Interactive comments on "Preservation of terrestrial organic carbon in marine sediments offshore Taiwan: mountain building and atmospheric carbon dioxide sequestration" by S.J. Kao et al.

Referee comments in *Italics*. Underlined text indicates changes made in the revision manuscript.

Referee #2– Dr. D. Burdige

Referee 2: This is an interesting manuscript with data that contributes to our knowledge of terrestrial organic matter input to the ocean. It also raises a number of interesting questions about this problem. The comments below are keyed as (x, y) referring to page x and line y.

Reply: Thank you for your positive comments on our manuscript and for the thorough review which has allowed us to clarify some important points in a revised version.

Referee 2: What exactly do "this" (181, 1) and "it" (181, 7) refer to? I think it would help if this was specifically stated.

Reply 2: Here "this" means "the incomplete understanding of $OC_{non\text{-}fossil}$ burial" and "it" refers "the reburial of OC_{fossil}" As directed by the referee, we have corrected these sentences as follows:

> "Firstly, the incomplete understanding of $OC_{non\text{-}fossil}$ burial reflects the challenge of accounting for fossil OC from sedimentary rock (OC_{fossil}) in terrestrial and marine sediments (Blair et al., 2003) which can contribute significantly to the particulate load of mountain rivers (Kao and Liu, 1996; Komada et al., 2004; Leithold et al., 2006; Hilton et al., 2010; Clark et al., 2013). OC_{fossil} transfer and re-burial lengthens the residence time of OC in the lithosphere (Galy et al., 2008; Hilton et al., 2011), however the reburial of OC_{fossil}…" (Introduction, Paragraph 3).

Referee 2: The sentence "In Taiwan,…" (181, 21) does not appear to be a complete sentence. I think this can be fixed by replacing "where" (after the comma) with "they". If not, then the authors should make the more appropriate correction(s).

Reply: As suggested, the revised sentence reads as follows:

> "In Taiwan, the rapid convergence of the Philippine Sea Plate with the Eurasian continental margin combines with a climate characterised by frequent tropical cyclones, driving high rates of fluvial sediment export to the ocean" (Introduction, Paragraph 4).

Referee 2: (181, 25) What does "They" refer to? I think it would help to specifically identify this here.

Reply: "They" refers to "Steep mountain rivers" and so we have inserted this term at the start of this sentence.

Referee 2: The sentence "To assess…" (183, 13) was very confusing as written. Here is a version that I think sounds better: To assess longer-term preservation, a box core was collected by R/V Ocean Researcher-1 in September and October 2009 at station K1 (160 m water depth), located at the thalweg of the Gaoping Canyon (Fig. 1). The core was sub-sampled at different depths (Table S2).

Reply: The above sentence has been adopted in the revised version of manuscript.

Referee 2: If the marine sediment samples referred to on p. 186, lines 5-6 are from core K1, why is the sample size 15 (and not 3)?

Reply: Here we refer to all of the sediments collected from the Gaoping Canyon (trap + core, n=15). We have modified the sentence to make this clearer:

"When we include the core samples collected from the canyon following Typhoon Morakot, all of the marine sediments from the Gaoping Canyon (n=15) have a mean C_{org} = 0.6±0.4%" (Section 3.2, Paragraph 1).

Referee: (186, 24) – "..result in a liner trend.." (add "a").

Reply: Corrected.

Referee 2: One thing that wasn't clear to me, but which I thought might be interesting / important here is how (or if) the composition and concentration of suspended river sediments varies with discharge. For example, a positive relationship such as in Fig. 2b could be obtained if the concentration of non-fossil OC in river suspended sediments is simply a constant across flow rates. But if this concentration changed with flow rate then I think you would still see a positive relationship. I have the idea that the slope and the y-intercept of a plot like the one in Fig. 2b could be used to address this question, but I haven't worked with the math. Also does the relative concentration of fossil vs. non-fossil OC change in the suspended sediments with river discharge? If this discussed in the text, I missed it.

