Snow depth spatial structure from hillslope to basin scales

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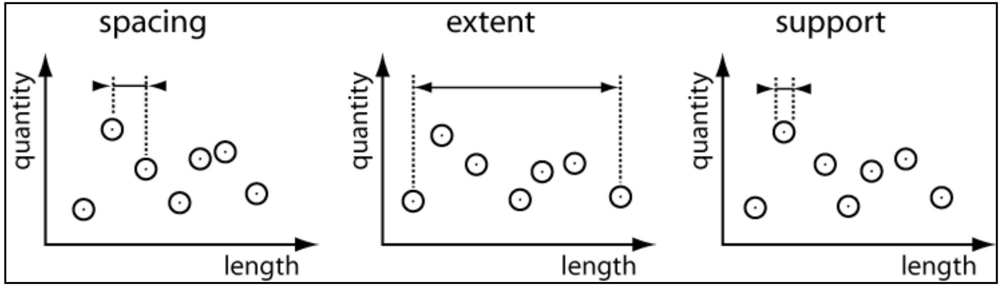
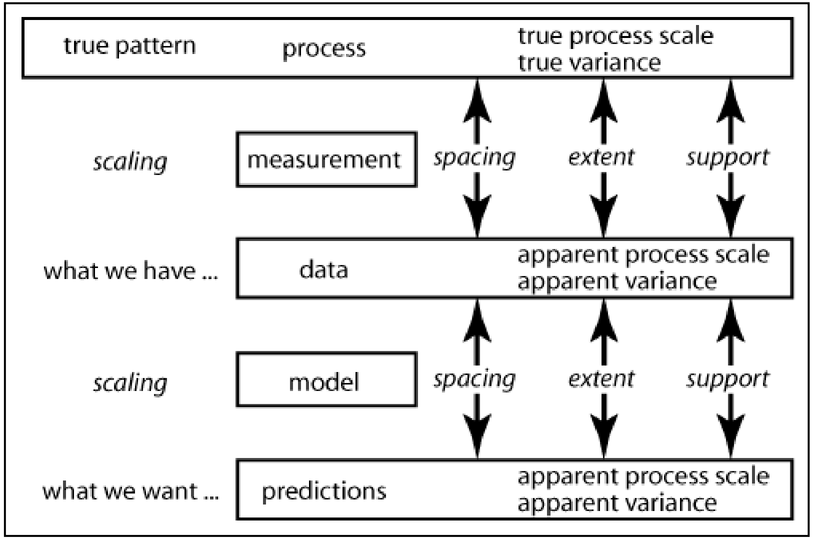
snow depth variability & scale

knowledge of process scales is key to:

- understanding impacts of measurement & model scale choices
- identifying optimal scales of measurement & modeling

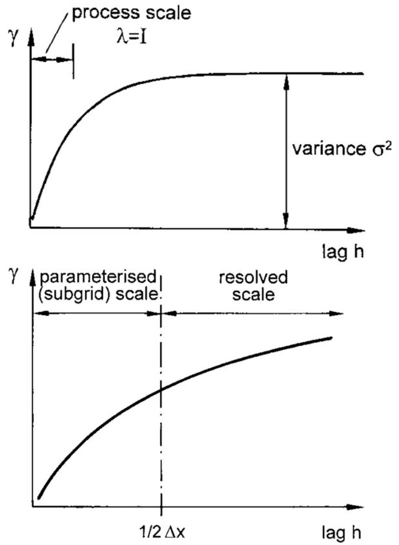


from Blöschl (1999)

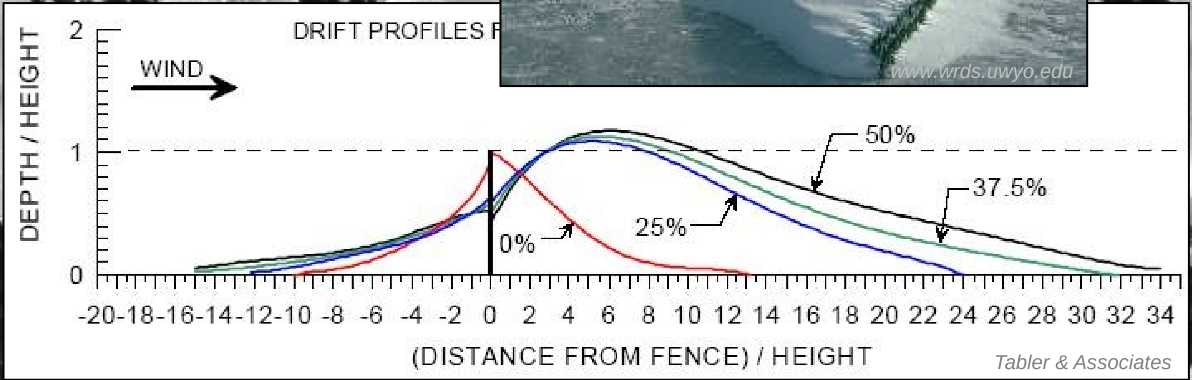


from Blöschl (1999)

- scale triplet describes the scale characteristics of the measurement or model
    - process scales should inform measurement/model designs/choices
- measurement/model scale choices often dictated by data availability, technology, $$
    - process scale knowledge is needed to assess bias/error due to scaling

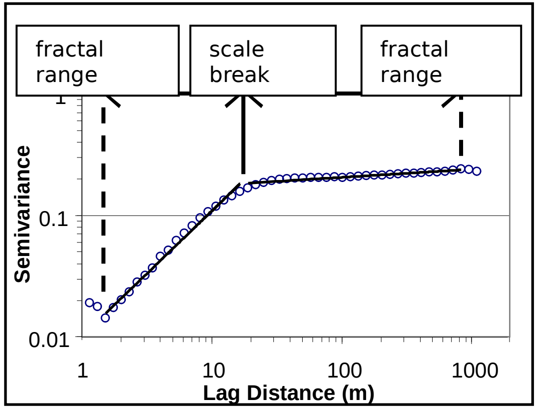


snowdrift geometries across scales



spatial complexity & fractals

- self-similarity
  - similar structure or statistical properties across scales
- geometric vs. statistical fractals
  - natural: specific scale ‘windows’
- fractal dimension
  - consistent with Euclidean/topological dimensions
  - measure of relative roughness, complexity
  - describes balance of small & large scale patterns/processes



fractal ranges:

