on comments: a.) io = “instead of” b.) Comments refer to page then line numberusing X Y

General Remark The study has a lot of value by presenting an expanded (in timeand process) treatment of AVHRR albedo over Greenland. The article makes several major analyses, the fourth of which I am not sure should be kept because of its very wide scope, complexity and limited finding.

Thank you for a carefully considered and thorough review. Please see below for our point by point responses. Some typos and unclear expressions were also corrected at the authors’ own initiative. All page numbers refer to revised manuscript.

Major critique

A.) The fourth major analysis should be more clearly explained or removed*, that with lag analysis, basin scale examination of hypothetical meltwater lubrication of ice dynamics. The study already has a lot of substance. Adding the lagged result only to confirm earlier studies is a bit much.

12 9-16 reinforces that the study is taking the empirical albedo relation too far.

1 24-27 recommend removing this part of the study as it does not directly examine melt-induced flow acceleration while much has been evaluated more directly on this topic. See SWIPA 2017chapter 6 https://www.amap.no/documents/doc/snow-water-ice-and-permafrost-in-the-arctic-swipa-2017/1610

In line with the feedback here and from the other reviewer, this analysis has been removed from the manuscript.

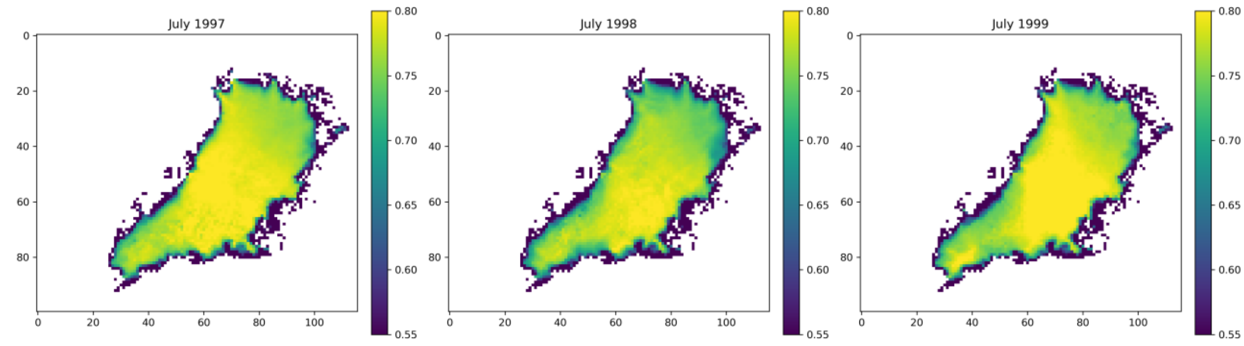
7 6-11 difficult to follow

Paragraph removed with the albedo-discharge time lag analysis.

B.) Discussion of this study vs Stroeve (2001) Stroeve, J.: Assessment of Greenlandalbedo variability from the advanced very high resolution radiometer Polar Pathfinderdata set, J. Geophys. Res.-Atmos., 106, 33989–34006, doi:10.1029/2001jd900072,2001. How does this study square with Stroeve (2001, see Fig 4 etc) who found de-creasing trends 1981-1998?

8 29 “majority of the albedo decrease signal originates after 2000” but Stroeve 2001 found a decrease before 2000

Stroeve (2001) pointed out that the negative albedo trends detected (at a set of grid points) were not statistically significant and they were largely driven by the anomalously low albedos detected during the summer of 1998. We agree that 1998 was a low-albedo year (see below for CLARA-A2 July monthly mean albedos for 1997-1999), but 1999 was not, therefore the finding by Stroeve might have been different if the following year had been included in the data. Also, our trends are based on the Theil-Sen trend estimator, which is by design robust against outlier influence in the data.



