Hydrological response of the Olivares River basin during severe droughts and glacier retreat scenarios

Eduardo Muñoz Castro [1], Álvaro Ayala [2,3], Pablo A. Mendoza [1,4] and Ximena Vargas [1]

(1) Department of Civil Engineering, Universidad de Chile, Santiago, Chile; (2) Swiss Federal Institute of Technology Zurich, ETH – Zurich; (3) Centro de Estudios Avanzados en Zonas Áridas (CEAZA), La Serena, Chile; (4) Advanced Mining Technology Center (AMTC), Universidad de Chile, Santiago, Chile

C21F-1416

Background and Objectives

- In the semi-arid Andes Cordillera of Central Chile (31-36°S), **mountain glaciers are important reservoirs of freshwater**, especially during droughts and at the end of summer, when the snowpack is exhausted.
- During the **last multi-annual drought in Central Chile (2010-2015), one of the most severe recorded in this region**, precipitation deficits were observed in more than 70% of the weather stations (Garreaud et al., 2017).
- We characterize the hydrological response of the highly-glacierized Olivares River basin to the 2010-2015 drought, and assess its **response to future droughts under scenarios of glacier retreat**.
- Further, we quantify hydrological changes using the **maximum global temperature increase (1.5° C)** defined in the Paris Agreement and the last report IPCC report (2018).

Key questions

1. What was the **glacier contribution to total runoff** during the 2010-2015 megadrought in comparison to normal climatic conditions?
2. How will **glacier area and volume** change under different emission scenarios?
3. What will be the glacier contribution to total runoff during **droughts under scenarios of glacier retreat**?

Study Domain

- Our test domain is the Olivares River basin (Fig. 1; area = 544 km²; mean elevation = 3703 m a.s.l.), which encloses 134 glaciers included in the national inventory.
- The study area is located in the Andes Cordillera, ~50 km northeast from Santiago, capital of Chile.
- The basin shows a snowmelt-driven hydrological regime (Fig. 2).
- Since the catchment has a negligible human intervention degree, we can directly assess natural hydrologic changes.

