

Response to RC1:

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Synopsis:

This paper presents a comprehensive analysis of XCO₂ observations obtained in the vicinity of coal-fired power plants using the ACDL spaceborne instruments on board the DQ-1 satellite. Leveraging the integrated differential absorption (IPDA) lidar technique, the work utilizes these data to derive emission fluxes and compare them against existing inventories.

The IPDA method offers a significant advantage over passive remote sensing technologies by enabling measurements at night and in high-latitude regions, where traditional methods are often limited or ineffective. By employing a Gaussian plume model to interpret the observed XCO₂ signatures, this study aims to infer CO₂ emissions from coal-fired power plants.

Answer: We greatly appreciate your valuable time for reviewing our research paper and providing suggestions. (The blue text is in response to your comments, and the green text is for specific modifications in the paper. We also highlight revisions in the manuscript.)

General Review:

In my opinion, this contribution provides a substantial step forward to infer CO₂ emission from satellite-borne instruments. As the first of its kind CO₂ lidar in space, the work provides new data and thus is significant for the scope of Atmospheric Chemistry and Physics.

The scientific approach and methodologies employed are clearly presented, and the results are discussed in a largely satisfactory manner. However, to strengthen the paper's credibility, I recommend adding references to relevant existing studies. The results themselves are presented concisely and effectively, with conclusions drawn by the authors that are well-supported.

The scientific approach and the methods applied are well presented. The results are mostly discussed appropriately, however, several references to related work need to be added. The results are presented in a clear and concise way. The authors developed their conclusion well. Some of the figures should be improved for the sake of readability and, language-wise, some expressions need improvement.

To estimate CO₂ emissions from power plants, the authors apply a Gaussian-shaped plume model derived from theoretical considerations.

In order to estimate the CO₂ emissions of power plants the authors fit the results to a Gaussian-shaped plume derived from model. It is suggested that the authors provide justification for choosing this approach over alternative methods, such as budgeting (Riemann sum) approaches e.g.

<https://doi.org/10.1364/AO.56.005182> .

The most significant deficiency of the paper is its failure to discuss potential implications of turbulence on CO₂ emission estimates. Turbulence can significantly impact the validity of applying a Gaussian plume approximation and may lead to biases in deriving emission rates, especially considering the expected differences between night-time and daylight measurements. This topic requires a more detailed discussion, given its complexity.

This is more detailed in the specific review below.

Answer:

We sincerely appreciate the reviewer's valuable comments and suggestions. We have carefully revised the manuscript and figures in accordance with the specific recommendations provided. **Regarding the first comment** on “*It is suggested that the authors provide justification for choosing this approach over alternative methods, such as budgeting (Riemann sum) approaches e.g.*” : While budgeting approaches (e.g., Riemann sum) do not require assumptions about the specific morphology of emission plumes (e.g., Gaussian distribution) and are more robust for complex or irregular plume distributions, the primary rationale for adopting Gaussian fitting in this study lies in our focus on detecting emissions from power plants in **nighttime and high-latitude** regions. For high-latitude plants, field observations reveal that most are located inland in areas with minimal interference from other anthropogenic emissions. By rigorously filtering cases based on wind direction consistency (deviation $<25^\circ$ from the plume axis) and cloud-free conditions, the atmospheric wind fields for the corresponding cases are relatively stable, resulting in emission plumes that closely approximate Gaussian distributions. The Gaussian fitting method allows us to determine the plume shape by incorporating atmospheric stability parameters and wind field variables, thereby enhancing model prediction accuracy in point-to-point fitting. Furthermore, this approach enables systematic uncertainty analysis for different error sources (e.g., wind field errors, background XCO₂ variability). We have revised in Line 58 : “Compared to the budgeting approach for estimating point source emissions (Amediek et al., 2017), the Gaussian plume model (GPM) is highly influenced by the precision of atmospheric background driving fields (Nassar et al., 2017; Brunner et al., 2023), it is not constrained by the spatial resolution of the model, and is more stable and effective in modelling point source dispersion if limited by the background wind field (Toja-Silva et al., 2017; Schwandner et al., 2017).”

Regarding the second comment “*The most significant deficiency of the paper is its failure to discuss potential implications of turbulence on CO₂ emission estimates*” we clarify that turbulence impacts the Gaussian plume model (GPM) in two primary aspects. Firstly, turbulence induces rapid changes in atmospheric wind fields, leading to non-Gaussian XCO₂ enhancement patterns in satellite observations. To address this, we excluded such cases through rigorous data filtering criteria. In Section 3, we retained only cases where the angle between the plume axis and wind direction was $<25^\circ$. When the deviation is $<25^\circ$, we attribute the discrepancy primarily to interpolation errors in ERA5 wind fields (the rationale for the 25° threshold will be elaborated in subsequent responses). For deviations $\geq 25^\circ$, observed XCO₂ profiles deviate significantly from Gaussian shapes, likely due to turbulence effects, rendering Gaussian fitting unreliable for emission quantification; thus, these cases were discarded. Secondly, turbulence affects the calculation of the horizontal dispersion coefficient σ_y (parameter a in Function 1). In this study, atmospheric stability was determined using Gordon's implementation of the Pasquill-Gifford scheme (Tables S1/S2/S3). We computed net radiation indices from ERA5 total/low cloud cover and solar elevation angles, then combined these with surface wind speeds to linearly interpolate the initial atmospheric stability parameter a_1 . The standard deviation of surface wind speeds was used to define a 1

