

# Leveraging experimental catchment data for model verification- Andes

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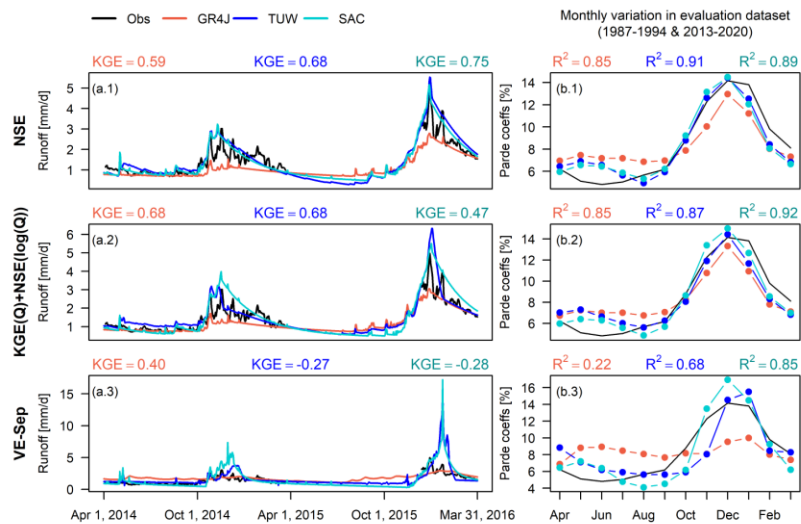


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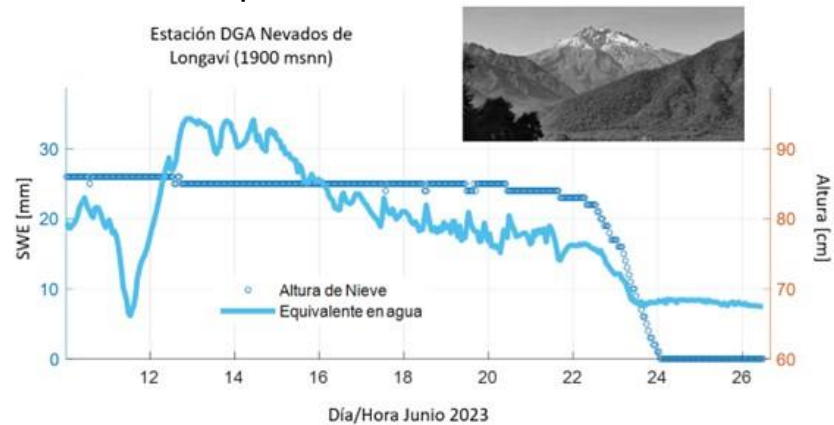
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# Motivation: the need to provide answers to specific questions

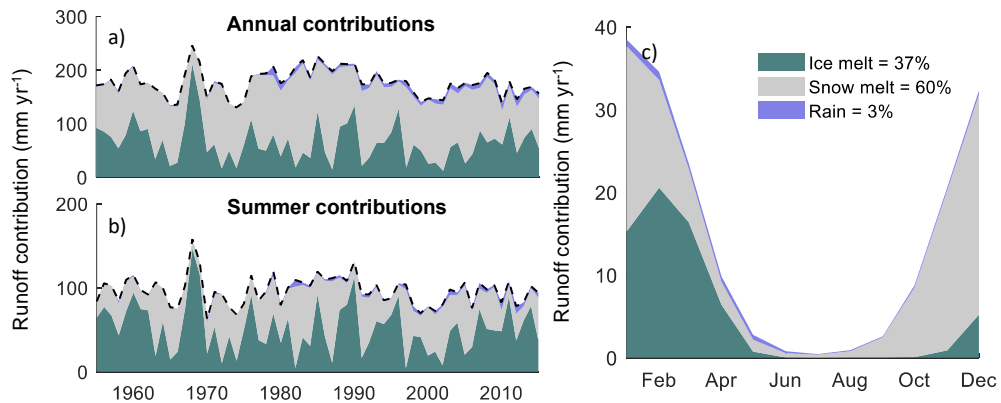


## Extreme event impacts



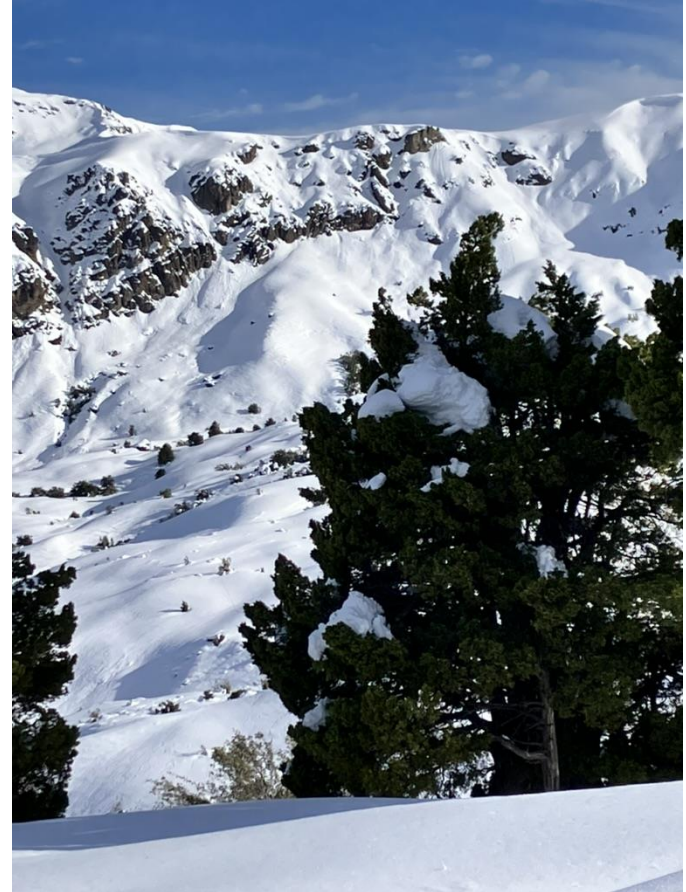
## Seasonal streamflow forecasting (Araya et al., 2023)

Glacier influence on streamflow (Ayala et al., 2020)



# Reliable hydrological predictions in high-mountain areas remain an elusive objective

- Little to no observational meteorological networks
- Mountain precipitation unknown
- Limited remote-sensing capabilities
  - complex topography
  - cloudiness
  - high SWE accumulation
- Modeling parameterizations not yet fully tested in diverse geographic settings
- Feedback cycles: understanding and modeling
  - eg. glacier albedo
  - eg. marginal snowpacks





