The Cryosphere Discussions

The Cryosphere Discuss., referee comment RC3
https://doi.org/10.5194/tc-2021-77-RC3, 2021

Comment on tc-2021-77

Anonymous Referee #3

Referee comment on "Multi-decadal (1953 – 2017) rock glacier kinematics analysed by high-resolution topographic data in the Upper Kauner Valley, Austria" by Fabian Fleischer et al., The Cryosphere Discuss., https://doi.org/10.5194/tc-2021-77-RC3, 2021

First of all, my apologies for this late review.

The paper is one of the first publication comparing the evolution of rock glacier kinematics for a set of landforms located in a single catchment area over a period of more than 60 years. The analysis is mostly based on historical aerial photographs and more recent airborne laser scanning data made available by the authors team. It permits to capture the evolution of rock glacier kinematics at roughly at a decadal time step.

This is a very interesting paper suffering however from several weaknesses, which I strongly recommend to improve in order to consider it for publication. The paper is relatively long and needs to be significantly shorten, either via the text content or the concision of some sentences or paragraphs. Any repetition must be avoided. I agree that this is a difficult exercise. The content of the illustration is mostly excellent, but usually much too small, what is deserving the paper. Some very important results are lost in large figures (e.g. evolution of the velocity flow field) and must be highlighted. Maybe some additional figures are needed.

The structure of the paper must be revised. The description of all rock glaciers, including their spatial flow pattern and connection to upslope unit must come in entrance. It helps the eventual splitting of some rock glaciers in distinct sub-areas to be envisaged. Then the results are presented. Finally a distinct discussion section must come. At present results and discussion are mixed. The discussion must avoid to be too hypothetical.

The methodology to calculate the rock glacier flow rate (single value) is unclear. It looks to be a mean of all parts of the rock glacier where any data is available, whatever the kinematic behavior. What is the sense of doing so ? Marginal areas, not moving homogeneously with the main rock glacier body, should not be taken in consideration. In addition, for some rock glaciers, it looks that calculating a mean velocity for the entire landform has no sense regarding the heterogeneity of the kinematic behavior over both space and time. Separating some rock glaciers in two or several kinematic sub-aeras could provide results (and conclusions) differing from the current ones.

The “3D displacement” is not one, meaning it is not a displacement in xyz coordinates, but an inadequate terminology to define somehow a vertical movement only, but not exactly. What is the interest of applying such an approach (movement normal to the surface)?

Both abstract and conclusions must be revised accordingly. They have not been reviewed, because they may change after having adapted the analysis procedure.

Since about L500, I have not performed an in-depth review.

The additional references indicated in my review are suggestions only.

The location of all rock glaciers must be provided.

Detailed comments :

Title : I guess it is more the multi-decadal kinematics of the rock glacier which is analyzed and not the morphodynamics

L14 : nine or eight ? Weird statement.

L33: "or pure ice". To be avoided. This would be a debris-covered glacier.

L38: "in part" can be omitted. Ice build-up within the ground might be the dominant process and the embedding of external (e.g. glacier, snowpatch) ice might be inexistent.

L42: Active layer is consisting of unconsolidated debris (not only "boulders")

L43: I don't see the causal relationship between the thermal regime driven by freeze-thaw cycles and the air-filled porosity of the active layer. There is also air and water advection. Are there some references to propose ?

L43: "These", but which ones ?

L46: No, the debris size is not smaller, but the proportion of coarser debris per volume is less.

L51: What does mean "long-term"?

L51-54: See also Cicoira et al. 2021 - A general theory of rock glacier creep…

L.54 : The shear zone is maximally a few meters thick.

L57ff: This is only valid in the European Alps.

