Fine-scale physical modeling

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10-times finer: 1 km to 100 m

- Why do we care?
  - Water Resources, late-season snow is worth more
  - Hydrology/glaciers need snow heterogeneity
  - Ecology, drifts matter!
  - Missing snow – lack of resolution leads to biases
- How do we get there with modeling?
  - Sub-grid statistics
  - Tiling
  - The power of repeating patterns

Snow heterogeneity matters!

Hydrological Processes
Hydrol. Process. 12, 1671–1683 (1998)

The influence of the spatial distribution of snow on basin-averaged snowmelt

Charles H. Luce,[1]* David G. Tarboton[2] and Keith R. Cooley[3]
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[2]*Department of Civil and Environmental Engineering, Utah State University, Logan, UT 84322-4110, USA*
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Snow heterogeneity results in less flow earlier and more flow later in the season.

Upper Sheep Creek in Reynolds Cr Watershed, Idaho, 26 ha, 1840-2040 m

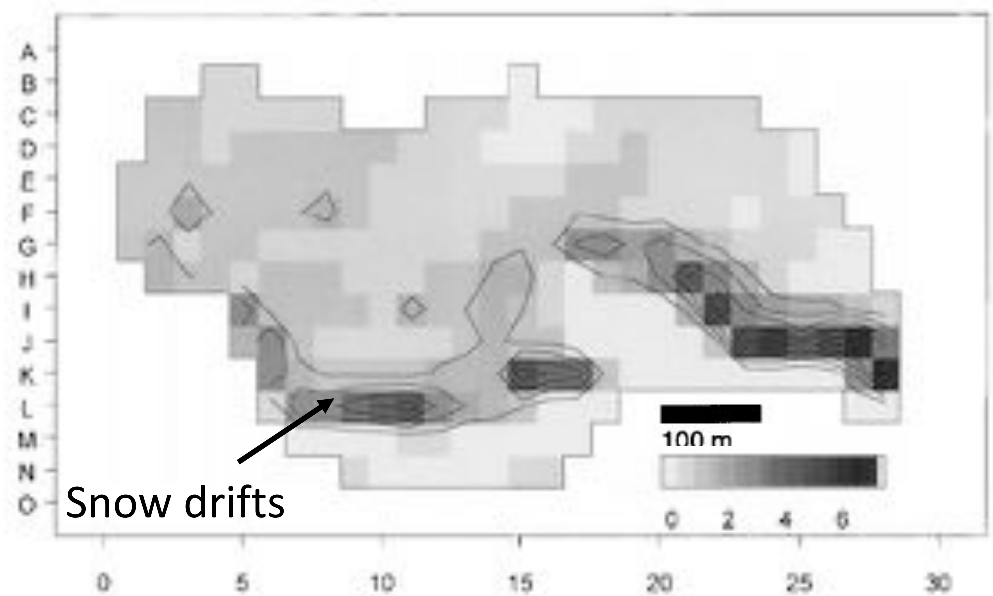
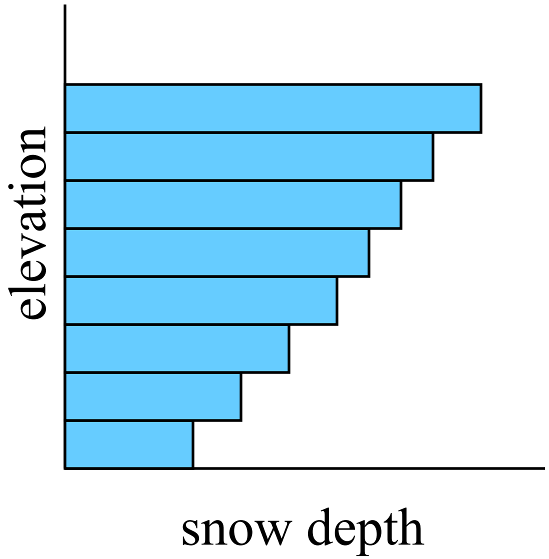
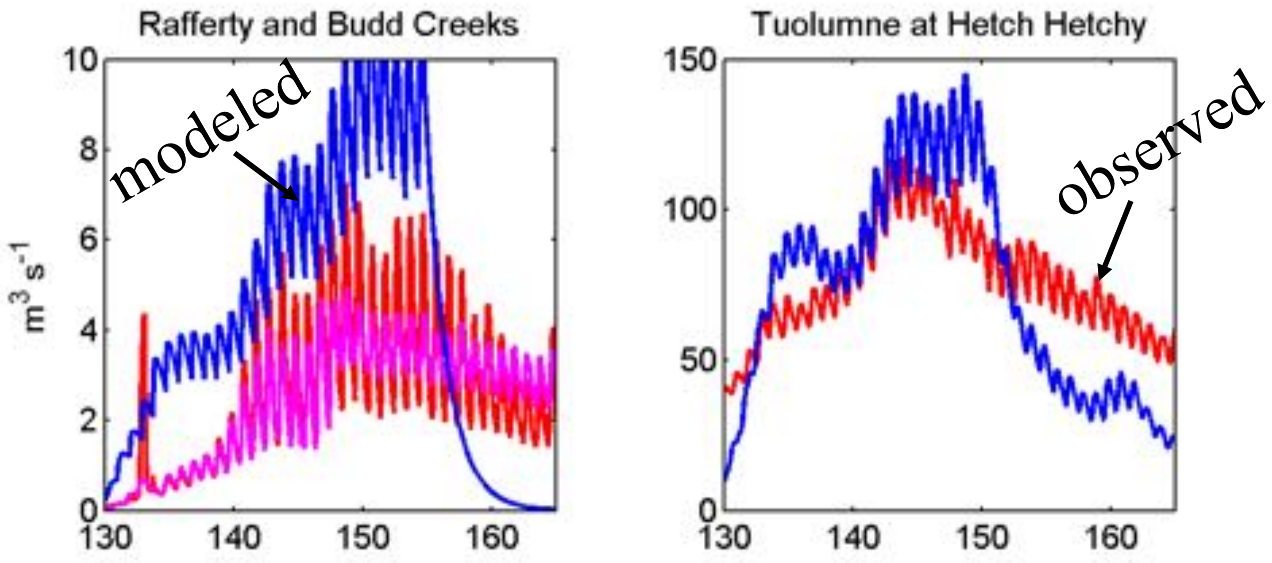


