Response to interactive comments from Referee #2

The referee is thanked for the careful reading of and constructive comments to the manuscript. The referee's comments are repeated below in italic font. The responses to the comments are shown in roman font.

Comments

- *p.1, "Introduction": Clarify if the ice cloud origin is volcanic. If yes, discuss briefly the ice formation mechanism and introduce the corresponding bibliography (ex.: Rose et al., 2nd Int. Conf. on Volcanic Ash and Aviation Safety, 2004; Durant et al., JGR, 2008).*

  The introduction has been rewritten and ice in volcanic clouds discussed, including referencing of the literature above and other papers.

- *p.2, r.27: Mt. Kelud is placed near the Equator and, in this region, the water vapour columnar abundance is in general high. As shown by different authors (Prata and Grant, Q. J. R. Meteorol. Soc. 2001; Corradini et al., 2008), the water vapour radiative signal can counteract, and in some cases delete, the ash signal. Could, the atmospheric water vapour, be the reason why the AVHRR/3 system is not able to detect the volcanic ash on 15 February? Has the author applied a correction to take into account of this effect?*

  No correction for water vapour has been applied to the AVHRR/3 brightness temperature differences (BTD) shown in the left panels of Figs. 1 and 2 of the manuscript. Yu et al. (2002) presented a scheme for water vapour correction of the BTD. The water vapour is mostly concentrated in the lower troposphere. Thus the correction is largest when the ash cloud is semi-transparent and no underlying ice or liquid water cloud obscures the surface. This behaviour is also demonstrated in Fig. 8 of Yu et al. (2002). Applying the correction from Yu et al. (2002) to the AVHRR/3 data gives the water vapour corrected BTDs shown in Fig. B1. In Fig. B1 the contour line is set at -1.0 K to avoid too many false positives. For the 14 Feb image (left panel, Fig. B1) the area deteceted as ash increases slightly compared to the left panel in Fig. 1 of the manuscript, but a few false positives are also included below 16°S. For 15 Feb (right panel, Fig. B1) the areas below the detection limit (bluish colors) are clearly not ash.

  The following has been added to section 3.1:

  As shown by for example Yu et al. (2002), tropospheric water vapour may increase the BTD such that ash clouds are not identified. Yu et al. (2002) devised a scheme for correction for water vapour absorption. Ash shown in their Fig. 8, the correction is largest for pixels with transparent ash cloud and no underlying ice and liquid water clouds. The AVHRR/3 scenes presented in the left panels of Figs. 1 and 2 are inhomogeneous with clouds of variable optical thickness at different altitudes.

