Dear Dr Lee,

Many thanks for your comments on our manuscript. Based on your very constructive comments, we have thoroughly revised the manuscript. Additional discussion and justifications have been added into the manuscript or into the Supplement. Please see below the detailed responses. Major changes have also been highlighted in the revised manuscript.

With best regards
Lishan Ran, on behalf of the coauthors

This study provides rich river carbon data from a watershed influenced by arid-semiarid climate. The data, including river carbon concentrations, exports, contents, and emissions in different carbon species, are very informative. I believe that more careful analyses of these comprehensive data can enhance our understanding of river carbon cycling and its role in linking terrestrial and marine biogeochemistry. I found some small and large problems which I think should be addressed for publication of this manuscript in Biogeosciences.

Estimation method of river carbon exports P4L156-160: River carbon exports are one of key results of this study, and thus should be estimated very carefully. However, I found that the estimate method of the exports is not clear. There are various estimation methods that could be applied. Aulenbach, B.T., Buxton, H.T., Battaglin, W.A., and Coupe, R.H., 2007, Streamflow and nutrient fluxes of the Mississippi-Atchafalaya River Basin and subbasins for the period of record through 2005: U.S. Geological Survey Open-File Report 2007-1080, https://toxics.usgs.gov/pubs/of-2007-1080/index.html Cohn, T.A., Caulder, D.L., Gilroy, E.J., Zynjuk, L.D., Summers, R.M., 1992, The validity of a simple statistical model for estimating fluvial constituent load-sâA˘T˘An empirical study involving nutrient loads entering Chesapeake Bay: Water Resources Research, v. 28, no. 9, p. 2353–2363. Runkel, R.L., Crawford, C.G., and Cohn, T.A., 2004, Load estimator (LOADEST)âA˘T˘A FORTRAN program for estimating constituent loads in streams and rivers: U.S. Geological Survey Techniques and Methods, book 4, chap. A5, 69 p.
Reply: Estimating riverine carbon flux is a very important part of this study in which we attempt to investigate the fate of carbon after entering the drainage network from terrestrial ecosystems. Just as you have pointed out, there are a number of methods to estimate the annual fluxes of dissolved and particulate matter transported by rivers. Major methods currently used include linear interpolation and ratio estimators, regression-based methods historically employed by the USGS, and recent flexible techniques such as Weighted Regressions on Time, Discharge, and Season (WRTDS), etc. As you have also suggested, the most commonly used USGS software package for estimating constituent load using regression is known as LOADEST (Runkel et al., 2004. Load Estimator (LOADEST): A FORTRAN Program for Estimating Constituent Loads in Streams and Rivers. U. S. Geological Survey Techniques and Methods Book 4, Chapter A5). Lee et al. (2016) recently reviewed the potential for flux estimation bias across a broader range of estimation methods and concluded that the Beale’s ratio estimator and WRTDS generally exhibit greater estimation accuracy and lower bias (Lee et al., 2016. An evaluation of methods for estimating decadal stream loads. *Journal of Hydrology*, 542, 185-203). Our annual carbon flux estimation in this study was based on the Beale’s stratified ratio estimator. Since the riverine carbon concentrations were measured with “sparse” sampling frequency while flow and

suspended sediment had a continuous daily measurement, this method could greatly reduce the bias introduced by relatively low sampling frequency, in particular the high flow events that are often undersampled (Parks and Baker. 1997. Sources and transport of organic carbon in an Arizona river-reservoir system. *Water Research*, 31, 1751-1759). Indeed, we have already used the Beale's ratio estimator in our earlier estimation of carbon flux in the Yellow River with success (i.e., Ran et al., 2013. Spatial and seasonal variability of organic carbon transport in the Yellow River, China. *Journal of Hydrology*, 498, 76-88). And the Beale's ratio estimator has proven to be highly reliable and is recommended if the relationship between discharge and concentration is weak (e.g., Fulweiler and Nixon, 2005. *Biogeochemistry*, 74, 115-130; Awad et al., 2017. *Environmental Pollution*, 220, 788–796; Chen et al., 2014. *Journal of Geophysical Research: Biogeosciences*, 119, 95-109; Sun et al., 2017. *Hydrological Processes*, 31, 2062-2075). In comparison, we have also estimated the carbon flux by using the LOADEST software package. The flux results show high consistency with each other, with a difference of less than 4.5%. We have added a detailed description of the estimate method (i.e., the Beale's ratio estimator) in the revised manuscript. Please refer to the highlighted changes in the text. (lines 161-180)

