Glaciers (and snow) in the Atacama Desert

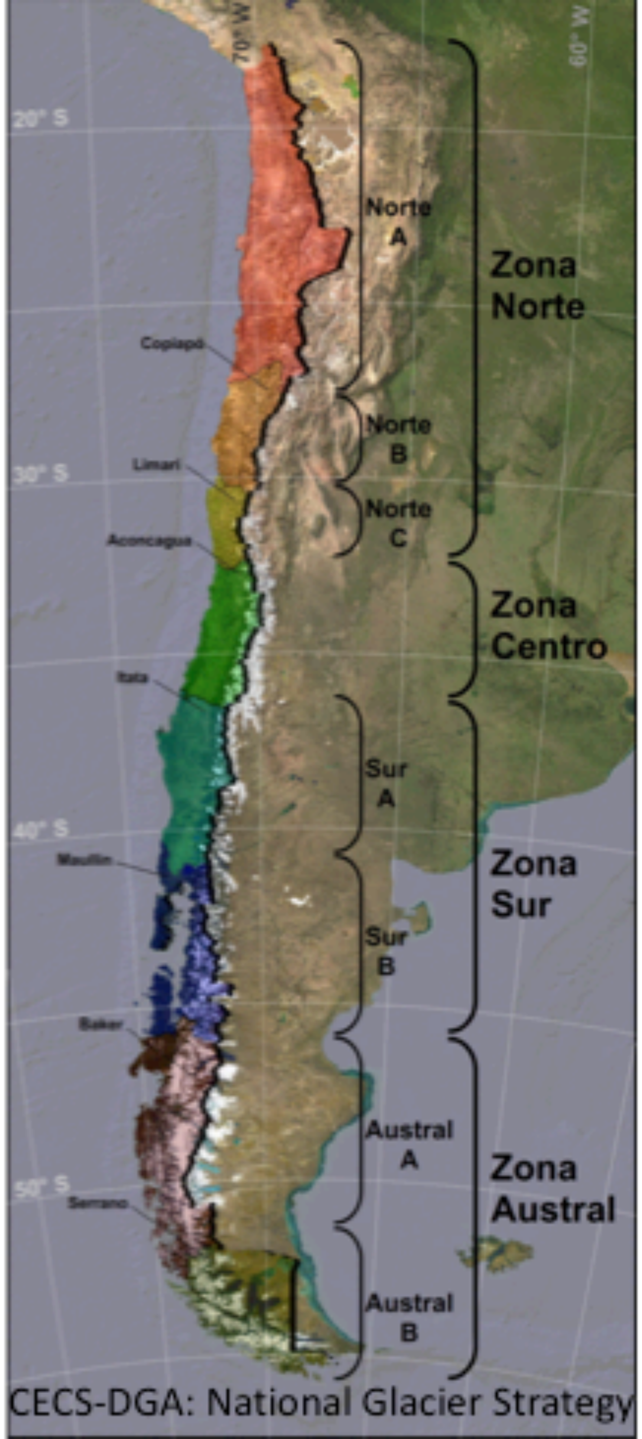
Shelley MacDonell

CENTRO DE ESTUDIOS AVANZADOS EN ZONAS ÁRIDAS
CEAZA

GOBIERNO REGIONAL
REGIÓN DE COQUIMBO

CONICYT
Ministerio de Educación
Gobierno de Chile

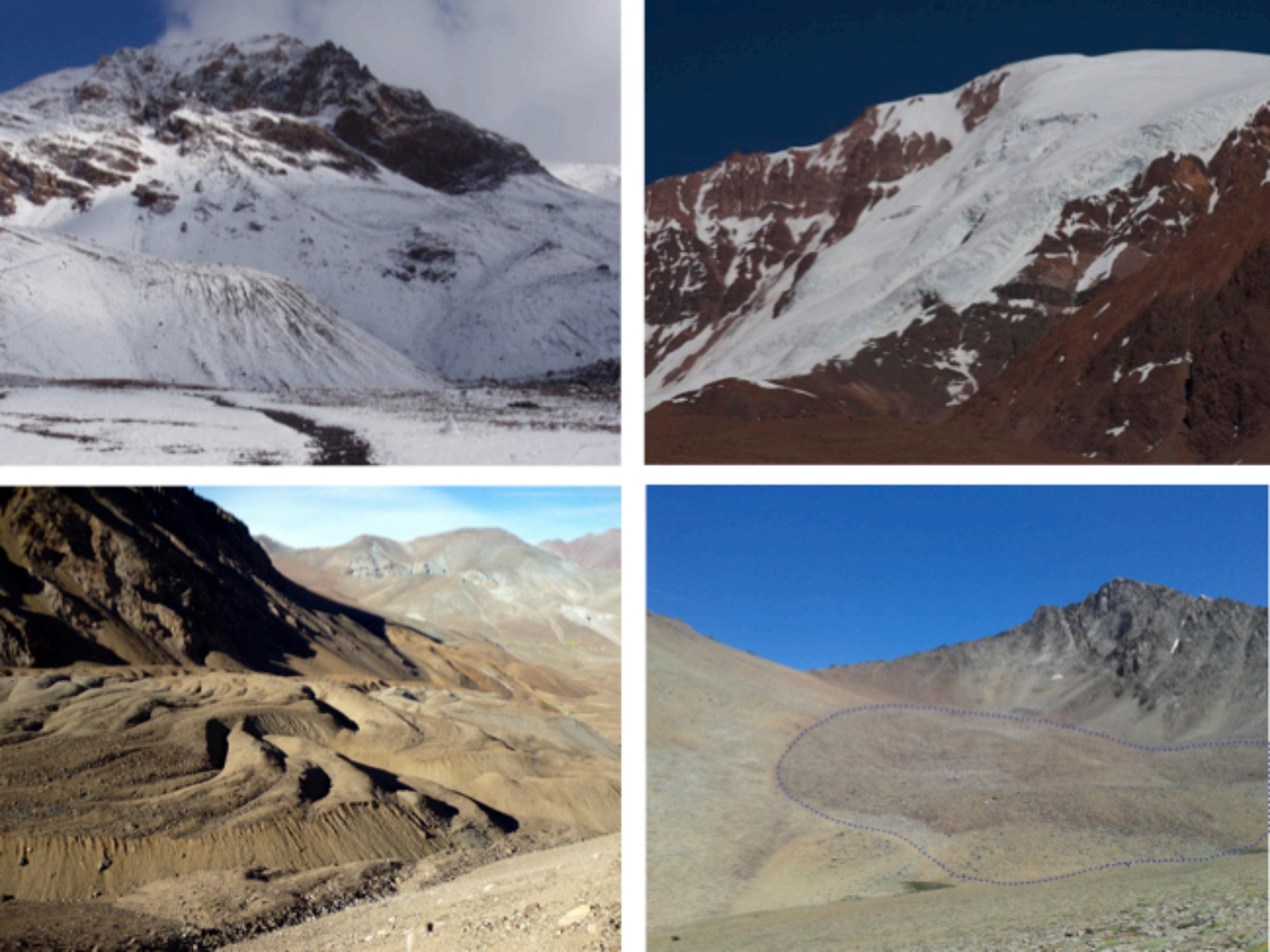
Dirección General de Aguas
Ministerio de Obras Públicas
Gobierno de Chile


70° W
60° W
20° S
30° S
40° S
50° S
Copiapó
Limarí
Aconcagua
Itata
Maullín
Baker
Serrano
Norte A
Norte B
Norte C
Sur A
Sur B
Austral A
Austral B
Zona Norte
Zona Centro
Zona Sur
Zona Austral
CECS-DGA: National Glacier Strategy

Driving research questions:

What is the contribution of the cryosphere to the catchment?

How might this change in future?

