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Discussions

Interactive comment on “Short-term velocity variations of three rock glaciers and their relationship with meteorological conditions” *by* V. Wirz et al.

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GENERALL COMMENTS

This paper is a contribution to rock glacier movement and potential meteorological influences. The authors combine novel automatic GPS measurements of rock glacier movement with measurements of meteorological conditions obtained by meteo stations and temperature loggers. They identify short-term velocity differences and explain their occurrence in an abductive way. The method presents an extension of rock glacier movement monitoring by photogrammetry, InSAR or manual GPS measurements and enables a kinematic analysis in a higher temporal resolution. Thus, the method has the potential to extend our understanding of rock glacier movement and contributions by meteorological factors.

However, this manuscript is not well structured and partly similar to the recent publication by Wirz et al. (2015). The authors insufficiently explain the 1) representativeness of their point-derived data for rock glacier measurements and 2) the influence of the spatial resolution on the derivation of velocity peaks. Furthermore, 3) mechanical movement and influencing properties are poorly introduced, thus, the analysis and draw of conclusion for 4) inter-annual, 5) seasonal intra-annual and 6) short-term velocity peaks show deficits and could be significantly improved (see specific comments 1-6). Thus, I recommend major revisions of the manuscript.

SPECIFIC COMMENTS

1) How representative are point surface measurements?

To identify rock glacier movement two GPS sensors are installed on large boulders located in the upper area of the rock glacier or on the rock glacier tongue. The authors assume a priori that these boulders are carried along with the displacement and their velocity is representative for the whole upper or lower rock glacier part. Rock glaciers consist of different lobes, ridges and furrows which implicates that parts of the rock glacier move with different velocities. Delaloye and colleagues are monitoring the Dirru rock glacier since 2007 with manual GPS and InSAR and identified areas which move with different velocities (Delaloye et al. 2008b, Fig.7 and 2013, Fig. 2). Thus, the selection of the GPS location is crucial for the representativeness of the movement data. However, the authors provide no or insufficient information about geomorphic features of the rock glacier such as lobes, ridges and furrows. Furthermore, they do not explain how they selected their measurement device location and on which geomorphic properties this selection is based. To compare automatic GPS-derived movement with movement from InSAR, manual GPS (Delaloye et al. 2008a, Strozzi et al. 2009a) or photogrammetric data in the future could resolve the representativeness of point surface measurements.

2) Spatial resolution of GPS-measurements

According to Wirz et al. (2013:387), the spatial resolution of 30s-sampling is in the range of cm. If this is correct, the observed peaks lay in the range uncertainty of the GPS instrument. Please address resolution and accuracy of the GPS and implications for velocity peak derivation.

3) Mechanical movement and response time

Rock glaciers can deform or creep (Haeberli et al. 2006) as a result of pore pressure in the active layer or as a result of permafrost warming in the shear horizon. The authors provide a figure (Fig. 1) to enable an overview about theses deformation or creep processes. The authors assume that “the movement observed at the rock glacier surface might be the result from movements occurring at different depth” (page 461:28ff). However, this figure stands alone without any explanation. Deformation or creep processes have different response times. Thawing of ice depends on conductive and non-conductive heat transport processes, thus, response time depends on the velocity of theses heat transport processes. Pore pressure increase results from water input, permeability and pore geometry. Response time and reaction time should differ from pure heat transport processes. I recommend the comprehensive study by Bull (2009) “Geomorphic Responses to Climatic Change” for an overview of response, reaction and relaxation time and to address this systematic view in the introduction. Response time is crucial for the understanding of short-term peaks.

4) Why do the rock glaciers show high inter-annual velocities?

The inter-annual variability is not the focus of this paper, however, the deviation of Mean Annual Velocities (MAV) is used to identify peaks. The Dirru and Breithorn rock glacier show high annual velocities (4.9 and 6.8 m/a) which are significantly higher than “typically” displacements mentioned by Haeberli et al. 2006 (page 461:20f.). Unfortunately, there is no detailed explanation why the investigated rock glaciers move so fast. An explanation could enhance the understanding of short-term peaks which are defined as deviation from the mean. Furthermore, the calculation of Mean Annual Velocities

(MAV) of R2a should be taken with care, thus, the periods differ in length. It excludes possible movement acceleration in autumn 2011 and could underestimate the MAV in 2011/2012. The current period naming is confusing and periods should be renamed to 2011/12, 2012/13 and 2013/14. Not all variables (σdisp) of Table 2 are explained in the text.

