

Topic editor decision: Publish subject to minor revisions (review by editor)

We thank the editor for working through the manuscript again, and appreciate the decision for publication after minor revisions. We went through the comments carefully, and applied them in the manuscript. Below, we report the editor's comments (grey, bold) along with our replies (blue). We only report comments, where we add further explanation or (slightly) deviate from the editor's recommendations. All comments not listed below were implemented precisely as suggested.

List of minor revisions (n.b. line numbers refer to the Track-Changes manuscript)

1) Introduction, line 93: This is one of the new segments of text added, from reviewer 1's comments, and although this now refers to several of the papers documenting other volcanic SO₂ emission inventories, the wording needs to be amended slightly, to first introduce the concept. A suggested change is to replace:

"Volcanic SO₂ emission databases are the basis for the correct implementation of volcanic eruptions in atmospheric models..."

instead with

"Several volcanic SO₂ emission databases have been developed, each providing a basis for implementing best-estimate source parameters for individual eruptions into global atmospheric models...."

or similar text to better introduce the concept. It's quite common to colloquially refer to the individual volcanic emissions as "simulating the eruption" or similar, which in a sense it is, but better to be clear it's the emission not the eruption that's being simulated.

We included the slightly adjusted sentence:

"Several volcanic SO₂ emission databases have been developed, each providing a basis for implementing best-estimate [emission] parameters for individual eruptions into global atmospheric [chemistry] models."

2) Introduction, line 94: Please re-word this short sentence "Timmreck et al. (2018) recommend four different emission inventories" to be clear you mean within this intercomparison of interactive stratospheric aerosol models. Remember it's a relatively small proportion of the global atmospheric models that simulate stratospheric aerosol interactively, so this needs to be clear you mean for this co-ordinated intercomparison of global interactive stratospheric aerosol models.

We adjusted the sentence to:

"Timmreck et al. (2018) recommend four different emission inventories within the Interactive Stratospheric Aerosol Model Intercomparison Project (ISA-MIP)."

6) Introduction, line 128: Although GMD papers can include a good depth of

technical information, please change "a newly developed historic default namelist setup" to be clear you mean "historic eruptions" and to explain this re: automation of the previous manual approach that established the magnitude of each individual tracer adjustment. Suggested minor re-wording is to delete the word "default", which I think is meant re: this automated approach, to instead mention that automated functionality later in the sentence. I mean "...this newly developed historic eruption namelist setup then automates this functionality" or similar.

We thank the editor for the suggestion, and we rephrased it. As "for stratospheric volcanic eruptions from 1990 to 2023 ..." directly follows, we omitted "historic eruption" here:

"The new submodel along with a newly developed namelist setup for stratospheric volcanic eruptions from 1990 to 2023 (based on the emission inventory from Schalloek et al. (2023) and Brühl et al. (2018)), that automates this functionality, is presented ... "

7) Introduction, line 151: I am not sure re: this sentence "and refined using observations from", is referring to something that was done within this study's activity, or if the present study only evaluates this. If the former please change "and refined using ..." to "and we further refine it here using...".

We actually refined it in this study, so we changed it accordingly.

8) Title of section 2 – "New MESSy submodel for Explosive Volcanic ERuptions (EVER)"

Although I get that the MESSy framework provides the basis for implementing the EVER sub-model, the wording of this section, putting the "MESSy" at the start of the title ("New MESSy submodel...") gives too much emphasis to this coupling, when the primarily functionality being documented is the EVER model for processing the individual eruptions to tracer increments.

Suggest to change the section 2 title to "New emissions submodel for Explosive Volcanic ERuptions (EVER)"

We changed it to:

"New submodel for emissions from Explosive Volcanic ERuptions (EVER)"

9) Section 2, lines 242 to 245 – The 2nd of these two sentences here seems the main information to begin this paragraph, or I am suggesting to integrate the point about the tracer tendencies into a re-worded version of the 2nd sentence here (then deleting the first). A suggested wording for this could be "The EVER module code converts the individual volcanic emissions into tracer increments..." (the text says "tendencies per second", but multiplying "tendency" by a unit of time gives an increment".

We reformulated to: "The EVER module code converts the individual emitted tracer masses into tracer increments, that are added to the total mixing ratios during runtime ..."

11) Section 2.2, line 312 – "...about 800 significant explosive volcanic eruptions", the wording "about 800" here seems too colloquial, for peer-reviewed journal paper. From the context of this para I wonder if could re-word also with combining with the preceding sentence, changing the start of the "Therefore, we established a

default namelist configuration....” to (rather than ”default”, say something like ”The inventory we have established, we advocate to become a standard namelist configuration...”, and then give the actual number of explosive injections included there.

