Review of manuscript 2025-2981 for Atmospheric Chemistry and Physics
"*Radiative forcing and stratospheric ozone changes due to major forest fires and recent volcanic eruptions including Hunga Tonga*", by Christoph Bruehl, Matthias Kohl & Jos Lelieveld

This manuscript presents findings from interactive stratospheric aerosol and chemistry simulations with a 3D composition climate model, to quantify the radiative and chemical effects on the stratosphere from recent intense wildfires and explosive volcanic eruptions.

The January 2022 Hunga eruption is found to cause a modest depletion of the stratospheric ozone layer throughout the 2022 Southern Hemisphere, with also the intense wildfires from Australia (Dec 2019) and Canada (NH summer 2019 and 2020) causing additional ozone loss in 2019 and 2020.

These impacts are found to be caused primarily by stratospheric aerosol particles from these sources, and although the emission of water vapour from Hunga is found to have altered the vertical location of the aerosol and caused some PSC-driven impacts, the direct effects from the emitted water vapour are smaller than these indirect effects.

The scientific writing style is generally quite good, and the findings presented are generally well-described and summarised. However, two of the initial Figures within the paper need to be revised, to give a clearer presentation of the stratospheric AOD and SAD enhancements after Hunga.

Specifically, Figure 1 gives the impression that the forest fires caused larger global stratospheric AOD enhancement, which is not the case.

The magnitude of the observed global stratospheric AOD in 2022 summer has been established (Khaykin et al., 2022; Legras et al., 2022; Knepp et al., 2024; Joerimann et al., 2025) to have been substantially higher in 2022 than in 2020 and 2021 (indeed 2022 had the highest since the Pinatubo aerosol in 1992), and this can be seen clearly for example within Figure 10c of Khaykin et al. (2022).

There is a similar issue with Figure 3, with the 2019-2023 variation in SAD shown only at 1 altitude level (68hPa), this being in the lowermost stratosphere, the altitude at which the wildfires emitted, but ~5-10km below the altitude of the Hunga aerosol.

Figures 18 and 19 of Knepp et al. (2024) show clearly that the Hunga aerosol was present at a higher altitude, much deeper into the stratosphere (20-30km; ~30-50hPa), and the 68 hPa level selected for the SAD comparison (Figure 3 upper-panel and lower-panel).

The submitted manuscript then presents readers with an incorrect impression that the 2022 Hunga SAD-enhancement was lower than that from the 2019-2020 wildfires, when it's simply that the stronger Hunga aerosol was at higher altitude than the level shown.

These are the 2 “main minor revisions”, that Figures 1 and 3 as currently drawn do not provide an adequate representation of the relative impacts on the stratosphere. Figure 3 shows only the impacts in the lowermost stratosphere (68 hPa), and Figure 1 gives stronger-looking lines to the more-uncertain limb-scatter instruments (OMPS-LP, OSIRIS) and weaker-looking dashed lines to the gold-standard SAGE-III aerosol measurements (these going off-the-scale on the plot).

The aerosol extinction derived from the OMPS-LP and OSIRIS limb-scatter instruments is known to be much more uncertain than SAGE-III, due primarily to having to make assumptions on particle size. In contrast, the SAGE-III instrument does not have to make an assumption about particle size, the solar occulation method measuring the extinction of sunlight directly.

In summary, Figure 1 needs to be re-drawn with a solid line used for the GloSSAC stratospheric AOD, this being the benchmark stratospheric AOD dataset (currently represented by a dotted line), and the current solid line used for OSIRIS changed to a dotted line. The y-axis range also needs to be increased accordingly (see revision M-MR1 below). And Figure 3 needs to show an integrated

I note however these are entirely presentational issue, and the required revisions remain at a minor level, and it will I expect be a relatively quick job to amend the Figures for this change.

Overall the paper presents a very interesting quantification of the relative magnitude of the effects, and the later Figures do compare like-for-like with the radiative forcing, albeit those based on this particular model’s predictions.

And then I am recommending minor revisions overall, referring to these Figure changes as the only two “main minor revisions” (M-MR1, M-MR2), these listed below with the specific info on the modifications needed for these 2 Figures. There may need also to be some changes tothe associated interpretation, the Hunga impacts to be given more prominence than currently, the 2022 enhancement to the stratospheric AOD clearly substantially larger than that from the wildfires in 2019-2021.

Whilst the model predictions of the ozone layer and radiative impacts may indicate a stronger effect from the fires, this is a model result, and I am aware from a current Hunga aerosol intercomparison (Aquila et al., in prep.) that the EMAC predicted Hunga aerosol is weaker than in other models.

