To Referee #2:

Dear Referee #2:
Thank you very much for your valuable comments and suggestions. We have revised the manuscript according to your comments and suggestions. We hope that the manuscript has been improved and is now acceptable for publication.

The detailed responses to your comments follow.

Yours sincerely,

Tomomichi KATO

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**General Comments:**

1. **The manuscript of Kato et al. deals with data assimilation for a semi-arid woodland site. The main scientific achievement of the study is that they are the first who optimise an ecosystem model against eddy covariance and remotely sensed data together. Being the first study doing this, the technical aspects of the procedure deserve more attention. The uncertainties used in the optimization determine how much weight is given to which data stream and therefore probably strongly influence the results. This part needs more discussion and I would also suggest additional sensitivity analysis. The results report the agreement between model and data and the improvement of the parameters. I don't see an investigation of mechanisms controlling the ecological and hydrological activities as promised in the abstract.**

   Answer: Thank very much for your comments. We revised our manuscript in many points. Please refer to the modifications that we made corresponding to your comments hereafter.

2. **One interesting finding is that the set of parameters with the highest uncertainty**

**reduction is similar for both data streams. This could be discussed more in detail. One reason for this could actually simply be the choice of the priors and the prior uncertainty.**

Answer: We agree that the similarity in the set of parameters with the highest uncertainty reduction for both data streams actually contains interesting information. The parameter set hints to influential points in the model formulation controlling eco-hydrological circulation of carbon/water. We agree that this should be to be discussed in the manuscript as you mentioned and added the following sentence in section 4.1:

> "It is also noteworthy that the two parameters with the highest uncertainty reductions (more than 36%) are the same in each of the three experiments: $\tau_W$ (for both PFT 2 and 10), and $W_{max}$ (Fig. 2 and Table 2). This suggests that those two parameters are generally very important to represent the eco-hydrological cycling of carbon/water in savannas ecosystem despite the different sets of assimilated observations."

Generally, a priori, we never know the realistic parameter values based on the measurements at this study site. Prior values and their uncertainties were in this study taken from previous studies (either laboratory or field measurements), and in our view this general approach does not institute particular problems with the chosen prior values. Obviously the choice of the priors and their uncertainties do effect the optimization procedure.

3. **Another that the overall reduction of parameter uncertainty is larger when assimilating both data streams. An analysis of the parameter correlations could maybe help to understand how parameters that are only slightly constrained by one observation stream can have a huge uncertainty reduction when using both.**

Answer: We have moved the discussion of the posterior parameter error-covariance matrices from the supplemental information to the main manuscript text as we agree that this is an essential part of the analysis of the results. We added the discussion in second paragraph of subsection 4.1., as follows,

> "For all three experiments, the posterior error covariance matrixes of the 24 parameters show values of less than 0.1 for the error covariances of $W_{max}$ with all other parameters (Tables 3, 4, and 5), suggesting that $W_{max}$ can be independently constrained by LHF and FAPAR observations."

and in the fourth paragraph of subsection 4.1.,

> "Focusing on the $V_{max}^{25}$ parameter, interestingly, Experiment 3 shows a fairly high negative error covariance with the respective $f_{ci}$ parameter (ratio of $CO_2$ concentration inside the leaf tissue to the outside concentration) of -0.43 for C3 trees and -0.25 for C4 grass as shown in Table 5. While the posterior $V_{max}^{25}$ value of 34 μmol $m^{-2}s^{-1}$ for PFT 2 in Experiment 3 is smaller than that in Experiment 2 (78 μmol $m^{-2}s^{-1}$), and thus should lead to lower GPP in Experiment 3 as compared to experiment 2, GPP is in fact in Experiment 3 larger than in Experiment 2. This seems to be caused by the larger $f_{ciC3}$ value, which increases the $CO_2$ uptake of plants by photosynthesis, to some extent."

4. **The manuscript is clear and well written, but could greatly improve through a more in depth discussion of the results and a sensitivity analysis on the methodology of combining eddy covariance and remote sensing data, i.e. on the way the priors and uncertainties are set.**

Answer: Thank you very much for your encouragement. We have revised our manuscript in many points (see for instance the above point on the analysis of the error covariances), and hope that they are acceptable for Biogeosciences.

