

Dear Editor,

Please find included in this document the two point-by-point replies to the reviewer reports and a list of changes. This list of changes includes changes following comments of the reviewers, in addition to some other minor changes which emerged during revision of the manuscript (these are marked yellow in the list of changes):

- In a few places the mention of 'the mean spectrum' was forgotten, we have added them where needed.
- We removed a speculative statement on the amount of SO<sub>2</sub> that ended up in the stratosphere.
- Following a recent paper on Nabro in ACPD (Fairlie, T. D.; Vernier, J.-P.; Natarajan, M. & Bedka, K. M. Dispersion of the Nabro volcanic plume and its relation to the Asian summer monsoon Atmospheric Chemistry and Physics Discussions, 2013, 13, 33177-33205) we think it is necessary and more precise to explicitly mention that it is the convective part of the transport which is debated. So we added in two places the extra word convective for clarity.
- In addition, also following the cited paper, we now have added a paragraph in the conclusion saying that the present paper doesn't answer the question whether the observed uplift was convective or isentropic, but that our observed vertical transport is consistent with isentropic flow and that a more quantitative approach is needed to determine whether it explains it completely. (see list of changes for the exact wording). We believe it is important to have a clear statement like that.

Thank you very much for your consideration.

Best regards,

Lieven Clarisse

# Replies to the comments of Reviewer #1

## General comments:

The paper by Clarisse et al. contains two major subjects. First, a new method for effective retrieval of SO<sub>2</sub> plume heights from IASI measurements is introduced and compared with external data, and, second, the evolution of SO<sub>2</sub> plume heights from the Nabro eruption is discussed. The presented work is a timely and valuable contribution which adds new data helping to understand this interesting event. Further the method seems to be well fitted for standard processing of huge amounts of data as in the case of the IASI instruments. My main comments are directed to a better understanding of the method itself, its limits and uncertainties:

We would like to thank the referee for his/her careful reading, review and useful questions and comments, which definitely helped to improve the paper. We have addressed all comments below and revised the manuscript where needed.

- It is mentioned that the altitude-resolution of SO<sub>2</sub> stems mainly from the interfering water-vapour lines (P31168 L20). How can it be explained then, that there is such a low sensitivity on the real atmospheric situation as stated on P31169 L28?

We did not observe large differences when we did the altitude retrieval using only one set of Jacobians, i.e. definitely not in the broad categorization low/mid/upper troposphere. We did not look in great detail in the low-mid tropospheric plumes, but differences were observed exceeding the +/- 2km uncertainty of the retrieval. We have therefore removed the sentence saying that the results were 'very similar' and also changed the next sentence on the recommendation for operational applications, which now reads: 'For operational applications Jacobians would need to be precalculated for such boxes and different time-periods of the year'

In addition, as we explain below, water vapour interference is not the only component responsible for the altitude sensitivity. Pressure and temperature dependence on the SO<sub>2</sub> line shapes also contributes. This also helps explaining the not-so-large dependence on the atmospheric state.

- On P31168 L18 it is mentioned that 'large differences in the Jacobians can be observed up to an altitude of 15 km'. Further, also in Fig. 1 the Z(h) functions are rather smooth, especially those for which the maximum is above 10 km (the blue curve). One would guess that this leads to a larger error in the height determination than suggested by the comparisons with CALIOP. Could you reason why this might not be the case?

This was indeed also surprising to us. One possible explanation is that the error on Z is very small (easily less than 10% for a few DU); and so while the curve appears to be smooth in a normalized graph, in absolute value it still offers enough resolution in practice.

This does not take away the fact that the resolution below 15 km is better, which we also demonstrate below with a forward simulation (see next point).

