P. Buri (Referee)

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 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:

> **Comment:** we thanks the reviewer for the revision of the paper. Generally, we hope that in the new version the key messages could emerge more clearly. All the suggestions have been followed. A new overall methodological section have been introduced.

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 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.

Answer: As suggested by the reviewer the supraglacial lakes in Mt Everest Region are very small. According to Watson et al. (2016) their size range from 0.09 to 0.36 10^4 m^2, while the unconnected ponds in the same region (this study) are on average 1.1 10^4 m^2, i.e., an order of magnitude larger. This is not the unique difference between the two kind of ponds. As described in the text, supraglacial ponds are strictly connected with glacier dynamics, thus, as describe by many authors (and by the same Watson et al. (2016)) their measurement is very uncertain. Landsat imagery is surely too coarse for these ponds.

Considering unconnected ponds, in general, we tracked the pond surface changes in many papers (Tartari et al., 2008, Thakuri et al., 2015; Salerno et al., 2012, Salerno et al., 2014). We wrote a specific work (Salerno et al., 2012), on the uncertainty related to the measurements of lakes from satellite imagery in the region, which is referenced also by Watson et al. (2016). In the methodological section there is a section devoted to the uncertainty of measurements.

Table 3 is a general summary of surface area changes related to all 64 considered ponds glaciers located within the basins. In the previous version of the paper was not explicitly written that the same table reported the uncertainty of measurements. This could have confused the reviewer, which though that we did not consider and discuss the uncertainty of measurements.

The ALOS was used to track the pond surface areas in 2008, this image was preferred considering the better resolution. In fact in table these period presents uncertainties slightly lower.

Correction: 1) the methodological section related to the uncertainty of measurements has been extended. 2) we corrected the caption of Table 3. Along the paper, where it was omitted, the uncertainty has been associated with relevant difference of measurement. The satellite images used for the analysis have been also reported in the main text and in the abstract.

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

Answer: This paper does not aim to provide an accurate estimation of the magnitude of the melt released from glaciers located in the pond basins. In fact, its value has never been discussed and mentioned. The melt factor could be unsuitable, but if it was wrong no analysis would be compromised. We compared its 2000-2013 trend vs the pond surface areas, and the correlation analysis is independent from the magnitude of the compared series. Consequently, we do not need different factors for snow and ice and to make a sensitive analysis.

Being interested in the melt trend and not in its absolute magnitude and considering that these small glaciers are ungauged, we do not more sophisticated melt models, which consider specific geometries and differentiated melt factors. We are aware of the autocorrelation between the maximum temperature and glaciers melt calculated from this variables, i.e., their fluctuation are similar. The added value is only due to that the positive temperature calculated for each glacier (elevation bends) are able to generate a melt, which we found to be significant related to the observed pond surface area changes. If ponds (and glaciers) were located some hundred of meters at higher elevation, surely the melt and Tmax would be less correlated and the application of the degree-day model would look less trivial. What is the knowledge contribution of the application of the degree-day model in this contest? Maximum temperature trend is here demonstrated to be responsible of processes able to modify the pond surface area. How processes? Glacier melt is a reasonable factor, due to we find significant relationships when glaciers are present in the pond basins, and no relationship with Tmax when glacier are not present in the basin.

Correction: these concepts has been inserted in the text.

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?

Answer: In the right of the Table 3 changes for each intermediate period are all referred to 1963, because they are expressed as commutative loss. Having fixed the reference year this kind showing results allows to create a trend. In fact these data are the same used in Figure 8. I f we were interested in the acceleration for each period, the same Table on the left provides the relative annual rate (for each period in this case). These data are discussed in Table 7. So you can directly compare periods.

In relation to the abrupt change observed by the reviewer (-7% vs -25%,i.e., -18%), we can start observing Table SI2. The resolution of the two images is the same. Moreover giving a look at fig. 8 Fig. 8. Probably here it looks much less strange. From 1992 to 2011 the decreasing is 20% (the computation can be done also from the table 3 from +13% to -7%). Surely -18% in two years is a lot, but in in line with the decreasing of precipitation observed since the early ‘90s (Fig. 8). Furthermore the behavior of surface are change has been observed significantly correlated with precipitation.

