

Spatial variations in snowpack density in SnowEx: Measurements and models



Mark S. Raleigh^{1,2,3} and Eric Small¹

¹ *Department of Geological Sciences, University of Colorado*

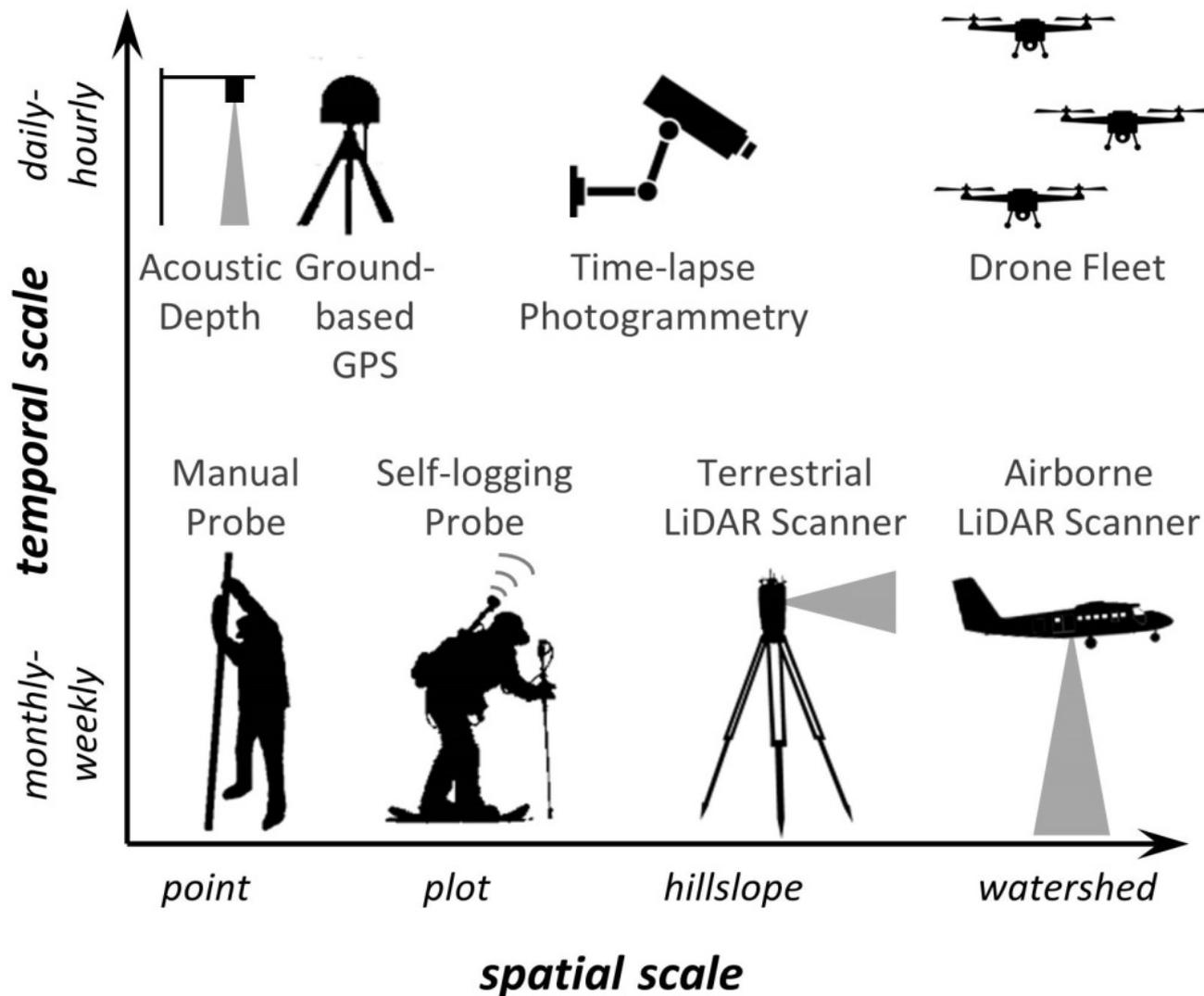
² *Cooperative Institute for Research in the Environmental Sciences*

³ *National Snow and Ice Data Center*



Photo: M. Raleigh (Feb 2017)

Many approaches for measuring snow depth...



...but all require snow density to get at SWE.



I have no idea!
- Theo B.

What if I dig faster?

How well do we know bulk snow density?

Observations are spatially limited because they are time-consuming, restricted access, safety risk

Photo: Anne Nolin

A photograph showing a person's legs and feet in winter clothing and boots standing in a snowy field. A shovel with a black handle and a blue section is stuck in the snow. A large pile of dead, brown branches (deadfall) is scattered across the snow. The scene is brightly lit, casting shadows.

