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Discussions

Interactive comment on "Volcanic ash infrared signature: realistic ash particle shapes compared to spherical ash particles" *by* A. Kylling et al.

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Response to interactive comments from Referee #3

We thank the referee for the careful reading of and constructive comments to our manuscript, quoted below in italic font. Our responses to the comments are shown in roman font.

Comments

1. *Only porous ash is considered (with the presence of vesicles). The conclusions of the paper therefore only apply to this type of ash. I would strongly suggest to change the title to reflect this, or alternatively expand the analysis to include non-vesicular ash types. I am not an expert in the topic, but the latter do not seem to be uncommon (e.g. Riley, C. M., W. I. Rose, and G. J. S. Bluth (2003), Quantitative shape measurements of distal volcanic ash, J. Geophys. Res., 108, 2504, doi:10.1029/2001JB000818, B10)*

   We only consider porous ash particle. Non-vesicular ash particles are beyond the scope of the present paper. To reflect this we suggest to change the title to "Volcanic ash infrared signature: porous non-spherical ash particle shapes compared to homogeneous spherical ash particles".

2. *In addition to this, a discussion is needed of how realistic the assumed particles are for those particles encountered in long-range transported plumes. How does wetting & coagulation processes affect the porosity and particle shape?*

   It is beyond the scope of the present paper to compare the vesicular shapes used with ground-based collected ash samples. However, please see our response to point 5 below.

3. *Using volume-equivalent spheres is a good idea, but I do not see the point of applying mixing rules. Instead I would find it more interesting and simpler to consider only volume-equivalence with the refractive index of the material.*

   Concerning volume-equivalent spheres please see our answer to comment p.8943 l.8 of Referee #1.

4. *For remote sensing, section 4 & 5 are the most important. However, the analysis lacks depth. In particular data is missing on the effect of the spherical assumption on the retrieved mass and radius. Only two examples are given for the mass*

and none for the radius. I would suggest color contour figures 'dbt vs BT 11', but this time showing the % difference of the retrieved mass/radius as a function of color for each pair (dbt, BT11). So BT11=259.3K, DBT=-5.1K, gets a color corresponding to 60%. So BT11=233.3K, DBT=-20.2K, gets a color corresponding to 80%. Here as the reference, you could take the average mass loading of all realistic ash shapes for that data point. The same type of plot can be made for the retrieved radius, which is not discussed in detail in this manuscript but also constitutes an important remote sensed quantity. Making these figures will allow to better more quantitative analyze the results and will make the current study more relevant for the remote sensing community.

We agree with the referee that section 4 and 5 are the most important for remote sensing. As such the two examples provided may not provide much depth. We thus suggest to replace the two examples (p.8947 l.14-p.8948 l6) with an ash mass retrieval example from a case measured by SEVIRI during the Eyjafjallajökull 2010 eruption as follows (including two new Figures and corresponding changes in the Conclusions. The new Figures are referenced in the comment as Fig. 1 (Fig. 7, left plot), Fig. 2 (Fig. 7, right plot) and Fig 3 (Fig. 8)):

" In the left plot of Fig. 7 is shown the ash mass loading retrieved from SEVIRI 10.8 and 12.0 μm channel measurements for a case during the Eyjafjallajökull 2010 eruption. The retrieval was made using an optimal estimation technique (Kylling, 2014, in preparation) and non-spherical ash particles with large vesicles were assumed. Furthermore, a monodisperse size distribution was used. For comparison retrievals were also made assuming mass-equivalent spheres. The difference between the ash mass loading when using the two types of model particles is shown in the right plot of Fig. 7. For all pixels the non-spherical particles give a larger ash mass loading compared to the mass-equivalent spheres. The difference in ash mass loading is plotted as a function of the mass loading for mass-equivalent spheres in Fig. 8. The difference between the ash mass load-

ings from the two different particle types is seen to increase nearly linearly with mass loading.

The uncertainty in the total mass of the ash cloud due to the assumption of particle shape and the treatment of porosity may be compared with the uncertainties in total mass arising from the lack of knowledge in other contributing factors (surface temperature, surface emissivity, plume geometry and altitude, aerosol type, atmospheric water vapor). Corradini et al. (2008) have estimated that typical uncertainty in total mass estimates due to these other factors are on the order of 40%. The total mass for the case in Fig. 7 retrieved with non-spherical ash model particles (mass-equivalent spheres) is 3.47e+08 kg (2.48e+08 kg). Mass-equivalent spheres thus underestimate the total mass by about 30%. The particle shape is thus as important as the other, previously considered factors. Assuming independent uncertainties the total uncertainty in the total mass is given by the square root of the sum of the squared uncertainties. Adding the uncertainty due to shape to the other sources of uncertainty, the uncertainty of the total mass increases from 40% to about 50%. "

5. *Please add also some scanning-electron microscope images of real volcanic ash particles for comparison*

   We do not have available scanning-electron-microscope images of real ash particles that could be added to Fig. 1. However, we suggest to add the following to the Introduction, p.8940 l.4:

   "Scanning-electron-microscope images of volcanic ash particles show the highly irregular shapes of the particles (see for example Riley et al., 2003; Muñoz et al., 2004; Schumann et al., 2011; Weber et al., 2012; Genareau et al., 2013). The shapes may be divided into three wide categories: vesicular, non-vesicular and miscellaneous shapes (Riley et al., 2003). Vesicular shapes may be present up to hundreds of km from the volcano (Muñoz et al., 2004). For the Eyjafjallajökull 2010 eruption, vesicular shapes were present close to the volcano (about 50 km), while non-vesicular shapes appeared to be dominant thousands of kilometers away from the vent (Schumann et al., 2011; Weber et al., 2012)."

6. *What is the particle size here? How was it calculated for the realistic ash shapes? Does one abscissa refer to one 'equivalent' particle (with different Rm, Rv, etc..?) or does it refer to different particles such that Rm = Rv = ?*

   Particle size in Figs. 2 to 6 is mass-equivalent radius. To clarify mass-equivalent radius has been adopted in all Figures.

7. *The red lines in Fig 2 and Fig 3 are almost identical, can you comment on this?*

   To further discuss the red lines in Figs. 2 and 3, we suggest to add the following text after l.19, p.8944:

   " For the non-spherical particles the differences between the various shapes increases with increasing mass-equivalent radius. The variation in the optical properties with shape is largest for the extinction and scattering efficiences and significantly smaller for the single scattering albedo and the asymmetry parameter. The differences in the optical properties between non-spherical particles with large and small vesicles (red lines in Figs. 2 and 3) are small. "

8. *Please expand the legend, currently it is absolutely unclear. Also, there seems to be more than 4 red curves.*

   Fig. 4 (and 6) has been simplified such that all lines are clearly labelled and distinguishable.