Spatio-temporal temporal analyses of the snowpack from ground observations

nlopez@ipe.csic.es

- Snow climatology
- Understand spatio-temporal dynamics of snowpack
- Hydrological forecasting
- Validating snow simulations.

CANADA
BRITISH COLUMBIA
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FRASER PLATEAU
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WASHINGTON
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Portland
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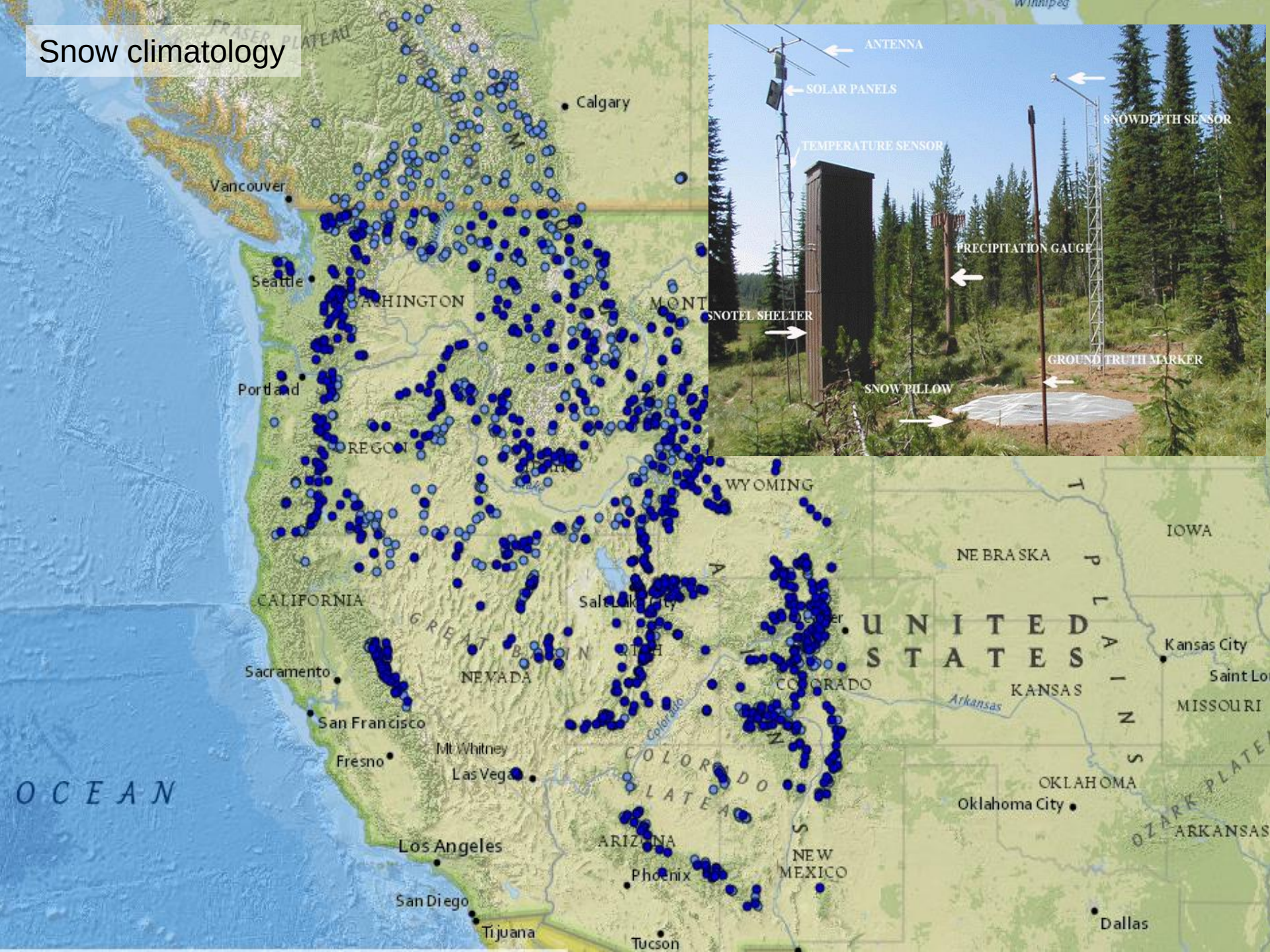
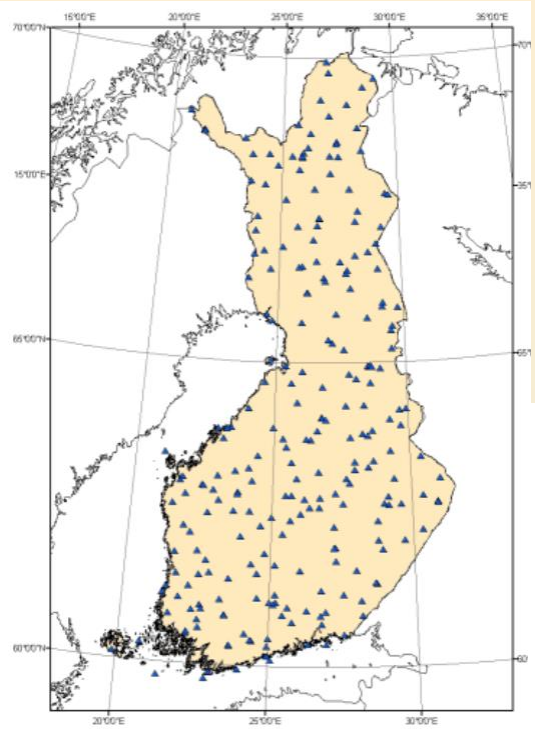
Fresno
Mt Whitney
Las Vegas
COLORADO PLATEAU
ARIZONA
Phoenix
NEW MEXICO
Los Angeles
San Diego
Tijuana
Winnipeg
Lake Manitoba
Lake of the Woods
NORTH DAKOTA
MINNESOTA
Missouri
Peace
Colorado
PACIFIC OCEAN
Stations by Network
SNOTEL
SCAN
SNOLITE
Other NRCS Hydromet
Snow Course/Aerial Marker
Manual Precipitation
Reservoir
Streamflow
ACIS
Cooperator Snow Sensors
NRCS Natural Resources Conservation Service
Created 2-19-2016, 11:14 AM GMT+0100
300 km
200 mi
SNOW COURSE MARKER
FEDERAL-STATE COOPERATIVE SNOW SURVEYS
SOIL CONSERVATION SERVICE
U.S.D.A.

Snow climatology



Snow climatology



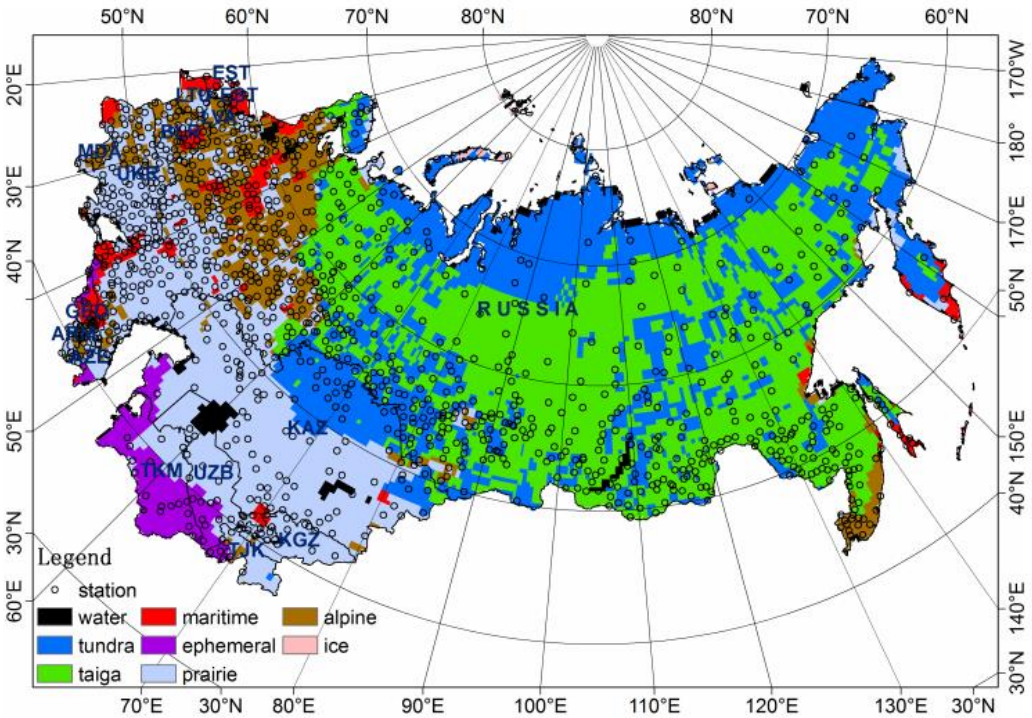
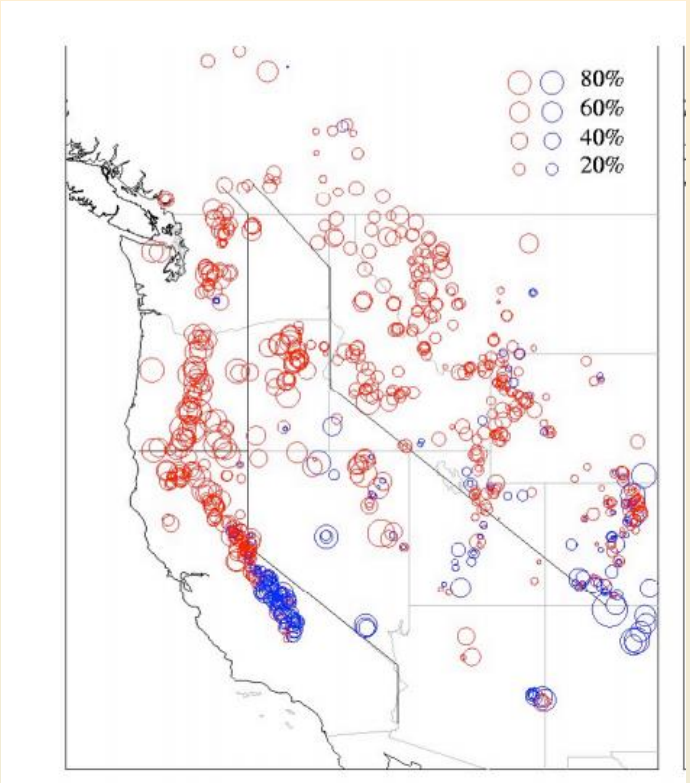
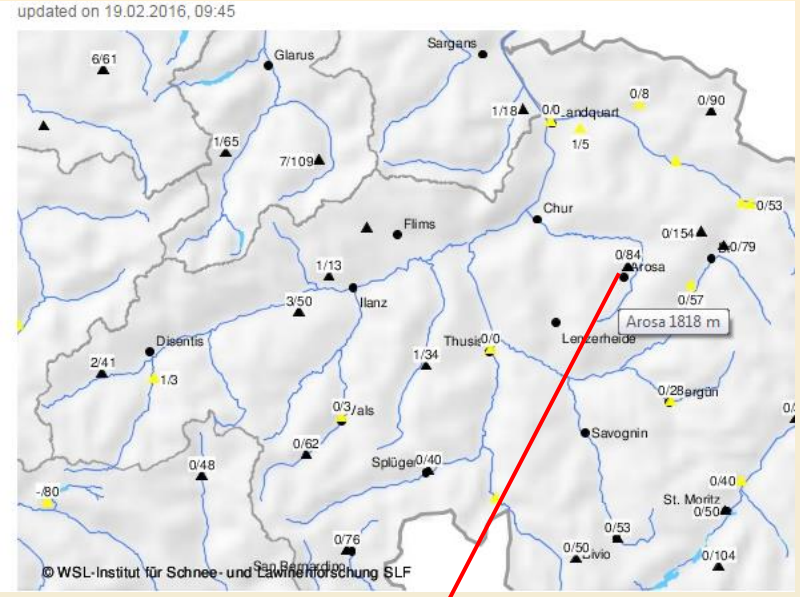


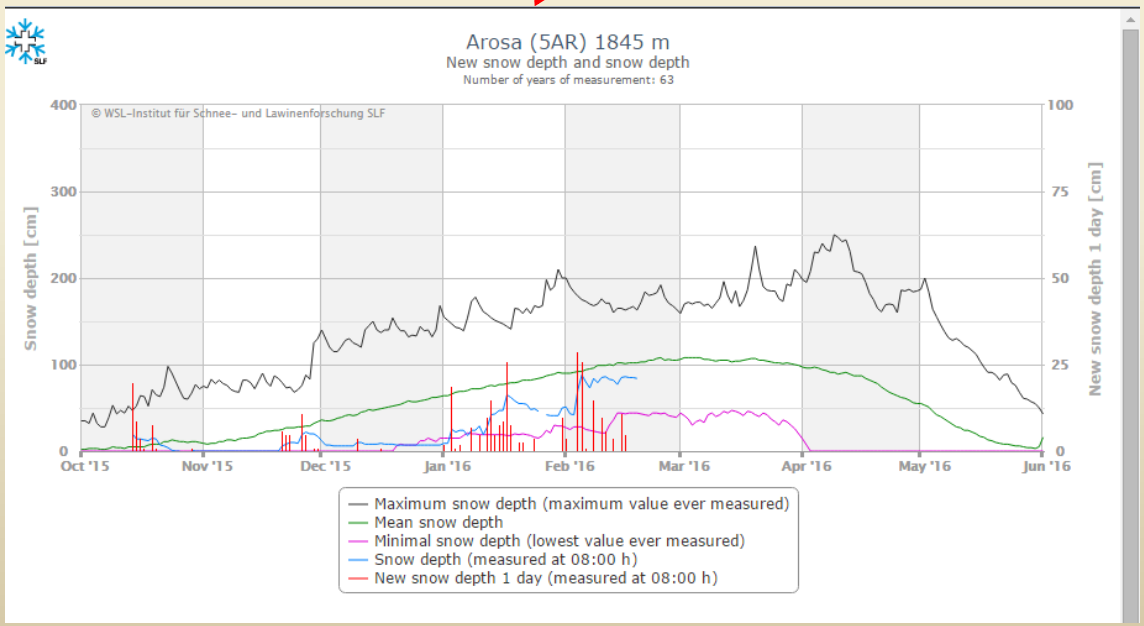
Fig. 1. Geographical locations and distribution of snow course stations and snow classes across the former USSR.

