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## Comment on acp-2021-1039

Anonymous Referee #1

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Referee comment on "Estimated regional CO<sub>2</sub> flux and uncertainty based on an ensemble of atmospheric CO<sub>2</sub> inversions" by Naveen Chandra et al., Atmos. Chem. Phys. Discuss., <https://doi.org/10.5194/acp-2021-1039-RC1>, 2022

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This manuscript presents inverse model estimates of global and regional CO<sub>2</sub> fluxes over the last two decades. The inverse model is based on a single transport model assimilating observations from 50 sites. A series of 16 model simulations is conducted by varying the prior fluxes and prior and observational errors. Results are evaluated against independent aircraft data. The authors found that the ensemble mean of 16 optimized fluxes outperformed individual model outputs. The spread of flux estimates from these 16 model simulations is considered as the uncertainty of the estimated fluxes.

### General comments

The manuscript presents a detailed study focusing on the inverse model estimation (using a single model) of CO<sub>2</sub> fluxes on a global scale for two decades. Therefore, the paper is worthy of publication in ACP after addressing the concerns listed below.

- Authors should present the novel aspect of this manuscript. This study uses a single inverse model and conducts a series of model simulations by changing model components, keeping the same observational dataset. Many model intercomparison projects (TransCom and GOSAT and OCO-2 inverse model intercomparisons) address the same aspects by including different transport models but by changing individual model components. Calculating the ensemble mean and spread using a single transport model is not the right way of quantifying the mean and uncertainty in CO<sub>2</sub> flux estimates (by not accounting for transport errors).
- To investigate the impact of different modeling components such as model transport, priors, and specification of uncertainties, there could be other systematic approaches, such as designing a series of simulations and quantitatively assessing the uncertainty components. For example, see Basu et al. (2018) and Philip et al. (2019). More rigorous experiments are required if this manuscript intends to assess the spread from priors and prior/observation uncertainties. Randomly selecting two different terrestrial biosphere models (TBMs) or ocean models is insufficient. Otherwise, reconsider the focus of the manuscript.

- This study mainly tests land flux scenarios with and without interannual variability (IAV) (CASA versus VISIT). They should consider using different TBMs as priors (diagnostic/prognostic/with and without IAV etc.) with significant regional differences. That can lead to a reasonable spread in the optimized fluxes. Also, how about conducting a sensitivity test by artificially imposing zero net annual flux in the VISIT model?
- The manuscript should be written more carefully, especially the introduction and conclusion sections. There are many empty/loose sentences, no connection between paragraphs, introduction not providing any motivation of the paper (it also discusses unrelated aspects), grammatical mistakes, etc., throughout the manuscript. See some of the corrections in the technical-correction section below.

### **Specific comments**

Line 17-21: These two sentences are not connected. You state that model errors and insufficient observations lead to uncertainties in regional flux estimates. However, it is unclear how you address these with your simulations using a single model. State clearly what uncertainty component you are addressing here in this article.

Line 26-28: This is just a general statement. Need more clarity here: "Interannual variability and seasonal cycle in CO<sub>2</sub> fluxes are more consistently derived for different prior fluxes when a greater degree of freedom is given to the inversion System".

Line 28-29: In line 261, you mention that fluxes are evaluated with aircraft observations. Are you using surface data as well? "...evaluated the inversion fluxes using independent aircraft and surface measurements not used in the inversion".

Line 28-29: Good if you can make it more quantitative, i.e., add some summary statistics or so: "which raises our confidence in the ensemble mean flux rather than an individual inversion"

Line 31: It seems like an empty/loose sentence: "Differences between 5-year mean fluxes

show promises and capability to track flux changes under ongoing and future CO2 emission mitigation policies.”

Line 36-38: Cite IPCC report.

Line 44: Be very clear (solutions to ...?): “The sinks on the land and ocean constitute a major component of nature-based solutions”.

Line 45-46: Cite proper references to support the statement.

Line 45-53: In this paragraph, mention global flux uncertainty first, and then note the regional issues, with some additional details. That is, lines 45-46 should come after line 53.

Line 55-69: It is not clear why you need this paragraph. “However, the impacts of biases in FFC emissions on inversion estimated CO2 fluxes remained relatively unexplored”. Are you exploring this aspect in this paper? Moreover, this paragraph is written poorly.

Line 70-73: I don't quite understand this statement! Who provides the metric, what is that metric? What's the meaning of “metric for evaluation of regional fluxes should be

evaluated"? Clarify.

Line 71-73: Is this something new? "...should be evaluated using a new transport model simulation of the predicted fluxes, not using the assimilated CO<sub>2</sub> field". Be clearer with sufficient details. Most evaluations in current published works are based on model simulation of optimized fluxes. For evaluation, using a different transport model than the one used in the inversion (as a forward model) is advantageous (not sure if this is what you mean here). Also, are you exploring this in this manuscript/study?

