

To Referee #3

We are grateful to you for your interest and comments on this manuscript.

Please find the point-by-point answers to your comments in green.

Please note that the present version of this manuscript reports mixing ratios in ppt and no longer in ppb to show the significant decimal digits.

Please note that, following the referee's comments, we have reformulated/refined the statistical analysis described in Section 2.3, updated the results and discussion accordingly, and have finally merged Section 3.1 with Section 3.2 (now Section 3.1).

(<https://doi.org/10.5194/egusphere-2025-5098-RC3>).

This manuscript presents an analysis of long-term atmospheric propane observations over Southern Europe, based on measurements conducted at the Monte Cimone GAW station (Italy). Long-term, high-quality VOC datasets are relatively scarce, and the availability of such measurements is valuable and worthy of publication. The manuscript focuses exclusively on propane measurements from 2011 to 2023.

That said, most of the analyses presented here are not particularly novel. Similar datasets, methodologies, and interpretations have been reported in numerous previous studies. While the data themselves are of interest, the scientific advancement beyond the existing literature is limited.

I am surprised that the authors did not incorporate measurements of other VOCs from the same instrument at Monte Cimone into the analysis. Including additional compounds would have enabled a more comprehensive and nuanced investigation of propane atmospheric behavior, sources, and chemical processing.

In my view, the comparison between bottom-up emission inventories and top-down estimates (Figure 11) represents the most valuable contribution of this study. I strongly encourage the authors to expand this part of the manuscript, providing a clearer explanation of the methodology and how the results were derived. This should also be accompanied by a more critical discussion of the uncertainties associated with the inversion results. While I am not a specialist in statistical methods, it seems that additional uncertainty analysis—potentially including a Monte Carlo evaluation—would substantially strengthen this section. Furthermore, the apparent underestimation of propane emissions in southern Italy by the inventory warrants deeper investigation and discussion of potential sources. And again, incorporating other VOCs as emission tracers might provide insight into emission categories.

The manuscript summarizes - a recap- the state of investigation of this specific compound in response to some recent papers (Helmig et al. 2016, Angot et al. 2021) presenting

anomalies on propane and ethane at the global scale. The aim of the present manuscript is to contextualise the discussion to the European domain based on the long-term dataset available from our station. The suggestions from the reviewer will be taken into account for future research based on additional VOCs measurements at the CMN station.

We thank the reviewer for the valuable suggestions on strengthening the inversion analysis. Following these recommendations, we performed an additional 20-member Monte Carlo ensemble simulation to robustly quantify posterior uncertainties, now reported as the 90% confidence interval. We have also expanded the methodological description to include details on the cost function, solver, and uncertainty estimation approach. Furthermore, we conducted a sensitivity analysis excluding the OH loss term to evaluate the influence of OH-related biases on the emission estimates, and added a discussion on potential sources contributing to the underestimation of propane emissions in the prior inventory.

Specific Comments

- **Line 4:** The term “vary” is likely inappropriate in this context. It would be more accurate to state that atmospheric propane mole fractions did not exhibit a statistically significant trend over the observational period.

To avoid confusion, we revised this sentence as follows:

“ Over the study period, C₃H₈ background mixing ratios exhibited a significant decrease of -3.8 [-5; -2.3; 95% confidence interval] ppt per year.”

- **Line 5:** I recommend reporting changes in seasonal amplitude in absolute units (ppb) rather than percent, as the reference value for the percentage change is unclear.

Following your suggestions, we revised the sentence by reporting changes in seasonal amplitude in ppt per year.

- **Line 6:** Jungfrauoch (JFJ) is mentioned without prior introduction. Please introduce the site and its relevance before referencing it.

Thank you for pointing this out. We revised the sentence as follows: “..Jungfrauoch (JFJ, Switzerland)..”

- **Lines 15–16:** The meaning of the reported 99.3% value is unclear. Please clarify what this percentage represents.

This sentence was rephrased as follows:

“According to Hodnebrog et al. (2018), the specific radiative forcing for the indirect effects of C₃H₈ is about 99% of its total specific radiative forcing through the interactions with O₃ formation and CH₄ removal.”

