

AUTHOR COMMENTS

The authors thank the Reviewer and Editor for their constructive comments and corrections that have increased the scientific quality of the manuscript and its clarity.

Here we present our answers to the reviewer's comments. In particular, the manuscript has been mainly modified in the classification method for glazed snow detection. Now, the methodology is more objective, based on a supervised classification and it is provided with an accuracy assessment. In addition, we now display a comparison between different combinations of parameters in order to define the best approach to automatically detect glazed surfaces. Finally, we expanded and better underlined the impacts and key points of the manuscript in the introduction, discussion and conclusion sections.

We hope that the revised version of the manuscript has improved the quality of the text and of the scientific message.

Changes and answers in response to the Reviewer's comments/suggestions (in italic) are highlighted in bold.

Major comments:

- *Impact: the authors claim in the abstract that their "results present significant implications for Surface Mass Balance estimation, paleoclimate reconstruction using ice cores and for the measurements using optical and radar images/data in the megadune area." but only in the conclusion clarify what these implications are. I think it is important to highlight this much more in the discussion which is currently mostly a technical discussion where it is difficult to extract the main messages.*

A: we have now modified the introduction and discussion sections, especially in the subsection regarding the automatic detection of glazed snow, better highlighting the impact of the manuscript on the detection of glazed surfaces using “morphological” parameters (SPWD) and the relevance of megadune migration. Atmospheric circulation models used to calculate SMB are not able to reproduce the ice sheet ablation areas (megadunes and glazed surface areas) that represent a negative value close to the total error reported for the Mass Balance of East Antarctica. In the present study, we have also demonstrated the importance of SPWD on the detection of glazed surface/ablation areas. For the first time, our manuscript measured the migration of the megadunes in all their components, previously hypothesized using only GPR surveys, and pointed out the significant difference (in direction and value) between the detection of surface velocity using optical and inSAR techniques. These new results represent a new ground truth and foundation of knowledge for ice sheet mass balance research, in particular for satellite altimeter and ice velocity derived by remote sensing measurements (e.g., radar vs optical/lidar). Moreover, the measurements, in all components (absolute, upgradation, ice flow), of megadune migration and their burying process (300 yrs) provide information about the distortion of reconstruction of paleoclimate based on firn/ice cores drilled in megadune or downstream areas.

- *Rigour of the classification method: Traversa et al present a method to classify glazed snow which is based on ad-hoc arbitrary thresholds (which could explain the large differences depending on the used method etc). The development/implementation of this method should be done much more rigorously with some sort of optimization (e.g. implementing a trained classifier instead of subjective thresholds) and a sensitivity analysis showing the sensitivity of the method to the used thresholds etc. Currently, it is a subjective analysis which cannot be trusted.*

A: we now propose a comparison of the previous self-defined-threshold method with a more objective approach, i.e., supervised classification. In both methodologies, we evaluated different combinations of key parameters (i.e., NIR albedo, thermal BT and SPWD) and in all the cases, we assessed the accuracy of the method in order to define which approach is the most suited to detect glazed snow surfaces. This analysis was performed both on the scene from 17-Dec-2015 (the highest quality image of the dataset) and on the entire 2013-2014 season (four scenes). The methods, results and discussion sections have been changed accordingly; see lines 212-226, 317-338, and 402-432 of the revised manuscript.

Specific comments:

- *L19-20: the classification with and without SPWD should be done much more rigorously with an automated classifier that allows to assess feature importance.*

A: we now propose a comparison of the previous method with a more objective approach, i.e., supervised classification (see answer to major comment above). The role of SPWD is now more evident and the accuracy can be better quantified. Therefore, the sentence has been modified to: “These parameters allowed us to characterise and perform an automated detection of the glazed surfaces, and we determined the influence of the SPWD by evaluating different combinations of these parameters. The inclusion of the SPWD significantly increased the accuracy of the method, doubling it in certain analysed scenes.” (lines 18-21 of the revised manuscript).

- L23 "significant implications" these implications are barely handled in the paper (not in results nor discussion) and should be stressed much clearer.