L59. Velocity decrease since the 1990s. Which of the mentioned studies are reporting this ? I agree that some rock glaciers are decelerating, but the general trend is a significant continuation of the acceleration (e.g. PERMOS 2019 in the Swiss Alps… must not be very different in the Austrian Alps, a couple of tens kilometers eastward)

L70. No one of both mentioned references is showing this, but Delaloye et al. 2013 – Rapidly moving rock glaciers… - and Eriksen et al. 2018 - Recent Acceleration of a Rock Glacier Complex, Ádjet ...- are doing so. About destabilization, see also Marcer et al. 2019 - Evaluating the destabilization susceptibility of ...

L83 I would suggest "e.g." because there are other studies, sometimes difficult of being accessible. Maybe also Kummert et al., (under final review in ESPL) - Pluri-decadal evolution of rock glaciers surface velocity and its impact on sediment export rates towards high alpine torrents. See also Kääb et al. 2020 - Inventory, motion and acceleration of

rock glaciers... for an example outside of the Alps

L85. There is something wrong in this sentence

L89. Are the rock glaciers the same, so 8 of 9 ?

L94. Never begin a chapter with a figure. But besides, it would good to precise what are the used coordinates, what is the unit (m ?) and to add (or replace them by) lat/long coordinates.

L97. m. a.s.l.

L108. Anthropic influence on the rock glacier as well ? Which ones precisely ?

L110. Inactive rock glaciers. How was this classification done ? On which parameters ? Does it fit with the IPA Action Group Rock glacier inventories and kinematics definition ?

L113. Replace by something like : Finally, eight active rock glaciers representing different characteristics and conditions were investigated in detail regarding flow velocities and one more regarding vertical displacements

L121. The rock glacier moving downwards, it does not make sense to write that it reaches the “highest elevation”. Would it not be that it is located at the highest elevation range among the nine selected rock glaciers ?

L129. Is the layer below the ice rich permafrost body really ice free ? Because it is very difficult to conceive an active rock glacier which is only frozen in its upper part. Where is the shearing zone developing on the long term ?

L130 How could the rock glacier develop from a debris-covered glacier (to understand a glacier-to-debris-covered-glacier-to-rock glacier transition and embedding of glacier ice) and have only 40-60% ice content. Or is this value an average for the entire thickness, including the active layer and ice free subjacent sediments ?

151-153. There was a paper in 2008 (Delaloye et al. - Recent interannual variations of rock glacier creep in the European Alps) showing that there was an almost good similarity of interannual variations of rock glacier velocity over the entire European Alps, confirmed a decade later by Kellerer-Pirklbauer et al. (2018) at EUCOP - Interannual variability of rock glacier flow velocities in the European Alps. There was also a short communication at ICOP 2016 by Staub et al. - Rock glacier creep as a thermallyâ□□-driven phenomenon: A decade of inter-annual observations from the Swiss Alps - showing that the interannual variations are basically driven by shifts in mean ground surface temperature for a period of about 2.5 years. For sure this is also influencing the liquid water content within the permafrost.

153-155. The effects of liquid water availability and snow cover on rock glacier morphodynamics must be precised. Does it mean on-set and melt-out of the snow cover influencing the ground surface temperature or water equivalent of the snow pack which will melt out in spring/suemmer and directly influencing the rock glacier hydrology. Or both ?

Finally, the paper is focusing on decadal velocity changes. What relation to short-term (less than annual) changes ?

L276ff. This is not a 3D displacement, but something else (the surface change normal to the surface). But what is the interest of doing so and not calculating simply the vertical

displacement? What are the advantages on a rock glacier ?

L323 "showed good agreement". Please, provide values, figure or table.

L.326 Is the stable area so stable? In principle, bedrock is more suited to be stable than a debris slope.

L361-363. The introductive part of the sentence could be avoided.

L.367. A significant trend cannot be calculated over 11 years only. What is this data meaning ? Is it a difference between the mean of the two periods or a trend in 11 years as expressed in the two previous sentences.

L370. Precise what are these seasons, e.g. spring is MAM, summer JJA ?

L371-372 Conditions causing heat waves in future is not the purpose of this paper looking back into the past. The sentences could be removed.

