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Atmospheric Chemistry and Physics Discussions

Interactive comment on "Estimation of the vertical profile of sulfur dioxide injection into theatmosphere by a volcanic eruption using satellite column measurements and inverse transport modeling" *by* S. Eckhardt et al.

S. Eckhardt et al.

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We thank referee 2 for the careful reading of and helpful comments on our manuscript. In the following, we address the comments point-by-point by repeating the reviewer's text in italic letters, followed by our response in normal letters.

Abstract: indicate that Jebel at Tair is in Yemen.

Done.

Abstract, line 17: not all the aerosol observed by CALIPSO was stratospheric (also see later comment on Figures).

Agreed. We have removed the word “stratospheric” in this place.

Abstract (and throughout the ms): I think ’a priori’ should be in italics to distinguish it from the surrounding text.

According to the ACP guidelines, a priori should be not italicized.

http://www.atmospheric-chemistry-and-physics.net/submission/manuscript_preparation.html says: Non-English Words and Phrases: Foreign words that have not come into general use are italicized. Words, phrases and abbreviations referenced in the Webster’s are not italicized. For example, “et al., cf., e.g., a priori, in situ, bremsstrahlung, eigenvalues, should not be italicized.

P3763, line 7: suggest replacing ’mineral’ with ’silicate’.

Done.

P3763, line 10: non-explosive volcanic eruptions can actually send plumes to upper tropospheric altitudes, e.g., the 1984 eruption of Mauna Loa (Hawaii) reached 10-11 km. Passive or quiescent volcanic degassing occurs at lower altitudes.

We have rephrased this to read: ’For passive degassing, the injection height is on the order of hundreds of meters and is dominated by thermal plume rise, whereas explosive eruptions have a substantial initial exit velocity.’

P3764: the sensor acronyms (SEVIRI, OMI etc) should be defined at their first occurrence in the ms.

We agree and have changed that accordingly.

P3765, line 3: ’..proxy for volcanic ash’

Changed.

P3765, line 10: insert ’(Yemen)’ after Jebel at Tair.

Done.

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P3765, section 2: the volcano seems to be somewhat displaced from the actual mouth of the Red Sea.

We have changed “at" to “near"

P3765, line 19: is “Yemeniti" an English word?

We have changed this to read “Yemeni"

P3765, line 27: UT and local time are mixed up here.

This has been corrected such that all times are in UT now.

P3766, line 26: please briefly explain what the WMO standard definition of the tropopause is. Using the temperature profiles provided in Fig. 2, one would probably place it higher, at 17 km. This is important as it determines whether the cloud did indeed penetrate the stratosphere or not. It would also be useful to provide (in Fig. 2) the wind profiles (if available) from the radiosonde sounding at Abha (Saudi Arabia), for comparison with the ECMWF profile.

According to the WMO, the tropopause is “the lowest level at which the lapse rate decreases to 2 degree /km or less, provided that the average lapse rate between this level and all higher levels within 2 km does not exceed 2 degree C/km." The tropopause in the close-by radiosounding at Abha is only slightly higher than the ECMWF tropopause. The altitude of 17 km that the reviewer is referring to is already above the cold point in the temperature profile (16.9 km), which is a clearly identifiable feature in the sounding that may have attracted the reviewer’s eye but is clearly located above the thermal tropopause. We added the tropopause definition to the paper.

The fraction of the emissions injected into the stratosphere is sensitive to the exact height of the tropopause. However, according to modern concepts of the tropopause region, there is no clear separation between the troposphere and the stratosphere. In fact, the region around the tropopause (both below and above) is often rather loosely referred to as the tropopause layer. Most of the material went into this tropopause

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layer, be it just underneath or above the tropopause.

We modified figure 2 and now also included the wind and temperature profile from a radio sounding at Abha.

P3767, line 10: at the end of this paragraph please specify the time range used to represent the "main explosive eruption."

Yes, we specified the time in the text.