A: we stressed the implications of our study on SMB, by adding the following sentence: "In conclusion, the detection of glazed surface/ablation areas by satellite images is challenging because of differences in illumination and meteorological conditions (cloud cover, blowing snow etc.) among different satellite images. Nevertheless, the high resolution digital terrain model (REMA) allows to calculate a SPWD with unprecedented detail, similar to the resolution of available optical satellites (Landsat 8-9, Sentinel), and significantly improves the detection of glazed/ablation surfaces at ten-meter scale across the continent; therefore, it could significantly improve research on the SMB of the Antarctic Ice Sheet." (lines 428-432 of the revised manuscript).

- Fig 2+3+5 look like poor quality screenshots of excel. Figure quality should be improved before it can be published

A: figures 2-3-4 (previously figure 5) have been now improved in quality and exported at 300 dpi.

- Fig1a+b: this figure uses a diverging color palette whereas data are continuous (not diverging). Check <https://www.nature.com/articles/s41467-020-19160-7> for advice and replace it with correct colors.

A: the figure has been modified according to the suggested paper using the correct colours.

- L208: *pluriannual* -> I think *multi-annual* is a more common term

A: the sentence has been modified as suggested

- L214-219: this methodology should be expanded to a more objective classification technique (e.g. based on supervised classification + optimization) instead of ad-hoc subjective thresholds

A: we now include a supervised classification with accuracy assessment (see answer to the second major comment for details)

- L222: "difference between topographic slope and SPWD. " seems like a ghost sentence

A: we have removed this sentence as suggested.

- L221: I miss a clear identification of the differences between the submitted paper and the Frezzotti paper. The main topic of this paper is megadune migration so it show much better the differences.

A: The analysis by Frezzotti et al. was based on the comparison between sedimentary structure from GPR and surface morphology. Here, the movement is calculated and then quantified by feature tracking of surface morphologies from satellite image pairs (Landsat and Sentinel-2) and comparison of surface topography (1999 traverse) with the REMA DEM (2014). The new modified sentence is: "Frezzotti et al. (2002b) and Ekaykin et al. (2015), based on the sedimentary structure of buried megadunes (using GPR and GPS), pointed out that the megadune migration and ice sheet surface flow show a similar intensity but opposite directions and that megadunes migrates upwind with time, burying the glazed surface of the leeward face. Here, by using different satellite images and field data, we are able to provide and quantify megadune migration components..." (new lines 228-231).

- L255 "5": *as a rule of thumb numbers below 10 should be written as text in the main text*

A: we have replaced the number with text as suggested

- Fig. 2a+b *would be clearer if homogeneous. A) shows non-normalized data while b) shows normalized data.*

A: we have modified the figure as suggested

- L289 *"in accordance with previous authors", if it is completely in accordance, then I wonder what the novelty/ added value is.*

A: this part of sentence was removed since none of the cited papers had analysed NIR and SPWD in relation with megadune flanks.

- L290-294: *I find it very difficult to see significant differences in variability between glazed on non-glazed surfaces, so I think this needs to be proven quantitatively to avoid it is a subjective interpretation.*

A: we have quantified the differences, finding that the variability of NIR albedo more than doubles between the two flanks of the dunes (0.3% vs 0.7%). The sentence was rephrased as follows: "Based on the transects, the variability in NIR albedo at seasonal (spring-summer) to pluriannual scale is observed to be twice as large in the snow accumulation area on the upwind flank and the bottom of the leeward flank (Fig. 2), compared to the glazed surface NIR albedo (0.7% compared to 0.3% NIR albedo variability), which remains more stable and more highly correlated at seasonal (spring-summer) and pluriannual scale" (lines 295-298 of the revised manuscript).

- L312-317: *I don't think this can be concluded based on a subjective classification algorithm*

A: we now include a supervised classification with accuracy assessment (see answer to second major comment for details), which has made the methodology more objective.

- Fig. 5b: *the GPR profiles are impossible to interpret (especially with the dashed lines) and it is not clear what they add to the story*

A: we have removed the GPR profiles from the image

- L364-369: *again not possible to interpret based on subjective analysis*

A: we now included a supervised classification with accuracy assessment (see answer to second major comment for details), which has made the methodology more objective.

- L371-394: *I found it difficult to find an impactful result in this part of the discussion*

A: we have modified and shortened this part of the discussion, in order to highlight only the relevant aspects.

- *Section: I think this section gets lost in the details and fails to convey a clear take home message*

A: it is not clear what section the comment refers to, since the reference is missing. Nevertheless, both the discussion and the conclusion were strongly modified in order to highlight the relevant aspects.