Snow climatology



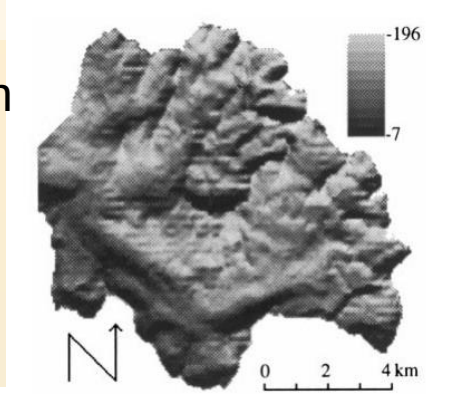
Trends in 1st April SWE
Mote et al., 2005

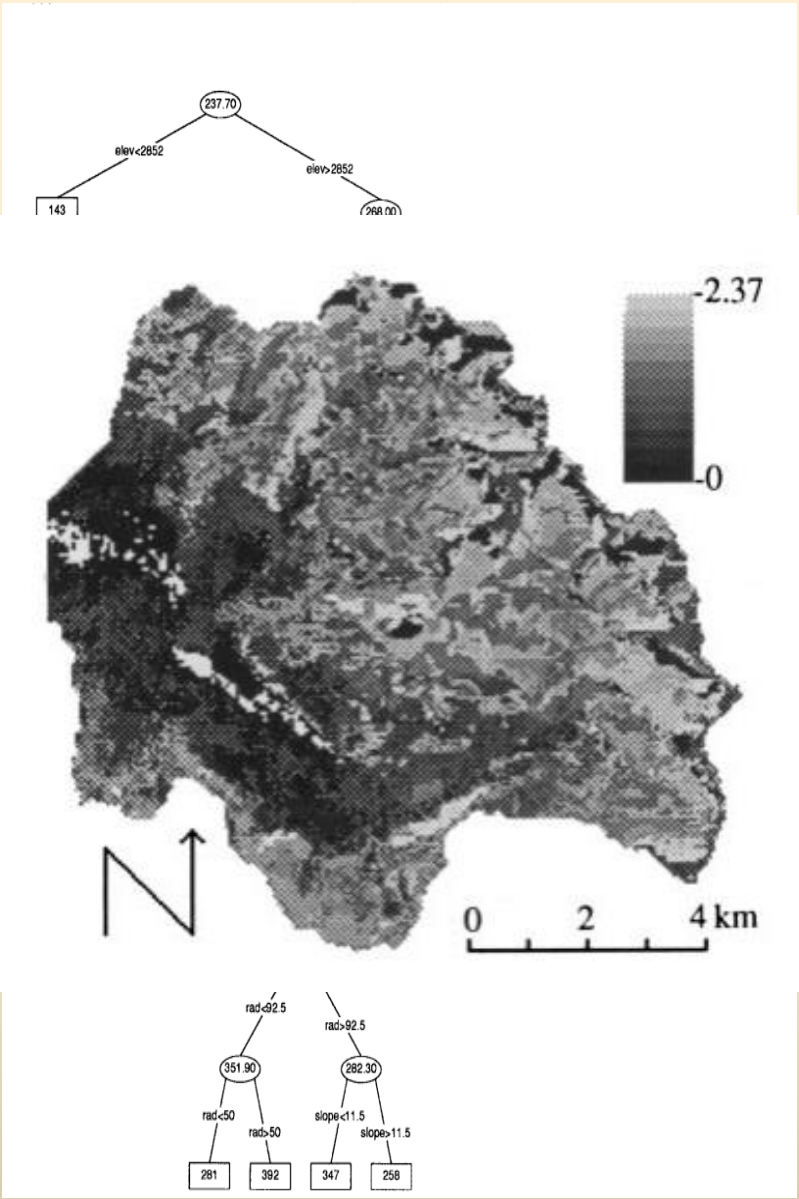




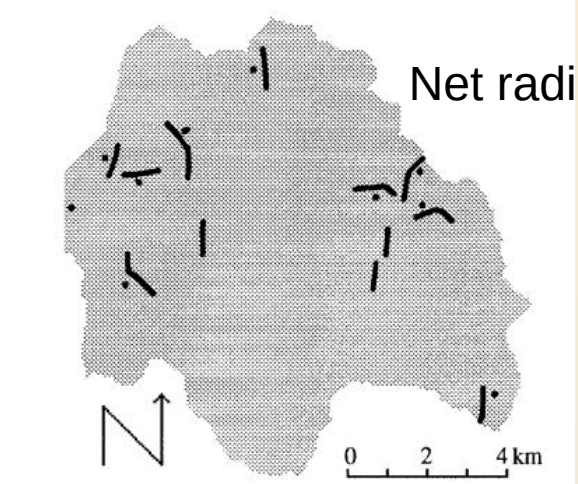
Analysis of snow distribution

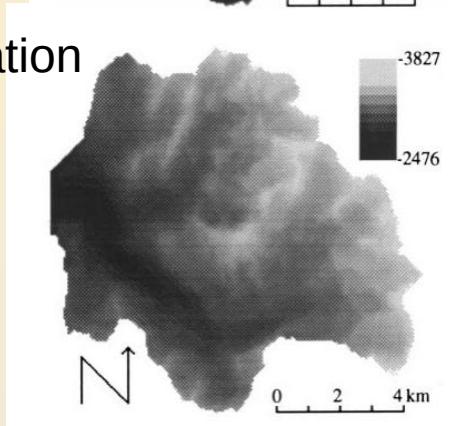
Elevation



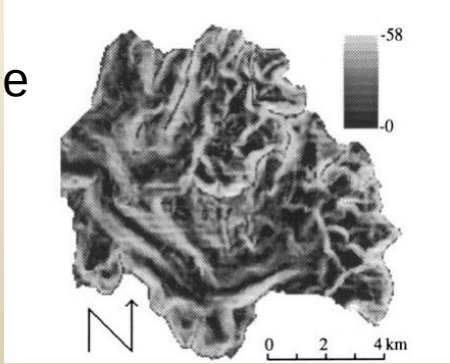


Net radiation



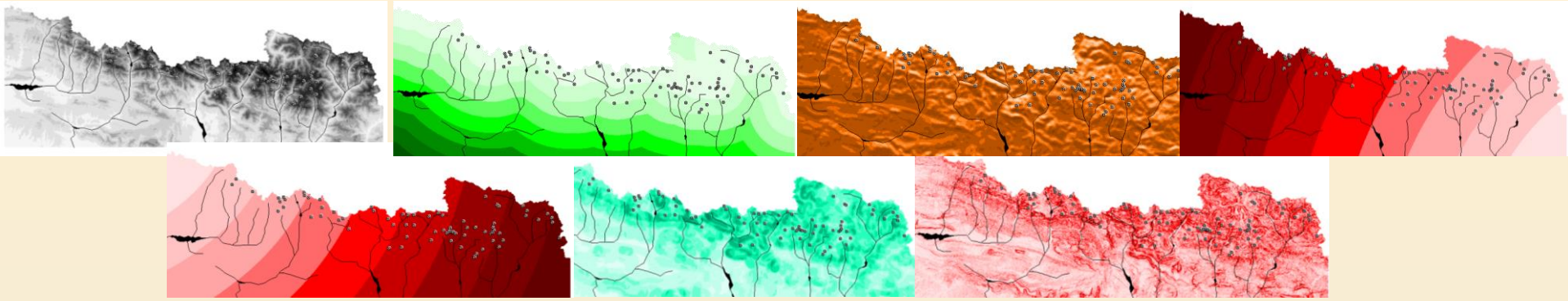


Slope angle



Elder et al., 1997. Estimating the spatial distribution of snow water equivalence in a montane watershed. Hydrological Processes

Spatial variability



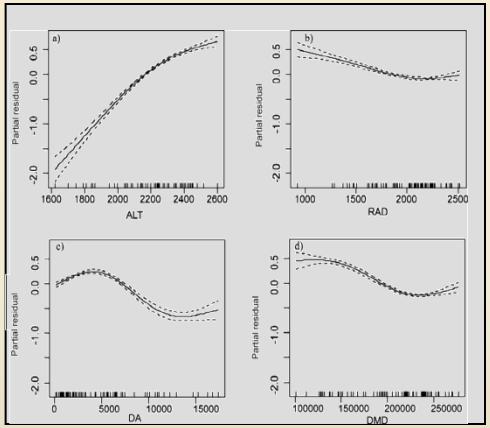
Predictors from DEMs

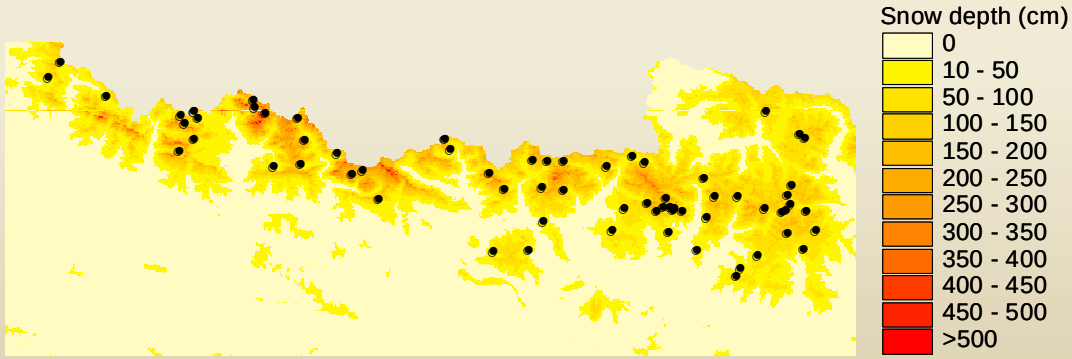
↓

Statistical models

↓

Snow maps

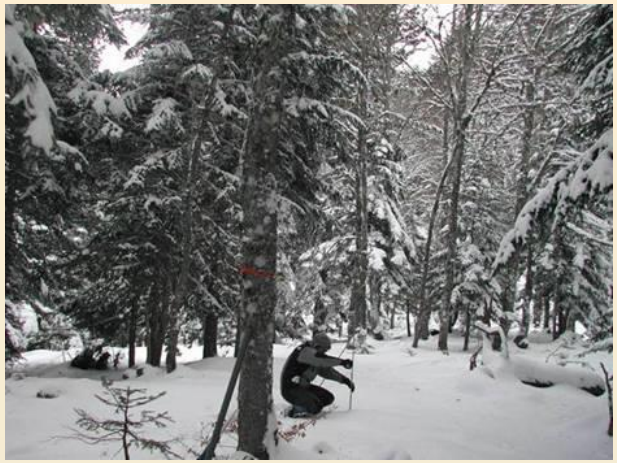




Long-term average snow depth in the Spanish Pyrennes at early April

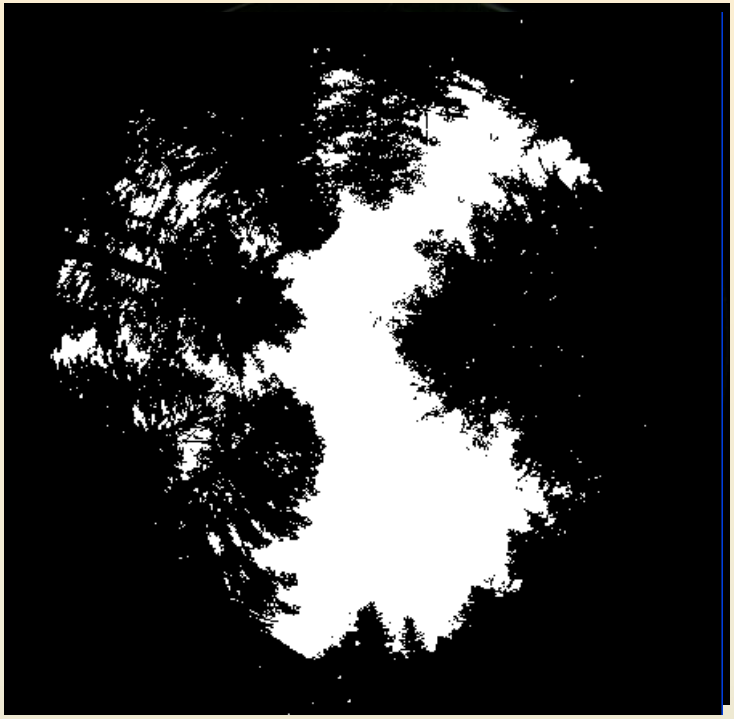
López-Moreno and Nogués-Bravo, 2006: Interpolating local snow depth data: an evaluation of methods