Furthermore, as Polar Pathfinder provides the blue-sky albedo, its seasonal/annual variability is also driven by variability in cloudiness and the cloud radiative properties. Also, the intercalibrations of (earlier) Pathfinder and CLARA-A2 are based on different methods, with the CLARA-A2 method (based on Heidinger et al., 2010) arguably more sophisticated as it leverages the high MODIS calibration as well as stable natural targets. Finally, the Polar Pathfinder dataset only contained data from the afternoon AVHRR satellites, meaning that for the pre-MODIS era, CLARA-A2 has additional observations available from NOAA-12 and NOAA-15 relative to Pathfinder (and additionally NOAA-17, NOAA-19 and METOP-A & B for the MODIS era).

The issue of correctly detecting clouds over bright snow/ice is a consideration for any AVHRR-based study; while some concerns remain on cloud detection accuracy over the high-elevation regions of Greenland (Karlsson et al, 2017), neither the in situ evaluations nor the stability evaluation undertaken here suggest that the large-scale CLARA-A2 ice sheet albedo estimates are significantly influenced by missed clouds. This is likely linked to the leveraging of all AVHRR satellites and the coarsened end product resolution, where typically hundreds or even thousands of reported clear-sky AVHRR GAC-resolution samples are aggregated in a 25 km resolution grid cell to form the grid cell monthly mean albedo. While missed clouds will certainly appear in the data, their impact at the end product scale is ameliorated by the majority of correct clear-sky samples. The 5-day means are more vulnerable to this effect, though, which is partially why statistical Gaussian Process smoothing was applied to the 5-day data in the manuscript.

The spatiotemporal consistency of albedo trends between CLARA and MOD10A1 also reinforces the idea that cloud masking issues are not a dominant driver of the observed trends.

9 19-26 bringing in Stroeve2001 agreement/disagreement seems important here Stroeve found NAO resonance,as one would expect. What about this study?

Please see the remarks above. To make these points to the reader as well, we will include a new paragraph here (pg 10, 7-16) summarizing these differences/likely causes relative to Stroeve (2001). Also, note that some remarks on the cloud masking are also included in the discussion section for clarity.

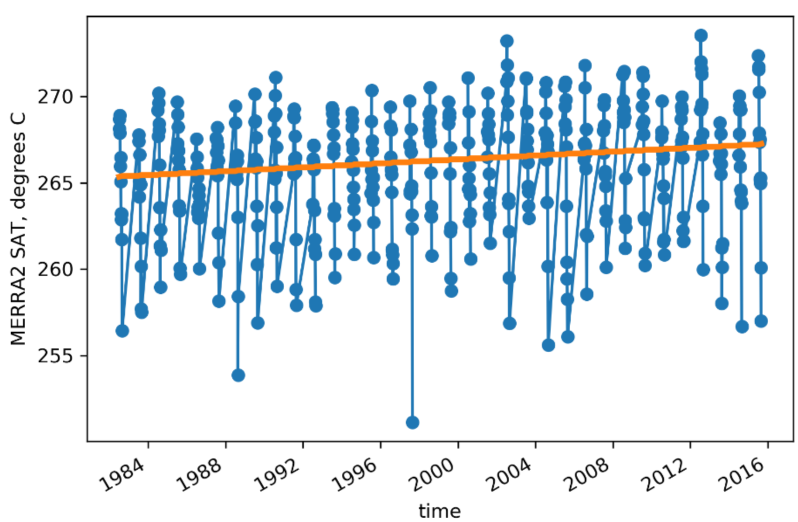
C.) conclusions . . . 16 12 "The albedo decrease of the northeastern and eastern mar-gins was initiated during the 1982-1999 period" . . . you offer a mechanism for the west but what about the east...any idea the cause? It should be either/and atmospheric circulation or sea ice -related.

This is a very good question, to which we presently have no clear answer. The topography of the SE/E coast is quite complex, and while CLARA-A2 SAL does contain a correction algorithm for both geolocation and radiative impacts of mountainous topography (areas with mean slope>5 deg), we remain bound by the overall geolocation accuracy of AVHRR. This implies that we cannot discount sampling errors as a source of influence in complex terrain.

