Answers to comments of Referee #1

We want to thank the referee for the comments to our submitted manuscript.

Our replies are structured as follows:

(1) Referee comment

(2) Author response

(3) Manuscript changes (given line numbers refer to the revised manuscript)

(4) References are listed in case they were not included in the original manuscript

I have only one critical comment on the manuscript:

The statements "the stronger a non-complete representation of the phase function will influence the simulated reflectance spectra" and "[the] sensitivity of the extraction method to the phase function" is one of the "strongest sources of uncertainty" are incorrect. In the case of multiple scattering, the details of the single scattering phase function are not important and in problems such as the one considered it is sufficient to use the so-called transport approximation with the correct value of the asymmetry factor of scattering

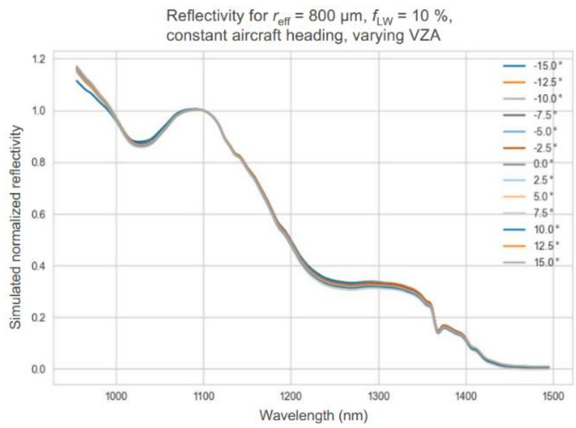
I would like to recommend the following literature on this subject:

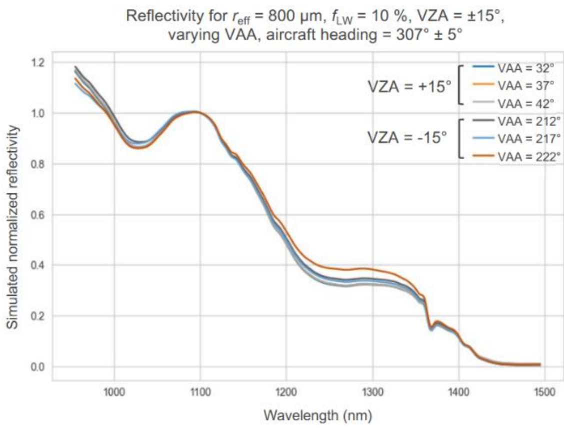
- L.A. Dombrovsky, The use of transport approximation and diffusion-based models in radiative transfer calculations, Computational Thermal Sci. 4 (4) (2012) 297–315. http://doi.org/10.1615/ComputThermalScien.2012005050

- L.A. Dombrovsky and A.A. Kokhanovsky, Solar heating of the cryosphere: Snow and ice sheets, Ch. 2 in the book "Springer Series in Light Scattering", edited by A. Kokhanovsky, Springer Nature, 2021, v. 6, pp 53-109. https://doi.org/10.1007/978-3-030-71254-9_2

Please consider including these articles in the reference list.

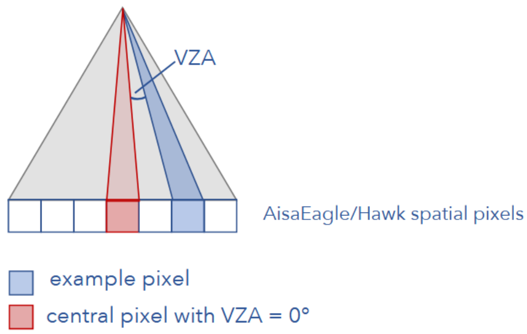
We assume that we did not clearly indicate the characteristics of the measured quantities in the manuscript. The measurements used in the retrieval are the spectral upward radiance (unit: W m^{-2} nm^{-1} sr^{-1}) and the spectral downward irradiance (unit: W m^{-2} nm^{-1}). In our opinion, the angular information of the scattering phase function can only be negligible, if hemispherical radiative properties are regarded as it would be the case for the irradiance. Contrary, the radiance has a directional dependence. Furthermore, low sun conditions are frequent in the Arctic and imply decreasing penetration depths into the snow layer. This results in an increased reflection and more single scattering (e.g., Warren, 1982). This introduces an angular distribution of the reflected radiance impacted by the scattering phase function. Additionally, the scattering phase function determines the dependence of the reflected radiance on the solar zenith angle (e.g., Carlsen et al., 2017). The same dependencies show up in our radiative transfer simulations suggesting that the angular information of the scattering phase function cannot be neglected. The left figure below shows the simulated normalized reflectivity for fixed effective radius and liquid water fraction and varying viewing zenith angle (VZA) with 0° as nadir and ±15° indicating the sensor pixels left and right from the central nadir pixel (a schematic illustration of the observation geometry is given below). The right figure considers an additional change of the aircraft heading with ±5°, which is affecting the viewing azimuth angle (VAA) that is determined by the aircraft heading ±90°. For both analyses an angular dependence of the reflectivity is apparent, especially regarding a variation of the aircraft heading and, therefore, viewing azimuth angle. Consequently, for the upward radiance used in our study we need to refer to the scattering phase function and its implications for the retrieval.

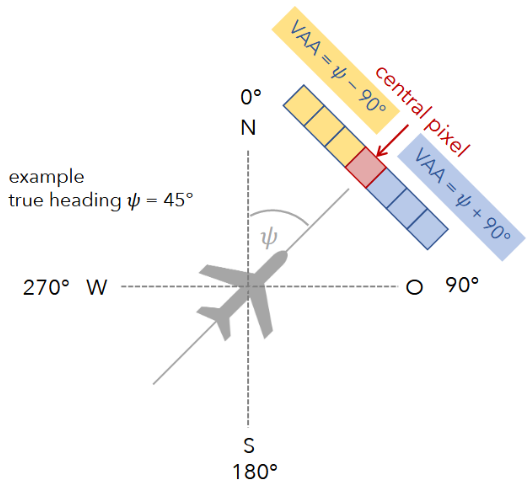




Observation Geometry – AisaEagle and AisaHawk

- viewing zenith angle VZA
- viewing azimuth angle VAA





References:

Carlsen, T., Birnbaum, G., Ehrlich, A., Freitag, J., Heygster, G., Istomina, L., Kipfstuhl, S., Orsi, A., Schäfer, M., and Wendisch, M.: Comparison of different methods to retrieve optical-equivalent snow grain size in central Antarctica, The Cryosphere, 11, 2727–2741,https://doi.org/10.5194/tc-11-2727-2017, 2017.

Warren, S. G.: Optical properties of snow, Rev. Geophys., 20, 67–89, https://doi.org/10.1029/RG020i001p00067, 1982.