Spatial variability: forests



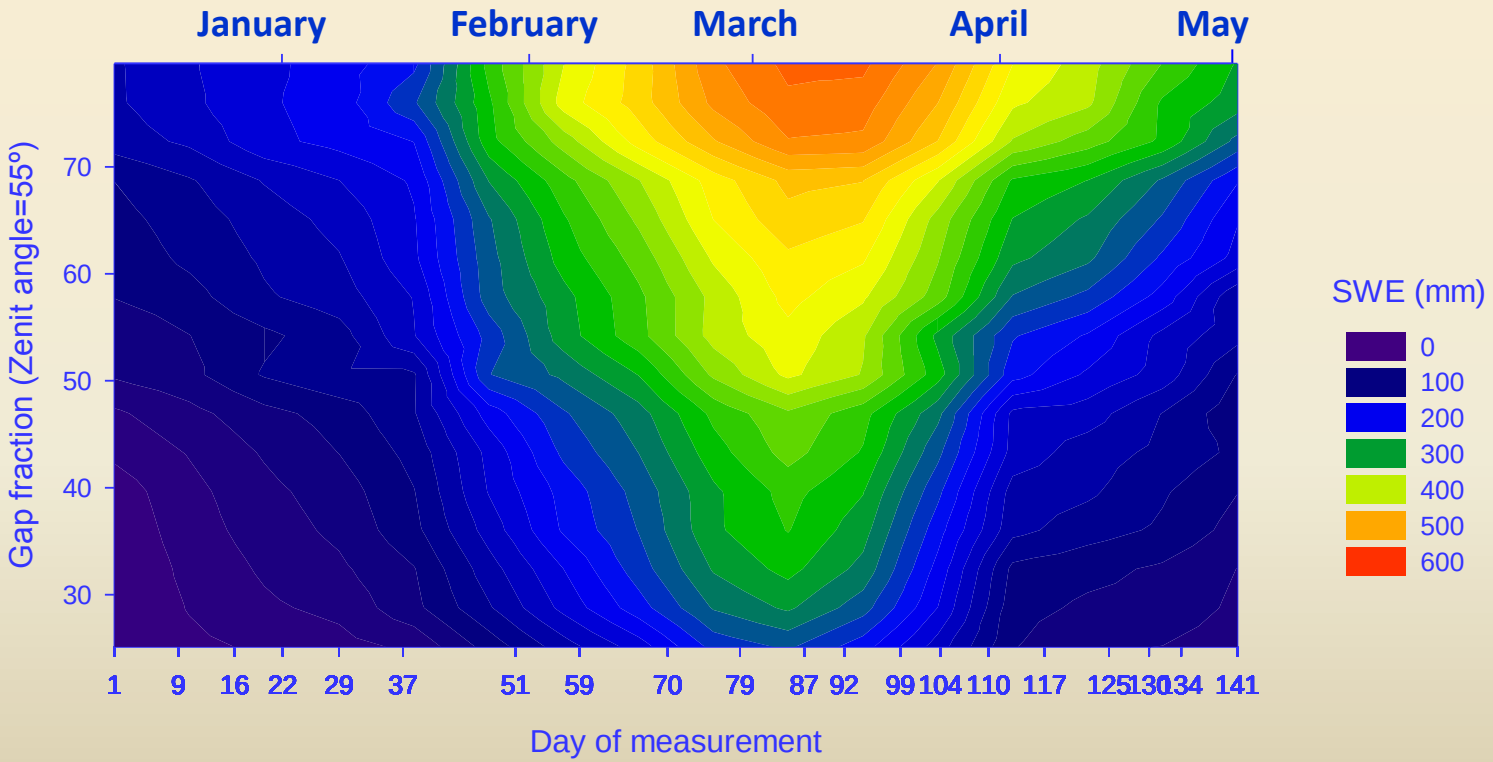
Spatial variability: forests

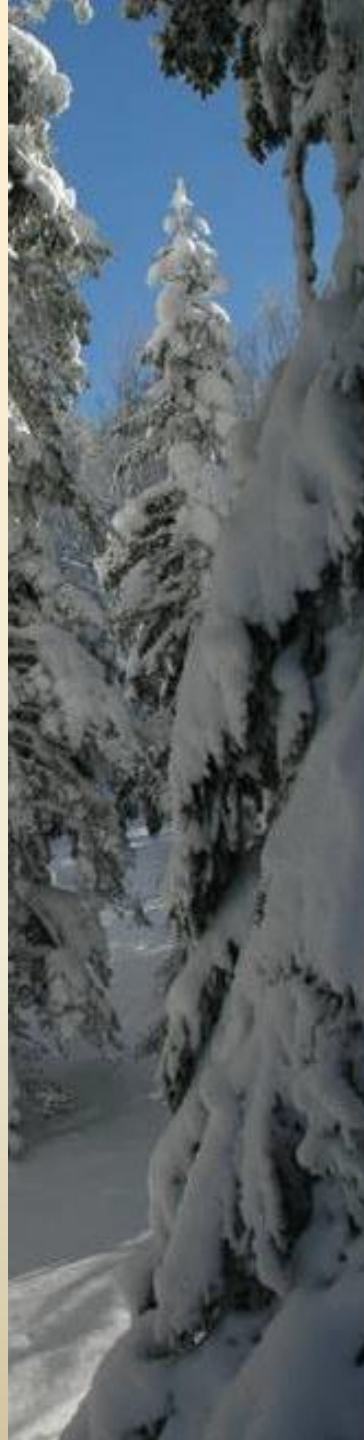
Canopy density from (GLA v2.0)



Spatial variability: forests

Relation between canopy density and SWE evolution

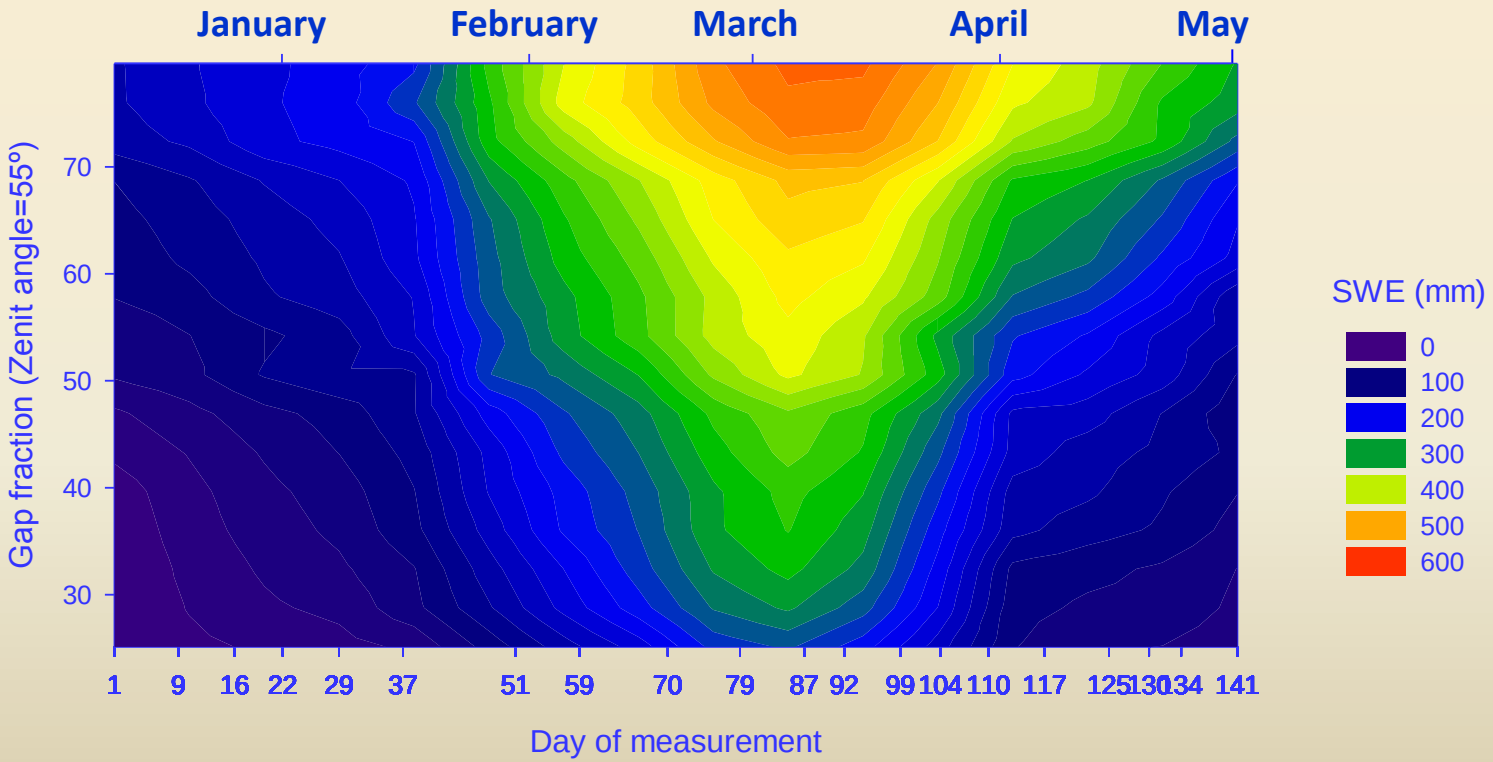


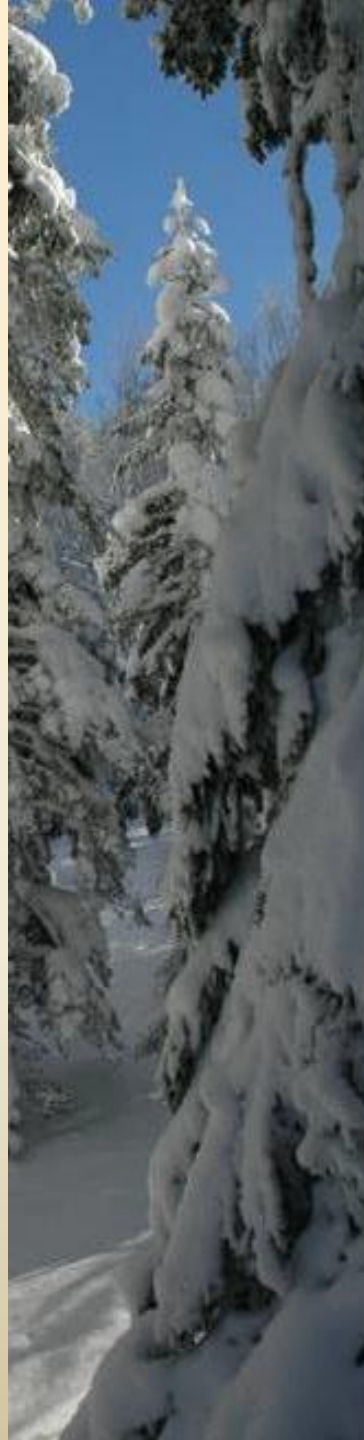


López-Moreno, J.I. and Latron, J. (2008). Influence of forest canopy on snow distribution in a temperate mountain range. Hydrological Processes 22 (1): 117-126. ISSN: 0885-6087.

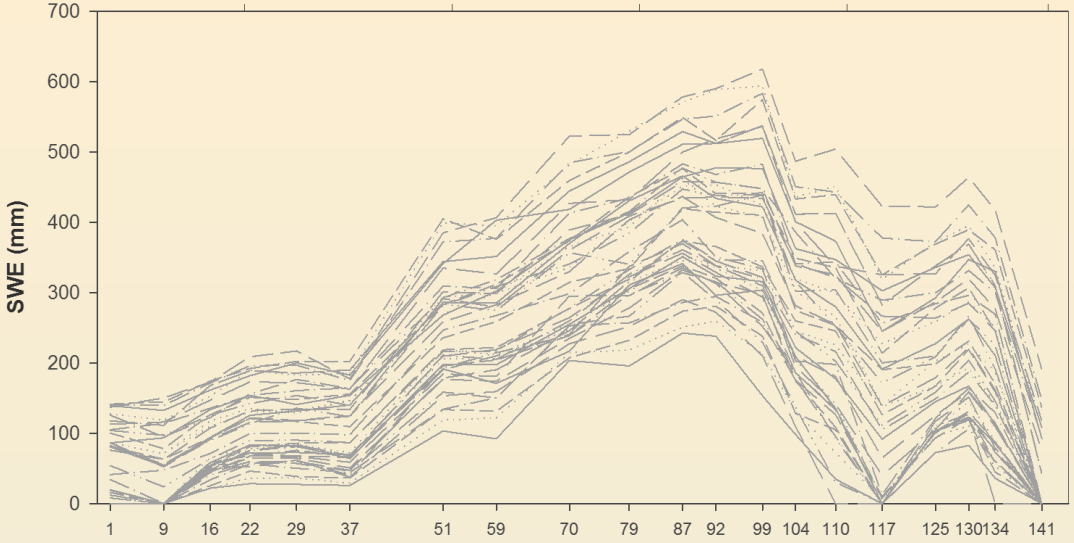
Spatial variability: forests

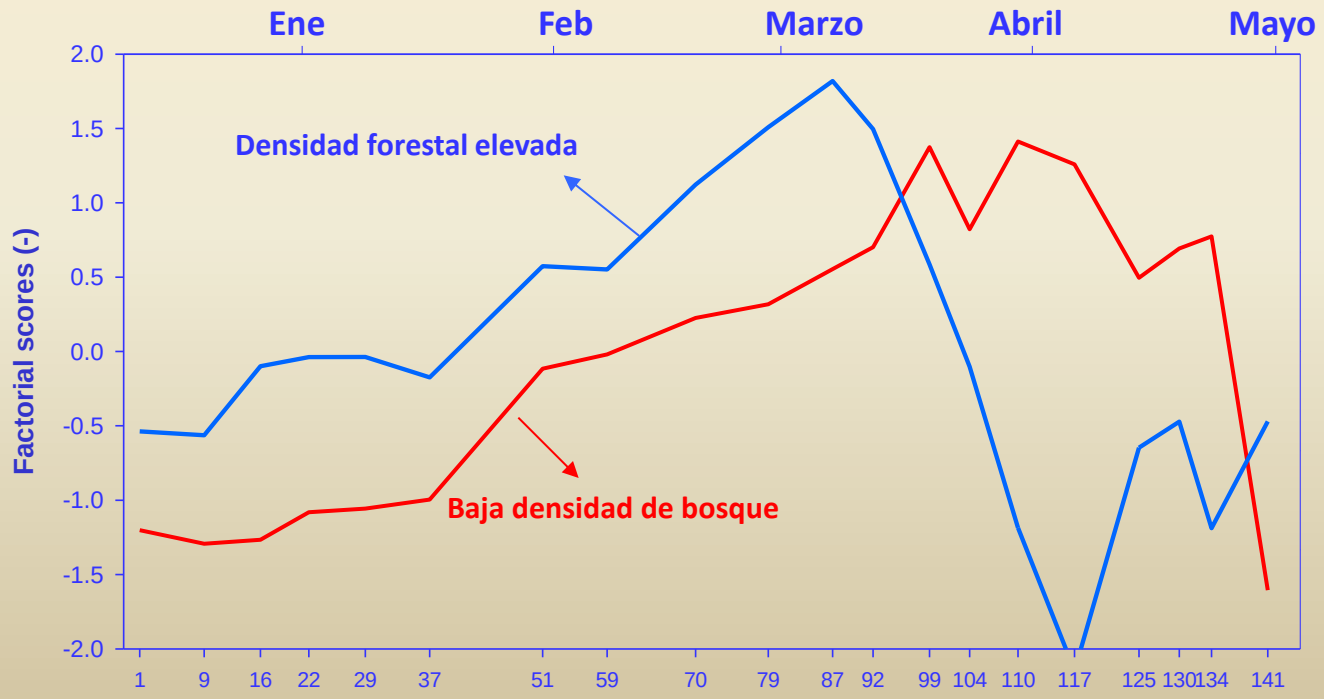
Relación entre densidad del dosel forestal y acumulación de nieve





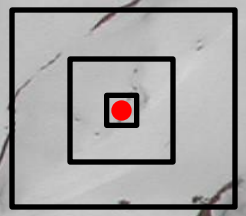
Spatial variability: forests

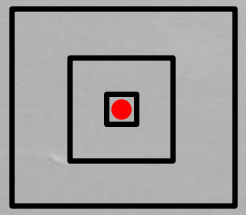




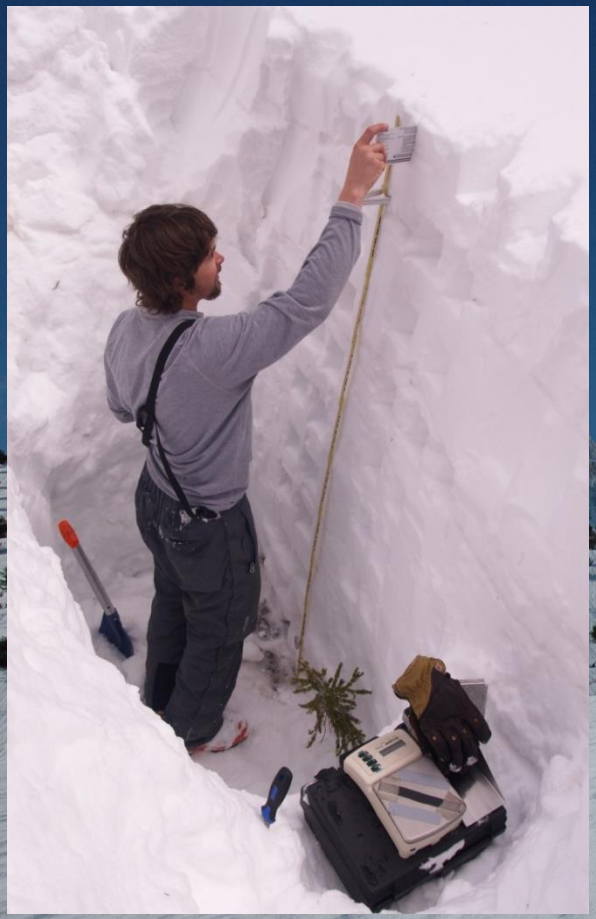
How much data is necessary?, which sampling strategy?

