

Answers to the reviewer comments for the paper: "Volcanic sulfur dioxide total columns and layer height from the IASI and TROPOMI Layer height products: preprocessing and assimilation on a 0.1° regional domain of MOCAGE"

We would like to thanks the reviewer for their detailed comments and suggestions, which will help improve the article. In the remainder of this document, we provide our full response (in blue) to the reviewers' comments (in black), which details what we did to address their concerns. We include in this document (in italics) some original passages of the article (in green), with modifications and improvements (in red). The following nomenclature has been adopted for the figures and tables: Figure.X are the figures in the initial version of the article, FigRev.x/TabRev.x are the figures/tables in the new version of the article and FigRep.x the plots used exclusively in this document.

The article describes two case studies where the assimilation of TROPOMI and IASI SO₂ products into MOCAGE are carried out, together with the use of layer height information. The manuscripts is well written, but the section about the methodology is not all clear to me, and in particular the key information on how the layer height products are actually used, which is problematic. Other important specifics are also missing. The evaluation of the two case studies is quite well carried out, but could be extended for the aerosol side for the Reykjanes case by including backscatter/extinction profiles products. The manuscript is promising and overall well written, but can be substantially improved by addressing these comments.

Line 21 : typo "obseervations" This typo mistake is corrected.

Line 36-42 : TROPOMI layer height is actually used in the operational IFS-COMPO version used for global CAMS (ie beyond tests for the June 2019 Raikoke eruption). We agree that the assimilation of TROPOMI Layer Height product is not limited to an unique case study. We modify the paper to reflect the operational status of this development.

In the Introduction:

Taking into account plume altitude during assimilation has already shown a significant improvement for the case of Raikoke in 2019 in the Integrated Forecast System for atmospheric composition (IFS-COMPO), where the TROPOMI Layer Height product was assimilated [inness'evaluating'2022]. This assimilation of TROPOMI Layer Height product is not limited to this test case but has since been implemented in the operational IFS-COMPO configuration. Nevertheless, several limitations remain. First, altitude diagnostics from the TROPOMI layer height product are only available when the total column exceeds 20 DU, limiting their use to the most concentrated parts of the plume. In addition, suspicious altitudes are frequently diagnosed at the edge of the plume, where a mixture of clear air and SO₂ plume can bias the retrieval and lead to artificially lower heights. In order to limit the impact of these artefacts on assimilation, a specific pre-processing algorithm was developed in our study to identify and exclude these unrepresentative altitudes.

Line 37 : please define the acronym for IFS The definition of the acronym has been added.

Line 64-70 : Could you please provide an estimate of the amount of SO₂ released by this eruption? (it is surely available from the usual volcanic eruptions databases, such as Carn et al, or from the reference cited). Approximately 23 Gg of SO₂ was calculated in the vicinity of the volcano during the eruption of Etna (https://so2.gsfc.nasa.gov/pix/daily/0824/etna_so2pca_trm_ts_plot).

html). This information is added to the paper:

In the Mount Etna eruption on 4 August 2024 subsection:

Mount Etna is a volcano located in Sicily (37.748°N, 14.999°E) that erupts regularly. In this study, we focus on the eruption that began on 4 August 2024 at 04:08 UTC and ended on 4 August 2024 at 13:18 UTC, with a significant decrease in volcanic activity from 09:10 UTC. According to [GVP'2024'Etna], this eruption released a large amount of ash and SO₂, with the main plume reaching an altitude of approximately 10 km above sea level (a.s.l). A second plume was detected at 6.2 km a.s.l. During this eruption, approximately 23 Gg of SO₂ was calculated in the vicinity of the volcano (https://so2.gsfc.nasa.gov/pix/daily/0824/etna_so2pca_trm_ts_plot.html). Both plumes moved toward the south east. During the most active phase of the eruption, the number of planes landing at Catania airport was reduced to six per hour due to volcanic activity. Under normal circumstances, the number of landings per hour reaches up to 18 per hour.

Line 72-76 : same comment, please provide the reader with an estimate of the amount of SO₂ released. Up to 10 Gg of SO₂ was detected in the vicinity of the Peninsula (https://so2.gsfc.nasa.gov/pix/daily/0824/iceland_so2pca_trm_ts_plot.html). This information is added to the paper:

In the Eruption on the Reykjanes Peninsula from 22 to 26 August 2024 subsection:

The end of 2023 marked the beginning of a period of intense activity on the Reykjanes Peninsula in south-western Iceland. According to [GVP'2024'Islande], seven eruptive episodes occurred between December 2023 and December 2024. In this study, we focus on the eruption that began on 22 August 2024 at 21:26 UTC and ended on 26 August 2024. The most active volcanic activity was observed during the first 24 hours. At the onset of the eruption, the SO₂ and ash plume reached an altitude of 1 km above ground level and drifted southeastward. By 24 August, the SO₂ plume reached Scotland. During this studied period, up to 10 Gg of SO₂ was detected in the vicinity of the Peninsula (https://so2.gsfc.nasa.gov/pix/daily/0824/iceland_so2pca_trm_ts_plot.html).

Line 83 : “Due to the wavelengths, there are no observations during night” – please rephrase and clarify. This sentence becomes:

Because TROPOMI retrievals rely on backscattered solar radiation in the ultraviolet range, no observations are available at night.

Line 109-110 : An accuracy of 2km for the SO₂ layer height is problematic for low level eruptions, no? The 2 km accuracy of the TROPOMI SO₂ Layer Height product is documented in the Algorithm Theoretical Basis Document (ATBD) [theys'atbd'so2'2025]. We agree with the reviewer, however, that this absolute uncertainty of 2 km represents a much more significant relative error for low-altitude, tropospheric eruptions than for stratospheric injections, given the strong vertical wind shear typically present in the lower troposphere.

The reference to the ATBD has been added to the paper.

Line 172 : “the September 2024 version of MOCAGE” – is there a more precise denomination, with a version number? Yes, we have a version number which is R11.23.3. We change the paper.

MOCAGE is the chemistry transport model developed at Météo-France to simulate atmospheric composition on both global and regional up to four days in advance [josse'radon'2004]. It relies on a semi-Lagrangian transport formulation and can operate using nested configurations with different spatial resolutions. In this study, a regional configuration with a horizontal resolution of 0.1° is used to represent volcanic plume transport over Europe and surrounding regions. In our study, the R11.23.3 version of MOCAGE is used. For the case of Mount Etna eruption, the regional domain of MOCAGE is forced by chemical boundary conditions of the IFS-COMPO system, operated by the European Center for Medium-Range Weather Forecasts (ECMWF). For the case of Icelandic eruption, the regional

domain is forced by MOCAGE on a 0.5° global domain. The vertical grid has 60 hybrid σ pressure levels distributed between the surface and 0.1 hPa, with seven levels in the planetary boundary layer, 20 in the free troposphere and 33 in the stratosphere.