- scale ranges of consistent process relationships

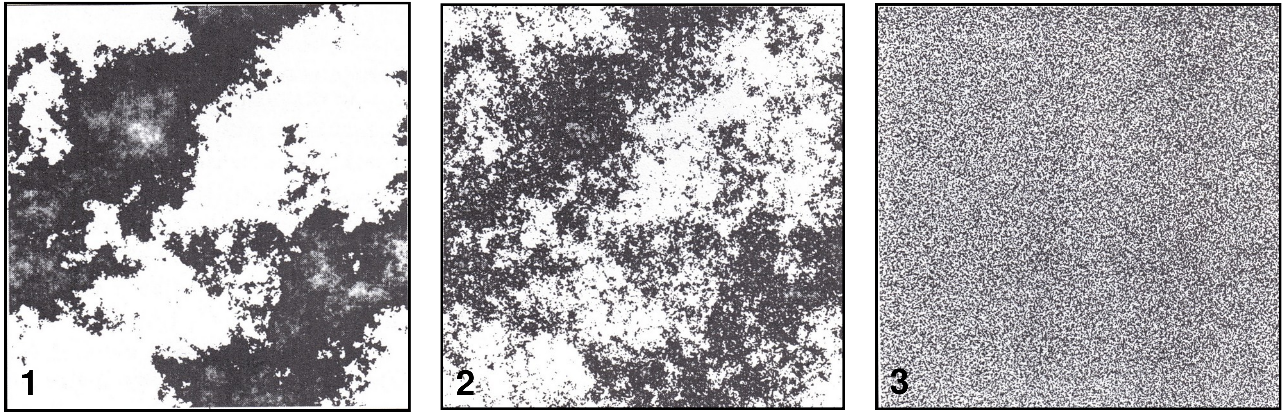
scale break:

- change in driving processes or interaction

scale ramifications:

- process
- measurement
- model

fractal geometry can characterize spatial variability of the snow cover



Turcotte & Huang (1995)

1. *D* = 2.1
Some small-scale detail, but generally smooth variation;
large scale processes dominate

2. *D* = 2.5
Rich complexity; balance of small scale & large scale processes

3. *D* = 3.0
White noise – spatially random;
no autocorrelation

prior examples

Shook & Gray 1996
  Variogram fractal structure of depth transects

Blöschl 1999
  Fractal geometry of SCA over wide range; *D* as variability metric

Kuchment & Gelfan 2001
  Fractal character of long depth transects

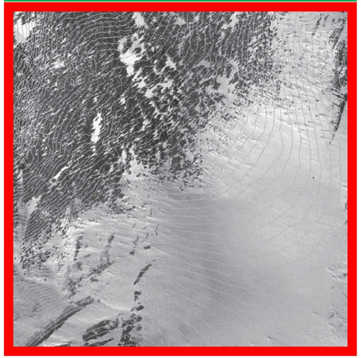
Deems et al. 2006, 2008
  Variogram fractal depth distributions over 1m-1km range; wind redistribution/vegetation linkage; interannually consistent.

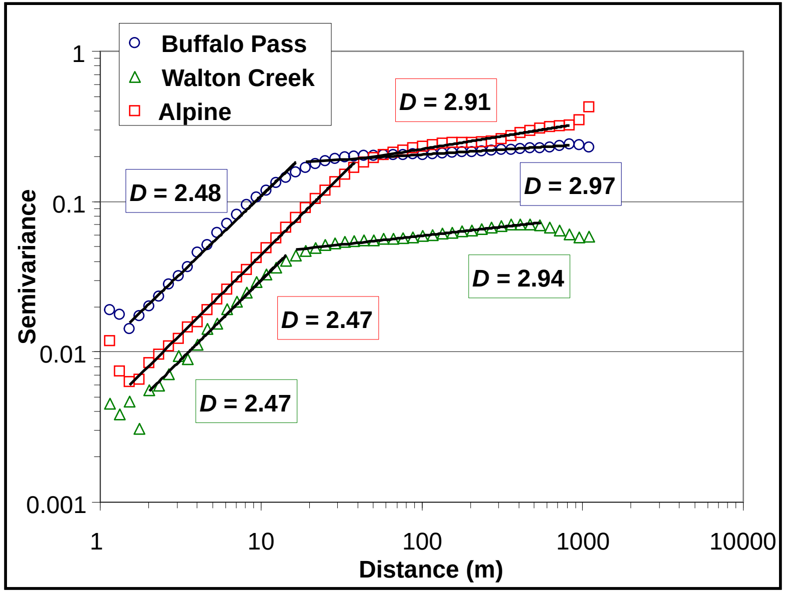
Trujillo et al. 2007, 2009
  Spectral scaling exponents of lidar depth transects; wind redistribution/vegetation linkage; interannually consistent.

Schirmer & Lehning 2011
Variogram fractal depth distributions over 0.1m-0.5km range; wind redistribution linkage; temporal evolution; interannually consistent.