Correction: the caption of the table has been changed to better clarify its content.

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.

Correction: the specific aims of the paper have been added.

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).

Answer: The glaciers within the pond basins are not debris covered. In this region debris covered glaciers are usually glaciers of a certain size with a developed flat ablation area. In all considered pond basins, the glacier are very small, steep (31°), clings to the mountain peaks, without having developed debris covered ablation area.

Correction: following the suggestion of the reviewer we specified in the text these features of glaciers within the considered pond basins.

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. **A)** 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. **B)** 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. **C)** 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 corresponding information in the text, and 2) splitting long sentences. **D)** 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).

Answer: A) the variably connected with “secondary” boundary conditions has been discussed in the conclusions; B) following the suggestions provided by the reviewer, accepting the specific comments provided below, we hope to have provided more details on these aspects; C) following the suggestion received by another reviewer, a section related to the overall mythology has been inserted; D) All figures and captions have been improved following the suggestions received by reviewers

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.

Answer: done

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

Answer: done

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

Answer: done

Line 16, word missing within ‘We inferred an increase in precipitation occurred until: : :’

Answer: done

Line 22, ‘remoteness’ is another main reason.

Answer: done

Line 36, ‘: : : body of research: : :’, try to use a better word.

Answer: done

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

Answer: done

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

Answer: done

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

Answer: done

Line 61, ‘: : :these lakes’, which type do you mean here?

Answer: done

Line 67, write ‘: : :opening’.

Answer: done

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

Answer: the mains terms of the water balance we consider at annual scale are as input, precipitation and glacier melt, and as output, the evaporation. If we considered ground water, avalanches we should also consider other terms as runoff, infiltration, seepage, sublimation…but this level of detail is not the aim of the work, and it is impossible to discern in this remote environments. These lakes are ungauged, remote. No information regarding the groundwater is available at those elevations, avalanches are never computed in the water balances because are they are episodic not easily quantifiable events.

Following the approach of other authors (e.g., Song et al., 2014; Wang et al., 2015, Salerno et al., 2015), precipitation, glacier melting, and evaporation are the main contributions in high elevated lake basins able to explain the causes of lake changes

Correction: the approach followed by these authors has been inserted.

Line 70, write ‘: : :lakes to potential indicators: : :’.

Answer: done

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.

Answer: done

Line 73, write ‘A valuable: : :’.

Answer: done

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).

Answer: He initially used a threshold of 1 ha, but his analysis shown that the threshold was 2 ha (abstract)

Line 94, ‘: : :characterized by: : :’, be more concise.

Answer: done

Line 97, ‘For the last twenty years: : :’, give specific years.

Answer: done

Lines 97-98, wrong word order.

Answer: done

Line 106, ‘: : :these glaciers: : :’, which glaciers?

Answer: done

Line 118, write ‘: : :and subsequently expanded continuously: : :’.

Answer: done

Line 122, write ‘: : :monthly cumulated: : :’.

Answer: done

Lines 125 and 127, write ‘Jensen-Haise model’.

Answer: done

Lines 136, gap between ‘: : :Unit-Time: : :’.

Answer: done

Lines 138, gap between ‘: : :Prediction-Climate: : :’.

Answer: done

Line 154, write ‘: : :through: : :’.

Answer: done

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

Answer: done

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

Answer: the choice has been described above.

Correction: this concept has been inserted in the text.

Line 174, ‘: : :close to the SNP.’, explain better why this field study on Glacier AX010 is the best solution and suitable in your opinion, specify where this glacier is located, which region, climate etc. See also major comments above.

Answer: this glacier is a small debris free glacier, located in the Dudh Koshi valley in same climatic and geographic setting of glaciers studied in this paper, just outside the SNP in the southwest part (27°42'N, 86°34'E). Several studies exist on this glacier . It is a reference glacier for long monitoring of mass balance changes. Some papers: http://onlinelibrary.wiley.com/doi/10.1029/2005JD005894/full, www.pnas.org/content/108/34/14011.full.pdf

Correction: this concept has been inserted in the text.