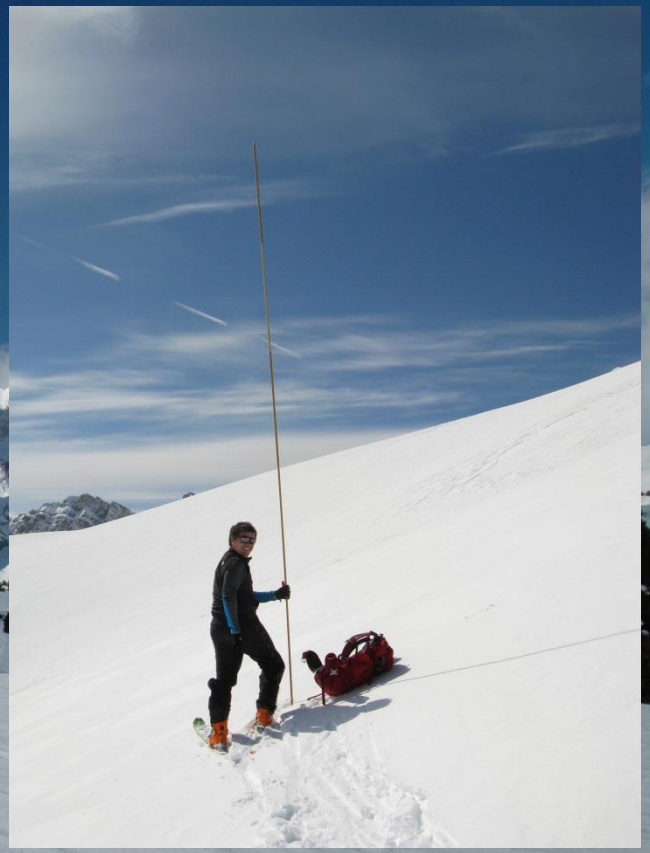
Importance of local snow variability for snow sampling





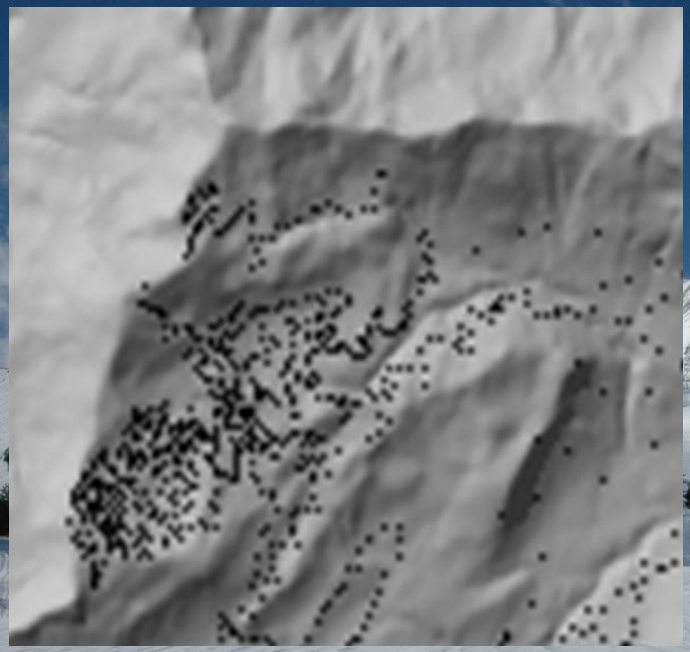
Is a single measurement representative of the immediate surroundings?

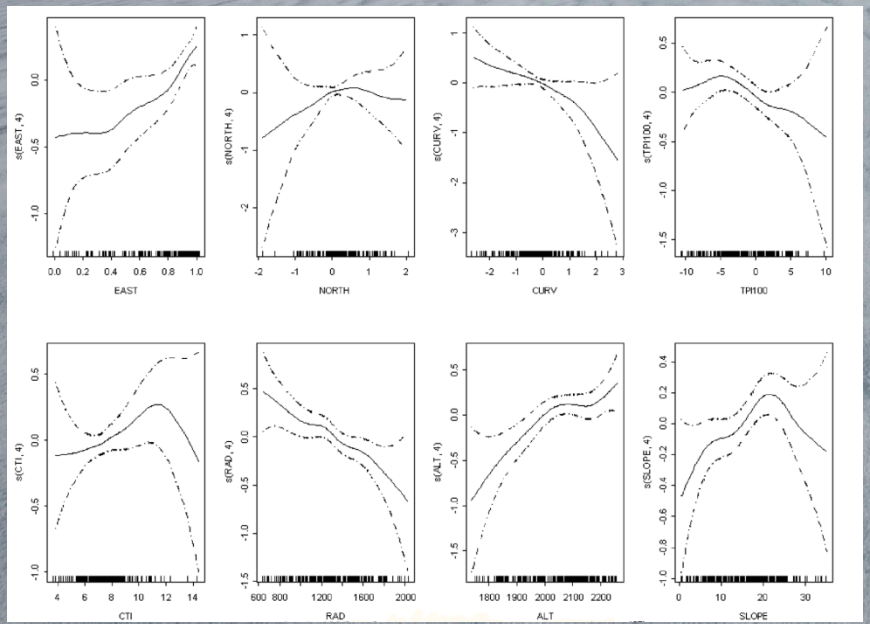


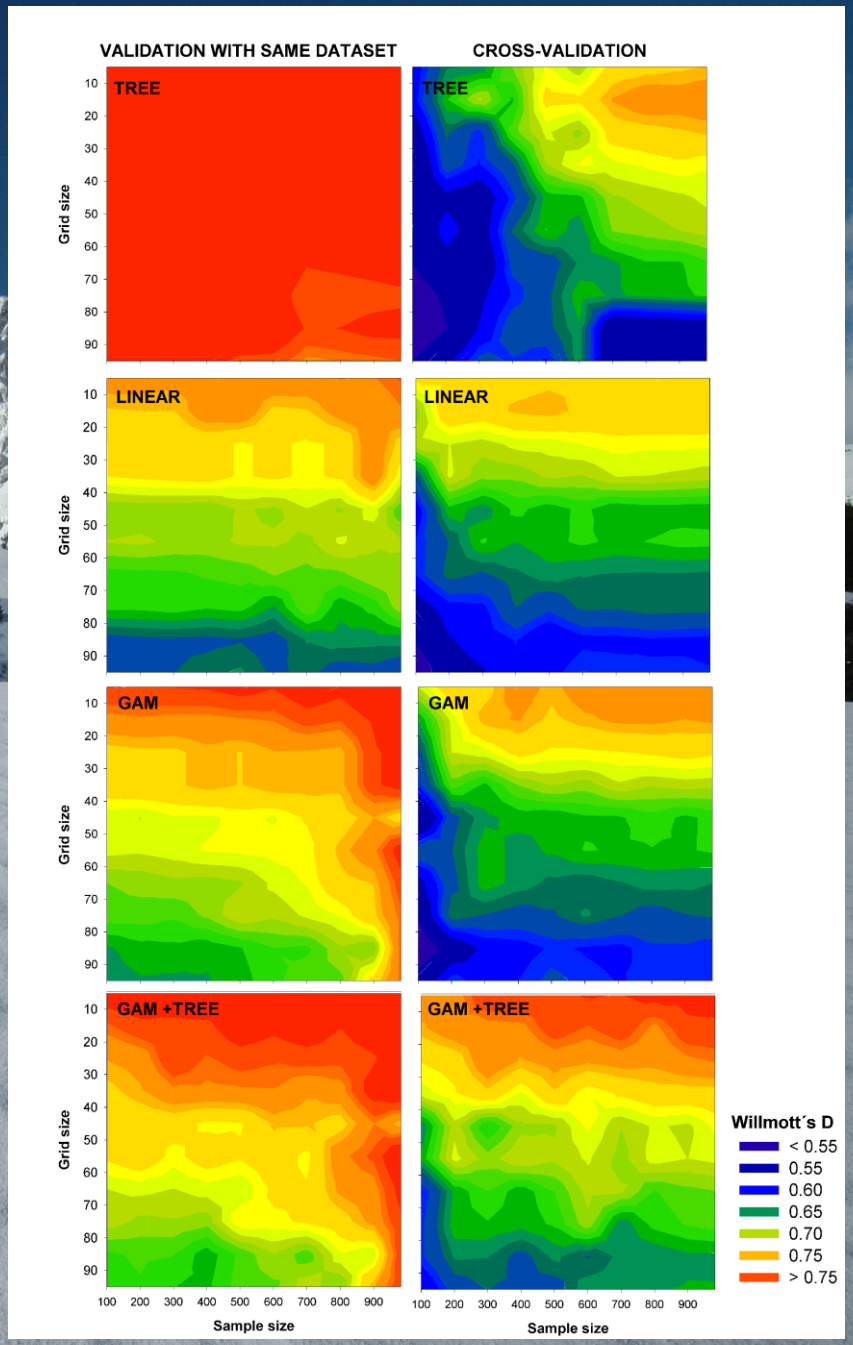


How many measurements of density and depth do we need for characterizing SWE?

How many measurements do we need?







•Is a single measurement representative of the immediate surroundings?

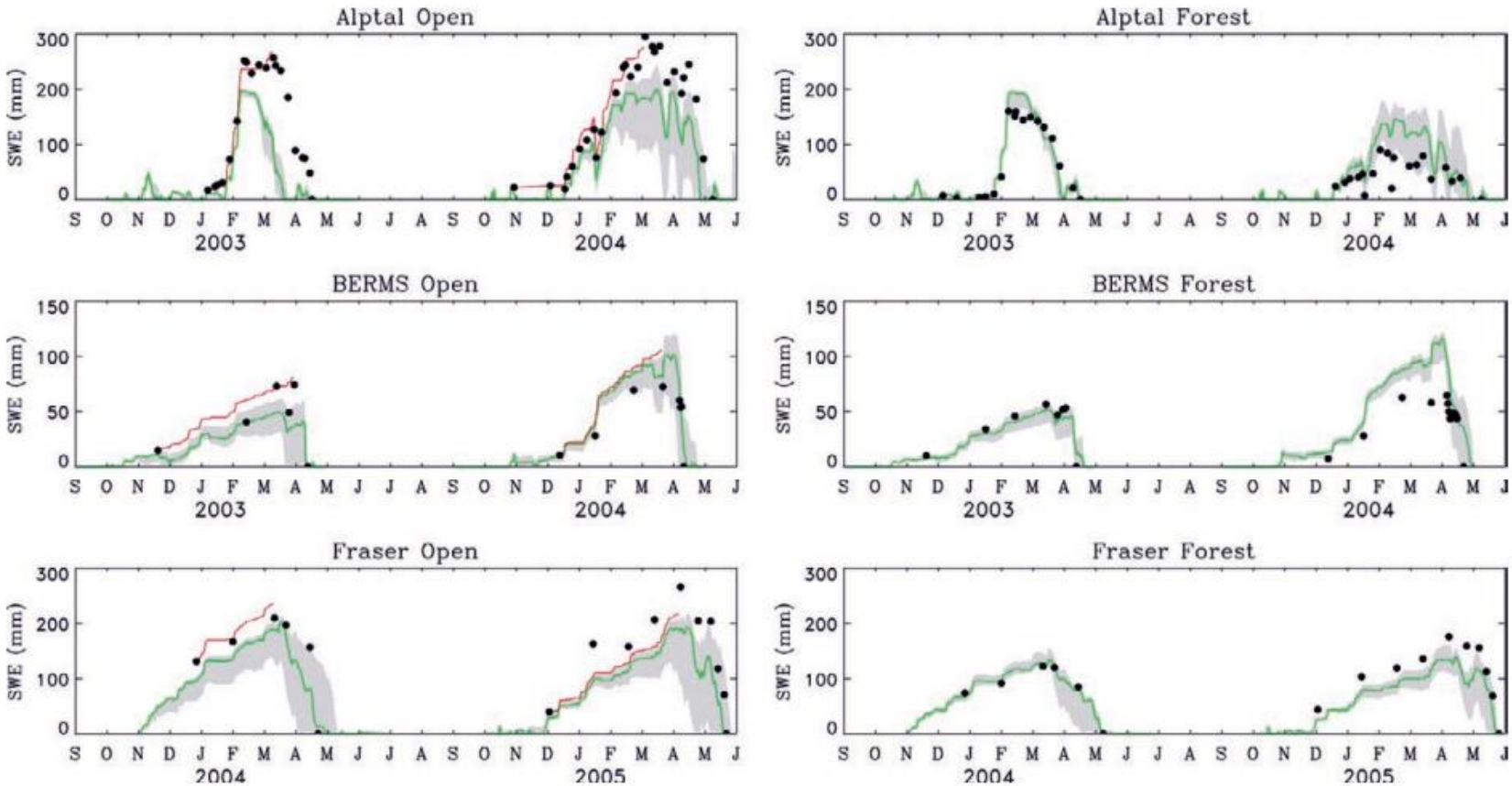
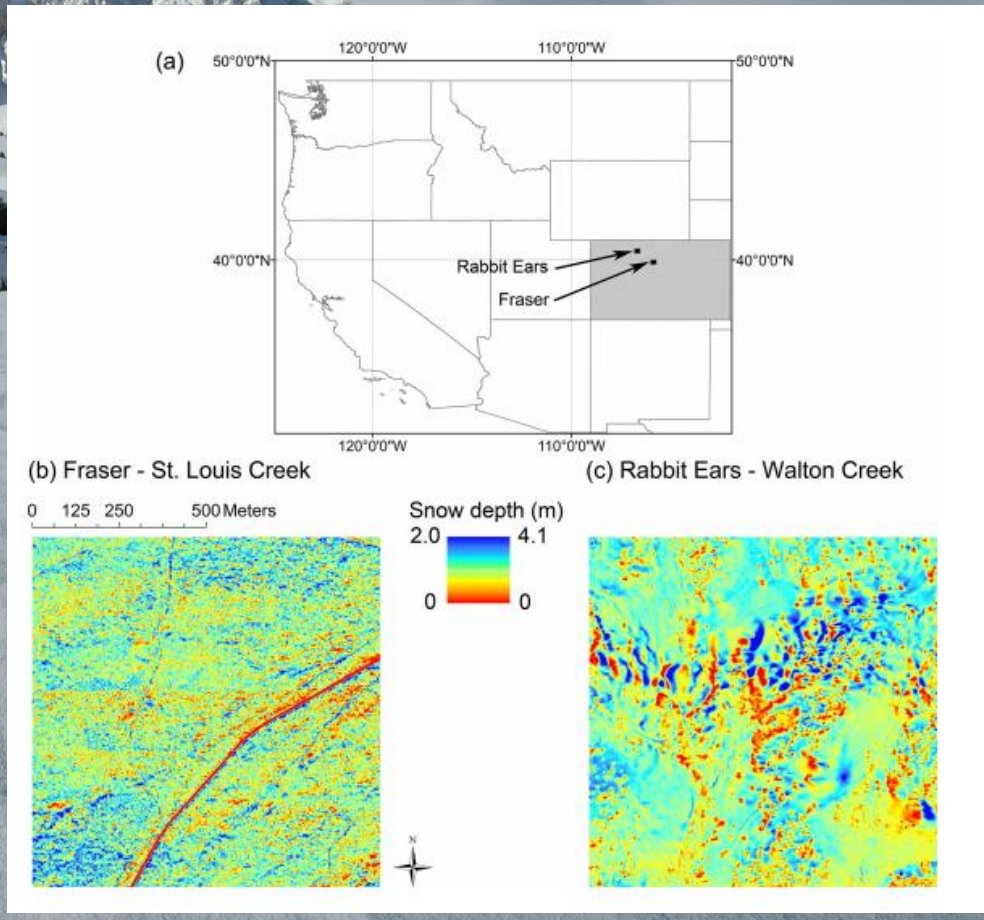


