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Interactive comment on "Darkening Swiss glacier ice?" *by* Kathrin Naegeli et al.

Anonymous Referee #1

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Dear Editor,

the paper by Naegeli et al. addresses the topic of glacier darkening in the Swiss Alps using Landsat derived surface albedo. The often-referenced "darkening" is still a debated topic in glaciology both regarding mountain glaciers and ice sheets. The paper is very interesting and fits the aims and scope of The Cryosphere journal. I have a couple of major concerns (and some minor issues) that have to be addressed before final publication in TC.

Major comments:

1- The authors use late-summer Landsat scenes for retrieving the seasonal minimum of glacier albedo of Swiss glaciers. Then they apply a trend analysis to bare ice albedo in order to detect positive or negative trends in the albedo series. My first concern regards the choice to study trends only on bare ice. Actually, important contribution

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to the radiative balance of glaciers comes also from the accumulation areas: in fact this part of a glacier plays an important role in determining its mass balance. Albedo decrease in the accumulation area is very important, and I don't understand why the authors did not include this part of the glaciers in their analysis. In the area across the ablation and accumulation zone the impact of light-absorbing impurities is important. Excluding this area from the analysis is not justified in my opinion.

For example, Gabbi et al. 2015 showed that black carbon and dust have an impact glacier mass balance. They used data from ice cores collected in the accumulation basin of two Swiss glaciers. I think that the comparison with mass balance should be done with averaged albedo over the entire glacier, and not only from bare ice. In fact, it is not straightforward that the mass balance is determined only by bare ice albedo. I'm not surprised that the authors did not find any correlation between those two variables (pg9 ln3-4).

Furthermore, in the whole paper I did not find any reference to 'cryoconite' (organic and inorganic sediment found on ice). I think that a discussion about "what" could be the cause of the darkening is necessary in this work to give a broader perspective to the remote sensing analysis. Further discussion should regard also the competing role of grain growth (due to ice melting) in potential ice darkening.

2- My second concern regards the choice of Swiss glaciers for the analysis, and the validation of the trends. I was a little surprised that Morteratsch glacier was not included in the analysis. As far as I know, it is the only Swiss glacier with a long series of albedo measured with an Automatic Weather Station in the time windows used in this paper (1999-2016). Oerlemans et al. (2009), was one of the first papers dealing with ice darkening in the Alps. In that paper, a decreasing trend of summer albedo was detected (from 2003 to 2006), and associated with dust deposition from lateral moraines. This series could have been a perfect validation for the methodology developed in Naegeli's paper. I don't understand why they excluded this glacier from their analysis. Furthermore, they also reference to "Swiss glacier ice" in the title. In my

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opinion, some validation is needed for the albedo series derived from Landsat. This trend analysis is strongly dependent on the availability of Landsat data during late summer. From table 2, it is evident that differences of more than one month in the dates of the images can create inconsistencies in the albedo retrieval. For examples, early snowfalls in September can generate strong overestimation of albedo.

Specific comments:

Title: it is correct? I think it should be something like "Are Swiss glaciers getting darker?" or "Is Swiss glacier ice getting darker?"

pg2 ln2: here a brief review of these "controversial discussions" should be reported, in particular for Greenland trends. Please, consider also a reference to Casey et al. (2017).

pg2 ln3: recently Baccolo et al. (2017) showed that also radionuclides and heavy metals are contained in cryoconite holes, and will be likely released with current and future melting.

pg2 ln6: I personally don't like references to Discussion papers that was not accepted for publication. I suggest to reference a successive paper by the same authors: Goelles & Boggild (2017).

pg2 ln11: here I suggest a reference to Dumont et al. (2012) that used downscaled MODIS data to estimate surface albedo of a glacier in the French Alps. Also a recent paper by Davaze et al. (2018) used a similar dataset to compare mass balance with albedo.

pg4 ln1-4: here there is no description on how you used this lithological-petrographic map. Please be more specific on the aim of this analysis. I don't see the added values of this analysis. Objectives must be clearly stated.

Section 4: In section 4 (Results), also interpretations are found. I suggest to merge this section with the Discussion, or to move all the interpretations and discussion to

Section 5.

pg8 ln6: "for some analysis". Please, be more specific here.

pg8 ln29: replace ";" with "."

pg10 Fig.4: In 1999, averaged albedo is already very low (about 0.2 from Figure 4). So it is possible that the darkening trend of Swiss glacier ice already occurred. I think that this discussion should be added to the paper.

pg10 ln3: "for some grid cells", please add the percentage.

pg12 ln2: Results from the lithological analysis should stay here

pg15 ln27: here a reference to organic material should be made. Probably the effect of the organic fraction of cryoconite may overwhealm the mineralogic signature of surrounding rocks.

pg16 ln 7: a recent paper by Rossini et al. (2018) also explored the relation between ice darkening, roughness and melting in a Swiss glacier

References:

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