

## ***Interactive comment on “On the statistical optimality of CO<sub>2</sub> atmospheric inversions assimilating CO<sub>2</sub> column retrievals” by F. Chevallier***

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I thank the referee for his helpful comments. I have addressed all the issues he has raised in the following. The full review is copied hereafter and my responses are inserted where appropriate.

Author provides arguments on desirable improvements in overall consistency in a two-step process of estimating CO<sub>2</sub> fluxes using firstly the atmospheric  $\chi_{CO_2}$  retrievals from satellite observations, and secondly CO<sub>2</sub> flux inversions. The discussion points at an inflated prior uncertainty for  
C4319

retrievals as a factor contributing to retrieval product deficiencies. It was found that tightening retrieval uncertainties can reduce posterior misfit between concentrations optimized with inversion and retrieved  $\chi_{CO_2}$  values. It is also mentioned that possible posterior adjustments to uncertainties are making empirical bias correction inconsistent. The methods and materials applied in the analysis appear valid, and the discussion and conclusions are valuable for those working on concentration retrievals and inverse modeling of the surface fluxes. Several minor changes are recommended before publication.

Suggestions on the text

Page 11896 line 19. The derivation of Eq. (4), with elimination of  $\tilde{x}^b$  should be included, to convince the reader that there is no omission or use of simplifying assumptions on the way.

I will develop the demonstration as suggested.

I have noticed a misplaced prime in Eq. (4), that induced missing primes in Eq. (6-7). Additionally, I have also noticed that, when we make Eqs. (5-6) consistent, the requirement of Equation (7) can be relaxed to  $\tilde{\mathbf{H}}\tilde{\mathbf{B}}\tilde{\mathbf{H}}^T = \tilde{\mathbf{H}}\hat{\mathbf{B}}\hat{\mathbf{H}}^T$ , which means that consistency needs only to be satisfied at the resolution (information content) of the retrieval. I will correct these equations and update the text accordingly.

Page 11898 line 3. It is mentioned "if enough intermediate variables were saved by the retrieval schemes, it would be possible to reconstruct the retrievals with a different prior". Reader may get impression that Level 2 products do not carry "enough intermediate variables", while the reality is

that a number of products include prior and posterior matrixes, as well as column averaging kernel and prior profile  $\check{x}^b$ . As author wrote, the information is not sufficient to reconstruct the retrievals with a different prior error covariance matrix  $\check{B}$ , but it is sufficient for a) getting approximation to  $\check{x}^a$  for  $\check{B}$  modified by multiplying it by scaling factor,

The gain matrix  $\check{K}$  depends on both  $\check{B}$  and  $\check{R}$ . Scaling  $\check{x}^a$  from a scaled  $\check{B}$  would not be a good approximation. Further,  $\check{B}$  is made of both variances, that indeed can be scaled, and correlations that cannot be changed with a scaling factor.

b) replacing the prior profile  $\check{x}^b$  with any other.

Atmospheric inversions are insensitive to  $\check{x}^b$  provided that  $\check{x}^a$  is assimilated with its averaging kernel (Eq. (4)). Therefore, we are not interested in changing  $\check{x}^b$ .

Thus if one wants to have the retrieval with deflated prior uncertainty as suggested in the manuscript, it can be done. For the sake of clarity it is better to mention that although we can not get retrieval result for different prior error covariance  $\check{B}$ , simple scaling should work.

This proposition is similar to what is done in the paper with  $\check{x}^{a,r}$ , but I do not recommend it because it does not improve the correlations in  $\check{B}$ .

I will make it clearer that we need to change both variances and correlations.

Page 11898 line 19. The comment that with large prior uncertainties for retrievals, "the retrieval averaging kernel would not peak low enough in the vertical" is not supported by discussion or reference.

C4321

I will make the sentence more general by changing it to "In particular, the sub-optimality of  $\check{K}$  affects the retrieval averaging kernel, that may not peak at the right height."

Page 11901 line 21. It is mentioned that "boreal forests are covered with needle-leaved trees". It is safer to say "are largely covered". Apart from the widespread light coniferous larch and pine forests, dark coniferous needle-leaved trees can not dominate the landscape and often appear in mosaic patches with broad-leaved trees mostly due to post-fire successional dynamics (eg Shvidenko and Nilsson, Tellus, 2003).

I will remove this mistake. The text a few lines later ("dominated by") was more cautious.

Page 11903 line 15. The test results introduced on Fig. 6 are most impressive, and show advantage of mixing retrieval with prior  $\chi_{CO_2}$ . Here it is worth mentioning that making weighted average of prior and posterior has similar effect with reducing prior uncertainty for retrieval. The result needs more discussion, as long as a) mixing proportion of 1/2 is chosen arbitrarily; b) the prior performed worse than retrievals on Fig.5 so it is not clear why mixing with it would improve the mismatch.

The interpretation is that the retrieval scheme overshoots the truth, i.e. that the increments are in the right direction but are too large. I will add this clarification in the paragraph.

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C4322