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Atmospheric Chemistry and Physics Discussions

Interactive comment on "Analysis of snow bidirectional reflectance from ARCTAS spring-2008 campaign" *by* A. Lyapustin et al.

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Anonymous Referee #1

Dear Reviewer,

Thank you for your review and specific suggestions which help improve our paper. We addressed all your comments on Instrumental Issues, Model related Issues, and Technical Corrections. Our response is given below.

2 SPECIFIC COMMENTS 2.1 Instrumental issues

There are some unclarities in instrument description and data processing for the ground-based instrumentation: p21998,l7-11 : The first sentence is incompatible with

the rest: "The cosine collector is designed to accept incident radiation with equal efficiency from any angle in the hemisphere." – this would be a light collector with isotropic characteristics where in fact the incoming radiation is weighted by the cosine of the incidence angle as you state in the next sentence. I would simplify these lines (just keep "cosine weighting" or "projected detector area"). This will also make it easier to understand.

Answer: This is correct and has been adjusted in the text.

p21998,l19-21 : Describe how the two light collectors are different – are they diffusers or integrating spheres – or something different?

Answer: The cosine-collectors are now described in the text.

p21998,l24 : Figure 1 caption is incorrect. It is a leveled, and not a leveling cosine collector.

Answer: The caption has been corrected.

p22000,l5 : Should 3.1 be called "ground-based measurements"? Otherwise the reader will wonder why the other cases are not discussed. (I believe they are not because there were no ground-based measurements available on that day.)

Answer: Ground based measurements were made on both 15 and 19 April, this has been made clearer in the opening sentence.

p22000,l19 : Can you discuss the effects of SZA, or is it not relevant for this manuscript?

Answer: The effects of SZA do not pay a role in this experiment; these effects are however described in cited work at the end of the sentence.

p22000,l20 : "Due to differences in cosine collector design..." - Please explain what type of cosine collector was used (please see also comment above).

Answer: The difference is now described at the beginning of section 3.

p22000,l23 : It should really be explained how this rescaling was done. If both UW ASD and NPI have "good" accuracy between 800-850, that means they should measure the same, why can you rescale the ASD instrument and how does this help the SW and near-UV wavelengths and/or the NIR wavelength range of the instrument of lower quality. Did you rescale all across the spectrum? What was the scale factor that you applied?

Answer: Rescaling is applied to all wavelengths and is relatively small, $\sim$1.5%. The scale factor and method are now included in the text.

p22003,l6 : "convert digital numbers into reflectance" - this is a bit confusing: First of all, you should get radiance from "counts" by multiplying with the spectral instrument response function. Then, use modeled (or ideally, measured) irradiance to convert this radiance into reflectance. You have omitted step #1 in your discussion.

Answer: You are absolutely correct. Yet, we prefer not to describe all intermediate steps in technical procedures, such as DN conversion to radiance or reflectance, which are considered to be standard.

p22003,4.2: Have you compared your modeled spectral irradiance with airborne measurements?

Answer: We did not make such a comparison using CAR measurements. A good agreement of derived CAR albedo with ground-based albedo didn't warrant such an effort. However, this com parison has been made, and it will be described in a separate paper by Sebastian Schmidt et al. on albedo measurements from P3B platform by SSFR instrument during ARCTAS experiments. SSFR measures spectral irradiance and reflected (upward) flux continuously through the visible - shortwave IR region with resolution of several nanometers. After required atmospheric correction, we achieved a very good agreement between measured and modeled irradiance in the full range

of 0.4-2.2 μm. The model results were based on data of the Solar Irradiance Monitor (SIM).

p22010,l10: Is it not TAU_g, the band-integrated absorption rather than the monochromatic absorption TAU_g(Lambda) that you need? You write it the other way round.

Answer: Thank you for noticing this. This typo was corrected.

section 4.3: Is it possible to give error estimates for (a) CAR-derived radiance, (b) CAR-derived reflectance and (c) CAR-derived surface albedo? It should be possible to give the reader an impression of how much of an impact the atmospheric correction has for the accuracy of each of these parameters - I assume it is negligible compared to radiometric uncertainty.

