Spatial distribution and scaling properties of lidar-derived snow depth in the extratropical Andes

Pablo A. Mendoza, Thomas E. Shaw, Miguel A. Lagos, Keith N. Musselman, Jesús Revuelto, Shelley MacDonell & James McPhee

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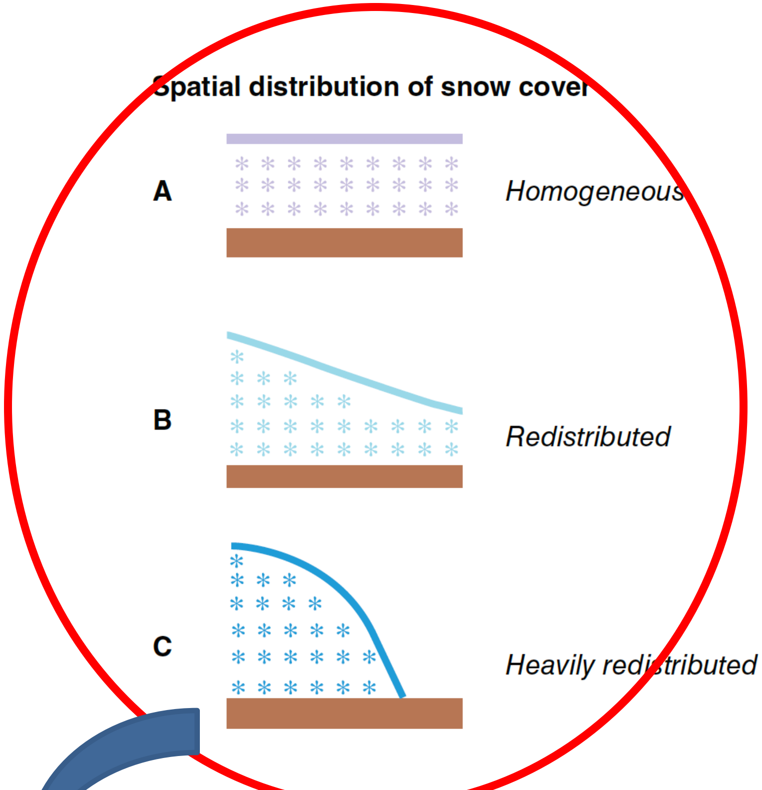
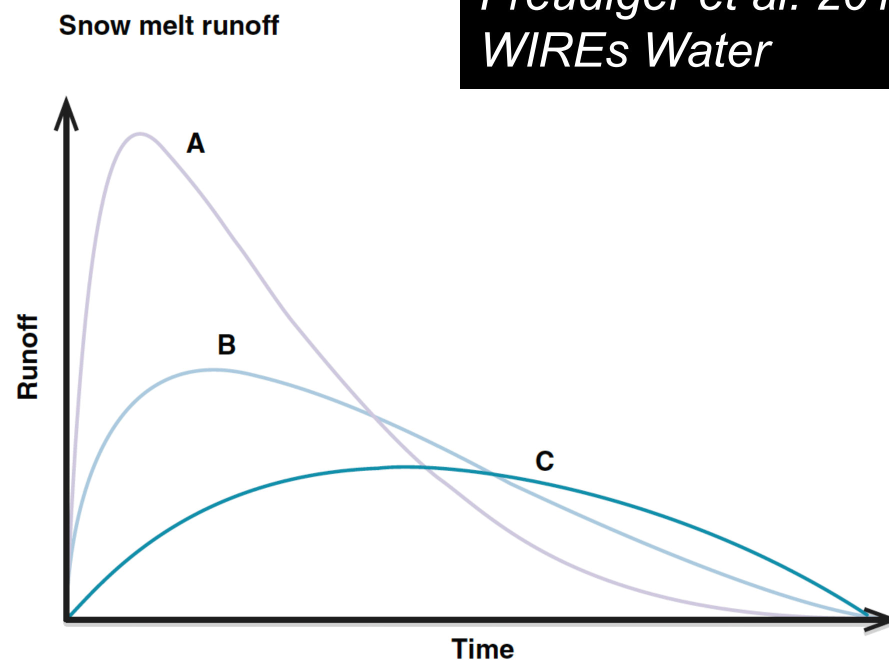
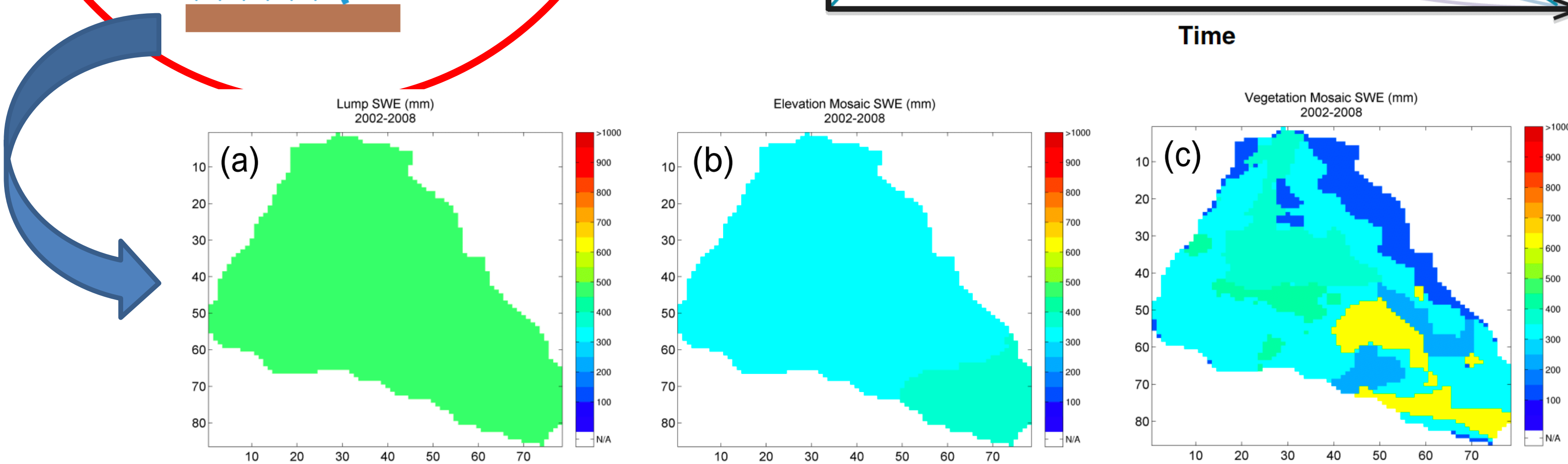
1. Motivation

