

Effects of surface roughness and light-absorbing impurities on glacier surface albedo, August-one ice cap, Qilian Mountains, China

The authors would like to sincerely thank the referee for the valuable, constructive and for opening the discussion. Referee' s detailed comments certainly helped to improve the manuscript. The corresponding changes and refinements have been made in the revised paper and are also summarized in our reply below.

Reply to comments from Anonymous Referee #1

General Comments

Authors measured the spatial and temporal surface albedo variations over the Qilian mountain glacier. They analyzed the albedo fluctuation considering the presence of small-scale surface roughness and light-absorbing impurities. They proposed an appropriate parametrization of albedo with these two parameters. Reviewer gives a certain appreciation for the reasons that authors show a strong impact of these contributions on the surface albedo at different location (snow cover, ice cape, bare ice) using an extensive dataset of in situ measurements. However, unfortunately, the organization of the manuscript and presentation of the data and results are too hard to follow. In particular, it is not clear what is the novelty of this paper compared on earlier work of Warren, Cathles, Pfeffer, Lhermitte and many others. The explanations and some results are insufficient. For now, the paper is not a significant advance or contribution, even though it has the potential with interesting measurements. In addition, the structure of the paper can also be much improved and the paper can be condensed. Substantial revisions are needed before having a merit for the publication in the TC. Reviewer is particularly concerned about the fact that no SSA measurements were acquired and the impact of the variation of the snow grain sizes with the metamorphism is barely spoken. It is difficult to believe in an exhaustive study of the impact of surface roughness/LAP on albedo without having an idea of the impact of snow metamorphism, since these 3 parameters are strongly linked in albedo variations. Authors should carefully confirm the results by including this analysis, maybe by adding a section speaking of this parameter (or using existing values of snow grain size published in the literature over this region). Moreover, reviewer suggest to modify the structure of the manuscript to present the results clearer. The organization of the manuscript and presentation of the data and results need some improvement. Indeed, sections are mixed, and there are many repetitions that can be easily avoid. The protocols of measurements are not enough detailed whereas it is very important to be confident on the measurement analysis. Finally, a deep revision of the english grammar has to be done to make the lecture easier.

Reply: Thanks for your comments. We have revised the manuscript based on your suggestions and comments. We have revised the manuscript substantially: the structure of the paper has changed to present the results of snow part and ice part clearer. The measurements of albedo are introduced in detail. We add snow metamorphism and corresponding surface roughness changed in the revised manuscript by adding detailed analysis of field observations and manual

photography(We carried out field observations of snow grain size and corresponding surface roughness based on you suggestion in July of 2020 in August-one ice cap). Especially the manual photogrammetry could give provide direct visual evidence of old snow have rougher surface over fresh snow. The revision of the English grammar are also done to make the lecture easier to read.

Specific comments :

1) The english has to be carefully corrected. Reviewer tried to highlight some errors in the 'technical corrections' section but there are many english mistakes making the reading difficult.

Reply: Thanks for your comments. We have revised the English mistakes based on you 'technical corrections' suggestions and polished by language services.

2) Sections have to be read carefully to remove repetitions and to make the conclusion clearer. For example, it is often that in a 'snow section' authors speak about ice albedo measurements. Moreover, reviewer suggests to add small sentences at the end of each section to highlight the result. For example 'over ice cape, the albedo increases while the surface roughness increases and the LAI decreases'.

Reply: Thanks for your suggestions. We have revised based on your suggestions, and add small sentences at the end of each section to highlight the result.

3) Explanation and results are insufficient: scatter plots presenting field observations have to be followed by physical analysis, according to what has been shown in the literature. Deeper explanations are needed to better understand the novelty of this work.

Reply: We have add physical analysis according literature of similar research or relevant topics. This work not only considers surface layers snow or ice surface characteristics (surface roughness), but also considers LAI, and considers these two factors as important surrogate variables to explain more albedo variation than formerly used parameters. We have cited works such as Jonsell et al. (2003) who mentioned that uppermost surface ice layer, including its density, crystal structures, surface roughness, impurity content and stratification and SSA, are subject to continuous changes and mainly responsible for the observed variability in ice albedo. In this work we abstract the surface layers surface roughness might be an effective surrogate variable to be applied in albedo parameterizations.