Lehning et al. 2011
  Fractal dimension as roughness index & predictor variable

Mott et al., 2011
  Fractal dimension variation with wind direction in lidar & simulated snow depth

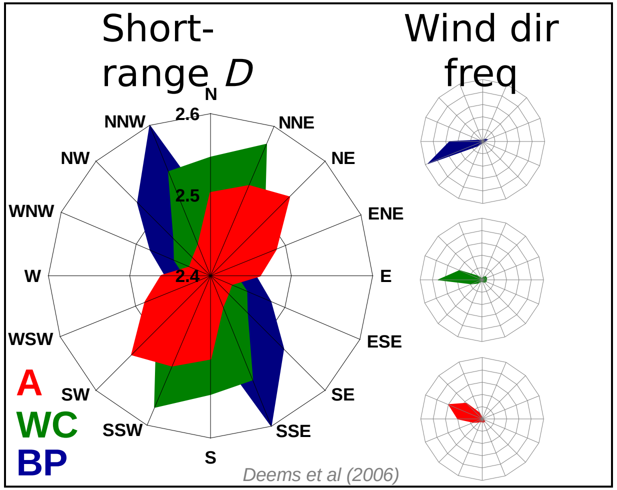


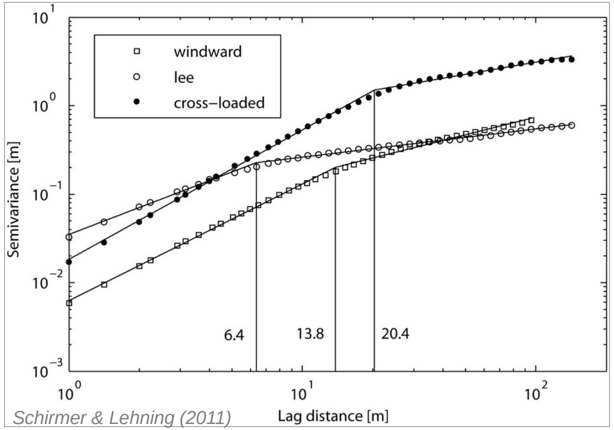


Deems et al (2006)

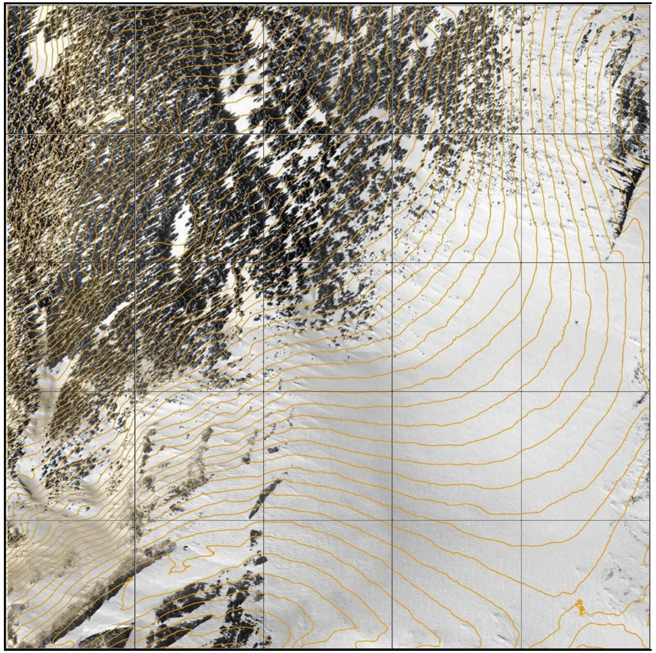
- short-range D values ~2.5 indicate balance in process scales
- scale breaks:
  WC: 15 m
  BP: 16 m
  A: 40 m
- high D beyond scale break – bulk of spatial structure is occurring at shorter distances
- directional variograms suggest process link to wind redistribution

linkage to physical processes

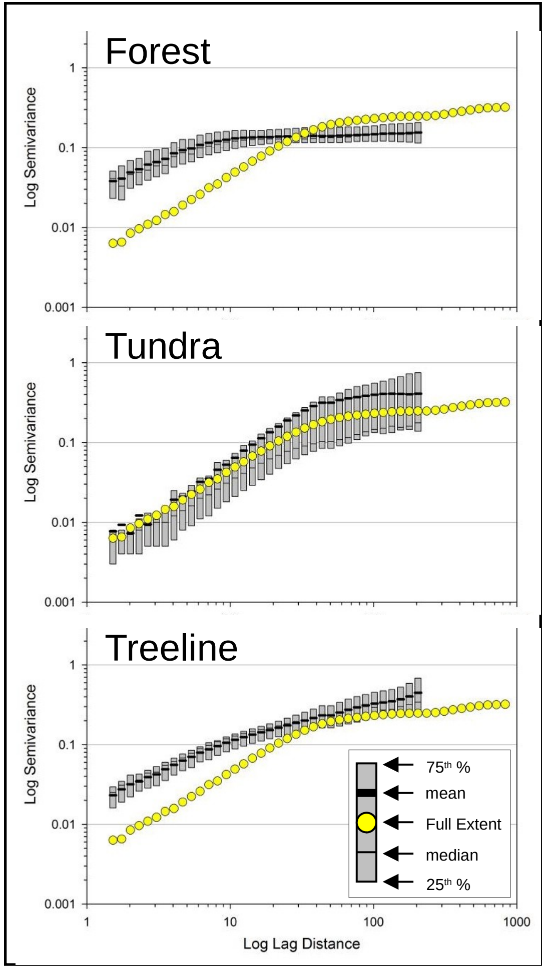




- forest: shorter scale breaks than tundra areas
- tundra subsets dominate full extent pattern
- treeline subsets show complex mix of patterns