σ uncertainty range for a_1 , within which both a and CO_2 emission rates were co-optimized to determine the optimal a_2 . The Pasquill classification effectively quantifies molecular diffusion: under strong daytime solar radiation, intensified turbulence enhances mixing, resulting in larger σ_y values, lower Gaussian peaks, and flatter plume distributions. However, our results indicate that daytime turbulence introduces errors in σ_y estimation via the Pasquill method, leading to higher uncertainties in emission quantification. Conversely, nighttime atmospheric stability yields better agreement between simulated and observed plume distributions, with reduced errors from atmospheric instability. In the article we have analysed the errors due to uncertainty in atmospheric instability, and we have analysed the diurnal differences in the errors due to atmospheric instability separately in the discussion of the results Line 387 : “The results show that during the daytime, the error in the surface wind field is higher due to turbulence, which can cause some invalid observations or increase the error caused by atmospheric instability to the model.”, the errors due to atmospheric instability have been further explained in Line 371: “Unlike prior studies, this research explicitly accounts for atmospheric instability uncertainty. Surface wind speed uncertainty, influenced by boundary layer turbulence and other factors, is significantly higher during daytime. Our analysis of 28 cases reveals that the optimized atmospheric instability parameter a shows average deviations of 19.5% from its prior value in daytime versus 15.8% at night. The results indicate that, under the assumption that plume dispersion aligns with the Gaussian plume model, ERA-5 surface wind speeds exhibit higher accuracy at night. However, daytime turbulence introduces small-scale wind field errors, which further amplify uncertainties in atmospheric instability.”

$$\sigma_y(x) = a \cdot (x/1000)^{0.894} \quad (1)$$

Table S1

Total cloud cover/low cloud cover (0-1)	nightime	Net Radiation Index			
		solar altitude angle			
		$\leq 15^\circ$	$15^\circ - 35^\circ$	$35^\circ - 65^\circ$	$> 65^\circ$
$\leq 0.4 / \leq 0.4$	-2	-1	+1	+2	+3
$0.5 - 0.7 / \leq 0.4$	-1	0	+1	+2	+3
$\geq 0.8 / \leq 0.4$	-1	0	0	+1	+1
$\geq 0.5 / 0.5 - 0.7$	0	0	0	0	+1
$\geq 0.8 / \geq 0.8$	0	0	0	0	0

Table S2

Surface wind speed (m/s)	Net Radiation Index (Table S1)					
	3	2	1	0	-1	-2
<2	A	A-B	B	D	(E)	(F)
2-3	A-B	B	C	D	E	F

3-5	B	B-C	C	D	D	E
5-6	C	C-D	D	D	D	D
>6	C	D	D	D	D	D

Table S3

stability parameter	A	B	C	D	E	F
Parameter a	213	184.5	150	130	104	77.6

Specific Review:

Abstract and Introduction:

1. The authors' conclusion in the abstract that their method is adequate for monitoring diurnal variations in power plant emissions strikes a note of caution, given that the satellite only overpasses the sources once per night and once per day, which does not provide better time resolution than what the method can account for.

Answer: Thanks, we modify diurnal variation to diurnal difference. We've also revised in Line 27: "This paper also analyses the diurnal differences in CO₂ emissions from power plants and finds emissions fluctuations directly correlated with regional electricity demand dynamics. This method is very effective for monitoring emissions from strong point sources such as power plants."

2. The authors provide a comprehensive review of studies utilizing passive remote sensing techniques. Notably, they accurately highlight the benefits of active over passive remote sensing methods. Nevertheless, it would be beneficial for them to extend this thoroughness to lidar-related references, which appear to be incomplete.

At least the following publications need to be cited:

Ehret et al.: <https://doi.org/10.1007/s00340-007-2892-3>

Menzies et al., <https://doi.org/10.1175/JTECH-D-13-00128.1>

Wolff et al.: <https://doi.org/10.5194/amt-14-2717-2021>

Answer: Thanks for the suggestion that these active remote sensing references should be mentioned, we have added the following to line 75: "Spaceborne active remote sensing of CO₂ primarily employs the integrated path differential absorption (IPDA) principle (Ehret et al., 2008), enabling nighttime and high-latitude observations. Kiemle et al. discussed the ability to monitor CO₂ emissions using spaceborne lidar in combination with the plume model and a mass budget approach (Kiemle et al., 2017). Recent studies have demonstrated the feasibility of laser-based detection techniques for CO₂ emission monitoring (Menzies et al., 2022; Wolff et al., 2024)."

3. This paper does not only present airborne IPDA measurement of CO₂ plumes from power plants, but also discusses the mass balance and Gaussian plume approximation using lidar cross sections.

