Understanding Alpine Snowpack

Measurement, Models, and Climate Change

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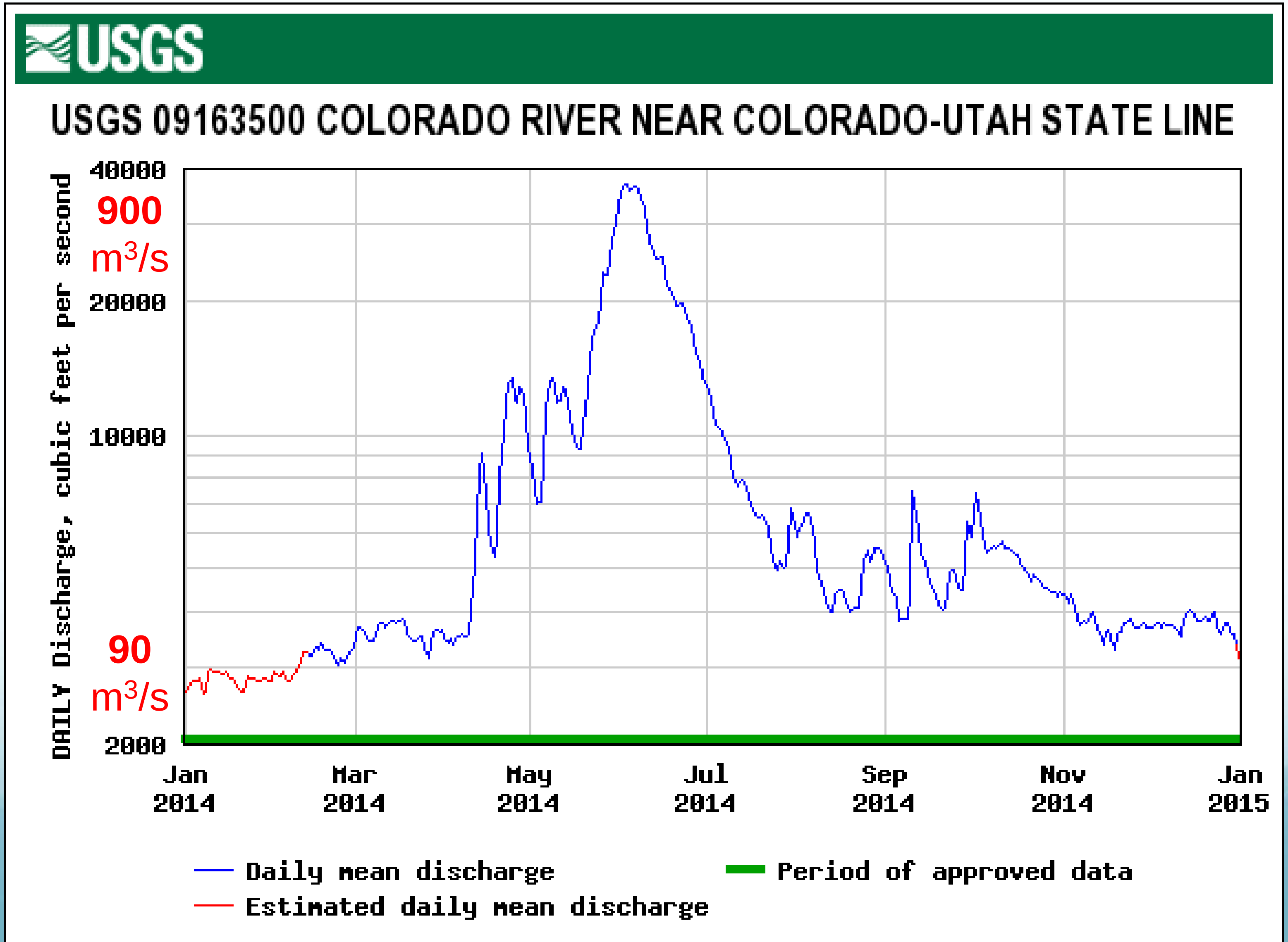
Importance of Mountain Snow



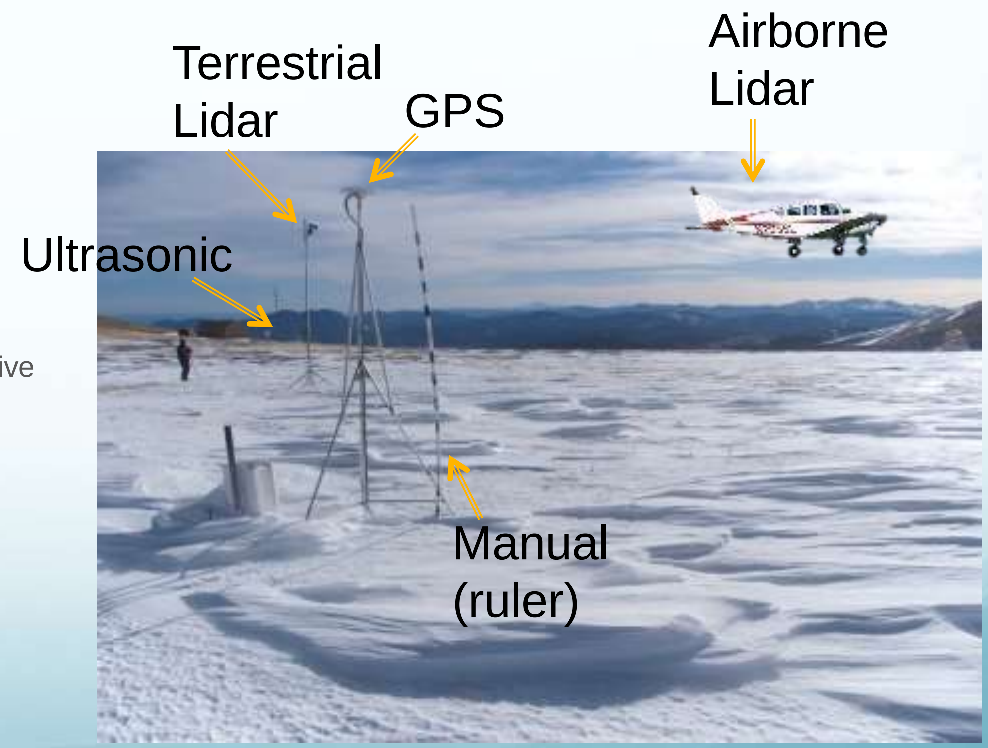
Alpine Snow Processes

- Snow transport by wind dominates the spatial distribution, yet we understand relatively little about the controls on this process

Snow Depth measurements

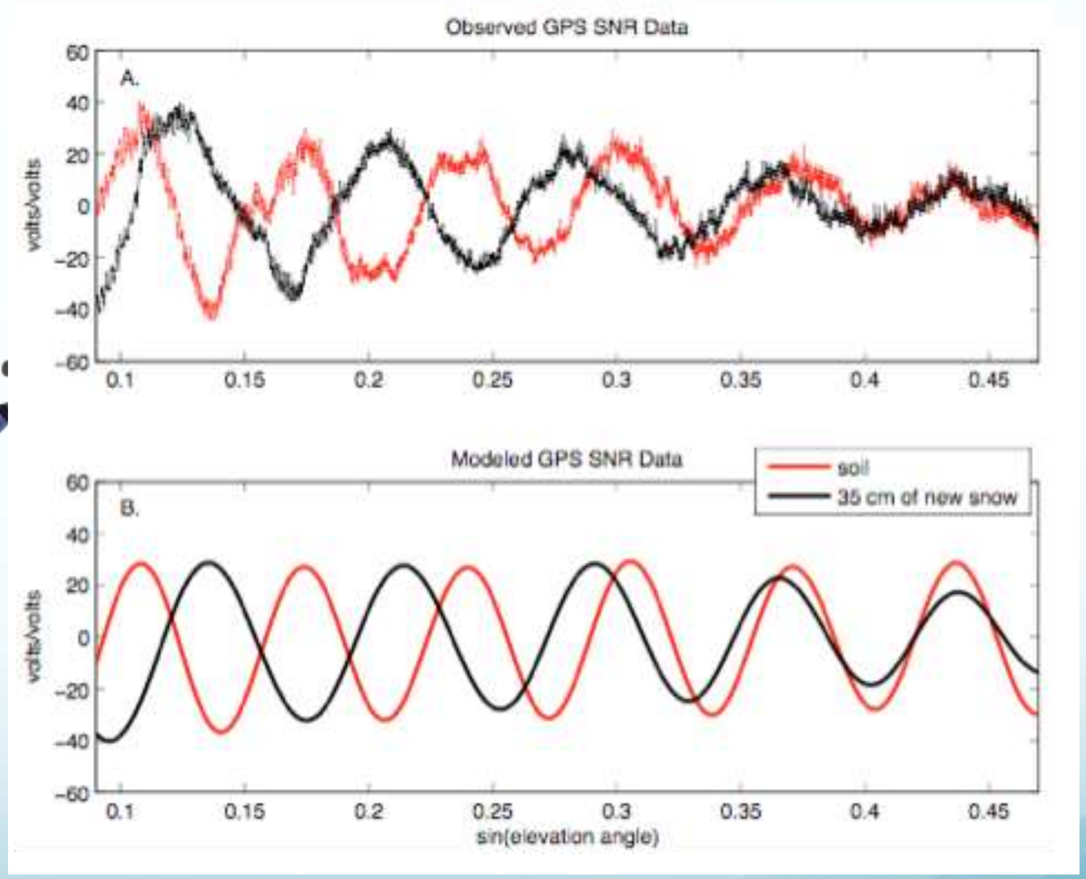
- Traditional:
  - Field measurement (ruler)
  - Automated (ultra-sonic rangefinder)
    - problems with wind, air temperature, limited sampling