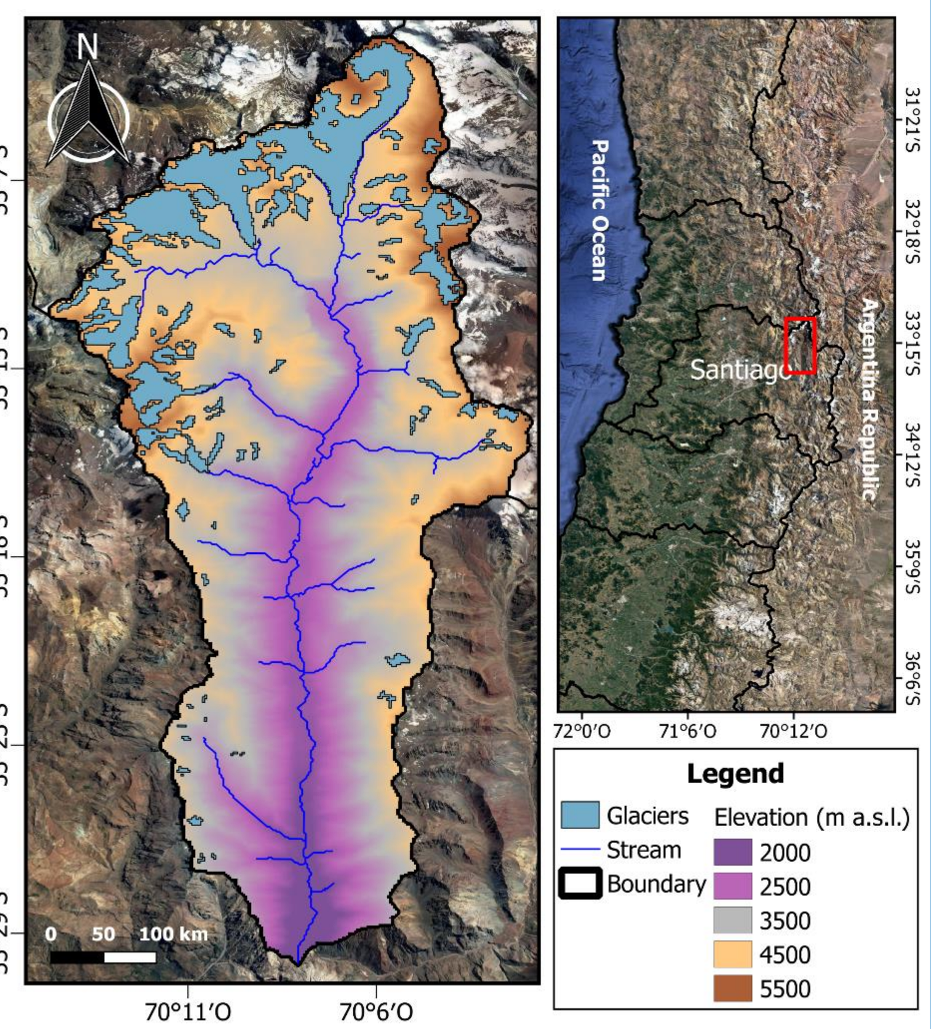


Figure 1: Location of the Olivares River basin

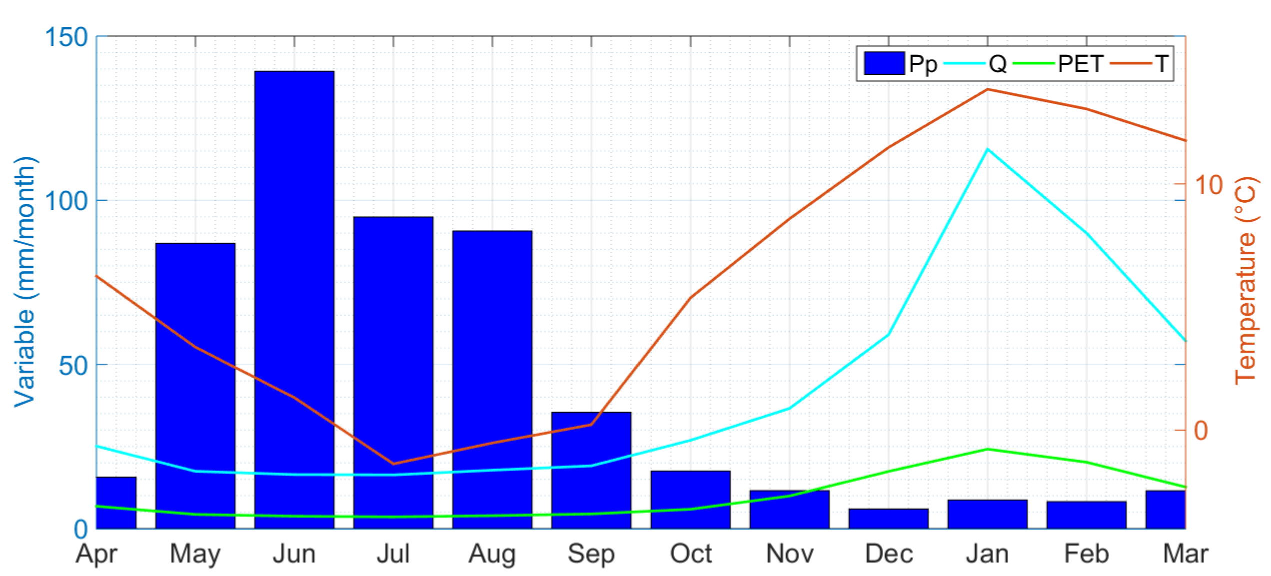


Figure 2: Seasonal cycles of basin-averaged hydroclimatic variables: temperature (T), precipitation (Pp), and runoff (Q) for the period 2000-2016, obtained from CR2MET and the CAMELS-CL dataset.

