Previous title: Spring and summertime aerosol optical depth retrieval over the Arctic cryosphere by using satellite observations

Revised title: Retrieval of aerosol optical depth over the Arctic cryosphere during spring and summer using satellite observations: A validation and evaluation

The authors thank the referee for her/his effort, and time taken to review our manuscript. The valuable criticisms and comments have helped us to improve our paper. We hope that we have been able to answer satisfactorily the questions raised and clarify parts of the manuscript which were unclear or ambiguous.

We have changed the title of the manuscript to make it more interesting to AMT's readership.

In the following the referee comments and criticisms, our responses, as authors, and our resultant changes to the manuscript are colored black, blue and red respectively.

Q1: The article titled "Spring and summertime aerosol optical depth retrieval over the Arctic cryosphere by using satellite observations" provides an analysis of AEROSNOW-retrieved satellite aerosol optical depth (AOD) statistics and validation using AERONET data over the Arctic region from 2003 to 2011. However, the main objective of the study is not clearly defined. The introduction highlights the importance of AOD retrieval using passive sensors, which suggests an algorithm development focus, which is suitable for the AMT journal. Nonetheless, the majority of the article discusses the distribution of retrieved AOD over the Arctic region and comparisons against AERONET data, with a greater emphasis on understanding the AOD distribution during spring and summer. The content of the article would be better suited for journals with a stronger emphasis on scientific aspects rather than technical aspects, as found in AMT. If the article intends to evaluate the accuracy and uncertainty of the retrieved AEROSNOW AOD, further investigation into uncertainties and comparisons with field campaign data would be necessary.

Response: We regret that the description in lines 65 to 69 of the manuscript did not convey to the referee clearly enough our objectives. Our main objective of the study described in this manuscript is to retrieve the aerosol optical depth (AOD) over the pan-Arctic cryosphere using a novel optimized algorithm, AEROSNOW, applied to measurements of the reflectance at the top of the atmosphere, measured by AATSR, made from the low earth orbit sun synchronous satellite Envisat from 2003 to 2011. Previous studies, retrieving AOD using the measurements of passive remote sensing instrumentation from space by others do typically not provide values over the pan-Arctic cryosphere region. So far, earlier versions of the retrieval were used to test the ability to retrieve AOD above Spitsbergen/Svalbard. In this manuscript, we describe an improved algorithm originally developed in house at the Institute of Environmental Physics at the University of Bremen and published by Istomina et al. (2009, 2011). As we have retrieved AOD over the cryosphere throughout the Arctic, an extensive validation of the algorithm is required. The validation is presented in Section 3 of this manuscript.

We agree with the referee that a short description of the algorithmic concepts used in AEROSNOW and its recent improvements, which include, the coupling of novel cloud identification scheme described in Jafariserajehlou et al. (2019), would also improve the quality of the manuscript and its suitability for publication in AMT.

We have expanded the AEROSNOW description in Section 2.1.2 in the revised manuscript to include additional information about the *mechanics* of the algorithm. Section 2.1.2 from line 91 to line 141 has been rewritten in the revised manuscript. We would like to humbly ask the reviewer to re-read Section 2.1.2 in the revised manuscript.

The discussion of the spatial distribution and seasonal behavior of the retrieved AOD dataset was introduced for a specific reason: Although measurements over the central Arctic are sparse and knowledge about them is also limited, we had expectations about these distributions. In this regard, the purpose of examining these distributions was to gain further confidence in this new dataset and to test the distributions with respect to our expectations. For example, the AEROSNOW observation of increased pan-Arctic AOD values during spring is a clear confirmation that Arctic haze events were well captured by this dataset. We will also address our motivation to discuss the distributions in the revised manuscript.

Therefore, this AMT manuscript aims to strengthen the confidence in the AEROSNOW approach. However, the actual use and corresponding geophysical analysis of the obtained results has been presented in our another manuscript: The preprint is available in Atmospheric Chemistry and Physics Discussions (ACPD) (https://doi.org/10.5194/egusphere-2023-730).

Considering the above and our envisaged adjustments and additions, we strongly believe that AMT is a suitable journal for this type of work and this manuscript.

The AOD data obtained by AEROSNOW is well validated with the ground-based AERONET data over the high Arctic stations, and the AERONET data are considered to be of high quality ground based observations. Data from campaigns and other ground-based measurements would also have been useful for comprehensive validation. However, to the best of our knowledge, no public dataset is available that provides sufficient spatial and temporal statistics for our study period from 2003 to 2011 particularly over the snow- and ice-covered regions of the high Arctic. Unfortunately, the most valuable recent field measurements do not fall within our study period (such as, MOSAiC in 2019-2020, ACLOUD/PASCAL in 2017 (Wendisch et al., 2023), PAMARCMIPs in 2018 and 2021 (Nakoudi et al., 2018; Ohata et al., 2021)).

