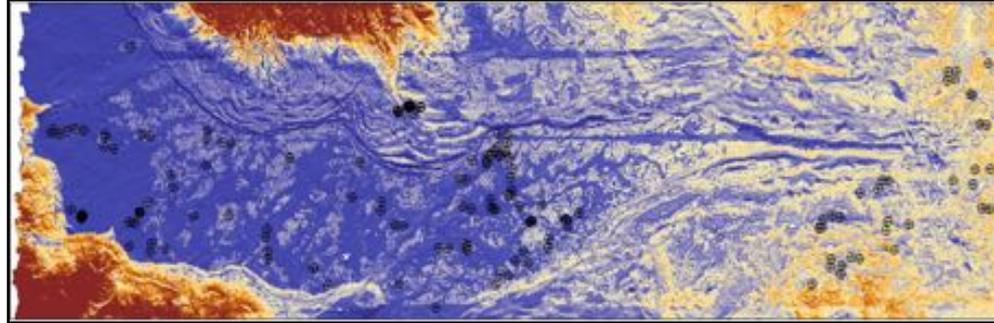


Field data reveal the opportunities and pitfalls of assimilating snow remote sensing for SWE



Mark S. Raleigh

and collaborators

(Small, Smyth, Deems, Webb, et al.)



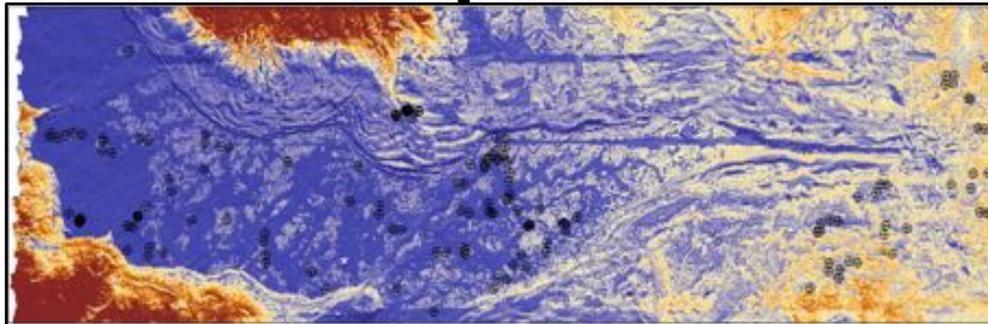
GEOLOGICAL SCIENCES
UNIVERSITY OF COLORADO BOULDER



Oregon State
University

or

Snow Wars: A New Hope



Mark S. Raleigh

and collaborators

(Small, Smyth, Deems, Webb, et al.)



GEOLOGICAL SCIENCES
UNIVERSITY OF COLORADO BOULDER



Oregon State
University

Snow-DA Systems are like Jedi

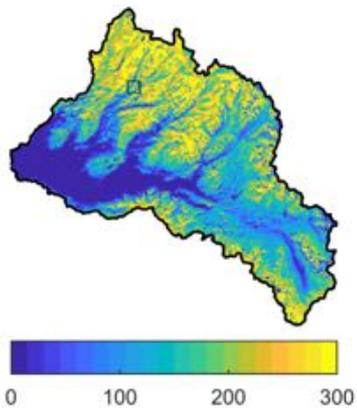


Remote Sensor = Light Saber

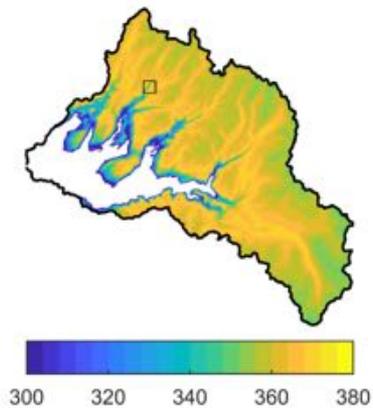
Model = a Jedi

Data Assimilation = The Force

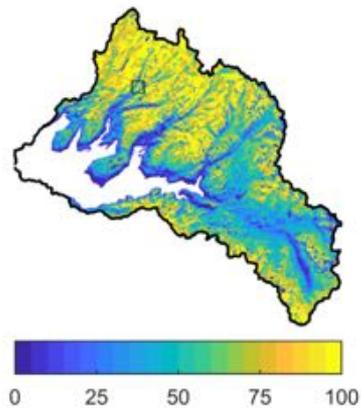
Sensor:
Snow Depth



Model:
Snow Density



What we want:
SWE



×

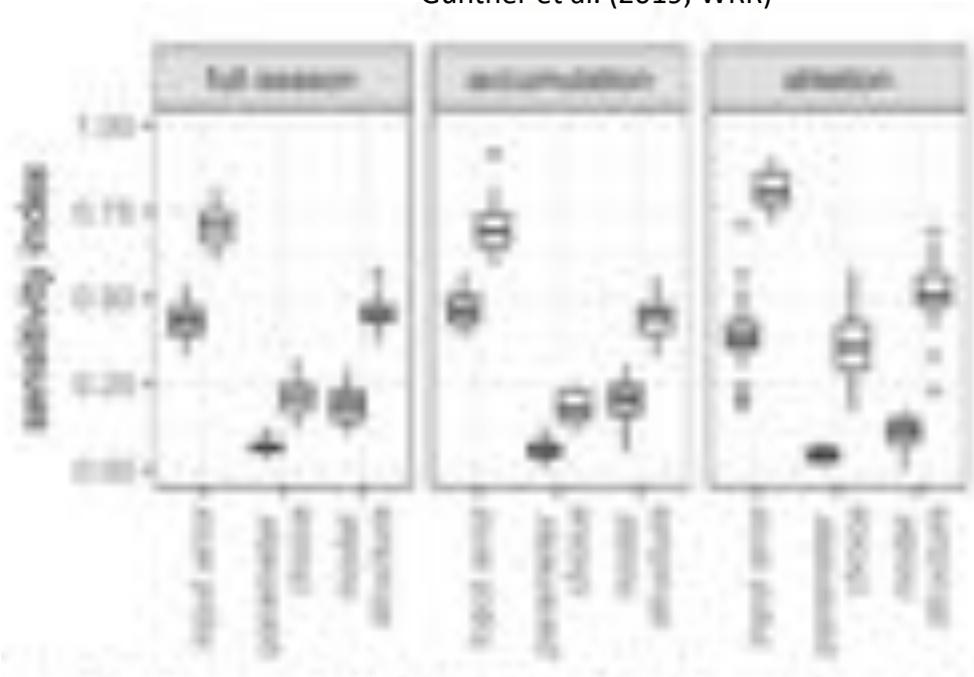
=



Data assimilation

Forcing data, model structure, and parameters are key uncertainties in process-based snow models

Günther et al. (2019, WRR)