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

Answer: the previous version was too hermetic and not clear.

Correction: the text has been corrected according to the suggestion of specifying better the use of the elevation bands.

Line 178, delete ‘Such’.

Answer: done

Line 179, write ‘: : :through: : :’.

Answer: done

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

Answer: done

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

Answer: done

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

Answer: done

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

Answer: done

Line 190, write ‘: : :effects as decribed in Salerno: : :’.

Answer: done

Line 194, write ‘: : :morphological: : :’.

Answer: done

Line 205, add reference to ‘: : :in the software R: : :’.

Answer: done

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

Answer: No there is not a minimum of years. However when a series is considered not such long, the associated significance should be considered with caution.

Correction: This specification has been inserted in the text

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

Answer: not done. We did not understand the comment.

Line 240, remove ‘very’ or use ‘relatively’.

Answer: done

Line 240, write ‘: : :oriented towards south-southeast: : :’.

Answer: done

Lines 243-245, wrong word order, write ‘: : :in the last fifty years (1963-2013).’.
Also: 10% is ambiguous: is this area or number?

Answer: done

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.

Answer: the suggestion has been considered

Lines 258-259, avoid using two times ‘However: : :’.

Answer: done

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

Answer: done

Line 284, replace ‘These authors: : :’ with ‘They: : :’.

Answer: done

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

Answer: done

Line 291, delete ‘both’.

Answer: done

Line 296, write ‘: : :than the mean: : :’.

Answer: done

Line 298, write ‘: : : more than the: : :’.

Answer: done

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.

Answer: we agree that it is redundant.

Correction: Therefore temperature has been deleted from the PCA and the text modified accordingly.

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

Answer: not done. We did not understand the comment.

Line 315, write ‘: : :basin: : :’.

Answer: done

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.

Answer: glaciers are not the hydrological buffer, the glacier cover is the discriminant variable

Correction: The concept has been added in the new version.

Line 328, remove ‘very’ or use ‘relatively’.

Answer: done

Line 330, write ‘compare’.

Answer: done

Lines 333-335, wrong word order and too long sentence. Write ‘The surface area of ponds-without glaciers strongly decreased (-25_6%, $p<0.001$) from 1963 to 2013. In contrast, the surface area of ponds-with-glaciers decreased much less (-6_2%, $p<0.05$) for the same period.’

Also: refer to Table 3 in that sentence.

Answer: done

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

Answer: the comparison should be done with ponds without glaciers (line 354).

Correction: we inserted the reference figures and type of lakes.

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.

Answer: see the comment above

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

Answer: done

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

Answer: done

Line 376, avoid using ‘study’ two times.

Answer: done

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.

Answer: done

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.

Answer: the concept has been clarified.

Correction: through the analysis of surface area changes of unconnected glacial ponds.

Line 403, write ‘: : :other climatic: : :’.

Answer: done

Line 409, verb missing.

Answer: done

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)?

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.

Answer: “Hydrological basin” has been inserted in many key points of the manuscript.

The errors have been corrected. The method used for deriving the mean, median, etc.. of aspect has been described. The hydrological basin has been delineated with ArcGIS® hydrology tools.

Correction: the circular statistic has been used for computing the (vector) mean and median values of glaciers and basins aspect (Fisher, 1993). The delineation method has been described.

Table 3:

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

Answer: done

Table 4:

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

Answer: (see the answer above), done

Figure 1:
Line 684, you could add the source of the two pictures.

Answer: done

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 ‘: : :’.

Answer: done (point a: we changed the text)

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)’

Answer: done

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: : :’.

Answer: done, units in the caption

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).

Answer: done

Figure 8:
Add units for right y-axes (precipitation, melt). Also: make lines and bars in both sub plots identifyable, label them.

Answer: done, units in the caption

Figure 9:
Low quality, too small (axes labels).

Answer: done

Technical corrections (supporting information):

Figure SI1:

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

Answer: done

Figure SI2:

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

Answer: done

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.

Answer: done

Figure SI4:

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

Answer: done

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