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Interactive comment on "Satellite observations of changes in snow-covered land surface albedo during spring in the Northern Hemisphere" *by* K. Atlaskina et al.

Anonymous Referee #1

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General comments

This paper documents changes in land surface albedo in snow-covered regions north of 50°N during spring months (March–May) based on monthly means of MODIS albedo data. The albedo changes are related to changes in snow cover fraction, temperature, precipitation (monthly sums and the number of wet days) and vegetation (an enhanced vegetation index for June). Not so surprisingly, snow cover fraction is found to have the largest impact on surface albedo. Further analysis is conducted for the albedo of regions covered by 100% snow. A significant negative correlation between snow albedo and temperature is found for the Labrador region in April and the Taymyr region and the

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Canadian Arctic Archipelago in May, but otherwise the results are mostly inconclusive.

The topic of this paper is relevant for The Cryosphere, and it provides useful information potentially contributing to the understanding of the snow-albedo feedback. The main limitations are (1) the limited length of the satellite data record (13 years is short from the climatological point of view) and (2) the use of monthly-mean data only (which could obscure, e.g, the relationships of albedo with temperature and precipitation). The general structure of the paper is good, but the writing could be clarified at some places.

Specific suggestions for improving the paper are given below.

Major comments

1. The interpretation of the results is complicated somewhat by the use of monthly data. In principle, a better temporal resolution could be achieved by averaging daily atmospheric reanalysis data (e.g. ERA-Interim) to the 8-day resolution of the MODIS data, although of course, reanalyses are partly model-dependent. Since such an endeavour would involve redoing most of this study, and probably quite a large amount of work, this suggestion is optional. At any rate, some more discussion of this issue should be included in the manuscript. One specific example concerns the relation between albedo and temperature for snow-covered regions. In the present study, the albedo is found to decrease with temperature at temperatures above $-15°$C, while Aoki et al. (2003) shows that the snow albedo is very stable at temperatures below -10 and decreases when the temperatures increases above ($-5°$C) (as noted on p. 2748). This difference might well arise from the use of monthly-mean temperature data. Even if the monthly mean is $-15°$C, substantially higher temperatures favoring faster snow metamorphosis could well occur within the month, and perhaps even the melting point is reached occasionally. In the same vein, even if the monthly-mean temperature is well

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below 0°C, occasional liquid-phase precipitation could occur.

2. The 13-year satellite record is still somewhat short from the climatological point of view. The geographical patterns and especially trends are bound to have “random” features related to short-term climate variability. Therefore, perhaps too much emphasis is put on describing the geographical patterns. E.g., the discussion on p. 2757, line 17 – p. 2758, line 17 could be shortened.

Instead, I would suggest adding an analysis of how the correlation (or alternatively regression coefficient) between albedo and various quantities depends on monthly-mean temperature. On physical grounds, I would expect a more negative albedo-temperature relationship at higher temperatures, as snow metamorphism accelerates with increasing temperature, especially if the temperature occasionally reaches the melting point. Similarly, the relationship between albedo and precipitation might change from positive at lower temperatures to negative in warmer conditions (snowfall generally increases the albedo by adding a layer of new, highly reflective snow, while rain very likely decreases the albedo). It would be interesting to see if these relationships can be seen from the monthly data. I suggest plotting the correlations (albedo–temperature, albedo–precipitation, albedo–wet days, perhaps also albedo–EVI) against monthly-mean temperature for each grid point (i.e., a scatter plot with temperature on the x-axis, correlation on the y-axis). This would enhance the analysis reported in Section 4.3.

Minor comments

1. p. 2746, lines 22–23: It is very appropriate to start the paper by defining surface albedo, but "reflected back into space" is not correct. Surface albedo is simply the fraction of solar energy reaching the Earth’s surface that is reflected upward. Part of the upward reflected radiation is absorbed in the atmosphere and does not reach space. Please also mention already here that you consider the broadband albedo

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integrated over the solar spectrum.

2. p. 2747, line 17: Which season and region does the 1°C warming refer to?

3. p. 2748, lines 2–8: The explanation of the effect of snow grain size is confusing. In particular, "larger grains not only scatter more radiation ..." is misleading. For a given mass of snow, the optical depth is larger (also for scattering) if the snowpack consists of small rather than large grains. The primary reason for the decrease of snow albedo with increasing grain size is that the single-scattering albedo decreases with increasing grain size (i.e., absorption increases when the path length of radiation within the snow grains increases). The size also influences the asymmetry parameter, but this is complicated if grain shapes also change with size (relationships typical of spheres may not hold).

4. p. 2750, line 8: State explicitly that you mean "ground-based albedo observations".

5. p. 2751, line 13: It would be helpful to list the wavelengths of the MODIS bands 1–7 explicitly.

6. p. 2754, line 22: "temporal resolution" should be "spatial resolution".

7 p. 2754, line 26: to avoid the impression that you use daily temperature data, replace "daily mean temperature" with "monthly mean of the daily-mean temperature", or simply, "monthly mean temperature".

8. p. 2755–2756: I found the description of spatial sampling (which data pixels are included and which not) confusing. In particular, you should be clear about the following:

- p. 2755, line 11: "All data pixels with corresponding SCF less than 1% were discarded from the analysis". Does this refer to SCF for the 25×25 km EASE

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grid cells? Was the spatial screening done separately for each month and year, or was the same screening used for a given month in all years?

- p. 2755, line 22: Which pixels did you include: only those for which SCF=100% in a given month for all years 2000–2012, or those in which SCF=100% for at least one year in 2000–2012?
- p. 2756, lines 1–3: In conducting the albedo analysis for snow-covered regions, it is clear that the mask is different for March, April and May. However, was the mask for a given month the same for all years considered, or was there further screening based on whether the ground was snow-covered?

