

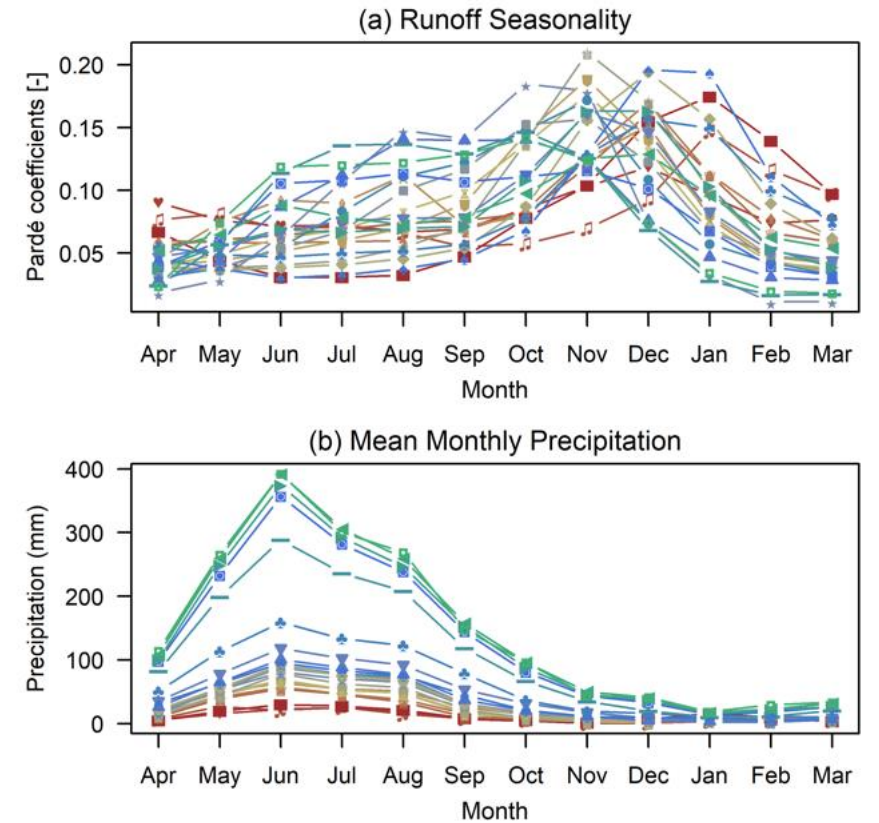
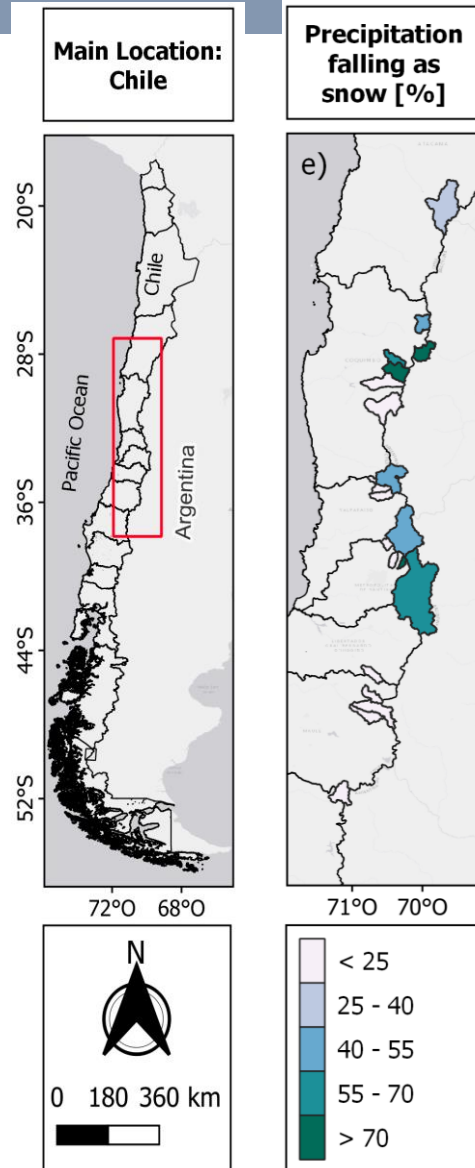
Relative influence of wind and avalanche redistribution at the mountain range scale in the South American Andes

María Courard
Diego Hernández
Alonso Mejías
James McPhee



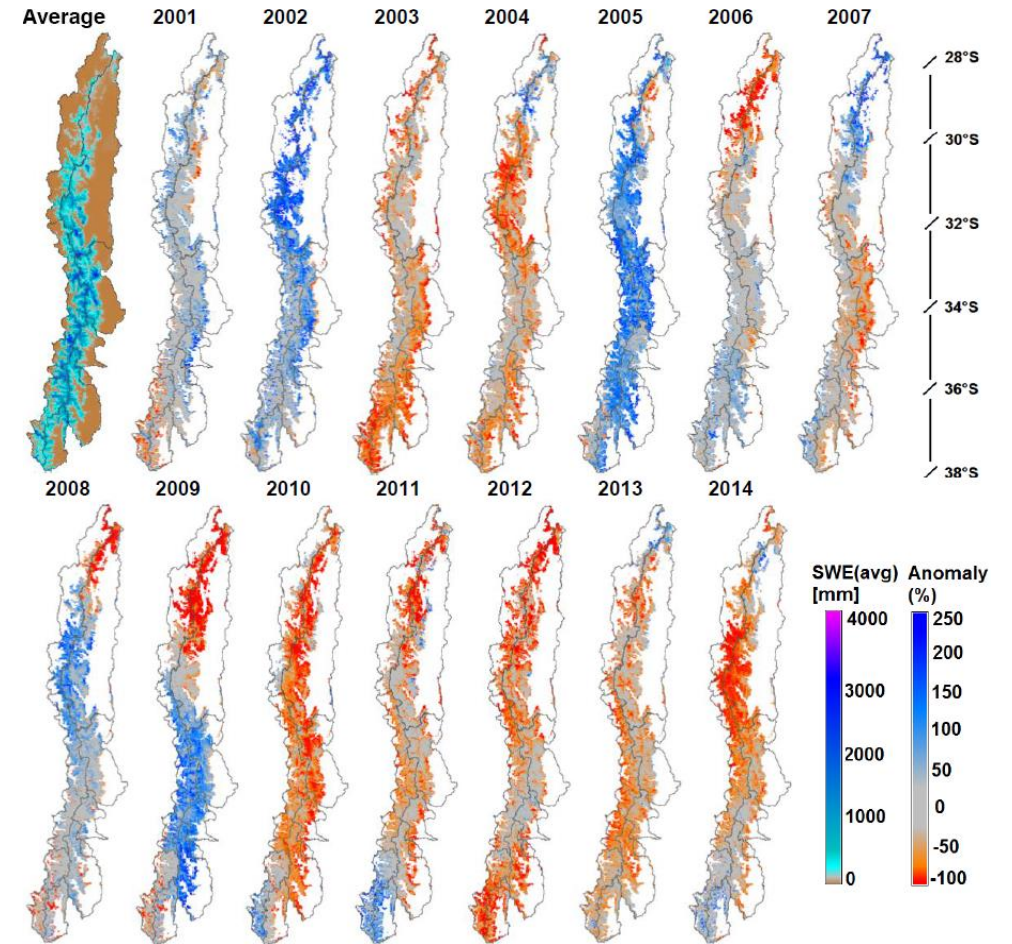
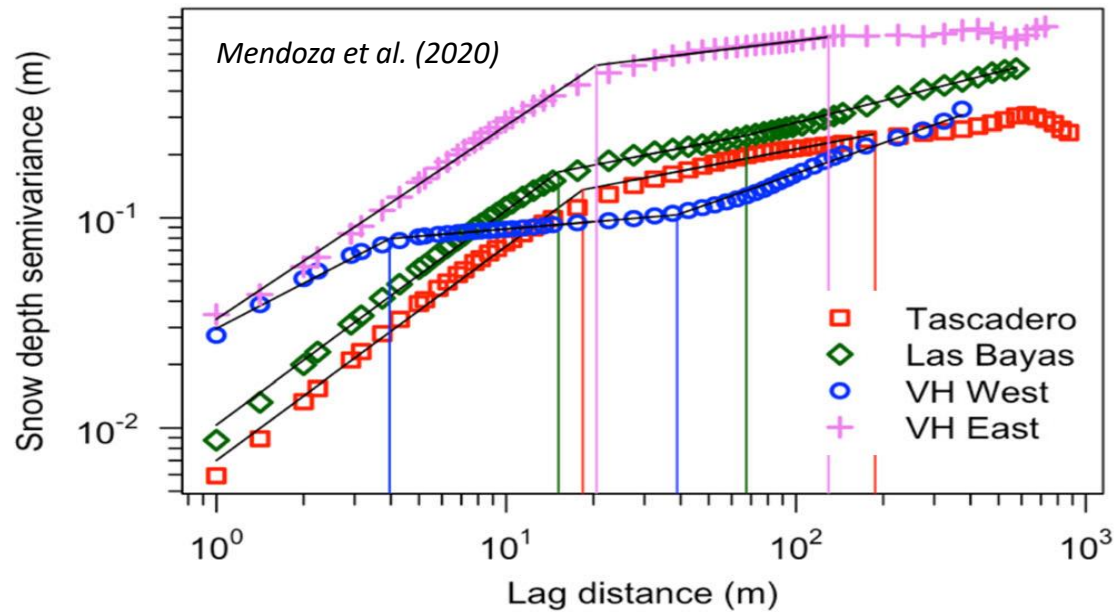
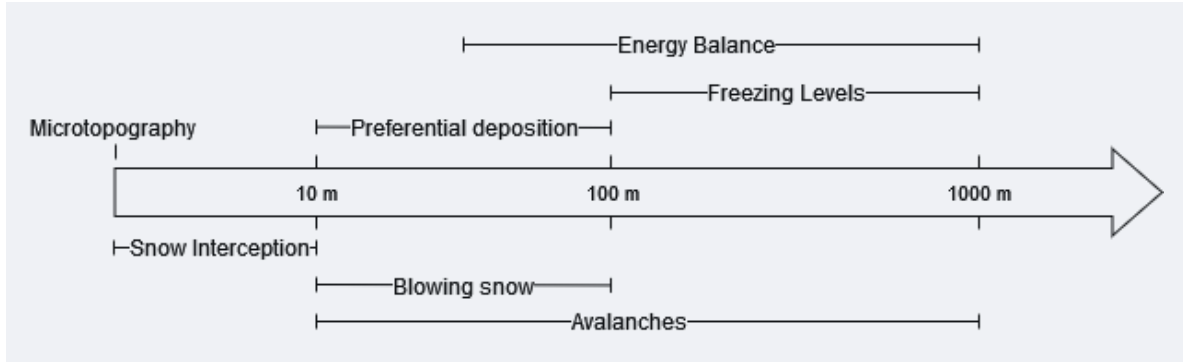
Chile is a mountain country where snow accumulation plays a critical hydrological role.

Recent efforts at retrospective modeling and reanalysis provide many insights, but no operational SWE estimates exist for the region.