- **Line 57:** Please specify the calibration frequency in hours or days; the term “regularly” is too vague. In addition, further details on propane quantification are needed. Was propane quantified using selected ion integration? Was the mass spectrometer operated in scan or SIM mode? How were blanks determined and treated? Was a single-point calibration used, or were dilution curves and system linearity assessed? How was instrumental drift corrected? Given that multiple VOCs were likely quantified during each run, please explain why the analysis focuses exclusively on propane. Were the propane measurements audited by the World Calibration Center for VOCs?

Details on the analytical protocol are illustrated in LoVullo et al. 2016. We rephrased /expanded the text in Section 2.1 to include the relevant information:

“The time frame of this study covered the period from January 2011 to December 2023. In situ online measurements were performed at the World Meteorological Organization’s Global Atmosphere Watch (WMO/GAW) global station on CMN (44°12’N, 10°42’ E, 2165 m above sea level). Monitoring of non-methane volatile organic compounds (NMVOC) performed at CMN station is generally representative of emissions occurring in the European continent as reported by Lo Vullo et al. (2016). Measurements of C₃H₈ were performed with a gas chromatograph-mass spectrometer (GC–MS Agilent 6820 + Agilent 5975C) operating in Selected Ion Monitoring (SIM) mode, preceded by an online sample enrichment using a preconcentration system Unity-2-AirServer-2 (Markes International), following a method described in Maione et al. (2013) and Lo Vullo et al. (2016), according to ACTRIS standard operating procedure (SOP) (https://www.actris.eu/sites/default/files/Documents/ACTRIS-2/Deliverables/WP3_D3.17_M42.pdf) and audited under the GAW programme of the WMO by the World Calibration Center for volatile organic compounds in 2018. Real ambient air samples are collected every second hour, intertwined by whole-air calibration mixture (working standard) to correct for any short term instrumental drift, resulting in 12 real air measurements per day. Each month the working standard is calibrated against a certified “30-compounds Ozone precursor mixture” at 500 ppt level in nitrogen from the National Physical Laboratory (NPL-UK). System blanks are evaluated on a weekly basis, with concentrations changing over time but limited well below 15 ppt, with results adjusted accordingly. Total uncertainty for each measurement is calculated as the error propagation of i) the reproducibility of the repeated working standard runs on the same day, ii) the detection limit, and iii) the scale propagation error (derived by the regular NPL/quaternary standard check). Final QC of the dataset is checked yearly by an external reviewer as part of the ACTRIS-EBAS SOP

procedures before submission for data release to the EBAS repository. In addition, C3H8 observations for the year 2022 from JFJ WMO-GAW global station have been used for atmospheric inversion modeling as described in Section 2.5. C3H8 measurements at JFJ are carried out within the framework of ACTRIS activities, following the same analytical protocol for CMN but with different instrumentation (i.e. the Medusa-AGAGE setup (Miller et al., 2008; Prinn et al., 2018)). Measurements of CO and CH4 were performed at CMN according to the methods described in Section A.”

- **Line 105:** If JFJ data are included in the analysis, the measurement techniques and quality assurance procedures for that site should be described with the same level of detail as those for Monte Cimone

The two stations follow the same ACTRIS standard operating procedures and calibration scheme, even though JFJ was -and still is- using a different instrumentation, for which proper citation is reported.

Following your suggestion, in Section 2.1, the text has been modified as follows:

“In addition, C3H8 observations from Jungfrauoch (JFJ, Switzerland) WMO-GAW global station have been used for atmospheric inversion modeling as described in Section 2.5. C3H8 measurements are carried out within the framework of ACTRIS activities, following the same analytical protocol of CMN but with different instrumentation (i.e. the Medusa-AGAGE setup (Miller et al., 2008; Prinn et al., 2018)). “

- **Line 133:** The text first states that no clear trend is present but then claims a statistically significant decrease at the 95% confidence level. Please reconcile this apparent contradiction and use appropriate statistical terminology. It is also unclear how the reported slope values were derived. The curve shown in Figure 1 does not appear to represent a linear trend. Please explain how these slope values were calculated and how they represent changes over the full data period.

A significant decrease of -3.8 [-5; -2.3; 95% confidence interval] ppt per year refers to the mean decrease [95% confidence interval] per year calculated with Theil-Sein regression and Mann-Kendall testing for significance on the trend curves with bootstrap sampled subsets consisting of 90% of the dataset for 50 iterations.

We added a description of the method followed for calculating the slope and significance in Section 2.3:

“The seasonal cycle and trend calculations were done on bootstrap sampled subsets consisting of 90% of the dataset for 50 iterations.....

