

## ***Interactive comment on “Glacier melting and precipitation trends detected by surface area changes in Himalayan ponds” by F. Salerno et al.***

**P. Buri (Referee)**

buri@ifu.baug.ethz.ch

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Summary:

The authors investigate surface area changes of ponds over a period of fifty years (1963-2013) in a high-elevation Himalayan region using a topographic map (1963) as well as various Landsat satellite images (1992-2013). They relate the observed area changes to precipitation, temperature and glacier melt trends. The meteorological dataset used in this study is based both on a high-elevation weather station in the catchment (operating since the mid 1990's) and regional gridded and reanalysis data used to extend the record back in time to the 1960's, for which the authors have the first inventory of ponds (1963). The authors find a high sensitivity of ponds to a change in climate and try to use water bodies as proxies to detect behavior of precipitation and

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glacier melt.

General comments:

The paper is generally well written and structured in a clear way. However, I have some major issues regarding the methods applied that question partly your conclusions. In addressing these points (mentioned below) the paper may could be improved considerably and your original dataset and conclusions could be presented in a concise way and more scientific value could be added to your work. You relate changes in the climate to changes in the lake areas, as meteorological parameters are often represented in a highly limited way in remote and high-elevation regions. This is an interesting but also novel concept and addresses a relevant scientific question within the scope of the journal, as e.g. temperature and precipitation build the base for many research questions in various fields of the cryosphere. However, it is questionable if the approach used in this study can be used to reconstruct changes in the climate as lakes respond to many inputs as say yourself, so pond area is only an integrated variable (see point 4 below). The provided references appropriate and referenced in a helpful way in the text. At least one new study (published after submission of this manuscript, see major point 1 below) should be added. The statistical analysis and the results, respectively, are not fully clear everywhere in the manuscript (e.g. Table 3, see point 3 below). The methods description is rather complete, with methods explained either directly in the text or by referring the reader to further literature. They major issues to address are listed here:

Major issues:

1) Satellite images used for the analysis:

First, you need to indicate in the main text, including abstract, which satellite images you use (not only in the supplement) as this is a key information. You use Landsat (from Table 2 of supplement) and there might be an issue of too coarse resolution with Landsat. Pond area strongly depends on the accuracy of the derived outlines. This is

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a key issue and you should provide some errors in your delineation, mainly due to the resolution of the images. Watson et al. (2016), looking at supra-glacial ponds though, show that resolution is an issue and they state that Landsat products cannot be used for this purpose. So may cite this paper (which came out after your submission) and also consider that issue. Maybe your ponds are very big and not affected by the coarse resolution of Landsat? A clear advantage of Landsat is that it allows going back in time – what the higher resolution products cannot as they are all for recent years. Also, from Table 3 of supplement there is an ALOS image listed, although it is not clear what is that used to. ALOS has a different resolution and so this should be discussed.

#### 2) Degree-day model for glacier melt:

The use of a degree-day model for glacier melt might be a key limitation, as this has been shown to be very sensitive to temperature fluctuations. Therefore the estimates of "glacier melt" might be erroneous, and responding too much to changes in temperature. I would suggest that you perform calculations with a better model. Also, a key concern is that you use a constant melt factor from another study - the model needs calibration. If you cannot do this, you should perform an uncertainty analysis by varying this factor in a given range. In addition, why did you only use one factor and not two for snow and ice? I would strongly recommend that you: 1. do an uncertainty analysis and see how sensitive your results are to changes in the degree-day factor 2. use a more appropriate model

#### 3) Table 3:

There are some very contrasting changes and it is not entirely clear how these values were derived: e.g. for ponds with glacier coverage <5% from 1963 to 2011 there is a decrease of -7% (+-6%, which is a lot) and from 1963 to 2013 (only two years apart), there is a decrease of -25%. This could be due to accuracy in the delineation and the use of different data sources rather than real changes. Also, why are changes from intermediate periods, i.e. 2000 to 2013 (or 2000 to 2011), not shown in the table?

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#### 4) Aim of the paper:

You want to study lakes as proxies for climate, but you cannot indeed as lakes changes can only be explained if changes in a variety of climatic and glacier variables are known. What you can do is relating lake changes to climate and glacier changes and see if there is a consistent interpretation for both. This has to be changed in the intro and the paper in general.

#### 5) Debris-covered and debris-free glaciers:

I strongly recommend that you carry out your analysis of glacier area changes separately for the two categories debris-covered and debris-free glaciers, and provide figures of how much of the glacier area in the catchment is covered by debris. Debris covered glaciers are known to shrink little in area and that area change is not a good indicator of glacier changes and melt (see e.g. lines 251-252).