Moreover, it discusses turbulence and its impact on IPDA measurements. Thus, it is of high relevance to this paper.

Kiemle et al.: <https://doi.org/10.3390/rs9111137>

Answer: Thanks, we have added the contribution of Kiemle et al. in line 76: “Kiemle et al. discussed the ability to monitor CO₂ emissions using spaceborne lidar in combination with the plume model and a mass budget approach (Kiemle et al., 2017).”

4. Even for results for passive remote sensing (eg. w.r.t EM27/SUN) a few important publications are missing and should be cited:

- Luther et. al: <https://doi.org/10.5194/amt-12-5217-2019>
- Ye et al.: <https://doi.org/10.1029/2019JD030528>
- Wu et al.: <https://doi.org/10.5194/gmd-11-4843-2018>

Answer: Thanks, we have added references to these literature in the citation and revised in the paper. Line 46: “In recent years, some studies have used “top-down” approaches, such as combining satellite observation data with WRF-STILT or WRF-Chem models to quantify urban greenhouse gas emissions (Turner et al., 2020; Pillai et al., 2012; Hu et al., 2022; Wu et al., 2018; Ye et al., 2020).” Line 54: “Ground-based equipment, such as portable Fourier transform spectrometers (EM27/SUN), combined with the Gaussian plume model and the cross-sectional flux method, has also been used to measure ground-level CO₂ concentrations for specific power plants and urban areas (Ohyama et al., 2021; Luther et al., 2019).”

5. Concerning plume shapes and results from different models, Brunner et al. need to be cited.
<https://doi.org/10.5194/acp-23-2699-2023>

Answer: Thanks, we have cited this reference and illustrated the need for plume models to incorporate high-precision background wind fields, in Line : “Compared to the budgeting approach for estimating point source emissions (Amediek et al., 2017), the Gaussian plume model (GPM) is highly influenced by the precision of atmospheric background driving fields (Nassar et al., 2017; Brunner et al., 2023), it is not constrained by the spatial resolution of the model, and is more stable and effective in modelling point source dispersion if limited by the background wind field (Toja-Silva et al., 2017; Schwandner et al., 2017).”

6. The number of power plants/ observations seems to be inconsistent within the abstract. It becomes not so clear how many individual power plants have been observed (10?), how many of those have been overflowed more than once, how many overflights were considered in total (38?) and how many overflights took place at night (15?) and day (23?). Please clarify. Possibly, table 2 can be improved with this regard. It would also be helpful to know about the percentage of “good” overflights versus all overflights.

Answer: In total, we analysed 10 power plants with a total of 28 observations. For the GRES plant, we analyzed

a total of 7 daytime and 11 nighttime results in order to analyze the diurnal and seasonal differences in CO₂ emissions, and for the remaining 9 plants, the main role in this study was to compare with the emission inventories and to validate the correctness of the model, so only one valid observation was selected. In response to the reviewer's question, the 15 times are the number of nighttime results and the 23 times are the number of high-latitude observations, not the number of daytime results. In response to the reviewer's second query, a total of 97 overpasses were obtained around several power plants, resulting in a total of 28 'Good' overpasses used in this paper. In Line 205: "A total of 97 satellite overpasses within 50-km circular regions centered on plant stacks were retrieved.....After filtering, 34 % of the overpasses were discarded due to excessive differences in wind direction, and a total of 28 overpasses were finally selected, including 15 nighttime cases and 3 cases where the power plant was located above 60° N."

7. Be more specific in what is improved versus the Han et al. paper.

Answer: The key distinction between the Gaussian plume model employed in this study and the EMI-GATE model used by Han et al. lies in the calculation methods for atmospheric instability parameters, background XCO₂ column concentrations, wind speeds, and wind directions. Our approach involves varying these parameters within their respective error bounds based on raw observational data, with each parameter adjusted independently to maximize the interpretability of results. In contrast, Han et al. utilized a Genetic Algorithm and Trust-rEgion (GATE) technique to simultaneously optimize multiple variables including emission rates, wind speeds, and atmospheric instability parameters. While this enhances model fitting performance, it compromises the interpretability of the results compared to our method. Furthermore, this study used different atmospheric instability calculation method and explicitly quantifies uncertainties arising from atmospheric instability, which were not systematically analysed in Han et al.'s methodology. In addition, in terms of the content of the study, two years of observations were obtained for a single power plant and the temporal differences in emissions were analysed. We have revised in Line 85: "The main differences between the Gaussian plume model used in this study and the EMI-GATE model used by Han et al. are the methods used to calculate the Gaussian plume model parameters such as the atmospheric instability parameters and the wind field, as well as the fact that we additionally quantify the uncertainty due to atmospheric instability."

Data and Methodology

8. Line 113: Explain why water vapour column information is needed.

Answer: Thanks, in order to convert CO₂ column increment to XCO₂, surface pressure and water vapour column content are required in Equation (2).

$$\Delta XCO_2(x, y) = \Delta Q(x, y) \cdot \frac{M_{air}}{M_{CO_2}} \cdot \frac{g}{P_{surf} - w \cdot g} \cdot 1000 \quad (2)$$

We have revised in Line 124: "Additionally, the conversion of emissions into XCO₂ enhancements requires surface pressure and water vapor column content data, which were derived from ERA5-Land datasets."