Estimation method and uncertainty of NEP P5L182-199 and P7281-291: For river carbon budget analysis, the NEP result is critical to drive the conclusion. However, I am a bit skeptical about the approach to calculate NEP. The authors are using different independent data sources for NPP and SR, and then, to calculate Rh, adapting another study's assumption "Rh accounts for 54% and 40% of SR in forested and non-forested areas,". This methodology probably led to large uncertainty in the final NEP estimate, which should be at least discussed.
Reply: Thanks a lot for your comment. Estimating NEP is quite important for the carbon budget analysis of this study. We divided the study catchment into two subcatchments, including the sandy subcathment and the loess subcatchment. While forest cover in the Wuding River catchment is quite low (less than 5%) as a result of low precipitation, grassland is the major land cover in the sandy subcatchment and agriculture and grassland predominate the loess subcatchment (Wang et al., 2014. Spatial-temporal changes of land use in Wuding River Basin under ecological restoration, *Bulletin of Soil and Water Conservation*, 34, 237-243 (in Chinese with English abstract). This is largely the result of the implementation of the Grain-for-Green Project which was initiated by the Chinese government in 1999. After more than 10 years of implementation of this vegetation restoration program, the vegetation cover (forest and grassland) has greatly increased. Please also refer to two photos below showing the landscape of the sandy subcatchment (left) and of the loess subcatchment (right). Both photos were taken by me in 2015 during the fieldwork). To better describe the landscape of the catchment, we have revised the description in Section 2.1 'Study area' (lines 88-90). Therefore, the landscape and land cover of the Wuding River catchment are generally consistent with the distinction of "forested" and "non-forested" by Hanson et al. (2000). With respect to the huge range of the "non-forested" fraction heterotrophic (i.e.,10-90%), we have discussed the potential uncertainty in the revised manuscript. (lines 560-563).

Our rate is consistent with recent measurements under different vegetation types in this arid-semiarid region (e.g., Fu et al., 2013). Fu et al. (2013. Soil respiration as affected by vegetation types in a semiarid region of China. *Soil Science and Plant Nutrition*, 59, 715-726) measured total soil respiration in this arid-semiarid region. Their mean soil respiration rates under 4 different vegetation types are in the range of 1-1.4 $\mu mol\ m^{-2}\ s^{-1}$, which are equivalent to 380-530 g C m^{-2} $year^{-1}$. Thus, our estimate is reliable. We have carefully revised the manuscript with new references to justify our arguments (lines 316-326). Using the ratios derived from Hanson et al. (2000) has been widely used in the world to assess heterotrophic soil respiration in river catchments under different land cover types (e.g., Brunet et al., 2009. Terrestrial and fluvial carbon fluxes in a tropical watershed: Nyong basin, Cameroon. *Chemical Geology*, 3, 563-572; Lee et al., 2017. A high-resolution carbon balance in a small temperate catchment: Insights from the Schwabach River, Germany. *Applied Geochemistry*, 85, 86-96). Just as you have commented, this portioning is associated with potential uncertainty. We have further discussed this in the revised manuscript. (lines 320-326; 560-563)

Figure: Landscape characteristics of the sandy (left) and loess (right) subcatchments.

Data availability and clarification A strength of this study is that it provides and interpret the very comprehensive river carbon data. Biogeosciences readers would be interested to see the data/results in more detail. There are many results which are described in texts, yet cannot be directly read by figures or tables. Also, the authors might want to have a simple table that lists the data with time (which year, season,...), units (concentration, contents, exports...), and brief estimation methods. This study covers a lot of interesting data, but I am confused by how they were presented. Also, I am confused by the use of “concentrations” and “contents”.