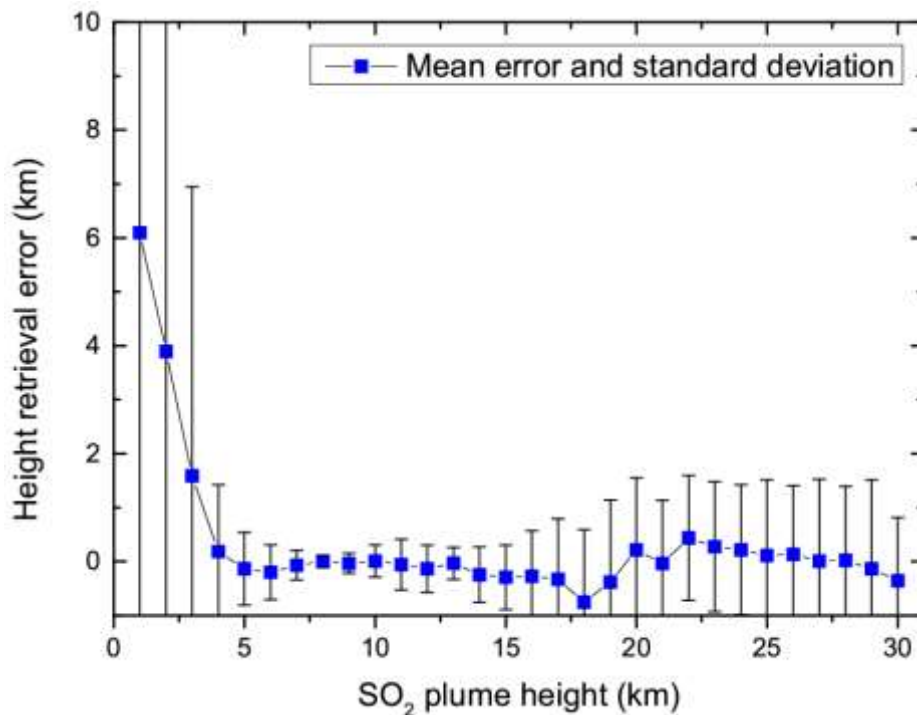
- Since in the stratosphere the water vapour is rather low, the altitude resolution of the method for stratospheric plumes (e.g. above 18 km in the tropics) should also be rather bad (if there is even any). Could you make any simulations to show that the method can resolve the altitude of plumes situated clearly above the tropical tropopause? Otherwise one could argue that stratospheric plumes cannot be resolved and even, might be put by the retrieval

to an altitude at or just below the tropopause (where a lot of the retrieved SO<sub>2</sub>-heights lie). Thus, can you really state from your observations how much of the early plume is directly injected into the stratosphere or is the method just not sensitive enough to make such a statement. This should be clearly expressed in the conclusions of the paper.

Thank you for suggesting testing the algorithm with simulations. We have now carried out such a simulation and discussed the results in the revised manuscript. The figure belonging to the discussion has also been reproduced here.

'To test the theoretical accuracy of this method for different altitudes, 10000 forward simulations of 5 DU SO<sub>2</sub> clouds between 1 and 30 km were carried out. To make the simulation as realistic as possible, spectral noise was added to these spectra. This noise was generated from the multivariate normal distribution with the mean bias and covariance matrix used for the quantitative SO<sub>2</sub> column retrievals (see end of this section). Calculating spectra in this way is a realistic way of simulating real observed spectra because biases in the forward model are removed, and because instrumental noise is added. However, note that the atmospheric parameters used in the simulation are the same as the ones which were used to construct the Jacobians. Using this method we hence obtain upper bounds on the accuracy of the algorithm.

The results are summarized in Fig. 2. As expected from the Z(h) profiles shown in Fig. 1, the best accuracy is achieved between 5 and 15 km with error bars below 500 meter. Below 3 km the tropical atmosphere is almost opaque in the spectral range of interest due to water vapour, and the algorithm therefore loses its accuracy drastically (a dryer atmosphere would allow to penetrate lower down). Above 18 km, the error bar is almost constant at around 1.5 km. At these altitudes, the water vapour column in the atmosphere is low, and the fact that such a good sensitivity is achieved is related to pressure and temperature dependence of the SO<sub>2</sub> lines (see also Clerbaux et al, Geophys. Res. Lett., 2008, 35, L22807). Although hard to see with the naked eye on apodized IASI spectrum, the simulation demonstrates that altitude information is contained in the spectrum even in the stratosphere.'



**Specific comments:**

P 31162 L 14 'Evidence is presented that emissions in the first 15 week of the eruption also contributed to the stratospheric sulfur input.': This sounds like direct emissions into the stratosphere. Perhaps add 'via slow ascent'.

We believe that the line below explains this sufficiently: 'This includes a second eruption between 15 and 17km on the 16th and continuous emissions in the mid-troposphere of which some were also entrained and lifted within the anticyclonic circulation.'