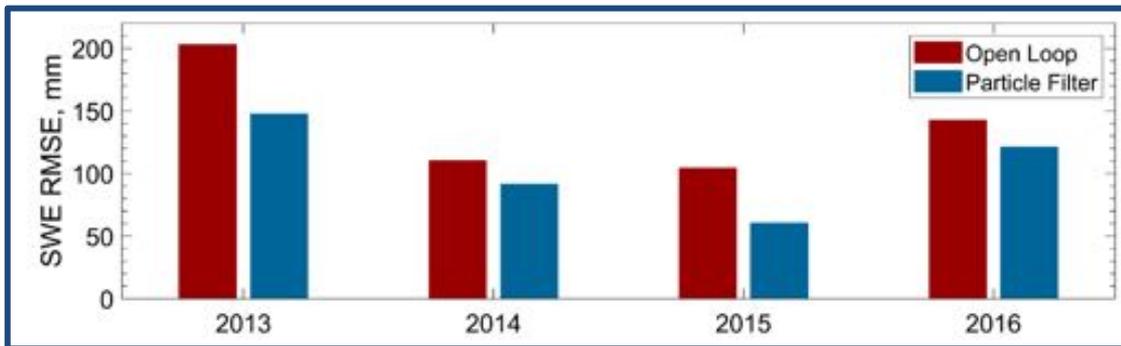
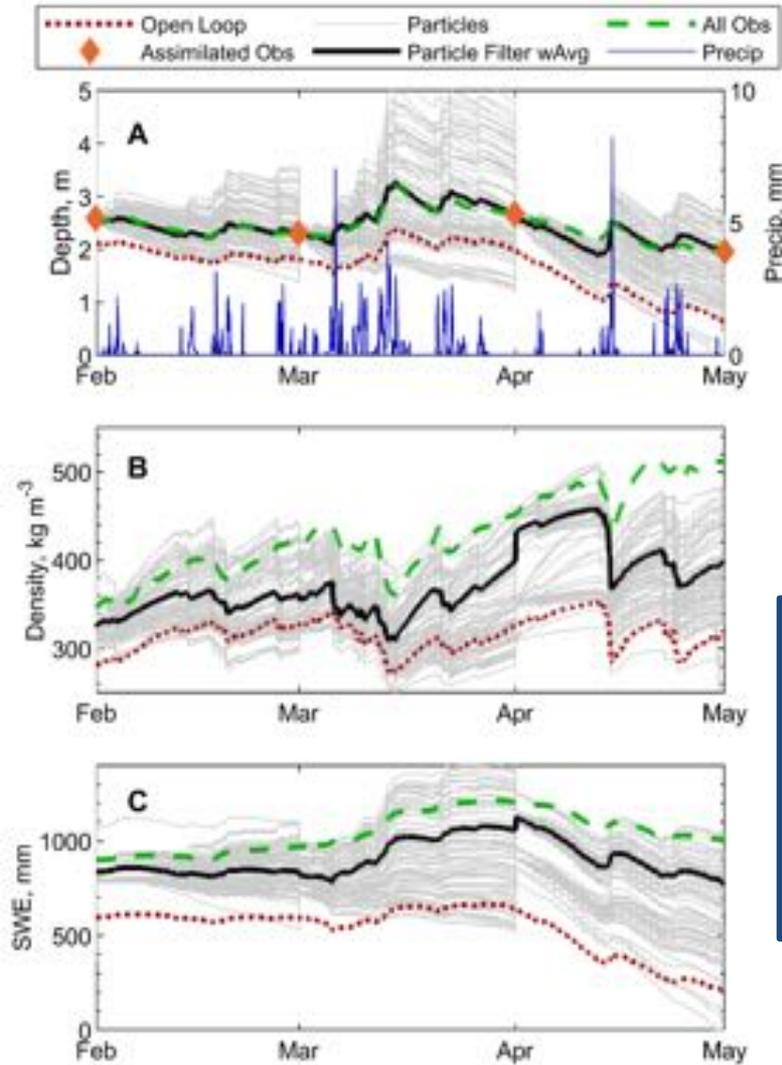


Recent publications show **forcing uncertainty** remains a major source of uncertainty [Gunter et al., 2019; Raleigh et al., 2015]

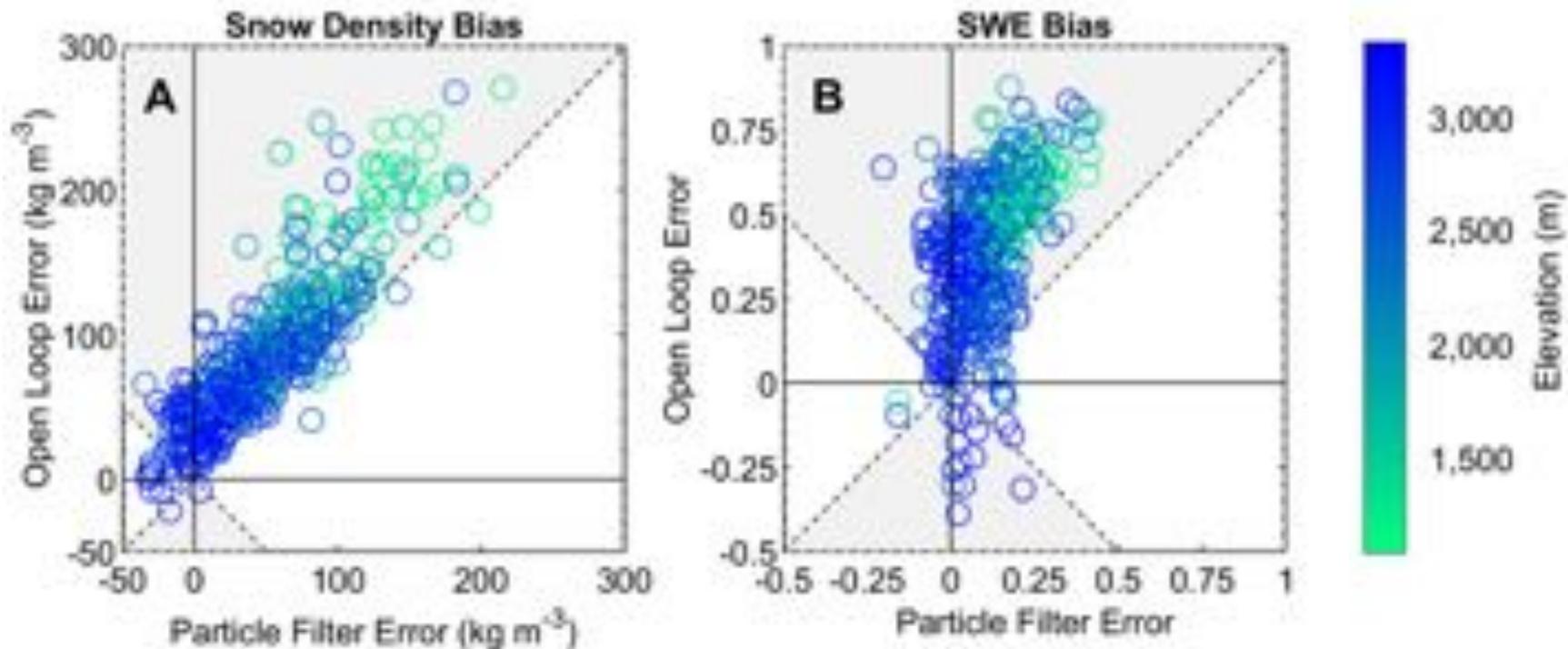
Data assimilation can account for all these uncertainties.