**Specific comments:**

1. **p. 3617, l.5: which mechanisms are investigated?**

   Answer: We changed from "mechanisms" to "key parameters".

2. **p. 3617, l. 22: the hydrological properties can be strongly linked to the soil parameters, e.g. soil texture, which is not included in the optimization**

   Answer: $C_w$, an empirical parameter representing root density and $W_{max}$, a maximum plant available soil water, are soil-related parameters, both of which are included in the optimization.

3. **p.3619, l.20: 1996 is not very recent**

   Answer: We changed "Recent model studies" to "Several model studies".

4. **p. 3621, l.15: why don't you use the meteorological observations of the site directly, to be sure to be consistent with the flux measurements? Especially the timing of precipitation would be better if the local measurements would be used**

   Answer: We did not use the actual meteorological observations of the site directly mainly because there is a lot of missing data in the local meteorological measurements, as is actually the case for the flux measurements. So we derived the meteorological data at the flux site from a global database, and corrected them by the existing measured meteorological data to keep the same temporally-averaged values. Although there could be an inconsistency in the timing of precipitation events, it is also important for us to prove that we can simulate local LHF and FAPAR by a globally based meteorological data product which is corrected by the local meteorological conditions.

This increases the applicability and compatibility of our method to other sites or regions..

5. **p. 3624, l. 3-9: the values for the uncertainties, seem to be set quite arbitrarily. Why do you use the energy balance disclosure? Although the evidence that the disclosure of the energy balance can be attributed to the turbulent fluxes, this would be a rather constant error, i.e., it would be strongly correlated in time that would need to be con-sidered in the costfunction, in the off-diagonal elements of the error-covariance matrix. Moreover, this assumes that the eddy covariance fluxes are underestimated, while in your combined assimilation the optimized fluxes are even smaller than the observations. Therefore, a larger disclosure would allow the optimized fluxes in the combined optimization to be smaller, while assuming that the observations are too small. The uncertainties determine the importance of the datastreams in the optimization, as they are set quite arbitrarily, it would be interesting to see how much this influences the results**

Answer: As you may know, eddy flux measurements still have a certain level of uncertainty in its accuracy. We think that a disclosure of energy balance is one of the most objective indices to assess how reliable the eddy sensible/latent heat flux measurements are as long as we don't get any other information. However, we also don't know any previous studies reporting that the disclosure should be a constant value and not a fractional rate against the flux intensity. A strong linear relationship in the regression line between Rn+G and sensible+latent heat fluxes rather proves that the disclosure is not a constant value, but a fractional ratio against net radiation. So we think that applying this disclosure ratio for determining the uncertainty of observed LHF is an objective way to optimize the parameters.

The posterior LHF after assimilating both data streams is certainly lower than the observed LHF as can be seen in Fig. 3 from June to October. But, it is still within the range of uncertainty of the LHF observation for most days. We think that FAPAR constrains the simulated LHF to lower values as evidenced by the lower LHF (for the period June to October) in exp. 3 when assimilating both data streams as compared to the LHF in experiment 2 when assimilating only LHF. This is actually one of the most characteristic points in our study and highlights the importance of assimilating multi-data streams. Such a multi-data stream assimilation can avoid a bias in the optimization results originating from a bias in the observations when assimilating only a single data stream. Under the circumstance that the potential underestimation of combined sensible/latent heat flux against net radiation could be attributed to underestimation of sensible heat flux, moreover, the lower simulated LHF compared to the observed LHF is still acceptable.

6. **p. 3624, l.15: You use the prior of previous studies? Why don't you use the posteriors, then you could also measure how much this adds to the uncertainty reduction, considering the work that has been done during the last years and not starting from zero again?**

Answer: The point is that we do not know real parameter values anyway. Especially, the savanna is thought to be one of the most difficult biomes for accurate modeling, i.e. containing large uncertainty in the parameterization, because of being subject to frequent shortage of water availability. Therefore, we don't think that the previously optimized parameters from a global assimilation based on atmospheric $CO_2$ measurements should be applied to such a site-scale simulation in an arid environment based on eddy flux measurement. In addition, this would be a sub-optimal use of the observational data because in any sequential approach (this would be a sequential approach as the previous study is considered a first step), later assimilation steps risk to degrade the compliance with data streams assimilated earlier.

