Response to Reviewer #1

General comment:

"This paper compared different methods on reconstructing spatiotemporal distribution of diffuse radiative fraction and explored the GPP responses to different diffuse conditions. Results show that the reconstruction of Fdf forcing fields need to be synchronous with aerosols and clouds amount. The topic is important and timely for exploring the diffuse fertilization effects. However, there are some important problems need to be solved on this paper:"

[Response] We thank the Reviewer for the review, comments and suggestions, which helped us to improve our manuscript. We have addressed all the suggestions and comments in our revision. Please find below the Reviewer's comments (italics), followed by our responses (roman font), with red color indicating relevant changes in the manuscript. We hope that the revised manuscript addresses all the issues raised by the Reviewer.

Comments:

"(1) The whole study does not present any observations to validate the model and to testify the importance of some Fdf modifications. The sensitivity of GPP to the changes of diffuse radiation should be validated against available observations. Mercado et al. (2009) provided a good example on how to perform such validations. Furthermore, several sensitivity experiments are performed with different settings of Fdf and show the consequent changes in GPP. However, such changes in GPP should be compared against observations to show which method can largely reduce modeling uncertainties."

[Response] We thank the Reviewer for this comment. Indeed, all models need to be validated or at least evaluated against observations before use. In this manuscript, we did not put the details of the validation. However, in our previous study (Zhang et al. 2020), we have extensively validated our model using observations from 159 flux sites and shown that ORCHIDEE_DF is able to reproduce the diffuse radiation fertilization effect in most vegetation types (Figure R1). We have mentioned this in the manuscript

(Line 86-88). Therefore, it is reasonable to use the current model to investigate the diffuse radiation impact.

"*(2) Figure 2a: the historical global mean Fdf are around 0.6-0.7 during 1900-2010, which is significantly vary from the results (0.4-0.5) from figure 3a by Mercado et al. (2009). What are the causes of such differences? Moreover, please show daily, seasonal and annual Fdf changes in supplement information so as to better validate predictions from different model. The global Fdf of DF-PI-ENS should be also added in Figure 1.*"

[Response] Thanks for this question. We also noted this difference on Fdf between this study and Mercado et al. (2009). In this study, the mean Fdf is calculated by averaging all the daytime 6-hourly Fdf over the land regions in each year. Mercado et al. (2009) did not explain how the average of Fdf was calculated, but they have done an adjustment of radiation (reducing the diffuse radiation under cloudy conditions) in their study, as described in their methods section. This might cause the difference in mean Fdf between the two studies. In this study we used the radiation from the CRUJRA dataset directly as this dataset is observationally-based and has widely been used in global simulations.

To address this suggestion, we have shown the diurnal and seasonal cycles of Fdf of some selected grid points in the supplementary (Fig. R2).

The DF-PI-ENS has three simulations, one of them, DF-PI-1901 has exactly the same Fdf pattern as Figure 1a, and DF-PI-1905, DF-PI-1916 has similar spatial variability as DF-PI-1901, which has been added to the supplementary (Fig. R3).

(3) Line 201: "This generally explains the spatial pattern of △GPP detected in this study (Fig. 3a)." Fig.3a shows DF-PI-AERO underestimates significantly global GPP than DF-HIST, especially East Asia, Amazon and west Africa. Why do the different results appear? There are very small differences in Fdf between DF-HIST and DF-PIAERO as shown in Figs 1a and 1d.

[Response] Thanks for this question, Fig. 1 and Fig. 3 correspond to different time scales and periods. Figure 3 is the mean aerosols impact on GPP during 1961-2010, when there are significant anthropogenic aerosol emissions in the regions mentioned by the Reviewer. If we compare the mean difference in Fdf during this period, *DF-PI-AERO* should have lower Fdf. In contrast, Figure 1 shows the different variability of Fdf in different reconstructions. Because the long-term mean Fdf of the reconstructions should always be the same due to the average method we used, we showed only the first time step in Figure 1, which is in 1901. We chose this time because the aerosol levels are similar between *DF-HIST* and the other reconstructions so the *DF-HIST* Fdf can be a reference to check the variability of Fdf in different reconstructions.