P 31165 L 27 'to retrieve vertically resolved SO<sub>2</sub> columns': Columns with vertical resolution seem inconsistent. Perhaps use 'profiles' or 'partial column amounts'.

Yes we agree. However, also a profile is not entirely correct in this context, since all SO<sub>2</sub> is assumed to be located in a narrow altitude band. We therefore replaced the word 'columns' by 'clouds' since this conveys better what is actually retrieved.

P 31167 L10 Eq. (2) and lines before:

Please clarify if  $x^{\wedge}$  here is not height-dependent, i.e. one number and not a vector.

This has now been clarified in the beginning of that section by explicitly referring to a total column retrieval.

P31169 L20 'using average atmospheric conditions':

Which input data have been used to determine these conditions?

These were calculated from the level 2 IASI data (from EUMETSAT) of several days in June 2011. This information has now been added in the manuscript.

P31168 L25: Do you need other Jacobians in case of clouds (I assume they look different since they shield the H<sub>2</sub>O-features from below) and if not, could you explain the reason?

P31170 L1 'covariance matrix S we used one million random IASI spectra': Has there been a selection with regard to cloud contamination? If not, why is it not necessary?

Clouds were not treated separately. As pointed out in the manuscript when the comparison is drawn with CALIPSO (where the location of clouds can be seen), the algorithm seems to perform no worse in the presence of meteorological clouds (below or above the plume),

The likely reason is that clouds have a broadband effect on the spectra, while in the spectral band of interest most of the spectral information on SO<sub>2</sub> and H<sub>2</sub>O is contained in sharper spectral feature originating from spectral lines. By including cloudy spectra in the covariance matrix, they become part of the spectral noise in the height/detection algorithm. This argument is made in the manuscript (end of page 31168, beginning 31169) In this context, see in also the discussion of clouds in Carboni, E.; Grainger, R.; Walker, J.; Dudhia, A. & Siddans, R. A new scheme for sulphur dioxide retrieval from IASI measurements: application to the Eyjafjallajökull eruption of April and May 2010 Atmos. Chem. Phys., 2012, 12, 11417-11434.

We have now added two sentences in the algorithm description to clarify that clouds are not treated separately (both for the height and SO<sub>2</sub> detection and the SO<sub>2</sub> column retrieval).

P31170 L5-10:

From the description of the quantitative column retrieval, the SO<sub>2</sub> column is retrieved as it would be situated only at the layer belonging to the previously retrieved maximum height. Is it then the case that only the Jacobians from these altitude are used? How does the retrieval

result depend on these Jacobians? How do the averaging Kernels of the result look like? Further, I assume that the retrieval is linear or do you use explicit forward calculations? In the first case: what is the error due to the linear fit? If an iterative fit is done, could you describe more in detail the forward-model and used input data (e.g. atmospheric profiles). Could you give in any case some error estimation?

The retrieval uses an (iterative non-linear) optimal estimation scheme (but with a generalized covariance matrix) as explained in the end of section 2. The forward model is fed collocated IASI L2 data (water and temperature profiles). These two facts are now explicitly mentioned in the manuscript.

As altitudes are assumed at the retrieval stage, it becomes a one-dimensional retrieval (with a scalar as an averaging kernel). For the vast majority of retrievals the choice of a prior is irrelevant, since the covariance matrix is chosen very large and since pixels are pre-filtered for having a large SO<sub>2</sub> signal.

Estimating errors from the retrieval is very difficult, since by far the most important error term comes from errors in the assumed altitude, for which the current scheme also does not explicitly quantifies the uncertainty (which is the reason why a comprehensive validation was offered for the retrieved altitudes). The error on the actual SO<sub>2</sub> retrieval, assuming perfect knowledge of the height is low (estimated below 25% for plumes above the lower troposphere and columns above 2 DU for a similar retrieval scheme presented in Carboni et al., ACP, 12, 11417–11434, 2012).

P31176 L13:

To get a better overview of how well the plume altitude fits with CALIOP aerosol height it would be good to show a summary of all matches from the single plots in form of a scatter-plot, like Fig. 10.

In preparation of the initial manuscript, this was attempted; however the manual attribution of many of CALIPSOs features makes this technically difficult. In addition, a plot like that would not represent the CALIPSO data independently, since IASI data is needed to locate the volcanic plumes.