THP-Funded Student Research: Snow depth DA improves model snow density and SWE by 20-50%

- **Data assimilation** with particle filter yields more physically-consistent snow depth (remote sensing) and density (model)

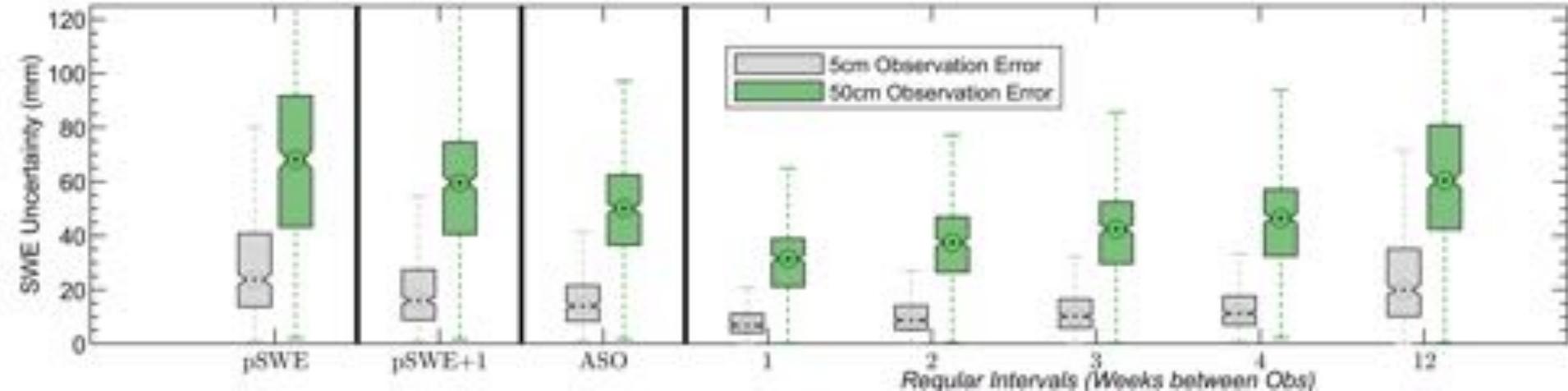


Assimilation of snow depth improves snow density and SWE across a range of snow climates and years

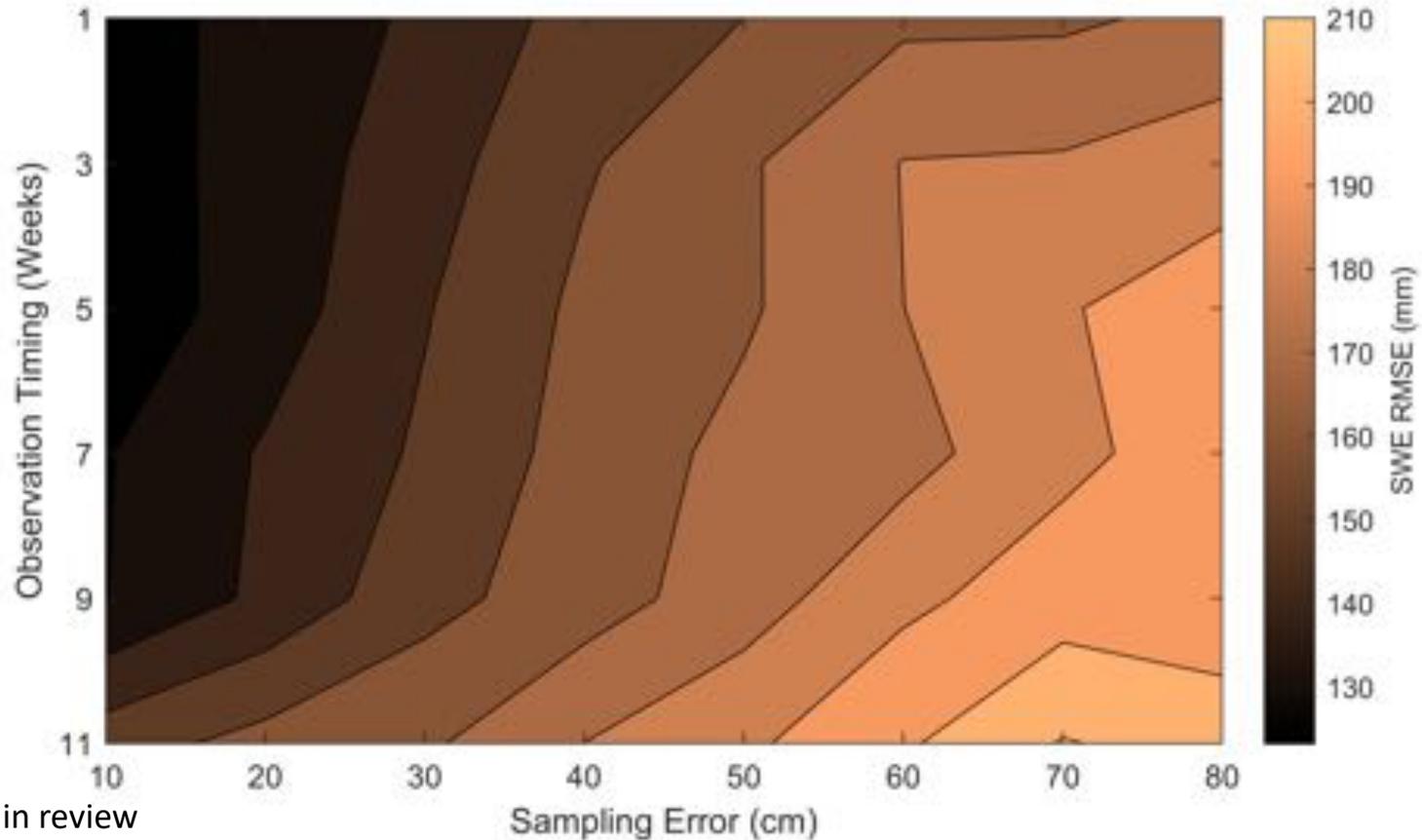


...and this can quantify tradeoffs in snow depth sensor specs, such as repeat interval vs. snow depth sensing accuracy

