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Comment on amt-2021-251

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Referee comment on "Laser Imaging Nephelometer for aircraft deployment" by Adam T. Ahern et al., Atmos. Meas. Tech. Discuss., https://doi.org/10.5194/amt-2021-251-RC1, 2021

The manuscript describes a new version of the LiNeph polar nephelometer that has increased stability as well as sensitivity to the second element of the aerosol scattering matrix, P12. Details of instrument design and calibration are presented, followed by example measurements of smoke plumes from the FIREX-AQ campaign.

The instrument provides airborne measurements of P11 and P12 which are currently very limited but have high potential value, especially to future remote sensing missions the will be flying advanced polarimeters like PACE and ACCP. The new LiNeph design represents several improvements over past nephelometers, particularly the addition of a second camera allows two roughly orthogonal input polarization states to be measured simultaneously which improves measurement accuracy and time resolution. Moreover, an important potential source of error, inhomogeneity in the sample volume, is discussed in much more depth than in previous studies involving imaging nephelometers. The work is therefore novel, has the potential for significant impact and is clearly relevant to AMT. There are, however, a few minor points that I feel must be addressed before the article can be published, most notably the magnitude and impact of the deviation from ideal input polarization states needs to be discussed.

GENERAL COMMENTS:

(A) In order to measure a range of scattering angles, the direction at which the chief ray enters the camera (and potentially the orientation of the scattering plane) must vary across the FOV (i.e., the lens cannot be object-space telecentric). Therefore, given an axial symmetric lens, it is geometrically impossible for the direction of linear polarization to be exactly perpendicular to the scattering plane in one camera and parallel in the other for both (not spatially coincident) lasers simultaneously. How far are the actual laser polarization orientations from the ideal orientations represented by Equations (3) and (5) in Section 2.1? Figure 1 implies potentially large deviations from the ideal case, but perhaps this schematic is not scale. Regardless, this issue must be addressed in the text as even small misalignments can lead to relatively large biases (see Dolgos and Martins, 2014).

(B) There is no direct validation of the new P11 and -P12/P11 products. This is generally understandable given the lack of polar nephelometer measurements available for intercomparison and the challenges associated with modeling scattering matrix elements of natural aerosol. However, in other polar nephelometers, observations of artificial PSL spheres have frequently been leveraged to gain a better understanding of instrument performance. The PSL measurements here cannot be used as a completely wholistic validation since they are also used in instrument calibration but examining PSL P11 and -P12/P11 could still help to increase confidence in (and help better understand the accuracy of) the measurement. This is especially true for the amplitude of the peaks and valleys of the measured scattering matrix elements, which are only very moderately affected by the scattering angular calibration. Moreover, imperfect input polarization states will strongly impact the amplitude of the PSL features, particular in -P12/P11, so good agreement with Mie theory there could be one way to confirm that slight misalignment of the laser polarization (as discussed in (A) above) is not a cause for significant measurement degradation. In my view, Figure 4 needs to be augmented (or possibly replaced) with a figure showing the processed P11 and -P12/P11 PSL data and corresponding Mie calculations.

DETAILED COMMENTS:

1) LN 21: The range of scattering intensities that can be accurately measured is actually never mentioned in the text (only in the abstract). How was this 50-80,000 Mm-1 estimate derived? On a related note, the Rayleigh scattering coefficient of the CO2 used in calibration is much less than 50 Mm-1, especially in the red channel. Thus, I am wondering if it is possible to measure at loadings less 50 Mm-1 under stable laboratory conditions (like those used in the CO2 calibration)?

2) LN 29: I'm having trouble following this sentence. Why is the observational geometry only important at certain distances? And I'm not clear specifically what "characteristics of the scattering entities" the authors are referring to. Please clarify.

3) LN 38: It should be clarified that Mie theory requires knowledge of particle size in addition to composition.

4) LN 52: It would be good to note that these are two different input laser linear polarizations (as opposed to analyzers on the detector/camera end).

5) LN 56: Upper and lower case "L" is used to represent liter at different points in the text. The abbreviation used should be consistent.

6) LN 69: It might be a little unfair to say cabin-based instruments cannot sample particles bigger than ~1μm. (Later in the text it is stated that the inlet used here has a cutoff around 4-5μm.)

