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***Interactive comment on “Glacial areas, lake areas,  
and snowlines from 1975 to 2012: status of the  
Cordillera Vilcanota, including the Quelccaya Ice  
Cap, northern central Andes, Peru” by M.  
N. Hanshaw and B. Bookhagen***

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General comments

Hanshaw and Bookhagen present a study on changes in glacier areas and lakes in the Cordillera Vilcanota region, southern Peru. They processed an impressive number of satellite images, mostly Landsat and Aster, which allows them to map in detail the respective changes, including details on intra-annual changes. The glacier area changes they found basically correspond to the results from the recent TC paper Salz-

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mann et al., 2013 for the Cordillera Vilcanota and Quelccaya Ice Cap, but also provide additional detail. Novel are the results on the lake area changes, which is important in terms of water resources for the region. Changes indicate that depending on their connection to glaciers lake areas have increased or decreased over the past years and decades. In my view, the main problem with the current manuscript are potential glacier mapping errors and uncertainties. While the authors do a good job on providing error margins for mapping results, they do not account for likely problems related to identification of glacier areas, especially due to snow cover, as far as I can see. I strongly suspect that the rapid increases in glacier area, e.g. for 2002 for Cordillera Vilcanota or 2011 for Quelccaya Ice Cap a 30% increase in glacier areas in only 0.5 year is glacio-dynamically virtually impossible (except may be for a surge which was not the case for Quelccaya). Or for the Cordillera Vilcanota, variations in glacier area from  $\sim 370$  km<sup>2</sup> in 1997/98 to  $<300$  km<sup>2</sup> in  $\sim 1$  yr and back to  $\sim 370$  km<sup>2</sup> in 2000 must be related to erroneously mapping areas with snow and classify them as glacier area. In the Discussion I recommend to elaborate on the novel aspects of lake variations for this region which has not previously been studied by other researchers. For instance, the connection of lakes to glaciers could be analyzed in further detail, and what processes could be related to the connection or disconnection of lakes and their variations over time. Is groundwater in-/out-flow a possible but probably hardly quantifiable process? It should also be considered that at least some of these lakes (most prominently Lake Sibinacocha) are used for hydropower generation and are therefore managed which can imply significant non-natural variations in lake levels (and area). Furthermore I think the paper provides too much detail in several sections, including the Discussion and Figure captions. I recommend to shorten the text.

In summary, I think the study has many aspects that are an important contribution to the current debate on glaciers and climate in Southern Peru where we currently still have limited understanding. Personally, I think the research on lake changes is most promising and novel and would deserve more research, in this and follow-up studies. For this paper I mainly recommend to try to further analyze and reflect on the possible

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drivers of lake changes, with glacier melt water being one of the important candidates, but a more complete picture would be interesting. The likely glacier area mapping errors must be corrected. This implies going back to the satellite images, re-analyze the critical ones, and possibly exclude those from the study which do not allow a correct assessment of glacier areas due to snow cover. As a word of caution, the publication of such results can cause significant confusion on a political (and societal) level. In Peru, for instance, people and government institutions are very interested and sensitive to such new results, and I must admit that I am not overly happy that these results that most likely bear important errors are published in TCD. I also recommend the authors to contact glaciologists working in tropical regions to discuss causes of glacier changes and effects of snow cover.

## Specific comments

p. 575: generally I do not recommend to play polar vs. tropical glaciers, I see no reason why they need to be compared or compete. I'm not really sure whether we can say that mass balance studies are extremely rare in this region (line 23), there is quite a number of studies available.

p-578: lines 3-5 but ablation is higher in the humid season than in the dry (cold) season. Temperatures are not constant year-round at this latitude. Line 6: consider that El Niño has limited influence in this region, the Amazon region is more important as a driver of humidity.

p. 580, line 25: This sounds like the study on the lakes is only a by-product of glacier mapping. I think it deserves a prominent place.

p. 582, lines 3-5: see also the paper Paul et al: On the accuracy of glacier outlines derived from remote sensing data.

p. 583, line 12: which ablation season? Do you mean the dry/cold season?

p. 584: it is not clear to me why apparently several images with significant snow cover

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classified as glacier area were analyzed if there is a method applied that detects the snow pixels. Where did an error occur? Method-wise or interpretation-wise?

Page 585: for the error equation an explanation of the equation and especially the number should be given.

Page 586, line 4: This comparison of decline rates is not meaningful. CV has a much larger area than QIC. If a comparison is made, then the glacier area should be normalized.

Page 587, first paragraph: the different decline rates for the same time period are confusing. I suggest to report only one decline rate in the text, and the rest in the table. Lines 12-19: I think it is worthwhile mentioning that Lake Sibinacocha formed in an topographic overdeepening left by glacier retreat during the Holocene while Qori Kalis Lake is a product of glacier retreat since the Little Ice Age. Lines 25-27: would be interesting to know whether the increase in area of Lake Sibinacocha is due to natural processes or due to lake management (for hydropower purposes)

Page 592: section 6.1.2. I agree that it is a problem that different studies used different extents of the CV region. A good reference for distinction of glacier basins is the Peruvian glacier inventory from 1989 (Ames, 1989) based on air photos from 1962-1970.

Page 596, line 2: permafrost is not a substantial water source here.

Page 597, lines 17-24: I'm wondering whether a some sort of hazard assessment should be made before making a statement that several of these lakes are dangerous. At least it should be mentioned on what basis this statement is made (historical events in other parts of Peru is not sufficient).

Figures:

In general I like the figures, as they are high quality and contain interesting information. I think, however, that the 24 figures is at the upper limit, and authors could consider to remove some of the figures. Candidates could be 13, 19, 22.

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Figure 12: Glacier regions 6, 8, 9, 10 are not included in Salzmann et al. 2013. G8 belongs to Cordillera Carabaya, I believe.

Zurich, 10 April 2013, Christian Huggel

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Interactive comment on The Cryosphere Discuss., 7, 573, 2013.

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7, C297–C301, 2013

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