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Dear Editor,

Our manuscript (bg-2014-138) entitled "Biophysical controls on net ecosystem CO2 exchange over a semiarid shrubland in northwest China" has been carefully revised in light of the comments from the two anonymous reviewers. Point-by-point responses to all comments are appended below. The authors are grateful to the two anonymous reviewers for their insightful comments and suggestions.

Revisions to the manuscript were highlighted using the blue font color. Please do not hesitate to contact me in case any questions arise regarding the manuscript.

Yours sincerely,

Dr. Tianshan Zha

Reviewer #1's comments:

1. It will be much better to list all the abbreviations and parameters in an appendix so that readers could easily lookup those terms and better understand the article.
RE: We have added a table of nomenclature in Appendix A to list all the abbreviations and parameters in the revised manuscript (Line 1, Page 12).

2. The gross ecosystem productivity (GEP) and net carbon sink were presented with standard deviation, i.e. 456 ± 8 g C m^{-2} yr^{-1} and 77 ± 7 g C m^{-2} yr^{-2}. No interpretation was ever described in the text, except the authors used bootstrap to analyze the uncertainty in gap-filled data. If it is from spatial variation, the vegetation in semiarid areas usually has extensive spatial and temporal heterogeneity, and the variation seems small to my understanding. The uncertainty analysis needs to be clarified.
RE: In the revised manuscript, we evaluated the cumulative effect of random measurement uncertainty on annual estimates of net ecosystem exchange (NEE) with the "successive days approach" (Hollinger and Richardson, 2005; Dragoni et al., 2007). This approach infers the statistical properties of the random error from the difference between half-hourly NEE measurements made exactly 24 h apart. A Monte Carlo

approach was then used to generate a random error for each measured half-hourly NEE. The simulation was repeated 2000 times and the uncertainty of the measured annual NEE was estimated by calculating the 90% prediction limits of all simulated annual NEE values. The random measurement errors derived from the "successive days approach" have several sources, primarily including (1) random instrumental errors, (2) flux footprint heterogeneity and (3) the stochastic nature of turbulent transport. In addition, the random errors could be contaminated by the mismatch of environmental conditions between the successive days. Therefore, the effects of imperfect environmental similarity between the successive days were controlled for following Dragoni et al. (2007).

We evaluated the random uncertainty for annual sums of gross ecosystem productivity (GEP) and ecosystem respiration (R_e) following a Monte Carlo algorithm detailed by Hagen et al. (2006). The algorithm infers the statistical properties of the random error from the residuals of the model for gap-filling and flux partitioning. Again, the 90% prediction limits of all (N = 2000) simulated annual GEP and Re values were calculated. The resulting GEP and Re uncertainties encompass sources from both measurement error and model parameterization (Hagen et al., 2006).

The cumulative annual uncertainties (the 90% prediction interval) calculated using the abovementioned methods was 68-87 g C m^{-2} yr^{-1} for NEE, 370-389 g C m^{-2} yr^{-1} for R_e and 449-463 g C m^{-2} yr^{-1} for GEP. The degrees of uncertainty were comparable to those reported by previous studies (Hollinger and Richardson, 2005; Hagen et al., 2006; Dragoni et al., 2007). Intuitively, the uncertainties seemed relatively small considering the heterogeneous vegetation in semiarid areas. However, previous analyses indicated that over long time periods, random uncertainty of eddy-covariance-based carbon fluxes is small compared to other potential sources of systematic bias (e.g., incomplete surface energy balance closure, choice of model type, and choice of a friction velocity threshold). Hagen et al. (2006) concluded that random uncertainty of eddy-covariance-derived GEP estimates at the half-hourly timescale is generally on the order of the observations themselves (i.e., ~100%), but is much less at annual timescales (~10%). In other words, the relative random uncertainty of eddy-flux decreases with increasing timescale (Hagen et al., 2006). The underlying explanation is probably that positive and negative errors tend to cancel out each other over long periods of time (Dragoni et al., 2007).

We clarified the method for uncertainty analysis in the revised manuscript (Line 14, Page 7).

