An assessment of the hydrological response of the Olivares River catchment during severe droughts and glacier retreat scenarios

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Abstract

In the semi-arid Andes Cordillera of central Chile (31–36°S), mountain glaciers are important reservoirs of freshwater, especially during droughts, contributing between 70 and 80% of the total runoff. In this work, we use the physically-oriented and spatially-distributed TOPKAPI-ETH glacio-hydrological model to simulate the response of glaciers to severe droughts in the Olivares River catchment. The glacierized area of this catchment is equivalent to 26% of the total glacier area in the Maipo River basin, the main source of surface water for Santiago de Chile – where more than 40% of the population in the country lives. To this end, we force TOPKAPI-ETH with synthetic droughts under several scenarios of glacier retreat, defined by two climate scenarios: i) current climate, preserving the mean and standard deviation of precipitation and temperature observed during the period 1990-2009, and ii) considering the Paris Agreement and constraining the global temperature rise – relative to preindustrial levels – to 1.5°C, projected by a small number of climate models under the RCP2.6 long-term scenario. We also use outputs from regional climate model simulations generated by the Center for Climate and Resilience Research (CR2) to represent what would be an increase of mean temperature in our domain. To assess the hydrological response of glaciers, and the contribution to total runoff under these scenarios, we compare our results with those obtained for droughts observed in this region during 1967-1969 and 2010-2015, considered as the most important events to date in Chile. Ongoing efforts are oriented to quantify ice loss under current climatic conditions, elevation line altitude variations during the long-term simulation, variations in glacier area and volume, and basin response to future drought under glacier retreat scenarios. Preliminary results show that glacier relative contribution to runoff at the end of the summer season increases up to 25% during the reference droughts, but decreases about 40% to 75% in comparison to the reference period considering climate scenarios.

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

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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.

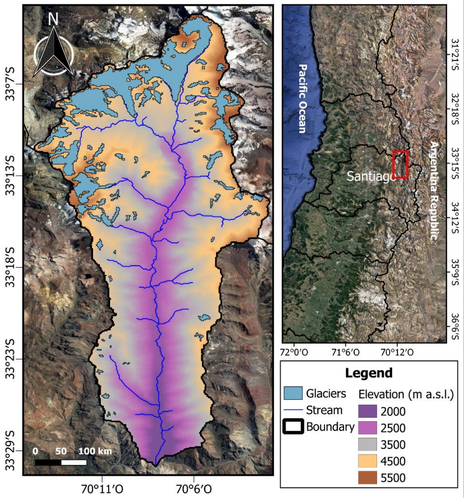

Figure 1: Location of the Olivares River basin

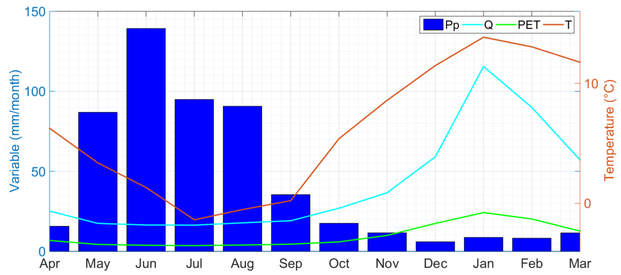

Figure 2: Seasonal cycles of basin-averaged hydroclimatic variables: temperature (T), precipitation (Pp), and runoff (Q) for the period 2000-2016, obtained from CR2MET and the CAMELS-CL dataset.

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

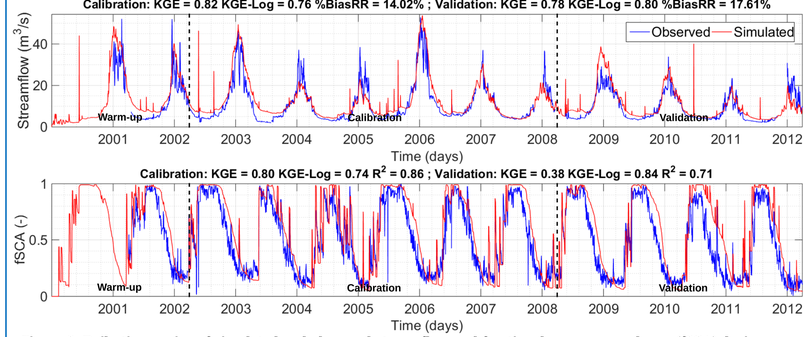

Figure 3: Daily time series of simulated and observed streamflow and fractional snow covered area (fSCA) during warm-up, calibration and validation periods.

