Occurrence and impacts of heat waves events in a glacierized basin in the subtropical Andes

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Background

- Heat Waves (HWs) are defined as a period of consecutive days with warmer than usual or expected conditions for a region and time of the year (Feron et al., 2019).
- Increased frequency and intensity of HWs events have been detected in the city of Santiago de Chile (~33°S) and an increase under climate change scenarios is projected (Feron et al., 2019).
- HWs are considered a regional phenomenon that requires local analysis (Feron et al., 2019).
- Overall, induced by anticyclonic anomalies in low levels of the atmosphere (Jacques-Coper et al., 2021).

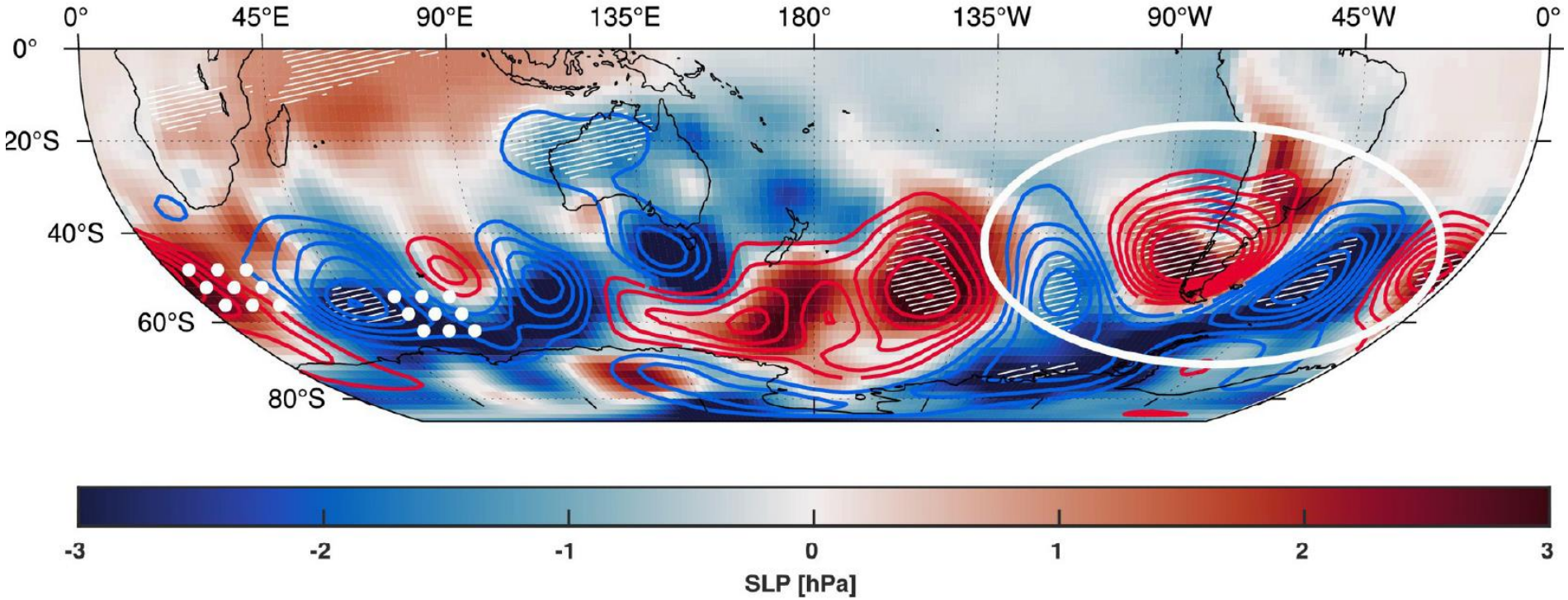


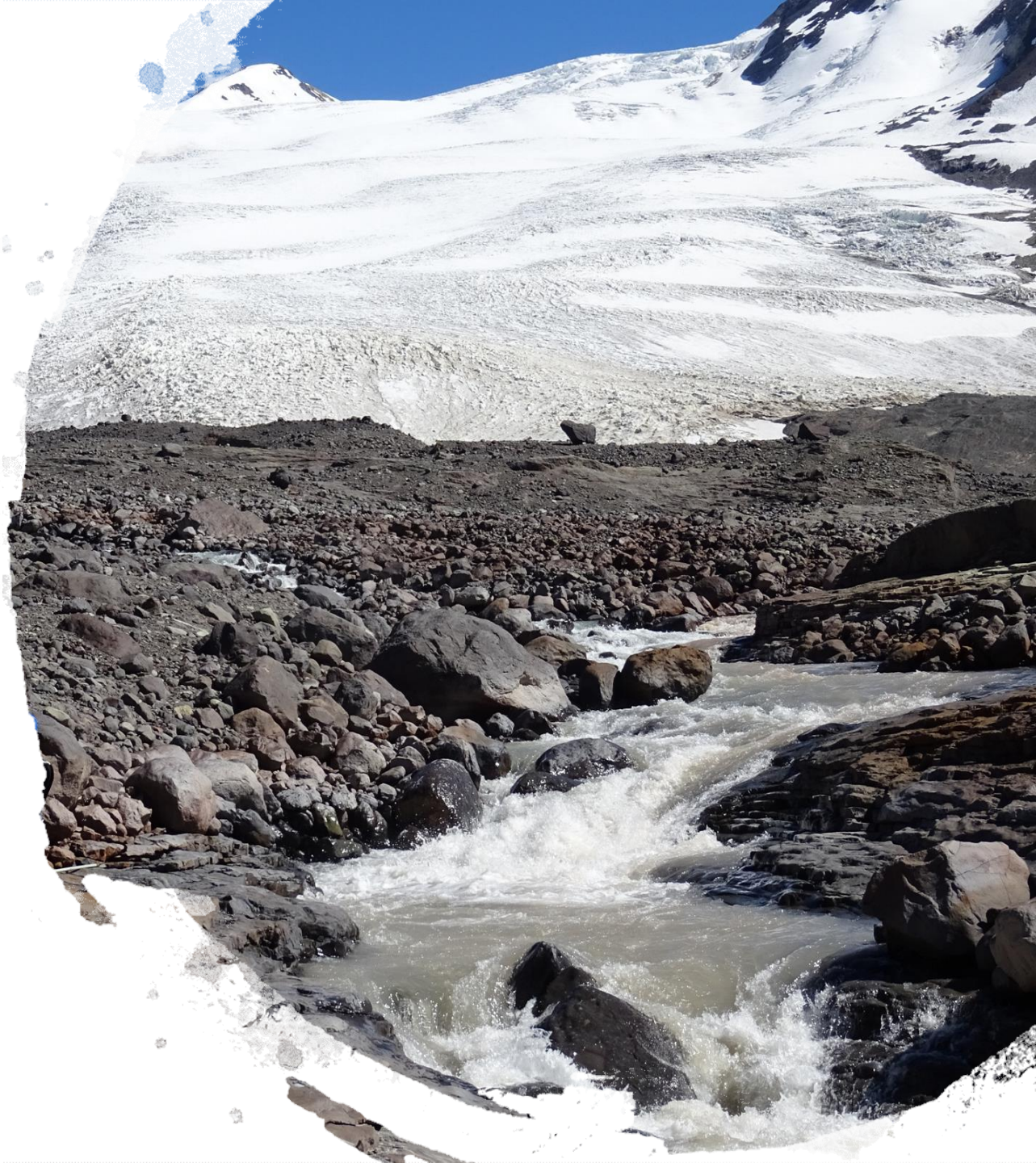
Fig. 1. Composite of 14 HWs during DJF classified as superactive at day 0. Red/blue contours represent positive/negative Z500' every 10 gpm up to ±60 gpm; shading for SLP' according to the colorbar; white hatching denotes significant Z500' anomalies at 95% (Jacques-Coper et al., 2021).