FIG. 4. Observed and modeled snow-water equivalent at open and forested sites. Observations (black dots), model medians (green lines), and interquartile ranges (gray bands) are shown. Red lines show cumulatve snowfall at open sites between the time of the first snow survey each winter and the time of maximum accumulation.

•Is a single measurement representative of the immediate surroundings?



•Is a single measurement representative of the immediate surroundings?

The Cryosphere, 9, 1249–1264, 2015
www.the-cryosphere.net/9/1249/2015/
doi:10.5194/tc-9-1249-2015
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Theoretical analysis of errors when estimating snow distribution through point measurements

E. Trujillo[1,2] and M. Lehning[2,1]

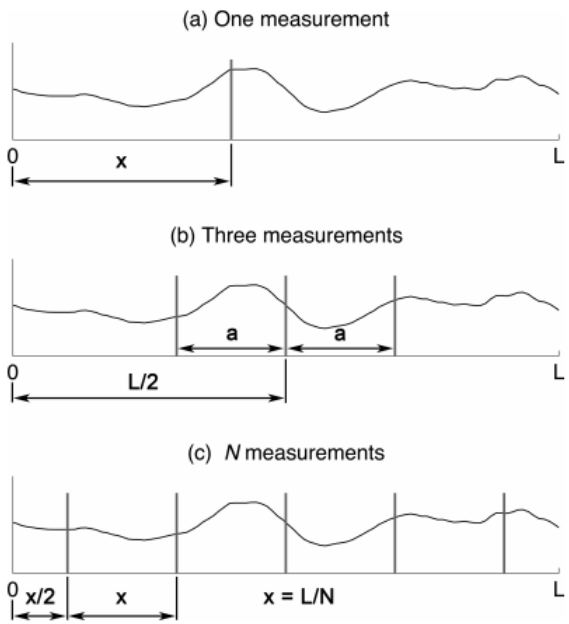

Figure 5. Survey designs for the sampling of a snow profile.

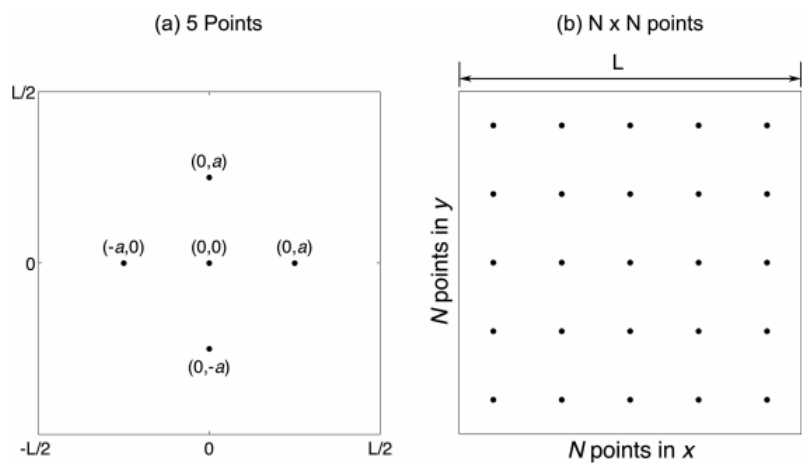

Figure 12. Sample survey designs with **(a)** a five-point pattern centered in the area, and **(b)** a regularly spaced pattern. For the five-point pattern, a can vary between 0 and $L/2$, while for the $N \times N$ points pattern, the separation between the measurements is determined by the number of points.

•Is a single measurement representative of the immediate surroundings?

The Cryosphere, 9, 1249–1264, 2015
www.the-cryosphere.net/9/1249/2015/
doi:10.5194/tc-9-1249-2015
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Theoretical analysis of errors when estimating snow distribution through point measurements

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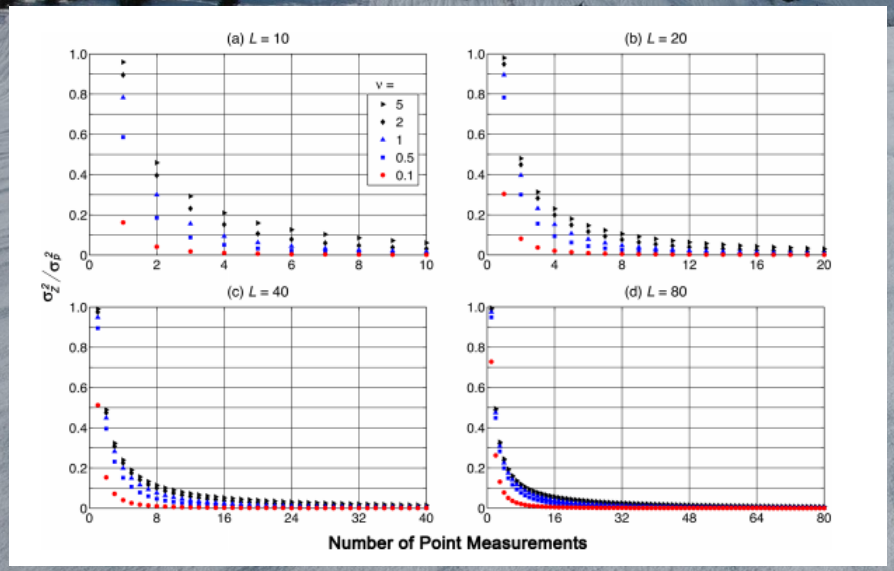
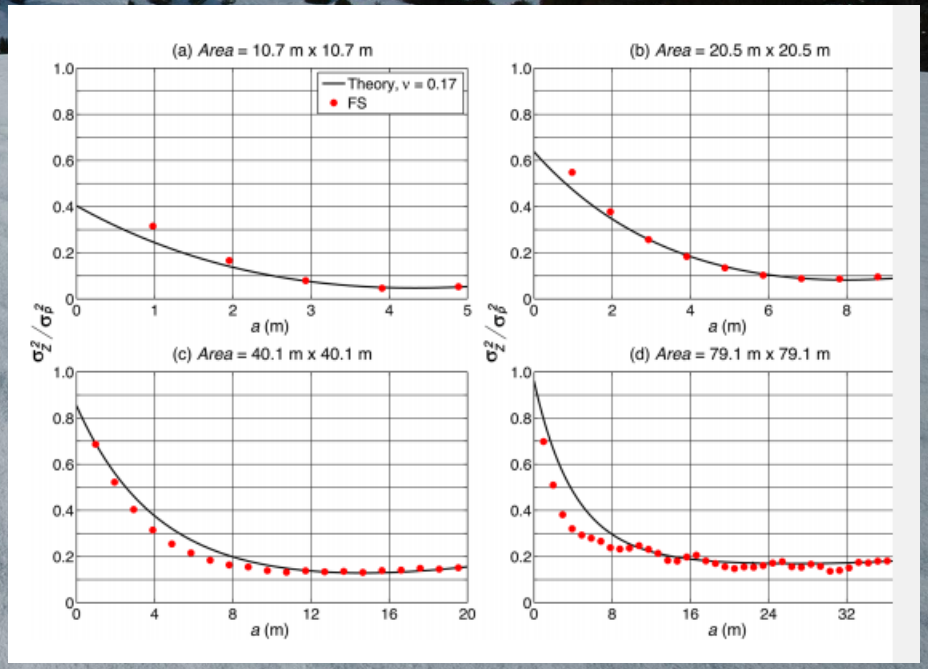
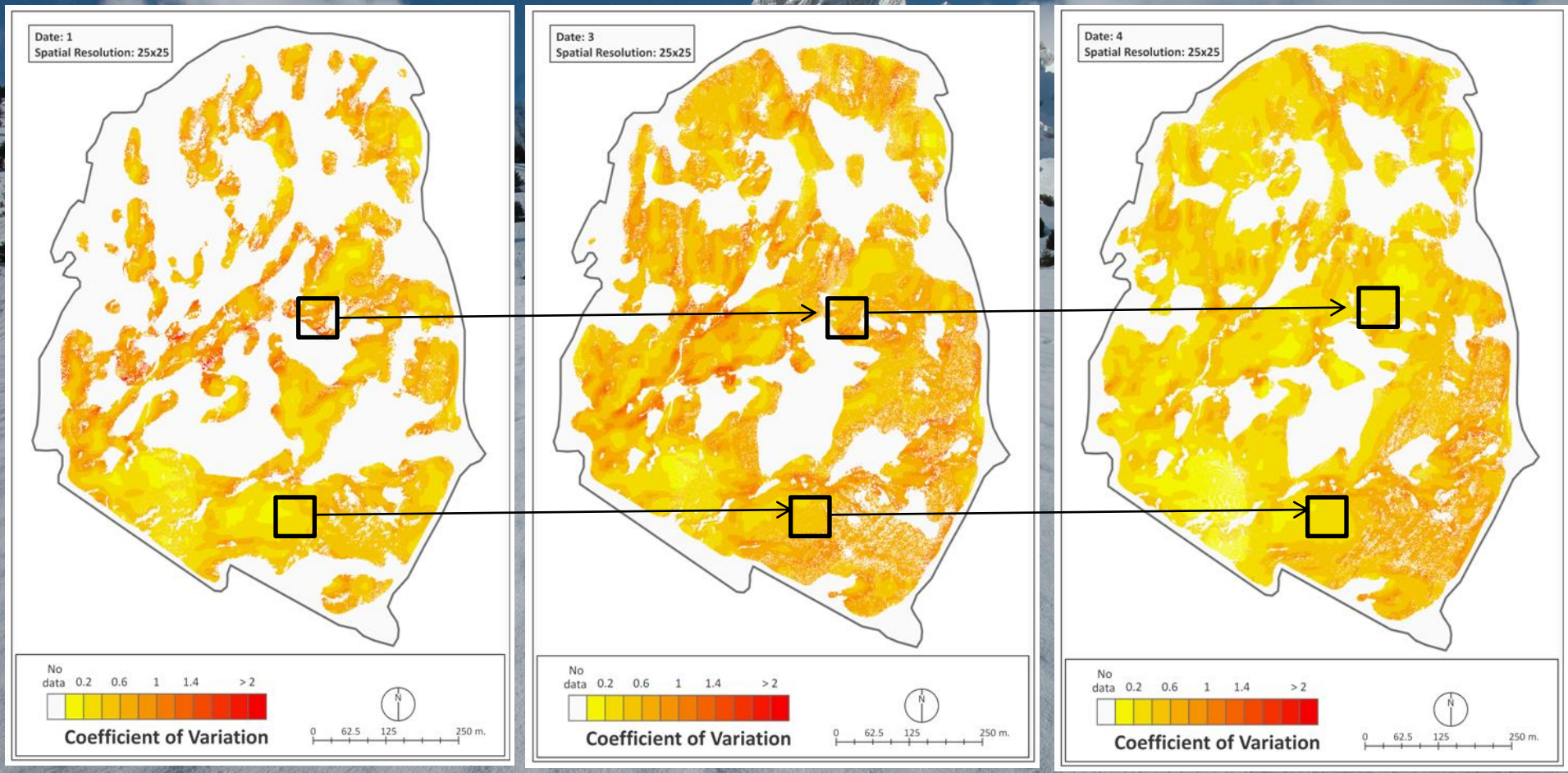




•Is a single measurement representative of the immediate surroundings?

