Reply to referee #1

The authors are grateful for this considerate and insightful review of their article.

1. Page 23132, line 14 “On the contrary, multiple layers of mineral aerosols deposited during episodic events evenly distributed play a similar role in the surface albedo of snow as a loading distributed throughout, even when the layers are further apart”. This sentence is really awkward to read without knowing the details of this study a prior. Do the authors mean that the albedo of two equal-depth snowpacks are similar as long as the dust loading of these two snowpacks are same, regardless of the number and positions of dust layers? This is a key message of the paper, and it should be made clearer.

The sentence has been reworded. The text now reads:

On the contrary, the surface albedo of two snowpacks of equal depth, containing the same mineral aerosol mass-ratio, is similar, whether the loading is uniformly distributed or concentrated in multiple layers, regardless of their position or spacing.

2. Equation (2), shouldn’t the mass absorption coefficient of sea ice equals to the sum of mass-weighted absorption coefficient of different materials (i.e. ice and mineral aerosols) within the study medium? Mass absorption coefficient of different materials cannot be added directly. Is this equation only applicable to sea ice? What about snow?

The referee is correct. The equation (2) (equation (1) in this document), has been corrected and now reads:

$$\sigma_{total} = \sigma_s(\lambda) + x_{mn}\sigma_{mn}(\lambda), \tag{1}$$

where $\sigma_s(\lambda)$ is the wavelength dependent absorption cross-section of sea ice or snow, x_{mn} is the mass-ratio of mineral aerosol deposits in the snow or sea ice and $\sigma_{mn}(\lambda)$ is the wavelength dependent absorption cross-section by mineral aerosols.

3. Page 23138, line 13. ”Data on the typical wavelength dependant refractive index of mineral aerosols is scarce in the literature“. More data and references on refractive index of dust can be found in Figure 7 of paper: Dang, C., R. E. Brandt, and S. G. Warren (2015), Parameterizations for

narrowband and broadband albedo of pure snow and snow containing mineral dust and black carbon. J. Geophys. Res. Atmos., 120, 5446–5468.doi: 10.1002/2014JD022646 . This might be useful for the authors' future research.

The authors are grateful for this reference. The sentence has been replaced and the text now includes the reference as following:

"*A selection of the imaginary part of the refractive index values of mineral dust found in the litterature was reported by Dang et al. (2015). Three different volcanic ashes and two dusts were chosen ...*".

5. Section 2.3, these experiments are very comprehensive. It would be good to add a diagram to illustrate the different schemes.

A diagram of the experiments has been added as figure 3 of the manuscript, which is shown as figure 1 in this response.

6. Page 23141, line 29. "The snow grain radius parameter was varied in SNICAR-online to fit three types of clean snowpacks to the output of TUV-snow". Does SNICAR online output scattering cross-section? If yes, are the scattering cross-sections similar?

Unfortunately SNICAR-online does not output scattering cross-section. Therefore, a comparison between scattering cross-sections was not possible in this study.

7. Table1: besides the values given in this table, it might be good to include the equivalent snow grain radius as well, since it is a commonly used parameter to character the type and age of snow. According to the comparison with SNICAR, the radii are 85 microns for cold polar snow, 220 microns for costal wind pack, and 1400 microns for melting snow.

A column containing the equivalent snow grain radius values has been added to the end of Table 1.

8. Figure 9: two consecutive dust events that each produce 800ng/g dust loading seems to be unusual in a short time period. Does the author have a feeling about the observed snow thickness between two such large dust events? In another word, would the distance between dust layers more similar to 8 cm? If in that case, it seems that only the surface dust layer matters for snow albedo.

Dong et al. (2013) show mass-ratios of dust in snow greater than 800 ng g^{-1} and the following text has been added:

Page 23141, line 22. Although typical mass-ratios are lower in polar regions (Zdanowicz et al., 1998), Dong et al. (2013) show values higher than 800 ng g^{-1} in snowpacks close to dust sources. The concentration of 800 ng g^{-1} was selected to provide a clear signal whilst remaining realistic.

Inspection of Figure 9 shows that as the distance between the layers increases, the difference between the albedo of the layered snowpack and the snowpack containing a single surface layer becomes small. Therefore the authors suggest that layer intervals significantly greater than 8 cm can be neglected as a first approximation. The following text has been added:

Page 23153, line 6. Dust layers within snowpacks are typically greater than 8 cm (Zdanowicz et al., (1998), Osada et al. (2004), Dong et al. (2013)) and inspection of Figure 9 shows that as the distance between the layers increases, the difference between the albedo of the layered snowpack and the snowpack containing a single surface layer becomes small. Therefore as a first approximation, layer thicknesses significantly greater than 8 cm may be neglected.

