Earth Surf. Dynam. Discuss.,
https://doi.org/10.5194/esurf-2018-21-AC1, 2018

Earth Surface Dynamics Discussions Open Access EGU

Interactive comment on "Development of glacial lakes and evaluation of related outburst hazard at Adygine glacier complex, Northern Tien Shan" *by* Kristyna Falatkova et al.

Kristyna Falatkova et al.

falatkok@natur.cuni.cz

Received and published: 22 November 2018

We thank both reviewers for providing valuable feedback on the original version of this manuscript. The referees' comments are marked with 'RC1'/'RC3' (Referee #1, Referee #3), our responses are indicated with 'AC'. Comments by referee #1 are grouped into general comments (A) and specific comments (B) that were embedded in the text. Page and line numbers in the (B) section refer to the original version of the manuscript. The manuscript with marked changes is attached in Supplements.

Referee #1 W. Haeberli

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Discussion paper

A) General comments

RC1: Geomorphology: The region under investigation is permafrost and rock-glacier country with numerous small to large landforms reflecting viscous creep of ice-rich frozen material. The corresponding modern scientific literature should be consulted and mentioned in order to understand the phenomena and the corresponding environmental conditions.

AC: The proglacial area is indeed a very complicated structure consisting of several landforms of varying age. It has been simplified e.g. in the paper of Erokhin et al. (2017) where most of the area is marked as 'stagnant ice' and the frontal part of the moraine complex is referred to as a 'rock glacier'. Shatravin (2000) determined by carbon dating several moraine generations just within the main body where the thermokarst lakes are located. Therefore, we decided to use the term 'moraine complex' and further explain its structure in the section Study site.

RC1: Glacier-permafrost relations/interactions: The polythermal structure in glacier is correctly mentioned in the text but should be documented with measured data or at least be discussed in comparison with, for instance, better-known polythermal glaciers in Tien Shan, in Svalbard or in the Alps.

AC: We added two references to the text – one is by N. V. Kovalenko et al. (2014; unfortunately, it is published in Russian only) and it involves results of GPR survey on Adygine glacier confirming its polythermal structure. The second reference is to a paper by D. A. Petrakov et al. (2014; in English) and it describes the same methods applied on Sary-Tor glacier, situated in Ak-Shiirak Massif, Tien Shan, also proving its polythermal structure.

RC1: Geophysical soundings: The corresponding sounding results should not only be mentioned but shown: what were the measured specific resistivity values and their distribution patterns at depth; how were the results interpreted and how do they compare with the many investigations in other cold mountain ranges? Where were the mentioned radio-echo soundings measured? What center frequency was used?

AC: We incorporated the geophysical sounding in the manuscript's methods (Section 2.2) and also added the resulting profiles and their location (Fig. 1) to support the description of lakes' dam structure.

RC1: How does the glacier bed look like? Are there overdeepenings where future lakes may form, will the expansion of lake 3 continue and how large could this lake become? Numerical models exist to calculate glacier-bed topographies and corresponding glacier-bed overdeepenings. Corresponding studies have been carried out over large regions (Alps, Peru, Himalaya/Karakoram, etc.) and should be mentioned. The results of such model calculations could be compared to the results of the radio-echo soundings.

AC: The potential overdeepenings where future lakes may form are depicted in the Section 3.3, Figure 7. This is supported by a topography of glacier bed based on GPR data, which was added to Appendices, a notice was inserted in the respective section. We do not intend to carry out numerical modelling of the glacier bed to compare with the sounding results (although it would be interesting), that is beyond the scope of this paper. However, we added a section about numerical models for calculating glacier bed topography to discussion. Lake 3 is not expected to grow to very large dimensions as there is a rock outcrop situated south of the lake, currently around 50 m from the lake shoreline. The lake will probably expand to south-east direction, we estimate that its volume may reach 2-3 times the current value (i.e. 0.2-0.3 mil. m3).

RC1: Future scenarios: What exactly is the relation of this part of the study to the primary subject of the paper (lakes, hazards)?

AC: We explained our motivation for incorporating past and future site evolution in the introduction section.

RC1: Realistic scenarios can also be estimated using simple extrapolation techniques.

Degree-day models are well established, empirical- pragmatic-useful rather than sophisticated approaches for calculating future glacier scenarios.

AC: The GERM model, which is used in this study, is based on a degree-day approach and thus rather simple using only air temperature and precipitation as driving data. However, it needs to downscale air temperature and precipitation from the large scale resolution of climate models.

RC1: What is the reason for the strong inter-annual variability of mass balances calculated for the time period 2020-2030?

AC: The statement on the high inter-annual variability was removed as only filtered values are shown, which does not allow to identify single years. For the period 2020-2030, variability of mass balances is not particularly high. We reworked and rephrased the entire paragraph describing results shown in Figure 6.

RC1: Why were point mass balances on the glacier measured parallel instead of perpendicular (elevation profile, mass balance gradient) to the ice margin?