9. Para 2.1.3: Can you comment on the accuracy of the Climate Trace Data and specifically about the emissions of those power plants considered in this study.

Answer: Since accurate emission data are unavailable, we conducted a cross-sectional comparison between inventories. We selected top 30 high-emission power plants and compared results from Climate TRACE with those from the Carbon Brief inventory, yielding an average relative deviation of

9.2%. Climate TRACE integrates machine learning with observational data, providing broader coverage of power plants—particularly smaller emitters. Among the 10 plants analyzed in this study, 6 have data in both inventories. For the Scherer power plant, emissions differed by a factor of two between the two inventories, while the average deviation for the remaining plants was 7 %. The primary rationale for selecting Climate TRACE data lies in its machine learning-derived monthly-resolution emission estimates, which facilitate temporal alignment with our results. We explained in line 133. “We also compared the emissions of Climate TRACE’s top 30 power plants with Carbon Brief, which had an average deviation of 9.2 %, and we considered their results to be reliable.”

10. Line 125: Bovensmann et al. is certainly not the original reference for the Gaussian plume approximation. The authors should probably look for a better suited reference.

Answer: Thanks, we have revised it to: *Pasquill, Frank, and Frank Barry Smith. Atmospheric diffusion. Vol. 437. Chichester: Ellis Horwood, 1983.*

11. Line 135: “gravitational acceleration” (rather than acceleration due to ...)

Answer: Revised

12. Figure 1: Please improve the graphs such that the labelling of axes can be read.

Answer: Revised

13. Line 148: Please describe why you use a 30-km distance as the limit.

Answer: 30-km was incorrect and has been revised to 50 km. For a power plant with an emission rate of 1000 Kg/s, ΔXCO_2 is less than 1 ppm at 50 km downwind of the plume at a wind speed of 10 m/s, which is less than the uncertainty of the XCO_2 observed by the DQ-1 satellite, and we believe that the results must be inaccurate at a distance far away from this distance, and therefore this condition was added during the screening of the data. It is also explained in the Line 160: “For a power plant with an emission rate of 1000 kg s⁻¹, the downwind XCO_2 enhancement at 50 km under 10 m s⁻¹ winds is <1 ppm, which is less than the uncertainty of XCO_2 observed by the DQ-1, indicating low reliability in distant plume detection. Therefore, to improve the model’s fit with satellite observation results, the selected DQ-1 orbital data require that the downwind direction of the point source intersects with the satellite footprint and that the distance between the XCO_2 enhancement location and the point source is less than 50 km.”

14. Line 153: Please describe why you use a 25° angle as the limit. It would also be interesting to know how many overflights had to be discarded due to wind directions outside of this criterion, i.e. the percentage of “good” overpasses versus all overpasses.

Answer: Thank you for your comments!

1) We consider that deviations of wind direction from the plume centre pointing of less than 25% are likely to be due to errors in the meteorological data, while data greater than 25% are likely to be due to large effects of atmospheric turbulence (Panofsky et al., 1984), which are not suitable for fitting with a Gaussian model. We revised in Line 206: “For 10 typical coal-fired power plants, 47 satellite overpasses intersecting the downwind direction were identified within the power plant area. Strict data filtering standards were applied when using the Gaussian plume model, requiring the absence of thick clouds (DQ-1 measured elevation discrepancies from DEM <100 m) and ensuring that the deviation of the wind direction from the plume spreading direction at the point source was less than 25°. We consider

that deviations of wind direction from the plume axis of less than 25 % are mainly attributable to meteorological data uncertainties, while larger deviations ($\geq 25\%$) may be due to atmospheric turbulence effects (Panofsky et al. 1984), when Gaussian plume modelling is not appropriate.”

2) For the second question raised by the reviewer, there are a total of 97 overpasses in the study area, 47 of which have their tracks intersecting the downwind direction, and after screening the wind field and clouds, there are only 28 “good” overpasses, with a percentage of good results of about 30 %. We have revised in Line 212: “After filtering, 34 % of the overpasses were discarded due to excessive differences in wind direction, and a total of 28 overpasses were finally selected, including 15 nighttime cases and 3 cases where the power plant was located above 60° N.”

15. Line 159: Please describe how cloud cover and solar altitude are considered in the study of atmospheric stability. What about solar altitude and night-time measurements?

Answer: Thank you for your comments, in this study, atmospheric stability was determined using Gordon’s implementation of the Pasquill-Gifford scheme (Tables S1/S2/S3). Solar altitude can be calculated by combining latitude, time and Equation 3. There are also corresponding results in Table S1 for the night time case.

$$\delta = \left[0.006918 - 0.399912 \cos \theta_0 + 0.070257 \sin \theta_0 - 0.006758 \cos 2\theta_0 + 0.000907 \sin 2\theta_0 - 0.002697 \cos 3\theta_0 + 0.001480 \sin 3\theta_0 \right] \times \frac{180^\circ}{\pi} \quad (3)$$

We have also revised in Line 174: “In this study, empirical interpolation of atmospheric stability parameters was implemented by accounting for surface wind speed, cloud coverage, and solar elevation angle, the latter calculated from latitude and time of observation (Nassar et al., 2021).”

