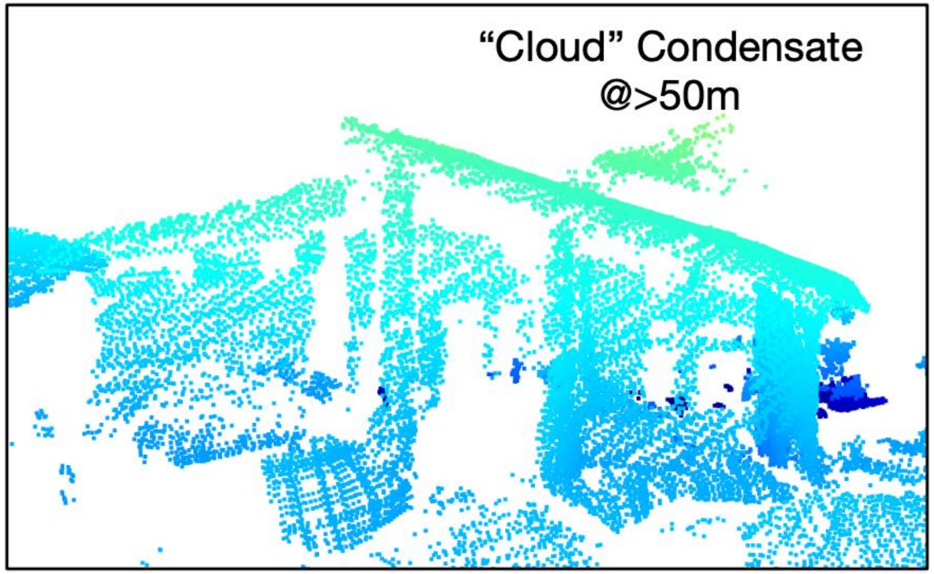
- Livox Mid-70 lidars
- ~200m range
- 200,000 points per second
- Scanning 10s every minute
- Tracking every snowflake (almost)





Livox Lidar





Livox Mid-70 ~$1200
(was $800 pre-supply-chain-crisis)

200,000
Points measurable per second

0.03°
Horizontal beam divergence

0.28°
Vertical beam divergence

70.4°
Circular FOV

~260 m
Maximum Range for Snow

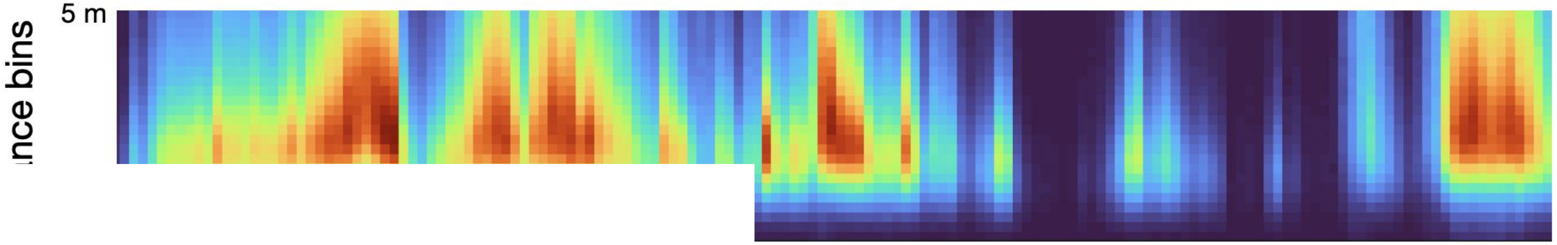
2 cm
Range Precision [2]