# What can we learn from alpine experimental catchments and research stations?



# CWARHM Approach (Knoben et al. 2022)

1. Workflow preparation: domain discretization in 1) TIN; 2) Grid; 3) HRU
2. Model-agnostic preprocessing
  - a. NWP and reanalysis 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
4. Model-specific preprocessing
5. Visualization and analysis

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

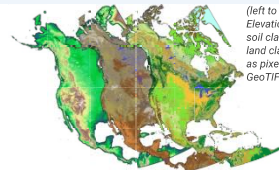
02

## 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.

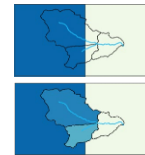
03

## (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.

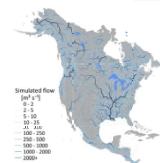
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## ANALYSIS AND VISUALIZATION

Goal: Answer questions of interest

### Actions:

- Analyze model simulations
- Visualize findings

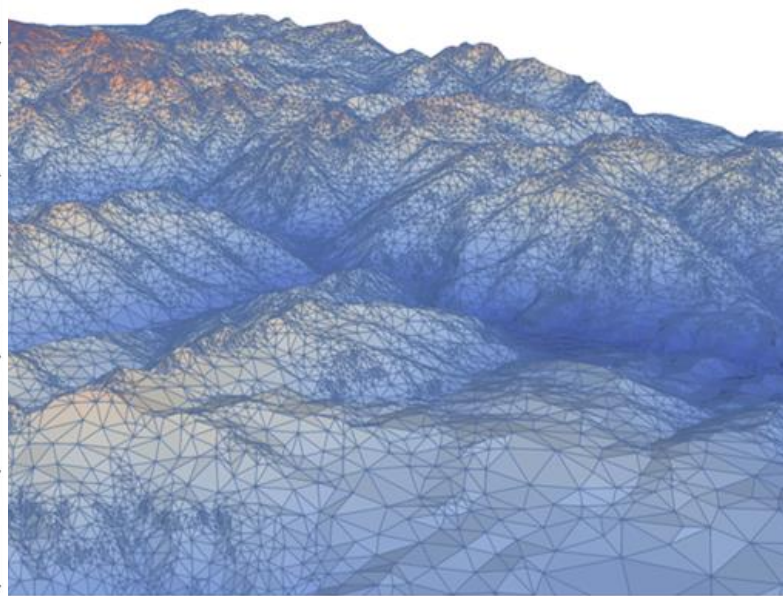
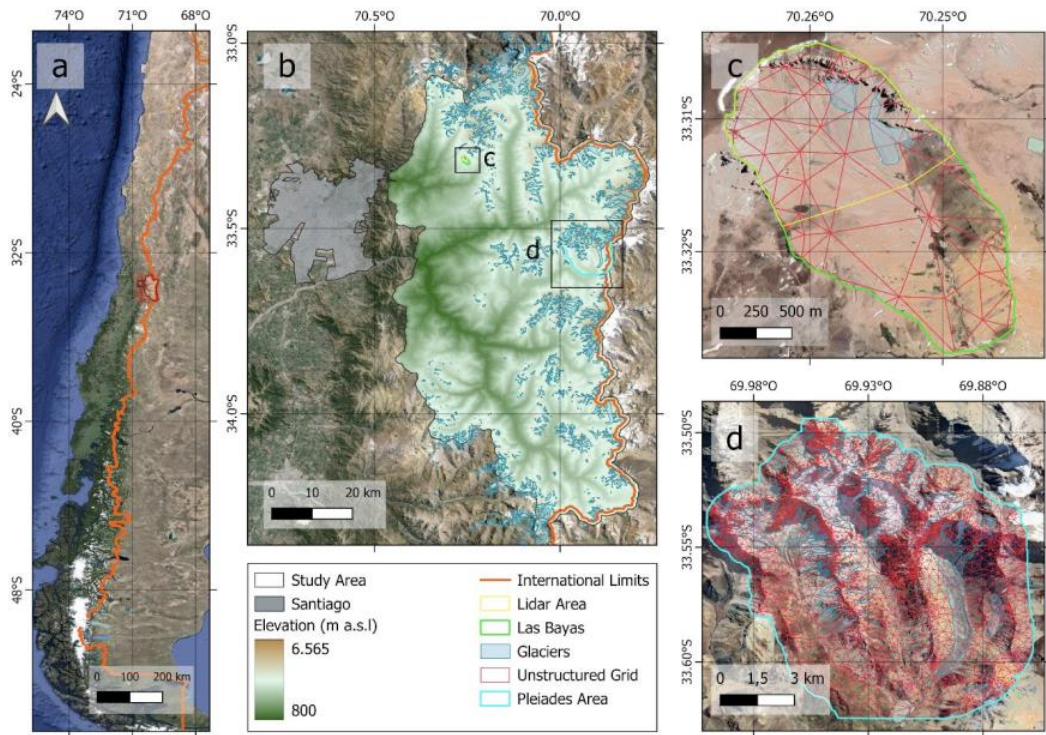


Often, more effort goes into creating functional model setups than into analyzing model simulations. Using standardized workflows streamlines model configuration tasks, leaving more time for analysis, and also leads to increased reproducibility and transparency of obtained results.



