Review of *'On the reflectance spectroscopy of snow'* by Kokhanovsky and 8 others

This manuscript describes an analytical method to derive snow grain size, the absorption Angstrom coefficient, the spectral absorption coefficient of impurities in snow, and the effective absorption length (EAL) from plane albedo and spectral reflectance measurements over snow. This approach is novel in its ability to model the ultra-violet to near-infrared hyperspectral reflectance of snow using between 3 and 4 snow reflectance or albedo measurements, given that at least one of the reflectance/albedo measurements is made in either the visible or near-infrared part for the spectrum. The manuscript provides a thorough step by step approach to extracting the important optical and microphysical properties of snow listed above but would benefit from editing to improve clarity and consistency with itself.

1. Consider referencing, and then numbering, the figures in which their data is discussed in the text. Section 3 describes the different measurement types and data presented in the manuscript. Section 3.1 begins describing the measurements of spectral plane albedo made at Dome C, Antarctica. The plot of this data should be referenced here as Figure 1. The next part of section 3.1 describes the measurements of spectral plane albedo made at Col du Lautaret. The plot of this data should be referenced as Figure 2. The related discussion and derived spectral probability of photon absorption then becomes Figure 3. Finally, Section 3.2 discusses measurements of spectral reflectance made at a second site in the Alps. This data should remain, as it currently is, Figure 4.

2. Table 1 is somewhat confusing. As is, the table presents two different types of data (plane spectral albedo and spectral reflectance), and data from two different locations (Col du Lautaret and a second location in the Alps). Additionally, the table caption only describes the first five rows of the table, which describe the plane spectral albedo measured at Col du Lautaret, and does not mention where the data included in rows 6-7 was measured. This lack of distinction can lead to confusion in the text itself, evidenced in line 244. Here, the authors are discussing the plane albedo measurements made at Col du Lautaret, which corresponds to rows 1-5 of Table 1. Line 244 gives the snow grain diameter range as 1.5 – 1.9 mm. However, the snow grain diameter range presented in rows 1-5 of Table 1 extends from 1.7 - 2.2 mm.

   At the least, I suggest including an additional row (or two) to the existing Table 1 to include the location and type measurements recorded in a specific row. Alternatively, splitting the data presented in Table 1 into two separate tables by data type and location to avoid confusion. A new Table 1 (Table1*) could present the plane albedo measurements made at Col du Lautaret (Table 1; rows 1-5), and a second table (Table 2*) could present the spectral reflectance measurements made at the second site in the Alps (Table 1; rows 6-7).

   Additionally, I suggest changing the notation of parameter description at the top of column 2 in Table 1 to match that of column 3. If I understand the table correctly, column 2 corresponds to the derived snow absorption coefficient for wavelength = 1000nm, while column 3 corresponds to the derived snow absorption coefficient for wavelength = 560 nm. The parameter notation at the top of column 3 clearly indicates this, while the parameter notation at the top of column 2 seems to suggest a completely different parameter is being described. If my above understanding is correct, I suggest changing the parameter description at the top of column 2 to match the form of column 3 and the table caption, i.e.:

$$\kappa_{abs}^{pol}(\lambda_0)$$

Line 42: "one to four wavelengths" → Discussion later in the manuscript refers to using a minimum of 3 wavelength measurements to derive *I*, *m*, and *f* from plane albedo measurements (see lines 174-175), and 4 wavelengths measurements to derive R_o, *I*, *m*, and *f* from snow reflectance (see lines 114-116). I don't believe the authors discuss using only 1 or 2 wavelength measurements to derive snow optical/microphysical properties anywhere in the paper. If it is possible to derive

snow properties from 1-2 wavelength measurements, the authors should elaborate on this, or adjust this statement in the introduction to reflect the need for 3-4 wavelength measurements.

Line 79: It's not clear to me how equation 7 follows from "$\alpha d \rightarrow 0$." The authors reference Kokhanovsky and Zege (2004), which presents the following definition for α:

$$\alpha = 4\sqrt{\frac{\ell_{tr}}{3\ell_{abs}}}$$

where ℓ_{tr} and ℓ_{abs} are the transport path length and absorption path length respectively. This is different from the definition for α given on line 81 of this manuscript. Further expansion on what is intended by "$\alpha d \rightarrow 0$" in the context of equation 7 would be helpful here.

Line 84: Identifying the variable "*m*" in the vicinity of this equation would be helpful.

Line 85: "σ_{abs}^{pol}" is used in the definition of κ_0, but is not explicitly defined itself. I.e., is this referencing the absorption cross-section for pollutants in the snow?

Line 108: Suggest rephrasing the beginning to the sentence. Perhaps, "Using the EAL, the equations for snow reflectance…".

Line 115: I don't believe "*m*" has been explicitly defined up to this point in the manuscript. If not back at equation 8 (see comment above), here would be a great place to do so.

Line 174: Delete "In case" and begin the sentence with "If the plane albedo…"

Line 194: It is not clear how the authors arrive at equation 45 from equation 48. Additional explanation would be helpful.

Line 204: "(Assuming that the grain size is exactly known)." – Generally, snow grain size is not known "exactly." Given this, the parenthetical aside should be deleted, leaving the remainder of the sentence ("…one finds that the positive bias in the measured albedo in the visible will lead to the underestimation of the concentration of pollutants.") still valid.