P31177 L3:

Could you name a source for the MLS data and a reference?

A recent reference on MLS SO<sub>2</sub> does not seem to be available, however the official product description can be found at [https://mls.jpl.nasa.gov/data/v3-3\\_data\\_quality\\_document.pdf](https://mls.jpl.nasa.gov/data/v3-3_data_quality_document.pdf). We have now added a sentence with the origin of the data (in the caption of the relevant figure for clarity):

'MLS data is from the v3.3 EOS MLS Level2 which was downloaded from the NASA Goddard Space Flight Center, Data and Information Services Center (<http://disc.gsfc.nasa.gov/>).'

#### **Technical comments:**

P31166 L15 Eq (1) and further mathematical expressions:

The ACP convention is that for vectors bold italic fonts should be used. Could you change it everywhere in the manuscript.

Corrected

P31167 L20: 'residues' -> 'residuals'

Corrected

P 31174 L16 'east side': -> 'west side' (?)

Corrected

P31177 L7: 'height altitude Nabro plume' -> 'high altitude Nabro plume' (?)

Corrected

P31177 L17: 'becomes' -> 'become'

Corrected

P31185 Fig. 2: Could the position of the volcano be indicated more clearly.

Corrected

P31194 Fig. 11: Overlapping tick labels in middle row.

Corrected

## Replies to the comments of Reviewer #2

### General comments:

This is solid scientific contribution that sheds additional light on the transport of volcanic emissions during the NABRO eruption into the lower stratosphere. It contributes new insights that both compliment earlier papers on this eruption and enhance our understanding of troposphere-to-stratosphere transport in the tropics. In order to remove some existing ambiguities in this paper, I ask that the authors address the specific comments that follow.

We would like to thank the referee for his/her careful reading, review and useful comments which definitely helped to improve the paper. All suggestions have been followed in the revised manuscript.

### Specific comments:

Page 31163, lines 11-16: This sentence is too long and awkward – particularly the use of ‘markedly’

We have changed the original sentence to:

‘The OSIRIS/Odin limb sounder for instance measured its largest aerosol load since it was launched in 2001. Other instruments that witnessed this process include CALIOP/CALIPSO lidar (Sawamura et al.,2012;Bourassa et al.,2012;Vernier et al.,2013), a network of ground-based lidars (Sawamura et al.,2012;Uchino et al.,2012) and a CCD camera (Mateshvili et al.,2013).’

Page 31163, lines 27-28: Imprecise, recommended change: ‘offsetting global warming’ to ‘offsetting the radiative forcing of greenhouse gases’.

We agree and corrected this.

Page 31167, lines 15-17: ‘better than any forward model could ever do’? This is a very strong statement. Can you prove this? Do you actually think that you can anticipate any forward model that could ever be conceived?

The main idea of this statement is that real observations will always beat simulations since these always dependent on a number of assumptions and simplifications (e.g. discretizing the atmosphere in homogenous layers). We believe therefore that a statement like this is true by definition for traditional forward models. It is not however unimaginable that a forward model could be constructed which is fed statistical data of the observations it is simulating. To include this scenario we changed the sentence to ‘better than any *traditional* forward model could do’

Pages 31167-8: The use of ‘apparent column’ and ‘true column’ is somewhat confusing and imprecise. By ‘column’, I understand you to mean ‘a vertical profile of constituent concentrations’. So, is the ‘true column’ the actual concentrations and ‘apparent column’ an estimate of the actual concentrations? Regardless of the accuracy of my interpretation, some clarification is warranted.

Pages 31167-8: The distinction between ‘apparent column’ and ‘true column’ seems disingenuous (unless the interpretation in the previous comment is totally wrong). Any measurement is an estimate of the actual value and the estimates of ‘poor’ measurements only differ from ‘good’ estimates in magnitude of the error – not in the existence of error.

Please reformulate the discussion so that you explain why your method reduces error – not as a claim that your retrieve values are ‘true’.

Here, column represents the (total) amount of molecules per unit of surface.

Here ‘apparent column’ is the value obtained after a *linear retrieval using a fixed Jacobian*. This definition is given on page 31167 L7. The ‘*true column*’ is the value obtained after an iterative fit to cope with non-linearity. So the word ‘true’ indeed does not signify a retrieval without error.