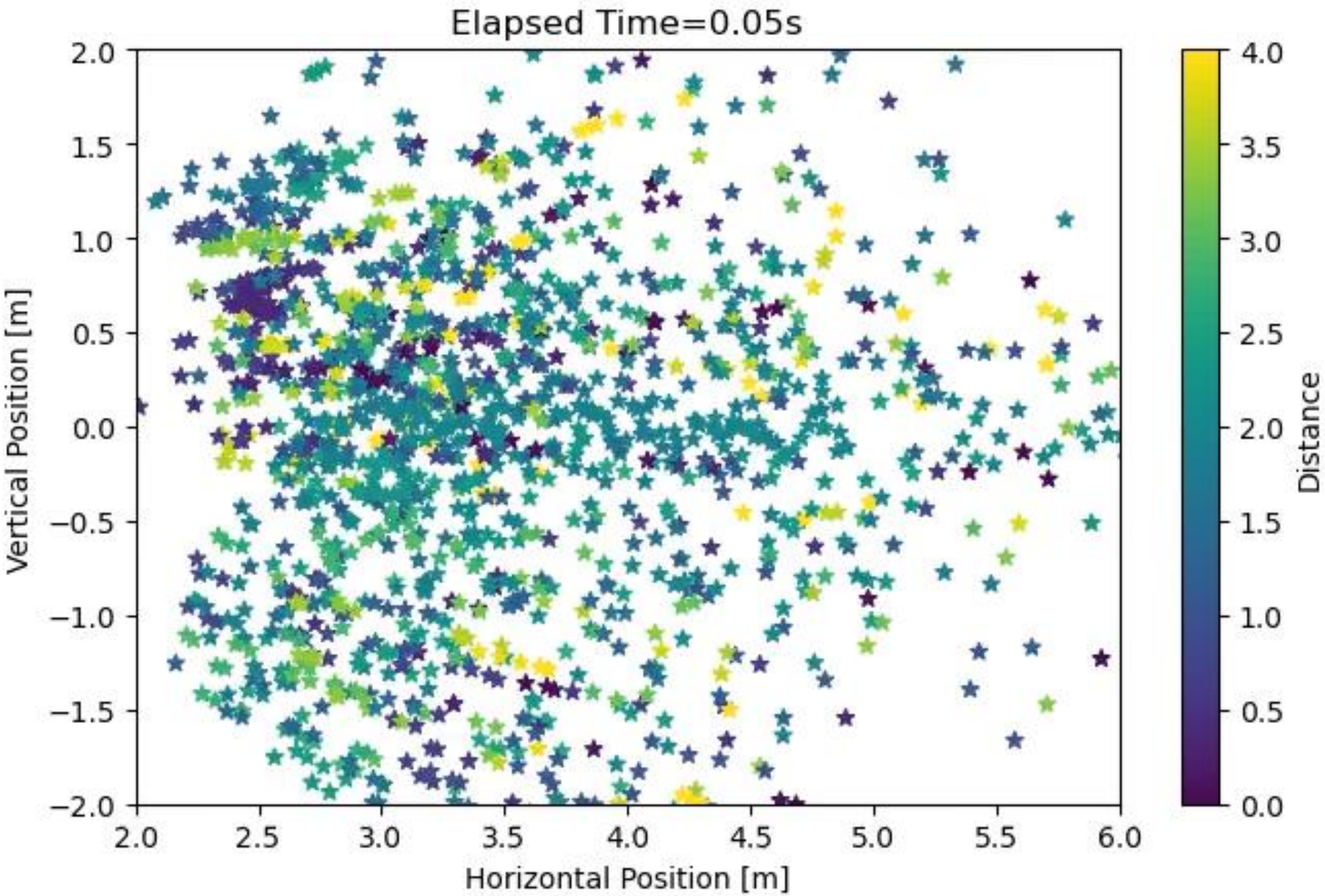
< 0.1°
Angle Precision

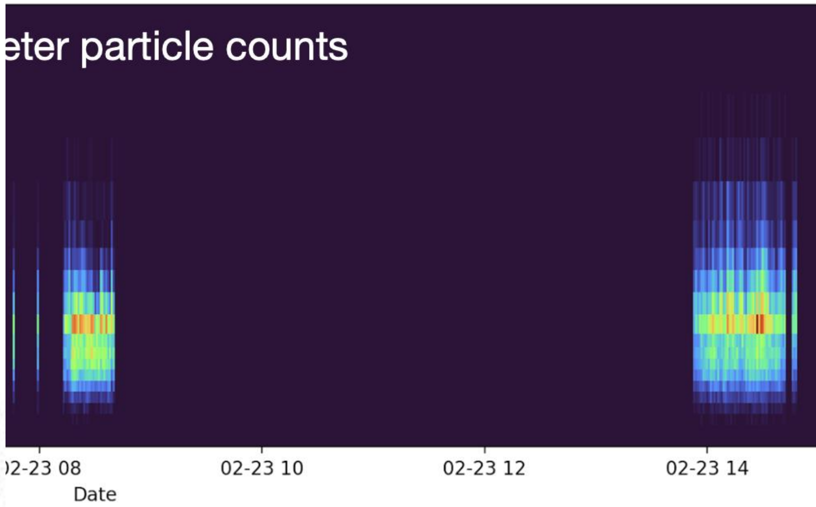
Model	MID-70
Laser Wavelength	905 nm
Laser Safety	Class 1 (IEC60825-1:2014)(Eye Safety)
Detection Range (@ 100 klx)	90 m @ 10% reflectivity 130 m @ 20% reflectivity 260 m @ 80% reflectivity
FOV	70.4° (Circular)
Range Precision (1σ @ 20m)	1σ (@ 20m) ≤ 2 cm [1] 1σ (@ 0.2~1m) ≤ 3 cm [2]
Angular Precision（1σ）	< 0.1°

