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Interactive comment on "Volcanic plume height during the 2021 Tajogaite eruption (La Palma) from two complementary monitoring methods. Implications for satellite-based products" by África Barreto et al.

Anonymous Referee #2

General Comments:

This manuscript offers a thoroughly conducted and significant investigation into the characterization of plume heights during the 2021 Tajogaite (La Palma) eruption, utilizing complementary datasets from IGN video observations, AEMET–ACTRIS aerosol profilers, and satellite instruments. The study emphasizes the essential role of precise, real-time plume height measurements in ensuring reliable satellite retrievals of volcanic emissions and establishes a valuable framework for future volcanic crisis management.

The primary enhancements required are minor, including the incorporation of fundamental statistical indicators such as RMSE and correlation for the AEMET-IGN comparison (see Fig. 4), a concise sensitivity analysis of CALIOP results, clarification or correction within graphical regions, and the explicit delineation of uncertainty ranges.

The manuscript is clearly written, well organized, and enhanced with high-quality figures. It makes a significant and original contribution to atmospheric measurement science**.** I recommend acceptance after minor revisions.

Answer from the authors to the general comments: The authors appreciate the constructive comments provided by this referee. The first comment, concerning the inclusion of statistical analyses in the comparison of volcanic plume height databases, will be addressed in the specific responses, as well as in our reply to Referee 1. The comment regarding the analysis of the results of the comparison with CALIOP coincides with Specific Comment number 5 from the Referee 1. In this regard, a detailed explanation has been provided on the validity of this comparison, as well as on the classification of aerosol types performed by the CALIOP products for the events selected for the comparison. Finally, regarding the expected uncertainty of the CALIOP product, all references in the literature aim to assess its quality through comparison and validation strategies, such as those carried out in this work and cited in the corresponding section. Unfortunately, to the best of our knowledge, it is not possible to provide further information on the specific uncertainty ranges of this satellite product. A detailed response related to the possible effect of a wide overpass distance has been also given in the Referee 1 Specific Comment number 5.

Technical Comments:

Regarding Figure 4: This plot would substantially benefit from the inclusion of a descriptive table that provides a comprehensive statistical analysis. This should include correlation coefficients between the AEMET-ACTRIS and IGN datasets for dispersive plume heights (h_d). Additionally, such a table could quantify differences stratified by AEMET instrument type in comparison to IGN

measurements, thereby enhancing the interpretability of inter-method consistency. Notably, multiple data points appear for the same day and source (particularly for h_d, IGN), which may introduce visual clutter; consolidating these into daily aggregates—such as means and standard deviations, where applicable—could improve clarity. Nonetheless, the table already presents a synthesized view, as it is effectively summarized in Figure 5a through daily averaged values by source. The proposed statistical table would thus serve as a valuable complement for a rigorous intercomparison.

As stated in the response number 3 to the Referee 1 Scpecific Comments, we fully agree on the advantages of extending the discussion of the different techniques by adding relevant statistical information, as pointed out by the Referee in this comment. The details of this expanded discussion are presented below and are the same as those provided in response 3 to Referee 1.

[Line 402] **In light of the comparison results shown in Table 1, it can be observed that the methodology used to derive the volcanic plume height from lidar data does not appear to play a dominant role in the comparison outcomes, with the best statistics obtained for the FUE and TAZ cases (Gradient Method in both cases).**

Table 1: Main statistical skill scores (in m) for the comparison between $h_{d,IGN} – h_{d,AEMET}$ differences, including also the multi-instrument and inter-method comparison between $h_{d,IGN}$ and the height of the volcanic plume measured by AEMET at the five different stations. The methodology for retrieving the altitude of the volcanic plume is also included. GM stands for the Gradient Method, and WCT for the Wavelet Covariance Transfer method.

	$h_{d,IGN} – h_{d,AEMET}$	$h_{d,IGN} – h_{d,ORM}$	$h_{d,IGN} – h_{d,FUE}$	$h_{d,IGN} – h_{d,AER}$	$h_{d,IGN} – h_{d,TAZ}$	$h_{d,IGN} – h_{d,EP}$
Methodology	Multi-approach	Qualitative	GM	WCT	GM	WCT
Mean Difference	258.6	-139.8	203.6	430.4	344.8	941.7
Standard Deviation	620.4	866.5	531.7	540.7	487.1	468.5
RMSE	672.1	877.7	569.4	691.1	596.8	1051.8
Pearson coefficient (r)	0.81	0.18	0.86	0.64	0.89	0.72
Slope	0.90	0.10	0.86	0.99	0.99	1.16
Intercept	103.4	3918.8	307.1	-426.4	-302.9	-1520.6

Regarding Figure 6: The discussion of wind direction analysis in lines 473–479 lacks sufficient clarity, particularly in elucidating the methodological basis for the wind rose construction. Intermediate directional sectors (intercardinal headings) between principal cardinal points (N–E–S–W) are incorrectly labeled; for instance, the sector between south and west should be designated SW, with analogous corrections for other quadrants. The boundary between W and SW, corresponding to 247.5° (referenced to 0° as north) as WSW, exemplifies this issue. Conventionally, wind roses depict the direction *from* which the wind originates (provenance), rather than toward which it blows. I recommend redrawing the wind rose with explicit labeling of the directional convention (e.g., "wind from" or "wind toward") to avoid ambiguity. Furthermore, while Figure 1 accurately positions the Tazacorte (west) and Fuencaliente (south) stations relative to the island, the text and

Figure 6 introduce confusion in their spatial referencing, which should be reconciled for consistency.