Yet there is some similarity in the negative albedo trends around Blosseville coast in MOD10A1 and CLARA (see next point), some of which are also reproduced by the earlier studies noted here based on various versions of the Pathfinder dataset – although the comparability is limited, as noted in the previous point.

On the other hand, Häkkinen and Rhines (2009) showed that the warm subtropical (surface) waters have begun to penetrate the seas around SE Greenland with increasing intensity, and Straneo et al. (2010) found them present in the Helheim glacier fjord. We could therefore postulate that when the increasing heat energy thus advected on the SE coast is released into the atmosphere, it provides additional energy for the surface melt of snow. This would be consistent with the localized but substantially negative albedo trends seen around Helheim and Kangerdlussuaq glaciers in both MOD10A1 and CLARA-A2. Note that the increasing precip only affects the coast south of Helheim glacier according to MERRA-2.

The case of the NE margins appears different in that oceanic forcing is less likely a cause; we noted that some modeling studies found increasing runoff and thus surface melt, and if downslope winds were increasing along with positive air temperatures, the turbulent flux exchange could also accelerate melt. In this perspective, MERRA-2 does show a statistically significant if unremarkable positive trend in SAT over the NE region (here shown for 78-79.5N, -29 to -32 E, July & August). However, the veracity of the wind fields is untested and thus the quantification of turbulent flux contribution is an uncertain process.

