Comments on the revised version of the manuscript on "Spatial patterns in glacier area changes from 1962 to 2006 in the Kangchenjunga-Sikkim area, eastern Himalaya", by Racoviteanu et al., submitted to *The Cryosphere Discussion*

Damodar Lamsal, December 2014

After the revision, this paper is notably improved. I commend the authors for its revisions. Specific comments given were mostly addressed. However, general comments were partly addressed: i) uncertainty/validation of elevation change was not carried out leading to authors' opting to taking out that part from the MS, ii) potentially erroneous surface area change analysis from 2000 to 2006 was removed as advised, and iii) issues on (in-) adequacy of spatial extent of glacier change analysis to draw conclusion on spatial pattern of change in the region and issues on debris-covered glaciers were not sufficiently addressed. There is still ample space to make the paper stronger, by clarifying and resolving some remained issues (see below). It would be nice if authors address below points carefully, taking enough time for manuscript improvement.

1. Central idea of the paper needs to be clarified and story should progress methodically to support that idea. Although the paper presents considerable amount of data, how the individual component support and connect with the main idea has not been well discussed/established.

Very first line of the abstract states and gives impression that main aim of the paper is to analyze spatial pattern of glacier changes; however, in the introduction section (aim of the paper), it states that 'primary goal is to estimate current glacier distribution and parameters'. If the main idea behind this paper is to present spatial pattern of glacier area change and to examine dependency of the glacier change/loss on climatic and topographic variables/settings, data and results should be presented accordingly in the right order and discuss the association of glacier change/loss with governing variables, providing only the strong evidences, relevant and substantial information. At times, arguments are not strongly supported by the data and discussion are rather qualitative and general: for instance, discussion in section 5.3 and 5.4 do not add significant knowledge to existing understanding due to nature of (constrain in) data in hand despite the lengthy arguments.

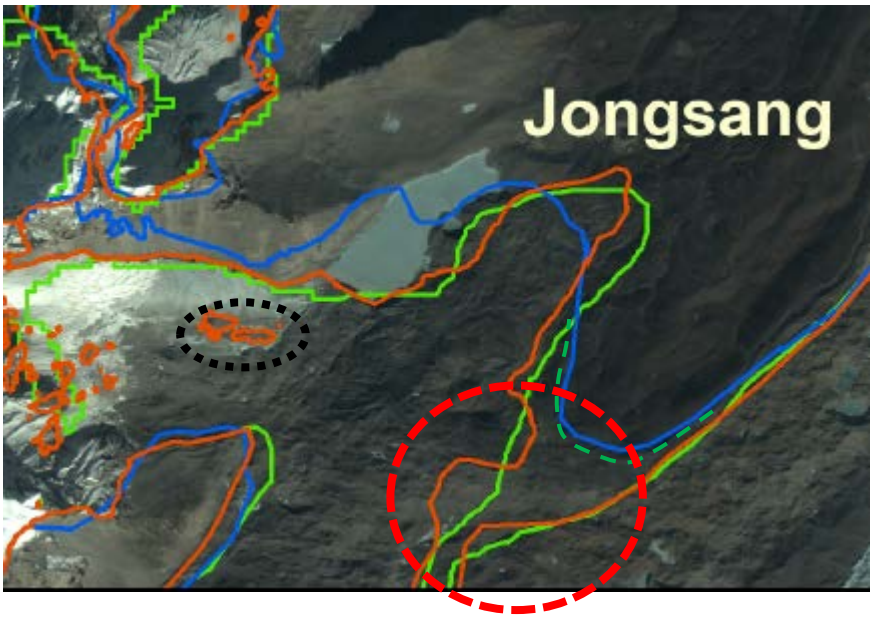
2. Only 50 glaciers in domain 2 is largely insignificant numbers to examine spatial pattern of glacier surface loss in the region. Moreover, rationale behind assigning domain 1 and domain 2 in the same paper is not justified/justifiable and it may be confusing to the readers to grasp the story. I suggest to make only one domain (wider) to examine both glacier area change/loss, and topographical and climatic controls on glacier changes. So I would recommend to expand domain 2, at least of the size of domain 1 (487 glaciers) at present, or preferably wider, so that (real tendency of) spatial pattern of glacier loss and their dependencies (on topographic and climatic) might be examined and inferred.

As authors said (in P8 and P9), study region has topographical and climatic variability (east west and/or north-south) and its division into 4 sub-regions (as in Table 3) is reasonable/justifiable (P9 L8-9). But the sub-regions were not taken up for analyzing glacier area change. I recommend to

consider either these four sub-regions or some other meaningful sub-regions/classes for analyzing such spatial patterns of glacier change.

