Response to Reviewer #1

General comment:

"There is a plethora of observational evidences supporting that diffuse d light favors higher plant productivity thanks to radiation being more evenly distributed and accessible across the shaded part of the canopy. Yet, few Land Surface Models (have a representation of light transmission within the canopy that explicitly accounts for the quality of light (direct vs diffuse) and its effect of primary productivity. Zhang et al. implemented such a capability in the ORCHIDEE LSM (ORCHIDEE_DF) and this paper provides the details of their modelling framework as well as a solid evaluation of ORCHIDEE_DF performance against a large set of ground site measurements (FLUXNET).

This paper reads very easily as it is well written and well structured.

The first part of the paper describes the model framework and the parameterisations. It is generally well written, although some symbols equations could be improved, and a couple of sections swapped together (see general comments).

The second part of the paper presents a very good evaluation of ORCHIDEE_DF The added value of introducing a representation of diffuse light fraction is convincingly exposed and rigorous efforts were made to disentangle this from other cofounding effects (e.g. VDP, Temperature). Despite the calibration of model parameter being sub-optimal for this new configuration of ORCHIDEE, the analysis and supporting plots are very useful and effectively achieve to highlight where the model performs well, and which future development efforts should be prioritized. This is a useful evaluation effort which will also benefit the wider LSM community beyond the ORCHIDEE user base. The effort that the authors went through in evaluating ORCHIDEE_DF against a large ensemble of observations goes much further than previous attempts published in the literature and is greatly appreciated.

Adding a representation of diffuse light fraction in the canopy can only be useful if the boundary conditions that is the fraction of diffuse radiation hitting the top of the canopy is known. This information is usually lacking from the dataset that are used to drive LSMs. Technically this is a problem that is external to land surface modelling, but it is

great to see that Zhang et al. provide a practical framework to retrieve that missing information and could offer some insight to the terrestrial carbon cycle community for a developing a harmonized framework in future LSMs inter-comparisons.
The topic covered in this paper is absolutely relevant to GMD and I therefore strongly support its publication after addressing those minor very few points."

[Response] We thank the reviewer for the careful review and helpful comments and suggestions, which helped us to significantly improve our manuscript. We have addressed all the suggestions and comments in our revision. Please find below the reviewer's comments, followed by our responses and relevant changes in the manuscript. We hope that the revised version addresses all the issues raised by the reviewer.

Comments:

"1. I believe it will be improved at production stage, but some equations are not easy to read in current form. Use of upper script and lower script could help bringing better separation between the terms in the equations (e.g. Km_C instead of KmC, C_c instead of Cc, etc)."

[Response] We thank the reviewer for this suggestion, the notations have been improved throughout the manuscript. (*Ac* to A_c, *Aj* to A_j, *Rd* to R_d, *Cc* to C_c, *KmC* to Km_C, *KmO* to Km_O)

"2. Would it make more sense to introduce section 2.1.3 (Light transmission in ORCHIDEE_DF) before section 2.1.2 (Light partitioning in ORCHIDEE_DF) so it follows naturally section 2.1.1 (Light transmission in ORCHIDEE_trunk) especially given that the calculation of the fraction of diffuse light hitting the canopy top could eventually be treated by the radiative transfer of the driving atmospheric model as it is done in an Earth System Framework (e.g. Yue et a l., 2017; Malavelle et al. 2019) making a specific parameterization for this not necessary in ORCHIDEE."

[Response] We agree with the reviewer that it is more reasonable to put the two light transmission sections together. Sections 2.1.2 and 2.1.3 have been swapped in the updated manuscript.

"3. For the evaluation framework described at P 11 L 324 to 326 - Getting the same level of PPFD that way may involves comparing GPPs at different time during the day which might not capture vegetation in similar physiological states. Wouldn't it be easier to simply normalize the cloudy and sunny GPPs by their respective PPFDs rather than removing a part of the dataset (likely the midday data for the sunny GPP when insolation is maximal and light saturation of the sunlit leaves possible)?"