AC: The main goal of the 2007 mass balance measurement was to test the method and setting the points near the terminus was favorable given the conditions. However, the following year the measurement was found rather unsuccessful and so the point network was not extended. We omitted this part from the manuscript (please, see the specific comment P10L17).

RC1: Hazard assessment: The authors should consult the GAPHAZ technical guidance document on hazard assessment concerning glaciers and permafrost in mountain regions (http://gaphaz.org/), the work of ICIMOD about dangerous lakes and also make themselves familiar with the extensive work on hazard assessments in connection with lakes in Peru by their university colleagues at Prague (Emmer, Vilímek, etc.).

AC: We thank the reviewer for notice on GAPHAZ technical guidance document, it involves a comprehensive summary approach that can serve as a basis for regional hazard assessment strategies. We are familiar with the work of ICIMOD on identifying potentially dangerous glacial lakes, the material includes many valid points and numerous relevant parameters. Our aim was to balance number of parameters that are important for the studied region and procedure‘s austerity to ensure feasibility of such assessment under the given conditions. We are, of course, aware of the work of our colleagues from the university. The regional specifics of glacial lakes in Cordillera Blanca do not correspond with the situation in northern Tien Shan, e.g. in terms of the most common lake (dam) type, outburst trigger, or presence of buried ice in the dam; that is why we would not be satisfied with simple adopting an assessment. We acknowledge the mentioned scientific works and will mention them in the manuscript's discussion.

RC1: English language: The English needs smoothing in places.

AC: The original version of the manuscript was proofread by an English native speaker, we plan to have the final version checked again as soon as it is approved.

B) Specific comments

RC1: P1L1: Some of these lakes are ponds rather than lakes. Such water bodies could also be called "periglacial“ or "proglacial“.

AC: Accepted, changed to ‘proglacial lakes‘.

RC1: P1L11: . . . or under the influence of impacts.

AC: Sentence amended.

RC1: P1L16: How is this related to hazards?

AC: Sentence corrected (inaccurate expression). It was meant to refer to the name of the model used (Glacier evolution runoff model). Nevertheless, the changes in glacier runoff have a certain impact on lake outburst hazard (provided such lake is fed by glacier meltwater). In case a lake has only subsurface drainage, its hydrological balance is an essential factor influencing lake‘s stability (the outburst of Teztor lake, discussed in the paper, can serve as an example).

RC1: P2L10: Define and use the term ‘thermokarst’

AC: The term thermokarst used in connection to thawing of ice-rich permafrost. Sentence amended.

RC1: P2L17: Add references.

AC: Sentence omitted.

RC1: P2L19: Refer to GAPHAZ Technical Guidance Document.

AC: We added reference to the GAPHAZ document.

RC1: P2L21: Add references or eliminate statement.

AC: Sentence amended.

RC1: P3L9: Provide a brief overview concerning the structure of the paper here.

AC: Introduction text amended, overview of the paper’s structure incorporated in the penultimate paragraph.

RC1: P3L19: This type of reference is problematic. Better show the statistics or eliminate the sentence.

AC: Problematic reference replaced, sentence amended. There is a lot of data related to potentially dangerous glacial lakes obtained by field surveys of employees of Kyrgyz Ministry of Emergency Situations, however, such information is disclosed only partially in form of annual reports. We are aware of the difficult verifiability of such data, therefore, we try to limit their usage to minimum.

RC1: P3L22: Provide annual values (% per year) - for better comparability.

AC: Accepted. Total area change recalculated to % change per year for both periods.

RC1: P4L3: Again a problematic reference. Explain precisely what has been done and where the information is accessible.

AC: Please, see explanation P3L19. Further explanation added to the figure caption.

RC1: P6L2: Eliminate: The same statement follows below.

AC: Sentence omitted.

RC1: P6L29: Confusing - clarify.

AC: Text amended, clarified.

RC1: P6L30: Sufficient for what exactly?

AC: Text amended, clarified.

RC1: P7L3: Why exactly?

AC: Text amended, clarified.

RC1: P7L17: Hazard specialists know that - unnecessary to mention.

AC: Sentence omitted.

RC1: P8L2: Crack formation in ice depends on critical strain rates under extension.

AC: Sentence omitted.

RC1: P9L26: Correct is 2017.

AC: Corrected.

RC1: P10L14: When exactly is that - 2018?

AC: Phrase specified.

RC1: P10L17: Ice thickness change results from ablation and the (vertical) movement component. What exactly was measured?

AC: We measured both horizontal and vertical shift of the points on the glacier using geodetic station. However, after having a deeper look at the data we concluded it would be better we omitted the glacier thickness part completely, as we are not able to distinguish the ablation component reliably.

RC1: P11L3: Numbering the lakes again here would be helpful. Mark rock outcrop with an arrow or so.

AC: Accepted. Lakes‘ numbers added, rock outcrop marked.

RC1: P11L10: This is an unusual term: rock glaciers are commonly called to be active - inactive - relict. Read the rich modern scientific literature about rock glaciers, mention the phenomenon earlier in the text and deal with it in an adequate way - it is an important part in the landscape and plays a key role in the glacier-permafrost interactions of the region.