16. Line 160: Over which distance smoothing was applied. In this context, the authors should be more precise. At some point the precision of the measurements (for the applied averaging interval) should be given.

Answer: In this study, a moving average over a distance of 10 km is used so that the XCO₂ uncertainty is less than 1 ppm, which corresponds to the pulse signals received by the satellite, and a moving average is performed for 30 pulses. We have revised in Line 179: “A 10-km moving averaging was applied to DQ-1 data, reducing the uncertainty of XCO₂ to below 1 ppm, which facilitated the detection of enhanced XCO₂ signals (Zhang et al., 2023).”

17. Para 2.2.: The authors should better distinguish between stack height and plume heights. To do so, a paper by Brunner et al. is considered to be important and must be cited:
<https://doi.org/10.5194/acp-19-4541-2019>

Answer: We have explained in the paragraph 2 that plume height = stack height + plume lift height, and add the reference. In Line 195: “The plume height is equal to the stack height plus the plume lift height (Brunner et al., 2019), and if there is no information on the stack height for a specific power plant, the default stack height is 240 m, and given the uncertainty in the plume lift height, the standard deviation of the emissions for lift heights of 160 m, 200 m, 240 m, 280 m, and 320 m is used to estimate the uncertainty.”

Results and Discussion

18. Line 186: Here, a radius of 50 km is given. This is inconsistent with the 30-km criterion given

above. Correct or explain!

Answer: Thanks for the correction. 50km is correct and has been corrected in the paper

19. Line 188: Please be quantitative in specifying the filter criteria. For example, what minimum optical depth of “thick” clouds leads to exclusion?

Answer: The condition for IPDA lidar to recognise whether there is cloud interference or not is not differentiated by optical thickness, DQ-1 also emits 1064 nm laser to measure the ground elevation, when there is a thick cloud, the laser elevation is the height of the top of the cloud, we compare the laser elevation with the Digital Elevation Model, the signal with a difference of more than 100m we consider it as a thick cloud interference (Gao et al., 2023), and we assume that this signal is invalid. We have also revised in Line 208: “Strict data filtering standards were applied when using the Gaussian plume model, requiring the absence of thick clouds (DQ-1 measured elevation discrepancies from DEM <100 m) and ensuring that the deviation of the wind direction from the plume spreading direction at the point source was less than 25°.”

Xuejie Gao, Jiqiao Liu, Chuncan Fan, Cheng Chen, Juxin Yang, Shiguang Li, Yuan Xie, Xiaopeng Zhu, Weibiao Chen. Carbon Dioxide Column Concentration Measurement Based on Cloud Echo Signal of 1.57 μ m IPDA Lidar[J]. Chinese Journal of Lasers, 2023, 50(23): 2310001.

20. Line 199: Pleas include (e.g. in Table 1 or 2) for which power plants the stack height is known to the authors. Moreover, the stack height is not uncertain, it is just not known to the authors.

Answer: We have searched and found the stack heights of four larger power plants and have added this column to the table. The main factor affecting the uncertainty in the calculation of the plume height is the uncertainty in the plume lift height, we have revised in Line 195: “The plume height is equal to the stack height plus the plume lift height (Brunner et al., 2019), and if there is no information on the stack height for a specific power plant, the default stack height is 240 m, and given the uncertainty in the plume lift height, the standard deviation of the emissions for lift heights of 160 m, 200 m, 240 m, 280 m, and 320 m is used to estimate the uncertainty.”

Table 1 Information on different power plants and the comparison of model predictions with emission inventories

Country	Station	Stack Height (m)	Latitude	UTC Time	Model Result (kg s ⁻¹)	Climate TRACE (kg s ⁻¹)	Carbon Brief (kg s ⁻¹)	Day or Night
Russia	GRES	330	57.11° N	2022/8/17 22:12	806.0±108	721.3	638	Night
Russia	GRES	330	57.11° N	2023/5/22 08:35	876.2 ±153	721.3	638	Day
Russia	GRES	330	57.11° N	2023/11/05 22:10	988.6±161	721.3	638	Night

Russia	GRES	330	57.11° N	2023/12/10 22:08	1027.5±177	721.3	638	Night
Russia	GRES	330	57.11° N	2024/2/8 08:29	1109±169	721.3	638	Day
Russia	GRES	330	57.11° N	2024/7/1 22:08	724.5±115	721.3	638	Night
America	Scherer	305	33.06° N	2022/5/3 02:37	478±72	267.4	607.5	Night
Poland	Belchatow	300	51.26° N	2022/5/8 19:18	771±134	867.5	925	Day
South Africa	Medupi	240*	23.71° S	2022/7/24 07:21	598±98	516.6	515.3	Day
South Africa	Matimba	240*	23.60° S	2022/7/24 07:21	708±118	617	664.6	Day
Russia	CHP-1	240*	69.33° N	2022/6/14 21:07	109.7±18	83	--	Night
Russia	CHP-3	240*	69.32° N	2022/6/14 21:07	57.1±12	44.1	--	Night
Russia	GRES-2	420	61.28° N	2022/7/24 21:36	1287.3±143	1001.1	--	Night
Korean	Taean	240*	36.90° N	2022/6/03 04:44	991.5±73	1022.2	900.5	Day
Korean	Daesan	240*	36.99° N	2022/6/03 04:44	30.4±3.4	23.9	--	Day

