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The Cryosphere Discussions

Interactive comment on "Review article: Inferring permafrost and permafrost thaw in the mountains of the Hindu Kush Himalaya region" *by* S. Gruber et al.

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Reply to comments made by Anonymous Referee #2 (doi:10.5194/tc-2016-104-RC2).

We thank Anonymous Referee #2 for their thorough review and constructive suggestions for improvement. These comments have been very useful. Referee comments shown as "RC:", author replies as "AR:". Only sections requiring a reply are reproduced.

RC: MAIN COMMENT 1. As reviewer#1 already pointed out there are large parts of textbook style text. I would say that the content on P.2 in the chapter "Principles governing...." is useful and important. Physical principles can and should be exchanged be-

tween regions while acknowledging that relative importance of processes may change. However, I think that particularly the chapter "Persistence and impacts of permafrost thaw in the HKH" draws too heavily on general permafrost research. The current text is a really nice summary of what can be expected based on known experience/knowledge but could be given more context by rooting in known events/ examples from the HKH in perhaps a more detailed case study style approach. Important topics/events could be GLOFS, landslides/rockfalls, engineering issues. The authors touch on all these topics but in a rather 'high level' manner. These more detailed "case-studies" could also be an opportunity for more figures in the manuscript, which I found quite sparse. I realize the challenge of providing a review over such a diverse area (as you state p7 l1-2) but still feel some more detailed examples would give the manuscript good grounding.

AR: Thank you for acknowledging the value of passages with textbook character in this manuscript. We agree that it would be beneficial to scaffold and illustrate Section "Persistence and impacts of permafrost thaw in the HKH" with case studies and images and have invested a lot of thought into this. At the same time, we would be speculating on the existence and role of permafrost in the absence of published studies (cf. reply to Anonymous Referee #2 with respect to inserting more images). Figure 2 is the best we thought we could do while making the uncertain character of permafrost estimates tangible via the model colors and the visible course-resolution grid: Part A refers to pastures (without having published evidence of the existence or role of permafrost at that location), Part B refers to engineering issues (roads in permafrost terrain) without having published evidence, Part C refers to the additional risk of GLOFs presented by large frozen summits over lakes as well as ground ice in dams without having to make a detailed argument at one location. We have now included photos in the new version of this figure.

At the end of this reply, we included another figure we produced but then decided not to use. This was because it selects two types of landscapes and thus possibly shapes the perception of impacts more restrictedly than what is useful. With this, we hope

to illustrate here that we are not lightly brushing this comment aside, but rather have chosen the current very lean form of illustration in the manuscript with great care.

RC: MAIN COMMENT 2. I think the chapter on "climate and climate change..." could be expanded as there is certainly a reasonable amount of work in this field in the HKH (as compared permafrost research) and several high elevation initiatives. Climate in the end plays a large part in controlling the distribution and evolution of permafrost and an expanded section would serve as a good starting point for "inferring permafrost". Here it could also be mentioned that the northerly side of the Hindu Kush (Afghanistan) experiences a unimodal precipitation pattern (winter, as shown in Fig1D) dominated by westerlies as effect of monsoon is largely blocked by southern edge of the Hindu-Kush in Pakistan. In this section there could also be an opportunity to discuss snowcover in more detail due to both a good observational record and its important controlling effect on ground temperatures.

AR: The chapter on climate and climate change has been significantly expanded based on this comment and the comments of F. Salerno. We also added: “In the far west of the HKH, a unimodal pattern of cyclonic winter precipitation can be found on the northern side of the Hindu Kush (Schiemann et al., 2008).” A new paragraph on snow cover has been inserted into Section “Climate and climate change in the HKH”.

RC: MAIN COMMENT 3. The climate change part of the climate chapter could be stronger as there is a good deal of literature on this topic that could be given coverage as this is central to inferring evolution of permafrost in different regions. Example being a discussion of the diverse effects expected in such a heterogeneous region as the HKH - how could relative changes in precip and temp play out with respect to permafrost in different regions?

