Dear Editor and Referees,

We would like to thank the two Referees for their valuable comments on the content of our manuscript and their suggestions for improving the document. Following the two reviewers' suggestions and comments, we carefully revised our manuscript. We believe that the revised version satisfactorily addresses the referees' questions and concerns. In this reply, we seek to clarify the issues, raised by the referees, point by point. Please find the detailed response (normal font) to the referees' comments (italic font). For your convenience, all the corrections in the revised MS are made in red.

Thank you again for your time and efforts on our manuscript. We look forward to your sympathetic handling of our manuscript.

Yours sincerely,

Responses to comments from Referee 1

[General comments] *Chang et al., couples a grassland module into a global dynamic vegetation model (DGVM) (ORCHIDEE). The revised model (ORCHIDEE-GM) is validated against 11 Eddy Covariance sites across Europe. Both the main DVGM and grassland module have been published previously and the integration and validation approaches are sound. My primary criticism of the study is that there are no validation sites outside of Europe where ORCHIDEE-GM is run. This limits the climatic space over which the integrated and original ORCHIDEE models are compared, and it limits testing in grasslands dominated by C4 photosynthetic pathway species. Only one validation site has a C4 grass (invasive species). Including validation sites outside of Europe (e.g. Ameriflux, OzFlux?) would increase the impact of ORCHIDEE-GM and would encourage use outside of Europe.*

[Response] Following your suggestion, we have already tried to contact the principle investigators (PI) of eddy covariance sites in both USA and China on the flux data and management information (e.g. harvest date, grazing period and corresponding stocking rate) that are necessary inputs for ORCHIDEE-GM simulations. Unfortunately we did not get any responses from site PIs in USA. In China, almost all of sites are fenced and protected from mowing and grazing, except the Xilinhot grassland site (CN-Xi2) that was mowed once per year. However, the exact date on the mowing was not recorded on this site.

In terms of mean climate state (e.g. mean annual precipitation and temperature), a majority of EC managed temperate grassland sites from USA and China are well within the climate ranges of the European grasslands used in ORCHIDEE-GM validation (mean annual temperature: 5.1 ^{o}C - 15.6 ^{o}C; mean annual precipitation: 439 mm - 1271 mm). Thus, we would like to argue that the ORCHIDEE-GM validation using European grassland sites can be safely extrapolated to other temperate sites outside of the Europe. In addition, the PASIM module introduced in ORCHIDEE-GM is mainly developed for simulating management impacts in temperate C3 grasslands instead of drylands (e.g. a majority of sites in OzFlux) and C4 grass. This is the reason why we only use the C3 temperate grasslands to validate ORCHIDEE-GM.

[Specific comments]

[Comment 1] *Page 2770 - Line 22: Do you have a citation for area coverage?*

[Response] The world grassland area (24 million km^2) was directly taken from Scurlock and Hall (1998). However, the estimates of the proportion of the land area covered by the grasslands vary between 20 and 40 percent, depending on the definition (Suttie et al., 2005). In the revised MS, now it reads as:

"Grassland is a widespread vegetation type, which covers 20 to 40 percent (26.8 to 56 million km^2) of the whole land surface on the earth depending on the grassland definition (Suttie et al., 2005), and plays a significant role in the global carbon (C) cycle."

[Comment 2] *Page 2770 - Line 25: Can you provide a quantitative range for the uncertainty?*

[Response] In fact, the uncertainty of the annual carbon sink on a global scale was not provided by Scurlock and Hall (1998). At the European scale the sink strength and its uncertainty has been estimated by Schulze et al. (2009), which has already been provided in the previous MS.

[Comment 3] *Page 2771 – Line 6: Is the radiative balance forcing reported in Schulze et al., 2009 or 2010?*

[Response] Thanks for your careful reading and we have changed Schulze et al. (2009) to Schulze et al. (2010) in the revised MS.

[Comment 4] *Page 2773 or 2774: Does either ORCHIDEE or PaSim account for nitrogen deposition? If not, please state so, since N deposition can be significant downwind of major urban areas.*

[Response] Nitrogen deposition is considered in PaSim but not in ORCHIDEE. The N cycle in PaSim considers four types of N inputs to the soil via atmospheric N deposition, fertilizer N addition, symbiotic N_2 fixation by legumes, and animal returns (Graux et al., 2012). In the revised MS, the following sentence has been added:

"The N cycle (including N deposition) is not included in current version of ORCHIDEE."

[Comment 5] *Page 2779 – Line 1: Again, I think validation at non-European sites could be highly useful.*

[Response] Please see details in the response to **[General comments]** above.

