

Anonymous Referee #1

General comments

Understanding the links between climate, glaciers and hydrology in high mountain area is a growing and very important topic. This paper builds on other work by this group. There is potentially an interesting paper in here, which is novel and might lead the way to demonstrating how the changing size of ponds in mountainous regions that are not in immediate contact with ice but which contain glaciers in their catchments might be used to infer spatial and temporal trends in climate (precipitation, temperature, evaporation, glacier melt). The paper uses a statistical approach to the problem and the authors are to be commended for such a detailed analysis. Eventually one might imagine being able to use perhaps a more robust physically based approach, similar to that used by, e.g., Leclercq & Oerlemans, to reconstruct climate from glacier length fluctuations. This paper could be a useful stepping stone in that direction. [P.W. Leclercq, J. Oerlemans 2012. Global and hemispheric temperature reconstruction from glacier length fluctuations *Climate Dynamics* 38 1065-1079, doi: 10.1007/s00382-011-1145-7]

Comment: we thanks the reviewer for the detailed revision of the paper. Generally, we hope that the readability is now improved and the key messages are emerged.

I see 4 key problems with the paper as it currently stands although I hope the authors might be able to deal with these, re-orientate, focus, correct things and rewrite the paper so that it provides a better contribution to the cryospheric sciences.

1. The aim, objectives and overall general methodology of the paper are not articulated towards the beginning of the paper, so that the reader [or this one at least] remains generally confused about what is being done and, more importantly, why things are being done and has to gradually piece things together while reading the paper.

Comment: more specific objectives have been inserted. The overall general methodology has been described in a specific new paragraph.

2. The paper is very involved and dense with lots of different levels of analyses, and lacks a clear focus of what it is trying to achieve. I'd encourage the authors to work out what the key take home messages of the paper are and to present only the material that leads to those conclusions.

Comment: we hope that after having described the overall methodology the reasons behind the analyses could be emerged.

3. The paper is hard to follow, with sufficient ambiguities, inconsistencies, apparent contradictions and small lapses in grammar and syntax, to justify rewriting quite large sections, especially the Abstract and Conclusions. It would benefit from running through a spell checker and from proof reading by a native English speaker if at all possible.

Comment: the abstract and conclusion have been largely rewritten. Considering we are not native English speaker, before submitting the last version of the paper, we provided to submit the paper to the

American Journal Expert for the proof reading. An expensive certificate was released. We hope the kind help of the three reviewers could have deleted the grammar and syntax errors.

4. I query some of the scientific assumptions / results

Comment: please read the answers reported below.

I elaborate on these points below.

Specific comments

1. The paper needs to articulate what the overall aims, objectives and methodology are. Currently, all we have on lines 83-86 is this: “This contribution examines the surface area changes of unconnected glacial ponds on the south side of Mt. Everest (an example is shown in Figure 1) during the last fifty years to evaluate whether they act as potential indicators of changes in the main components of the hydrological cycle (precipitation, glacier melting, and evapotranspiration) at high elevations in the Himalayan range.” Even as a general aim, this is rather vague. This needs tightening up, we need to be given some more specific objectives and told an overall methodology of how these objectives will be achieved. Currently, after these 5 lines, we have an introduction to the field area (Section 2) followed by a detailed section on Data and Methods (Section 3). But when reading Section 3, we don’t know why we’re being told about the climate data, digitization of ponds, calculation of glacier surface area and melt, derivation of morphological parameters, etc. For example, on line 203 you refer to “degree of correlation among the data” But we have no idea what precise data you’re talking about, nor why you want to correlate them.

Comment: More specific objectives have been inserted. The overall general methodology has been described.

