

## Review of “Effects of dust particle internal structure on light scattering”

By Emppinen et al.

### General comments

This article presents a detailed analysis and study of the effects of different kinds of internal inhomogeneity on the light scattering properties of atmospheric aerosol. The authors provide a detailed account of how they analysed the aerosol internal structure and geometrically modeled the particles. They employ the DDA method to study the resulting light scattering behaviours assuming different kinds of aerosol inhomogeneity, and these results are compared to an effective medium approximation. In general, they find that the chosen effective medium approximation to be inadequate in predicting the polarized and intensity-related elements of the scattering phase matrix. They conclude that to represent the light scattering properties of aerosol, the interior dielectric properties as well as their distributions throughout the particle volume should be taken into account explicitly. They also show that the effects of the internal inclusions on light scattering are not cancelled out when integral optical properties are considered such as  $\omega_0$  and  $g$ . These latter quantities are parameterized in climate models, and so one might be able to say, based on this paper, that current climate models are biased, as these naturally assume effective medium approximations to parameterize the integral optical properties. The conclusions of this paper are equally important for remote sensing studies of aerosol, as they use the angle-dependent quantities contained in the scattering phase matrix. It was a surprise to read that the authors did not explicitly advocate a greater use of polarization measurements to help identify aerosol types as their polarized matrix element figures suggest a distinct dependence of polarization on the particular case being considered. The authors should state this more distinctly, as this will help to promote more polarization measurements of atmospheric aerosol, especially from space.

There are no objections to this paper being published, although there are comments below, which the authors should address before eventual full publication.

1. The authors take great pains to stress the importance of internal inhomogeneities. My question is how important is surface roughness and might this be more prominent than inclusions or are they both as important as each other? The authors do not actually discuss surface roughness until the very end, and there they state that an opposite effect on the linear depolarization ratio is found. Is the effect only on that ratio or are the other matrix elements similarly affected? Please discuss.
2. Only one effective medium approximation is compared against. Do the results in this paper hold for all effective medium approximations? For instance, if they were to assume the Maxwell-Garnett mixing rule, would it be true to say that this approximation provides better agreement with their exact calculations. Please discuss and show an example in reply.
3. Is the error in the EMA, in calculating the integral optical properties, significant with respect to current experimental uncertainties? What are the current experimental uncertainties in determining  $\omega_0$  and  $g$ ? The effective

- medium approximation is within -6% of the exact calculations. Are the current experimental uncertainties now less than the at most -6% difference?
4. Was the aerosol shown in Figure 1 collected on the ground or when suspended in the atmosphere? If collected on the ground, then that aerosol may not necessarily be representative of the aerosol suspended in the atmosphere as it might have been modified? Please discuss possible aerosol modifications if picked up off the ground.
  5. How might the differences presented in the light scattering figures change if the real PSDs were to change from say narrow to broad PSDs? Might there be some cancellation in error over a fully integrated PSD to obtain the volumetric aerosol optical properties? Please discuss.

#### Minor Points

1. Citations. The following citation might also be deserving of inclusion in this paper. Short-wave and long-wave radiative properties of Saharan dust aerosol. Osborne, S.R.; Baran, A.J.; Johnson, B.T.; Haywood, J.M.; Hesse, Evelyn; Newman, S. In: Quarterly Journal of the Royal Meteorological Society, Vol. 137, No. 658, 2011, p. 1149-1167.
2. The author list in Haywood et al. (2011) is incomplete. It should be as follows: Haywood, J. M., Johnson, B. T., Osborne, S. R., Baran, A. J., Brooks, M., Milton, S. F., Mulcahy, J., Walters, D., Allan, R. P., Klaver, A., Formenti, P., Brindley, H. E., Christopher, S. and Gupta, P.
3. Introduction. Surface roughness is also an important contribution to the radiative properties of aerosol. Please discuss.
4. Page 4 line 7 coinciding->coincident
5. Page 4 line 20 is "perfectly" true? As there are approximations in the model constructions.
6. Section 2. Page 5. Line 9 "...in a" redundant -> "transported long-range"
7. Section 2. Page 5. Line 26. Do you mean to say that orientations are more common with coarser mineral inclusions? The current sentence is difficult to follow. Please re-write.
8. Section 3. Page 6. Line 2. Potential to do what? Incomplete sentence.
9. Section 3. Page 6. Line 11. "establish the population" with respect to what?
10. Section 3. Page 7. Line 2. "with"->in
11. Section 3. Page 7. Line 7. "where"->which
12. Section 3. Page 8. Line 11.  $S_{11}=S_{22}$ ,  $\delta=0$  is only true for a single sphere, you use the word "particles", which implies multiple scattering, in which case  $\delta \neq 0$ .
13. Section 3. Page 7. Line 18. "is the scattering angle, i.e., ...."
14. Section 3. Page 9. Why 8192 orientations? Were solutions convergent with this number of orientations? Please state accuracy.
15. Section 4. Page 10. Line 6. A useful measure of a particle model is comparison of its area ratio to measured area ratios. Are these available? Or can you obtain from the data? Are ratio is a ratio of cross sections, so obviously this ratio will be of importance in light scattering calculations.
16. Section 5. Page 16. Line 7. By definition spheres are perfect unless otherwise stated.
17. Section 5. Page 17. Line 20. "smoothened"->"smoothed"
18. Section 5. Page 17. Line 22. Why not compare your results against the Amsterdam-Granada light scattering experimental results?

19. Section 6. Page 22. Line 29. "is in.." -> is on the macroscopic scale..

Comments on tables

Tables 1-5. The total volume fraction of each of the  $i$ th elements contained in each of the tables do not sum to exactly 100%. Please correct. This may have a slight impact on the EMA refractive index but will not alter any of the conclusions presented in the paper.

Comments on Figures.

Figure 1. The yellow labels in (b) are difficult to read suggest you use bold black and in (c).

Figure 4. Differences are difficult to see. Suggest you plot results as  $\text{Log}_{10}(S_{11})$ ?

Figure 10. In climate models heating rates are important. A measure of this is the emission, which is related to the co-albedo, so rather than plotting  $\omega_0$ , suggest you plot  $(1-\omega_0)$  as that is the more useful parameter in atmospheric energetics.