4) Figures need to be well called in the text, it is hard to follow the analysis when the text does not refer to the right figure. Moreover, reviewer suggests small changes in the graphs to be clearer (in the 'technical corrections' section). For example, It could help the understanding if authors replot the Figure 3 with different symbols/colors associated to 1) measurements taken over snow cover 2) measurements taken over ice surface.

Reply: we have revised accordingly, in the revised manuscript, we differentiate the manual and automatic observations, we also differentiate the snow and ice surface. We also include key meteorological air temperature and precipitation information in the revised manuscript.

5) As said in the 'General comment' section, it is not clear what relationships have been high lighted in this paper. There is a strong relationship between SZA/SSA/LAI/roughness/albedo.

The impact of the solar zenith angle and SSA variations needs to be analysed deeper.

Reply: Thanks for your excellent suggestions. We have add SSA, LAI, SZA effect in analysis. The impact of the solar zenith angle are mentioned in the observation part. In the August-one ice cap, the ice surface is not sensitive to zenith angle because of high concentration of LAI over surface and melt water. The snow surface is sensitive to zenith angle. For that reason, we calculated daily albedo from the integrated sum of incoming and outgoing shortwave radiation of only 10min albedo data taken when zenith angles were less than 60°, in an effort to minimize solar zenith angle effects.

6) The Protocols/Measurements sections need more explanations. For example, the accuracy of the instruments should be precise, and references presenting the instruments are missing. Reviewer has some questions about the protocol performed to acquired albedo measurements: How do you estimate the direct/diffuse part of the albedo? Measurements are acquired in clear sky conditions? At which height was located the sensor (ie what is the area actually seen by the sensor) ? What if you measure the aluminium square in addition to the snow surface?

Reply: we have detailed the observation in the revised manuscript. We do not differentiate direct and diffused part. The observation include cloudy and clear sky conditions. The sensor is 1m above surface for manual observations, and 1.5m above surface for automatic observations. The surface roughness is measured first. After then, the aluminum square is moved and albedo was measured.

7) There is a problem of unity in equation 2, epsilon is in cm while the h^* variable is in meters.

Reply: We have revised accordingly.

8) Nothing is new in the discussion part, except the parametrization method. Authors insist on the fact that it is physically-based, but it is not, it is fitted over the area so it is empirical. The sections should be better organized, this is very confusing. Moreover, the new parametrization should be investigated deeper, the associated error needs to be estimated for each type of surfaces (using control points over the snow covered surface, the ice surface).

Reply: we have revised the physically-based as surrogate variable. The validation of new parameterization method was not present because of lake snow and ice surface LAI observation in 2019.

Technical corrections

L13: 'Fluctuations in surface albedo are due primarily to variations in micro scale surface roughness (ξ) and light-absorbing impurities (LAIs) in this region.' => Please add the SSA+solar zenith angle

Reply: Thanks for your suggestion. We have add SSA and solar zenith angle in the abstract and revised as' Fluctuations in surface albedo are due primarily to variations in micro scale surface roughness (ξ), snow surface area, solar zenith angle and light-absorbing impurities (LAIs) in this region.'

L.22: by consider => by considering

Reply: we have revised accordingly.

L.43: english => if we want to improve the accuracy of the energy budget estimate

Reply: Thanks, we have revised accordingly

L.52: can accelerates => can accelerate

Thanks, we have revised accordingly.

L.54: which enhance => which enhances

Thanks, we have revised accordingly

L. 60: Please rewrite: 'For the Qilian mountain glaciers, where the measured daily mean albedo decreased to the lowest of 0.13_0.06 due to the effect of LAIs for four glaciers observed during melting season'=> For example: For the Qilian mountain glaciers, the measured daily mean albedo decreased to 0.13_0.06 due to the effect of LAIs for four glaciers observed during melting season

Reply: Thanks for your suggestions, we have revised as 'For the Qilian mountain glaciers, the measured daily mean albedo decreased to 0.07~0.13 due to the effect of LAIs for four glaciers observed during melting season (Jiang et al., 2010; Liu et al., 2014; Qing et al., 2018; Sun et al., 2018)'

L63: Please put this sentence before, in the section above: 'As the snow melts, insoluble LAIs are retained at the snow surface, so concentrations of LAIs in surface snow increase with snow melt, further reducing snow albedo (Doherty et al., 2013).'

Reply: Thanks for your suggestion, we have revised and delete this sentence here accordingly. We add this sentence in the before section.