3. Should the uncertainty generated by bootstrap be standard deviation or standard error?

RE: In the revised manuscript (Line 42, Page 7), we used the 90% prediction interval to quantify uncertainty following Hagen et al. (2006). Many other studies (e.g., Dragoni et al., 2007; Savage et al., 2008; Yu et al., 2011) used standard deviation instead. We also calculated uncertainties in terms of standard deviation, and their relative magnitudes were comparable to previous studies.

4. Table 1 and figure 2: as the authors described in the text that October in 2012 is an exception when study the correlation between NEE and PAR. However, there is no

further explanation about the causes of the exceptions.
RE: We clarified this in the revised manuscript (Line 46, Page 10). This exception was partially a result of senescent leaves and reduced LAI at the end of the growing season. Temperature and radiation also decreased at the late season, contributing to reduced CO_2 uptake by the vegetation.

5. This work analyzed the relationship between NEE and environmental variables. Is it possible to generate comprehensive models to predict the NEE_{day}, NEE_{night}, and GEP using related environmental variables together?
RE: We agree that it is important to develop comprehensive models to predict ecophysiological processes in arid and semiarid ecosystems. The objective of this study was to examine how biophysical factors regulate CO_2 fluxes at multiple timescales. Gaining such an understanding is needed to develop mechanistic models suitable for arid and semiarid ecosystems. The authors feel that comprehensive modeling efforts are beyond the scope of the present study. However, process-based ecosystem modeling is one of our ongoing research focuses. We clarified this point in the revised manuscript (Line 10, Page 10). Our results could provide some implications for modeling. For example, our result that the T_s-REW model over-performed the T_s-only model (Fig. 7) indicated the need to take water availability into account when modeling short-term (e.g., hourly) changes of respiration in dryland ecosystems (Line 37, Page 9).

References

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Reviewer #2's comments:

1. An arbitrary approach in used to separate the environmental factor into different levels, for example, soil water content > 0.1 or <0.1 m^3 m^{-3}, is there any valid bases to

justify this? Similarly, for vapor pressure, and so on.

RE: We have clarified the bases for selecting such threshold values in the revised manuscript (Line 28, Page 6). These threshold values were not arbitrarily chosen. In data analysis, we explored a range of values for a given environmental factor (VPD, soil water content or air temperature), and finally selected the values to most clearly show the differences between levels. Secondly, we tried to choose the threshold values which could avoid having too few data points in a certain group. Thirdly, the selected threshold values were equal or close to those used by previous studies in dryland areas, so that our results can be easily compared with other studies.

2. In data processing, 29% of the data has been determined as bad data and excluded and gap-filled. Although you have used approaches to linearly gap-fill the small gaps with but NEE-PAR relation for a large gaps (e.g., gaps lasting for a few days), a gapfilling with consideration of solar radiation may be too coarse as described in Xing et al (Ecological modeling, 2007, 2008). In addition, you have also found "at the half-hourly scale, water stress exerted a major control over daytime NEE, and interacted with heat stress and photoinhibation in constraining C fixation by the vegetaion". How can you justify your approach to fill gaps.

RE: We clarified the gap-filling method in the revised manuscript (Line 26, Page 5). Firstly, although 29% of the annual dataset was missing/rejected and filled with estimated values, 87% of all the gaps occurred during nighttime. Similar to many previous studies, the low turbulent mixing at calm nights rejected a large proportion of nighttime fluxes. As a result, only 7% of all daytime data needed to be gap-filled in order to obtaining annual sums of carbon fluxes, compared to a proportion of 52% at nighttime. In fact, there was only one gap longer than 24 h in 2012 (4-12 May). Therefore, using a simple NEE-PAR relationship for filling daytime gaps would not have caused a large bias in estimating annual sums of carbon fluxes (although it might be too coarse when modeling NEE dynamics at the hourly scale). Secondly, we did not apply a single parameterization of the NEE-PAR relationship to the entire growing season, but rather fit the light response function to consecutive windows of 500 non-missing daytime data points to obtain seasonally-varying parameter values. The seasonality of the parameter values could reflect the ensemble effects of confounding factors on daytime NEE, including soil water content, VPD, air temperature and leaf area index. Thirdly, many previous eddy-covariance studies have used non-linear regression (NLR) gap-filling methods very similar to that in the present study, although many other kinds of techniques exist (for a comprehensive review see Moffat et al., 2007). Most of the NLR methods also applied the light response curve to consecutive time intervals to (empirically and implicitly) incorporate the effects of confounding factors.