* The default stack height is 240 m (Nassar et al., 2021)

21. Line 200: What is meant by: “OCO-2 satellites have no valid Gaussian plume data?”

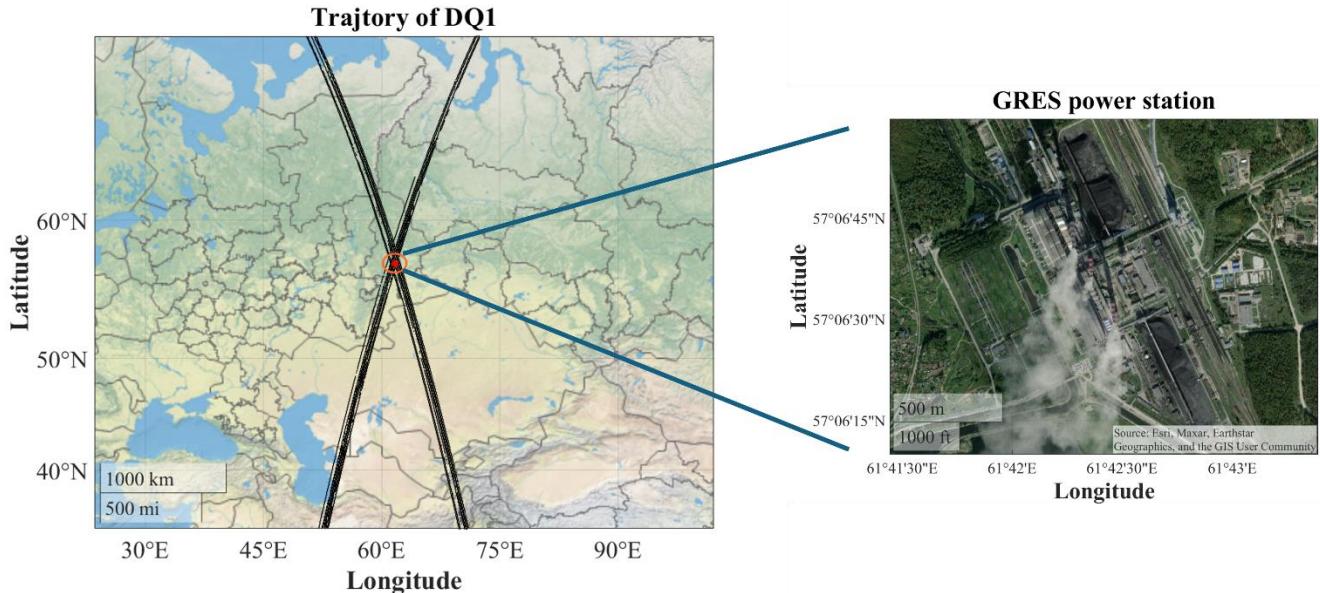
Answer: Due to the high latitude of this power plant, the small amount of passive remote sensing data and the low coverage of satellite data, we downloaded the OCO-2 satellite data for 2022-2024, which did not have enough ‘good’ overpasses to analyze the temporal differences in emissions from this power plant. We have revised in Line 223: “Due to the plant’s high latitude, around 57° N, passive remote sensing satellite data are sparse (Insufficient OCO-2 overpasses were available for GPM at this plant), making it difficult to estimate.”

22. Table 2: Please provide also the year of the respective overpass.

Answer: Revised

23. Figure 2: The source of the maps should be given. It would be nice to provide a map insert providing a better information about where the GRES power plant is located. Please increase the axis labels on the left figure.

Answer: Revised.



24. Figure 3: Please increase the figures and labels for better readability. It might be more instructive to show the overpasses in the same map cutout and scale. Is there a significance in the size of the wind arrows? I suggest to provide approximate wind speed information and local time of overpass. Probably it makes no sense to apply the same scale to all graphs due to different background values, but at least the same spread (2 ppm?) should be applied to all figures.

Answer: Thanks for your suggestion. We have modified the figure 3 as you suggested. The size of the wind direction arrow is meaningless; the arrow point indicates the wind direction after interpolation of the ERA-5 data.