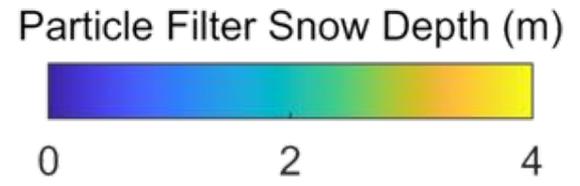
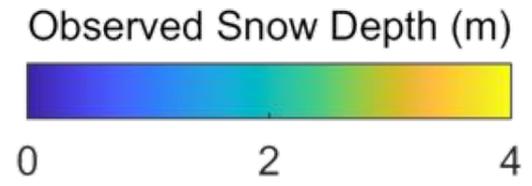
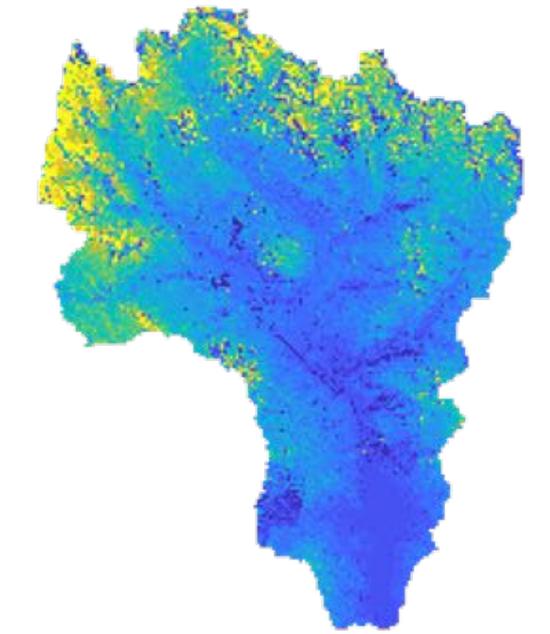
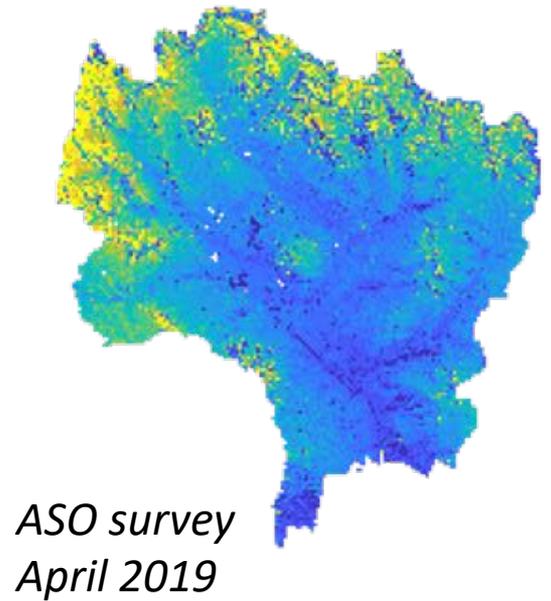
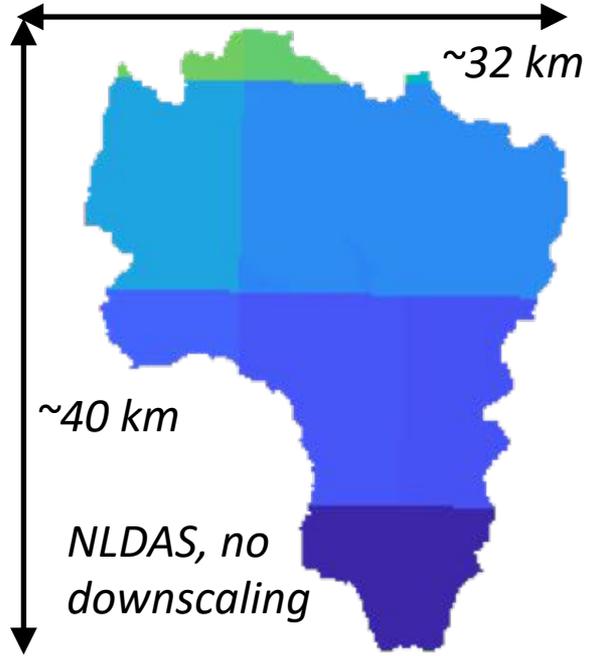
← timing achievable with *airborne platforms* ← timing achievable with *satellite platforms* →



...and this can quantify tradeoffs in snow depth sensor specs, such as repeat interval vs. snow depth sensing accuracy



Snow depth assimilation is feasible at the basin scale: East River



So what is the catch?