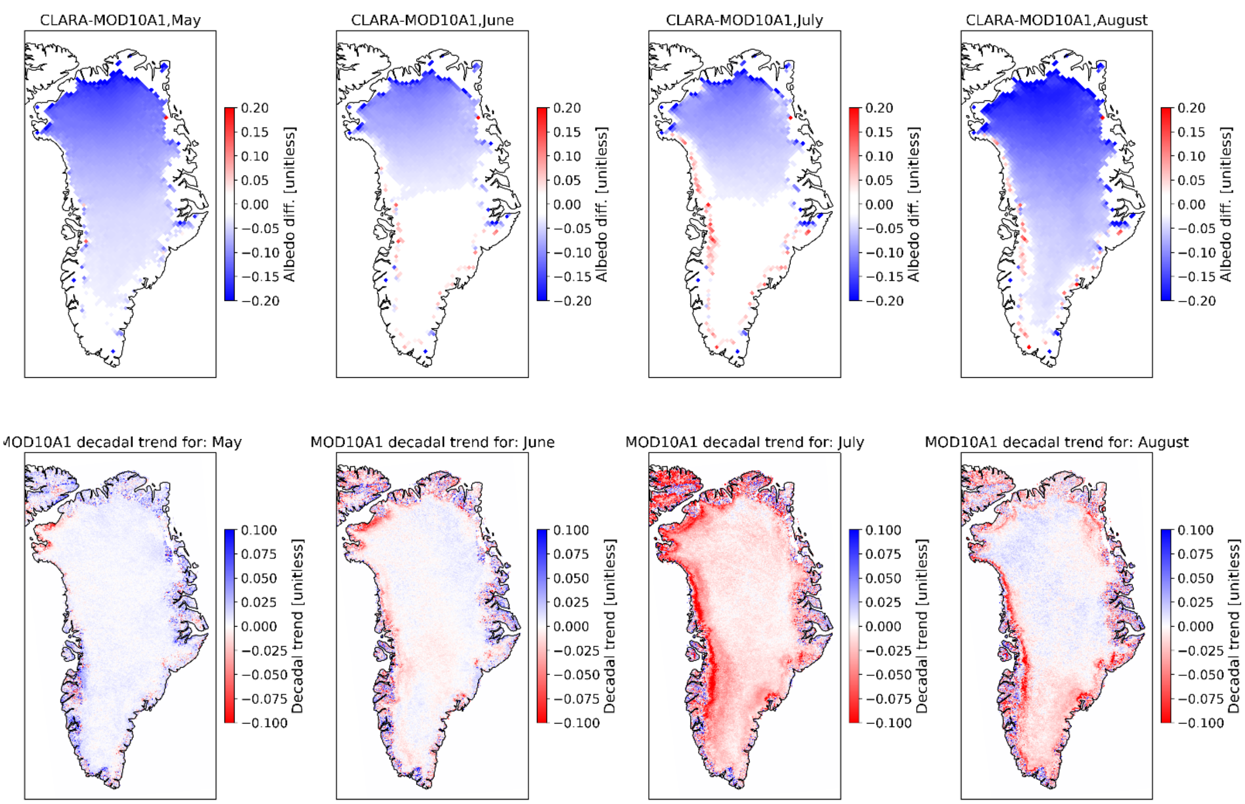


We propose to add new content in the results section (3.1, pg.9) and the discussion section (pg 16) summarizing the arguments here.

D.) A direct comparison between albedo data sets: CLARA-A2-SAL and MODIS MOD10A1 seems warranted. How well do they agree in the overlapping period?

We performed a comparison between the datasets, showing the results here for the reviewer's interest, and also propose to add them as supplementary material in the manuscript (Supplementary Figure 4), with commentary in the discussion section (pg 16, 9-17). This is motivated by the fact that a rigorous intercomparison should account for factors which require substantial additional work to quantify, e.g. differences in diurnal sampling, and analysis for the impacts of various downscaling methods to reduce MOD10A1 into the coarse CLARA grid.

We calculated the decadal Theil-Sen albedo trend estimators for the 2000-2015 May-August months for MOD10A1 in its native 5km resolution on the polar stereographic grid (Box et al., 2017, denoised, gap-filled). For the calculation of per-month mean differences during the 2000-2015 overlap, we resampled MOD10A1 to the CLARA grid with a radial weight algorithm with a 25 km radius. While this choice should be broadly acceptable, we note that a more careful intercomparison is deserving of a separate manuscript.



The spatiotemporal distribution of the decadal trends is highly similar. Most of the small-scale albedo decrease features, such as decreases around Helheim and Kangerdlussuaq glaciers, are consistent if limited by the coarse CLARA resolution. The trends in MOD10A1 have larger maxima than CLARA-A2 most likely because of the considerably finer spatial resolution (5 km vs. 25 km) – in CLARA-A2, the narrow regions of sharpest albedo decreases at the (west) margins are smoothed by the spatial aggregation.

The by-month mean difference maps (top row) only show differences above an estimated joint CLARA/MOD10A1 uncertainty envelope of 0.03. As expected considering the results by Alexander et al. (2014), the difference is large in the North during May and August. This difference is stable, though, and does not appear to impact the decadal trends, which agree even for the large-difference regions.

General comments

7 16 agree with "empirically suitable threshold albedo of 0.58"... compositing with many PROMICE years yields 0.56 (unpublished)

Thank you, this information is good to know also for future reference.

Recommend to not use abbreviation "GrIS". Instead, use "Greenland ice sheet" until it (very quickly) becomes obvious the study is on Greenland, afterward, use "ice sheet". Should title have"mass balance" io "surface mass balance and ice discharge"

GrIS -> Greenland Ice Sheet revised as suggested throughout the manuscript. However, the title is in our view accurate; the proxy investigation is limited to surface mass balance only, and the manuscript contains a comparative investigation of annual ice discharge and albedo anomalies, even though the time-lag analysis has been removed according to the reviewer's critique.

1 9 "driven in part by " io "primarily driven by "

Revised as suggested.

1 13 "We then subtract ice discharge from the mass change estimates from the GRACE satellite mission to estimate surface mass balance" io "We then correct the mass balance estimates observed by the GRACE satellite mission with state-of-the-art ice discharge"

Revised as suggested.

1 23 "rapid surface mass" io "rapid mass"

Revised as suggested.

