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Comment on acp-2026-2575

Anonymous Referee #2

Referee comment on "Optical properties and global distribution of the Hunga aerosols 2022 observed by Aeolus and atmospheric lidars: new insights into the vertical sedimentation of stratospheric sulfate plumes" by Dimitri Trapon et al., Atmos. Chem. and Phys. Discuss., https://doi.org/10.5194/egusphere-2026-2575-RC2, 2026

This study is overall well written and clear. It demonstrates the value of ALADIN for sensing and optically characterizing sizable stratospheric aerosol plumes. The work is technically solid and publication-worthy. The manuscript is, however, rather technical in nature. It often focuses more on how the observations were made than on why the observed properties matter scientifically. For that reason, I would argue that the manuscript does not fully meet the ACP standard in terms of scientific novelty. It brings only limited new findings on the Hunga aerosol plume and mainly corroborates results already established in the literature. Conversely, the study would fit well as a measurement report, since it primarily describes original observations, but the scientific narrative leaves the reader wanting a stronger interpretive framework.

Major comments

- **Scientific framing and novelty**: The paper is technically strong, but the overarching scientific question is still underdeveloped. The introduction should more clearly state what new understanding the study adds about the Hunga plume beyond an instrument demonstration.
- **Interpretation and discussion**: Several sections describe interesting observational patterns, but the discussion often stops before explaining why those patterns arise. The paper would benefit from a more explicit physical interpretation of altitude-dependent optical properties, plume branching, and sedimentation.
- **Reference choices and terminology**: Some references could be better aligned with the specific point being made, especially for eruption timing, injection altitude, lidar ratio interpretation, and particle size estimates. This is mostly in the introduction. A few terms also need tightening for accuracy and consistency.

We would like to thank the reviewer for these comments. The title, the introduction and the discussions sections have been restructured as suggested and following the ACP guidelines. The importance of measuring the light scattering of the Hunga aerosols, as well as studying their zonal and meridional dispersions, have been emphasised. The description of the Aeolus instrument concept and settings have been moved to sections 2.1 and 2.2. Physical interpretations of the Aeolus observations have been added in section 3.2.2 and in the discussions. Hypotheses have been formulated regarding the altitude-dependent optical properties alongside new references on the optics of sulfate-water droplets.

Detailed comments

- **Abstract line 4**: The plume descended from the initial injection, but the sentence wording makes it ambiguous. Please clarify.
  CORRECTED. The two sentences in lines 3-5 have been rephrased as follows : "Extinction and co-polarized backscatter coefficients for particles have been measured independently, with aerosol profiling up to ≈ 30 km in altitude. The vertical and horizontal characteristics of the Hunga plumes by 24 January 2022 are shown, as they descent into the lower stratosphere."

- **Abstract line 6**: Measurements
  CORRECTED with the rephrased sentence.

- **Intro general comment**: The introduction is heavily instrument-centric. Please foreground the science question earlier: why does the Hunga plume matter, what is the open knowledge gap, and what specific new insight is gained from Aeolus beyond a technical demonstration? As written, the section reads more like an instrument overview than an ACP-style science introduction.
  We thank the referee for this comment and recommendation. The introduction has been updated accordingly, i.e. moving the descriptions of the Aeolus concept and settings to sections 2.1 and 2.2, and emphasizing the importance of characterizing both the optical properties and the dispersion of the Hunga aerosols which may have climate effect. The value of lidar measurements in the ultraviolet to better study the light scattering of sulfates is also reminded.

- **Lines 22-23**: Clarify the range-bin description, maybe: "24 altitude bins ranging from 250 m to 2 km".
  CORRECTED as suggested. The sentence has rephrased as follows : " 24 altitude bins ranging from 250 m to 2 km, and referred as range bins."

- **Line 29**: shape and size are comprised within microphysical properties - LR also depends on the particle chemical composition, please clarify.
  We thank the referee for pointing out this lack of clarity. The sentence has rephrased as follows : "As the LR depends on particle shape, size distribution, and chemical composition, it is often used for aerosol classification (Floutsi et al., 2023; Muller et al., 2007).".

- **Line 30**: Reference: Muller et al 2007 https://doi.org/10.1029%2F2006JD008292 is also a good reference to underline the historical use of LR for aerosol typing.
  We thank the referee for the suggestion. The new reference has been added to the manuscript and cited in the text.

- **Line 32**: Choice of reference could be better - Khaykin et al 2022 maybe
  CORRECTED; the reference to Khaykin et al., 2022 has been added.