Araya et al. (2024)

We aim to characterize and represent snow spatial variability relevant for hydrological applications

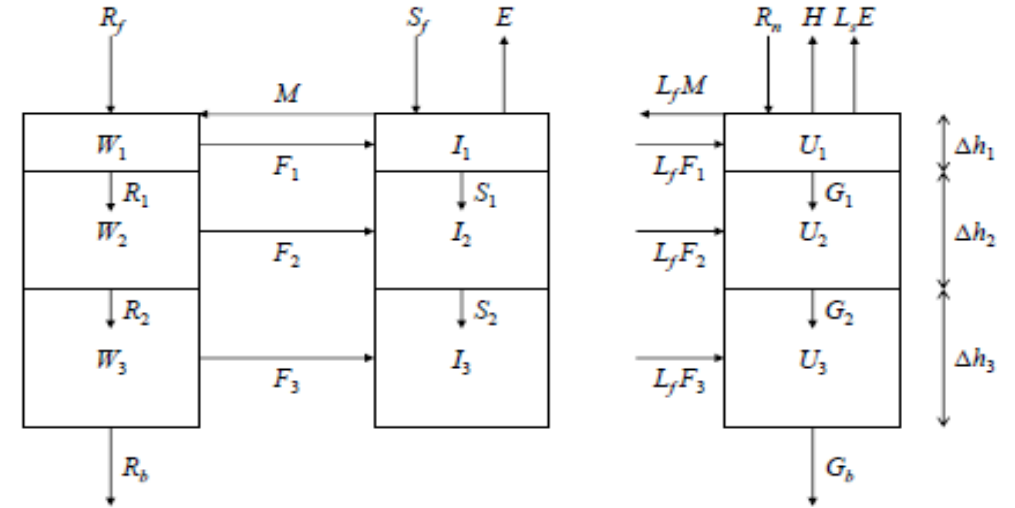


Cornwell et al. (2016)

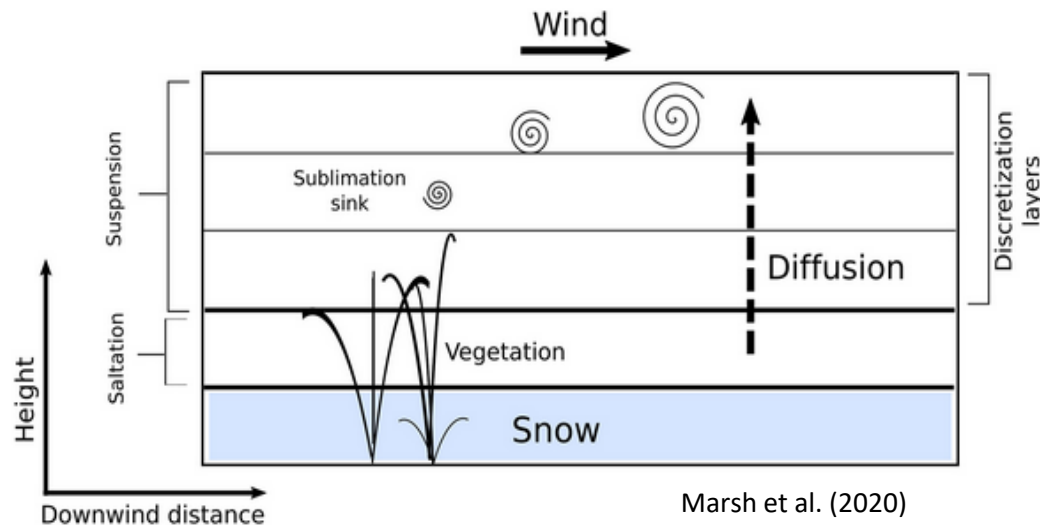
Snowpack modelling with CHM

Canadian Hydrological Model (CHM; Marsh et al., 2020):

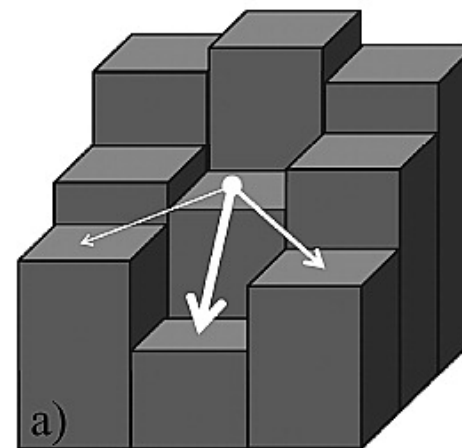
- Cold regions: snow processes
- Modular: activate/deactivate processes
- Spatially distributed: unstructured triangular meshes
- Designed for high-performance computing



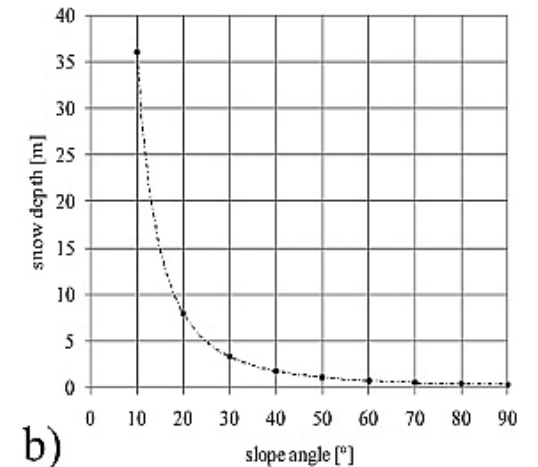
Essery (2015)



Marsh et al. (2020)



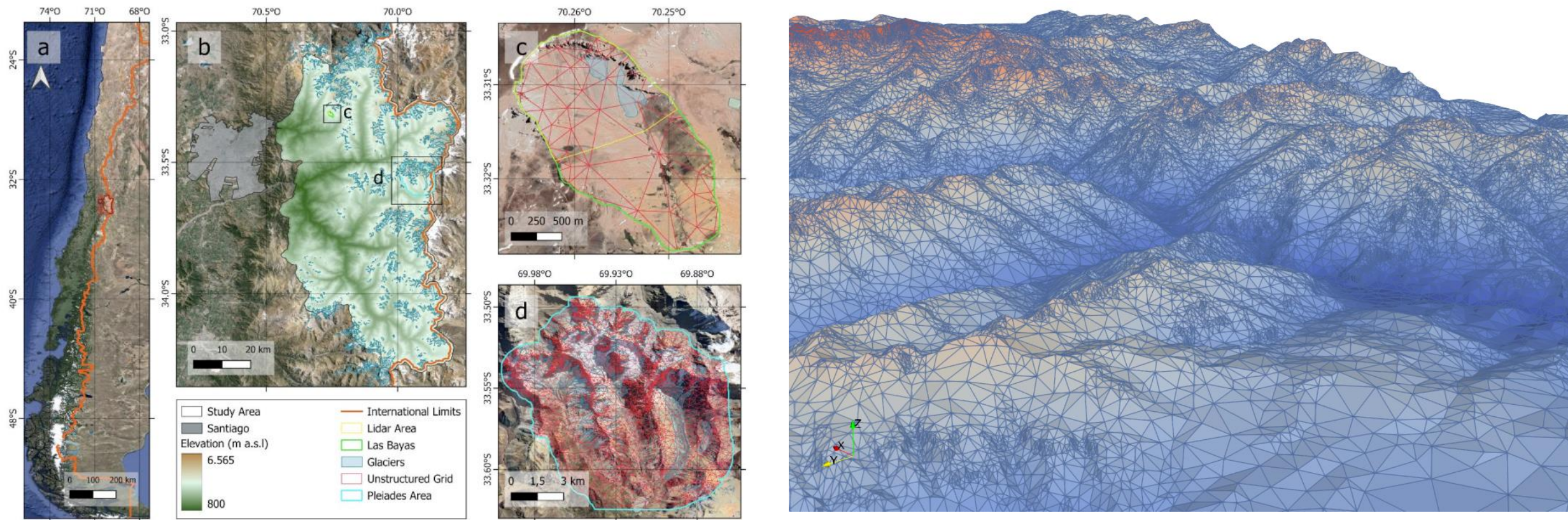
a)



b)

Bernhardt and Schultz (2010)

Initial model deployment in the Santiago area



Min theoretical area (m ²)	Max RMSE (m)	Number of triangles	Area range (m ²)	Median area (m ²)	Mean area (m ²)	Mean resolution (m)
2 500	15	215 000	400 – 1 780 000	18 000	27 600	166

The model domain contains two experimental catchments plus operational snow and met stations



Model-agnostic and model-specific preprocessing steps kept separate.

01

WORKFLOW PREPARATION

Goal: Initialize workflow execution

Actions:

- Create data folder structure separate from code folder
- Make domain discretization accessible
- Define workflow settings



Models may require the modeling domain to be discretized into model elements. Here, these take the shape of sub-basins and river segments, stored as polygons in an ESRI shapefile.

User interaction after workflow setup has been prepared is minimal

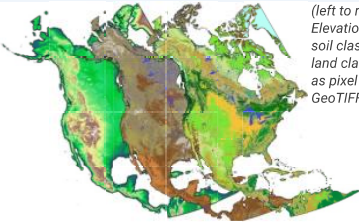
02

MODEL-AGNOSTIC PREPROCESSING

Goal: Prepare meteorological and geospatial input data

Actions:

- Download raw meteorological and geospatial data
- Data-specific processing (e.g. set consistent Coordinate Reference Systems, ensure standard file formats)
- Subset data to domain of interest



(left to right) Digital Elevation Model, soil classes and land classes, stored as pixel values in GeoTIFF files.

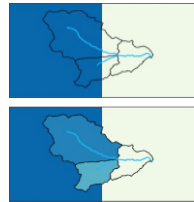
03

(OPTIONAL) REMAPPING

Goal: Unify spatial discretization of data and model elements

Actions:

- Map preprocessed input data onto model elements (e.g. re-grid, grid-to-polygon, polygon-to-polygon, etc)



Top: sub-basin polygons (step 1) are superimposed on gridded meteorological data and pixel-based geospatial data (step 2).

Bottom: a representative value is determined for each polygon. Here, gridded source data are converted into an area-weighted mean value. Other statistical operators such as the mode or counts are possible too.

Data standardization layer: preceding steps ensure data reaches this point in standardized formats. (i.e., GeoTIFF, netCDF, ESRI shapefile)

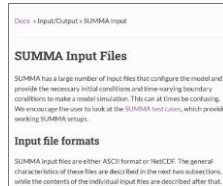
04

MODEL-SPECIFIC PREPROCESSING

Goal: generate simulations with selected models and data

Actions:

- Convert model-agnostic input data to model-specific input files
- Install model(s)
- Run model(s) to generate simulations



Models can be quite particular in how they expect their input data. Separating model-agnostic and model-specific processing steps lets the pre-processed data feed efficiently into multiple models. By standardizing model-agnostic output formats, new data can be used without changing model-specific code.

05

ANALYSIS AND VISUALIZATION

Goal: Answer questions of interest

Actions:

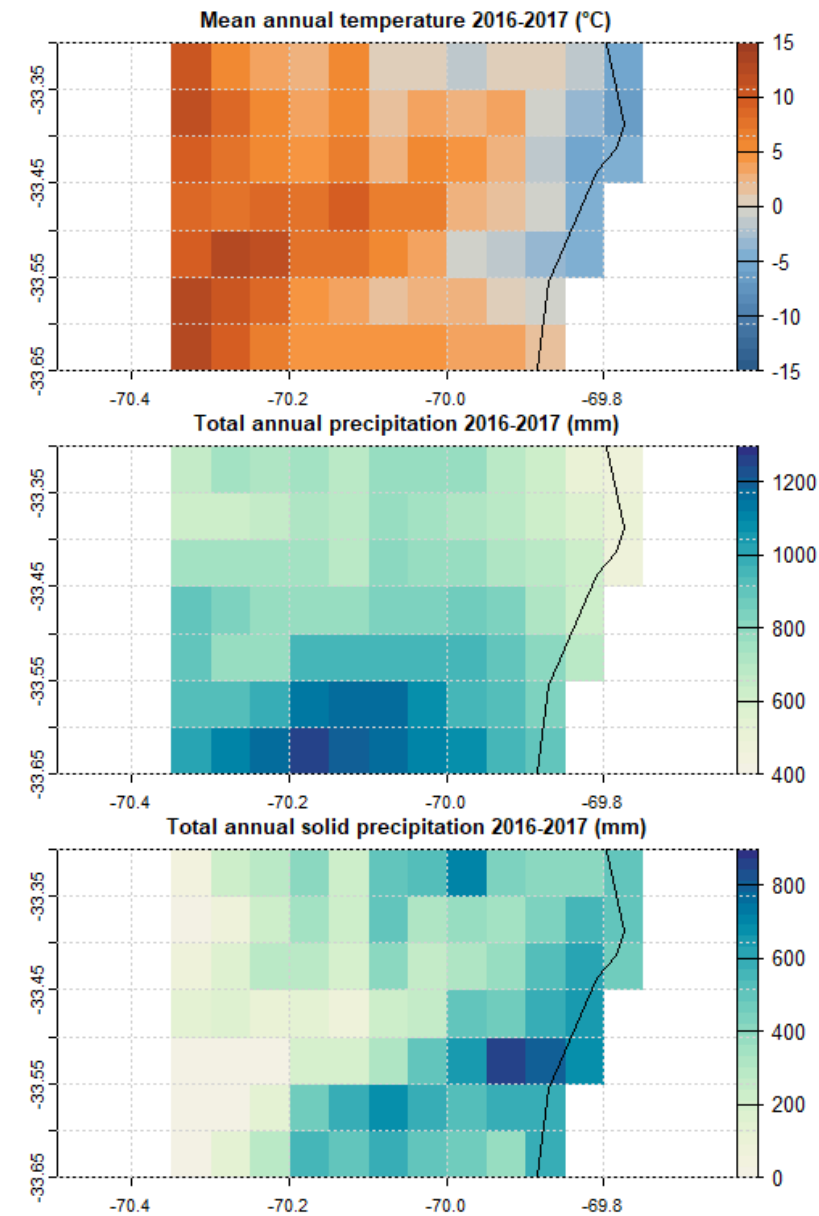
- Analyze model simulations
- Visualize findings



Often, more effort goes into creating functional model setups than into analyzing model simulations. Using standardized workflows streamlines model configuration tasks, leaving more time for analysis, and also leads to increased reproducibility and transparency of obtained results.

