Referee #1

Title: Retrieval of aerosol optical depth over the Arctic cryosphere during spring and summer using satellite observations

The authors would like to thank the reviewer for her/his interest and efforts to review our manuscript.

We hope that we have been able to answer satisfactorily the questions raised and clarify parts of the manuscript which were unclear or ambiguous.

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 revised version of the paper significantly enhances the clarity of the fundamental structure of the research. It is now evident that the primary achievement of this study lies in the fusion of two previously unrelated algorithms into AEROSNOW, while incorporating quality control measures. This combination allows the algorithm's application for the reliable retrieval of aerosol optical depth (AOD) over the Arctic region. Once the outstanding issues are addressed, this paper appears suitable for publication in the Atmospheric Measurement Techniques (AMT) journal.

Nevertheless, certain areas still require clarification. In the prior review, several questions arose due to the reviewers' misunderstanding of the content. Although the author guided the reviewers to relevant sections within the article, it highlights a fundamental issue with the paper - its difficulty in comprehension. While all the necessary information may be present, it lacks a logical organization that would enable someone unfamiliar with the research to grasp and follow it seamlessly.

As a proposed improvement, restructuring the paper is recommended. Section 2 should exclusively focus on data, encompassing descriptions of all data used in the algorithm, such as the MODIS data employed in the quality assurance (QA) process. Section 3, dedicated to the algorithm, should begin with a clear presentation of the algorithm's flowchart, emphasizing that this paper's core contribution is the development of a robust aerosol retrieval algorithm over the Arctic. This is achieved by amalgamating two existing algorithms and implementing dependable QA procedures, expanding the algorithm's applicability across a wider region and time span. Sections 3.1 and 3.2 can address the pre-existing algorithms, while Section 3.3 should expound upon the novel elements (notably, the "new contribution" seems to occur in the post-processing phase).

Response: According to the referee's suggestions, we have reorganized the Section 2 and 3 in the revised manuscript.

We have added "Space-borne observation: MODIS cloud products" in Sec.2.2 of the revised manuscript.

Q2: In the introduction, it is imperative to elucidate the limitations of exclusively using Istomina, 2009 and underscore the key advantages of uniting these two algorithms. Distinguishing between a research algorithm tailored to specific cases and a robust algorithm capable of operating across an entire region and data records is pivotal. The paper should emphasize this crucial distinction to effectively persuade its readers.

Response: We have presented the limitations of exclusively using Istomina et al., 2009, and advantages of uniting these two algorithms in the manuscript at line 58-63 and 72-74.

We propose to modify the paragraph at line number 58 to 63 as follows to further highlight the advantages expected from uniting the two algorithms: Several dedicated algorithms for passive satellite remote sensing over snow and ice have been developed. Istomina et al., 2009 and later Mei et al., 2013, 2020a, b have provided valuable pioneering research. However, these attempts have been mostly confined to the island of Spitsbergen in the Svalbard archipelago in northern Norway. Thus far, there have been no attempts to apply these algorithms together with the Arctic-adopted cloud masking algorithm systematically in the Arctic cryosphere to address the data gap identified above. Studies using active satellite remote sensing such as Sand et al. (2017) and Xian et al. (2021) are valuable, but the observational data are limited over the Arctic cryosphere.

We propose to modify at line number 72 to 74 as follows: We retrieve the total AOD using an approach first described by Istomina et al. (2009), which we have further integrated with the cloud masking algorithm of Jafariserajehlou et al. (2019) and named AEROSNOW. This AEROSNOW approach was then systematically applied over vast Arctic cryospheric regions.

Q3: I have some algorithm related questions as well, particularly concerning Istomina, 2009. Although this isn't the primary focus of your research, it's crucial due to its centrality in the algorithm. I'm not clear about where τ fits into the equations, which is the goal parameter. In my experience, τ should be in the ρatm term in Eq. 3, which includes contributions from aerosol and Rayleigh and gas. Once you know how much is ρ atm you can get τ using an assumed aerosol model.

