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Atmospheric Measurement Techniques Discussions

Interactive comment on "Probabilistic retrieval of volcanic SO_2 layer height and cumulative mass loading using the Cross-track Infrared Sounder (CrIS)" *by* David M. Hyman and Michael J. Pavolonis

Anonymous Referee #2

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In this manuscript, Hyman and Pavolonis present a method to derive the altitudes and total column amounts of SO2 distributions caused by volcanic eruptions from infrared nadir sounding instruments. They apply their method to the measurements taken by the Cross-track Infrared Sounder (CrIS). Both retrieved quantities are provided as probability distributions. Especially for height, this is a further development of the method by Clarisse et al. (2014) where one distinct height value is provided. Because of this novelty, I support publication of this contribution in AMT.

However, I do have some points which I strongly suggest to be considered before

publication. While specific comments are listed below, my major concerns are the following:

- The description of the method in chapter 2 is provided in a way which is rather difficult to retrace. Partly this is due to a quite mathematical 'high-level' way with which rather obvious issues are presented. However, some aspects also need a better description with more details provided to understand and be able to reproduce the new method. Thus, I think a major revision of chapter 2 is essential.

- The retrieval of total column amounts of SO2 in the presented method is achieved under the assumption of linearity. However, most previous methods apply for this purpose a non-linear iterative retrieval. E.g. Clarisse et al. (2014) state with regard to their linear retrieved column amounts (a side-product of their SO2-layer-height retrieval): 'The conditions of the retrieval, namely constant Jacobians K and linearity are usually not satisfied. The quantity is therefore an apparent column which should be interpreted as a qualitative estimate of the column.' So the authors have to make clear, if they see their linear retrieval of total column amounts in the same way as more qualitative description (but in that case providing a probability distribution would not make much sense), or provide compelling evidence why an iterative approach should not be necessary here.

Specific comments:

L7 'These methods leverage the relative simplicity of infrared radiative transfer calculations':

It is not at all clear what this should mean? Radiative transfer simulations are no retrieval.

L14 'readily incorporated into Monte Carlo forecasting of volcanic emission transport':

This issue is only mentioned in the Abstract and not discussed in the main text. It should either be skipped or discussed in more detail.

L15 'We highlight results including successes and challenges':

There is no information contained in this statement -> skip

L42 ‘These methods leverage the relative simplicity of infrared radiative transfer calculations’:

See comment regarding abstract L7 above.

L57 ‘We highlight results including successes and challenges’:

See comment regarding abstract L15 above.

Between L61 and L63:

A description of the CrIS instrument is missing. Especially it should be stated why only the v_3 band of SO2 has been used and not also the v_1 band which should be more appropriate for sounding higher amounts of SO2 and at lower altitude since it is much less influenced by water vapour (e.g. see Carboni et al., 2012 for IASI).

L64 ‘2.1 Classical methods for height retrieval’:

There is no consistent description of the classical methods in this paragraph. It is rather confusing since the descriptions of ‘classical’ methods are intermixed with the new method presented. I would strongly suggest to concentrate here on the previous 2-3 methods. I would suggest to substantiate this description by providing a table about the characteristics of these and adding in this table the characteristics of the new approach. This would make it much easier for the reader to get an overview of the major similarities and differences.

Further, since height is a major retrieval quantity coped with in this manuscript, a physical explanation should be provided why there is any information on SO2 plume height in nadir spectra. (According to Clarisse et al., 2014 this is mainly due to the interference with water vapor lines.)

L68 ‘by Carboni et al. (2012), Clarisse et al. (2014), and Carboni et al. (2016) utilized the ability to linearize a forward radiative transfer model around a climatological mean

state for the concentration of trace SO2,..’:

But, Carboni et al., perform non-linear retrievals, as well as Clarisse et al., 2014 in case of column amounts.

L72 ‘As in Pavolonis (2010), all radiative transfer model simulations used in this study . . .’:

This is not fitting in this paragraph (see comment on L 64 above).

L88 ‘retrieving only the total column SO2, the mean pressure and the standard deviation (spread).’:

Why ‘only’? There is hardly more in formation in nadir-observations of SO2. Further, Carboni et al., 2012 mention that in case of low and mid-sized eruptions, the spread is not retrieved.

L95 ‘concentration profile’:

What is the unit of the ‘concentration profile’ (concentration vs. column); please use ’partial column’ to describe clearly the variable.

L99 ‘Below we refer to the height-dependent Jacobian calculated at the zero-background’:

Nowhere in the manuscript is it clearly stated which input parameters are used to determine the Jacobians. E.g. which atmospheric conditions (pressure, temperature, water vapour concentration profiles) have been used for their calculation (meteorological analyses?, observations from CrIS?)?

L117 ‘it is unsuitable for the height retrieval in particular as follows. Instead of calculating..’:

After ending of the first sentence I would have expected an explanation why this is unsuitable. However, there follows the description how it is implemented in the new

method.

L118 'Y':

Please describe more clearly what Y contains. Why is it called a vector, but it is a matrix. Please provide the dimensions of all the vectors/matrices used here. (AMT rule: 'Matrices are printed in boldface, and vectors in boldface italics.')

L118 'correlated':

Please describe which dimension is correlated and why (spectrally?, temporally?).