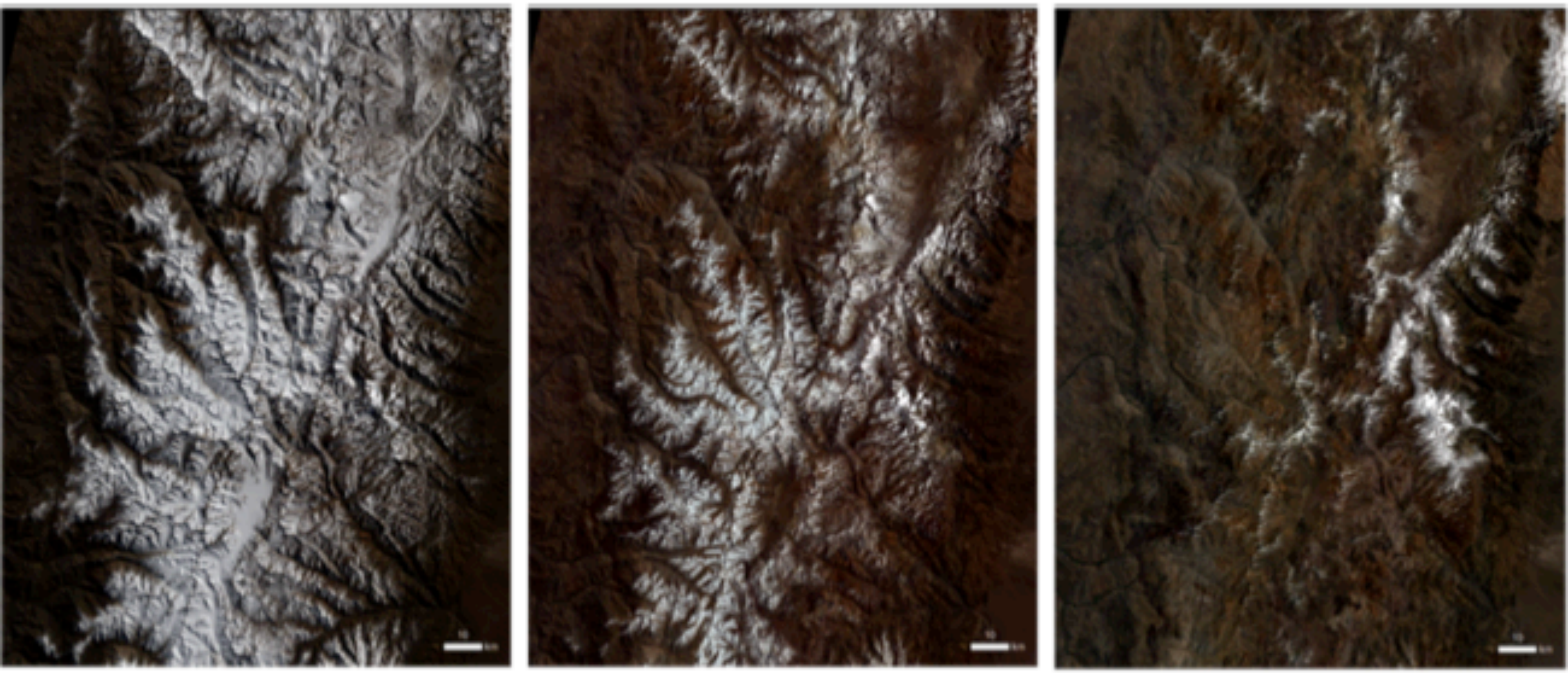


- Dry: ~200 mm/y

ARID ANDES
La Serena
SANTIAGO
PATAGONIAN ANDES
ADUANA 50
VICUÑA 138
COQUIMBO 210

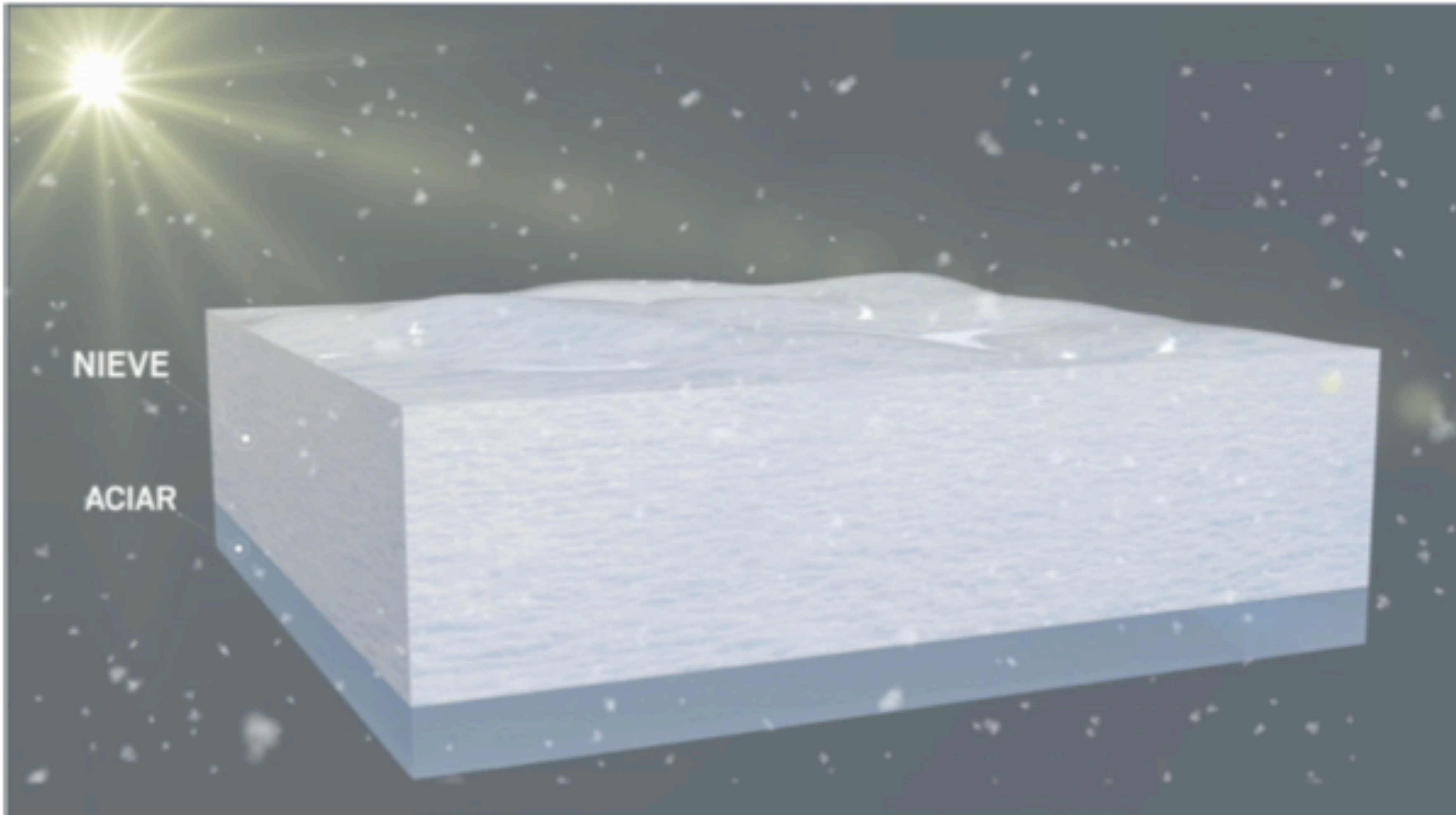
- Dry: ~200 mm/y
- Episodic precipitation events
- 90 % of precipitation: May - August

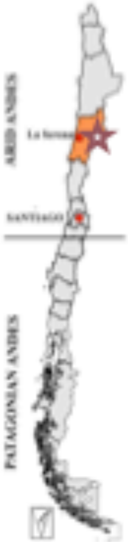
- Dry: ~200 mm/y
- Episodic precipitation events
- 90 % of precipitation: May - August
- The snow cover disappears during the spring - summer period



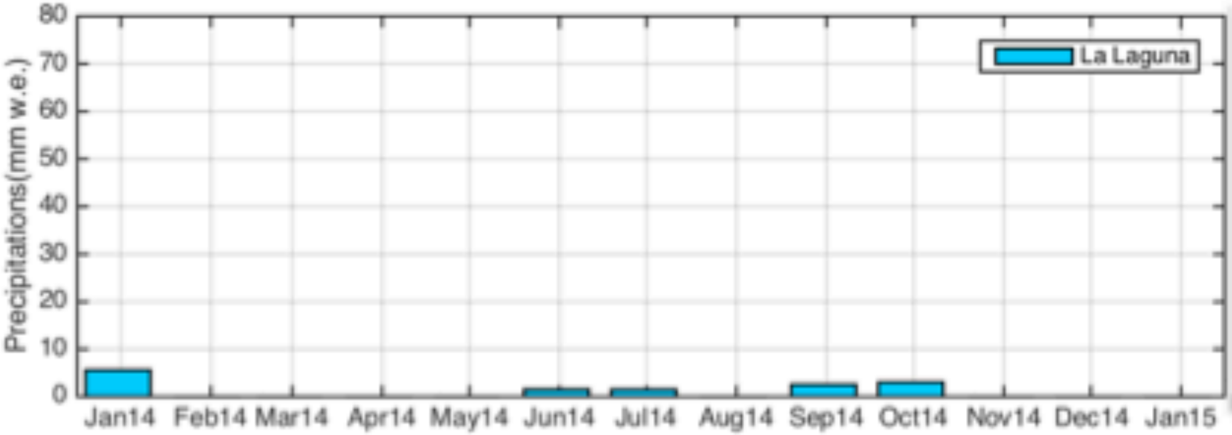
August 10 | October 13 | December 16

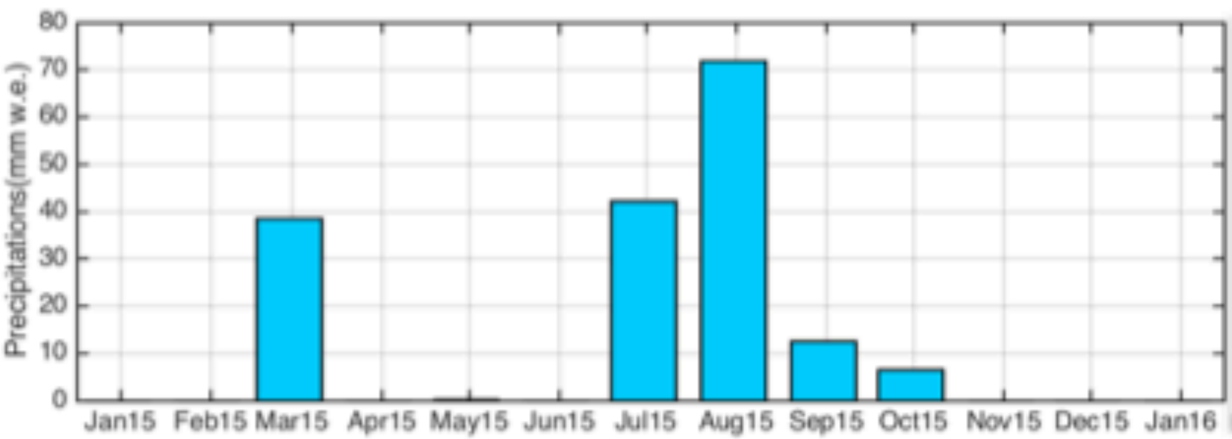
- Sublimation is the dominant ablation process on glaciers
- Snow depth can disappear during winter only due to sublimation.



