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Interactive comment on "The effect of snow/sea ice type on the response of albedo and light penetration depth (e-folding depth) to increasing black carbon" *by* A. A. Marks and M. D. King

A. A. Marks and M. D. King

amelia.marks.2006@live.rhul.ac.uk

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We thank the referee for their comments. Our answers and corrections are below.

Referee comment: The asymmetry parameter equals the single-particle forward scattering efficiency divided by the single particle total scattering efficiency. The scattering cross section is also proportional to the single-particle scattering efficiency. Yet, Table 1 indicates that the same asymmetry parameter is assumed for different scattering cross sections. The asymmetry parameter should be calculated consistently with the scattering cross section and should not be independently varied

Response: *As shown by Warren and Wiscombe (1980), figure 4, the asymmetry pa-*

rameter, g, is almost constant over the visible wavelengths considered in our paper, for grain sizes ranging from 50 to 1000 μm. Warren and Wiscombe's work thus demonstrates we can assume a constant value of g i.e. g=0.89 (+/-0.005). Two of our own previous papers (cited in the paper) Marks and King (2013) and France et al. (2012) demonstrate that changing the asymmetry parameter by +/- 0.005 had negligible effect on the scattering cross-section of snow and sea ice. The comment below will be added to explain why g is kept constant. "The value of asymmetry parameter remained fixed during the work presented here for snow and sea ice. Warren and Wiscombe (1980) demonstrated with Mie calculations of spherical ice grains (50 to 1000 μm) that g is almost invariant across the visible spectrum as considered in this paper. Marks and King (2013) and France et al. (2012) have previously demonstrated that changing g between sensible limits +/-0.005 (from figure 4 of Warren and Wiscombe (1980)) has negligible effect on the value of the scattering cross-section of snow and sea ice. "

Referee comment: Similarly, the density of snow or ice will depend on the grain size, which also affects the scattering cross section, asymmetry parameter, and optical depth through the snow. Yet, in Table 1, the authors are varying density independently of the other parameters, so there seems to be an inconsistency. In other words, it is probably not realistic that one would find the conditions of density, asymmetry parameter, and scattering cross section that the authors assume in Table 1. The authors should define the most basic input parameters (e.g., grain size, refractive index, mass concentration of black carbon, size of black carbon inclusion), and calculate all output parameters from those (e.g., scattering and absorption cross sections, density, asymmetry parameter, single- scattering albedo, etc.)

Response: *The referee suggests calculating all optical properties of snow and sea ice ab-initio from basic properties of ice. This will require the assumption of spherical snow grains and snow grains are not spherical. In our work we empirically trained our radiative-transfer model using field measurements of albedo and e-folding depth and make no assumption about grain size or shape. The snow is modeled as a highly* *scattering layer with low absorption and characterised by two cross-sections for scattering and absorption respectively. We have recently considered the large effect grain shape has on light penetration depths, Libois et al (2013), published in this journal. Our method offers a different approach to the ab-initio of others and is based on field measurements of real snow. The referee is incorrect to suggest that "it is not realistic" that one would find the conditions of density, asymmetry parameter and scattering cross-section listed in table 1 because all the values of the table have been derived from either our fieldwork (e.g. Fisher et al. (2005), King et al (2005), France (2008), France et al. (2011)) or others referenced in our paper.*

Referee comment: The authors should compare their prediction of spectral albedo for some base case with predictions from another study or data to ground-truth their model.

Response: *The following comment will be added to the paper: "The method of parameterising snow and sea ice optical properties to values of scattering and absorption cross-section has been discussed elsewhere in detail (Lee-Taylor and Madronich, 2002, Marks and King 2013) and shown to reproduce the original albedo and e-folding depths as a function of wavelength accurately (Marks and King, 2013). The model presented here is not an ab-initio model based on calculated optical properties of spherical grains. The model presented here is a coupled atmosphere-snow model with a snowpack that is described by a scattering cross-section, an absorption cross-section and an asymmetry parameter. The asymmetry parameter is fixed (see previous comment) and the scattering and absorption cross-section are selected to reproduce the field measurement of albedo and light penetration depth (see Lee-Taylor and Madronich, 2002 for full method). The method has previously been used successfully to find scattering and absorption cross-sections for snow and sea ice (e.g. Marks and King, 2013)". As such a comparison with field data is only a test of how well our model parameterises the field data and has been shown to be excellent in Marks and King (2013), Libois et al. (2013) and Reay et al. (2012).*

Referee comment: How does the refractive index of black carbon used compare with that recommended in Bond et al. (2013)?

Response: *The refractive index for black carbon in this work is based on the original work of Warren and Wiscombe (1982 a,b). In France et al. (2012) we demonstrate how well the absorption cross-section for black carbon calculated from Warren's refractive index captures the experimental absorption cross-sections reported in the review of Bond et al. (2013) as well as the recommendation of Bond et al. (2013). To be consistent with our earlier work we have decided to use Warren's values of refractive index for black carbon. An interested reader could use the very simple techniques described in the supplement of Reay et al. (2012) to change between the two black carbon absorption cross-sections. It is not a big effect and does not distract from the message of the paper. The following text has been added to the paper "A comparison of the absorption cross-section for black carbon calculated using the method of Warren is compared to experimentally measured absorption cross-sections reviewed in Bond et al. (2013) and presented in (France et al. 2012). France et al. (2012) demonstrate good agreement between the absorption cross-section of black carbon used here and previous experimental measurements"*

Referee comment: Solving for surface albedos with upward divided by downward surface irradiances over snow and sea ice with an atmosphere-snow-sea-ice radiative transfer model treating black carbon inclusions in and between snow and sea ice grains was previously done in Jacobson (2004). Calculated albedos over both sea ice and snow for different conditions, including grain size, were given in Figure 1 of that paper. It seems the methodology used in the present study is quite similar but the tests were different and the method of calculating optical properties was different. Please indicate whether this is the case

Response: *Presented in our paper we show the response of different snow and sea ice types to black carbon, represented by different scattering cross-sections (which may be related to grain size). Interestingly the paper cited by the referee, Jacobson (2004),* *suggests the influence of black carbon on snow and sea ice albedo is independent of the snow type/grain size "The choice of grain size, which effects the absolute albedo to some degree, has relatively little effect on the albedo difference arising because of the addition of BC to snow or sea ice." Thus the results of Jacobson (2004) are potentially in contrast to the work we present in our paper which show a large difference in albedo response with different snow and sea ice types, a result also previously suggested by the modelling study of Warren and Wiscombe (1982) and the experimental study of Hadley and Kichstetter (2012). An additional comment will be added to the paper to mention the results from Jacobson (2004) and compare them to our results. "The modelling study of Warren and Wiscombe (1982) and the experimental study of Hadley and Kichstetter (2012) suggest the sensitivity of albedo to black carbon is sensitive to the grain size of snow or sea ice. Agreeing with the detailed study presented here. Jacobson (2004) suggests the choice of grain size has relatively little effect."*

Interactive comment on The Cryosphere Discuss., 8, 1023, 2014.