Interactive comment on “Effects of surface roughness and light-absorbing impurities on glacier surface albedo, August-one ice cap, Qilian Mountains, China” by Junfeng Liu et al.

Junfeng Liu et al.

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We’d like to than the referee of Alvaro Ayala for the valuable, constructive and detailed comments which greatly helped to improve the manuscript. The corresponding changes and refinements will made in the revised paper with track changes. We are intend add some new observations in melting season in 2020. New observation data has include surface roughness and snow grain size. This could give some robust evidence of snow metamorphism process connect with snow surface roughness change. So the revised paper might take another 1-2 month to add our new data and results. Reviewer comments in normal font, our reply to each comment is provide after the comment and given in bold font.

Reply to comments from referee 2

Effects of surface roughness and light-absorbing impurities on glacier surface albedo, August-one ice cap, Qilian Mountains, China. Authors: Liu, Chen, Ding, Han, Yang, Liu, Wang, Guo, Song, Qing

PAPER SUMMARY AND RECOMMENDATION

Liu et al. present a dataset consisting of field measurements of albedo, surface rough- ness and surface concentration of Light-Absorbing Impurities (LAIs) collected during a

melt season on the August-one ice cap in the Qilian Mountains, China. The measure- ments were collected from July to October 2018, spanning most of that melt season (July to September) and one month (October) of the next accumulation season. The collected data are used to propose statistical relations between the three main mon- itored variables (albedo, surface roughness and surface concentration of LAIs), and to discuss the physical relations between them, among other

analyses. In particular, they propose that there is a combined effect of surface roughness and LAIs surface concentration on the albedo of snow and ice.

I think that the topic of this investigation is relevant for the scientific community and The Cryosphere. Although some additional details about the sampling methodology are needed, the data seem well collected, and the physical processes that are proposed to explain the observations are interesting and reasonable. Unfortunately, I don't think that the authors convincingly prove their hypothesis about the combined influence of surface roughness and LAIs, because i) they tend to ignore or minimize the role of snow metamorphism on snow albedo, and ii) the impact of snow patches on a bare ice surface. Please see my main point below for details in this regard. Importantly, the structure of the article is confusing, and the text and figures can be condensed and better organized. Finally, the use of English language should be revised, as it sometimes obscure the ideas of the authors. My recommendation is to reconsider this article after major revisions.

GENERAL COMMENTS

Physical connections between surface roughness, LAIs and albedo Process understanding

My main comment is that the authors tend to overestimate the influence of surface roughness on albedo in their analyses and conclusions. I have no doubt that there is a statistical relation between these two variables (as shown in Figure 5), and also some physical connection (Larue et al., 2020), but the collected data does not necessarily suggest a causal relation. As the authors do in the paper, I divide my arguments for the periods of snow melting and bare ice melting.

Period of bare ice exposure: Figures 2b and 2c present a good summary of the main idea discussed by the authors. A rough ice surface (with a surface roughness of about 1-10 cm) hides some LAIs, raising the area-average albedo relative to surfaces with uniform debris cover (Bøggild et al., 2010). If the surface smooths over the melting season, the LAIs emerge and the albedo decreases. The authors parameterized this effect using equation (4). However, based on the data shown by the authors, I would say the positive relation between surface roughness and albedo over an ice surface (Figure 5b) can be solely explained by the high-albedo snow patches (shown in Figure 4f) resulting from the snowfall events discernible from the occasional albedo increases during August (Figure 4a). In that respect, can the authors add a figure with the meteorological variables measured at the AWS shown in Figure 1? I think that in order to demonstrate that the albedo increases are only due to changes in surface rough- ness, the authors would need to show data without snow patches. Otherwise, it seems very plausible that the high-albedo snow patches resulting from the occasional summer snowfall events

are responsible for the positive relation between surface roughness and albedo, during the ice melt period.

Reply：Thank you for your comments and suggestions. In the revised manuscript, we will exclude patchy snow surface in bare ice surface analysis. In the revised manuscript, we also add precipitation data and half-hour air temperature observations which also analysis snow metamorphism.

Period of snow melting. It is well known that snow albedo decreases due to snow metamorphism and large grain sizes, which affects the light scattering. The increasing grain size can have an effect on the surface roughness, but the latter is also explained by differential melting of the surface. From lines 505-507, the authors seems to suggest that the lowering of the albedo is caused only by the increasing surface roughness.