The long term trend, the trends on the long-term trend curve (Section 3.1), and trend of seasonal amplitude (Fig. 4) are estimated with the Theil-Sein regression

(scikit-learn Python package \citep{pedregosa2011}) and Mann-Kendall (pyMannKendall Python package \citep{hussain2019}) testing for significance.”

In Section 3.1, the sentence was rephrased as follows:

“Between 2011 and 2023, C₃H₈ mixing ratios exhibited a significant decrease of -3.8 [-5; -2.3; 95% confidence interval] ppt per year (solid green line in Fig. 1, and Fig. 2). “

- **Line 134:** The unit should be ppb yr⁻¹, not ppb.

Thank you for pointing this out. The unit is now ppt per year.

- **Lines 134–146:** Differences observed over relatively short time windows (e.g., 2–3 years) may be strongly influenced by interannual meteorological variability. Such variations should not be readily interpreted as emission changes without longer observational periods (at least five years) or appropriate meteorological normalization.

We agree with the reviewer about the importance of assessing the potential influence of meteorological variability when discussing short-term changes in mixing ratios. As a result of the revised statistical analysis, the two trends previously identified are now less “evident”, leading to a slightly different discussion of results. Therefore, we removed the comments on short term variation of C₃H₈ on the trend curve between 2018 and 2023.

- **Lines 148–166:** The seasonal behavior of propane has been well documented and explained in the existing literature, including studies cited here. This section offers limited new interpretation and could be substantially shortened.

Following your suggestion, this section was shortened from 18 to 11 lines.

- **Line 167:** Meteorological influences should be considered more explicitly in this context.

We agree that year-to-year variation in transport may influence the variability in the concentration of atmospheric tracers. However, no evidence of trends or changes in transport patterns was reported by previous studies on the characterization of long term measurements of O₃ (Cristofanelli et al. 2021a), NO_x (Cristofanelli et al. 2021b), and mineral dust (Vogel et al. 2025) at CMN.

In Section 3.1, we added the following:

“Previous studies (Cristofanelli et al. 2021a; Cristofanelli et al. 2021b; Vogel et al. 2025) about long term measurements of atmospheric components at CMN did not observe any trends or changes in the transport patterns.”

- **Line 171:** Please provide additional detail on how seasonal minima and maxima were determined, as this procedure is more complex than implied.

Is the reported change in seasonal amplitude statistically significant? An annual change of 0.16% over 12 years amounts to less than 2% in total, which is relatively small. It is unclear whether this signal exceeds measurement noise or reflects meaningful changes in chemistry or emissions.

Thank you for this comment. Following your comment, we realized that the CCGCRV curve-fitting method developed at NOAA for discrete and discontinuous flask samples performs better on daily mean mixing ratios rather than hourly measurements. Therefore, the present version of the manuscript presents the curve fitting as performed on the daily mean mixing ratios, filtered for days with at least eight out of 12 measurements.

Moreover, calculations were done on bootstrap-sampled subsets consisting of 90% of the daily mean values instead of 80% of the observations because the CCGCRV curve-fitting method is not meant to handle abundant data gaps. The new analysis resulted in a more robust description of the long-term decreasing trend and a substantial steady, slightly decreasing trend of the seasonal amplitude,

We revised the 2.3 Statistical analysis section by adding the following description of the method performed for evaluating seasonal minima and maxima:

“...The smoothed curve is obtained by combining the harmonic components and the residuals from the filter with a short-term cut-off value of 60 days. Following previous studies (Angot et al., 2021; Dlugokencky et al., 1997), for each year, the amplitude (peak-to-trough) of the C₃H₈ seasonal cycle was calculated as the difference between the maximum and minimum values of the smoothed curve (red line in Fig. 2) according to the analysis of the first derivative of the smooth curve. The seasonal cycle and trend calculations were done on bootstrap-resampled subsets consisting of 90% of the daily mean values for 50 iterations.”

- **Line 181:** According to the recent literature, NO_x emissions in the Northern Hemisphere have generally been decreasing over the past decade rather than increasing. Please revisit this statement.

We agree with the referee about this point. We reorganized the discussion about the seasonal amplitude trend and removed the sentence with a mention of NO_x

emissions that was wrongly related to the Northern Hemisphere instead of East-Asia (China).

- **Line 203:** Please clearly define how the seasons are classified.