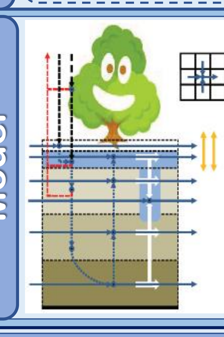
Methodology

Modeling approach

Inputs Required

Daily Meteorological Data: temperature, precipitation, cloud cover, transmissivity of solar radiation	**Observations:** runoff, snow covered area, snow water equivalent
Ancillary Data: SRTM-DEM, Glacier Outlines	**Ice Thickness:** SRTM-DEM + Huss & Farinotti (2012) method

Model



TOPKAPI-ETH: Physically oriented, daily time steps, spatially distributed (100 m).

Warm-up: 2000/01 – 2001/02
Calibration: 2002/03 – 2007/08
Validation : 2008/09 – 2011/12
➡ Set of Parameters

Future Scenarios: Climate Forcings

Scenario A: "Committed Ice Loss"

- Bootstrapping between 1990 – 2009
- 10 Daily synthetic time series.
- Verification of mean and variance (monthly, annual and entire period).

Scenario B: "Paris Agreement"

- Kraaijenbrink et al. (2017) → GCMs that represent a global temperature increase of 1.5°C
- CR2 → Regional climate model simulations.
- Synthetic time series under current climate + equivalent to ΔT = 1.5°C.

Step 1	Step 2	Step 3
Observed glacier response	Future scenarios of glacier retreat	Response to future droughts