Reply：Thanks for your comments. We neglect the snow metamorphism process in snow albedo and roughness analysis in the manuscript since we lack snow grain size observations in 2018. In the revised manuscript, we have revised and add snow metamorphism in melting season and accumulation season and connect surface roughness with snow grain size process with new data collected in summer of 2020.

“Physically-based” parameterizations and their potential for large-scale albedo estimates

The statistical relations between albedo, surface roughness and concentration of LASs presented by the authors are described as “physically-based”. Although it is interesting

that the authors include these variables in an albedo parameterization, these equations are not “physically-based”, because they are not derived from a fundamental principle or process (e.g. energy conservation) and their parameters (obtained from a scatter plot) cannot be directly measured in the field.

Reply: Thanks for your comments. We revised ‘physically-based’ as ‘surrogate variables’. In the revised manuscript, we add more physically based analyzed of snow metamorphism, snow surface roughness and albedo.

In the abstract and conclusions, the authors suggest that albedo can be retrieved from surface roughness at large scales. However, this seems unrealistic because the nec- essary high-resolution DEMs to derive surface roughness can only be obtained by sen- sors carried by Unmanned Aerial Vehicles (UAVs), which are only used at the glacier- scale. Are the

authors referring to that scale? Using satellite products, albedo is much easier to retrieve than surface roughness at regional scales.

Reply: Thanks for your comments.High-resolution DEM data can be acquired by unmanned aerial vehicle photogrammetry or terrestrial laser scanning. Right now these methods can only applied at glacier scale. We have revised the large scale as glacier scale.

LAIs sampling

More details are needed regarding the LAIs sampling. How did you calculate the vol- ume of each sample? Is that the volume of the stainless steel spoon mentioned in line 150? How did you make sure that the volume was the same in every collected sample? Can you include a picture of the spoon? How did you sampled sites with a rough surface, such as one with cryoconites? Did you take the samples at the top or the bottom?

Response: We revised and add more details about sampling of snow and ice surface roughness.

The sample volume of snow or ice is not same. The sample volume depend on surface roughness and LAIs concentration. For example, if the surface is smooth and clean snow, we sampled 3 cm depth with an area of 20*20cm. If the snow is thin and underneath is dirty ice. The collected snow sample and the dirty ice layers. For the smooth ice surface, we collect surface 2-3cm ice. Most of the LAIs basically concentrated at surface and the underneath ice is looks clean. For rough ice surface, the sample depth depend on the surface roughness. The cryoconite holes usually 6-7cm deep. The collect sample could be 9 cm. Bellow this depth, the ice is looks clean.

In this study, we used a 20*20cm*10cm nonrust steel box without cover and bottom to sample snow or ice. The sample procedures are: we put the steel box over sample area. Excavate the snow or ice surrounding the steel box to the depth we needed and keep the ice or snow in the steel box intact. After then, we lift the steel box, and sampled the snow or ice sample by a flat bottom shovel. Most of the time, ice is very hard, we use chisel to chip the ice.

Figure 1 sample procedure in field.

Paper structure and English language

Please improve the paper structure. I have the following suggestions: - Section 2.1 is neither data nor methods. Please add a new section called “Study Site”. - Sections 3 and 4 consist of results. I suggest including these sections in a traditional “Results” section. - Sections 3 and 4 have a confusing structure, partly because the titles are ambiguous and repetitive. - The numbering of sections 7 and 8 is wrong. They should be 5 and 6.

Response: Thanks for you excellent suggestions, we ill revised based on your suggestions.

I have provided many suggestions to improve the use of English language, but I think that the authors should perform a full revision of the text.

Response: Thanks for your suggestion, we will revised based on your suggestions and comments and referee 1’s suggestions.

SPECIFIC COMMENTS

11: “Fluctuations in surface albedo are due primarily to variations in micro scale surface roughness (ξ) and light-absorbing impurities (LAIs) in this region.” I guess you mean fluctuations of bare ice albedo, because snow albedo variations are very large and are due to metamorphism. See my main comment 1a.

Reply: Thanks for your suggestions and comments, we have revised it accordingly.

21: “ξ could explain 68%of snow surface albedo and 38%of ice surface albedo variation in melt season.” When you write that surface roughness explains 68% of the snow albedo variation, I think that you need to explicitly state that this is a statistical analysis, because the physical explanation for snow albedo variations is snow metamorphism and an increasing grain size. See my main comment 1.

