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.

Anonymous Referee #1

Referee 1: I found this paper very timely and well written. The quality of the data seems excellent. The figures seem of good quality and the statistics are also sound. I would like to suggest that reviewers perhaps include some comparisons, just a few sentences, with river delivery of carbon in passive margins. However, there are a few places where such comparison would bring a broader view of carbon delivery by global rivers into perspective, rather than just mountainous rivers.

Reply: Thank you for your positive comments on our manuscript and your useful suggestions for revisions to further improve our work. While our manuscript focuses on the fate of organic carbon delivered to marine sediments offshore a mountain island (where we have very good constraint on the composition of terrestrial organic carbon and marine sediment samples), we agree that a comparison with cases from passive margin systems would be useful at points in our manuscript. We include a new paragraph in the discussion on this issue and in our reply below we detail where we have made these additions to the revised manuscript.

Referee 1: Goni and Bianchi have a number of papers on the Mississippi and the Changjiang that might be particularly useful. For example, when they talk about the saturation of woody material and its settlement before reaching the coast…For example, in Bianchi, T.S., Galler, J.J., and M.A. Allison, 2007. Hydrodynamic sorting and transport of terrestrially-derived organic carbon in sediments of the Mississippi and Atchafalaya Rivers. Estuarine Coastal Shelf Sci. 73: 211-222, they talk about small lighter density woody material that gets entrained in the bedload of the river and how that can be significant…

Reply: We thank the author for pointing out this paper. The findings of Bianchi et al. (2007) on the hydrodynamic sorting of organic carbon in large rivers (here the Mississippi) provide a useful base to slightly expand our discussion on this issue. We observe macro-particles of terrestrial $OC_{non\text{-}fossil}$ in the Gaoping Canyon trap and surface sediments, which must have overcome their natural buoyancy to be deposited here. In the original manuscript, we very briefly comment that, in the absence of additional information, this suggests "…that the density of the turbid river plume may be high enough to effectively sequester woody debris and/or that water logging can occur prior to entrainment or during transport. This observation warrants further investigation." In light of the referees comment, another by Referee #1 on the paper of West et al., (2011) (see below) and a comment by Referee #3, we have slightly expanded our explanation of this interesting observation as a distinct paragraph (underlined text indicates inserted text):

> "…that the density of the turbid river plume may be high enough to effectively sequester woody debris carried in the sand fraction, while coarser woody material (e.g. logs) float upon discharge to the ocean (West et al., 2011). In addition, water logging of sand sized woody debris may occur prior to entrainment or during transport, as observed in the sand-sized bedload of larger fluvial systems (Bianchi et al., 2007). In the short mountain rivers of Taiwan, it is unclear whether this mechanism operates and the observation warrants further investigation of the transport of macro-particles of $OC_{non\text{-}fossil}$ in mountain rivers." (Section 4.2, paragraph 3)

Referee 1: In another paper on the Mississippi export across the shelf by Bianchi, T.S., T. Sampere, M. Allison, E.A. Canuel, B.A. McKee, S. Wakeham, and B. Waterson, 2006. Rapid export of organic matter to the Mississippi Canyon. EOS 87 (50): 565, 572-573, they talk about rapid export to the Mississippi

Canyon due to the presence of mobile muds, this can provide a nice comparison to the mechanisms in an active margin.

Reply: Bianchi et al. (2006) identified a rapid (day to weeks) export of labile organic matter sourced by in-situ diatom production in the Mississippi River plume to Mississippi Canyon. The findings suggested that large rivers on passive margins can serve as efficient conduits for transporting labile marine organic carbon from highly productive plume waters on the shelf to fuel deeper biotic communities.

While we acknowledge the importance of this mechanism in those locations, we note that the mechanisms we propose are quite different and involve enhanced burial of terrestrial organic carbon. High terrestrial clastic sediment inputs at active margins, coupled with the strong linkage between land and ocean on small mountain islands, can export terrestrial OC (both non-fossil and fossil) to the deeper parts of the canyon, especially during extreme rainfall events which can trigger hyperpycnal flows. Therefore, to keep our discussion of mechanisms focused on our dataset, we have not included text which details this paper's findings. However, we do cite this paper with regard to the comparison with 'mobile muds' and preservation of terrestrial OC, which we explain in reply to the next point.

Referee 1: Finally, in terms of lignin terrestrial OM decay, Sampere, T.P., T.S. Bianchi, S.G. Wakeham, and M.A. Allison, 2008. Sources of organic matter in surface sediments of the Louisiana Continental Margin: Effects of primary depositional/transport pathways and a hurricane Event. Cont. Shelf Res. 28: 2472-2487, shows that is a passive margin you do see active decay of lignin during slower transport compared to the active margin systems discussed here. Also, when the authors' talk about hyperpycnal flow, how is this comparable to fluid muds, a distinction between the two might nice because we do see these in the more passive margins with similar particle densities...

Reply: Detailed lignin and pigment biomarkers analyses of surface sediments collected along two transects (along shore and offshore to the Mississippi Canyon) of the Louisiana Continental Margin revealed a ~30% decrease of lignin concentrations in canyon sediments compared to riverine sediments (Sampere et al., 2008). Such active decay of lignin during slower transport in river-dominated passive margins is in stark contrast with the more efficient preservation of OC found in active margins fed by steep mountain rivers.