L75: Studies have indicates => Studies indicated

Reply: Revised.

L80: the distribution LAIs=> the distribution of LAIs

Reply: Revised

L85: Surface roughness structure => 'Surface roughness features' seems more appropriate.

Reply: Revised

L88: 'During the past 5 years the August-one ice cap has become darker due to the accumulation of LAIs' => Please add a reference.

Reply: Thanks for your suggestion, we have revised as' Successive time-lapse photography of the August-one ice cap has indicate that ice surface become darker due to the accumulation of LAIs in melting season (Qing et al., 2018).'

L90: has indicate => has indicated

Reply: revised

L97: we try to investigate => we investigated

Reply: revised

L100: at different altitudes and times => and resolution? Or please add the resolution. => This section needs to be rewrite to present clearly the plan of your study. For example: 'first, to study the spatial variation.../second: : : Considering the following structure of your paper: 1rst objective: spatial variation, just the relationship between manual photo/lai/albedo 2nd objective: temporal variation.

Reply: Thanks for your valuable suggestion, we have revised. This paragraph is revised as''

L100: Combine with => these measurements were combined with

Reply: we have revised it.

L108: based on => using only : : : or both : : :

Reply: we have revised 'either' as 'only'.

L118: It ranges in elevation => the elevation ranges from : : :

Reply: Revised.

L125. The glacier becomes darker with years? It was said in the introduction. Please clarify.

Reply: we have 3 automatic time lapse photography site distributed over the August-one ice cap from terminal to top. The ice surface LAIs (most cryoconites) concentrated over ice surface in summer. For the last 6 years, no accumulation was observed even at top of the ice cap, the concentration of cryoconites has increased because of negative annual mass balance.



Figure 1 Cryoconites covered ice surface (grey part is sun dried cryoconite, brown part is wet cryoconite).

L134: Please specify if you are talking about 3D photogrammetric acquisitions or 2D photogrammetry, and the references need to be adapted (for instance, Manninen = 2D acquisitions with a board, Irvine-Fynn = 3D acquisitions)

Reply: we have revised as '3-D photogrammetry'

L139: of $_1.75 \text{ m}^2$ => it is a very small area, is it representative ? How was the area chosen?

Reply: The August-one ice cap is a small ice cap without obvious surface movement. The cap surface shows no relevant morphologies. Structures such as crevasses, cracks, and seracs are not formed. Only water channels formed over ice surface with very small proportion. In this study we selected all ice surface types except water channels. The selected snow or ice surface include smooth snow covered surface, partial snow covered surface, cryoconite holes, weathering crust and smooth ice surface.

In the revised manuscript, we have add the selection standard for manual photogrammetry on 12 and 25 July, and 28 August.

L 139: Please clarify: 'by surrounding the target area of snow or ice surface', do you mean by turning around? If yes, what is the space between each step/picture?

Reply: Thanks for your question, we have revised as 'Seven to fifteen photos were taken at each survey site by surrounding the portable aluminum square. At each cardinal direction of aluminum square, we took 2 or 3 photos to cover the target area. Rough ice surface such as cryoconite holes need take additional photos close to nadir angle.'

L143: Please specify the number of sampled areas.

Reply: we have revised 'several' as '37'

L147: 'Glacier surface albedo was calculated from measurements of up and downward

shortwave radiation.’ => how were acquired the up and downward shortwave radiation? Please add details about this protocol and sensor.

Reply: we have revised it as ‘ **After manual photogrammetry and removal of aluminum square, a Kipp & Zonen CMP11 albedometer consists of two identical pyranometers that measure the incoming global solar and the radiation reflected from the surface below. Albedo is the ratio of the two irradiances. Pyranometer is sensitive to radiation in the wavelength range 0.285 to 2.8 μ m. The albedometer was mounted on a camera tripod 1m above glacier surface and readings were made in a horizontal plane by means of a spirit bubble.**’

L160: ‘For automatic photogrammetry’: how were process the pictures? With a software? Did you use only one reference target? Did you use control points? What is the error of the final DEM? Please clarify.

Reply: we have used Agisoft to acquire the 1mm resolution DEM data. For manual photogrammetry, the reference control frame have 4 control points and 4 check point (eight crossshaped screws on the aluminum frame). For automatic photogrammetry, we have 4 control points and 3 control points over the control frame. The error of the final DEM have provided in the revised manuscript.