L122, Eq. 8:

What is the difference here compared to S used by Clarisse et al., 2014?

L123 'samples':

Please state clearly which samples are meant.

L 125, Eq. 9 '(y-Y)':

What is meant here? Is it a difference between the actual spectrum 'y' to each of the background spectra contained in 'Y' ? But one cannot construct an 'S' for each of those single spectra.

L131 'because the z-score is the sum over all of the channels in bvecY':

(1) I don't think it is only the 'sum' of all channels. (2) What is bvecY?

L142 'The likelihood function is constructed by Monte-Carlo (MC) sampling of Y and retrieving the height due to a background spectrum given by MC random sampling according to the marginal PDFs of Y and its covariance S (Fig. 1). The process for sampling this non-Gaussian correlated random vector is detailed in Appendix A.':

This should be explained more in detail and more clearly. What dimensions do the vectors have? Do you use any artificially noisy spectra? How/why do you have to

normalize the samples like in Appendix A.? There should be more description here.

L150 'We impose a Gaussian prior with mean and variance given by MC sampling using the model columns that make up the Jacobian with noise added.':

This description has to be expanded. What is the relation of the MC sampling to the MC sampling when calculation the Likelihood just before?

L151 'specifically, we use the Jacobian corresponding to the traditional Clarisse et al. (2014) height retrieval (h_C).':

How are those Jacobians calculated here? Where do p,T, H2O-concentration profiles come from?

L158, Eq. 15:

In this Bayesian formulation it should be made clearer what is the proposition A and what the evidence B. (E.g. if 'A' means 'SO2 layer at altitude h' and 'B' means 'actual spectrum y measured', then the Likelihood L should be B|A, i.e. 'actual spectrum y measured'|'SO2 layer at altitude h'. I don't see that Eq. 13 defines L like this – please make this clearer in the text.

L164 'Probabilistic Mass Loading':

Above I've expressed my concern about not applying an iterative retrieval here.

L230 'partitioning the data into four seasons':

As I've understood, spatially a smoothness is achieved by interpolation. However, how are jumps avoided due to this seasonal sampling?

L235:

A section about the influence of other effects on the error budget is missing. How, e.g. does ash in combination with SO2 affect the retrieval results? (Since ash is not included in the background S-matrix).

L306:

Can you weight the different explanations for not detecting the southern SO2-cloud? Given Fig. 9f, it seems clear that the initial z-score is more important.

L311 'with a z-score below this threshold':

Why is a z-score threshold at all used in this method? Does this example not show that at least a lower threshold would provide more information?

L311 'this discrepancy may also be due to spectral interference from water vapor in the CrIS SO2 infrared band':

Is there any indication that the water vapor vertical distribution is strongly different from the one further north?

L320 'although exact comparison is not possible due the orbital separation between the satellites carrying IASI (METOP-A,B) and those carrying CrIS':

But you could apply the IASI cloud-height method to your CrIS dataset and compare both. It would be very interesting to see the difference, e.g. as a further plot in Fig. 9 and Fig. 8.

L342 'are first interpolated to fill space and then sampled at the points given by the CALIPSO':

What is the difference with directly interpolating to CALIPSO?

L343 'there is good agreement':

'good agreement' does contain no information. Please try to be more quantitative.

L346 'leading to unrealistically high altitudes there (Fig. 10 e).':

I've tried to detect those in the Figure, but this is very difficult. Please be more specific.

L353 'If the background spectrum has multiple modes (for example, one mode repre-

senting deep convective cloud radiances and another for cloud-free radiances), then multiple populations of the Monte-Carlo height samples may accumulate, leading to a multimodal height PDF':

This should be discussed in the section about systematic error sources (see comment to L235).

L374-390:

In my opinion, the discussion about the e-folding-times is out of scope of the actual paper. Therefore, it would be better to skip it. (E.g. the authors do not discuss, that this is an apparent time because the effect of dilution and therefore not being detectable any more for the nadir-sounder is also included in this measure.)

L391 'Conclusions':

Please discuss also the limitations of the method applied to CrIS: no retrievals in nue_1 band of SO2, only linear assumption for retrieval of total column amounts.

L402 'improved spatial resolution over IASI':

Please mention here explicitly the CrIS and IASI pixel-size (km x km). What is the S/N in comparison of the two instruments?

L414 'analysis of errors in the trace gas technique induced by a warming background atmosphere':

What does this mean? Please provide an example.

Technical comments:

L24 'subtly':

-> 'subtle.

L27 'Because':

-> ‘Because’

L308 ‘(f)’:

-> ‘(d)’ (first appearance)

L395 ‘exceedence’:

-> ‘exceedance’

Fig. 11:

The difference between ‘red’ and ‘blue’, and (a) and (b) are not clear.

L412 ‘applyication’:

-> ‘application’

L427 ‘CDF’:

Please spell out.

References:

Carboni, E., Grainger, R., Walker, J., Dudhia, A., and 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., 12, 11417–11434, doi:10.5194/acp-12-11417-2012, 2012.

Clarisse, L., Coheur, P.-F., Theys, N., Hurtmans, D., and Clerbaux, C.: The 2011 Nabro eruption, a SO2 plume height analysis using IASI measurements, Atmos. Chem. Phys., 14, 3095–3111, doi:10.5194/acp-14-3095-2014, 2014.

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