

Interactive comment on “Erosion-induced massive organic carbon burial and carbon emission in the Yellow River basin, China” by L. Ran et al.

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Dear reviewer,

We thank you very much for your comments on our manuscript.

GENERAL COMMENTS: Many previous studies have documented the large quantities of sediment transported from terrestrial landscapes into Asian Rivers, including the Yellow (Huanghe) River Basin (Millman and Meade, 1983, Ren and Shi, 1986, Millman et al., 1987, Jionxin, 2003, Weng et al. 2007). The objectives of this new study are to: 1) investigate the sediment and organic ‘carbon’ redistribution across the landscape in the Yellow River Basin, 2) investigate the amount of carbon decomposed during soil erosion and riverine transport during the period 1950 to 2010, and 3) determine the

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“fate” of eroded organic carbon by constructing a bulk sediment budget.

The authors assembled organic carbon, sediment transport, and deposition values from previously published literature sources into a basin-wide sediment and organic carbon budget. While I appreciate the significant amount of effort it took to assemble this manuscript, I question two main things: 1) whether this study provides enough new material and/or analysis to merit publication as a stand-alone manuscript, “Although numerous studies have investigated the spatial and temporal changes of sediment flux and their underlying factors; little work has been done on the basin-wide sediment budget. More importantly, constructing the sediment budget is only the approach to investigate the associated OC cycle. Our focus is to study the redistribution of the eroded OC on the landscape. Organic carbon redistribution in the Yellow River has received less attention, although its amount is great given the high soil erosion intensity. According to our knowledge, we for the first time analyze the organic carbon redistribution through a sediment budget in the Yellow River basin.” and 2) if the appropriate methods were used to meet the stated objectives “We analyze the organic carbon redistribution after soil erosion through an established sediment budget and estimates of organic carbon content of individual sediment transfer components. A similar budget-based method has been used by Smith et al. (2001. *Global Biogeochemical Cycles*, 15, 697-707) to evaluate the deposition for sediment and organic carbon across the conterminous United States”. I describe these issues in more detail below, along with several other aspects of this paper that I find both challenging and confusing.

SPECIFIC COMMENTS: 1. Except for the derivation of a soil organic carbon term, the budget values were derived from previously published manuscripts or bulletins. This study does not provide a rigorous statistical uncertainty analysis of the derived “hill slope redistribution” or “organic carbon decomposition” estimates, which are the main results of the study. “Because the hillslope sediment redistribution and the OC decomposition components can only be determined through the budget equations (Eqs. 1 and 3) and there are uncertainties with each individual component, the uncertainties of the

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individual components are treated as being statistically independent (not entirely true, of course) in propagating the errors for the hillslope sediment redistribution and the OC decomposition components. A similar uncertainty assessment method was also used by Smith et al. (2001. *Global Biogeochemical Cycles*, 15, 697-707). We have more clearly clarified these statements in the revised version.”

2. The authors claim that the methods used in this study are better than previously modeled ones, because those have many uncertainties and assumptions associated with them. A bulk sediment budget approach also has many assumptions and uncertainties associated with it too, right? Sections 4, 5.1 and 5.2 of this manuscript describe some of them. Therefore, in the introduction, please give a better description about how the methods used in this study offer something new and improved about sediment and carbon cycling in the Yellow River basin. “Because soil erosion at uplands and sediment transport are far from being in balance for the Yellow River basin (Walling and Fang, 2003. *Global and Planetary Change*, 39, 111-126), an advantage of our estimate is that we estimated the amounts of erosion, sedimentation, and transport independently to derive a sediment budget. Furthermore, in contrast to conventional methods that usually use models, we provided estimates of the eroded OC redistribution on the landscape and OC decomposition in proportion to soil erosion and sediment deposition through the established sediment budget. These description sentences have been added into the revised manuscript.”

3. The methods used in this study do not enable the authors to “determine the fate” of carbon, as this implies that carbon molecules will be tracked from source to sink, using some type of tracer methodology. Therefore, the authors should revise the way that they express their study objectives. One possibility is to state simply that they provide estimates of “carbon redistribution on the landscape” and “organic carbon decomposition”. “We thank the reviewer for this constructive suggestion that helped to better express our study objectives. We have adopted the reviewer’s suggestion and rephrased the objectives to ‘to provide estimates of the organic carbon redistribution

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on the landscape and organic carbon decomposition’. ”

4. Budgets are often presented with descriptions of key “sources” and “sinks” within the system, yet these terms are not used in the budget description in this manuscript. The authors need to clarify budget terminology and processes affecting source and sink strength. Additionally, some important terms of a sediment carbon budget may be missing. What about carbon sequestration on the terrestrial landscape following erosion (Harden et al. 1999)? Nutrient additions in agricultural watersheds increase aquatic net primary productivity, so isn’t there a possibility that greater carbon can be stored in the Yellow River Basin watershed because of this autochthonous carbon production and storage (Stallard, 1998)? “Point 1: for the ‘sources’ and ‘sinks’ terms, we have clarified these in the bulk sediment and organic carbon budget description in the revised manuscript, and the processes affecting them were discussed.