3. Exact delineation of debris-covered glacier (front) is extremely difficult job due to debris mantle, resulting in obscure glacier front; delineation is usually based on rather subjective judgment of the operators. Moreover, although area change/loss may be a (highly) reliable parameter or mode of investigation of clean type glaciers and for assessing their response to climate change, but less effective (sometimes it might be ineffective too) for debris-covered glaciers unless debris-covered glaciers accompany pro-glacial lakes. Through volumetric/elevation change studies, it has been already demonstrated and becoming increasingly clearer that debris-covered glaciers have been losing ice mass similar to those of clean type glaciers (e.g., Bolch et al. 2011, Kääb 2012, Nuimura et al. 2012). With keeping above facts in mind, I would reiterate that studies of surface area change of debris-covered glaciers generally do not manifest real glacier changes/loss and may not be comparable with clean type glaciers. I would suggest to analyze only the sub-region-wise (4 sub-regions!) area changes of clean type glaciers or to consider, though less preferable alternative, clean type and debris-covered glaciers separately (analyze/compare only clean type vs. clean type and only debris-covered vs. debris-covered glaciers) across sub-regions.

4. It seems (seeing Figures 10 and 11) glacier delineation/outlines may yet be improved: please see below image, a small portion of figure 11 for illustration.



Small polygons inside the glacier outlines are not always exposure/rock out crops. Seeing on Google Earth image 2010, it is apparent that the small polygons inside the main glacier polygon in 2006 glacier outline (as shown within dotted oval in black) are not outcrops, but the glacier surface: such erroneous polygons need to be cleaned/removed from throughout the maps. Further, 2006 glacier front (Jongsang Glacier) extends below the 1962 glacier front, is it really a glacier terminus advancement? or mis-delineation? Further, inside the dotted red circle, the 2006

glacier polygon (in bright green) most likely should have been drawn along the dotted green line: median moraine on the glacier surface is apparently considered as non-glacier surface (moraine). Therefore, careful quality or cross-check of delineated glacier outlines (e.g., against Google Earth images) has not been fully carried out, but if doing so, it would improve quality of glacier outlines, producing more accurate glacier change estimation.

Specific comments:

P2

L11 ‘glacier area and elevation changes’ -> ‘glacial changes’

L13 ‘helped improve estimates’ -> ‘helped estimates’ or ‘helped improve estimates over …?’

L20 ‘… may not be suitable … glacier parameters’ -> citation; how about the quality of the RGI or other regional glacier inventories in the current study area, were not those inventories suitable for extracting glacier parameters? Any quality check or comparison with them?

L22 GAMDAM (Glacier Area Mapping for Discharge in Asian Mountains) glacier inventory, Nuimura et al. 2014 in TCD is relevant here

P3

L22 if mixing up area change and mass/volume change of debris-covered glaciers, influence of debris-cover on glacier change might be debatable as stated in the manuscript citing Scherler et al. 2011 and Kääb et al. 2012, otherwise, recently it has been increasingly clear that debris-covered glaciers have also been experiencing similar mass loss/change that of non-debris covered glaciers (e.g., Kääb et al. 2012, Nuimura et al. 2012).

L23-24 ‘Modelling of melt under the debris cover is subject to uncertainties’ -> is this uncertainties due to unviability of updated and precise glacier inventories or other reason?

P4

L19 ‘valley’!

P5

3.1 Data sources: shorten general information about satellite images as much as possible, as are available elsewhere

L20 ‘1960s decade’ may not be right choice as data were acquired in 1962 only-> ‘year 1962’

P6

L4 due to

L13-14 ‘GCPs were identified on the Landsat image’ -> is not fully correct as there is no elevation information in Landsat imageries. Normally GCPs represent long., lat., and elevation information (X, Y, and Z) together, so please clearly state that long. (X), lat. (Y) values were collected from the Landsat scenes and the elevation information (Z) was extracted from SRTM DEM

L15-16 LPS automatically (though manual is also possible) generates a large number of tie points in the overlapped area of the images being processed using ‘image matching technique (IMT)’ module. Here, authors stated that tie points (number?) were manually digitized taking Landsat image as a reference data. Although automatically generated tie points may contain some erroneous match (operators should remove them later), it generally produces very accurate object match. I wonder why the authors opted to manual tie point generation, was there any issue with automatically generated tie points?

P8

L1-10 SRTM DEM is now used only for ortho-rectification of imageries (not for the elevation change study), detail information about SRTM and its uncertainty is not needed as nothing additional processing has been carried out on the DEM to improve its quality.