AR: This section has been strongly expanded and this includes more information on observed climate change and its patterns (regional, elevation, season). As for the consequences in different regions, the mechanisms are explained in the text. Making re-

gional statements is difficult given the fact that differing landscape facets in one region already may show very different reactions. For this reason, a more general statement along these lines was inserted into Section “Persistence and impacts of permafrost thaw in the HKH”: “Climate change (air temperature, precipitation, cloudiness. . .) in the HKH exhibits diverse regional patterns as well as differing trends at high/low elevation or during differing seasons. As these changes are further overprinted by topography, the resulting effect on permafrost is likely to be spatially highly diverse as well.”

RC: MAIN COMMENT 4. Although a lot of research questions are presented in the final chapter "Perspectives", I think a useful contribution this paper could make would be to clearly identify and focus on key current knowledge gaps on this topic in the HKH and possible strategies to addressing them. In this context the authors mention simulation and remote sensing (c.f. "Perspectives") but a section on what’s needed in terms of ground-based measurements/ networks would be good and how this compliments remote methods by assessing model performance or calibrating RS algorithms.

AR: The clear identification of key knowledge gaps requires prioritizing some issues over others and thus attaching value to differing outcomes (e.g., scientific versus practical relevance or large engineering projects versus traditional livelihoods). Many of the rather diverse research questions presented have been developed by the authors and many others have been “. . .inspired by the outcomes of a group discussion during the International Symposium on Glaciology in High Mountain Asia, Kathmandu, Nepal, in March 2015.” (Acknowledgements). We feel that a prioritization may be too subjective and speculative to be useful here. We agree that a high-level description of ground-based measurements and networks would be very useful and, at the same time, we do not want to be too descriptive on its form or implementation We have changed a sentence in the beginning of the Perspective Section: “Long-term monitoring of ground temperature, ice content, and other variables at selected sites (cf., Vonder Mühll et al., 2008) will contribute to national and international programs and provide a basis for the evaluation of simulation and remote-sensing products.” and included a reference to

similar activity.

RC: MAIN COMMENT 5. As authors from ICIMOD are present on this paper it might be a good opportunity to see what scope for regional initiatives there are. What's going on currently in this topic (if anything) and what are the possibilities in the future?

AR: In our opinion, this would challenge the scope of a scientific article. For the context of this reply, ICIMOD has been exploring and preparing regional initiatives via its Permafrost pilot study (http://www.icimod.org/?q=11478) and held a corresponding Scoping Meeting in 2015 (http://www.icimod.org/?q=13932). Some initiatives are starting and interested parties should contact: Dorothea Stumm Senior Glaciologist and Permafrost Project Coordinator dorothea.stumm@icimod.org

RC: TECHNICAL COMMENT 1. p.3 l.6: "In combination, these effects can cause differences in mean annual ground temperature of more than 10 _C within a distance of less than one kilometer.": reference would be useful here.

AR: The statement can now be better traced based on three references given "(Gruber et al., 2004b; Gubler et al., 2011; Hasler et al., 2011b)".

RC: TECHNICAL COMMENT 2. I think some references from Bodo Bookhagen's precipitation work could be included in the climate section.

AR: Included Bookhagen and Burbank (2006, 2010).

RC: TECHNICAL COMMENT 3. p.6 l.30 additional measurements references - Ishikawa 2001, Regmi 2008 (you already have these elsewhere).

AR: The sentence specifically refers to ground temperature measurements. Ishikawa at al. (2001) report rock glacier distribution, air temperature and geophysics; Regmi (2008) reports rock glacier distribution.

RC: TECHNICAL COMMENT 4. p.9 l21-23 - awkward sentence, perhaps review.

AR: Restructured and shortened into: "In summary, permafrost thaw results in an in-

creased frequency and possibly in unexpected locations of mass movements, as well as in increased sediment loads available for further downstream transport."

RC: TECHNICAL COMMENT 5. p.12 l15-16; "or noticed" sounds odd, perhaps reconsider this sentence.

AR: Deleted: " – or noticed"

RC: TECHNICAL COMMENT 6. I'm missing Kaab et al 2005 - as an important mountain permafrost hazards reference.