We thank the editor for this suggestion. We agree that the word ”default” is not optimal here. Consequently, we also changed it in the title of the section. However, we already advocate for the inclusion of the submodel three times (Abstract, Discussion and Conclusion), and we first want to present the setup here and evaluate it. Thus, we combined the sentences as follows:

”Therefore, we established a historic volcanic eruption namelist configuration for the EVER submodel based on the SO₂ emission inventory developed by Schallock et al. (2023), which we extended to the period from 1990 to 2023 (now encompassing 774 significant explosive volcanic eruptions), and refined with observations from the IASI satellite.”

12) Section 2.2, lines 348-350 – ”.. For eruptions occurring before 2007, or those not observed...” Please re-word ”not observed”, you mean within the ”not observed by IASI”, right? I think you mean in these cases it’s done fully interactively, (i.e. via an explicit emission flux of SO₂), rather than making a tracer mixing ratio adjustment. Then suggest to change ”we utilize the” instead to ”an explicit emission of SO₂ is carried out at the geographical location, with the source parameters for the corresponding eruption....” or similar.

Indeed, we mean not observed by IASI. However, we treat these volcanic eruptions similar as the others, with the difference, that we do not update the timing and geographical location of the injection. To clarify this, we reformulated it as follows:

”SO₂ injections from volcanic eruptions occurring before 2007 or those not observed by IASI are introduced with the same vertical distribution, however, at the geographical location of the volcano and from 9:00 to 15:00 UTC on the date provided by the emission inventory from Schallock et al. (2023).”

13) Section 3.2.1, line 496 – ”IASI faces limitations capturing the mid-term evolution of volcanic plumes with SO₂ columns falling below the detection limit.” I’m not sure I’m understanding the point being made here, but I guess you mean a limitation with the satellite-nudged tracer adjustment approach, right? I mean any satellite instrument would have that limitation (not only IASI), and its more a limitation of the approach to adjust the tracers, rather than the instrument itself.

Please re-word accordingly, but in fact since the requirement of the method is to realistically capture the enhancement to SO₂ very-soon after the eruption, I don’t see what the issue is here. I mean the model predicts the progression of the tracer concentrations, after the initial adjustment, and then doesn’t require to continually adjust the tracers as the plume disperses.

I’m not sure if maybe the authors mean in the case of two eruptions occurring within a few days of each other (e.g. from two neighbouring volcanoes) or from an explosive eruption occurring near to a continuing significant high-altitude volcanic emission source?

But even in that case I'm not sure this "mid-term evolution" would be an issue, because there presumably are relatively few cases where that is the case, within this particular inventory's time-period anyway.

I'd suggest to potentially delete the lines 496 and 497 (including the ". Conversely"), and just have the paragraph begin "Observations from the ..." I'm not 100% sure of the distinction being pointed out here between IASI and MIPAS, the current wording is not so clear about that. Suggest to re-word into a combined sentence that then makes clearer the difference seeking to be communicated here.

We actually refer to the evaluation here. We use IASI for the evaluation of the short-term dispersion and development of the plume, however, this evaluation is not possible any more after the SO₂ columns fall below the detection limit of IASI. Thus, we use the MIPAS observations to qualitatively and quantitatively investigate the mid-term evolution of the plume. We agree, that this can be slightly confusing here. We rephrased and considerably shortened the text in combination with the preceding paragraph, including the changes from the following comment 14, as we agree that the explanations are too comprehensive and unclear:

" IASI observations of SO₂ columns and plume altitude are used for the qualitative evaluation of the short-term plume evolution (Sect. ...), by sampling simulated SO₂ columns at the time of the satellite's overpass using the SORBIT submodel (Jöckel et al., 2010). For the mid-term plume evolution and quantitative assessment of simulated SO₂ mixing ratios, we use three-dimensional observations from the MIPAS instrument¹ (Sect. ...). "

14) Section 3.2.1, line 501-502 – "Indeed, MIPAS observations become more reliable approximately three weeks after the initial eruption". There is no citation given here, and although the scientific writing style is generally good, this is an isolated instance of poor writing. Suggest to delete this or cite the specific case being referred to here (with citing a study that found this to be the case), as this is presumably relating to a study or report that analysed the observations through a specific post-eruption period? If the sentence is deleted, note the follow-on sentence "Its ability to provide..." then needs to be adapted accordingly, to state the instrument name again.