Results

Model Performance

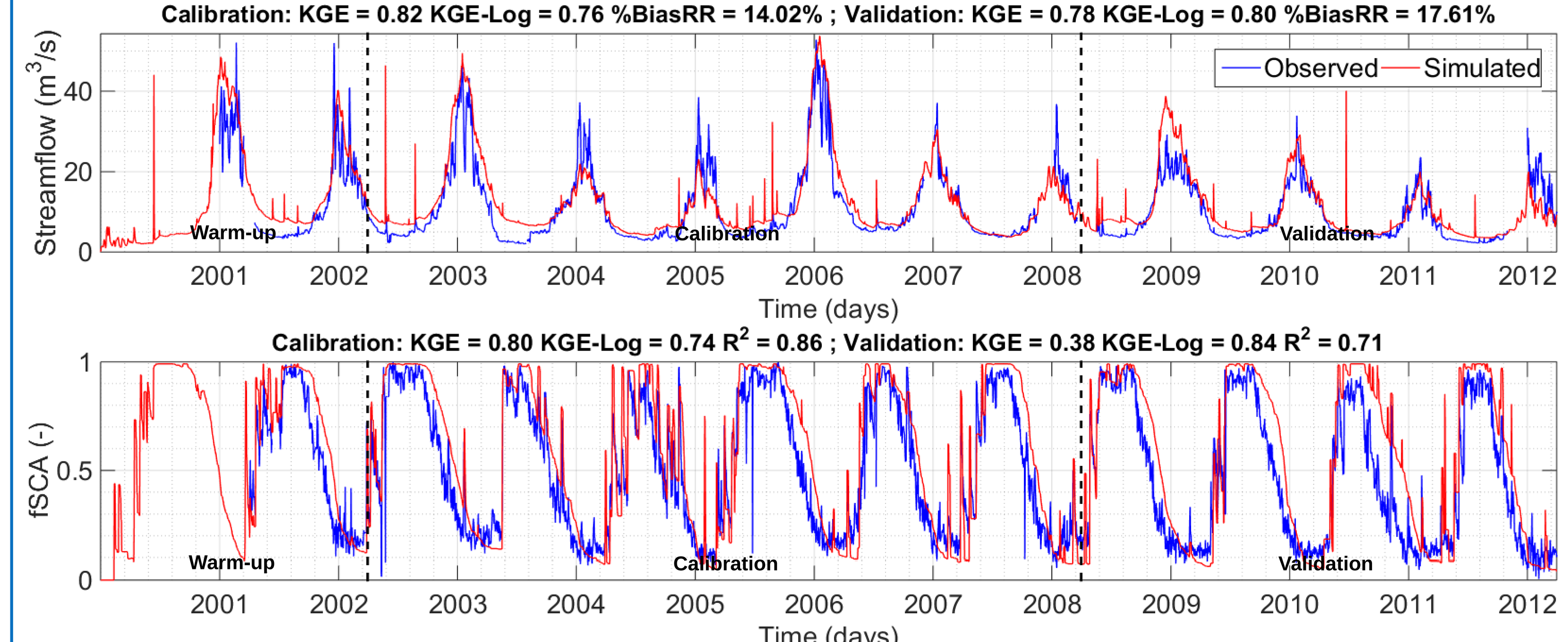


Figure 3: Daily time series of simulated and observed streamflow and fractional snow covered area (fSCA) during warm-up, calibration and validation periods.

Reference Period

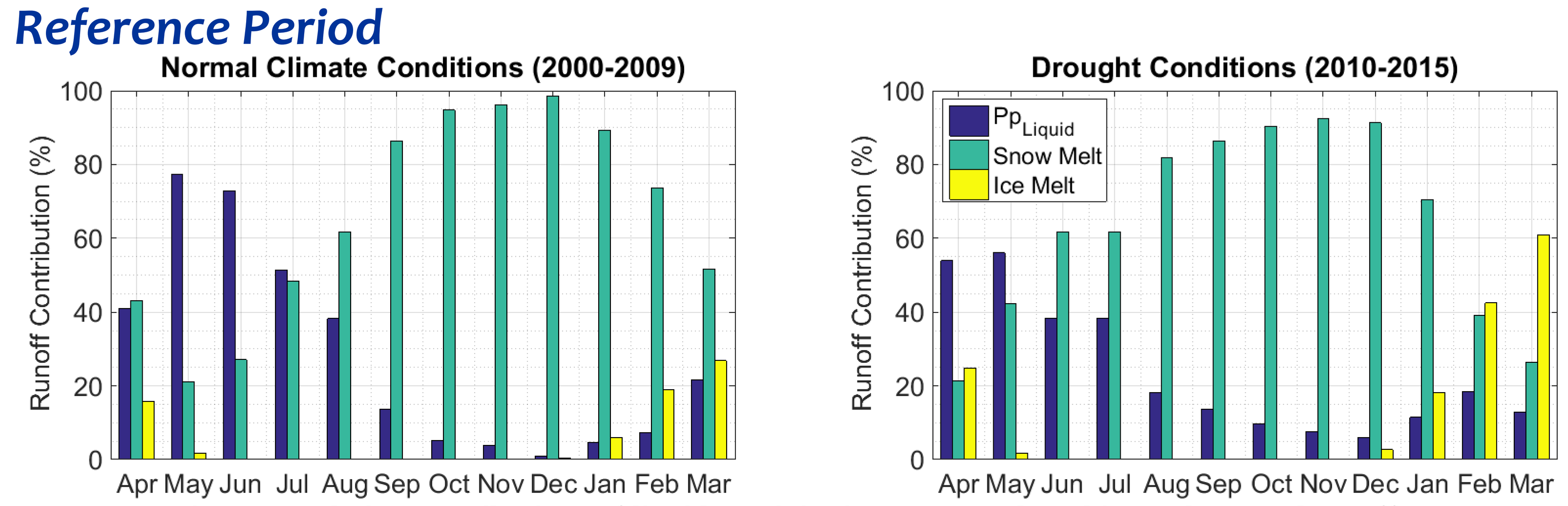


Figure 4: Relative contributions of liquid precipitation, snow melt and ice melt to total runoff.