At the end of line 69, we propose to add: After retrieval and validation, we discuss the distribution of AOD over Arctic snow and ice in spring and summer, since ground-based or space-borne observational data on AOD covering the entire high Arctic cryosphere are limited. In this regard, the purpose of examining these distributions is to gain further confidence in this new data set and to test the distributions with respect to our expectations. For example, we examine whether the AOD retrieved by AEROSNOW is able to capture the increased pan-Arctic distribution of AOD in spring compared to summer (Willis et al., 2018), which would be a clear confirmation of whether or not Arctic haze events are well captured by this dataset.

Q2: Several significant sources of uncertainty are mentioned in the article but not adequately addressed. Firstly, cloud contamination poses a major uncertainty source, requiring further examination. Additionally, the assumption of a fixed snow surface parameterization is mentioned but not sufficiently analyzed. The article should discuss the uncertainties associated with these assumptions and explain why they hold true for the study region.
Response: This question is addressed in the answer to ***Q4*** *(for cloud)* and ***Q5*** *(for NDSI)* of the comments by the referee below.

Q3: In line 94-95, the author claims that the cloud identification algorithm meets the requirements for high-latitude AOD studies, but this statement requires a citation to support it. Additionally, the phrase "a given sampling period" in line 96 needs to be clarified since a larger time window could introduce risks to this assumption.
Response: We agree with the reviewer and propose to change the lines as mentioned below to clarify the reviewer's question. We have followed Jafariserajehlou et al. (2019) who have proven that the AATSR-SLSTR cloud detection algorithm (ASCIA) meets the requirements for high latitude AOD studies. See also the answers to **Q4** for additional details. Cloud-free scenes are assumed to be unchanged or only slightly changed for a given sampling period. The sampling period used in this study is ±30 minutes, while cloudy or partly cloudy scenes have much greater spatial and temporal variability.

At the end of line 95, we propose to add the citation: The AATSR-SLSTR cloud identification algorithm (ASCIA) meets the requirements for the high-latitude AOD study and uses a dedicated set of thresholds for radiation and time-series measurements (Jafariserajehlou et al., 2019).

Line 97, we propose to modify: Cloud-free scenes are assumed to be unchanged or only slightly changed for a given sampling period. We set this value to ±30 min in this study (Jafariserajehlou et al., 2019), while cloudy or partly cloudy scenes exhibit much greater spatial and temporal variability.

Q4: Line 172 introduces the use of cloud fraction as a parameter in the quality flag, yet the uncertainty associated with cloud fraction over the Arctic region is not discussed. It would be valuable to explore whether the limited impact of cloud fraction is due to the large uncertainty associated with this parameter.
Response: The ASCIA data product (see above) was validated by comparison with independent observations, such as synoptic surface observations (SYNOP), AErosol RObotic NETwork (AERONET) data, and the following satellite products: (i) the ESA standard cloud product from the nadir cloud plume of AATSR L2; (ii) the product from a method based on a clear snow spectral shape developed at IUP Bremen (Istomina et al., 2010); and (iii) the Moderate Resolution Imaging Spectroradiometer (MODIS) products. Compared to the ground-based SYNOP measurements, ASCIA achieved promising agreement of more than 95% and 83% within ±2 and ±1 okta, respectively. In general, ASCIA shows better performance in identifying clouds over a ground scene observed at high latitudes than other algorithms applied to AATSR measurements.

At the end of line 97, we propose to add: The ASCIA cloud detection algorithm achieved promising agreement of more than 95% and 83% within ±2 and ±1 okta, respectively, compared to ground-based synoptic surface observations (SYNOP) (WMO, 1995). In general, ASCIA shows better performance in detecting clouds in a ground scene observed at high latitudes than other algorithms applied to AATSR measurements.

Q5: In line 118-119, the article mentions a fixed snow surface parameterization, the uncertainties related to this assumption should be analyzed and discussed. Specifically, it is important to explain why this assumption is valid for the study region, considering the Arctic's limited precipitation. Additionally, line 166 mentioned mixed snow regions, but its impact on AOD retrieval is not mentioned.
Response: To apply the fixed snow grain size approach and the assumption of snow contamination, we rely on the snow cover. Furthermore, the presence of snow in a pixel is defined by the Normalized Difference Snow Index (NDSI), an index that refers to the presence of snow in a pixel and is a more accurate description of snow detection compared to fractional snow cover (Riggs et al., 2017). Snow typically has a very high reflectance in the visible spectrum (VIS) and a very low reflectance in the shortwave infrared (SWIR). The NDSI is defined as the ratio of the difference

between the VIS and SWIR reflectance, i.e., NDSI = (($band_{vis}$ - $band_{swir}$) / ($band_{vis}$ + $band_{swir}$)). A pixel with an NDSI > 0.0 is considered to have snow cover, while a pixel with an NDSI <= 0.0 represents a snow-free land surface (Riggs et al., 2017).