The authors fully agree with this comment. We appreciate this observation regarding the issues in the figure, as it has helped us improve the presentation of the results and avoid potential confusion for the reader. Indeed, there was a clear error in the labels corresponding to the half-axes of the cardinal points, which has now been corrected. Additionally, a new plot has been produced, this time using bars, to allow a clearer analysis of wind direction. This analysis has been conducted taking into account the origin of the wind to avoid any ambiguity, as the referee states in his/her comment.

This is the new corrected figure and figure caption:

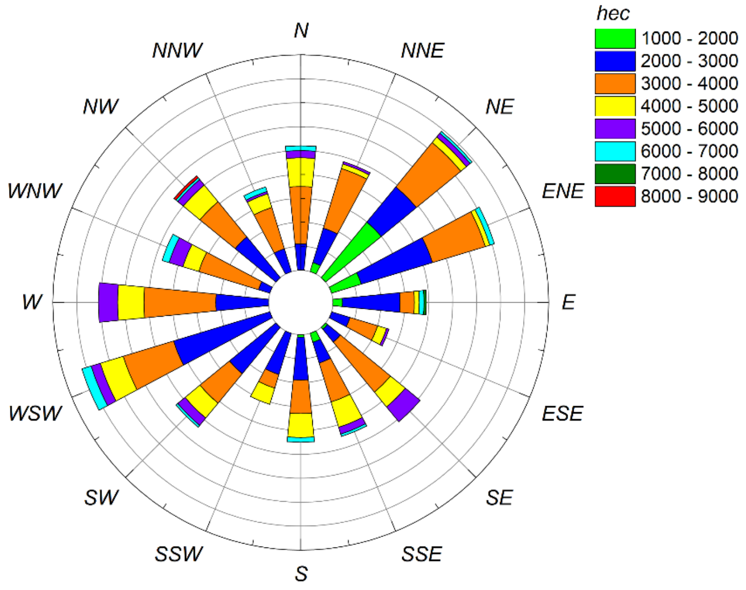

Figure 6. Wind rose diagram for the volcanic eruptive column hec (in m a.s.l.) and HARMONIE-AROME wind **direction** at the pixel **above** the volcanic edifice in Cumbre Vieja. **Wind direction is given following the meteorological convention (direction of origin).**

The new text in the corrected manuscript is the following (lines 478-479):

"This distribution highlights the role of wind direction in plume transport and vertical dispersion, further evidenced in Fig. 6, which displays the wind rose diagram for the study period. **The trade wind regime (originating from the NE) remains predominant while the volcanic plume height stays within the marine boundary layer (up to 2000 m a.s.l.). Above this level, a change in prevailing wind direction occurs, as expected from the vertical balance of forces at this latitude. Up to 4000 m a.s.l., two predominant components are observed (NE and W–WSW). It must be noted that this analysis reflects the wind structure under the specific meteorological conditions of the 85-day eruption period and cannot be interpreted as a climatological pattern.**"

Regarding Figure 8 and section 4.4: the data points representing the eruptive column height (h_ec) are indicated by blue circles, not orange as might be inferred from the caption or legend—please verify and rectify this for accuracy. Additionally, the use of the color "red" may be preferable to "light red." The SO_2 emission rates are expressed in kilotonnes, yet they seem to pertain to daily fluxes (kt day^{-1}); explicitly stating the temporal averaging (e.g., daily emission rates [kt·day^{-1}]) in the axis labels and accompanying text would prevent misinterpretation. Furthermore, it is advisable to review the bibliography to include any prior studies that report similar underestimations of satellite-derived emission rates during volcanic eruptions (e.g., via UV hyperspectral retrievals). If applicable, incorporate references to complementary ground-based or alternative methodological estimates of SO_2 emission rates (kt day^{-1}), such as differential optical absorption spectroscopy (DOAS) or flux tower measurements related to Tajogaite, in order to provide a more comprehensive contextualization of the findings.

The authors fully agree with this comment, which has allowed us to correct the error in the color attribution in Figure 8, as well as the typographical error related to the units of the SO_2 emission fluxes.