Point 2: soil erosion not only affects the OC cycling of the eroded soils, but also the OC dynamics at the eroding sites. Under conditions of fertilizer use and improved soil management, exposure of the subsoils due to erosion would enhance carbon sequestration by increasing net primary productivity. This has been validated in European and North American watersheds that have humid climate and relatively weak soil erosion (e.g., Harden et al. 1999. *Global Biogeochemical Cycles*, 13, 885-902; Van Oost et al., 2007. *Science*, 318, 626-629).

While for the Yellow River with extremely strong soil erosion (>3000 t/km²/yr), arid climate (precipitation: 300-500 mm/yr on the Loess Plateau), and serious land degradation, the eroded carbon is difficult to be replaced. Feng et al. (2013. *Scientific Report*, 3, 2846; doi: 10.1038/srep02846) investigated the ecosystem carbon storage dynamics on the Loess Plateau and discovered its ecosystem had been a C source until 2000 when widespread vegetation restoration programs (e.g., the Grain-for-Green Project) were launched. They found that the annual net ecosystem productivity was -0.011 Gt in 2000 and it increased only in recent years. With stronger soil erosion and less vegetation cover before 2000, it is believed that the net ecosystem productivity had been

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much lower than that in 2000. Therefore, it can be concluded that the OC replacement at the eroding sites over the 61 yr was very weak. Similar assessment on ecosystem productivity dynamics can also be found in Cao et al. (2011. *Critical Reviews in Environmental Science and Technology*, 41, 317-335). Limit of water availability is another important reason for the small ecosystem productivity. Although we cannot suppose that the SOC is in a steady state with time, due to the unavailability of SOC data of every year, we assume the used SOC map represents the average SOC replacement dynamics over the period because the soil survey was conducted (in 1980s) in the middle of the period 1950-2010. The SOC of the topsoils used in this study has already been at least partially replaced following previous erosion events. Hence, our study has already taken into account the OC replacement at the eroding sites. We have more clearly clarified these statements in the conceptual framework description and the result and discussion sections in the revised version.

Owing to extremely high suspended solids concentration (average: 29 kg/m³, or 29,000 mg/l) and low light availability/high shading effect, autochthonous aquatic carbon production in the Yellow River waters is believed to be low (Wang et al., 2012. *Global Biogeochemical Cycles*, 26, GB2025). Radiocarbon studies also indicate that most of the riverine organic carbon in the Yellow River is of terrestrial origin from their investigation results.”

5. The authors claim (p. 13498, L7), “It is clear that D_c depends on the total eroded OC amount”, yet the only evidence for this claim is the equation. It would help if there were literature citations supporting this method for deriving a carbon decomposition term. “By constructing bulk sediment and OC budgets for production, transport, and sedimentation of sediment and OC, Smith et al. (2001) have used this method to estimate the redistribution of eroded OC in the United States. They concluded that the decomposition flux to CO₂ gas to be insignificant (close to 0). Furthermore, Smith et al.(2005. *Ecological Applications*, 15, 1929-1940) have used a similar method to estimate the redistribution of eroded OC in the Mississippi River basin, and found erosion

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in the basin is a net carbon sink. We have added literature citations to support this method in the revised manuscript.”

6. Constructing a budget or a balance over a sixty year period must assume some steady state properties, meaning that the properties of the basin remain relatively unchanged over time. However, sedimentation rates rapidly decreased between 2000 and 2005 (Wang et al. 2007). The authors vaguely address this (page 13509, 27 -28), but it isn't clear what “we adopted the reconstructed soil erosion rates and then applied it to the study period” really means. Also, it isn't clear why the authors selected this extensive time period. Why not construct a budget for a shorter, more recent time? “Table 1 compiles the total erosion amount during the period before significant human impacts (i.e., 1950-1970s) estimated through different methods. The soil erosion amount is mostly in the range of 1.7-2.5 Gt/yr. We applied this soil erosion rate to the whole study period (1950-2010), and considered that the reduced sediment load in the following period (i.e., 1970s-2010) was mainly the combined result of dam trapping, soil conservation, channel sedimentation, and water diversion, etc. As has been widely recognized, the Yellow River has experienced significant changes in sediment transport during the past decades, since the 1970s in particular. Sedimentation rates in the lower Yellow River reaches have even decreased rapidly during 2000-2005 as a result of upstream dam trapping and water withdrawal (Wang et al., 2007). To better reflect these changes, in this study, we estimated the amount of the redistribution components in Eq.1 independently. For example, for channel sedimentation in the lower Yellow River reaches, we calculated the sedimentation amount in different time periods, and obtained the total for the whole study period. We have clarified this argument in the revised manuscript.