Reply: Previous work by some of the authors of this manuscript has examined the transport behaviour of $OC_{non\text{-}fossil}$ and OC_{fossil} in river sediments of Taiwan in detail (Kao and Liu, 1996; Kao and Liu, 2000; Hilton et al., 2008; Hilton et al., 2011; Hilton et al., 2012). The key variable is either the total mass of $OC_{non\text{-}fossil}$ in the river load (g/L) or instantaneous flux of $OC_{non\text{-}fossil}$ in the river load (g/s). If these increase with discharge (as we rain on the catchment) it indicates that we increase the supply rate of $OC_{non\text{-}fossil}$ from the catchment by eroding vegetation and soils (Hilton et al., 2008; Hilton et al., 2012). If these decrease (or don't change), then it would suggest that we have exhausted the supply of $OC_{non\text{-}fossil}$ (Hilton et al., 2012). In contrast, the weight % concentration of $OC_{non\text{-}fossil}$ (as a fraction of the suspended load) may be less informative. If $OC_{non\text{-}fossil}$ supply increases with flow rate, it is very likely that suspended sediment supply will also increase, meaning that the % concentration of $OC_{non\text{-}fossil}$ is damped. In contrast, OC_{fossil} is simpler because it is intimately associated with the bulk suspended sediment load and previous work has established that the OC_{fossil} and suspended sediment transfer are strongly correlated in this mountain belt (Hilton et al., 2011).

In this manuscript (Section 4.1), we focus on the aspects relevant to our assessment of the fate of terrestrial OC offshore Taiwan. The new data are important because they greatly expand the number of radiocarbon measurements made on POC from Taiwan's rivers, which allows us to trace the fate of terrestrial OC offshore Taiwan. We attempt to summarise what is known about the erosion and transport of $OC_{non\text{-}fossil}$ in Taiwan and other mountain rivers and report how the new ^{14}C measurements (Fig. 3) confirm conclusions of those studies. For example: "Hilton et al., (2010) reported that rivers draining the eastern flank of Taiwan can have higher $\delta^{13}C_{org}$ values than those draining the west due to different bedrock geology leading to variable OC_{fossil} composition. The ^{14}C-depleted samples are consistent with this observation (Fig. 2a)"; and "This confirms a strong climatic control on the erosion and fluvial transfer of $OC_{non\text{-}fossil}$ highlighted in several Taiwanese catchments using a slightly different method for quantifying the mixing of OC_{fossil} and $OC_{non\text{-}fossil}$ (Hilton et al., 2010; Hilton et al., 2012)."

However, we acknowledge that this section could have been clearer on how the new data contribute to this understanding. As such, we have modified the opening paragraph to point the reader toward this previous work:

"Landslides also erode organic matter from the terrestrial biosphere and supply OC, mixed with clastic sediment, to rivers (Hilton et al., 2008; West et al., 2011). In addition, the high runoff intensity promotes mobilisation of soil organic matter by overland flow processes (Hilton et al., 2012). These previous studies have examined the erosion and transport of $OC_{non\text{-}fossil}$ in detail and estimated rates of $OC_{non\text{-}fossil}$ transfer which rank amongst the highest in the world (Kao and Liu, 1996; Stallard, 1998; Kao and Liu, 2000; Hilton et al., 2008; Hilton et al., 2012). Here we summarise the key findings of this previous work in light of the new ^{14}C-POC data from Taiwan (Fig. 3) and to inform our assessment of the offshore fate of terrestrial OC (Sections 4.2 and 4.3)." (Section 4.1, Paragraph 1)

Referee 2: For completeness I think you might note that on p. 188, line 9 you are talking about the fraction of non-fossil OC in river suspended sediments.

Reply: We agree, we have added 'in river suspended sediments' to this sentence.

Referee 2: (189, 4) - I would add a comma between "fraction" and "in".

Reply: Corrected.

Referee 2: (191, 21-24) – This long sentence seems incomplete. In particular, the phrase after the comma on line 24 seems to be missing something.

Reply: The sentence has been shortened and modified to improve its clarity in the revised version and in light of Referee #3 comments:

> "The modelled bulk terrestrial OC loss results in a trend which is perpendicular to that observed in the samples (Fig. 5b). Thus, it appears that the patterns in the data are not consistent with either selective (i.e. $OC_{non\text{-}fossil}$, Fig. 4b) or pervasive ($OC_{non\text{-}fossil}$ and OC_{fossil}, Fig. 5b) loss of terrestrial OC." (Section 4.3, Paragraph 3).

Referee 2: (191, 26-27) – Some additional explanation is needed for how this >70% preservation efficiency is obtained from the model output.