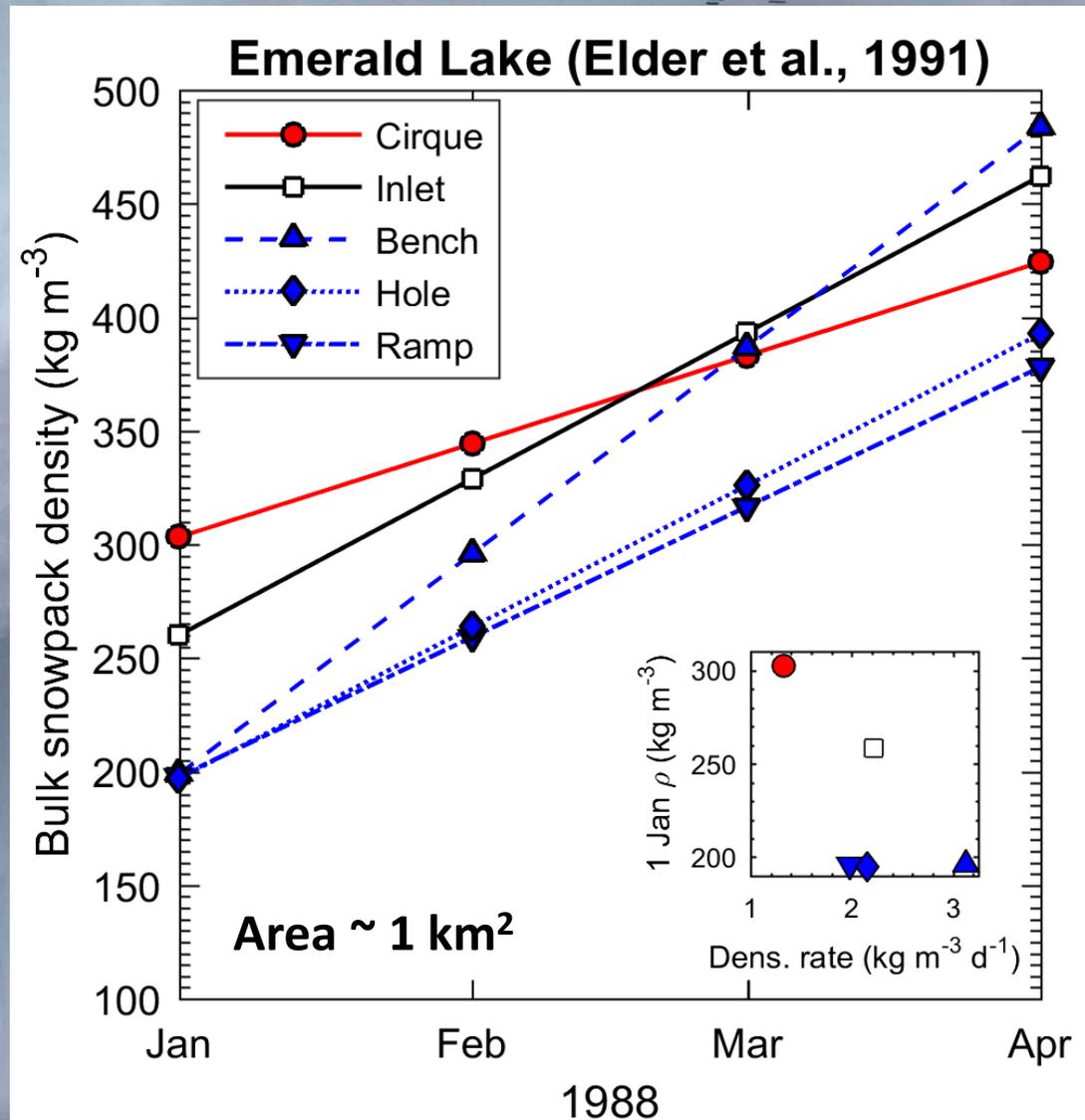
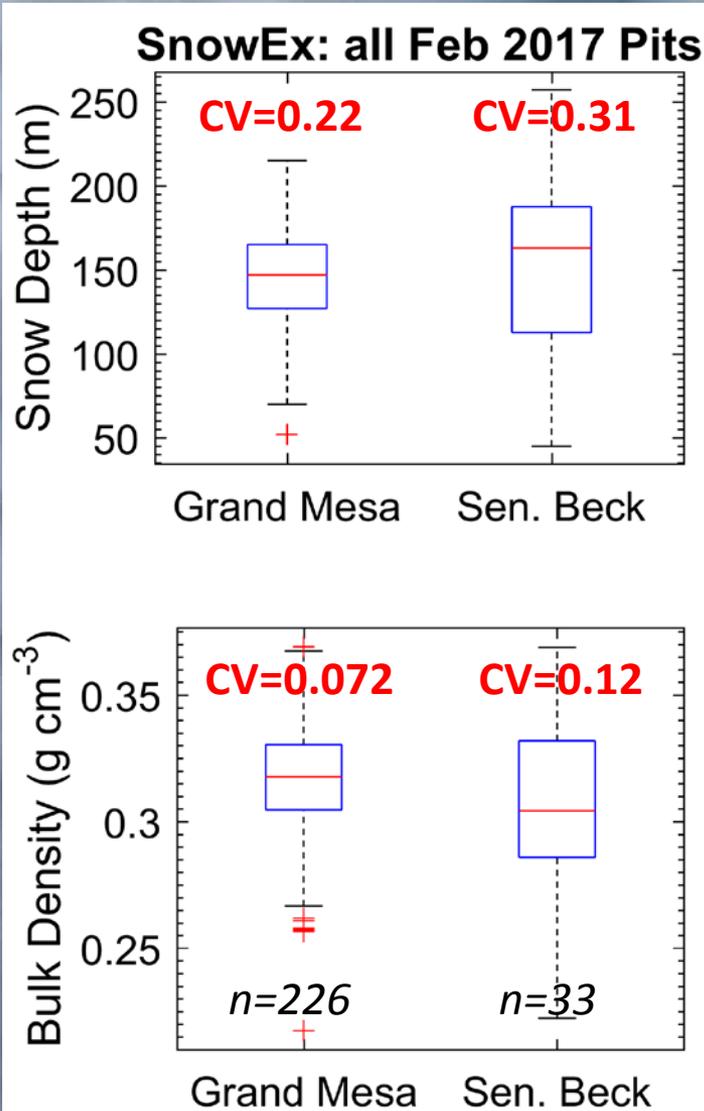
When we measure
density in snow pits,

uncertainty is
~5-10% due to:

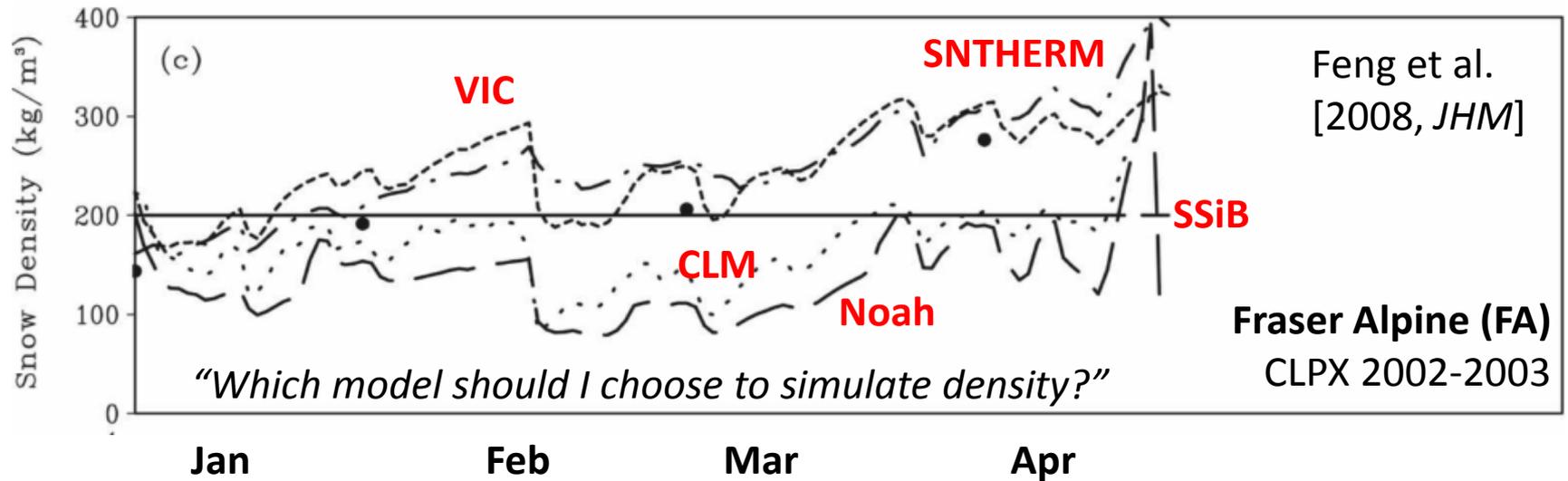
- cutter type
- variable crusts
- shrubs/deadfall

Conger and McClung [2009]
Proksch et al. [2016]

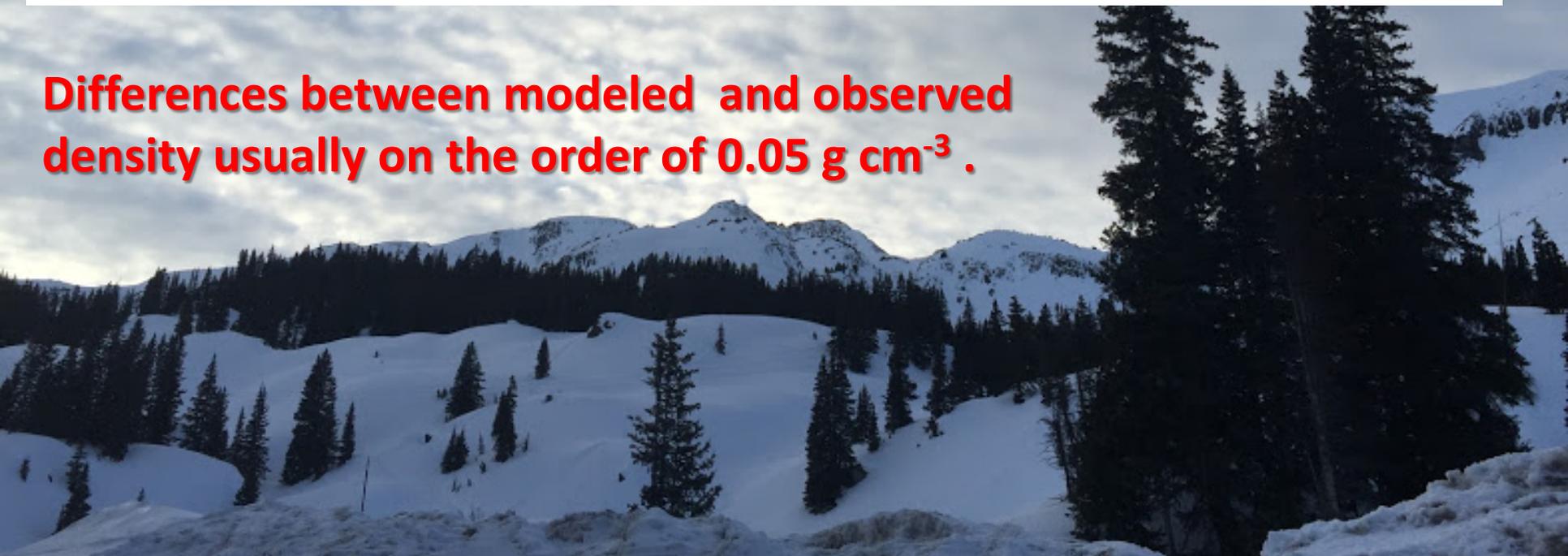
Field campaigns show greater variability in snow depth... ... but snow density variations are not negligible



