Review: *Gałkowski et al. Impact of atmospheric turbulence on the accuracy of point source emission estimates using satellite imagery*

Summary

Gałkowski et al. present the effect of atmospheric turbulence on CO_2 emission rate estimates They apply a high-resolution simulation with temporally tagged tracers and discuss the decomposition of the plume variability. This is novel and useful for analyzing high-resolution satellite data. However, the study only shows one timestamp result, and this point needs to be addressed in a revision. Finally, there are a number of minor technical corrections that are needed for readability.

General comments

1. The authors pick the time between 9 April 2020 and 10 April 2020 for the simulation. Since the turbulence is the key point, it is better to discuss the variation of wind speed and direction before further analysis.
2. It makes sense to only pick the simulation at noon, which is “consistent with typical observation times of passive remote sensing”. As mentioned above, the wind speed may limit the application. More simulations with different wind speed would make the conclusion more concrete. The authors may aim to compare the result with Fuentes Andrade et al. (2024), if so, I would suggest picking more OCO-3 observations and running the simulations.
3. Since the turbulence effect is important for estimate uncertainty, could authors define a new effective wind (Ueff) based on simulation and apply it to correct emission rates derived from satellite observations?

Specific comments and technical corrections

- L8: “However, a realistic evaluation of the accuracy and precision of the obtained estimates is essential.”
- L12: “…. significant uncertainties … on the order of 10 % of the total source strength, in retrieved …”
- L21: “The ongoing warming is already driving widespread adverse impacts across various components of the Earth’s system, not only degrading the environment but also directly affecting communities by intensifying extreme events such as heatwaves, heavy precipitation, droughts, and tropical cyclones.” And please add the references.
- L23: “Furthermore, if left unmitigated, the consequences of elevated CO_2 levels will persist for centuries.”
- L31: Please add the references.
- L35: “Independent, science-based observations of GHG emissions offer a promising approach to enhancing the confidence of all stakeholders.”
- L37: “Moreover, the monitoring of atmospheric greenhouse gases through a combination of in situ and satellite-based measurements, integrated with modern top-down frameworks, can reduce uncertainties in global anthropogenic flux estimates, which averaged 9.6 ± 0.5 GtC yr^{-1} over the past decade.”
- L43: What is the definition of “currently available tool”? Statistic model or satellite observations?
- L48: Please add the reference for “… strongest emissions occur (US, EU, China, India).”
- L62: “Satellite observations offer a distinct advantage due to their global coverage and lower cost per observation.”
- L73: "*(GPI, Krings et al., 2011; Nassar et al. (2017)*"
- L75: “… has been widely used in practical applications in recent years.”
- L77: Missing the definition of “estimation statistics”.

- L81: What's the wind speed range for the "10~20% uncertainty"? Is the wind speed the most important one in these parameters (*the estimation method employed, wind speed, stability conditions, time of day*)?
- L85: How are the data collected virtually?
- L89: Figure 1 is copied from another paper and too small. It would be better to apply the CSF method and make a new plot. Or just remove it.
- L93: "We employ high-resolution WRF-GHG simulations over a previously studied point source, enhancing the modeling system with temporally tagged tracers."
- L100: "The Bełchatów Power Plant (BPP) is one of the largest anthropogenic CO2 point sources globally, relying on lignite coal for power generation."
- L103: "Under both national and EU legislation, accurate information on GHG emissions and operational status is publicly accessible, making the Bełchatów Power Plant an ideal target for developing and testing new instruments and methods."
- L116: Please introduce the WRF model briefly.
- L126: " .... (ECMWF, 2022)"
- L169: How did the authors define the segmentation? Will that affect the turbulence analysis?
- L170: "The resulting CO2 signals are conceptually similar to the "particles" or "air parcels" used in Lagrangian models."
- L171: Adding the illustration of puff to the main text could help readers better understand it. I would suggest plotting three puffs with same time steps to show the transport and turbulence. As the authors discuss the difference between tracer and the sum of puffs around L310, it is also useful to include that in this figure.
- L173: As mentioned in the "General comments", analysis with more cases would be better.
- L202: Do the lower and upper integration limits of y depend on the segmentation described in L169?

- L207 and L227: The definition of Ueff at L227 is different from Varon's paper: "*U*eff in the cross-sectional flux method is different than *U*eff in the IME method. For each plume in the training set, *U*eff is computed from Eq. (6) based on *C* and the known source rate *Q*.". Please clarify the Ueff definition.
- L233: How about normalizing the data by the true emission rates?
- L237: What is the definition of "typeB uncertainty"?
- L241: It would be better to explain the ACF in detail.
- L265: The sentence is duplicated with L263—L264.
- L301: "As shown, the model ..."
- L337: The true emission value is within the full-tracer estimates. It would make readers feel that this method is better. Is this conclusion still true for other cases? Another point: Is the full-tracer method standing for the application of CSF to real satellite observation? It is better to mention the relationship between simulation estimate and real observation.
- L355: As mentioned before, please clarify how the authors calculate the Ueff values.
- L357: Correct the format: "using ueff = 2.9 ms−1) (value at 12:00)."
- L358: Which regression is better?
- L368: I could not find the source of "11.6 Mt yr-1". Please correct me if I missed.
- L380: Please add the definition to Table 1. It is difficult to find out which variable is "*emissions for uncorrelated uncertainty*".
- L383: The comparison makes me curious how to apply author's method to real satellite data? or does the comparison mean the dispersion uncertainty in *Fuentes Andrade et al., (2024)* is accurate enough?
- L390: What is the reference of "*in that study*"?
- L400: Does this mean that the turbulence will cause a larger uncertainty for GPI and IME method? Please make it clearer. It is valuable to apply the IME

with different limits (e.g. 2-22 and 2-40 km) and check the differences in the supplement.

- L444-445: Please combine them into one paragraph.
- L454: Why does the real uncertainty can only increase? As the effective wind speed aims to minimize the difference between estimates and true emission rates, the turbulence effect can be included there.