The manuscript can of course present the model findings, but the model being low-biased compared to the main Hunga enhancement in 2022 (compared to the benchmark SAGE-III/GloSSAC observations) needs to be noted as a significant caveat in the interpretation.

With the current administration of the US, the SAGE-III instrument may well be ended prematurely, and then model-observation comparisons in the future may have to rely more exclusively on the limb-scatter instruments. The large difference between the OSIRIS limb scatter stratospheric AOD retrievals, and that from the benchmark GloSSAC/SAGE-III solar occultation, during the Hunga period, illustrates the importance of retaining SAGE-III.

Figure 3 needs to be re-drawn to show impacts comparing vertically-integrated stratospheric column-SAD, then inclusive of both impacts, and providing readers of the article with a balanced representation of stratospheric variations through the 2019-2023 period.

The 3rd main minor revision relates to the axis-label presentation of the Figures being quite poor, the y-axis values in Figure 1 given simply as log10 of the stratospheric AOD, and there being no y-axis labels for the reader to appreciate what quantity is shown there.

Again, these presentational issues are relatively easy to correct. And whilst this is somewhat disappointing that the authors should have submitted an article that seems not yet ready for expert peer review, I am aware of the APARC Hunga impacts report has a deadline of 31st July for papers to be citable, and may have affected the authors decision to submit prematurely.

It is also understandable, though somewhat regrettable, that a time-pressed Topical Editor (TE) was not able to flag these basic axis-label issues within an initial TE review.

Overall this is a solid paper, and the article is certainly within scope for ACP, and the findings presented are important, and will be of substantial interest to the community, once the revised manuscript can adequately represent the stratosphere's variation through this period.

The scientific writing is generally quite good, and although the writing style is quite brief, the main results are presented in a fair way, aside from the initial Figures 1 and 3.

<u>Main minor revisions</u>

M-MR-1) Re-plot Figure 1 with solid black line for GloSSAC (benchmark for stratospheric AOD)

As noted in the general comments above, please switch-round the dotted and solid lines given currently for the stratospheric AOD for GloSSAC and OSIRIS.

This is needed because the OSIRIS is a limb-scatter instrument, then much less certain aerosol retrieval than for the SAGE-III instrument, providing the main basis of GloSSAC.

The colour black should also be reserved for observations, and please also use then change the model lines to be coloured green, with black used for the observation datasets.

Please also update the y-axis range, to include the peak post-Hunga GloSSAC sAOD values. The GloSSAC observed stratospheric AOD "off the scale" during 2022, in the lower-panel of the current version of Figure 1 (for southern hemisphere stratospheric AOD).

M-MR-2) The current Figure 3 needs to be re-drawn for vertically-integrated SAD, to include the main Hunga impacts being at higher altitude than those from the 2019/2020 wildfires.

This is particularly evident within Figure 3, the Surface Area Density shown only for 1 selected altitude (68hPa). It is clear when referring to Figures 18 and 19 from Knepp et al. (2024) or

Figure 7a from Joerimann et al. (2025) that the observed post-Hunga SAD is significantly higher in magnitude than the wildfires (and also at higher altitude).

Had a 50hPa or 30hPa level been chosen for this southern mid-latitude comparison (the upper panel of Figure 3) the reader would have been presented with a timeline showing only a very minor enhancement in 2020 and 2021, and a much larger enhancement in 2022 (see Knepp et al., 2024, Figure 19).

Other minor revisions

O-MR-1) Abstract, line 1 – It's important to be clear the causality requires a conditional clause. Please insert "can" before "affect stratospheric chemistry" (it's only the exceptionally intense wildfires in 2019/2020 that have been shown to have this effect).

O-MR-2) Abstract, line 3 – Similarly to above, the Abstract needs to be clear it is these particular wildfires that are shown to have this effect (the majority of wildfires do not have this effect). Change "emitted from wildfires" to "emitted from intense wildfires in 2019/2020".

O-MR-3) Abstract, line 4 – Change "due to increased solubility of HCl in particles containing organic acids" -- the "due to" is not quite right there – it's the abundance of the smoke in the stratosphere that causes the effect (from the intense fires). Suggested re-wording is "related to a high solubility of HCl in aerosol particles containing organic acids".

O-MR-4) Abstract, line 5 – Change "the upward transport of the pollution plumes resulted in".

The "upward transport" could be misunderstood by some readers to mean a longer timescale effect. But it was actually the extreme intensity of the fire, that then caused a very deep plume, to then detrain the smoke at altitudes above the tropopause.