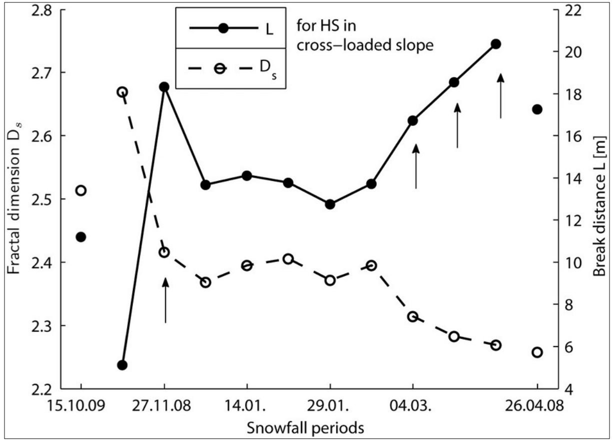


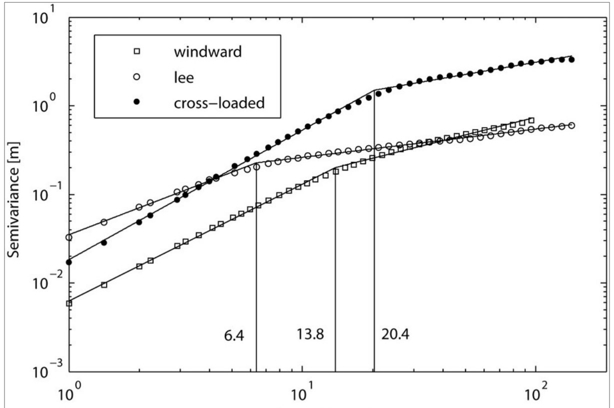
200 m Alpine Subsets



Deems, unpublished

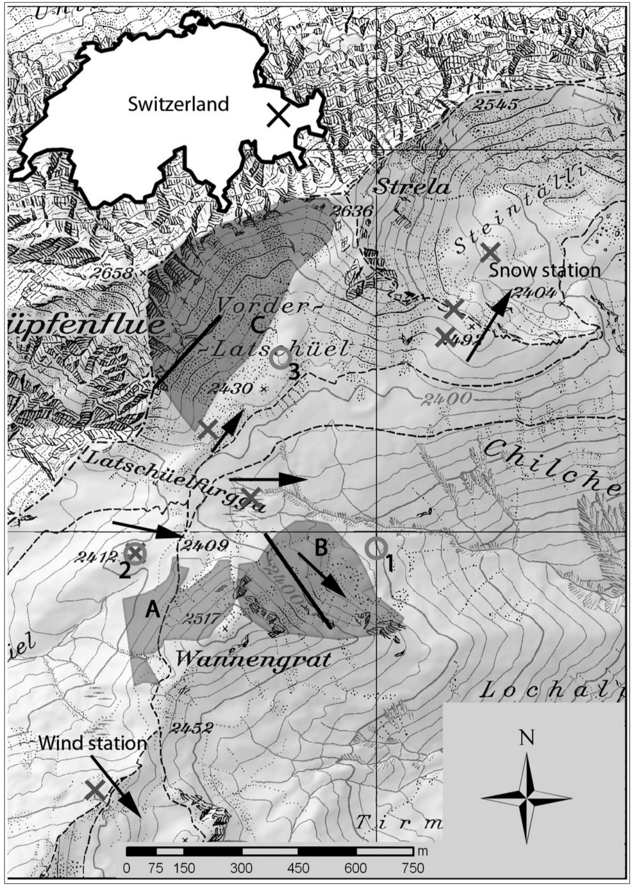
fractal dimension & scale break as metrics





Schirmer & Lehning (2011)

- *D* characterizes balance of process over a specific scale range
- *SB* bounds that scale range
- are these parameters stationary across the landscape &/or through time?



Airborne Snow Observatory: Tuolumne river basin

- 1200 km^2
- 1100-4000m ASL
- montane to alpine
- maritime snow climate

ASO data

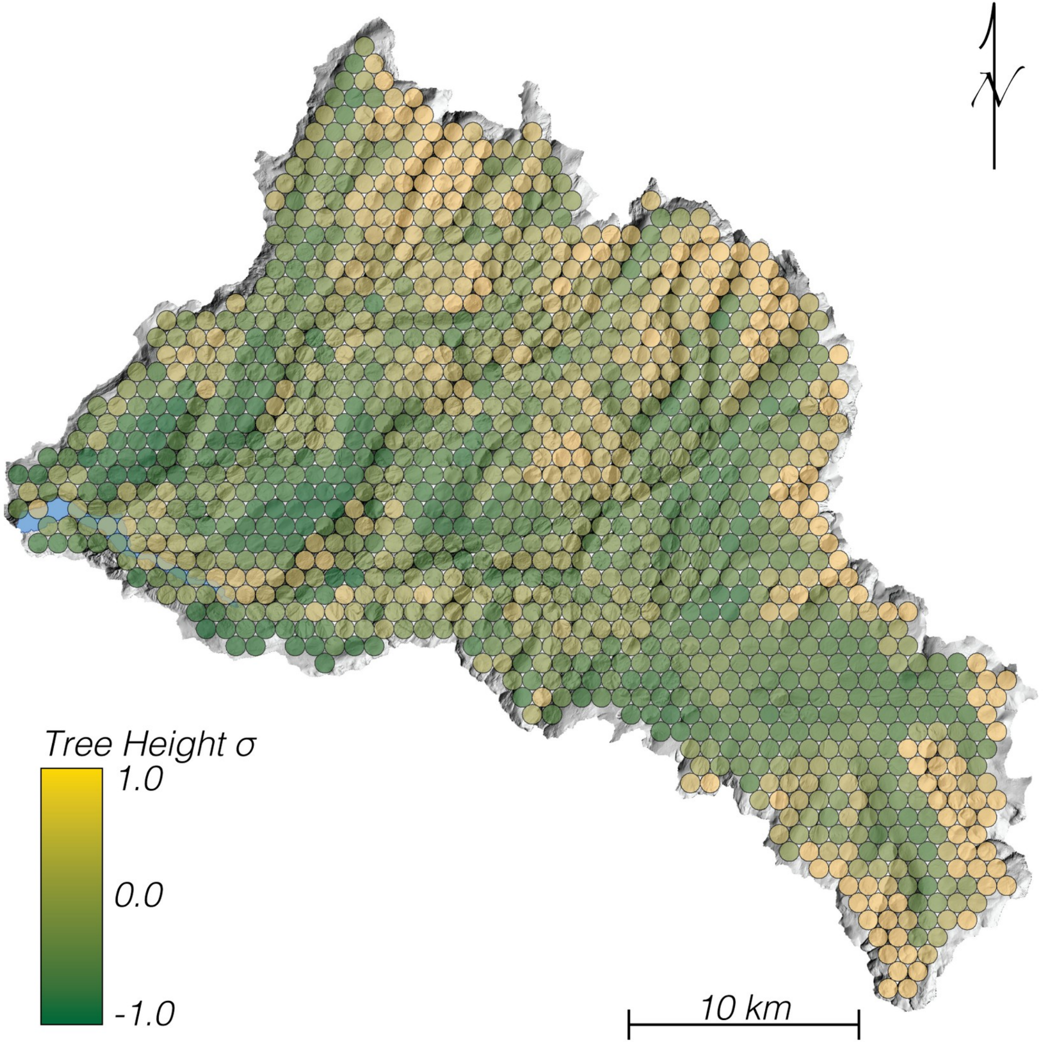
- lidar DEM & tree height
- CASI land cover class
- lidar snow depth maps:

2013:	6 flights
2014:	11 flights
2015:	10 flights
2016:	12 flights
2017:	8 flights

methods

- fill basin with 1km circles
- static physiographic parameters
  - DEM *(μ, σ)*
  - slope *(μ, σ)*
  - northness *(μ, σ)*
  - tpi *(μ, σ)*
  - veg height *(μ, σ)*
- snow depth variograms
  for each circle, for each ASO flight
  - **zero depths not included
- calculate scale break *SB* &
  fractal dimensions *D*
  for each circle
  - segmented power law fit

$$\gamma(r) = a\,r^b \qquad D = 3 - \frac{b}{2}$$

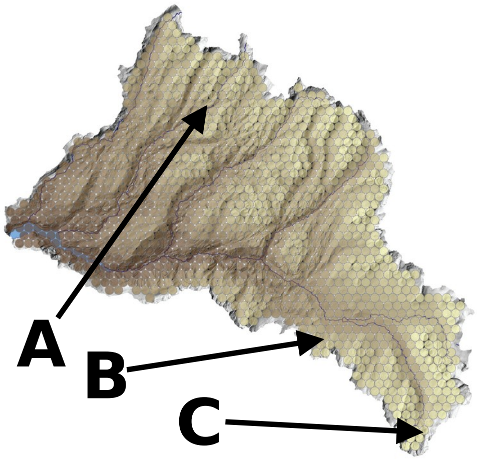


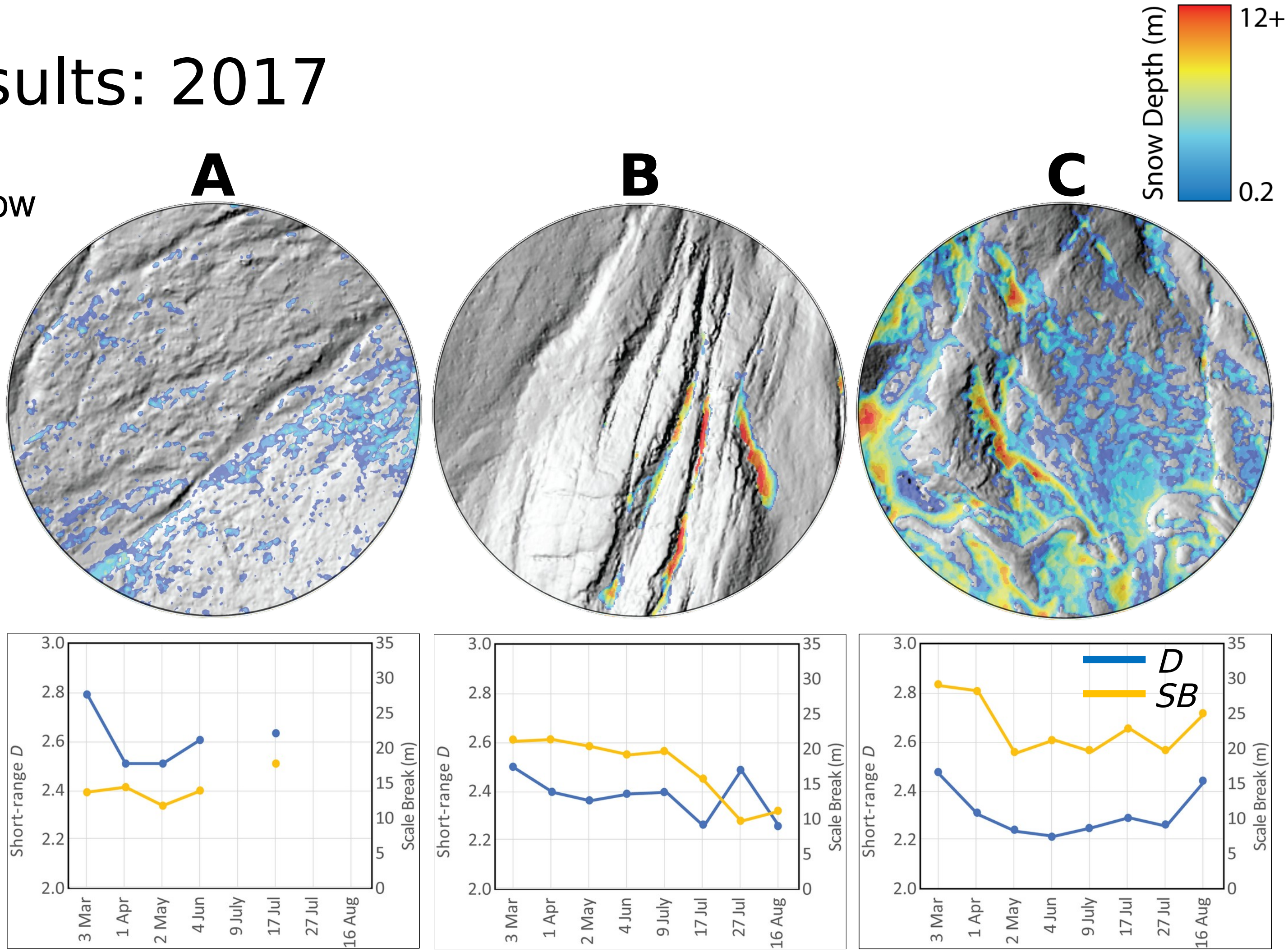
example results: 2017

A: forested; shallow snow

B: treeline; strong geomorphic controls

C: alpine; deep snow

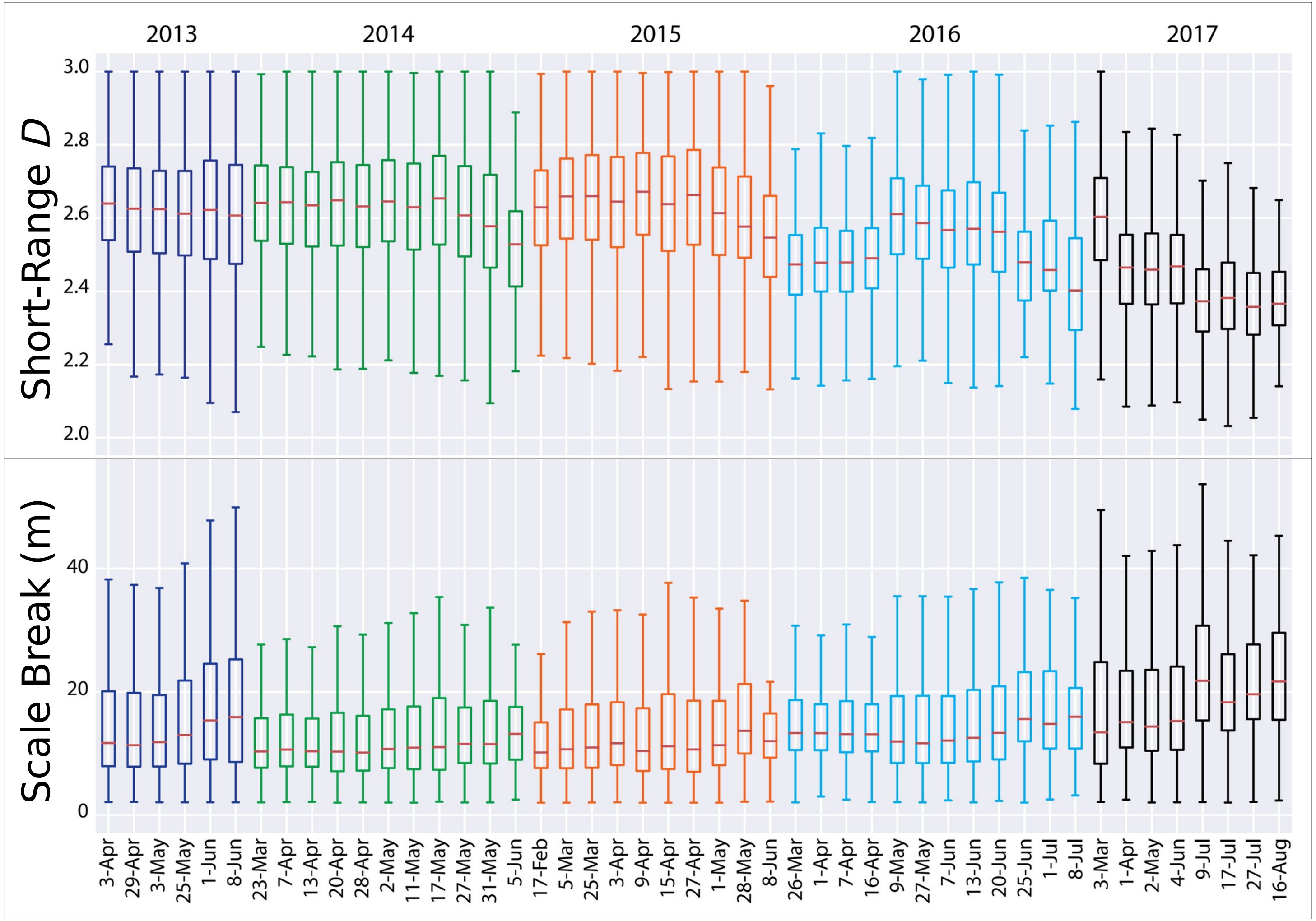




temporal patterns

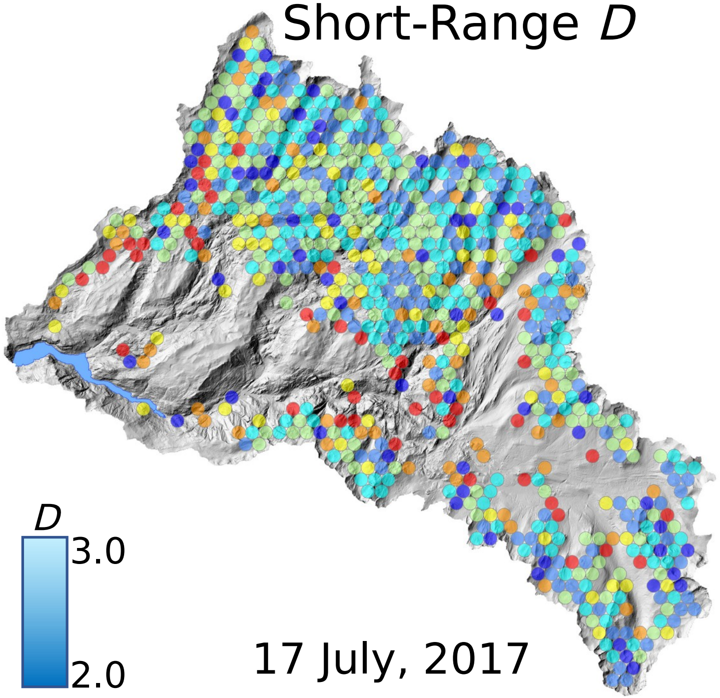
Short Range *D*
- decrease in spring
- smoother/less-variable depth as melt progresses
- stronger effect in wetter years