Perhaps the answers to all of these questions are available in the text, but it should be made easier for the reader.

9. p. 2757, lines 14–16: When you say that the snow cover changes have influenced a certain fraction of the area, how is this defined? A trend different from zero? Or a trend statistically different from zero? If so, how is the statistical signficance determined?

10. p. 2758, line 20 (and elsewhere): the period studied is from year 2000 to 2012, 12 years from the beginning to the end. Should the trends be ± 0.3 12 years^{-1}?

11. p. 2758, line 23: How is "moderate and strong correlation" defined? It would be helpful to give a typical value for the correlation coefficient corresponding to $p = 0.05$.

12. p. 2759, lines 3–5. Whether or not this holds true depends on month. E.g. in Eastern Siberia, the albedo change in May is clearly associated with reduced snow cover. Please specify which months you are referring to.

13. p. 2759, lines 11–15: Here, it would be helpful to remind the reader that this analysis is confined to the region with 100% SCF (or is it?).

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14. p. 2759, lines 17–18: Mention explicitly that you consider monthly-mean temperature. It is important for the interpretation of the $-15°$C threshold.

15. p. 2764: In discussing the role of snow metemorphosis on albedo, the possibility of melting (and refreezing) should also be considered. The temperature can occasionally rise to $0°$C even if the monthly-mean temperature is much colder — this is something that may be obscured by the use of only monthly data in this study.

16. p. 2765, line 2: "albedo might decrease and surface air experience cooling"? I find two problems with this sentence. First, if the metamorphosis rate decreases, the snow grains remain smaller, which should increase the albedo. Second, you are discussing feedback effects resulting from warming. A negative feedback as suggested here does not turn warming into cooling; it just reduces the warming. Therefore, a better formulation would be (e.g.) "Albedo might increase, reducing the increase of surface temperature." Whether this mechanism is important in practice is of course another matter (e.g., in comparison to changes in snowfall amount/frequency, let alone changes in snow cover).

17. p. 2765, line 5: You could add a reference regarding sublimation, e.g.

Ulrich Strasser, Michael Warscher, and Glen E. Liston, 2011: Modeling snow–canopy processes on an idealized mountain. J. Hydrometeor, 12, 663–677. doi: http://dx.doi.org/10.1175/2011JHM1344.1.

18. Fig. 3: It is very difficult to draw any quantitative information from this figure, beyond the fact the albedo and SCF area positively correlated. Consider using another (discrete?) colour scale.

19. Fig. 6: In practice, it is hard for the reader to link the p values shown in one map to the correlation shown in another. It would be better to display the correlation map only,

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but so that statistically insignificant values are screened out. Possibly, a more liberal significancce threshold than $p = 0.05$ could be used, e.g. $p = 0.10$.

Technical and language corrections

1. The definite article "the" is missing at a number of places. E.g., p. 2748, line 24 (before "amount"); p. 2749, line 2 (before “NH”); p. 2759, line 2 (before “variation of albedo"); p. 2760, line 7 (before “regions”); p. 2762, line 17 (before "exception"), p. 2762, line 18 (before “results”); p. 2765, line 11 (before "obtained”); p. 2765, line 28 (before "decrease of albedo"); p. 2765, line 29 (before "forest fraction"); p. 2766, line 2 (before "albedo"); p. 2766, line 18–20: (before "presence", "snow density" and "albedo decline rate").

2. p. 2747, line 28: The publication year for Groisman et al. is 1994.

3. p. 2748, line 2: Do you mean "Taillandier"?

4. p. 2748, lines 2-3: "at higher temperatures . . . as the air temperature is higher"??

5. p. 2748, line 20: simpler to say: "independent of temperature".

6. p. 2749, line 7: Do you mean "Winkler"?

7. p. 2749, line 19: this should probably be: "may exceed *the effect of* increased carbon uptake"?

8. p. 2750, line 4: The publication year for Qu and Hall is 2014.

9. p. 2751, line 18: replace “inverse algorithm” with “inversion algorithm”.

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10. p. 2752, lines 17–18: replace “accuracy” with “uncertainty” or “errors”. If accuracy is less than something, uncertainties/errors are larger.

11. p. 2752, lines 20–23 and p. 2754, lines 15–18: This is also said in the acknowledgments, so it could be omitted from the main text for brevity.

12. p. 2753, lines 5–6: "The 11% threshold excludes liquid water pixels". Do you mean "eliminates" or "screens out" liquid water pixels . . . ?

13. p. 2755, line 27, and elsewhere: replace “Taymir” with “Taymyr”

14. p. 2756, line 25: replace "snow fall" with "snowfall"

15. p. 2758, line 20: This should be "Correlation coefficients between SCF and albedo . . . ”.

16. p. 2758, line 29: "varies" should be in plural: "vary".

17. p. 2762, line 25: "of area" can be omitted.

18. p. 2765, line 1: probably, this should be "temperature gradient threshold in the snowpack".

19. p. 2765, line 15: This should be "involved in".

20. p. 2765, line 27: Replace "densening" with "densification".

21. The following papers appear in the reference list but are not cited in the manuscript: Essery et al. (2001), Matthias et al. (1999) and Naito et al. (2011). Furthermore, Allan et al. (1999) is cited (on p. 2747, line 4) but does not appear in the reference list.

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22. p. 2773, line 1: "Apple" should be "Appel".

23. Caption of Fig. 2: Mention that Greenland and Iceland are also marked in green (they are not snow-free).

24. Caption of Fig. 6: replace "coefficients maps" with "coefficient map" and "ofdays" with "of days".

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