L388. +152 mm in 65y. Is it a lot or not ? What is the annual value ?

L393-395. This sentence about precipitation predictions could be removed (not of interest for this paper)

L408. Snow melt trend: How much ? What are the starting dates and durations ?

L420. Provided max flow values are valid for a single period or as a mean for 1953 to 2017 ?

L421. How is the mean value spatially calculated ? How is delimitated the area taken into consideration for the calculation ? It looks from the figures that they comprise marginal areas (with velocity close to 0) to sectors moving much faster. Why not to split into sub-areas and perform a comparative temporal analysis ? See also the definition of moving areas within the IPA Action Group Rock glacier inventories and kinematics - https://www.unifr.ch/geo/geomorphology/en/research/ipa-action-group-rock-glacier/ - documents (kinematics as an optional attribute in rock glacier inventories)

L.421. A mean velocity of 3.5 cm/year is rising some questions about the accuracy and reliability of the results (in particular changes over time). Is such a low value significant ?

L424. One should note that the period 1997-2006 is marked by the peak of 2000-01 (described for instance by Ikeda et al. 2003 - Rapidly moving small rockglacier at the lower limit of the mountain permafrost belt… - and 2008 - Fast deformation of perennially frozen debris in a warm rock glacier…) and the famous 2003-04 peak (e.g. Delaloye et al. 2008), The period 2012-2017 is embedding the extreme peak of 2015 (e.g. Kellerer-Pirklbauer et al. 2018, PERMOS 2019), whereas the period 2006-2012 contains no peak of activity.

L431. 2006 is often a low, the period with the lowerst velocity recorded since 2000 (e.g. PERMOS). More generally the sentence is difficult to understand unambiguously.

L431-433. You could refer to Delaloye et al. 2008 for the low in 2006 in the European Alps and to PERMOS 2019 for the description of the entire period.

L434. RG 04 : A detailed spatial analysis (of the morphodynamics) is necessary, with the help of (time-lapsed) maps. It should be the same for the other rock glaciers.

L435-7. “Many studies mentioned periods of slight decrease or constant flow velocities following the strong acceleration in the 1990s”. Not really. This is mostly related to the deceleration drop in 2005-06. Read the related papers (already mentioned earlier), and in particular the PERMOS reports.

L437-9. There are various examples of recent deceleration (or absence of acceleration), particularly in the Swiss Alps (e.g. Aget – see PERMOS 2019 – or Dirru – see Delaloye et al. 2013 – Rapidly moving rock glaciers…- Cicoira et al. 2019 - Water controls the seasonal rhythm of rock glacier flow – and Kummert et al. (under final review in ESPL) Pluri-decadal evolution of rock glaciers surface velocity and its impact on sediment export rates towards high alpine torrents). Probably Val Sassa and Val dal’Acqua rock glaciers in the Swiss national park have done so, but on a longer term since the end of the LIA (e.g. when comparing Chaix 1923 - https://www.persee.fr/docAsPDF/globe_0398-3412_1923_num_62_1_5609.pdf - p.11 and more recent measurements ba the National parc - https://www.parcs.ch/snp/pdf_public/2016/33398_20160921_121930_Sassa_Aqua_Bericht_2012.pdf, the movement rate appears to have been divided by 20 along the last century) . There are also some examples in Roer’s PhD (2005). See Roer et al. 2005 - Rockglacier acceleration in the Turtmann valley (Swiss Alps): Probable controls

What is the mean velocity of RG04 ? This must be given. What is the uncertainty of the values.

L452 (and others around). Why to be so precise in the values, taking into account their uncertainty?

L.451-453. Increase of the 2012-2017 velocity in comparison to which period ? Note that a pluri-decadal acceleration by a factor 2 to 10 has been observed in the Swiss Alps as well (PERMOS 2019 or other related documentation), e.g. Gemmi/Furggentälti, Grosses Gufer, Tsarmine.