2. The paper is very detailed, convoluted and involved, with a lot of separate components:

- i) looking at correlations between reanalysis climate data and ground climate data after 1994 to see which reanalysis products may most reliably be used to infer climate in the region prior to 1994;
- ii) generating other proxy data ultimately from the climate data, notably evapotranspiration and glacier melt (using a simple temperature index model);
- iii) calculating glacier shrinkage and “unconnected pond” area shrinkage (where “unconnected ponds” refer to those not physically in contact with glacier ice) for 6 time periods since 1963 from a map (1963) and satellite imagery (1992, 2000, 2008, 2011,2013);
- iv) performing a suite of non-parametric statistical tests to investigate whether trends in pond area, glacier area, climate & climate derivatives (evapotranspiration and glacier melt) are statistically significant in different time periods (e.g. the whole period 1963-2013 or sub-periods 1963-1992, 1992-2013); between different types of unconnected pond (those whose upstream catchment is > 10% or < 10% glacierised) or for different “morphological boundary conditions” (e.g. elevation, aspect);
- v) performing a Principal Components Analysis on the variables to investigate climate drivers of pond area change.

Furthermore, some of the analysis is done on the full set of 64 ponds, and some is done on a sub-set of 10 ponds. Similarly, some of the analysis splits the time period into two (1963-1992 and 1992-2013) and some

splits the time period into three (1963-1992, 1992-2000 and 2000-2013). All in all, the reader gets rather bogged down in the detailed analysis and loses a sense of the big picture.

Comment: we thanks the reviewer for this tentative of summary. We used this scheme for generating a paragraph related to the overall methodology.

3. Because the paper has many different strands, it is particularly important to have a very clear abstract and conclusion. Reading the abstract, it is not at all clear what the key take home messages of the work are. Unfortunately, having ploughed my way through the paper and emerged somewhat exhausted from the final sentence of the conclusions, I was still rather unsure what the key conclusions were.

Lines 369-371 tell us that during the monsoon period the “unconnected ponds” declined in area (by 10%). Fine, this is clear.

Lines 371-372 tell us that this is due to a drop in precipitation and a decrease in maximum temperature (and therefore glacier melt). Also quite clear.

Then it gets confusing. Lines 372-373 tell us that “the continued shrinkage of glaciers likely due to the effects of less precipitation than an increase in temperature”. This is not a grammatically correct sentence but I assume the authors mean that “the continued shrinkage of glaciers [is] likely due to the effects of less precipitation [rather] than an increase in temperature.” I don’t recall where in the paper this was discussed. The paper involved a statistical analysis explaining variation in pond area not glacier area. By “continued shrinkage” I assume the authors are referring to the actual shrinkage that occurred in the past, and are not speculating about shrinkage that may or may not occur in the near future? Note how we’re told that pond area shrinkage is due to a “decrease in maximum temperatures” but that glacier shrinkage is likely not due to an “increase in temperature”. It’s a little ambiguous whether temperatures have, in fact, increased or decreased over the time period. On line 280 we’re told that the mean temperature decreased, although not significantly. On line 281 we’re told that maximum temperatures decreased. On line 282 we’re told that minimum temperatures increased. Actually we’re told that the increase in the minimum temperature “balanced” the decrease in the maximum temperature, although this isn’t strictly correct as then, I assume, the mean would stay exactly the same. Is it really the case that mean temperature decreased? Figure 4a, shows that the mean temperature increased over the time period!

Comment: we provided to underline the key messages; the main conclusions have been rewritten and clarified; Figure 4a shows the trend of the mean annual temperature (which is increasing). Lines from 280 to 282, as specified in the text, report the trends during the monsoon period (the mean temp is slightly decreasing). However, in general, we accept the general suggestion that the discussion is too much convoluted. Therefore our efforts were devoted to simply the discussion.

Section 4.3 is virtually impossible to follow. It spans just a side of A4 during which we’re asked to study Table 4, then Table 2, then Fig SI3, Table 3 and Figure 4. That’s just the first short paragraph. We then need to look at Fig 5, SI4 and SI5, Fig 6a and SI4, back to 6b, back to SI4, then again, and again, then flip back to 2b. We then have to jump forward again to 6b, move to Table SI5, Figure 5, and Fig 5 again, Table 4, Figure 6 and finally back to Table 4.

I was concerned throughout this section that I was moving the pages back and forth so much that I’d accidentally end up making some sort of 3D origami animal. I’d encourage the authors to cut down on the Figures and Tables and discuss things in a way that doesn’t involve so much movement.