Line 194 : Not directly relevant to the discussion, but why are you using MACCCity emissions when much more recent emission datasets (CAMSGLOB, MOSAIC) are publicly available from the same group? This is a mistake, we use the CAMSGLOB inventory for the anthropogenic emission. This mistake has been corrected in the paper.

Lines 205-208 : This paragraph should be reviewed for English standard – a few works are clearly “gallicisms”.

This paragraph has been reviewed:

Many species can be assimilated in MOCAGE, including total ozone columns [emili’combined’2014], ozone profiles [emili2019comparison] and radiances [coopmann2026preparation; vittorioso’assessment’2024; el’aabaribaoune’estimation’2021], which improve the representation of ozone in MOCAGE, as well as aerosol optical depth (AOD) [el’amraoui’pre-operational’2022] and lidar observations [cornut’assimilation’2023], which improve aerosol modelling.

Line 215-225 : Please provide (also with plots) the actual values of B that are used for the assimilation of IASI/TROPOMI SO₂ not just the theoretical framework. If not done already, please do the same for the R values.

The **B** and **R** matrices used are described in Sections 5.1 and 5.2, as two different B profiles were used: one for the initial assimilation configuration (TROPOMI) and another for the assimilation of TROPOMI LH and IASI. The method used to compute **R** depends on the instrument and is presented in these subsections.

For the initial TROPOMI assimilation, the background error standard deviation is a unique profile containing strong values (1×10^{-8} ppv) between levels 49 and 38, corresponding to altitudes between 3 and 10 km. Elsewhere, this profile contains low values (1×10^{-29} ppv), preventing any modification of the model outside this altitude range. For the assimilation of TROPOMI LH and IASI, a constant profile (5×10^{-8} ppv) is used as the background error standard deviation. These descriptions are given in the section describing the practical setup.

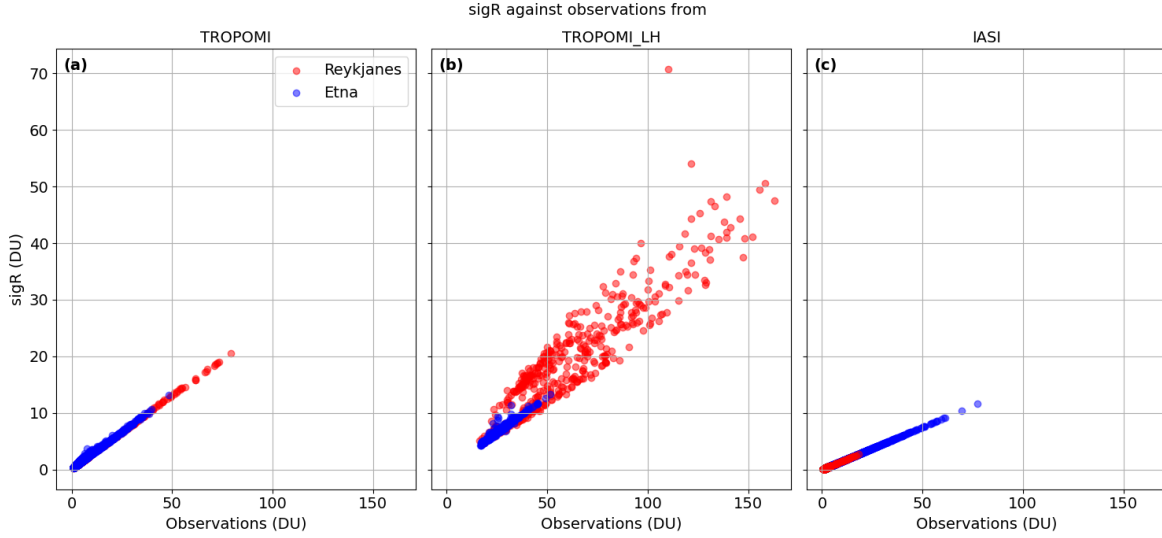
The observation error standard deviations are shown in FigRep.1 for TROPOMI, TROPOMI LH and IASI. For IASI, the observation error standard deviation was fixed to 15% of the observed total column value. For TROPOMI and TROPOMI LH, we used the measurement uncertainties as the observation error standard deviations. We can note that the values provided for TROPOMI roughly correspond to 25% of the observed total column.

Lines 215-225 : How is TROPOMI SO₂ layer height used in this framework? I am not sure that I understand correctly – is it assimilated (ie the first guess layer height – how is it computed? Is modified by DA? How are “increments” of layer height applied to simulated SO₂ concentrations?). Or is used in a different way? In IFS-COMPO, the layer height is used to modify the B matrix – is something similar done here? Please clarify.

Only SO₂ concentration is changed during the assimilation. The layer height is not part of the control variable. Diagnosed altitudes are used before the assimilation process. Indeed, instead of assuming a SO₂ total column distributed along the entire vertical axis, we assume that the entirety of the SO₂ is located in a 2 km-thick layer, as for a partial column. The $\mathcal{H}$ operator then computes the modelled SO₂ column between these two altitudes.

Subsection 5.2 is modified as follows:

In this configuration, only the SO₂ concentration is changed during the assimilation. Diagnosed



FigRep.1: Values of the observation error standard deviation (sigR) according to TROPOMI (a), TROPOMI Layer Height (b) and IASI observations. Blue and red dots represent observations during the Mount Etna eruption and the Sundhnukagigar eruption.

altitudes are used before the assimilation process. Indeed, instead of assuming a SO_2 total column distributed along the entire vertical axis, we assume that the entirety of the SO_2 is located within a 2 km-thick layer centered on the altitude provided by the instruments (shown in Figure 2), as for a partial column. This thickness is consistent with the uncertainties of the TROPOMI Layer Height product. Only SO_2 concentrations between these two altitudes can be changed during the assimilation process.

To further illustrate this mechanism, FigRev.1 shows the analysed SO_2 concentration together with the corresponding analysis increment (analysis minus background) for the joint Assim experiment during the Mount Etna eruption, at 09:00, 12:00 and 19:00 UTC on 4 August. At 09:00 UTC, the positive increment is co-located with the plume (first IASI overpass), adding SO_2 within the corresponding 2 km-thick layer at the diagnosed altitude. At 12:00 UTC, the increment is located at a lower altitude than the simulated plume, resulting in a thickening of the plume rather than a simple reinforcement of its existing structure. At 19:00 UTC, both positive and negative increments are present, illustrating a horizontal repositioning of the plume: negative increments remove SO_2 while positive increments introduce it. This figure and the corresponding discussion have been added to Section 7.1 of the revised manuscript.