Following your suggestion, we revised the sentence as follows: "... in winter (i.e., December, January, and February) and at 15:00 UTC in the other seasons (i.e., Spring- March, April, and May; Summer- June, July, and August; Autumn- September, October, and November).

- **Line 230:** Several studies report increased ozone levels during the COVID-19 pandemic. Please discuss your findings in the context of this broader literature.

We agree with the reviewer about the fact that the COVID lockdown was often associated with increases in O₃ ambient levels.

In this context, several studies (e.g., Sicard et al. 2020, Collivignarelli et al. 2020, Grange et al. 2021) about changes in air quality in European cities during the COVID lockdown explained the increases in ozone ambient levels with decreases in NO_x emissions.

On the contrary, several studies (e.g., Bouarar et al. 2021, Steinbrecht et al. 2021, Chang et al. 2022) observed negative O₃ anomalies in the free troposphere.

Putero et al. (2023) observed persistent negative anomalies for O₃ mixing ratios in four European high-elevation sites in 2020 in both spring (March–May) and summer (June–August), except for April.

High-elevation monitoring sites such as Monte Cimone are representative of boundary layer or background atmospheric conditions depending on whether the measurements are performed below or above the boundary layer height.

Therefore, different changes in ozone ambient levels occurred during the COVID lockdown depending on the area (e.g., urban or remote sites) and the elevation (high elevation or not) of the measurement stations.

- **Lines 230–243:** This section appears highly speculative and inconclusive. I recommend removing it or substantially shortening it.

Following your suggestion, lines 229-243 were rephrased as follows:

"With regard to the lower values in summer 2020, our results align with previous findings that suggested a link between lower emissions of O₃ precursors and decreases in O₃ mixing ratios measured at CMN (Cristofanelli et al., 2021a) and several high-elevation sites in Europe (Putero et al., 2023). The main drivers of variations in atmospheric C₃H₈ mixing ratios are changes in emission sources, atmospheric chemistry, and transport. Cristofanelli et al. (2021a) observed no

substantial variations in the synoptic-scale circulation and vertical transport related to the thermal circulation system at CMN in summer 2020 compared to the previous five years. In this context, the CAMS (Soulie et al., 2023) and EDGARv8.1 (Crippa et al., 2024) inventories estimated that the 2020 anthropogenic emissions of propane from Europe were 91% and 99.3%, respectively, of the emissions averaged over the period 2011-2019. In addition, comparisons of aircraft campaign measurements across Europe showed lower OH mixing ratios in the free troposphere during the COVID-19 lockdown compared to previous campaigns (Nussbaumer et al., 2022). The expected longer residence time due to the lower reaction rate between C₃H₈ and OH is therefore at odds with the lower C₃H₈ concentrations recorded at CMN in 2020, which is likely attributable to reduced emissions.”

- **Line 248:** Please be more precise in this description. If a 96% cutoff is applied, it is unclear how 11–15% high-occurrence values can simultaneously be reported. These metrics appear to use different reference definitions, which need to be clearly explained.

The events with high C₃H₈ mixing ratios were calculated based on a threshold of 96% of the seasonal daily mean mixing ratios. Between 11 and 15% of the events with high C₃H₈ mixing ratios occurred in 2013, 2015, 2018, and 2023.

- **Figure 6:** I recommend adding bold numerical labels for the median values, as these are used for the statistical comparisons.

Following your suggestion, we added bold numerical labels for the median values.

- **Line 295:** A period is missing after the word “located”.

Thank you, this typo was revised.

- **Line 310:** Deriving a linear trend over a period that includes a pronounced anomalous minimum during the COVID-19 pandemic is questionable. This limitation should be explicitly acknowledged and discussed.

Thank you for pointing this out.

Following your suggestion, the trend analysis was also performed on two sub-datasets (i.e., pre-COVID from 2011 to 2019, and post-COVID from 2022 to 2023), to avoid any influences on the trend analysis resulting from the drastic changes in activities and emissions during the COVID-19 pandemic, the associated lockdowns and recovery phase between 2020 to 2021.

The trend in pre-COVID time (2011-2019) was comparable to the long-term trend of the full study period, with a significant decrease of -2.6 [- 4.7; -0.6] ppt per year.

Post-COVID (2022-2023) showed a significant decrease of -10 [-14.1 ; -6.7] ppt per year.

