Current changes in mountain permafrost creep: possible causes and consequences

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Beside its thermal characteristics creeping mountain permafrost is substantially defined by its kinetics. Due to the - in general considerable - ice content of rock glaciers, their dynamics are believed to respond sensitive to climate forcing. For a number of rock glaciers in the European Alps a significant creep acceleration has been observed in recent years. Questions arise if these changes reflect current or recent climatic changes, and what the further consequences of such behaviour could be. In this contribution, we compile globally observed rock glacier speeds as a function of local air temperature. In fact, air temperature can be identified as a major factor determining rock glacier speed. The remaining scatter clearly points to other influences such as slope, ice content, thickness or liquid water. In a next step, we summarize current monitoring results on rock glacier speed from other authors and ourselves. A surprisingly large number of Alpine rock glaciers showed an increase in speed in recent years. The large number points to other than solely local influences but rather to some regional-scale impact such as the observed increase in air temperatures. Using a one-dimensional thermo-mechanically coupled numerical model we simulate the potential response of rock glacier creep to a change in near-surface ground temperatures. It turns out that variations in temperature could affect indeed rock glacier creep in the currently observed order of magnitude. Other influences, however, clearly act as well. Among these, the occurrence and complex influence of liquid water in the frozen debris might be the most important for permafrost close to 0°C, though difficult to model. Our monitoring and modelling work implies that ’warm’ rock glaciers (i.e. close to 0°C) creep faster than ’cold’ ones. Furthermore, the findings suggest that the creep of ’warm’ permafrost is more sensitive to climate forcing than ’cold’ one. From this, we conclude that increasing rock glacier temperatures may lead to its marked, but both spatially and temporally highly variable speed-up, before a significant loss of ice content by melt-out is able to reduce the deformation rate of the frozen mass towards its entire deactivation. By means of three scenarios, we finally demonstrate the possible consequences of an increase in rock glacier temperature and subsequent acceleration: **(1)** increasing sensitivity of rock glacier creep to seasonal influences, **(2)** dynamic activation of so far stable debris slopes, and **(3)** non-linear instabilities or ruptures of rock glaciers. Thereby, special focus is on applied aspects and consequences for natural hazard management.

Documentation of the creep process of Weissenkar rock glacier (Central Alps, Austria)

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Weissenkar (46° 57.5’ N, 12° 45’ E) is a glacially shaped cirque in the Schober mountains of the Central Alps which are built of crystalline rocks. These rocks tend to be weathered to coarse debris favouring the formation of permafrost ice under climatic conditions with a mean annual air temperature of approximately -2 °C in 2500 m a.s.l. Due to the vertical extent of the cirque ranging from some 2600 m to 3100 m a.s.l. and the steep slope in its upper part continuous deformation of the permafrost by force of gravity has created an active rock glacier as it is also the case in a great number of sites with comparable topography in this mountain group. The creeping permafrost body has actually reached a plateau where its motion is retarded due to low inclination resulting in a very pronounced surface topography. This poster is focused on the documentation of the kinematic state of Weissenkar rock glacier. Geodetic and photogrammetric measurements have been carried out in order to obtain quantitative information on surface deformation, in general, and creep velocity and surface height change, in particular. In 1997 a geodetic network consisting of two stable reference points located in the vicinity of the rock glacier and 18 observation points on the rock glacier was installed and measured with substantial support of the Institute of Navigation and Satellite

Geodesy of the Graz University of Technology. These measurements have been repeated every year until now, with one interruption in 2002. Annual horizontal creep velocities obtained are rather small and range between 5 to 11 cm a^{-1}. In this poster selected results of the measurements (1997 to 2004) will be presented numerically and graphically. Furthermore, a comparative analysis of the data will be given. Large-scale aerial photographs of three different epochs, i.e., 1974, 1998 and 2003, covering Weissenkar rock glacier were acquired in order to obtain area-wide information on the surface movement. Dense fields of three-dimensional surface displacement vectors were computed applying modern digital-photogrammetric methods. Results obtained for the time period 1998 to 2003 were compared with the respective values of the geodetic survey. The poster also comprises various thematic maps showing the mean annual creep velocity and surface height change for the time periods 1974 to 1998 and 1998 to 2003. As a basis of cartographic work a orthophoto map of the area of interest was compiled. Finally, the kinetics of Weissenkar rock glacier will be discussed in respect to its morphology and its specific topographic situation.

Studying the movement of the Outer Hochebenkar rock glacier: Aerial vs. ground-based photogrammetric methods

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The Outer Hochebenkar rock glacier is situated in the vicinity of the village Obergurgl in the Oetztal Alps, Austria. This tongue-shaped rock glacier is about 1 km in length and 42 ha in size. It has a comparatively high but periodically changing flow velocity of up to several m a^{-1}. At the lower end of the rock glacier a landslide has occurred, which is caused by the rather steep terrain. The upper part is characterized by a steady-state creeping process. The maximum velocity can be observed right above the sliding zone (at about 2580 m).

In this work aerial as well as ground-based photogrammetric methods were used for deriving metric information of surface deformation and flow velocity. Aerial photogrammetry is a standard method for rock glacier monitoring tasks, whereas ground-based photogrammetry, being the historically older method, has not been used anymore. Nowadays, it might become a valuable tool for the monitoring of small scale periglacial phenomena again. This is due to the availability of high resolution digital consumer cameras and modern, fully automated digital-photogrammetric methods. The following aerial photographs have been acquired from the Federal Office of Metrology and Surveying (BEV): **(1)** a stereo pair dated from September 7th, 1977 (panchromatic film), **(2)** a stereo pair dated from September 11th, 1997 (panchromatic film) and **(3)** a stereo triplet dated from September 5th, 2003 (color film scanned with 20 micron). The ground-based photographs have been taken during three field campaigns using four different (metric and semi-metric) camera systems: **(1)** a stereo pair from September 23rd, 1986 (Photheo 19/1318), **(2)** stereo pairs taken on September 9th, 1999 (Linhof Metrika and Rolleiflex 6006) and **(3)** stereo pairs taken on September 19th, 2003 (Linhof Metrika, Rolleiflex 6006 and Nikon D100). Photogrammetric evaluation was done for the aerial case (1977 to 1997 and 1997 to 2003) and for the ground-based surveys (1986 to 1999 and 1999 to 2003). First, all analog images were scanned with the UltraScan 5000 photogrammetric scanner of Vexcel Imaging Austria with a resolution of 10 micron. Then an all digital photogrammetric workflow was implemented using the digital workstation ISSK of Z/I Imaging and various software tools. These have been developed for geometric and radiometric correction of the (terrestrial) images and for automatic measurement of digital terrain models (DTM) and 3D flow vectors. The results derived from the two different data sets are presented numerically and graphically. This allows to compare the ground-based method directly with the aerial case and to verify both of them with geodetic measurements provided by the University of Innsbruck. Finally the pros and cons of this two methods are discussed in detail.