Response to Anonymous Referee #3

We thank the reviewer for their valuable comments. Throughout the document reviewer comments are in standard font while author responses are presented with blue text.

This paper investigates the impact of prior biospheric CO_2 flux models on inverse estimates of terrestrial CO_2 fluxes when using synthetic satellite observations. The paper is clear written and well prepared. Only some aspects are still not clear to me, as following:

1 It is concluded that "Overall, even with the availability of dense OCO-2 data, noticeable residual differences (up to ~20-30% globally and 50% regionally) in posterior NEE flux estimates remain that were caused by the choice of prior model flux values and the specification of prior flux uncertainties". From my understanding for inverse problem, if observations contain sufficient information for the target state vector, the results should be, for large part, insensitive to prior. When it strongly depends on prior, either because satellite observations have limited information for flux inversion or the flux inverse problem is very ill-posed. Could you explain a bit more what is the reason behind?

In this paper, we designed Observing System Simulation Experiments (OSSEs) using synthetic XCO_2 retrievals sampled at the OCO-2 satellite spatio-temporal frequency. Figure 2 in the manuscript illustrates the fact that OCO-2 observation density/coverage has noticeable seasonality and incomplete global coverage. For example, during the fall and winter months, minimal OCO-2 observations are obtained in the Northern Boreal regions and observations are limited year-round in the tropical regions of South America and Africa. OCO-2 data is "dense" in comparison with other CO_2 observing satellites (e.g., GOSAT) and in situ observations, however, due to cloud coverage and light limitations OCO-2 data coverage is still a limiting factor for a "perfect" inverse model estimate of net ecosystem exchange (NEE). The incomplete global observation coverage of the OCO-2 satellite is a primary reason for the sensitivity of CO_2 flux inversions to the assumed prior flux and uncertainty statistics. Previous studies using other observational frameworks also suggest similar sensitivity to prior flux assumptions (e.g., Gurney et al., 2003; Chevallier et al., 2005; Baker et al., 2006, 2010).

2 In section 2.4.8, a sanity check has been performed for all the four OSSEs. I am surprised that the check was performed with observational data uncertainty of 0.001%, which is around 0.004 ppm. What assumed is far too unrealistic, current satellite observations can only provide XCO_2 observations with uncertainties >= 1.0 ppm. I can understand you do this for sanity check but I am wondering why not give identical inputs (including biosphere model) to all the four OSSEs but under a reasonable observational data uncertainty? You can check if all OSSEs can give similar results which do not have to be the truth. Otherwise, you may still interpret mode-dependent uncertainties as prior dependent uncertainties.

As noted correctly by the reviewer, these "pseudo" experiments were 'sanity checks' for demonstrating the robustness of the inversion setup using synthetic OCO-2 data. We applied the very low uncertainty values to our synthetic OCO-2 observations (0.001%), using all four variable prior flux estimates, in order to test two aspects of the inversion: 1) spread in posteriors (uncertainty) and 2) ability to reproduce the "truth" (accuracy). Both of these are important when testing/demonstrating the robustness of the inversion system. In order to eliminate the impact of observational uncertainty, we apply this very small uncertainty value which is justified in the OSSE framework since the synthetic observations are produced with known CO_2 fluxes and transport. If we set observational uncertainty to realistic values (such as ~1.0 ppm) in these test simulations we would systematically get posterior NEE spread which is not specifically caused by variable priors, but a combination of variable priors and observational uncertainty. It should be noted that we do use more realistic observation uncertainty for OCO-2 data in this study for OSSEs outside of the "pseudo" simulations.

We agree with the reviewer that if we ran the four OSSEs, with the four different prior fluxes, applying a realistic observational error we could compare the spread of the posteriors, however, would inherently not fully reproduce the truth due to the lowered constraint by observations. Therefore, this setup would only test one aspect of the system (uncertainty) while the current "pseudo" simulations test both accuracy and uncertainty.

3 Page 10 line 6"The differences between individual model simulations of XCO_2 values deviated among themselves by up to ~10 ppm. These large differences in XCO_2 values across the four-different prior NEE flux models show that the choice of prior NEE has a large impact on simulated XCO_2 values." Even a very strong anthropogenic CO_2 source can only introduce a few ppm variations. Are there any explanations for such a large difference?

We agree with the reviewer that variations in atmospheric CO_2 concentrations due to strong anthropogenic sources are only on the order of a few ppm. However, global atmospheric CO_2 concentrations are primarily controlled by biospheric CO_2 fluxes (e.g., Fung et al., 1983, Schimel et al., 2001, Le Quéré et al., 2018). On a global scale, anthropogenic annual CO_2 fluxes (~10 PgC yr^{-1}) are far less compared with natural biospheric CO_2 fluxes (~250 PgC yr^{-1}, sum of the absolute value of photosynthetic uptake and respiration) (Ciais et al., 2013). Furthermore, biospheric CO_2 fluxes are among the most uncertain components of the carbon cycle (Huntzinger et al., 2012, Schimel et al., 2015, Zscheischler et al., 2017). Recent studies have shown that global fossil fuel emissions have an estimated uncertainty of < 10% (e.g., Le Quéré et al., 2018) while we show from the Multiscale Synthesis and Terrestrial Model Intercomparison Project (MsTMIP) biospheric NEE model ensemble (Huntzinger et al., 2013; 2018, Fisher et al., 2016a; 2016b) that global land NEE uncertainties are as high as ~50-70%. Overall, due to the large impact of NEE on atmospheric CO_2 concentrations, and the significant difference between prior NEE estimates (i.e., large uncertainty), it is expected that XCO_2 values would be noticeably different when changing the prior NEE flux.

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