5) The intra-annual variability of rock glacier movement

The intra-annual variability is compared to air temperature derived from the meteo station and GST, zero-curtain and snow-cover period derived from all iButtons. The movement obtained at one point of the rock glacier is compared to statistical calculated ground temperature, snow cover and zero-curtain conditions of the whole catchment. Air temperature maybe shows no large differences on short distances. However, GST and snow cover can vary significantly on short distances (Gubler et al. 2011) due to surface properties. Snow can be redistributed due to avalanches and wind and accumulate with higher depths in depressions and lower depths on ridges. This results in different snow height with different potential of insulation and snow water equivalent. The authors conclude snow cover and snowmelt as an important factor of seasonal rock glacier movements. Unfortunately, literature on snow cover distribution, influence of snow cover on permafrost such as Keller (1994), Hanson and Hoelzle (2004) or Luetschg et al. (2008) is absent in the manuscript. Thus, snowmelt is reduced to pore pressure increase and rapid warming. Thermal influences of snowmelt, response time due to heat transport and mechanical influences of snow cover and snowmelt are insufficiently introduced and discussed.

6) Short-term velocity peaks

Short-term velocity peaks are identified of two rock glacier lobes and statistically related to meteorological factors. Why only two locations are analyzed remains unexplained. The velocity peaks are correlated to liquid precipitation of the meteo station, GST from iButtons next to the GPS and zero curtain of all iButtons. The latter use of all iButtons makes no sense. Not all snowmelt of the catchment area will drain through the rock glacier and affect rock glacier movement. Most observed velocity peaks are in the range of centimeters and lay in or close to the measurement uncertainty of the GPS instrument. However, the spatial resolution of the GPS is not discussed in the manuscript. A strong correlation between precipitation and velocity peaks is observed which is interesting and should be emphasized in the paper. However, the calculation of meteorological parameters for the peak and 7 days before the peak assumes a fast reaction time of the rock glacier to meteorological influences such as precipitation. This excludes a priori movement processes with longer reaction time such as rock glacier creep due to active-layer thawing. Peaks that are triggered by rainfall all occur in summer to autumn after an active-layer has developed or is developing. A path-dependence of precipitation influence could be possible which means that a sufficient active-layer needs to be present. However, path-dependency and active-layer development is not included in this manuscript. From my opinion, underground information derived from boreholes, temperature modeling or geophysical measurements are necessary to understand how the rock glacier is influenced by meteorological factors. Unfortunately, the authors use a black box approach measuring meteorological influences and kinematic response without having any information on the internal structure of the rock glaciers or movement relevant properties such as active-layer depth, ice content or shear horizon depth. As a consequence, all attempts to explain the sources of kinematic behavior remain speculative.

TECHNICAL COMMENTS

Page 460 ff: The introduction is comprehensive, however, the required background for the discussion of the observed mechanism is insufficiently introduced. As a consequence, the introduction should be reduced to approximately two pages and should sharpen the system understanding (landform, material, process and response time), mechanical basis of rock glacier movement, thermal influences on rock glaciers and snow cover interaction with permafrost. The appendix table A1 should be included into

the text to give an overview about existing previous studies that the authors want to confirm (Hypothesis 1). The mechanical basis of rock glacier movement can be illustrated with Fig. 1, however, a more detailed description of the processes associated with movement is required. Potential meteorological factors influencing rock glacier movement should be introduced (Hypothesis 2).

Page 465: The three rock glaciers are insufficiently introduced. The site description should be extended with special focus on movement-relevant properties. I would advise a table which summarizes topographic, geomorphometric and kinematic properties of upper and lower parts of the rock glaciers. Inter-annual velocity can be included in this section to illustrate differences of kinematic behavior.

Page 467 ff: The instrumentation section (2.2, 2.3, 2.4) is very similar to the corresponding sections in Wirz et al. (2015). The section should be reduced to one method section which shortly summarizes the set up. The instrumentation is published in 3 previous papers which can be cited. Only instrumentation which is used in this paper should be addressed with special focus on the spatial resolution of the GPS. Non-working meteo stations can be excluded. The method section (3.) can be slightly shortened and merged with the instrumentation section.

Page 502: Table 2, all included variables should be explained in the text. Please change the confusing period naming to 2011/12, 2012/13, 2013/14.

Page 504: Please include a column in Table 4 which explains the variables of the models. The table should be self-explainable without searching for the abbreviations in the text.

Page 509: Zero-curtain is not visible, thus, it is derived from all iButtons. If you use only local IButtons and split the image into 6 subfigures zero-curtain will be visible. The correlation between occurrence of zero-curtain and acceleration of rock glacier movement will be highlighted. Please rename the periods.

Page 510: This figure is confusing and overloaded with information. If direction of movement is constant it is not necessary to visualize it. Snow cover and zero-curtain show different ranges due to the use off all iButton data or only iButton data next to the GPS. This different use is confusing. Exclude the iButton numbers in the figure to enhance the clarity of the figure. Try to reduce the information to highlight the data which supports your argument.

Interactive comment on Earth Surf. Dynam. Discuss., 3, 459, 2015.