Reply: We agree that this important point would benefit from more detail. To help do this without leading to an overly long section of the manuscript, we have sub-divided Section 4.2 so that we now have: "Section 4.2 - Fate of terrestrial OC offshore Taiwan: Hyperpycnal inputs" and "Section 4.3 - Fate of terrestrial OC offshore Taiwan: Hypopycnal inputs" which provides us space to discuss this and the next three comments from the reviewer.

The >70% preservation efficiency is a conservative bound placed by the scatter of the data points around the linear trends observed between $\delta^{13}C_{org}$ and $\Delta^{14}C_{org}$ (Fig. 4a) and $1/C_{org}$ and $\Delta^{14}C_{org}$ (Fig. 5a). As we explain carefully in the manuscript, the only modelled scenario which can explain these trends is a mixture of marine OC with terrestrial OC (itself a mixture of $OC_{non\text{-}fossil}$ and OC_{fossil}). However, the scatter around the linear trends may be consistent with some terrestrial OC loss, and this is what we account for that in our estimation of preservation efficiency:

> "The scatter around the linear trends in the data may reflect second-order temporal (or spatial) variations in the $\Delta^{14}C_{org}$, $\delta^{13}C_{org}$ and C_{org} values of the marine and terrestrial OC end members which can explain the sample compositions. However, the scatter may also reflect some terrestrial OC loss. The instantaneous loss model provides constraint on what percentage of terrestrial OC loss is compatible with the variability around the linear trends (Fig. 5). For bulk OC loss, the scatter corresponds to ~20% loss (Fig. 5b). To acknowledge the uncertainty on this value, and to provide a conservative estimate of terrestrial OC burial efficiency, we suggest <30% loss (i.e. preservation efficiency >70%) has occurred in these deposits." (Section 4.3 Paragraph 4)

Referee 2: The discussion here only considers preservation of with respect to land-to-sea transport and deposition in the sediments. It doesn't really consider losses that might occur with sediment burial and diagenesis. I think this should be mentioned and perhaps briefly discussed.

Reply: This is an important detail to clarify. As the referee identifies, the marine surface sediments and sediment trap samples which form the majority of our data points allow us to assess preservation with respect to land-to-ocean export and deposition. We now explicitly state this in the manuscript:

"To assess the offshore transfer of terrestrial OC and its preservation in marine sediments upon deposition, we have collected seafloor sediments and material from sediment traps from the Gaoping Canyon off Southwest Taiwan, which is prone to hyperpycnal inputs and from the Okinawa Trough, Taiwan Strait and Gaoping Shelf where hypopycnal inputs are thought to be more important (Fig. 1). To assess longer-term terrestrial OC preservation and burial, we examine sub-surface sediments and Holocene sediments from the Okinawa Trough." (Introduction, final paragraph)

However, we also provide sub-surface samples from box-cores and sediment samples from the Holocene collected from the Okinawa Trough (where planktonic foraminifera have been ^{14}C-dated to assess $\Delta^{14}C_{org}$ of the sediments at time of deposition, Section 3.2) which allow us to assess longer-term preservation and sedimentary burial. While these data are modest in number, so it is difficult to make irrefutable conclusions, they are consistent with the observations from the surface sediments and suggest no significant difference in terrestrial OC loss. To make this important detail clear we have modified the abstract and the discussion:

"Here we use the OC content (C_{org}, %), radiocarbon ($\Delta^{14}C_{org}$) and stable isotope ($\delta^{13}C_{org}$) composition of sediments offshore Taiwan to assess the fate of terrestrial OC, using surface, sub-surface and Holocene sediments." (Abstract)

"In marine sediments fed by dispersive river inputs, the C_{org}, $\Delta^{14}C_{org}$ and $\delta^{13}C_{org}$ are consistent with mixing of marine OC and terrestrial OC and suggest that efficient preservation of terrestrial OC (>70%) is also associated with hypopycnal delivery. Sub-surface and Holocene sediments indicate that this preservation is long-lived." (Abstract)

"Note that this sample set is dominated by surface marine sediments (Table S3) and so the preservation efficiency refers to the land-to-ocean transfer and deposition of terrestrial $OC_{non\text{-}fossil}$ and OC_{fossil}. However, sub-surface sediments from the Gaoping Shelf and the Holocene sediments from the Okinawa Trough (Table S3) are consistent with the trends (Figs. 4a and 5a). While the limited number of these sub-surface samples (n=7) makes it difficult to draw irrefutable conclusions, it appears that high preservation efficiencies are also a feature of sedimentary burial on longer-timescales in this setting (Kao et al., 2008)." (Section 4.3, Paragraph 4)

Referee 2: (193, 13) – I think I understand what they are referring to here as the cause for this increase in OC burial efficiency, but I think some additional explanation might help other readers. Also, just so I'm sure of things, are they referring to burial efficiency of all OC in the sediments (i.e., the sum of marine, fossil terrestrial, and non-fossil terrestrial).