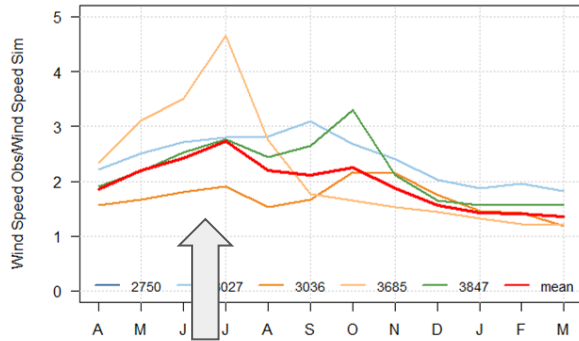
# SP-1. Regional Snow Modeling with CHM

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

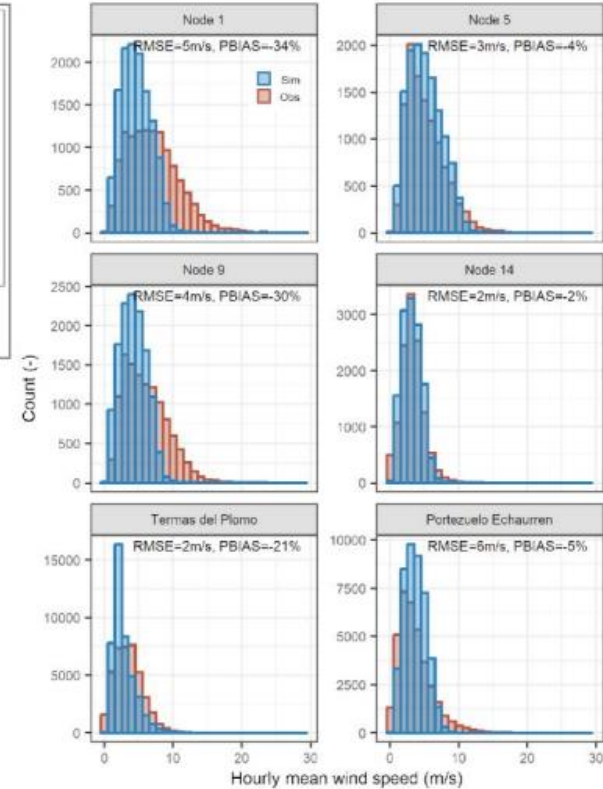
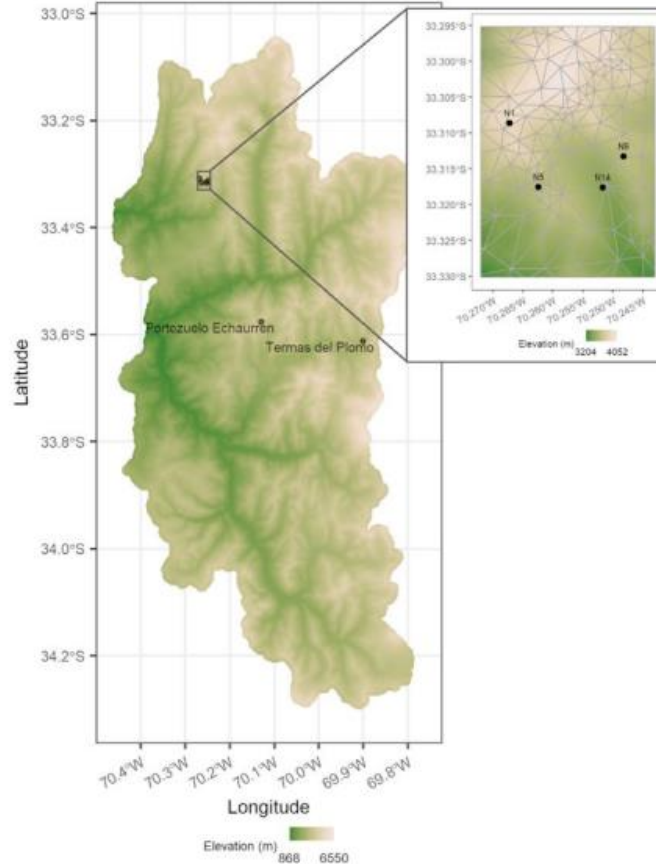


# Local wind speed observations

Wind speed: monthly correction factor applied to NWP output (ECMWF)



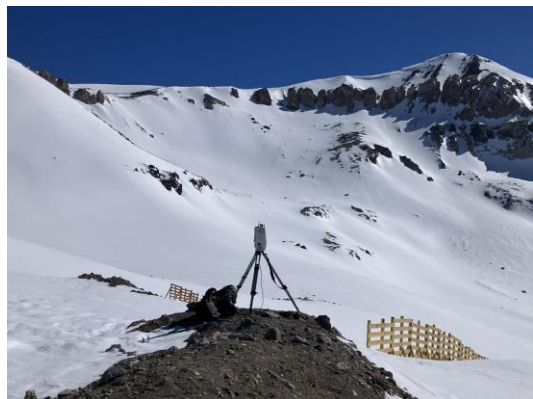
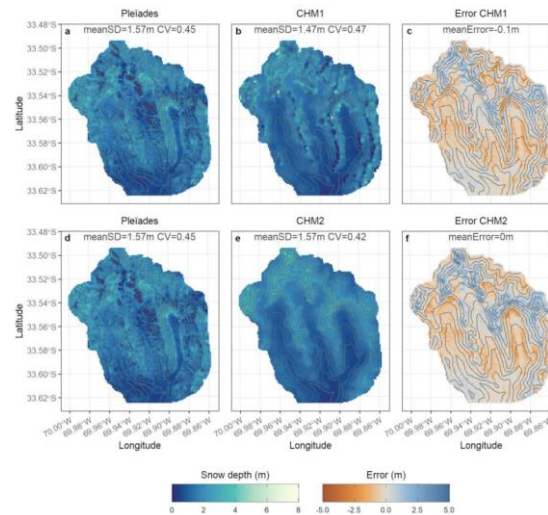
2-3 fold increase in w.s. during winter months.