We have revised as ‘ For manual photogrammetry, we put the aluminum frame horizontally over the ice surface, the plot is detrended by setting 4control points and 4 check points at z axis of the same values. For automatic photogrammetry, the control field of wooden frame was also laid horizontally over the ice surface that lowered as the ice melted and maintained a horizontal position between the control field and ice surface. 4 control points and 3 check points are on the wooden frame was applied for georeference and precision check. Both manual and automatic photographs were imported into the Agisoft Photoscan Professional 1.4.0 application, which produced plot-surface point clouds and generated a detrended micro scale DEM of 1 mm resolution at plot scale. Based on the Agisoft PhotoScan processing report, automatic photogrammetry average geo-referencing errors fluctuated at around 1 millimeter. Total root mean square error (RMSE) of the automatic check points was 3.62 ± 1.6 mm. Standard deviation of control and check point errors were all within 15mm. Manual measurements average geo-referencing errors fluctuated at around 1 millimeter, RMSE of 4 check points was 0.99 ± 0.3 mm, vertical accuracy was 0.66 ± 0.3 mm. Standard deviation for x, y and z axis were all within 5mm’

Figure 2: Please rename a) and b) because they have the same caption. + remove ‘[Figure 2]’ in L 181 => please removed this typo for all figures.

Reply: Thanks for your suggestions, we have revised and rename a) and b). [Figure 2] also removed in the revised manuscript.

L185: repetition => ‘Ice surface albedo is very sensitive to the LAIs concentration over ice surface.’ Please add a sentence of transition, for example ‘the surface roughness features impact the distribution of the snow impurities’.

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

We revised as ‘The surface roughness features impact the distribution of the glacier

surface impurities’

L190: by direct => by directly affecting

Reply: revised.

L 192: There is a problem with the unity of equation 2. epsilon is in cm while the h* is in meters?

Reply: We have revised ‘m’ as ‘cm’ for the h*.

L192 : equation 2 is the first equation => it is equation 1 here. Please correct the other equation notations in the text.

Reply: we have revised accordingly.

L 195: ‘from Lettau (1969) developed aerodynamic surface roughness’ => ‘from Lettau (1969) who developed aerodynamic surface roughness...’

Reply: Done

L198: adopted => adapted

Reply: Done

L202: Please add a reference to introduce this metric.

Reply:Done

L205: This sentence needs to be rewrite: For rough ice surface means more surface area and less concentration of LAIs over ice surface, I don’t understand.

Reply: we have revised.

L207: by consider => by considering

Reply: Done

L207: this is a new metric? If yes, please change ‘defined’ by ‘introduced’

Reply: It is a new metric, we have revised ‘defined’ as ‘introduced’ accordingly.

L220: ‘For that reason, we used only half-hour albedo data taken when zenith angles were less than 60_’ => Did you test the accuracy of the sensor considering the zenith angles? Is this a known angle of limitation? Or please add a reference.

Reply: we analyzed the the Kipp & Zonen CNR4 10-min up and downward shortwave radiation data. When the zenith angles are larger than 60 degree, the 10 min data shows great fluctuation especially for snow covered surface. For bare ice, especially when it was smooth and dirty, the zenith angle have very limited effect over albedo. Other studies also suggest measurement under

L222: from 11:00 to 17:00 o’clock => what range of zenith angle it is? It strongly depends to the date of your measurements + elevation of the studied site. Please clarify. => It seems that this section should be written in the protocol of albedo measurements, not here in this ‘result’ section.

Reply: we have revised this part and add in the ‘2.2 data collection’ section

L225: field investigation => is it based on your automatic photogrammetric measurements? Please clarify.

Reply: We have revised ‘field investigation’ as ‘manual observation’. The sentence has revised as’ On July 12, manual photogrammetry alone the main flow-line of the August-once ice cap indicated that at the ice cap terminals of 4600m’

L230: Surface roughness => replace it by ‘the associated epsilon measurements decreased ...’

Reply: Thanks for your suggestion, we have revised as’ The associated ξ measurements decreased decreased from $5.49 \pm 1.5\text{cm}$ to $0.5 \pm 0.6\text{cm}$ as altitude increased’

L236: 'Surface roughness fluctuated between 1.4_0.4cm to 3.3_1.1cm; An increasing trend of surface roughness could be detected as altitude increased (Figure 3e). ' => please, inverse these two sentences to be clearer.

