Atmos. Meas. Tech. Discuss.,
doi:10.5194/amt-2019-382-AC3, 2020

Interactive comment on "Microwave and submillimeter wave scattering of oriented ice particles" *by* Manfred Brath et al.

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Received and published: 31 January 2020

Answers to Interactive comment on "Microwave andsubmillimeter wave scattering of oriented ice particles" by Manfred Brath et al.

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January 31, 2020

Reviewer:

The paper presents an important step forward in the currently available scattering databases of snow particles at microwave frequencies by assuming the possibility of ice particles with preferential orientations. This is an important contribution which I recommend for publication, but I would also like to list some comments aiming to improve the value of the paper.

1. The orientation averaging technique lacks some validation. A very basic sanity check would be to calculate the integral over $\cos(\beta)$ at the various θ_{inc} and compare with the previously published database (DB) for total random orientation (TRO). Another useful plot to include would be the convergence of the integral with respect to the number of points of the icosahedral grid. At line 195 it is stated that a variable number of points is used (between 162 and 2562), per-

haps these convergence plots would clarify why, sometimes, a smaller number of orientation samples is sufficient.

Answer:

You are right this is missing. We forgot to mention it in the text. We tested our method by simulating the scattering of azimuthally randomly oriented prolate ellipsoids and compared the results against T-matrix calculations. The overall differences in view of the extinction matrix and the scattering matrix were in the order of a few percent. We added a similar statement to the text. Considering line 195, we revised it. We now explain, why sometimes, a smaller number of orientations are sufficient.

Reviewer:

2. The averaging scheme is presented as a solution to various challenges that sequentially appear in the text. It is hard, sometimes, to follow this approach because it requires to rethink about the setup many times without a clear final goal to aim to. I want to suggest to introduce the three main reference frames of the problem from the beginning: these are the laboratory (satellite) reference frame, the particle reference frame, and the wave reference frame. By doing so, one can states from the beginning that the scope is to have the polarized scattering properties defined with respect to the satellite reference frame and some transformations are needed because for scattering calculations the wave reference frame is a more natural option used in scattering codes. Also what is called the orientation of the non-rotated particle is nothing less than the particle reference frame.

Answer:

We agree that it is sometimes hard to follow. We revised that part considering on your suggestion.

Reviewer:

3. Line 62. This phrase, somehow implies that there is a special subset of rotation matrices that are orthogonal and no couple of rotation matrices are commutative with respect to multiplication. I think all rotation matrices are orthogonal and some rotation matrices do commute (the ones around the same axis).

Answer:

We rephrased the sentence to: " It is important to note that in general the order of the rotations must not be changed, because the combination of rotations is generally not commutative."

Reviewer:

4. Line 87. For TRO $p\left(\beta\right)$ should be $\frac{1}{2}$ and β should be uniformly distributed in terms of $\cos\left(\beta\right)$. Otherwise, the integral does not compute to 1 when K=1

Answer:

We corrected it. We now define $p\left(\beta\right)$ according to Mishchenko and Yurkin (2017) Eq. 4. This means

$$p\left(\beta\right) = \frac{\sin\beta}{2}\,. \tag{1}$$

Due to that we adjusted all equations in the text that involve averaging over the tilt angle β (Eq. 2,3, and 37).

Reviewer:

5. Line 110. I think here the non-symmetry is respect to the scattered azimuth, not the incident which is actually irrelevant for Zaro.

Answer:

We removed "to incidence azimuth direction" from that specific sentence.

Reviewer:

6. Line 121. ADDA can actually also compute scattering properties for distributions of angles through input files, this includes azimuthally averaging. The reason why this is not used in the study is that this approach involves the solution of the computationally demanding DDA problem for slightly different orientations many times (for the different combinations of tilt angle and wave incidence).

Answer:

We rephrased it. We now state that the internal averaging method of ADDA is not suitable for our approach.

Reviewer:

7. Line 130. D_0 should have explicit units, which I assume are μm.

Answer:

We added the unit.

Reviewer:

8. Line 179-182. I do not see why a regular grid is advantageous for resolving the for/back-ward scattering peaks. A regular grid means that the azimuth and polar angles are equally spaced. The points at the same polar angle are getting closer in azimuth distance as the polar angle approaches the poles. The scattering peaks mean that there is a high variability of the scattering intensity with respect to the polar angle and thus would demand an increased resolution in polar angles. The polar angle resolution is always the same here.

Answer:

We removed that sentence.

Reviewer:

9. Lines 209-214. In my opinion, two points are missing in the list of steps: first is the projection over spherical harmonics of the scattered fields. And the second is the barycentric interpolation of the gridded data. The second is important because it clarifies that the computed properties for a certain β and θ_i are actually coming from slightly different angles.

