Atmospheric Measurement Techniques Discussions

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Comment on amt-2022-170

Reed Espinosa (Referee)

Referee comment on "Information content and aerosol property retrieval potential for different types of in situ polar nephelometer data" by Alireza Moallemi et al., Atmos. Meas. Tech. Discuss., https://doi.org/10.5194/amt-2022-170-RC1, 2022

– General Comments –

The manuscript describes a polar nephelometer information content study performed in the context of multiple polydisperse laboratory and ambient aerosols. The potential to retrieve aerosol concentration, size, spherical particle fraction and complex refractive index is evaluated for various instrument designs with different detection angles, wavelength configurations and polarization resolving capabilities. Overall, the work shows that retrievals of data from even a rudimentary polar nephelometer can theoretically provide a very significant amount of information on the sampled aerosol.

The content of the manuscript is novel, and it has the potential to be a very useful, and much needed, resource for future developers of polar nephelometer instruments. The material is inevitably a bit dense, but the text is well written, and the methods are clearly described. In my view, the manuscript could be slightly improved by the addition of a few more readily applicable results that would be more accessible to the casual reader. For example, it would be very informative to provide expected retrieval errors for the considered variables of state given the instrument configurations show in Figure 12 and the atmospheric measurement-derived a priori values. Overall though, the manuscript is clearly very appropriate for AMT, and I can recommend publication once the minor points below have been addressed.

– Specific Comments –

1. Ln 71: Phase function is sometimes normalized but I believe absolute phase function (i.e., βsca*P11, where P11 is the phase function normalized such that the integral over all angles is 4π) is used here. It would be good to expectedly state the definition and/or units used for phase function in this work.

2. Eq 2: I believe this equation is only valid for systems in which F(x) is linear

everywhere, not just locally. Since Mie (and spheroid scattering) is very non-linear, I'm wondering if it is appropriate here.

3. Sec 3.1.3: Is the angular Field-Of-View (FOV) of the sensor at a given scattering angle assumed to be negligibly small? This is not always the case for real instruments and should be clarified in the text. On a side note, in the PI-Neph $\Delta\theta \approx 0.2°$ but, due to smearing of the image by imperfect optics, the FOV of each pixel ends up being about ~1°, with significant overlap between pixels. Ultimately, data is reported at 1° resolution to avoid the need for a complicated deconvolution procedure.

4. Ln 292: Covariance in polar nephelometer error can be large and quite complex, especially in imaging nephelometers. Do the authors have a sense of how sensitive their results are to this assumed covariance? How was the value $\rho=0.7$ selected?

5. Table 3: This table defines the PSD using GSD while the following two tables use ln(GSD). It might be clearer to use a consistent metric throughout the manuscript.

6. Ln 432: It would be good to provide a reference supporting the idea that refractive index values have significant spectral correlation. Two possible candidates would be Xu et al. (2019) and Gao et al. (2018).

7. Table 5: I'm having trouble tracking which refractive indices were used to determine the percentage-based a priori covariance values in the bottom row. Each cell of the bottom row has two values: an absolute quantity and a percentage. My understanding from Figure 5 is that the absolute quantity listed is actually used for all λ and aerosol species in the information content calculations. If so, which wavelength and species does the percentage shown apply to? Please clarify.

8. Figure 4: Would it be possible to show the σ_a values within each subplot as they are in shown in Figure 5. This would greatly ease contextualization of these results for the reader.

9. Figure 5: In the coarse, k subplot, I interpret $\sigma_a=0.0005$ and DOFS≈1 for even the single wavelength non-polarized nephelometer to mean that the corresponding instrument has the potential to retrieve k to an accuracy much better than 0.0005. Although coarse mode state may have been slightly different, prior work has not noted very significant changes in PF resulting from changes in k as small as $\Delta k=0.0005$ (e.g., see Figure 2 of Espinosa et al. (2019)). Section 4.4 and Figure S4 provide a bit more context regarding the situations in which the present authors have observed PF to change significantly with k but I'm wondering if any intuitive explanation of the exact mechanism driving this high sensitivity is available, given that this feature has not been observed in prior work.

10. Figure 6: Are these DOFS (and the results in Fig S4) based on the percentage- or atmospheric-based a priori variance values?

11. Ln 750: Do the authors know of a particular nephelometer that suffers from side angle truncation? If so, it would be good to add a reference to this instrument. If no reference is available, it may be better to soften this statement and say that some designs could potentially suffer from side angle truncations.

12. Ln 777: Intuitively, I imagine there to be two relatively separate mechanisms that lead to improvements in DOFS with increasing N_θ: (1) an improved ability to capture angular features in the PF and PPF that encode information about the aerosol and (2) an increase in measurement statistics that helps to beat down noise and effectively increase the accuracy of the measurement. The two mechanisms are likely quite difficult to disentangle but I'm wondering if the authors have any sense of their relative contributions here. If mechanism (2) was dominate, I would expect the N_θ value where "plateauing" starts to occur to be strongly dependent on the assumed error covariance (specifically the value of ρ). Is the conclusion that the plateau generally occurs $20<N_\theta<40$ robust to different choices of ρ? This could be quite relevant in terms of instrument design considerations where there is frequently a choice between adding more angles or increasing the accuracy in a smaller subset of angles.

13. Ln 781: I would recommend restating the sentence that begins on this line. As it is currently written, it almost sounds like the plateau in IC is more prominent with complex particles or low instrument noise, which I think is the opposite of what the authors intended.

14. Ln 784: It may be worth noting that these conclusions all apply only to polydisperse aerosols. Monodisperse aerosols, or even reactively narrow polydisperse size distributions, will have significantly more angular features and likely continue to benefit from more angles, well beyond the plateaus observed here.

– Technical Corrections –

Ln 88: "Polarized Imaging Nephelometer" should be capitalized.

Ln 290: "Wavelength" should be one word

Ln 446: This sentence contains an extra "it".

Ln 456: I might suggest something like "detection angles" in place of "sensor" since some instruments (e.g., Imaging Nephs) only have a single CCD sensor.

Ln 471: Should read "...with an increasing..."

– References –

Xu, Feng, et al. "A correlated multi-pixel inversion approach for aerosol remote sensing." Remote Sensing 11.7 (2019): 746.

Gao, M., Zhai, P.-W., Franz, B., Hu, Y., Knobelspiesse, K., Werdell, P. J., Ibrahim, A., Xu, F., and Cairns, B.: Retrieval of aerosol properties and water-leaving reflectance from multi-angular polarimetric measurements over coastal waters, Opt. Express, 26, 8968–8989, https://doi.org/10.1364/OE.26.008968, 2018.