In this study, the NDSI was used in a rigorous post-processing of the datasets to filter out the mixed and snow-free regions to minimize the impact of the surface on the top of atmospheric reflectance (TOA), therefore minimizing the impact on AOD retrieval.

Further, NDSI alone cannot describe the reflective properties of the surface. Therefore, the bidirectional snow reflectance distribution function (BRDF) model is also used. The BRDF model reproduces the directional variations in measured reflectance with an RMS error that is typically 0.005 in the visible wavelength range (Kokhanovsky and Breon, 2012), assuming a fixed snow grain size and snow contamination.

Please note that the retrieval is based on Equation 7 in the revised manuscript, which uses the ratio of simulated nadir BRDF values for the nadir and forward views of the dual-viewing instrument AATSR. With this strategy, we mitigate absolute errors in the BRDF but rather rely on the *shape of the BRDF* as seen from both directions. For our study, a narrow interval of NDSI was required to limit the BRDF-induced error in retrieving the AOD, which is less than 30% according to Istomina's approach (Istomina 2011, Section 3.3.3). Since we consider this error to be critical, we additionally introduced the Quality Flagging (QF) approach in our post-processing scheme, where we weighted the snow cover fraction even higher than the cloud fraction.

At the end of line 119, we propose to add: The BRDF model reproduces the directional variations in the measured reflectance with a root mean square (RMS) error that is typically 0.005 in the visible wavelength range (Kokhanovsky and Breon, 2012), assuming a fixed snow grain size and snow contamination. This assumption is valid because the model is also able to reproduce the directional signature of snow, although its directional signature is very different from that of other types of surfaces such as vegetation or bare soil.

At the end of line 166, we propose to add: The AEROSNOW retrieval is based on Equation 7 in the revised manuscript, which uses the ratio of the simulated nadir BRDF values for the nadir and forward views of the dual-viewing instrument AATSR. With this strategy, we mitigate the absolute errors in the BRDF but rather rely on the shape of the BRDF as seen from both directions. For our study, a narrow interval of NDSI was required to limit the BRDF-induced error in retrieving the AOD, which is less than 30% using Istomina's approach (Istomina 2011, Section 3.3.3). Since we consider this error to be critical, we additionally introduced the Quality Flagging (QF) approach in our post-processing scheme by adopting independent additional support from MODIS Terra and Aqua cloud fraction (Ackerman et. al., 2007) apart from ASCIA cloud detection algorithm, where we weighted the snow cover fraction even higher than the cloud fraction.

Q6: Some additional points to address include providing information about the basic aerosol properties of the models used (e.g., single scattering albedo and asymmetry factor) in line 137. Furthermore, the impact of a solar zenith angle cutoff of 75 degrees mentioned in line 160 should be discussed in terms of its impact on data sampling, particularly if there are specific times within a season when aerosol retrieval is not possible. Additionally, all monthly plots should display the variation in data for both AERONET and AEROSNOW datasets, including the number of retrieved data points aggregated into the monthly data. Lastly, in line 233, Figure 8 is introduced before Figure 7, which should be corrected.
Response: The basic aerosol properties used in the model, such as single scattering albedo (SSA), real part, and imaginary part of the refractive index for the coarse and accumulation modes of water-soluble, oceanic, dust, and soot aerosol components, are given in Table 1 in the revised

manuscript, which is adopted from the Istomina et al. (2011). Further, to avoid possible inaccuracies associated with particle shape, in this work on Arctic aerosol satellite retrieval we used the phase function for 550 nm measured ground-based by the Alfred Wegener Institute for Polar and Marine Research during one Arctic haze event on 23 March 2000 at Spitsbergen, Ny Ålesund, Svalbard, 78.923°, N 11.923° E, instead of the asymmetry factor.

We follow the recommendations in Istomina (Istomina 2011, Section 3.3.5) for a solar zenith angle (SZA) cutoff of 75 degrees based on sensitivity analysis using the SCIATRAN radiative transfer model (see also Mei et al., 2023). We agree with the referee that such a cutoff of the SZA leads to below average light conditions where the retrieval is working at the limit of its feasibility. We have done this deliberately, because March, being an important haze-event month, is also having such low light conditions and would have been excluded when we would have filterered more conservatively. Thus, keeping March in this dataset is an approach to extract as much as possible from the data to provide the most comprehensive view for the scientific community. March is already a time when Arctic haze events are relevant. Keeping March in this dataset was an attempt to extract as much as possible from the data to provide the most comprehensive view to the scientific community. A similar argument applies to summer, when persistent cloud cover also has a significant impact on the representativeness of the data. In our approach, we have applied a compromise between data yield and statistical representativeness.

We revised Fig.4: The revised presentation in monthly data is shown in the figure below and is also added in the revised manuscript of Fig.4.