February, 22nd | **April, 17th** | **May, 14th**

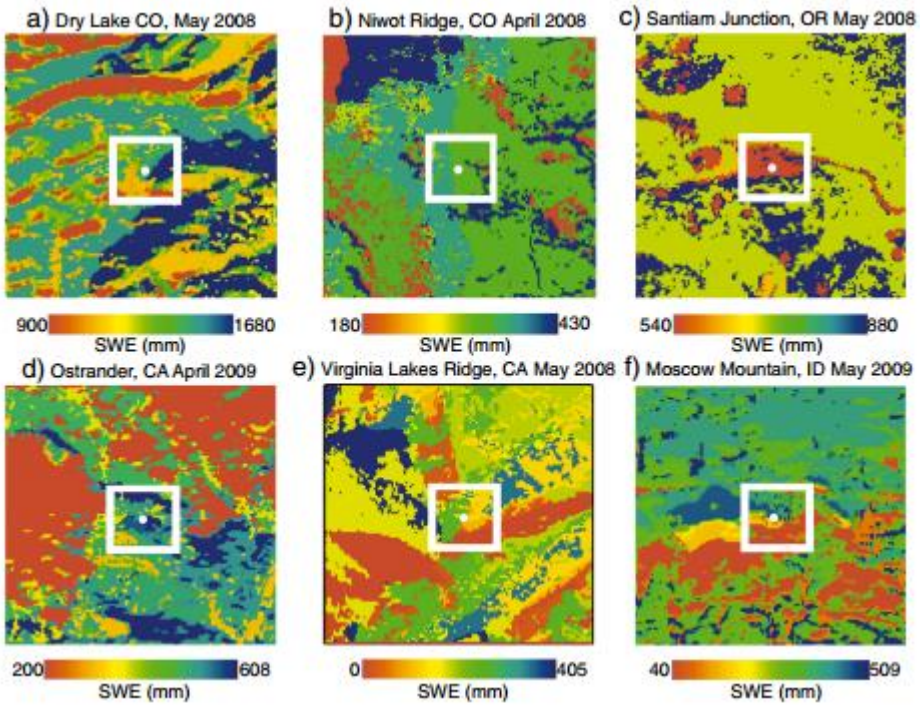


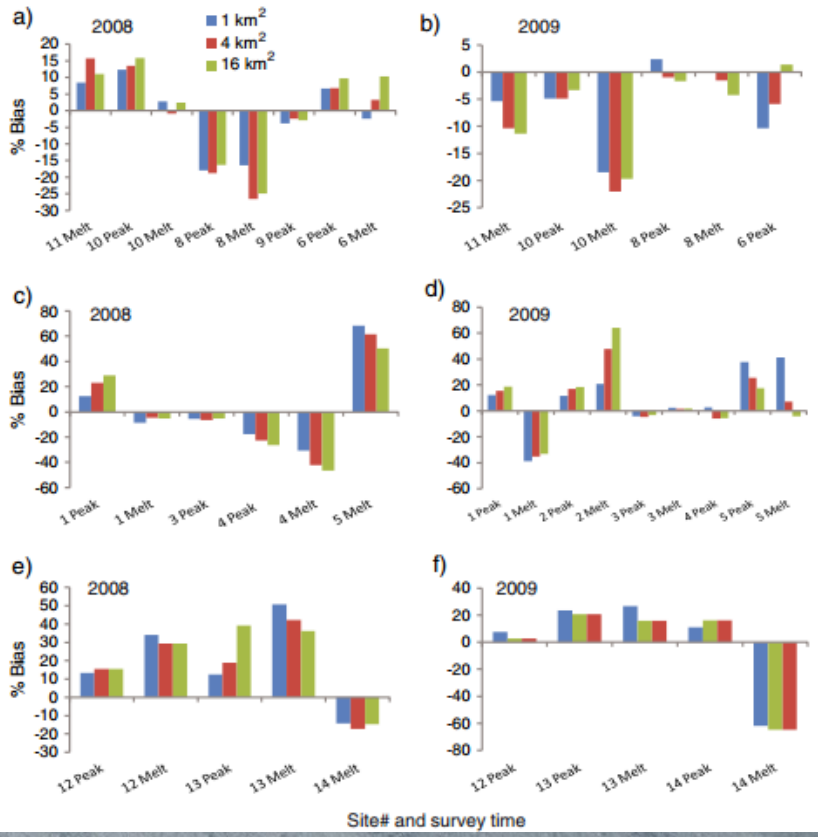
•Is a single measurement representative of the immediate surroundings?

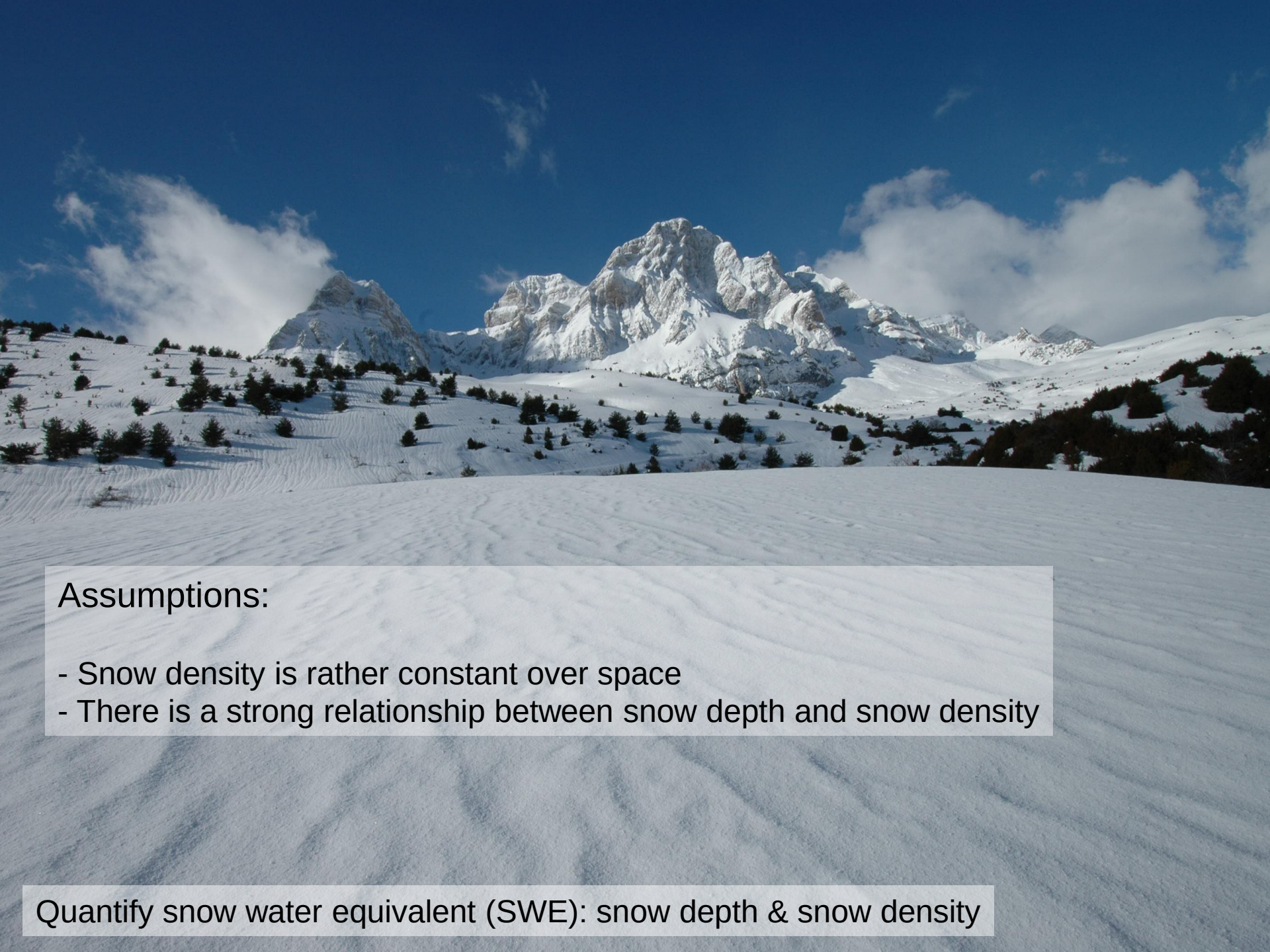
HYDROLOGICAL PROCESSES
Hydrol. Process. (2012)
Published online in Wiley Online Library
(wileyonlinelibrary.com) DOI: 10.1002/hyp.9355

Subgrid variability of snow water equivalent at operational snow stations in the western USA

Leah Meromy,[1]* Noah P. Molotch,[1,2] Timothy E. Link,[3] Steven R. Fassnacht[4] and Robert Rice[5]







Assumptions:

- Snow density is rather constant over space
- There is a strong relationship between snow depth and snow density

Quantify snow water equivalent (SWE): snow depth & snow density

Estimating Snow Water Equivalent Using Snow Depth Data and Climate Classes

MATTHEW STURM,* BRIAN TARAS,+ GLEN E. LISTON,# CHRIS DERKSEN,@ TOBIAS JONAS,& AND JON LEA**

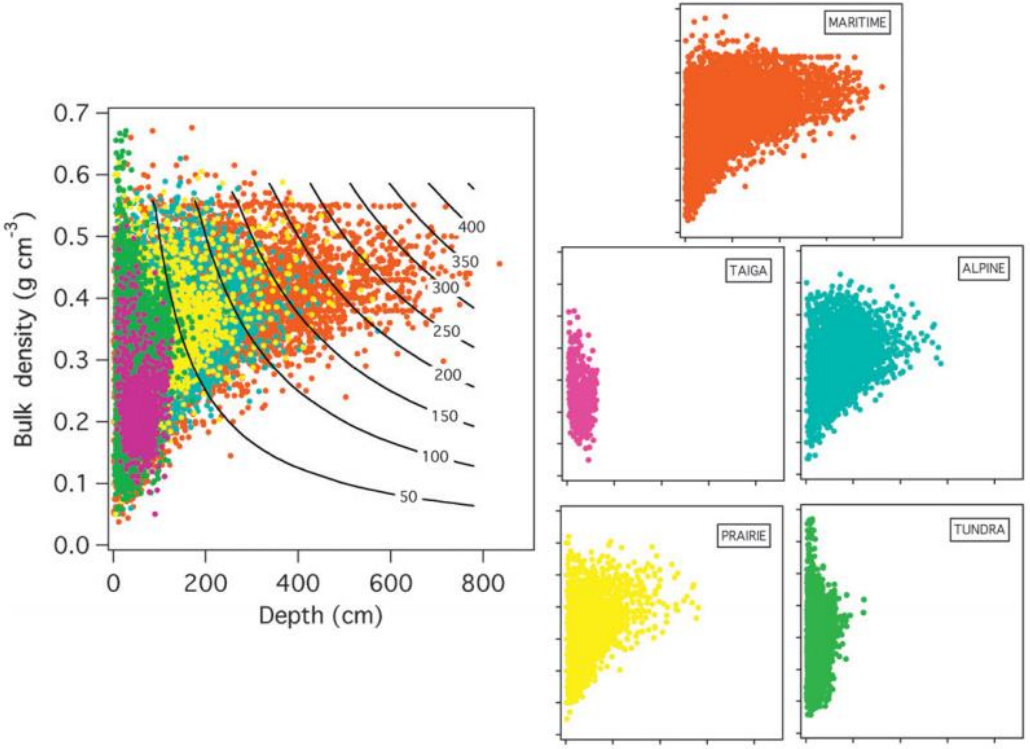


FIG. 4. Different density patterns by snow classes for the training dataset. Contours in the main figure are for SWE (cm) and satisfy Eq. (1). The patterns are similar for the test dataset.