However, the relatively short time span of two years of the post-COVID time does not assure the fact that the observed trend is the result of local fluctuations.

Therefore, there is the need for analysis of a longer propane dataset to provide a more robust evaluation of the trend following the COVID-19 pandemic.

We added the following to the Section 3.1:

“The trend analysis was also performed on two sub-datasets (i.e., pre-COVID from 2011 to 2019, and post-COVID from 2022 to 2023), to avoid any influences on the trend analysis resulting from the drastic changes in activities and emissions during the COVID-19 pandemic, the associated lockdowns and recovery phase between 2020 and 2021. Both sub-datasets confirmed a significant decreasing trend. Specifically, the pre-COVID time trend of -2.6 [-4.7 ; -0.6] ppt per year was comparable to the long-term trend of the full study period.”

References

Angot, H., Davel, C., Wiedinmyer, C., Pétron, G., Chopra, J., Hueber, J., Blanchard, B., Bourgeois, I., Vimont, I., Montzka, S. A., et al.: Temporary pause in the growth of atmospheric ethane and propane in 2015-2018, *Atmospheric Chemistry and Physics*, 21, 15 153–15 170, 2021. <https://doi.org/10.5194/acp-21-15153-2021>

Bouarar, I., Gaubert, B., Brasseur, G. P., et al.. (2021). Ozone anomalies in the free troposphere during the COVID-19 pandemic. *Geophysical Research Letters*, 48(16), e2021GL094204. <https://doi.org/10.1029/2021GL094204>

Chang, K.-L., Cooper, O. R., Gaudel, A., Allaart, M., Ancellet, G., Clark, H., Godin-Beekmann, S., Leblanc, T., Van Malderen, R., Nédélec, P., Petropavlovskikh, I., Steinbrecht, W., Stübi, R., Tarasick, D. W., and Torres, C.: Impact of the COVID-19 economic downturn on tropospheric ozone trends: an uncertainty weighted data synthesis for quantifying regional anomalies above Western North America and Europe, *AGU Advances*, 3, e2021AV000542, <https://doi.org/10.1029/2021AV000542>, 2022.

Collivignarelli, M. C., Abbà, A., Bertanza, G., Pedrazzani, R., Ricciardi, P., & Miino, M. C. (2020). Lockdown for CoViD-2019 in Milan: What are the effects on air quality?. *Science of the total environment*, 732, 139280. <https://doi.org/10.1016/j.scitotenv.2020.139280>

Cristofanelli, P., Arduni, J., Serva, F., Calzolari, F., Bonasoni, P., Busetto, M., Maione, M., Sprenger, M., Trisolino, P., and Putero, D.: Negative ozone anomalies at a high mountain

site in northern Italy during 2020: a possible role of COVID-19 lockdowns?, *Environmental Research Letters*, 16, 074 029, 2021a. DOI 10.1088/1748-9326/ac0b6a

Cristofanelli, P., Gutiérrez, I., Adame, J., Bonasoni, P., Busetto, M., Calzolari, F., Putero, D., and Roccatò, F.: Interannual and seasonal variability of NO_x observed at the Mt. Cimone GAW/WMO global station (2165 m asl, Italy), *Atmospheric Environment*, 249, 118 245, 2021b <https://doi.org/10.1016/j.atmosenv.2021.118245>

Grange, S. K., Lee, J. D., Drysdale, W. S., Lewis, A. C., Hueglin, C., Emmenegger, L., and Carslaw, D. C.: COVID-19 lockdowns highlight a risk of increasing ozone pollution in European urban areas, *Atmos. Chem. Phys.*, 21, 4169–4185, <https://doi.org/10.5194/acp-21-4169-2021>, 2021

Helmig, D., Rossabi, S., Hueber, J., Tans, P., Montzka, S. A., Masarie, K., Thoning, K., Plass-Duelmer, C., Claude, A., Carpenter, L. J., et al.: Reversal of global atmospheric ethane and propane trends largely due to US oil and natural gas production, *Nature Geoscience*, 9, 445 490–495, 2016. <https://doi.org/10.1038/ngeo2721>

Hussain et al., (2019). pyMannKendall: a python package for non parametric Mann Kendall family of trend tests.. *Journal of Open Source Software*, 4(39), 1556. <https://doi.org/10.21105/joss.01556>

