Edward Bair (Referee)

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We are very grateful for the referee's critical comments. The followings are our point-by-point responses to the comments. Our responses start with "R:".

Aside from the Data Statement section, the authors responded to my comments, but did not make changes to the manuscript addressing my suggestions in my Access Review. Given the preliminary nature of the Access Review, that's fine with me, but during this formal review stage I ask that my comments be addressed in the manuscript. I have provided a copy of the Access Review below.

R: We are really sorry for making no changes to the manuscript addressing your suggestions aside from the Data Statement section. We really appreciate the reviewer's comments, which can help us to improve the paper quality substantially and encourage us to do more in-depth research in the future. We have addressed all the comments very carefully in this section as detailed below.

Limitations:

In the manuscript, the authors have not addressed the problem of distinguishing between absorbers in the air and on the snowpack as stated by Warren (2013). Some of the regions examined have extensive air pollution. The MCD43C3 albedo product used relies on MOD09 surface reflectance which masks out snow when estimating aerosol optical thickness. Snow is difficult to mask, and the "dark and dense vegetation technique" used to estimate aerosol optical thickness (Vermote & Saleous, 2006) has shown errors over snow cover in the past that have supposedly been addressed (Vermote et al., 2002). However, one can still find errors. For example, MOD09 surface spectra sometimes show strong hook features over relatively clean fully-snow covered pixels in the visible wavelengths that are not present in the top of atmosphere reflectances and can only be ascribed to problems with atmospheric correction. I'm not suggesting that the MCD43C3 product is unsuitable, rather I'd like to see its limitations over snow discussed in the manuscript. Saying that "more [sic] in-situ observations and hyperspectral imagery are needed." is not a sufficient response.

R: The referee's opinions are very valuable. Indeed, the absorbers in the air can disturb the retrieval of MODSI surface reflectance. According to the MODIS Surface Reflectance User's Guide (Collection 6, https://modis.gsfc.nasa.gov/data/dataprod/mod09.php), the accuracy of the atmospheric correction is typically: ±(0.005 + 0.05*reflectance) under conditions that AOD is less than 5.0 and solar zenith angle is less than 75°. Therefore, we estimate the uncertainty of calculated radiative forcing based on the level of accuracy of the atmospheric correction in our study. Details could be found in Section 4.5.

MYD10C1 does not use spectral unmixing; it uses the 2-band NDSI which shows high scatter when converted to fractional snow cover using Equation 5. Thus, the fractional snow cover filter used is an undiscussed bias in the approach, where LAP could be mistaken for non-snow objects and vice-versa.

R: The referee's opinions are very valuable. We have added an estimation and discussion on the uncertainty of calculated radiative forcing from the uncertainty of converting NDSI to fractional snow cover. According to (Rittger et al., 2013) and Riggs et al. (2016), the converted percentage error assumed in this study was 10%. Details could be found in Section 4.5.

Note that MODIS is a multispectral, not a hyperspectral sensor.

R: We have revised the mistake.

Exclusion of midlatitude mountains and other vast snow-covered areas in the Northern Hemisphere is substantial and should be stated in the Abstract. As Referee #1 and #2 both point out, the domain (non-vegetated & non-mountainous areas) and time periods (Jan-Feb) are limited. These limitations undermine global application (e.g. p3 l1 & p6 l2).

R: We have added a statement for exclusion of midlatitude mountains in the Abstract and an explanation for why we exclude midlatitude mountains in the main text in p. 20, lines 7-11. We have extended the study period from January-February to December-May, so that the snow cover area over the Arctic can be retrieved. Also, we have replaced the clear-sky radiative forcing with all-sky radiative forcing, which makes more sense to the research community.

Further discuss limitations

Consider addressing the challenges in measuring LAP stated in Warren (2013) directly, such as distinguishing between absorbers in the air and those in the snowpack. Equation 5 when applied in the MOD10A1 product shows an RMSE of 0.227 and a positive bias of 0.11 (Rittger et al., 2013). These errors and biases are important because darker objects at visible wavelength in mixed snow-covered pixels (e.g. shadows and vegetation) can be misidentified as LAP.

R: As mentioned above, we have added estimations and discussions about the uncertainty of calculated radiative forcing from converting NDSI to fractional snow cover in Section 4.5.

Section 3.2.3

This basis for the snow grain size retrievals cites studies (Nolin & Dozier, 2000; Painter et al., 2013; Seidel et al., 2016) which use hyperspectral imagery at an more than order magnitude greater spatial and spectral resolution than a multispectral instrument like MODIS. The authors are relying on the albedo retrieval from a single MODIS band at 1.24 μm to estimate grain size. This approach has high uncertainty due to errors in albedo retrievals from MODIS. In a previous study, Pu et al. (2019) state the MAE is 71μm or 3 times greater than in the studies cited above using hyperspectral instruments. The previous two comments suggest why substantial correction factors for the remotely-sensed measurements (Section 4.3) are needed.

R: The referee's opinions are very valuable. We have added an estimation and discussion about the uncertainty of calculated radiative forcing from snow grain size retrieval. The percentage error of snow grain size retrieval assumed in this study is 30% according to the study of Wang et al. (2017) and Pu et al. (2019). Based on the discussion of the uncertainties from atmospheric correction, snow cover fraction calculation and snow grain size retrieval, we further demonstrate the necessity of substantial correction factors for the remotely-sensed measurements and why the correction factor is different over relatively polluted snow and relatively clean snow. Details could be found in Section 4.5.

Section 4.1

The study area does not include most of the midlatitude mountains in the northern hemisphere. Snow and ice melt in these areas provides a valuable water resource to over 1B people worldwide (Barnett et al., 2005) and studies cited by the authors in the Introduction (Painter et al., 2012; Seidel et al., 2016) show this snow is heavily affected by LAP.

R: In this study, the MODIS surface albedo data used is MCD43C3, which has a resolution of 0.05° × 0.05°. Usually, the snow cover faction over midlatitude mountains at such a coarse resolution is low, which cause that most of midlatitude mountains are not mapped as snow-covered area. In addition, midlatitude mountains are characterized as complex terrain, which will cause high biases in radiative forcing retrieval at a coarse resolution of 0.05° × 0.05° in spite of topographic correction. Therefore, we didn't report the results over midlatitude mountains in this study. We have added an explanation why midlatitude mountains are not included in Section 4.1 in p. 20, lines 7-11. However, we agreed with the referee that the radiative forcing over midlatitude mountains are quite important, so that we will focus on these areas using finer resolution MODIS data (MCD43A3, MOD/MYD09) or data from high resolution satellites (e.g. Sentinel-2 and Landsat 8) in the future.

Data availability

No data statement is provided. Please see the ACP Data Policy which requires a statement of how the data can be accessed.

R: We have added more descriptions about the data access referring to the ACP Data Policy in Data availability.

References:

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