Comment: we tried to simply this section.

4-1. Can you explain better how melt is being derived for the glaciers? In lines 171-176, is it necessary to refer to the work of Salerno et al (2015) regarding the calculation of temperature at the mean elevation of each glacier? Is it not the case that the pyramid data are used together with a lapse rate (tell us what the lapse rate is) and the melt factor to calculate the melt across each elevation band (tell us what the band width is and what DEM is used) and that these are then summed for each glacier to calculate the melt to each glacier?

Correction: the text has been corrected according to the suggestion.

4-2. Given the way that you're calculating glacier melt, there will be huge autocorrelation between Tmax and Glacier melt. So it's not surprising that your correlation coefficients involving Tmax and Glacier melt are so similar. I'm therefore surprised by Fig 5 where you seem to show that glacier melt and Tmax are two strong independent variables contributing to the principle components. Have I understood this correctly?

Comment: The PCA shown in Figure 5 attempts to provide an overall overview of the relationships among the trends related to the potential drivers of change and the pond surface areas: glacier melt and precipitation, while evaporation is excluded. Following the suggestion Tmax probably needs to be removed to avoid that the reader could think that our aim is to show similarities between Tmax and melt (Tmax).

Correction: Tmax has been removed from the PCA.

4-3. Table SI5. Do I understand this analysis correctly? For each pond, are you only working with 14 data points? Is this sufficient to demonstrate every variable is normally distributed so that you can use the parametric correlation test (as you state you do lines 203-5)

Answer: Yes the interpretation is correct. We used the annual ponds surface area for the 2000-2013 period and we compared the area with the correspondent driver of change (14 comparisons). The number of years considered in the analysis is given by the availability of satellite imagery. Given a not so much elevated number of comparisons, however, we need considered that the same analysis is repeated for (corroborated by) 10 lakes which present very similar relationships with the selected variables. No other data is available for the past.

Moreover, to test the normality of the comparisons there is not a minimum number of data. Razali and Waph, 2011 demonstrate that the Shapiro-Wilk test (used in this paper) presents the highest power for small sample size (analyzing sample size ranging from 10 to 2000).

Correction: we wrote in the text that Razali and Waph, 2011 demonstrate that the Shapiro-Wilk test presents the highest power for small sample size.

4-4.k On line 100 you tell us that the precipitation has a specific gradient. Given that you go to all the trouble of calculating glacier melt using a lapse rate, and given the importance of precipitation for your analysis, why do you not use this lapse rate in the calculation of precipitation from the pyramid station when analysing the precipitation relevant to the different ponds? The ponds are at different elevations, and the catchments above them have different elevation ranges (and hypsometries). The pptn gradient above 2500m is non-linear. All these things will mean the precipitation falling above the lakes in your analysis will be very different for the different lakes.

Comment: In this analysis we are not interested in the absolute (annual cumulate) value of precipitation on each specific ponds. If it was this case, as suggested by the reviewer, applying the precipitation

gradient analyzed by Salerno et al., 2015, we could be able to estimate it. In order to analyze the possible relationships between pond surface area changes and precipitation variations we need to compare the just the trends of these variables. Therefore, 10 ponds were selected and their surface areas tracked yearly. For each pond, the series of annual surface areas has been compared vs annual precipitation series. We carried out the same procedure for the glacier melt. The assumption behind this analysis is that the precipitation trend along the gradient and along the valleys is the same. This is a reasonable assumption/limitation due to the fact that land precipitation series at this elevation are so rare. However, the last paragraph aims to investigate this assumption: the result is that there is not an altitudinal or spatial pattern.

Correction: the assumption has been specified in the text, as well as, its analysis in the last paragraph.

4-5. Section 3.5. I'd like to see a better articulation of the sources of error and how they were calculated for this study. First you imply error is a function of linear error and perimeter. Then you refer to a linear resolution error and a co-registration error. This all needs explaining more carefully and precisely.

