Interannual and subseasonal rock glacier displacement by exploiting different SAR techniques

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Abstract

Active rock glaciers are slow-moving, permafrost landforms that characterize high mountain periglacial terrains. Their complex movement, with interannual and subseasonal rhythms, are of interest for interpreting the evolution of the permafrost in response to meteorological and climatic variables. Given the generally remote location of the rock glaciers, we propose a methodology to monitor their interannual and subseasonal dynamics using a satellite-based approach with different types of Synthetic Aperture Radar (SAR) imagery (i.e. Sentinel 1 and TerraSAR-X), limiting the need of in-situ measurements. This proposed methodology is tested on an active rock glacier, where many in-situ measurements are available to compare the satellite results.

Keywords: rock glacier, permafrost, remote sensing, Sentinel 1, TerraSAR-X, GB-SAR.

Introduction

Rock glaciers are the most common geomorphological evidence of permafrost in alpine regions and are characterized by creeping processes that generate a downstream displacement, with velocities ranging from a few cm to more than 1 meter per year (Haeberli et al. 2006). Displacement over several years is related with climatic variables such as air temperature, and subseasonal displacement is related with shorter time-scale events such as rainfall, snow melting and other environmental factors (Kääb et al., 2007). The slope instability related to rock glacier and permafrost dynamics is monitored for a proactive management of natural hazards. Moreover, as permafrost is sensitive to climate change, observing its dynamics is a key issue in alpine environments.

Ground-based monitoring of rock glacier dynamics, such as GPS or total station, is limited by the complexity of acquiring measurements over these remote areas. For the same reasons, rock glacier dynamics at subseasonal scale are even less monitored.

Remote sensing methods based on SAR data are part of technologies at disposal to study rock glaciers at different space and time scales. In fact, SAR satellites are capable to acquire data over remote areas independently from weather conditions and with high temporal frequency (up to a few days).

In this work, we propose a satellite-based approach for monitoring rock glacier dynamics at different temporal scales. This approach aims at supporting in-situ measurements for well instrumented study areas, and at monitoring rock glaciers dynamics when in-situ measurements are not available or difficult to be carried out.

Our approach is based on the use of SAR data with different characteristics (i.e. different spatial and temporal resolution) and processed through different techniques, i.e. differential interferometry (DInSAR), multi-temporal interferometry and amplitude tracking, in order to study the annual, seasonal and subseasonal rock glacier dynamics with high precision. We tested our methodology over an active rock glacier called Lazaun and located in Val Senales (South Tyrol, Italy, fig. 1), whose internal structure is well known thanks to detailed analysis conducted in the last years (Krainer et al. 2015), but its flow pattern is still poorly investigated.

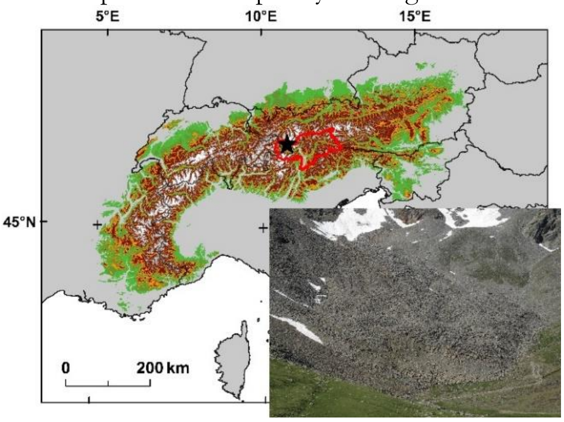

Figure 1: picture of Lazaun rock glacier and its location indicated by the black star (Val Senales, South Tyrol, Italy).

The accuracy of satellite-based products is assessed exploiting ground-based data, such as GPS and Ground-Based SAR (GB-SAR) data.

Materials and method

Subseasonal monitoring

The high acquisition time frequency of Sentinel 1 data (6 days) allowed studying the subseasonal displacement and understanding the displacement rate variation during the snow free period. Two datasets of Sentinel 1 from relative orbits 117 and 168 were used, taking into account the images from the snow free period 2017 (about mid-June to mid-October). The images were processed using Persistent Scatter (PS) technique (Ferretti et al., 2001). Interferometric techniques allowed obtaining only the displacement along the Line of Sight (LOS) of the satellite. Exploiting the combination of 117 and 168 relative orbits, displacements in two different direction can be derived.

As the Sentinel 1 images have a low spatial resolution (15 meters), to study with higher spatial accuracy the rock glacier surface dynamic, three Very High Resolution (VHR) TerraSAR-X (TSX) images acquired in summer 2017 were processed by using differential interferometry (DIn-SAR).

Interannual monitoring

Annual rock glacier displacement cannot be investigated with DIn-SAR due to decorrelation and unwrapping issues, therefore amplitude tracking technique was applied on two VHR TSX images from summer 2016 and summer 2017. In addition, exploiting the combination of the displacement along the LOS and along the satellite flight direction, we will have the possibility to further improve the accuracy of the displacement direction.

Ground-based data

A 10-days GB-SAR campaign was carried out during summer 2017 (Monserrat et al., 2014). The high acquisition time frequency (5 minutes) of this instrument enabled the comparison of daily displacement data with satellite SAR results. Moreover, seasonal and annual displacement were compared with GPS measurements conducted three times over summer on the rock glacier, in order to validate the results.

Results

DIn-SAR technique with TSX data provided high resolution displacement maps, where different velocity sectors are visible (fig. 2A). In particular, the fastest areas are located above the frontal slope and in the middle part of the rock glacier. This velocity pattern is confirmed by the GPS and GB-SAR measurements, and will be further compared with the Sentinel 1 PS results.

As the flight direction of TSX data used for amplitude tracking was roughly the same of the GB-SAR LOS, we were able to directly compare the results. In particular, annual displacement measured with amplitude tracking showed values up to 100 centimeters (2.7 mm/day), which is in the same order of magnitude of the GB-SAR velocity measurements (about 3 mm/day, fig. 2B).

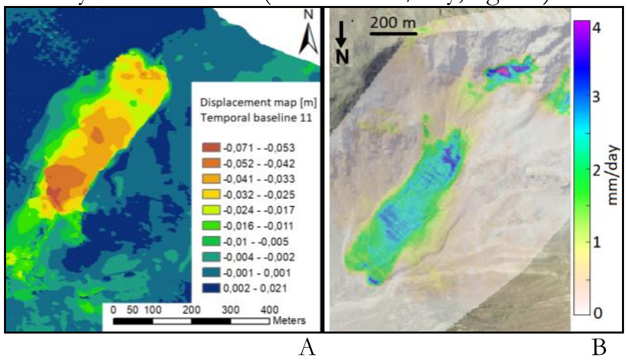

Figure 2: (A) displacement map obtained by TSX DIn-SAR. (B) Daily average velocity obtained by GB-SAR.

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