Figure 2. Map of drift multipliers used at Upper Sheep Creek (after Jackson, 1994)

Model with average snow



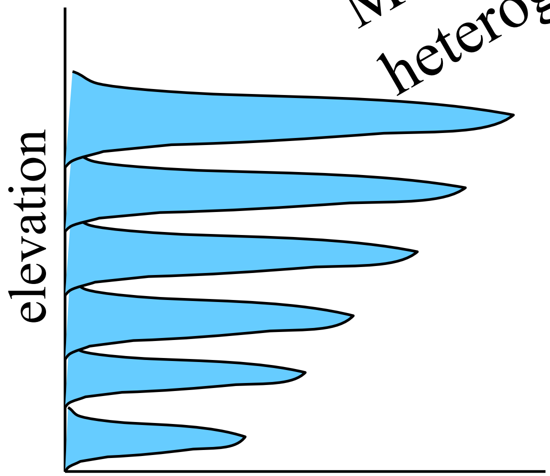


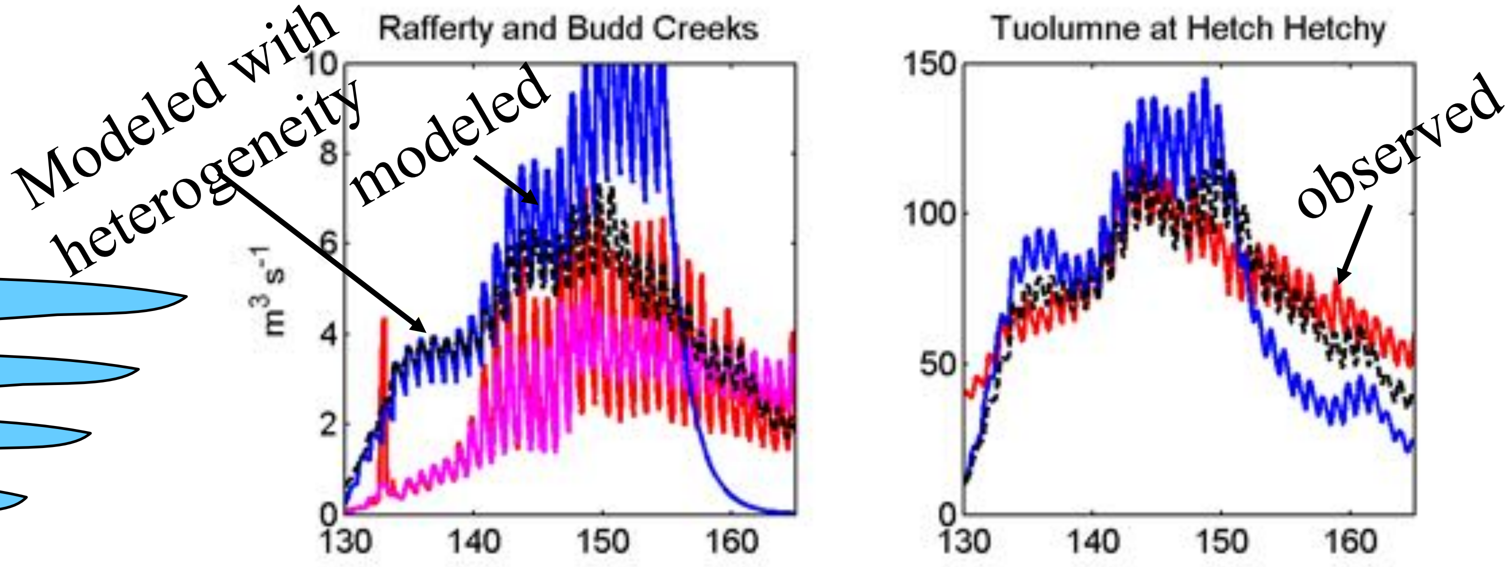
Snow melts too early!

Simple melt model distributed over elevation bands for the Tuolumne River above Hetch Hetchy.

From Lundquist et al. 2005, Water Resour. Research

Model with heterogeneity works better





Seasonal melt is better represented.

Same model, now each elevation has a range of snow depths and melt rates = snow is patchy!