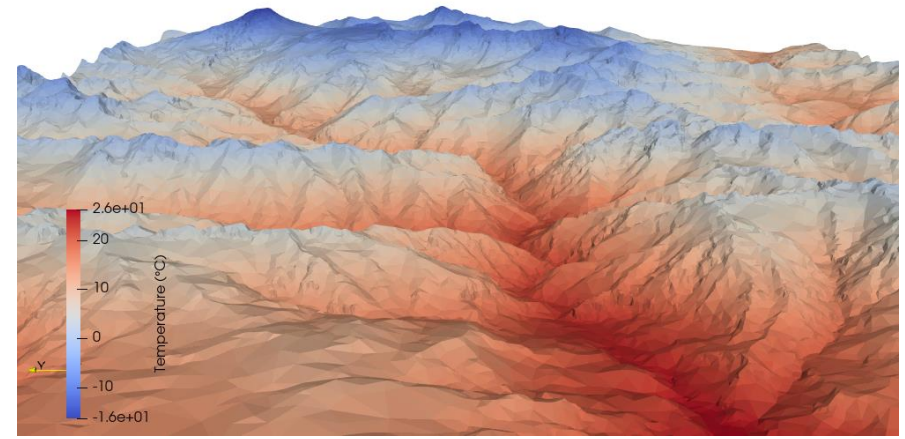
1. Workflow preparation: domain discretization in TIN
2. Model-agnostic preprocessing
 - a) NWP met forcings: ECMWF, ERA5-Land)
 - b) Scaled station-based local gridded met. reference product (Álvarez-Garretón et al., 2018; Boisier, 2023) -> daily precipitation, max/min air temperature
 - c) Downscaling of a. based on b.
3. Remapping of preprocessed forcings to model elements
 - a) Elevation gradients
 - b) Wind mapping
4. Model-specific preprocessing

We force the model with ECMWF-HRES downscaled to station-based local products -> development stage aimed at real-time forecasts

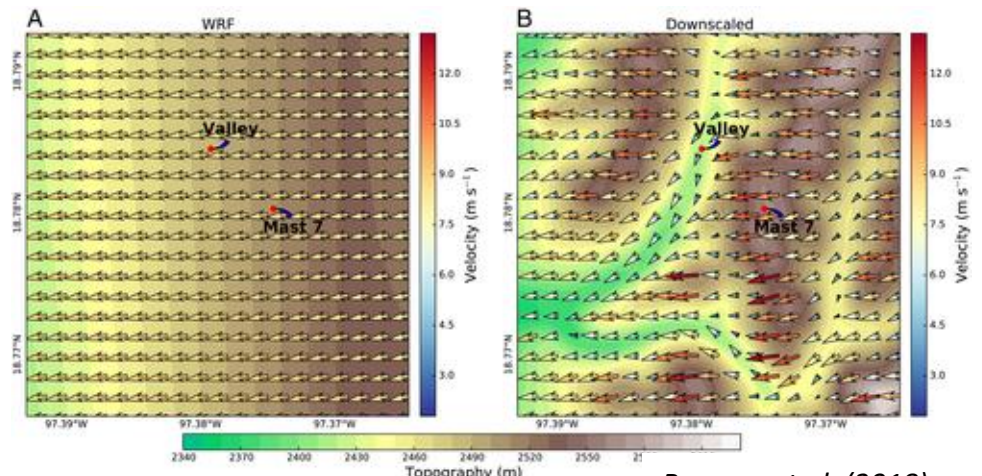


↓
DOWNSCALING
→

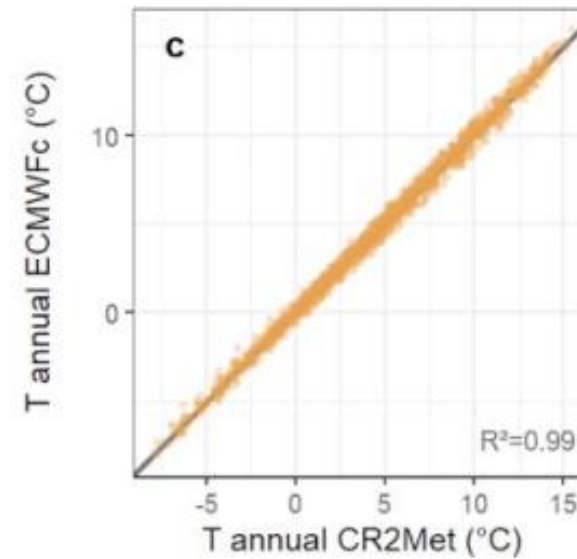
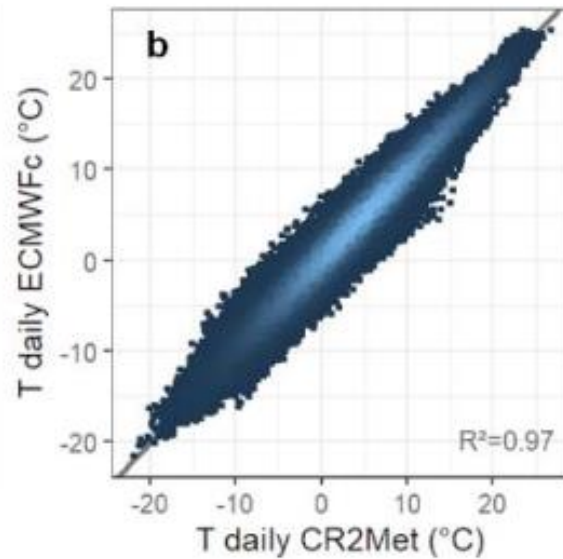
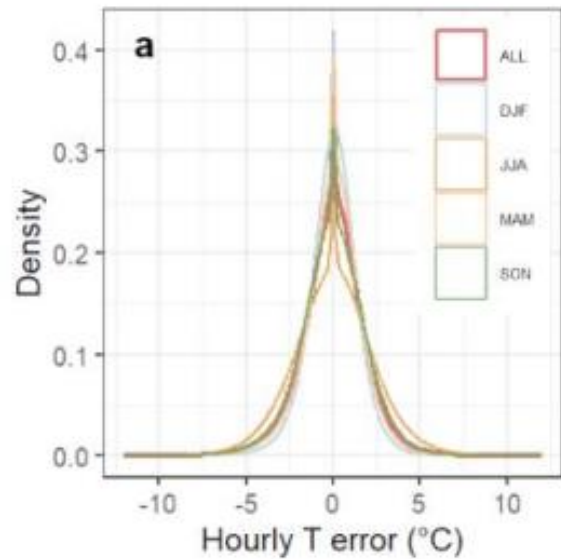
Precipitation and air temperature: monthly lapse rates



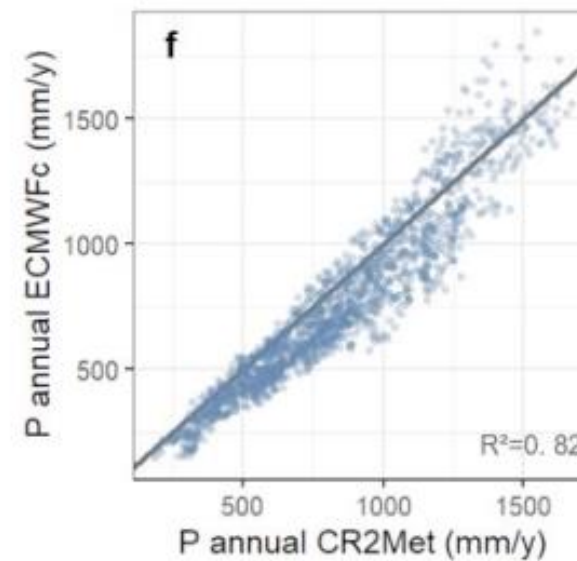
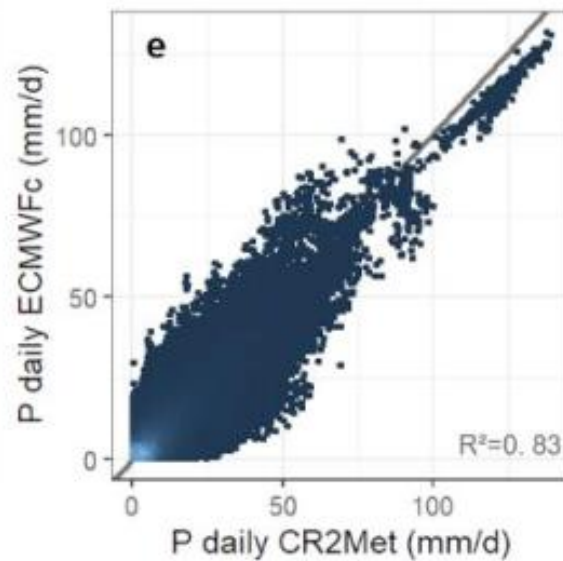
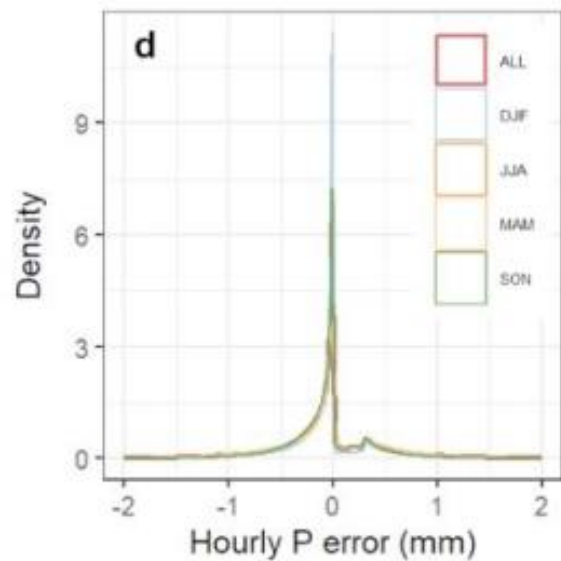
Wind: WindNinja



Assessing the skill and downscaling of NWP data through experimental catchment observations and gridded product