Response: We agree with the referee and have added 'τ' in Eq.3 of the revised manuscript.

Q4: However, between line 249 to line 267, you describe two different methods of estimate ρatm. Many questions regarding these two paragraphs. First, is this ρ atm the same in Eq. 4 vs. Eq. 3. If so, what is the point of having BRDF estimation if you already got ρatm . I assume this roughly estimated ρ atm is only for atmosphere correction to get a better BRDF ratio, which is used in iterative process to fine tune the ρ atm contribution. Eventually the ρ atm in Eq. 3 will be the same as ρ atm in Eq. 4. Not sure if my understanding is correct. Because it is not clearly stated in the paper. Second, both methods of estimating ρ atm has their own uncertainties, one assuming coastal aerosol properties are the same with inland, another uses pre-defined aerosol models, plus assuming negligible ocean surface contribution, which also raises big concerns. It is not clear whether any of the method considered sedimentation or other watercolor contribution.

Response: We are sorry for the confusion. The aerosol retrieval algorithm presented in section 3.1.2 of the revised manuscript has undergone a comprehensive rewrite. Eq. 4 is derived from Eq. 3 and

$\rho_{atm}(\lambda, \mu 0, \mu, \varphi, \tau)$, which includes τ, is defined in Eq. 3, as the contribution of atmospheric reflectance to the one at the top of the atmosphere in the revised manuscript.

Further, two possible methods can be used for the estimation of $\rho_{atm}(\lambda, \mu 0, \mu, \varphi, \tau)$ but in Istomina et al., 2009, they have used Lookup table (LUT) approach for the retrieval.

We propose to remove the paragraph from line 249-256.

Other clarification questions:

1. It is still not clear to me how can ρ atm converted to τ without an aerosol model (or maybe it is the same model stated in Table 1 and Figure 2?).

Response: The response to this question was described in part in our answer to Q4. In Istomina et al., (2009), SCIATRAN radiative transfer model has been used to calculate the look-up table.

This has been clarified at line number 270-274 of the aerosol retrieval algorithm section (Section 3.1.2) as follows, "The aerosol properties used in model simulations, such as the single scattering albedo (SSA (λ)), 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). Subsequently, a look-up table was calculated using the SCIATRAN radiative transfer model (Rozanov et al., 2014; Mei et al., 2023a). This LUT has been used for the determination of $\rho_{atm}(\lambda, \mu 0, \mu, \varphi, \tau)$".

2. The airmass factor and Angstrom equation discussion from line 269 to line 275 does not provide sufficient connection to the previous text.

As, we have rewritten the aerosol retrieval algorithm section (Section 3.1.2), we propose to remove the line from 269 to 275.

3. Eq. 18 is still very hard to understand because there is no specific definition of what ρ is, on the second term in the right hand side. If ρsfc is calculated from Eq. 15, then I assume ρ is from observation. But based on which equation, is it Eq. 3? Which the ρ in Eq. 4 is the ρ in Eq. 5? I assume is the left-hand side ρ. But when I read until Eq.15, I realized the ρ in Eq. 5 maybe ρ sfc,sim. To enhance clarity, it would be helpful to move Eq. 15 to the beginning and explain how you solve Eq. 15 instead of Eq. 4.

Response: In response to these questions, we have rewritten the aerosol retrieval algorithm section and hope that your questions are now answered.

To make it more clear we have removed the Eq.15 and formulated it more straight forward in Eq. 11 and Eq. 12 in the revised manuscript. As mentioned in question Q4, we have rewritten the aerosol retrieval algorithm section and hope that it is clearer and addresses your questions.

5. Line 241 to 249 discuss uncertainties in Eq. 4, which again, doesn't align with your approach completely, so it requires further discussion.

Response: The response to this question was described in question Q4 in this authors response.

Other points:

1. The abstract should explicitly state that AEROSNOW is a result of merging two existing algorithms.

We propose to add at line 7 to 8 in the abstract as follows: AEROSNOW incorporates an existing aerosol retrieval algorithm with a cloud masking algorithm, alongside a novel quality flagging methodology specifically designed for implementation in the high Arctic region (≥ 72°N).