- New Measurements:
  - Laser rangefinder
    - Very accurate, limited sampling
  - GPS
    - Large spatial foot print, existing measurement network
  - Terrestrial scanning lidar
    - Very accurate, good sampling, moderately expensive ($10k-500k) limited areal coverage, can operate continuously
  - Airborne lidar
    - Lower Accuracy, many locations, very expensive (>>$1M), larger areal coverage



GPS Making use of Noise

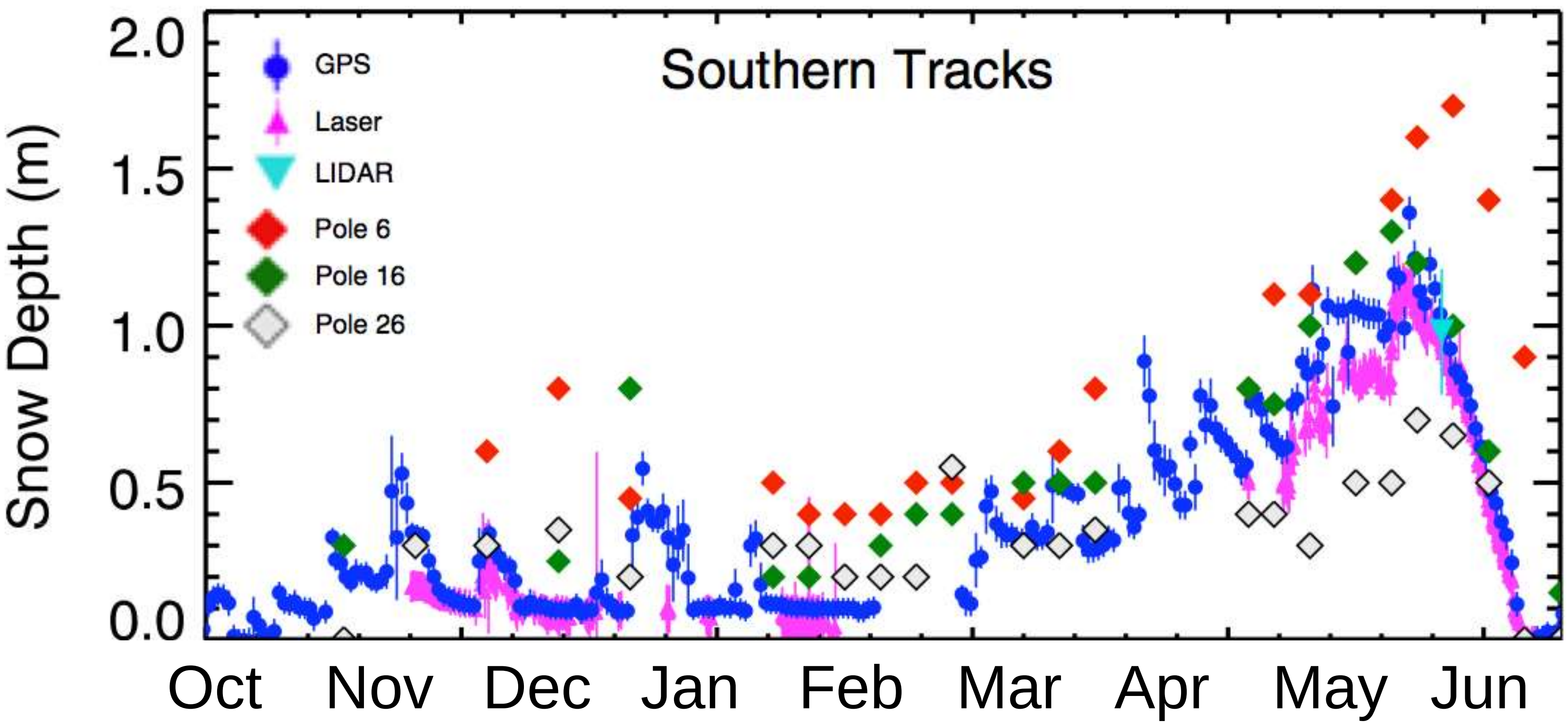
GPS signal bounces off the ground at different locations as the satellite rises, the two path lengths (direct and reflected) change and cause the two signals to come in and out of phase with each other



GPS Data

GPS & Laser in practice

Niwot Ridge Snow Depth

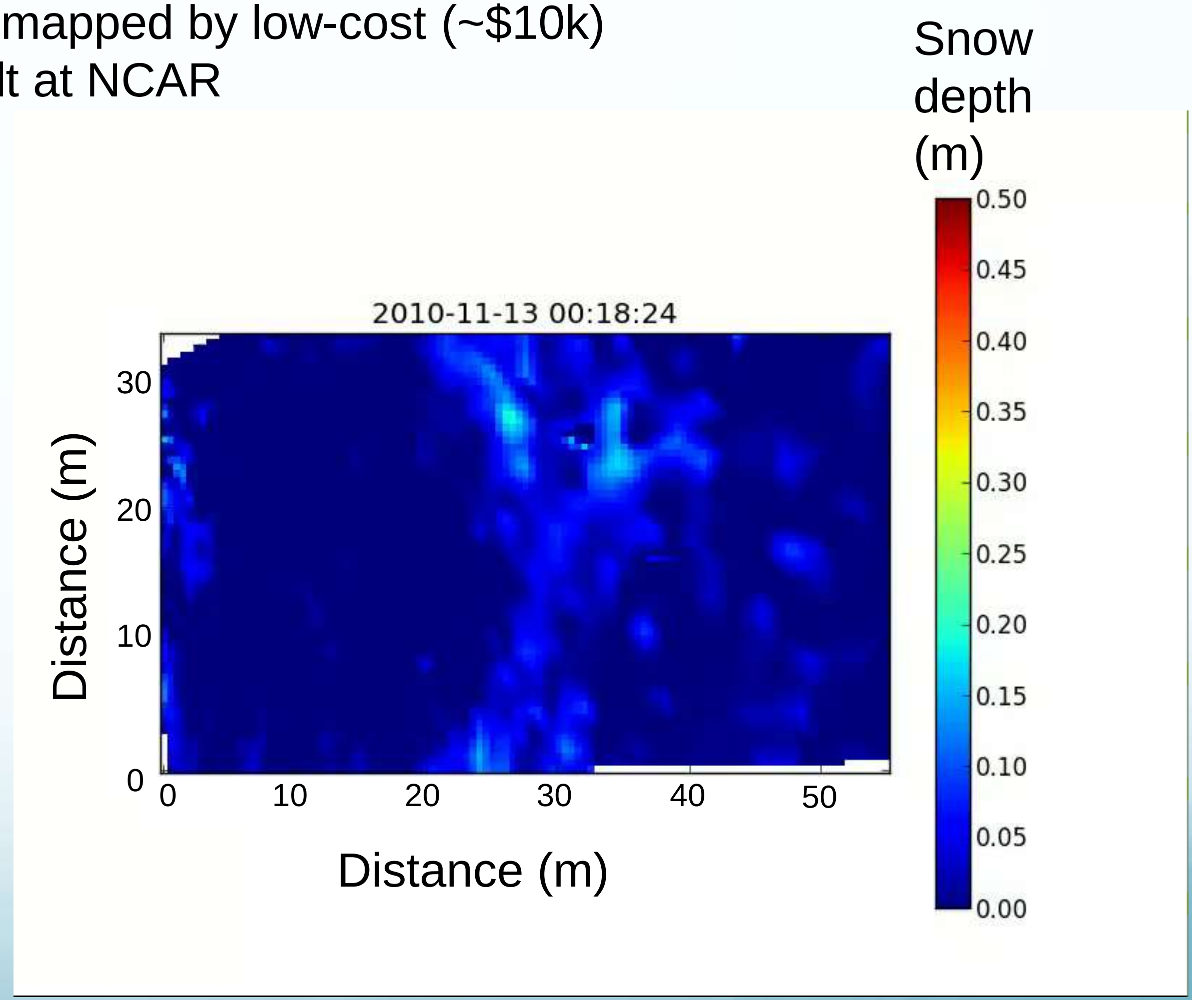


Terrestrial Scanning Lidar

Snow depth at Niwot Ridge mapped by low-cost (~$10k) terrestrial scanning lidar built at NCAR

