

Summary:

This manuscript proposes the unique methodology for optimal selection of angles while ensuring high instrument's sensitivity and information content retrieval for polar-integrating nephelometers (AURORA 4000, ACOEM).

The authors use Generalized Retrieval of Aerosol and Surface Properties (GRASP) analytical framework to perform forward model simulations of aerosol light scattering, using predefined aerosol microphysical properties to mimic AURORA 4000 measurement.

The study combines multiple statistical and mathematical analytical approaches such as Derive-Based Global Sensitivity Measures analysis (GDSM), Fisher Information Matrix and Parameter Correlations, assessment of Degrees of Freedom for the Signal (DFS) and variance-ratio analysis to determine optimal measurement conditions and the restraints of data applicability.

The results suggest that for fine particle mode, the change in volume concentration less than $1 \mu\text{m}^3 \text{cm}^{-3}$ is sufficient to change aerosol light scattering signal by 3%, while changes exceeding $10 \mu\text{m}^3 \text{cm}^{-3}$ are needed for particles larger than $5 \mu\text{m}$.

The authors propose the 4-angular setting for AURORA 4000. The total aerosol light scattering and 20° angle shutter position should provide sufficient distinction of fine and coarse aerosol modes; 60° angle shutter position should effectively separate absorbing aerosol components whereas 90° angle (backscattering) is proposed to distinguish between different non-absorbing aerosol components. Such setting is considered to sufficiently retrieve total aerosol concentration, fine-to-coarse particle ratio as effective particle radius.

General comments:

The problematics addressed in this manuscript is very relevant for aerosol in-situ monitoring community (including ACTRIS Infrastructure). The novel attempt to assess the best angular measurement alignment using synergy of GRASP, GDSM and SVD can play a substantial role in air quality long-term monitoring and better understanding of aerosol-radiation interactions.

However, this work is purely based on modelling and statistical analysis and the methods used in the manuscript were not applied to the real experimental or ambient aerosol data. My biggest concern regarding this manuscript originates from two uncovered topics: the uncertainty of the measurement of the real instrument (including calibration uncertainty, truncation error, limit of detection, instrumental noise, etc.) and the complexity of real ambient aerosol samples. The approach presented in the study contains a lot of simplification coupled with strong outcome claims which is questionable regarding application of methods in the field experiments.

The authors are also performing only forward model simulations using GRASP. It may be beneficial to run additional inversions and compare the retrieved parameters with the input ones. This can simplify the evidence of applicability of GRASP algorithm to in-situ nephelometry and enable the use of more robust DFS analysis introduced by Rodgers (2000).

The current method proposed by the authors is also unapplicable to black carbon (BC) aggregates as the assumption of sphericity completely rules out their morphology and the whole section regarding separation of absorbing aerosol species from non-absorbing is thus highly questionable.

I also recommend additional revision of the manuscript, as it contains some inaccuracies and formatting typos within the text (See Technical comments section).

Therefore, I suggest major manuscript revisions to be made before publication.

Specific comments:

Whole manuscript: The work is purely based on simulations and modelling. However, in a real measurement scenario, one must account for multiple aspects of uncertainty, e.g. calibration uncertainty, truncation error, detector noise or different wavelength performance. Thus, the present analysis may represent only a very optimistic upper limit of instrumental performance and should be addressed in the manuscript.

Was any kind of noise representing real instrumental performance added to the analysis? Without the noise analysis, the outcomes can be highly exaggerated.

Chapter 2.2 Information Content and Degrees of Freedom, Equation 10:

The determination of $DFS_{forward}$ almost solely relies on the threshold parameter ϵ . Why did authors choose this threshold and how is it determined? It may be beneficial to show $DFS_{forward}$ in several cases.

L124-126: This scenario is very unlikely to happen.

L150-152: This claim can be misleading. The singular value should be generally judged relative to noise (single-to-noise ratio). This value can be large relative to the others but still small relative to instrumental noise.

Table 1.: The authors present parameters used in forward simulations. For aerosol size distribution, the range 0.05-15.0 μm is used. However, the standard polar/integrating nephelometer cannot optically detect particles as low as this lower bound. Although authors are referring to the standard GRASP configuration as the default for parametrization, the in-situ nephelometry may require different choice of input parameters.

Moreover, information on the number of runs/combinations or repetitions of simulations could introduce additional insight into the method. Please comment.

L243-245: The forward simulations were run with the assumption of particle sphericity = 0.99. However, the simulations included various types of aerosols, e.g. dust, sulphate, absorbing matter, etc. This approach can result in unrealistic outputs.