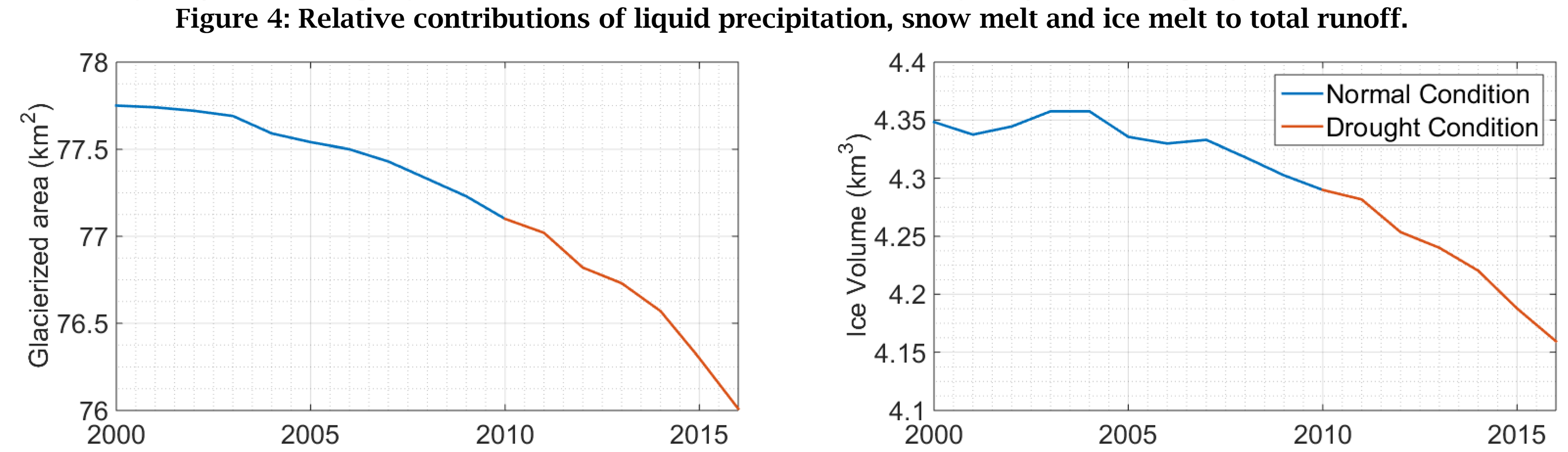


Figure 5: Glaciarized area and ice volume during current climatic conditions (2000-2009) and drought conditions