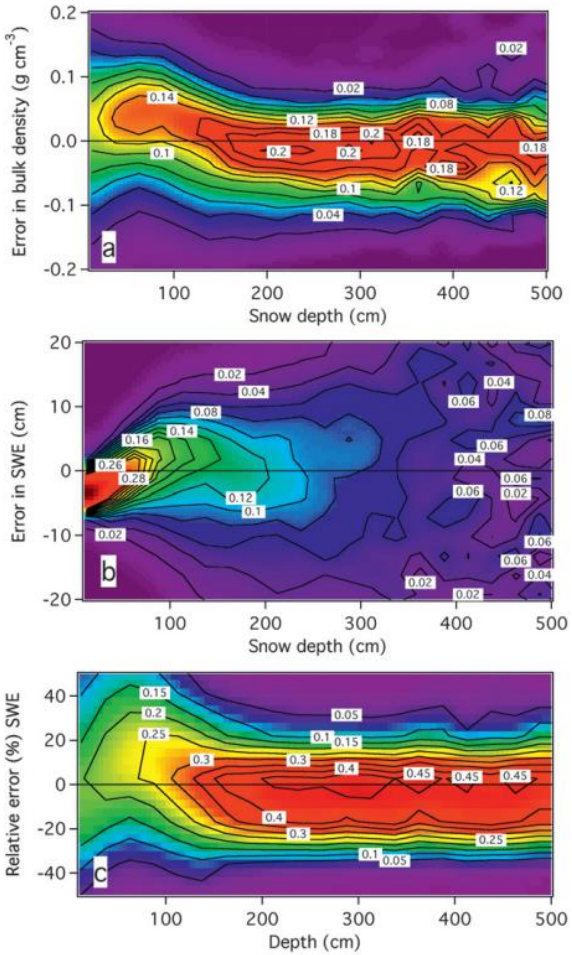
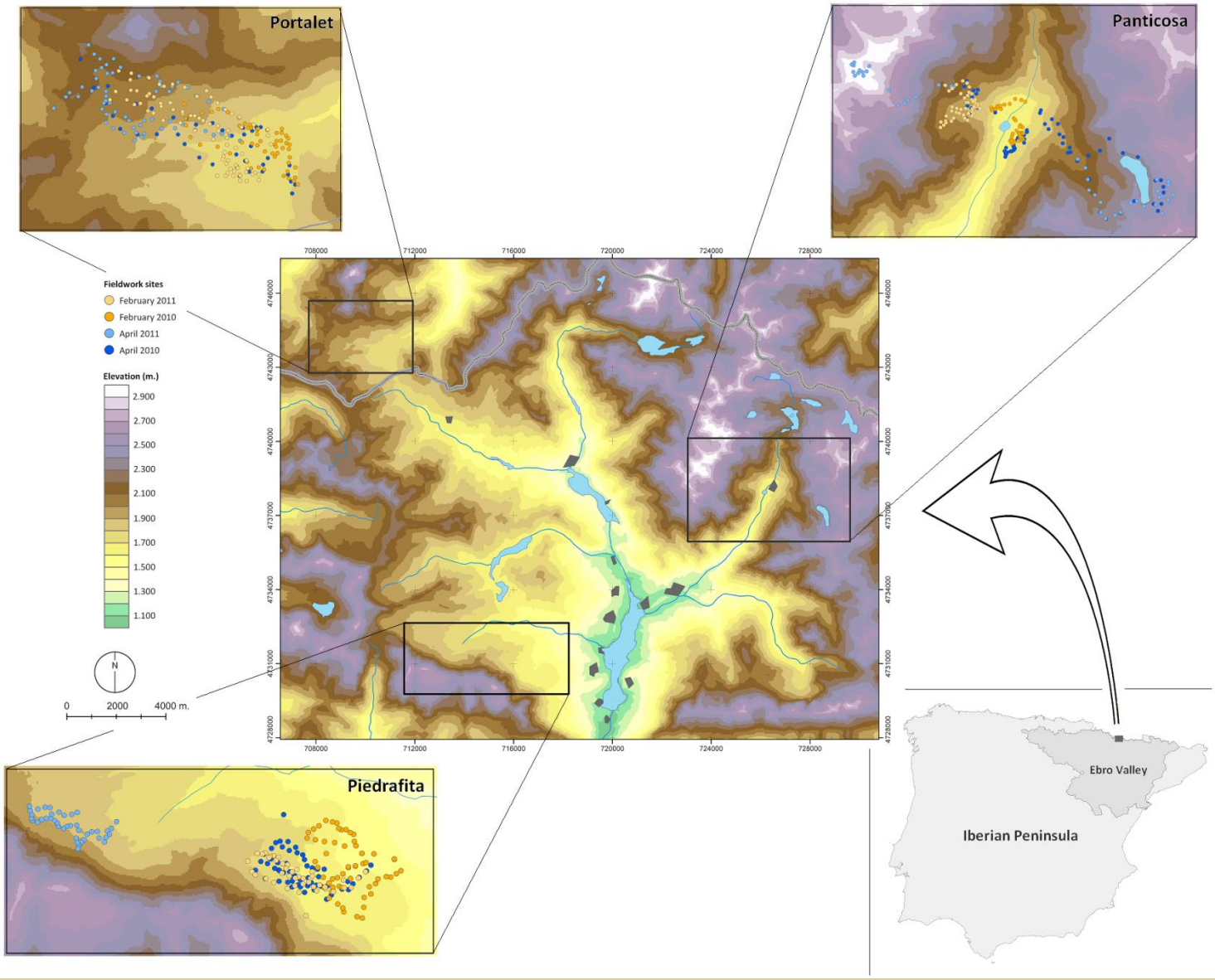
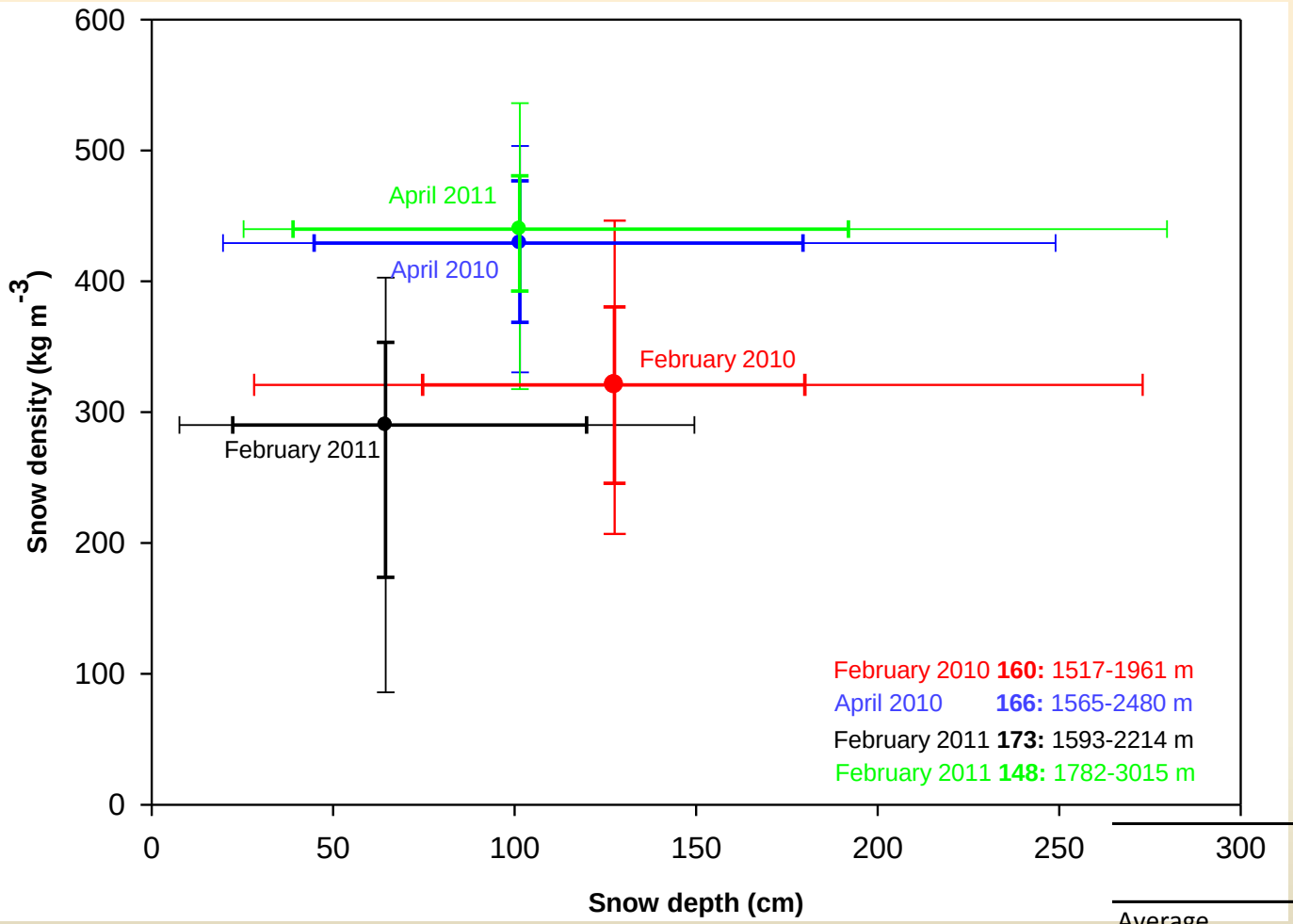


FIG. 10. Contours of probability density for (a) the error in bulk density as a function of snow depth, (b) the error in SWE as a function of depth, and (c) the relative error in SWE (error/SWE) as a function of depth.

Quantify snow water equivalent (SWE): snow depth & snow density

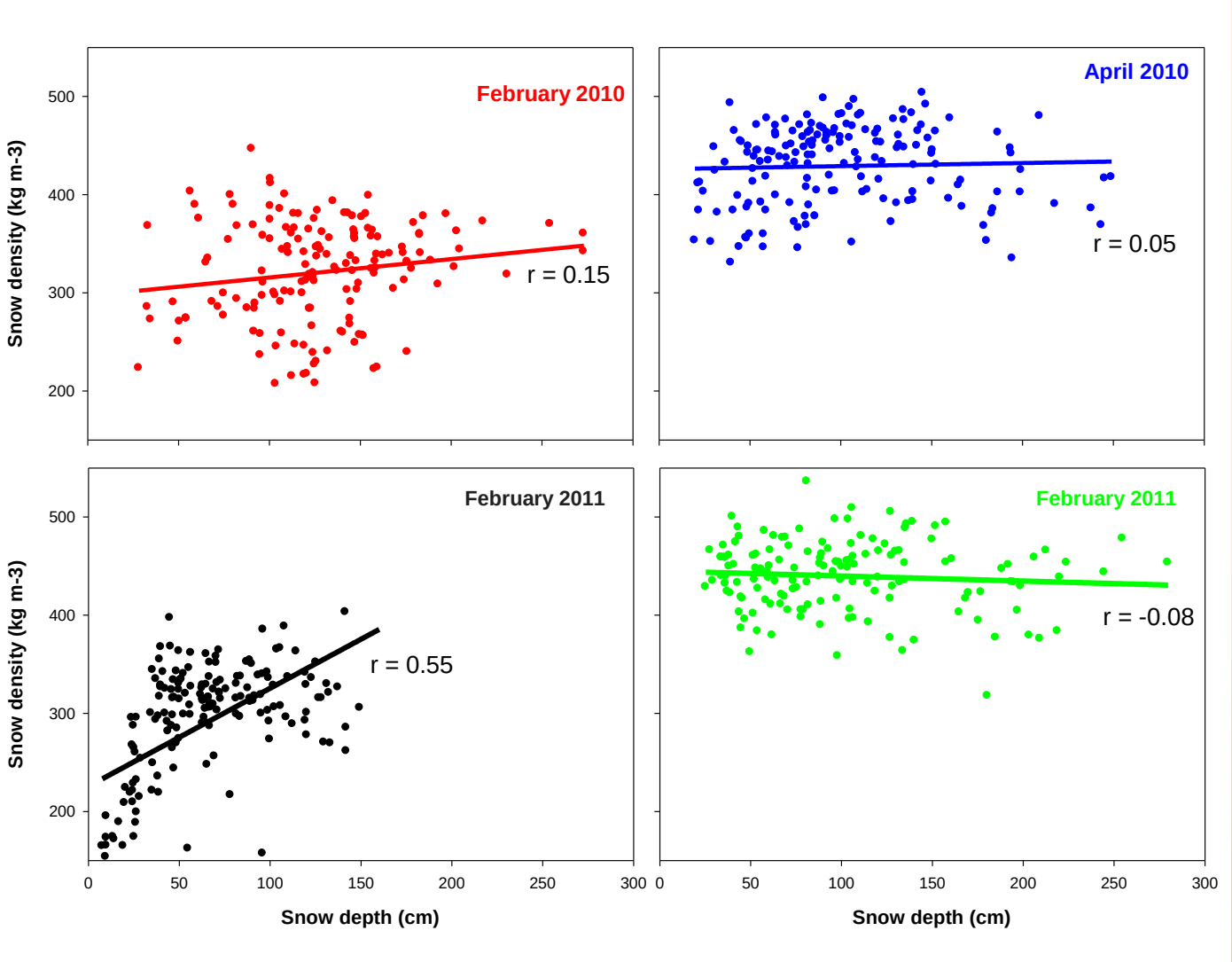

Portalet
Panticosa
Piedrafita
Fieldwork sites
February 2011
February 2010
April 2011
April 2010
Elevation (m.)
2.900
2.700
2.500
2.300
2.100
1.900
1.700
1.500
1.300
1.100
N
0
2000
4000 m.
708000
712000
716000
720000
724000
728000
4746000
4743000
4740000
4737000
4734000
4731000
4728000
Ebro Valley
Iberian Peninsula

Study area

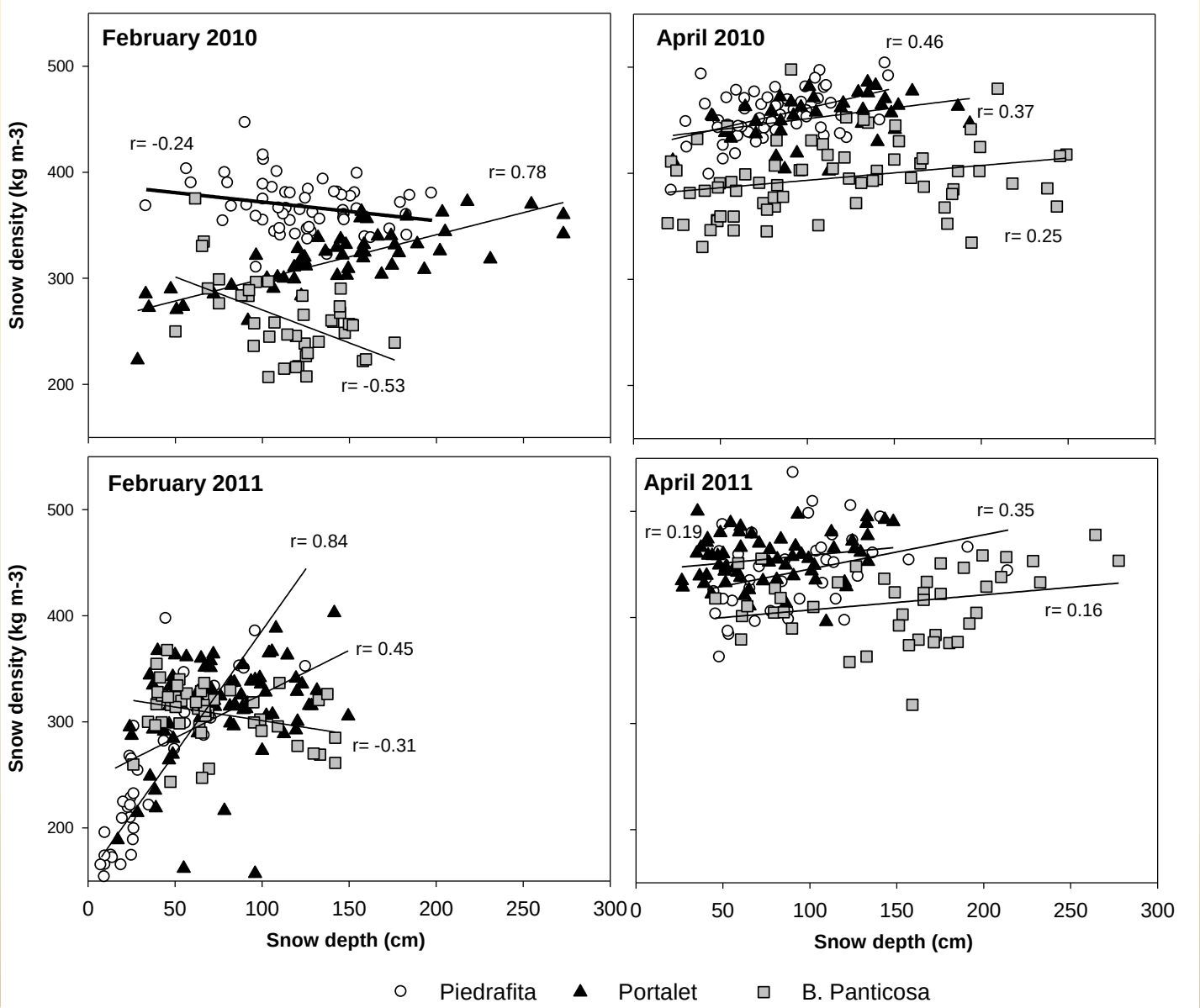


	Snow density (kg m^{-3})			
	F10	**A10**	**F11**	**A11**
Average	320.8	429.1	290.1	439.9
Standard Dev	51.2	40.1	63.5	35.1
CV	0.16	0.09	0.22	0.08
Var.Max-Min	74.7	40.3	109.2	49.7
Var.C90-C10	41.6	24.7	61.0	19.7
Var.C75-C25	23.6	14.4	22.0	9.9