Differences in the shape of the plume between the assimilation of each instrument are mainly due to differences in retrieval altitude. Figure 9 shows vertical cross sections at 36.55°N on 4 August at 09:00, 12:00, 18:00 and 19:00 UTC for the simulation in which TROPOMI, TROPOMI LH, IASI, and both IASI and TROPOMI LH are assimilated. The last row of the plot displays the plume altitudes between 35.45°N and 35.65°N observed with IASI in blue and TROPOMI LH in red.

The assimilation of IASI leads to the simulation of a SO_2 plume located between 7 and 15 km of altitude at 9:00 UTC. At the same time, IASI observations detect a plume between 10 and 14 km of altitude. At 12:00 UTC, the simulation that assimilates IASI data shows a plume located between 10 and 14 km of altitude. The modelled plume is higher than that observed by TROPOMI LH, which is located between 7 and 11 km altitude. Due to this altitude discrepancy, the plume in the simulation assimilating TROPOMI LH data is located between 5 and 12 km of altitude. In the joint assimilation experiment, the plume is vertically more extended with a plume located between 5 and 14 km of altitude. In the ref experiment, the assimilation of TROPOMI leads to a simulated plume between 3 and 10 km of altitude around 20°E and 15°E . The simulated concentrations are weaker in this simulation compared to those where altitudes are explicitly considered. The plume simulated around 15°E is not reproduced in the simulation assimilating TROPOMI LH, as the observations do not reach 20 DU. At 18:00 UTC, high

concentrations are simulated around 25°E at an altitude of approximately 10 km when IASI data are assimilated. In the other experiments, the plume is more spread out, both vertically and horizontally. The assimilation of TROPOMI LH results in the highest simulated SO₂ concentrations. Simulations assimilating the TROPOMI LH and both IASI and TROPOMI LH instruments yield similar results. The assimilation of TROPOMI produces the lowest concentrations, but the plume structure remains consistent with the experiment assimilating TROPOMI LH.

To better illustrate the assimilation process and its impact on SO₂ concentrations, FigRev.1 shows the analyzed SO₂ concentration and the corresponding analysis increment for the joint Assimilator experiment at 09:00, 12:00, and 19:00 UTC on 4 August. Before 09:00 UTC, no plume is simulated by MOCAGE. At 09:00 UTC, IASI observations are assimilated, allowing SO₂ to be added to the model between altitudes of 7 and 15 km, as indicated by the positive increments. A plume is thus present within this altitude range. At 12:00 UTC, SO₂ is added at the altitude diagnosed by TROPOMI LH, between 4 and 12 km. However, positive increments occur at a lower altitude than the simulated plume, thanks to the IASI assimilation. Consequently, the thickness of the plume becomes larger. At 19:00 UTC, both positive and negative increments are present, illustrating a horizontal repositioning of the plume: negative increments remove SO₂, while positive increments add it.

Line 217: “Only results for a 0.15° horizontal length scale are shown” : why is that? And what was the impact of the correlation length in B? That is something that should be discussed and is of interest to the reader. Different values of the horizontal length scale had been tested. Results obtained for the Mount Etna eruption are shown in FigRep.1. In this figure the modelled SO₂ total columns are shown on 4 August 2024 at 12:00 UTC and 19:00 UTC, and on 5 August at 12:00 UTC by using a 0.05°, 0.1°, 0.15°, and 0.25° horizontal length scale.

The use of a 0.05° horizontal length scale leads to the simulation of an underestimated SO₂ plume, both in size and intensity. On the contrary, the use of a 0.25° horizontal length scale produces a plume which is too spread out and too intense. The use of a 0.1° or a 0.15° horizontal length scale enables the simulation of a plume whose size is more consistent with observations. However, the intensity of the plume seems to be closer to the observations when a 0.15° horizontal length scale is used.

Results obtained by using different length scale are shown in an appendix of the paper.

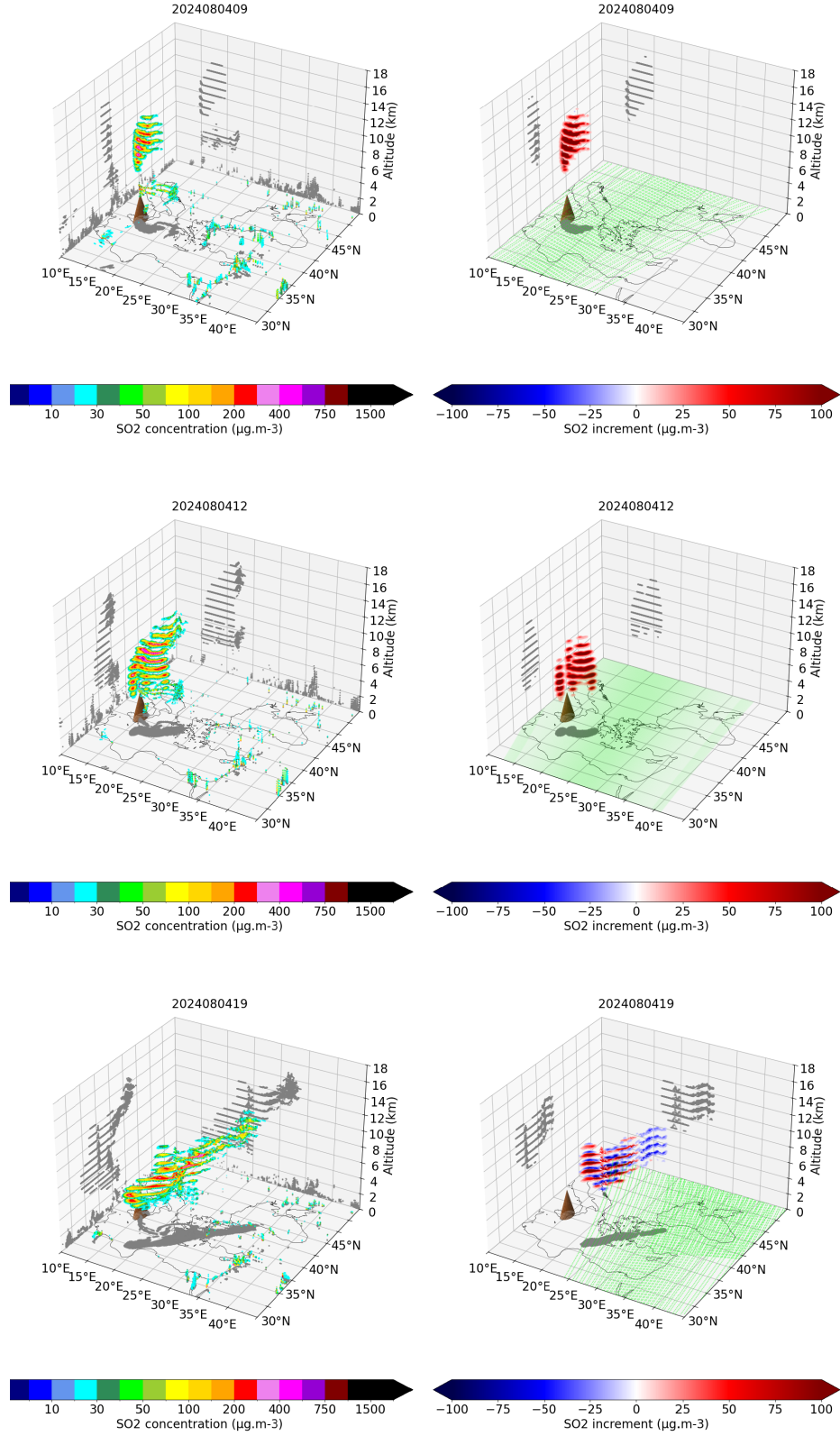
We remove the sentences “In this study, different length scale values are tested for the assimilation of IASI and TROPOMI LH. Only results for a 0.15° horizontal length scale are shown.” Indeed, I realize there is a mistake. For the assimilation of TROPOMI, we use a horizontal length scale of 0.1°, corresponding to the resolution of the regional domain of MOCAGE.

