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Long term hydrological dynamics of an Alpine glacier

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Several studies have been showing that major environmental changes will occur in mountainous regions, with dramatic effects in glacierized areas. In particular, the Alps are experiencing a sharper rising in air temperature, compared to other regions. The European Alps are water towers providing fresh water to highly populated areas in a fragile environment with ecosystems and human activities that adapted to low flow and storage in winter followed by high flow in summer. This dynamic is in phase with agricultural use and touristic needs while hydropower makes use of reservoirs to allow
flexibility and increase production in the most profitable periods. Climate change may significantly impact this timing, thereby changing the scenario and introducing new challenges in water resources management.

In the present work, we comprehensively analyzed the long-term (1976-2019) meteorological and streamflow time series of a small (8.5 km^2) Alpine glacierized catchment, fed by the Careser glacier, in Peio valley, Italy. A Dense Deep feed-forward Neural Network (DNN) was employed to gap-fill the daily time series of the streamflow, available since 1976. Daily temperature and monthly precipitations at the glacier were obtained by interpolating the measurements at the 32 closest meteorological stations by Kriging with the External Drift.

The resulting reconstructed time series were used to investigate the changes in streamflow from 1976. The analysis revealed that precipitation did not change significantly in the observed period. On the contrary, a statistically significant temperature increase was observed (ΔT = 0.022, 0.052, 0.046 $^{o}C\ y^{-1}$ for the maximum, minimum and mean daily temperatures), which is, therefore, the main driver of the observed changes in the streamflow. Ablation, in terms of loss of glacier thickness, continued to increase, but the glacier's contribution to summer runoff first increased, up to the middle of the nineties of the previous century, and successively decreased dramatically as an effect of the reduction of the glacier area. In addition, significant anticipation of the summer streamflow peak was observed in the last decade.

The proposed analysis evidenced how the rise of temperature in the Alpine region is already having a profound impact on streamflow seasonality, which is expected to exacerbate in the near future, given the projected further increase of the temperature. More from a technical point of

view, the combination of classical geostatistical methods with DNN allowed a reliable reconstruction of meteorological and hydrological missing data. The algorithms developed in this study can be easily exported in other similar situations.