- **Lines 32-33**: It also erupted on the 13, but indeed the 15th eruption is the one of stratospheric magnitude. HTHH is the name of the couple of islands atop the Hunga volcano, partly obliterated during the eruption.
  CORRECTED; the sentences have been rephrased as follows : "On 13 January 2022 the submarine Hunga volcano (20.54° S, 175.38° W) located beneath the Tonga-Hunga Ha'apai islands in southwest Pacific Ocean erupted. A second eruption occurred on 15 January 2022 with a high-magnitude volcanic explosion...".

- **Line 34-35**: Proud et al 2022 (https://www.science.org/doi/10.1126/science.abo4076) and Carr et al 2022 (https://onlinelibrary.wiley.com/doi/abs/10.1029/2022GL098131) are better suited as reference for the injection altitude. The one referenced are mostly on the radiative impact of the perturbation.
  CORRECTED; the references have been modified as suggested.

- **Line 47**: Referencing size - maybe better to cite Asher et al. 2023
  CORRECTED

- **Line 61**: Knepp et al did not measured effective radius. It's inferred from SAGE-III extinctions.
  CORRECTED. We thank the referee for this comment. The sentence has been rephrase as follows : "Moreover, the aerosol effective radius derived from extinctions measured by NASA Stratospheric Aerosol and Gas Experiment III onboard the International Space Station reached ≈ 0.3 to 0.4 µm for the main Hunga plumes above 24 km in altitude (Knepp et al., 2024)."

- **Line 82**: please define "co-polar"
  The section 2.1 has been modified. The sentence has been deleted and brief descriptions of the co-polarized and cross-polarized component of the light have been added earlier in the text when introducing the Aeolus ALADIN instrument concept.

- **Line 91**: restrictive or conservative?
  It is proposed to shorten the sentence as follows to avoid confusion : "They have been gradually fine tuned by the Aeolus Data, Innovation, and Science Cluster (DISC) using sensitivity test."

- **Line 106**: ESA?
  The reference to ESA: A Guide to Aeolus Range Bin Settings, https://earth.esa.int/eogateway/news/a-guide-to-aeolus-range-bin-settings. has been replaced by Reitebuch et al., 2024 which includes a clear description of the Aeolus multiple Range Bin Settings (RBS).

- **Lines 105-111**: The RBS paragraph is technically important but would read more smoothly if the sentence explaining the Tonga-band purpose were moved earlier. That would help the reader understand why the vertical sampling changes before the details of the setting are listed.
  CORRECTED

- **Figure 1 caption**: It is quite hard to see the OPAR location with a blue marker on a blue background.
  CORRECTED, i.e. a lighter blue color code has been selected for better contrast with the background. Kindly note that

- **Line 125**: The wording can be improved.
  The sentence has been rephrased as follows : "Aerosol plumes have been successfully observed with ground-based lidar instruments at OPAR (A1.1) 4 days after the eruption (Baron et al., 2023)."

- **Line 128**: Here and later, the use of "cross" is confusing. "Compare" seems more appropriate.
  CORRECTED as suggested.

- **Figure 2 caption**: "cross of 2D", what is a 2D profile?
  CORRECTED with "cross-comparison with lidar profiles".

- **Line 137**: Please address the altitude discrepancy between Aeolus and the ground-based lidars. It would help the reader to know whether the difference is mainly due to geolocation offset, temporal averaging, horizontal sampling, or a genuine vertical structure in the plume.
  A sentence has been added in section 3.1.1. The vertical sampling of Aeolus, which comes with coarser resolution of 1.25 km up to 28 km altitude for the Hunga band, appears as one of the limitations and therefore a cause of altitude offset. Moreover, as the Aeolus range bins are considered homogeneously populated by particles, one could argue that any gradient and stratification inside each range bin could be missed. Nevertheless, the ground-based lidars show peaks in the signal at 19.3 km altitude and this is really close to the upper limit of the very Aeolus range bin where the centre of mass of the Hunga plume has been identified (i.e. from 18.04 km to 19.29 km altitude). Note that the Aeolus MLEsub SR has been added in Fig. 2b with markers. This helped understanding the selection of the centre of mass of the plume with the column maximum value of SR.

- **Line 153**: transported westward.
  CORRECTED

- **Line 163**: "at lower altitudes".
  CORRECTED and replaced with "in altitude ≈ 19 km" with a rephrased sentence to mention the lower values observed at OPAR.