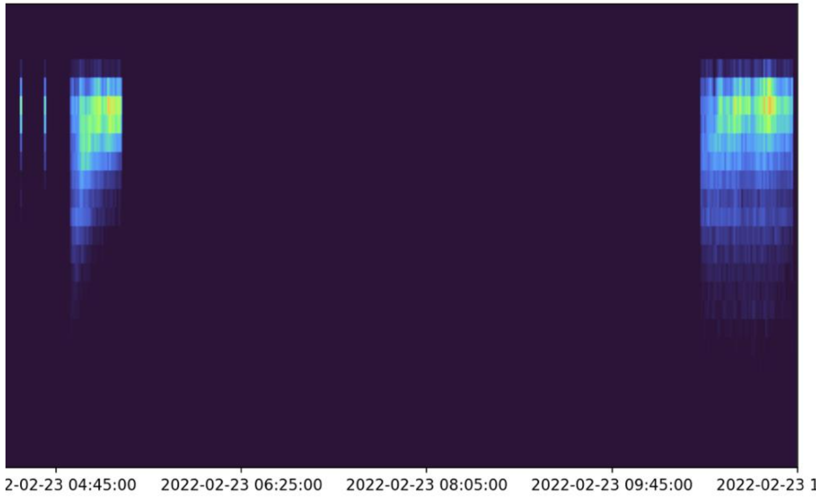
Lidar snow particle analysis

Lidar particle counts. Counts are 50x larger than disdrometer



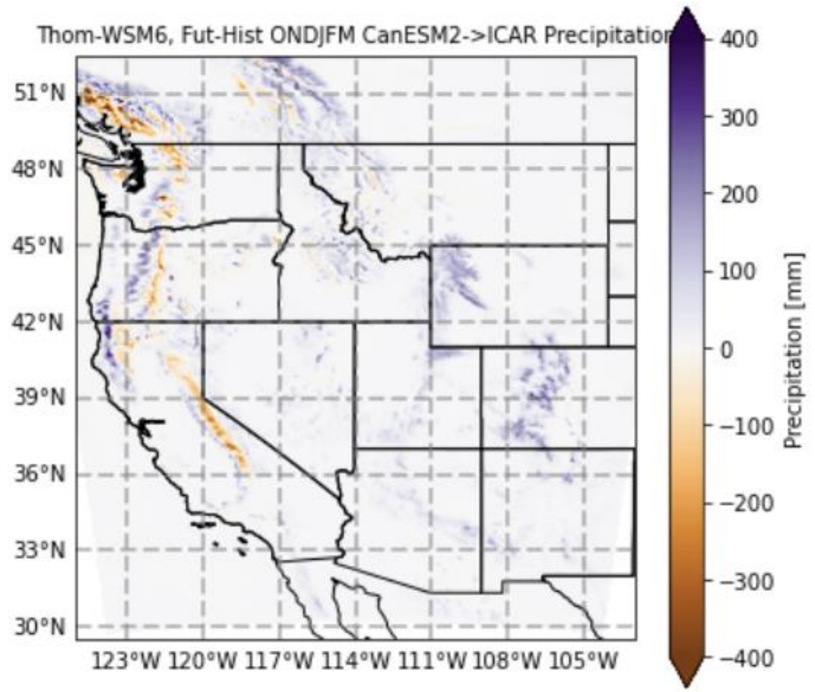


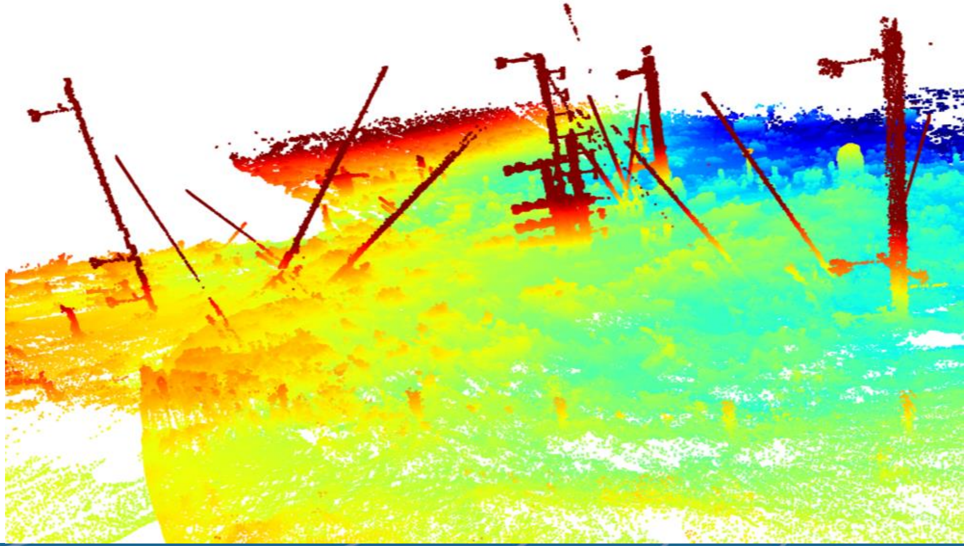




Summary

- Mountain catchments face large uncertainty in future climate (precipitation) as well as known challenges (temperature)
- Large scale predictive modeling needs COPE observations to support protective action
- Regional climate projections can be very sensitive to often overlooked model physical assumptions and approximations
- New observation techniques being explored for snow sublimation study





To bias correct or not to bias correct