Understanding snow distribution patterns can help to improve hydrological predictability

Freudiger et al. 2017, WIREs Water







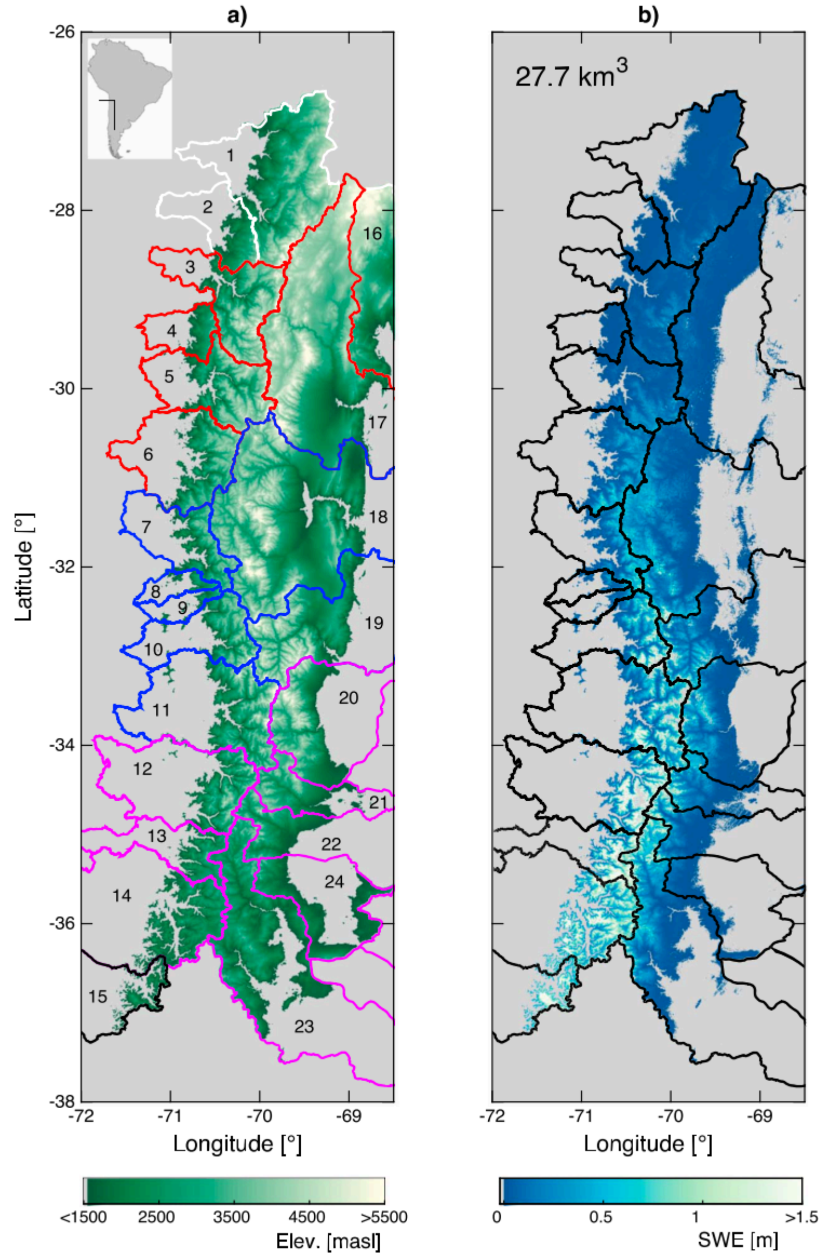
Newman et al. 2014 (JHM)

1. Motivation

- **In the semi arid extratropical Andes,** spring snowmelt runoff that accounts for more than 60 % of the total annual streamflow.
- The characterization of spatial variability in snow depth and SWE has been **historically challenged by data limitations**.
- Past studies describing the spatial variability of snow are based on scales >60 m.
- Emergence of lidar technology in Cryosphere studies, including the Andes (Shaw et al., 2020).

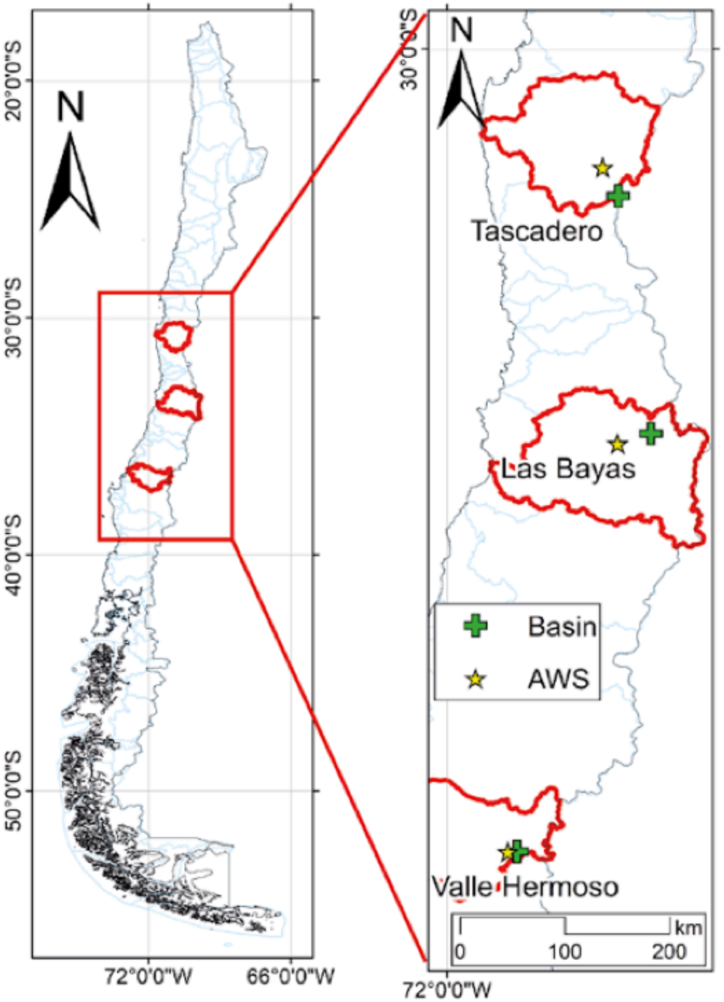
Key questions:

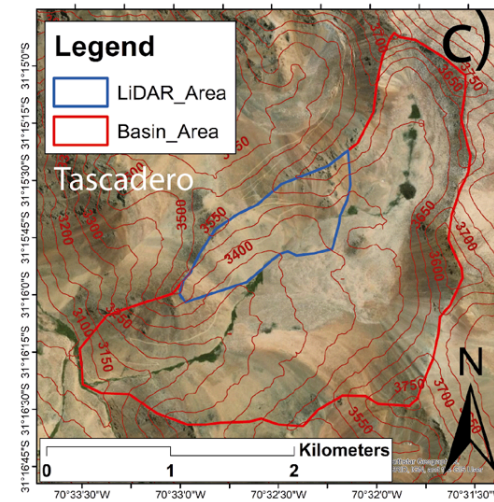
1. How is the spatial distribution of snow depth at the **hillslope scale (1-100 m)** along the extra-tropical Andes?
2. How is the **snow depth scaling behavior in the Andes**, and how does it compare with other regions in the world?

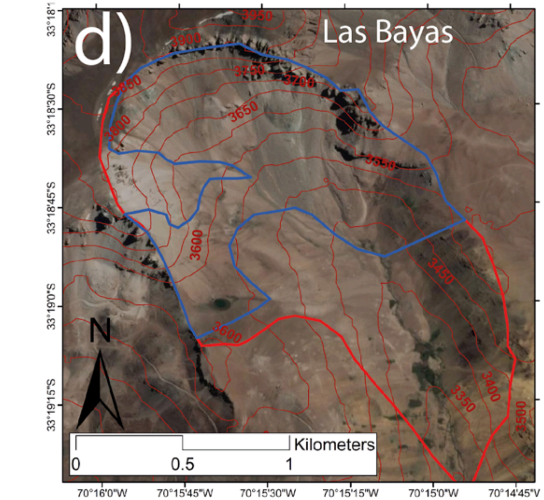


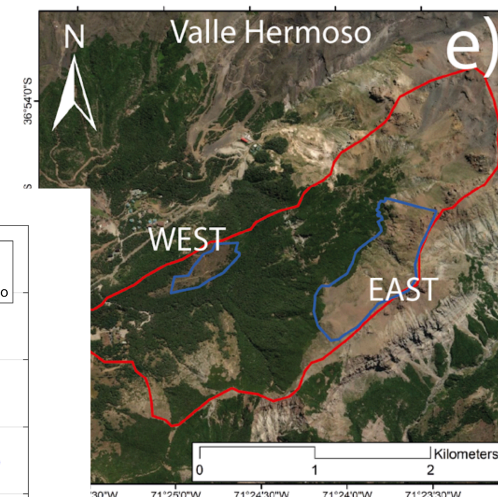
Cortes & Margulis 2017, GRL

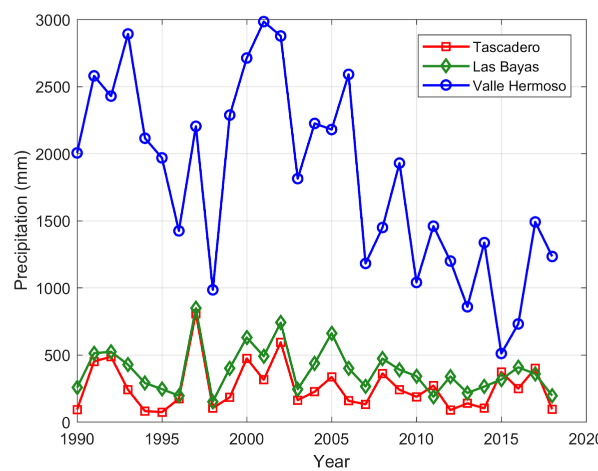
2. Study domain & data





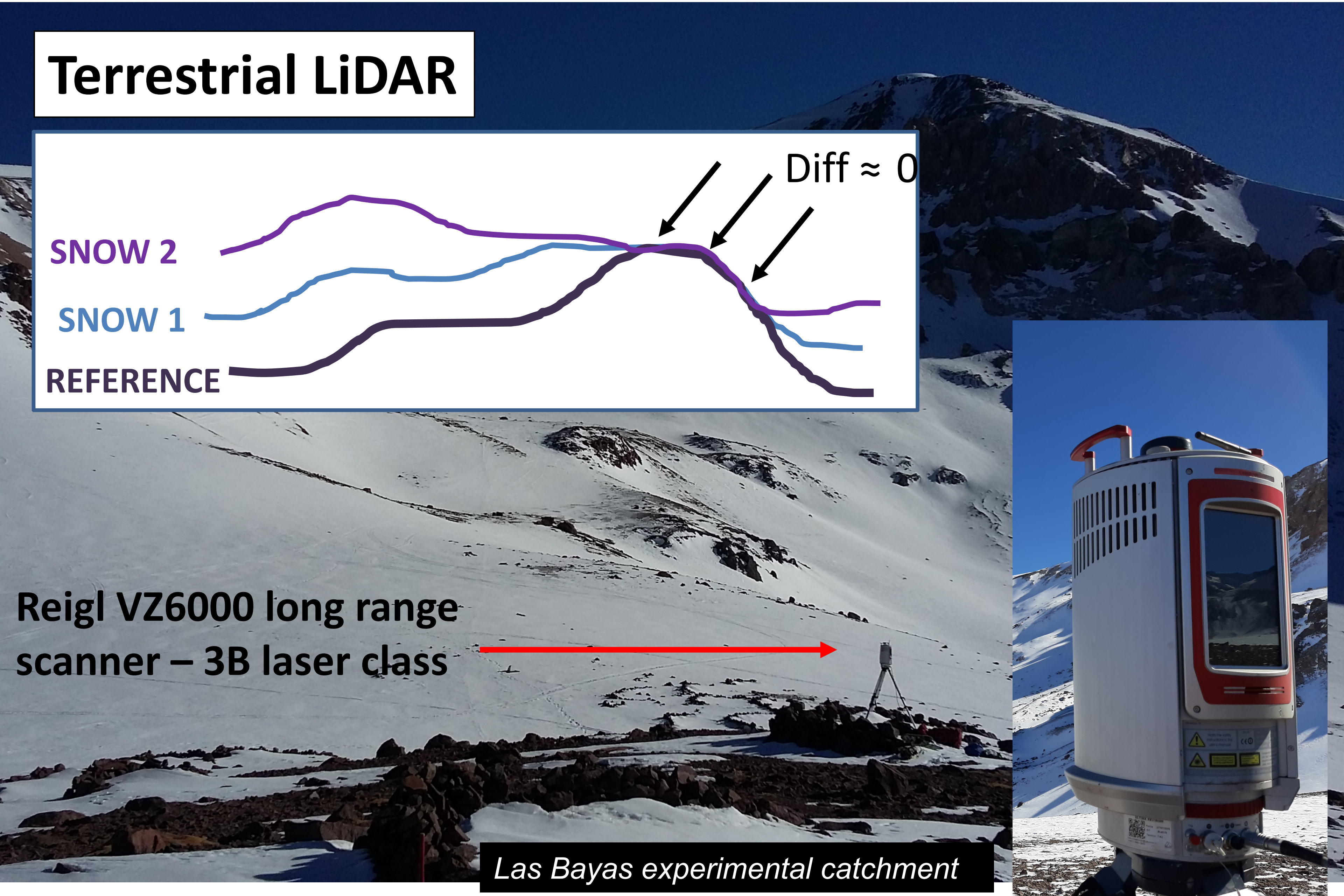






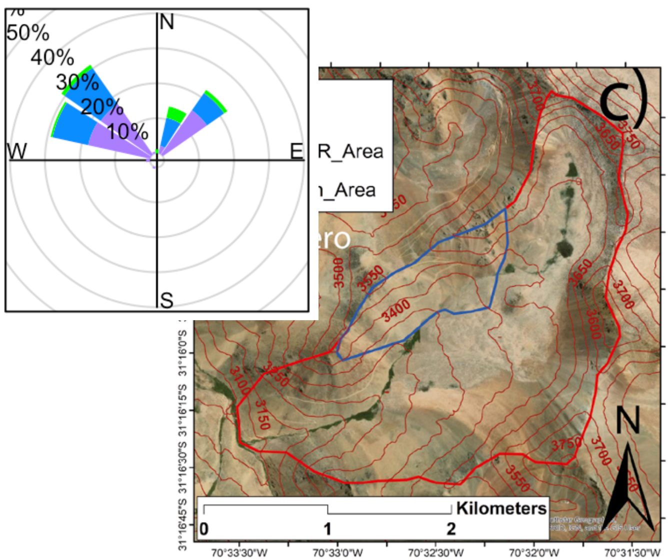
- The three sites span a north-south hydroclimatic gradient, and high inter-annual variability in precipitation.
- VH west has some shrurbs and trees.