We agree, that this was poorly written and justified, and removed this part, as it is not necessary (see previous reply).

15) Section 3.2.1, line 504 – I'm not sure if a grammar-tool such as "grammarly" or similar has recommended to split the text into 2 sentences, but the 2nd of the two sentences here seems to be the 2nd half of a logical sentence that's then been split into a separate short sentence, that no longer makes sense. Although shorter sentences sometimes make for easier reading, within an academic peer-reviewed journal paper, that rule may not always apply, and the information being explained may require a longer sentence than might be seen to be better practice in a more informal communication, such as a webpage or similar primarily online-accessed info-resource.

Indeed, combining the two sentences improves the readability:

¹MIPAS observations are not well-suited for the short-term evaluation due to potential rejection of plume air masses and saturation of spectral lines (Höpfner et al., 2015).

"For the comparison with MIPAS observations, we calculate the stratospheric SO₂ burden, applying fixed lower integration limits depending on latitude (16 km for 0-30°, 14 km for 30-60° and 12 km for 60-90°), as the model tropopause does not necessarily coincide with the observed tropopause."

16) Section 3.2.2, lines 511-521 — "Second, we performed a numerical simulation spanning from...." For a journal paper, paragraphs needs to be stand-alone (grammatically) and suggest to simply replace "Second, we performed a numerical simulation spanning January 2008 to December 2011 to evaluate..." with "To evaluate the implementation (within EMAC) of the new EVER historic eruption module" or similar.

We formulated to:

To evaluate the newly developed historic volcanic eruption setup for the EVER submodel (see Sect. ...), we performed an EMAC simulation spanning from January 2008 to December 2011, using the same model configuration as detailed in Sect.

As the next section faces the same issue, we reformulated:

"Third, we evaluate the submodel's capability to simulate ..."

to:

"In addition to the evaluation of explosive volcanic eruptions, we evaluate the new submodel's capability to simulate ..."

17) Section 3.2.2, line 517 — "To additionally validate the simulation, we evaluate the extinction.." Further to the general comments re: Referee 1's rejection being primarily from requiring more aerosol evaluation, suggest here to explain the strategy of the study being to assessing the operation of the EVER module, via evaluating simulated SO₂, but to show also this Figure for context within the climate impacts originating from simulated aerosol.

Suggest to replace the sentence with something like "Whilst this study focuses primarily to analyse simulated SO₂, that being the emitted species handled by EVER, we present here also the EMAC simulated extinction and sAOD at 750nm....".

We reformulated the paragraph, and included the disclaimer, mentioned in the next comment:

" We use 3-dimensional observations from the MIPAS instrument to evaluate the total stratospheric SO₂ burden (Sect. ...) with the same lower integration limit as described above. Whilst this study primarily focuses on the evaluation of simulated SO₂, being the emitted species handled by EVER, we present here also the EMAC simulated extinction and sAOD at 750 nm, evaluated with observations from the OSIRIS instrument in the tropics (0-25°N, lower integration limit 16 km) and at higher northern latitudes (45-80°N, lower integration limit 12 km), as the tropopause altitude is fairly constant in these regions (Sect. ...). The additional evaluation of the simulated aerosol optical properties shall not evaluate the model's microphysics described below, but serve as an additional validation of the approach, for context within the climate impacts of the resulting stratospheric aerosol, and as a comparison to the simulation done by

Schallock et al. (2023), who used a similar setup. ”

18) Section 3.2.2, lines 527-529 – further to comment 17) this one-sentence para I’m not sure if maybe is then explained in the suggested edit above. And then this comment could potentially be deleted.

This paragraph was integrated into the one mentioned in the previous comment (see above).

19) Section 3.2.3 title (line 530) and lines 531-544 – further to the differences in the chemistry regime with the Kilauea case, re: the short-lived duration of the volcanic SO₂ oxidation product, suggest to hint at this with adding the word ”tropospheric” before degassing, and maybe replace ”volcanoes” with ”case” – i.e. ”SO₂ from tropospheric degassing case – Kilauea (2018)”

I leave it to the authors whether to make that change, but the test here needs to give some recognition of the issue raised by reviewer 1, re: chemical sinks for SO₂ also being important. The text added now mentions a difference between the SO₂ oxidation products in the stratospheric chemistry and tropospheric chemistry schemes available within EMAC.