Reply: In light of Referee #1's comments, we have expanded the discussion of OC burial efficiency with a new final paragraph in Section 4.3 (see reply to Referee #1). To clarify, we are referring to the preservation of terrestrial OC (both fossil and non-fossil), not marine OC, and so modified this sentence:

"The transfer of $OC_{non\text{-}fossil}$ together with clastic sediment may enhance the terrestrial OC burial efficiency (Canfield, 1994; Burdige, 2005; Blair and Aller, 2012) even when materials are delivered by hypopycnal river plumes (see Section 4.3)" (Section 4.4, Paragraph 2)

Referee 2: (193, 24) – Again for completeness (and avoid any confusion) tell us what type of OC is being referred to here with this burial flux value.

Reply: We are referring to the burial of terrestrial $OC_{non\text{-}fossil}$. We now state this clearly in this section:

"to estimate a terrestrial $OC_{non\text{-}fossil}$ burial flux of 8–11 TgC yr^{-1} from the mountain islands of Oceania. This estimate may is likely to be conservative because the high sediment yields in Taiwan of ~9000 Mg km^{-2} yr^{-1} result in a lower percent of $OC_{non\text{-}fossil}$ in sediments when compared to other mountain rivers (Leithold et al., 2006; Hilton et al., 2012; Clark et al., 2013; Smith et al., 2013). It also does not consider marine OC burial associated with these clastic sediments. Alternatively, it could be assumed that the $OC_{non\text{-}fossil}$ burial yield from Taiwan (13–16 MgC km^{-2} yr^{-1}) holds over the Oceania area (2.7 × 10^6 km^2), giving a terrestrial $OC_{non-fossil}$ burial flux of 35–40 TgC yr^{-1}." (Section 4.4, Paragraph 2)

Referee 2: In Figure 3, the symbols for the marine box core and sediment trap are too similar to make a clear distinction between the two. I would fix this. In the figure legend I would say, "River suspended sediment" (versus load) to be consistent with the rest of the manuscript. Also, are the river suspended sediment values in Fig. 3A the same values from Fig. 2A? If so, you might state this explicitly (also in Fig. 3B).

Reply: We now use a distinct shading to distinguish the sediment trap and marine box cores samples, but keep the same symbol to indicate they were collected from the same location. In the figure legend, both corrections have been included, as suggested by the referee.

Referee 2: Fig. 3B where do all the data points for the canyon sediments come from? This relates (I think) to comment 5 above.

Reply: All these 15 data points are collected from the Gaoping Canyon, including the sediment trap materials from the channel thalweg (n = 12) and subsamples of core K1 (n = 3). We have added the following text to the caption to make this clear to the reader:

> "**b,** Organic carbon concentration (C_{org}, %), with mean ± standard deviation shown by large symbol and whiskers for river suspended sediments and canyon sediments (trap and core) from the Gaoping Canyon."

Referee 2: I wonder if Table S2 (and perhaps S5) should be included in the main text (versus in the Supplementary Material).

Reply: As suggested, Tables S2 and S5 have been shifted from the Supplementary Material to the main text as Tables 1 and 2.

Additional references added to the revised version:

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Aller, R. C., Blair, N. E., and Brunskill, G.J.: Early diagenetic cycling, incineration, and burial of sedimentary organic carbon in the central Gulf of Papua (Papua New Guinea). J. Geophys. Res., 113, F01S09, 2008.

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Buesseler, K.O., Antia, A.N., Chen, M., Fowler, S.W., Gardner, W.D., Gustafsson, O., Harada, K., Michaels, A.F., Rutgers van der Loeff, M., Sarin, M., Steinberg, D.K., and Trull, T.: An assessment of the use of sediment traps for estimating upper ocean particle fluxes. J. Marine Res., 65, 345–416, 2007.

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