AC: The landform‘s description extended (section 2.1 Study area). Please, see comment in the Geomorphology section (General comments).

RC1: P12L4: Be precise: when, where, how much, what were the effects?

AC: Text clarified. Changes in the lake’s basin morphometry are continuous, yet of a small scale (at most a few tens of m3 of material sliding from the basin walls per year). This backwasting takes place mainly in the northern and north-eastern part of the basin, here the changes are recognizable even by visual inspection only. Our aim was to highlight the fact, that these changes occur constantly and are documenting melting of buried ice adjacent to lake basin.

RC1: P12L13: Again: be precise: did the lake level change or the lake bottom?

AC: Text clarified. The statement is related to the previous sentence, both lake area and depth decreased due to siltation.

RC1: P12L15: This sounds interesting - please show the sounding results and discuss them in detail with reference to comparable soundings published in the literature.

AC: The geophysical sounding profiles and their location were included in the manuscript, similar case mentioned in discussion.

RC1: P12L29: What exactly is the evidence for that? Is there permafrost forming now as a consequence of glacier retreat?

AC: Text clarified. Exposed buried ice lenses were observed in the lake's vicinity.

RC1: P13L15: Which lakes - comments?

AC: Comment added to the figure caption.

RC1: P14L9: Better "scenarios“?

AC: Accepted.

RC1: P15L10: In glacier-bed overdeepenings determined by radar soundings? Make correct reference to other studies simulating sites of possible future lake formation. Show bed topography without ice.

AC: Text amended, clarified. Glacier bed topography added to Appendix, numerical modeling studies added to discussion.

RC1: P16L5: What causes the large future (!) inter-annual variabilities in runoff?

AC: See the comment above. This was a misinterpretation in the first version of our paper. Inter-annual variability of glacier mass balance and also discharge will not be that significant in the future, according to our simulations.

RC1: P18L14: This part (=Discussion) is far too long and not always to the subject of the paper. Shorten and focus.

AC: The discussion section was shortened, some parts were amended. We omitted the part on glacier retreat as it is not an essential part of the paper. Instead, we added a section about modelling of glacier bed overdeepenings.

RC1: P19L3: At glacier terminus?

AC: This part of discussion was omitted.

RC1: P20L20: This seems to be a peak discharge? Where would this have been reached - far from the glacier? Better provide an estimate of the volume.

AC: Text clarified. The peak discharge was estimated at 350 m3 s-1 at the junction of Testor Valley and Adygine Valley, i.e. about 3 km from the glacier. The estimated volume of debris deposited at the Adygine fan (where it reaches the main Ala Archa Valley) was 200 000 m3.

RC1: P21L18: 2017.

AC: Corrected.

RC1: P22L9: And by 2100? 2050 is not the end of the development.

AC: Yes, that is definitely true. However, with respect to a hazard assessment, a time period until 2050 is already long in the future for practitioners. We argue, that the general line of development of glacier development and related potential for lake development is well captured by the period until 2050, clearly showing the development of future hazard. Additionally, going beyond 2050 would make a more detailed sounding of glacier bed topography (by e.g. GPR) necessary.

Referee #3 P. Thakur

RC3: The area, length and depth of given glacier lakes are based on ground based surveys and satellite images, but no uncertainty or accuracy of these measurements is given in the text?

AC: Accepted. More information on accuracy added to the section 2.2 Field mapping.

RC3: The climate change scenarios refer to old AR 3/4 time (A1B etc.), as now IPCC 5 report is also already over and CORDEX data (with RCPs 4.5/8.5 etc) can be used to get the latest climate change scenario or As per upcoming IPCC 6 AR, the temperature change of 1, 1.5 and 2.0 degree, along with precipitation change, can use used for future climate simulations, and its impact on glacier lake evolution.

AC: Thank you, we are aware of that. Though the SRES scenario data are meanwhile replaced by the representative concentration pathways (RCP) approach of IPCC (IPCC, 2013), the uncertainty ranges of future large scale temperature and precipitation fields (which are the input data for our mass balance model) from the global climate model simulations are in a similar order and main part of uncertainty will come from the further downscaling (which is limited because of sparse data availability of observed air temperature and precipitation series). We argue that for our purpose of assessment of future glacier extent, in particular for the future development of glacial lakes, these scenarios are sufficiently realistic.

RC3: The GPR profiles can be shown along two surveyed lines, A and B.

AC: Accepted. A figure with geophysical profiles and their location were added. The section 2. Data and methods was supplemented with additional information on the geophysical survey.

RC3: Final glacier lakes hazard map can be shown as a figure.

AC: We summarized the lakes‘ hazard in Table 5 and also showed the potential triggers of lakes‘ outburst in Figure 9.

Please also note the supplement to this comment:
https://www.earth-surf-dynam-discuss.net/esurf-2018-21/esurf-2018-21-AC1-supplement.pdf

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