[Response] Thanks for this question. We considered carefully and tried to use the proposed normalization method (Fig R1). The results are similar to what we found controlling PPFD level in the manuscript. However, we did not use it in the manuscript due to some concerns. It is known that the light response curve is not linear. Therefore, the LUE (GPP/PPFD) should depend on PPFD level. Due to the nature of atmospheric

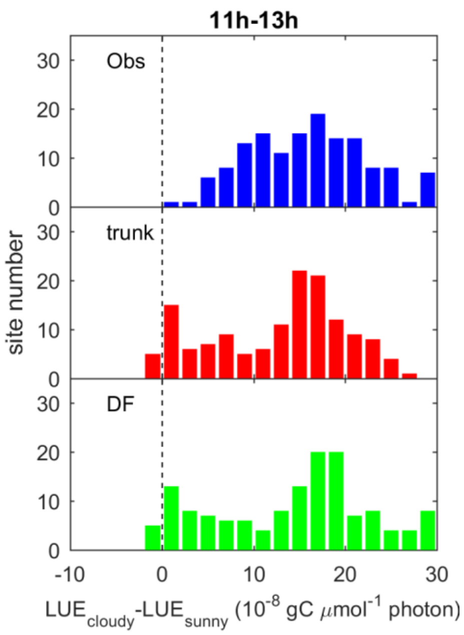

Figure R1. Site distribution of the observed and modeled LUE difference between cloudy and sunny conditions at midday during the peak growing season (monthly GPP>90% of the mean monthly GPP maximum).

light transmission, the cloudy PPFD should be smaller than the sunny PPFD for a given solar zenith angle. If the PPFD level is not controlled, it would become difficult to explain whether the difference in LUE is due to diffuse radiation fraction or to the PPFD level. Therefore, in the manuscript, we compared the GPP and LUE with PPFD controlled at different times of the day (Fig. 7), which, we think, has ensured the vegetation to have similar physiological states in each period.

"4. P 13 L 387 389 It is interesting to note that both ORCHIDEE trunk and DF underestimate the dGPP and the dLUE around midday. Could it be related to the relative high proportion of sunlit leaves which is primarily a function of the solar zenith angle in the DF configuration? Segregating the dataset in to latitudes may help to appreciate if this behaviour occurs more in the tropic or the mid latitude sites"

[Response] Thanks for this point. We had made an extra analysis to investigate the latitude dependence of the ratio between modeled dGPP vs observed dGPP at midday (Fig. R2, two outlier sites not shown on the plot). There are no sites having similar midday PPFD level under sunny and cloudy conditions in low latitudes. According to the remaining data, positive relationship between the dGPP ratios and latitudes is not significant for both trunk and DF simulations. From our perspective, the underestimation in midday dGPP could be a result of parameterizations of processes other than diffuse radiation in ORCHIDEE because both the trunk and DF configurations have this problem. This will be added to the manuscript (Lines 387). "The underestimation of midday ΔGPP could be a result of error in current ORCHIDEE parameterizations". With better parametrization and/or calibration done in the future, this midday underestimation could be corrected.

Minor comment:

P02 L050 VPD acronym has not been defined yet.

[Response] It is now defined.

SC2: P02 L 55 "large scale aerosol changes". [optional] You could add "and long term changes in cloudiness".

[Response] It is added accordingly to the manuscript.

P03 L 075 How come? Is it because of the large reduction in radiation under cloudy