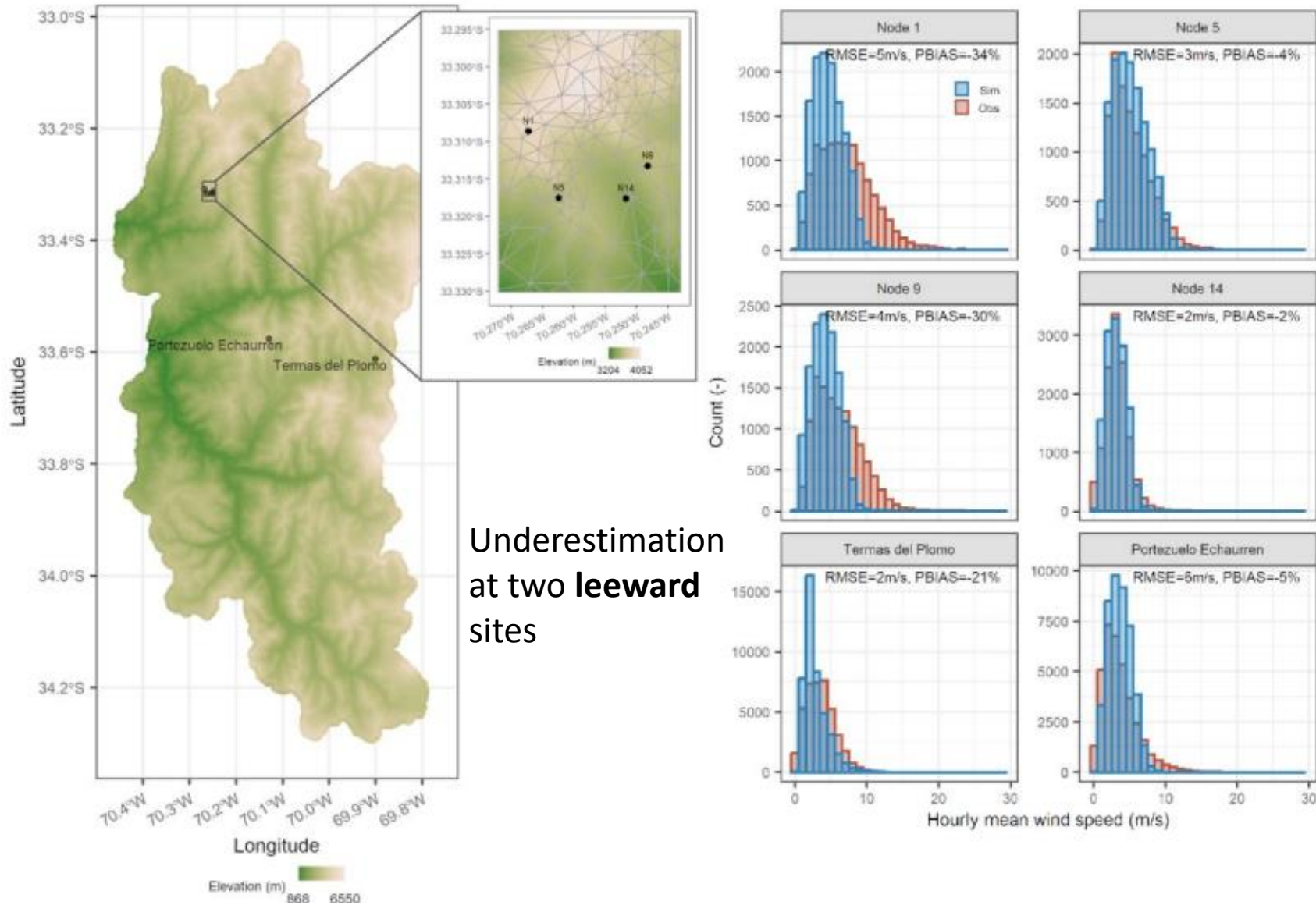


$\pm 5^\circ\text{C}$ uncertainty in daily air temperature



$\pm 50\%$ uncertainty in annual precipitation

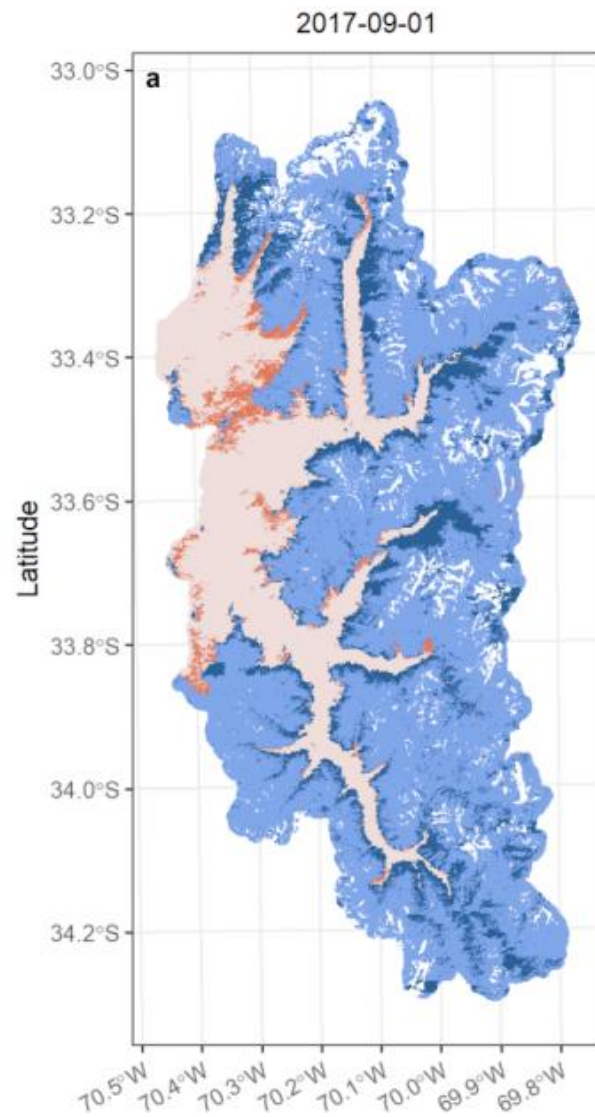
Assessing the skill and downscaling of NWP data through experimental catchment observations and gridded product



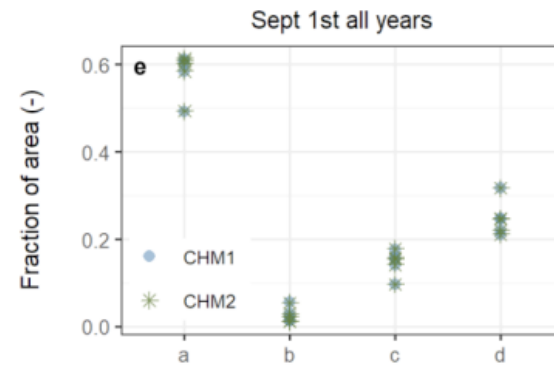
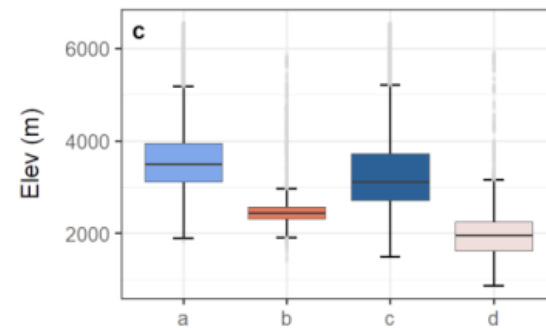
Underestimation
at two leeward
sites

Wind properties reasonably
represented at existing
stations.

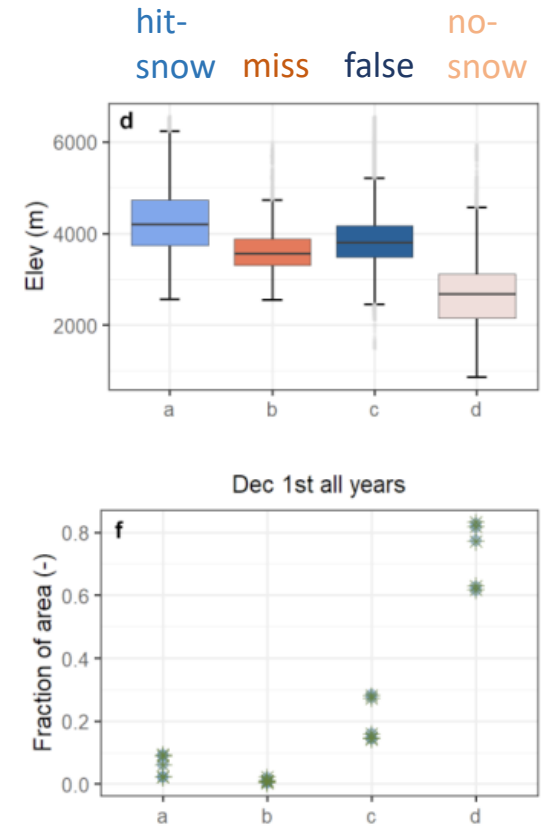
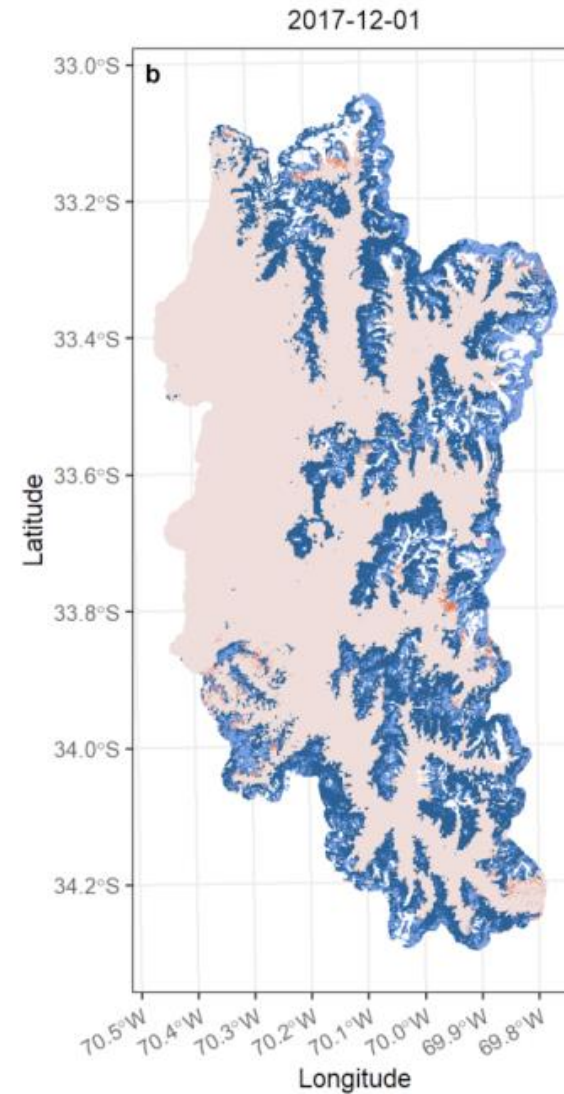
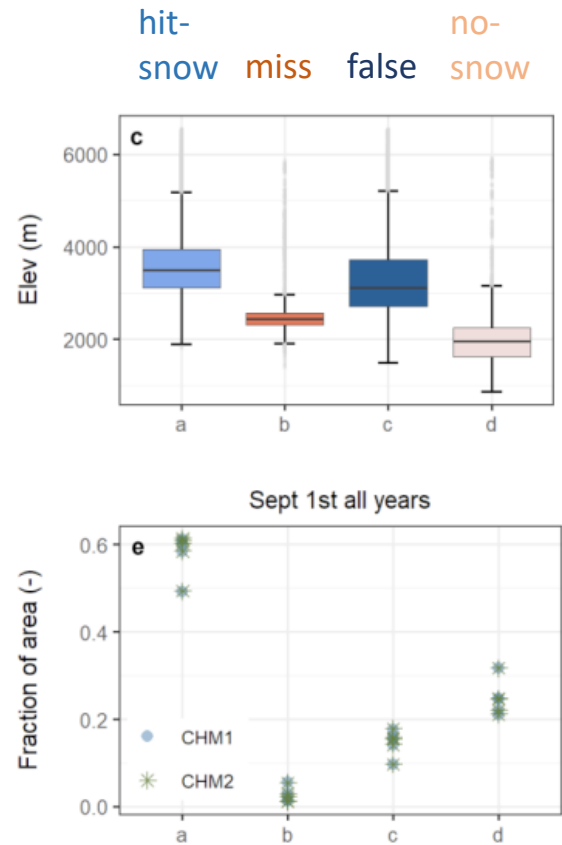
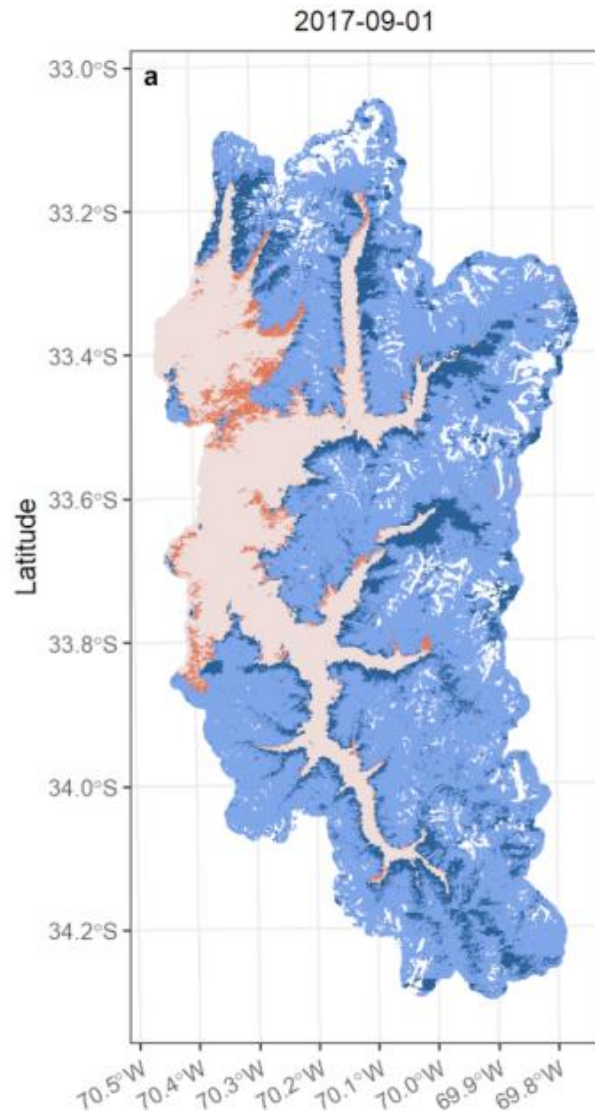
Model evaluation – SCA distribution