Motivation

- Synoptic and meteorological conditions at the glacierized basin-scale during HWs events, in conjunction with the topographic characteristics of glaciers, triggers a series of feedbacks that defines the glacier response to extreme weather events as HWs.

- HWs impacting glaciers of the southern Andes can markedly affect the surface mass balance at the annual scale, playing an important role in the overall regional glacier mass loss determined in the last decades. For instance, in the glaciers located in the upper Olivares sub-basin.

- Implications related to water resources for Central Chile and the ~8 millions inhabitants.



Study area: Olivares sub-basin

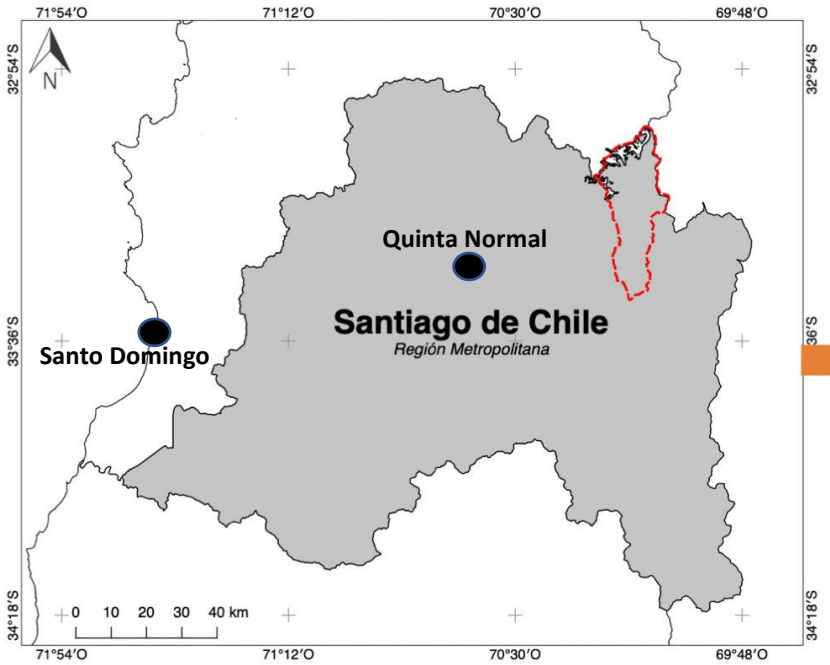
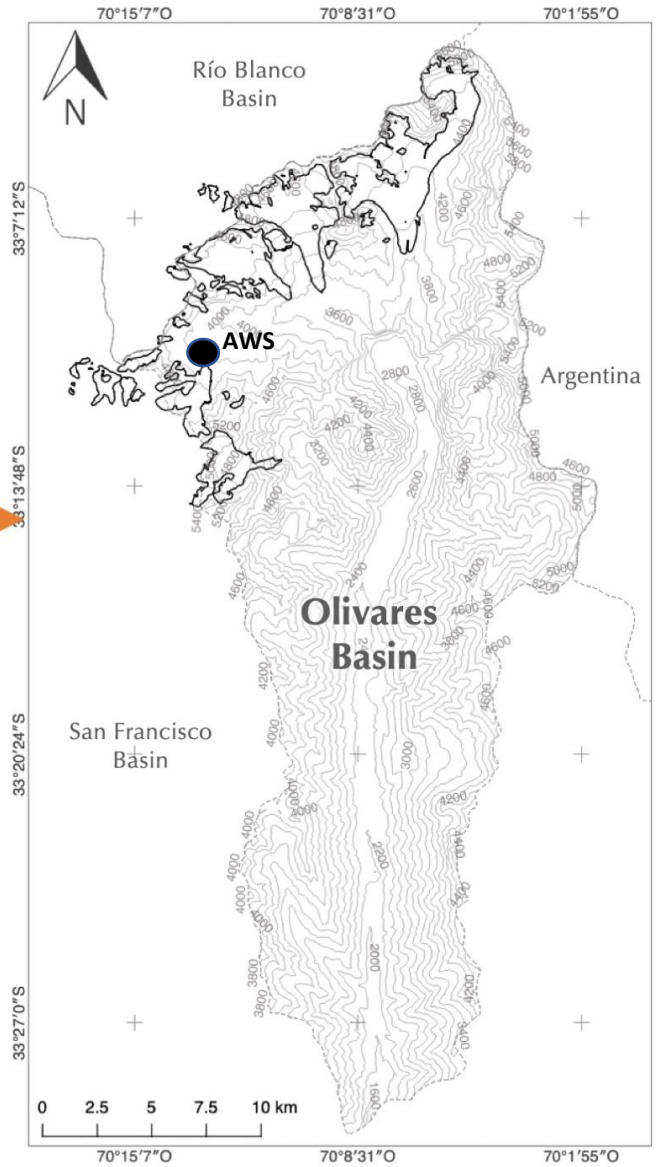
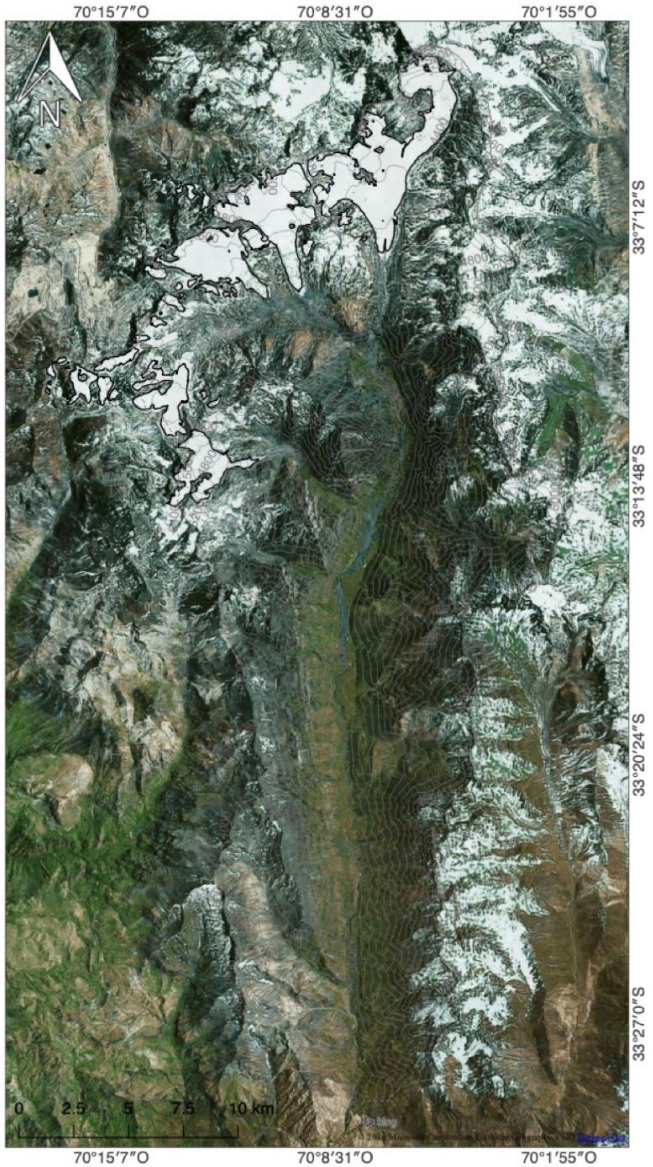