Answer: With the possible exception of the red band, the radiometric uncertainty may be somewhat smaller than the uncertainty of atmospheric correction (AC) in the visible - near IR region. The AC uncertainties are defined by several main factors: 1) the accuracy of AOT measurements by field sunphotometers is known to be within 0.01-0.02; 2) there are some uncertainties associated with AERONET inversion products, specifically single scattering albedo of aerosol. These uncertainties may be case-specific and hard to quantify, especially at relatively low optical thickness and very bright background; 3) Despite the best effort on aircraft pitch-yaw correction, there may be a small uncertainty in the view geometry; 4) There is some uncertainty associated with inhomogeneity of the surface (most probably due to variable snow thickness over Elson Lagoon, which was clearly visible at 200m flight altitude) in the CAR footprint at different view angles. Most probably, the impact of all these sources is small as we see a good agreement of derived CAR albedo with ground-based measurements. On the other hand, the effect of atmospheric correction on albedo should not be underestimated: in the blue-red region, the atmospherically corrected albedo is higher than uncorrected albedo by 0.03-0.06 in the processed cases.

Regarding CAR calibration/radiometry: CAR was calibrated pre-flight using NISTtraceable calibration sphere at NASA facilities. There is a specific routine of in-flight calibration assessment preceding the experiment. It may also be mentioned that the CAR calibration was thoroughly tested over dark deep ocean in CLAMS experiment, where the combined accuracy of CAR calibration and atmospheric correction was assessed as ∼0.002 reflectance units in the visible - near IR bands.

2.2 Model related issues p22002,formula(4): Is TAU_0 really column optical depth, or path integrated? How about TAU_(z) - vertical integral above or below aircraft, or path-integrated?

Answer: TAU_0 and TAU(z) refer to the total and above aircraft vertical atmospheric column, respectively.

p22002,l20: From the manuscript alone, it is not clear why you should need additional RT calculations for computing the MRPV parameters. Can you clarify?

Answer: The best-fit MRPV parameters are computed by fitting to the found snow BRF at all angles. This procedure does not require additional radiative transfer computations.

p22005,l20-l21: "Although the use of SIM irradiance reduces the reflectance..." - how so if SIM is your only source for irradiance how can it reduce radiance - compared to what?

Answer: SIM measures instantaneous time-dependent irradiance. The CAR calibration is based on a certain static solar irradiance model typical for calibration routines. To avoid confusion, we modified the relevant sentence as follows:

1) To exclude the possibility of error in the calibration conversion coefficients from radiance digital number (DN) counts to reflectance, the irradiance F used in the CAR calibration was compared with irradiance from the Solar Irradiance Monitor (Harder et al., 2000) integrated over the CAR spectral response (see Table 1).

p22011,l16: Define "SPD". Done. p22012,l15: Define parameter D. Done. p22014,l8-

l9: You can make this discussion easier by introducing something like "effective" surface roughness as a term. p22014,l10: Replace "a" with "actual". Done.

2.3 Suggested re-structuring of manuscript In light of the issues raised in the instrument section, it might be helpful to have a separate section dedicated to "instruments". Writing this as a separate section has the advantage that you can add a discussion of CAR, its calibration etc. which is completely missing so far. Also, you should probably expand a little bit upon uncertainties, as far as they are relevant for the message of the paper. If you decide to omit CAR error bars in, e.g., Figure 2, please provide at least a qualitative discussion.

Answer: Both instruments, including their calibration, are well described in the literature and paper provides the necessary references. The current version also better explains the instrument-related details. Regarding CAR error bars, as we described above, the errors are difficult to quantify accurately. When possible, we discussed different error sources and their magnitude in sec. 4.3 and 5.

There could also be some benefit in having a separate "model" section. It may be confusing to a non-expert to clearly categorize the various models used. For example, RTLS and MRPV are simply used for MODIS and MISR, as analytical BRF models. SHARM, in contrast, is a numerical code that delivers the "true" BRF based on any given microphysical snow composition. When it comes to AART (specialized for snow, but also analytical, that is, it has to live with assumptions) in section 7, it is sometimes unclear what it is that you use: Even though the title of section 7 is AART, you use SHARM in 7.1 and 7.2. A brief (one-two paragraph) general introduction which model belongs to which class: numerical, analytical, (semi-)empirical, and telling which one(s) are used for MODIS, MISR (is AART also used for satellites, e.g., from the ESA fleet?) right up front could help.