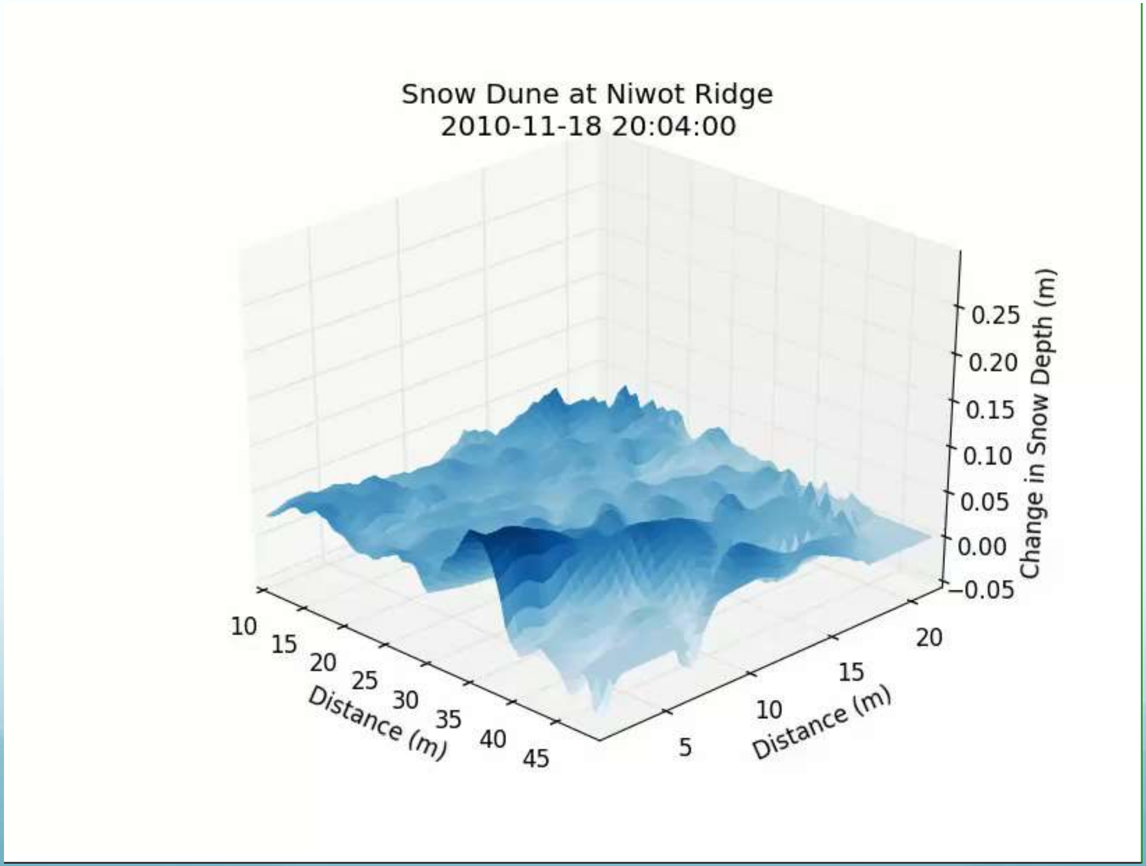
- Can map an area
  - 100s m^2 to 10s km^2

- Can operate continuously to map snow processes
  - watch for snow dunes in the movie

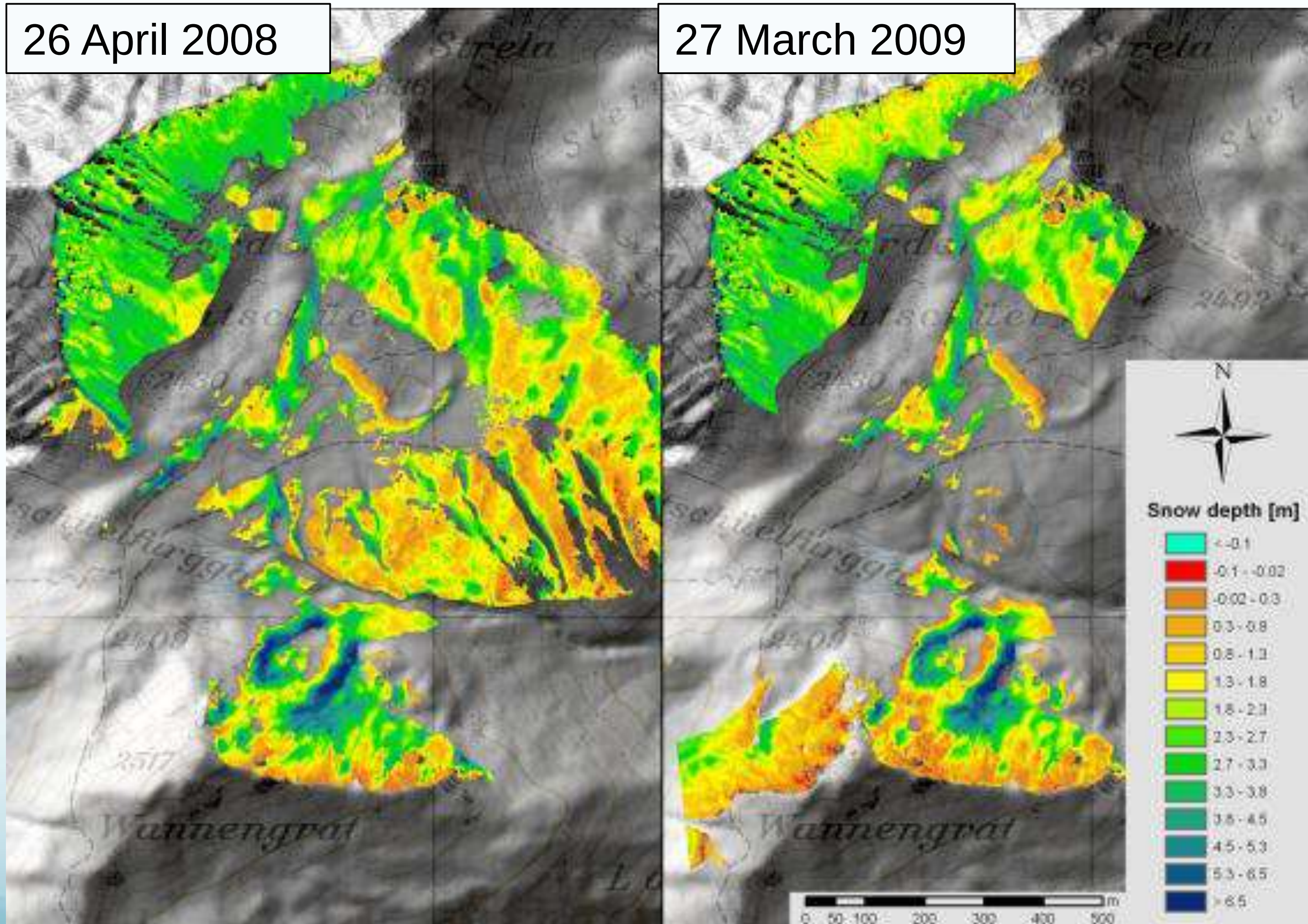


Snow Dunes captured by Lidar

- The ability to continuously map snow depth in harsh environments creates the opportunity to drastically increase our knowledge of the important processes involved



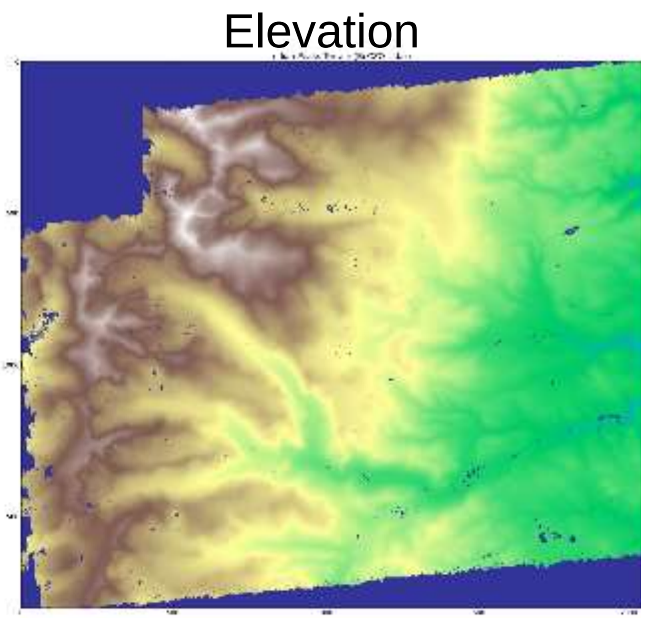
Persistence in intra-annual snow depth distributions