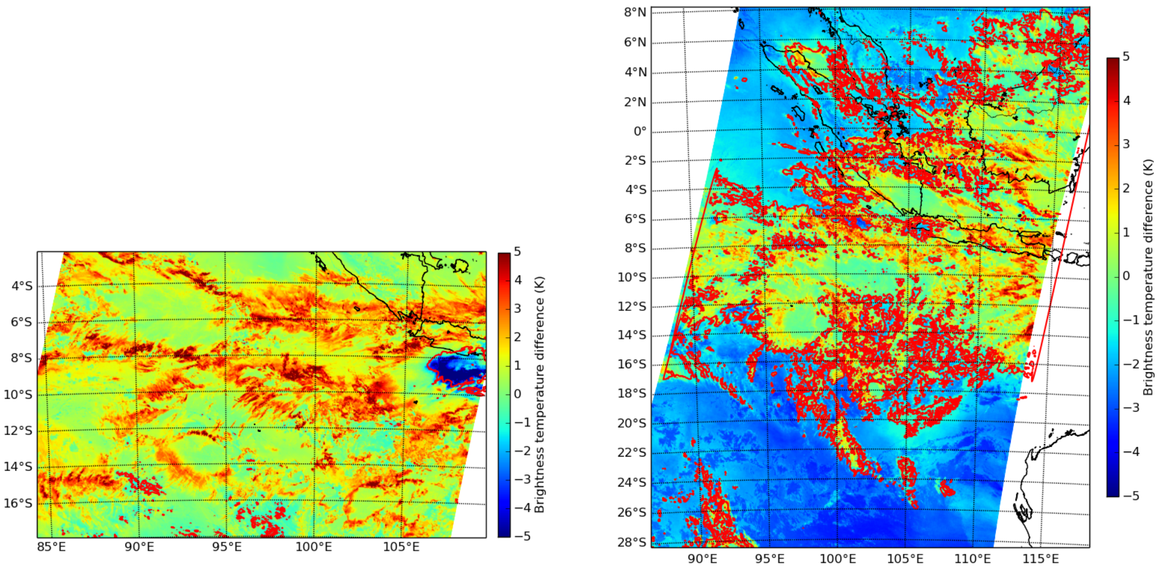

Figure B1: (Left panel) The water vapour corrected brightness temperature difference between AVHRR/3 channels 4 and 5 ($BTD_A = BT_4 - BT_5$). The contour line (red) is at -1.0 K. To be compared with left panel, Fig. 1 of the manuscript. Data from 14 Feb 2014, 0253 UTC. (Right panel) Similar to left panel, but data from 15 Feb 2014, 0229-0235 UTC. To be compared with left panel, Fig. 1 of the manuscript. Note that the color scale is different in this figure and the left panels of Figs. 1 and 2.

The presence of scattered high altitude clouds masks the radiation emitted from the surface. Including water vapour absorption correction (not shown) introduces a large number of false positives. It has hence not been included.

- *p.3, Figure 1: Substitute "plot" with "panel".*

  Change made as suggested. In addition "plot" has been replaced with "panel" throughout the manuscript.

- *p3., r.15-16: What it is not so clear to me is why the 1097.25 cm-1 channel is considered. This channel is "little affected" by the SO2 (as stated by the author). If the aim is to avoid the SO2 influence, why a channel outside the SO2 signature has not been considered? For example a channel around 1070 cm-1.*

  A channel at around 1070 cm^{-1} is within the ozone absorption band. To clarify this the sentence "The channel at 1097.25 cm^{-1} is little affected by SO_2 ν_1 absorption" has been changed to "The channel at 1097.25 cm^{-1} is little affected by SO_2 ν_1 absorption and outside the ozone absorption band between 1000 and 1080 cm^{-1}."

- *p.3, r.18-19; p.4, r.1-2: The simulations realized to compute BTDI for different SO2 amounts, give the values of -0.31, -0.99 and -0.47 for 0.13, 10 and 100 DU respectively. Why the BTDI values are not monotonic (growing the SO2 amounts)?*

There is an error in the manuscript. The background BTD_I should be -1.05. This has been corrected.

- *p.4, Figure 2: Substitute "plot" with "panel".*

  Change made as suggested. In addition "plot" has been replaced with "panel" throughout the manuscript.

- *p.3, r.15: Insert "," between "channel" and "radiative".*

  Change made as suggested.

- *p4., r.4-6: This sentence is not clear to me. What does it mean that "using the 1097.25 cm1 channel instead of the 1168.25 cm-1 channel implies that the wavelength dependence of the refractive index of water ice may have an effect"? The refractive index is higher (which part?) at 1097.25 cm1 instead of 1168.25 cm-1? Could you plot the real and imaginary parts of the refractive index for this wavelength range? Moreover, also the water droplets should have the same effect, then also these clouds could affect the volcanic ash cloud detection.*

  The real and imaginary parts of the refractive index for ice are shown in Fig. B2. Between 1050 and 1250 cm^{-1} the real part increases monotonically. The imaginary