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

L245: 'surface roughness and LAIs decreased as altitude increased.' => not clear because it is only the case in July. In August 3: surface roughness increased as altitude increased and there was some snow cover at the top of the ice cap. Please clarify.

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

L247: 'There was a much higher concentration of LAIs on the uncovered ice surface than snow surface' => I don't understand the 'much', the trend is not so strong? It could help the understanding if you replot the Figure 3 with different symbols/colors associated to 1) measurements taken over snow cover 2) measurements taken over ice surface.

Reply: Thanks for your suggestions, we have revised Figure 3 based on your suggestions.

L248: 'As a consequence, albedo tended to be low on the ice surface and higher on snow-covered surfaces.' => be careful with this sentence, this is also mainly due to SSA values that strongly impact the albedo. There is a strong relationship between SSA/LAI/roughness/albedo. Please rewrite this sentence.

Reply: we have revised accordingly.

L251: repetition with L240-243 => this section needs to be re-structured in order to remove repetitions and to be clearer on conclusions.

Reply: we have rewrite this part and make it more clearer.

L260: 'The automatic measurement setup in the middle of the ice cap' => 'The automatic measurement setup was in the middle of the ice cap'

Reply: Done.

L.264: 'Intermittent snowfall decreased surface roughness and increased albedo' => you should add that it is because there is fresh snow, and fresh snow has high SSA, inducing a high albedo.

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

Figure 4: It could be clearer if you add the intermittent snowfall with vertical lines + air temperatures (to know when it is melting).

Reply: Thanks for your excellent suggestion, we have revised Figure 4 based on your suggestion.

L265: 'When snow began to melt'=> when is it ? How do you measure that? Do you have air temperature or snow surface temperature? If yes, you could add it on Figure 4 (see comment above).

Reply: we have meteorological observations at top of the ice cap including precipitation, surface temperature and air temperature. We have revised Figure 4 and add air temperature accordingly.

L276: 'When the snow melted, leaving patchy snow cover, surface roughness increased and albedo decreased quickly to around 0.3_0.05 within two day'. Here again the sentence needs to be rewrite: snow melting = lower SSA = lower albedo, the decrease of albedo is not only due to the increase of surface roughness and LAI. Please clarify.

Reply: we have revised based on your suggestions.

L276: 'from September 4 to 15, ice surface roughness fluctuated and increased to 2.63 cm on September 13.' => not clear, is it increasing from september 4 to 15, or for September 4 to 13?

Reply: we have revised it.

L277: 'Ice surface micro scale structures of cryoconite holes hidden LAIs from direct sun light.' => this sentence needs to be detailed to highlight the observations. => Reviewer suggest to recall this section (for example '3- Field observations'), since it details all the field observations, but not clearly enter in the physical analysis of the relationships between LAI/roughness/albedo. The analysis should include SSA variations. Even if no measurements were taken, it has to be mentioned (relating to the snow type of the area for example).

Reply: Thanks for your suggestion, we have revised based on your suggestion

Figure 5: Please rewrite the x axis 'Surface roughness (cm)' with the epsilon metric.

Reply: we have revised accordingly.

L301: Figure 2s => I am not sure this figure provides a lot, since it is well resumed in Figure 5a. In Figure 5a, the measurements taken manually and automatically should be separated by two different symbols to be clearer.

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

L302: 'The combined manual and automatic scatter diagrams of Figure 5a display a significant negative power function between snow surface roughness and snow albedo (Figure 5a, $r=0.82$).' => this is a repetition.

Reply: we have revised this part accordingly.

L314: Figure 3s => same as above, the Figure 5b gives approximately the same information. Authors could put different symbols for manual/automatic measurements on Figure 5b. Figure 4s: snow, patchy snow and bare ice surface => In the 'data and methods' section you should defined this terms. How do you classify an area as a 'patchy snow'? Is there a quantitative measurement of the proportion of snow in the area, or is it qualitative? How do you distinguish areas with very dense snow surface to ice surface? Please clarify.

Reply: Thanks for your excellent questions. During filed observations, the albedo or roughness measurement is very sensitive to the snow covered and ice covered proportion on plot scale. In July of 2018, surface melt induced ice surface firstly appeared at terminal of glacier surface. The patchy snow cover formed a belt which shift upward in the melting season until all snow disappeared In August of 2018. A glacier surface is classified as patchy snow cover based on uncover of old dirty ice layers which induced very rough surface. In this study, we only have qualitative measurement based on the manual observations. In Figure 4c, we could tell it is patchy snow cover. We have add information in the 'Data and methods' section to clarify difference of snow, patchy snow and ice.

