Contribution de la fonte des glaciers à l'évolution des débits dans le bassin du Rhône

Glacier melt contributions to future streamflow in the Rhône bassin

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RÉSUMÉ

Les Alpes sont soumises à de profonds changements dans le contexte du changement climatique avec un fort impact sur l'hydrologie. Le bassin du Rhône, qui draine une bonne partie des zones de hautes montagnes des Alpes françaises et suisses, fait déjà l'objet de modélisation hydrologique avec le modèle J2000-Rhône. Cette étude présente l'intégration d'un module de dynamique glaciaire dans J2000-Rhône, sa validation, et les projections hydrologiques sur le 21e siècle en prenant en compte une évolution simulée des surfaces glaciaires. Les résultats montrent que la fonte de la neige et de la glace ainsi que les débits sont simulés de manière satisfaisante à l'échelle du bassin du Rhône par J2000-glaciers. D'ici la fin du 21ème siècle, les changements les plus importants seront une hausse du débit hivernal et une baisse du débit estival. La baisse de débit estival sera très importante car due à la concomitance d'une baisse de précipitations, une fonte plus précoce de la neige et une baisse des surfaces glaciaires. Sur les bassins de l'Arve et du Rhône-Amont la contribution glaciaire resteras importante pour soutenir les débits durant certains été secs.

ABSTRACT

The alps are impacted by dramatic changes in the context of global warming with large implications for hydrology. The Rhône bassin, draining a large part of the french and Swiss Alps, has already been the subject of hydrological modelling using J2000-Rhone. In this study, we present the integration of a glacier algorithm in the hydrological model J2000-Rhône, the validation of snowmelt, icemelt and streamflow, and the future projections of these processes. The results show that snowmelt, icemelt and streamflow are satisfactorly simulated by J2000-glaciers in the Rhone basin. By the end of the 21st century, the major changes will be a large increase of streamflow in winter but a decrease in summer associated to earlier snowmelt, a decrease of precipitation and glacier shrinkage. On the Arve and upper Rhône catchments, the remaining glaciers will still be crucial to sustain the streamflow in dry summers.

MOTS CLÉS

Bassin du Rhône, glaciers, J2000, Modélisation hydrologique, projections climatiques

Climate projections, glaciers, hydrological modelling, J2000, Rhône bassin

1 INTRODUCTION

The Rhone, as one of the major river flowing from the Alpine mountains, is impacted by a strong warming favouring a large increase of winter streamflow and a dramatic decrease of summer flows. The high altitude watersheds covered with ice, can still benefit from ice melt water sustaining the summer streamflow, but the amount of ice-melt is starting to decrease in a large number of alpine glaciers (Huss and Hock, 2018). In this region, the society is highly dependent on the river water level and the question of the future contribution of glaciers to the hydrology is an outstanding area of research.

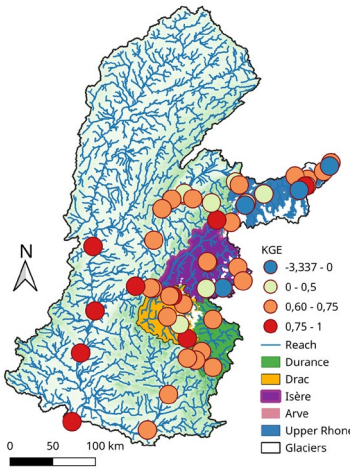

Figure 1: KGE of the simulations against observations in stations receiving icemelt

The impact of climate change on the Rhone River streamflow has been studied for many years (Etchevers et al., 2002) and started recently to take into consideration glacier dynamics in the simulations (Hanus et al., 2024; Huss and Hock, 2018). These studies show that part of the decrease in summer streamflow is associated to a reduction of glacier surfaces (Hanus et al., 2024). However the contribution of ice-melt has not been thoroughly investigated in the Rhone subbasins. The goal of this study is to assess the contribution of glaciers to the future streamflow in several watersheds of the Rhone basin using a new glacier algorithm integrated in J2000 hydrological model.

2 DATA AND METHODS

J2000 is a conceptual distributed hydrological model, developed by Krause (2002), already applied to the Rhone catchment (J2000 classic, Branger et al., 2016). In this study a glacier algorithm developed in J2000 for the Himalaya and recently used in a small alpine catchment (Bolibar Navarro, 2020) has been implemented for the entire Rhone basin (J2000 glaciers). The input data of the models for the historical period are the glacier surfaces from 3 inventories (1970, 2003, 2015) and temperature and precipitation from the Safran reanalyses. For the projections we used the climate simulations from 6 RCM-GCM couples forced with the Representative carbon pathway 8.5 (RCP8.5) and bias corrected using the Adamont method that were also used to simulate the future glacier extension.