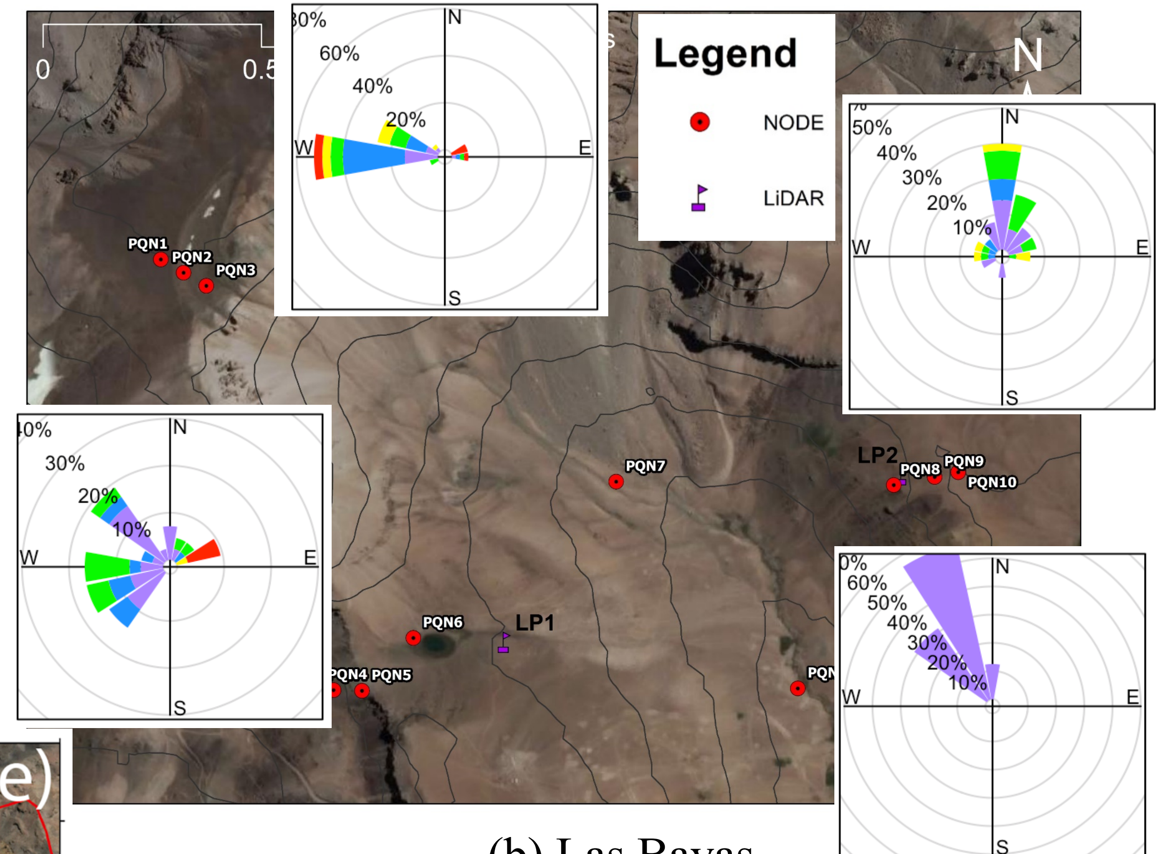
2. Study domain & data



2. Study domain & data

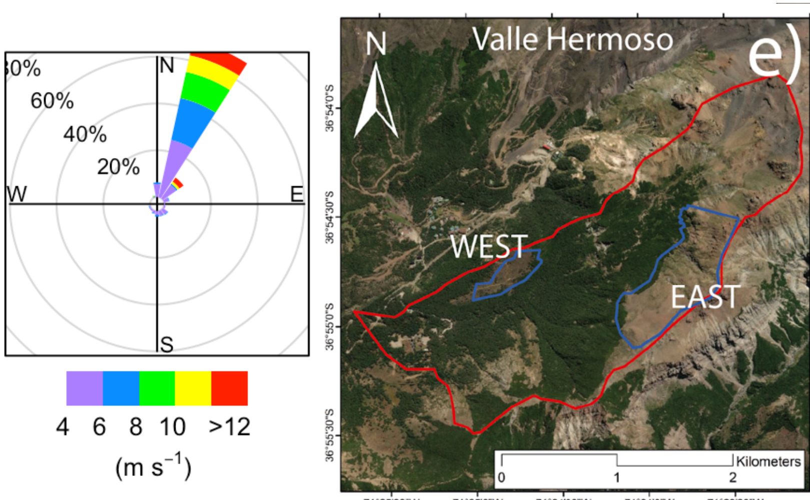
(a) Tascadero





(b) Las Bayas

(c) Valle Hermoso

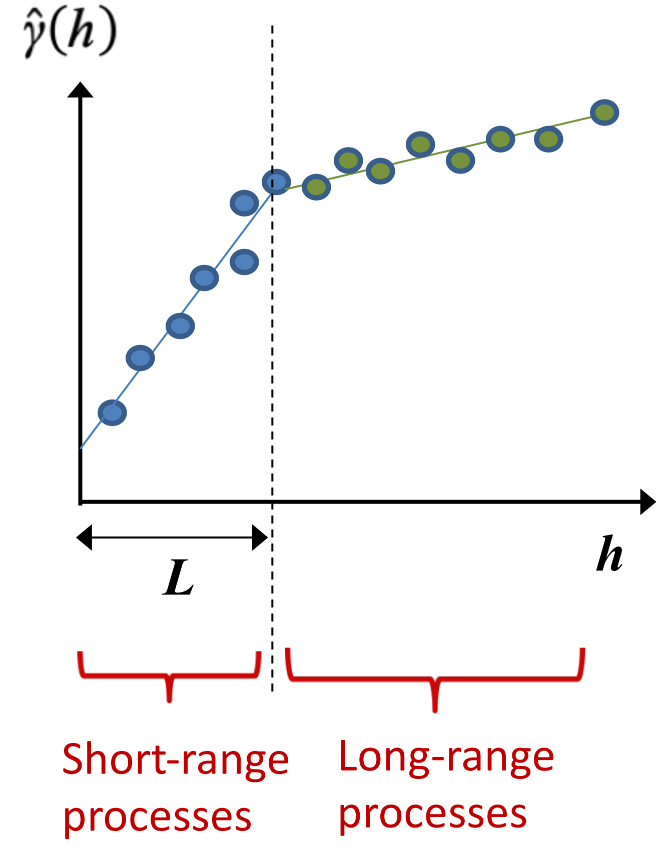


- Wind roses for the three days preceding lidar scans, considering only wind speeds > 4 m s^{-1}.

3. Methods

1. Statistical distribution

- Snow depth statistics per elevation band.
- Probability distributions fit.