(4) Some of the conclusions are model dependent. For example, Lines 244-245, "This difference implies that the mismatch between Fdf and radiation is more important than the mean diffuse radiation over a long period." It remains unclear whether other models also support this conclusion. Again, the missing of observational validations makes this conclusion unconvincing.

[Response] Thanks for this point. Indeed, the results could be model dependent. However, as discussed in Section 4.2, if the model represents well the mechanism how Fdf affects photosynthesis, it should get biased GPP when using mismatched Fdf and SWdown in a simulation. Nevertheless, we added in Line 245: "Nevertheless, GPP always differs between LSMs. The magnitude of the GPP bias due to the mismatch between Fdf and SWdown detected here is only for ORCHIDEE_DF model and needs to be further investigated in other LSMs. Nevertheless, the framework that we propose is applicable to any LSM" For the validation, please check the response to Comment 1.

Specific comments:

Lines 38-45: Please add some recent references on aerosol-induced diffuse effects, such as Rap et al. (2018) and Yue and Unger (2018).

[Response] Thanks, the references have been added in Line 42: "Rap et al. (2018) and Yue and Unger (2018) also used simulation under different scenarios, but with different reconstruction of diffuse radiation." And Line 251: "Similar methods have been used in Rap et al. (2018) and Yue and Unger (2018)."

Lines 100-104: Are you using SW as input and calculate PAR for vegetation model? Please explain how PAR and SW is connected in the model.

[Response] Yes, SWdown is used as input. A factor of 0.5 is used to calculate PAR from SW.

Figure 2: if possible, the interannual variations of Fdf from four reconstructions can be shown in Fig 2a.

[Response] Thanks, we have added the reconstruction Fdf in Figure 2a (Figure R4). The description of the updated figure has been added to the manuscript (Line 147): "Because the no-anthropogenic-aerosol reconstructions DF-PI-6H-CLIM, DF-PI-ENS, DF-PI-MON-CLIM use the volcano-free years during 1901-1920, they produce the same or very similar global yearly mean Fdf around 0.615 during the entire study period. For the DF-PI-AERO reconstruction, the Fdf increased by about 0.005 after the 1950s, which is not comparable to the increase of Fdf in DF-HIST. This increase is mainly due to the changes in cloudiness and natural aerosols."

Line 175: "dGPP" should be replaced as "ΔGPP".

[Response] It has been corrected accordingly.

Lines 207-209: "Because the solar zenith angle is large due to longer light path in *atmosphere in the morning and afternoon, the Fdf is usually large in the morning and afternoon but low at midday (Iziomon and Aro , 1998)." These are conflicting with lines 124-125, which say: "This method accounts for the periodical diurnal increase of Fdf from morning to mid-day and its decrease from mid-day to afternoon."*

[Response] Thanks for pointing out this error in Lines 124-125, which is now corrected: "This method accounts for the periodical diurnal decrease of Fdf from morning to mid-day and its increase from mid-day to afternoon."

References

Zhang, Y., Bastos, A., Maignan, F., Goll, D., Boucher, O., Li, L., Cescatti, A., Vuichard, N., Chen, X., Ammann, C., Arain, M. A., Black, T. A., Chojnicki, B., Kato, T., Mammarella, I., Montagnani, L., Roupsard, O., Sanz, M. J., Siebicke, L., Urbaniak, M., Vaccari, F. P., Wohlfahrt, G., Woodgate, W., and Ciais, P.: Modeling the impacts of diffuse light fraction on photosynthesis in ORCHIDEE (v5453) land surface model, Geosci. Model Dev., 13, 5401–5423, https://doi.org/10.5194/gmd-13-5401-2020, 2020.