Like Jedi, this method can turn to the dark side

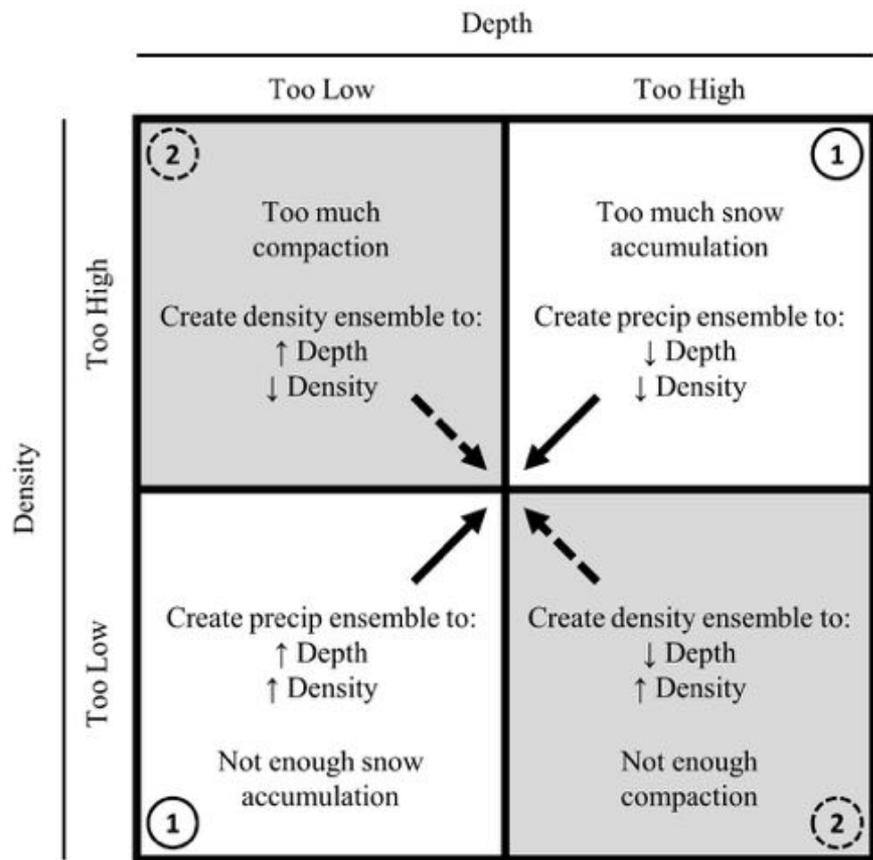
Remote Sensor = Light Saber

Model = a Sith

Data Assimilation = The Force



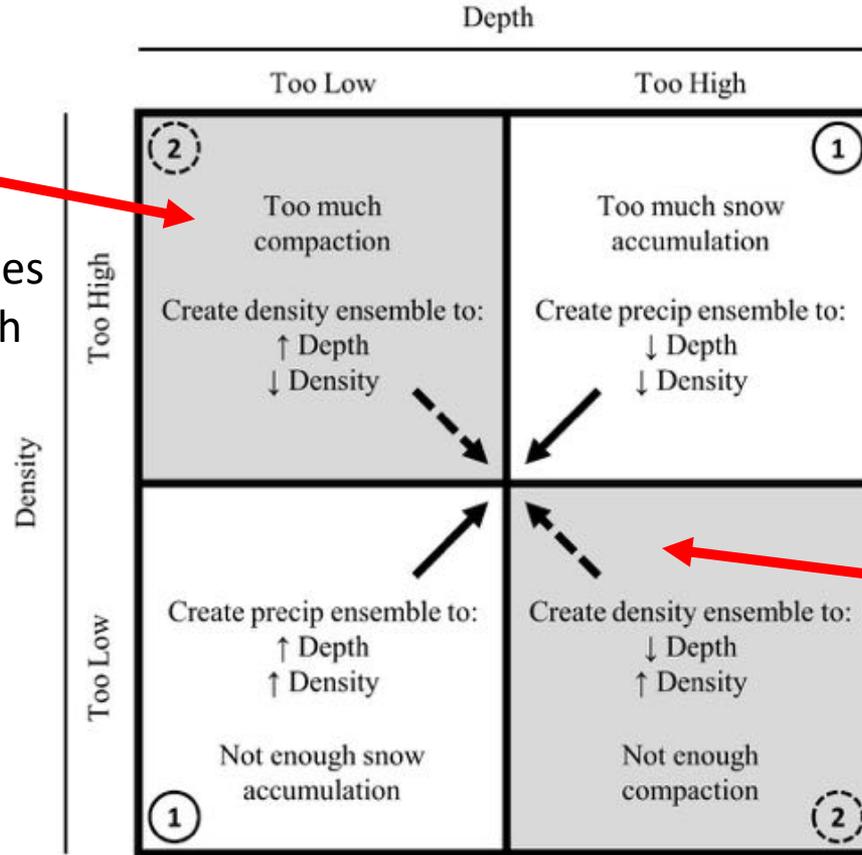
What are the pitfalls of assimilating snow depth?



- Given remotely sensed snow depth, we can quantify errors in model snow depth
- BUT we do not know WHY the model was “wrong” or the direction of the density errors!
- If the ensemble mischaracterizes the source of model error, it can degrade snow density (and SWE)

Consider a DA approach that only corrects precipitation

- Depth too low
- Increase precip
- Overburden increases
- Density was too high and is now higher!



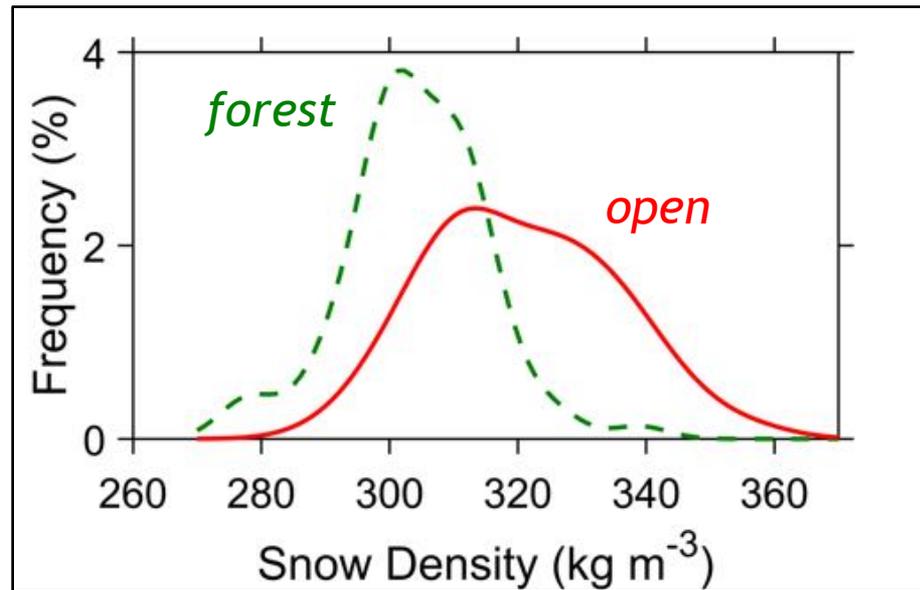
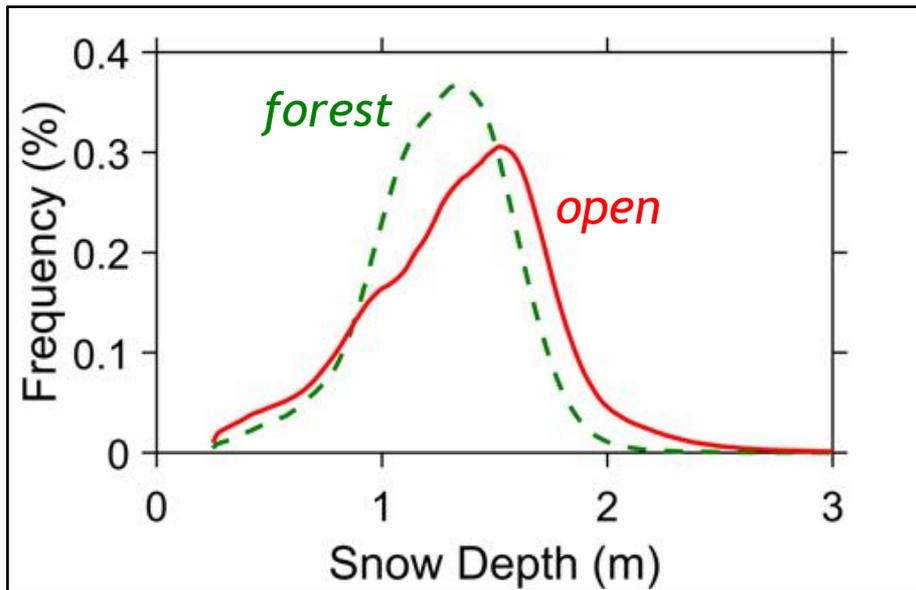
- Depth too high
- Decrease precip
- Overburden decreases
- Density was too low and is now even lower!

**A long time ago
on a mesa far, far away...**

Grand Mesa 2017: snow pit data illustrate the potential for snow process models “going to the dark side”



Grand Mesa 2017: our snow data show lower snow depth and lower snow density in forests relative to open sites