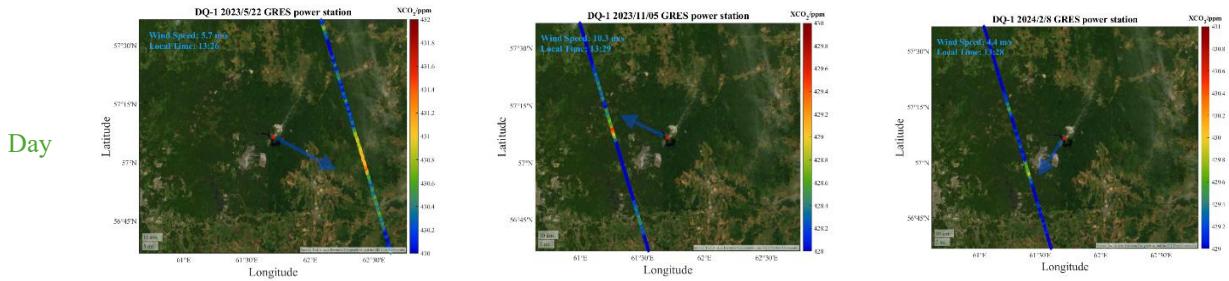


Figure 3: Typical daytime and nighttime DQ-1 overpasses around the Reftinskaya GRES power station, with the red six-pointed star indicating the location of the power station and the arrow representing the wind direction at the plume.

25. Line 216: How is the lift height derived from stack height and atmospheric stability. Does the temperature of the gas play a role?

Answer: Thank you for your suggestion, as we have already explained in Section 2, the plume lift height is uncertain, we have assumed a lift height of 250m as a default value based on the study according to Nassar et al. (Nassar et al., 2021) and the uncertainty of this assumption is analysed later.

26. Line 253: Provide a number for the linearly varying background.

Answer: We have revised in Line 274: “In this observation, the atmospheric background field exhibited a strong linear variation trend (About 0.015 ppm per kilometer along the track), and the Gaussian linear fitting results are shown in Fig. 6b, with an average XCO₂ background concentration of 428.9 ppm.”

27. Figure 7: Climate Trace (not Change?); The reader may think that this is continuous data, but the lines consist of 7? individual daytime and 9? nighttime observations. Please plot the data points!

Answer: Thanks for your comments, at the time the article was submitted, ClimateTRACE had not yet published the monthly resolution data, and so far, the official website has provided monthly emissions data up to November 2024 for each power plant. I have modified this graph, and labelled the data points as requested.

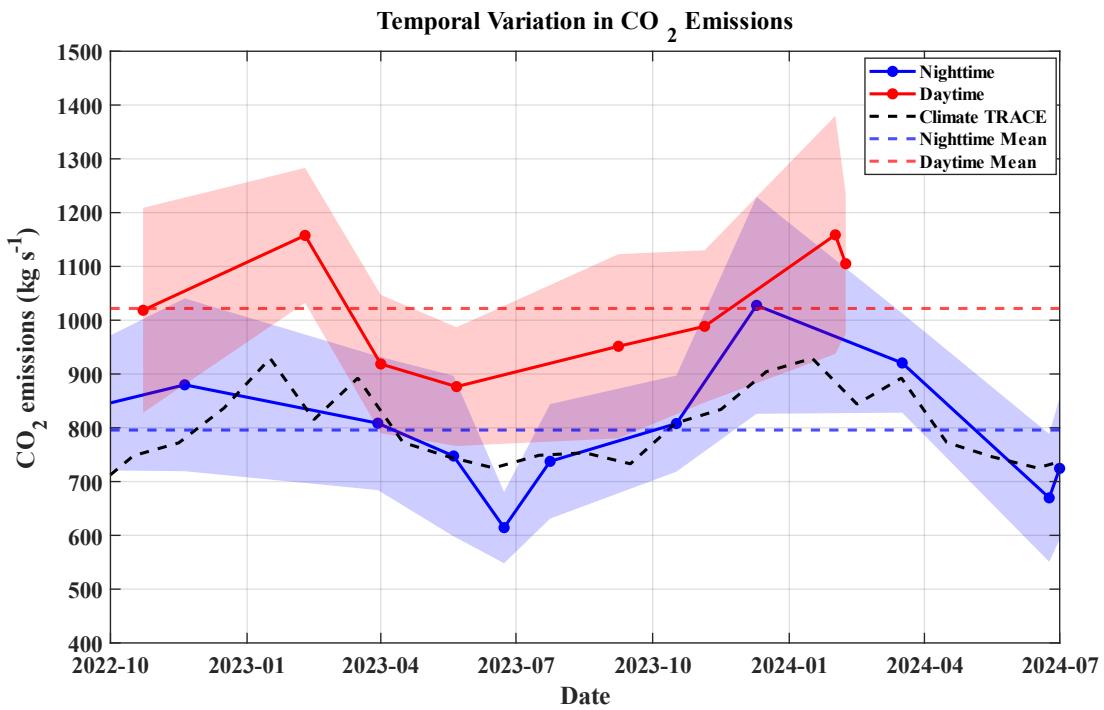


Figure 7: Daytime (red) and nighttime (blue) CO₂ emission rates from GRES power plants (2022–2024). Solid lines represent modeled estimates with uncertainty bounds (shaded areas); red and blue dashed lines represent average daytime and nighttime emissions, and black dashed lines represent Climate TRACE emission inventory values.

28. Line 298: Which power plants provide stack heights? Include this information in one of the Tables.

Answer: We have added the corresponding stack heights for the power plants in Table 2 and labelled the plants for which no stack information was provided.