Glacier retreat and Hydrological response to severe drought

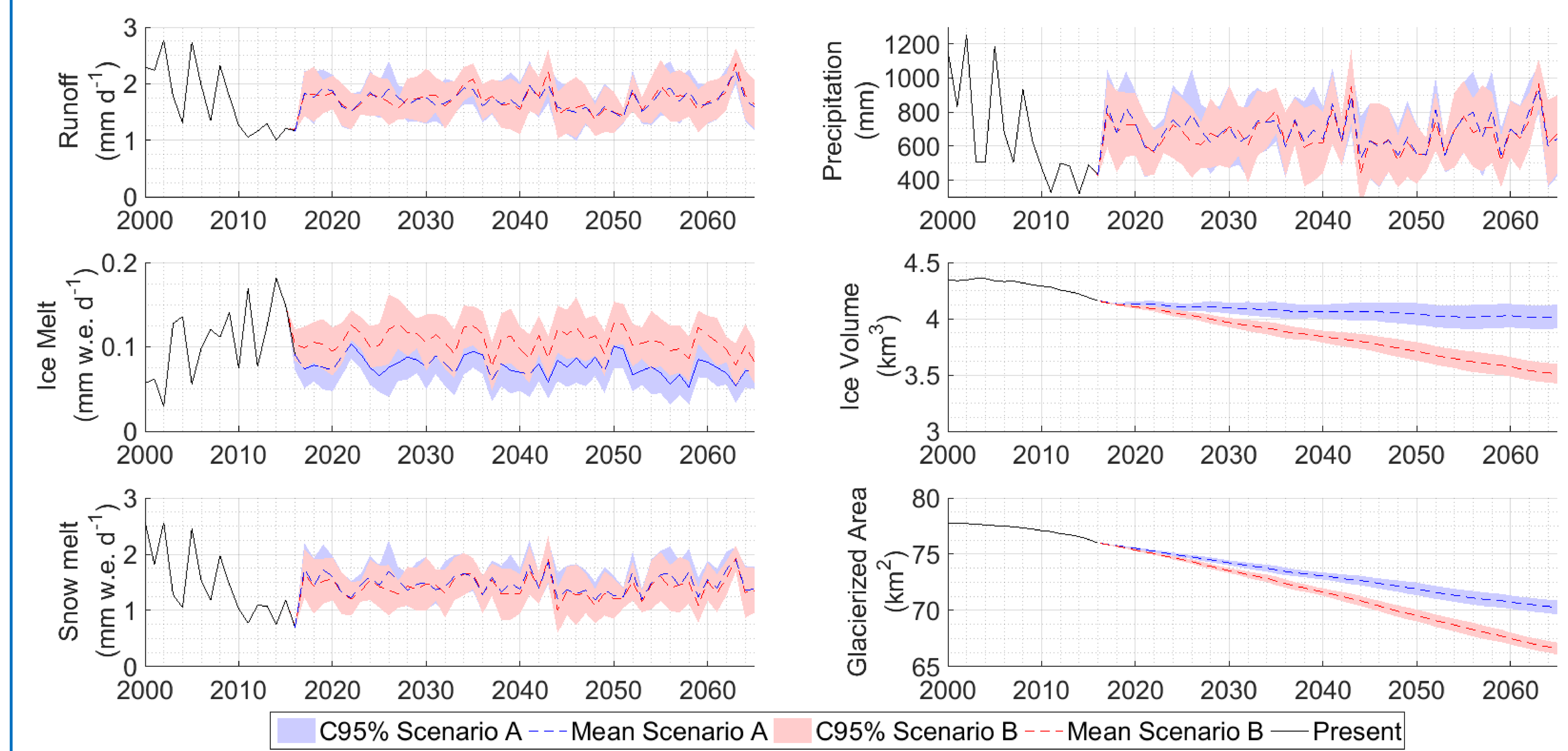


Figure 6: Annual time series of Runoff, Ice Melt, Snow melt, Precipitation, Ice volume and Glaciarized area under Scenario A and B. Each chart display the 95% confidence interval of significance (C95%) and mean value for all scenarios.

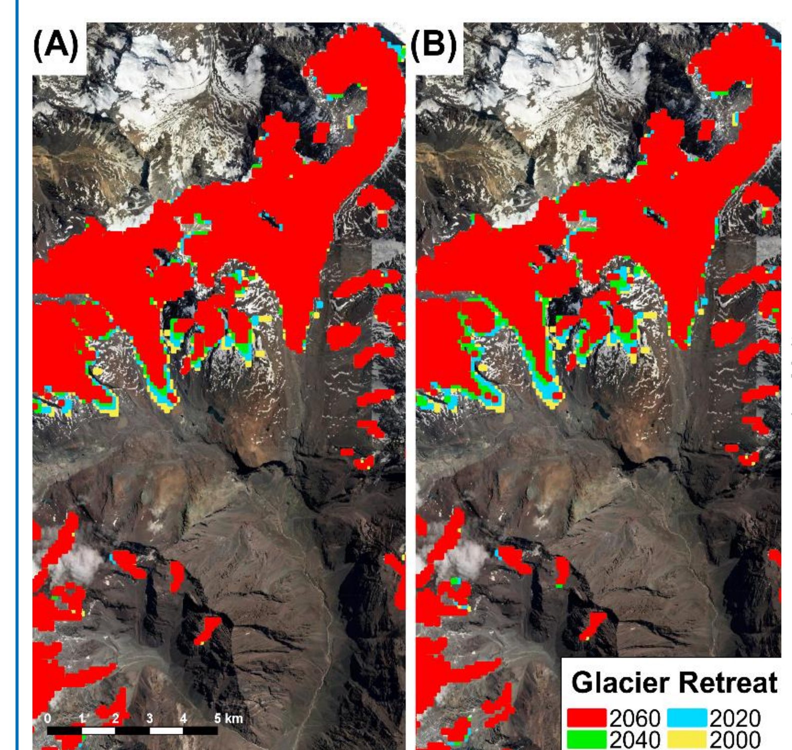


Figure 7: Glacier retreat maps. (A) Glacier retreat under climatic forcings defined by Scenario A. (B) Glacier retreat under climatic forcings defined by Scenario B.