Reply: Thanks for your suggestions and comments, we have revised it based on your suggestions.

37: “According to Hock (2005), on average it accounts for over 70% of the net energy input to glacier surfaces.” You should mention that that number was obtained for a particular glacier (Storglaciären). In any case, what do you mean exactly by "net energy input"? Net = input - output. Table 1 in Hock (2005) shows that incoming longwave radiation (L_in) is the largest energy input. In general, L_in and S_net are the largest energy inputs to glaciers at daily, and longer, time scales (Ohmura, 2001).

Reply: Thanks for your comments, we have revised it accordingly.

78-79: “poorly investigated, and snow surface albedo parameterization methods based on surface roughness are rarely reported.” However, the relation between snow surface albedo and grain size has been largely analyzed. Please see my main point 1a for snow surfaces.

Reply: Thanks for your comments, we have revised this part.

86: “Surface roughness structures developed during melt season such as crevasses, cyroconite holes, can increase ice surface albedo by hiding LAIs from direct sunlight have been widely reported.” Although, more than "increasing" surface albedo, I would say that they “prevent”, or at least “delay”, a further decrease, because they hide LAis that would otherwise reduce the area-average albedo.

Reply: Thanks for your excellent suggestions, we have revised based on you suggestions.

229: How do you calculate the average value and uncertainty of albedo, surface roughness and LAIs concentration at a particular elevation?

Reply: we have measured up and downward shortwave radiation 3 to 6 times (measured more times when weather

conditions is cloudy or changed from sunny to cloudy). The data is quite variable for snow surface under cloudy weather. But it is not sensitive to weather for dirty ice surface.

242: "LAIs decreased from 0.04±0.03g/ cm3 at middle part to 0.003±0.002g/ cm3 at higher elevations (Figure 3i)." This is based only in one sample at 4700 m, if you delete it, you don't have any trend. Did you try any other topographic parameter?

Reply: we measured elevations, latitude and longitude. Slopes and aspect are not measured. Basically, the ice cap is flat. Aspect and slope changed not so great along the main flow line.

247-249: "There was a much higher concentration of LAIs on the uncovered ice surface than snow surface. As a consequence, albedo tended to be low on the ice surface and higher on snow-covered surfaces." This is not only explained by the LAIs. Ice albedo is usually lower than snow albedo.

Reply: Thanks for your suggestions, we revised accordingly.

378-379: "Although we do not have tandem surface roughness and grain size observa- tions, the evolution of surface roughness calculated at 1mm resolution in snow covered period should quite similar with fluctuation trend of grain size evolution." Certainly, you have a correlation between grain size and surface roughness, but surface roughness is not only explained by grain size. Differential melting of the surface could be also important.

Reply: Thanks for your excellent suggestions, we have revised and add the differential melting here accordingly.

423-424: ". . .a significant positive relationship rather than a negative relationship was established over ice surface based on manual and automatic measurements. We expect it is related with abundant LAIs over ice surface at the August one ice cap." This might be explained by the snow patches. See my main comment 1.

Reply: Thanks for your suggestion. In the revised manuscript, we analyzed the pure ice surface without inclusion of patchy snow surface. More detailed results will provided in the revised manuscript. We also want include the comparative measurement of snow grain size and surface roughness data acquired in July of 2020.

448-450: "The performances of the establishes albedo methods either based on sur- face roughness, LAIs or effective LAIs

concentration shows a great improvement over the assumption of a constant mean ice albedo or surrogate variables, such as air tem- perature, accumulated melt and elevation." I don't agree that surface roughness is much better than air temperature or melt to parameterize albedo. Please see main comment 1b.

Reply: We will take it more carefully. In here, we try to say surface roughness and LAIs as surrogate variables show improvement over ice surface. In the revised manuscript, we have add new references which talk about ice surface albedo parameterizations such as Brock (2000) or Jonsell et al. (2003). The upmost ice surface characteristics of this layer are mainly responsible for the observed variability in ice albedo at any given site. The surface roughness and LAIs are surface properties which might more connect to surface albedo than air temperatures or melt amount.