In the Subsection 5.1:

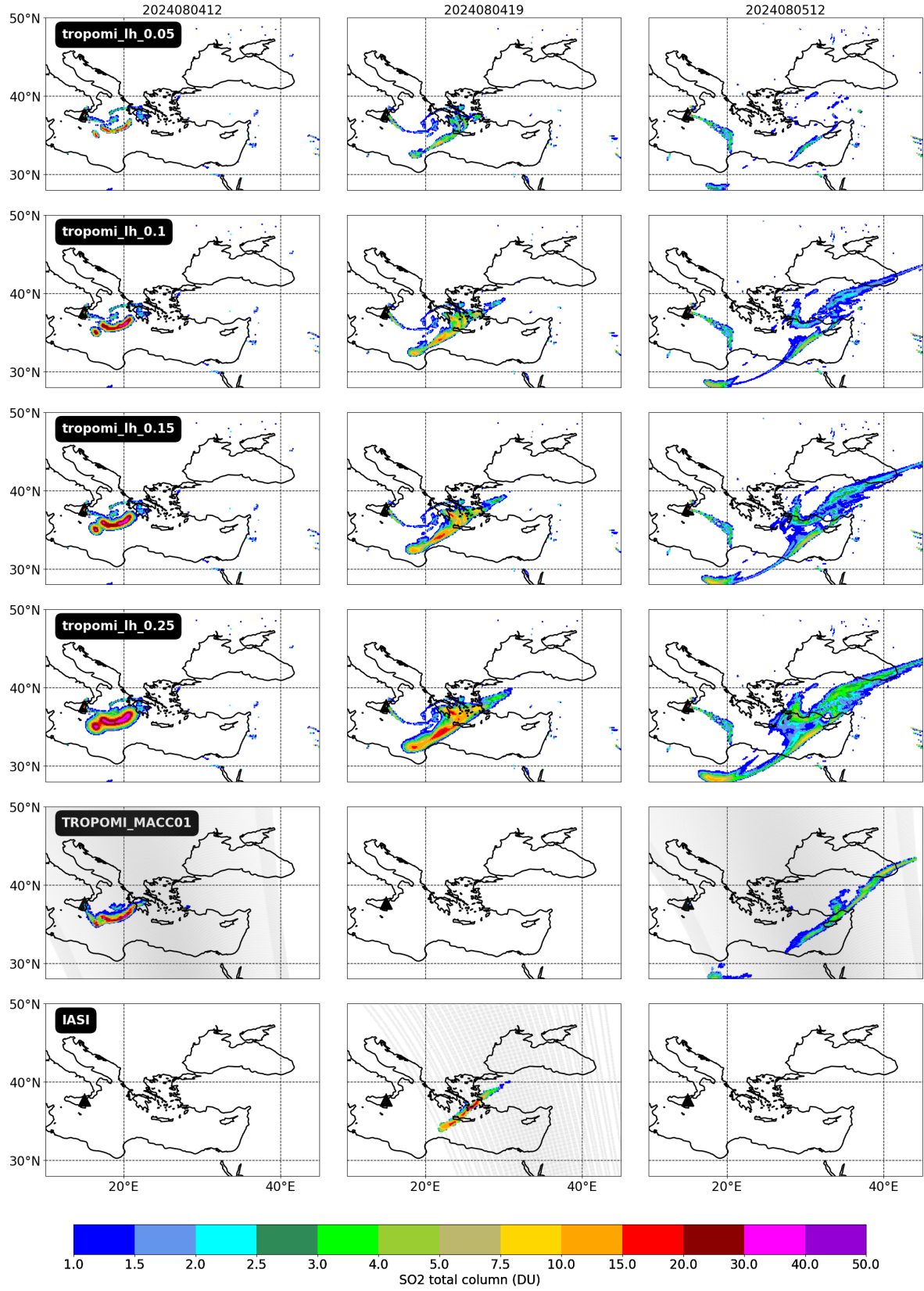
To vertically constrain the injection of SO₂ during assimilation, a background error standard deviation profile was defined with strong values (1×10^{-8} ppv) between vertical levels 49 and 38, which correspond approximately to altitudes between 3 and 10 km. These altitudes are generally representative of volcanic eruptions that occur in the regional domain used for the study. Nevertheless, the altitudes of the plume can be outside this altitude range, as shown in Figure 2. In this figure, assimilation using the configuration described above allows the SO₂ concentration in the grey area to be corrected. However, the plume is outside this range for TROPOMI LH in the case of the eruption on the Reykjanes Peninsula and for TROPOMI LH and IASI in the case of the Mount Etna eruption. Regarding the horizontal correlation, a length scale of 0.1° is used in this baseline assimilation, corresponding to the resolution of the regional domain.

The description of the horizontal length scale used to assimilate TROPOMI LH and IASI is in the Subsection 5.2:

A constant background error standard deviation profile is prescribed, with values of 5×10^{-8} ppv. Several tests are performed using different values for the horizontal correlation part of the **B** matrix by changing the horizontal length scale ($\alpha \in [0.05, 0.1, 0.15, 0.25]$). The obtained results are shown



FigRev.1: SO₂ concentration obtained after the assimilation (left column) and analysis increment (right column, analysis minus background) for each model grid point for the joint_assim experiment during the Mount Etna eruption, at 09:00, 12:00, and 19:00 UTC on 4 August 2024. Grey dots show the projection of the plume on the borders of the plot. The green pixels represent satellite overpass.



FigRep.2: *SO₂ total columns simulating on 4 August at 12:00 and 19:00 UTC and on 5 August at 12:00 UTC by assimilating TROPOMI LH product and by using different values as the horizontal correlation length (0.05°, 0.1°, 0.15°, and 0.25°). The two last rows show the TROPOMI and IASI observations.*

in Figure ??. The use of a 0.15° horizontal length scale leads to a better representation of the SO_2 volcanic plume in the model.

