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Impact of the glacier retreat and snow melt on the seasonal cycle of streamflow of the Arve catchment since the 1960s (Northern French Alps)

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The hydrological regime of the Arve river and its tributaries is highly driven by glacier and snow melt, with high flow in summer and low flow in wintertime. This study aims to explore how melt rates of glaciers and snow influence the streamflow since the 1960s of five nested catchments (Bisme du Tour, Arveyron d'Argentière, Arveyron de la Mer de Glace, Arve at Pont des Favrands and at Sallanches). Their area ranges from 13 to 588 km^2, their elevation from 532 to 4808 m a.s.l. and their glacial cover from 16% to 64% (in 2003).

The seasonal cycle of daily measured discharges is fitted using an asymmetric peak model, composed by two half-gaussian functions, able to detect the snow and glacier contributions. The obtained functions can be synthetized by four parameters that change year by year: the position and the height of the peak and the width of the curve at the left and right of the peak. The calibration framework is applied to each catchment, for each year, minimizing the residuals using the simulated annealing algorithm. The curves' parameters have been analysed and compared with climatological and glaciological variables in order to detect trends and relations between them. The Aqua and Terra MODIS snow products are used to generate a daily gap-filled time series of the extent and the duration of the snow cover area since 2000. Snow cover melt is investigated using the Hock (1999) approach.

Examining goodness, the fits quality indicates that the seasonal cycle is well represented for all the catchments (r^2 = 0.8-0.9), over the period 1960-2004 at daily time step. Annual discharge volumes simulated with the asymmetric peak model are characterized by a RMSE ranging from 5.5% to 7.5%. The analysis of the interannual variability of the seasonal parameters of the curves over the period 1960-2004 shows opposite results depending on the catchments glacier coverage. Indeed, we identified a significant increase in the discharge peak and the volume production in highly glacierized catchments (Bisme du Tour, Arveyron d'Argentière, Arveyron de la Mer de Glace) and a significant decrease in the low glacierized ones (Arve at Pont des Favrands and at Sallanches). Such discharge increases might be due to the increase in glacier melt contribution, while the decreases are probably due to changes in land and/or water uses. Furthermore, a significant trend toward earlier snow melt is detected for the three highly glacierized catchments. The correlation between the height of the discharge peak and the average daily maximum temperature (15 July - 15 August) is higher for the highly glacierized catchments. This correlation is stronger for Bisme du Tour (r=0.85) and Arveyron d'Argentière (r=0.90) than for Arveyron de la Mer de Glace (r=0.67). These differences could result from different spatial distribution patterns of solid and liquid precipitation amounts over these catchments.