462-464: "Since surface roughness is dependent and sensitive to topography data resolution (Figure 8a), so which resolution is appropriate for snow and ice surface albedo estimation?" Was this part of the objectives? Are you writing about the DEM resolution? Please be more explicit in this section and present this analysis earlier in the text.

Reply: Thanks for your suggestions, we have revised and introduced in introductions. We also revised here accordingly.

496-498: "By using manual and automatic photogrammetric measurements of sur- face roughness, manual LAIs samples and measurement of broadband albedo at the August-one ice cap, we have a general understanding of the surface roughness that controls the albedo of snow and ice surface are quite different." Can you really conclude that surface roughness controls the albedo of snow and ice? See my main comment 1.

Reply: Thanks for your suggestion, we have revised as "surface roughness is a good surrogate variables can be used to parameterize surface albedo ". More detailed will proved in revised manuscript.

505-507: "For snow-covered surfaces, ice particle metamorphism and surface melting and refreezing induced grain size increasing synchronously happened surface rough- ness increasing, which induced decreasing snow surface albedo in melting season." The last part of the sentence suggests that is the increasing surface roughness that induces the snow albedo decrease.

Reply: Thanks for your suggestion, we make mistake here. we have revised it. Snow metamorphism which could induced snow grain size increase, snow surface roughness increase, and albedo decrease. Snow surface roughness increase is not induces the snow albedo decrease.

SUGGESTED TECHNICAL CORRECTIONS

4: Please make the format for last names uniform (sometimes is uppercase and some- times not).

Reply: Thanks for your suggestions, we have revised and revised and uniform the names.

11: influence on melt

Reply: we have revised it.

16: the present study consisted of an intensive. . .

Reply: we have revised based on your suggestions.

19: the middle

Reply: we have revised it, thanks.

19: A detailed analysis indicates that. . .

Reply: we have revised it accordingly.

20: a positive linear

Reply: revised.

21: for snow and ice, respectively

Reply: revised.

22: consider -> considering

Reply: we have revised accordingly.

25: constant mean -> uniform

Reply: we have revised as ‘uniform’ in the revised manuscript.

33: The energy balance and resulting melt rates. . .

Reply: we have revised it accordingly.

33: the meteorological conditions

Reply: we have add ‘ the ‘ in the revised manuscript.

34: the physical properties

Reply: we have add ‘ the ‘ in the revised manuscript.

34: Delete “, which determine glacier melt process”

Reply: Thanks for your suggestions, we have revised based on your suggestions.

35: the melting of glacier -> glacier melt

Reply: Revised.

35: dominated-> controlled

Reply: Revised.

35: in the glacier surface -> at the. . .

Reply: we have revised.

36: Shortwave radiation is the main energy input causing snow and ice melt

Reply: we have revised it based on your suggestions, Thank you.

39: net radiation: do you mean net shortwave radiation?

Reply: we have revised as net shortwave radiation.

45: “Glacier albedo varies much more dramatically than other land covers” -> Albedo varies much more dramatically on glacier surfaces than on other land covers.

Reply: Thanks for your suggestions. We have revised it based on your suggestions.

47: “constantly changing surface characteristics”-> I think that you should explicitly mention snow metamorphism here.

Reply: We have revised based on your suggestions.

47: the solar incidence angle

Reply: we have revised It accordingly

52: accelerate

Reply: Revised.

57: Simulations

Reply: Revised.

59-62: In general, I suggest improving the writing style by making sentences shorter and more fluid. Here, I would suggest something like: LAIs have decreased the surface albedo of glaciers in Qilian mountains to values as low as 0.13+-0.06 during the melting season (LIT).

Reply: Thanks for your suggestions, we have revised it based on your suggestions.

59: Please introduce the Qilian mountains before this sentence.

Reply: Thanks for your suggestions, we have introduced the Qilian mountains in here accordingly.

64: I think that you should start a new paragraph when you mention surface roughness.

Reply: Thanks for your suggestions. We have start a new paragraph to introduce surface roughness.

70: do you mean “first recognized by Kuhn”?

Reply: Yes, here, we have revised it based on your suggestions and make more clear.

71-72: In which way these field campaigns advanced the influence of roughness on albedo?

Reply: Thanks for your question. In the revised manuscript, we will make more clear.

75: Studies. Which ones?

Reply: Studies by Roujean et al. (1992), O’Rawe (1991), and Larue et al. (2019). There we have revised and accordingly.

75: indicated

Reply: Revised.