Snow models often yield different estimates in density

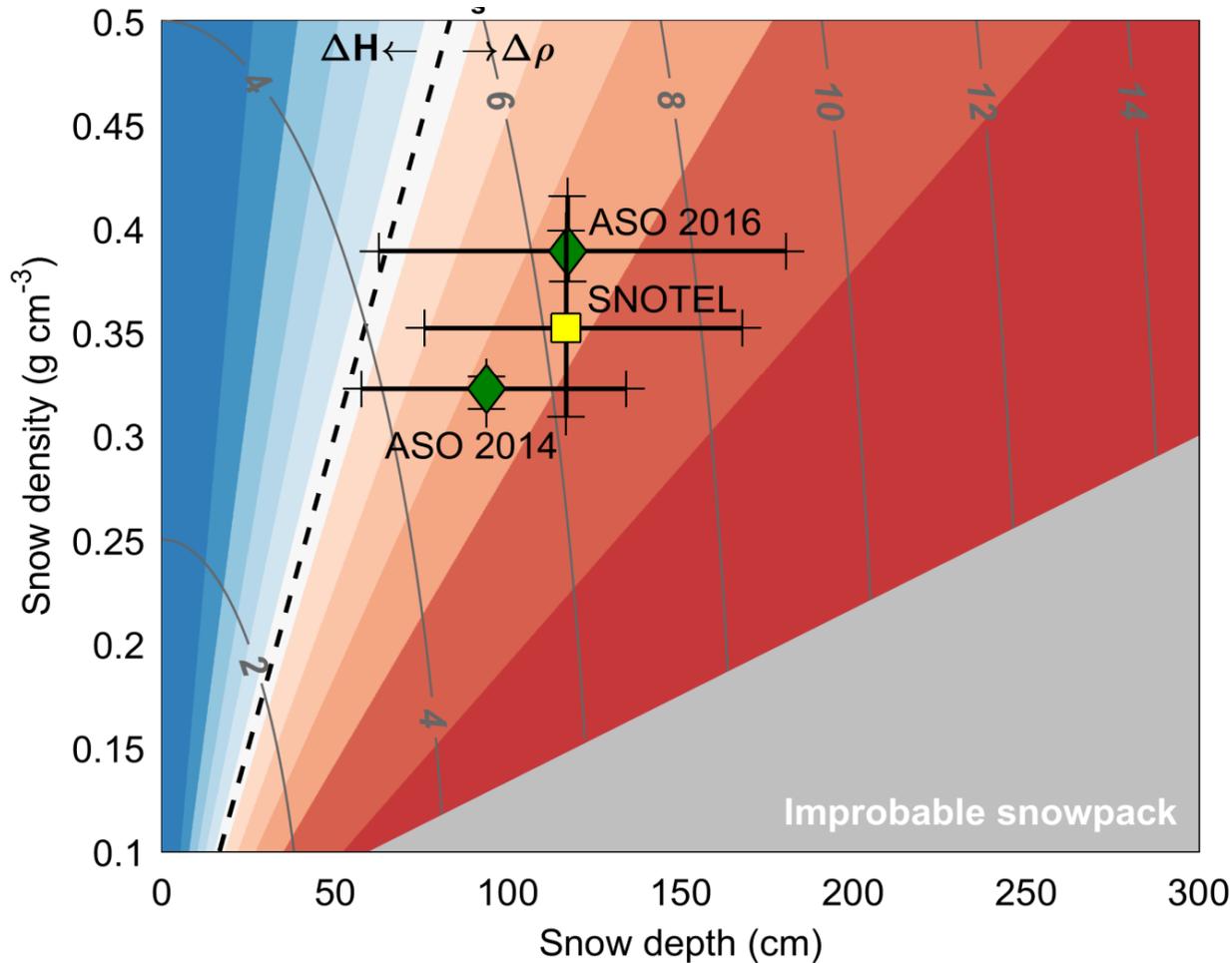


Differences between modeled and observed density usually on the order of 0.05 g cm^{-3} .



Does $\sim 0.05 \text{ g cm}^{-3}$ density uncertainty matter to SWE?

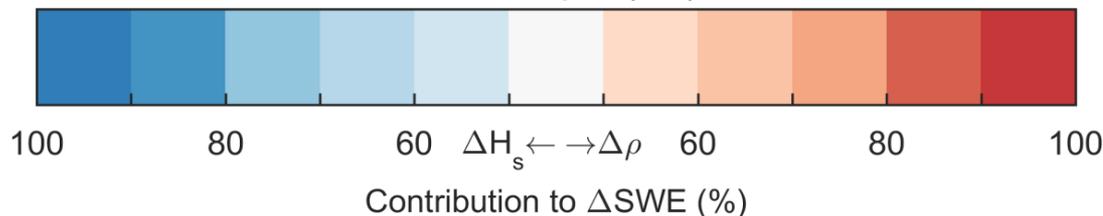
Yes, for lidar retrievals with snow depth unc. < 10 cm