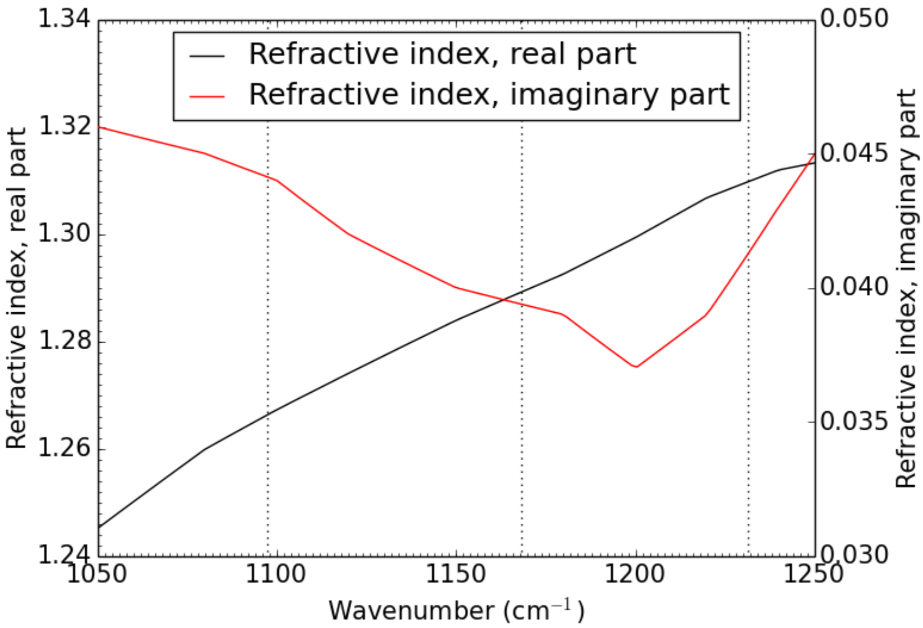

Figure B2: The real and imaginary parts of ice as a function of wavenumber. The dotted vertical lines are at 1097.25, 1168.25, and 1231.5 cm^{-1}.

part decreases between 1050 and 1200.5 cm^{-1}, has a minimum at 1200.5 cm^{-1} before it increases. When using wavenumber pairs for BTD_I that are further apart the wavelength dependence of the optical properties other atmospheric constituents, here ice clouds, may increase the impact of the constituent. The effect of ice clouds on the BTD_I was thus quantified and presented in the right panel of Fig. 3 of the manuscript. The text of the manuscript has been changed to clarify this.

Water droplets may certainly also affect the retrieval. This is discussed in the second paragraph of the **Discussion** section.

- *p.4, r.8-12: Being 1.5 K the BTDI threshold over which the pixels are certainly affected by the presence of volcanic ash, the volcanic ash area extent, shown in Figure 1 and 2 (right panel), represent a sort of 'minimum' area affected by volcanic ash. Minimum because if the ice content is greater than 0.1g/cm3, the BTDI threshold should be lower, than more pixels could satisfy the condition. Is it correct? Please clarify.*

  In Fig. B3 is shown the area identified as ash if the BTD_I detection limit is set 0.5 K used by Clarisse et al. (2010). Clearly some ice clouds are wrongly identified as ash, thus justifying the more conservative 1.5 K limit based on the results presented in the right panel of Fig. 3 in the manuscript. This choice represents a sort of