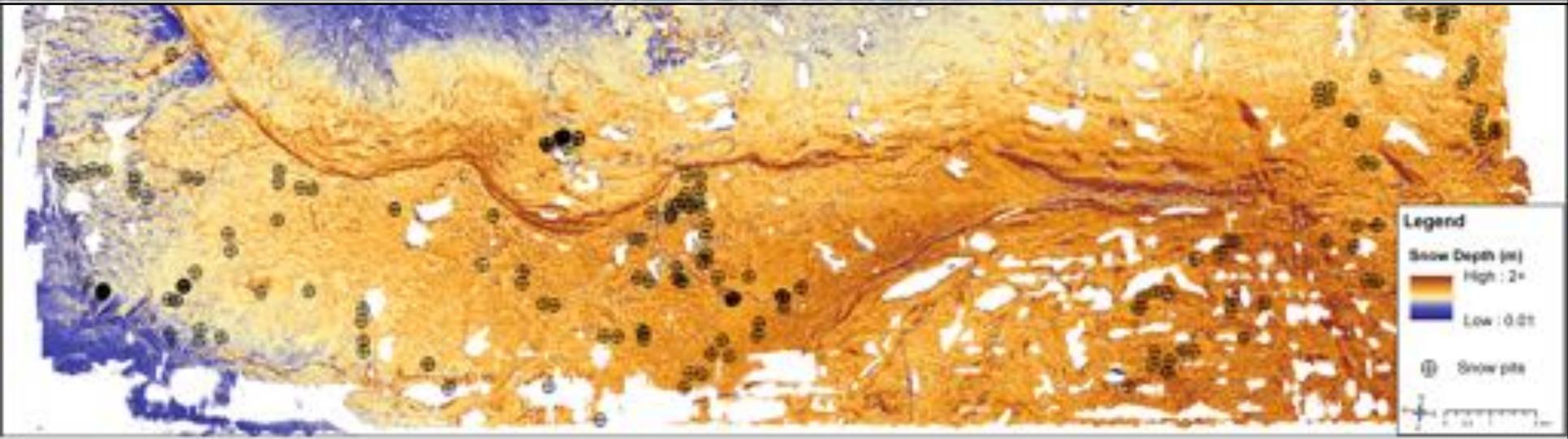
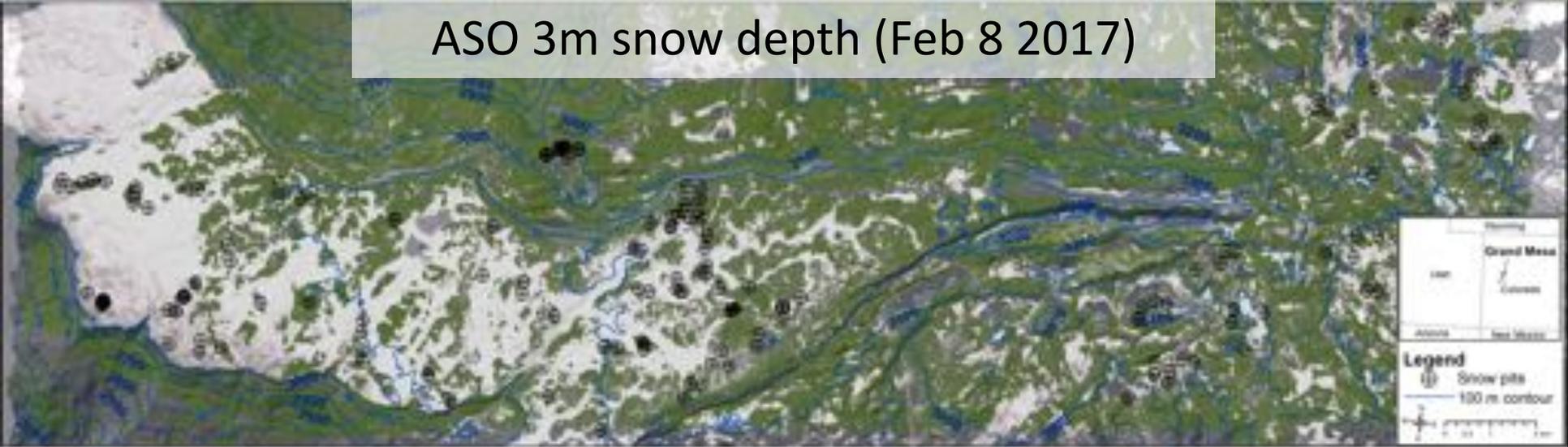


Can models reproduce these patterns?

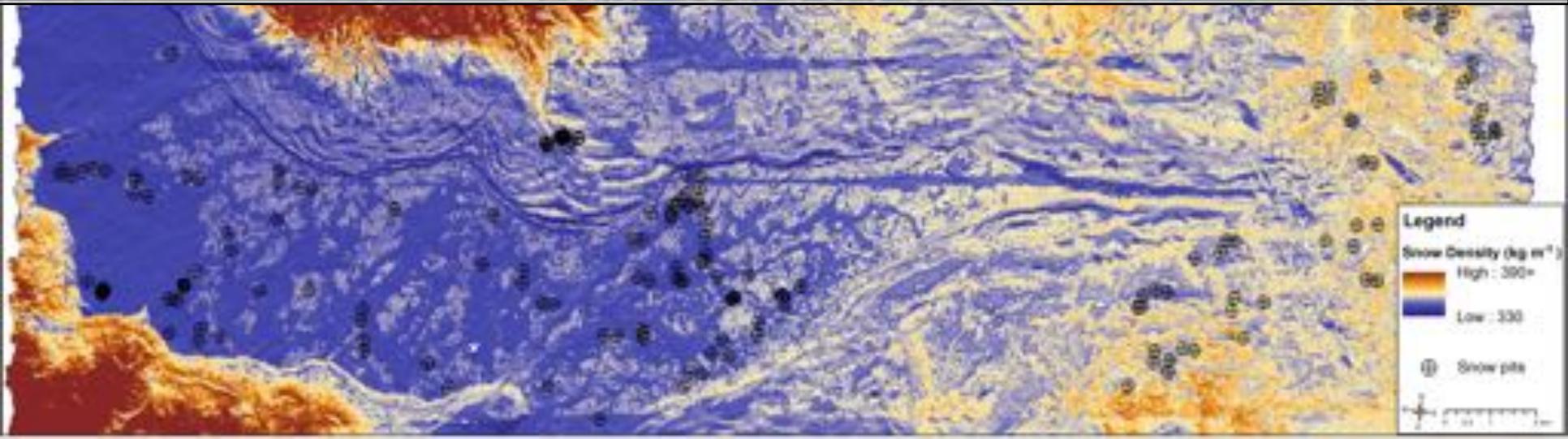
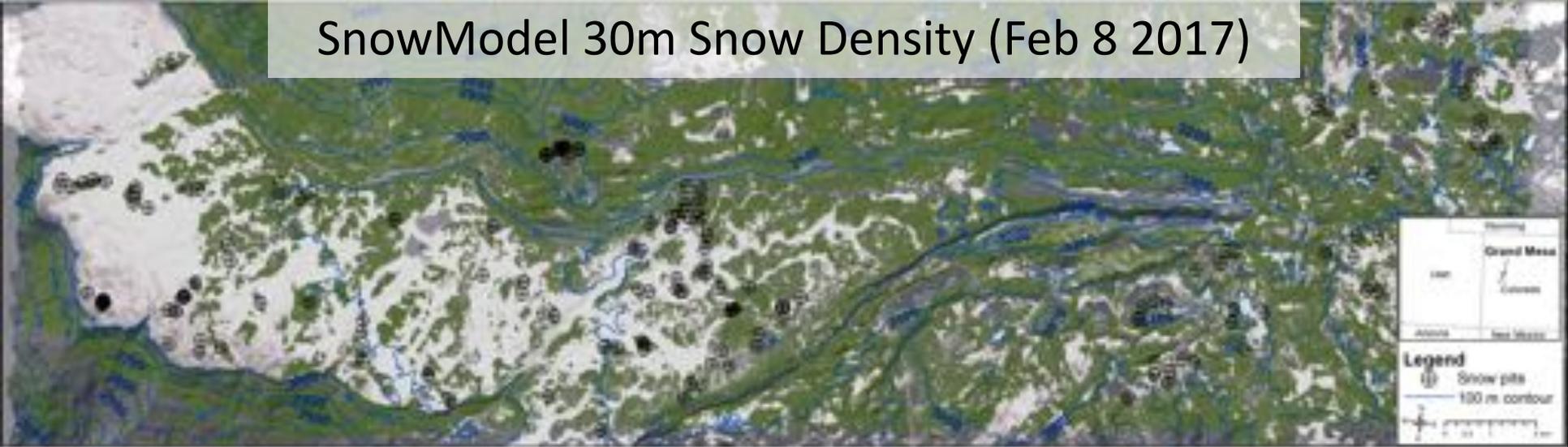