L 324: 'Scatter plots of Figure 5c and 5d shows relationship between C LAIs and albedo' => Reviewer suggests to introduce a new section dedicated to LAI-albedo relationship, or to separate the section to put the analysis of the LAI-albedo relationship over snow surface in the 'snow surface section', and over ice surface in this 'ice surface melting season'.

Reply: Thanks for your excellent suggestions, we have add snow surface LAI-albedo relationship to the 'snow surface in melting season' section. The ice surface LAI-albedo

relationship to the ‘ice surface in melting season’ section.

L325: ‘LAIs concentration is lower than patchy snow surface’ => ‘ LAIs concentration is lower than the one measured over patchy snow surface’

Reply: Done

L327: Figure 4c => Figure 5c, and Figure 4d => Figure5d Please a particular attention should be taken on the notation of Figures in the text, this is confusing.

Reply: We have revised accordingly.

L329: Please introduce a new section, or reorganise this section into the ‘snow surface section’ and the ‘ice surface section’.

Reply: we have revised accordingly.

L329: ‘the effective LAIs concentration of C_{eff} ’ => ‘the effective LAIs concentration (C_{eff})’
‘ by considers roughness effect’ => ‘by considering roughness effect’

Reply: Done.

L330: C_{eff} is estimated based on equation (4). => this is a repetition

Reply: Done.

L334: ‘It indicates that the Ceps concentration IS not affectED by surface roughness.’

=> english L335: ‘Equation (3) is more appropriate to calculate LAIs concentration than equation (4) over snow surface.’ => I don’t understand. Do you mean ‘to retrieve LAI concentration directly from albedo measurements’? Please clarify.

Reply: Here we try to express the view that microcale snow surface features do not hidden snow surface LAIs like ice surface does. In the revised manuscript, we have revised it.

L339: ‘by consider surface roughness effect over not consider it in Figure 5d’

=> english L341: ‘It means equation (4) estimate C_{eff} could explain more ice surface albedo than equation (3) calculate C LAIs .’ => please clarify. Do you mean: could explain ice surface albedo variations?

Reply: Yes, we mean equation (4) could explain ice surface albedo variations than equation (3). In the revised manuscript, we have revised it to be clearer.

L352: English mistakes

Reply: Done.

L354: ‘In accumulation season, except snow particles metamorphism process, constant blowing snow and intermittent snowfall was the main reasons which induced surface roughness fluctuation;’ => More explanations are needed. In this Result section: the english has to be carefully corrected, some sections has to be restructured, the field observations and scatter plots have to be followed by physical analysis, according to the litterature, with more explanations. Figures need to be well called. Some changes in the graphs are suggested to be clearer.

Reply: Thanks for your suggestions, we have revised this section accordingly.

L380: ‘The grain size is one of the most critical factors affect snow albedo’ => ‘The grain size is one of the most critical factors affect ING snow albedo.’

Reply: Done

L385: ‘which is very similar with scatter plot of surface roughness and snow albedo provided in this study in Figure 5a and Figure 7.’ => Please specify if this studies worked with the same snow type as you.

Reply: We have revised it to wet snow type.

L386: 'It means surface roughness as substitute of grain size is quite suitable for snow surface albedo explanation and parameterization at millimeter scale' => Please be careful with this conclusion, the study areas are not the same. To conclude this you should have both measurements (ssa and roughness) at the same site, at the exact same time (same sza) and over a dry and clean snow (no impurities, no liquid water content). Please clarify. Several contributions affect the albedo, and it is very difficult to separate each contribution to better understand/quantify their impacts on the albedo.

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

L388: english L406: 'We expect that different mechanism of surface roughness evolution over melting season and accumulation season are the main reasons of different statistical relationship.' => This is not the main reason, the SSA variation also plays a strong role. Please clarify.

Reply: We have revised this part accordingly.

Section 7.2: The name of the section should be changed: authors speak about macro-scale surface roughness effects in this section, and in the section before it was at millimeter-scale.

Reply: we have revised and not mentioned macro scale roughness effect in this part and only talks about micro scale surface features effects over albedo.