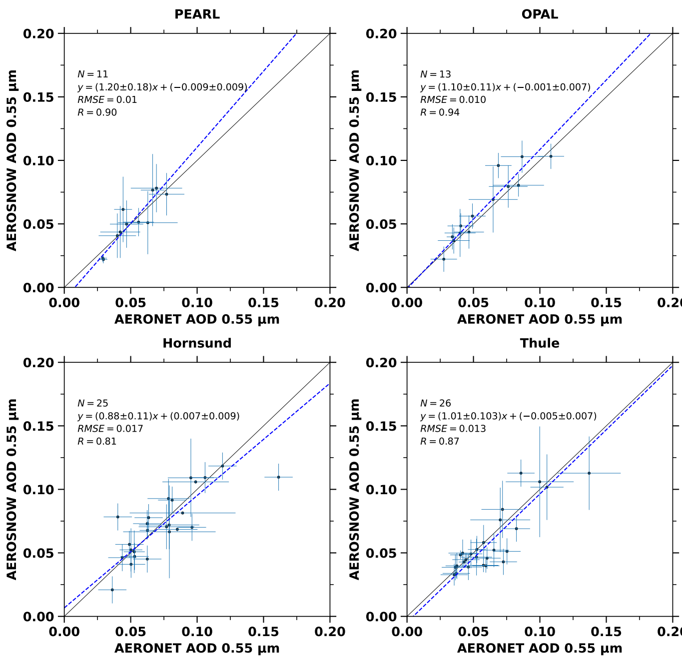

Figure 1: Figure 4. Validation of monthly mean AEROSNOW retrieved AOD colocated with monthly mean AERONET observation AOD obtained over PEARL, OPAL, Hornsund, and Thule stations. The linear regression lines are shown as blue dashed line and the bars are of one standard deviation.

Yes we agree with the referee, we will cite both Figure 7 and 8 in line 233 of the revised manuscript.

At the end of line 137, we propose to add: The basic aerosol properties used in the model, such as the single scattering albedo (SSA), the real part, and the imaginary part of the refractive index for the coarse and accumulation modes of the water-soluble, oceanic, dust, and soot aerosol components are given in Table 1 adopted from Istomina et al. (2011). Further, in this work, we used the phase function for 550 nm measured ground-based by the Alfred Wegener Institute for Polar and Marine Research during the Arctic haze event on 23 March 2000 at Spitsbergen, Ny Ålesund, Svalbard, 78.923°, N 11.923° E.

At the end of line 160, we propose to add: In this work, we adopted the recommendations in Istomina (Istomina 2011, Section 3.3.5) for a solar zenith angle (SZA) of 75 degrees based on sensitivity analysis using the SCIATRAN radiative transfer model (see also Mei et al., 2023).

We propose to change line 233: However, comparing the seasonally averaged climatology from 2003 to 2011, the AEROSNOW results indicate higher AOD in the spring, and smaller values in summer shown in Fig. 7 and Fig. 8, which was expected due to the Arctic haze events (Willis et al., 2018).

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- Istomina, L.: Retrieval of aerosol optical thickness over snow and ice surfaces in the Arctic using Advanced Along Track Scanning Radiometer, http://nbn-resolving.de/urn:nbn:de:gbv:46-00102463-15, 2011.

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Revised title: Retrieval of aerosol optical depth over the Arctic cryosphere during spring and summer using satellite observations: A validation and evaluation

The authors thank the referee for her/his effort, and time taken to review our manuscript. The valuable criticisms and comments have helped us to improve our paper. We hope that we have been able to answer satisfactorily the questions raised and clarify parts of the manuscript which were unclear or ambiguous.

We have changed the title of the manuscript to make it more interesting to AMT's readership.

In the following the referee comments and criticisms, our responses, as authors, and our resultant changes to the manuscript are colored black, blue and red respectively.

Q1: The title of the manuscript indicates some kind of development work regarding AOD retrievals over cryosphere. However, the manuscript is mainly about an analysis of AEROSNOW algorithm produced AOD from AATSR. The manuscript is basically lacking the development work that the title is suggesting. This makes me think if AMT is a suitable journal for this type of work.
Response: **[***We agree with the referee. The criticism expressed is also very similar to that of referee #1. We respond to both referees with the same text.***]**

Response: We regret that the description in lines 65 to 69 of the manuscript did not convey to the referee clearly enough our objectives. Our main objective of the study described in this manuscript is to retrieve the aerosol optical depth (AOD) over the pan-Arctic cryosphere using a novel optimized algorithm, AEROSNOW, applied to measurements of the reflectance at the top of the atmosphere, measured by AATSR, made from the low earth orbit sun synchronous satellite Envisat from 2003 to 2011. Previous studies, retrieving AOD using the measurements of passive remote sensing instrumentation from space by others do typically not provide values over the pan-Arctic cryosphere region. So far, earlier versions of the retrieval were used to test the ability to retrieve AOD above Spitsbergen/Svalbard. In this manuscript, we describe an improved algorithm originally developed in house at the Institute of Environmental Physics at the University of Bremen and published by Istomina et al. (2009, 2011). As we have retrieved AOD over the cryosphere throughout the Arctic, an extensive validation of the algorithm is required. The validation is presented in Section 3 of this manuscript.