2 31 "examining the role of albedo" io "both highlighting and confirming the dominant role of surface melt" would seem to improve the statement by making it not a conclusion placed in the intro of the paper and otherwise clarifying that albedo is the predictor variable here.

Revised as suggested, proposing to amend "albedo" to "albedo-inferred", as albedo is a proxy for surface runoff here.

4 1 “uppermost areas” io “innermost parts”

Revised as suggested.

4 1 - 4 8 . . . Fig3A in Box, J.E., D. van As, K. Steffen, 2017. Greenland, Canadian and Icelandicland ice albedo grids (2000-2016), Geological Survey of Denmark and Greenland Bul-letin, 38, 53-56 available from http://www.geus.dk/DK/publications/geol-survey-dk-gl-bull/38/Documents/nr38_p53-56.pdf supports the idea that 2012 was not anomalously low AND that variability is small (in the Summit GC-Net example; max-min = 0.03) in the dry snow area‘

Thank you for the additional reference, added to the text here.

4 12 “~0.02 increase of the GrIS albedo” io “~0.02 overestimation of the GrIS albedo” . . . it was a real climate event so the measurement is not an over-estimation

While the reasoning by Stroeve (2001) that the Pinatubo eruption caused cooling which inhibited e.g. Greenland melt for 92-93 is principally valid, the relatively large albedo increase on the top of the accumulation zone in CLARA-A2 for these years (Fig 1) is difficult to fully explain in terms of less surface melt or snow metamorphism– as we normally expect negligible surface melt or metamorphism there anyway. The Pathfinder as well as CLARA records are based on climatological mean aerosol loading over the Arctic – for want of a reliable and spatiotemporally complete aerosol record reaching the 80s – so that some part of the albedo increase could also be explained by unaccounted-for change in atmospheric composition. As the albedo estimates for these years are thus more uncertain than the rest of the CLARA record, we prefer keeping the analysis and text here as is, with some additional explanation for the logic w.r.t. the discussion here (pg 4, 11-21).

8 25 I expect some readers/reviewers will dislike excluding 92 and 93. Yet,I think it’s not too questionable as long as you’re clear. Here, better I think would be“externally forced” io “less reliable”

Please see the point above. We propose amending the mentioned text to “likely both externally forced and less reliable” to account for both possible explanations.

8 25 “largely remained stable” discuss relative toStroeve 2001

Revised w.r.t. the discussion around major comment B.

8 31 “may be”? Seems more testing needed to address this hypothesis.

Revised w.r.t. the discussion around major comment D, relocated to the discussion section.

9 1 “is” io “may be” . . . see/cite Box, J.E., D. van As, K. Steffen, 2017. Greenland, Cana-dian and Icelandic land ice albedo grids (2000-2016), Geological Survey of Denmarkand Greenland Bulletin, 38, 53-56

Relocated to discussion section.

9 5 “rarely examined” “the ice sheet’s albedo was primarily stable” see Fig 9c and related discussion in the following where from 1988-1999 eastern Greenland has the largest AVHRR albedo decrease. Some discussion of that seems warranted. Box, J.E., D.H. Bromwich, B.A. Veenhuis, L-S Bai, J.C. Stroeve,J.C. Rogers, K. Steffen, T. Haran, S-H Wang, 2006: Greenland ice sheet surface massbalance variability (1988-2004) from calibrated Polar MM5 output, Journal of Climate,Vol. 19(12), 2783–2800.

Thank you, the authors did not recall that the stated study also contained satellite-based data evaluation. We note that the limitations on Pathfinder/CLARA comparisons as discussed in response to major comment B also likely apply here. However, this reference will naturally be added here and the manuscript revised to reflect these past efforts. The sentence “primarily stable” will be revised to enhance that the finding is only based on CLARA data, and that significant negative albedo trends are apparent on the NE and E margins – in itself the E decreases being consistent with the Pathfinder analysis in the given manuscript.