Line 234: For consistency with the language used in the last sentence of the previous paragraph, suggest changing "inter-comparison" → "comparison"

Line 236-237: My understanding is that 5 different spectral albedo measurements were taken and subsequently averaged to create the solid line in Figure 1. Line 234 seems to state that this average is what is shown and compared with the theory estimates in Figure 1. However, the sentence staring on line 236 and ending on 237 "At all measurement sites…presented in Fig. 1," makes it sound like measurements were taken at more than one location, even though the previous paragraph lists only one site (Col du Lautaret). Is the intent of this sentence to convey that the 5 independent albedo measurements taken at Col du Lautaret are similar to/consistent with their average? If so, I would suggest removing references to "sites" (e.g., Albedo measurements at all 5 points along the 100 m transect are similar to their averaged spectra show in Figure 1…).

Line 238: Consider combining with the previous sentence along the lines of: "All 5 albedo measurements are consistent with the average shown in Fig.1, supporting our assertion that the theory presented here can be used to derive snow optical/microphysical properties for a polluted snow pack."

Line 242: If "*m*" as used here is referring to the absorption Angstrom parameter, it should again be defined as such earlier in the manuscript.

Line 244: If I understand this paragraph correctly, the authors are referring to rows 1-5 in Table 1. While line 244 lists the grain diameters as 1.5 – 1.9 mm, the grain size diameter range given in rows 1-5 of Table1 is: 1.7 – 2.2 mm.

Additionally, this sentence could benefit from a reference as to why the low snow albedo values at 1020 nm are consistent with snow grain diameters 1.7 – 2.2 mm. There is a local minimum in hyperspectral snow albedo around 1020 nm (Wiscombe and Warren, 1980; Warren, 1982; Nolin and Dozier, 1993; Grenfell et al., 1994), but it varies by grain size. Citation of how the grain sizes discussed in this manuscript are consistent with these observations would help bolster the stated expectation of consistency.

Line 245-248: These two sentences seem a little cumbersome and could benefit from some rephrasing. Perhaps something like: "Application of our technique results in excellent agreement with measured albedo over pure snow (no pollution) in Antarctica. Because the snow at Dome C is clean/pristine, the absorption Angstrom parameter (*m*) and *f* are negligible, resulting in snow albedo depending only on *l* (characteristic length)."

Line 247-248: The authors refer to the "characteristic length." Is this a reference to the EAL defined in equation 14? If it is not, this is a new topic that I do not think has been addressed earlier in the paper and should be if it has not.

Line 267: This paragraph is discussing the measurements of spectral reflectance presented in Figure 4. It's unclear why the HCRF was calculated for dust concentration of 0.92 ppm, since spectral reflectance is only presented for dust concentrations of 39.6 ppm and 107.4 ppm. I would recommend either explaining why the calculations for 0.92 ppm are mentioned here, or just removing it entirely as its inclusion suggests there is addition data not presented in the manuscript.

Line 276: Suggest replacing "first case" and "second case" with "39.6 ppm dust concentration" and "107.4 ppm dust concentration" respectively for clarity.

Line 285-286: This sentence is a little confusing as is. Suggest changing to something like: "The difference between the two ratios is < 3%, which is within the measurement uncertainty, and suggesting that the absorption coefficients at the two sites are consistent with each other."

It would also be helpful to state what the measurement uncertainty for the dust concentrations.

Line 293: Define the acronym "MAC" at line 286. (i.e., "The mass absorption coefficient (MAC)…")

Line 299-301: Suggest editing the end of this sentence for clarity → "…snow reflectance measured at four wavelengths: two in the visible and two in the near-infrared as suggested by Warren (2013)."

Line 303-308: Since the authors state in the previous sentence that they do not attempt to determine the refractive index of dust in this manuscript, the sentences starting at line 303 and ending at 308 ("The method for the retrieval of complex refractive index…. complicated procedure.") are unnecessary and should be removed.

Line 319: An acronym for effective absorption length, EAL, is presented on line 98. I would suggest either using throughout the paper, or don't define the acronym.

It may also be useful to list the EAL in lines 297-299 as one of the parameters derived from the analytical equations.

Figure 3: Include a legend in this figure as was done for the other figures.

Figure 3: Y-axis range should be 0 to 1 as in Figure 1.

Figure 4: Only latitudes are given in the figure caption. Add the longitudes as was done in the captions for Figures 1 & 3.

ALL Figures: Set x-axis to have the same range across all figures (e.g., 400-1050nm).

References

Wiscombe, W. J., & Warren, S. G. (1980). A model for the spectral albedo of snow. I: Pure snow. *Journal of the Atmospheric Sciences*, *37*(12), 2712-2733.

Warren, S. G. (1982). Optical properties of snow. *Reviews of Geophysics*, *20*(1), 67-89.

Nolin, A. W., & Dozier, J. (1993). Estimating snow grain size using AVIRIS data. *Remote sensing of environment*, *44*(2-3), 231-238.

Grenfell, T. C., Warren, S. G., & Mullen, P. C. (1994). Reflection of solar radiation by the Antarctic snow surface at ultraviolet, visible, and near-infrared wavelengths. *Journal of Geophysical Research: Atmospheres*, *99*(D9), 18669-18684.