Answer:

SHARM is a generic radiative transfer code which is first mentioned in sec. 4.1 describing the atmospheric correction algorithm of CAR data. It is used to compute function R0 which is part of the AART model. To better explain relationship between AART and SHARM, the following sentence was added in the description of AART model (Appendix A): "In this work, R0 is computed with radiative transfer code SHARM (Lyapustin, 2005)."

In order to better explain different BRF models used in our study, the third paragraph of the Introduction was modified as follows: "We also study the accuracy of the common analytical BRF models used in operational satellite data processing, including the reciprocal Ross Thick - Li Sparse (RTLS, Lucht et al., 2000) and Modified Rahman-Pinty-Verstraete (MRPV, Martonchik et al., 1998) models. The three-parameter RTLS and MRPV models are used in the MODIS and MISR processing, respectively. A specialized Asymptotic Analytical Radiative Transfer (AART, Kokhanovsky and Zege, 2004) model, which has been actively explored for the snow grain size retrievals (Zege et al., 2008; Tedesco and Kokhanovsky, 2007; Lyapustin et al., 2009), is also evaluated in this paper."

3 TECHNICAL CORRECTIONS / TYPOS p21997,l6: Insert , after Alaska p21997,l22: Insert , after sampling p21998,l23: "...roughness was in the form of..." is grammatically incorrect (you need another verb in addition to was) – maybe "...roughness was dominated by..."? p22000,l13: "incident" - Do you mean "incidence"? p22001,l18: replace: term non-linear –> term that is nonlinear

p22002,l3: replace: according to current –> according to the current p22002,l12-l14: insert "the" in 3 instances: after "Once", "altitude z of", and "representing". p22005: insert "the" in two instances, after "coverage of" (l11) and "used in" (l18).

All suggested corrections were implemented.

Anonymous Referee #2 Received and published: 27 January 2010

The paper describes the analysis of CAR and ground truth data in a snow region during

the ARCTAS spring 2008 campaign. I found their work to be quite extensive and very well done, providing a great deal of detail concerning how the data were collected and analyzed and reasonable conclusions as to the significance of the results. This paper provides some well-needed snow/ice BRF information for satellite remote sensing, where relatively little information is available. I had some questions while reading the paper: In section 2, describing the directional snow reflectance experiment, a number of participating instruments are noted, including the HSRL, MISR and MODIS. Data from these three instruments, however, were not included in your analysis. Are they to be analyzed in a later publication on this topic, were found to be not useful, or used in your analysis in a very supplemental way as not to be mentioned?

Answer. Concurrent data from MISR and MODIS have been collected and will be analyzed in the future. In particular, we plan to study the possibility of aerosol retrievals over the snow. This is a very challenging problem which requires a good knowledge of the snow BRDF studied in the current paper. HSRL was used in several ARCTAS experiments studying atmospheric and aerosol properties but it did not participate in the Snow BRDF experiment.

How much of the AATS and AERONET data were used in the CAR data atmospheric correction analysis? Clearly spectral optical depth is a fundamental parameter (shown in Table 2), but what about the aerosol phase function which could be derived from the AERONET data? What choices were made for the phase function (and aerosol height distribution) when working with Eqns. (1-4)?

Answer. We used AATS (above airplane) and AERONET (total column) aerosol optical thickness and water vapor measurements. A combination of these data provides the vertical profile. We also used AERONET aerosol phase function (a part of inversion suite) available for April 17, 2008.

In section 5, the CAR-derived snow BRF is described. It would be useful to have more information concerning the footprint size of the CAR data as a function of view zenith angle and height, With this information the reader can better interpret the surface inhomogeneity comments scattered throughout the text. In fact, it's not clear how large a footprint size the retrieved surface BRF corresponds to.

Answer. The footprint is about 4 m (at nadir) for 200 m flight height, and about 10m at 600m flight height. This information was added in text (sec. 5, second paragaph).

In Fig. 5, I presume that the BRF figures in the right-hand column for both 0.68 and 1.22 micrometers are high contrast versions of the BRFs in the left-hand column, If so, this should be stated explicitly in the caption.

Answer. Corrected.

Interactive comment on Atmos. Chem. Phys. Discuss., 9, 21993, 2009.