9. For the figures that only show relative albedo change, please add the albedo that compared against with as well. A relative change in albedo cannot be converted to energy change directly, which is what actually matters to snow/ice energy budget. Some readers may want to do a quick calculation.

The reference albedo values have been added to the captions of Figure 5 and 8. The captions now read:

Figure 5. Relative change in albedo at a wavelength of 550 nm for an increasing mass-ratio of (a) Asian mineral dust (b) Saharan mineral dust (c) Mt St Helens volcanic ash (d) Eyjafjllajkull volcanic ash relative to a mass-ratio of 1 ng g^{-1} throughout three semi-infinite snow and sea ice types. The albedo for 1 ng g^{-1} of mineral aerosol deposits, valid for a, b, c and d, is 0.988 for cold polar snow, 0.981 for coastal windpacked snow, 0.953 for melting snow, 0.727 for first year sea ice, 0.867 for multi year sea ice and 0.494 for melting sea ice. The values presented for a wavelength of 550 nm are indicative of the same behaviour for wavelengths between 400 and 600 nm.
Figure 8. Relative change in albedo for an increasing surface layer of 100 ng g^{-1} of mineral dust between 1 and 10 cm at 450 (a), 550 (b), 650 (c) and

750 nm (d). The albedo without a surface layer is 0.996 at 450 nm, 0.988 at 550 nm, 0.973 at 650 nm and 0.950 at 750 nm for cold polar snow, 0.989 at 450 nm, 0.980 at 550 nm, 0.957 at 650 nm and 0.920 at 750 nm for coastal windpacked snow, 0.943 at 450 nm, 0.932 at 550 nm, 0.892 at 650 nm and 0.815 at 750 nm for melting snow, 0.611 at 450 nm, 0.575 at 550 nm, 0.452 at 650 nm and 0.267 at 750 nm for first year sea ice, 0.950 at 450 nm, 0.866 at 550 nm, 0.721 at 650 nm and 0.542 at 750 nm for multi year sea ice and 0.505 at 450 nm, 0.412 at 550 nm, 0.215 at 650 nm and 0.079 at 750 nm for melting sea ice.

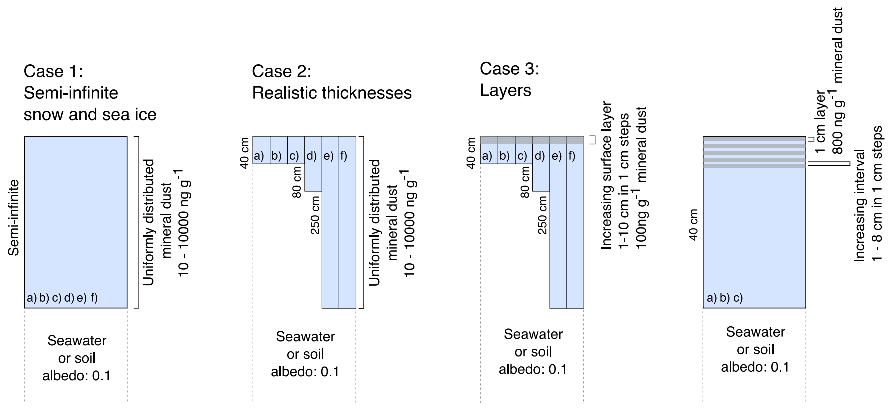

Figure 1: Snow and sea ice configurations modelled for a) cold polar snow, b) coastal windpacked snow, c) melting snow, d) first year sea ice, e) multi year sea ice, f) melting sea ice (not to scale).

[1] Zhiwen Dong, Zhongqin Li, Wenbin Wang, Kaiming Li, and Ping Zhou. Characteristics of atmospheric dust deposition in snow on glacier no. 4, mt bogeda, china. *Environmental Earth Sciences*, 70(3):1423–1433, 2013.

[2] J. L. France, H. J. Reay, M. D. King, D. Voisin, H. W. Jacobi, F. Domine, H. Beine, C. Anastasio, A. MacArthur, and J. Lee-Taylor. Hydroxyl radical and nox production rates, black carbon concentrations and light-absorbing impurities in snow from field measurements of light penetration and nadir reflectivity of onshore and offshore coastal alaskan snow. *Journal of Geophysical Research: Atmospheres*, 117(D14), 2012. D00R12.

[3] Kazuo Osada, Hajime Iida, Mizuka Kido, Katsuji Matsunaga, and Yasunobu Iwasaka. Mineral dust layers in snow at mount tateyama, central japan: formation processes and characteristics. *Tellus B*, 56(4):382–392, 2004.