Suggested re-wording is to change

"Following the 2019/2020 Australian megfires, the upward transport of the pollution plumes resulted in ozone depletion in the..." to

"The extreme intensity of the 2019/2020 Australian wildfires, meant the smoke plume reached the stratosphere, causing in significant ozone depletion in the..."

O-MR-5) Abstract, line 6 – Please change "It diminished column ozone" – the preceding sentence already stated there was significant ozone depletion, and this "It diminished" phrasing also needs to be improved for peer-reviewed article.

Suggest to change

"It diminished column ozone in the following two years..."

to

"With the long residence time in the stratosphere, the wildfire smoke diminished column ozone for the following two years....

O-MR-6) Introduction, line 16 – Re-word “Since about 2017 it was observed…”. This is the 1st sentence of the Introduction, and the “about” is really quite poor wording there. Suggest to adapt the sentence, and cite Mike Fromm’s earlier papers (e.g. Fromm et al., 2004, 2005) which pointed out these effects from intense boreal forest fires.

O-MR-7) Introduction, lines 19-20 – “This holds for the Australian wildfires” – not clear what was meant here.

O-MR-8) Introduction, line 24 – Re-word sentence – improve “like for example Hunga Tonga” for scientific language.

O-MR-9) Introduction, line 25 – Similarly, the tense here is not quite right, change “lifting” to “lifted”.

O-MR-10) Introduction, line 28 – Again, improve the scientific writing here, re-word “This and the about 10km thick layer” to be more precise. This is also the first time the depth of the smoke aerosol is mentioned, and suggest to hint at the timescale being significant prior to becoming this 10km deep, e.g. maybe “The initial layer of smoke aerosol progressed to a 10km depth enhancement …..” or similar.

O-MR-11) Introduction, line 30 – Scientific writing poor here also – “has been analyzed in several studies” – please be clear what type of studies these are – presumably it was meant the observational studies in the initial period after the eruption? If you meant modelling studies, be clear if you mean interactive stratospheric aerosol studies -- and there’s actually been relatively few of these – the study of Zhu et al. (2022) and Li et al. (2024)

O-MR-12) Line 40, heading for section 2 – the “and used satellite data” is not great. And suggest to include the words “interactive aerosol” to be clear these are interactive stratospheric aerosol CCM simulations. Suggest to change to:

“Interactive chemistry-climate model simulations and satellite measurement datasets”

O-MR-13) Section 2.1 -- Line 42 – It seems too abrupt to simply begin “EMAC consists of” – and I think the acronym has not yet been introduced. Suggest to re-word to:

“For this study, we analyse interactive stratospheric aerosol simulations with the ECHAM/MESSY Atmospheric Chemistry model (EMAC)…”.

O-MR-14) Line 44 – put “up to 100 hPa” in brackets here, i.e. “(up to 100 hPa)”.

O-MR-15) Line 54 – Re-word “accelerating the classical PCS reactions for chlorine activation also in mid-latitudes”. I think you meant that the presence of the extra aerosol means there’s substantial additional heterogeneous chemistry occurring in mid-latitude, adding to that on the PSCs at high latitudes. Please re-word to better explain what you meant here.

O-MR-16) Line 80 – Section 2.2 heading – change “OSIRIS” to “OSIRIS aerosol extinction”.

O-MR-17) Line 89 – Section 2.3 heading – change “OMPS-LP” to “OMPS-LP aerosol extinction”.

O-MR-18) Line 99 – Section 2.4 heading: change “AURA-MLS” to “Aura-MLS trace gas retrievals”

O-MR-19) Lines 105-107 – Please specify which species you are using to evaluate the model here.

O-MR-20) Caption to Figures 1, 2 and 3– The captions to these Figures notes 500 kt SO2 in the red-line sensitivity simulation, but this is difficult for a time-pressed reader to interpret. Please add “All simulations other than the no-Hunga or 500 kt Hunga run apply 400 kt of SO2.

References

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Joerimann, A., Sukhodolov, T., Luo, B. et al. (2025), “A REtrieval Method for optical and physical Aerosol Properties in the stratosphere (REMAPv1)”, in review, in Geosci. Mod. Dev., https://doi.org/10.5194/egusphere-2025-145

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Zhu, Y., Bardeen, C., Tilmes, S. et al. (2022) “Perturbations in stratospheric aerosol evolution due to the water-rich plume of the 2022 Hunga-Tonga eruption”, Comms. Earth Env., 3, 248 https://doi.org/10.1038/s43247-022-00580-w