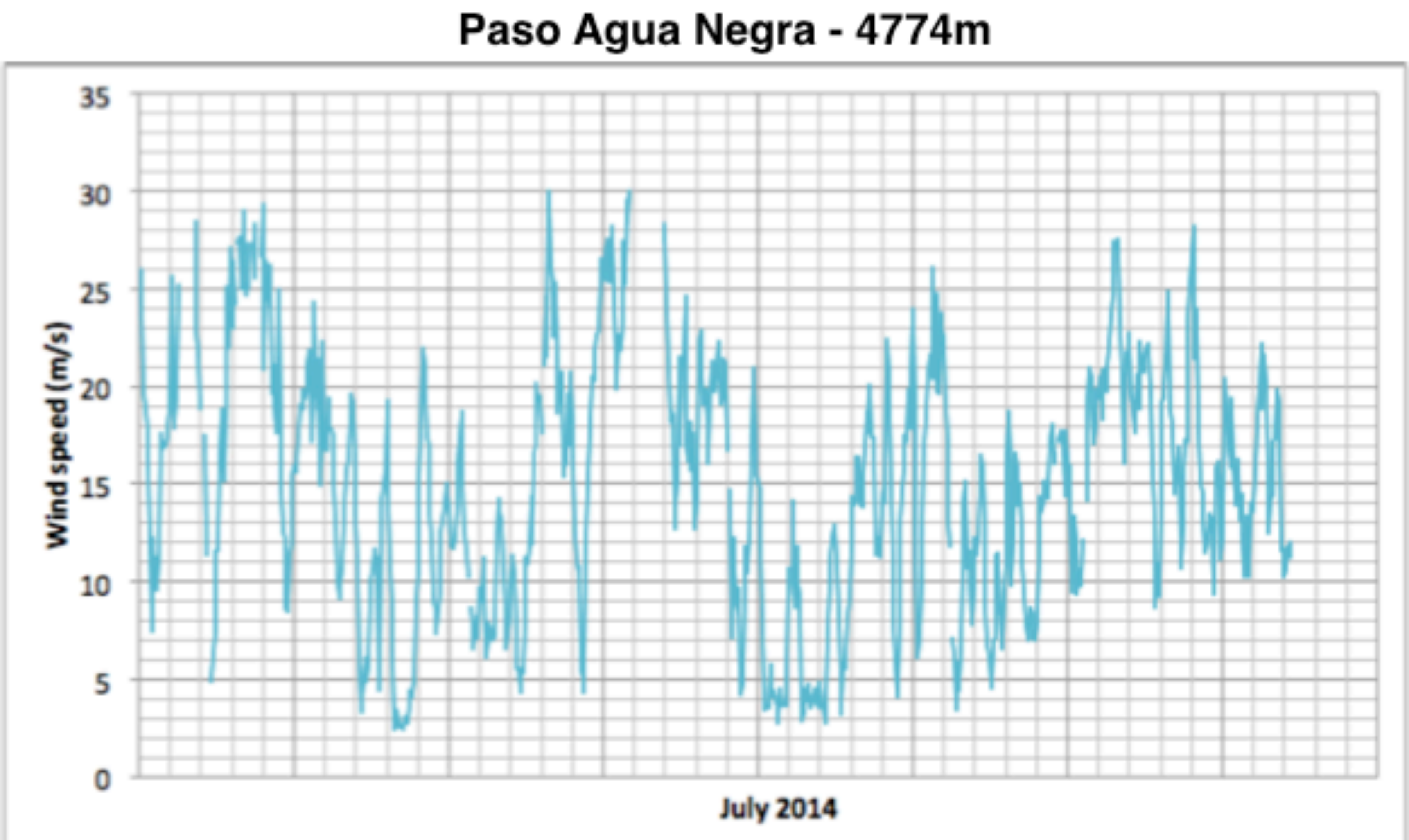


- Precipitation:
  - Temporal variability: dry and wet years (ENSO events)





- Wind:
  - Strong wind speed
  - Importance of sublimation of blowing snow



Snow processes

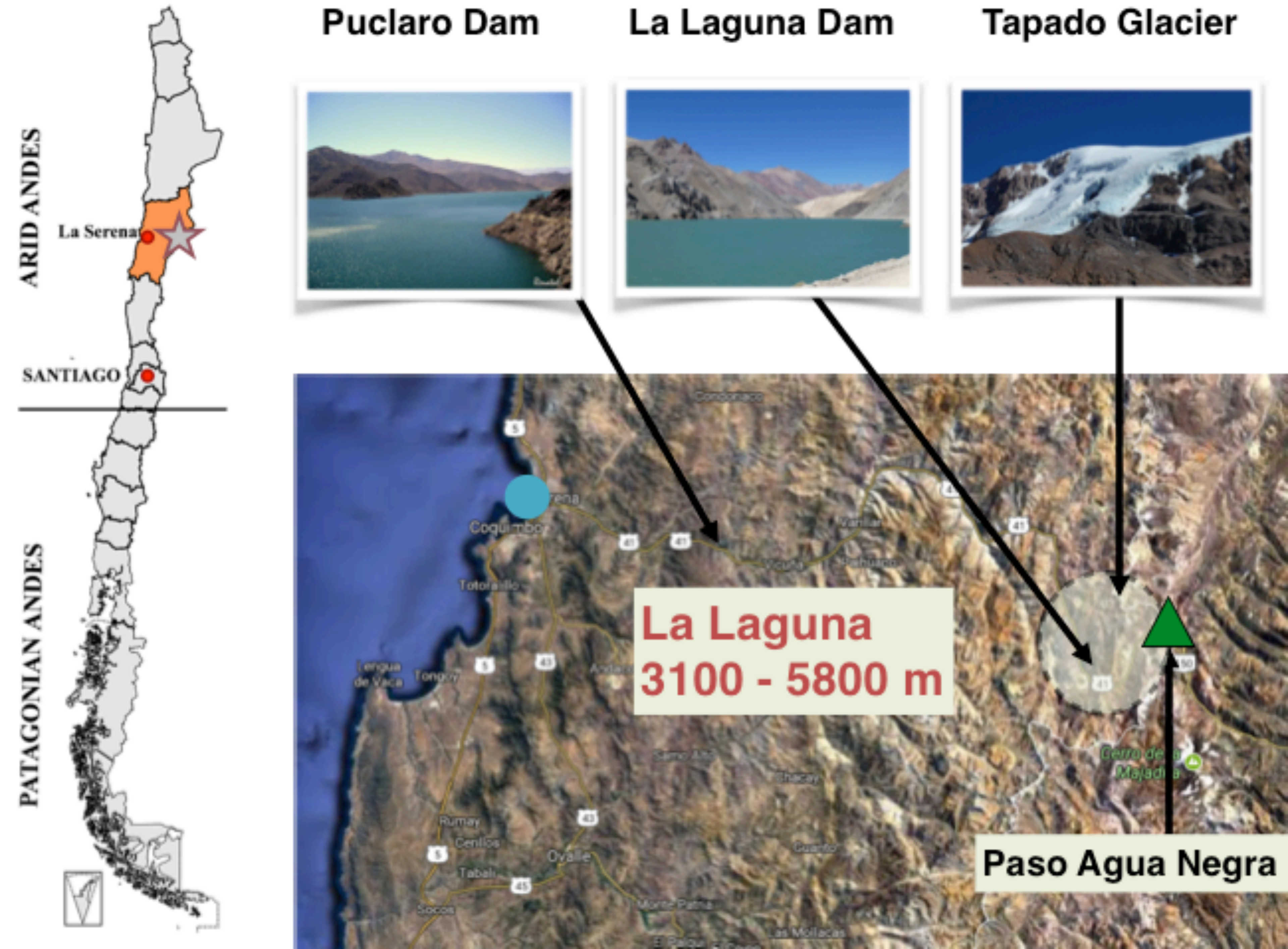
How is precipitation distributed across the catchment?

What is the sublimation to melt ratio?

What is the hydrological contribution?

Can we reduce the sublimation rate?

Marion Réveillet, Simon Gascoin, Christophe Kinnard, Stef Lhermitte, Nicole Schaffer, Annelies Voordendag, Álvaro Ayala



Puclaro Dam
La Laguna Dam
Tapado Glacier
ARID ANDES
La Serena
SANTIAGO
PATAGONIAN ANDES
La Laguna
3100 - 5800 m
Paso Agua Negra
Coquimbo
Totoralillo
Lengua de Vaca
Tongoy
Vicuña
Rumay
Cerrillos
Ovalle
Tabali
Socos
Monte Patria
Cerro de la Majadita

SnowModel (Liston and Elder 2006)

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Met. Forcing

MicroMet

Creates distributed atmospheric fields based on spatial interpolations

SnowTran-3D

3D model that simulates snow depth evolution (deposition and erosion)

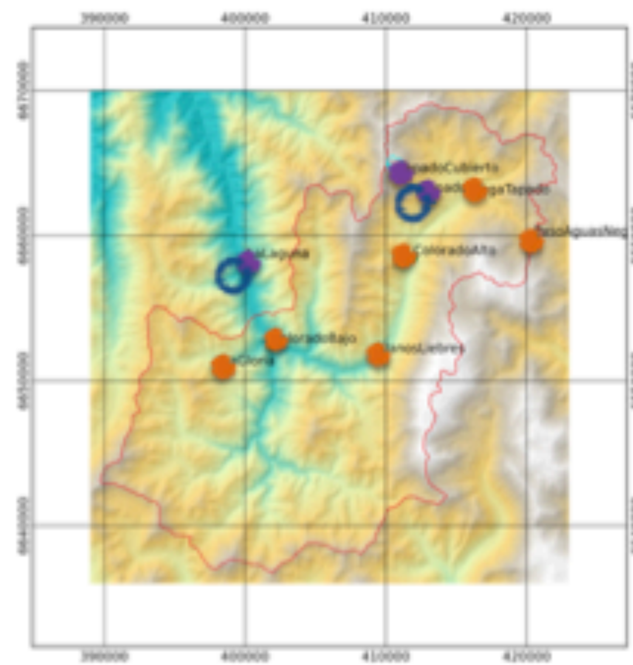
EnBal

Performs standard surface energy balance calculations

SnowPack

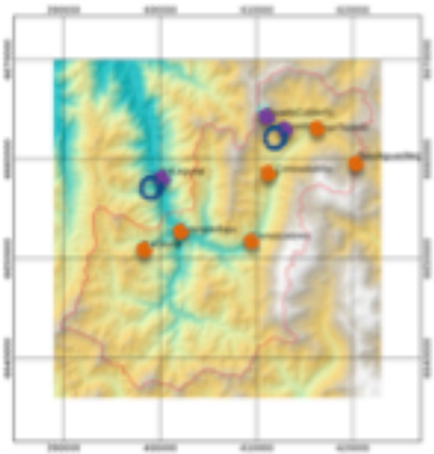
Describes snowpack changes in response to precipitation and melt fluxes defined by MicroMet and EnBal