From *Lundquist et al.*, WRR, 2005

Why does heterogeneity work?

1) To recreate observations, we need less melt at the peak and more snow left late in the season

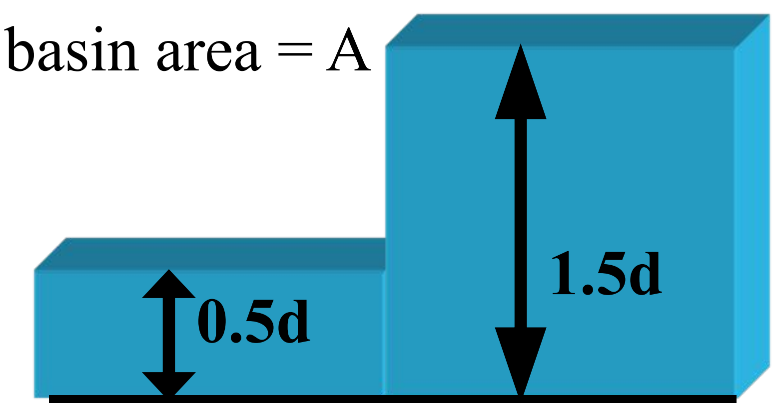
2) Patchiness/heterogeneity, helps…

Uniform snow:
average depth = d

basin area = A

Heterogeneous snow:
average depth = d

basin area = A



Melt outflow = Melt Rate x Snow-covered Area

Half of the snow melts…

1) To recreate observations, we need **less melt at the peak** and more snow left late in the season