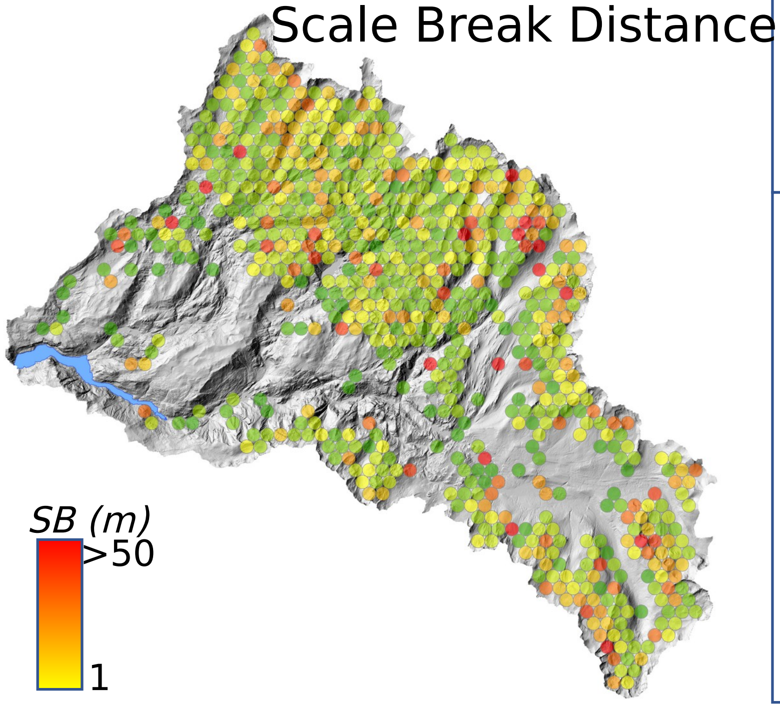
Scale Break
- increase through season
- melt processes consistent over wider range than accumulation processes?

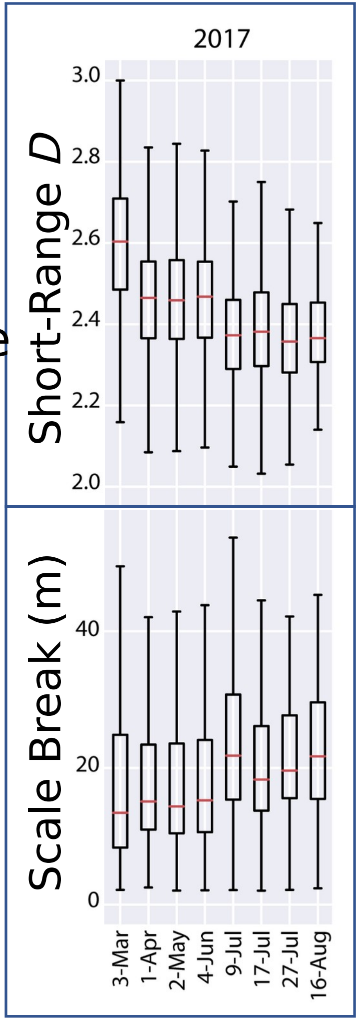


spatial & temporal patterns

- distribution of Short-range *D* & scale break
- *D*↓ & *SB*↑ over time
- not spatially uniform trajectories

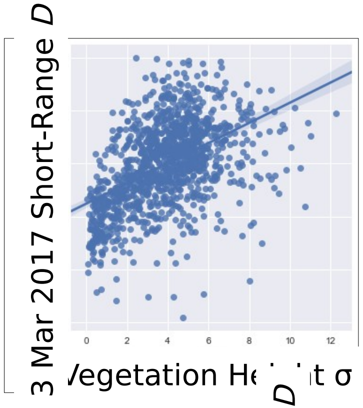


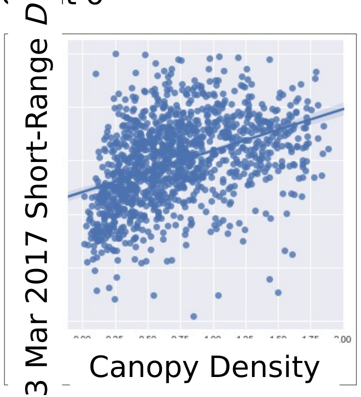




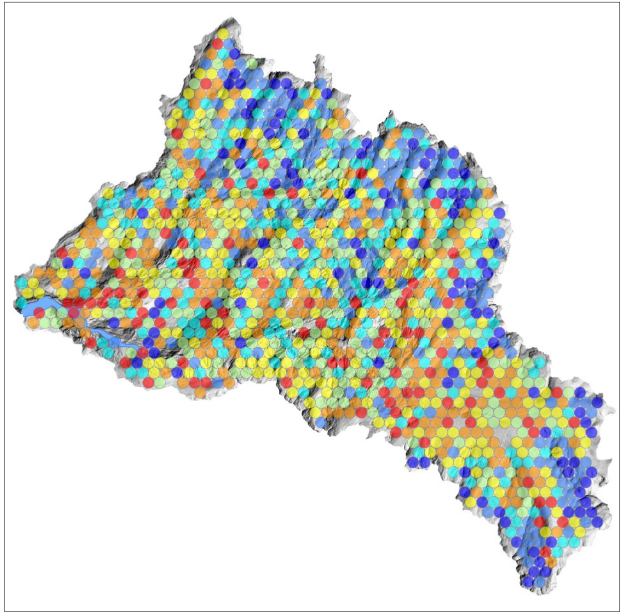
physiographic influences – bulk properties

- positive relationship between short-range *D* & veg height σ
- similar with canopy density