Fig. 2. Basin location and regional context





- Basin between ~1500 and ~6000 m a.s.l.
- Glacier area ~70 km^2

Study area: Olivares sub-basin

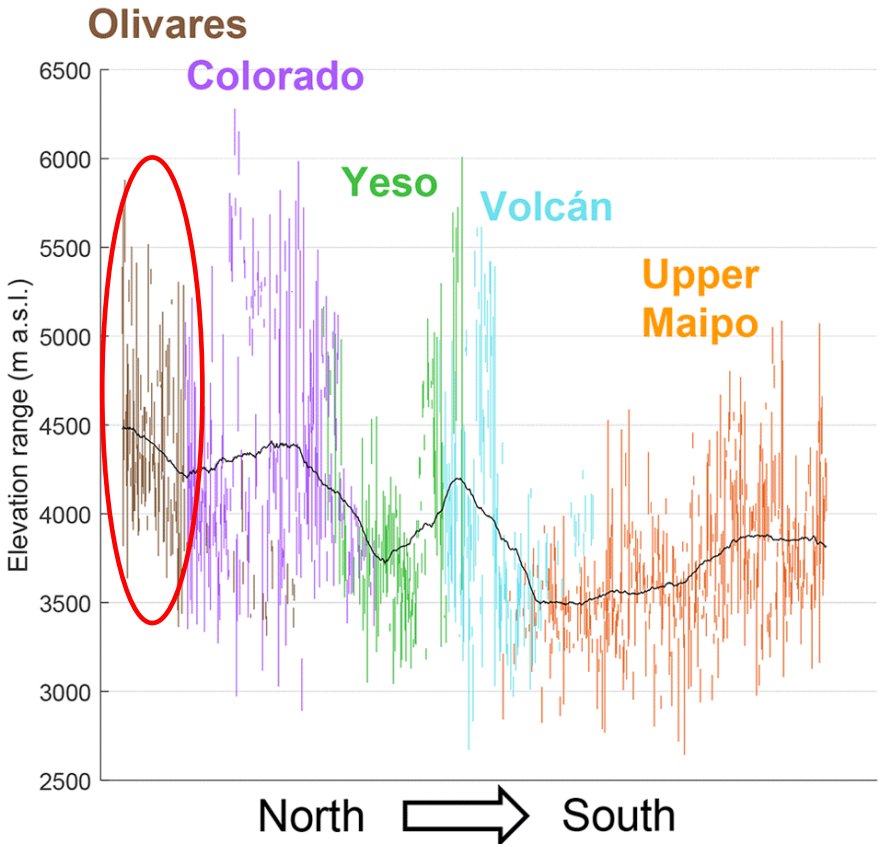


Fig. 3. Maipo river sub-basins, elevation range of glaciers per-basin (Ayala et al., 2020).

Olivares sub-basin contains the highest glaciers in the Maipo basin (Fig. 3, Ayala et al., 2020), however, shows the largest rate of ice loss in comparison with the other Maipo sub-basins (Table 1, Farías-Barahona et al., 2020)

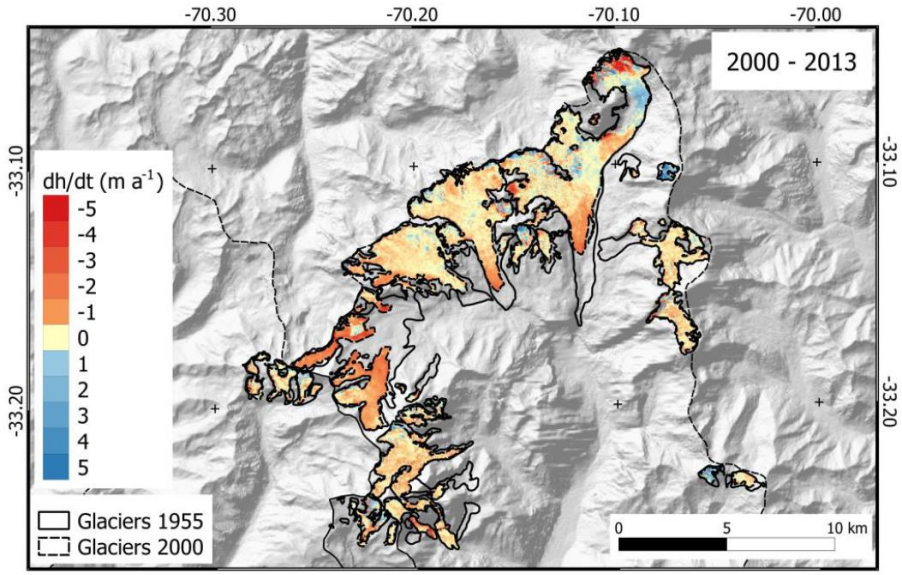


Fig. 4. Spatially distributed elevation changes in the Olivares sub-basin for the period 2000–2013 (Farías-Barahona et al., 2020).

Table 1. Summary of elevation and mass changes during the periods 1955-2000 and 2000-2013 (Farías-Barahona et al., 2020).

Sub-Basin	Area 2000 (km^2)	Mass Balance Rate 1955–2000 (m w.e.a^{-1})	Mass Balance Rate 2000–2013 (m w.e.a^{-1})	Glacier Runoff Contribution
Olivares	71.94	−0.28 ± 0.07	−0.32 ± 0.13	Maipo River
Colorado	63.11	−0.18 ± 0.07	0.05 ± 0.12	Maipo River
Yeso	21.58	−0.13 ± 0.07	−0.15 ± 0.12	Maipo River
Volcán	50.22	0.14 ± 0.07	−0.17 ± 0.13	Maipo River
Maipo (Upper)	46.56	−0.01 ± 0.07	−0.16 ± 0.13	Maipo River
Rio Molina	2.02	0.18 ± 0.07	−0.17 ± 0.12	Mapocho River
San Francisco	3.01	−0.04 ± 0.07	−0.17 ± 0.13	Mapocho River

Study area: Olivares sub-basin

Fig. 5. Glacier area reduction 1986-2020. Outlines estimated using Landsat 5 (1986, 1991), Landsat 7 ETM+ (2004), Spot 6 (2018) and Kompsat 3 (2020).