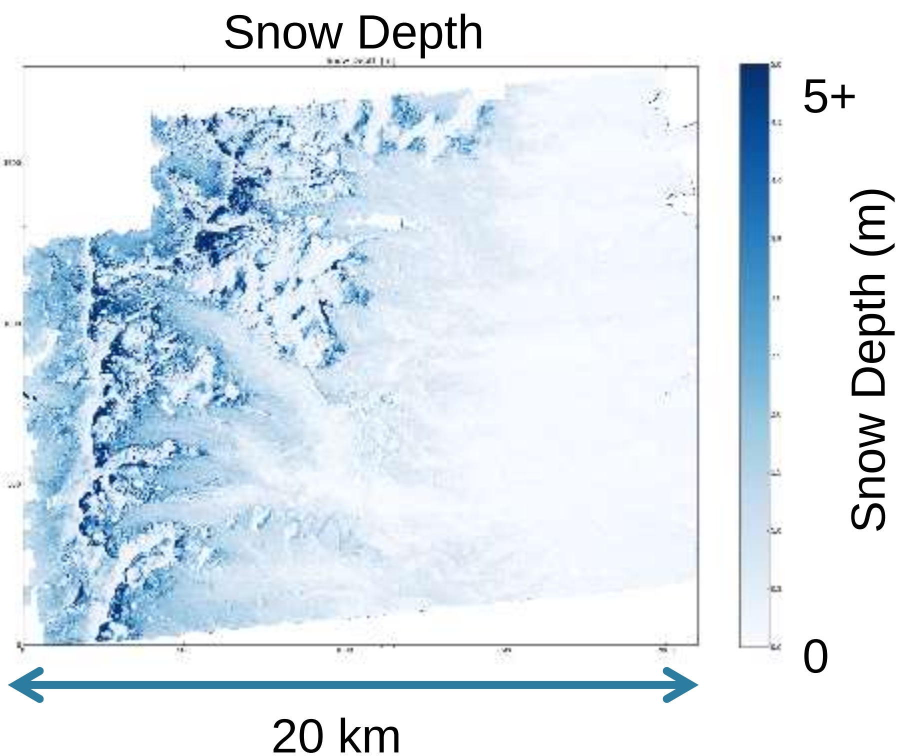


Schirmer et al Water Resources Research
[Volume 47, Issue 9,](http://onlinelibrary.wiley.com/doi/10.1029/2010WR009426/full#wrcr12739-fig-0005) W09516, 17 SEP 2011 DOI: 10.1029/2010WR009426
http://onlinelibrary.wiley.com/doi/10.1029/2010WR009426/full#wrcr12739-fig-0005

Airborne Lidar

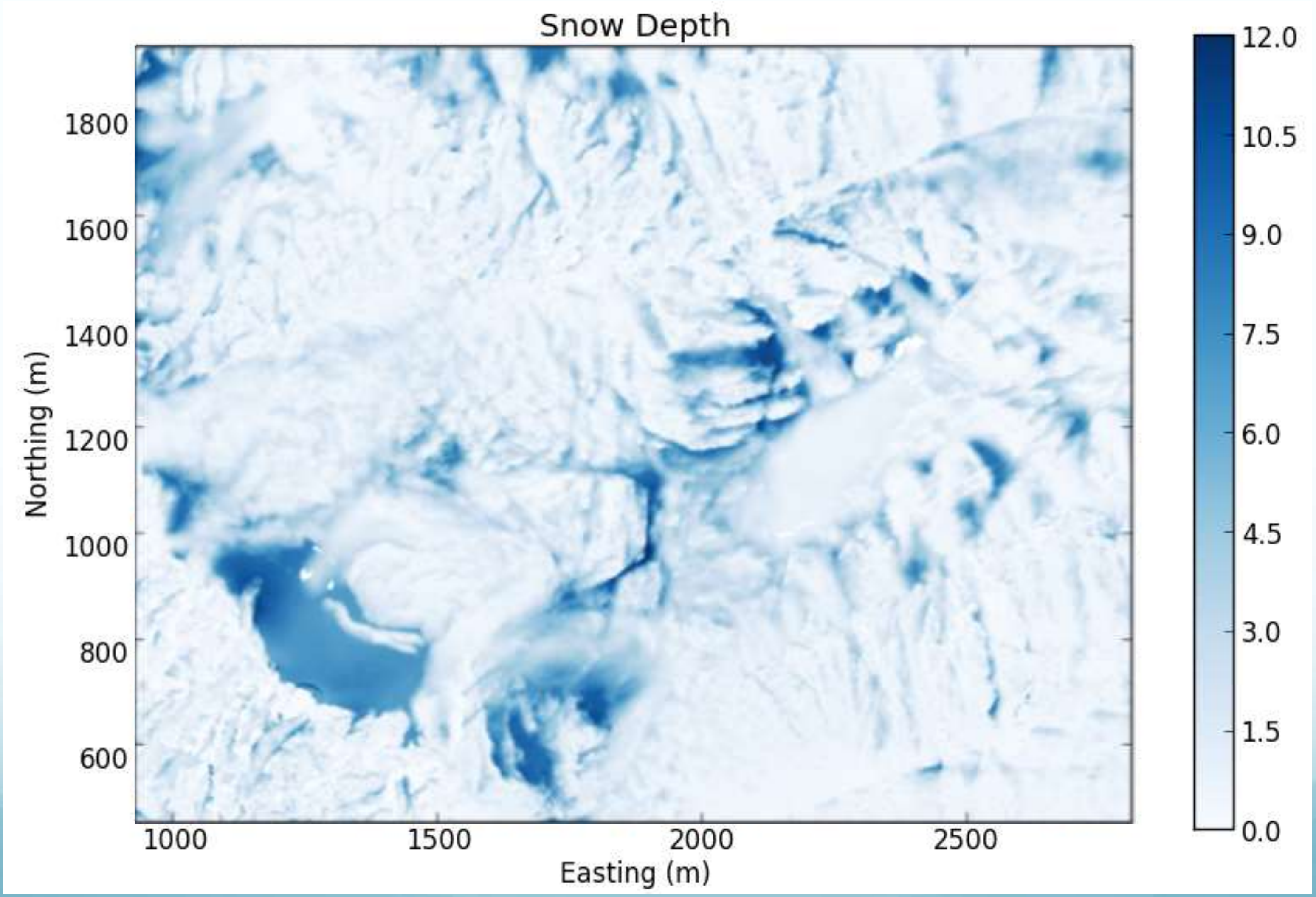
- Very expensive but provides great spatial coverage