Lo Vullo, E., Furlani, F., Arduini, J., Giostra, U., Graziosi, F., Cristofanelli, P., Williams, M. L., and Maione, M.: Anthropogenic non-methane volatile hydrocarbons at Mt. Cimone (2165 m asl, Italy): Impact of sources and transport on atmospheric composition, *Atmospheric Environment*, 140, 395–403, 2016. <https://doi.org/10.1016/j.atmosenv.2016.05.060>

Liu, G., Shen, L., Ciais, P., Lin, X., Hauglustaine, D., Lan, X., Turner, A. J., Xi, Y., Zhu, Y., and Peng, S.: Trends in the Seasonal Amplitude of Atmospheric Methane, *Nature*, 641, 660–665, <https://doi.org/10.1038/s41586-025-08900-8>, 2025

Miller, B. R., Weiss, R. F., Salameh, P. K., Tanhua, T., Grealley, B. R., Mühle, J., and Simmonds, P. G.: Medusa: A sample preconcentration and GC/MS detector system for in situ measurements of atmospheric trace halocarbons, hydrocarbons, and sulfur compounds, *Anal.Chem.*, 80, 1536–1545, <https://doi.org/10.1021/ac702084k>, 2008.

Nussbaumer, C. M., Pozzer, A., Tadic, I., Röder, L., Obersteiner, F., Harder, H., Lelieveld, J., and Fischer, H.: Tropospheric ozone production and chemical regime analysis during the COVID-19 lockdown over Europe, *Atmospheric Chemistry and Physics*, 22, 6151–6165, 2022. <https://doi.org/10.5194/acp-22-6151-2022>

Pedregosa, F., Varoquaux, G., Gramfort, A., Michel, V., Thirion, B., Grisel, O., ... & Duchesnay, É. (2011). Scikit-learn: Machine learning in Python. *the Journal of machine Learning research*, 12, 2825-2830.

Prinn, R. G., Weiss, R. F., Arduini, J., Arnold, T., DeWitt, H. L., Fraser, P. J., Ganesan, A. L., Gasore, J., Harth, C. M., Hermansen, O., Kim, J., Krummel, P. B., Li, S., Loh, Z. M., Lunder, C. R., Maione, M., Manning, A. J., Miller, B. R., Mitrevski, B., Mühle, J., O'Doherty, S., Park, S., Reimann, S., Rigby, M., Saito, T., Salameh, P. K., Schmidt, R., Simmonds, P. G., Steele, L. P., Vollmer, M. K., Wang, R. H., Yao, B., Yokouchi, Y., Young, D., and Zhou, L.: History of chemically and radiatively important atmospheric gases from the Advanced Global Atmospheric Gases Experiment (AGAGE), *Earth Syst. Sci. Data*, 10, 985–1018, <https://doi.org/10.5194/essd-10-985-2018>, 201

Putero, D., Cristofanelli, P., Chang, K.-L., Dufour, G., Beachley, G., Couret, C., Effertz, P., Jaffe, D. A., Kubistin, D., Lynch, J., Petropavlovskikh, I., Puchalski, M., Sharac, T., Sive, B. C., Steinbacher, M., Torres, C., and Cooper, O. R.: Fingerprints of the COVID-19 economic downturn and recovery on ozone anomalies at high-elevation sites in North America and western Europe, *Atmos. Chem. Phys.*, 23, 15693–15709, <https://doi.org/10.5194/acp-23-15693-2023>, 2023.
<https://doi.org/10.5194/acp-23-15693-2023>

Sicard, P., De Marco, A., Agathokleous, E., Feng, Z., Xu, X., et al. (2020). Amplified ozone pollution in cities during the COVID-19 lockdown. *Science of the Total Environment*, 735, 139542. <https://doi.org/10.1016/j.scitotenv.2020.139542>

Steinbrecht, W., Kubistin, D., Plass-Dülmer, C., Davies, J., et al. COVID-19 crisis reduces free tropospheric ozone across the Northern Hemisphere, *Geophys. Res. Lett.*, 48, e2020GL091987, <https://doi.org/10.1029/2020GL091987>, 2021

Vogel, F., Putero, D., Bonasoni, P., Cristofanelli, P., Zanatta, M., and Marinoni, A.: Saharan dust transport event characterization in the Mediterranean atmosphere using 21 years of in-situ observations, *Atmos. Chem. Phys.*, 25, 15453–15468, <https://doi.org/10.5194/acp-25-15453-2025>, 2025.