Response to Referee #2

The authors thank the referee #2 for his/her very valuable review of the manuscript. Our responses to referee's comments are in a regular form while referee's comments are in the italic form.

Q: The study of Zhang et al. addresses the topic of systematic errors in observation data used for model optimization. This topic is important as in previous studies the systematic error was usually simply assumed to be zero and not mentioned, although it is obvious that model optimization results must be biased if systematic errors are in the used data. Zhang et al. use synthetic LAI data, including various types of systematic errors, to optimize vcmax in a process-based ecosystem model. To reduce the influence of the systematic error they apply three different normalization methods and find that the z-score normalization performs best in retrieving the true vcmax value. They conclude that the z-score normalization should be applied for parameter estimation, especially when potential systematic errors are unknown.

A: Thanks for the summary. No response is needed.

Q: Although the results show a great improvement in the parameter estimation, there are limitations of the method that need to be addressed, not only in the discussion but also in the general conclusion:

1) Is the artificial experiment of the study really representative for real world parameter estimation problems? On the one hand the errors in the data could be more complex, on the other hand usually more than 1 or 2 parameters are optimized. A comparison of the model output that is used as "true" values with observed LAI could be insightful to understand whether the synthetic error mimics the real world error well.

A: We agree with the referee that the synthetic experiments can not totally represent for real world parameter estimation problems. However, the synthetic experiment was an effective way to examine the performance of parameter estimation on the basis of known true values and errors. To further investigate the effect of normalization for real world data, we added the analysis on parameter estimation against MODIS LAI data in the revised manuscript. Compared with the estimation using z-scored normalization, the estimate from absolute values of MODIS LAI observation underestimated the parameter $V_{\mathrm{cmax,25}}$ by 5% and overestimated the parameter t_{opt} by 18%.

The referee is right that the errors in the data could be more complex. Considering the suggestion of the two referees, we designed more complex errors added to the true value in the revised manuscript. We conducted parameter estimation experiments by synthetic data with two different types of systematic errors, to examine if the z-score normalization method was applicable when different systematic errors existed in different parts of the LAI data. Our results showed that the z-score normalization method still worked well when the two parts of the data had a similar magnitude, but the effect of the z-score normalization was weakened when the two parts of the data had a big difference in magnitude.

Although we acknowledge that more parameters can be allowed to be estimated simultaneously by the observation, not all parameters can be well constrained and only those parameters relative to the observed variable can be constrained. Thus, we selected three key model parameters related to the simulation of leaf area index to be estimated in the revised manuscript. If we use more kinds of observed data such as soil organic carbon content, soil moisture, evapotranspiration, to estimate model parameters, then we can allow more parameters to be optimized simultaneously.

As mentioned by the referee, we did not compare the absolute values of modeled and “observed” LAI data, but the pattern of the modeled and “observed” LAI data. In addition, we applied the z-score normalization method to the real MODIS LAI data as mentioned above.

Q: 2) The information content of the observations is reduced by the normalization, e.g. the information about the absolute values is lost and only the information about the relative variability of the variable remains. This must have an effect on the optimization, probably on the number of parameters that can be constrained, e.g. equifinality could occur for a smaller number of parameters included in the optimization. This is not addressed in the manuscript, but is a major limitation of the proposed approach. For instance if the model was only y=ax+b, where x is a driver, y the model output that we want to fit to observations, then neither the parameter a nor b could be estimated applying a z-score normalization. Thus it depends on the model structure, whether the approach is applicable or not. An additional analysis could be to compare the sensitivity of the LAI model output to variations of different parameters with and without z-score normalization. For the linear model y=ax+b, varying a and b does not change the normalized output. A comparison of the correlation structure between the parameters when using the normalized and not normalized cost function could indicate whether normalization increases equifinality issues.

A: The absolute values of remotely-sensed LAI and fAPAR data have been usually used to optimize model parameters. These absolute values of remote sensing data contain unknown errors, but their spatial patterns are reliable. Thus, to make good use of the information of spatial pattern of LAI data, we used normalized observed and simulated data to calculate the cost function $\Omega^{'}$ (Eqn. 2) in our study. When the observation was normalized in calculating the cost function, the modeled variable was normalized at the same time. If the observation was normalized alone, the information content of the observations will be reduced by the normalization as the referee mentioned. However, in our study, the observation and model output were normalized simultaneously so that the cost function measured the mismatch of spatial pattern between modeled and observed LAI data. Our results of model experiments with synthetic data also demonstrated that the information of LAI spatial pattern was useful in estimating three key parameters related to LAI. The situation illustrated by the referee is not the same as that in our study.