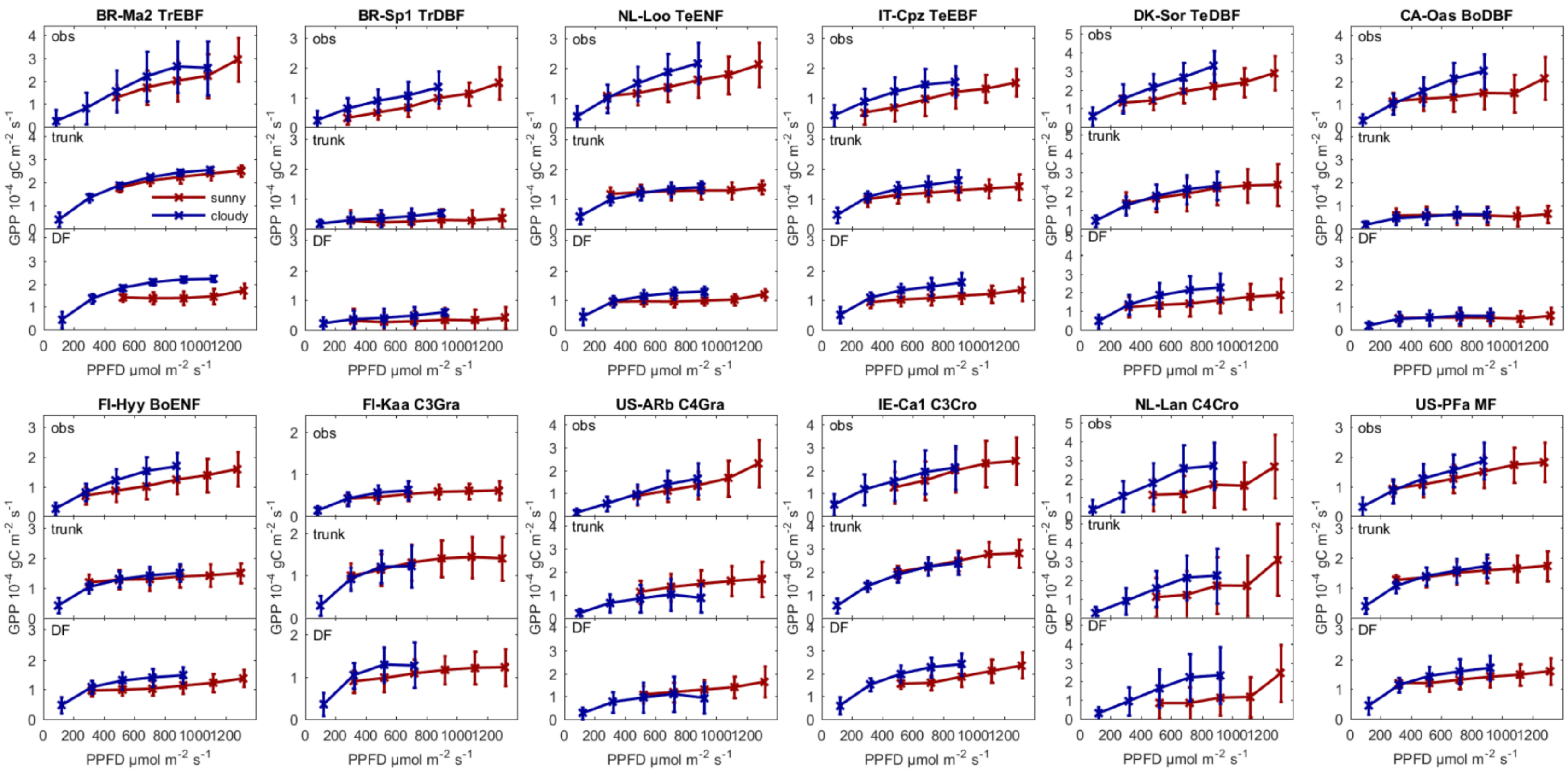

Figure R1: Observed GPP and GPP modeled by ORCHIDEE trunk and ORCHIDEE_DF under cloudy (diffuse light fraction >0.8) and sunny (diffuse light fraction<0.4) conditions at selected sites (with relatively long time series) from each PFT. Figure from Zhang et al. (2020)