Line 230 : “set to 0.5” – any justification for this? Other values have been tried?

Other values have been tried (0.25 and 1). The use of different vertical length scales leads to similar simulated SO_2 total columns. We noticed that a higher vertical length scale leads to slightly higher SO_2 total columns, while a lower vertical length scale leads to slightly weaker total columns. As the results are not highly sensitive to this parameter, a value of 0.5 was retained as a reasonable intermediate choice.

Paragraph 5.2 : It is not clear to me how the layer height from TROPOMI or IASI information is used here. Also, what happens is the two contradict – as is the case for Reykjanes? Only SO_2 concentration is changed during the assimilation. Diagnosed altitudes are used before the assimilation process. Indeed, instead of assuming a SO_2 total column distributed along the entire vertical axis, we assume that the entirety of the SO_2 is located in a 2 km-thick layer. The $\mathcal{H}$ operator then computes the modelled SO_2 column between these two altitudes.

Subsection 5.2 is modified as follows:

In this configuration, only the SO_2 concentration is changed during the assimilation. Diagnosed altitudes are used before the assimilation process. Indeed, instead of assuming a SO_2 total column distributed along the entire vertical axis, we assume that the entirety of the SO_2 is located within a 2 km-thick layer centered on the altitude provided by the instruments, consistent with the uncertainties of the TROPOMI Layer Height product. Only SO_2 concentrations between these two altitudes can be changed during the assimilation process. The altitudes of the centre of the plume that are assimilated are plotted in Figure 2.

The case for the Reykjanes with contradictory altitudes is added to the paper in Section 8 Eruption on the Reykjanes Peninsula: 22 to 25 August 2024:

Modification occurs at the beginning of the Subsection 8.1:

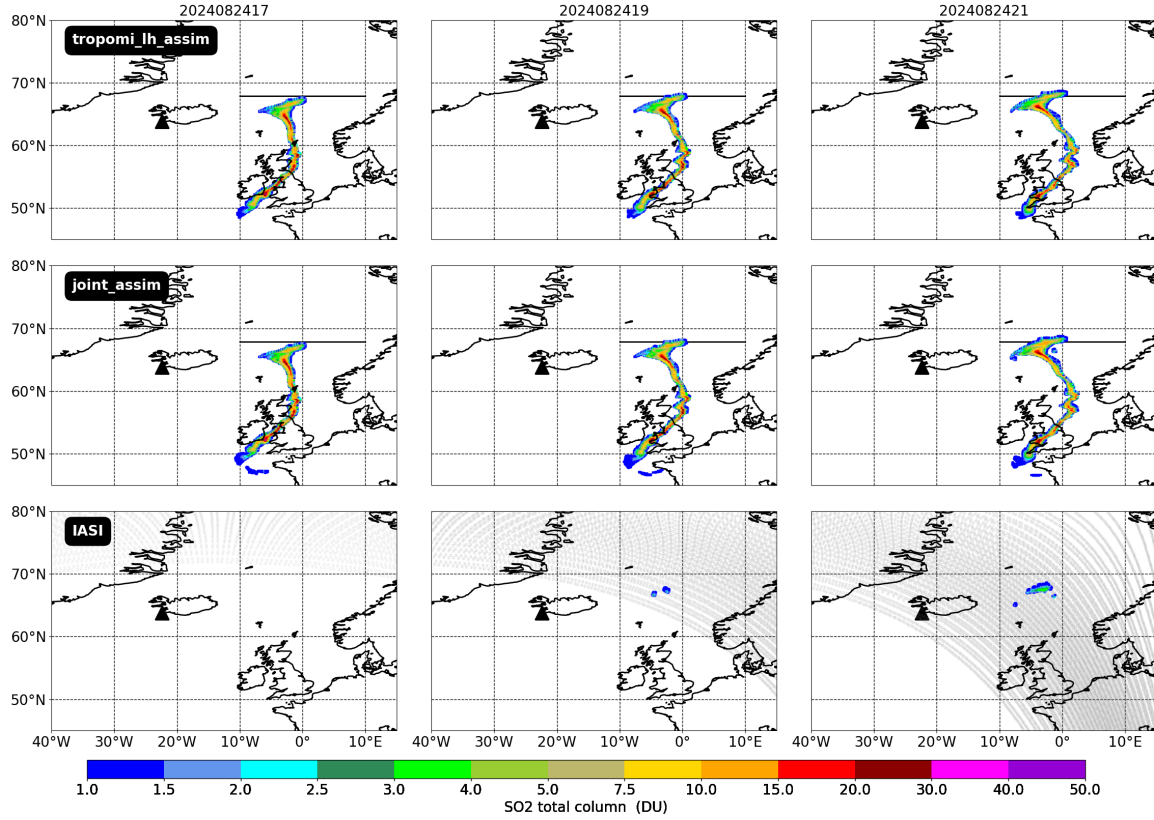
Figure 15 shows SO_2 during the eruption on the Reykjanes Peninsula on 23 August 2024 at 13:00 UTC, on 24 August 2024 at 10:00, 12:00, 13:00 UTC and on 25 August 2024 at 12:00 UTC. The first two rows show the analysis outputs: the assimilation of TROPOMI and the assimilation of TROPOMI LH. In this subsection, only the results of the TROPOMI LH assimilation are shown, and the joint assimilation of IASI and TROPOMI LH is discussed later. The last three rows display the corresponding satellite observations from TROPOMI LH, TROPOMI assuming a plume from ground level to 1 km of altitude, and OMPS assuming a plume around 3 km of altitude, respectively.

A new subsection has been added:

8.3 Joint assimilation of TROPOMI LH and IASI

For this case study, the altitudes diagnosed by TROPOMI LH and IASI differ. TROPOMI LH indicates the presence of an SO_2 plume at an altitude of 1–3 km, whereas IASI indicates a plume at an altitude of 5–7 km (Figure 2). When TROPOMI LH is assimilated alone, the model represents a plume near the surface. Furthermore, assimilating this product reproduces an increase in SO_2 concentration that is also captured by AirBase observations. Assimilating IASI alone results in the simulation of a plume later, starting on 24 August at approximately 19:00 UTC. This plume is located at an altitude of around 6 km.