This is the new corrected figure and the figure caption:

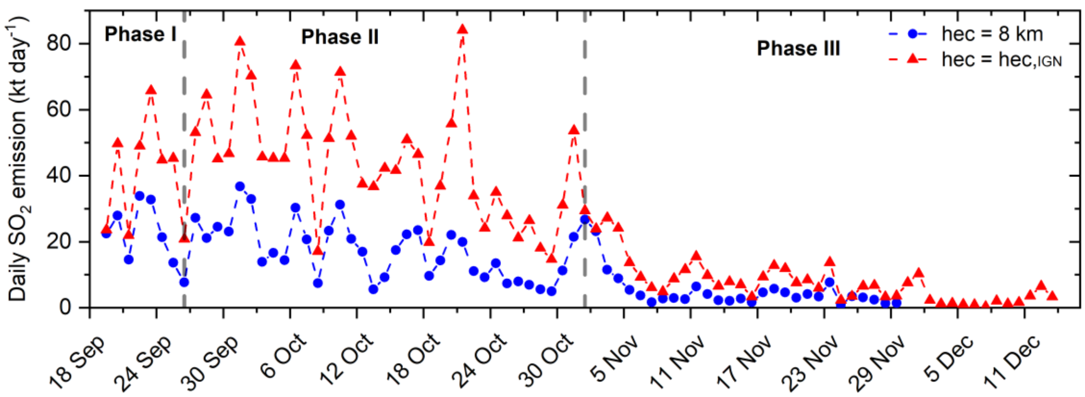

Figure 8. NASA **daily** SO_2 **emission** (in kilotons **per day**, kt **day^{-1}**) calculated as the average of OMI, OMPS and TROPOMI UV backscatter radiances considering a standard columnar injection height of 8 km (**blue circles**) and the real h_{ec} measured by the IGN (in **red triangles**). Dotted vertical lines represent the three eruptive phases derived from RSAM data series.

Regarding the new references to be added in the text, the new paragraph is the following:

"Consistent daily emissions for the Tajogaite volcano were calculated by Esse et al. (2025) by means of a novel forward trajectory approach using PlumeTraj, a pixel-based trajectory analysis of an SO_2 cloud Pardini et al. (2017). Ground-based miniDOAS observations of SO_2 emissions were also carried out during the Tajogaite eruption. This is exemplified by the studies of Albertos et al. (2022) and Rodriguez et al. (2023), which reported SO_2 emissions ranging from 670 to 17 tons per day and observed a clear decreasing trend in SO_2 during the post-eruptive phase."

The authors have also added new reference to SO_2 emissions published by Esse et al. (2025) as a result of the Specific Comment number 6 of the Referee 1. The following information has been included in the corrected manuscript (line 506):

“Comparable daily SO_2 emission values to those retrieved using $h_{ec,IGN}$ were reported by Esse et al. (2025) for the same eruption, based on the PlumeTraj analysis, with lower mean relative differences of 21.6%.”

References:

Pardini F, Burton M, Vitturi MD, Corradini S, Salerno G, Merucci L, Di Grazia G (2017) Retrieval and intercomparison of volcanic SO_2 injection height and eruption time from satellite maps and groundbased observations. J Volcanol Geoth Res 331:79–91.

Albertos, V. T., Recio, G., Alonso, M., Amonte, C., Rodríguez, F., Rodríguez, C., Pitti, L., Leal, V., Cervigón, G., González, J., Przeor, M., Santana-León, J. M., Barrancos, J., Hernández, P. A., Padilla, G. D., Melián, G. V., Padrón, E., Asensio-Ramos, M., and Pérez, N. M.: Sulphur dioxide (SO_2) emissions by means of miniDOAS measurements during the 2021 eruption of Cumbre Vieja volcano, La Palma, Canary Islands, EGU General Assembly 2022, Vienna, Austria, 23–27 May 2022, EGU22-5603, https://doi.org/10.5194/egusphere-egu22-5603, 2022.

Rodríguez, O., Barrancos, J., Cutillas, J., Ortega, V., Hernández, P. A., Cabrera, I., and Pérez, N. M.: SO_2 emissions during the post-eruptive phase of the Tajogaite eruption (La Palma, Canary Islands) by means of ground-based miniDOAS measurements in transverse mode using a car and UAV, EGU General Assembly 2023, Vienna, Austria, 23–28 Apr 2023, EGU23-3620, https://doi.org/10.5194/egusphere-egu23-3620, 2023.

Esse B, Burton M, Hayer C, La Spina G, Pardo Cofrades A, Asensio-Ramos M, Barrancos J, Pérez N. Forecasting the evolution of the 2021 Tajogaite eruption, La Palma, with TROPOMI/PlumeTraj-derived SO_2 emission rates. Bull Volcanol. 2025;87(3):20. doi: 10.1007/s00445-025-01803-6. Epub 2025 Feb 26. PMID: 40028348; PMCID: PMC11865176.