Reply: Based on your and other reviewers’ comments, we have compiled all the data that are not included in our earlier work (i.e., Ran et al., 2017. *Journal of Geophysical Research: Biogeosciences*, 122, 1439-1455) in the Supplementary Information. In the Supplementary Information of the Ran et al. (2017) paper, we have already made most of our raw data used in this study available. These data include the physiochemical parameters (e.g., sampling time/season, location, elevation, channel slope, flow velocity, wind speed, pH, water temperature, dissolved oxygen, Chl *a*, etc.), CO_2 emissions (pCO_2 and areal flux), and dissolved carbon concentration (DOC and DIC) in both river and reservoir waters. To facilitate future review studies and/or comparison analyses, we have made the leftover data available by presenting them in the Supplementary of this study. Specifically, these data include POC of sediment samples (2015 and 2017) and of drilled sediment from check dams (2015), monthly DOC and DIC concentrations at the catchment outlet (Baijiachuan gauge, 2017) as well as the concomitant flow information. Please refer to the Supplement for these data (Tables S1-S3).

P1L15: What do you mean by “redistribution”?

Reply: Here we meant the fate of riverine carbon during its transport from headwater streams to the catchment outlet, including downstream export to catchment outlet, CO_2 evasion from water surface, and organic carbon (OC) burial through sediment storage. We have replaced the word 'redistribution' with 'fate' for clarity in the text. (lines 15 and 69)

P1L17-18: I am not sure what you meant with this "While the DOC concentration was spatially comparable within the catchment," I would remove this.
Reply: Based on your comment, we have removed this ambiguous claim and rephrased the abstract. (lines 17-20). Many thanks.

P1L18-19 vs. P8L312-314: Is this sentence consistent with your claims in P8L312-314? I am confused. "it was generally higher in spring and summer than in autumn, especially in the loess subcatchment." vs. "There was no discernible seasonal difference in DOC concentrations in both subcatchments, although the hydrograph varied significantly among the three seasons."
Reply: Many thanks for your comment. We have reworded these inconsistent arguments in the text. The DOC concentration showed no significant seasonal differences among the three sampling campaigns and was not sensitive to flow dynamics, although the flow discharge changed by a factor of 3. This likely reflects the predominance of groundwater input over the entire year and its highly stable DOC, which may have masked the 'dilution effect' with lower DOC concentrations usually observed in high-flow periods. Please refer to the highlighted changes in the manuscript. (lines 17-20; 351-355; 605-609)

P1L19-21 vs P8314-321 vs P9L375-377: I am also confused that these discussions appear to contradict each other. High soil carbon leaching due to high rainfalls in many cases leads to high river carbon exports (massC/time), but not high river carbon concentrations (massC/volume H2O). High rainfalls increase river flows as well, so concentrations can increase or decrease.
Reply: We completely agreed with your comments. High soil organic carbon leaching due to high rainfalls tends to result in high riverine carbon export (mass C), but not high DOC or POC concentrations (mg/L or POC% in suspended solids). This largely reflects the 'dilution effect' during high-flow periods, especially in (sub)tropical and temperate catchments with continuous surface runoff contribution in the wet season. In the arid-semiarid Wuding River catchment, although there were no significant seasonal differences in the riverine carbon concentrations (massC/water volume) between the three sampling campaigns, the carbon fluxes in the wet season (high-flow periods) were much higher than that in the dry season. This can also be discovered from the annual carbon flux at the catchment outlet estimated from monthly sampling. Based on your comments, we have carefully revised these claims in the manuscript. (lines 17-21; 417-429; 434-438; 442-447)

P1L23 and P5L209: Did you mean "showed" by "shown"?
Reply: Changed.