L.453-454. About rock glacier destabilization, see also Delaloye et al. 2013, Eriksen et al. 2018, Marcer et al. 2019 (already mentioned earlier in this review) and Marcer et al. 2020 - Investigating the slope failures at the Lou rock glacier front…

L.456-458. Agreed, but this must come in the discussion part and must be explain in details (provide maps/topographical profiles, etc.)

L.459. “The relative changes regarding the remaining rock glaciers ranges between 23.45% and 271.87%” is a huge difference ! 23% means about constant velocity and 271% an acceleration by a factor close to 4 ! This is not the same behavior.

L.459-460. I don’t understand the sense of the sentence… If you remove RG04, because it has a very low slope, then one could say that higher elevated rock glaciers (in the set) are steeper, but not that they change their relative flow velocity to a greater extent. If they do so, this is then because of their elevation (and eventually thermal state/structure) or steepness ?

L.463. What are these “topographic factors” ?

L.464. “On rock glaciers RG 01 and RG 08, higher flow velocities have been measured between 1953/54 and 1970/71 compared to the subsequent periods”. Be more precise. What are the subsequent periods ?

Agree... but there was then an increase since the 1990s.

L474-476. “These peaks might not be found on the other rock glaciers due to superimposing effects over the long time steps and indicate a slightly different sensitivity, response or response time of individual rock glaciers to intra-annual, inter-annual or multi-annual fluctuations in external forcing parameters.” Obscure sentence, which must be either precised, or removed.

L476. “the three investigated rock glaciers”. Which ones ? There were only two mentioned at the beginning of the paragraph

L474. “differing substantially in the other characteristics measured”. I do not understand.

L479. « higher error ». To be precised.

L481-2. “analyzed for altitudinal zones of 20 meter ». Why to do so ? And not comparing central to marginal zones, or else ?

L482-4. “rock glaciers do not move uniformly, but have zones with higher and lower flow velocities”. It must come at the beginning... and frame the velocity analysis of the previous sections.

L484-5. in the terminal section of the rock glacier ? In the front would mean in the frontal (talus) slope.

L489. Relative instead of « percentage »

L491-2. “This could point to the fact that from 2006 to 2017 higher elevated rock glaciers enter an unstable state as a reaction of changes in the external forcing”. This is a very tricky interpretation, which in any case must be moved to the discussion section.

L493. There is no lag to permafrost temperature. What temperature is talked about ?

L.494. “temperature limits or similar”. I do not understand.

L.494. Time lack or time lag ?

L500. Figure 5. Great figure… if made larger. This is obvious here that most rock glaciers are not moving uniformly both in space and time. The multi-decadal kinematic analysis must imperatively be conducted on rock glacier sub-areas separately.

Unit of the color scale ?

L.501. Section 4.4 is mostly an hypothetical discussion, not results.

L579. Figure 7. Never start a chapter with a figure. Moreover, I don't understand what is this 3D displacement. Is it the vertical shift at fixed locations ?

L582. “0.031”. Unit ? How is such a value calculated ? What is then its meaning for the rock glacier geometry change ?

L592. This is not a mass balance, as the value looks not to be computed over the entire landform, which is also changing in geometry.

L608. Figure 8. How is this calculated ? How to take into account the geometry change ? The quality of the figure is poor (labels are much too large for instance).

L614-5. This is a setting, not a result. This should come before any kinematic (or

morphodynamic) analysis. In addition, the aspect is for sure very different as well. What about the connection to the upslope unit ?

L616. “These changes are mostly spatially clustered, but in some cases they also show a clear temporal clustering”. I guess, this is what is explained in the next paragraphs? If not, please do so.

L.618. “Overall, the picture already described for the general trends is confirmed.” That is.. ? What is this picture ? What are the general trends ?

L620 (and elsewhere). Avoid all "clear" and "when looking"... You have to show/express for the reader what is so “clear” “when looking”, but not let him figure out.

L621. “Therefore, the characteristic topography for rock glaciers is formed”. I do not understand.