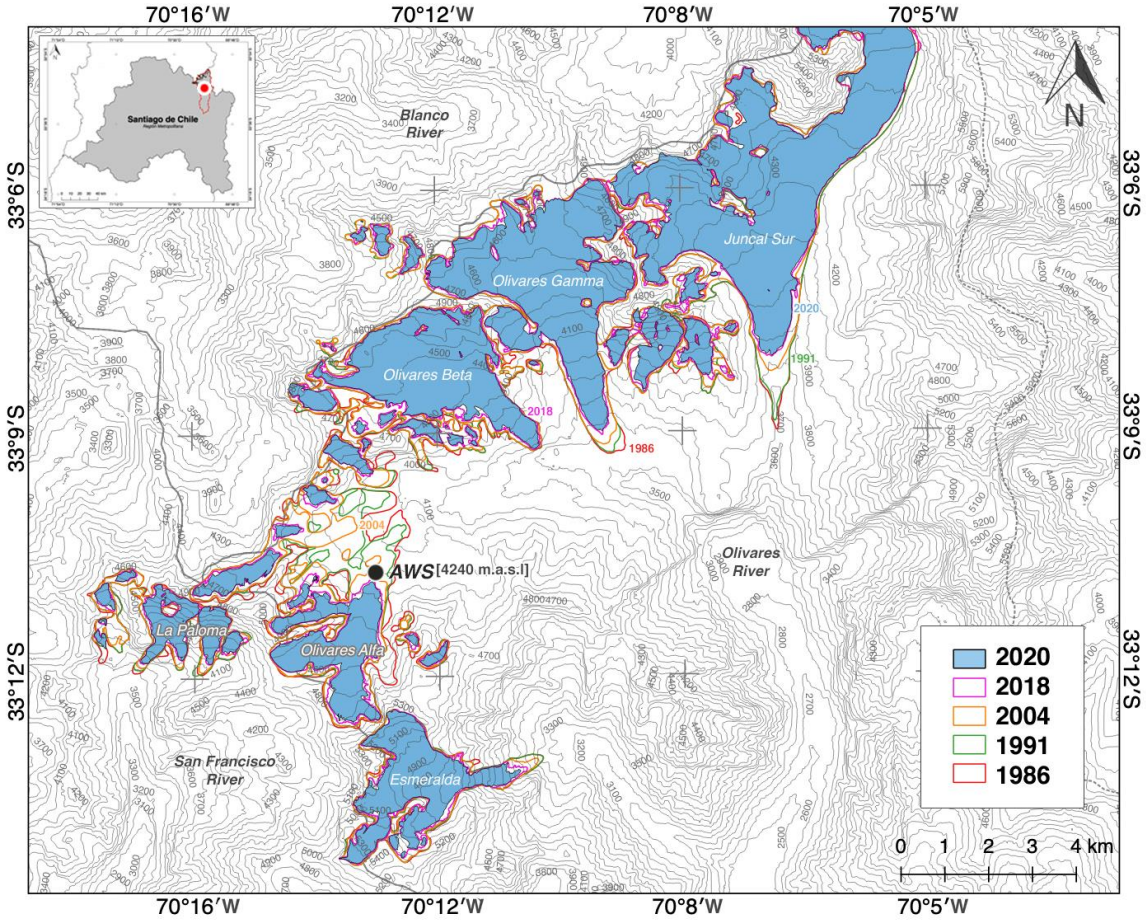
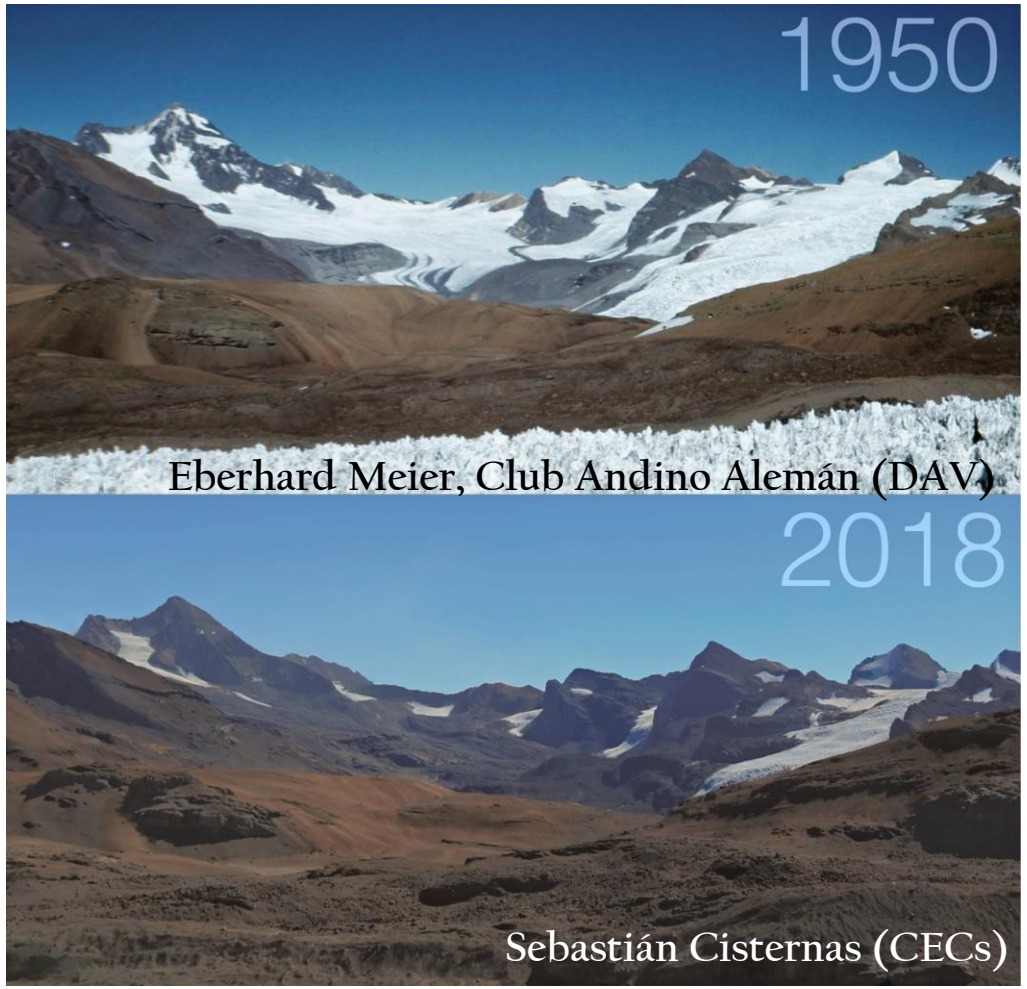


Fig. 6. Example of glacier fragmentation in the sub-basin. Comparative photographs of the western upper Olivares basin.