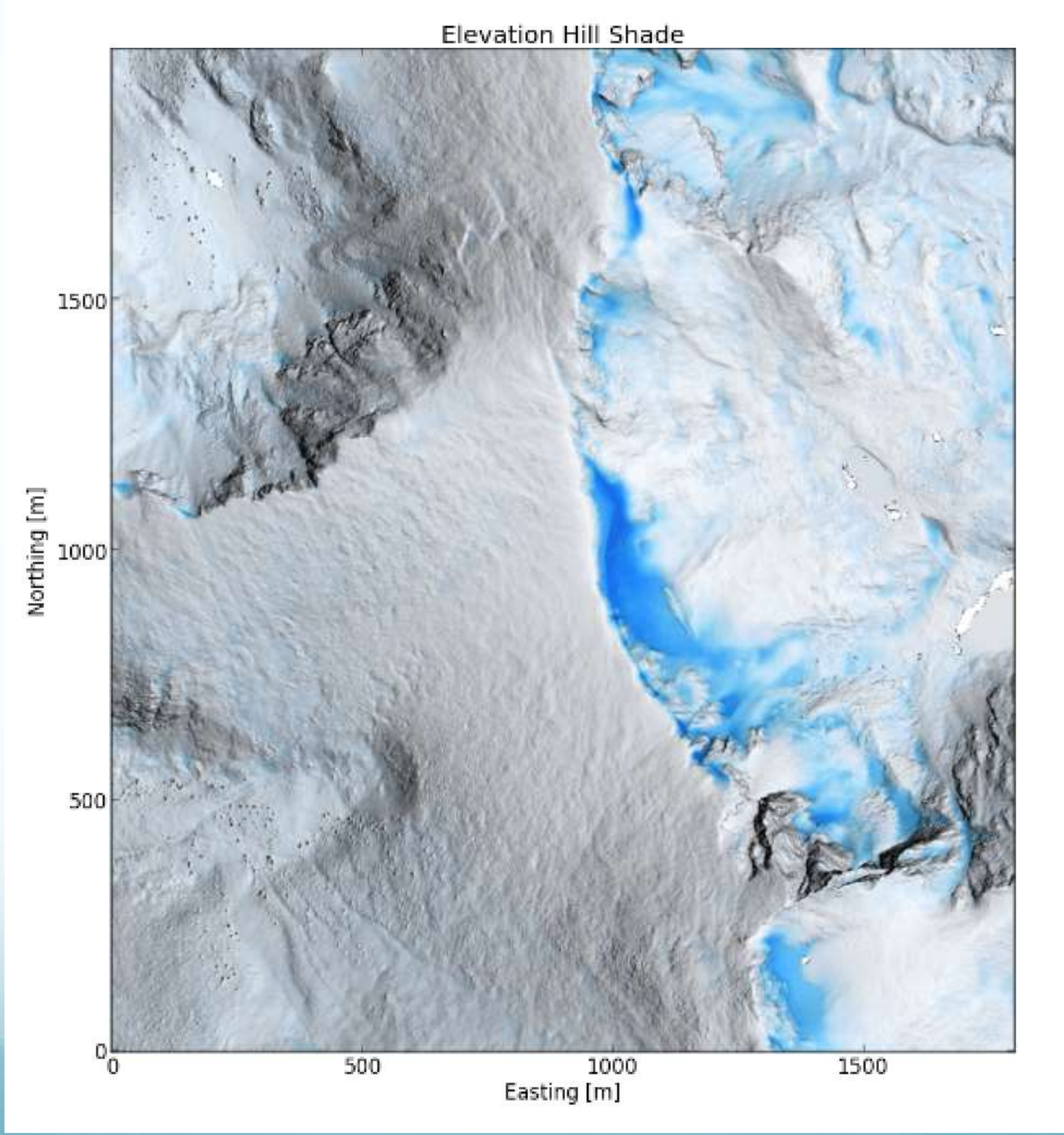


Snow Variability

Map of snow depth in the mountains



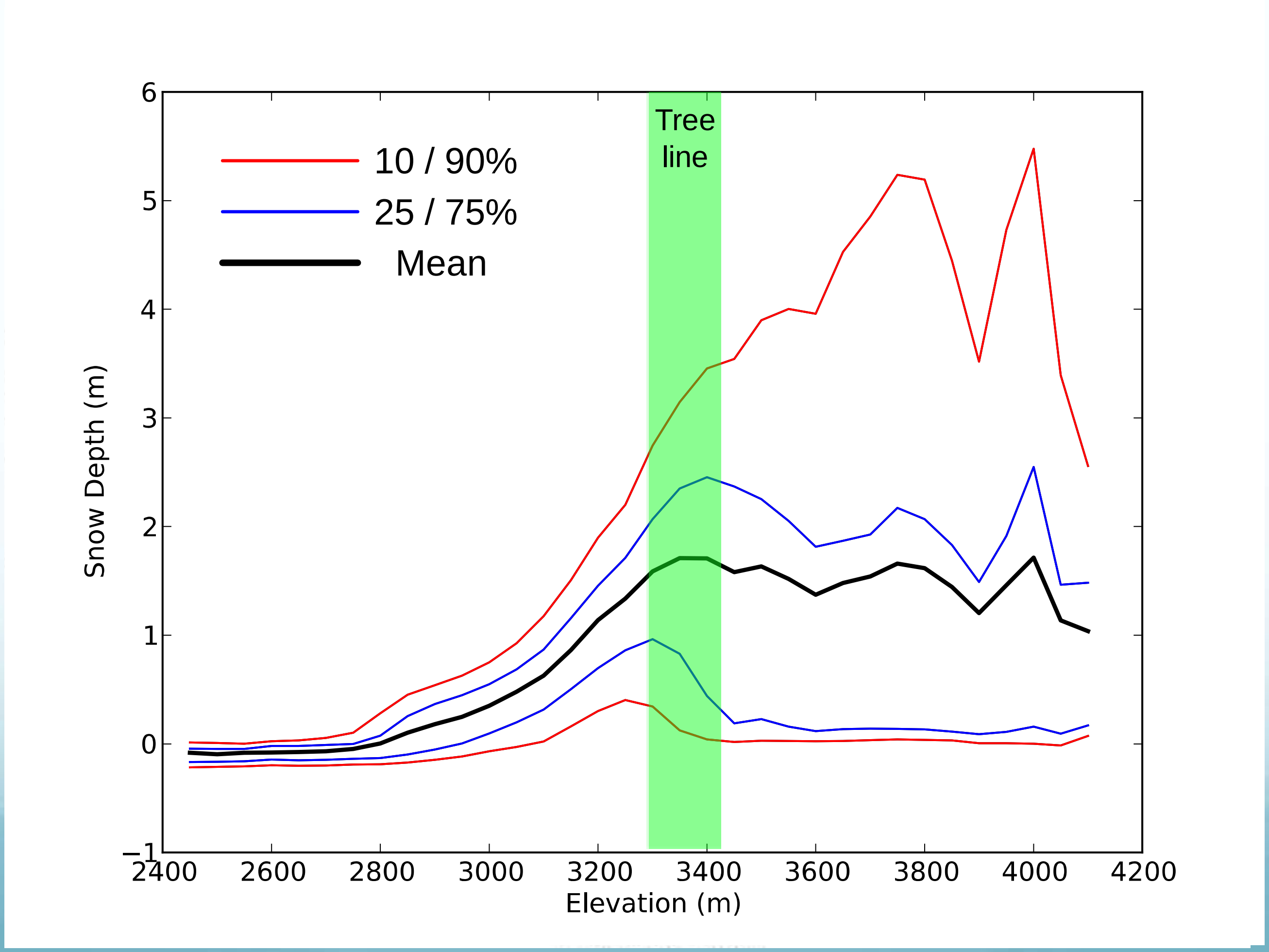
Depth varies from 0 to >15m



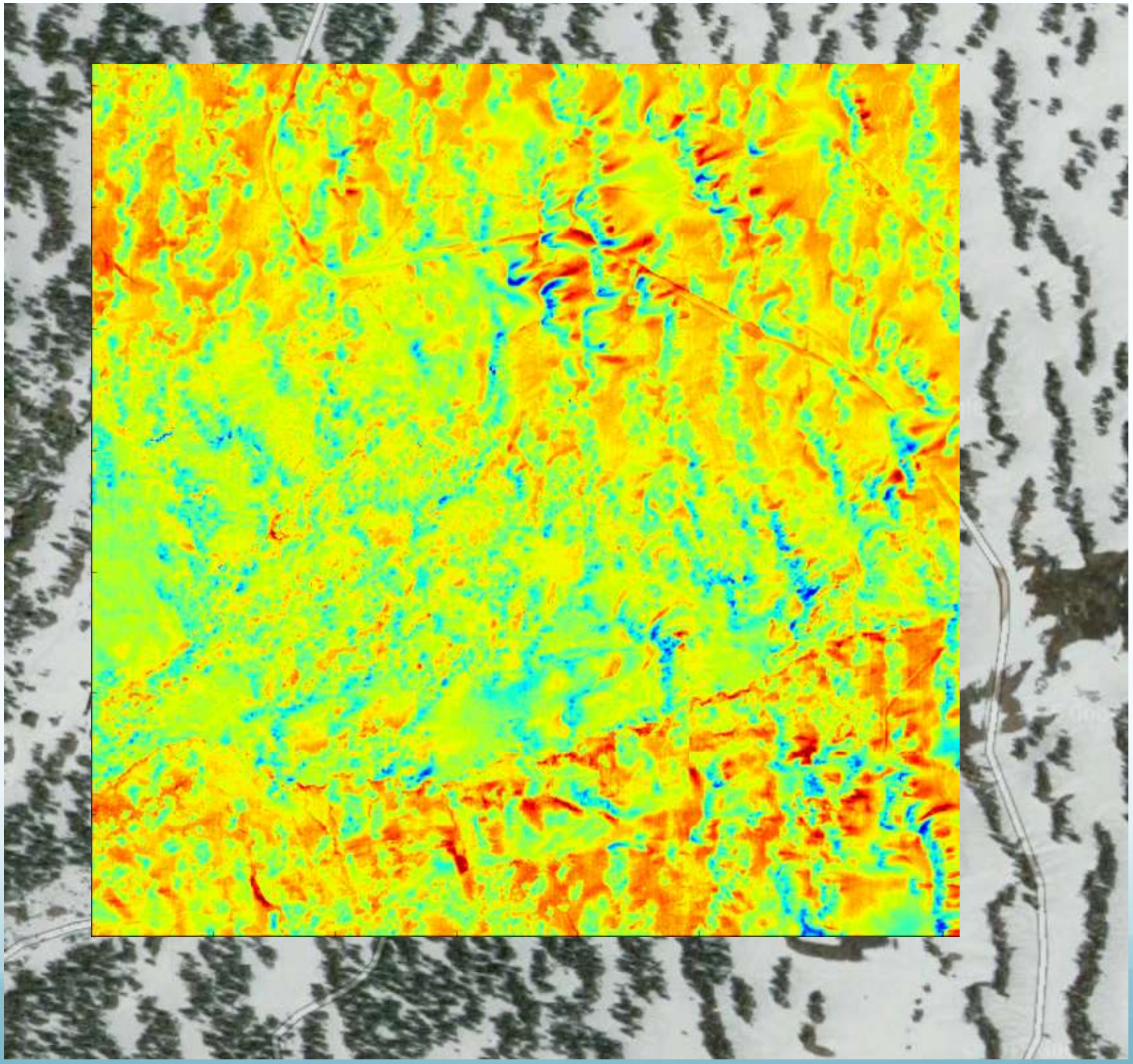
Elevation Hill Shade
Northing [m]
Easting [m]
1500
1000
500
0
0
500
1000
1500

