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Estimate of the 3D kinematics of an Alpine glacier by merging terrestrial radar interferometry and image cross-correlation

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We present a new methodology for coupling two distinct and independent datasets to estimate the 3-dimensional surface kinematics of an Alpine glacier. These datasets were collected by different remote sensing systems that can measure complementary components of the surface motion vector. The method was applied to the data acquired during the monitoring campaign of the Planpincieux glacier (Italian side of the Mont Blanc massif) carried out on 4-27 September 2015 with a ground-based SAR (GBSAR) and a monoscopic visual-based system (VBS) equipped with two SLR cameras with different focal length. Overall, we collected and processed more than 2300 radar images and 300 photographs.

We designed the method in order to apply it purely from remote; thereby, it is suited for applications where the access in the investigated area is not possible. Moreover, the two remote sensing systems can be placed either in the same or in different locations. The methodology we developed involves four main procedures: i) interferometric processing of the radar images, ii) image cross-correlation (ICC) in the frequency domain, iii) radar and image data georeferencing and iv) data coupling.

In the interferometric phase, we developed a new approach for dealing with the atmospheric phase screen (APS) of the interferometric data; the model takes into account the elevation coordinates as an explicit regressor. The GBSAR data measured the motion component parallel to the line-of-sight (LOS) and they had a resolution of approximately 0.4 m in range and 11 m in azimuth.

Concerning the ICC, one image per day was manually selected to guarantee the more suitable visual conditions, i.e. when the diffuse illumination prevailed. The ICC provided the motion components orthogonal to the LOS, represented on a 3.5 x 3.5 m and 8.7 x 8.7 m grid (according to the focal length).

The accuracy and precision of the motion results were of the order of mm/day.

In the third step, we orthorectified the photographs with the support of a 1 m-resolution DSM; we computed the transformation matrix using 30 pairs of ground control points (GCPs) easily recognizable both on the images and on the DSM. We estimated a georeferencing uncertainty of approximately 1.7 m.

For georeferencing the GBSAR data, it was necessary to estimate the orientation angle of the local reference system (RS) w.r.t. to the north. We assessed it through spatial correlation of the geographic area visible from the GBSAR location and the scattering areas of the radar beam, identified by a high signal amplitude. Then, the GBSAR RS was rotated according to the estimated orientation. This approach returned an estimated georeferencing uncertainty of 4.4 m.

Finally, the GBSAR data were rotated to make them represented from the point of view of the VBS; the data merging was fulfilled through the summation of the linear independent (i.e. orthogonal) components of the motion vectors.

As a result, we obtained the 3-dimensional representation of the glacier surface kinematics; this allowed observing that the motion vectors were not parallel to the slope as usually assumed.