Technical note: temporal change in averaging kernels as a source of uncertainty in trend estimates of carbon monoxide retrieved from MOPITT

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We thank the anonymous reviewer for the constructive comments, which replies are listed on the supplement.

Specific comments from Anonymous Referee #2

- The example chosen to illustrate the effect seems rather malign to me. If I understand correctly, the state vector x contains a vertical CO profile with N layers (N=10?, Fig. 3). The corresponding averaging kernel matrix is an (N x N) matrix. What is called "CO at the surface" is the lowest layer of the profile with the Nth row of the averaging kernel matrix being the relevant smoothing operator (eg. illustrated in Fig.3). Is this correct or do you refer to >800 hPa as the surface layer?

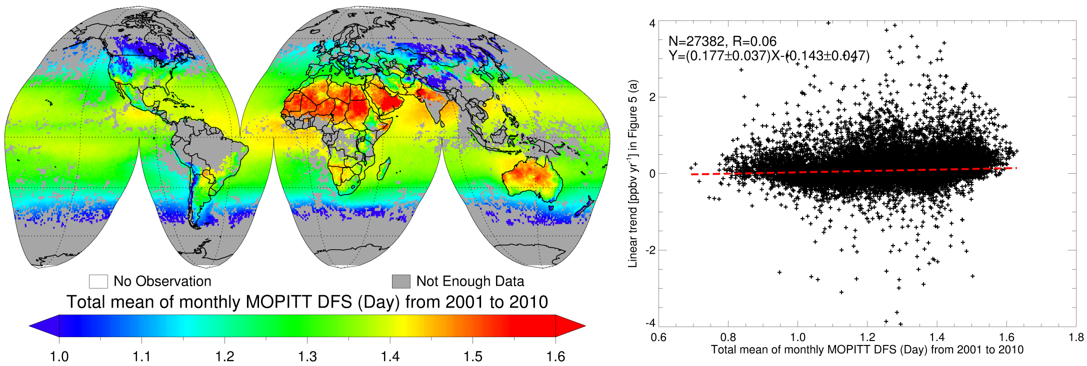
-> Yes, you are correct. We used the MOPITT surface products (i.e. the data at the lowest layer) in all figures in this study. Additional texts and equations for the surface data are included to explain them more clearly.

- Figure 3 indicates that the degrees-of-freedom-for-signal (DFS) for this quantity are probably well below 1. This makes the second term - the contribution from the real trend - on the right-hand-side of equation (4) small. How would the temporal change of averaging kernels affect a better constraint quantity such as total column CO or "boundary layer CO" (eg. averaged between surface and 800 hPa)?

-> We agree with your comment that the small value of DFS can lead to the small contribution of the real trend in Equation (4). However, the small DFS doesn't indicate that the AKs don't change over time and the difference between true and a priori states is negligible, but it just means large weighting of a priori profile information. Not knowing the true state, the first term on the right hand side of Equation (4) cannot be estimated, and therefore it cannot be considered negligible independently on the value of the following term presented in Equation (4). Finally, if the true CO changes over time, then the AKs (or DFS) and retrieved CO do as well, independently of their absolute magnitude because the a priori information is fixed inter-annually. Hence, AKs uncertainty discussed in the manuscript is not evitable in the trend estimation of the retrieved CO.

- Do you detect a correlation between DFS and CO trend for real data and/or the sensitivity study in Fig. 5?

-> As you suggest, we have checked the global mean of MOPITT DFS and its correlation with the CO trend in Figure 5 (a) as following figures.



However, the DFS doesn't show a correlation with the trend caused by the time varying AKs.

- Typically, optimal estimation retrievals provide the sum of smoothing and noise error as the a posteriori error estimate. Temporal change of the averaging kernels should induce temporal change of the smoothing error. Could this be used to detect the effect or even to take it into account for trend estimates?

-> Studying the smoothing error separately from the measurement errors is a good idea, however, these error terms are not reported separately in the current data sets. The MOPITT team is also investigating time dependence in noise values, but the potential effects on trend determination are not conclusive.

- I agree with the other review that the description of the sensitivity study (p20326,l5; Fig. 5) to estimate the magnitude of the averaging kernel effect should be revised and more detail should be provided. Partially, the section is hard to understand because the algebra is presented in full vector format, while the example only uses a single component of the state vector. In particular, I do not exactly understand how dA/dt is calculated. Is this the change in matrix elements determined from spatially (1x1?) and temporally (1 month?) averaged AKs (similar to equation (1))?

-> The trend in Figure 5 was derived using the simulated MOPITT surface CO ($\hat{\mathbf{x}}$) with the assumption that $\mathbf{x} = \mathbf{x}_0 \pm 50\% \times \mathbf{x}_0$ (i.e. $\hat{\mathbf{x}} = \mathbf{x}_0 + \mathbf{A}\left(\pm 50\% \times \mathbf{x}_0\right)$), not using Equation (4). The equation was shown to clarify how the temporal change in

averaging kernels can influence on the satellite-derived trend. In the revised version additional text and slightly modified equations are included, so to improve the clarity of the equations. We have additionally clarified how to derive the trends in Figure 5 as follows: "Nevertheless some significant trends of the hypothetically retrieved CO ($\frac{\partial \hat{\mathrm{x}}^{surface}}{\partial t}$**) at the surface are present, ranging from -10.71 to +13.21 ppbv yr**$^{-1}$ **(-5.68 to +8.84 % yr**$^{-1}$**) in Figure 5. They are derived by fitting the hypothetically retrieved MOPITT surface CO (i.e.** $\hat{\mathrm{x}}^{surface} = \mathrm{x}_0^{surface} + \mathbf{A}^{surface}\left(\pm 50\% \times \mathbf{x}_0\right)$**) to Equation (1).".**

- p20323,l4: I do not understand what ~ym is. Please clarify the text.

-> We have clarified it as follows: "where x_t**,** μ**,** n_t**, and** $\tilde{y}^m$ **denote the time index term (**$t/12$**), the constant term, the monthly noise for the analysed periods (**$t = 1 .... T$**), and the monthly climatology mean of** y_t **(**$m = 1 .... 12$**) (i.e. the climatological monthly varying pattern), respectively.".**