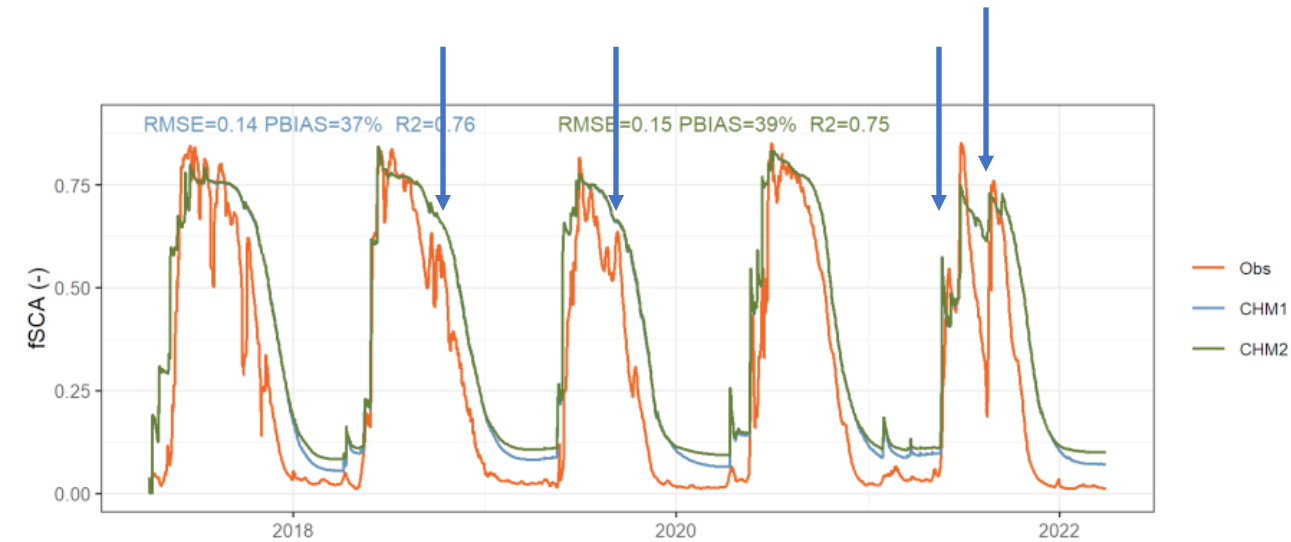
hit-snow miss false no-snow



Model evaluation – SCA distribution



Model evaluation – SCA time series



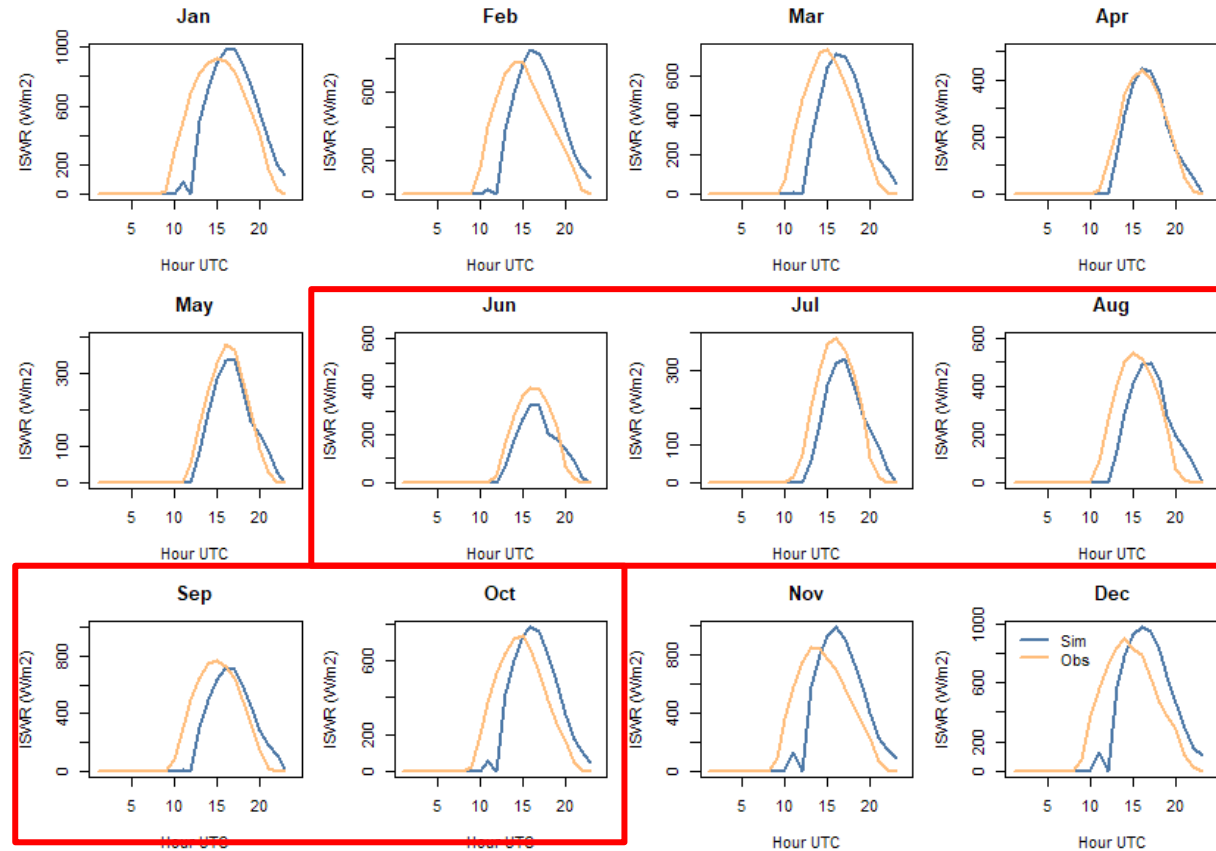
+ Good correlation

+ Events well represented

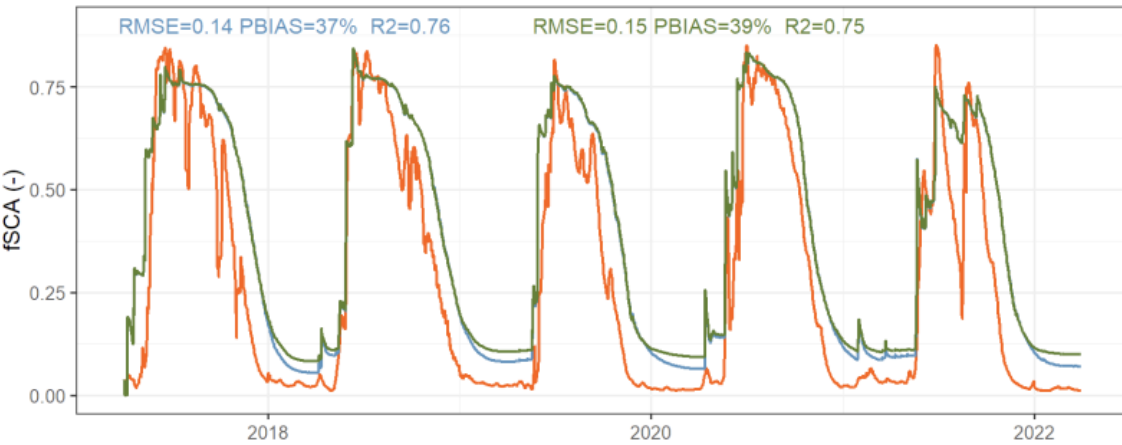
- Systematic bias in spring (but maybe in the reference product, too)