In the revised manuscript we have therefore avoided the use of the expression “true columns”. In addition we have reformulated several passages for clarity:

- Page 31167 lines 6-8 now reads “The conditions of the retrieval, namely constant Jacobians  $K$  and linearity are usually not satisfied. The quantity  $x$  is therefore an apparent column which should be interpreted as a qualitative estimate of the column.”
- Page 31167 lines 17-18: We removed the word ‘true’
- Page 31167 lines 26-7 now reads: “Retrievals performed in this way, then yield quantitative estimates of the column amounts and heights, as opposed to the apparent columns discussed above.”

Pages 31169, line 25: Change ‘extend’ to ‘extent’

We removed this sentence now altogether following a comment of reviewer #1.

Pages 31170, line 17: Provide context for altitudes; e.g., ‘Displayed altitudes reach...’

Corrected

Pages 31170, line 18: Change ‘Central in’ to ‘Central to’

Corrected

Pages 31170, line 22: Change ‘either’ to ‘any’

Corrected

Pages 31171, line 25: Change ‘below 20°’ to ‘south of 20°’

Corrected

Pages 31172, lines 4-5: Change ‘conclusion from such data only’ to ‘conclusions from such data alone’

Corrected

Pages 31172, line 14: Please use a more meaningful phrase than ‘reveals an excellent match’ –for example –‘reveals that the trajectories capture important features of SO<sub>2</sub> transport’.

Corrected to ‘reveals that the trajectories match the retrieved SO<sub>2</sub> transport features’.

Pages 31176, line 11: Choose a more meaningful descriptor than ‘excellent match’



Pages 31176, lines 12-13: The phrase 'with agreement almost systematically below 2 km' is awkward and confusing. Do you intend to say something like 'altitude discrepancies are, for the most part, less than 2 km'?

We have reformulated this sentence now as 'Despite these limitations, altitude discrepancies between observed IASI retrieved SO<sub>2</sub> altitude and CALIOP aerosol measurements are for the most part, less than 2 km'.

Pages 31176, line 24: Again –'excellent'? This is a solid scientific paper why ruin it?

The sentence now reads 'The CALIOP data reveals that the performance of the algorithm for plumes located below meteorological clouds, is not any worse than in cloud free scenes.'

Pages 31177, line 3: Excellent! (just joking) Please change it.

Pages 31177, line 5: The standard deviation of the differences can't possibly be 0.1. The standard deviation can never be negative. I think you might mean that the bias is 0.1. From your plot I would guess that the standard deviation is closer to 1 km (maybe it's 1.3?). Also, a correlation of 0.68 is hardly 'excellent' when comparing two fields that should be identical. This corresponds to only 46% explained variance.

The notation in the original sentence 'with mean and standard deviation of the differences equal to  $-0.1 \pm 1.3\text{km}$ ' was meant to represent mean differences of -0.1 with a standard deviation of 1.3. When interpreting the correlation coefficient, one should keep in mind that there are uncertainties on both products, not just on the IASI height retrievals. The MLS SO<sub>2</sub> product has a vertical resolution around 3 km. As a test, we performed a numerical simulation where a reference altitude was drawn uniformly between 10 and 20 km and superimposed with Gaussian noise of 2 km (to represent the IASI) and 1.5 km (to represent MLS). The correlation coefficient between these two equals 0.73 (a value which can also be obtained analytically). Given the issues with collocation and the fact that IASI and MLS might be sounding different air masses in case of overlaying plumes, we therefore think that the 0.68 correlation coefficient is still very good and in line with the expectations.

We have now rewritten the sentence to make the notation more clear (and also got rid of the 'excellent'): 'Given the measurement uncertainties of both products, the plot reveals a good match between both instruments, with a mean bias of -0.1 km, a standard deviation of 1.3 km and a correlation coefficient of 0.68.'

Pages 31177, line 10: Change the phrase 'The agreement between the two instruments is very good' to something like 'The agreement between the two instruments is not as good as it is during the early days of the plume'.

Corrected, the full sentence now reads:

'The agreement between the two instruments is not as good as it is during the early days of the plume, especially in the parts where the aged higher altitude plume overlays fresher lower altitude plumes

## List of changes

Changes not suggested by the referees are marked in yellow.