L415: 'more incident radiation is absorbed by the slope facing the sun than by the slope facing away from it.' => this is not the only reason (see Warren et al 1998). The main reason is that photons are trapped between cavities, which increases the chance of a photon to be absorbed. Please clarify and detail the physical analysis.

Reply: Thanks for your suggestions, we have revised it and add photons trapped effect for rough surface.

L430: filed investigation => english L430-433: Please rewrite the sentence, I do not understand

Reply: we have revised accordingly, the revised part was' Additionally, field investigations over mainly flow line across the August-one ice cap find protrusions on the ice surface visually have less LAIs over depressions. The LAIs concentrated in depressions rather than evenly distributed over rough ice surface reduced its absorption of solar radiation effect (Figure 8e).'

L441: 'Rough surface means lower concentration of LAIs and high albedo over smooth ice surface with heavy loading of LAIs and low ice surface albedo.' => this is confusing to speak about rough surface of a smooth ice surface.. how do you define a smooth ice surface? What is the scale of roughness features that you are talking about? Please clarify.

Reply: we have revised and clarify that we are talking about microscale surface features.

=> this is very confusing between Sections 7.1 and 7.2 => when are you talking about ice surface and snow surface? For example: the first section of the section 7.2 is talking about snow surface (see the litterature), and not the ice surface. Please clarify.

Reply: we have revised and add snow surface to the Section 5.1, and ice surface to the Section 5.2.

L447: 'Most of the established and widely used snow surface albedo parameterization ARE either based on snowpack age, snow depth, snow density, air temperature' => english => Please add the SSA and SZA (see the litterature of Kokhanovsky) => This sentence should be

put in the section 'snow surface', not 'ice surface'.

Reply: we have revised and removed snow part to the 'snow surface' section.

L450. Please add a reference

Reply: we have revised accordingly.

L451: 'We expect the new parameterization methods provides' => english 'are more physically based than some of the studies presented.' => What new parametrization? Please refer to the equation here. (as equation 5 but for ice surface) This sentence needs to be rewritten: this is not a physically based parametrization, it is empirical. Indeed your equation 5 strongly depends of your study site and your measurements.

Reply: Thanks for your suggestions, we have rewritten this part and make it more clear than before.

L466: 'For snow covered surface, the coefficient increases quickly from -0.67 to - 0.74 when 1m plot resolution increases from 333.3 mm to 200.0 mm' => but the Figure 8a shows a very flat and smooth snow surface. Please clarify the studied surface.

Reply: we have clarify in the revised manuscript, the snow covered surface actually include flat surface and rough partially snow covered surface. The statistical between surface roughness and albedo include partially snow cover and flat snow surface. It could be the reason the snow surface roughness and albedo still sensitive at around 100mm resolutions.

L485: 'This could be a practicable way to parameterize surface roughness and albedo on a whole-glacier scale' => Please add some details. It could be interesting to apply the method proposed by Smith et al 2016 here, to estimate a temporal mean albedo at the whole-glacier scale.

Reply: we have revised accordingly.

Section '7.3 Glacier surface albedo parameterization at whole-glacier scales based on surface roughness' => the title needs to be changed since you investigate the sensitivity of the albedo relationships at a plot-scale, but not at the whole-glacier scale in this section. => Moreover, please rely your analysis with the litterature (Irvine-Fynn et al 2014; Smith et al 2016 ..) to clarify what is the novelty of what you propose. => It could be interesting to estimate the LAI coverage with your photogrammetric acquisitions as Takeuchi et al 2018.

Reply: we have revised the title as 'Glacier surface albedo parameterization based on surface roughness'.

In the revised manuscript, we talk about micro scale surface roughness effect and macro scale surface roughness effect. We talked about this manuscript's merit and deficiencies of the article.

L497: 'we have a general understanding of the surface roughness that controls the albedo of snow and ice surface are quite different.'

Reply: we have rewrite this part accordingly.

=> english L502: 'necessity to consider'

=> english L504: 'Surface roughness seems play a quite'

=> english L535: 'field data of LAIs, surface roughness and albedo need to collect to help us to present more detailed analysis and modeling research about surface roughness and LAIs at micro scale over ice or snow surface energy and mass balance process.'

=> SSA measurements should be acquired too.

Reply: Thanks for your valuable advices, we have revised and revised accordingly.