- **Line 164**: “Hunga aerosol optical properties”
  CORRECTED

- **Lines 166-167**: Wording a bit redundant.
  CORRECTED, i.e. the sentences have been rephrased, and the benefit of the 7-days revisit cycle has been outlined in the introduction.

- **Line 176**: “the world map”. Also – “Global map”, the map is not global.
  It is proposed to replace the terms “world map” and “Global map” by “zonal band”. The manuscript has been corrected accordingly.

- **Line 178**: white or transparent?
  The particles-free regions with MLE SR below 2 appear with white color code. The dots with SR above 2 may appear semi-transparent due to the figure rendering set for a better visual impression.

- **Line 183**: values of SR
  CORRECTED

- **Line 184**: These values are roughly of the same order of magnitude – relative to the background they are significant and there is still something to be said about the observed range.
  Figure 4c shows IMS SA OD above 0.020 for the southern branch with Aeolus MLEsub SR above 10 which then point to compact patches of sulfate aerosols. The northern West branch is located at lower altitude ~ 25 km (i.e. Fig. 4b), with lower MLEsub SR below 10. They may correspond to different stage of sulfate coagulation and condensation. Hypothesis regarding the observed optical properties and the reported fast hygroscopic growth of the sulfate-water droplets have been added in section 3.2.2 and into the discussions section.

- **Line 188**: different altitude
  CORRECTED

- **Line 206**: the red box crosses LR isolines down to 40 sr. Please revise or clarify.
  The Fig. 5 boxes have been fine-tuned to better match the ranges of LR mentioned in the text.

- **Figure 5 caption**: It is a scatterplot rather than a histogram, because no counts are accumulated. Please rename it accordingly (there and in the text, as well as in all the other mislabeled figures in appendix).
  We thanks the referee for this comment. The Figs. 5, A3, A4, A5 have been renamed as “two-dimensional scatter plots”. The text and the figure labels have been corrected accordingly.

- **Line 227**: Tales --> tails
  CORRECTED

- **Line 231-232**: Interesting to note but could you provide/discuss some possible explanation?
  The upper part of the sulfate compact patches in late January 2022 correspond to the highest IMS SA OD values and match the highest scattering ratio, extinction and lidar ratio values. This is likely due to the hygroscopic growth of the sulfate-water droplets : upper parts of the plume (above altitudes of 27 and 30 km) have been associated with moist air (Zhu et al., 2025) and with ascent of water vapour, as reported by Legras et al., 2022 and Schoeberl et al., 2022, whilst the sulfates settle and descend under the influence of gravity as they grown in size. Our hypothesis is that hygroscopic growth, which caused rapid condensation (Asher et al., 2023), altered how the Hunga particles interacted with UV radiation, and this may have optimized their UV extinction efficiency. The strong particles extinction coefficient measured by Aeolus may be rather link to increase in scattering than in absorption as sulfates droplets possess an imaginary part of the refractive index that is near zero in the UV range. The persistence of a high scattering ratio throughout the transport period up to March 2022 and beyond supports this hypothesis. This explanation and hypothesis has been added in section 3.2.2 and in the discussions and conclusion section. New references to Palmer and Williams, 1975, Beyer et al., 1996, and Wandinger et al., 1995 have been added.

  One could argue that Aeolus missing cross-polarized light may affect our conclusions in case of non-spherical particles in the plume, e.g. overestimation of lidar ratio and underestimation of backscatter with the presence of remaining ash. But ash could not be observed in late January 2022 (Kaykhin et al., 2022; Boichu et al., 2023) and the derivation of CALIOP volume linear depolarization ratio at 532 nm, obtained by dividing the perpendicular attenuated backscatter at 532 nm by the parallel (i.e. Total – perpendicular) attenuated backscatter at 532 nm with Level 1B data product version 4.51, confirmed close-to-zero values (i.e. dark blue) for the cross sections illustrated in Fig. 3.