2. Variogram analysis

Semi-variance:

$$\hat{\gamma}(h)=\frac{1}{2|N(h)|}\sum_{(i,j)\in N(h)}\left(z_j-z_i\right)^2$$

If the variable shows self-similar behavior:

$$\gamma(h) = \alpha h^{\beta}$$

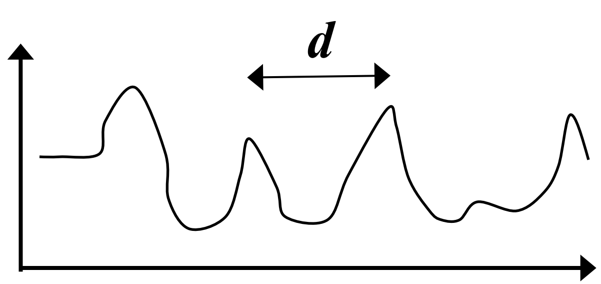
Fractal dimension:

$$D_{S,L} = 3 - \frac{\beta_{1,2}}{2}$$

Mark and Aronson (1984)

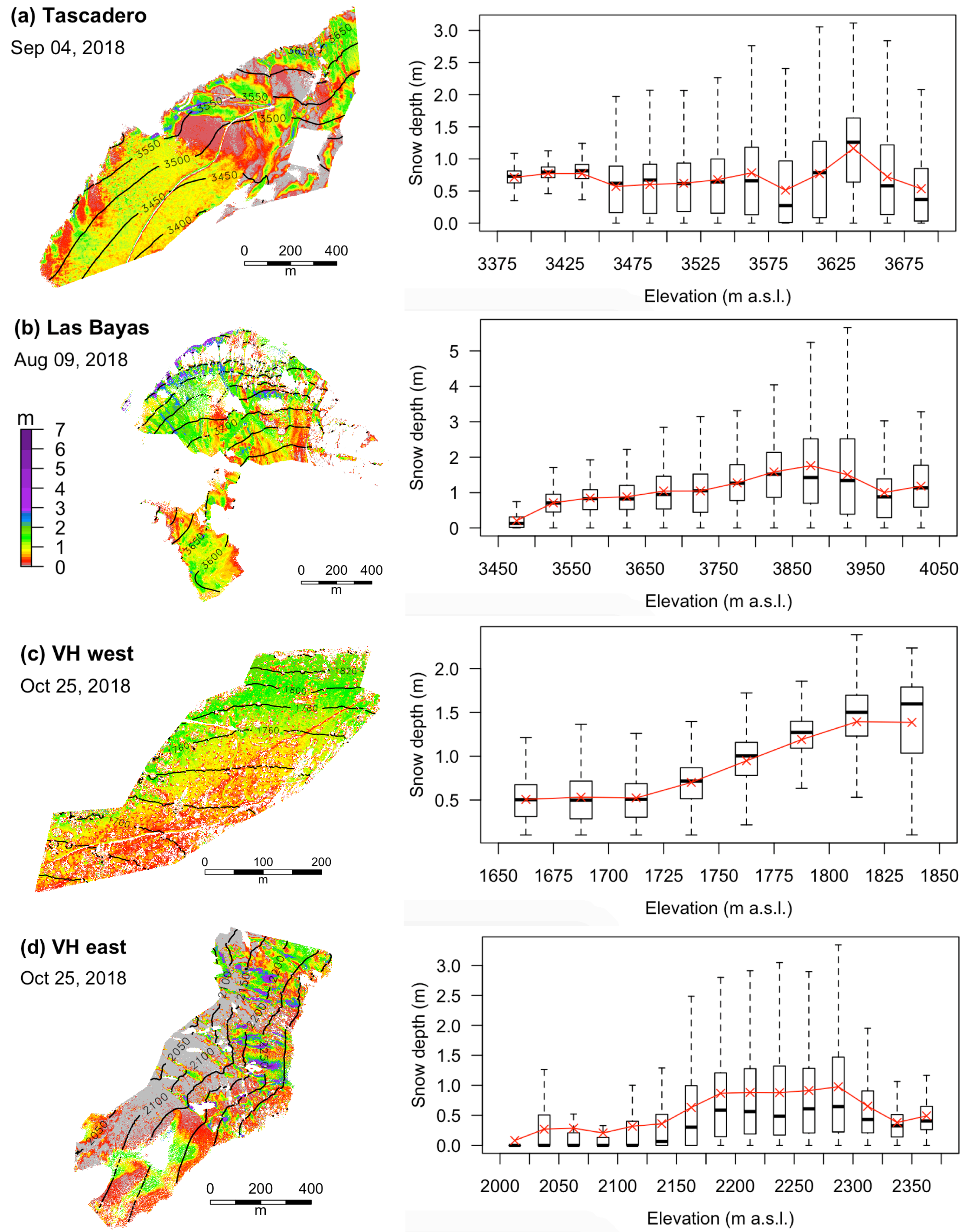
L is the scale break length
Relevant for model scale selection