Turrel (2019)

Objectives

1. to identify the occurrence of HWs in the Olivares sub-basin and to compare with those occurring in the central valley (city of Santiago) during the period 2013-2021.

2. to compute the 0°C isotherm under the HWs events and assess the potential impact on glaciers of the sub-basin.

3. to assess the impact of HWs in glaciers, quantifying the melt during HWs and define if these events are significant in the annual surface mass balance.

4. to recognize the mechanisms that drive the response of glaciers under HWs events by modelling and observe the surface energy balance fluxes, using data from an Automatic Weather Station (AWS) and an eddy covariance station (EC).

*This is an ongoing project. This presentation is focused on objectives 1 and 2 and must be considered as preliminary results.

Data and methods

Fig. 7. Meteorological Station in Quinta Normal, Santiago (534 m asl). Location in Fig. 2.

Fig. 8. Automatic Weather Station (AWS) in Olivares sub- basin (4240 m asl). This AWS is located close to the Olivares Alfa glacier front (Fig.2).

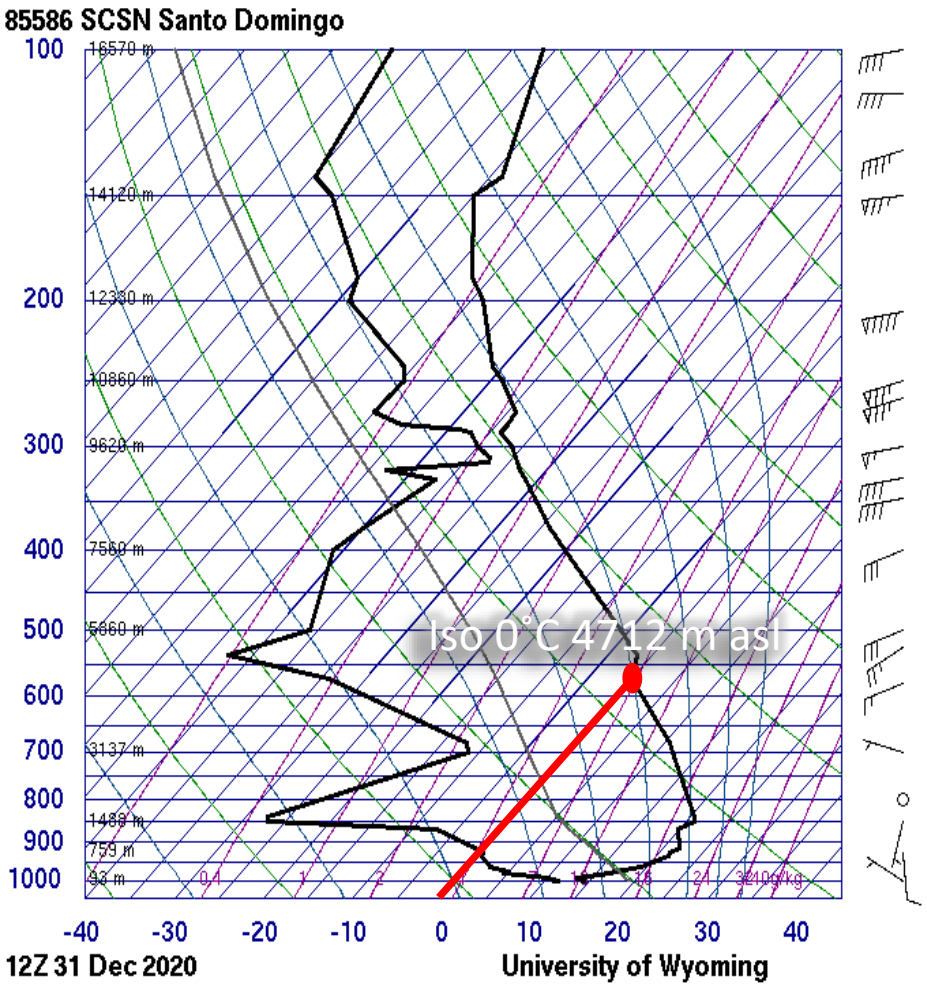


Fig.9. Atmospheric soundings from Santo Domingo (location in Fig. 2) to compute 0°C isotherm under HWs events. Example of sounding done during HW event (31 Dec. 2020). Red line is the 0°C isotherm and the black line at the right is the sounding.

Heat wave events were estimated using the monthly 90th percentile and the adjustment of a moving average function.

Results: Events in Santiago (Quinta Normal station)

- An increase in the p90 threshold is determined for the period 2013-2021 compared to 1981-2010.
- Duration of HWs events can reach 6 days.