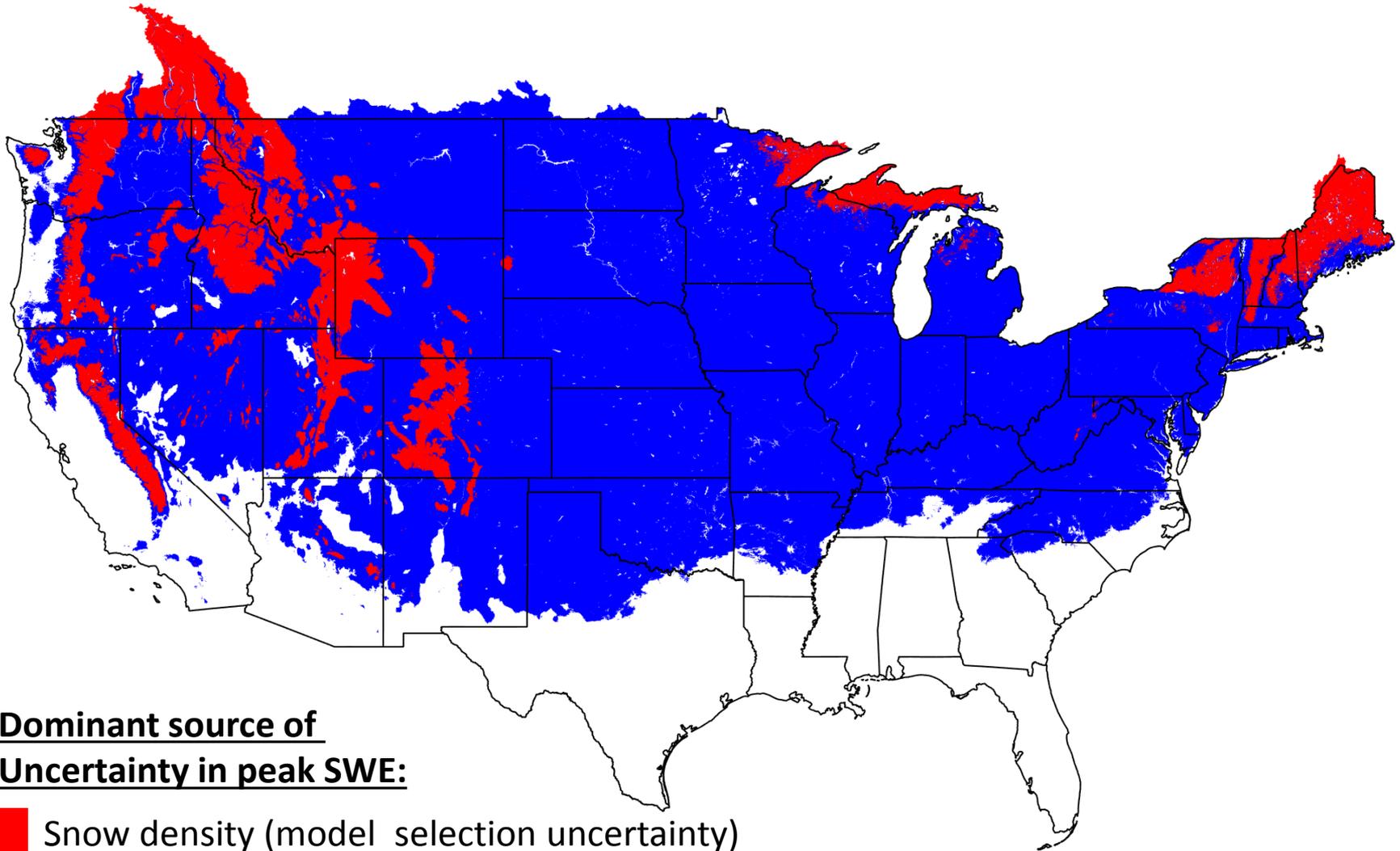
**Relative
SWE
uncertainty
of 15-20%.**

**Density
contribution is
>70%.**

Raleigh and Small
[2017, *GRL*]



Lidar-based retrievals of peak SWE are limited by density uncertainty in areas with deeper snow



Dominant source of
Uncertainty in peak SWE:

■ Snow density (model selection uncertainty)

■ Snow depth (lidar measurement uncertainty)

60 cm critical snow depth

Can we reduce the snow density uncertainty by constraining to snow pit observations?

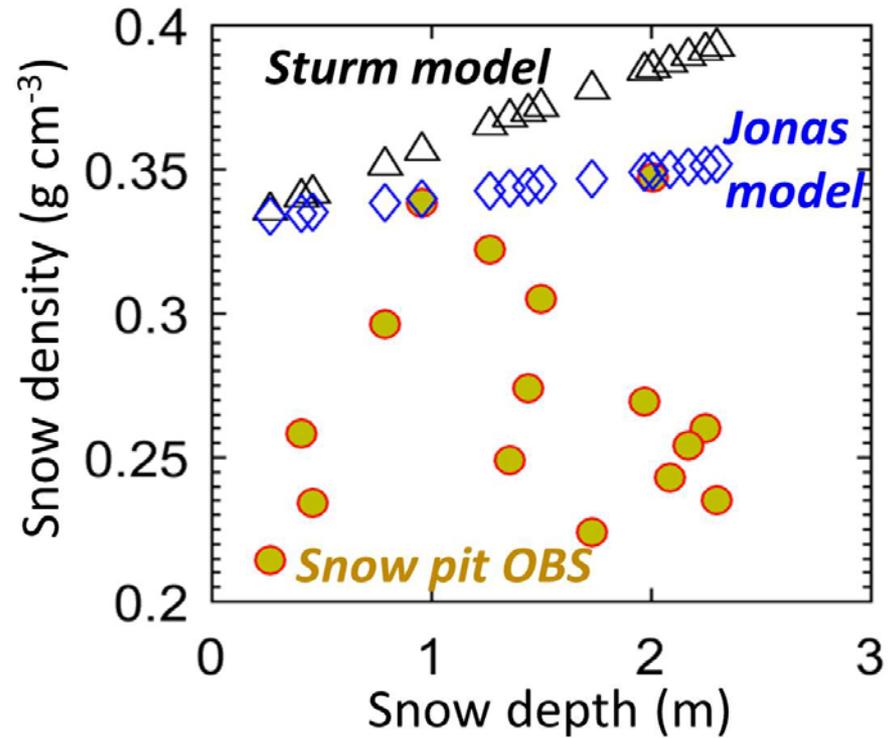
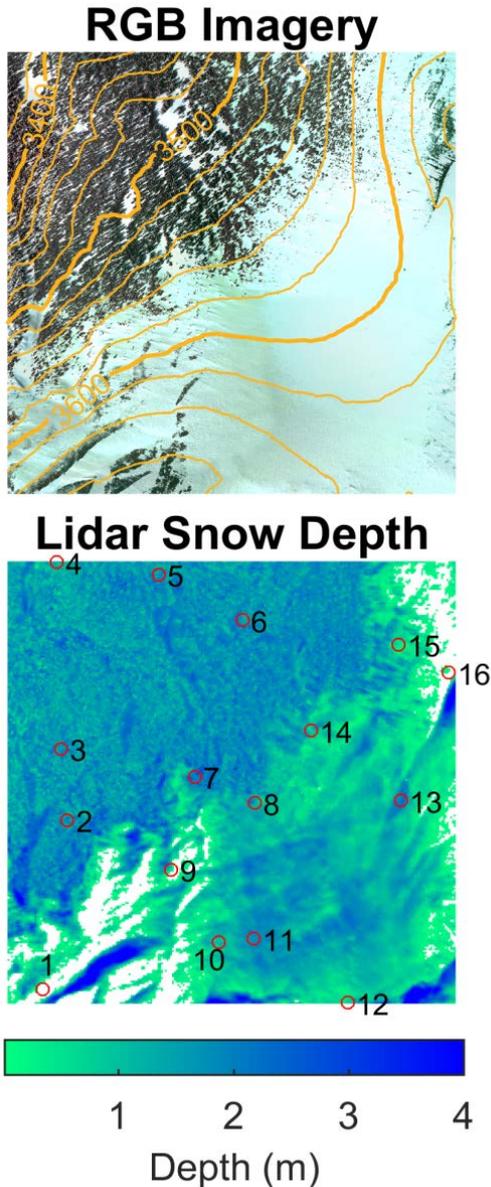
How does this advance knowledge of processes influencing density?