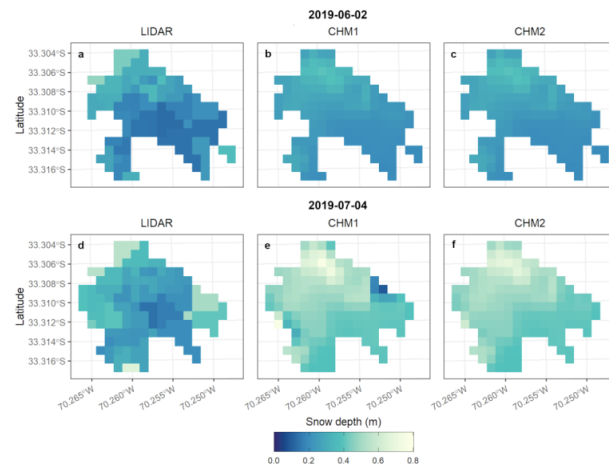
# High-resolution snow depth



100 km<sup>2</sup>  
Few acquisitions  
per season+  
m-scale

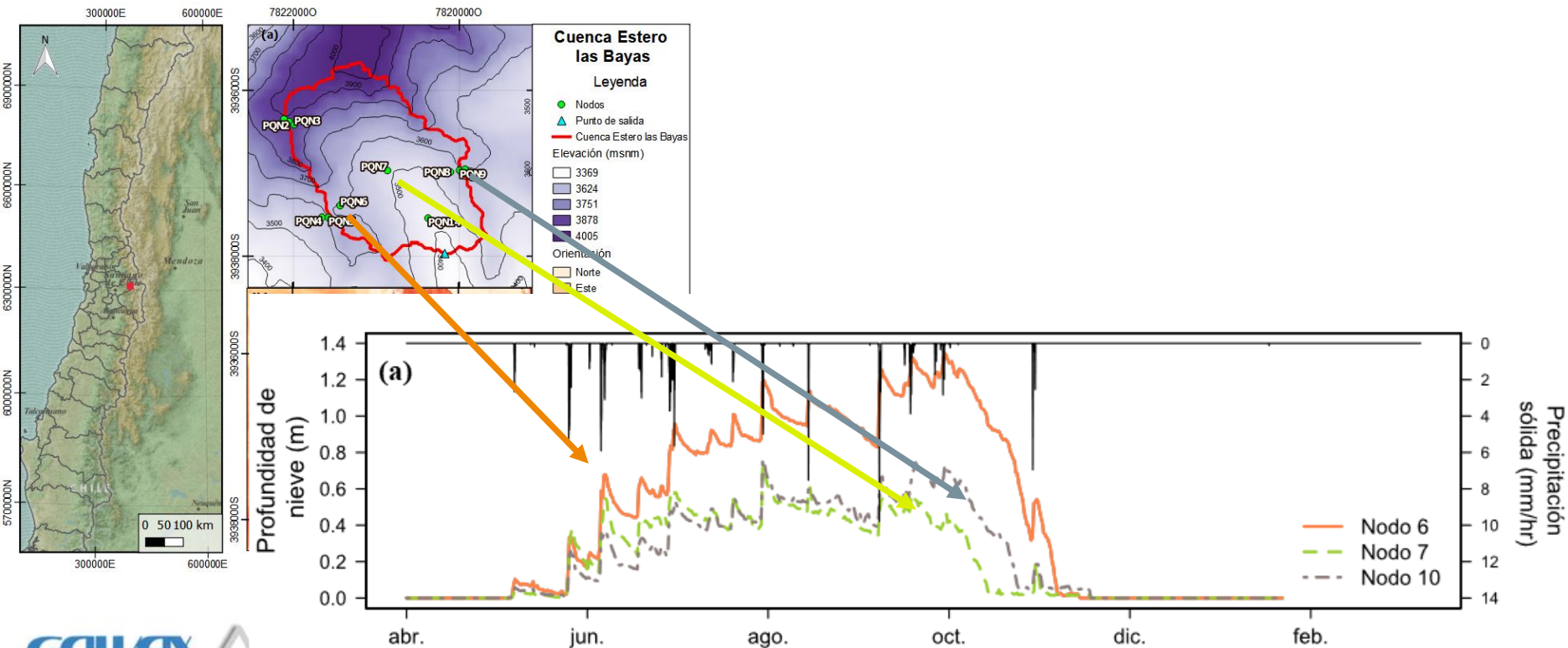


1 km<sup>2</sup>  
Few acquisitions  
per season  
cm-scale

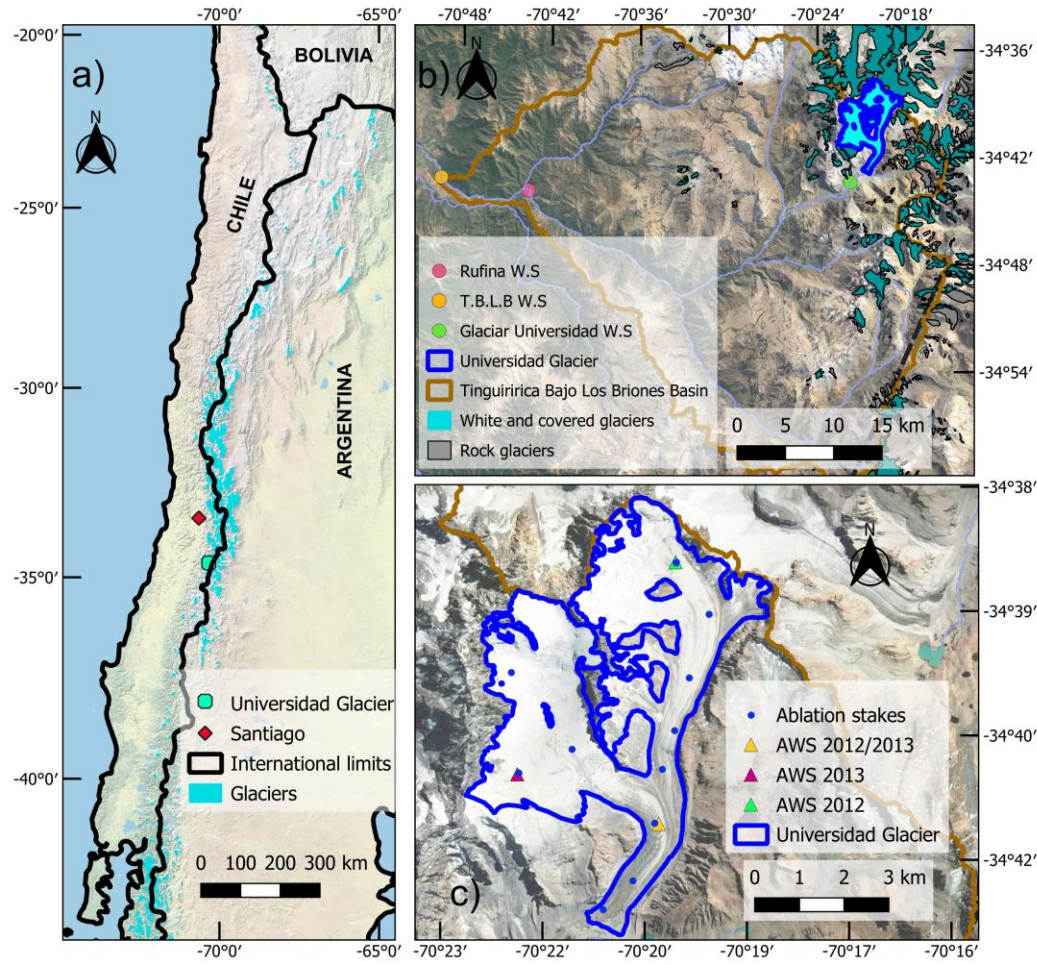




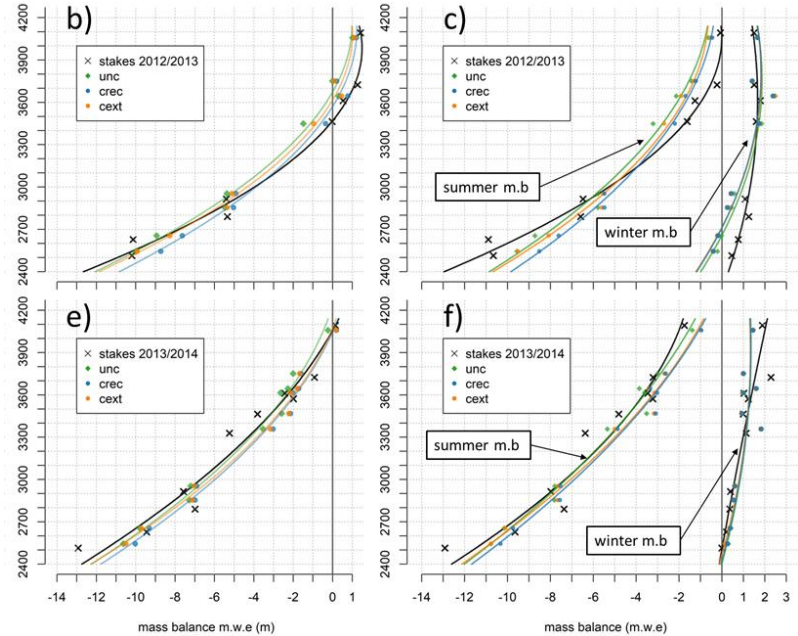