We agree with the referee that a short description of the algorithmic concepts used in AEROSNOW and its recent improvements, which include, the coupling of novel cloud identification scheme described in Jafariserajehlou et al. (2019), would also improve the quality of the manuscript and its suitability for publication in AMT.
We have expanded the AEROSNOW description in Section 2.1.2 in the revised manuscript to include additional information about the *mechanics* of the algorithm. Section 2.1.2 from line 91 to line 141 has been rewritten in the revised manuscript. We would like to humbly ask the reviewer to re-read Section 2.1.2 in the revised manuscript.

The discussion of the spatial distribution and seasonal behavior of the retrieved AOD dataset was introduced for a specific reason: Although measurements over the central Arctic are sparse and knowledge about them is also limited, we had expectations about these distributions. In this regard, the purpose of examining these distributions was to gain further confidence in this new dataset and to test the distributions with respect to our expectations. For example, the AEROSNOW observation of increased pan-Arctic AOD values during spring is a clear confirmation that Arctic haze events were well captured by this dataset. We will also address our motivation to discuss the distributions in the revised manuscript.

Therefore, this AMT manuscript aims to strengthen the confidence in the AEROSNOW approach. However, the actual use and corresponding geophysical analysis of the obtained results has been presented in our another manuscript: The preprint is available in Atmospheric Chemistry and Physics Discussions (ACPD) (https://doi.org/10.5194/egusphere-2023-730).

Considering the above and our envisaged adjustments and additions, we strongly believe that AMT is a suitable journal for this type of work and this manuscript.

The AOD data obtained by AEROSNOW is well validated with the ground-based AERONET data over the high Arctic stations, and the AERONET data are considered to be of high quality ground based observations. Data from campaigns and other ground-based measurements would also have been useful for comprehensive validation. However, to the best of our knowledge, no public dataset is available that provides sufficient spatial and temporal statistics for our study period from 2003 to 2011 particularly over the snow- and ice-covered regions of the high Arctic. Unfortunately, the most valuable recent field measurements do not fall within our study period (such as, MOSAiC in 2019-2020, ACLOUD/PASCAL in 2017 (Wendisch et al., 2023), PAMARCMIPs in 2018 and 2021 (Nakoudi et al., 2018; Ohata et al., 2021)).

At the end of line 69, we propose to add: After retrieval and validation, we discuss the distribution of AOD over Arctic snow and ice in spring and summer, since ground-based or space-borne observational data on AOD covering the entire high Arctic cryosphere are limited. In this regard, the purpose of examining these distributions is to gain further confidence in this new data set and to test the distributions with respect to our expectations. For example, we examine whether the AOD retrieved by AEROSNOW is able to capture the increased pan-Arctic distribution of AOD in spring compared to summer (Willis et al., 2018), which would be a clear confirmation of whether or not Arctic haze events are well captured by this dataset.

Q2: The analysis shown in the manuscript is based on AEROSNOW algorithm. The authors state that the AEROSNOW algorithm is based on Istomina et al. (2011) that has been further developed by the authors of this manuscript. There are no citations to any work that would describe the further developments by the authors neither any detailed descriptions is given in this manuscript. If this manuscript describes the further development, it is very much lacking the details necessary even to basic understanding on how the algorithm works. There are no details to reproduce the results used in AEROSNOW retrievals based on this manuscript or at least it would require an extensive literature search and details from multiple cited papers. This is a big issue in this manuscript.
Response: Yes, we agree with the referee that a brief repetition of the algorithmic concepts of AEROSNOW and its improvements, which include a novel cloud identification scheme by Jafariserajehlou et al. (2019), would also improve the quality of the manuscript and its suitability for publication in AMT.

As explained in our response to the question (**Q1**) we have expanded the AEROSNOW description in Section 2.1.2 in the revised manuscript to include additional information about the *mechanics* of the algorithm. Section 2.1.2 from line 91 to line 141 has been completely rewritten in the revised manuscript. We would like to humbly ask the referee to re-read Section 2.1.2 in the revised manuscript.

Kindly note that retrieving AOD over a poorly understood complex system such as the Arctic with low-level clouds and very highly reflective snow-covered surfaces is a challenging task. Therefore, to tackle this AOD retrieval, we need to use different aspects of the concepts, especially from these three different works, such as the AEROSNOW algorithm by Istomina et al. (2009, 2011), the bidirectional snow reflectance distribution model (BRDF) by (Kokhanovsky and Breon, 2012), and the AATSR-SLSTR cloud identification algorithm (ASCIA) by Jafariserajehlou et al. (2019). Further, we have tried our best to put all the information in the revised version of the manuscript.

We have rewritten section 2.1.2 from line 91 to line 141 regarding the AEROSNOW algorithm in the revised manuscript and added all the information from the multiple cited papers for the reader.