29. Line 300: The authors must comment on the single pulse-pair precision that is used to fit the Gaussian plume. On short spatial scales, this information is more important than the accuracy of the IPDA measurement since the background is subtracted.

Answer: The results of the fitting in this study are the result of a 10-km moving average of the original single pulse echo signal, as explained above, and the results of the model simulations were similarly smoothed to ensure theoretical support during the least-squares fitting. After smoothing, the pseudo-observations are generated at the same 330-m interval, while the uncertainty of each of their footprints is less than 1 ppm, resulting in an average relative error of 47.3 % in the XCO₂ enhancement at the peak of the plume. We have revised in Line 362: “The uncertainty of XCO₂ around the studied power plants is less than 1 ppm by moving average, but the average relative error of XCO₂ enhancement at the peak of the plume is as high as 47.3%. Compared to the statistical uncertainties reported in Han et al (Han et al., 2024), both investigations identified that uncertainties in the DQ-1 satellite’s XCO₂ observations dominate the error budget, accounting for approximately 50% of the total error.”

30. Table 1/2: Swap the order of the tables. Table 1 should contain the basic information about the power plants and Table 2 the uncertainties.

Answer: Thanks, we switched the order of sections 3.2 and 3.3 as you suggested, comparing the results with the emission inventories first, and analysing the uncertainties later.

31. Figure 8: See comment above about the error of the data base.

Answer: We do not have access to the statistical errors for these specific emission inventories, so we are unable to include an error bar for the emission inventories in Figure 8. Because the emission inventories themselves are uncertain, we include cautionary language in the text to indicate that this is only a comparison with the emission inventories and is not representative of the true emissions. We have revised in Line 333: “It is critical to acknowledge that direct validation against stack monitor measurements is unavailable, and emission inventories are inherently uncertain and not independently validated. Therefore, comparisons between estimated results and inventories should be interpreted cautiously and serve as a provisional reference rather than definitive conclusions.”

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32. Line 325: Without robust evidence on the diurnal (day-night) and seasonal (winter-summer) variations in power plant emissions, any claims about these differences are speculative and should be clearly labeled as such.

Answer: Thank you for your suggestion, we have modified the expression in Line 323: “Overall, the CO₂ emissions predicted by the Gaussian plume model are generally higher than those in the emissions inventory. This discrepancy may be due to the timing of observations, as some were conducted during winter and summer in the Northern Hemisphere when increased electricity demand (e.g., air conditioning usage) prompts power plants to elevate generation capacity.”

33. Line 333: Quantify the higher emission rates vs. Carbon Brief and Climate TRACE.

Answer: Revised in Line 331: “Overall, Quantify the higher emission rates vs. Carbon Brief and Climate TRACE, a difference that might arise because conventional power plants undergo annual shutdowns for inspections, lowering annual averages relative to instantaneous emissions.”

Conclusions:

34. In the conclusions, I would like to see suggestions for potential improvements in emission estimate accuracy, such as utilizing more advanced models or those with higher spatial resolution. For instance, the authors briefly mention WRF (Weather Research and Forecasting) model in the introduction. However, it would be helpful to provide a more detailed discussion on what enhancements can be expected from using this model instead of a Gaussian plume model, as well as any challenges that might arise.

Answer: The WRF-STILT model was used to estimate the assessment of urban emission sources, for point sources it is not suitable to use the WRF-STILT model, for Gaussian plume models, the wrf can provide refined small and medium scale meteorological fields, and I think the results will be more accurate than the results after interpolation by reanalysing the information such as the ERA5, especially in the case of a complex underlying surface with the influence of turbulence, and it would be better to

use the WRF-LES model as the meteorological driving field for Gaussian model may be able to further improve the accuracy of the model and substantially reduce the model error due to wind field uncertainty. We have revised in Line 389: “Utilizing high-resolution wind fields simulated by the WRF-LES model around power plants to drive the Gaussian plume model may reduce uncertainties in wind field. Establishing automatic weather stations around the power plant for real-time monitoring of atmospheric radiation and surface wind speed could reduce errors caused by uncertainties in atmospheric stability.”

Data availability:

35. Please give a hint about the availability of ACDL data, since this is the major data source used in this work.

Answer: Thank you for your advice. The ACDL data is not yet open for access, and researchers can download the satellite's data by making an official request through this website: <https://data.cresda.cn/#/home> We have also given the official link to the data and explained it in the article Data Availability.

“The ACDL dataset is under restricted access, the data can be requested at <https://data.cresda.cn/#/home>”

Summary:

To summarize, the manuscript presents valuable findings based on new data, but also exhibits some shortcomings, including missing citations and a critical oversight regarding the impact of turbulence on the results. Notably, this omission is particularly concerning in light of potential differences between daytime and nighttime measurements. In order to ensure the manuscript's credibility and thoroughness, I believe it is essential to address these issues before publication.

Answer: We greatly appreciate your valuable time for reviewing our research paper and providing suggestions. We have revised the manuscript according to your comments point-to-point