- **Domain:** Grand Mesa, Colorado
- **Period:** October 2016 – June 2017
- **DEM:** 10 m USGS NED
- **Land cover:** 30 m Landfire
- **Models**
 - Alpine3D
 - SnowModel
 - Factorial Snow Model (FSM)
- **Forcing data**
 - SnowEx weather stations (Houser et al.)
 - GM Study Plot (Skiles/Deems, et al.)
 - Data distributed w/ model pre-processors (MeteoIO, MicroMet)
- **Base case** (no assimilation yet)

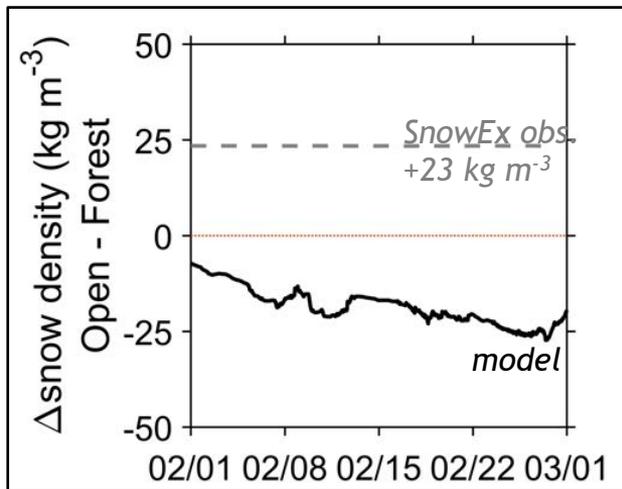
ASO 3m snow depth (Feb 8 2017)



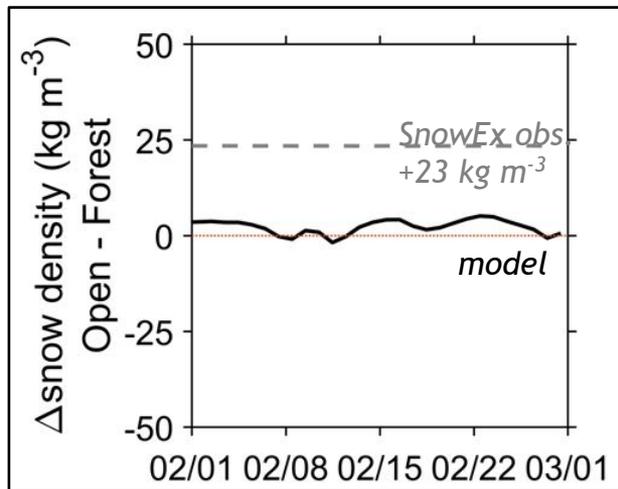
SnowModel 30m Snow Density (Feb 8 2017)



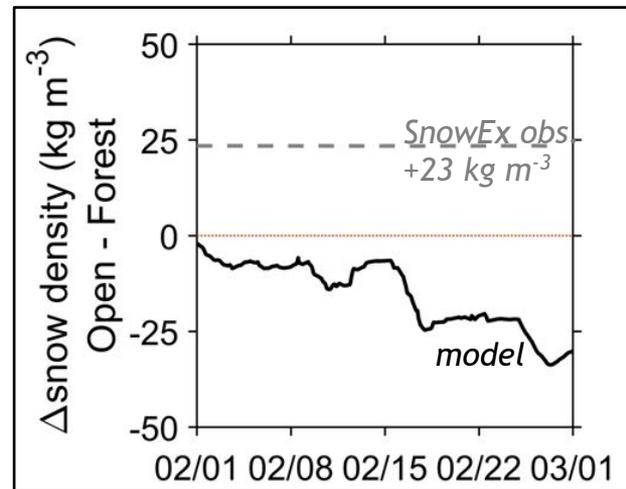
None of the three models consistently reproduced the observed forest-influenced changes in snow density across Grand Mesa



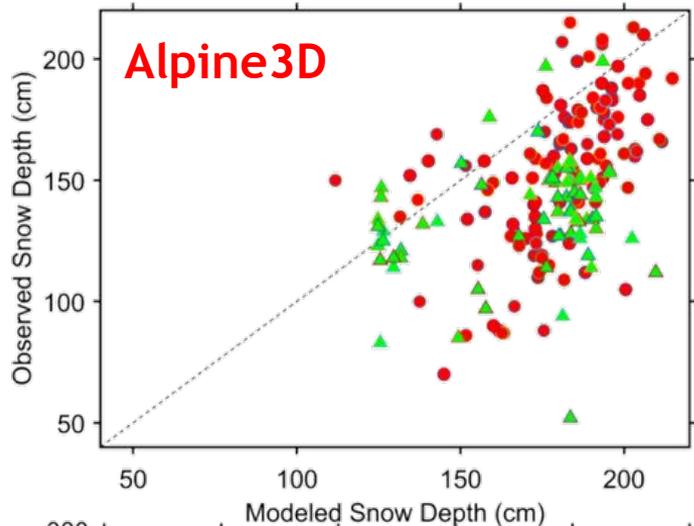
Alpine 3D model



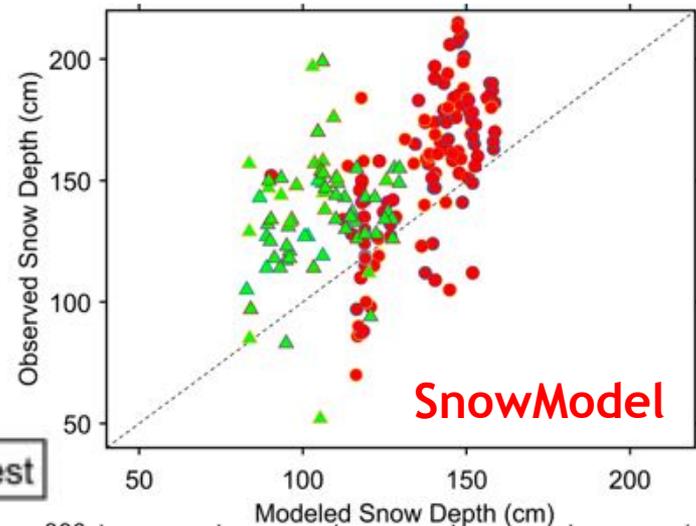
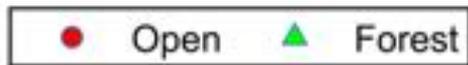
Flexible Snow Model