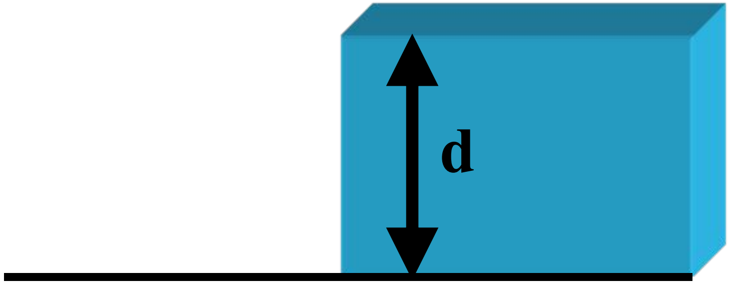
2) Patchiness/heterogeneity, helps…

<u>Uniform snow:</u>
average depth = 0.5d

basin area = A

<u>Heterogeneous snow:</u>
average depth = d

basin area = 0.5A



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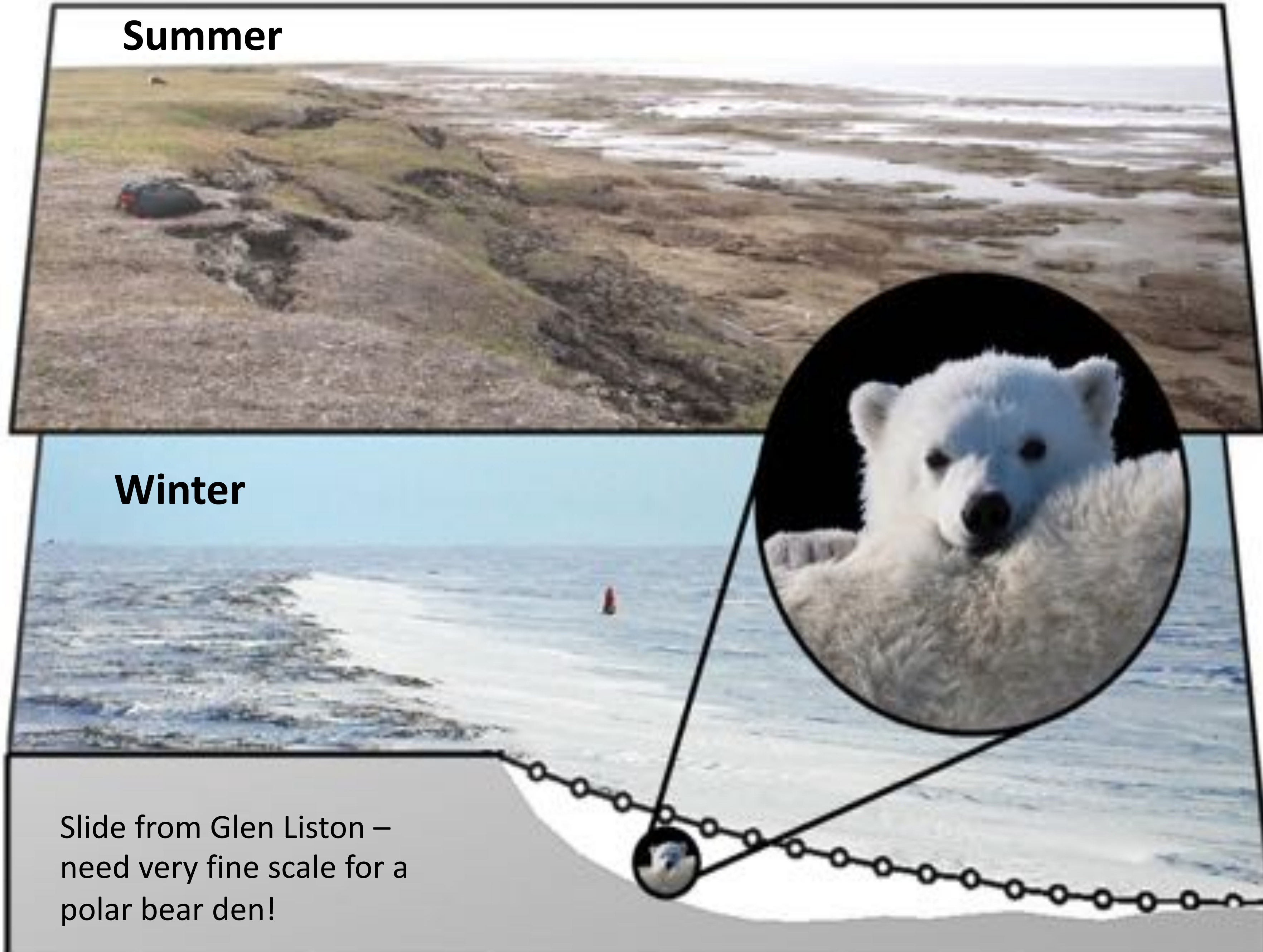
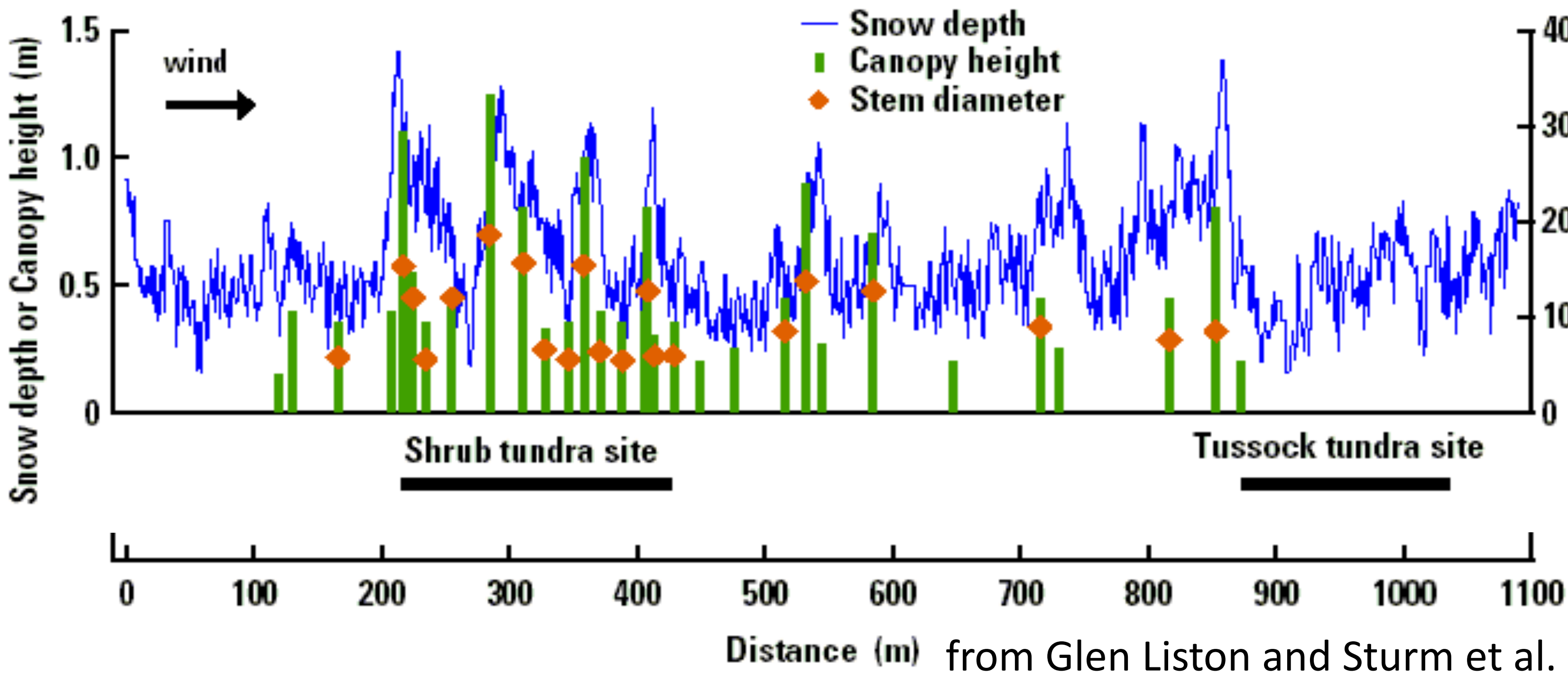