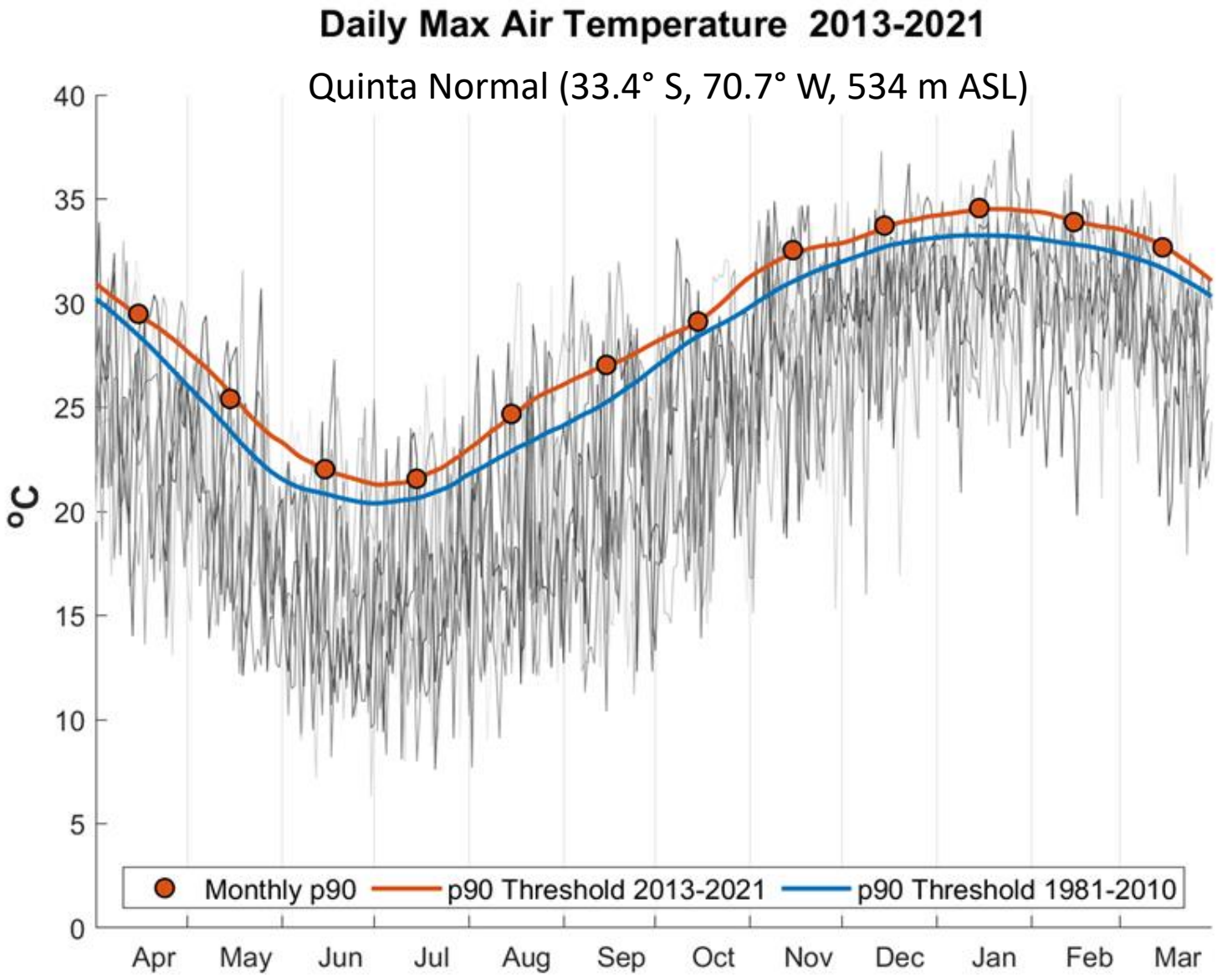


Fig. 10. Time series of maximum air temperature in Quinta Normal. Orange lines and dots are the p90 threshold for the period 2013-2021 and blue line is the threshold for the period 1981-2010.

Results: Events in Olivares sub-basin

- HWs events shows positive temperatures even in winter. Potential melt events in winter.
- Maximum temperature recorded in a event was 15°C (Jan. 2017).
- Largest HWs event lasted 8 days (March 2020).

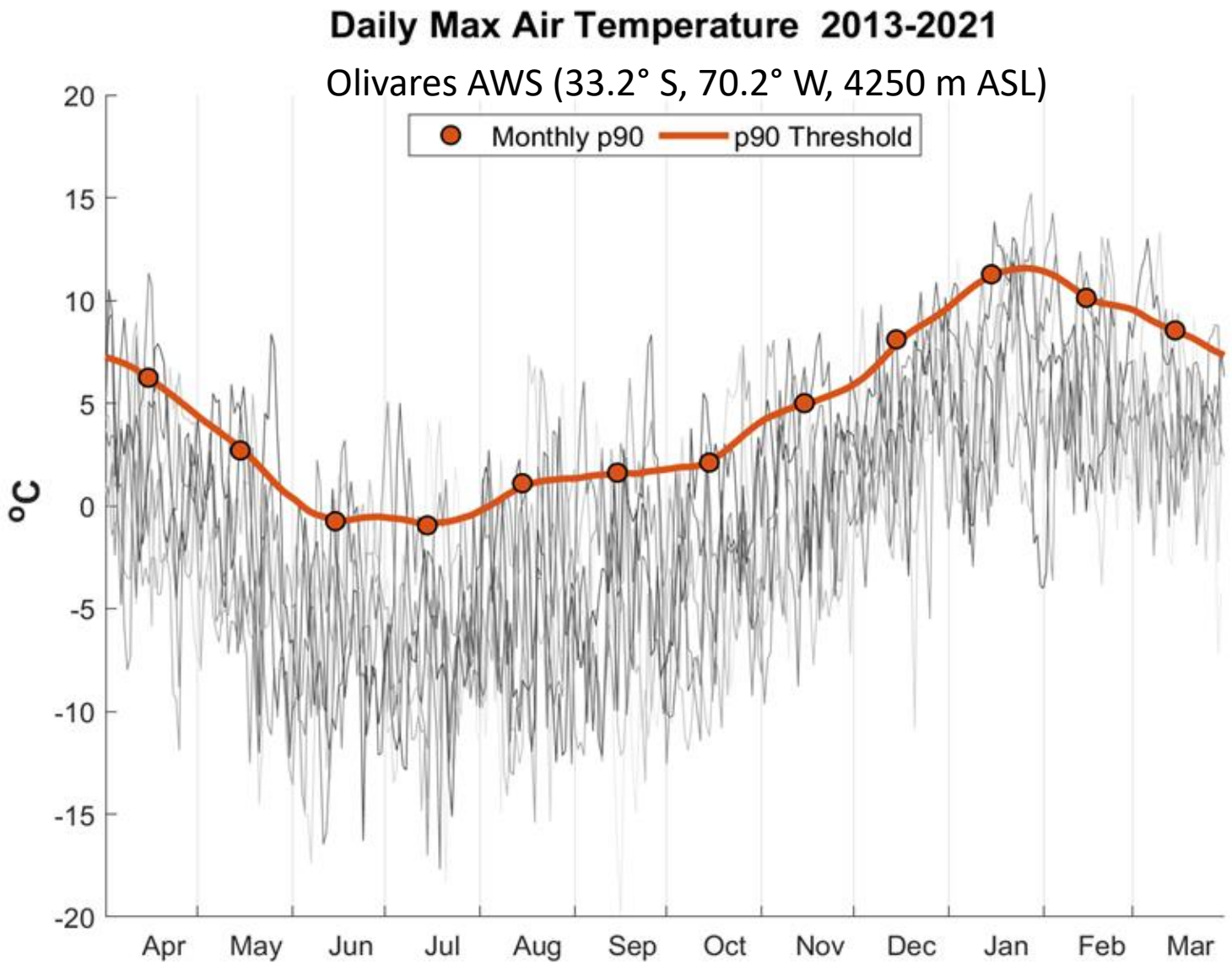


Fig. 11. Time series of maximum air temperature in Olivares AWS. Orange lines and dots are the p90 threshold for the period 2013-2021. Days over this threshold are considered HWs events.

