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Atmospheric Measurement Techniques Discussions

Interactive comment on "Retrieval of volcanic SO_2 from HIRS/2 using optimal estimation" *by* Georgina M. Miles et al.

Anonymous Referee #1

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The manuscript presents a new scheme for the retrieval of atmospheric SO2 total column amounts after volcanic eruptions from HIRS/2 observations. An optimal estimation retrieval using radiances from three HIRS/2 channels in the mid-infrared region is presented. Retrieved parameters are cloud top and the total column amounts of water vapour and SO2. Major error sources, which are identified by synthetic observations, are cloud/ash interference and the assumptions on the altitude and vertical extend of the SO2 plume. Through simulations it is further demonstrated that the new scheme is superior compared to simple brightness difference methods. The method has been applied to the case of the eruption of the Cerro Hudson volcano in 1991.

This is an important piece of work since it presents an improved retrieval scheme to obtain SO2 from TOVS measurements and, thus, opens the possibility to obtain climatological time series of this important trace species. After some modifications/extensions

as detailed below, I strongly support its publication in AMT.

General comments:

The optimal estimation scheme is used but not explained nor referenced. I would propose to add a paragraph with the main formulas (adapted to the actual retrieval problem) and add the main references. It would be very helpful to add a table or some graph summarizing the major error terms which have been investigated and how those are handled (some explicitly, some implicitly as part of the measurement error).

Specific comments:

P1L20: 'detection method': The method presented here is more than pure 'detection' – it's quantification.

P2L6: could you specify more precisely the channel boundaries for the different HIRS/2 instruments. How much does this affect the retrieval scheme?

P4L24: It would help the reader if a higher resolved spectrum of the single major contributors to the radiance could be provided, overlaid by the channel-boundaries. Are there any other gases contributing in each channel?

P5L19, 'up to 300 DU': Could you give examples from literature how this number covers the upper limit of volcanic eruptions. In addition, the spectral plots (see comment P4L24) should include lines of SO2 for different column amounts.

P5L24 'see Fig. 1': Fig. 1 has not been described up to this point, but only later in the text. Further, it does not show the cost 'up to the training limit' of 300 DU, but only to 200DU.

P5L30 'calculated numerically': Could you explain this more in detail. Are the analytic Jacobians used at all?

P5L31, 'manually': What does this mean? How large are the limits for H2O, SO2? How does it work when it is mentioned 'The weighting functions are allowed to make linear

extrapolations. . .'? Is this only valid for the last iteration step?

P6L25, 'The estimate accounts for inaccuracies that arise due to modelling the atmosphere at reduced spectral resolution, limited vertical resolution, inclusion of non-retrieved trace gases at a climatological level or their preclusion entirely, relative to a reference case.': What is meant with 'limited vertical resolution' and 'modelling .. at reduced spectral resolution'? How has this error been derived (line-by-line compared to band model)? How strong does this error depend on the atmospheric situation?

P7L9, '100 DU': Could you put this number in perspective of the typical maximum column amounts e.g. after Pinatubo?

P7L16: How are the a-priori errors of the state vector element for water vapour set? Is this error only considered in the measurement space? Further, could you explain how the off-diagonal elements of the a-priori covariance matrix are set.

P8L1, Chapter 3.1, and Fig.1: Regarding the error bars shown in Fig. 1: Could you summarize which errors they contain? Have these errors been incorporated in the synthetic observations? (I assume no or only partially, otherwise the retrieval results should somehow scatter around these errors). Further, do the error bars represent 1 or 2-sigma values? The maximum value tested here seems to be 150 DU. Could you extend this range? You should also show, at which values the method fails and at which column amount of SO2 the channel signal becomes saturated.

P8L25, 'Measurements were simulated for a plume at a range of altitudes from 8-18 km': However the caption in Fig. 2 says vice-versa: 'A 2 km thick triangular profile centred at 12 km is used to simulate measurements. The profile is then used in a retrieval with the retrieved height assigned to a range of altitudes.' Could you tell in which way the test retrievals have really been performed?

P8L28: In this paragraph it is only referred to the Figure, however the results are not described. Please give also in the text at least some quantification of the resulting

errors.

P9L1-3: It is not clear what is different here compared from the paragraph before.

P9L6-13: Also here in the text some numbers (%error) should be mentioned. Further, could you explain, why there is such a large difference between the errors when the plume thickness is over- versus underestimated. Would this result not speak for application of a rather sharp profile in the retrieval to minimize the errors?

P9L29: 'water vapour clouds' should perhaps read 'liquid water clouds' ?

P9L29, 'above 5 km': However in Fig. 4 the retrieval seems to be OK up to 8-9 km. Can you give an explanation why the retrieval has problems to fit cloud heights above a certain altitude. How much does it depend on the atmospheric situation (tropics vs mid/high latitudes)?

P10, chapter 3.4: What is the upper limit of the retrieved SO2 (e.g. due to saturation effects)? This could also affect the total mass calculation in very dense plumes. Also some information about the convergence criteria of the retrieval and how many iterations are necessary are missing.

P12L28: Could you state which SO2 altitude profile has been used for the case study and how it has been derived. Is the resulting SO2-altitude error included in the column errors in Fig. 5?

P14L5: To make this calculations more clear and give the reader a better feeling for the derived e-folding times and its possible uncertainties it would be necessary to plot derived daily masses after 17th August and show the fitted exponential decay line.

P14K19, '2300 +- 600 kT': How has the error of 600 kT been calculated?

P14L22: Please give also the total masses (including errors) of TOMS, Carn et al., 2016 and Prata et al., 2003.

Technical comments:

P1L31, ‘The TOVS instrument’: But in the sentence before it is explained as a suite of instruments.

P1L32, ‘TIROS’: Is written ‘TIrOS’ in L28.

P4L21, ‘Table 1’: Shouldn’t this read ‘Table 2’?

P11L7: ‘(Constantine et al. 2000)’ -> ‘(Constantine et al., 2000)’

P12L14: ‘verses’ -> ‘versus’

P13L4: ‘317 channel’ -> ‘317 nm channel’

P13L5: ‘340 to’ -> ‘channel at 340 nm to’

P14L3: Should the formula not read: N(t) = N_0 exp(- lambda t) ?

P15L15: ‘satellites’ -> ‘satellite’

P23Fig3: ‘11.5, 12, 13 km’ should read ‘11.5, 12, 12.5 km’

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