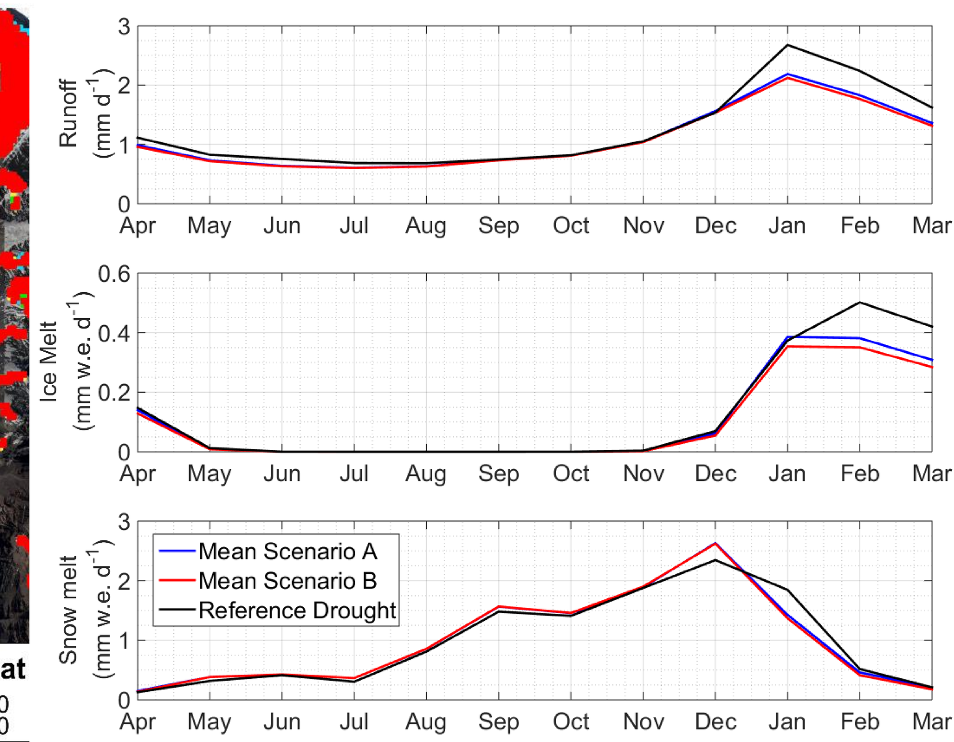


Figure 8: Monthly Runoff, Ice Melt and Snow melt averaged over the reference drought period (2010-2015) and future scenarios of glacier retreat.

- During the 2010-2015 drought, the relative summer runoff contribution from glaciers increased from 20 % to 50 % (Fig. 4).
- ~0.1 km³ of ice was lost during the last drought (2.3% of initial volume).
- Similar projections of mean annual runoff and snow melt contribution were obtained under scenarios A and B. However, ice melt increases 60% considering the latter one ($\Delta T > 0$ and $\Delta P < 0$).
- Fig. 7 shows a frontal retreat that results in 8.5% and 20% decreases in ice volume under Scenarios A and B, respectively (Fig. 6).
- Monthly runoff, ice melt and snow melt decrease under future droughts in comparison to the reference drought (Fig. 8).

Summary and Future Work

- In the future, glaciers will keep sustaining minimum flow levels at the end of the summer, but they will release less water as their volumes decrease towards an equilibrium point.
- Future efforts will focus on improving the calibration of TOKAPI-ETH using a multi-objective approach, and incorporating Landsat-derived glacier descriptors to validate model results.

Acknowledgments and Contact

- AA and EM thank ETH-Global seed grant
- PM received financial support from Fondecyt grant Nº 3170079.
- **Contact: Eduardo Muñoz Castro (eduardo.munoz@ug.uchile.cl)**