Summer
Winter
Slide from Glen Liston –
need very fine scale for a
polar bear den!

Key questions of vegetation, climate, permafrost change and relationships to snow require fine scales.



from Glen Liston and Sturm et al. 2001

What are the primary processes leading to spatial variability in snow?

- Drifting (wind interactions with terrain)
- Vegetation (interception and/or wind interaction)
- Sloughing and avalanching
- Precipitation patterns (local rain shadows)
- Rain vs. snow patterns
- Variability in melt energy (radiation, shading, local albedo, emerging shrubs)

How to add heterogeneity? Option 1: Statistics

Snow can be assumed log-normally distributed with coefficients of variation dependent on vegetation cover and terrain

Pomeroy, 2004b]. For example, *Liston* [2004] used a log-normal probability distribution

$$f(S) = \frac{1}{S\zeta\sqrt{2\pi}} \exp\left\{-\frac{1}{2}\left[\frac{\ln(S) - \lambda}{\zeta}\right]^2\right\}, \qquad (1)$$

with

$$\lambda = \ln(\mu) - \frac{1}{2}\zeta^2 \qquad (2)$$

$$\zeta^2 = \ln(1 + CV^2), \qquad (3)$$

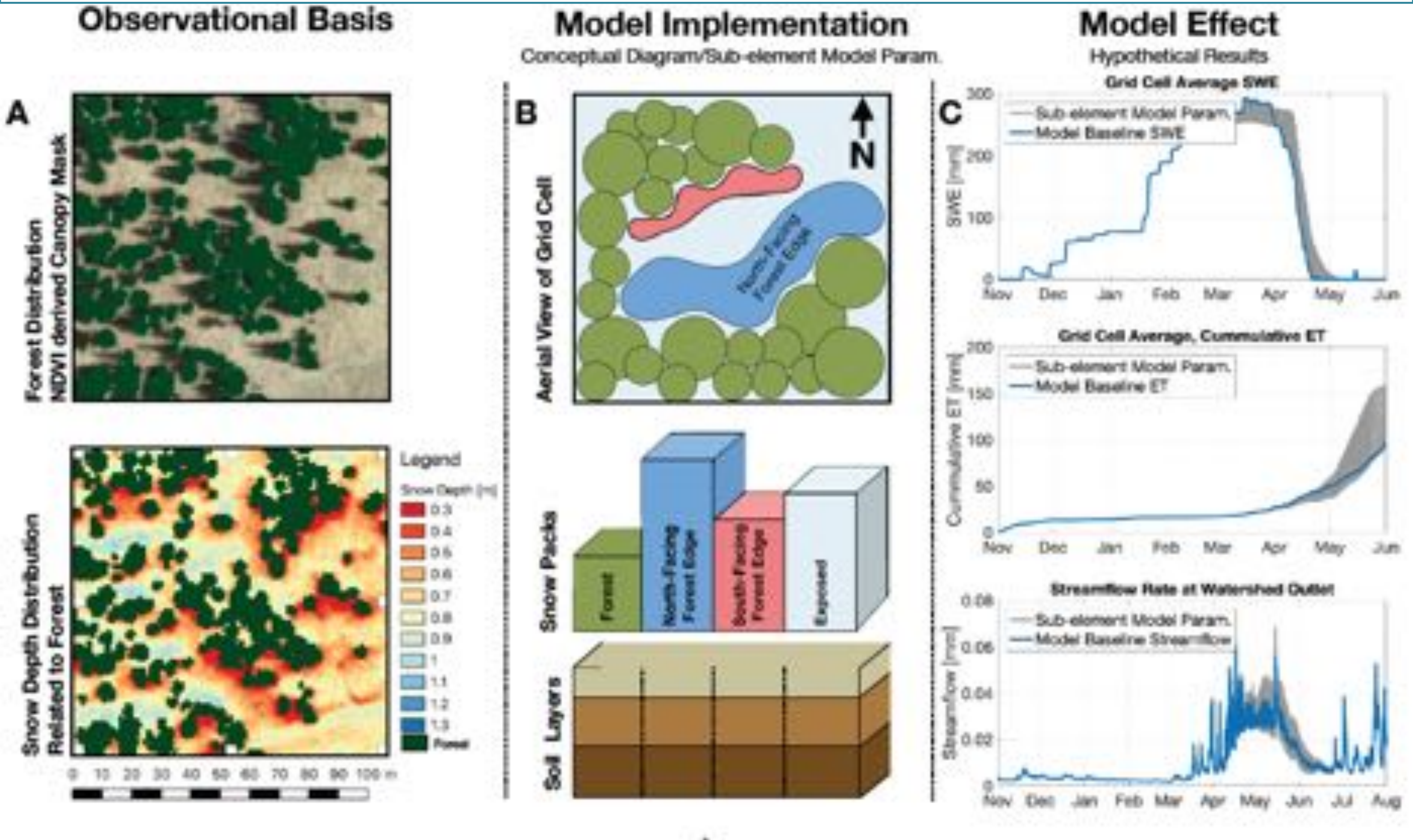
See review in Clark et al. 2011

Table of CV (σ/μ) by veg type:

Boreal Forests:	0.05-0.14
Arctic Tundra:	0.11-0.34
Prairies:	0.30-0.58

Pomeroy et al. 1998, An evaluation of snow accumulation and ablation processes for land surface modeling, Hydrol. Processes

Option 2: Tiling (from William Ryan Currier) – use high-res imagery & classify percent cover of subgrid elements by functional type