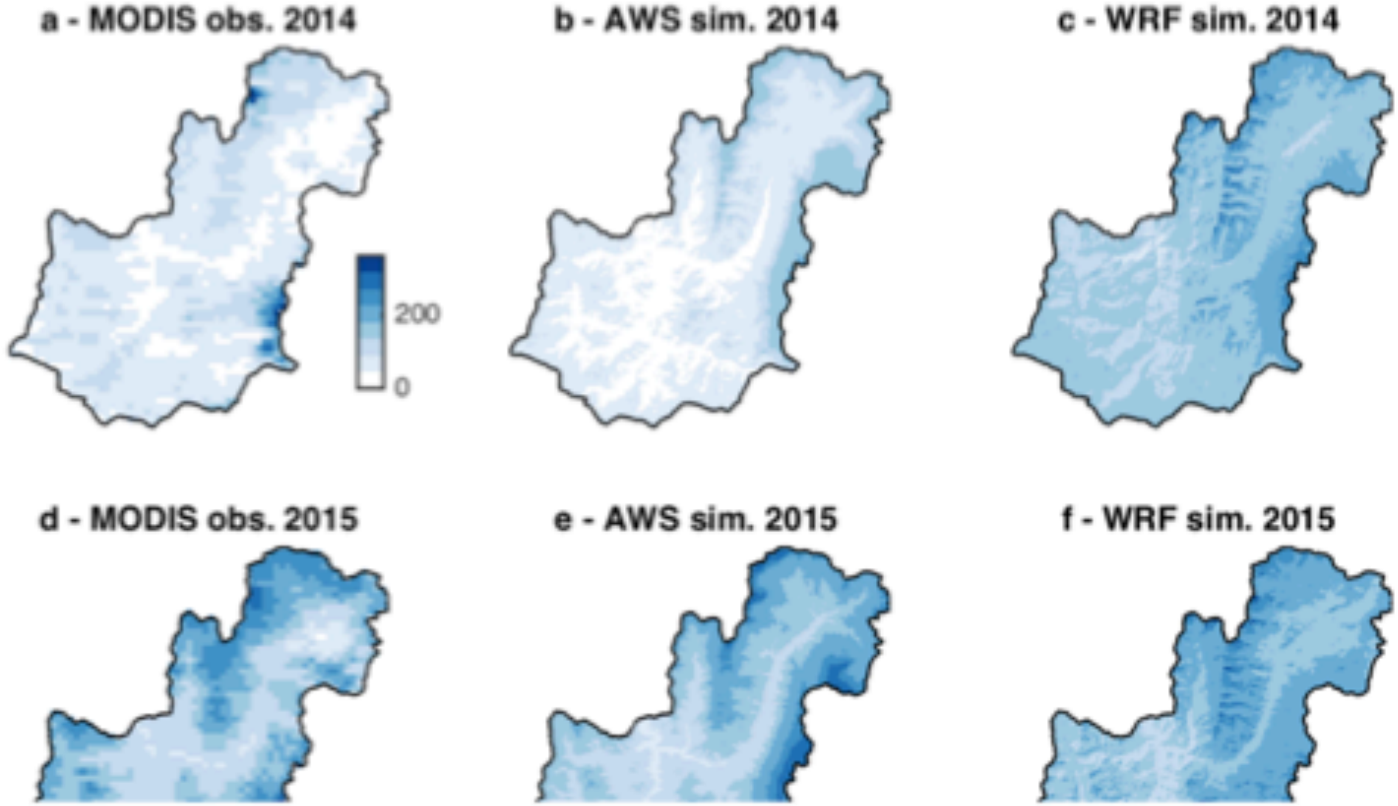
AWS network

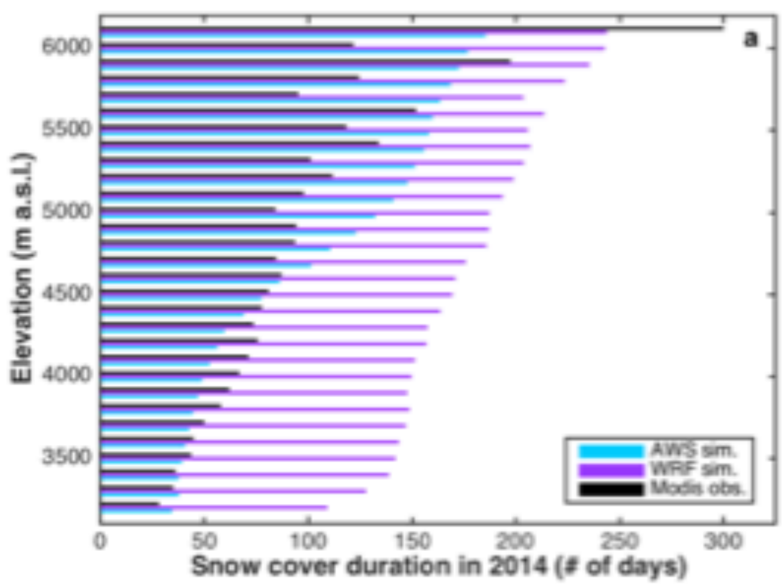


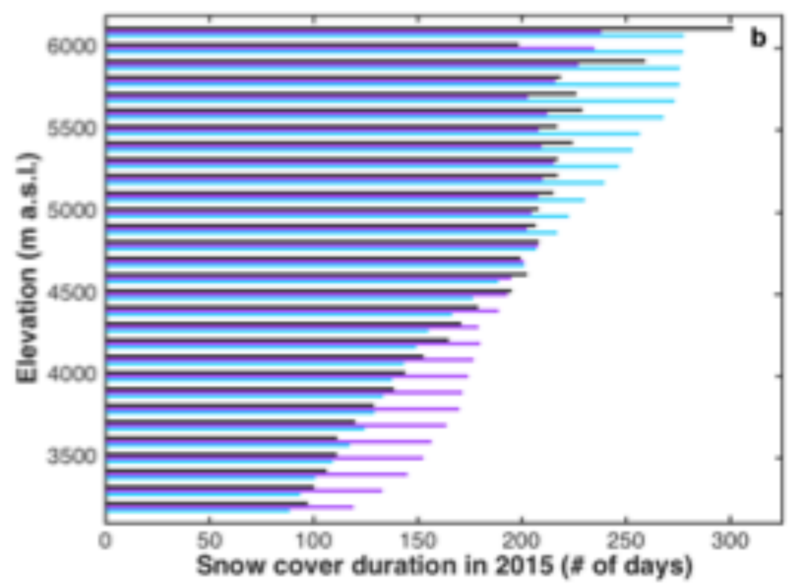
WRF output (3 km)

Snow depth evolution




a - MODIS obs. 2014
b - AWS sim. 2014
c - WRF sim. 2014
200
0
d - MODIS obs. 2015
e - AWS sim. 2015
f - WRF sim. 2015


a
Elevation (m a.s.l.)
6000
5500
5000
4500
4000
3500
AWS sim.
WRF sim.
Modis obs.
0
50
100
150
200
250
300
Snow cover duration in 2014 (# of days)


b
Elevation (m a.s.l.)
6000
5500
5000
4500
4000
3500
0
50
100
150
200
250
300
Snow cover duration in 2015 (# of days)

Rates per elevation band:

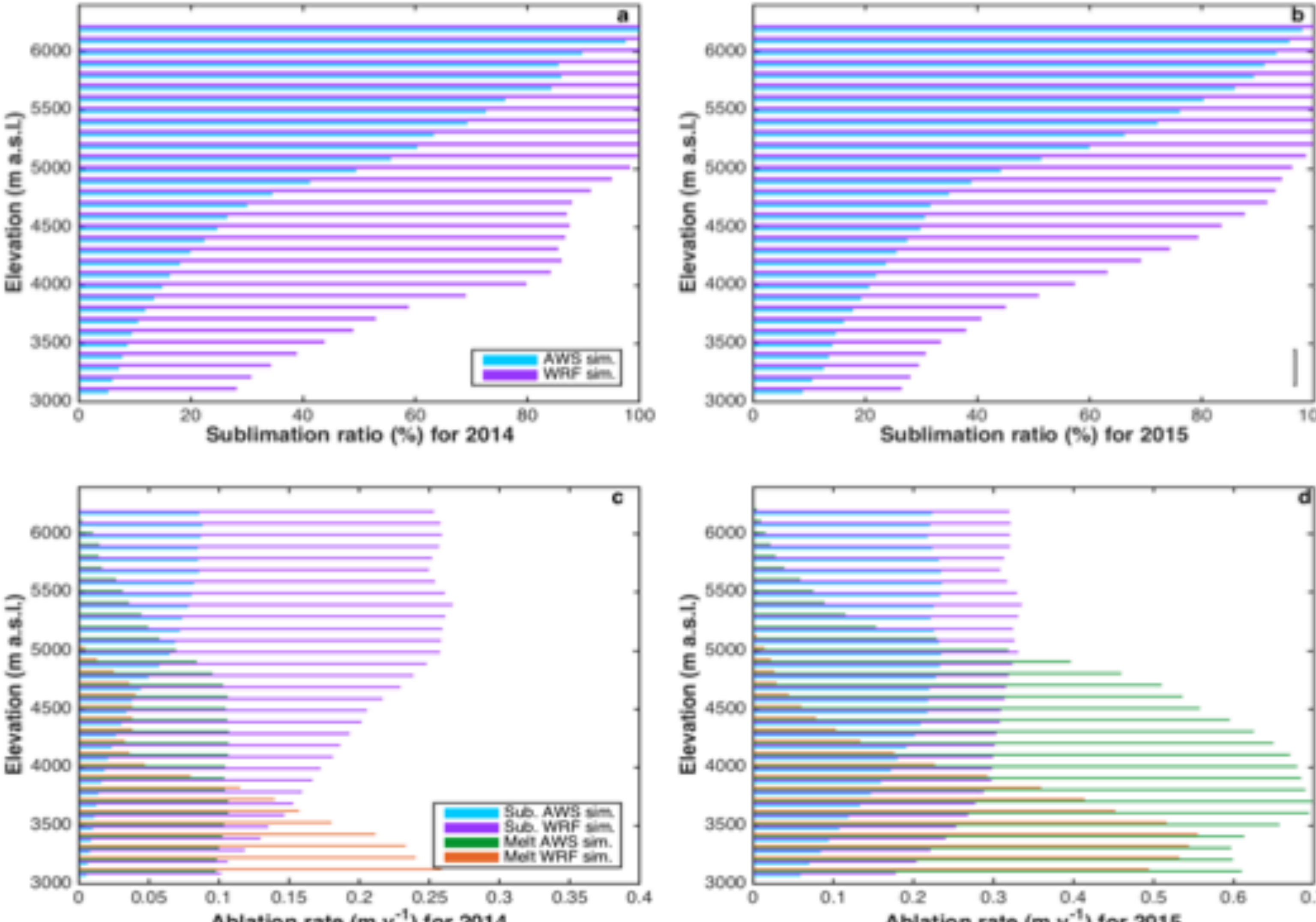
Overall sublimation %:

	AWS	WRF
2014:	39	81
2015:	31	86

2014 2015

Sublimation (%)

Ablation rate



Next steps:

→ Improve WRF quality (help welcome)

→ Extend timespan

→ Hydrological importance and connection to glaciers

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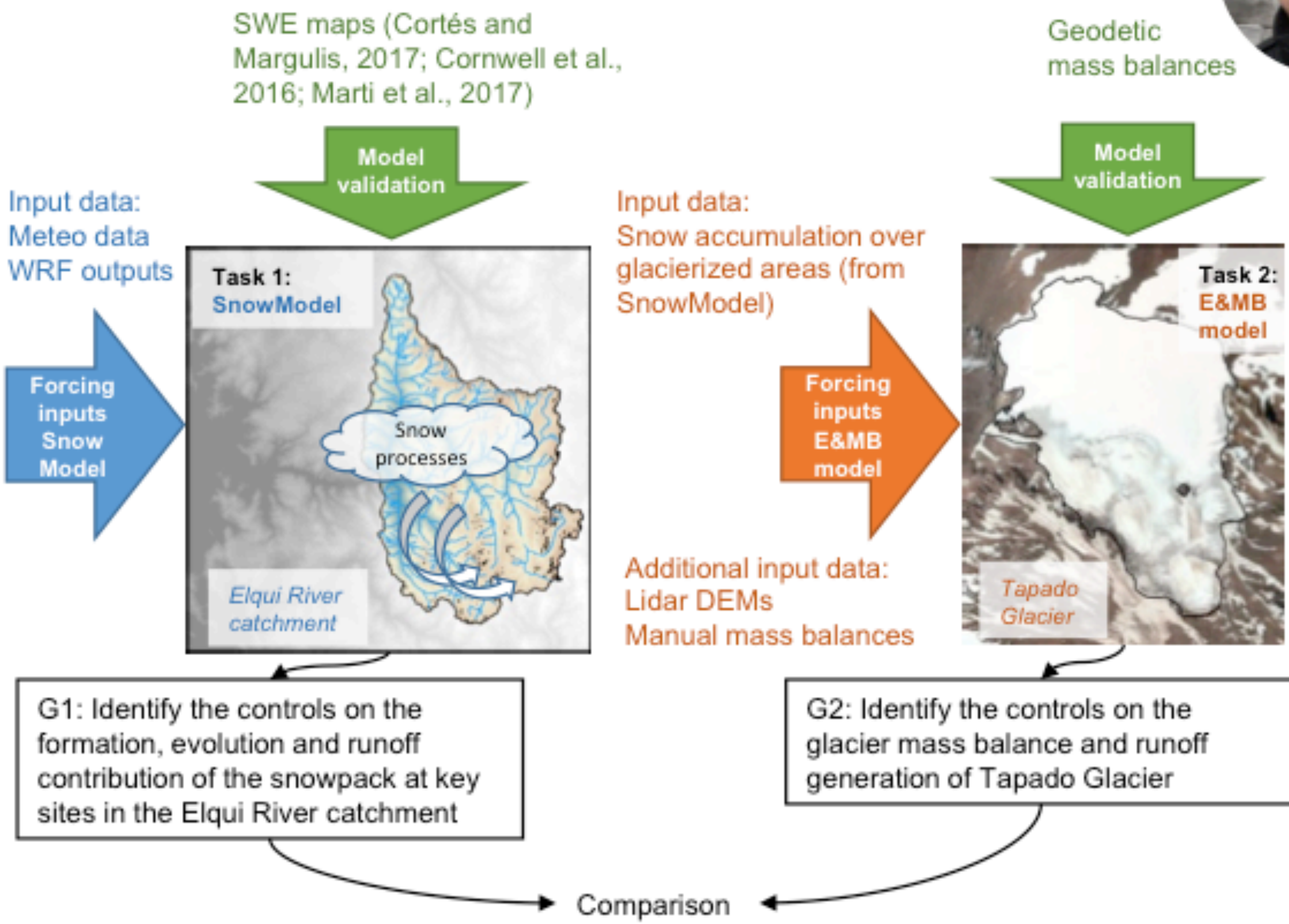


Glacier processes

What is the sublimation to melt ratio?

What is the role of penitentes in the energy and mass balance?

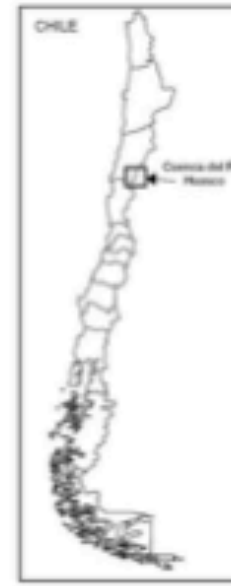
What is the hydrological contribution?

Álvaro Ayala, James McPhee, Francesca Pellicciotti, Marion Réveillet, Christophe Kinnard

Glacier mass and energy balance modelling

Guanaco Glacier

Toro 1 Glacier

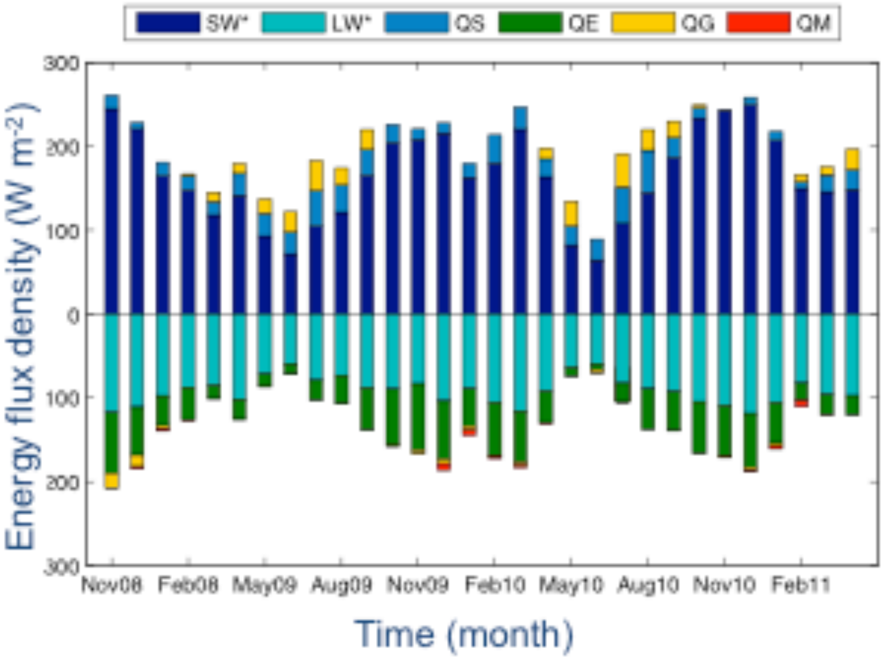


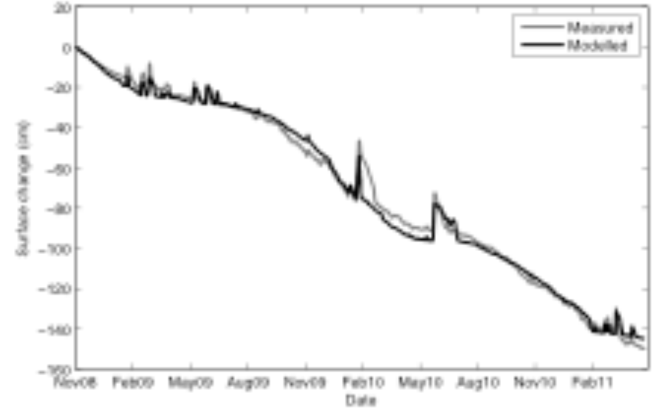
What is the effect of penitentes on the turbulent heat fluxes?