7. **p. 3625: how strongly is the reduction of the parameter uncertainty determined by the definition of the prior?**

Answer: We demonstrate here the brief calculation of the effect by the prior values on the cost function at the end of optimization from the posterior values. $W_{max}$, which shows the highest reductions in relative uncertainty (Fig. 5), has a prior value of 1500 mm. Now consider changing the prior from 1500 to 500mm, all else being equal and its impact on the cost function $J$ ($\Delta J$) against the change in the cost function from prior to posterior is as follows:

Exp1: $\Delta J$ from lower Wmax prior is 0.60 (while $J$ changes from 470 (prior) -> 313 (posterior: the reduction is 157)).
Exp2: $\Delta J$ from lower Wmax prior is 0.81 (while $J$ changes from 1825 (prior) -> 32 (posterior: the reduction is 1793)).
Exp3: $\Delta J$ from lower Wmax prior is 0.77 (while $J$ changes from 2295 (prior) -> 908 (posterior: the reduction is 1387)).

Thus, the change in $W_{max}$ prior from 1500 to 500 mm does not make a large change for the cost function $J$, suggesting that the results would not be very different with a different $W_{max}$ prior. This is mainly due to the large prior uncertainty for $W_{max}$ (1500 m).

8. **p.3629, l. 3 : : :: how does the uncertainty reduction compare to previous studies? Instead of focussing only on the uncertainty reduction, it would be interesting to see, whether the optimized values of the combined optimization, are within the uncertainties of the single data stream optimization. If they are, this would support the statement, that the data streams can be consistently used in an optimization, in spite of the different scales.**

Answer: It is difficult to compare the uncertainty reduction with previous studies, even with those done by CCDAS, because the set of selected parameters for optimization and the combination of assimilated observations are specific to this study and thus different to the previous ones. However, only Knorr et al. (2010) provided that information for the case of assimilation by FAPAR and the phenology scheme, which is used here as well. We added the following sentence:

"The high reduction in the relative parameter uncertainty of $\tau_W$ for PFT 2 and 10 by more than 30%, which is also apparent in a previous study with the same phenology scheme assimilating only FAPAR at seven eddy flux sites (Knorr et al., 2010), suggests a strong constraint by the FAPAR observations on the phenology component of BETHY, as expected."

The optimized parameter values, which have a high uncertainty reduction (as can be seen in Table 2), are mostly outside the 1-sigma uncertainty interval in the single data stream optimizations. Nevertheless, we think that the parameters optimized by two data streams are not necessarily constrained within the uncertainties of the single data stream optimization due to possible inconsistency among two data streams and the model formulation, which may not have affected the parameter optimization when assimilated with single data stream.

**9. p.3630: mention the comparison against GPP in the abstract/introduction.**

Answer: We added the sentences in the abstract as a follow.

"Simulated gross primary production (GPP) indicates a moderately good fit in seasonality to observed GPP when assimilating both data simultaneously with a smaller root-mean-square-erorr (RMSE) as compared to assimilating only FAPAR."

We modified the Introduction as a follow.

"We apply CCDAS to simultaneously assimilate eddy-covariance LHF and remotely-sensed FAPAR observations at a single point for a semi-arid savanna site at Maun, Botswana, and investigate the effect of assimilating multiple data streams on the accuracy in both the simulated variables. In addition, we analyse the effect of the assimilation of the two data sets on simulated gross primary production (GPP), which is not assimilated."

10. **p.3631, l. 18: GPP is not observed! Please check the quality flags of your data sources.**

Answer: We changed from "observed" to "observation-based".

**Technical Comments:**

1. **p 3618, l. 22: typo: photosynthetically**

Answer: It was corrected.

2. **Tab. 2 and Fig. 5: the relative uncertainty in table 2 does not agree with fig. 5, what is the difference?**

Answer: We are sorry for that. We mistakenly made this figure from the old version of simulation. Now the figure was remade to be consistent to Table 2.

3. **Fig. 2 and Fig. 4: the blue values can hardly be seen, maybe plotting a line or smaller symbols can improve this.**

Answer: We revised the Figs 2 to 4 (now Figs 3 to 5) with different coloring.