Airborne Lidar

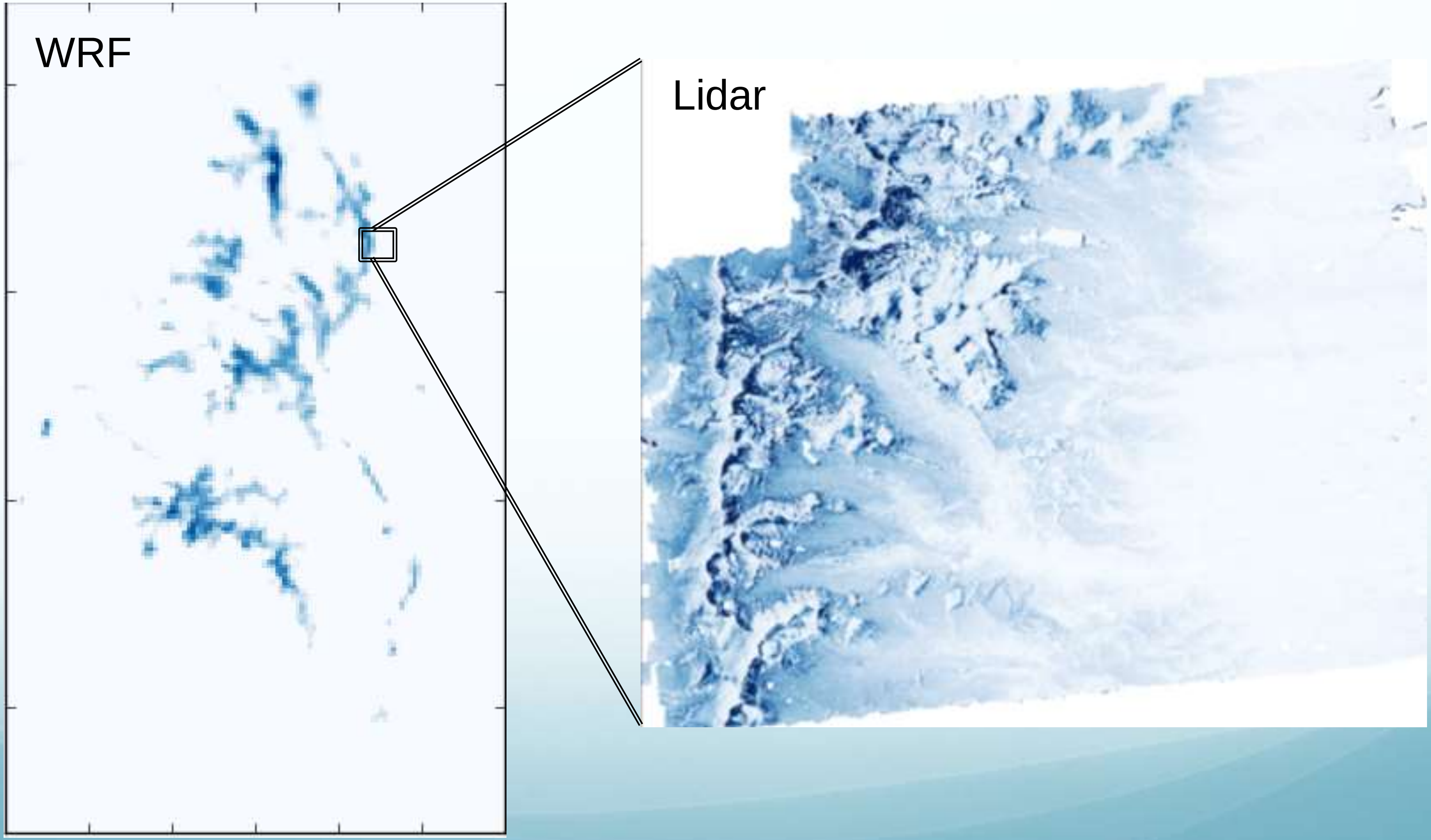
- Provides opportunity to assess large scale impacts, and evaluate models