3. Snow depth transects



- Examine potential relationship between *d* and scale break lengths *L*.

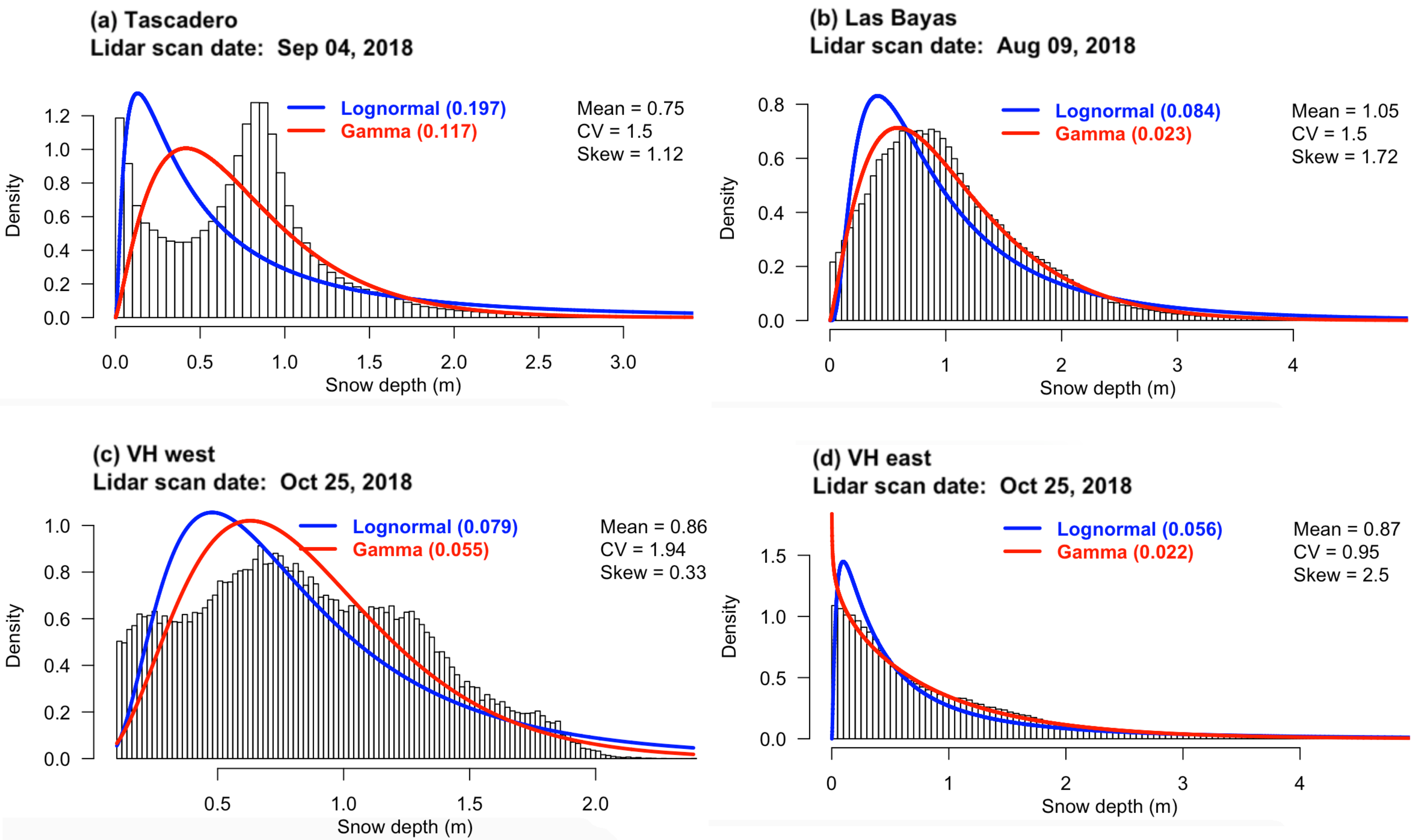
4. Results



Spatial distribution for the entire domain and per elevation bands

4. Results

Probabilistic distribution

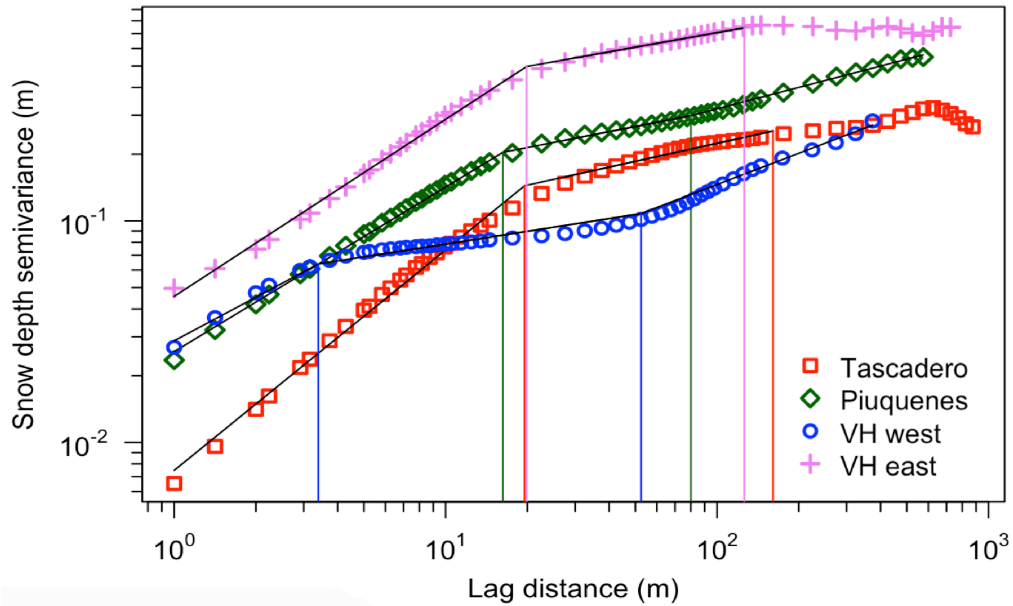


❑ Gamma distributions are preferred over lognormal distributions.

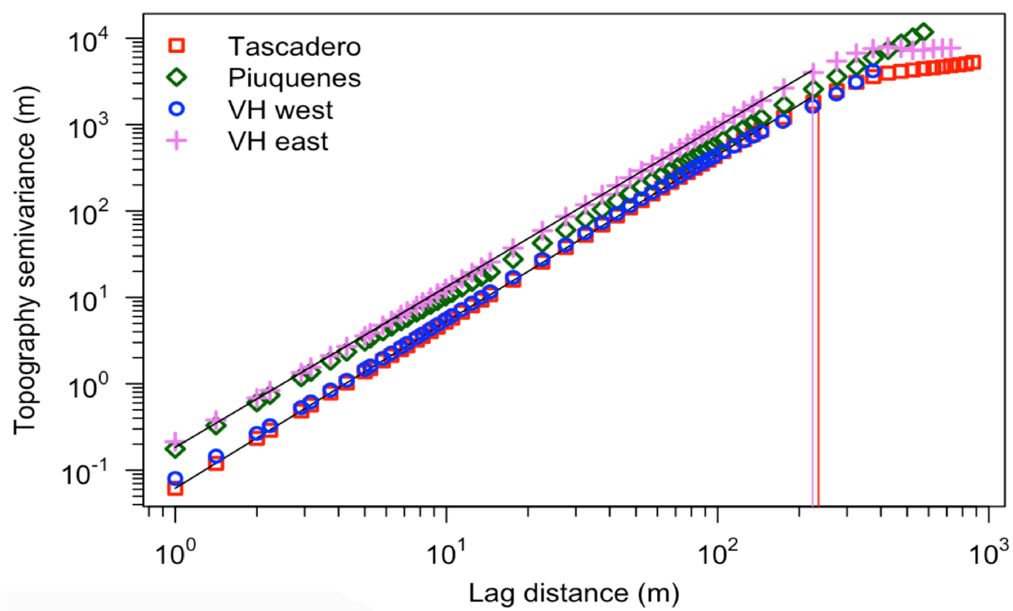
4. Results