# Continuous snow depth



# SP-3. Glaciohydrological impacts with CRHM

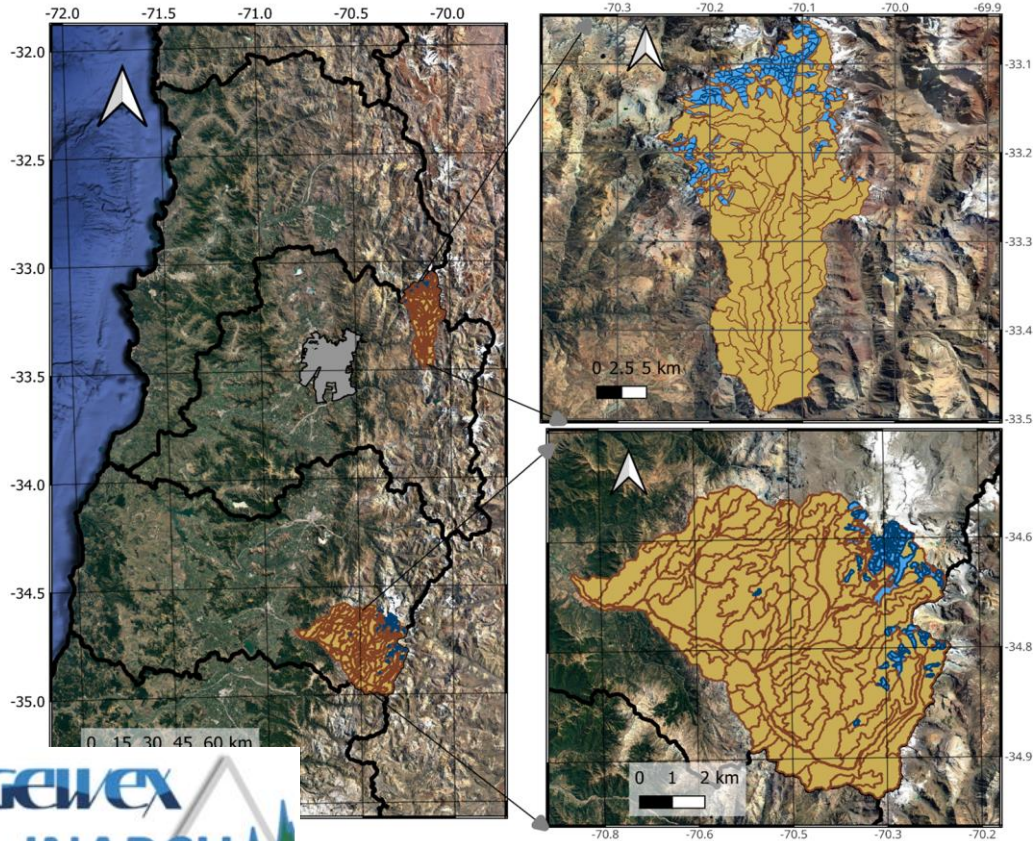


Just a few ablation measurements allow to identify strengths and weaknesses





# SP-3. Glaciohydrological impacts with CRHM

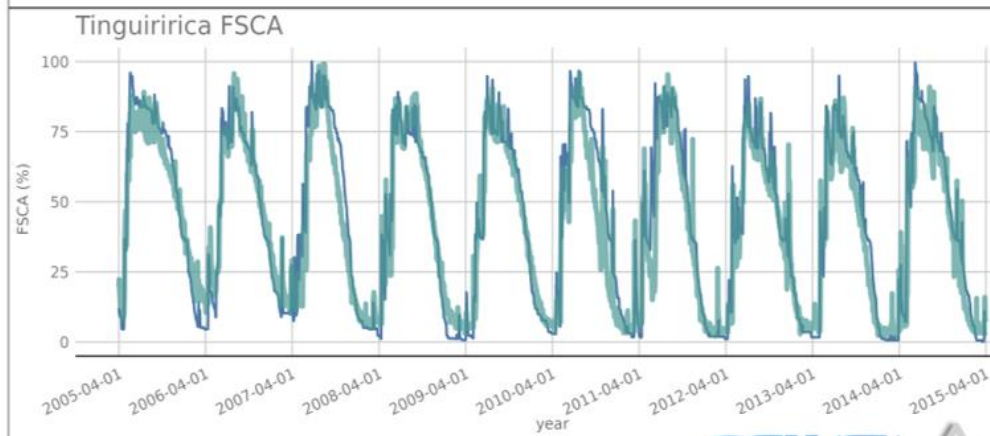
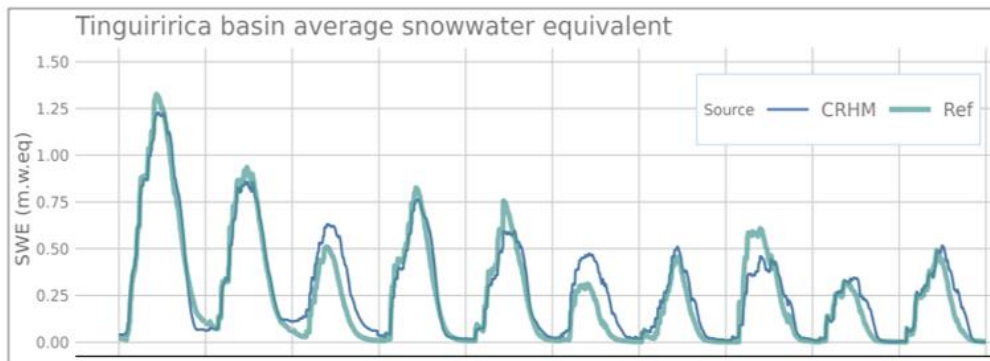
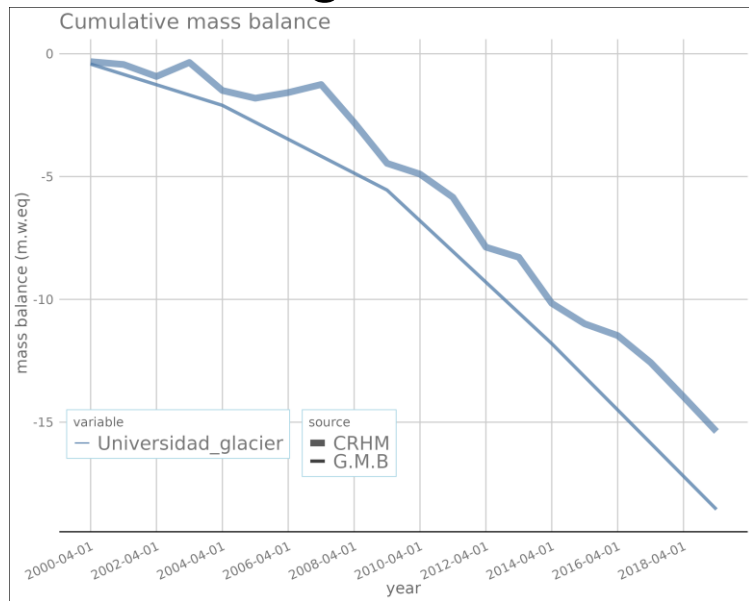