To control soil erosion and to reduce sediment transport, large-scale soil conservation and dam construction in the Yellow River basin started in the 1970s. Since then, both soil erosion intensity and sediment flux have greatly decreased. Because this study attempts to analyze the cumulative OC burial and carbon emission, and to investigate

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the impacts of human activities in redistributing sediment and OC transport on the landscape, we selected this extensive time period and constructed sediment and OC budgets. In addition, continuous measurement at >100 gauge stations throughout the Yellow River basin started from 1950 also allows us to estimate various budgetary components.”

7. One of the main findings of this study (p13515, L16 -17) is that 63% of the soil is deposited on land. I assume that the 63% is the sum of the following terms: 30% (dam trapping), 7.7% (slope redistribution), 4.5% (slope soil control), 7.8% (sediment diversion) and 13.3% (channel sedimentation). I would not consider trapping, sediment diversion as the result of water diversion, or channel sedimentation “land” deposits, since the deposition occurs in rivers. Once the proper terminology has been assigned, an interesting comparison study is Meade’s (1990) paper which concluded that ninety percent of the sediment being eroded off the land surface of the conterminous United States is stored in river systems between the uplands and the ocean. “We agree with the reviewer’s comment. These deposits do not occur on ‘land’, but in the Yellow River. Because in this study these eroded soils were stored somewhere in the river system between the uplands and the Bohai Sea, we have re-worded this as ‘63% of the eroded soils was deposited in the river system. . .’. In addition, we compared our results with Meade’s (1990) conclusion. Higher sediment delivery ratio in the Yellow River is possibly due to its sediment transport characteristics. The Yellow River has a very high sediment delivery ratio (>0.9, Gong and Xiong (1980) in Walling and Fang. 2003. Global and Planetary Change, 39, 111-126). It can be concluded that, without human impacts (e.g., dam trapping and soil conservation), a larger proportion of sediment would have been discharged into the ocean.”

TECHNICAL CORRECTIONS In many cases, word choice and syntax could be improved. Here are some specific examples: p.13491, L4: Instead of “sedimentation” author should use “burial” “done”. p.13491, L6: Instead of “budgets” author should use “estimates” “done”. p.13491, L7: The “estimates” of various terms were “as-

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sembled” not “analyzed” “done”. p.13491, L10, Rephrase this sentence that begins, “Among the produced sediment, approximately 63% of it was deposited on land”. An alternative could be, “Approximately 63% of the eroded sediment was deposited on land. . .” “done” p. 13491, L19: “Although with several uncertainties to be better constrained”, could be re-worded to read as, “Although several uncertainties need to be better constrained. . .” “done”

p. 13493 L3-5 “With the estimated reservoir trapping (Ran et al., 2013c), this study was to investigate the sediment and organic redistribution”. This statement is an important one, as it describes the goals of the study. However, the phrasing is awkward and vague for several reasons: a. Why is the introductory phrase of this thesis statement connected to the 2013c Ran et al. study? “this sentence has been rephrased as you suggested in c” b. The word “carbon” is missing after organic. “added” c. The author might consider the beginning the sentence, “The aim of this study was to”. “the sentence was rephrased as suggested” d. Is the author’s aim to “estimate” not “investigate” the amount of carbon decomposed, right? “agreed and changed”

p. 13495, L6-7. No proper citation for the Yellow River Sediment Bulletins. “done”

p. 13495 L15 How is the spatial variation of the soil map integrated into the SOC term in the equation? “To estimate the total eroded SOC from the river basin, the SOC map was analyzed in combination with a sediment yield map. Based on the sources of sediment (e.g., the middle reaches contribute 90%), an average SOC content of the total eroded soils was estimated. Please also refer to our response below.”

p. 13496 L21 How is the uncertainty associated with the calculated terms, such as Rs, being addressed? “The errors on the individual budgetary terms were treated as being statistically independent, although not entirely true, in propagating the uncertainty for the RS and Dc terms. A similar assessment method was also used by Smith et al. (2001).”

p. 13497 L20-21 Link the estimate of the Ec term to specific data sources. “done”

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p. 13498 Equation (4) Specify what C and S represent. “done”

p. 13498, Equation (5) Connect each term of the equation to specific data sources. “done”

p. 13504 L11-13 Explain more clearly how the variability in erosion intensity was connected with SOC. “Based on long hydrological records, Ran et al.(2013. Global and Planetary Change, 100, 308-319) analyzed the spatial variability of soil erosion and sediment yield by generating a sediment yield map through spatial interpolation. The SOC map and the sediment yield map were overlaid to account for the SOC content of sediment from major erosion areas. For example, although the SOC content in the upper reaches is very high, its weight is very low because its contribution to the total sediment is very low. Based on the spatial variability of soil erosion and SOC throughout the basin, the average SOC content was estimated. We have more clearly explained this in the revised manuscript.”

