

Response to Reviewers

Manuscript number: egusphere-2025-6470

Title: Elucidating CO₂ accumulation and dispersion in a semi-enclosed bay industrial park using Lidar and WRF-GHG modelling

We thank Reviewer #1 for the positive assessment and the constructive comments. We have revised the manuscript carefully. The point-by-point responses are given below. All changes made in the revised manuscript are marked in blue.

Reviewer #1

1. In Figure 3d and the corresponding text, the authors point out that the WRF-GHG model systematically underestimates CO₂ levels, simulating concentrations of 420-460 ppm, whereas the Lidar measured 450-800 ppm. Although the authors provide a reasonable explanation by attributing this to the coarse spatiotemporal resolution of the EDGAR inventory and the complex bay topography, the simulated values still appear to be overly close to the background concentration levels. The authors are suggested to carefully double-check their emission flux inputs, boundary conditions processing, and the overall simulation setup. Furthermore, it is recommended to add a paragraph in the Discussion section to specifically explore the detailed reasons why the WRF simulated values are significantly lower in the specific industrial park where the Lidar was deployed.

We thank the reviewer for this comment. We re-checked the emission inputs, boundary processing, and model setup. We found a unit-conversion error in the original inventory preprocessing and corrected it. We then refined the EDGAR inventory in two steps. Industrial emissions were redistributed onto actual plant footprints, and land-sea mixed grids were corrected (EDGAR_S). A SNAP3 vertical profile (Brunner et al., 2019) was then added (EDGAR_P). These steps sharply reduced the low bias, with the mean bias improving from -169.5 ppm (raw EDGAR) to -115.9 ppm (EDGAR_S). Section 4 now discusses the remaining near-source underestimate: EDGAR_P still places part of the emissions above the true (low) stack height, so the model misses the highest Lidar values under calm nights. Details are in Figs. 2, 11 and Section 4.

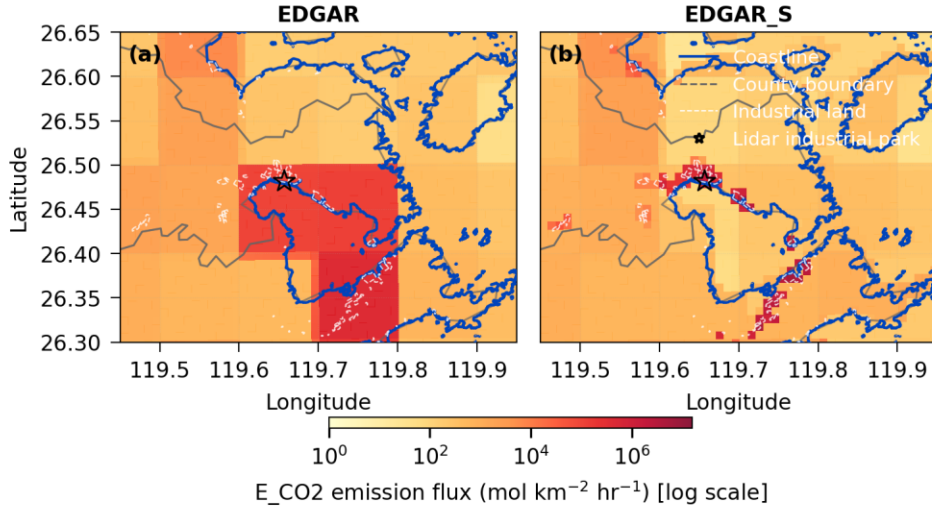


Figure 1 Comparison between raw EDGAR and EDGAR_S emission fields at 08:00 on 25 March 2025. EDGAR_S denotes the emission inventory after industrial-source spatial redistribution and land-sea mixed-grid correction.