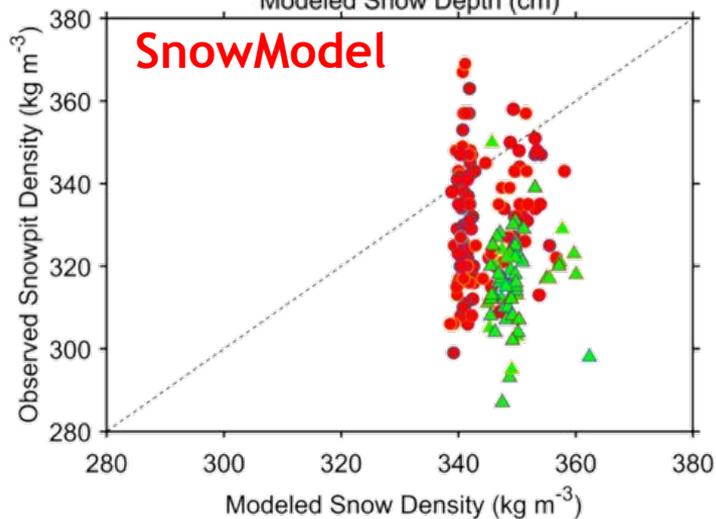
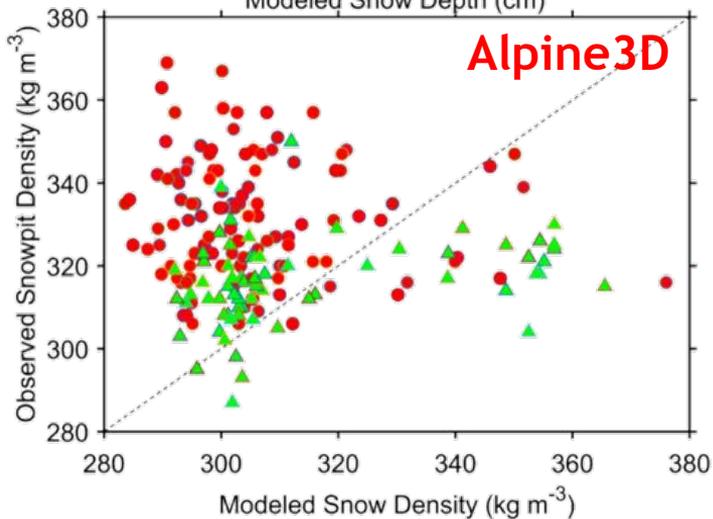
SnowModel



In agreement with
snow pit data,
models show
deeper snow in the
open



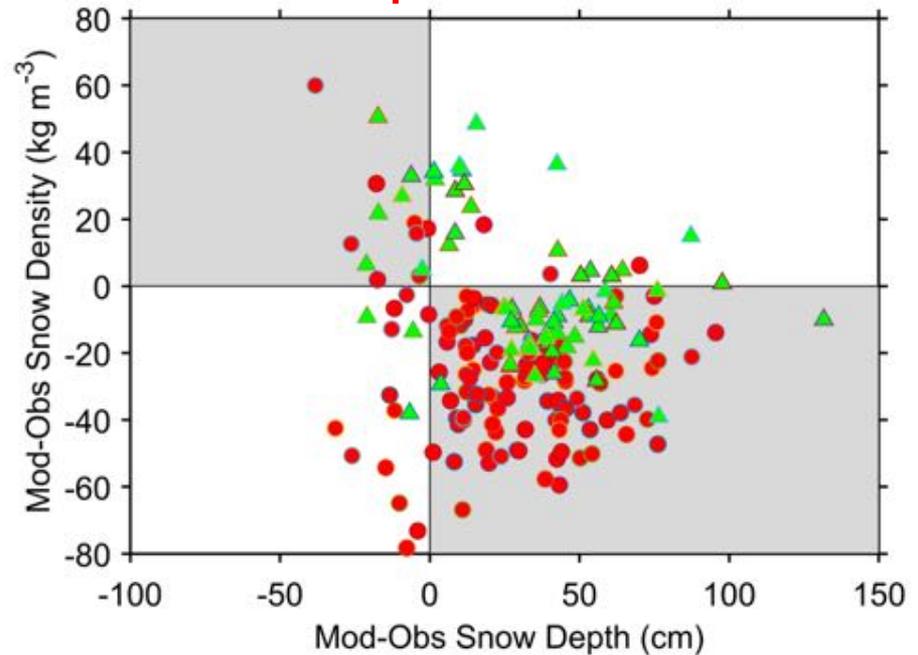
Contrary to snow
pit data, models
show denser snow
in forests



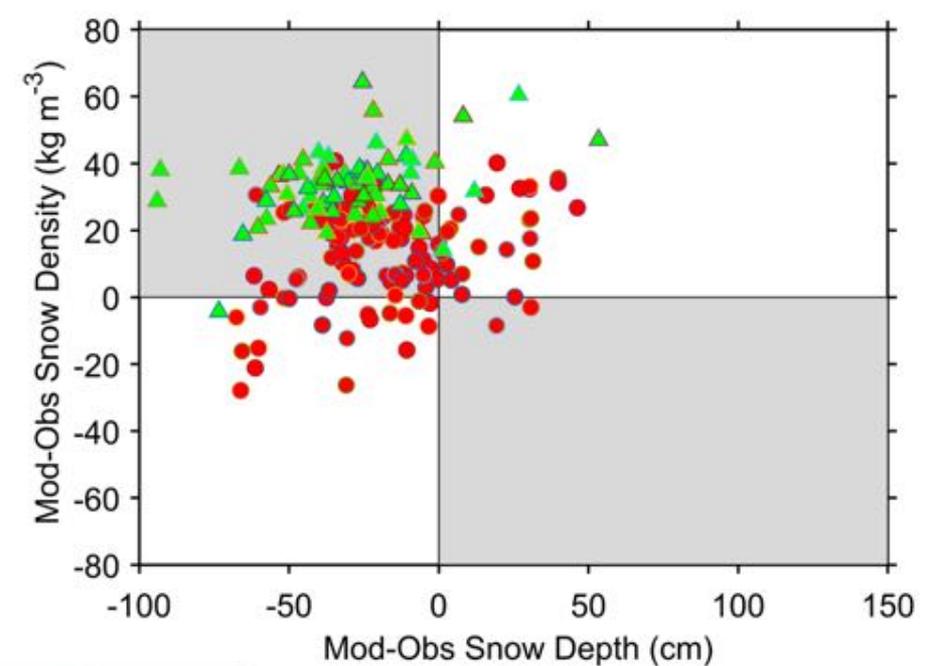
Both models have many cases in the “dark side” where precipitation assimilation will degrade snow density estimates

Both have precipitation-based assimilation code

Alpine3D



SnowModel



● Open ▲ Forest

Summary and Ongoing Work



- **Jedi:** Assimilation of snow depth has potential for great utility in SWE mission design and operational campaigns
- **Sith:** Assimilation may yield sub-optimal estimation of snow density when snow depth errors are due to factors other than precipitation forcing errors
- **Ongoing:** still assessing reasons for models' disagreement with snow pit observations across forest gradients
- **Need:** continued observations of snow pits in forest and open areas, in time and across climates

Thanks! Questions?

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extras

Other modeling activities:
Process/scale experiments and
spatial snow data integration
over the East River (CO)