#### Specific comments:

I think you should also analyze and discuss the fact that some ponds undergo geometrical changes over such a long time due to changing boundary conditions. Depending on the location and size of a water body, possibly enhanced or reduced sediment supply from glaciers, landslides etc. could change the lake area considerably. Also groundwater may play a role for the hydrology of some ponds. And if you think these processes are negligible, mention this in the text at the beginning in the introduction or at the end in the discussion. Regarding the topographical analysis, there are some hidden steps which need to be explained better in the text, e.g. selection of basins, aspects etc. (see specific comments below) or how you distinguish between a connected and an unconnected pond, i.e. how far the latter is located from the glacier tongue. There are sections in the text which need to be improved. Due to many different datasets, time periods and pond categories it is sometimes hard to follow step by step the selection and analysis of the data (is a certain result about ponds/season/years etc.). This could be improved by 1) using a clearer structure and repeating more frequently correspond-

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ing information in the text, and 2) splitting long sentences. This clarity is also lacking in a few figures, where it is sometimes not possible to get the right information of all plot elements. Some additional legend elements and a more precise caption would help substantially in these cases (see technical corrections below).

Technical corrections (text):

Line 11, '...ponds not directly connected to glaciers,' try to give a clearer definition to avoid mixing physical and hydrological connection, something like '...ponds not in direct contact with glacier ice' could fit.

Lines 14-15, wrong word order, write '...unconnected ponds have decreased significantly by approximately 10% over the last fifty years (1963-2013 period).'

Also: '10%' is area or number? Needs to be specified as it is ambiguous like that.

Line 16, word missing within 'We inferred an increase in precipitation occurred until...'

Line 22, 'remoteness' is another main reason.

Line 36, '... body of research...', try to use a better word.

Lines 46 and 54, '...high Asian mountains...', better to use 'high mountain Asia' or 'Asia's high mountains'.

Line 47, 'decreased evaporation', add explanation why evaporation was assumed to have decreased.

Lines 59-61, wrong word order, write 'Therefore the potential risk of GLOFs in the Himalaya has been, ...'.

Line 61, '...these lakes', which type do you mean here?

Line 67, write '...opening'.

Line 69, '...only influenced by glacier melting and precipitation.', is this valid? What about e.g. evaporation, ground water, avalanches?

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Line 70, write '...lakes to potential indicators...'

Line 72, not sure you can use 'evapotranspiration' here, but also in several other parts of the text. Don't you mean 'evaporation' in general? Sometimes you use evaporation, sometimes evapotranspiration. Try to be consistent.

Line 73, write 'A valuable...'

Line 79, it seems to me that Hamerlik et al. (2013) used a threshold of 1 ha (page 3), better cite Biggs et al. (2005).

Line 94, '...characterized by...', be more concise.

Line 97, 'For the last twenty years...', give specific years.

Lines 97-98, wrong word order.

Line 106, '...these glaciers...', which glaciers?

Line 118, write '...and subsequently expanded continuously...'

Line 122, write '...monthly cumulated...'

Lines 125 and 127, write 'Jensen-Haise model'.

Lines 136, gap between '...Unit-Time...'

Lines 138, gap between '...Prediction-Climate...'

Line 154, write '...through...'

Lines 156-159, sentences about selection are confusing, try to explain this more clearly.

Line 172, specify why you selected this T-index model. See also major comments above.

Line 174, '...close to the SNP', explain better why this field study on Glacier AX010

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is the best solution and suitable in your opinion, specify where this glacier is located, which region, climate etc. See also major comments above.

Line 175, why didn't you apply the daily temperature per elevation band of each glacier?

Line 178, delete 'Such'.

Line 179, write '...through...'

Line 180, use proper reference instead of URL-address.

Line 182, use proper reference instead of URL-address.

Line 185, maybe more correct to use 'mountainous terrain' or 'steep terrain'.

Line 189, use proper reference instead of URL-address.

Line 190, write '...effects as described in Salerno...'

Line 194, write '...morphological...'

Line 205, add reference to '...in the software R...'

Line 213, '...trends has been tested...' on how many years? Isn't there a minimum of years to be able to speak about trends?

Line 233, description for Figure SI2b confusing and not consistent with actual plot.

Line 240, remove 'very' or use 'relatively'.

Line 240, write '...oriented towards south-southeast...'

Lines 243-245, wrong word order, write '...in the last fifty years (1963-2013)'.

Also: 10% is ambiguous: is this area or number?

Line 257-258, This depends on the status of the glaciers, see e.g. Pellicciotti et al., 2010. You can have a decrease in area and decrease in glacier melt.

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Lines 258-259, avoid using two times 'However...'

Line 261, '...extremely broad...' not clear to me what you mean here, use clearer/better word(s).

Line 284, replace 'These authors...' with 'They...'

Lines 284-287, wrong word order, write 'They observed...'. Too long sentence, make two out of it.

Line 291, delete 'both'.

Line 296, write '...than the mean...'

Line 298, write '... more than the...'

Line 303, what do you mean with '...relevant...'? Try to be more clearly. Also: mentioning 'maximum monsoon temperature' and 'glacier melt' as main drivers of change is somehow redundant in my opinion, as the last is clearly directly dependent of the former one in your calculations. Maybe explain here better the dependencies.

Lines 303-305, too long and complicated sentence, untangle and make two out of it.

Line 315, write '...basin...'

Line 317, maybe you can mention, that based on your findings it can be clearly seen, that glaciers act as buffers of the hydrological cycle.