Snow surveys



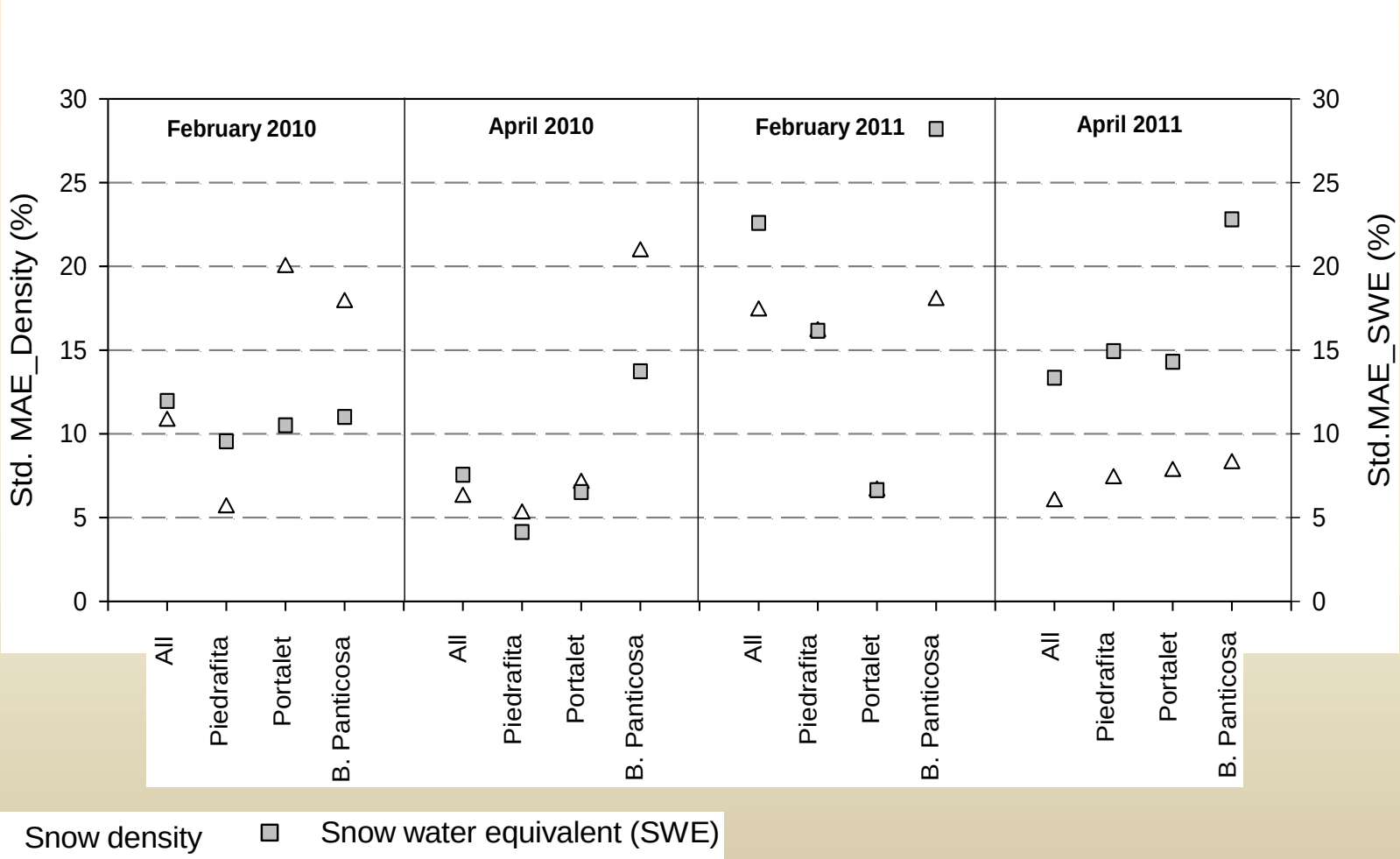
Snow depth *vs.* Snow density



Snow depth *vs.* Snow density

Linear regression models			
			Explained variance (r^2)
February 2010	All sites	Slope	34
	Piedrafita	Snow depth	34
	Portalet	Snow depth	62
	Panticosa	Snow depth; slope	24
April 2010	All sites	Snow depth, elevation, radiation, curvature, slope	34
	Piedrafita	Snow depth	21
	Portalet	elevation	33
	Panticosa	radiation	24
February 2011	All sites	Snow depth, elevation, radiation, curvature, slope	37
	Piedrafita	Snow depth, elevation, radiation,slope	79
	Portalet	Snow depth, radiation	21
	Panticosa	Snowdepth, slope	31
April 2011	All sites	Elevation, slope	16
	Piedrafita	Snow depth, radiation	21
	Portalet	Slope	14
	Panticosa	Slope, radiation	39

Correlation between snow density and different variables

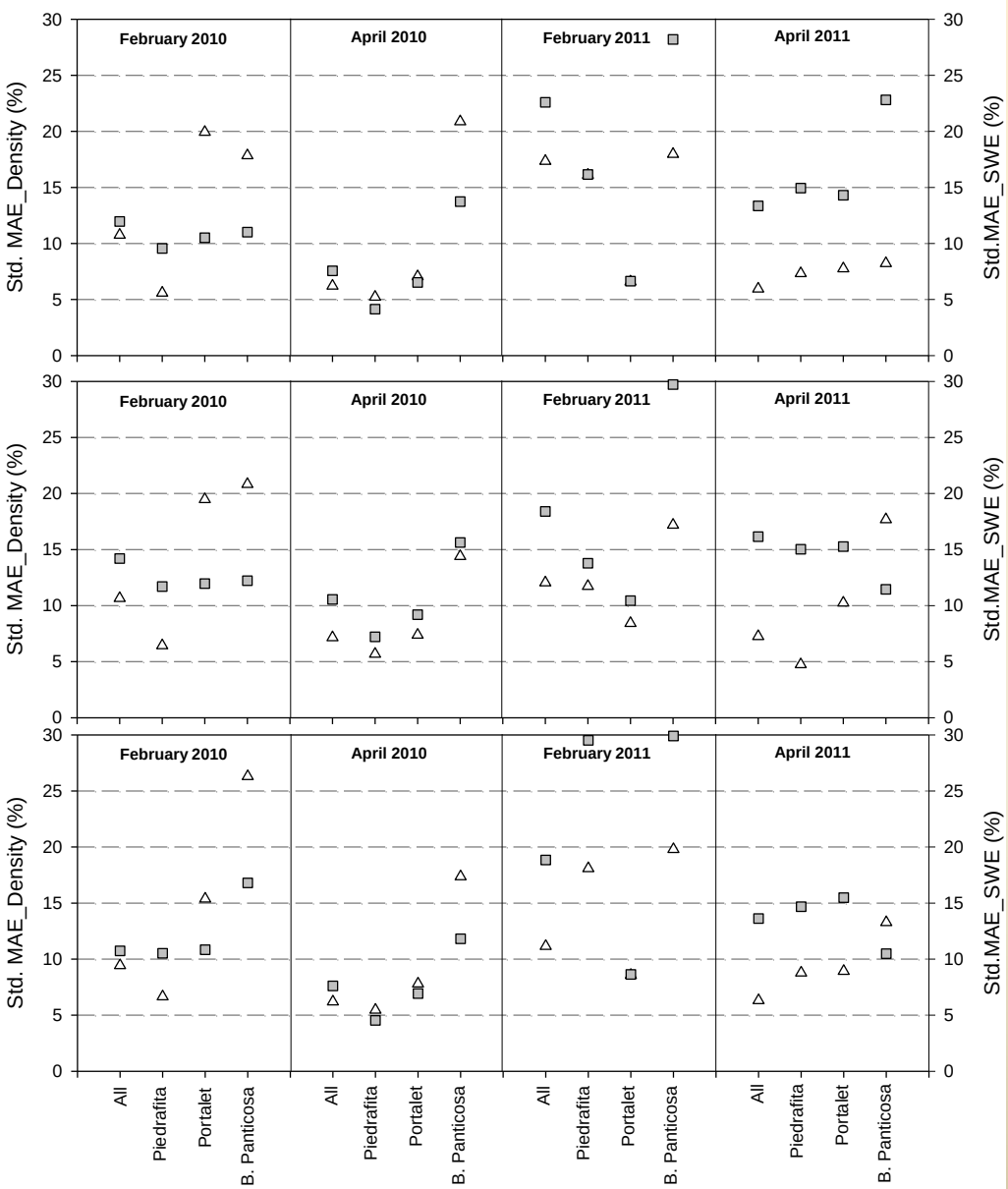


Standardized mean absolute error for snow density and SWE estimation using linear models

Linear

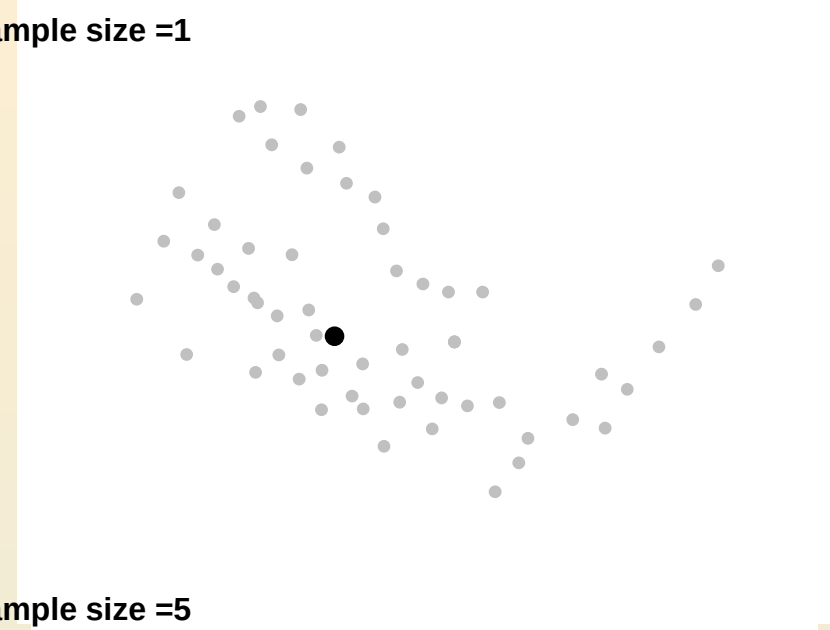
Tree

GAM

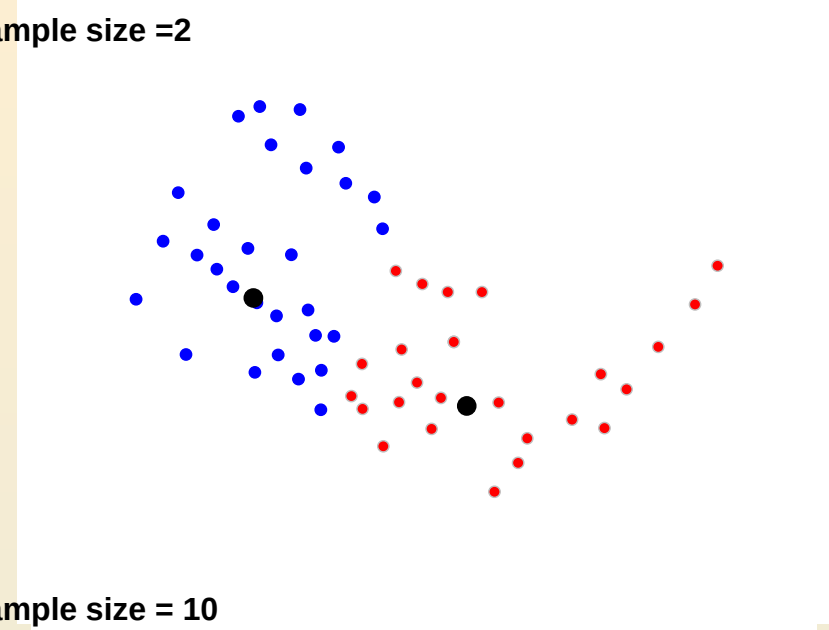


Standardized mean absolute error for snow density and SWE estimation using linear, tree and GAM models

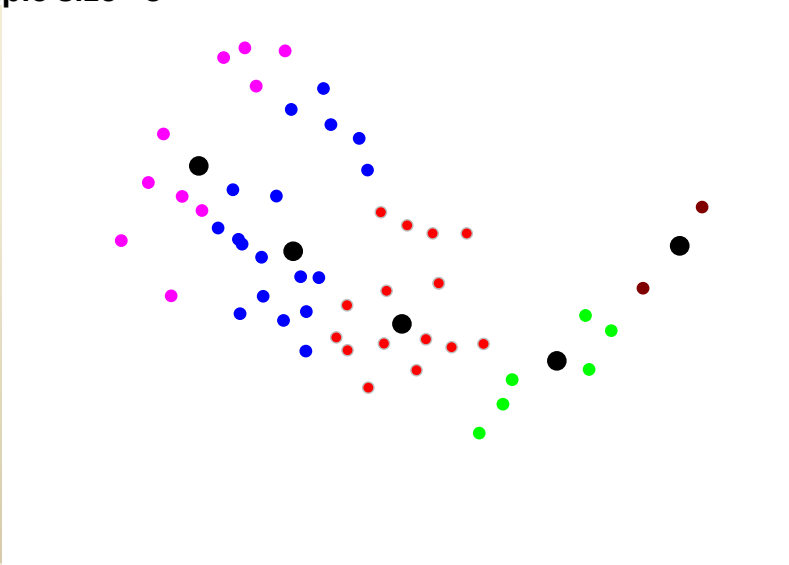
Sample size =1



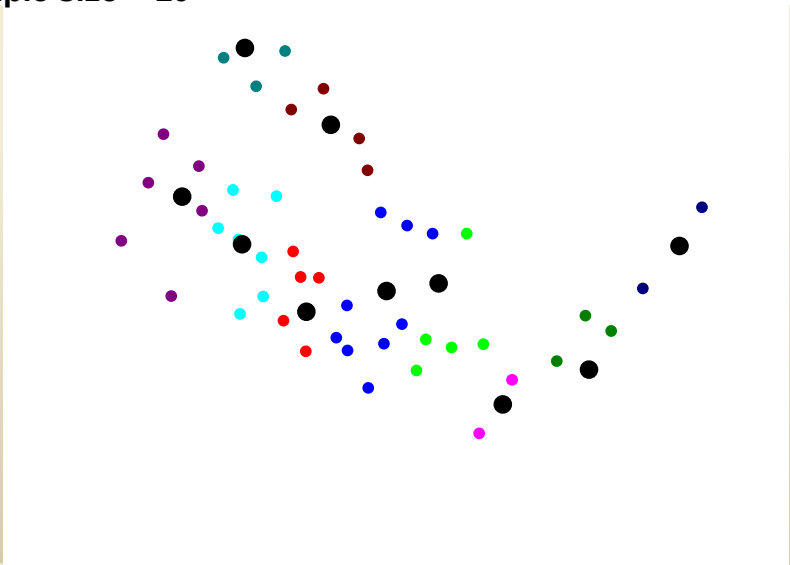
Sample size =2



Sample size =5



Sample size = 10



Sampling strategy for different sampling sizes to minimize distance to density measurements