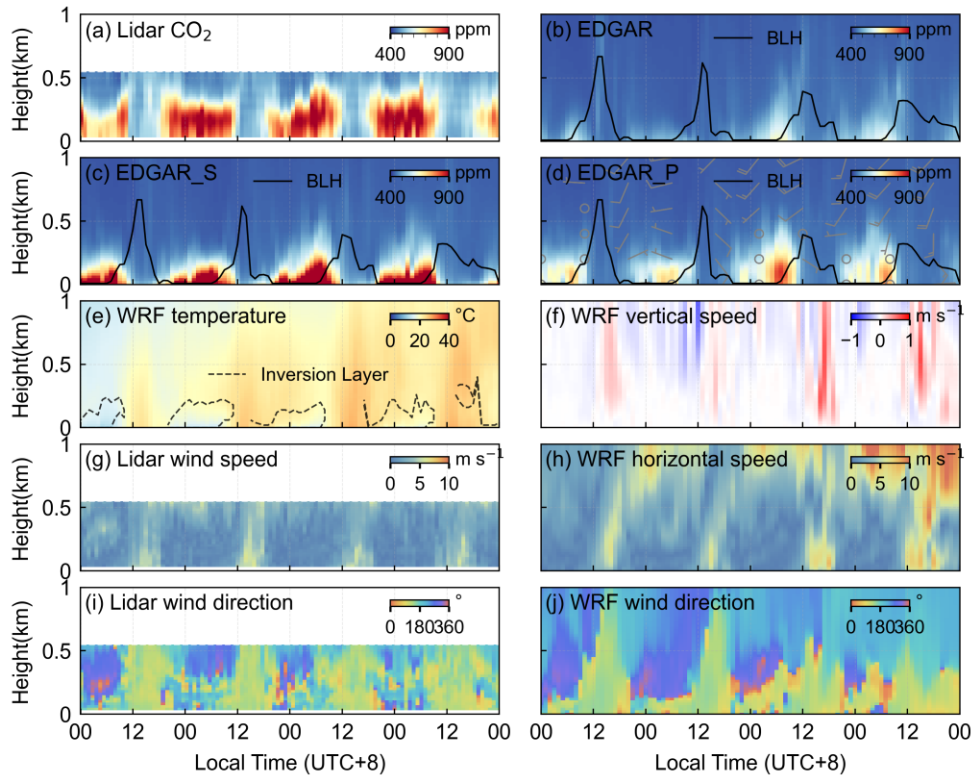


Figure 2. Time-series heatmaps of CO₂ Lidar observations and WRF simulation results from 00:00 local time (LT; UTC+8) on 23 March to 00:00 LT on 27 March 2025; (a) shows the distribution results of CO₂ detected by the CO₂ Lidar converted to vertical height, where the portion above 500 m (white dashed line) is invalid data; (b) presents the WRF-simulated CO₂ concentrations at the park location, with the black solid line representing the model-output BLH; (c)–(e) are the model-output vertical wind speed, horizontal wind speed, and horizontal wind direction, respectively; (f) is the model-output air temperature, where the black dashed line denotes the strongest temperature inversion layer with a temperature gradient exceeding 0.5 °C 100 m⁻¹.

2. From the WRF surface simulation results in Figures 4 to 6 (panels i-p), a large area of high CO₂ concentration is visible in the southern region of Luoyuan Bay. The southern bank hosts thermal power plants and petrochemical projects. Does the current Lidar scanning range (azimuth 306-16) fail to cover this high-emission southern area? It is recommended to add a sentence or two in the main text (e.g., Section 3.3) to clarify the spatial relationship between the Lidar field of view and the high-emission areas in the southern bay.

We thank the reviewer for this comment. We clarified the spatial relationship in Fig. 1 and Section 3.3. The Lidar scans the northern industrial park core at an azimuth of 306-16. The high-emission southern bank (thermal power and petrochemical plants) lies outside this sector. The Lidar statistics therefore represent the northern park. The southern high-concentration area shown in Figs. 4-6 comes from the WRF simulation only.

3. The manuscript describes that the Lidar used a fixed elevation angle of 10 degrees during synchronous detection. At a radial distance of 1-2 km, the actual beam height reaches about 170-350 m above ground. However, in the comparison of Figures 4 to 6, the authors present WRF-GHG results for the surface layer. The authors should clarify whether they extracted the lowest model layer or the layer matching the actual beam height, and discuss the potential uncertainty from this altitude mismatch if the surface layer was used.

We thank the reviewer for raising this. We originally used the model surface layer, which mismatched the Lidar beam height. We now extract WRF-GHG output at the layers matching the actual Lidar sampling altitude (layer-averaged over 80-300 m, the beam height for the 10 degree elevation over the source region). This removes the altitude mismatch in the comparison. The change is applied in Figs. 7-11 and Section 3.

4. Regarding the VPRM model used for the online calculation of biogenic CO₂ fluxes, its accuracy highly depends on vegetation-specific parameters (e.g., maximum light use efficiency and respiration parameters). Could the authors briefly clarify the VPRM parameters used in the study?

We thank the reviewer for this question. The VPRM (Ahmadov et al., 2007) was run online within WRF-GHG. We used the Copernicus CLMS 100 m land-cover dataset (2019) and MODIS-derived EVI/LSWI via pyVPRM (Glauch et al., 2025). The VPRM parameters used in this study are taken from the parameter table of Li et al. (2020). These settings are now stated explicitly in Section 2.3.1.

5. The simulation period is stated as 5-31 March 2025, and the detailed analysis focuses on the high-concentration period of 24-26 March. Chemical transport models typically require a spin-up

period. It is recommended to briefly state the length of the spin-up time allocated for the WRF-GHG simulations before the analysis period.

We thank the reviewer for this suggestion. We now state the spin-up explicitly in Section 2. The model was initialized on 5 March 2025 and run with a 13-day spin-up (5-17 March). The formal analysis uses 18-29 March, after the initial and boundary fields have stabilized.

6. The innermost domain (d03) is set to 1 km x 1 km. While this is high resolution for regional modelling, Luoyuan Bay has a highly complex semi-enclosed terrain with steep mountains and narrow valleys. The authors are suggested to add a brief discussion on whether the 1 km grid is fine enough to resolve the microscale mechanical turbulence and terrain-forced wind channeling that dictate local CO₂ accumulation, or whether LES scales (e.g., 100 m) might be needed in future works.

We agree with the reviewer. A 1 km grid captures the dominant accumulation and dispersion patterns, but may not fully resolve the microscale mechanical turbulence and terrain-forced channeling in the steep, narrow valleys. We have added a short discussion in Section 4 (future work). It notes that large-eddy simulation (LES) at sub-kilometre (about 100 m) resolution is needed to capture these local topographic effects in follow-up studies.

Reference

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