L622. “or the rock glacier advances”. It does. It has been shown before. But how is this scattering looking like ?

L622. « changes in activity ». Activity in what ? A vertical displacement is in particular the sum of the downslope movement of the rock glacier, the strain pattern (compression/extension), aggradation/melt of excess ice. If the flow rate of the rock glacier is increasing, the related component of the vertical movement is increasing proportionally.

L625. “inactive”. The activity must be related to the flow rate, not the vertical movement.

L627. “show hardly any 3D displacements » Is it not a question of scale ? More generally, what about the uncertainty ?

L628. Where to look at on the figure ?

L628. “Here”. Where ?

L629. What are these active and inactive areas ? I guess the terminology is inappropriate.

L629. “eleveation dependency”. Absolute or relative to the rock glacier extent?

"Looking" at the figures, it becomes obvious that aggradation has frequently occurred at the front, whereas subsidence is systematic in the rooting zone, no ?

L632. “show very clear activity in subsidence”. How much, please ?

L.635ff. Figure ? Where to see that ? Could it be else (than what has been observed) ? How is a null or a positive balance possible ? There should be a feeding of the rock glacier, which is equaling or exceeding the melt of excess ice at the front. For most rock glaciers, it cannot be reached because the motion rate is too fast (should be only a couple of cm/year maximally for most landforms) or there is no connection with any active feeding mechanism (for all glacier forefield-connected rock glaciers or when a small glacier occupied the rock glacier rooting zone during the Little Ice Age, what should be the case for most rock glaciers of concern by this study).

The methodology to calculate the volume balance must be explained, as well as its limitations and uncertainties.

A volume balance cannot be calculated for a rock glacier unit, which is not entirely

covered by the data.

L637-8. Provide figure.

L650. Figure 9. The figure is very interesting, but too complicated, too small, and almost impossible to read

L657. Provide illustration, map, figure.

L660. What about local loading (by displaced debris) ?

L664. Provide values !

L665. But most rock glaciers in the European Alps accelerated since the 1990s ! Why to state here specifically that "a strong increase in flow velocity was measured since 1997, which makes a delayed reaction of the rock glacier to the road construction 17 years before very likely". This is tricky and even false (i.e. no specific reaction).

L.667. "It is known". Add reference(s)

L667. "both factors". Which factors ?

L669. Slope, altitude and ice occurrence are not an internal forcing. They are almost not changing over time. The ice/water content ratio does it.

L669. "It is evident". ???

L690. Thermokarst lakes "become a more common feature on rock glaciers due to warming and degradation of permafrost ». But there are not so frequent ! And only where massive (glacier) ice is embedded in the rock glacier.

L.693. "shifted its location". Or evolved in size and location consecutively to rapid ice melt at its margins.

L705ff. This section must be heavily synthetized. See also comments on vertical movement in 4.x.x. Has not been reviewed, because the 3D displacement is somehow an obscure concept to me in this paper.

Figure 10 looks very interesting, whereas it should be adapted to rock glacier sub-areas. The insert in the upper right is not fully necessary.

Table A1:

Elevation: I've tried to identify the rock glaciers on Google Earth. I don't know how these elevations have been determined, what do they represent. In particular, the max elevation appears to be often exaggerated.

Connection to the upslope unit : Reference and abbreviations ?

RG 01 : I would say GFC for the main unit.

RG 03: GFC. There is no glacier in connection with the rock glacier at present.

RG 04: GFC. There is no glacier in connection with the rock glacier at present.

RG 05: Not sure about the site. The rock glacier I guess is RG-05 is TC, but maybe it is

another one.

RG 06: But for sure with a glacier in the rooting zone during LIA, as attested by the thermokarst lake development in probably glacier ice embedded into the rock glacier.

RG 09: GFC. Why TC ?

Connection to the upslope unit and area covered by 1850 glacier extent : These two characteristics show that the rock glaciers cannot be treated all in the same way. This is extremely important.