Q3: The performance of the AEROSNOW show in the manuscript is in principle very good. I, however, feel there is a major issue in the analysis. The authors derive a quality flag (QF) parameter. The derivation and use of this parameter is not clear in the manuscript. As far as I understand both AERONET and AEROSNOW AOD are used in computing these results. Furthermore, the QF parameter is later applied to post-process filtering of the AEROSNOW data. This makes the AEROSNOW data dependent on AERONET and it is a major issue as no independent validation data is available. Then all the analysis is based on the dataset that has a dependency on AERONET data. This may result in overoptimistically good results. As mentioned, due to unclear description of the QF parameter I may have misunderstood this as well. In any case, the derivation and use of QF needs to be clarified and analysis of the results needs to be carried out using independent AERONET data.
Response: **[***The first part of this answer is identical to the one to Referee #1 for the response to question* ***(Q5)*****]**

To apply the fixed snow grain size approach and the assumption of snow contamination, we rely on the snow cover. Furthermore, the presence of snow in a pixel is defined by the Normalized Difference Snow Index (NDSI), an index that refers to the presence of snow in a pixel and is a more accurate description of snow detection compared to fractional snow cover (Riggs et al., 2017). Snow typically has a very high reflectance in the visible spectrum (VIS) and a very low reflectance in the shortwave infrared (SWIR). The NDSI is defined as the ratio of the difference between the VIS and SWIR reflectance, i.e., NDSI = $((band_{vis} - band_{swir}) / (band_{vis} + band_{swir}))$. A pixel with an NDSI > 0.0 is considered to have snow cover, while a pixel with an NDSI <= 0.0 represents a snow-free land surface (Riggs et al., 2017).

In this study, the NDSI was used in a rigorous post-processing of the datasets to filter out the mixed and snow-free regions to minimize the impact of the surface on the top of atmospheric reflectance (TOA), therefore minimizing the impact on AOD retrieval.

Further, NDSI alone cannot describe the reflective properties of the surface. Therefore, the bidirectional snow reflectance distribution function (BRDF) model is also used. The BRDF model reproduces the directional variations in measured reflectance with an RMS error that is typically 0.005 in the visible wavelength range (Kokhanovsky and Breon, 2012), assuming a fixed snow grain size and snow contamination.

Please note that the retrieval is based on Equation 7 in the revised manuscript, which uses the ratio of simulated nadir BRDF values for the nadir and forward views of the dual-viewing instrument AATSR. With this strategy, we mitigate absolute errors in the BRDF but rather rely on the *shape of the BRDF* as seen from both directions. For our study, a narrow interval of NDSI was required to limit the BRDF-induced error in retrieving the AOD, which is less than 30% according to Istomina's approach (Istomina 2011, Section 3.3.3). Since we consider this error to be critical, we additionally introduced the Quality Flagging (QF) approach in our post-processing scheme, where we weighted the snow cover fraction even higher than the cloud fraction.

Furthermore, there is no dependence on AERONET data in the QF, rather we used AERONET data only for comparison with AEROSNOW AOD when the ratio of AEROSNOW and AERONET AOD values was greater than 1.6 to figure out the weighting of the influence of snow cover fraction and cloud fraction on the high AOD observed by AEROSNOW compared to AERONET, using independent additional support from MODIS Terra and Aqua cloud fraction products (Ackerman et. al, 2007), apart from the ASCIA cloud detection algorithm, which may have confused the referee. As discussed above, we will explain the need for deriving and using the QF post-processing approach in the revised manuscript.

At the end of line 166, we propose to add: The AEROSNOW retrieval is based on Equation 7 in the revised manuscript, which uses the ratio of the simulated nadir BRDF values for the nadir and forward views of the dual-viewing instrument AATSR. With this strategy, we mitigate the absolute errors in the BRDF but rather rely on the shape of the BRDF as seen from both directions. For our study, a narrow interval of NDSI was required to limit the BRDF-induced error in retrieving the AOD, which is less than 30% using Istomina's approach (Istomina 2011, Section 3.3.3). Since we consider this error to be critical, we additionally introduced the Quality Flagging (QF) approach in our post-processing scheme by adopting independent additional support from MODIS Terra and Aqua cloud fraction (Ackerman et. al., 2007) apart from ASCIA cloud detection algorithm, where we weighted the snow cover fraction even higher than the cloud fraction.

More specific comments:

l.8 "The AOD is retrieved assuming that the surface reflectance observed by the satellite can be well-parametrized by a bidirectional snow reflectance distribution function, BRDF." More detailed analysis on the effects of this assumption needs to be carried out.
Response: [The answer to this question is explained above in **Q3.** Kindly see the above answer]

l.19 As Arctic is changing rapidly this almost 20 year old study already gives outdated information. More recent studies indicate AA of about 4 (e.g. Rantanen et al., "The Arctic has warmed nearly four times faster than the globe since 1979", Communications Earth & Environment, 3:168, 2022).
Response: We agree with the referee. We have changed the text and citation in our revised manuscript.