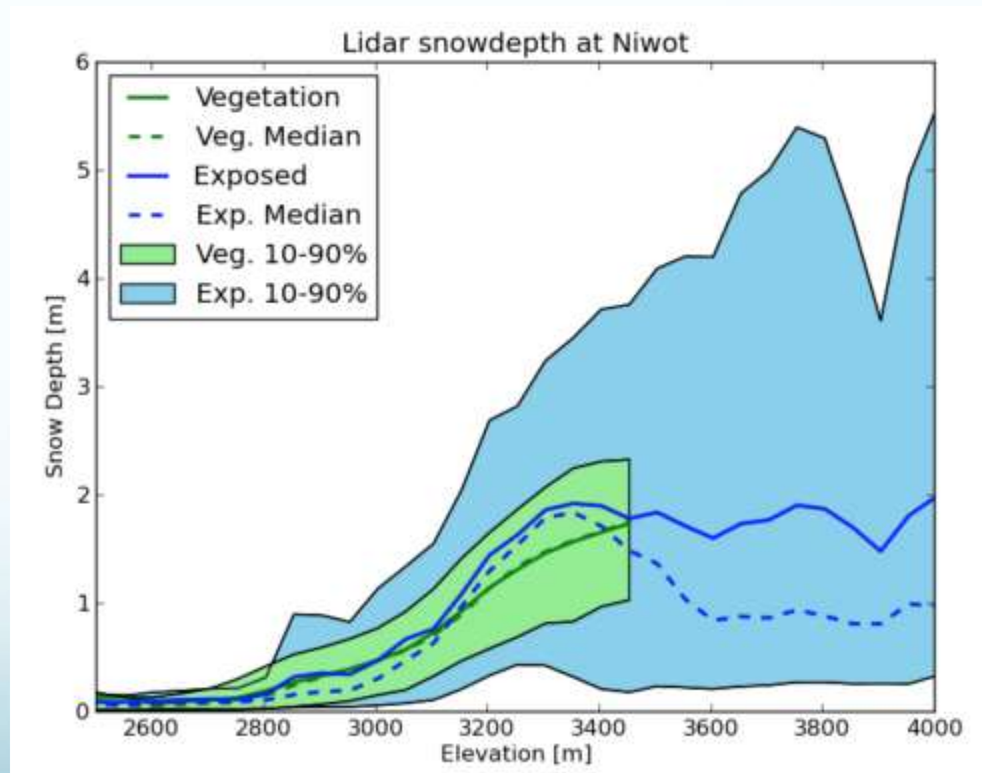
Snow and Vegetation



Larger Domains

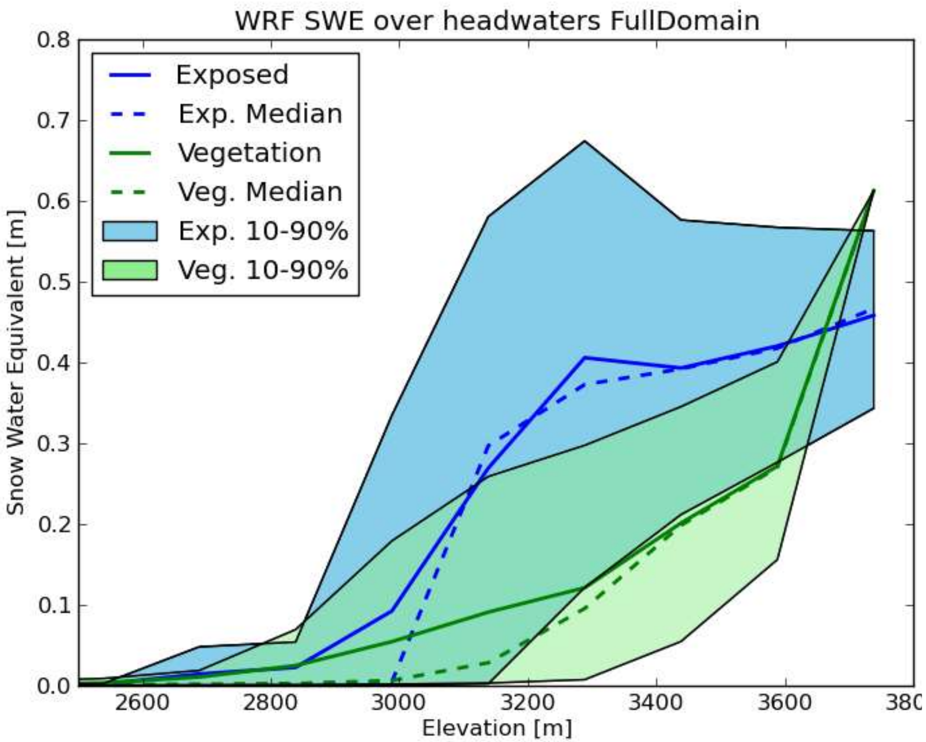


Snow and Forest

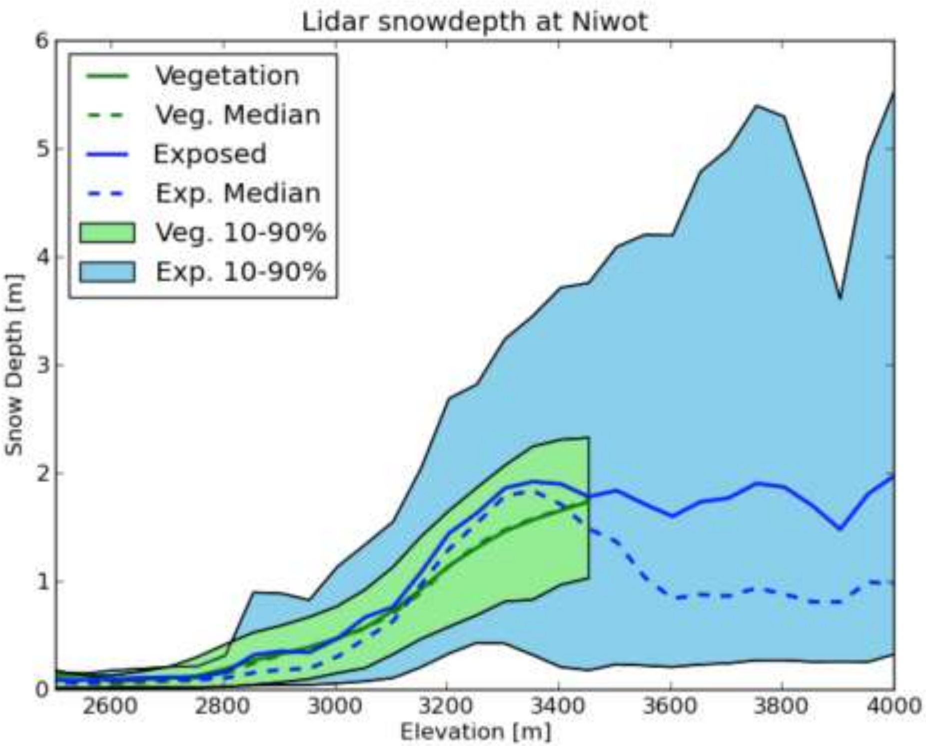


Comparison to other products

WRF
30-60% of snow above treeline



Lidar
50% of snow above treeline

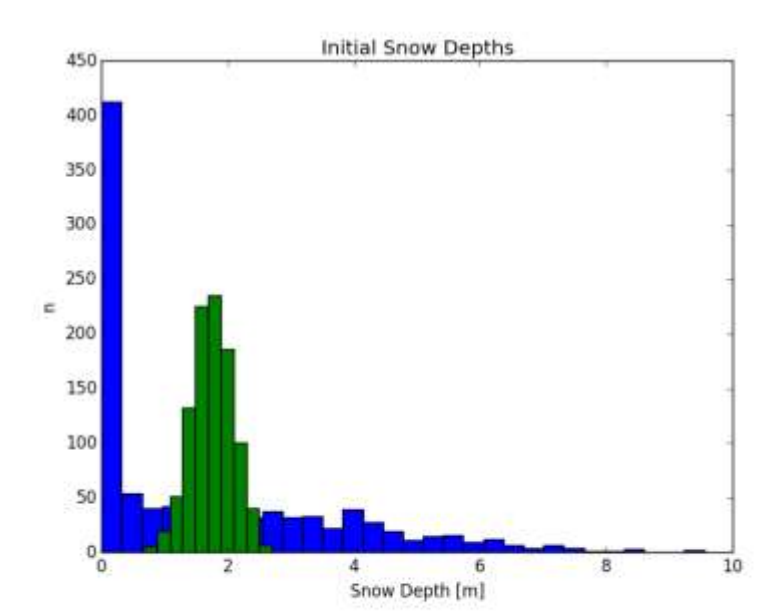


Sensitivity tests

- What effect does this have on modeled runoff?
- What effect does this have on a climate change simulation?

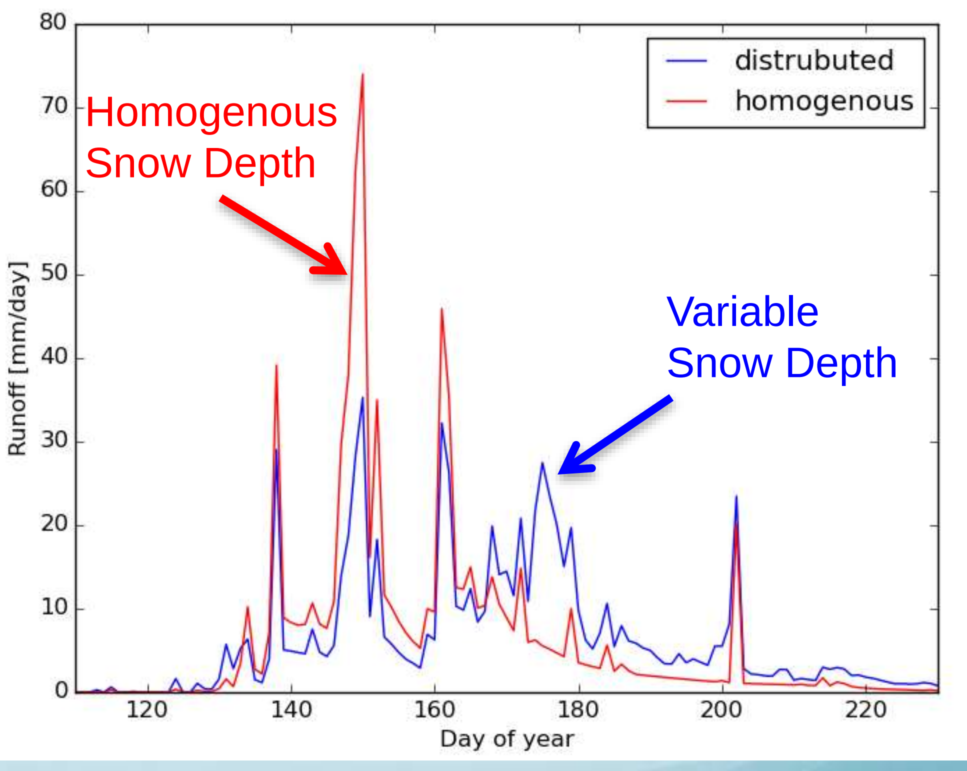
Tests:

- Noah LSM melt simulations
  - March 1st – Sept. 1st
  - 1000 ensemble members
  - As Initialized with a broad distribution of SWE (0-5m)
  - As Initialized with a narrow distribution of SWE (0.5-1m)
- Repeat with a 2K warming scenario



Effects on Runoff

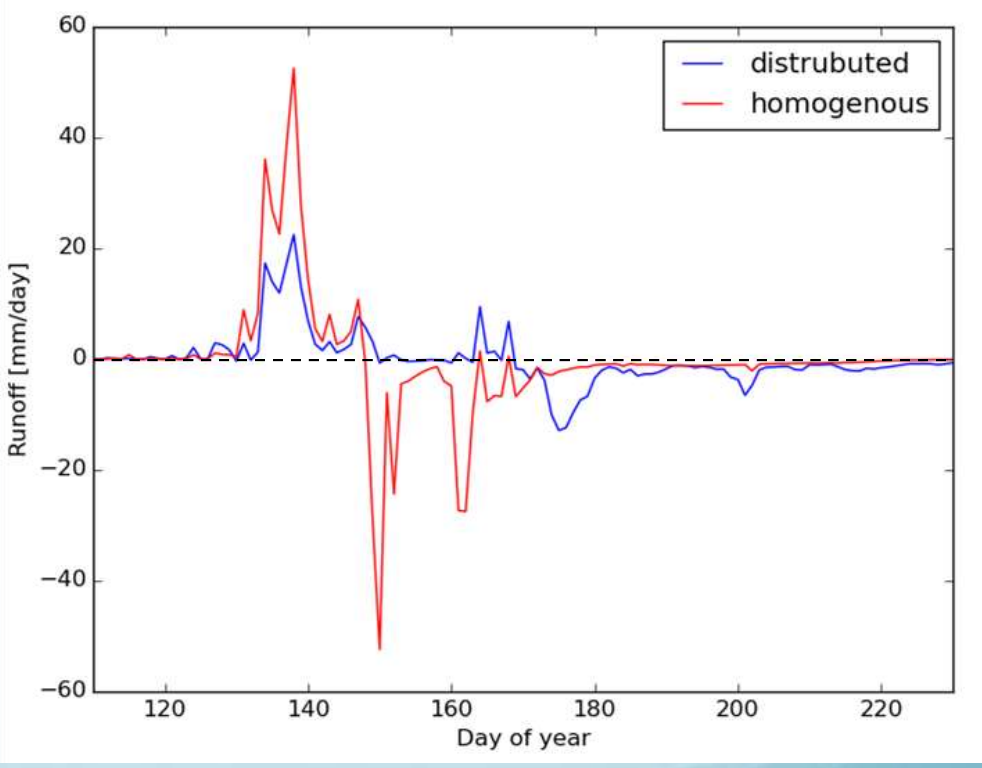
- **More** late season snowmelt and runoff
- **Less** early spring runoff
  - Less surface area to melt
  - And less to evaporate/sublimate
- ~2% more runoff in total