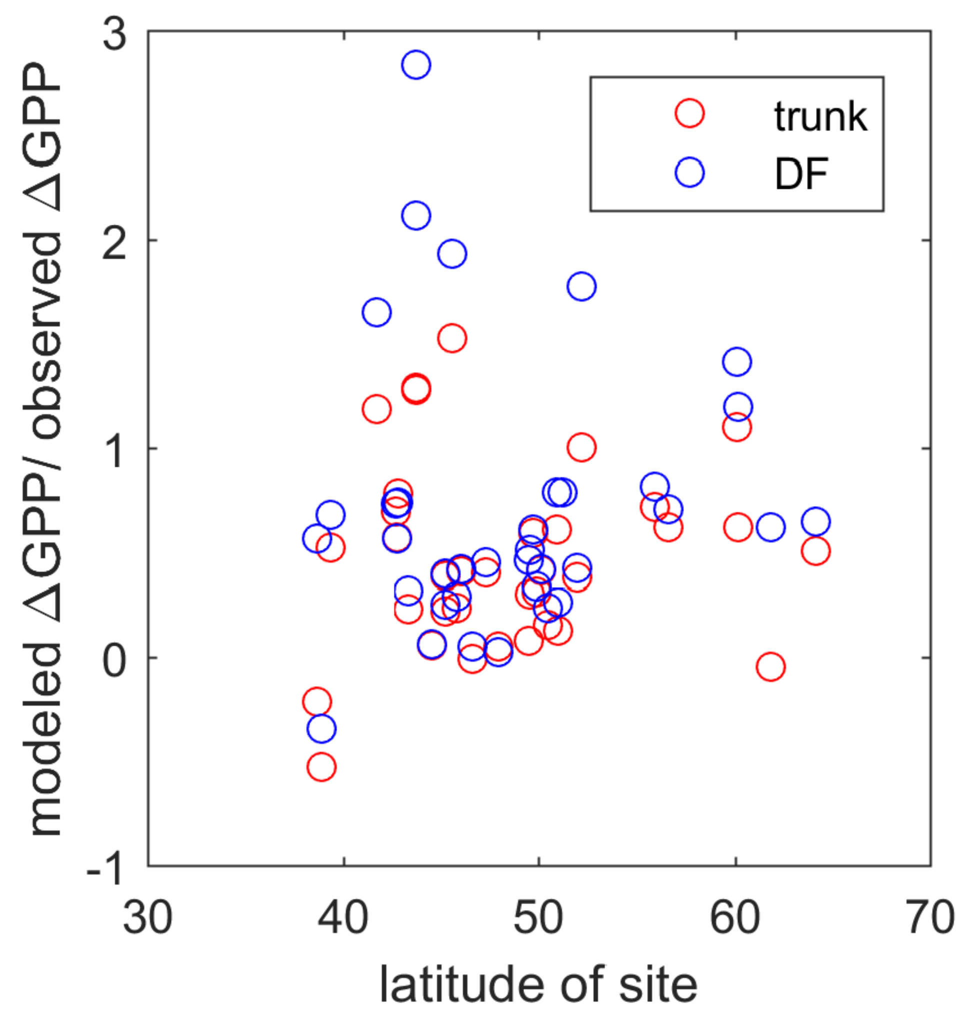

Figure R2. The dependence of the ratio between modeled cloudy-sunny GPP difference and observed GPP difference at midday (11:00-13:00). Neither ratios show a significant positive relationship with latitude.

sky that tends to outweigh beneficial the effect of increased diffuse light?

[Response] The reduction in radiation under cloudy sky can change the radiation budget at land surface and cause a cooling effect. This effect may decrease the VPD and mitigate its stress on stomatal conductance and finally affect GPP. The cooling itself can also influence directly photosynthesis rates in the model. Therefore, in the manuscript we wrote: "The covariance of these environmental factors may also cause the GPP to increase under cloudier conditions, although not being a direct effect of diffuse light".

P03 L 076 My bad, explanations for my comment above are provided in the following sentences I would remove the word "Finally", which creates confusion during the transition between the two sentences.

[Response] The word "Finally" has been changed to "Lastly" to avoid confusion.

P03 L 077 Williams et al. 2016 (year not matching the reference at the end i.e. 2014).

[Response] The year has been correctly accordingly.

P03 L 087 Le Quere et al. 2018 missing from the reference list.

[Response] The reference has been added to the list.

P05 L 143 You can maybe point the reader towards Fig 3 as well. This schematic is useful for visualizing what eq. 4 calculates. I initially misunderstood what the cumulative LAI represente. It only represents the cumulative LAI above the current layer but does not include the current layer (if I got it right).

[Response] Fig 3 is cited here. And yes the cumulative LAI above the current layer but does not include the current layer.

P05 L 152 Shouldn't it be dI_i /$dLAI\_c_i$ instead of dI/dLAI_c in eq. 6 What does the vertical bar | symbol represents? Is it a derivative at fixed LAI_c_i?

[Response] Here *dI/dLAI_c* indicates the derivative of light with respect to cumulative LAI from the top of the canopy. Since this equation is continuous and for all canopy position, no subscript *i* is added here. To calculate $Iabs_i$ which is the absorption at layer *i*, the derivative is calculated at layer *i*, noted $|LAI\_c_i$. This calculation is based on the assumption that all canopy layers are thin enough to neglect the difference in light absorption within each canopy layer (explained after Eq. 6).

P06 L 170 Either explicitly provide the relationships or give a reference where those are documented.

[Response] The reference has been added to the manuscript.

P06 L 175 "forcing datasets": Do you mean dataset used to drive LSMs?

[Response] Yes, the manuscript has been clarified to use "datasets to drive LSMs".