Model evaluation – SCA time series

Daily incoming shortwave radiation cycle at Valle Nevado station



— Obs
— CHM1
— CHM2

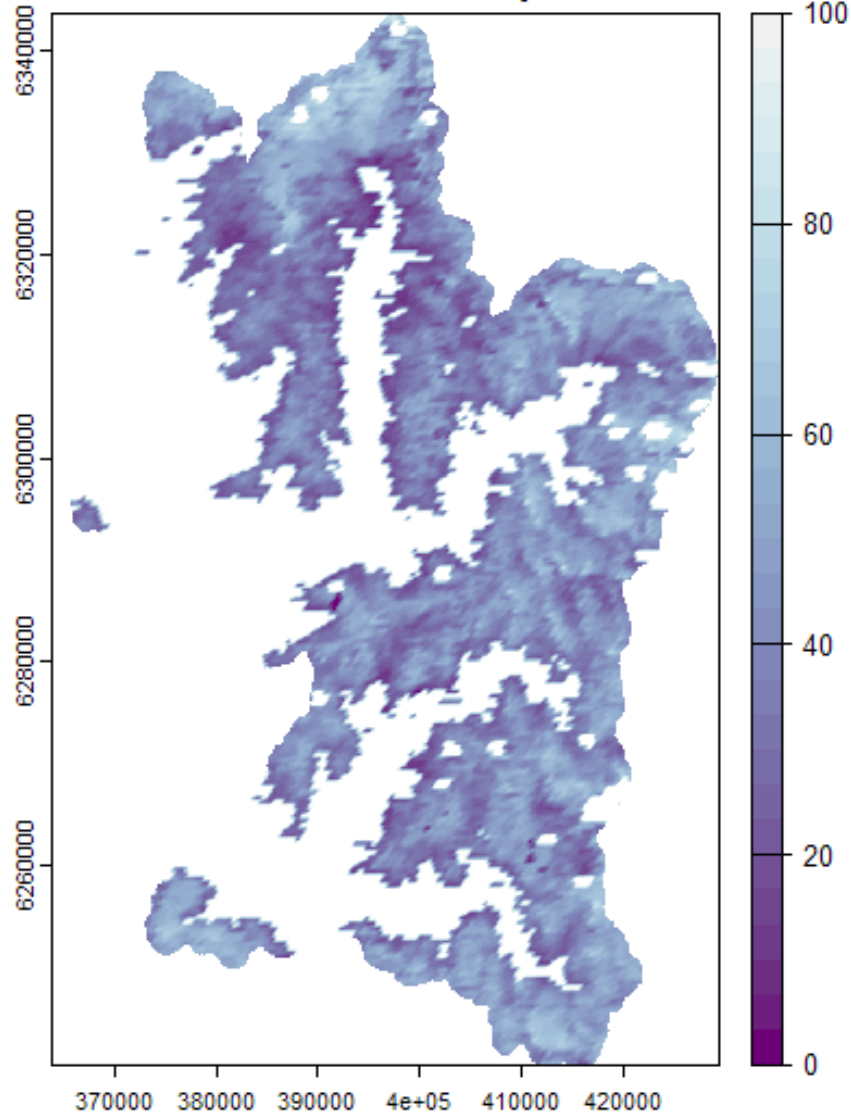


- + Good correlation
- + Events well represented

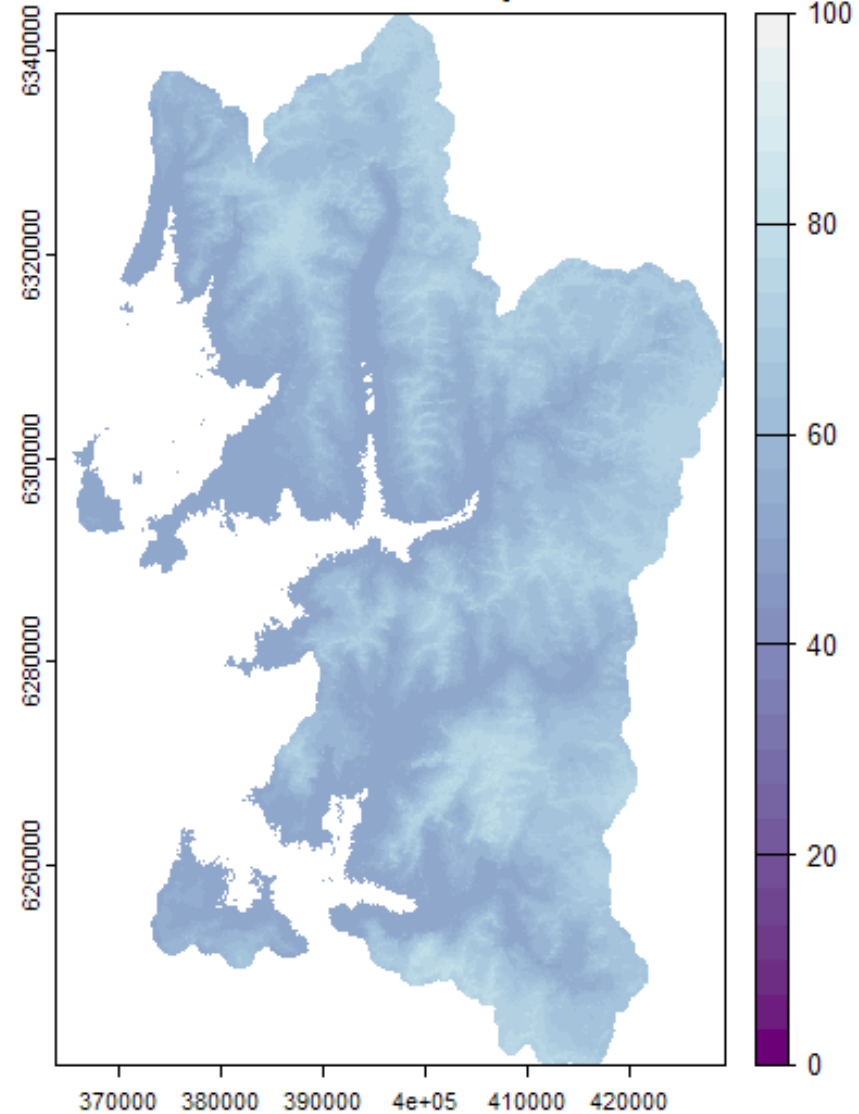
- Systematic bias in spring (but maybe in the reference product, too)

Simulated albedo seems high compared with R.S. retrievals

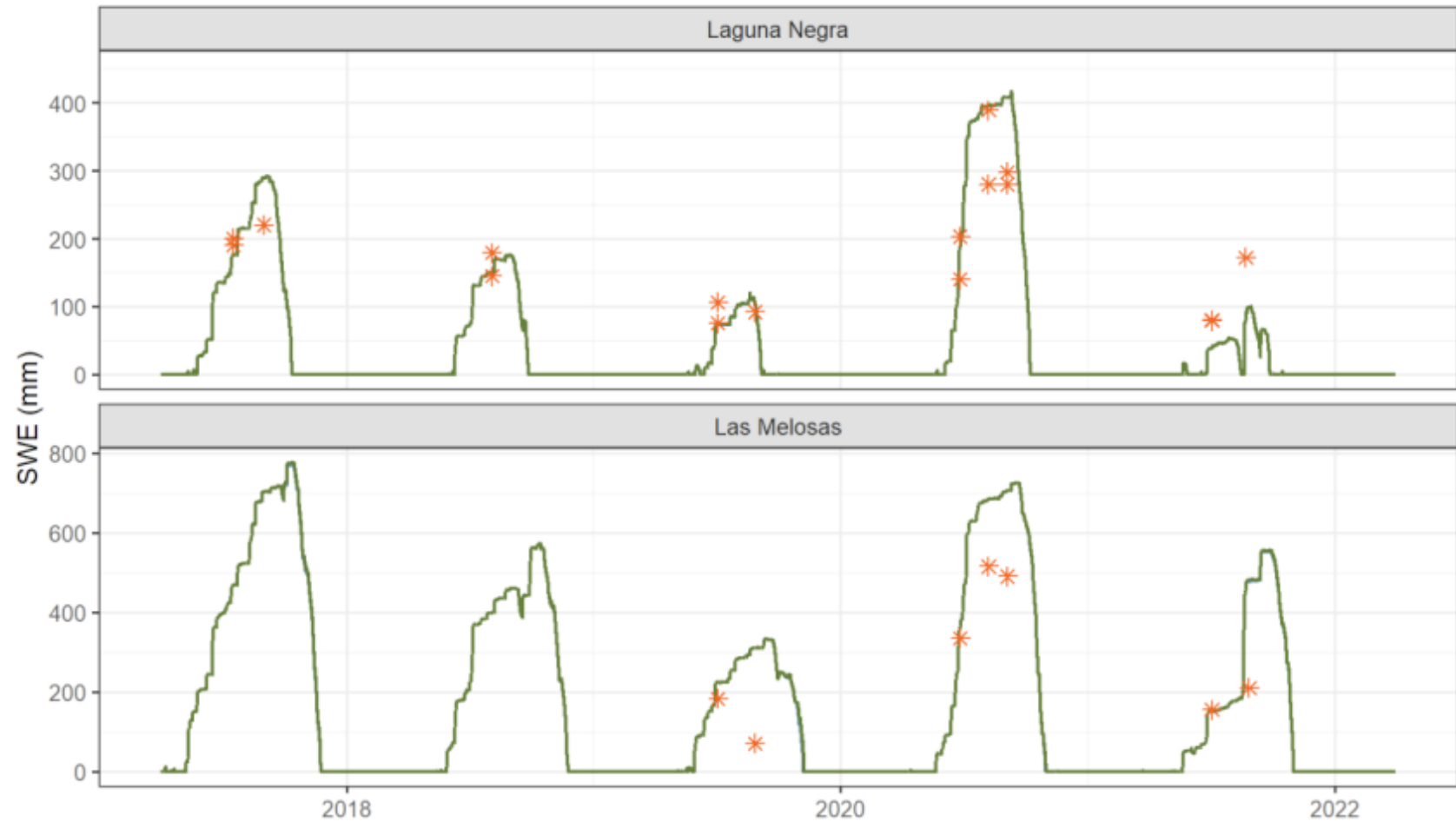
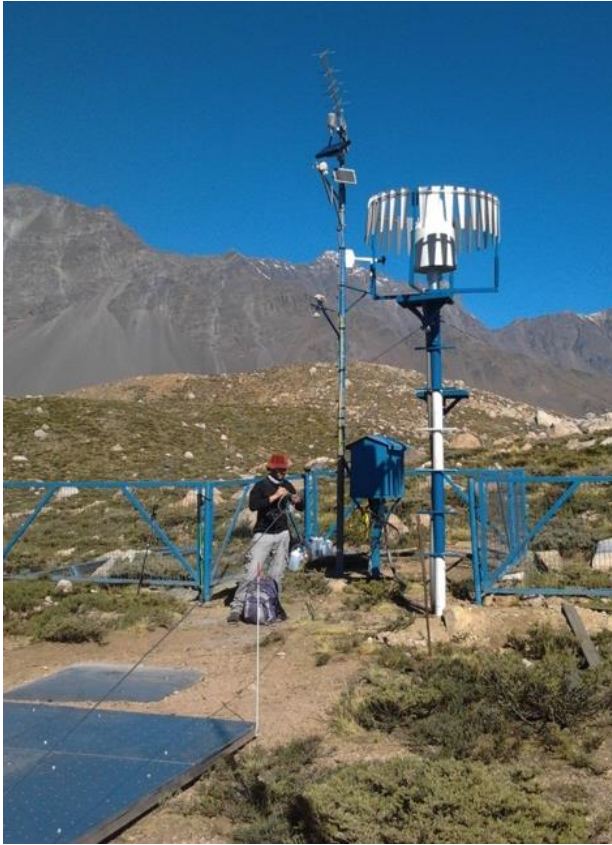
MODIS snow albedo Sept 30 2016



CHM snow albedo Sept 30 2016

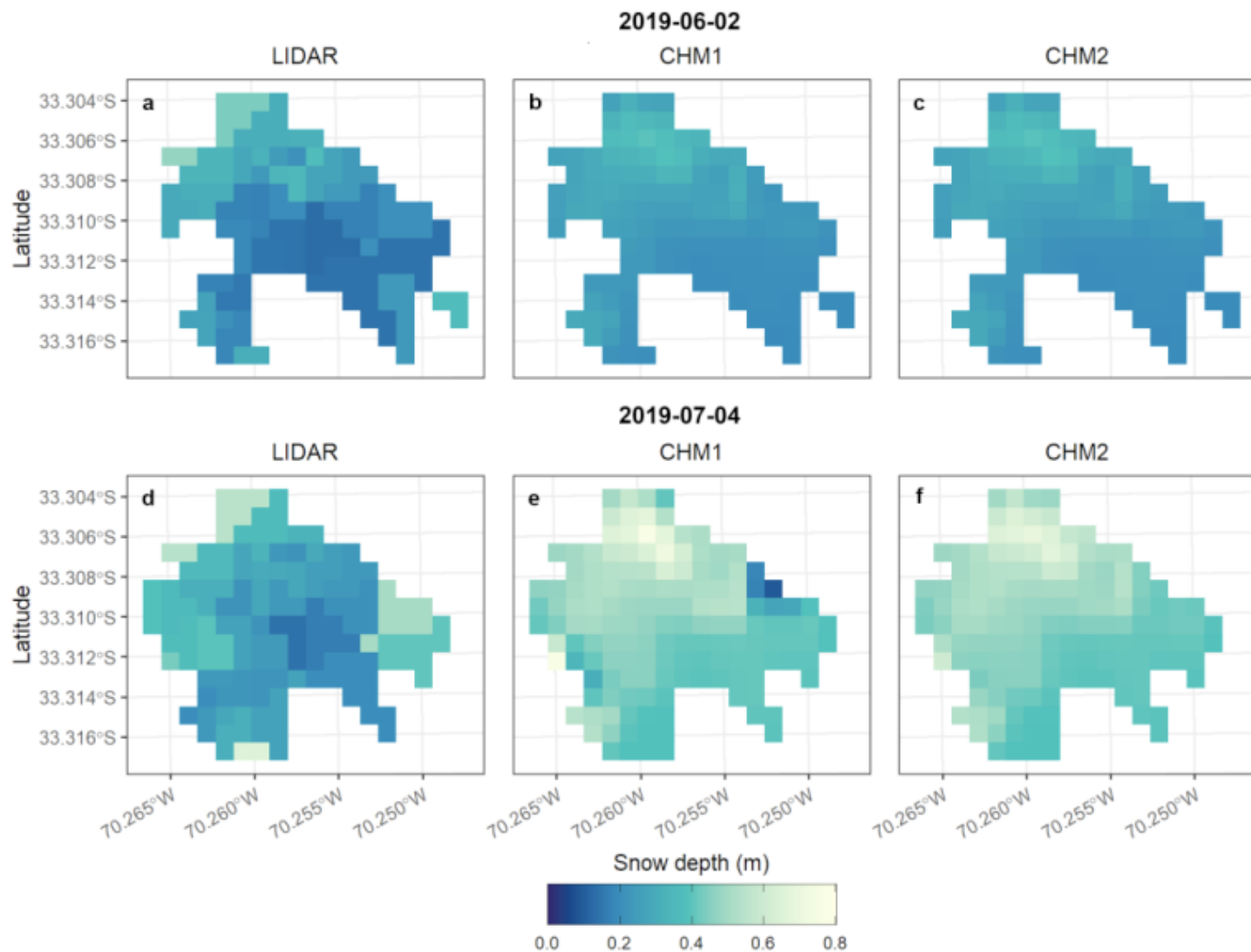


Against the few point-scale SWE observations in the area, adequate timing and magnitude.



