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Interactive comment on "Glacier change and glacial lake outburst flood risk in the Bolivian Andes" *by* Simon J. Cook et al.

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We thank Mauri Pelto for his insightful comments and questions about our manuscript. This provides us with an opportunity to elaborate on some points in our study. Taking each point in turn:

2-27: It's hard to quantify exactly what the level of GLOF risk is in this region. One of the points of our paper is to highlight that there is a risk, and that this risk has not been assessed before. Hoffmann & Wegenmann (2013) described the only documented GLOF in Bolivia, as far as we are aware, but that does not necessarily mean that it is the only GLOF that has occurred here. It is worth remembering that, for the most part, the people affected by such events live in rather remote communities. GLOF events may simply go undocumented. Last year, we travelled to Agua Blanca, in the

Apolobamba Region (Northern part of our study area), where we spoke to the village leader about the work we were doing there and this led him to recount a story from his father who had witnessed a GLOF event some years ago in a neighbouring valley. There is no documentation of this event, and it is hard to verify, but the point is clear: there may be other undocumented GLOFs that have taken place in Bolivia.

4-1: OK

4-27: I think this is a reasonable point. I suppose the issue is whether a lake that occupies a basin that has been carved out by a glacier or dammed by glacial sediment constitutes a 'glacial lake', and hence if it were to burst can be considered a 'glacial lake outburst flood'. I agree that the term 'GLOF' would normally be used for outbursts from ice-contact lakes or lakes that had formed 'recently' following deglaciation (whatever you take 'recent' to mean). I hope that most readers would appreciate what is meant when we use the term 'GLOF' in the context of our work in Bolivia.

5-1: Not necessarily. In Bolch et al.'s (2008) paper, the whole study region is classified according to slope, with the slopes of 45 deg or steeper representing the greatest mass movement risk. They aren't necessarily recently deglaciated. We just wanted to make the extra point here that recently deglaciated slopes can be particularly susceptible to mass movements.

5-28: Good idea. We have reworded.

6-3: No, not that I am aware of. In compiling data for an earlier study (Cook and Quincey, 2015), we generated a list of studies that had employed the lake volume-area relationship of Huggel et al. (2002). At the time of doing that (c. 2014-15) there were some studies that borrowed the relationship to estimate lake volume for glacial lakes in the high mountains of Asia (Nepal, Tien Shan, etc), but none for the Andes. We have subsequently removed the equation from Huggel et al. (2002) in response to comments by Reviewer 1 (Wilfried Haeberli).

7-10: I suppose the extent to which a table vs. a figure best illustrates a trend in data is debateable. But I would like to emphasise a key issue here – we are not only making the point that ice-contact lakes have declined over time, but also that the pattern of change over time has been rather chaotic. I would argue that this is best illustrated with a figure because it is more immediately comprehensible.

7-17: As with the previous point, I would argue instead that the graph shows the complexities in lake change over time more effectively than a table of numbers, which would be harder to digest. I take the point that a Table would be useful in terms of information on lake type, but this is perhaps most relevant for potentially dangerous lakes – for these lakes, information on moraine-, rock-dammed lakes, etc, is provided in Table 2.

8-10: No, we did not determine the number of dangerous lakes for other years. Our reasoning for this is that, although understanding how the GLOF risk has evolved over time would certainly be interesting, the more pressing issue is to determine which of the lakes from the most recent dataset would be most likely to represent a GLOF risk. This seemed to us to be the more urgent question, and hence the one that should be given over to journal page space. This is something we could follow up on though – thanks for the thought.

9-26: Thanks very much. This is useful to know. Actually, we added some new material here in response to Reviewer 2. Soruco et al. (2015) found that reduced glacier area had been compensated by increased melt rates.

9-29: This is an important point, and I'm not sure that there is a clear answer in the literature about how important (or otherwise) glacial meltwater is for water supply in Bolivia (although see previous point and reference). One of the purposes of our paper is to stimulate further interest in this issue. Some studies have suggested that up to 40% of the water supply in La Paz is derived from glacial meltwater during the dry season (e.g. Vergara et al., 2007), whilst more recent estimates indicate a lower dependency of $\sim$15% (Soruco et al., 2015). Likewise, some studies have indicated

significant impacts of glacier decline on rural populations (e.g. Oxfam, 2009), whilst others have revealed that glacier change is not perhaps the most dominant force driving people away from rural locations (Kaenzig, 2015). Much of this information is already stated in the manuscript, and hopefully there is enough here to stimulate researchers to look more closely at this issue. We also made some changes relevant to this point in response to Reviewer 2.

10-26: This serves as a reason for keeping the information on ice-contact lake change as a figure rather than a Table (as discussed above). Whilst the headline is that there has been a reduction in the number of ice-contact lakes, the trend is rather chaotic over time. If the glaciers continue to shrink, then their perimeter too shrinks, and the potential for there to be ice-contact lakes reduces. Hence, I would guess that there will continue to be an overall reduction in ice-contact lakes, but that there could be a lot of variability along the way. Much will depend on what is revealed by glacier recession – there could be large overdeepenings under these glaciers that will become sites of lake development in the future. Studies along the lines of Frey et al. (2010) and Linsbauer et al. (2016), which attempt to derive glacier bed topographies, would be very welcome in this regard.

11-7 to 14: The ultimate end point would be that all glaciers disappear and hence that all potential for GLOFs disappears too - notwithstanding issues around using GLOF terminology in deglaciated regions as discussed above. The question of whether deglaciating landscapes are becoming more dangerous because of GLOF events and other hazards, or whether they become less hazardous over time because there is less area within which these hazards can take place is interesting. The record of GLOFs in Bolivia is also very poor, so it's hard to say what the longer term trend is. These issues vary on a site-by-site basis too. For example, if you take the example of Laguna Glaciar (Lake 23 in our inventory – see Supplementary material), this lake has got bigger and bigger through the course of the study period, and so arguably has become more dangerous as more of the overdeepening has been exposed. We also considered a similar

point made by Reviewer 1 (Wilfried Haeberli).

12-5: Yes, interesting point, and one that we encountered when writing Cook and Quincey (2015). From that study, “As yet, there is no reliable technique available for measuring lake bathymetry or volume from satellite imagery where turbidity precludes the derivation of reflectance–depth relationships (e.g. Box and Ski, 2007)”. Recent work by Pope et al. (2016) developed techniques for estimating supraglacial lake depths (http://www.the-cryosphere.net/10/15/2016/tc-10-15-2016.pdf), but obviously, these are not affected to the same degree by turbidity. Lake bathymetry is a crucial measure for GLOF hazard assessments, but remains a labour-intensive, field-based measurement.

12-25: We have re-worded this, but we maintain that the lack of reporting of GLOFs in Bolivia does not necessarily mean that they haven’t occurred, nor that they won’t be more frequent in the future. Reviewer 1 (Wilfried Haeberli) makes a comment on our paper that also suggests that deglaciating environments could become more hazardous.

Figure 3: Interesting – good spot. We traced our Peru-Bolivia border from the National Geographic basemap layer in ArcGIS. We double-checked our mapping, and it is correct. However, we have seen maps (e.g. GoogleEarth) where the border is drawn slightly to the east.

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