Answer:

We agree that the projection on spherical harmonics was missing in that list especially due to the truncation of them to reduce the amount of data. Therfore, we added it. We do not think that the barycentric interpolation is missing, because we think it is part of the averaging operation as the Gauss-Legendre quadrature is part of the averaging operation. Furthermore, the interpolation is explicitly stated in the paragraph before the list of steps. Therefore, we did not add it to the list.

Reviewer:

10. Line 220. The three rotation matrices are different. Perhaps a better notation would be $R_{\alpha\beta\gamma} = R_{\alpha}(\alpha)\, R_{\beta}(\beta)\, R_{\gamma}(\gamma)$

Answer:

Changed as suggested

Reviewer:

11. Line 284. What is called accuracy $\epsilon = 1\%$ I think is the internal stopping criterion for the ADDA iterative solver and should not be confused with the accuracy of the calculations which is hard to evaluate and yet not clearly understood. Perhaps the authors should include in the supplementary material, for just one particle and one orientation what is the effect on the scattering properties (just plot phase functions) of this choice of ϵ with respect to the default value of 10^{-5} (three orders of magnitude smaller!).

Answer:

Your are right. We revised that part. We now say explicitly that it is the internal stopping criterion. Furthermore, we state that we aim for an accuracy of a few percent for our database. Therefore, setting the stopping criterion to 10^{-2} is a compromise in terms of accuracy due to the high demands in view of computation time and the amount of data. Considering the measurement errors of existing and upcoming passive MW and SubMM sensors, which are in the order of $\mathcal{O}(1\,K)$, and the brightness temperature depression due to scattering of frozen hydrometeors, which is typically $< 100\,K$, an accuracy of the scattering database in the order of a few percent seems sufficient.

Reviewer:

12. Line 381. In the figure, I see β= 0, 50, 90 but in the text, β=30 is mentioned, perhaps there is a typo?

Answer:

Yes, that were typos.

Reviewer:

13. Line 397-402. Here the authors state that the database is not optimized for radar calculations because the spherical harmonics projection is not good at forward and backward scattering. Perhaps the authors should better describe what they meant at line 177 with RMSE of less than 0.5% due to the spherical harmonics. 0.5% is actually quite insignificant for radar applications. Also this problem can be immediately solved by making available the original DDA computations at single orientations, perhaps by request to the corresponding author. I think this last piece would also make the paper fully compliant with the Copernicus open-data policy.

Answer:

Considering line 177, we revised that. We now relate the truncation of the spherical harmonics in Section Scattering calculations to the desired accuracy. We have to admit, that due to the missing statements on the desired accuracy of the database, it was not clear why we used an RMSE of 0.5%.

We cannot make the original DDA computations available. We could not store them permanently, because the data was too big. But we can make the truncated data from DDA computations available upon request. We added a statement considering the data availability to the text.

Reviewer:

14. The scattering properties of hexagonal crystals are symmetric with respect to θ_i due to the planar symmetry of the particles. This is not true for aggregates that are not symmetric. The authors have oriented the aggregates according to their principal axis of inertia. This is, in general, a good fast approach, but it introduces an arbitrary decision about what is the direction of the main (vertical) axis of inertia. In my opinion, there is no clear criterion to decide whether this axis should look up or down. As a consequence, one could argue that the scattering properties for $\theta_i = \lambda$ should be averaged with those for $\theta_i = 180 - \lambda$ giving planar symmetry also to the aggregates and reducing the storage footprint of the database.

Answer:

You are correct. When using the axis of inertia there is no unique criterion to decide whether the axis should be upward or downward. Therefore, we use an additional criterion, see Appendix Initial particle alignment step 4. We define, if the center of the circumscribed sphere of the particle is found to be below the mass-center of the particle (with respect to the z-axis), then the particle is said to be aligned upright and vice versa. We did not consider your suggested averaging, because we want the users to decide what they want or need.

Reviewer:

15. Equations (20) and (21) show how to rotate the polarization vectors of the Mueller matrix. I wonder if this is done before the barycentric interpolation. In my view, the scattering properties of the three vertexes should be first aligned

with the direction and polarization of point D. If the forward/backward scattering direction lies within the triangle ABC this can cause quite dramatic cancellation due to the flipping of the polarization direction among the points A, B, and C.

Answer:

We do not fully understand your point. Equations (20) and (21) describe how the Mueller matrix and the extinction matrix are transformed. The interpolation is done with respect to the incidence direction not with respect to the scattering directions. Actually, the points (vertices) of the triangle are the three nearest sample points to our desired incidence direction at point D after the rotation of the particle system. The sample points are the set of the incidence directions at which we have calculated the Mueller matrix with ADDA. At each of the three nearest sample points we transform the polarization according to Eq. 22 using the Stokes matrices. And after that we do the interpolation, which is essentially a weighted averaged of the Mueller matrices of these three sample points.

0.1 Refrences

Mishchenko, M. I. and Yurkin, M. A.: On the concept of random orientation in far-field electromagnetic scattering by nonspherical particles, Optics letters, 42, 494-497, 2017.