9 28-34 geolocation errors were attributed in the following study for the relatively noisy ice margin trends. See Box, J.E., D.H. Bromwich, B.A.Veenhuis, L-S Bai, J.C. Stroeve, J.C. Rogers, K. Steffen, T. Haran, S-H Wang, 2006:Greenland ice sheet surface mass balance variability (1988-2004) from calibrated PolarMM5 output, Journal of Climate, Vol. 19(12), 2783–2800.

Certainly they may contribute; the referenced discussion will also be noted as a potential cause of the effect seen. The discussion section now contains the reference as a part of a new paragraph summarizing the MOD10A1-CLARA comparison (pg 16).

10 7 “where the trend signal originates” io “where they are expected to be more robust”

Revised as suggested.

10 10 “larger” io “faster”

Section revised for clarity, phrase removed.

10 21 “earlier” io “faster”

Faster is our preferred term; Figure 7 clearly shows increases in albedo decrease rate (per 30 day period).

10 25 the “increases in winter snowfall” finding is very interest-ing AND is related to the GRACE correlation because when there is snowfall, mass is added and albedo increases. So, be sure to make that point. The following may be relevant if you want to discuss more about how increasing snowfall may be from climate change. https://iopscience.iop.org/article/10.1088/1748-9326/10/11/114008/meta Fur-ther Box et al. (2013) find a climate change signal, an increase in snowfall with NH AirT, N Atlantic Air T, etc. Comparison of Greenland accumulation history with northernhemisphere air temperatures suggests a 6.8% (or 51 Gt) per degree C climate sen-sitivity (Box et al.,

2013). See Box, J. E. 2013. Greenland ice sheet mass balancereconstruction. Part II: Surface mass balance (1840-2010), Journal of Climate,Vol.26, No. 18. 6974-6989. doi:10.1175/JCLI-D-12-00518.1

Thank you, the reference has been added. The work by Wong et al. has been referenced in a new paragraph in the discussion section (pg 13, 16-22) on the NW bare ice exposure changes in context of observed precip trends – which appear quite different from MERRA-2 over the region.

15 20-26 Including discus-sion of Rajewicz and Marshall, 2014; McLeod and Mote 2016 is warranted. e annual frequency of extreme high pressure 'blocking event' days that deliver warm air onto western Greenland peaked in 2010 and 2012 (McLeod and Mote, 2016). Greenland mass loss accelerated between 2003 and 2012 primarily due to increasing surface meltwater runoff (-6.3±1.1 Gt/y2) driven by persistent southerly flow across the western ice sheet (e.g. Rajewicz and Marshall, 2014; McLeod and Mote, 2016). McLeod,J.T. and T.L. Mote, 2016. Linking interannual variability in extreme Greenland blocking episodes to the recent increase in summer melting across the Greenland ice sheet.International Journal of Climatology, 36:1484-1499. Rajewicz, J. and S.J. Marshall,2014. Variability and trends in anticyclonic circulation over the Greenland ice sheet,1948–2013. Geophysical Research Letters, 41:2842-2850.

Thank you, the additional references are added and the raised points noted in the revised manuscript (discussion section, pg 15, 27-34)).

16 20 "A notable exception to the widespread albedo decrease was" io "A notableexception was"

Revised as suggested.

Figures Fig 2, 4,6 Increase text size.

Revised as suggested.

In Fig 4 a tiny a, b, c . . . text is problematic.

Text size increased.

Figs3-5 would be an improvement to zoom in to the island of Greenland in each map

Revised the figures to provide a tighter zoom on Greenland itself.

Fig 4 inset trend map too small? The analysis is v interesting and deserves highlight. Maybe too many maps compressing the results too much. Remove the grey area.

Thank you. The Figure was split into independent figures per period, also providing the inset figure as an independent figure.

Fig 5 units per day? Small number, multiply to get per month?

Revised to reflect change per 30-day period.

Fig 7 sorry but I think this analysis does not add sufficiently to the study

In line with the earlier comment and feedback from Reviewer 1, we have omitted this analysis and the corresponding figures from the manuscript.