P3768, line 1: "A-Train" may require a little more explanation.

We added a reference describing the A-Train. NASA, 2003, Formation Flying: The Afternoon "A-Train" Satellite Constellation, NASA Fact sheet, FS-2003-1-053-GSFC, GSFC, Greenbelt, Maryland, USA. Available from: http://www.gsfc.nasa.gov.

P3768, line 14: V003 OMI SO_2 data are now available from the NASA DAAC. If V002 data were used for the analysis, this should be stated.

We have stated in the paper that V002 was used.

P3768, line 25: capitalize "IFOV"?

Done.

P3769: the interference of water vapor on the IR SO_2 retrievals is discussed here. wondered if there is any information on the expected vertical water vapor distribution in the ECMWF data that could be used to assess the precision of the IR retrievals?

We don't think the ECMWF data would pick up any water vapour anomaly in the plume. The water vapor in the plume would be more significant, but retrieving that is beyond the scope of this study.

P3770, line 26: should be 532 nm.

Thanks, we changed 53 to 532 nm.

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P3771, line 6: the eruption was of Soufriere Hills volcano, on Montserrat.

Changed.

P3772: Here there is a discussion of the differences in SO_2 vertical columns retrieved by OMI, SEVIRI and AIRS. Presumably this is at least partly due to the variable sensitivity of the instruments to the altitude of the SO_2, but the discussion of height sensitivity appears later (section 3.6). I think that the discussion of height sensitivity should occur before the measurement comparison in section 3.5. Also, the SO_2 altitude used in the AIRS and SEVIRI retrievals should be clearly stated it doesn8217;t seem to be at present.

We added height information concerning the retrieval scheme in the section 3.2.: The SEVIRI retrieval scheme assumed the SO_2 had reached a height of 16 km.

And in Section 3.3 as well: As for the SEVIRI retrieval, it was assumed that the SO_2 had reached an altitude of 16 km.

P3772, line 18: deposition (wet or dry) is unlikely to be significant for a cloud at this altitude on a timescale of a few days.

It is certainly true that neither dry nor wet deposition were significant for the stratospheric part of the plume, but parts of the plume, which were released at lower altitude have undergone some deposition. We included deposition processes for completeness, even though they were not critically important for our results.

P3774, line 19: check that the correct OMI averaging kernel from Yang et al. (2007) has been used for this case, with SO_2 distributed between 15-20 km (Umkehr layer 3). Note that this does not correspond to a "clear atmosphere" as stated in the ms but to an atmosphere perturbed by SO_2.

This has been checked. We did use the curve for Umkehr layer 1 and should have used layer 3, but on inspection of the curves it looks like the curve for layer 3 is just a scaled version of that for layer 1. So this should make no difference at all.

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We changed the sentence on p3774, line 20 to read: "... for a cloud free atmosphere with SO_2 uniformly distributed in Umkehr layer 3 as illustrated in Fig. 5."

P3775, line 14: again, dry deposition seems irrelevant for a volcanic cloud in the UTLS, but I suppose there is no harm in including it in the model. But how much SO_2 is removed by this process in the model?

According to the model 1% of the total mass is removed after 3 days. So it is indeed a small contribution. We added the number and following statement in the text:

The model shows that only 1% of the tracer is removed by dry deposition after 3 days, so chemical conversion plays a greater role.

P3776, line 15: here and elsewhere the authors use "prior" where it appears that they mean "a priori" " please check and replace if necessary.

It is probably a too sloppy wording, we substituted all 'prior' by 'a priori'.

P3776, line 23: "squared deviations between model and observations."? P3777, line 11: "done by minimizing.." P3777, line 14: "misfit between model and observations.."? P3778, line 15: "all three satellite data sets.." (delete "the") P3779, line 14: replace "satellite" with "sensor8217;8216;. P3779, line 20: delete "they8217;8216;. P3781, line 11: replace "during the hours8217;8216; with "from 10-24 hours after the eruption.8217;8216;

All 7 points were changed according to the reviewer8217;s suggestion.