Variogram analysis

- ❑ Scale breaks span 15-20 m in unvegetated areas.
- ❑ Shorter scale breaks are found in VH west.
- ❑ Multiscale behavior is found in all sites.

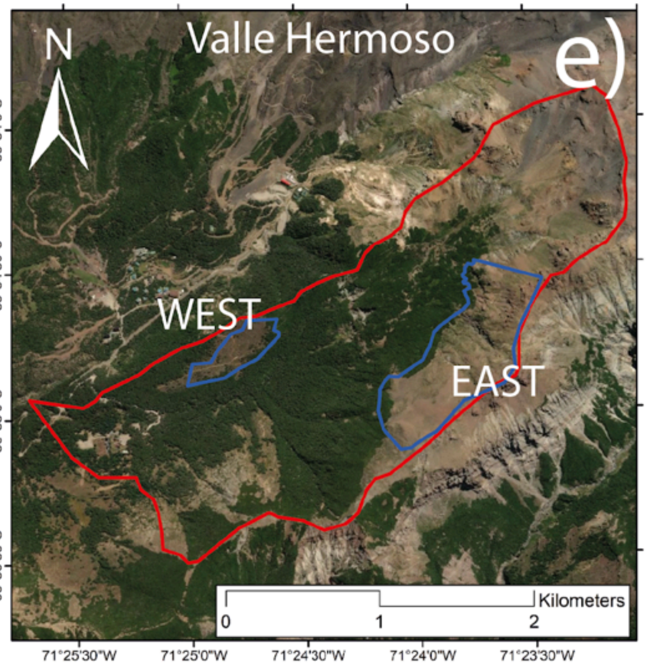


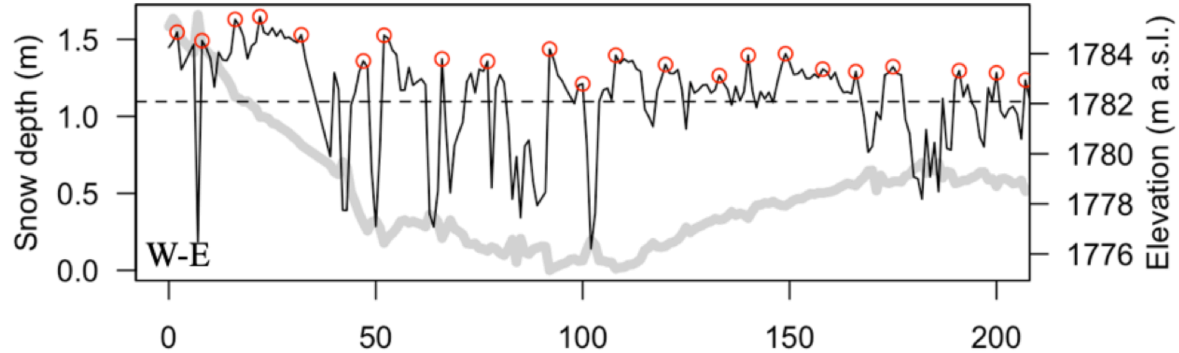
- ❑ Fractal behavior in bare earth topography up to 200-300 m.
- ❑ No direct links between spatial structure of topography and snow depth are found at the hillslope scale.

