Atmospheric
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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 #2

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.

General comments

1. *The premise that for spherical ash particles the detection (then the retrieval) is possible only for radii below 5 μm is not generally true. Such a detection limit depends in particular on ash optical properties then on ash refractive index and particle size distribution. Different authors (also cited in the paper) showed the possibility to retrieve ash parameters (AOD, effective radius and mass) until 10 μm.*

   Wen and Rose (1994) showed and stated that for spherical andesite particles and a monodisperse size distribution the radius of the particles have to be less then 5 μm to give negative brightness temperature differences. For other ash optical properties/composition and size distributions this limit will be different. Other authors have shown the possibility to retrieve larger effective particle radii. They have then typically used a fairly broad size distribution which gives large effective radii compared to the monodisperse size distribution, which has zero variance. However, of the various particles in the size distribution it is the particles with radii smaller than 5 μm (assuming they are of andesite) that give the negative dBT. The particles with radii > 5 μm contribute to the mass and the effective radius, but very little to the dBT (for a given particle type and cloud and surface temperature).

   To clarify this we have re-formulated p.8938 l.18-20

2. *The computation of the bell-shaped curves (dBT vs BT11), needed to define the ash detection limit and used to compute the ash parameters, is one of the key point of this work. Some clarifications are necessary on how the brightness temperatures have been computed. The SEVIRI response functions centered around 10.8 and 12 μm varies between approximately 10 and 13 μm but the ash optical properties are obtained only for the fixed wavelength of 11 and 12 μm.*

The calculations were originally performed at 11.0 and 12.0 μm. We have replaced the 11.0 μm results with results for 10.8 μm throughout the paper as 10.8 and 12.0 μm are representative of the central wavelengths of the SEVIRI channels 9 and 10. This approach has been explained in the revised manuscript. Please see specific comments below.

3. *Some figures should be improved because the lines result totally indistinguishable.*

We have improved Figs. 4 and 6 such that indistinguishable lines are no longer present.

Specific comments:

- *p.8938 r.18-20. "For spherical ash particles the radii have to be below 5 μm to give a negative brightness temperature difference (Wen and Rose, 1994, using monodispersed particle distributions)." This sentence is not generally true. The upper limit of the detection is function of different variables as in particular the ash optical properties (i.e. the ash refractive index and the size distribution) but also the volcanic cloud geometry (altitude and thickness) and the instrument response function. Many authors showed the possibility to retrieve the ash particles effective radii until at least 10 μm (see for example, Prata et al., 2001, Yu et al., 2002, Corradini et al., 2008). In these papers the bell-shaped curves have been computed by considering different ash refractive indexes (andesite-Pollack, pumice-Volz) and instrument response functions (MODIS, AVHRR). Change "radii" with "effective radii"*

Please see our response to General comments #1 above.

- p.8939 r.11-13. *"For a refractive index with a larger imaginary part (larger absorption), the electromagnetic field will not penetrate that far into the particle." Please clarify this sentence.*

<center>C4183</center>

Please see our response to referee #1 who had a similar comment for the same sentence.

- p.8939 r.18-29. *" . . . while infrared (IR) detectors, such as the Spinning Enhanced Visible and Infrared Imager (SEVIRI), measure the radiation emitted by the Earth's surface and atmosphere." Together with SEVIRI, also MODIS, AVHRR and IASI should be cited. All these satellite instruments are used for the ash retrievals in the TIR spectral range.*

Mentioning of MODIS, AVHRR and IASI have been included as suggested.

- p.8942 r.20. *" . . . for 10 sizes of 1, 2,. . . , 10 μm, and for 2 IR wavelengths, 11 and 12 μm". What does "size" mean? Is it the effective radius? Which refractive index has been used for these computations? Andesite?*

By size is meant the mass equivalent radius. In the text we have replaced "sizes" by "mass equivalent radii". The andesite refractive index from Pollack et al. (1973) was used.

- p.8944 r.8. *" . . . for particle size larger than . . .". As above, what does "size" mean?*

"particle sizes" has been replaced by "mass-equivalent particle radii".

- p.8944 r.14-15. *"The asymmetry parameter is quite insensitive to the shape assumptions, which is surprising." A deeper discussion on that sentence is required. Have the authors an explanation of such a result?*

Please see our response to referee #1 who had a similar comment.

- p.8944 r.15-19. *"Nevertheless, for thermal emission the phase function is not important. It will play a role when scattering is involved, and, as shown in the third row of Figs. 2 and 3, the single scattering albedo is sufficiently large to make scattering effects have an impact for particles larger than about 2 μm."*

<center>C4184</center>

This sentence is not clear to me. It states that for thermal emission the phase function is not important. But it play a role when the scattering is involved, then for particle larger than about 2 μm that are the particles interested in the TIR retrievals. Please clarify.

Please see our response to referee #1 who had a similar comment.