We selected two of the basins with the largest glacier area in the extratropical Andes: Rio Olivares (-33.49°) and Tinguiririca Bajo los Briones (-34.72°)

Basin	Area (km <sup>2</sup> )	Glacier area (km <sup>2</sup> )	Annual pp (mm)	Mean temp (°C)
Olivares River	542	73	455	2.8
Tinguiririca Bajo los Briones	1438	66	1418	4.2

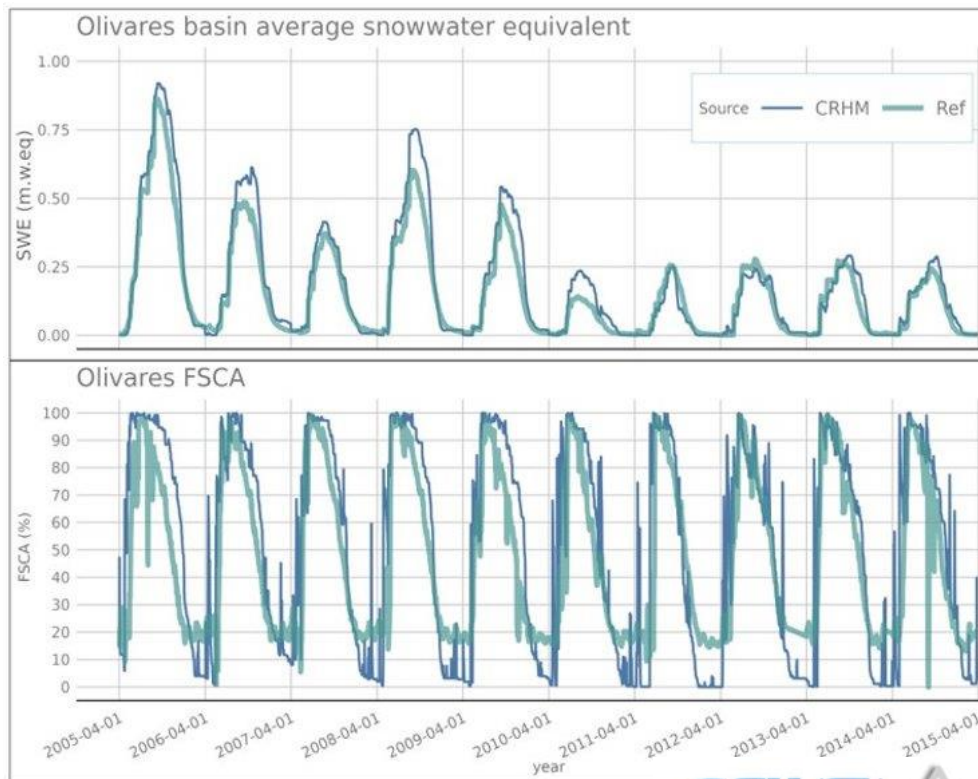
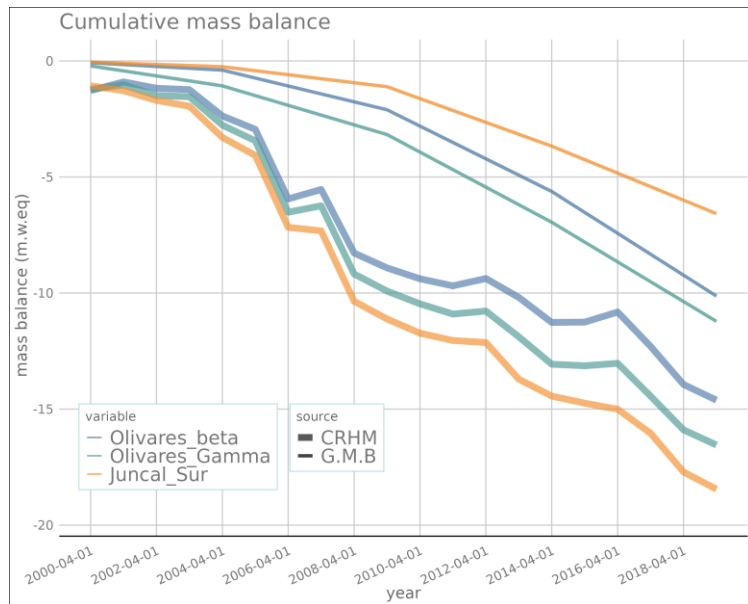


# SP-3. Tinguiririca basin evaluation



Variable	RMSE	R2	KGE	r pearson	$\alpha$	$\beta$
SWE (m.w.eq)	0.10	0.90	0.85	0.96	0.91	1.11
FSCA (%)	9.86	0.85	0.89	0.95	1.06	1.08