Comparison of the HWs event between Olivares and Santiago 2013-2021

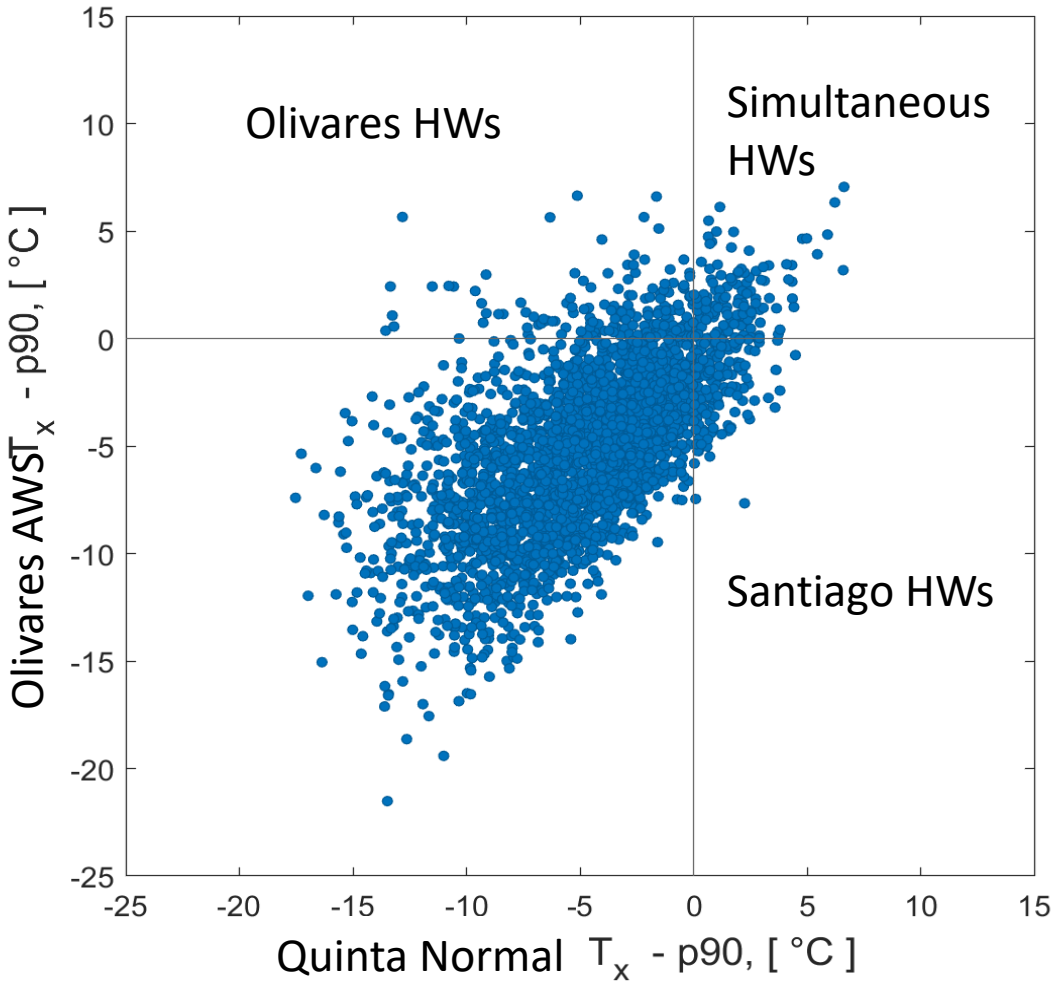
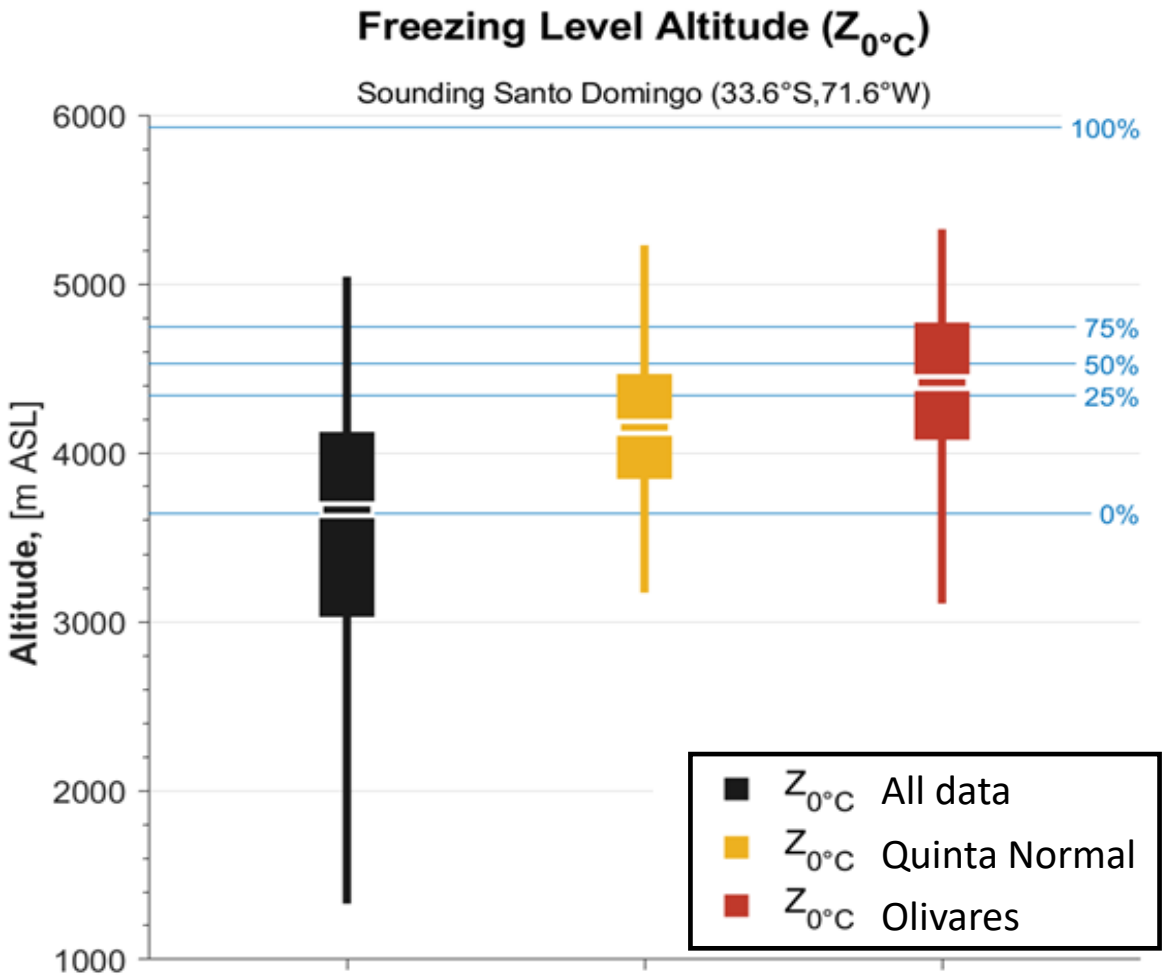


Fig. 12. Scatter plot of the differences between daily air temperature and the p90 for Olivares AWS and Quinta Normal meteorological station.

These results reveal high spatial variability in the occurrences of HWs as only 55% of the events in Santiago were concurrent with those detected in the Río Olivares basin.

Impacts in glaciers: Area under melt



Glacier basin hypsometry

- There is an increase in the glacier area under melt when HWs occurs. This increase is higher for the Olivares basin events (~Δ 750m) in comparison to Quinta Normal events (~Δ 490 m).
- Highest iso 0°C isotherm reached ~5400 m asl in February 2016.