The results of the joint assimilation are presented in FigRev.2, with the modelled total columns obtained by assimilating TROPOMI LH alone in the first row and by jointly assimilating both instruments in the second row. IASI observations are shown in the last rows for 24 August at 17:00, 19:00,



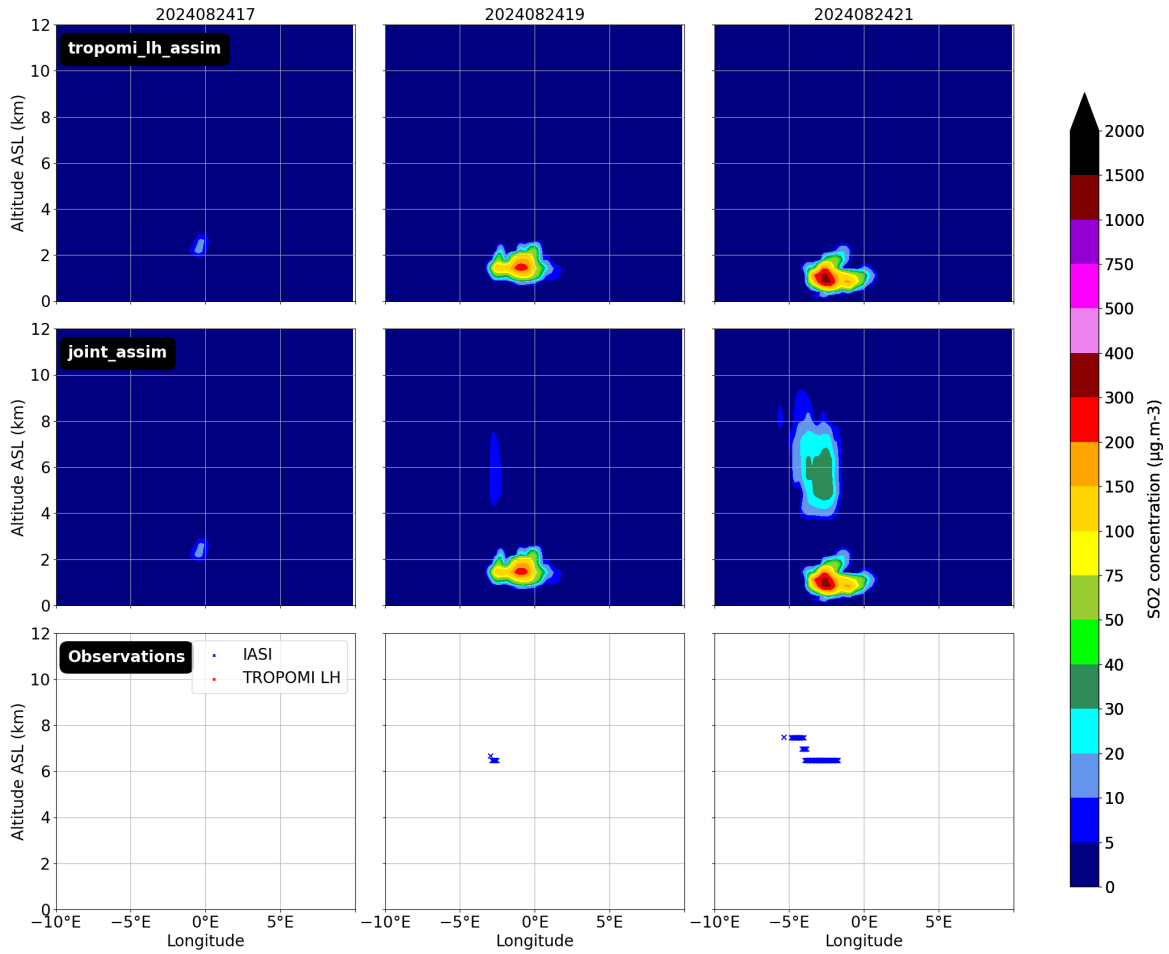
FigRev.2: Analyses of SO₂ total columns on 24 August 2024 at 17:00, 19:00 and 21:00 UTC. The first two rows correspond respectively to the outputs of the assimilation of TROPOMI LH observations and the joint assimilation of TROPOMI LH and IASI products. Observations from IASI are plotted on the last row. Overpasses of satellites are plotted in light grey. The black line indicates the location of the vertical cross-sections at 67.85°N.

and 21:00 UTC.

At 17:00 UTC, the plume is identical in both experiments since no IASI observations were assimilated. At 19:00 UTC, although observations were assimilated, the total SO₂ column values are similar. At 21:00 UTC, additional, more numerous IASI observations are assimilated. Although the observed column values are low, slightly higher total columns are simulated by MOCAGE in the experiment where IASI and TROPOMI LH data are assimilated.

Although few differences are observed in the total column maps, significant differences are illustrated in FigRev.3, which shows a vertical cross-section at 67.85°N when TROPOMI LH is assimilated (top row) and when IASI and TROPOMI LH are jointly assimilated (middle row). The bottom row shows the plume altitude diagnosed by IASI on 24 August 2024 at 17:00, 19:00, and 21:00 UTC.

On 24 August at 17:00 UTC, no IASI observations are assimilated. Consequently, an identical plume is simulated in both experiments between 2 and 3 km in altitude. At 19:00 UTC, both experiments indicate the presence of high SO₂ concentrations between 1 and 2 km in altitude. At this altitude, the simulated concentrations are identical in both experiments. However, IASI observations indicating the presence of a plume at an altitude of 7 km are assimilated. In the experiment assimilating data from both instruments, low concentrations appear at altitudes between 4 and 7 km. At 21:00 UTC, numerous observations are assimilated. Higher concentrations are modelled between 4 and 8 km in altitude, as the altitudes diagnosed by IASI range from 6 to 8 km. Due to the differences in altitude diagnosed by the two instruments, two distinct plumes are simulated along the vertical profile.

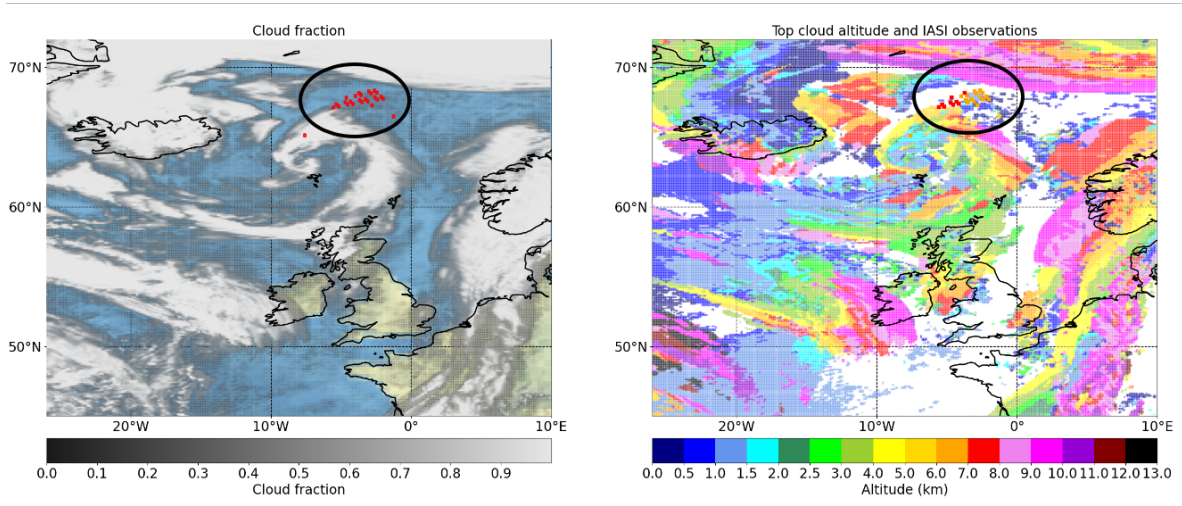


FigRev.3: Vertical cross-sections of the analyzed SO₂ concentration at 67.85°N on 24 August 2024 at 17:00, 19:00, and 21:00 UTC. Rows correspond to the assimilation of TROPOMI LH product, the joint assimilation of TROPOMI LH and IASI and height of the SO₂ plume diagnosed by TROPOMI LH (in red) and IASI (in blue).