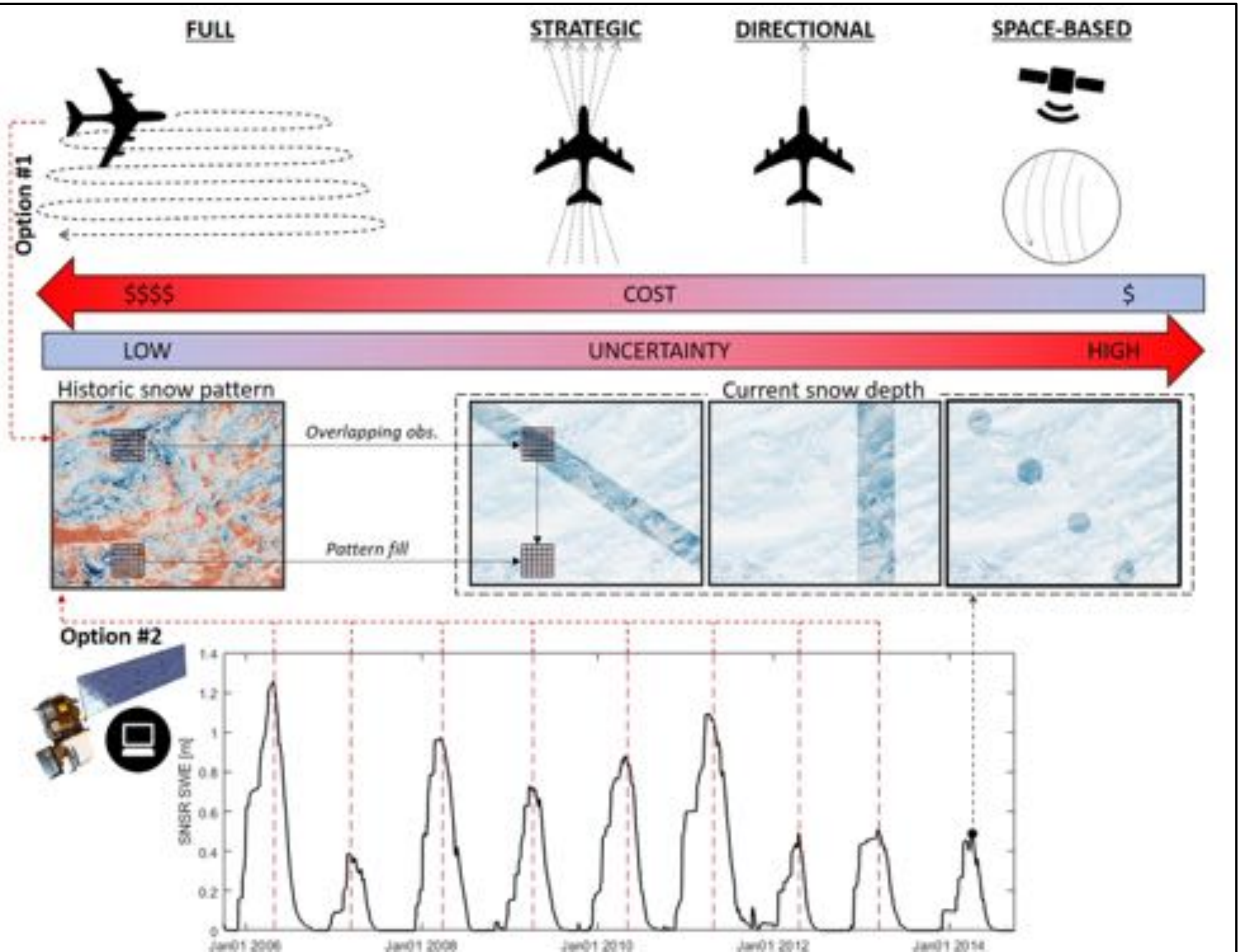


Option 3: Spatial Patterns are Repeatable!

Figure 1. (left) Mountain of the Holy Cross in Colorado, United States, painted in 1875 by Thomas Moran (courtesy of the Museum of the American West, Los Angeles; 91.221.49) with an inset 1873 photo by W. H. Jackson (courtesy of the U.S. Geological Survey) on which the painting was based compared to (right) a modern photo (2004) by Pete Fox. The snow pattern repeats annually even after 127 years and shows well-documented changes in climate.

Sturm and Wagner 2010

Option 3: Lidar for testing, patterns from SWE-reconstruction, offsets from Satellite



Satellites to be tested: Ice-Sat2 or other altimetry

Model assimilates both an observation (lidar strip, satellite dots) and a pattern map (from prior years), works well

See poster by Justin Pflug

Conclusions

- High resolution modeling is essential for applications (hydrology/ecology) and for process-based understanding (how do land-use change, forest-disturbance, permafrost, etc., interact with snow) and forecasting
- Also essential to relate to ground observations (always point specific)
- Very do-able with current knowledge – just need to invest in the NASA infrastructure to run over wider scales, and then determine which methods work best where and when