# SP-3. Olivares basin evaluation (parameters from Tinguiririca)

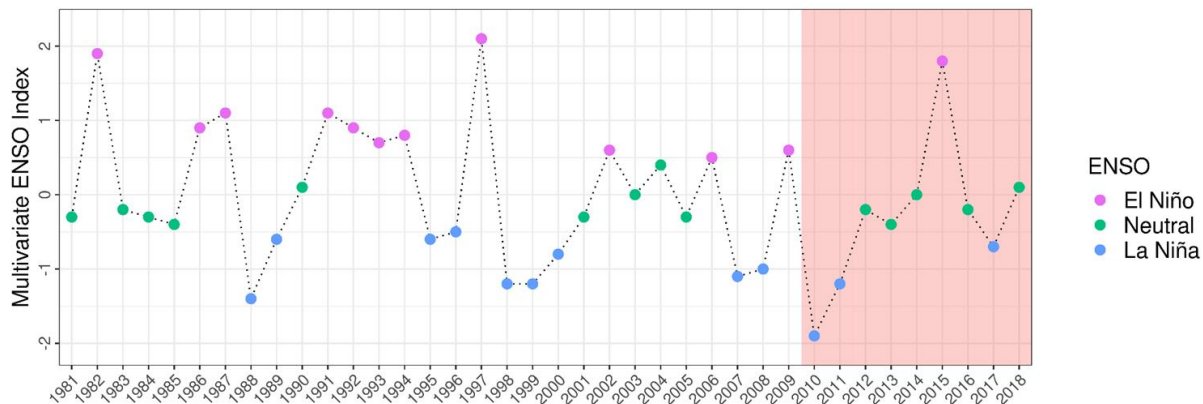
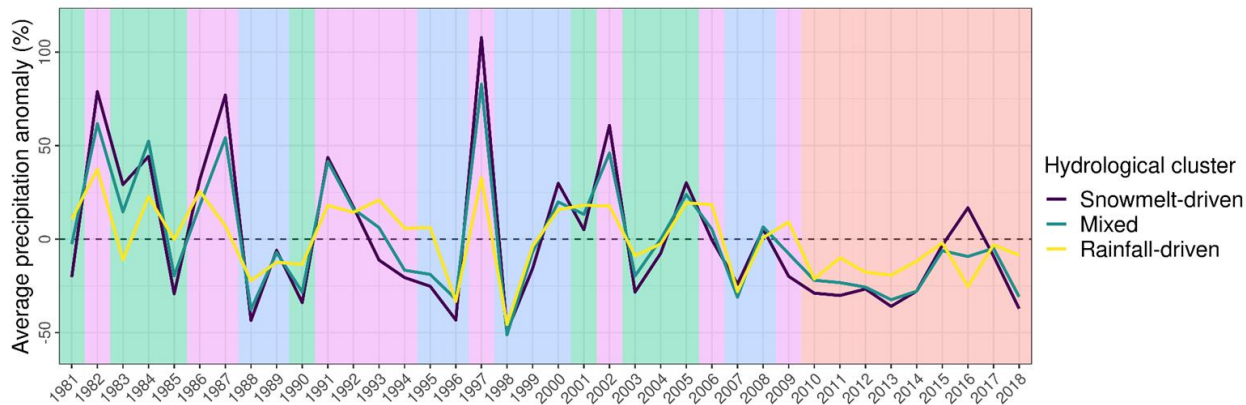


Variable	RMSE	R2	KGE	r pearson	$\alpha$	$\beta$
SWE (m.w.eq)	0.08	0.80	0.85	0.96	1.15	1.23
FSCA (%)	19	0.70	0.70	0.87	1.25	1.09

# SP-2. Drought impacts with MESH

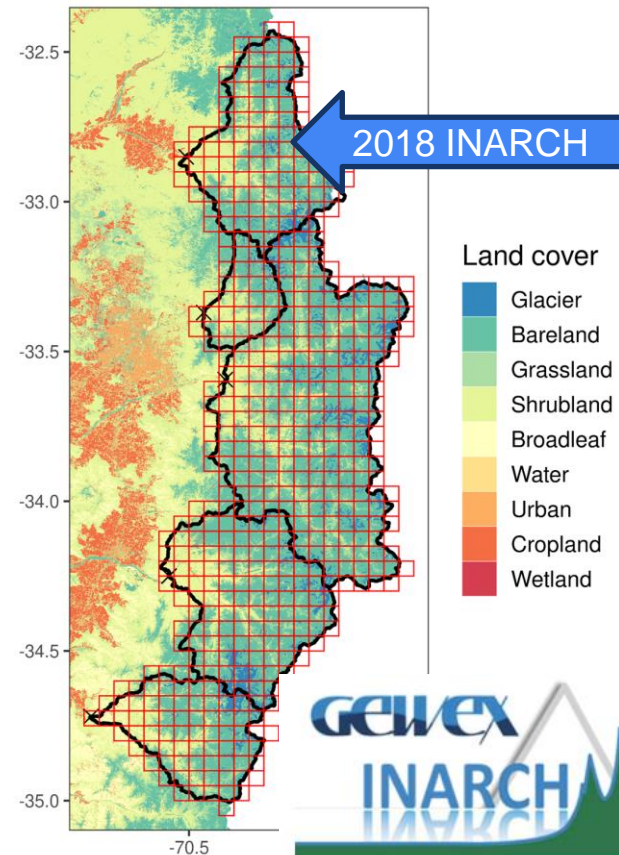
Dominant land cover classes:

Bareland: 57 to 68 %  
 Shrubland: 9 to 20 %  
 Grassland: 4 to 22 %  
 Glacier: 3 to 11 %