Line 73-81: I'm lost here. From re-reading this, I understand that the assessment of the spread of optimized fluxes obtained by conducting multiple simulations using different model inputs is a better way of quantifying the uncertainty than simply evaluating the optimized CO<sub>2</sub> concentrations against independent measurement data. Revise the entire paragraph to be more apparent.

Line 82-85: These uncertainty sources have been investigated previously. Cite some of those critical studies here.

Line 92-95: This statement is not correct: "Such intercomparisons used single inversion from different modeling groups and provided the range in CO<sub>2</sub> flux uncertainty due to differences in transport models.". These intercomparisons assessed uncertainty arising from different model components, not just the transport model differences. For example, see Crowell et al., 2019 and Peiro et al., 2022.

Line 123-124: This sentence is not clear to me.

Line 128 and 129: Just "used" not "simulated" (?): "... is simulated using ..."

Line 135: "...downscaled to 3-hourly time intervals...": Mention how you downscaled; which variable used; and cite proper literature.

Line 136: Double-check if it is version 4.1? "...fire emissions are used from GFEDv4s (van der Werf et al., 2017...)".

Line 145: Complex notations: gc3t and gvjf. What is "3" and "t" in gc3t?

Line 149-150: Revise: "to evaluate the strength of MIROC4-ACTM simulations to derive fluxes consistently". How do you evaluate the strength of simulation? Why did you mention "consistently" here? Fluxes will be derived using the inverse model, so how can you "evaluate the strength of forward simulation"?

Line 159: Cite proper references: "WDCGG websites as appropriate"

Line 162: Is this the grid cell with the observation location? "...nearest grid of observation location at hourly intervals...".

Line 164: "These temporal data gaps (1-6 months) are filled using the curve fitting method based on the digital filtering technique". Have you conducted simulations without using curve-fitted data? Why was this data filling necessary?

Line 200-210: How about conducting a simulation with "gpp\_v4" along with "ocean PFU = 0.5"? Explain the rationale for selecting different prior error scenarios you considered in this study.

Line 234: "High values (FUR towards 100)": If FUR is in percentage, then revise the equation in line 233.

Line 244: Not clear: "... indicative of the observational constraint regional fluxes..."

Line 245: "...we recommend that the spread of ensemble inversions provide more representative estimation of the regional CO<sub>2</sub> sources and sinks.". "Spread" represents "a measure of uncertainty", not a "representative estimation of...". Why do you add "recommend" here?

Line 309 and 311: Revise this sentence: "Hence, the magnitude of biases and RMSE indicates predominantly the accuracy of the predicted fluxes.". Model transport is one of the sources leading to uncertainties in the predicted fluxes.

Line 649: "CO2 simulations are derived from three sets of prescribed fluxes: "gc3t", "gvjf", and "ensm".": I'm assuming that the evaluation is conducted for all 16 inversions (?).

Lines 709-720: I'm not sure if these details (+ Figure S10) are required in this paper.

Line 775-782: Empty/loose sentences.

### **Technical corrections**

Line 14: Better add "atmospheric" here: "chemistry-transport model (ACTM)".

Line 16: Better avoid text in parenthesis: "regional flux (+ve: source to the atmosphere; -ve: sink on land/ocean)".

Line 21: Move the number of the sites (50) from here to the appropriate part of the sentences: "data uncertainties (50 sites)".

Line 24: Is this "22-33% and 16-18%" for land vs ocean? Not sure this is clear enough here.

Line 25: Not clear what this approximate means here: "best estimations for (approx. 2000-2009)".

Line 52: Revise and add more clarity: "partitioning exists greatly in the ... release".

Line 55-56: Revise this sentence: "...because inversion calculations do not optimize...".

Line 90-91: You can write these in a better way: "inversions from ... for inversions using ... or for inversions".



Line 99: Revise: "observed and model data processing".

Line 100: Avoid capital letter: "the Results and discussion".

Line 155-156: Avoid repetition of "from".

Line 1120: Correct this: "lower panel (b)".

Line 242: Correct: "...West Asia, Northern Africa. The Tropical Indian Ocean...".

Line 252: Correct: "as per analysis".

Line 302-307: Use simple notations. For example, avoid "aircraft" from "x".

Line 308: Correct: "CO2 mixing ratios".

Line 317: Use the term "grid cells".

Line 336: Avoid ".": "3.2. Global totals."

Line 346: Use "mean": "Ensemble means land".

Line 563: Revise: "It is not easy for us to explain".

Line 763: Avoid "Please".

Line 766: Correct: "is unanimously located".

Figure 4: Choose a different font that is clearer.

Figure S2: Correct to CO2: "monthly-mean CO fluxes"

## References

Basu, S., Baker, D. F., Chevallier, F., Patra, P. K., Liu, J., and Miller, J. B.: The impact of transport model differences on CO<sub>2</sub> surface flux estimates from OCO-2 retrievals of column average CO<sub>2</sub>, *Atmos. Chem. Phys.*, 18, 7189–7215, <https://doi.org/10.5194/acp-18-7189-2018>, 2018.

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