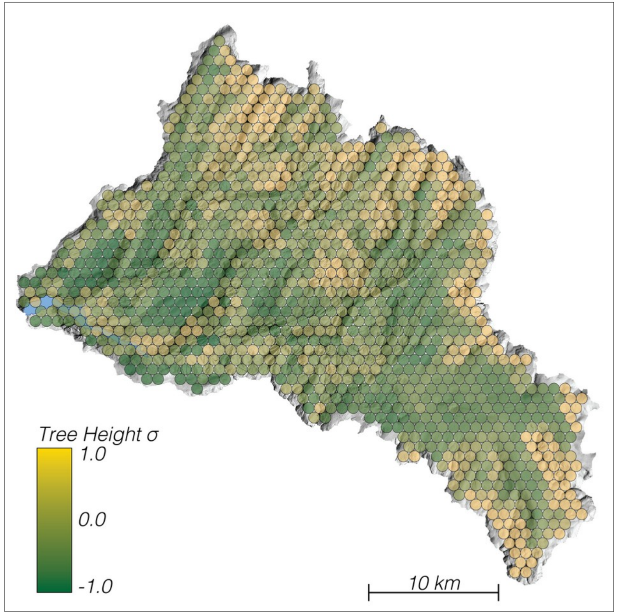




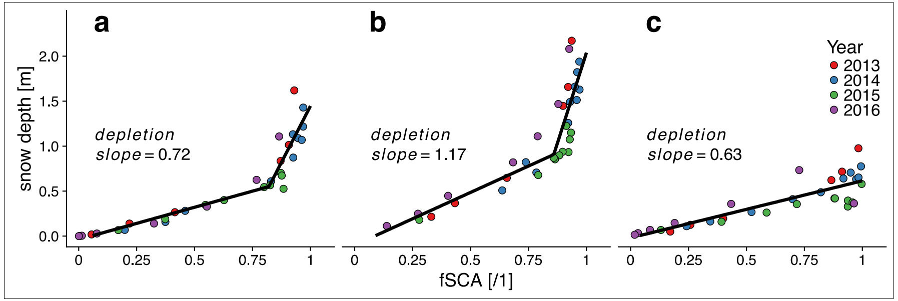
3 Mar 2017 Short-Range *D*



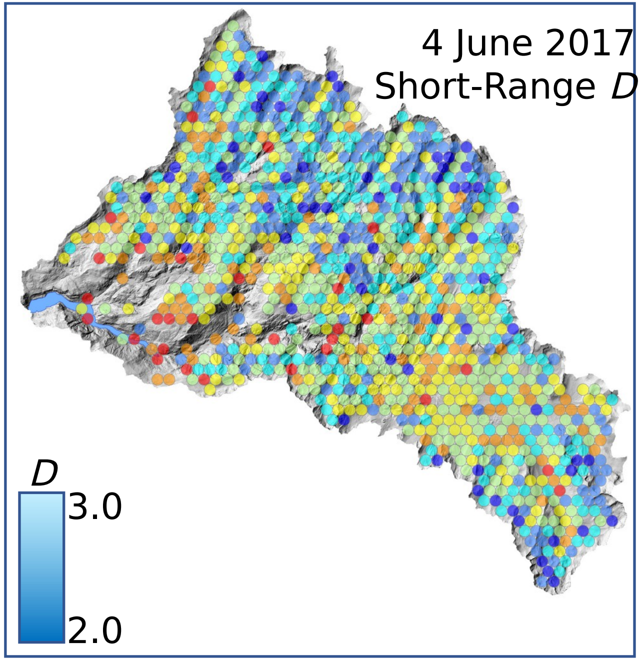
Vegetation Height σ

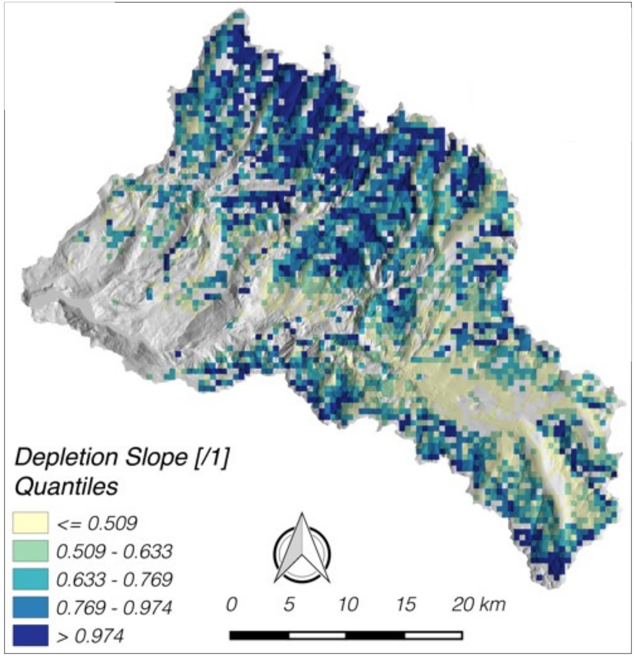


fractal dimensions, depletion curves, & terrain roughness



- snow depth/fSCA depletion curve slopes vary with terrain roughness
- roughness variation occurs over a range of length scales
  - 10^{-2} m – rocks, talus
  - 10^{0} m – trees, outcrops
  - 10^{1}-10^{3} m – geomorphic features
- *D* describes balance of roughness scales





Schneider, D., N.P Molotch, J.S. Deems, T.H. Painter (2017) Analysis of topographic controls on depletion curves derived from airborne lidar snow depth data, *Geophys. Res. Lett., in review*.

summary & ongoing work

initial results

- *D*, *SB* vary across the domain
  - relationships to bulk physiographic parameters; vegetation strongest
- temporal evolution through the snow season
  - accumulation & melt processes seem to show different scale properties

ongoing

- comparison to wind parameters & physiographic scaling
- other sites with different physiography, vegetation, snow climate
- different max variogram extents
- SCA thresholds

Friday sessions: *Quantifying Spatial and Temporal Variability of Snow and Snow Processes*
C51E & C52B – Oral C53B - Posters

Ian Bolliger C53B-1023: *Spatiotemporal Variability in Topographic and Vegetative Controls on Basin-Wide Snow Distribution in the Tuolumne River Basin*