Fig. 12. Boxplot of the distribution of the 0°C isotherm during HWs events in Santiago (yellow) and Olivares (red). For comparison purposes, the distribution under no-HW event condition is also showed.

Preliminary conclusions

- A total of 290 days over the air temperature threshold defined (p90) during the period 2013-2021 were detected in Olivares.
- HWs events are spatially variable. 55% of the Olivares HWs events were simultaneous with HWs events detected in the central valley (Santiago).
- Overall, during Olivares HWs, a higher 0°C isotherm was estimated compared to Santiago HWs events. Synoptic conditions that define this difference will be analysed.

Future work

Define the HWs events based on the duration (consecutive days) and analyse in detail the synoptic conditions.

Quantify the surface glacier melt during these HWs events. Are these events significant in the annual surface mass balance? Are these events responsible for the long-term ice loss detected in these glaciers?

To recognize the mechanisms that drive the response of glaciers under HWs events. Here, the **working hypothesis** is that the ultimate proof of the impact of HWs, are the changes in the magnitude and role (source or sink) of the energy fluxes in the glacier-atmosphere interface. It is expected to find notable differences in the radiative and turbulent fluxes between days under HWs events and days with no-events. These changes control the rates of the glacier surface ablation and therefore the overall glacier response to the event.

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Questions?

Muchas gracias

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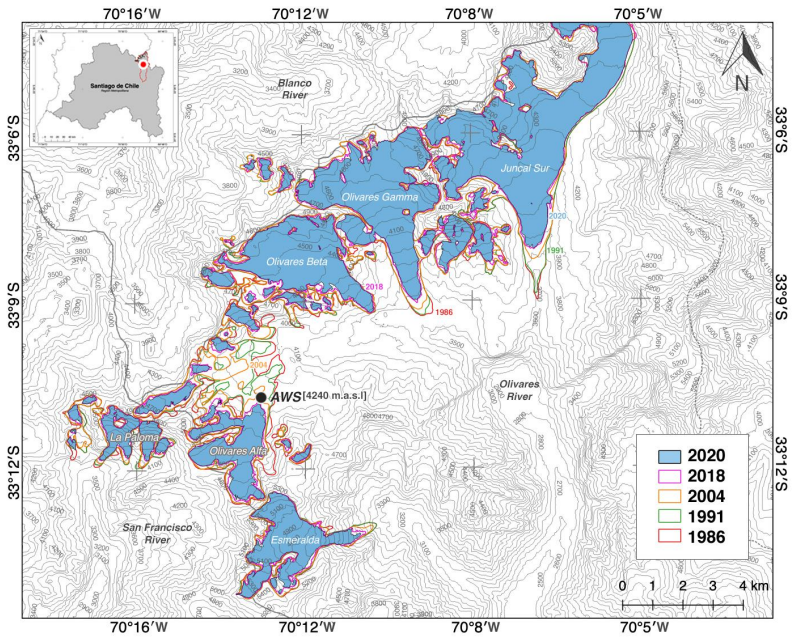
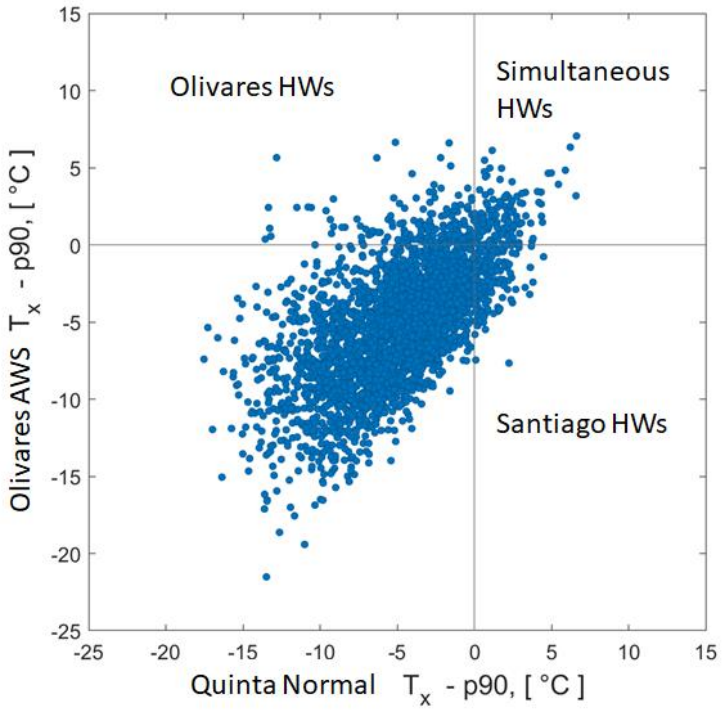
Occurrence of HWs is evaluate in the Olivares basin in central Chile (33°S).



Glacier retreat, fragmentation and ice volume loss has been detected in the glaciers of the upper Olivares basin.

Comparison of HWs events with those occurred in the city of Santiago.

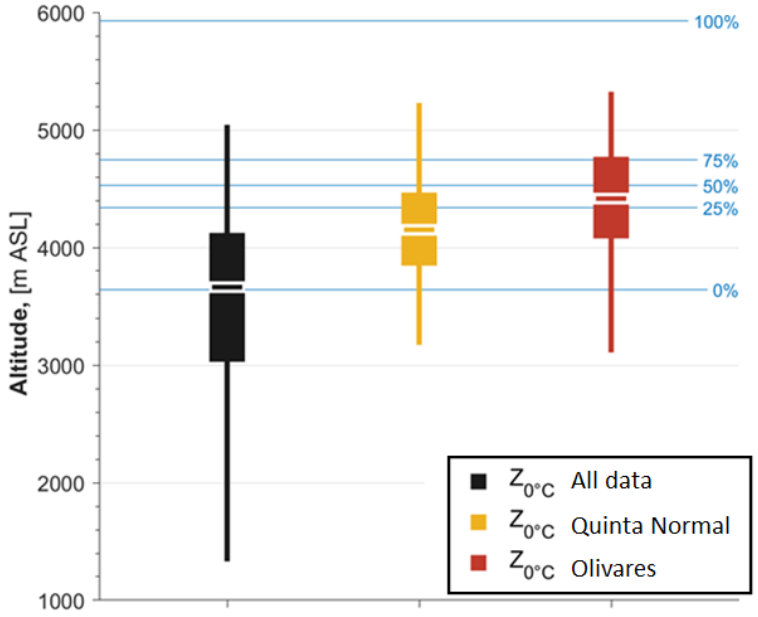
Percentile 90th using observed data.



High spatial variability in the occurrences of HWs as only 55% of the events in Santiago were concurrent with those detected in the Olivares basin.

Potential impact of HWs in glaciers.

0°C isotherm computed with sounding data (Santo Domingo).



Increase in the glacier area under melt when HWs occurs. This increase is higher for the Olivares basin events (-Δ 750m) in comparison to Quinta Normal events (-Δ 490 m).

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