P2L84, P2L89, P2L94: An exact time period or years should be provided.
Reply: The time periods of mean water discharge (1956–2007), annual precipitation (1956–2004), and soil erosion (1956–1969) have been added into the revised manuscript. (lines)

P6L225-228: The assumption should be justified better. Why did you particularly use hydrological data for 2015?

Reply: The flow regime in 2017 was significantly biased due to an extreme flood on 25-26 July caused by heavy rainstorms (maximum daily rainfall: 203 mm; spontaneous discharge: 4490 m3/s with a return period of 200 years. Figure S1 in Supplement). In comparison, the multi-annual mean water discharge is 35 m^3/s. As a result, the annual water flux in 2017 is 1.5-fold the recent mean annual water flux (2000-2015). Because both CO_2 emissions and NPP were measured in 2015, we used the hydrological data for 2015 to calculate downstream carbon export by assuming that carbon concentration was comparable in 2015 and 2017 and evaluated the carbon budget. We realized that this may have caused errors to the flux estimation. We also calculated the carbon flux based on the 2017 flow data. The results show that, if the extreme flood on 25-26 July was excluded, the carbon flux in 2017 is close to that in 2015 (7.3×10^{10} vs. 7×10^{10} g). We have revised the statement in the manuscript for clarity and a new reference has been added to justify the impact of this extreme flood (He et al., 2018. G*eomatics, Natural Hazards and Risk*, 9, 70-18) (lines 256-261). In addition, we have also added a detailed description of the extreme flood event on 25-26 July 2017 in the Supplement (Figure S1).

P7L298: Did you mean “concentrations” by “contents”?
Reply: To make it clearer, we have revised the term and now use the ‘POC content (POC%) in sediments’ throughout the manuscript. Please also refer to our response to your comment below P8L326-328.

P7L299: Specify by providing values to support “both DOC and POC contents in the Wuding catchment were relatively low compared with most rivers in the world.”
Reply: For the Wuding catchment, its DOC concentrations are comparable to the global average DOC of 5.4 mg/L while its POC% is lower than most rivers in the world (mean: 0.95%; Ludwig et al., 1996. *Global Biogeochemical Cycles*, 10, 23-41). These global averages have been inserted into the text. (lines 333-335)

P8L303: I am not sure if this statement is valid. “This decomposition is generally associated with increasing water residence time for bacterial respiration in downstream streams due to decreasing flow velocities.” I don’t think that flow velocity generally decreases toward downstream. I think that travel time generally increases toward downstream and longer travel times provide more opportunity for decomposition.
Reply: Thanks a lot for the comment. We completely agree with your explanation on the downstream decrease in organic carbon concentrations after checking the flow velocity changes along the stream order. Thus, we have revised this claim: ‘This mineralization is generally associated with increasing water residence time for bacterial respiration in downstream streams due to longer travel times which increase the potential for in-stream processes on DOC’. (lines 340-342).

P8L326-328: I don’t understand what you mean here.
Reply: For POC, we used the POC content (POC%) in the total suspended solids (TSS) to present the results. This is because we tried to compare our results in the Wuding River catchment with the POC% values of the global rivers. Ludwig et al. (1996. *Global Biogeochemical Cycles*, 10, 23-41) synthesized global POC export into the oceans by continental erosion via major rivers. The average POC% values of the global rivers vary from 0.3% to 10.1%, although values above 1.5% are only observed in rivers with very low suspended

sediment concentrations (i.e., <300 mg/L). In addition, Meybeck (1993) assumed that riverine suspended loads have an ancient sedimentary OC origin of about 0.5% on average (Meybeck, 1993. C, N, P and S in rivers: from sources to global inputs, in: Interactions of C, N, P and S Biogeochemical Cycles and Global Change, Edited by: Wollast, R., Mackenzie, F. T., and Chou, L., Springer-Verlag, Berlin, 163-193). Comparing the POC% in the Wuding River basin with that of the global rivers shows the POC% in the Wuding River is at the lower end of the global rivers, which reflects the ancient sedimentary OC origin of about 0.5% for fluvial sediments. We have revised our justifications with new references in the revised version. (lines 333-335; 366-368)