[Comment 6] *Page 2802 – Table 1: Validation would be good at additional mountain sites (altitude>1500 m) and sites with warmer mean annual temperatures.*

[Response] In reality, the sites used for ORCHIDEE-GM validation cover a major climatic gradient over Europe, with large spans of altitude (111 m -1770 m), mean annual temperature (5.1 ^{o}C - 15.6 ^{o}C) and mean annual precipitation (439 mm year^{-1} - 1271 mm year^{-1}). In this study, the sites with the highest altitudes are ES-VDA (1770 m) and IT-MBo (1550 m), and the warmest EC site is PT-Mi2 (mean annual temperature: 15.6 ^{o}C).To our knowledge, sites involved in this study have already included the highest (or warmest) one that can be currently available.

[Comment 7] *Page 2811 – Figure 6: It would be good to include r and RMSE at higher timescales (daily).*

[Response] As we have already indicated in the previous MS (Section 4.3.2), the impacts of grassland management processes on CO_2 fluxes only act at inter-monthly, and seasonal-annual timescales. The high frequency variability (daily to weekly) is mainly affected by the short-term climate fluctuation instead of the management. Thus, the model-data misfit (RMSE) of NEE at high frequency variability (daily to weekly) is nearly the same in ORCHIDEE (1.04 ± 0.26 g C m^{-2} day^{-1}) and in ORCHIDEE-GM (1.04 ± 0.22 g C m^{-2} day^{-1}). For correlation coefficient (r), the same pattern with RMSE was found (Section 4.3.2). This information has been added in the revised MS.

Responses to comments from Referee 2

[Overall assessment] *The paper presents the integration of a grassland management module into the ORCHIDEE global vegetation model and the evaluation of the new model setup against measurements of biomass and carbon fluxes from 11 European flux-net sites. The paper is clearly structured and overall well written. Nevertheless there are several critical issues that should be addressed in a revision.*

[Comment 1] *The management module introduced into ORCHIDEE is essentially the one already developed, tested and applied within the framework of the PaSim model, and there is a necessity to justify the additional efforts. This is done only vaguely in the Introduction. There is also a need to take* *up again the comparison of plot and global vegetation models and to stress the benefits of ORCHIDEE-GM as compared PaSim and other plot models when discussing the results and implications.*

[Response] Thanks for the suggestion! Compared to the PaSim model developed at the plot scale, ORCHIDEE is designed for the global application and has the advantage in simulating C dynamics of different vegetation types. Incorporating the grassland management into the land surface model ORCHIDEE improves the model ability in estimating C balance for cultivated grasslands, which enables us to go a step further in assessing C dynamics attributed to climate change and human cultivation. We have added some statements to justify the implementation of management module in ORCHIDEE (**P1** in Section 1), and emphasized the advantages and the utility of the ORCHIDEE-GM in the revised MS (**P2** in Section 5.4).

P1: "Currently, most of the land surface models have a poor (or no) representation of the management impact on grasslands. Incorporating the grassland management into the land surface model ORCHIDEE can improve the model ability in estimating C balance for cultivated grasslands, which enables us to go a step further in assessing C dynamics attributed to climate change and human cultivation."

P2: "Nevertheless, a more complete picture of NBP provided by ORCHIDEE-GM enables us to separate the role of grassland management from those of other factors (e.g. CO_2, climate and land use) in the attribution of the grassland C sequestration (Soussana et al., 2010). "

[Comment 2] *ORCHIDEE is a global vegetation model that can be employed to study different issues. Given this background, the overall goal of the present exercise is not always clear. Title and Conclusions (p. 2792, line 23: "[The paper is an attempt] to realistically represent the impacts of management on the C balance of European grasslands . . .) suggest that the main aim is the simulation of carbon fluxes (and other greenhousegases), while line 7, p. 2774 of the Introduction indicates a need for modeling the "cultivation of European grasslands".*

[Response] Thanks for your suggestion! In order to make it consistent throughout the MS, we have modified the previous sentence as:

"Here, in order to model the impacts of cultivation on European grasslands, we include parameters and functions related to management (e.g. harvested biomass, enteric CH_4 emissions and animal production) in the model ORCHIDEE DGVM."

[Comment 3] *More clarity could be achieved by reconsidering the title, which could be made more specific.*

[Response] To be more specific, the title now reads as "Incorporating grassland management in ORCHIDEE: model description and evaluation at 11 eddy-covariance sites in Europe"

[Comment 4] *With regard to the evaluation of the ORCHIDEE-GM, much emphasis is on the assessing the model performance in simulating the variability of carbon fluxes at different time scales. However, the importance of the variability [of the carbon fluxes] is not addressed in the introductory section. Therefore it is not always clear why a relatively detailed analysis has been undertaken, employing a technique that I believe] is still not a standard outside the flux community.*

[Response] Following your suggestion, we have added the following into the revised MS.