Are these corrections transferable to other basins?

Are the density observations representative of the entire basin?

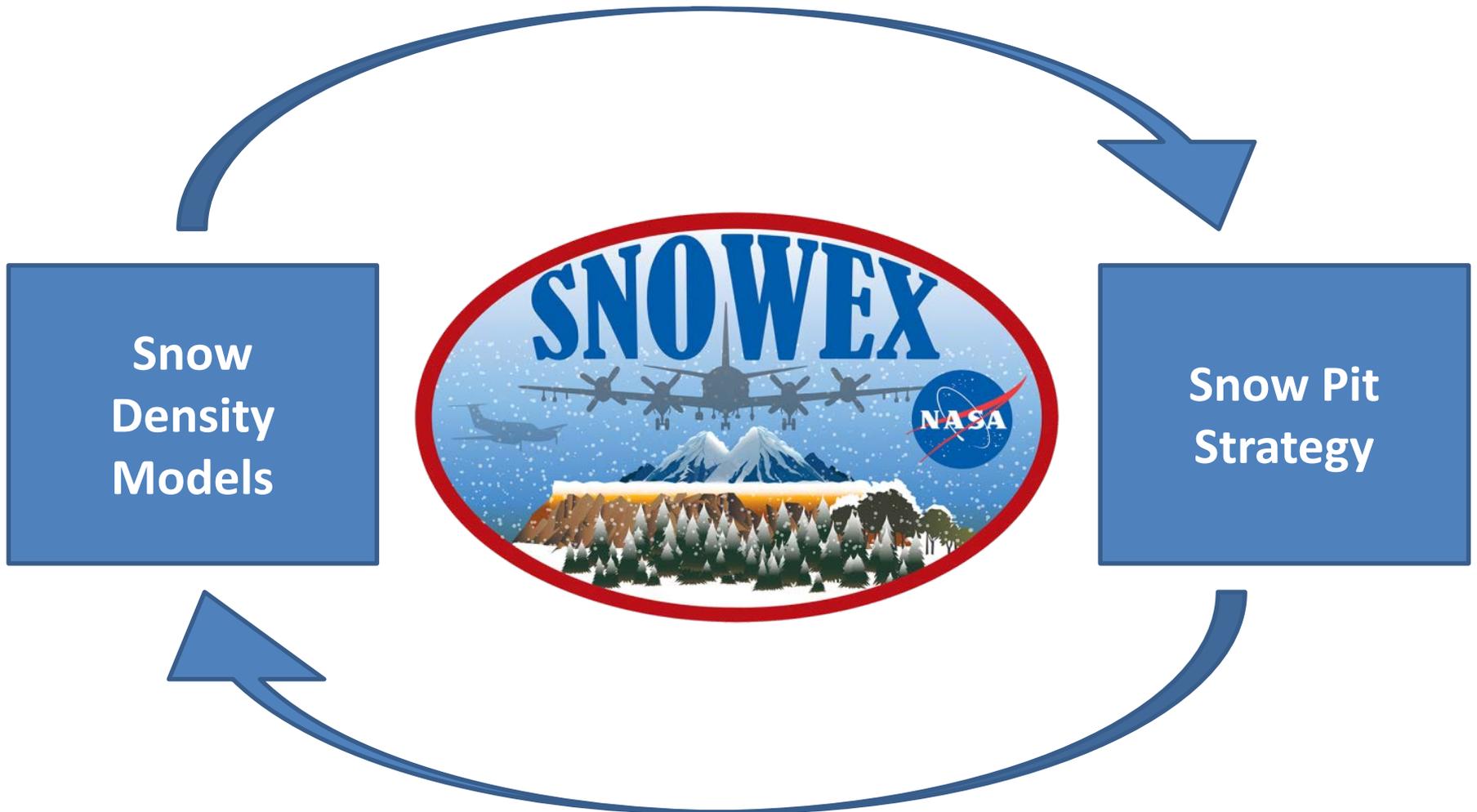
How many snow pits are needed to measure basin density?

