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Three-dimensional surface velocity variations of the Argentière glacier (French Alps) monitored with a high-resolution continuous GNSS network

Anuar Togaibekov[1], Andrea Walpersdorf[1], Florent Gimbert[2], Christian Vincent[2], Agnès Helmstetter[1], Delphine Six[2], Luc Moreau[3], Juan Pedro Roldan-Blasco[2], Laurent Ott[4], Stéphane Mercier[1], Olivier Laarman[2], Luc Piard[2], Ugo Nanni[2], Marguerite Matthey[1], Benoit Urruty[2], Christian Sue[1], Jean-Noël Bouvier[1], Mathilde Radiguet[1], Olivier Romeyer[5], and Jean-Louis Mugnier[5]

[1]University Grenoble Alpes, CNRS, IRD, UGE, ISTerre, 38000 Grenoble, France (anuar.togaibekov@univ-grenoble-alpes.fr)
[2]University Grenoble Alpes, CNRS, IRD, Grenoble-INP, IGE, 38000 Grenoble, France (florent.gimbert@univ-grenoble-alpes.fr)
[3]University Savoie Mont-Blanc, CNRS, Laboratoire EDyTEM, 73000 Chambéry, France (moreauluc@chx.fr)
[4]Grenoble INP, CNRS, GIPSA-Lab, 38000 Grenoble, France (laurent.ott@gipsa-lab.grenoble-inp.fr)
[5]University Grenoble Alpes, University Savoie Mont Blanc, CNRS, ISTerre, 73000 Chambéry, France (olivier.romeyer@univ-smb.fr)

Glacier dynamics exhibits a strong variability in response to climate forcing. To better understand the effects of this forcing, it is essential to provide continuous deformation measurements that must be long-term (over a full or several melt seasons) and high-resolution (from daily to sub-daily). GNSS monitoring represents a valuable mean to better apprehend mechanisms of basal sliding and provide high-resolution 3D constraints on physical models of glacier flow. In this study, we investigate motions and deformations of the Argentière Glacier in the French Alps at 2400 m altitude, derived from up to 12 permanent GNSS stations continuously operating since April 2019, covering two melting seasons. The Argentière glacier is particularly interesting due to (i) its long-term subglacial observatory measuring basal sliding velocity and subglacial discharge, and (ii) the wide range of complementary observations currently being acquired there, which give access to internal ice deformation thanks to tiltmeters in boreholes, and to basal stick-slip and englacial fracturing thanks to seismic observations. We present the results (i) over relatively long timescales (days to months) using the fast static positioning approach to evaluate mean variations and compare to the independent measurements mentioned above, and (ii) kinematic approach to focus on high temporal resolution velocity variations during specific short-term events that cannot be seen from the static processing. The horizontal surface velocities on daily time scales reveal spring acceleration due to meltwater followed by steadily high velocities over the summer, and significant episodic accelerations in the fall in response to the storm events. We quantify strain rates and their evolution in time that can be related to the vertical surface motions. We combine the GNSS with the englacial tiltmeters results to deduce the basal speed variations. The GNSS confrontation with other independent observations also allows analyzing the surface motions that combine horizontal speed-ups with uplift due to bed separation of the ice sheet. We will further search for evidence for surface motions that might occur in daily cycles in summer, as hinted at by

the basal sliding measurements. But before analyzing daily cycles of glacier motions, it is critical to remove positioning artefacts due to multipath effects with a repeat period close to 24 hours. These effects are enhanced on the Argentière Glacier by the limited number of visible satellites in the narrow valley. Moreover, it evolves with the dynamically changing environment (snow accumulation and snowmelt that create variations in ground reflectivity properties). A multi-GNSS analysis combining GPS and GLONASS data helps overcome the lack of satellite data and increase the time resolution on a sub-daily scale. If daily cycles are resolvable from the improved GNSS analysis, their phase offsets with respect to meteorological, hydrological and seismic observations can give us indices of eventual mechanisms of sliding at the bedrock interface.