One possible explanation for the detection of a plume at a higher altitude using IASI is the presence of clouds within the observed pixels. FigRev.4 shows the cloud fraction and cloud-top altitude predicted by IFS for 24 August 2024 at 21:00 UTC. The locations of the IASI observations are marked by red dots in the left panel, while the altitudes diagnosed by IASI are represented by the dots in the right panel. These altitudes range from 6 to 8 km.

IASI observations are generally located in regions where cloud cover is predicted by the IFS. However, the cloud fraction in these regions is approximately 0.4, indicating that the pixels are not necessarily fully cloud-covered. Consequently, an IASI pixel may contain both volcanic SO₂ and clouds. In such cases, the signal measured by IASI can be influenced by both the SO₂ spectral signature and the radiation emitted by the clouds. Since the clouds are located at altitude, their temperature may be lower than that of the surface and—depending on the situation—lower than that of the volcanic plume when the latter is at a lower altitude. The presence of clouds could thus alter the radiative signal measured by IASI, leading to a diagnosed SO₂ altitude that is higher than the actual plume altitude.

This hypothesis is consistent with the presence of clouds in the region of the observations. Cloud tops predicted by IFS generally range from 1 to 7 km in altitude in this area, whereas IASI observations indicate plume altitudes between 6 and 8 km. However, clouds reaching higher altitudes are present in the vicinity of the IASI observations. Furthermore, the cloud fields used here are derived from an IFS



FigRev.4: Cloud fraction (left) and cloud top altitude (right) from the meteorological forcings used by MOCAGE on 24 August 2024 at 21:00 UTC. Red points in the left panel indicate the location of IASI observations. The altitudes diagnosed by IASI are plotted in the right panel (altitudes ranging from 6 to 8 km).

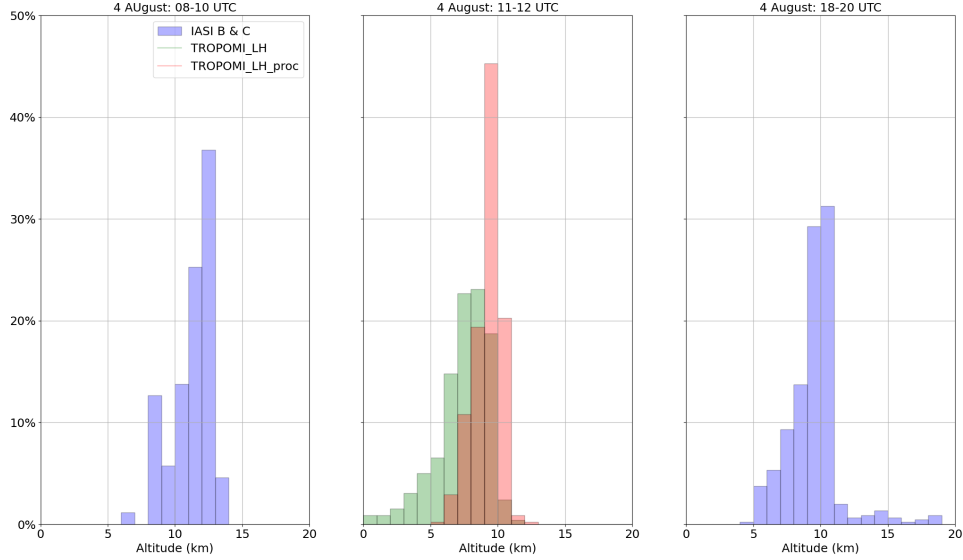
forecast and are therefore subject to their own uncertainties. It is thus possible that the cloud cover reaches a higher altitude than predicted. However, confirming this hypothesis is difficult because these observations are located at the edge of the domain, or even slightly further north relative to the MSG satellite's view. Nevertheless, at the edge of the domain, the cloud top height product from MSG suggests clouds with tops at altitudes between 5 and 10 km. The presence of clouds is therefore a plausible hypothesis to explain the high altitudes diagnosed by IASI.

We add this important limitation to the conclusion:

One potential source of discrepancy lies in the assumption of a fixed plume thickness. In the present study, the same vertical thickness is prescribed for both case studies, although the actual plume thickness may vary depending on eruption intensity, atmospheric stability, and injection dynamics. An inaccurate specification of plume thickness can lead to an excessive vertical spreading of SO_2 in the model, which in turn may enhance horizontal dispersion and contribute to an overestimation of plume extent. In addition, differences in plume altitude diagnostics between instruments constitute another source of discrepancy. TROPOMI Layer Height and IASI rely on distinct spectral ranges and retrieval methodologies, which may result in different estimated plume heights for the same event. When such differences are assimilated, especially in a multi-instrument framework, they may induce corrections at multiple vertical levels and contribute to an artificial vertical broadening of the simulated plume. This was illustrated for the Reykjanes eruption, where IASI diagnosed a plume altitude 5–7 km higher than TROPOMI LH, likely due to cloud contamination of the IASI signal, resulting in an artificial high-altitude SO_2 layer in the joint assimilation experiment.

Line 298 : the section about the preprocessing of LH is very interesting. The impact seems to be significant, but it is not quite properly evaluated – would it be possible here to include a comparison against independent estimates of SO_2 layer height, such as those provided by IASI (other products are also likely available). It is mentioned that “the resulting plume altitudes are consistent with IASI observations” : please include and show them. Has there been a study on more than one plume to show that the preprocessing is improving the retrieved LH?

Thanks you for your positive feedback on this preprocessing. We add a comparison between the diagnosed altitude by IASI B and C between 08:00 and 10:00 UTC and between 18:00 and 20:00 UTC, TROPOMI LH between 11:00 and 12:00 UTC (green for altitudes without preprocessing , red for preprocessed altitudes). The distribution of the altitudes is shown in FigRev.5 and has been added to the paper.