Eddy covariance measurements

What is the difference in ablation rate and fraction between sites?

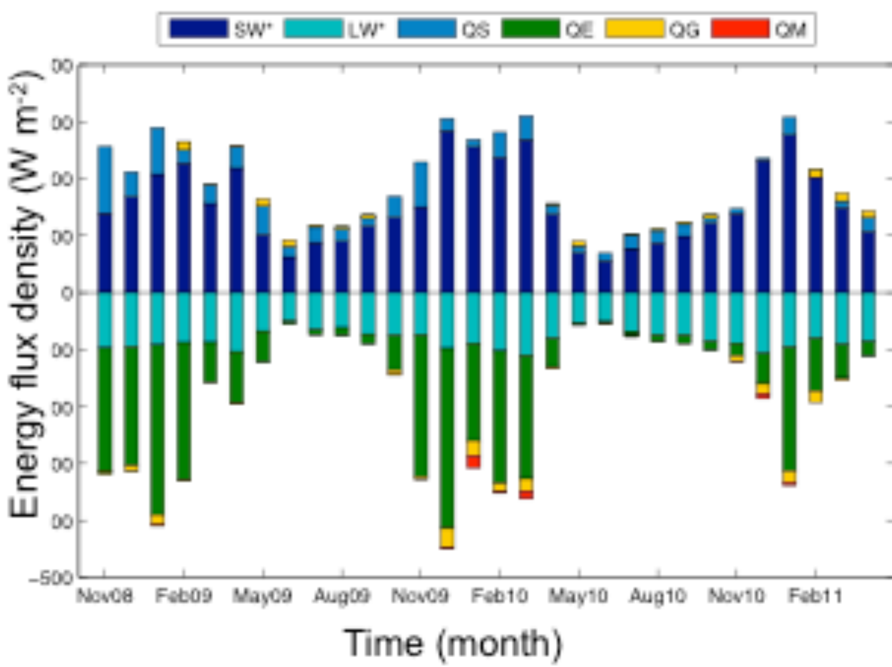
Energy/mass balance modelling

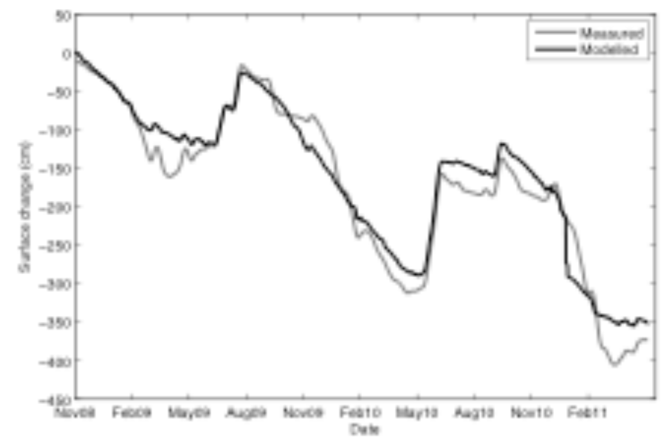




Surface change (mea) = -1500 mm
(mod) = -1450 mm
RMSE = 4.1 mm
MacDonell et al. (2013)

Guanaco



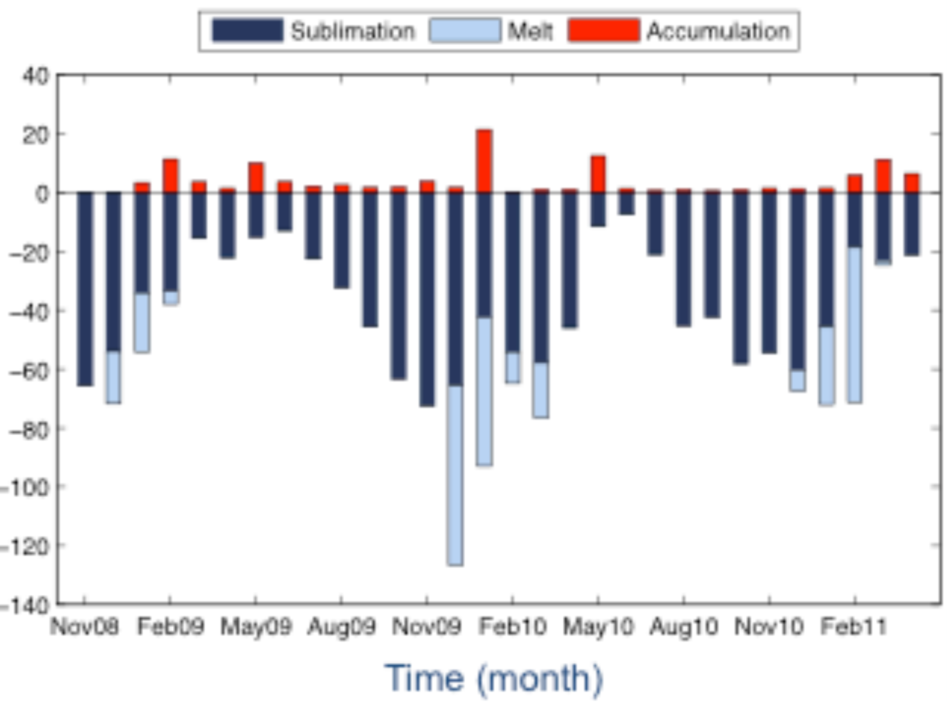


Surface change (mea) = - 3728 mm
(mod) = - 3511 mm
RMSE = 25.9 mm

Toro 1

Mass balance results

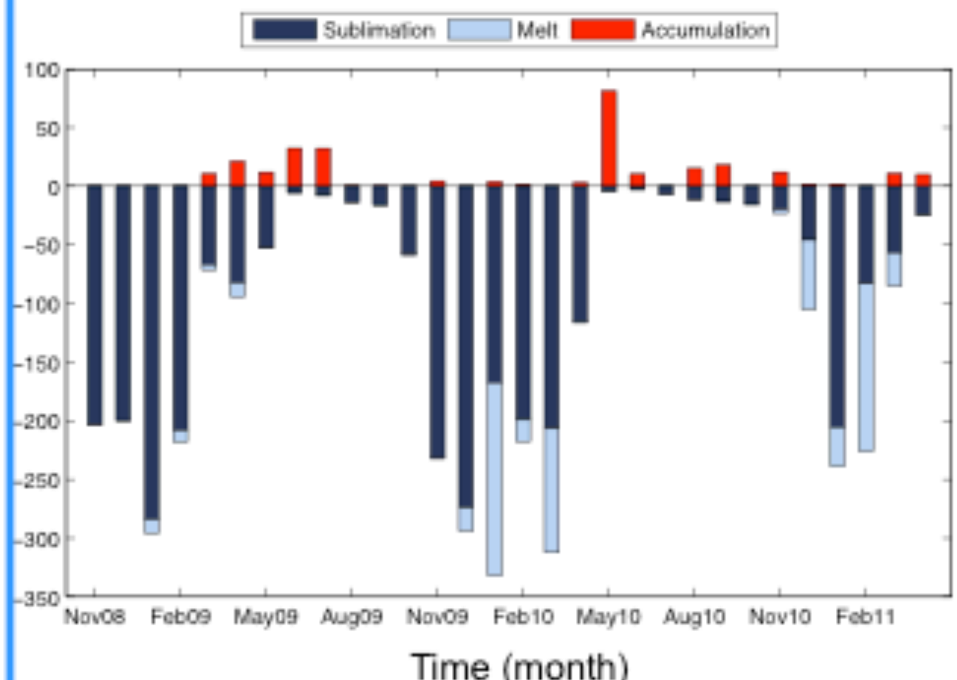
Guanaco



Total melt = 271 mm w.e.
Total sublimation = 1164 mm w.e.
Melt % of total ablation = 19%

MacDonell et al. (2013)

Toro 1



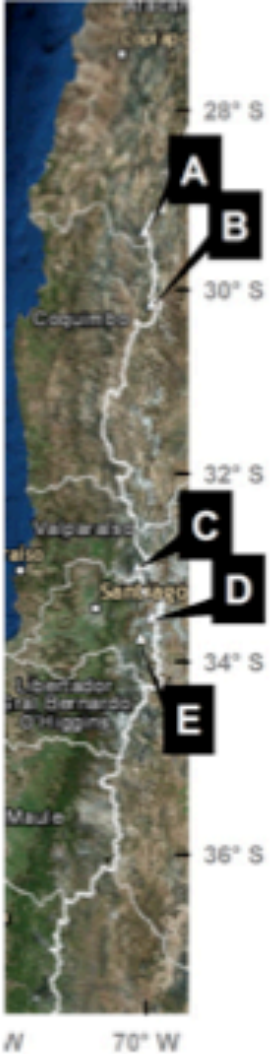
Total melt = 613 mm w.e.
Total sublimation = 2882 mm w.e.
Melt % of total ablation = 18%

In subsequent studies:

- Chemistry to analyse whether permanent features + sublimation rate
- Kinect to analyse ablation spatially (and validate ablation frames)

And now:

What is the accumulation in a penitente field?



