**The Cryosphere
Discussions**

Interactive comment on "Multi-temporal airborne LIDAR-DEMs for glacier and permafrost mapping and monitoring" *by* J. Abermann et al.

Anonymous Referee #2

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The paper presents an interesting method for assessing glacier borders using visual analysis of very high resolution multi-temporal digital elevation models. The glacier is delineated based on the elevation and roughness change. The method is fairly new, but presented by Knoll & Kerschner (2009), who applied automated delineation of elevation models made using lidar data. The method is very interesting and has very high potential in mapping glaciers and glacier changes. The high amount of excellent data compiled during the last years and the long history of glaciological investigations over Hintereisferner and Vernagtferner is also excellent material for the study.

However, I have to present some criticism towards the way the study is carried out and the paper is prepared even though I like the method presented. I think the paper has excellent scientific significance, but the presentation decreases the scientific quality.

First of all, I would like to make a small change to the title of the paper by removing word permafrost. The methods is tested also with rock glaciers (which would require explanation), but I do not see the method applied for other type of permafrost areas. I understand permafrost mapping as mapping the areas which are frozen (terrain, soil etc.).

The main weakness of the methods is that the results are not ground truthed thus the quality control is not really there. Would it have been possible to ground truth the 2006 data? Despite of knowing that glaciers have been melting since 2006, it would have been possible to check the delineations in some location around the glaciers studied.

The language is somewhat complicated and makes the understanding difficult in places. Most of the figures should be corrected and figure captions simplified. For few things number of terms is used, like tongue and snout for the end of the glacier. Please use only one term.

Introduction

Reading the title, I understand that the multi-temporal DEMs are the main topic of the paper, but in that case the authors should tell more about the data type, its acquisition and processing until it is a DEM or a hillshade. This may be part of the introduction or method section. If the main point is the method for studying changes, then the title should be modified.

I would also like the study areas (their climatic conditions, temperature, snowfall and glacier changes) during the last 10 years presented to have the processes presented understood by wider audience. At least this is needed for the years from which the remote sensing data is used. This data should exist from the measurement network in Hintereisferner and Vernagtferner at least. This may be part of the introduction or the test site chapter.

Test sites and data

A map or photo compilation of the glaciers studied would be interesting. Instead of field truth word "ground" truth is more often used in remote sensing. Other remote sensing data should be listed in test sites and data section.

A comment about the data acquisition date: October is close to minimum snow extent, but it is highly potential that the areas are covered by new snow in October. The lidar data of 2006 is acquired 6-7 weeks earlier than others, which would require some discussion or comment related to the surface lowering of glacier. This is needed especially with the Rotmoosferner case, in which the accumulation zone is studied. The snow depth in accumulation zone can vary lot year by year even if the data were from the same date each year. What was the snow cover during the time of data acquisition on glacier surfaces and surroundings?

Methodology

This chapter needs to be re-written to be clearer. The term hillshade should be explained as it is the main image type interpreted. You may even consider changing the whole word, for example as shaded relief, as it is done by projection of sunlight from certain azimuth angle to DEM

Results

In this chapter the reader wishes to have more information about the typical accumulation and meteorological conditions in the study areas. The aerial photograph 2003 is not mentioned in the data section.

I see bit awkward to add the adjacent snow covered areas to be part of the glacier even though UNESCO 40 years ago suggests that. Inclusion of debris covered glacier makes more sense.

Accuracy assessment is rather weak as ground truthing is not tried. The test carried out with two interpreters is 1%, while the other errors given were +/-1.5% for glaciers more than 1 km2 and +/- 5% for smaller ones. It would be more descriptive to describe the

error simply in meters: how much of the glacier border may be mis-delineated. It was mentioned in the introduction that the method was developed in order to improve the mapping of small glaciers, but it seems that the relative error increases with decreasing glacier size. How much is the error for glaciers smaller than 0.5 km2 or 0.1 km2?

Discussion

The whole discussion should be re-written, as it mainly describes methods and results when applying other data types. The cell size study belongs definitely to method section as it is author's own study. The cell size should changed as spatial resolution to be more meaningful.

The comparison with other remote sensing data is also part of the method section, or could be introduced in the introduction as the traditional methods or state of the art having certain weaknesses for the justification why this new method is needed. After the removal those parts, the discussion is quite short and should be totally written again in traditional way by discussing with other papers about (comparing the methods, accuracy, cost-efficiency, etc.). Lot of references exists, for example few last ones from Knoll and Kerschner (2009), and Hendriks and Pellikka (2007), Paul et al. (various).

Conclusions

The conclusions are somewhat too long.

Tables and figures

The figure captions should be simplified for all the figures. There is text which belongs to text itself. I wrote examples for Figures 8 and 9.

Table 1 gives high detail for lidar data 2006, but for the other lidar data such information is not given.

Figure 1: the caption is too long and confusing. Comments about RR should be removed, since reason for it is given in the text.

Figure 2: Legend is needed for ground, snow, ice and debris.

Figure 3: Here there is somewhat too much text and lines. Text could be simplified, for example the 315 and 135 degrees are unnecessary.

Figure 4: Too long figure caption. North arrow is missing.

Figure 5: The line colours of 5a are mixed and years are misspelled. There is no 1969 and no black and no yellow colour nor dots or dashes. The figure caption is also long, and part of the caption could be in text. Otherwise the example is good, but it is not shown which ambiguous area is included to the glacier area. North arrow is missing.

Figure 6: Here as well the figure caption is difficult to follow as a, b and c are at a start or at the end of the explanation. Please use years 2005 and not 05 in the figures. The lines in c are confusing: best estimate glacier 05 is presented as a box in legend, but as a line in the map. What area is the best estimate glacier? Potential dead ice extent line is missing from the southern side. North arrow is missing.

Figure 7: Explanation for c is missing. North arrow is missing. What is the 9c mentioned? Consider revising the caption.

Figure 8: The caption should be: "Figure 8. Shaded relief images of Mittlerer Guslarferner's tongue calculated out of the LIDAR-DEMs (year) in a) 5 m spatial resolution, b) 20 m resolution and c) 50 m resolution." The last sentence belongs to text itself. North arrow is missing and legend is mixed with the lines.

Figure 9: The caption should be simply: "Figure 9. Ice thickness changes between 2004 and 2005 using a) 5 m spatial resolution, b) 20 m resolution and c) 50 m resolution." North arrow is missing. The 04 and 05 in the figure should be changed to 2004 and 2005, or deleted if the year is given in caption.

Figure 10: The caption is much too long and part of that should be in the text.

Figures 11-14: These figures may not be needed at all.