At the end of line 19, we propose to add: The Arctic has experienced a significant increase in near-surface air temperatures over the past three decades: the rate of temperature increase being about four times larger than the global mean (Rantanen et al., 2022). This phenomenon is known as Arctic Amplification (AA).

l.104 "...an iterative procedure to obtain the AOD over Arctic snow and ice regions at 555 nm." No real details of the retrieval are given, e.g. what is the cost function in the iterative procedure.
Response: The cost function is defined by Equation 7 and minimized with respect to the aerosol optical depth (tau) in the revised manuscript, together with Equation 4 it defines the cost function. We will add at the end of the Section 2.1.2 the additional information that clarifies the cost function.

At the end of Section 2.1.2, we propose to add: The actual retrieval is working on Equations 7 and 4, and is minimized with respect to the optical depth (tau) at 555nm as a cost function.

l.118 "We fixed the free parameters for the entire time series of AATSR, which involved a fixed snow grain size and snow impurity assumptions." How do these assumptions affect the retrievals?
Response: [The answer to this question is explained above in **Q3.** Kindly see the above answer]

l.161 Please define the NDSI.
Response: The Normalized Difference Snow Index (NDSI) is an index that refers to the presence of snow in a pixel and is a more accurate description of snow detection compared to fractional snow cover. Snow typically has a very high reflectance in the visible spectrum (VIS) and a very low reflectance in the shortwave infrared (SWIR). The NDSI is defined as the ratio of the difference between the VIS and SWIR reflectance, thus NDSI = $((band_{vis} - band_{swir}) / (band_{vis} + band_{swir}))$ and is defined in Equation 8 of the revised manuscript.

The NDSI is defined in Equation 8 of the AEROSNOW algorithm in Section 2.1.2 of the revised manuscript.

l.166 To better understand the effect of post-processing with NDSI, it would be nice to know how much of the data was filtered out and how much the metrics changed because of the filtering.
Response: Typically, we found bimodal distributions of AOD for the stations we considered, with the frequency of the second mode influenced by clouds and problematic surfaces. We filtered out 40% over problematic surfaces and residual clouds and 100% over central Greenland by using rigid post-processing with NDSI.

At the end of line 166, we propose to add: For the stations considered in this study, we found bimodal distributions of AOD, with the frequency of the second mode influenced by clouds and problematic surfaces. We filtered out 40% over problematic surfaces and residual clouds and 100% over central Greenland using rigid post-processing with NDSI.

l.171 As mentioned earlier. The derivation and use of QF parameter needs to be clarified. Also independent validation data to validate AEROSNOW needs to be taken into account. Filtering cannot depend on AERONET data.
Response: [This question is similar to the question above in **Q3**. Kindly see the response to the question is explained above in **Q3**]

l.195 "Uncertainties due to both space and time sampling differences are minimized." No details are given on how this is done and if the uncertainties really are minimized.
Response: The uncertainties due to spatial and temporal sampling differences are minimized according to the collocation strategy described in line 157 of the manuscript as "AERONET observations were averaged and compared to values measured within a 25-km radius and 30-minute time collocation of the AERONET stations for AEROSNOW".

l.202 "...the latter does not take into account the relationships between geophysical variables." I do not believe this statement is true. Ordinary Least Squares regression is used exactly to determine the linear relationship between variables. Ordinary least squares does not take into account the uncertainties in x variable at all and, for example, therefore leads to biased slope estimates. Maybe this is what the authors meant here.
Response: The referee is right because these sentences are incorrect. The reduced major axis (RMA) regression takes into account the uncertainties (or errors) on the two variables, while the ordinary least squares (OLS) regression takes into account the uncertainties on one variable. Here we are looking for the best linear agreement between the two variables (which must be the same regardless of the variable in X or in Y, therefore we are looking for a symmetrical relationship). For this, different methods are possible (for example by minimizing the perpendicular distance or the triangle), and we choose the RMA (so by minimizing the triangle).

The line 202, we propose to modify: RMA regression takes into account the uncertainties or errors of the two variables, while ordinary least squares (OLS) regression takes into account the uncertainties of one variable. Here, the best linear fit between the two variables is sought, which must be the same in X or in Y regardless of the variable, that is, aiming for a symmetric relationship. For this, different methods are possible, for example, by minimizing the perpendicular distance or the triangle, and we choose the RMA, that is, by minimizing the triangle.

l.203 "Therefore, it is recommended that the use of reduced major axis (RMA) regression replace the use of standard linear regression" RMA regression is not the only one tackling the issues of OLS. There are many other methods as well. This statement written by the authors may give the reader a wrong impression here.
Response: [The answer to this question is explained above in **l.202** question. Kindly see the above answer]

l.218 "This difference can be explained by using an optimal chemical transport model by separating the total AOD to aerosol components." This is a vague statement not explained well enough and not supported by any results shown in this manuscript.
Response: Here we would like to cite our manuscript using AEROSNOW data to evaluate GEOS-Chem model, the preprint is available in Atmospheric Chemistry and Physics Discussions (ACPD) (https://doi.org/10.5194/egusphere-2023-730).