"Ecosystem-atmosphere fluxes are shaped by a variety of fluctuations on different scales of characteristic variability. Scalar error estimates and residual analysis used to summarizing model-data disagreement provide only limited insight into the quality of a model (Mahecha et al., 2010). A more sophisticated way could be localizing model-data mismatches in time (Gulden et al., 2008). Thus to evaluate time-frequency localized model performance on CO_2 fluxes (GPP, TER and NEE), we used a time domain decomposition method called SSA (Singular System Analysis; Broomhead and King, 1986; Elsner and Tsonis, 1996; Golyandina et al., 2001; Ghil et al., 2002). "

[Comment 5] *There is no critical discussion of key technical aspects of the modeling exercise. As pointed out in the Discussion (p. 2788-2792) model parameterization, model initialization, etc. all play a crucial role in determining the overall model performance. Actually, at the end my impression is that these issues are even more relevant than a realistic representation of management, which brings me back to the need to better justify and specify the goals of this work.*

[Response] We would like to state that the objective of this study is to realistically represent the impacts of management on European grasslands including the C fluxes in ORCHIDEE. Compared to ORCHIDEE, ORCHIDEE-GM after considering impacts of grassland management can realistically capture the intra-annual variations of LAI, AGB and CO_2 fluxes that are induced by cut or grazing practices (e.g. higher IOA and lower RMSE; Table 3, Fig. 4, Fig.5 and Fig. 7). A global vegetation model ORCHIDEE is based on a set of PFT-dependent parameters, which however only represent the mean state of global vegetation (e.g. SLA, Vc_{max}, and J_{max}). This model characteristic can not treat diverse plants (e.g. species with different functional traits) within each PFT. Thus, we only focused on the improvement achieved by incorporating grassland management module in this study, instead of the accuracy of the model in reproducing C fluxes. In order to provide possible directions for further investigation, we also investigated the potential drivers of the residual model-data discrepancy. For example, the model-data discrepancy could be reduced if the N limitation is considered in the model. To achieve this, a fully N cycle interactive with C cycle should be included, however which was beyond the scope of this study. In response to your comments, we have added the following text into the revised MS (Section 6).

"However, we should inform that this study is not designed for fully bridging the gap in simulating C fluxes but more for understanding the contributing effect of improved management practices to C fluxes simulations in temperate grassland."

[Comment 6] *Similarly, I would like to have some comments concerning the coupling strategy. In particular the question arises of whether the fact that the management module feeds back only two variables to ORCHIDEE (p. 2776, line 3) is appropriate or not.*

[Response] The ORCHIDEE has several C pools including vegetation, litter and soil. Grassland management practices reduce aboveground biomass (including leaves, stem and ear) through harvest, herbage intake and trampling. Subtracting the C exported as forage, animal products (milk/meat), respired by animals and CH_4 emissions, the residual of C returns to the field in the form of litter (e.g. harvest loss, grass trampled by animals and excreta). Thus the two variables (residual aboveground biomass and newly formed litter) are suitable and enough to represent the effects of grassland management practices on C pools in ORCHIDEE.

[Comment 7] *Apart from a few details in Section 2.3 (p. 2776, lines 9 and 10) there is very little information concerning grazing. Since one of the main conclusions is that "improvements at grazing sites are only marginal" (Abstract, p. 2770, line 13) there is a need for a more through introduction of how grazing is modeled and which processes having an effect on vegetation are considered. Questions come up for instance concerning the types of herbivores are considered (Only cattle? Others?), how are the returns of nitrogen and carbon in excreta and urine taken into account, etc. etc.*

[Response] The animal module concerning grazing practice was described in Section 2.2. To further clarify this process, we added a short description of it in the revised MS (Section 2.3).

"The management module simulates harvested biomass, herbage intake and animal trampling during grazing, and the following C fluxes by animal respiration, milk production, CH_4 emissions, and excreta returns."

[Comment 8] *Estimates of the carbon balance of European grasslands obtained with ORCHIDEE-GM are only briefly compared to previous estimates in Section 4.4 (p. 2788, line 1 ff.). In view of the scientific and political relevance of this question, a more thorough discussion seems could be of interest.*

[Response] Following your suggestion, we have added the following paragraphs into the revised MS (**P1** in Section 4.4, **P2** and **P3** in Section 5.4).

P1: "After accounting for C export (input) from (to) the site, ORCHIDEE-GM estimates a positive NBP of 37 ± 30 g C m^{-2} $year^{-1}$ ($P < 0.01$) over the 11 sites, which is comparable to the previous estimate (57 ± 34 g C m^{-2} $year^{-1}$) by Schulze et al. (2009) and lower than that (104 ± 34 g C m^{-2} $year^{-1}$) from the GREENGRASS network (Soussana et al., 2007)."