2. The paragraph that commences with "Recently, Toth et al., (2018)" around line 65 lacks a clear connection with the preceding content. This connection should be established earlier in the paragraph.

We propose to modify the paragraph at line 64-68 as follows: With respect to using active satellite remote sensing, recently, Toth et al. (2018) and Xian et al. (2021) reported that the active satellite sensor, the Cloud-Aerosol Lidar with Orthogonal Polarization (CALIOP/CALIPSO) (Winker et al., 2004) has a significant fraction of aerosol profile data comprising retrieval fill values (-9999s, or RFVs) and thus rejected. This is partly due to the minimal detection limits of the lidar when measuring the signal scattered back to space. In fact, in some areas of the Arctic, over 80 % of CALIOP profiles consist entirely of RFVs (Toth et al., 2018 and Xian et al., 2021).

3. The repetitive mention of "use AATSR to retrieve aerosols over the Arctic" should be minimized throughout the paper.

Response: This should not be the case anymore in the revised version of the manuscript.

4. Lines 93 and 95 both refer to "cloud masking." It's important to clarify that these are distinct cloud masking procedures, and a detailed explanation is necessary. However, if the suggested structural changes are implemented, this may no longer be an issue.

Response: We have made the structural changes in the revised manuscript as suggested by the referee in question Q2 of this author's response.

5. Ensure proper citation is provided in the AATSR data section.

We propose to add the citation at line 99: The AEROSNOW algorithm is applied to the dual view Level 1B data product reflectance at the top of the atmosphere made by AATSR (Llewellyn-Jones and Remedios, 2012).

6. The paragraph discussing the lack of other field campaign validation data should be relocated from the AERONET data section to the introduction within the Data section.

We propose to move the paragraph to line 103-106: In addition, the use of validation sources other than AERONET would have been very helpful. Unfortunately, data from valuable campaigns and expeditions such as POLAR-AOD (Mazzola et al., 2012), MOSAiC Expedition and MOSAiC-ACA (Mech et al., 2022), and AFLUX/PASCAL - Arctic (Mech et al., 2022) were only available after 2011.

7. In line 246, "but The ..." the capitalization of "T" in "The" is unnecessary.

Response: We are sorry for the typographical error, which has been rectified in the revised version.

8. Clarify whether this LUT is used for retrieval or solely for atmospheric correction in line 286.

Response: We hopefully clarified the use of LUT in our answer to question Q4.

We propose to add at line 286: This LUT has been used for the determination of $\rho_{atm}(\lambda, \mu0, \mu, \varphi, \tau)$.

9. Enhance the clarity of the flow chart by using color-coding to differentiate existing algorithms from new elements. The algorithm section should also encompass any additional pre-processing and post-processing steps applied, such as solar zenith angle (sza), snow-only filtering, and other quality control (QF) requirements.

Response: We have made changes in the flow chart as per the referee's suggestions in the revised manuscript.

10. Despite previous inquiries, there remains confusion regarding whether this algorithm is designed for partial snow cover or exclusively for 100% snow cover. Line 340 implies the consideration of snow cover fraction, suggesting applicability beyond 100% snow cover. However, line 225 states that "only pure snow-covered areas (100% snow cover) are used." This discrepancy requires clarification.

Response: At line number 340 the snow cover fraction is a variable name in MODIS Terra and Aqua data product, which is 100% snow cover. The AEROSNOW is used for AOD retrievals for scenes having 100% snow cover.

11. Specify whether the seasonal mean is calculated from level 2 data or monthly mean data.

Response: The seasonal mean is calculated from level 2 data.

We propose to add at line number 365: The seasonal mean is calculated by using level 2 data

12. Figure 7 still lacks standard deviation information; consider including it for greater completeness.

Response: We have added standard deviation information in Fig.7 as per the referee's suggestions.