P3781, line 13: there is also a prominent peak at 9 km (larger than the 5 km peak). I am not sure of the significance of the minor peaks in the inversion profile below 15 km, as they are dependent on the wind profile and hence on the accuracy of the ECMWF model winds.

The whole inversion depends on the accuracy of the ECMWF model winds. This is true both for the higher-altitude peaks but also for the secondary lower tropospheric

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peaks.Though we admit that we have no proof for these minor peaks, they are consistent with the layered atmospheric stability structure as shown by profiles of the Brunt-Vaisala frequency derived from the part B of the radiosounding in Abha and also soundings in Jeddah (not included in the paper). The 5 km peak is larger than the 9 km peak in the SEVIRI-based inversions and it is co-located with a layer of high stability related to the trade-wind inversion.

P3781, line 14: move the "10%" to the next line, before "above the cold point8217;8216;

Done.

P3781, line 20: please clarify what indicates the layers of enhanced stability in the temperature profile.

See answer to previous question.

P3784, line 14: replace "a too slow" with "insufficiently rapid"?

We replaced "too slow8217;8216; by "insufficiently rapid8217;8216;.

P3787, line 2-3: a comment here by the authors suggests that "some more text8217;8216; was due to be added. Perhaps a discussion of the lofting of sulfate aerosol to explain the location of the aerosol detected by CALIPSO at the top of the simulated volcanic plume.

We removed the remark, there is a discussion on this issue in the conclusions.

P3787, line 15: I think only OMI observed the SO_2 plume for more than a week.

We changed the text indicating it was just one instrument.

P3788, line 15: not all the aerosol observed by CALIPSO was stratospheric it was mostly upper tropospheric.

We agree, in 2 of the 3 shown plots the aerosols were in the upper troposphere and

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in one in the lower stratosphere. We changed the text to:On different days, CALIPSO observations showed thin veils of aerosol in the upper troposphere/lower stratosphere region that were well collocated with the FLEXPART plume.

P3789, line 5: as I mention above, I think the "real-time8217;8216; application is a stretch, at least using the aviation industry definition of real-time. The main constraint is the availability of the required satellite observations.

This is only partly true. Our method would work in 2 steps. Until the first satellite data are available we can do no prediction. But after they are available the emission profile can be calculated within minutes to a few hours and a prediction of the plume dispersion for the next few days could be made. This means from this time onwards, we do our prediction; it is a real-time application because it would show the actual position of the plume as well as a projection into the future.

We added text for clarifying this (see also reply to Reviewer 1)

Fig. 2: give the location (lat, lon) of the ECMWF profile. The criteria used to define the tropopause need clarification.

The location is the closest grid point to the position of the volcano (15.50 N,41.80E), which is 16 N and 42 E we clarified this in the text. For the tropopause definition see above.

Fig. 4: it8217;s a little difficult to distinguish the blue and black data points suggest using higher contrast colors.

We changed the blue points to empty circles.

Fig. 5: check that the correct curve is plotted for OMI.

Yes, we used the wrong curve, the one we should have used is a factor of .9 different. As we just use it for normalization it makes no difference for the calculations. However, we corrected the figure and changed the text, referring to Umkehr layer 3 instead of 1.

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Figs 9-11: check the magnitude of the CALIOP attenuated backscatter values as they seem too high (greater than 0.2) - CALIOP data I have seen have much lower values of attenuated backscatter (0.0001-0.001) for volcanic aerosol layers. Why does the tropopause altitude plotted in Figs. 9 and 11 show a sudden plunge at a certain latitude?

Yes, thanks, we made a mistake when converting the units. They are by a factor 1000 too high. We corrected the graphs.

The plunge is a feature known as the tropopause break, which exists near the subtropical jet.

Interactive comment on Atmos. Chem. Phys. Discuss., 8, 3761, 2008.