P2: "Given a lower C usage at grazed grasslands than that at cut grasslands, the NBP difference between them indicates a possible relationship between the C usage and NBP found by Soussana et al., (2007). This relationship is also found within cut grasslands and grasslands having both grazing and cutting respectively (Table 4). The results from paired sites (FR-Lq1 and FR-Lq2, see Table 4) further confirm that increased C usage (higher herbage intake at extensively grazed grassland, FR-Lq1) may diminish C sequestration (lower NBP) in managed grasslands, given the fact that intensive grazing reduces LAI and further decline NPP (Parsons et al., 1983)."

P3: "Fully accounting for NBP still take into account dissolved organic / inorganic (DOC/DIC) C losses to water, which however is not implemented in ORCHIDEE-GM. If the average DOC/DIC loss estimated at European scale (11 ± 8 g C m^{-2} $year^{-1}$; Siemens, 2003) reduced the NBP by 30%, the residual NBP (positive, $P < 0.05$) still indicates a C sequestration in European managed grasslands."

[Comment 9] *As previously mentioned, ORCHIDEE is a global model, whereas the focus of this work is on European grasslands. Possible applications of the new model version outside Europe are briefly brought up in the Conclusions (p. 2793, line 9 ff: "This model with a realistic management process could enable us to re-examine the C balance in the regions e.g. Europe and China which distribute a large area of managed grasslands"). It is not clear, however, whether the current model version can be used to tackle issues that may arise in a different context.*

[Response] Grassland management over the world has a unified objective of feeding animals that would provide animal food for human consumption. The modes of grassland cultivation is relatively similar around the world, which include N fertilization, cut and grazing practices that have already been considered in ORCHIDEE-GM. Cutting and grazing practice in ORCHIDEE-GM only modify the amount of AGB and litter but maintain the same biochemical and biophysical processes (e.g. photosynthesis, respiration, allocation, turnover, soil respiration, and water / energy cycle) with the ORCHIDEE. Thus, compared to ORCHIDEE, ORCHIDEE-GM is more eligible to be applied in different regions with diverse climate when the information on management practices is available.

In addition, as already indicated in the response to **[General comments]** from referee 1, in terms of mean climate state (e.g. mean annual precipitation and temperature), a majority of EC managed temperate grassland sites from USA and China are well within the climate ranges of the European grasslands used in ORCHIDEE-GM validation (mean annual temperature: 5.1 ^{o}C - 15.6 ^{o}C; mean annual precipitation: 439 mm - 1271 mm). Thus, we would like to argue that the ORCHIDEE-GM validation using European grassland sites can be safely extrapolated to other temperate sites outside of the Europe.

[Comment 10] *Introduction. There is a nice review of grassland ecosystem models, but little information concerning how management is taken into account in these models.*

[Response] In the revised MS, we have added a brief description of grassland ecosystem models with or without management practices. CENTURY and GEM only consider natural grasslands.

LINTUL_GRASS takes cutting into account (it is “cut practice” not “tillering”; we have already corrected it in the revised MS). SPUR2.4 and HP model are able to consider the impacts of livestock grazing on grassland. PaSim takes into account N fertilization, cutting and grazing practice.

[Comment 11] *Section 3.3 (Model set-up), p. 2781, line 20: what is the “(idealized) management history of each site” used for the model spin-up?*

[Response] To clarify this point, we have added the following into the revised MS.

“In reality, the equilibrium state of natural ecosystem C pools (after spin-up 1) can be changed by management practices. But the management history is not clear at the site level. Thus, we assume a general (idealized) management history for each site, i.e. the management practice from nowadays has been applied for additional 40 years after spin-up 1 to obtain the ecosystem C pools under the grassland management. ”

[Comment 12] *Section 3.4 (Methods for evaluating . . .): replace “index of agreement indicator” (p.2781 line 25) simply with “index of agreement”*

[Response] We have already corrected it in the revised MS (Section 3.4).

[Comment 13] *Section 3.4 (Methods for evaluating . . .) The discussion of the Singular System Analysis should be either shortened (assuming that most of the readers are acquainted with it) or than a little bit expanded (assuming that readers from outside the flux community are not necessarily familiar with it).*

[Response] Following your suggestion, now it reads as:

“In this study, based on the signal decomposition and reconstruction from SSA technique (Golyandina et al., 2001; for technical details see Mahecha et al., 2010 Appendix B), the original time series can be separated into four timescale variability: instantaneous to weekly, inter monthly, seasonal to annual, and low-frequency variability (Table 2).”

[Comment 14] *Table 1 could be accompanied by a map of Europe showing the location of the 11 sites considered for the analysis.*

[Response] Thanks for your suggestion. We have added the map in the revised MS (Section 3.4).

[Comment 15] *Axes labels in Fig. 6 (print version) are relatively small. Please also label the x-axis of the upper panel.*

[Response] Thanks for your suggestion. We have updated this figure in the revised MS.

Reference:

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