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Regional analysis of ice-debris landform kinematics in the central Andes of Argentina.

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High-mountain environments often constitute the water towers for their adjacent lowlands, as large amounts of water are stored in their glacial and periglacial zones. In contrast to clear ice glaciers of the southern Andes, the latitudes between 30-33°S are predominated by rock glaciers and transitional landforms between debris-covered glaciers and rock glaciers (hereafter referred to as ice-debris complexes). Therefore, knowledge on the size, distribution, and state of activity of periglacial landforms is important, especially in arid regions where human livelihoods critically depend on meltwaters, such as the central Andes of Argentina. Close to Mendoza, one of the large population and agricultural centers, the frontal Cordillera rises sharply to nearly 6000 m asl in the Cordón del Plata range. Here, a comprehensive inventory of all glaciers, rock glaciers, ice-debris complexes and permanent snow patches is available (glaciaresargentinos.gob.ar). We exploit this inventory and quantify the horizontal movement of >600 ice-debris landforms to gain insights on their state of activity. We further compare the horizontal surface movement of these landforms to topographic parameters.

For our analysis, we used a least square matching algorithm to automatically track surface movement in two subsequent RapidEye satellite images acquired in 2010 and 2018. Images were orthorectified using a 12x12 m resolution digital elevation model (TanDEM-X) and resampled to 5x5 m ground resolution. For all 613 ice-debris landforms that cover a total surface area of 147.3 km^2, we tracked all pixels of a 10x10 m grid. Results were corrected for upslope flow and high flow-direction variance in a 3x3 pixel search window. We had to exclude 244 landforms from our analysis, as we could track less than 10% of their surface area due to snow cover, shadow effects, or bad image quality.

Of the 369 landforms, covering a surface area of 110.3 km^2, 189 mostly smaller features (27.8 km^2) showed surface velocities that fall below the limit of detection of $\sim$0.9 m yr^{-1} (1.5 pixels) and can be considered inactive. Based on our analysis, the remaining 180 features (82.6 km^2) show significant surface movement between 2010 and 2018. Average rates of movement mostly fall between 1 and 2 m yr^{-1}, with maximum velocities exceeding 5 m yr^{-1} for at least 20 features. Assessing the accuracy of our approach, we compare satellite derived horizontal surface velocities with repeated D-GPS and UAV surveys that we carried out on an ice-debris complex within the study area. We find good agreement between the different approaches, both for the general pattern of movement and for the magnitude of measured surface velocities. To further constrain parameters determining the horizontal velocities, we analyze the distribution of movement with respect to topographic parameters that we derive from the TanDEM-X digital topography. Our topographic analysis does not show a coherent picture: generally, higher horizontal velocities are associated with steep gradients but also coincide with higher elevations, where colder temperatures potentially allow for higher ice-contents.