

Summary:

Fan and Li presented a study on investigating information transfer in CO₂ flux inversions using the approach of Ensemble Kalman Filter based on Monte Carlo. The authors examined the information transfer pathways between CO₂ concentrations and fluxes through analysing their spatial and temporal correlations across 500 ensemble members varying by fluxes and transported using WRF-Chem transport model. They introduced a comprehensive analysis highlighting the effect of applying different correlation length scales across several selected sites representing both surface station and remote sensing networks at different seasons. The authors suggested to use longer spatial and temporal length scales where a resonance can be achieved to maximize gains in the inversions, particularly when using limited observations from sparse sites. The study is well written and worthy of publication, as it provides useful insights for improving CO₂ inversion estimates. I recommend publication after the authors address minor issues listed below.

General comments:

The introduction needs to be more comprehensive to align with the scope of atmospheric inversions. Specifically, there is still a gap in literature review that needs to be bridged to help introduce the scientific objectives.

Some elements in Table 1 need further clarifications, e.g., aim of using offline and online perturbations, the selection of 40% of the variance (and make sure you do not mix it with standard deviation as is through Section 2.3).

The emphasis in some conclusions on using longer spatial correlation scales is somehow not fully understandable because it is not about increasing correlation length to get fluxes constrained by distant observation sites as long as there is surface influence. Instead, it is about to what extent the errors of fluxes are dependent spatially and temporally in biosphere models compared to reality. I agree, longer correlation lengths allow for more information transfer from observation space to flux space in inversions, but this is not always true or at least differs among biosphere flux models used as priors in inversions.

Although the effect of CO₂ concentration and fluxes correlations is clear, quantifying the impact in flux estimates would be more useful by implementing inversions using the similar setup as in Table 1. This would give some insights on how much spatial and temporal variations in fluxes can be explained by tuning correlation scales. I know this might be beyond the setup of this study as such an inversion should be conducted for a longer period of time than one week.

Specific comments:

L26-29: The first sentence feels quite squeezed in its flow. So, there should be a sentence before to briefly describe what are the various estimation methods, used to quantify GHG fluxes besides atmospheric inversions. Also, consider splitting and rephrasing this sentence to clearly first define atmospheric inversions and then you can indicate their usefulness afterwards.

Comments on egusphere-2026-615 research article

L30-31: It does not matter how many inversions participating to GCP but what would be worthy of mentioning here is what information atmospheric inversions add on top, or alongside, of the other methods to estimate GCB, for example.

L41-46: Here is a big jump in the flow with lack of literature. You need to elaborate the objectives of your study (in the next paragraph) with more details and relevant literature. For instance, there are many studies elucidating their assumptions and approaches for the construction of covariance matrices that consist of autocorrelation information in space and time.

L87: Indicate clearly what method you adopt here, e.g. nonlinear Kalman filter, as “the latter” is still ambiguous at this stage, or just link the sentence like: “.....(Tanizaki, 1996), which we adopt in this study.”

L129-130: You need to mentioned what is meant by ACM2 scheme as it was not defined previously.

L196-197: Although correlations between observations and fluxes affect how much observational information to the state space variables, atmospheric transport and uncertainties assumed in fluxes and observations play a major role in that. So, they are worthy of mentioning in this context to provide a full view of the most impactful components in inversions for the reader.

Through all texts, clearer to use “long or short” instead of “large or small” once referring to spatial and temporal correlation scales.

L221-222: The negative correlation between CO₂ simulations and fluxes in Fig. 1Bg requires further explanation than diffusivity or perhaps diagnostics to find out the main reason if it is something physical property of the transport (in advection and in vertical convection) but also to ensure this is not just an artifact due to transport error at that local scale. I would suggest to displace the location of that site one or a few grids around and see whether this phenomenon still persists.

L280-283: In indication to Kountouris et al. (2015, 2018), the use of a shorter correlation length than 100 km was coincided with applying a different decaying function (hyperbolic), which has another property with longer tails compared to the exponential function. This also allows for adjusting fluxes based on distant observations and that experiment relied on analysis of model-data mismatch using the same biosphere model VPRM used in this study as well. Of course, you are using here a statistical method to generate the covariances that are associated with what you indicated “resonant effect” that maximises the gain in information transfer but the question remains is how realistic is this in terms of flux estimates compared to the truth, despite the issue of data sparsity.

Comments on egusphere-2026-615 research article

Cross comparison between Fig. 1 and Fig. 2 is confusing. To simplify it with minimum redundancy, you can choose only one site as best example for each case (surface vs airborne and winter vs summer). This will clearly help compare the resulting effect for each case you specified in Table 1, e.g., ONLINE and OFFLINE perturbations, long and short correlation length scales (e.g., OFF600 and OFF100), etc. The rest can be moved to the supplements.

In Fig. 3, correlations cannot be added linearly, at least need to be normalized by the sample size. In addition, captions of figures are not fully clear and need to be well explained even with lengthy text, and better to avoid cross mentions from figure to figure, provided that each one is very busy with too much info.

Throughout Section 3.1.3, replace “CO₂”_{BIO,ANT,OCE} with any code else (like C or M) to differentiate between concentration and flux (F), because both relate to CO₂.

Fig. 4: please see note above regarding Fig. 1 and 2.

L414: color lines for F_{BIO} looks much more into cyan other than green!

L437-439: Transport influence plays a more important role in designing station network and thus correlation effect is stronger at sites with broader transport influence and can be beneficial for inversion.

Technical corrections:

L35: Missing object!

Sentence starts in L280 suggesting to be joint with the next one!