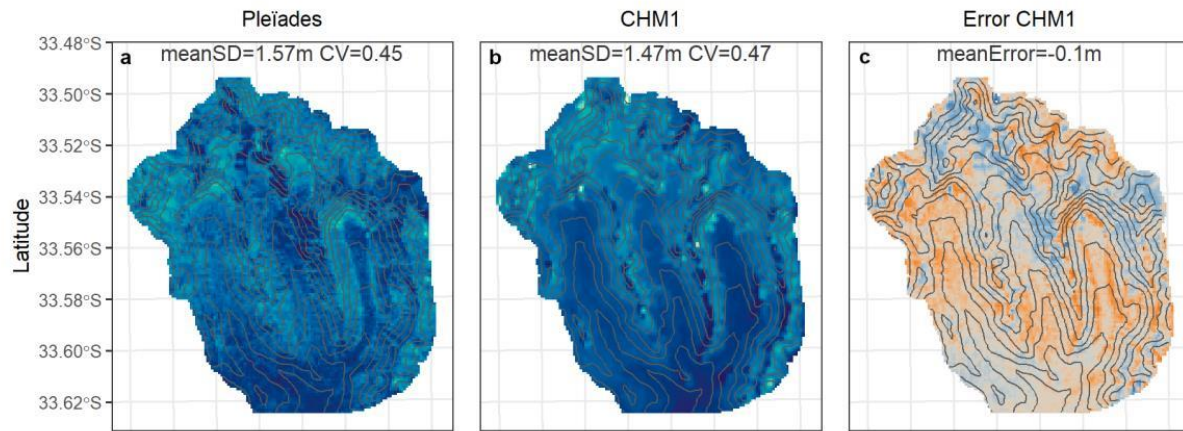
Manual Snow Survey CHM1 CHM2

Snow Depth evaluation: 1 km²-scale

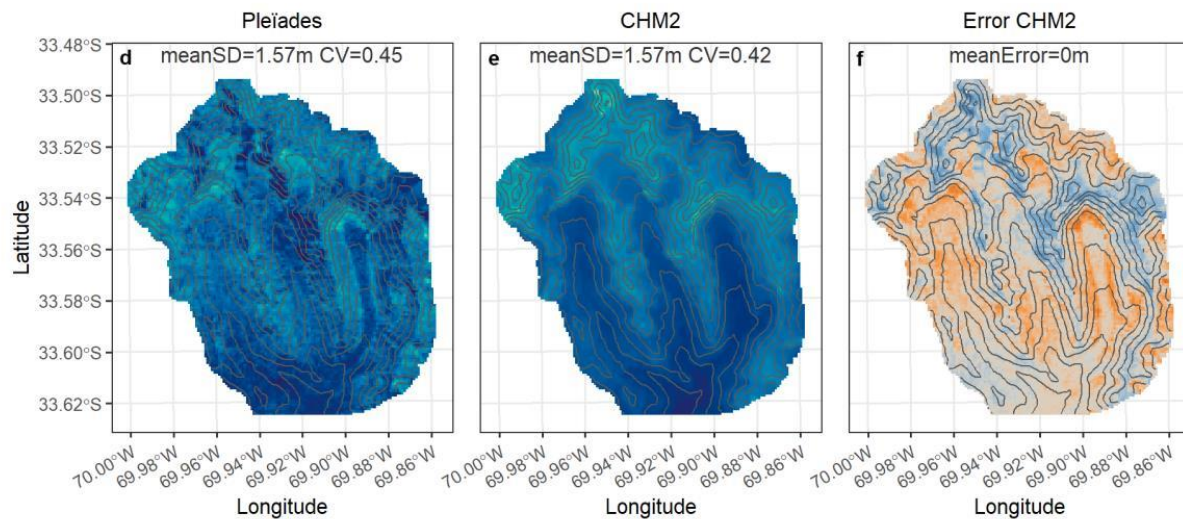


	Depth			CV		
	Lidar	CHMr	CHMn	Lidar	CHMr	CHMn
Avg 7 scans	0,75	0,61	0,62	0,52	0,26	0,19

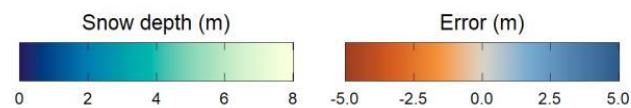
Snow depth evaluation: 100 km² -scale



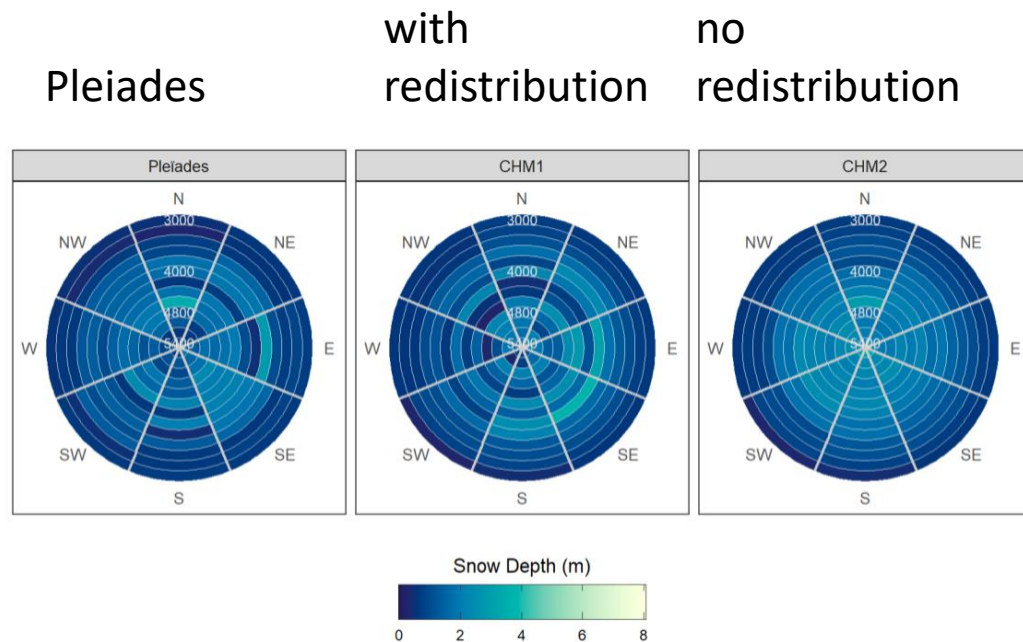
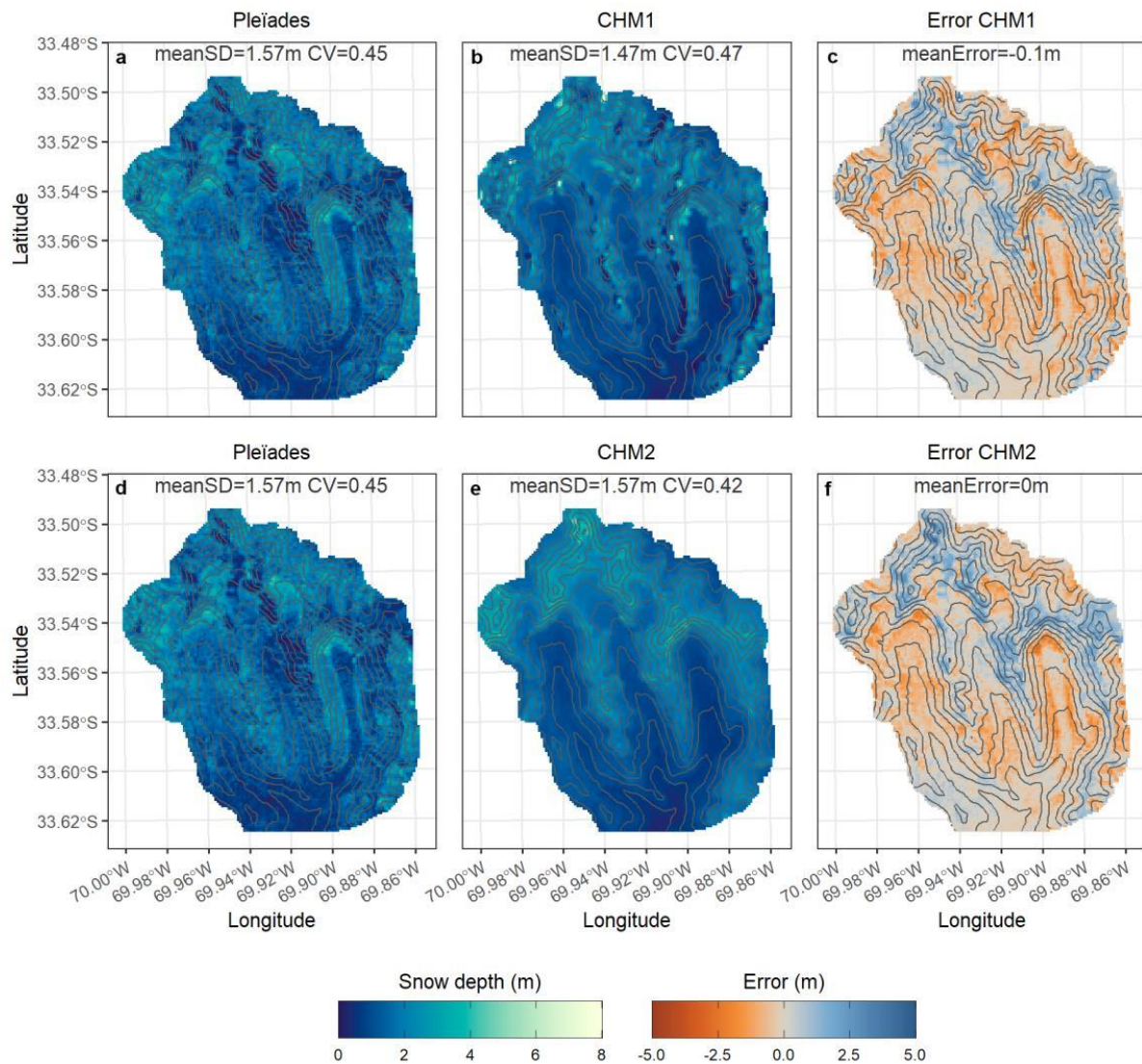
with redistribution