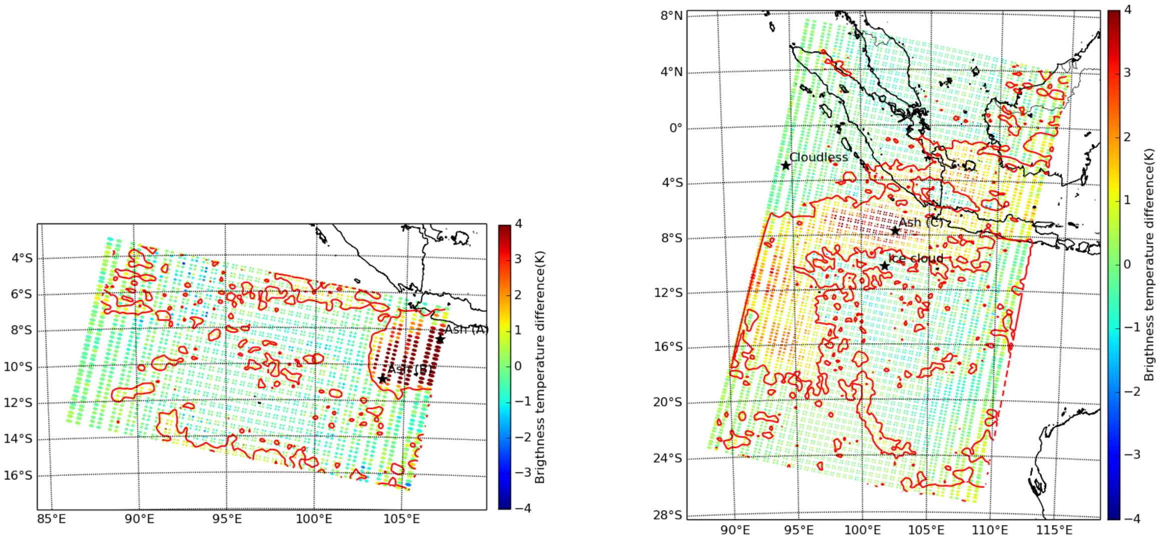

Figure B3: (Left panel) The 1231.5-1097.25 cm^{-1} brightness temperature difference from IASI/Metop-A spectra. The contour line is at 0.5 K. Data from 14 Feb 2014, 0253 UTC. To be compared with right panel, Fig. 1 of the manuscript. (Right panel) Similar to left panel, but data from 15 Feb 2014, 0229-0235 UTC. To be compared with right panel, Fig. 2 of the manuscript.

  'minimum' area affected by ash. This has been clarified in the text.

- *p.5, Caption of Figure 3: Insert the description of the two dashed vertical lines.*

  A description of the two dashed vertical lines have been inserted.

- *p.5, Caption of Table 1: Delete "." after "BT4-BT5". The BTDA values are in column 8. Insert the "reff" definition.*

  The "." has been deleted, "column 7" has been corrrected to "column 8", and r_{eff} has been defined.

- *p.6, r.10: Which surface temperature has been used for the simulations of the IASI spectra?*

  The same data source was used for the surface temperature as for the atmospheric profiles. This has been clarified in the text.

- *p.9, r.3: The "magenta" line seems "green" in Figure 5 right plot.*

  The colour of the line has been changed from magenta to green. The text has been updated accordingly.

- *p.9, r. 19-20: From Figure 4, left plot: the BT spectra increase above 1200 cm-1 only for Ash (A). For Ash (B) and Ash (C) it decrease.*

  This sentence is not clear. What is meant is that for the ash spectra the brightness temperature increase with increasing wavenumber for the channels not affected by gaseous absorption. This has been clarified in the text.

- *p.10, Figure 6: The brown lines can be confused with the red lines. Could you change the color from brown to green?*

  Change made as suggested.

- *p.11, r.7: Could you please insert comments on the results shown in Figure 8 and 9? In particular emphasizing the differences between the two days.*

  A discussion of Figs. 8 and 9 have been included.

Bibliography

Clarisse, L., Hurtmans, D., Prata, A. J., Karagulian, F., Clerbaux, C., Maziére, M. D., and Coheur, P.-F.: Retrieving radius, concentration, optical depth, and mass of different types of aerosols from high-resolution infrared nadir spectra, Appl. Opt., 49, 3713–3722, 2010.

Yu, T., Rose, W. I., and Prata, A. J.: Atmospheric correction for satellite-based volcanic ash mapping and retrievals using ”split window” IR data from GOES and AVHRR, Journal of Geophysical Research: Atmospheres, 107, AAC 10–1–AAC 10–19, doi: 10.1029/2001JD000706, URL http://dx.doi.org/10.1029/2001JD000706, 2002.