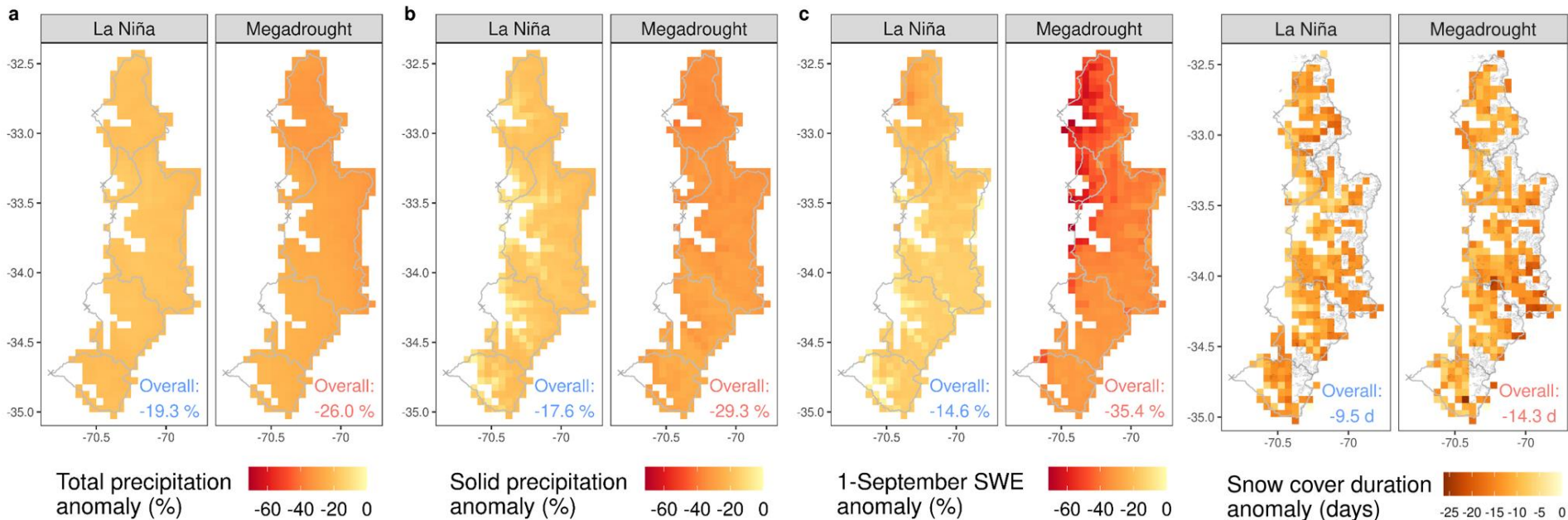
Water years are classified into El Niño, Neutral, La Niña, and Megadrought.

Setup: 5 x 5 km grid cells, GRUs defined by land cover and aspect, MMESH enabled.





# SP-2. Drought impacts with MESH



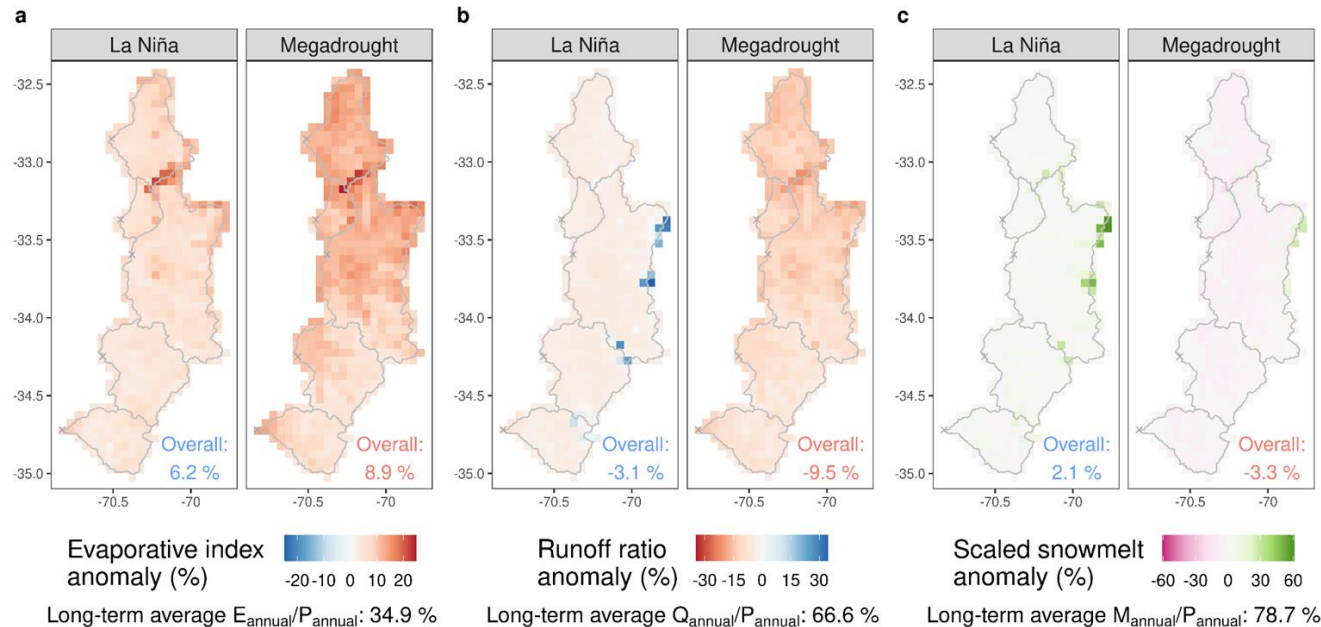
From total precipitation to solid precipitation and then snow accumulation, the deficit amplifies for the megadrought but softens for La Niña years (in %).

This modulation is possibly related to the seasonal temperature anomalies (LN and MD capture well-defined meteorological signatures).

Average anomalies		
Variable	La Niña	Megadrought
Precipitation (%)	-19.3	-26
Storms temperature (°C)	-0.3	0.2
Temperature JJA (°C)	-0.3	0.2
Temperature OND (°C)	0.2	0
Temperature JFM (°C)	-0.3	0.5

# SP-2. Drought impacts with MESH

Glacier GRU variables:



These three variables are already scaled by annual precipitation and could be interpreted as efficiencies.

The MD depicts less efficiency in producing snowmelt (compared to the long-term average) and producing runoff (compared to LN), and more efficiency in producing evaporation.

Long-term average	Annual contribution: $Q_{\text{glacier}}$ to $Q$ (%)	Summer contribution: $Q_{\text{glacier}}$ to $Q$ (%)		
Aconcagua	3.6	7.8		
Mapocho	2.8	5.9		
Maipo	6	16		
Cachapoal	7.8	23.2		
Tinguiririca	5.8	20.3		
Average anomaly	Annual $Q_{\text{glacier}}$ compared to long-term average (%)		Summer $Q_{\text{glacier}}$ compared to long-term average (%)	
	LN	MD	LN	MD
Aconcagua	-39	-80	-66	-84
Mapocho	-36	-77	-64	-83
Maipo	-22	-49	-37	-53
Cachapoal	-22	-34	-46	-43
Tinguiririca	-22	-32	-50	-45

# Summary and perspectives

- Physically based modeling tools offer the opportunity to assimilate data from diverse sources
- Experimental catchments are key to test hydrological hypotheses and identify avenues for improvement in hydrological predictions
- Combination of defensible models + assimilation of remote/in-situ data emerging as desirable strategy for timely hydrological predictions for social preparedness.



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