75: the inclusion

Reply: revised.

76: measurements of albedo? Sorry, this is not clear.

Reply: Thanks for your question, we will revised it more clear.

76: equations

Reply: revised.

77: and sastrugi

Reply:revised.

80: heterogeneous: Please explain better what do you mean by this.

Reply: here we try to express the uneven distribution of LAIs induced differential absorbing of shortwave and melting differences. In the revised manuscript, we revised clearer.

80: of LAIs.

Reply: revised.

83-85: Please improve the structure of this key sentence.

Reply: Thanks for your suggestions, we will revised clearer.

85: the melt season,

Reply: revised.

85: crevasses and

Reply: revised.

86: the direct sunlight

Reply: revised.

88: Please introduce the ice cap more formally. Where is it? You can give the details in the next section, but give at least

some indication here.

Reply: Thanks for your suggestion, we introduce the ice cap and add the location here

90: indicated

Reply: revised.

93: LAIs on ice

Reply: revised.

95: combined effects: This is very interesting, and difficult, how do you isolate both

effects? Please see my main comment 1.

Reply: we are not trying to isolate surface roughness effect and LAIs effect in this study. Studies by Larue et al.(2020) have quantify the impact of surface roughness on albedo on clean snow surface. In this study, we find surface roughness affect ice surface albedo by hide LAIs from direct sunlight. For snow surface, the surface roughness do not affect LAIs concentration. It is very difficulty try to differentiate surface roughness and LAIs effect especially in summer, since other factors such as water content, solar incidence angle, snow grain size, or snow specific area, snow metamorphism affect snow surface albedo.

96: have been rarely

Reply: revised.

92: we investigate

Reply: revised.

93: better understand and simulate. I think that these are very wide and general objec- tives. Can you be more specific?

Reply: thanks for your comments, we will revised based on general comments and make it more specific in the revised manuscript.

106: at the daily scale

Reply: revised.

101: we investigate

Reply: revised.

104: on the middle

Reply: revised.

104: in melting season and accumulation season of 2018 -> in the melting and accu- mulation season of 2018.

Reply:revised

107-108: This is not clear at this point.

Reply: we have revised and make it clearer.

114: Study area is neither data nor methods. Create another section.

Reply: Thanks for your suggestion, we have revised it.

116: the Qilian Mountains

Reply: revised

120: May to September. Mention that this is summer.

Reply: revised

120: How short is summer?

Reply: revised

126: has been observed.

133: This section should be called data collection and image processing.

Reply: Thanks, we have revised accordingly.

137: In some parts of the text you write "we" and in others you write "researchers". Please make it uniform. I would suggest to use an active voice, i.e. "we".

Reply: Thanks, we have revised as ‘we’ in the revised manuscript.

142: several different locations. How many? Make a reference to Figure 1. You don’t have any table in your article. It would be good to have one with the coordinates, number of measurements, etc.

Reply: we have revised and add the number of measurements in the revised manuscript.

142: the top of the ice cap

Reply: revised.

144: the micro scale topography over different altitudes

Reply: revised

145: Physical->You mean topographical in opposition to the turbulent heat fluxes pa- rameter (surface roughness length)?

Reply: Here, we have revised as surface roughness. It is not surface roughness length.

145: was estimated. How?

Reply: The surface roughness is estimated based on equation (2). In the revised manuscript, we have revised and make it clearer.

146: putting->placing a Kipp and Zonen CMP11 radiation sensor

Reply: revised.

152: in an oven

Reply: revised.

156: its operation

Reply: revised.

157: geo-reference: what do you mean?

Reply: we have used a wooden control field with 8 control points on it as control frame to geo-referencing pictures to DEM data.

159-160: “The photography was repeated at three hour intervals from 9:00 AM to 18:00 AM, UTC+7 time.” But later you work with daily means, don’t you?

Reply: we select one of the four sets of photos and merged to produce a 1mm×1mm resolution surface topography. Not all four sets was used to produce surface DEM data, since some of the data sets was affect by fog or too dark to be applied for DEM data.

159: how many different locations?

Reply: we have revised and add the number of 37 locations in the revised manuscript. In the revised manuscript we will include new observations at 20 locations carried out in 2020 over snow surfaces.

168: How did you make sure that the frame stayed horizontally?

Reply: we put the frame over ice or snow surface. The frame is horizontally with ice or snow surface. It make the generated DEM detrended.