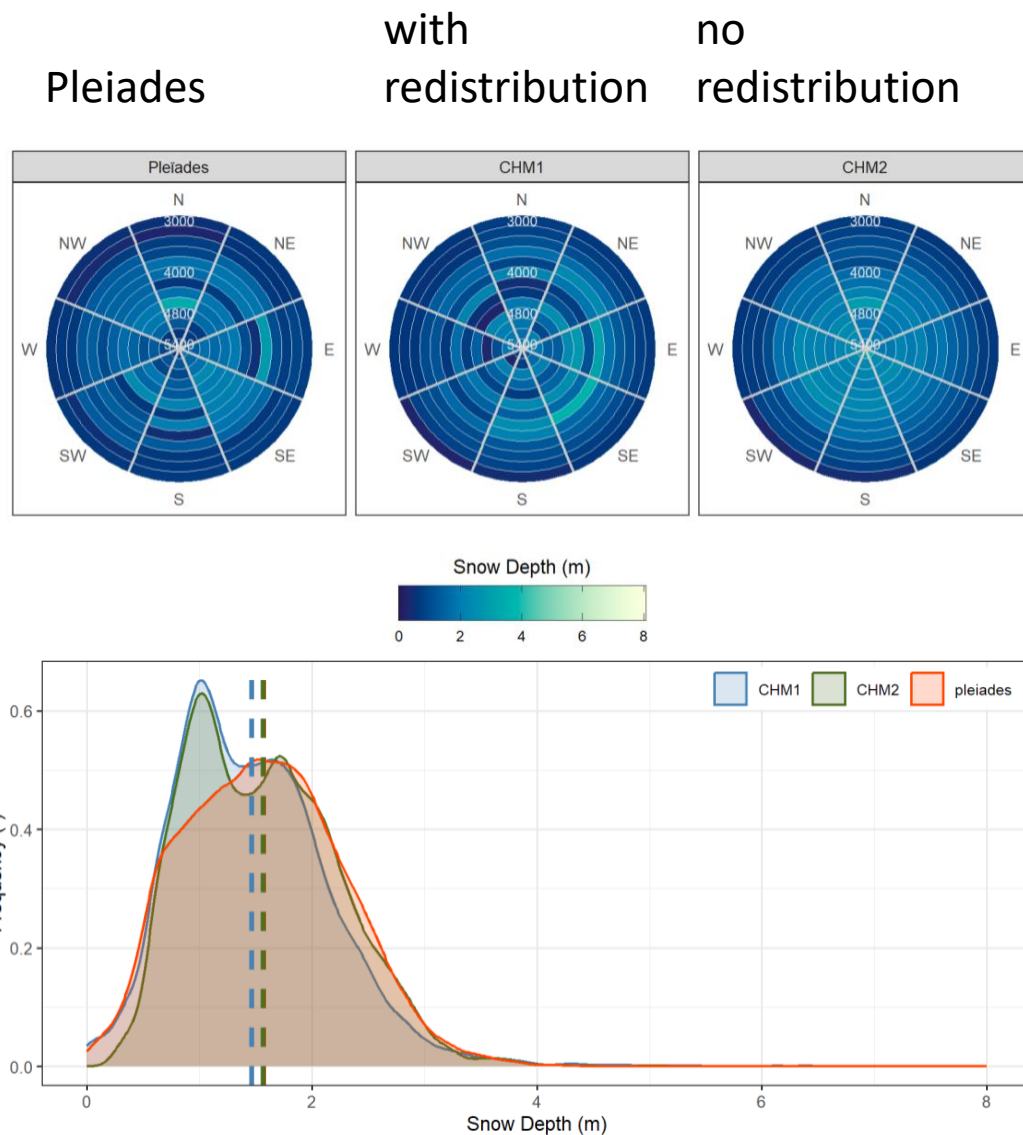
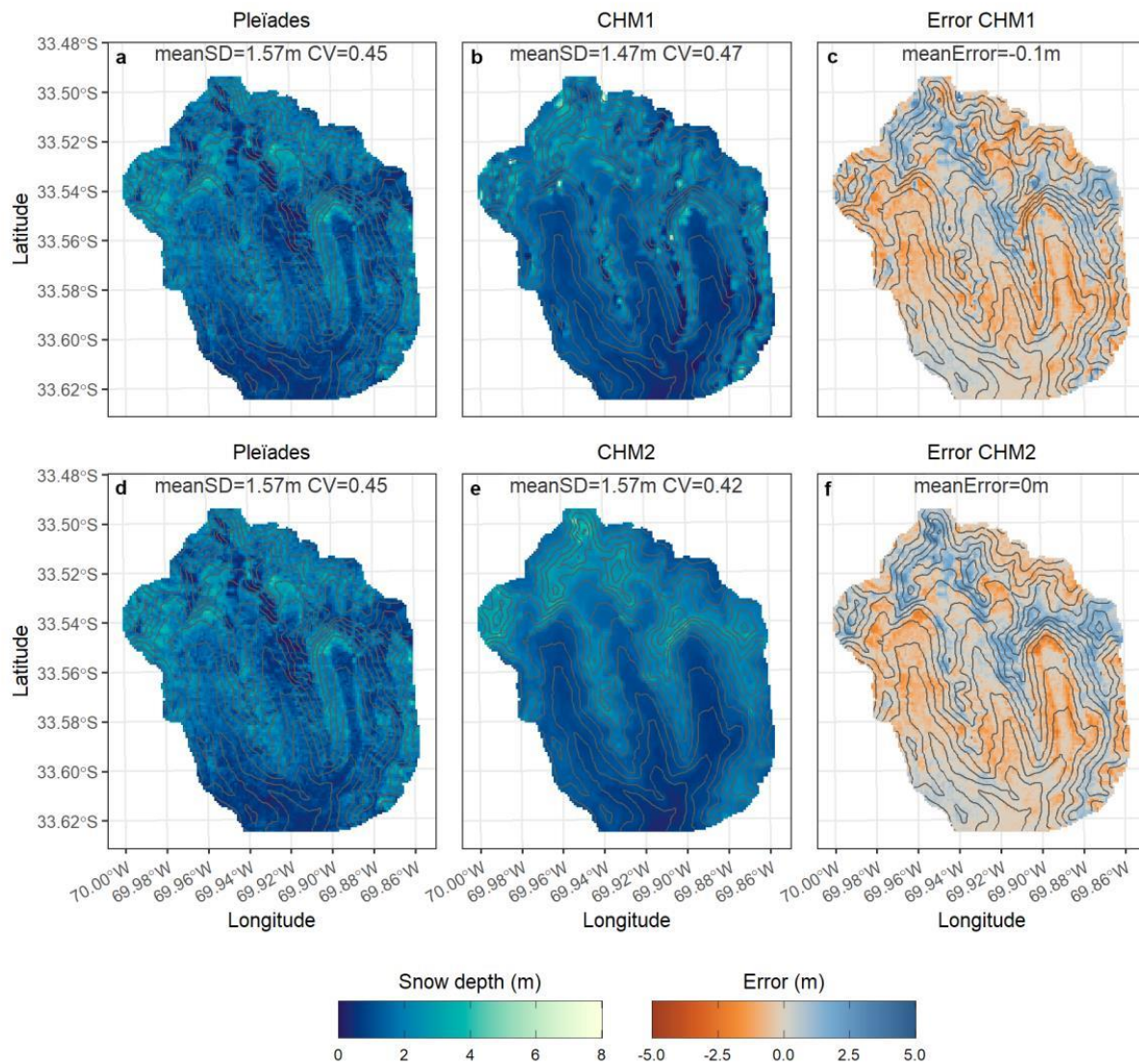
no redistribution



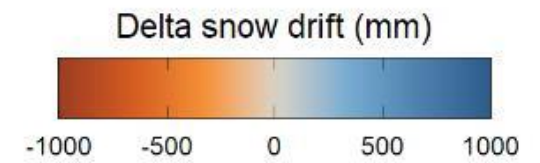
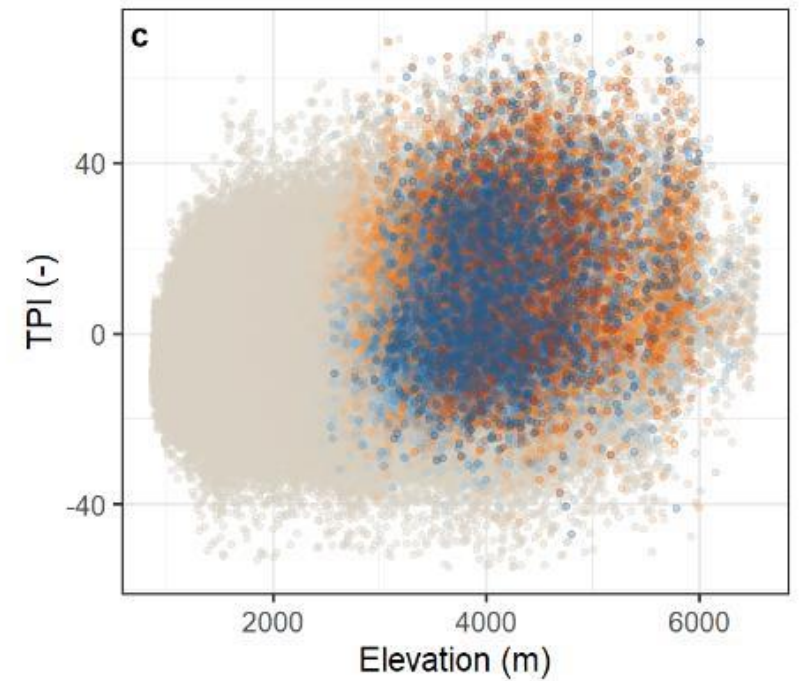
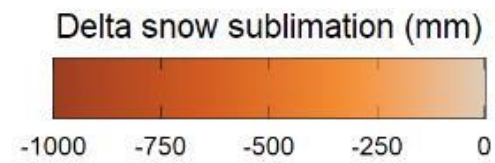
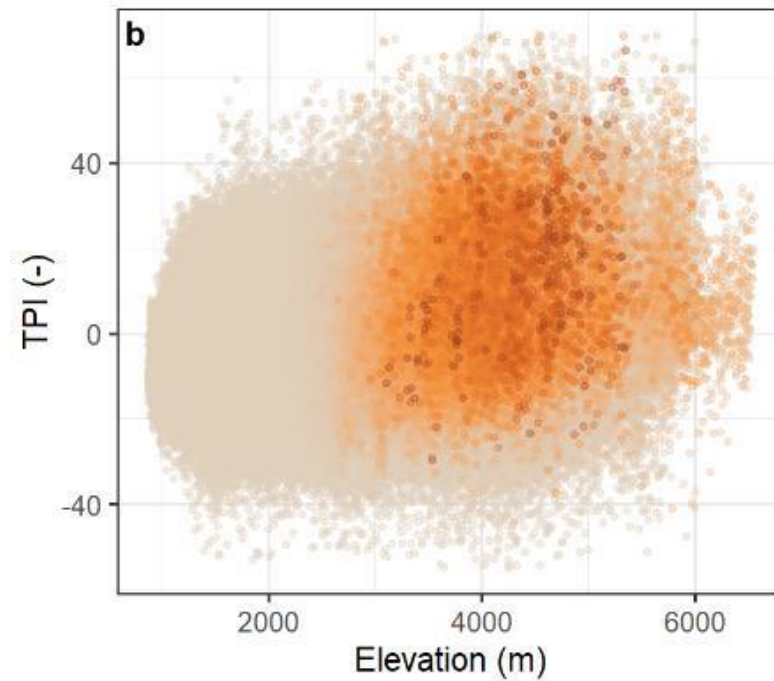
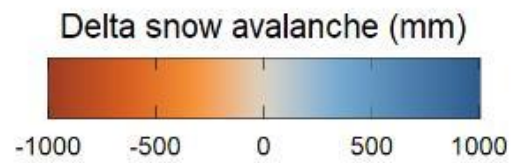
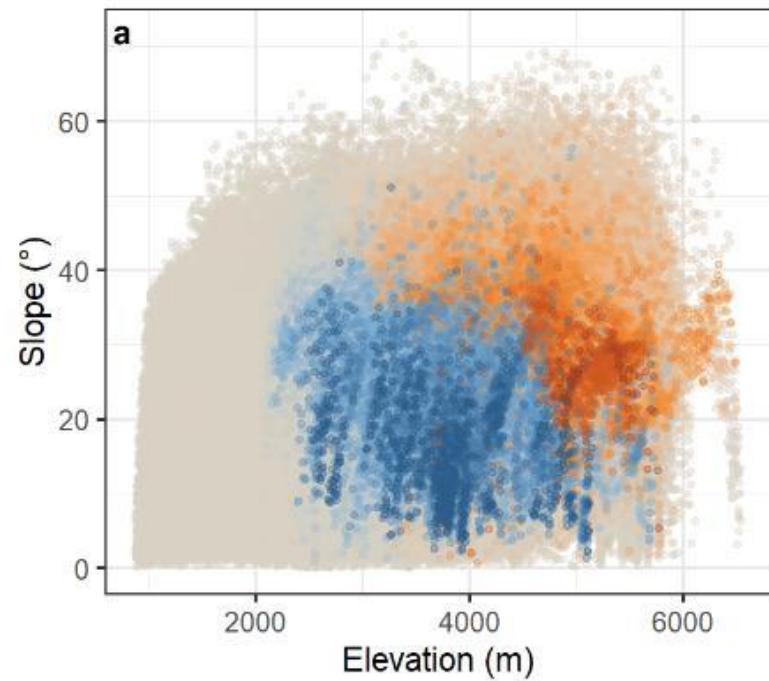
Snow depth evaluation: 100 km² -scale



Snow depth evaluation: 100 km² -scale



Contribution of simulated redistribution processes



Summary

- Efficient implementation of high-resolution snow model with redistribution by wind and avalanching
- Bias corrected NWP forcings reproduce:
 - Timing of SWE accumulation
 - Large-scale precipitation patterns
- Ongoing work:
 - Better assessment of density vs. depth estimation
 - Melt dynamics -> albedo, S_w input
 - Structural uncertainty **Yerel Morales**
 - Parameter estimation **Elizabeth Ramirez**
 - Data assimilation **Cristobal Sardá**

Relative influence of wind and avalanche redistribution at the mountain range scale in the South American Andes

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