We agree with the referee in the equifinality issue. More estimated parameters may have a similar effect on model outputs so as to become difficult to be identified. Even thought all model parameters are allowed to be optimized simultaneously, equifinality might occur also. Moreover, not all parameters can be well constrained against observations. The utilization of additional information on prior estimates for the parameters and more kinds of observations, or the fixation of some parameters might reduce the uncertainty (Wang et al., 2009). In our study, we successfully searched the optimized values of parameters that made the cost function minimum, although we can not make sure that the estimation is not the local minimum. Global search methods, such Markov Chain Monte Carlo (MCMC) or genetic algorithm, could be more powerful in avoiding multiple minima problem. As suggested by the referee, we added sentences to discussion it in the revised manuscript.

Q: These limitations need to be addressed, either by additional analysis or by a more differentiated conclusion.

A: As suggested by the referee, we did additional analysis in the revised manuscript, such as parameter estimation experiments by synthetic data with two different types of systematic errors, and the application of normalization in real data. We also revised related parts in the sections of discussion and conclusion.

Q: It should be further discussed why the methods work and why not. The reason why the z-score normalization works for the linear errors is that for a linear model y=ax+b that is assumed for the synthetic errors the normalized output does not change. Other error structures may not have this property.

A: Thanks for the suggestion. We added sentences to discuss the reason why the z-score normalization works for the linear errors in the revised manuscript. Given the observed data are normalized by the z-score normalization method, the difference of normalized observed and “true” data can be expressed by

$$x' - x_t' = \frac{(cx_t^2 + bx_t + a) - \overline{(cx_t^2 + bx_t + a)}}{\sigma(cx_t^2 + bx_t + a)} - \frac{x_t - \overline{x}}{\sigma} = \frac{c\sigma(x_t - \overline{x})(x_t + \overline{x} - \sigma)}{c\sigma^2 + b\sigma}$$

The difference between x' and x_t' is equal to zero when the error is linear (c=0), $(x_t - \overline{x}) = 0$ or $(x_t + \overline{x} - \sigma) = 0$. It indicated that the spatial pattern keep the same when LAI data with linear errors was normalized by the z-score normalization method. That is why the z-score normalization works well when linear errors exist.

Specific comments:

Q: P.10448, l. 24-25: the normalisation is not only applied to the observations, but also to the model ouput, please rephrase.

A: Done as suggested.

Q: P. 10448 l. 26: remove "especially", the normalization should be applied only then, if the errors are known they should be removed.

A: Done as suggested.

Q: P. 10449,l. 18-20: Maybe the sentence is incomplete? The variations at one site could be used as uncertainty of vcmax. Please rephrase.

A: We rephrased the sentence in the revised manuscript.

Q: P. 10451,l.22-26: you use synthetic data, the exact distribution of this vegetation type does not matter. Please remove this sentence. If the coupling between LAI and vcmax is different for other vegetation types it would be helpful to include them to support the general conclusion.

A: Done as suggested.

Q: P. 10453: It would be good to have a description of the phenology module here to understand what causes the spatial variability of LAI and how it is coupled to the photosynthesis and vcmax.

A: Thanks for the suggestion. We added a description to describe the simulation of phenology and the leaf area development in the section 2.2.

Q: P. 10454, l. 15: do you use the LAI of one specific year? It should be clear from the beginning that you use August LAI and that the seasonality of LAI is not included.

A: Done as suggested. We clarified that "Here we used the LAI data in August to conduct such experiments and the seasonality of LAI was not included." in the first paragraph of the section 2.3.

Q: P. 10456, l. 28: what are the true observations? This chapter should be extended and parameters also estimated for different types of errors.

A: The observations are synthetic data based on the modeled LAI and different assigned errors. In this case, the true observations are the model output with the default parameter values that had been used in the AVIM2 model. These parameters had been estimated for different types of errors that we arbitrarily assigned in the original manuscript.

Q: P. 10459, l.5: in the figure it looks like a1 is hardly constrained.

A: To show the result of estimated parameters better, we used another figure to illustrate the distribution of cost function instead of the original figure. According to the new figure, we can find that the parameter a1 can be constrained.

Q: P. 10459, l. 17: direction means positive or negative? please rephrase the sentence it is difficult to understand. Explain why the z-score transformation works fine for linear errors.

A: We rephrased the sentence and added sentences to explain the reason why the z-score transformation works fine for linear errors.