- Abstract: We replaced 'It has been debated whether the anticyclone associated with Asian Summer Monsoon played a vital role in the vertical transport of the plume.' By the more precise 'It has been debated whether deep convection associated with the Asian Summer Monsoon anticyclone played a vital role in the vertical transport of the plume.'
- Page 31163, lines 11-16: We replaced 'Several instruments witnessed this process, markedly the OSIRIS/Odin limb sounder which measured its largest aerosol load since it was launched in 2001 but also the CALIOP/CALIPSO lidar (Sawamura et al.,2012;Bourassa et al.,2012;Vernier et al.,2013), a network of ground-based lidars (Sawamura et al.,2012;Uchino et al.,2012) and a CCD camera (Mateshvili et al.,2013). by 'The OSIRIS/Odin limb sounder for instance measured its largest aerosol load since it was launched in 2001'. Other instruments that witnessed this process include CALIOP/CALIPSO lidar (Sawamura et al.,2012;Bourassa et al.,2012;Vernier et al.,2013), a network of ground-based lidars (Sawamura et al.,2012;Uchino et al.,2012) and a CCD camera (Mateshvili et al.,2013).'
- Page 31163, lines 27-28: We replaced 'offsetting global warming' by 'offsetting the radiative forcing of greenhouse gases'.
- Page 31164, line 5: replace 'transport' by the more precise '(convective) transport'
- Page 31166, line 13-14: The sentence now reads 'Consider a spectral retrieval of a trace gas total column  $\hat{x}$  of the form (we assume that the background target columns  $x$  are negligible)'
- Page 31166, line 18: We added ' $\bar{y}$ ' to the formula (was erroneously omitted in the original manuscript)
- Page 31167, lines 15-17: We replaced 'better than any forward model could ever do' by 'better than any traditional forward model could do'
- Page 31167, lines 6-8: We replaced "It should be noted that the retrieved  $x$  is only an apparent column, and will deviate from the true column as the Jacobian  $K$  is taken constant and as the linearity condition is usually not satisfied." by "The conditions of the retrieval, namely constant Jacobians  $K$  and linearity are usually not satisfied. The quantity  $x$  is therefore an apparent column which should be interpreted as a qualitative estimate of the column. "
- Page 31167, lines 17-18: We removed the word 'true'
- Page 31167, line 20: We replaced 'residues' by 'residuals'
- Page 31167, lines 26-7: We replaced "Retrievals performed in this way then yield true column amounts and heights, instead of just an apparent column." by "Retrievals

performed in this way, then yield quantitative estimates of the column amounts and heights, as opposed to the apparent columns discussed above.”

- Page 31167, lines 26-7: We added the sentence ‘Cloudy scenes are at no stage in the algorithm treated separately.’
- Page 31169, line 22: We added the following sentence ‘Average water vapour and temperature profiles were calculated in each box from the Eumetsat IASI L2 data of several days in June 2011.’
- Page 31169, line 25-27: We removed the following passage ‘This method of obtaining Jacobians is to some extent redundant. For comparison, we also tried using just one set of Jacobians representative for the Middle East and Asia and found the results to be very similar.’
- Page 31169, line 27-29: We replaced ‘Therefore, for operational applications it would suffice to precalculate Jacobians in a few broad longitudinal bands for different times of the year.’ By ‘For operational applications Jacobians would need to be precalculated for such boxes and different time-periods of the year.’
- Page 31169, line 27-29: Here we added ‘global mean spectrum  $\bar{y}$  and ..’, which was forgotten in the original manuscript.
- Page 31170, line 5: We added the word ‘iterative’ in front of optimal estimation
- Page 31170, line 6: We added the sentence ‘Atmospheric water and temperature profiles were taken from the collocated Eumetsat IASI L2 data. As we retrieve altitude independently, the fit is one-dimensional with only...’
- Page 31170, line 6: Here also the mention of the mean spectrum was forgotten. The new sentence now reads: ‘For this retrieval a different mean spectrum and covariance matrix are needed, ones that are built up from spectral residuals (see above). Here we used 15000 forward simulations ..’
- Page 31170, line 9: We replaced ‘residues’ by ‘residuals’
- Page 31170, line 10: We added the line ‘Again no distinction is made between cloudy and cloud-free scenes as the algorithm is largely robust for the presence of clouds (Carboni et al, 2012).’
- Pages 31170, line 17: We replaced ‘Altitudes...’ by ‘Displayed altitudes ...’
- Pages 31170, line 18: We replaced ‘Central in’ to ‘Central to’
- Page 31170, line 22: We replaced ‘either’ by ‘any’
- Page 31171, line 25: We replaced ‘below 20°’ by ‘south of 20°’
- Page 31172, lines 4-5: We replaced ‘conclusion from such data only’ by ‘conclusions from such data alone’