Line 328, remove 'very' or use 'relatively'.

Line 330, write 'compare'.

Lines 333-335, wrong word order and too long sentence. Write 'The surface area of ponds-without glaciers strongly decreased ( $-25\pm 6\%$ ,  $p < 0.001$ ) from 1963 to 2013. In contrast, the surface area of ponds-with-glaciers decreased much less ( $-6\pm 2\%$ ,  $p < 0.05$ ) for the same period.'

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Also: refer to Table 3 in that sentence.

Lines 361-362, contradiction to line 355 and Figure 9b., should be the other way round I suppose.

Lines 362-363, here you could think about glacier morphology to further explain differences in glacier melt at different elevations (area, steepness, debris), if this is valid in your case study.

Line 369, be more precise when using the term 'glacial ponds' in order to separate them from supraglacial ponds etc.

Line 372, missing word(s) in 'The continued shrinkage of glaciers likely due to...'

Line 376, avoid using 'study' two times.

Line 377, I wonder if the behavior of precipitation and glacier melt can be detected separately based on tracked pond areas. Maybe you can state something about this here.

Lines 382-387 & lines 389-391, did you directly observe constant (until the 1990s) or reduced glacier melt (in the early 2000s) or is this assumption based on the decreased max. air temperatures? It would be good if you could add here more background from your findings.

Line 403, write '...other climatic...'

Line 409, verb missing.

Technical corrections (tables/figures):

Table 2:

Line 629, write '...of all considered...'

Pond area, rounding error for max. value in 2nd and 3rd column (56.3 vs. 56.2)?

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Basin, maybe you can add once in the paper how the basin is defined (= 'hydrological catchment?') and how you calculated it (algorithm?).

Basin aspect, did you consider the calculation for directional values? Mean, median, range etc. of aspects have to be derived carefully, as e.g. the mean and median of the three values 45°, 345° and 360° doesn't make sense if calculated normally. Add a short note how you deal with this once in the paper where 'aspect' occurs first.

Also: How did you derive the mean basin aspect? Add used method ('vectorial mean').

Glacier aspect, same as 'basin aspect', see comment above. Here it seems that the median is not within the range.

Table 3:

Asterisks, what do they stand for? Statistical significance level? Add explanation.

Table 4:

Basin aspect, again, how did you calculate mean and median basin aspect(s)? Asterisks, what do they stand for? Add explanation.

Figure 1:

Line 684, you could add the source of the two pictures.

Figure 2:

a), use decimal degrees as written in text (line 91).

Also: black triangle and 'SNP' somehow misleading in inset map.

b), write '...isotherms corresponding...'

Also: write 'max. temperature'

Line 715, remove '...'

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Figure 4:

Low image quality, especially axis labels. Try to improve.

Also: change x-axis labels to more 'intuitive' years, e.g. 1980, 1985, . . . and add year labels to all subplots a-d for better readability.

b), write 'Precipitation (anomaly)'

Figure 6:

Low quality, labels and lines.

Also: units missing.

a), y-range seems to be too small, missing points.

Also: wrong labels both at y-axis and in legend ('cumulate').

b), the left and right y-axes seem to be shifted vertically.

Line 777, a) and b) mixed?

Line 779, write '...Figures...'

Figure 7:

Especially subplots a) and c) too small.

Also: size of circles in subplots b) and d) not clear, explanation below not clear as well.

Line 783, write 'Increased pond surface areas' and 'Decreased pond surface areas'.

Lines 785-786, description of subplots a) and c) not consistent with actual titles in plot (with/without glaciers).

Figure 8:

Add units for right y-axes (precipitation, melt). Also: make lines and bars in both sub-

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plots identifiable, label them.

Figure 9:

Low quality, too small (axes labels).

Technical corrections (supporting information):

Figure SI1:

Last sentence in caption: write 'In Table 1 the relevant coefficients of correlation are reported.'

Figure SI2:

a), add more space in between x-axis-labels. b), change x-axis-labels to more 'intuitive' years (e.g. 1980, 1985, . . .).

Figure SI3:

Very low quality of all labels, axes, wrong number of digits etc., too small. Also: add units or write that the anomalies are relative or dimensionless.

Figure SI4:

Low quality of all labels, too small. Second last sentence in caption: write '...considering Tmax and Tmean.'

References:

Biggs, J., P. Williams, M. Whitfield, P. Nicolet and A. Weatherby, 2005. 15 years of pond assessment in Britain: results and lessons learned from the work of Pond Conservation. *Aquatic Conservation: Marine and Freshwater Ecosystems* 15: 693–714.

Pellicciotti, F., A. Bauder and M. Parola. Effect of glaciers on streamflow trends in the Swiss Alps. *Water Resources Research*, 46: W10522.

Watson, C.S., D.J. Quincey, J.L. Carrivick and M.W. Smith, 2016. The dynamics of

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supraglacial water storage in the Everest region, central Himalaya. *Global and Planetary Change* 142: 14–27.

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Interactive comment on *The Cryosphere Discuss.*, doi:10.5194/tc-2016-39, 2016.