FigRev.5: Distribution of plume altitudes (as a percentage of observations within each 1 km bin) for IASI B and C (blue), TROPOMI LH before preprocessing (green) and TROPOMI LH after preprocessing (TROPOMI_LH_proc, red), for three time windows on 4 August 2024: 08:00–10:00 UTC (left), 11:00–12:00 UTC (middle), and 18:00–20:00 UTC (right).

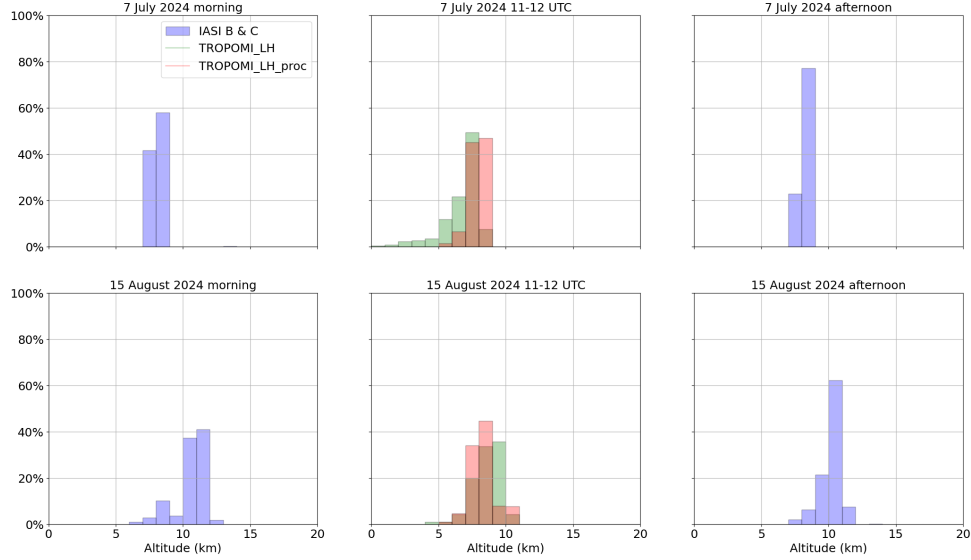
FigRev.5 has been added to the paper:

Figure 3 displays the TROPOMI LH observations before (a, c) and after (b, d) the application of the previously described algorithm. The algorithm removes several isolated observations near Greece and increases the plume altitude, particularly around 19°E/36°N and at the plume edges. FigRev.5 shows the distribution of plume altitudes diagnosed by IASI B and C (in blue) for three time windows on 4 August (08:00–10:00, 11:00–12:00, and 18:00–20:00 UTC), together with the TROPOMI LH altitude distribution before (in green) and after (in red) preprocessing, for the 11:00–12:00 UTC window corresponding to the TROPOMI overpass. Before preprocessing, the TROPOMI LH distribution is broader and centered at a lower altitude than the IASI distributions observed before and after. After preprocessing, it narrows and shifts toward higher altitudes, becoming more consistent with the altitudes diagnosed by IASI. In the following, the observations shown in Figures 3 b and d are assimilated.

We performed the same comparison for two additional eruptive windows: 7 July 2024 and 15 August 2024, both also on Mount Etna. FigRep.3 shows the resulting altitude distributions. For 7 July 2024, the preprocessed TROPOMI LH distribution shifts toward higher altitudes, in better agreement with IASI. For 15 August 2024, the preprocessing instead shifts the distribution toward slightly lower altitudes. However, TROPOMI LH altitude information is only available for total columns exceeding 20 DU, whereas IASI has no such threshold. Consequently, the two instruments do not necessarily sample the same part of the plume, which may explain part of the discrepancy observed for this case rather than indicating a failure of the preprocessing algorithm itself.

Section 7.1 title : sulfate aerosols are barely discussed (one line), so please remove “sulfate” from title. The title is modified and become “*Impact on SO₂*”

Figure 7 : please explicit what are the shaded areas for the retrieval rows (availability of data I suppose) The shaded areas represent the overpasses of satellites. We modify the caption of this figure:



FigRep.3: Distribution of plume altitudes (as a percentage of observations within each 1 km bin) for IASI B and C (blue), TROPOMI LH before preprocessing (green) and TROPOMI LH after preprocessing (TROPOMI.LH.proc, red), on 7 July and on 15 August 2024 between 14°E/32°E and 28°N/45°N.

Observations assimilated and analyses of SO₂ total columns on 4 August 2024 at 09:00, 12:00, 19:00 UTC, and on 5 August 2024 at 12:00 UTC. The first four rows correspond respectively to the ref, tropomi.lh.assim, iasi.assim and the joint.assim analysis outputs. Observations from TROPOMI LH, TROPOMI, IASI and OMPS are plotted on the four last lines. Overpasses of satellites are plotted in light grey.

Figure 9 : I am not sure what is the added value of Figure 9 as compared to Figure 7, which already includes independent data (OMPS). A limitation of OMPS is that its overpass time is close to that of TROPOMI. Consequently, OMPS mostly evaluates the model at the same time as the TROPOMI/TROPOMI LH assimilation window. The added value of evaluating the model against MSG is to assess the dispersion of the plume and indirectly to validate the altitude at which the plume is transported within the model. We find that repeating the maps from the simulations makes it easier for the reader to compare.

Figure 10 could be discussed right after Figure 7 as it includes the same information (independent such as OMPS, and not for the others). Actually I think sections 7.1 and 7.2 could be merged based on Figs 7, 8 and 10.

We have chosen to keep Sections 7.1 and 7.2 as separate subsections, as they serve different purposes. Section 7.1 describes the qualitative evolution of the simulated plume structure and intensity across experiments, using all available satellite observations (assimilated and independent) as visual references (Figures 7 and 8). Section 7.2 focuses specifically on the quantitative evaluation of model performance against independent, non-assimilated observations, using dedicated metrics such as plume area, SO₂ burden (Figure 10), and detection scores (Figures 11 and 12).

The section about the threshold skill scores is very interesting to read.
Thanks you for your positive feedback on this metric.

Lines 565 and following : for sulfate aerosols, it would be good to include a comparison of simulated backscatter or extinction profiles to observations either from the e-profile network, or from

Earthcare/ATLID (data should be available for these dates). Here, a difference is noted but we have no information whether this is a positive or negative change. We looked at observations from EarthCARE and the E-PROFILE network. However, the EarthCARE sulfate aerosol product is only available for the stratosphere, and is therefore not suited to this case, in which the plume remains within the troposphere. E-PROFILE instruments detect aerosols during this period, but it is difficult to determine what proportion of the detected aerosols corresponds to volcanic sulfate. Indeed, in addition to the plume from the eruption (SO_2 and sulfate aerosols), aerosols originating from wildfires in Canada are also present in the region during this period, making it difficult to attribute the observed backscatter signal unambiguously to the volcanic plume.