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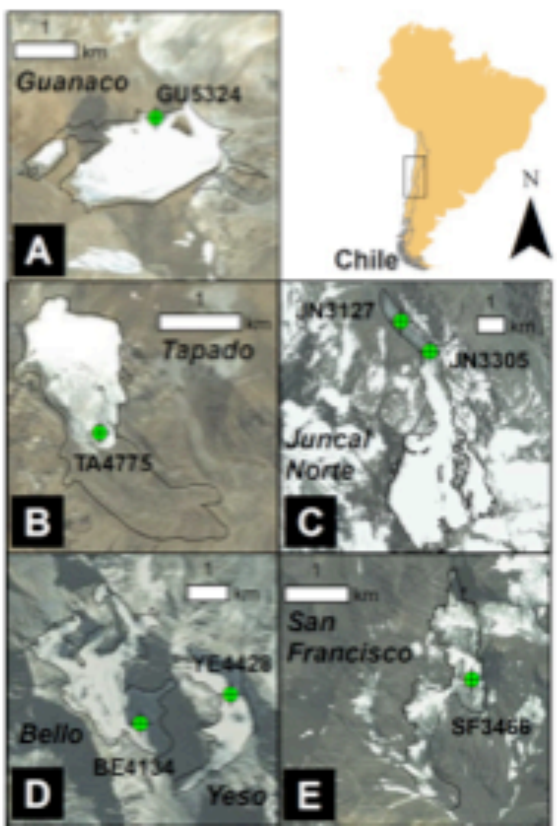
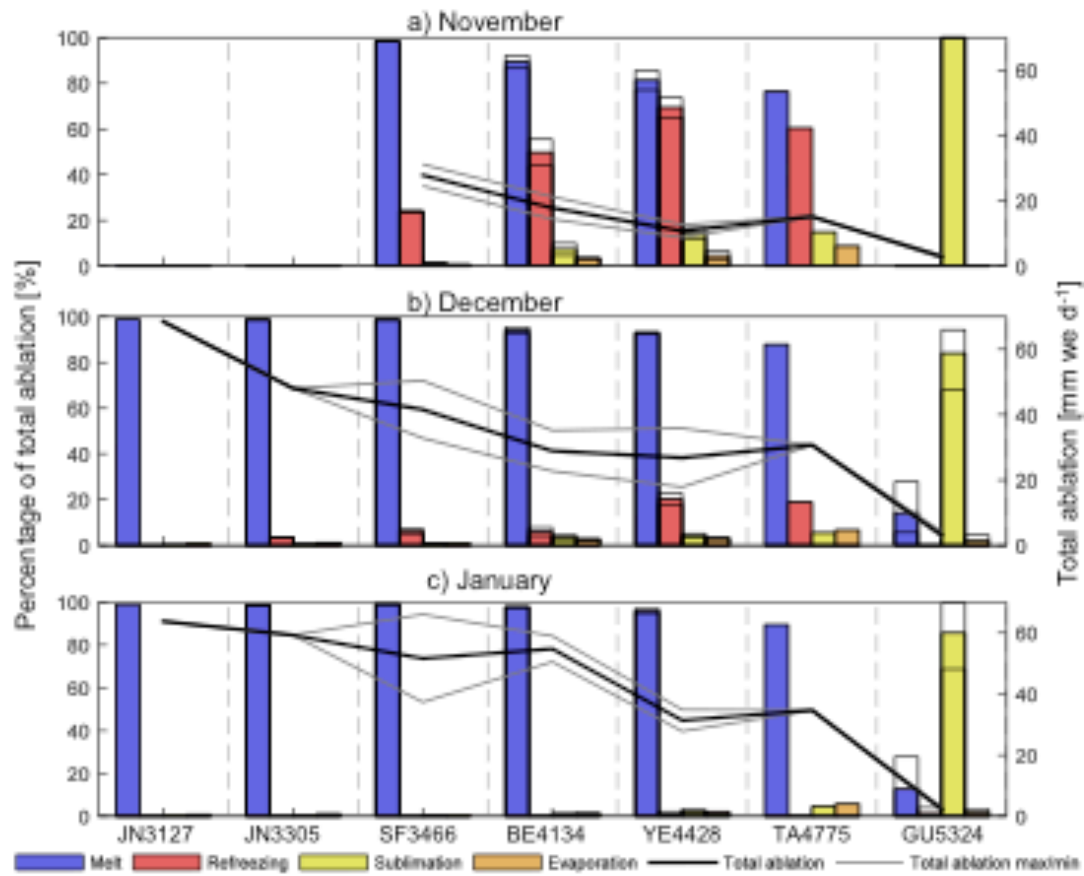
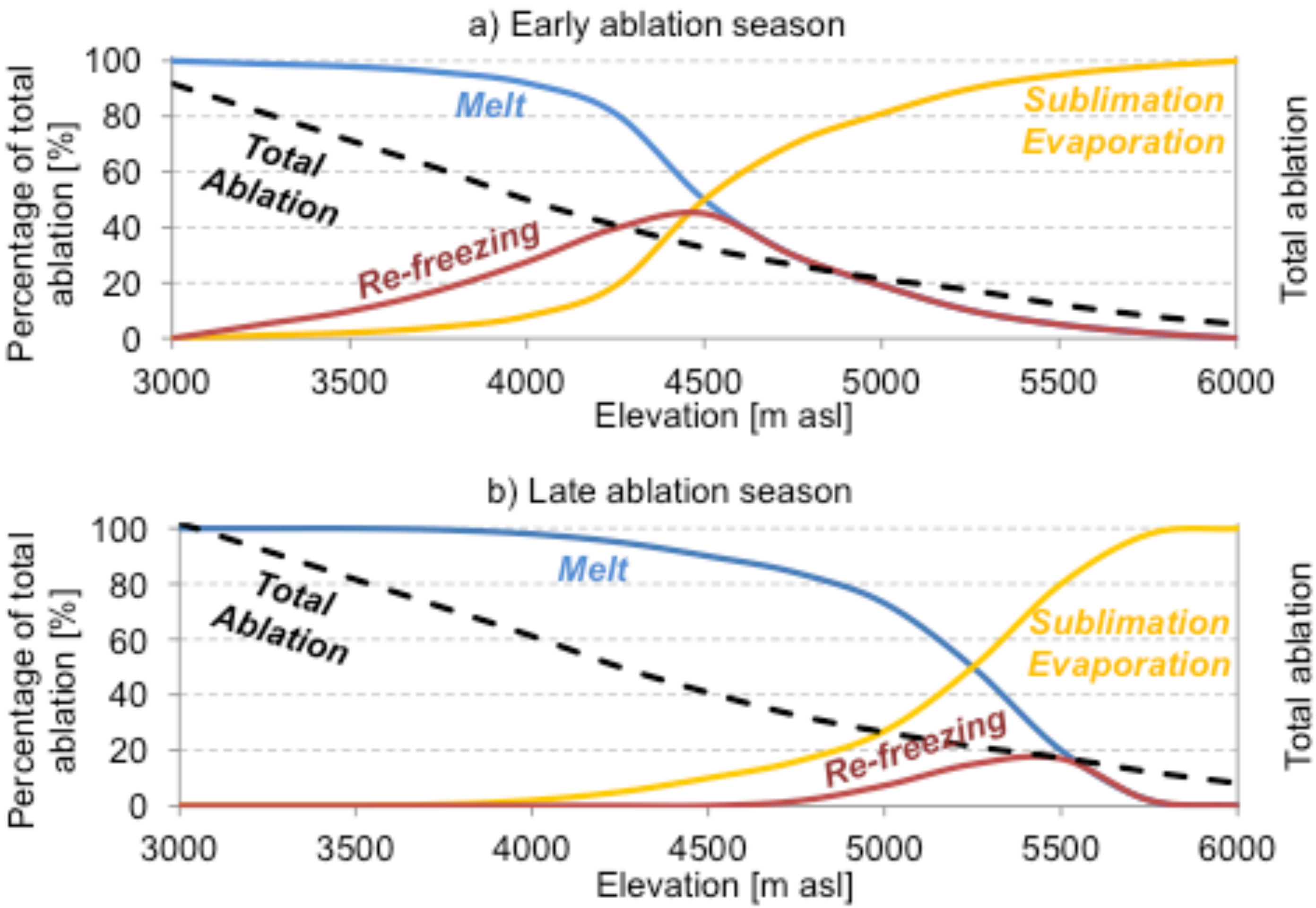
How do ablation processes change with latitude and altitude?





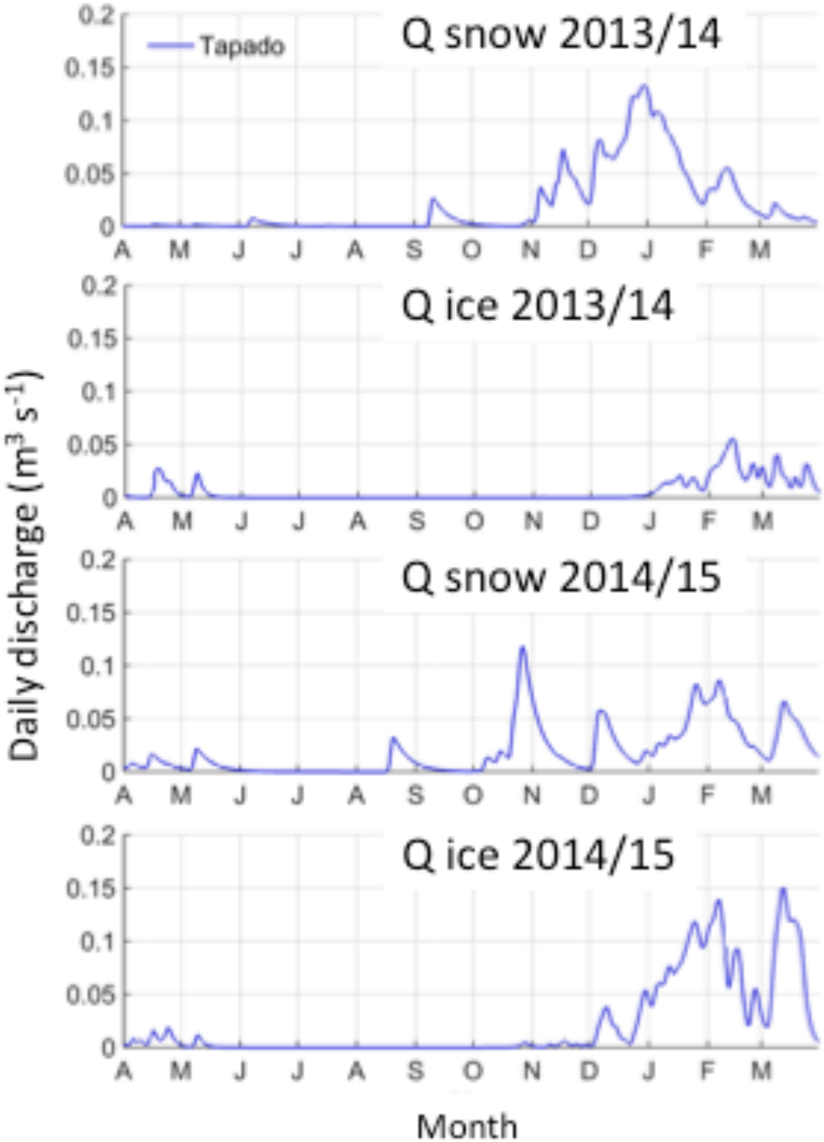
Ayala et al. (2017)