AR: Yes, indeed. The hazard paragraph of section 'Persistence and impacts of permafrost thaw in the HKH' now finishes with: "Often, processes related to glaciers and to permafrost conspire in producing high-mountain hazards. These represent a continuous threat to human lives and infrastructure and related disasters can kill thousands of people at once and cause damage on the order of 100 million dollars per year, globally (Kääb et al., 2005)."

RC: TECHNICAL COMMENT 7. Figure 1: Hopefully this can be full page in final publication and perhaps consider adding country outlines (even if these are complex in places) in a subtle way to aid orientation. Glacier outlines are plotted on each subplot but only on legend of 1E I think - I found this slightly confusing at first. Perhaps this legend item should relate to the entire figure.

AR: Thank you, we agree on the glacier outlines with respect to the legend. We have changed the figure and hope it is now less confusing. Concerning country outlines: The figures already contain very much information, and including boundaries would make them even denser. We have considered adding them but decided against it, thereby also following ICIMOD's publication policy for this rather delicate issue. Names of countries are given in 1A, which we hope will be sufficient.

RC: TECHNICAL COMMENT 8. I think figure 2 would be enhanced if you could pairwise match the Google earth/model overlays to existing photos of each example you

give, even if its just a small sample of the landscape you show. This would give informative local context.

AR: Done.

Given that several additions were asked in terms of expanding the climate section, we hope that exceeding 100 references will be tolerated.

Figure 1: Possible impacts of permafrost exemplified in sample catchments: (A) Impacts on hydrology and water quality. 1) Drying near-surface soil caused by deepening active layer. 2) Drying of depressions and small creeks due to increasing deep percolation in catchment. 3) Increased soil moisture and discharge in small creeks due to meltwater release from ice-rich ground. 4) Increased solute availability through release from ground ice melt and leaching of newly permeable soil. 5) More base flow in larger streams and additional discharge from melt of old ground ice during and after hot summers. 6) Changed water chemistry in streams draining catchments with large permafrost extent. Vegetation will respond to changes in moisture and nutrient availability. This will likely results in large-scale reduction in vegetation density overprinted with local and transient greening. (B) Impacts on geohazards. 7) Large rock/ice fall or landslides with far reach. 8) Small rockfall. 9) Debris flows from thawing debris or remobilized rock fall deposits. 10) Lake outburst flood following impact of rock/ice fall. 11) Outburst flood following ground ice loss in lake dam. 12) Changes in stream geometry following increased sediment load. The environments and configurations for actual impacts may differ from the examples shown. Other impacts described in text. Images derived from Google Earth.

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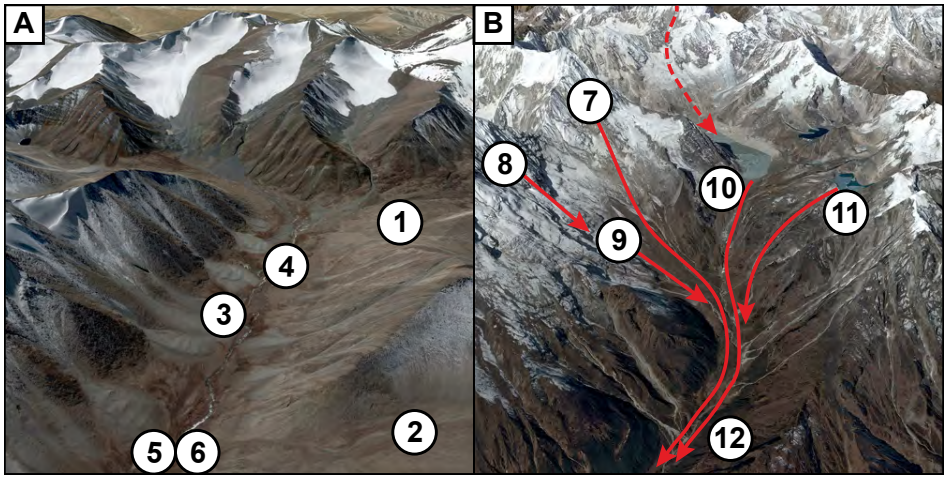

Fig. 1.