L288-292: The claim from the text is not clearly visible in Figure 1a nor 1b. Please reformulate or add more interpretation of the sentence “*In particular, enhanced variability ... for large shutter positions exceeding about 80 degrees.*”

Moreover, for sake of clarity, I kindly advise authors to always refer to particular subplot in the text if multiple plots are presented, otherwise the interpretation can be confusing for readers.

Figure 1.: Please always describe all subplots in the title of the Figure.

L293 + L354-357: The authors claim that the angular ranges of polar nephelometers may not provide sufficient information about coarse modes of aerosols. Current recommendations for ACTRIS aerosol light scattering instruments are to measure at PM₁₀ cut-off size. Polar nephelometers may eventually join the list of recommended instruments at the measurement sites in the future. Based on the presented work, do authors suggest that switch to smaller cut-off (PM₁) may be more beneficial when running polar nephelometers? Please elaborate.

Figure 2. and Figure 3.: The explanation of all 4 subplots is missing in the titles. Moreover, it is not clear whether the y axis: *Bin Position (μm)* depicts radius or diameter in Figures 2c/3c and 2d/3d.

L296-302: The resulting claims are too strong without sufficient explanation and without referring to subplots in Figures 2. and 3. Moreover, as mentioned in the General comments section, the retrieval of absorption from these calculations is highly questionable due to assumption of sphericity.

L307: What was the motivation behind assuming that a relative measurement sensitivity of the nephelometer is 3%?

L316-320: The authors are using realistic reference of median integrated scattering signal from Racibórz observatory. What time of the year was the reference taken? What time resolution was considered for the statistics? What was the prevailing type of aerosol during this time? Could this method be applied to other environments (e.g. remote, rural, marine, etc.) with different scattering signals?

Specifically line 318: Was the same reference scattering signal applied to both scattering and strongly absorbing fine aerosols? The scattering signal may diverse a lot as well as the PNSD is very different.

L323: Talking about different aerosol types, the unified particle density of 1 g cm⁻³ is not representative to all.

L325: This applies only to non-absorbing aerosols.

Figure 4. Please describe subplots in the title and add units to the color-coded legend (and title).

L340-348: Such simplifications should be treated with caution and the potential uncertainties regarding usage of ambient data should be addressed.

L402-404: From Tables A1. and A3., the coarse mode modal concentration with distribution width is also anticorrelated, as well as the coarse mode modal concentration with modal radius.

Tables A1.-A3.: A lot of correlation coefficients are close to ± 0.95 . What is the threshold authors used to effectively separate coupling-uncoupling of the parameters?

L460-462: Applies for fine particles too?

L466-469: May be too strong claim for the provided analysis of Fisher matrices. Please add additional explanations.

Table 3.: Where do the predefined values come from? Does it originate from the analysis of aerosols at Racibórz observatory or coming from the literature? Please indicate and add literature sources if needed.

L524-527: Figure 7c and 7d are almost identical (except magnitude). Please explain the conclusion that shutter position of 60° is better for discrimination of absorbing from non-absorbing particles whereas position of 90° should show more differences between various classes of non-absorbing aerosol.

L533-536: The authors reflect the substantial simplification of light scattering modelling compared to the real ambient data. However, how much do authors think this can be applicable to the atmospheric measurements?

Figure 7a: Shutter position 5° for AURORA 4000 is not applicable - 10° is defined as the minimum by the manufacturer.

Technical comments:

Please unify citation withing text. Currently both “()” and “[]” brackets are used.

L129: ...From Hansen (1998), the eigenvalues...

Table 1 is introduced before being mentioned in the text. On the other hand, Table 3 is mentioned way too early in the text.

L240: “*following*”

L242: ...(*Dubovik and King, 2000; Dubovik et al., 2006*)...

L254: “*These limitations arise from the optical geometry and truncation characteristics of the instrument (Müller et al., 2011).*”

L282: Sentence with double negative. Please rewrite it to make it clearer for readers.

L362: “forward”

Title of Figure 1: Please replace fo with of.

L471: “*The purpose of this section is therefore....*” - there is no previous paragraph, thus the word “therefore” does not make sense in this context. Please rephrase.

Figure 5.: X axis title – “*Narmalized sacttering*”

Please rewrite the plot title. For example: *Angularly resolved light scattering nephelometer signal $P_{11}(\Theta)$ at 525 nm normalized by total scattering signal for each class of the aerosol.*

Figure 7.: Please provide better description of all subplots in the title.

Fig 7d: X axis title – should be 90°.

In References, the hypertext links do not work for: Engl et al., 1996; Espinosa et al., 2017; looss et al., 2010; Laj et al., 2024; Michibata et al., 2025. Moreover, please add DOI references where possible.