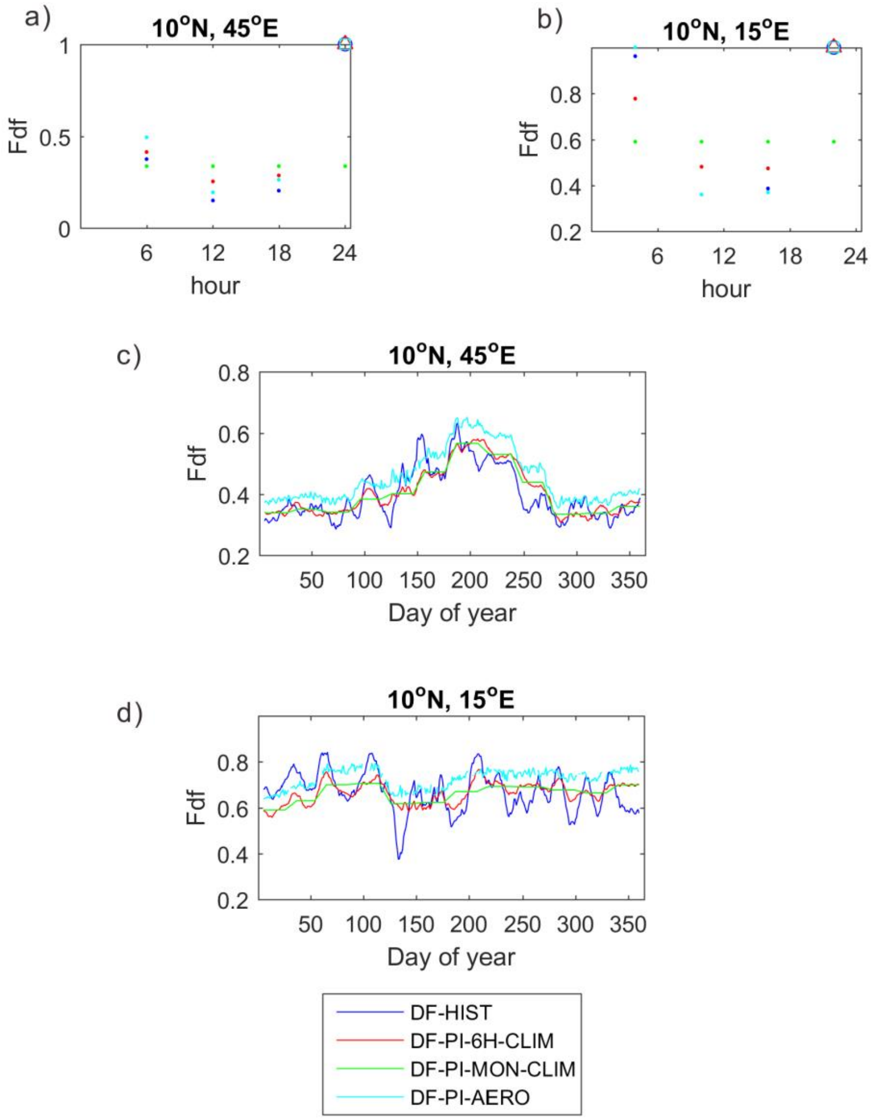

Figure R2. The diurnal cycle of Fdf on 1901-01-01 (a) and (b), and the seasonal cycle of Fdf in 1901 (c) and (d) in different reconstructions at selected grids. The open markers in (a) and (b) are night time values filled with 1.