- p.8944 r.20-21. *"For discrimination of volcanic ash from other atmospheric constituents the ratio of the extinction coefficients at 11 and 12 μm is of importance." Such statement is not obvious. Please clarify the sentence with a small description of the link between the extinction coefficient and the TOA radiance (then brightness temperature) to understand why if this ratio is positive the BTD should be negative.*

Please see our response to referee #1 who had a similar comment.

- p.8945 r.12-14. *"Brightness temperatures were calculated for the 11.0 and 12.0 μm (BT11 and BT12, respectively) channels of SEVIRI for various ash optical depths and particle sizes." The SEVIRI channels used for the BTD computation are centered around 10.8 and 12 μm. Please substitute 11 with 10.8. More, the brightness temperatures are computed for the two SEVIRI response functions (centered at 10.8 and 12 μm) that vary approximately between 10 and 13 μm, but the ash optical properties are computed only at the fixed wavelength of 11 and 12 μm (see comment above). Please clarify. Change "particle sizes" with "particle effective radii".*

We have redone all calculations for 10.8 μm and replaced Figures 2-6 with 10.8 μm results. We suggest to change the text as follows:

" Brightness temperatures were calculated for wavelenghts 10.8 and 12.0 μm ($T_{10.8}$ and T_{12}, respectively), representative for the central wavelengths for channels 9 and 10 of SEVIRI, for various ash optical depths and mass-equivalent particle radii. "

- p.8945 r.22. *"The upper left plot is similar to those used to visualize the retrieval of ash mass loading and effective radius from BT11 and BT12 measurements under the assumption of spherical ash particles (Wen and Rose, 1994; Prata and Prata, 2012)." I think there are significant differences between this plot and the curves published in Wen and Rose 1994 and Prata and Prata 2012. The first is the solid line for effective radii equal to 2 μm that, in Figure 5, is too close to the curve of effective radius equal to 1 μm, and the second is the detection limit that can be derived from the plots. The bell-shaped curves in Figure 5 indicate that such a detection limit is around 5 μm, while in the paper of Prata and Prata (that uses the same response functions and refractive index) is certainly higher than 8 μm. I think that the RTM simulations should be checked. In the introduction on RTM simulations (chapter 3) the authors stated that they use the DISORT routine. How many streams do you use to take into account the multiple scattering?*

The word similar was used to describe the similarity between our Fig. 5 (upper left plot) and those of Wen and Rose (1994) and Prata and Prata (2012) on purpose. A careful comparison of Fig. 2 in Wen and Rose (1994) and of Fig. 2 Prata and Prata (2012) reveals that, in the former, ΔT has a minimum for an ash cloud optical depth of about 1.5, while in the latter the minimum is at an optical depth of about 0.7. This is most likely due to differences in viewing geometry. However, the viewing geometry is not specified in the papers, thus making it hard to reproduce these results. Other differences are caused by different ash cloud and surface temperatures and particle size distributions. We have redone our calculations using 10.8 μm instead of 11μm. Our Fig. 5 (upper left plot) now resembles closer Fig. 2 of Wen and Rose (1994). Concerning the detection limit of 5 versus 8 μm, please see our reply to the first general comment.

DISORT was run with 16 streams which is considered sufficient for calculation of radiances for smoothly varying phase functions. This information has been added to the manuscript.

- p.8947 r.10. *Add the description of the term tau(lambda).*

  The following explanation have been added to sentence in l.10: "τ is the optical depth a wavelength λ".

- p.8947 r.11. *substitute "radius" with "effective radius"*

  "radius" changed to "effective radius" as suggested.

- p.8947 r.10-27. *This part is a bit confused. At first the ash retrieval differences are computed by considering "the mass-equivalent sphere model and the ash large vesicle model" (r. 15-16), then the "effect of particle shape may be quantified comparing nonspherical particles and volume-equivalent spherical particles" (r. 20-21), and finally the "difference between the mass loading retrieved with mass-equivalent spherical particles and porous ash particles may be compared with the uncertainty arising from lack of knowledge of other factors" (r.23-25). Please clarify.*

  This section has been completely rewritten with a new example. Please also see our answer to comment 4 by Referee #3.

- p.8947 r.21. *Substitute "BT12" with "dBT".*

  This section has been completely rewritten with a new example.

- p.8947 r.5-6. *" . . . the total mass error estimate, will increase the total mass error estimate to 45-50 %." Is the total error computed by considering the 25% of ash mass loading difference found by comparing the "non-spherical particles and volumeequivalent spherical particles" (r. 20-21)? Maybe the total error would be more representative if computed by comparing the ash retrieval obtained by mass-equivalent spherical particles and the non-spherical particles instead of the volume-equivalent spherical particles vs non-spherical particles.*

C4187

  This section has been completely rewritten with a new example. The total uncertainty in the mass is now obtained by comparing mass-equivalent spheres and non-spherical particles. See also answer to comment 4 by Referee #3.

- Figure 4 and 6. *many of the lines are completely indistinguishable each other. Please simplify the plots.*

  Both figures have been simplified.