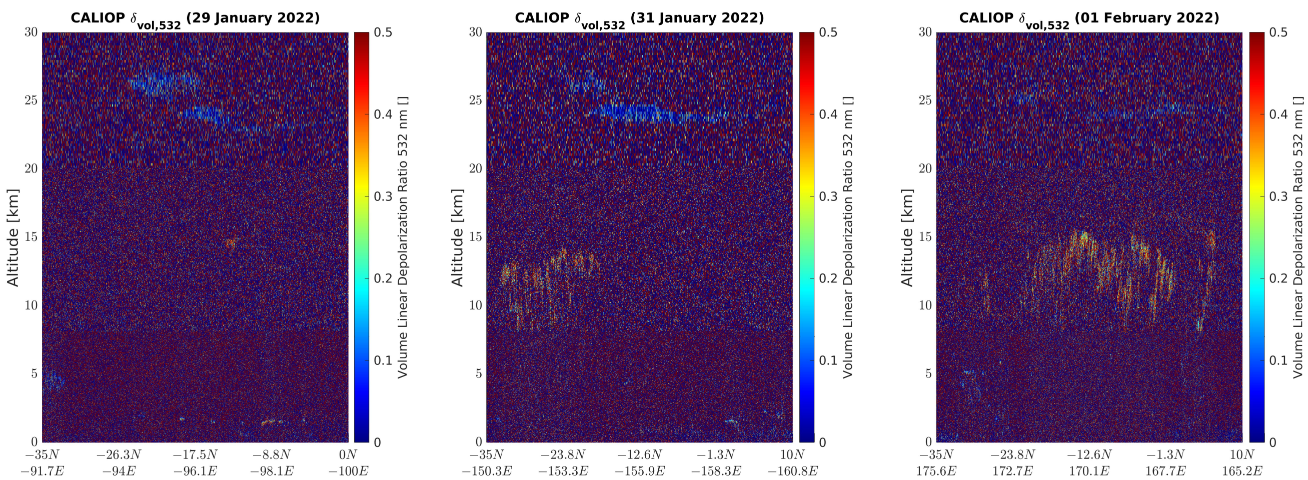

Figure : CALIOP volume linear depolarization ratio at 532 nm for cross-sections on 29 January 2022 (left), 31 January 2022 (middle), and 01 February 2022 (right)

- **Line 240**: “coarse mode” can be loosely defined can you precise?
  CORRECTED, replaced by “larger particles”.

- **Figure 6 caption**: The markers all look to be of the same size, aren’t they?
  Yes. The captions of Figs. 6-7-8 have therefore been corrected as follows : “The marker size do not correspond to their footprint.”

- **Lines 272-274**: The discussion is strongest when it stays close to the observations, but it should go one step further and explain why the plume shows the observed altitude-dependent LR, LOD, and sedimentation behaviour. Where you speculate about particle growth or water vapour, either support the claim with data or clearly label it as a hypothesis.
  We thank the referee for this remark. Several hypothesis have been added in the discussions section:
    - The role of water vapour is reminded. An hypothesis has been formulated regarding the reported ascend of water vapour which may have induced an acceleration of SO_2 oxidation in upper part of the plume.
    - The vertical gradient of LR measured by Aeolus may be interpreted as high UV scattering capacity of the newly converted sulfate-water droplets that rapidly increased in size by hygroscopic growth.
    - Hypothesis has been formulated in section 3.2.2 : the plume vertical sedimentation affects the ambient conditions of temperatures and humidity which may impact the optical behaviour of the sulfate-water droplets by changing their UV real part refractive index.

- **Line 285**: “The decrease towards/ down to lower values”.
  CORRECTED, i.e. “The decrease towards lower values”.

- **Line 288**: Nucleation will yield much smaller aerosol - not sensed by lidar. Processes of condensation and coagulation must be at play to produce the observed particle size.
  We thank the referee for this comment. A sentence has been added in line 371 to reminder the increase in radius of the sulfate aerosols which coagulated (Asher et al., 2023). Moreover, the rapid condensation reported for the sulfates in the moistest parts of the plume are reminded in section 3.2.2.

- **Line 291**: Did see much about the role of water vapour. Is it a possible future analysis you are referring to?
  The role of water vapour has been emphasized and several sentences have been added in the introduction, in section 3.2.2, and in the discussions section. The reported ascend of water vapour in Legras et al., 2022, Schoeberl et al., 2022, and Sellitto et al., 2022 indeed corroborates the finding of the present study, i.e. higher sulfate aerosols concentration in upper parts of the plume above 26 km in altitude where compact patches are observed (i.e. with highest MLEsub SR, and highest LR), and where the SO_2 oxidation was likely active.

- **Lines 293-294**: The wind product was never used here. Not sure it is relevant to mention it now.
  The wind-aerosols interaction being still under-investigated for the equatorial stratosphere, we propose to keep the sentence. The simultaneous measurement of aerosol properties and horizontal line-of-sight (HLOS) winds by Aeolus are unique to better understand the long-term persistence of the Hunga plume and the role of stratospheric winds in tropical humidity and temperature profiles which may affect the concentration of H_2SO_4. A new reference to Tiszenkel et al., 2019 has been added.