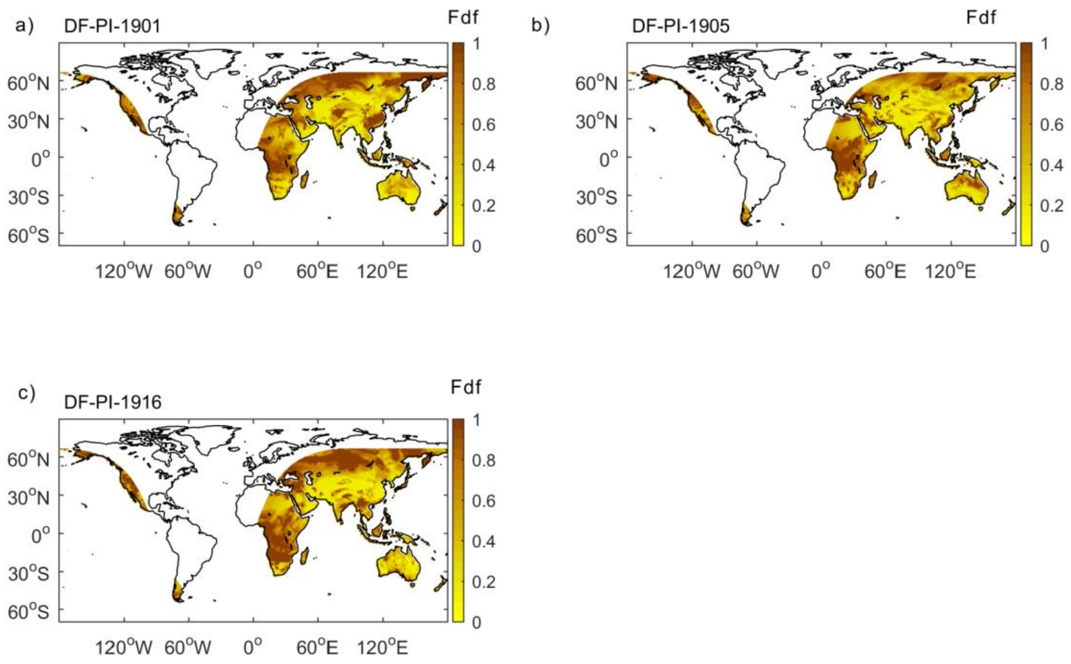

Figure R3. Same as Fig 1 but for DF-PI-1901, DF-PI-1905 and DF-PI-1916

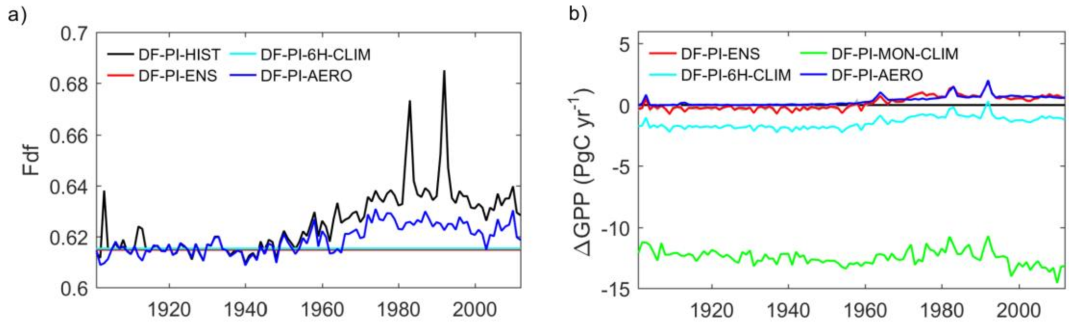

Figure R4. Time series of (a) global mean Fdf of different reconstructions and (b) ΔGPP between DF-HIST and no-anthropogenic-aerosol scenarios. The shaded area along the red curve in (b) indicates the range of the three ensemble members of the DF-PI-ENS simulations. The DF-PI-MON-CLIM has the same mean Fdf as DF-PI-6H-CLIM, thus not shown in (a). This is the update of Fig 2 to include the mean Fdf of PI level reconstructions.