P 06 L 179 Fdf_{PAR} *Should it be rewritten* $fPAR_{df}$ *to be consistent with the notation in other equations?*

P 07 L 216 Same as above, $fPPFD_{df}$ *instead of* Fdf_{PPF}

[Response] In the manuscript, we use Fdf_{PAR} or Fdf_{PPFD} to distinguish the fraction of diffuse light from the radiation variables in W m^{-2} or in µmol m^{-2} s^{-1} using subscript "$_{df}$" for diffuse light (see Table 1).

P08-09 eq. 26, 28, 30. Should it be LAI_c_i *instead of* LAI_a_i *in the exponentials?*

[Response] Thanks for finding this error, the equations have been corrected.

P08 L 253 Ref to Hikosaka et al. (missing from the reference list)

[Response] The reference has been added to the list.

P09 L 2 68 27 0 Same as eq. 6. The notation for the derivative is not clear to me. Could you explain?

[Response] Please see the response to the above comment.

P09 L 289 Change to "from 252 sites in total".

[Response] The manuscript has been changed accordingly.

P10 L 292 Good job getting the references for all the sites!

P10 L 292 "annual climate" sounds weird. Could be rephrased by saying, "(climatological) annual mean temperature span the range xx to yy while (climatological) annual mean precipitation … span the range" Same for Fig S2 legend.

[Response] It has been rephrased as: "The annual mean temperature of the sites spans from -9 to 27°C, while the annual precipitation spans from 67 to over 3000 mm yr^{-1}" in the text. Fig S2 legend has been changed accordingly.

P13 L 411 This (fig 9 & 10) is an extremely useful way of presenting the sensitivity of the two models

P14 L 422 Could that result be related to similarities in parameter traits and optimum *points (e.g. Vcmax) between PFTs used to represent temperate and tropical biomes?.*

[Response] The ORCHIDEE model calculates the optimum points for Vcmax according to the growth temperature the vegetation is adapting to during the season. The range of the acclimation spans from 11 to 35ºC in the current ORCHIDEE model. Therefore, the model should be capable of distinguishing temperate and tropical biomes. However, considering the limiting observation data for calibration (P16 L 499), it is possible that current parameters are not good enough to represent sufficiently well temperature acclimation.

Figure 2 The subtle light gradient makes it hard to appreciate the density of points. Could you maybe add a Probability Density Function along the x (respectively y) axis to represent the distribution of modelled (respectively observed) fraction of PPFD.

[Response] Figure 2 has been improved accordingly (also Fig R3).

Figure 6 "is controlled the same" feels a bit clunky Could be rephrased by just saying that the sunny and cloudy days are sampled at equal light levels

[Response] The caption has been modified accordingly.

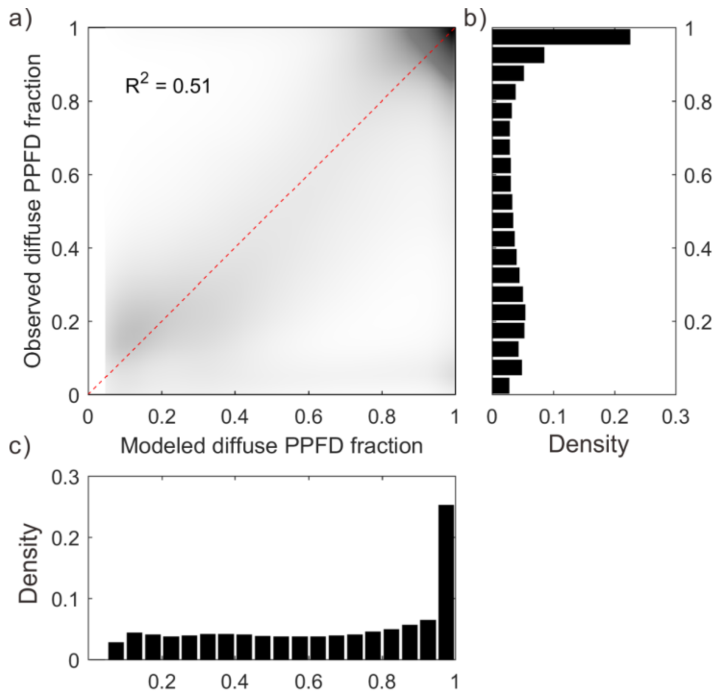

Figure R3. Modeled and observed diffuse PPFD fraction. (a) Scatter plot with the dark area indicates high data density, while light area indicates low data density, (b) Density distribution of the observed diffuse PPFD fraction, (c) Density distribution of the modeled diffuse PPFD fraction.