p. 13504 L23 Why was an enrichment ratio of 1.1 used in this study? “During soil erosion, the light OC fraction will be preferentially removed and enrich in the eroded soils (e.g., Quinton et al., 2010. Nature Geoscience 3, 311-314). Wang et al. (2008. Environmental Science, 29, 1020-1026, in Chinese) analyzed the enrichment ratio for the eroded soils from the Loess Plateau, and found it is very low (1~1.2). Thus, given the low enrichment, we used 1.1 as the enrichment ratio for the sediment eroded from the topsoils.”

p. 13505 L10-13 It is not clear to me how the authors “estimated” an OC content from previous literature values. “Because the OC content shows a range as presented in Table 3, here the seaward sediment OC content was estimated by calculating the average and the uncertainty range. This has been clarified in the revised manuscript.”

p. 13506 L14-15 It is not clear how or why the sediments trapped by dams were weighted to produce a value of 0.65. “Because the OC content of the sediments trapped by silt check dams (21 Gt) is $0.80\pm 0.11\%$, and the OC content of the sedi-

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ments trapped by reservoirs (19.3 Gt) is $0.49\pm 0.29\%$. Therefore, the total trapped OC is 0.262 ± 0.077 Gt. To get an OC content for the sediments trapped by all dams (θ_T) for comparison with other budget terms, the θ_T ($0.65\pm 0.19\%$) was calculated by dividing the total trapped OC (0.262 ± 0.077 Gt) by the total trapped sediments (21Gt+19.3Gt). We have re-worded this as ‘The mean OC content for the sediments trapped by all dams (θ_T) was estimated at $0.65\pm 0.19\%$, and the accumulated OC trapped by these dams during 1950-2010 was 0.262 ± 0.077 Gt’.”

p. 13507 L28 Use specific years (for example, 2000 to 2010) instead of the phrase “modern times”. “done”

Table 1. Heading. Are these “notes” or “literature sources”? “Two different columns for ‘literature sources’ and ‘notes’ have been made as you suggested for Tables 1 and 3.”

Table 2. Footnote. Why is sediment trapping estimated to the year 2005? “These data were retrieved from a report from the Ministry of Water Resources of China. For the two largest reservoirs (i.e., Sanmenxia and Xiaolangdi, located downstream of the Loess Plateau and play an important role in regulating downstream channel sedimentation, see their locations in Fig. 1), sediment trapping is investigated every year. While for the other reservoirs, only periodic surveys are conducted as sedimentation in these reservoirs is not severe.”

Table 3. Make two different columns, one giving the literature reference, and one giving the “notes” about how the estimates were made. “Agreed and changed”

Figure 2. Use “conceptual diagram” instead of “sketch map”. Aren’t most basins eroding? How exactly does this diagram show the impact of human activity? This diagram illustrates CO₂ emissions, but what about CO₂ sequestration? “Agreed and the caption has been changed. Yes, most basins are eroding, so the caption has been reworded as ‘a conceptual diagram showing production, transport, and deposition of bulk sediment and organic carbon within a river basin and the impact of human activity’. In the case of the Yellow River basin, human activity affects sediment and OC transport

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mainly through soil conservation on the slope lands and dam trapping on the channel. Carbon burial with sediment deposition has been added into the diagram.”

Figure 3. and Figure 4. Are these figures necessary? How do they relate to the stated study objectives? “Figure 3 is retained here to show the spatial and temporal variations of sediment load at gauge stations on the Yellow River mainstem channel, and also the impacts of constructed dams on changing sediment redistribution. Figure 4 has been removed.”

Figure 5. There is a great amount of spatial variability in soil organic carbon within the Yellow River basin, but doesn't all this variability get reduced to just one SOC term in the budget? “The SOC in the Yellow River basin shows great spatial variation, from 0.2% to 39%. To better estimate the mobilized SOC due to erosion, we took into account the spatial variability of both the SOC and the soil erosion throughout the river basin. The average SOC content of the eroded soils was mainly dependent on the middle reaches (Loess Plateau), because about 90% of the sediment comes from the middle reaches while ~10% comes from the upper reaches. With this variability in SOC and soil erosion in mind, we reduced it to an average SOC content for following estimates.”

Figure 6. Consider presenting carbon yields ($\text{g m}^2 \text{ yr}^{-1}$) or carbon fluxes (Tg yr^{-1}) instead of two separate sediment and organic carbon terms in this figure. “The figure has been re-drawn to present the organic carbon fluxes (Tg/yr) as suggested.”

Figure 8. Is this figure necessary? “removed”

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