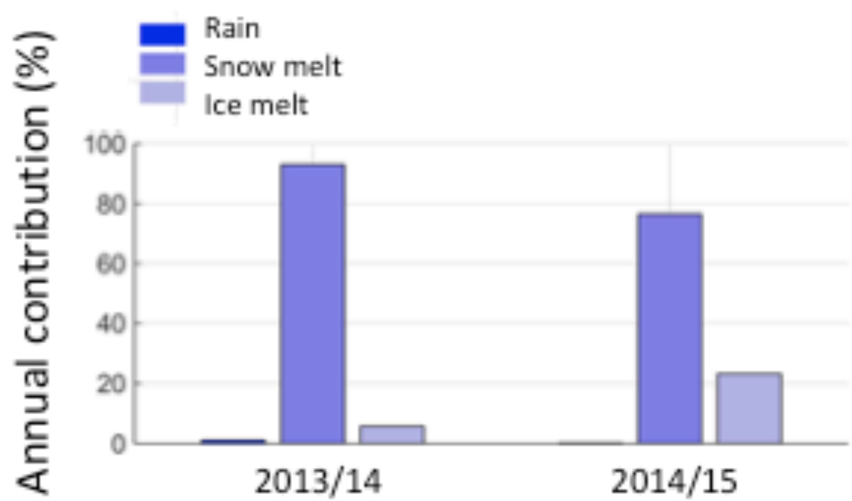


a) Early ablation season
Percentage of total ablation [%]
100
80
60
40
20
0
Melt
Sublimation
Evaporation
Total Ablation
Re-freezing
Total ablation
3000
3500
4000
4500
5000
5500
6000
Elevation [m asl]
b) Late ablation season
Percentage of total ablation [%]
100
80
60
40
20
0
Melt
Sublimation
Evaporation
Total Ablation
Re-freezing
Total ablation
3000
3500
4000
4500
5000
5500
6000
Elevation [m asl]

Tapado catchment – Hydrological Implications

Daily discharge totals





Rock glacier processes

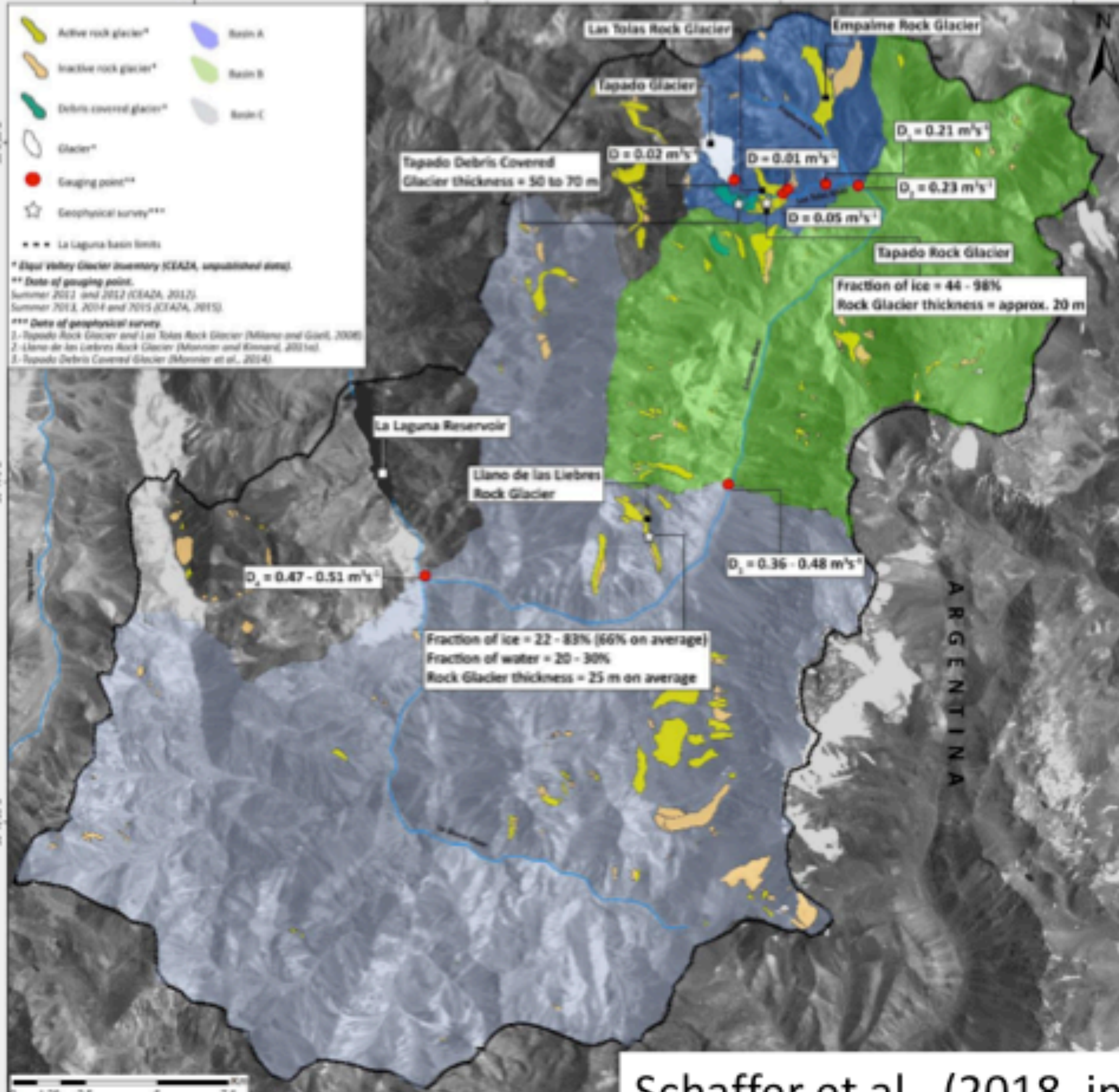
What is the distribution of active and inactive rock glaciers?

How have they changed through time?

What is the amount of ice stored?

What is their hydrological role?

Nicole Schaffer, Francesca Pellicciotti, James McPhee, Ben Robson, Camilo Guzmán, Eduardo Yáñez, Iván Fuentes, Benjamín Castro



Schaffer et al., (2018, in review)

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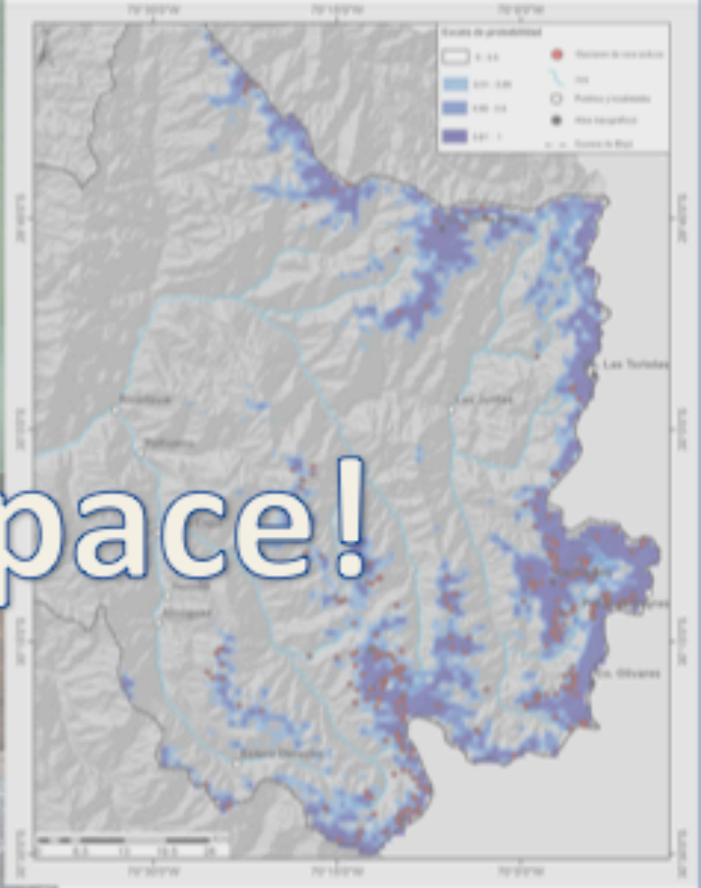
Rock glacier field programme re-started 2018:

- How much ice?
  - Is there a difference between different rock glacier types (or expressions)?
  - Where is it?
    - Has it been changing? And in response to what?

Watch this space!



+ Geophysics
+ Geodetic mass balance
+ Hydro-glacio modelling

Points for discussion

- Should we explicitly include rock glaciers in catchment models? How?
- Do we need to treat active and inactive rock glaciers differently?
- Does a rock glacier lose mass, or just channel water generated at the surface?
- How should we consider contributions to / interactions with groundwater?
- What’s happening on the other side of the border?