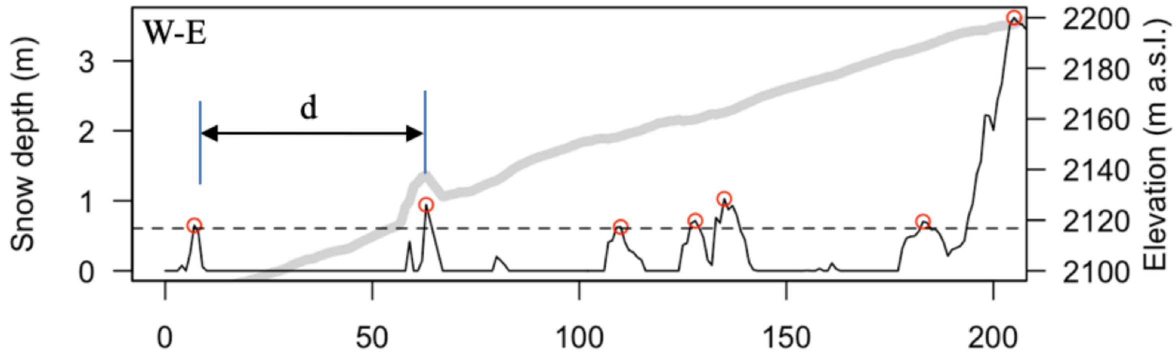


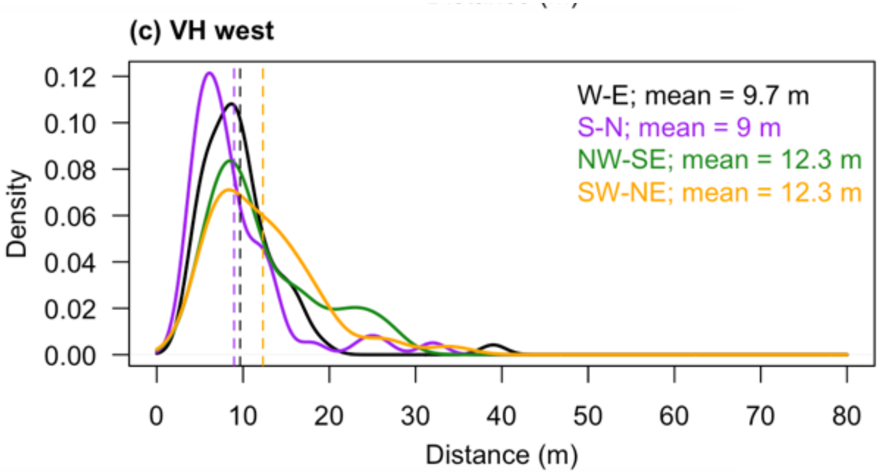
4. Results

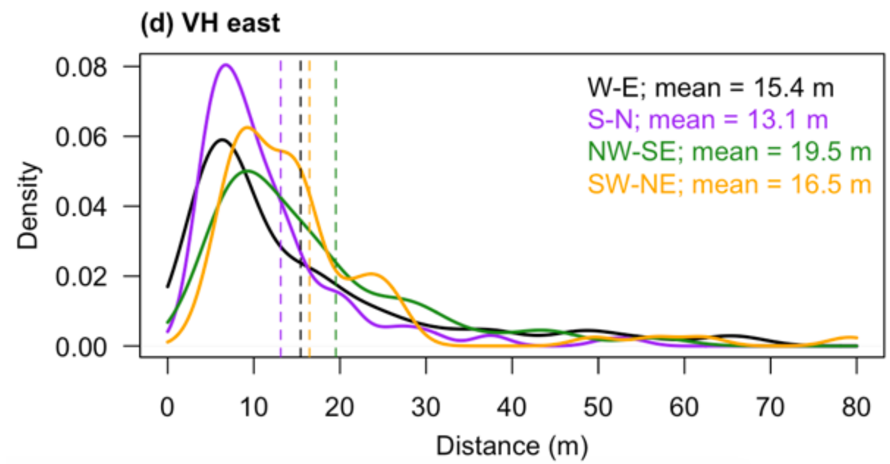
Snow depth transects











- ❑ Primary scale break lengths are of the same order of magnitude than mean ‘d’ values.

5. Summary

- We present, for the first time, a characterization of snow depth patterns at the hillslope scale in the extratropical Andes using lidar measurements.
- Our results suggest **multiscaling behavior of snow depth along the extratropical Andes**, and **primary scale breaks of the same order than other mountain regions in the world** (e.g., Colorado Rockies, Pyrenees, Swiss Alps).

- <u>Other findings</u>:

    - Gamma distributions are better than lognormal function to characterize probability of snow depth.
    - Links between scaling patterns of bare earth topography and snow depth are not evident in the domains analyzed.
    - Transect analyses suggest that primary scale break lengths are related with horizontal distances between local maxima in show depth fields.

Thank you!

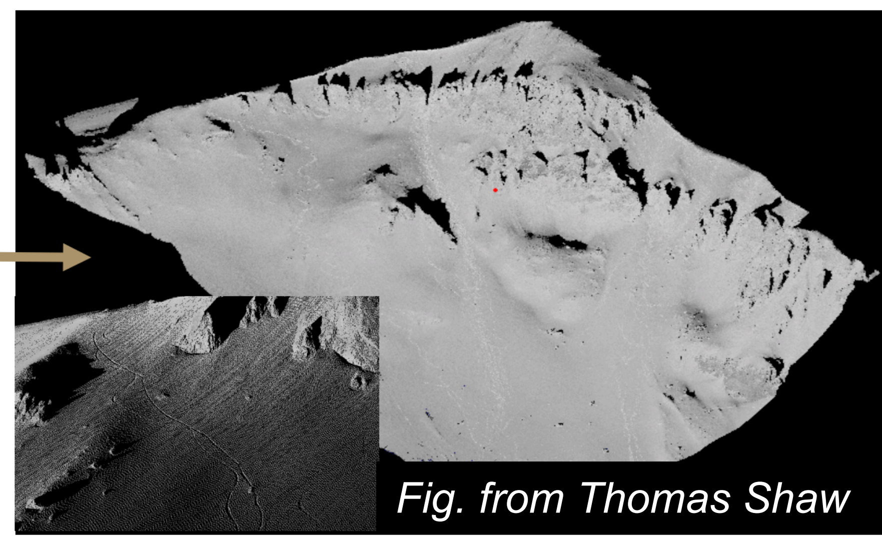


Fig. from Thomas Shaw