Answer: we applied this procedures in other papers, probably here was too much hermetic.

Correction: the paragraph has been rewritten.

Technical corrections; typing errors, etc.

There are a lot and I don't have time to give them all. Below I give some of the key ones. Numbers refer to line numbers.

14. "unconnected ponds" This is defined in the paper but the abstract should be intelligible on its own. Explain what is meant here.

Answer: done

15. "We infer an: : :"

Answer: done

17-19. Rewrite. I think this should be at least 2 sentences. Meaning not at all clear.

Answer: done

31. glacier

Answer: done

44. " : : increases in the evaporation / precipitation ratio: : : " [refer to evaporation / precipitation ratio also above on line 41 to be consistent]

Answer: done

51-53. Vague. Rewrite.

Answer: done

61. What do you mean by "these lakes"? Just proglacial lakes or all 3 categories?

Answer: done

64. "decidedly similar". To what?

Answer: done

67 opening

Answer: done

67. Ref to glacial conduits is relevant to supraglacial lakes but not proglacial.

Answer: done

54-72. Para could be shorter with tighter articulation of key relevant points.

Answer: done

73 A valuable

Answer: done

75 glacierized not glaciated.

Answer: done

75-6. “: : region has the largest number of lakes in: : :”

Answer: done

78. reduced dimensions. Do you mean “relatively small size”?

Answer: done

80 “: : make them especially: : :”

Answer: done

78-82. This sentence is confusing. Is it their small size that’s relevant or the low water volumes and high surface area to depth ratios. You start the sentence implying it’s the first, and end saying it’s the 2nd & 3rd attribute that’s important. Rewrite.

79. Can you check the entire document? Here you define lakes and ponds according to size. But earlier and later you use the terms interchangeably and (according to this definition) sometimes incorrectly. You need consistency. Define at the very start of the paper. You could use “water bodies” if you want a generic term.

Answer: done

89. Do you need the abbreviation “CH”? Do you use this term again?

Answer: done

93-4. “: : of the territory contains temperate glaciers and less than 10% is forested.”

Answer: done

97. “For the last 20 years” Avoid phrases like this. Later you refer to “the last decade” I think too. These phrases are ambiguous. The last 20 years means 1996-2016 to me, but actually pyramid station has been operating since 1994. Always state the precise dates to avoid confusion.

Answer: done

99 “: : precipitation falls between June and Sept: : :”

Answer: done

102. “: : large glaciers in the SNP are: : :”

Answer: done

103. Delete “In the SNP”

Answer: done

109. “realised the complete cadaster” What does this mean?

Answer: done

110. “univocal” suggest change to “unique”

Answer: done

113 “: : Everest after the: : :”

Answer: done

118. check grammer here.

Answer: done

122 “: : and the monthly cumulated: : :”

Answer: done

123 delete “recently”

Answer: done

125. Why evapotranspiration not also calculated for 1994-2002?

Answer: done

126. “recorded continuously” Is this a monthly time-series too? Or calculated more frequently and averaged?

Answer: done

130. You casually say “before the 1990s” but you should say before 1994. See other instances of this throughout the paper,

Answer: done

143. “intermediate periods” is confusing. Why not just say “scenes”?

Answer: done

146. “environments” is completely the wrong word. Do you mean “biases”?

Answer: done

147-8 “For the 2000 – 2013 period, due to the wider availability of satellite imagery, ten ponds were: : :”

Answer: done

155. Semester is the wrong word

Answer: done

158. “these characteristics” What characteristics are you talking about here?

Answer: done

161. “The acceleration disappears” This is wrong. No acceleration has been discussed

Answer: done

previously. Do you mean that there is a decrease in area?

Answer: done

167. “pond basins” This is a bit unclear. You’re referring to the basins (or catchments) containing? Or Upstream of? The ponds.

Answer: done

178. remove the phrase “such”. Just list all the parameters you use.

Answer: done

180-181. Vertical accuracy greater than horizontal? Are you sure?

Answer: yes we have checked, please refer to Tachikawa et al., 2011.