7) LN 85: I had a bit of trouble following the remaining sentences in this section and sometimes found it difficult to tell if the orthogonal orientations mentioned were in reference to the polarization state of the lasers or the optical axes of the cameras. The text should be adjusted for clarity and made more precise. A new figure (or even reference to figure 1) might also help convey the geometric details of the different designs.

8) LN 100: 4πr^2 would mean that the normalization is dependent on the distance between the observation and scattering event. Is this what is intended here, or is the normalization such that the integral of P11 over all angles equals 4π? Also, the definition of r should be included in the text.

9) LN 103: Random orientation alone is not completely sufficient to guarantee only six unique scattering matrix elements (e.g., see Chapter 4 of Mishchenko et al. 2002). The scope of the statement should be appropriately narrowed.

10) LN 106: It should be clarified that this sum must be weighted by the scattering cross section of the individual particles. (The normalized scattering matrix elements do not account for differences in the total, angularly integrated scattering between particles).

11) LN 108: The year of the Mie reference should be 1908.

12) LN 109: I'm struggling to follow this sentence. It would be good to clearly define coordinate system in which the Stokes vectors that follow are written.

13) Figure 1: Would it be possible to add the location of the 3D-printed apertures to this figure?

14) LN 138: It would be helpful to state the volume of the LiNeph sample cell earlier in the text so that the reader can better contextualize the flow rate presented here.

15) LN 159: Could the authors double check the columns specified? The main stray light feature I see is centered below pixel 50.

16) LN 215: I would usually refer to this as a 2-D matrix (the values of intensity specified over the two dimensions of rows and columns). Although, in some sense it is 3-D because polarization state (i.e., camera) could also be considered a dimension. Either way, I would rephrase this sentence to avoid confusion.

17) LN 248: I think perhaps the authors mean the signal in the "para" camera goes to zero at $\theta=90°$? The P11 element of the scattering matrix never goes to zero for Rayleigh scattering. Also, it might be more accurate to say the signal becomes very weak since the Rayleigh depolarization correction will prevent it from going completely to zero (see below).

18) LN 257: Was a Rayleigh depolarization correction (i.e., see Eq 2.15-16 of Hansen and Travis, 1974) used here? The effect can be relatively large for CO_2 (Young, 1980).

19) LN 258: Why is this unit bit^2? Isn't the value just the sum of bits in all pixels at a given angle?

20) LN 276: Was this test performed in the lab? In an aircraft context, is there a possibility of slight changes in mechanical alignment altering the calibration, especially where the laser passes through the 3D-printed apertures? I would suggest adding a short discussion of potential impacts of mechanical vibrations on calibration.

21) LN 277: The advantages of performing a Gaussian fit over using the intensity at the peak of the signal are made clear here. A third approach that has been used in other imaging nephelometers (e.g., the PI-Neph) is to take the sum of the counts of all pixels containing the beam in each column. Perhaps there are strengths and weaknesses to both approaches, and it would be interesting if the authors could provide some discussion of the motivation for their particular Gaussian fit based approach.

22) LN 297: It might also be worth noting that multiple scattering inside the chamber also has the potential to bias the measurement (e.g., see Gogoi et al., 2009), although that effect is also likely small at the concentrations sampled here.

23) LN 299: The abstract says the measurement is valid to 80,000 Mm-1, which would presumably produce close to 8x0.7%=~6% attention. The values in the abstract should be backed-up by and made consistent with the corresponding discussion in the text.

24) LN 323: Does the use of the term "polarimetric measurements" mean that only P12 is

filtered, or is the filter also applied to P11? This should be clarified in the text.

25) LN 324: I would have expected this to be 1/0.24Hz = 4.2 seconds later. Why is it ~2.5 seconds?

26) LN 334: The method used for handling the truncated phase function angles in the integral yielding total scattering should be specified. (Presumably the nearest neighbor approach that was used to calculate g?)

27) LN 397: Would it be possible to show some asymmetry parameter data? If not in the main text, then perhaps in the supplement? This would be especially interesting if it could be plotted against other estimates of g, or even just the backscattering fraction from the integrating nephelometer on an adjacent axis, but perhaps these comparisons are best saved for a later work.

28) LN 412: The use of the word "polarimetry" here strikes me as a little misleading given that the observable differences were in P11.

29) LN 416: This sentence needs to be softened, as only the precision of g was demonstrated to be better than 3% (not the accuracy).

30) Figure S2: Which camera does this plot correspond to? Would it be possible to show data from both?

31) Figure S4: The meaning of the black lines should be stated.

REFERENCES:
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