Effects on Climate Change Signal

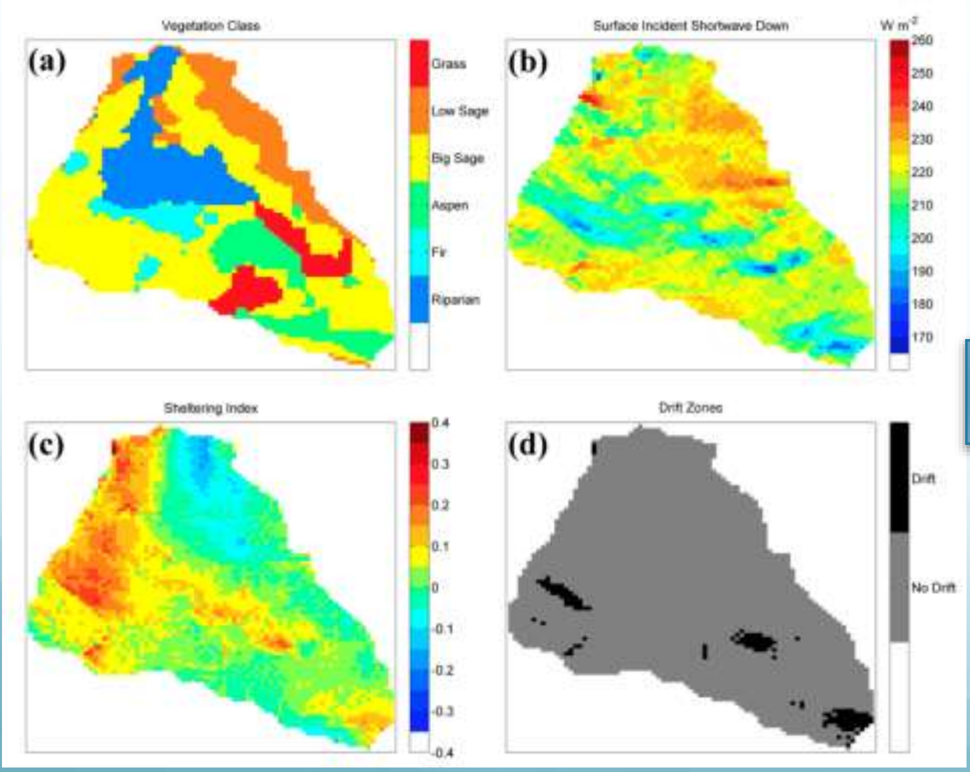
- **Less** increase in early spring runoff
- **Less** decrease in mid-season melt and runoff
- **More** decrease in late-season runoff
- Smaller, longer Change signal (might be easier to manage)
- Slightly smaller change in total runoff (–0.5mm vs –4mm)

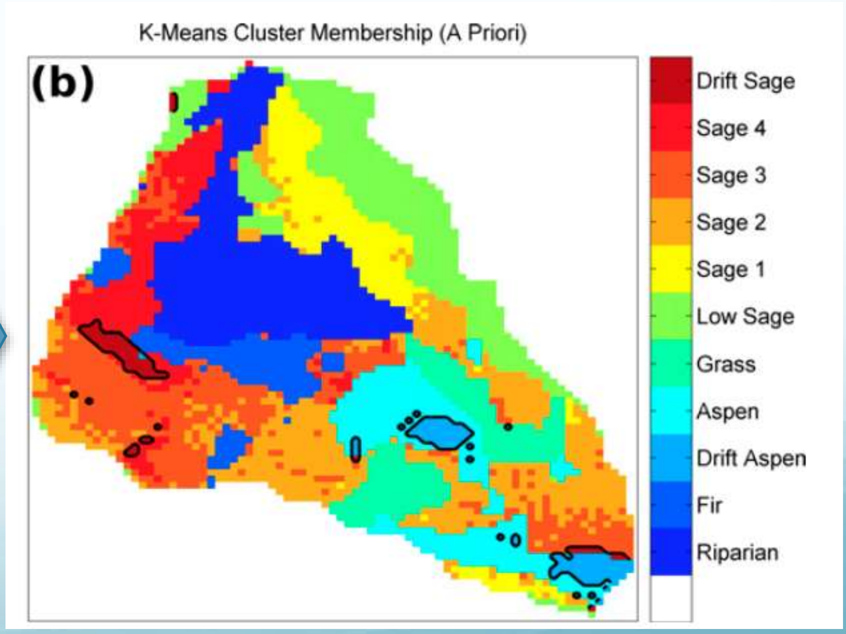
Change in Runoff



New Modeling Approaches

- Calculate spatial distribution of key features
- Classify/cluster the landscape
- Run one model column per cluster





Newman et al (2014) JHM
DOI: 10.1175/JHM-D-13-038.1

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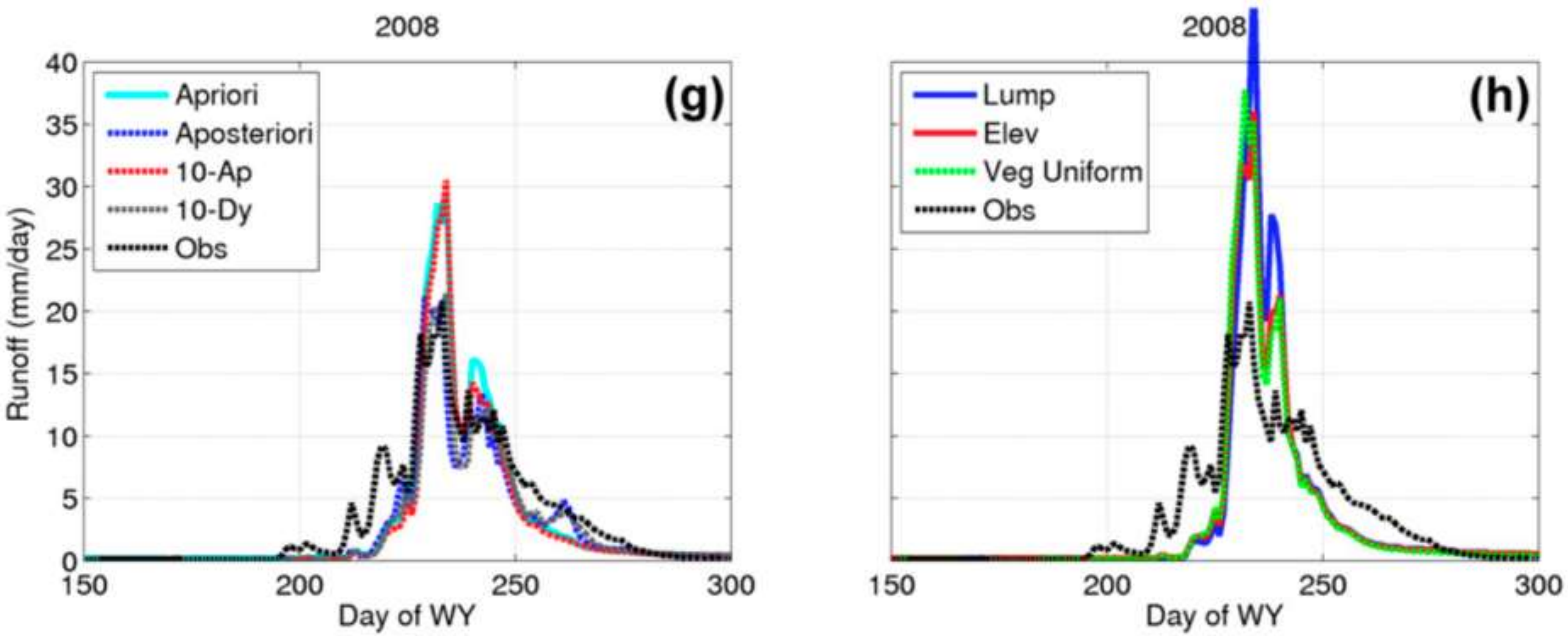

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Summary

- New Snow Measurement techniques provide a better way of measuring snow
  - **Terrestrial Laser Scanner** provides time evolution for process oriented understanding
    - lower cost, better accuracy, moderate spatial coverage
  - **Airborne Lidar** provides better spatial coverage for evaluations and model parameterizations
    - but higher cost and lower accuracy
- Tremendous **spatial variability** of snowpack not represented in many models
- Locally **deep** snowpacks have a different climate sensitivity than regional shallow snowpacks