L11-16 According to the authors (in p3), quality of the topographic maps (1960s and 1970s) remain uncertain. I did not understand why the maps were used and how the maps helped improve the glacier outlines delineated from Corona images.

P9

L4-7 Authors noted ‘well-known biases in the TRMM data’ and asserted ‘they were not concerned with absolute values’ citing its purpose was for only characterizing the sub-regions. It would be worth to add a few lines on how much biases are expected in the data in the region, this is because in the later part precipitation data (Table 7 and in the discussion) have been used as one of the factors to see glacier change dependency on it.

L17 ‘elevation change’ by Thakuri et al. 2014? You mean SLA (snow line altitude) change?

L18-20 ‘To facilitate comparison with this study and others from the same climatic area, we excluded glaciers from China and Bhutan from the glacier area change analysis’: wider area including China and Bhutan would be better to see glacier change pattern, should not have restricted analysis extent only for the sake of comparison.

P10

L22-24 ‘Some transient snow persisting in the deep shadowed valleys was manually removed from the glacier outlines on the basis of the topographic map’: to check 2006 glacier outline quality, Google Earth Images would be better than using topographic maps of 1960/70s, whose quality is, as stated by the authors (p3), uncertain.

P11

L13-15 Glacier thickness calculation? Don't really understand how well the model fits in this region with high relief and rugged topography, relatively smaller glaciers, many with debris-covered types. How much uncertainty is expected?

3.4 Uncertainty estimates: shorten the description of error types, particularly, which is not considered, for instance, *Geolocation error.*

L10-12 'The error in glacier surface area change (E) was computed from the errors due to rock inconsistencies (E_{rock}) and classification errors ($E_{classif}$) embedded in each dataset as the RMSE' -> it seems that only $E_{classif}$ is considered based on P13, L5 (image classification error 3-6%) and P14 L3 (total uncertainties ±3%, ±6% and ±3%): don't they represent the same thing/value? Here also, if the uncertainty/error is not taken into account (E_{rock}?), shorten its description.

P14

L14-18 (and elsewhere when relevance) this comparison fits/goes to discussion section.

L19- (whole paragraph and elsewhere when relevance) -> Please move your interpretation of the results to discussion section.

P16

L10-14 It would be worth of specifying how (manual or automatic and how is it determined) the length of glaciers were calculated.

L20 Obviously, glaciers follow (local) topography. So more meaningful and insightful analysis is needed, particularly, in relation with glacier area loss.

Showing portion/percent loss, with excluding absolute loss, not necessarily represents the degree or severity of loss. In the paper, all the glacier losses are shown in percent to show small glaciers have experienced larger losses. Note that in terms of total surface area loss, larger glaciers have lost considerable area. So it would be nice to show absolute change/loss as well.

P24

Section 5.3: surface temperature distribution on debris cover tongues: as argued here and based on already established knowledge, higher temperature towards glacier termini may indicate thicker debris cover. To characterize debris-covered glaciers, temperature profiles/maps definitely help, but how is the temperature data/results relate to current purpose, the glacier area change. Also please show the temperature pattern on clean type glaciers, particularly in the same elevation range of debris-covered glaciers, so that the true contrast could be seen.

P26

Section 5.4: role of glacial lakes: discussion here is mostly referring to the findings of the previous studies (Basnett et al. 2013, Bajracharya et al. 2014 and Gardelle et al. 2011, Fujita and Sakai 2014). I don't think this section/study adds any new knowledge to existing understanding on the subject.

Table 8: % glacier area change from 1962 to 2000 (this study) -> sign should be negative (-13.5 ± 6.4)

Figure 7: % area loss from 1962-2000 (figure caption)? But 1962-2006 (y-axis label)?

Figure 9: It would be better to measure the distance/profile from terminus (0 m) to up-glaciers, to see temperatures (variation) pattern. Common/same x-axis scale should work fine. It would be nice to present surface temperature variation of clean and debris-covered glaciers so that the contrast could be seen.

Figure 11: 2000 glacier outline (and legend) is not contextual here.

Nuimura, T., Sakai, A., Taniguchi, K., Nagai, H., Lamsal, D., Tsutaki, S., Kozawa, A., Hoshina, Y., Takenaka, S. Omiya, S., Tsunematsu K., Tshering, P., and Fujita, K.: The GAMDAM Glacier Inventory: a quality controlled inventory of Asian glaciers, The Cryosphere Discuss.,8, 2799–2829, doi:10.5194/tcd-2799-2014, 2014.