3 VALIDATION OF THE MODEL

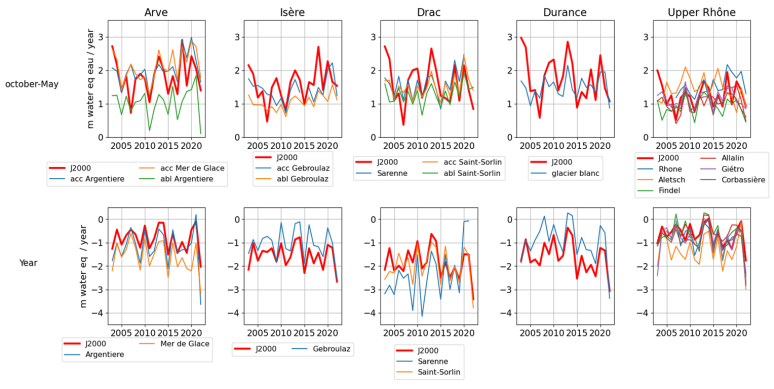

Figure 2: J2000 and observed mass balance from GLACIOCLIM and GLAMOS

The parameters of the glacier module have been adjusted with a trial and error approach using the meteorological and snow cover reanalysis (S2M) and mass balance from French and Swiss glaciers. The parameter precip_mult adjusting the snow in high elevation (>2900m) has been calibrated against winter mass balance (accumulation period) for each watershed (Figure 2). A single ice-melt factor for the entire watershed was then defined (3.5mm/°C/days). The results of the mass balance from J2000 show a good agreement with

the observations overall (Figure 2). The streamflow shows also a satisfactory Kling-Gupta efficiency (KGE) for most watersheds excepted few watersheds in switzerland (Figure 1).

4 FUTURE CONTRIBUTION OF ICEMELT TO STREAMFLOW

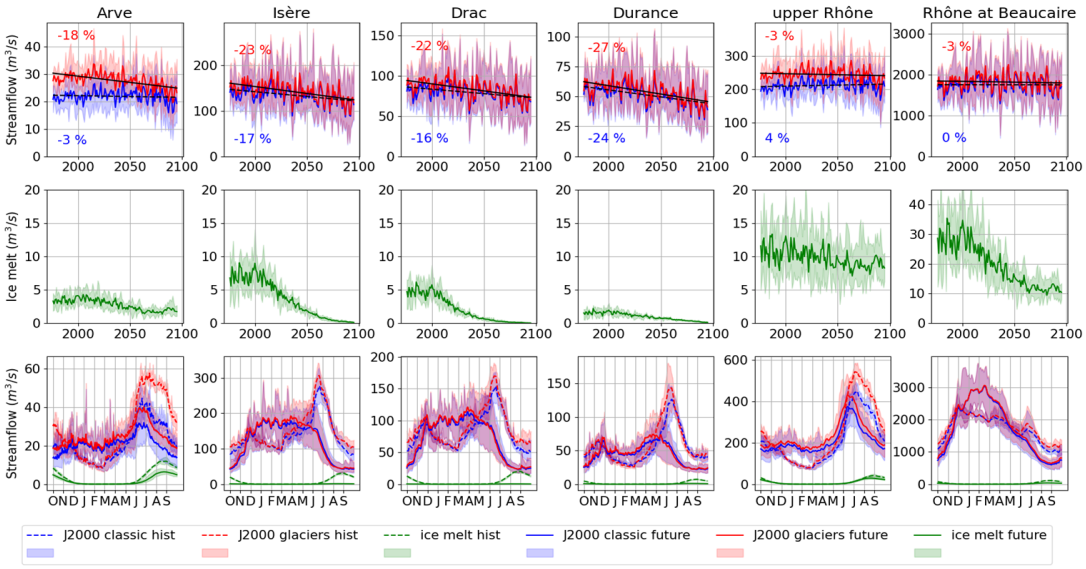

Figure 3: interanual evolution of streamflow (first row) icemelt (second row) and seasonal evolution (third row) simulated by J2000 classic and J2000 glaciers forced by 6 chains of modelisations between 1976-2005 and 2065-2096.

By the end of the century, annual streamflow will decrease in all watersheds. The streamflow reduction will mostly be due to a decrease of summer precipitation in the South (Isère, Drac, Durance) but a decrease of evapotranspiration in the Arve catchment. Icemelt, consecutive to a reduction of glacier surface, will represent 50% of the streamflow decrease in the Arve catchment, 25% in the Isere and Drac, 10% in the Durance, and 20% in the overall Rhône (Figure 3). The hydrological regime will dramatically change with a large streamflow decrease in summer and an increase in winter mainly due to a reduction of snowfall consecutive to the warming. By the end of the 21st century, icemelt will become insignificant in the south, but will remain a component of August streamflow in the Arve (25%), upper Rhône (13%) and the entire bassin (5%).

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