1 km x 1km
Fraser Alpine
CLPX

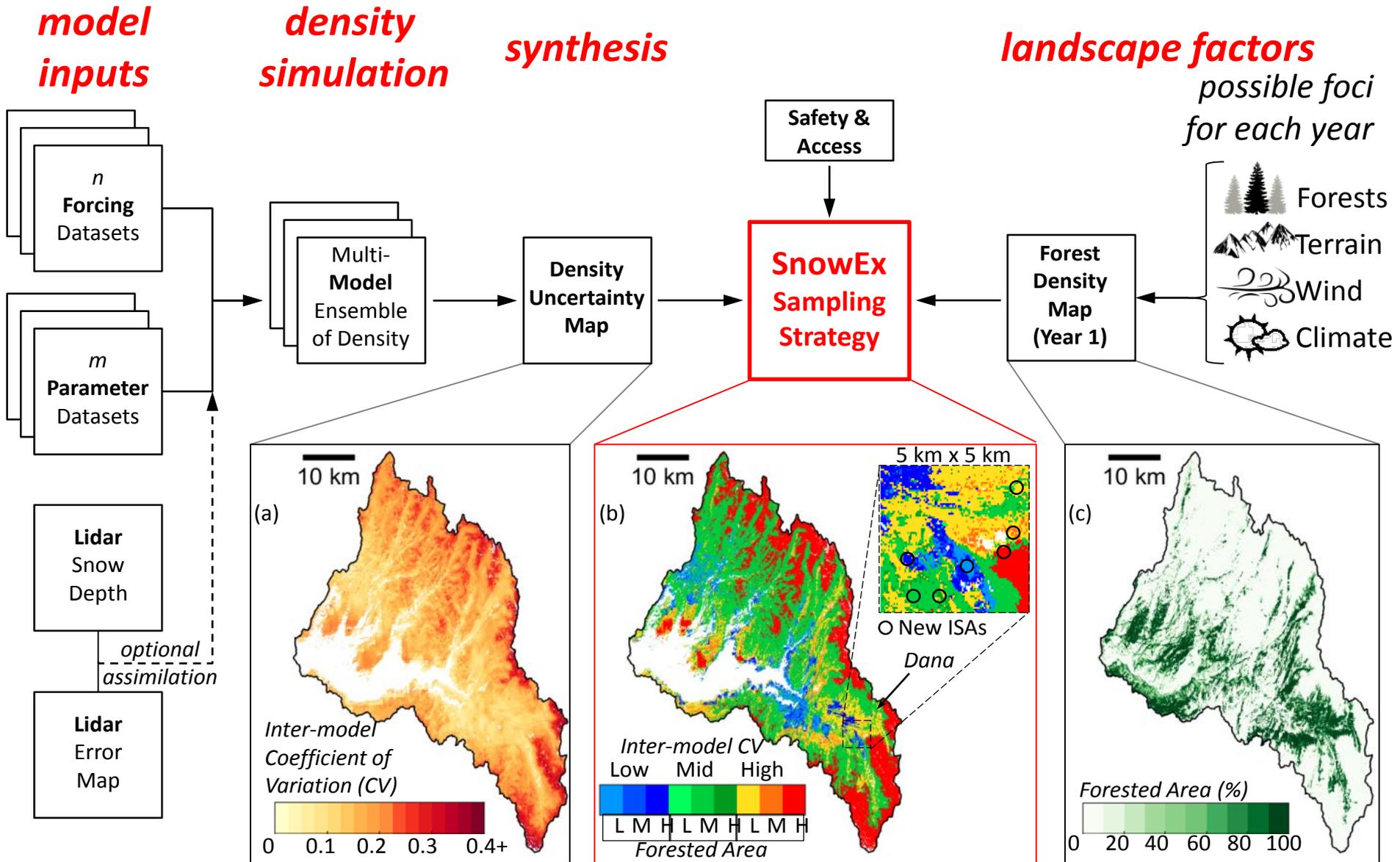


Multi-model snow density mapping:

- (1) determine where to sample
- (2) quantify basin-wide density uncertainty



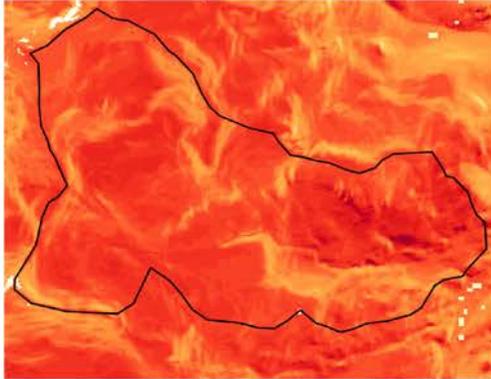
Our vision: targeted strategy for evaluating snow models



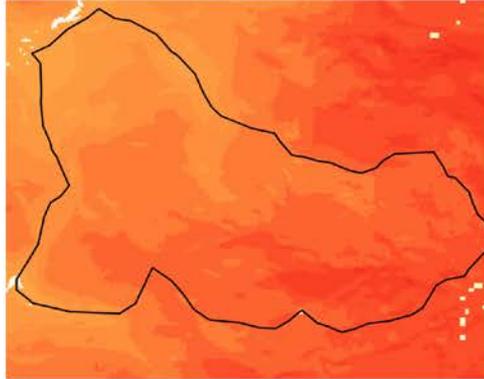
Example: 10m modeled density at Senator Beck

Mid-February

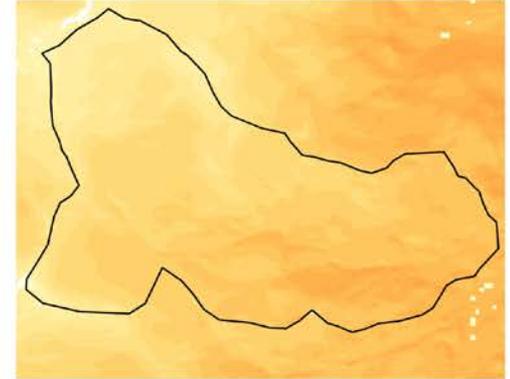
Alpine-3d



Sturm Model

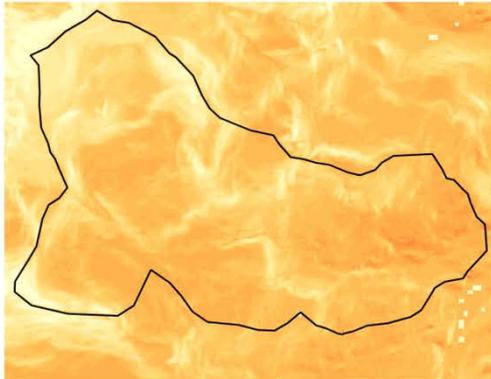


Jonas Model



Late February (after snow storm)