Q: P. 10459, eq. 7: i can't follow the transformation

A: We used Eqn. 7 to explain that if the observed data are normalized by the maximum value, then the spatial distribution will be changed in most cases when ($a–cx_tx_{max}$) is not equal to zero. Using the similar method, if the observed data are normalized by the minimum and maximum values, the difference of normalized observed and "true" data can be expressed by

$$x^{'} - x_t^{'} = \frac{(cx_t^2 + bx_t + a) - \min(cx_t^2 + bx_t + a)}{\max(cx_t^2 + bx_t + a) - \min(cx_t^2 + bx_t + a)} - \frac{x_t - x_{\min}}{x_{\max} - x_{\min}} = \frac{x_t - x_{\min}}{x_{\max} - x_{\min}} \bullet \frac{c(x_t - x_{\max})}{c(x_{\max} + x_{\min}) + b}$$

The difference between x' and x_t' will be equal to zero when c=0, i.e. the error is linear. It indicated that the spatial pattern did not change when LAI data was normalized by the min-max normalization method.

Q: P. 10460,l. 14: normalization can't change the spatial distribution.

A: As explained above, the maximum normalization can change the spatial distribution when ($a–cx_tx_{max}$) is not equal to zero. Only if ($a–cx_tx_{max}$) is equal to zero, then it will not change the spatial distribution.

Q: P.10461, l.2-4, does this mean most sensor have only linear errors? Consider that usually the "observation" is not a pure measurement it usually involves models, for *instance to derive the LAI, or in case of eddy covariance data complicated corrections need to be applied. Nonlinear errors can arise in this step.*

A: As the referee reminded, the remote sensing data errors include the direct measurement error associated with the sensor, and the representation error in estimating surface radiances from radiances at sensor associated with atmospheric correction, and in relating surface radiances to biophysical variables (e.g. LAI) used in a terrestrial biosphere model. Even though nonlinear errors can arise from the estimation of biophysical variables from radiances at sensor, the validation and intercomparison of LAI products derived from remote sensing data (Cohen et al., 2003; Wang Yujie et al., 2004; Garrigues et al., 2008) show that the remotely-sensed LAI data have approximate linear relationships with ground based measurements. We added sentences to discussion this issue in the revised manuscript.

Q: P.10461, l.5: you showed only that the method can be applied to observations with a linear error model, you cannot conclude that it can be applied to "any other observations"

A: Done as suggested.

Q: P. 10461, l. 24-26: you did not show this for an increased numer of parameters, not even for the example of 2 parameters. If you would show that the uncertainty of the 2 parameters do not increase using the normalization this would support this statement, but still equifinality problems could arise for a higher number of parameters.

A: We deleted the example of 2 parameters in the revised manuscript. We would like not to show the uncertainty will not increase with the number of parameters using the normalization and to obtain the estimated values of parameters. The main objective of our study is to give an example of parameter estimation with the AVIM2 model to investigate if normalization can be used to reduce the impact of systematic errors on parameter estimation. In the revised manuscript, we selected three parameters related to the simulation of LAI to be estimated.

Q: P.10468 please remove the c unequal 0, it is zero in most cases.

A: Done as suggested.

Q: P. 10469 please add, that it is LAI in August, here a comparison of the "true" values with observations would be interesting to see whether the assumed errors are realistic.

A: Thanks for the suggestion. We added that "in August" in the figure legend. Here the black lines just represented the “true” values of LAI in August.

Q: P. 10471 please add the not normalized cost function.

A: The no normalized cost function was described as equation 1. We added the interpretation for it in the revised manuscript.

Q: Fig 5a: why does the uncertainty decrease for min-max and max normalisation? Please, add without normalization

A: The uncertainty decreased for min-max and max normalization because that the estimated parameters almost always hit the edge of the parameter range with the increasing random errors. As suggested by the referee, we added the estimated values without normalization.

Technical comments:

Q: P.10448, l.2: “modelling carbon cycle”, please insert “the”

A: Done as suggested.

Q: P. 10448,l. 21-24: I don’t understand the sentence.

A: We rephrased the sentence.

Q: P. 10450, l. 26: please change: “How systematic...” into “How do systematic...”

A: Done as suggested.

Q: P.10450, l. 27/28: please change: “Do the potential impact of systematic errors on parameter estimation can be : : :” into “Can the potential impact of systematic errors on parameter estimation be : : :”

A: Done as suggested.

Q: P. 10451, l.1: please change “Whether the three normalization methods is effective: : :” into “Are the three normalization methods effective: : :”

A: Done as suggested.

Q: P.10453, l. 3: add "or simulation"

A: Done as suggested.

Q: P. 10470 please explain a,b,c and add uncertainties, if no random error is added, bootstrapping can be used to derive the parameter uncertainty. It will be interesting to see, that for the systematic errors the true values are not within the uncertainty of the estimate.

A: We revised the figure 2 where the estimation of the other two parameters was also illustrated. The uncertainties were presented in this figure.

Q: P. 10471: what is the dotted line?

A: We deleted the dotted line in the figure 3 and added the uncertainty.