3. In your examination of rain pulse, you illustrated a period of 61 mm rainfall event (Day 178-184). Although there is no clue how long the event lasted but I am pretty sure that figure 9 is providing other information as well. If you look at the panel a in the figure, there are other small rainfall events as well but their NEE do not show a significant responses to the rainfall events as the largest rainfall event, in particular the event

around Day 210. Therefore, a further explanation may be useful. By the way, I would suggest to add rainfall data to panel b so that reader can clearly see the delay of 1-2 day described in your paper. In addition, the figure can be enlarged at the x direction to see a clear trend.

RE: We agree with the referee and have added the following passage in the revised manuscript (Line 33, Page 10): "It is worthy of note that not all rain events caused an equal response of NEE (Fig. 9a). For example, NEE seemed relatively insensitive to a smaller rain event on DOY 202 (31 mm). This may be due to other biophysical factors that confound the NEE responses to sudden increases in water availability (Chen et al., 2009). Both temperature and radiation were much less affected over the DOY 202 rain event (data not shown) than over the DOY 179-180 event (61 mm, Fig. 9b and c), which could partially explain the result that the DOY 202 rain event did not cause a large fluctuation in NEE. The behavior of NEE over a rain event also depends on the size and timing of water pulse, the environmental conditions prior to the rain, plant phenology, functional type and rooting depth, all of which affect the rainfall-response of NEE (Aires et al., 2008; Liu et al., 2011; Gao et al., 2012).". We also revised Fig. 9 according to the referee's suggestions. However, we did not add rainfall data to panel b because rainfall was measured with a manual rain bucket before DOY 204, and with a tipping bucket rain gauge thereafter. Therefore, only daily rainfall data were available for the selected rain event (DOY 179-180). We added the daily rainfall values on figure 9, and also added a shadow pattern on the two rainy days so that the responses of NEE to the rain event could be clearer to reader.

4. The abbreviation PPT during growing season is not accurate. I would use term rainfall instead.

RE: We agree with the referee and have made revisions throughout.

5. Line 17 on page 5092, Mu Us desert, not clear to me.

RE: The "Mu Us desert" is also referred to as the "Mu Us sandland", which is located in northern China. The northern edge of the Mu Us desert touches the Ordos Plateau, Inner Mongolia and the southern edge boarders on the Loess Plateau. Our research site (Yanchi Research Station) lies in the southern edge of the Mu Us desert (Line 39, Page 3 and Line 12, Page 4 in the revised manuscript).

6. Figure 2, the June and July pattern are similar. There is a third order polynomial pattern, any explanation to this?

RE: We also noticed the third-order polynomial pattern. It also appeared in Figure 3, for example, for both the high and low soil water level. This was an unexpected yet interesting pattern. We propose that the third polynomial pattern may be related to confounding factors such as VPD and temperature. Although VPD and temperature covaried with PAR at the diurnal scale, they lagged PAR by 3-4 hours (Fig. 10). Therefore, their depression effects on NEE could be strongest when PAR is below its daily maximum. We mentioned this hypothetical explanation in the revised manuscript (Line 6, Page 10). Further studies are needed, however, to corroborate this hypothesis.

7. Figure 3, the marker size in the top panels is too big.
RE: We reduced the marker size in the revised manuscript (Line 1, Page 21).

8. Figure 5 is in poor quality. The letter font in the figure is not proportion to the figure size.
RE: We have made revisions accordingly (Line 1, Page 23).

9. Figure 9, reduce the marker size on the top two panels.
RE: We have made revisions accordingly (Line 1, Page 27).

References

Moffat, A. M., Papale, D., Reichstein, M., Hollinger, D.Y., Richardson, A. D., Barr, A. G., Beckstein, C., Braswell, B. H., Churkina, G., Desai, A. R., Falge, E., Gove, J. H., Heimann, M., Hui, D., Jarvis, A. J., Kattge, J., Noormets, A., Stauch, V. J.: Comprehensive comparison of gap-filling techniques for eddy-covariance net carbon fluxes, Agr. Forest Meteorol., 147, 209-232, 2007.