185-189: Repetition

Reply: revised.

190: that surface roughness

Reply: revised

190: by directly affecting

Reply: revised

195: from the aerodynamic surface roughness parameter developed by Lettau (1969)

Reply: revised

196: except that we changed the silhouette area facing upwind to. . .

Reply: revised

203: Is V the volume of the spoon?

Reply: Yes, V is calculated based on the spoon, the spoon is a 20*20cm*10cm box without cover and bottom. The sample area is 20*20cm, the depth is measured ever time base on the insert depth.

210: We assumed that

Reply: revised

220-224: This sounds like methods to me. Is this the Results section? See my minor

comments.

Reply: we have revised it and add to the methods part.

225: You also have temporal variability here, not only spatial. Please change the title.

Reply: revised.

226-227: Again, I suggest shorter and more fluid sentences, something like:

We found a patchy snow cover with many cryoconite holes on the glacier terminus (~4600 m) at the date of the first field trip (July 12).

Reply: thanks for your suggestion, we have revised accordingly.

230: Be consistent with the digits, i.e. 5.49 cm = 5.5 cm.

Reply: revised

244-245: On July 12, surface. . .

Reply: revised.

246-247: the transient snowline retreated up-glacier.

Reply: revised

247-248: On what plot do you base that sentence

Reply: We have revised and differentiate snow and ice covered surface in the revised manuscript in Figure 3. In the revised manuscript, we could find snow covered surface LAIs concentration is much lower than ice surface.

248: bare ice surface than on snow.

Reply: revised

249-250: Albedo didn't really increased over time.

Reply: we try to express the increasing trend of albedo from terminal to top. The albedo is not increase over time. We will revised it and make clearer.

251: minimal albedo: Do you mean the season minimum?

Reply: The minimal is not precise, we have revised. The albedo in August is very low when the ice cap if all bare ice from terminal to top

251: "but it also did not increase"-> and it did not show a clear trend with altitude

Reply: revised.

259: This is almost the same title as the previous sub-section.

Reply: we have revised as Automatic observation of surface roughness and albedo

262: October 17

Reply: revised.

270: mostly bare ice with occasional snowfall events

Reply: revised

285: was mainly induced

Reply: revised

259: The title of this section is very similar to that of section 3.

Reply: we have revised and differentiate with section 3.

298-300: Snow surface albedo and the corresponding surface roughness are analyzed using. . .

Reply: revised.

301: functions

Reply: revised

301: observations

Reply: revised

304: Please use the same coefficient in the text and the figure (either r2 or r).

Reply: revised

321: What is a patchy ice cover? A bare ice surface covered by snow patches or by debris patches?

Reply: we have revised as snow patches

322-323: This is not clearly written. Better say that the patchy snow cover is the limit between the two periods that you identified.

Reply: Thanks for your advances, we have revised accordingly.

324: the relationship

Reply: revised

324-325: Delete “without consider surface roughness effect over LAIs concentrations.”

Reply: revised.

328: Do you mean 5d?

Reply: we make mistakes here, we have revised.

328: manually

Reply: revised.

331: power function, do you mean linear function?

Reply: revised.

333: that considering

Reply: revised

334: . . .albedo during the snow period.

Reply: revised

334: It indicates

Reply: revised

365-373: All these lines can be removed, moved to the introduction, or condensed.

Reply: Thanks for your suggestion, we have revised accordingly.

369: Meltwater

Reply: revised

378: should be quite similar

Reply: revised

380-383: This should be mentioned earlier in the text.

Reply: revised.

386: it means that

Reply: revised

388: LAIs are another critical factor affecting snow albedo

Reply: revised.

392: “increasing surface roughness decrease albedo” But, only in your snow melting

Period

Reply: revised.

396-400: This should be in results.

Reply: revised

400: What is the explained variance of each variable?

Reply: we have add the explained variance of surface roughness and LAIs in the revised manuscript.

402: During the accumulation season

Reply: revised.

403: Please explain better the observed snow metamorphism in the accumulation pe- riod

Reply: Thanks for your comments, we have revised and add more citetations about snow metamorphism in the accumulation period in the revised manuscript.

403: During the accumulation period

Reply: revised.

413-421: This belongs to the introduction

Reply: Thanks for your suggestion, we have revised accordingly

430-433: Please re-write this sentence in a clearer way.