However, I’m not sure if the model actually switches between these 2 schemes, within the operation of the model integration here, i.e. do only gridboxes above the tropopause ”see” this extra intermediate oxidation product in the stratospheric SO₂ oxidation approach (sulphur trioxide). Are there two different chemistries being integrated within the same model run, or is the scheme applying the same chemical integration across the troposphere and stratosphere.

Obviously air is exchanged between the stratosphere and troposphere, and for eruptions emitting near the tropopause, and then if two chemistries are integrated, is the cut-off for the change at the tropopause, or some distance below the tropopause (e.g. considering the upper tropospheric air likely has more commonalities with the stratosphere, albeit considering the dehydration etc. re; the water vapour affecting the sulphur trioxide chemical-sink timescale.

Whichever approach is used, this needs to be set clearly within this section, and with the re-factoring of the text there is some space to set out a good depth of information to clarify the operation of the two SO₂ oxidation schemes now mentioned in the approach (and where the intermediate product is resolved).

I must admit it wasn’t 100% clear to me whether the Kilauea case used the tropospheric chemistry scheme because this operates only over the lower-atmosphere domain or so, as presumably this is one integration through the entire period with the same chemistry scheme, albeit presumably operating a hybrid approach of both schemes being integrated.

And whilst the explanation of the chemistry schemes added does partly address reviewer 1’s concerns, it should also be clarified here, within this re-structured section 3, the methodological specifics of how the two chemistry schemes mentioned are combined and operate for this hindcast EMAC integration.

We thank the editor for the suggestion, and adjusted the title of the section accordingly.

Regarding the SO₂ chemistry: In the simulation for the degassing case, the simplified chemistry is applied globally (i. e. in the troposphere and the stratosphere), due to the high computational cost to run with the increased horizontal resolution. We clarify this in the revised version. We do not perform simulations with a hybrid chemistry, combining the two chemistry schemes, but either use one or the other.

” Simulations for the degassing case are performed at a horizontal resolution of T255 (approximately 50×50 km at the equator) and 31 model levels (up to an altitude of about 30 km) to capture the tropospheric transport. The timestep has to be decreased to 2.5 minutes to account for the increased horizontal resolution. We use a simplified chemistry globally in this simulation covering the basic tropospheric chemistry (as we do not focus on the stratosphere here), including O₃, OH, NO_x, NO_y and basic sulfur chemistry (see supplement for details), reducing the high computational cost due to the increased horizontal resolution and decreased timestep. Oxidation of SO₂ to H₂SO₄ is directly realized via reaction with OH in this simplified chemistry, without producing any intermediates. We do not consider DMS and OCS here (see supplement), leading to a potential underestimation of background maritime SO₂ concentrations. ”

20) Section 3.2.3, lines 550-551 – Please re-word these 2 sentences, and again I think it might be easier to explain what’s being communicated here within 1 longer sentence here. The 2nd sentence seems to be the 2nd half of the same point being explained, but has been cut-off part-way through making the point. Please also mention the specific satellite instrument here (S5P-TROPOMI), and clarify the specifics of the approach to fit to these observations. OK this is explained in Appendix B, but some summary-specifics should be given here so the reader can get the general gist of the issue being summarised..

We reformulated the paragraph, and summarised the optimization process more clearly:

” In addition, we perform a simulation with tuned emission rates, based on the results of the reference simulation with the emission rates from Jost (2021). For that purpose, we establish a linear relationship between SO₂ emissions and simulated SO₂ by fitting the implemented emission rates of the three preceding days to the resulting simulated SO₂ columns for each day in June 2018, and subsequently use this linear relationship to derive optimized emission rates resulting in the observed columns from TROPOMI, applying a stochastic gradient descent algorithm (e. g. Ruder, 2016). More details on the optimization can be found in Appendix B. ”

21) Section 4.1.2, lines 788-790 – The approach to begin the para ”So far, we focused on...” is too colloquial, suggest to re-word again to be clear the SO₂ is the main focus of the manuscript’s observational evaluation (that being the emitted species handled by the EVER module). That’s what the 1st sentence says, but please expand the sentence slightly to communicate that more formally (less colloquially).

We reformulated to:

”The main focus of the observational evaluation of EVER is on the spatio-temporal evolution of volcanic SO₂ as the emitted species. However, once in the atmosphere, ...”

22) Section 4.1.2, line 837 – ”Interestingly, in the sensitivity simulations...” Similar

to comment 21, please re-word for more formalised and objective language (delete "Interestingly" – it's a subjective point, different readers will find different aspects more or less interesting).

We removed "Interestingly, ..." here, and also at two other occurrences

References

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