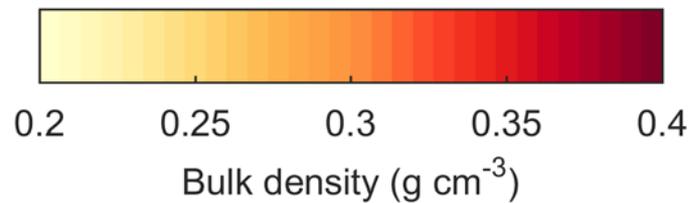
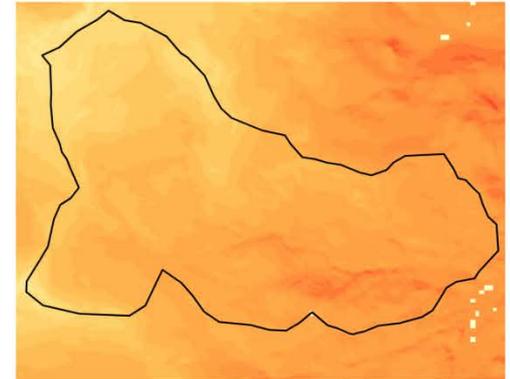
Alpine-3d



Sturm Model

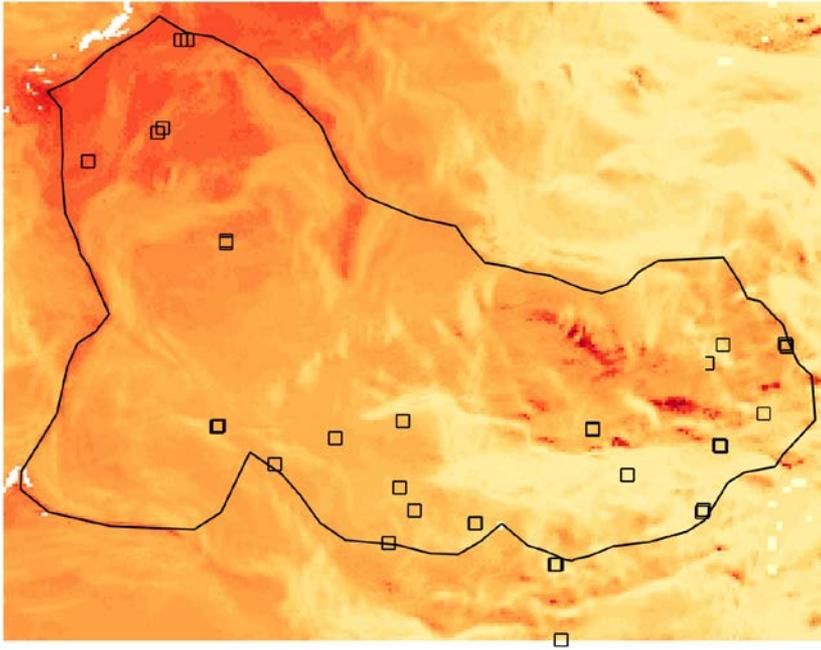


Jonas Model

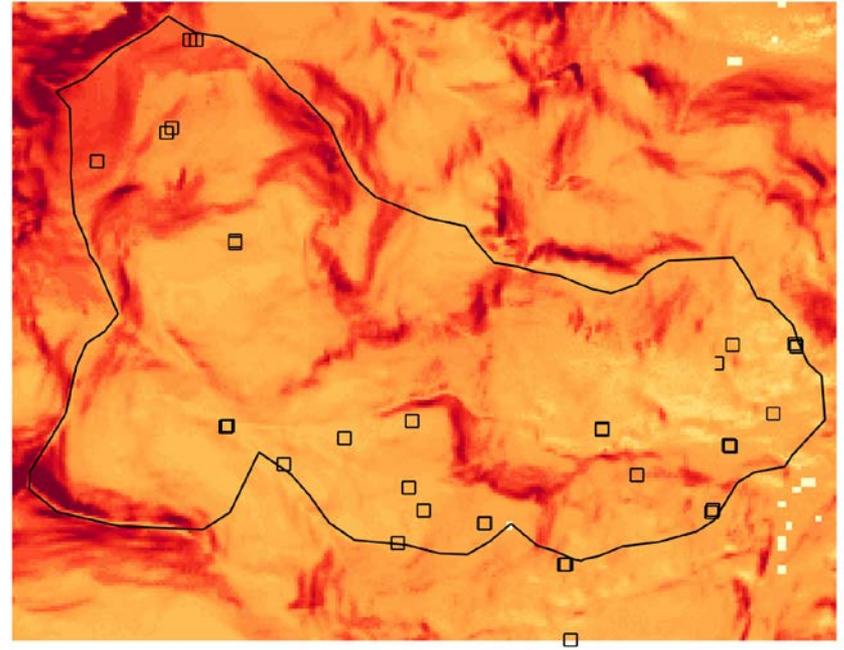


Maps of density uncertainty can inform snow pit selection

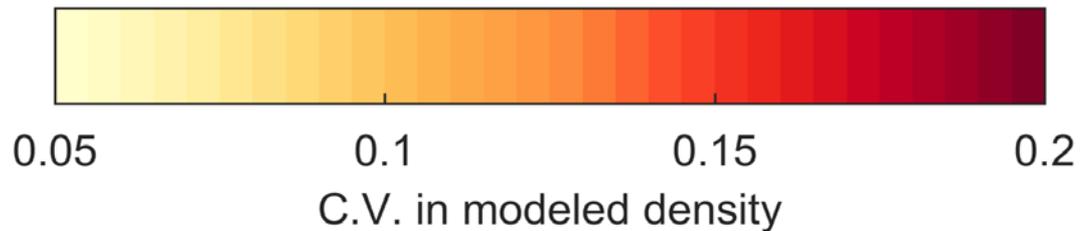
Mid-February



Late February



squares = snow pit locations in 2017 SnowEx



Summary and Ongoing Work

- Setup SUMMA modular model
- Incorporate landscape and safety dimensions
- Apply concept over Grand Mesa and Senator Beck to retroactively evaluate 2017 snow pit locations
- Develop near real-time framework to support site selection in future SnowEx field campaigns
- Contribute to site selection in future SnowEx or ASO-like campaigns

A winter landscape at sunset. The sky is filled with dramatic, orange and yellow clouds, with the sun low on the horizon. The foreground is a snow-covered field with a path leading towards the trees. The trees are dark silhouettes against the bright sky.

Questions?

Mark Raleigh

mark.raleigh@colorado.edu