At the end of line 218, we propose to add: This difference can be explained by using a chemical transport model by separating the total AOD to aerosol components (Breider et. al., 2014, Swain et. al., 2023).

l.246 The whole paragraph is a bit confusing. The paragraph is in the results section and no comparison between AEROSNOW and model data has been carried out.
Response: We propose to remove the paragraph at line 246 "The comparison of the AEROSNOW data with model data is the next logical step. We test the quality and limitations of the model as well as of the satellite dataset in the high Arctic. Further, the seasonal variability of AOD observed from AEROSNOW can then be attributed by investigating aerosol properties, components, long-range transport, and local sources. This is possible by using an optimal chemical transport model with updated emission inventories for this study period." in the revised manuscript.

We propose to remove the paragraph at line 246 in the revised manuscript.

l.254 "The AEROSNOW algorithm uses the dual-viewing capability of the AATSR instrument to minimize retrieval uncertainties" It was not shown that the use of dual view instrument really minimizes the retrieval uncertainties.
Response: [The answer to this question is explained above in **Q3.** Kindly see the above answer]

Yes, dual-viewing capability of the AATSR instrument has already been used to minimize retrieval uncertainties in other works such as, Istomina et al., (2009, 2011), and Mei et. al., 2020.

At the end of line 254, we propose to add: The AEROSNOW algorithm uses the dual-viewing capability of the AATSR instrument to minimize retrieval uncertainties (Istomina et al., 2009, 2011, and Mei et. al., 2013b).

l.255 "It showed good agreement with ground-based AERONET observations, with a correlation coefficient R = 0.86 and a low systematic bias." It may be totally misleading to give retrieval metrics without stating any details. Use of different time averaging for example hugely affects the metrics.
Response: We thank the referee this valuable comment, we agree with the referee that such a distinction is important. For this purpose we once performed the validation on daily basis and monthly validation. The daily validation shown in the Appendix Figure A1 of the manuscript and exhibit similar characteristic as the one for the monthly plot. The monthly mean values are derived from daily based investigations.

l.256 "The high anthropogenic aerosol loading (Arctic haze events) due to long-range transport over Arctic snow and ice is captured by the AOD determined by AEROSNOW." There were no well justified experiments in the manuscript that would confirm this exact statement about long-range transport of anthropogenic aerosols. The authors themselves listed this type of experiment as future work.
Response: We would also like to cite our manuscript using AEROSNOW data to evaluate GEOS-Chem model, which is available as the preprint in Atmospheric Chemistry and Physics Discussions (ACPD) (https://doi.org/10.5194/egusphere-2023-730). Further, the monthly mean spatial maps shown in Fig.2 confirmed that the haze events are captured well.

At the end of line 256, we propose to add: The high anthropogenic aerosol loading (Arctic haze events) due to long-range transport (Willis et al., 2018) over Arctic snow and ice is captured by the AOD determined by AEROSNOW (see also Swain et. al., 2023). Further, the monthly mean spatial maps shown in Fig.2 confirmed that the haze events are captured well.

l.263 "The promising AOD results obtained with AEROSNOW indicate that these can be used to evaluate and improve aerosol predictions for various chemical transport models." In previous parts of the manuscript, the authors say that in the future models can be used to test and validate the AEROSNOW retrievals. Here in the conclusions, the authors say that AEROSNOW can be used to evaluate and improve the models. This is confusing.
Response: We are sorry for the confusion. We consider the AOD data retrieved by AEROSNOW as a space-borne observational basis and therefore AEROSNOW can be used to evaluate state of the art models instead. Here it would make sense, that we cite our manuscript in which we use AEROSNOW data to evaluate the GEOS-Chem global chemical transport model. The preprint is available in Atmospheric Chemistry and Physics Discussions (ACPD). (https://doi.org/10.5194/egusphere-2023-730).

We propose to remove the paragraph at line 246 “The comparison of the AEROSNOW data with model data is the next logical step. We test the quality and limitations of the model as well as of the satellite dataset in the high Arctic. Further, the seasonal variability of AOD observed from AEROSNOW can then be attributed by investigating aerosol properties, components, long-range transport, and local sources. This is possible by using an optimal chemical transport model with updated emission inventories for this study period.” in the revised manuscript.

The line 263, we propose to modify: The promising AOD results obtained with AEROSNOW indicate that these can be used to evaluate and improve aerosol predictions for various chemical transport models, especially over the Arctic sea ice in spring and summer for the important period 2003-2011 (Swain et. al., 2023), which is within the period of Arctic amplification.

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