Reference Period

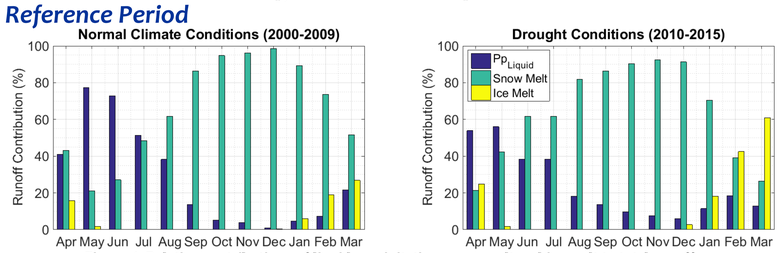

Figure 4: Relative contributions of liquid precipitation, snow melt and ice melt to total runoff.

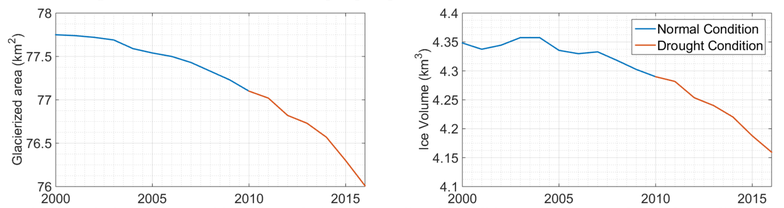

Figure 5: Glaciarized area and ice volume during current climatic conditions (2000-2009) and drought conditions

Glacier retreat and Hydrological response to severe drought

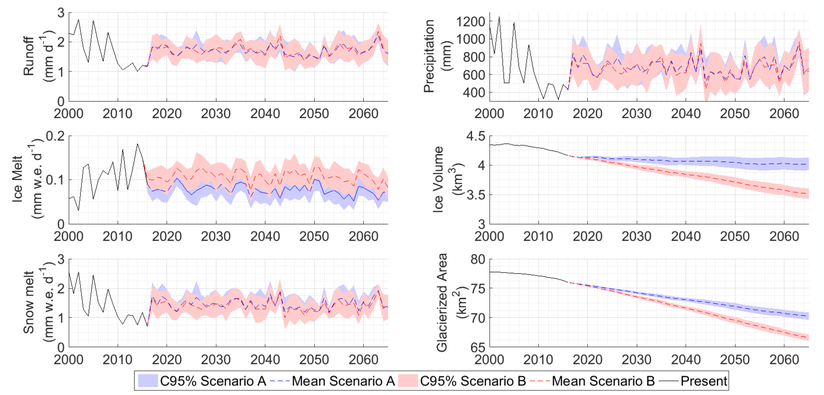

Figure 6: Annual time series of Runoff, Ice Melt, Snow melt, Precipitation, Ice volume and Glaciarized area under Scenario A and B. Each chart display the 95% confidence interval of significance (C95%) and mean value for all scenarios.

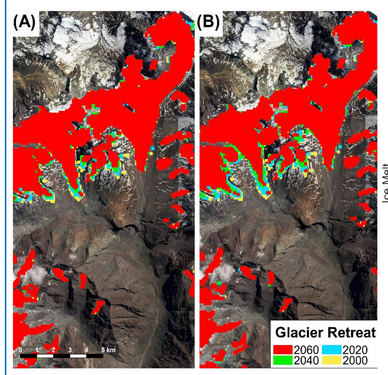

Figure 7: Glacier retreat maps. (A) Glacier retreat under climatic forcings defined by Scenario A. (B) Glacier retreat under climatic forcings defined by Scenario B.

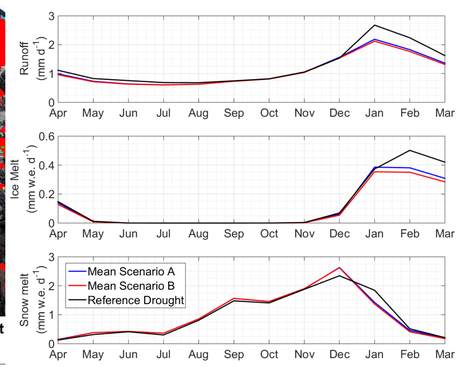

Figure 8: Monthly Runoff, Ice Melt and Snow melt averaged over the reference drought period (2010-2015) and future scenarios of glacier retreat.

- 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.

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