- Page 31172, line 14: We replaced “reveals an excellent match” by ‘reveals that the trajectories match the retrieved SO<sub>2</sub> transport features’.
- Page 31174, line 16: We replaced ‘east side’ by ‘west side’.
- Page 31174, line 8-10: We removed the line ‘It is very likely though, also given the amount of stratospheric aerosols measured by OSIRIS, that it exceeds the 400 kT of the initial injection above 10 km’ since this is a too speculative statement.
- Page 31165, line 27: We replaced ‘columns’ by ‘clouds’.
- Page 31176, line 11-13: We replaced ‘With these caveats in mind, an overall excellent match is observed between IASI retrieved SO<sub>2</sub> altitude and CALIOP aerosol measurements, with agreement almost systematically below 2km’ by ‘We have reformulated this sentence now as ‘Despite these limitations, altitude discrepancies between observed IASI retrieved SO<sub>2</sub> altitude and CALIOP aerosol measurements are for the most part, less than 2 km’.
- Page 31176, line 24: We replaced ‘The CALIOP data does reveal the excellent performance of the algorithm for plumes located below meteorological clouds, which is seen not to perform any worse than in cloud free scenes.’ by ‘The CALIOP data reveals that the performance of the algorithm for plumes located below meteorological clouds, is not any worse than in cloud free scenes.’
- Page 31177, line 3-5: We replaced ‘The plot reveals an excellent match between the two instruments, with mean and standard deviation of the differences equal to  $-0.1 \pm 1.3$  km and a correlation coefficient of 0.68’ with ‘Given the measurement uncertainties of both products, the plot reveals a good match between both instruments, with a mean bias of -0.1 km, a standard deviation of 1.3 km and a correlation coefficient of 0.68.’
- Page 31177, line 7: We replaced ‘height altitude Nabro plume’ by ‘high altitude Nabro plume’.
- Page 31177, line 10: We replaced ‘The agreement between the two instruments is very good, except in the parts where the aged higher altitude plume overlays fresher lower altitude plumes’ with ‘The agreement between the two instruments is not as good as it is during the early days of the plume, especially in the parts where the aged higher altitude plume overlays fresher lower altitude plumes.’
- Page 31177, line 17: We replaced ‘becomes’ by ‘become’
- Section 2: vectors are now written in bold italic font
- Figure 2: The volcano symbol is now larger
- Figure 10: The caption now mentions the source of the MLS data: ‘MLS data is from the v3.3 EOS MLS Level2 which was downloaded from the NASA Goddard Space Flight Center, Data and Information Services Center (<http://disc.gsfc.nasa.gov/>).’
- Figure 11: Fixed the problem of overlapping tick labels.

- A discussion of a simulation to test the height retrieval algorithm has been added in Section 2, in addition to an extra figure (now figure 2) belonging to this discussion.
- Following a recent paper (Fairlie, T. D.; Vernier, J.-P.; Natarajan, M. & Bedka, K. M. Dispersion of the Nabro volcanic plume and its relation to the Asian summer monsoon Atmospheric Chemistry and Physics Discussions, 2013, 13, 33177-33205) on the Nabro eruption, we have added the following few sentences to our conclusion: 'In this paper we did not address the exact mechanism of the observed rapid descent/ascent of the plume. A recent study suggests that quasi-isentropic flow is enough to explain most of the transport of the Nabro plume (Fairlie et al, 2013). The IASI-observed vertical transport is consistent with isentropic levels sloping downwards towards higher latitudes (see e.g. Fig. 3 in (Uchino et al., 2012)) but a more quantitative approach would be needed to determine whether it explains it completely.'
- We now thank the two reviewers for their comments and corrections.