Reply: Revised, we have revised and re-write it clearer.

437: over smooth ice -> than smooth ice?

Reply: we have revised 'over' as 'than' .

447: are based

Reply: revised.

TABLES

There are no tables in the article. At least one summarizing the distributed measure- ments would be useful.

Reply: Thanks for your suggestion, we will add tables introduce automatic observations and manual measurements involved in this studies.

FIGURES

Figure 1: Please add an inset showing the ice cap and the Qilian Mountains in the Tibetan Plateau.

Reply: Thanks for your suggestions, we will revised based on your suggestions, and add the cap cap location and the Qilian Mountains

Figure 2: Why is important to have rain or fair weather? Provide a brief explanation.

Reply: Thanks for your suggestions, we find rough ice surface developed in cold and sunny day, and warm and cloudy or rain day favors smooth and dark ice surface. We will explain it in the revised manuscript.

Figure 3: I would place altitude in the x-axis. Elevation should not be a dependent variable.

Reply: Thanks for your suggestion, we will revised based on your suggestions, we also differentiate snow and ice surface in the revised manuscript based on referee 1's suggestions.

Figure 3: In the text of this figure, you write several times that there is a relation with the altitude, but based on your data, this is true only for 3a and 3b.

Reply: The relation with altitude is established based statistical significance.

Figure 4: Make a uniform tick spacing in the x-axis. Example, 1-07 15-07, etc.

Reply: Thanks, we will revised based on your suggestion.

Figure 4: From this plot is evident that there were 3 or 4 snowfall events in August. See my main comment 1.

Reply: Yes, there are snowfall events in August, we have add these short period snow surface roughness and albedo as snow covered surface rather than bare ice cases. During this snowfall period, the snow melt quickly, and snow surface roughness also changes fast.

Figure 4: Add a line in panel a to show when were the pictures taken.

Reply: Thanks for your suggestions, we have add the panel date in the revised manuscript.

Figure 4: Show the dates of the pictures in the pictures.

Reply: revised

Figure 5a: Note that for low albedo (<0.4) you can get very different surface roughness (1-6 cm).

Reply: Low albedo for snow surface are all patchy snow covered surface. Patchy snow shows great surface roughness differences. The thick snow patches usually shows larger surface roughness, and thin snow patches shows smaller surface roughness.

Figure 5: Consider the use of different markers (in a-b and c-d) to reduce the number of panels. As in Figure 4s.

Reply: Thanks for your advices, we will revised based on your suggestions.

Figure 5: I would strongly suggest using only one paragraph to describe one figure. This is a big help for readers.

Reply: Thanks for your suggestion, we will adopt your advice.

Figure 5: How many different sites are included in the manual measurements shown in this figure?

Reply: we have 37 sites of surface roughness observations. In the revised manuscript, we have add these information in the revised manuscript.

Figure 6: Can you merge both plots in one panel by using different markers? A loga- rithmic scale might be useful.

Reply: Thanks for your suggestions, in the revised manuscript, we have revised and talk snow and ice surface separately in different figures. It will be clearer.

Figure 7: Apart from the high albedo for low surface roughness, there is a poor relation between the two variables. Maybe move to the supplementary?

Reply: In the revised manuscript, we have discussed snow metamorphism in cold season. I think it is an interesting topic which could be a complementary for melting season.

Figure 8: What is the difference between these pictures and those shown in Figure 1s?

Reply: In Figure 8, we calculated surface roughness under different resolutions. Figure 8 shows rough surface are more sensitive to resolution than smooth surface. It means ice surface are more sensitive to snow surface.

Figure 1s calculated surface roughness at 1mm resolution for all manual and automatic observations.

In Figure 8, and figure 9, we try to find under what resolution, the calculated surface roughness have more significant statistical significance with albedo. We find finer resolution of than 50 mm and 100 mm resolution is recommended for ice and snow surface roughness calculations.

Figure 2sa-3sa: How many different sites did you use to build this plot?

Reply: we have 37 manual observation sites. The automatic observation in melt season include 65 days. We applied 63 plots of automatic observations. We have revised and include these information in the revised manuscript.

Figure 4s: This is a very nice figure, because it shows both periods in the same plot. Can you move this figure, or a similar one, to the main text?

Reply: Thanks for your suggestion, we will revised accordingly.