185. Is this EM also used for defining the elevation bands for the calculation of melt? Should have been referred to earlier.

Answer: done

187. Map not maps.

Answer: done

194. morphological? Or best to use morphometric for consistency.

Answer: done

217 pond size

Answer: done

221 before 1994

Answer: done

223. Why are seasonal data shown for temperature but not precipitation in Table 1?

Answer: during the monsoon, as described in the text, the precipitation are the 90% of the annual cumulated amount. Therefore outside the summer, during the pre and post monsoon season, the seasonal cumulated amounts are often equal to zero. Thus the parametric statistic does not make sense. We decided to present the data aggregated at annual level, as compromise.

235. Are the 170 ponds all from the SNP region?

Answer: done

237. delete “prefer to”

Answer: done

238. “environments”? Do you mean ponds? Water bodies?

Answer: done

235-242. You don't refer to columns 1 & 2 in Table 2. Are these redundant? Remove them?

Answer: we think that the two columns are important and cannot be removed because they point out the different features of the two groups of data.

248. “glacier surface differences” ? Do you mean glacier surface area changes?

Answer: done

250. Further loss of area (-18%) is ambiguous. It's not an extra 18% loss since 2011.

Answer: done

251. Poor grammer

Answer: done

255 “Having analysed: : :”

Answer: done

257. delete “Usually and”

Answer: done

258. “this inbound component” Do you mean glacier melt input?

Answer: done

259-264. Vague, confusing and poor English here.

Answer: done

302. don't need the word “monsoon” at the end of this line with reference to temperature here do you? All these variables are for the monsoon right?

Answer: done

303 “relevant” is the wrong word

Answer: done

307 “sensible factor” is incorrect.

Answer: done

322 “: : ponds were in catchments with a glacier: : :”

Answer: done

323-3. Needs writing.

Answer: done

324-5. Why are you calling ponds in catchments that are <10% glacierised “ponds without glaciers”? Why not just call them “ponds in catchments that are <10% glacierised”?

Answer: because we need to identify this group of data a lot of times, using “ponds-with-glaciers” this need is simplified.

336. “during the intermediate periods” is confusing. Do you mean in the 1st, 2nd and 3rd part of the 1963-2013 period?

Answer: done

344 “: :glaciers had significantly: : :”

Answer: done

344-5. Rewrite.

Answer: done

359. “: :tracing of pond surface area”. The word “tracing is not quite correct” Check entire document as this has been used a few places. The word “measuring” would be better.

Answer: done

370 and 374. First you talk about “over the last 50 years” and then “over the last decade”. Why not first discuss the full conclusions of the long term 1963-2013 analysis and then talk about the full conclusions associated with the 2003-2013 work. As stated earlier, I suggest you avoid these phrases.

Answer: done

394-405. This part of the conclusions seems rather weak and not a good place to end.

Answer: done

Table 2. Lakes & Ponds seem to be used interchangeably here. In the Table heading, explain the 3 columns. And is this the sample of 64 or 10 ponds shown here? Median is written twice in the column 3 heading. And in the final column the maximum area for pond area should read 56.3 not 56.2.

Answer: done

Figure 2a. I may be wrong but I think it’s only once we look at this Figure that we learn that some ponds do not have glaciers in them. There are 10 selected ponds on this Figure but in the text referring to it I think you said you selected 64 ponds.

Answer: Probably there is misunderstanding. To avoid further problems, we avoided in the new text to use the verb “selection” for the entire population of ponds considered in this work (64 ponds). From this population 10 ponds were selected.... Moreover in the caption the number of ponds is added.

Fig 4c and d. Y axis label should read “fraction” not “%” or the numbers should be multiplied by 100. First data point needs to be plotted against 1963 not 1962!

Answer: done

Fig 7. Blue dots depicting the mean in the box plots are barely legible, esp. in the blue 2000-13 Figure c. Is there some distortion as the circles look like ovals?

Answer: done

Fig 8. Heading is wrong.

Answer: done

Fig 9. Change colour scheme as blue dots are invisible.

Answer: done