With regard to the distinction between 'mobile fluid muds' and hyperpycnal flows, we agree that unlike small mountain rivers, successive resuspension and deposition episodes of mobile muds in large river-dominated deltas (e.g. the Amazon delta and inner continental shelf of northeast South America) can act as efficient decomposition systems of organic carbon (Aller, 1998). In these systems, fresh marine organic material is constantly entrained into mobile deposits, which can drive early diagenetic reactions and also facilitate loss of refractory terrestrial OC during sedimentary refluxing and suboxic diagenesis (Aller and Blair, 2006). Previous studies have shown the importance of mobile muds as an "incinerator" of terrestrially-derived OC in other deltaic systems that have mobile mud belts, such as Amazon and Fly rivers (Aller et al., 1996; Aller and Blair, 2006).

To make these useful comparisons, while keeping the focus of our discussion on active margin settings, we have followed the referee's suggestion and added sentences to the introduction to detail important features of terrestrial organic carbon preservation in passive margin settings:

> "<u>and higher OC preservation efficiencies than rivers draining passive margins (Galy et al., 2007a; Blair and Aller, 2012). U</u>nlike…" (Introduction, Paragraph 2)
>
> "However, large amounts of terrestrial OC and clastic sediment are also delivered to the surface ocean by rivers in hypopycnal plumes with density lower than seawater. Such plumes disperse fluvial materials over a larger region, <u>which result in re-suspension and reworking of terrestrial OC</u> (Mulder and Syvitski, 1995; Dadson et al., 2005; Kao and Milliman, 2008). <u>In analogy with passive margin settings, this</u> may have a

lower terrestrial OC burial efficiency (Aller et al., 1996; Aller, 1998; Aller and Blair, 2006; Sampere et al., 2008; Blair and Aller, 2012)." (Introduction, Paragraph 3)

Finally, we now include a specific paragraph which discusses this comparison in more detail:

"Our findings are consistent with oxic marine sediments undergoing rapid accumulation elsewhere, with bulk OC preservation efficiencies of 70–100% (Galy et al., 2007a; Blair and Aller, 2012). These tend to exceed terrestrial organic carbon preservation rates in other depositional settings (Burdige, 2005; Blair and Aller, 2012). Unlike steep mountain rivers, large river deltas on passive margins can experience successive re-suspension and deposition episodes within mobile muds (e.g. the Amazon Delta). In these systems, marine organic material can be entrained into mobile deposits, driving early diagenetic reactions and facilitating loss of refractory terrestrial OC during sedimentary refluxing and suboxic diagenesis (Aller, 1998; Aller and Blair, 2006). While conditions in large rivers on passive margins can promote rapid export and deposition of marine OC (Bianchi et al., 2006), re-suspension and re-working of sediments on shallow-sloping deltas can also promote incineration of terrestrial OC (Aller et al., 1996; Aller and Blair, 2006; Aller et al., 2008) even following a rapid sediment accumulation event (Sampere et al., 2008). In contrast, apart from the ~100 m deep Taiwan Strait (Fig. 1) which may be analogous to some of these passive margin settings, rivers export materials to deep basins around the island. The rapid accumulation rates offshore Taiwan and the delivery of terrestrial OC to water depths >500 m in O_2 poor waters (Garcia et al., 2009) are conditions more analogous to the Bengal Fan system, where terrestrial OC burial efficiencies are also very high (Galy et al., 2007a)." (Section 4.3, final paragraph)

Referee 1: Finally, I know of paper by West et al published in L&O that showed huge amounts of trees material being exported from Taiwan after a typhoon, the authors' make no mention of this, where do the trees go and have they been detected in their transects.

Reply: Since we sample mostly fine sediments (using box and piston cores), the methods are unlikely to recover large wood debris during our sampling of marine sediments. However, as we explain, we did recover visible plant fragments in some depth intervals of sediment trap materials collected in the Gaoping Canyon and those depths are consistent with the periods of typhoon invasion in Taiwan ("The trapped sediment included an organic rich sub-sample (Fig. 3b) with visible woody debris (C_{org} = 1.6%, $\Delta^{14}C_{org}$ = –112‰)". We also state in Section 4.3 that our burial flux estimates may "…be a lower bound if material coarser than ~500 µm (i.e. coarser than most suspended load) contributes importantly to $OC_{non-fossil}$ transfer and burial (West et al., 2011)". We agree that the fate of large woody debris (e.g. logs and branches) is interesting, and the observations from West et al., (2011) suggest that the majority of this material may float when it enters the ocean. We have therefore added text to expand on this important distinction between sand-sized terrestrial $OC_{non-fossil}$ and the large woody debris:

"…that the density of the turbid river plume may be high enough to effectively sequester woody debris carried in the sand fraction, while coarser woody material (e.g. logs) float upon discharge to the ocean (West et al., 2011)…" (Section 4.2, paragraph 3)

We also slightly modify a statement in our wider implications section to clarify that our organic carbon transfers do not account for large woody debris, whose fate remains poorly constrained:

"…$OC_{non-fossil}$ burial flux of 0.5–0.6 TgC yr^{-1} in basin fills derived from Taiwan. This may be a lower bound if material coarser than ~500 µm (i.e. large woody debris, whose fate remains poorly constrained) contributes importantly to $OC_{non-fossil}$ transfer and burial (West et al., 2011)." (Section 4.4, paragraph 1).

We also clarify that our sampling techniques are unlikely to recover large woody debris:

"The methods employed to sample terrestrial and marine sediments mean that the study focuses on the transfer and offshore preservation of sand and finer materials. Large woody debris (e.g. logs and trunks) are not likely to be recovered and so their fate remains a question for future research (e.g. West et al., 2011)." (Section 2.2, paragraph 2)

Additional references added to the revised version:

Aller, R.C.: Mobile deltaic and continental shelf muds as suboxic, fluidized bed reactors, Mar. Chem., 61, 143–155, 1998.

Aller, R.C., and Blair, N.E.: Carbon remineralization in the Amazon-Guianas tropical mobile mudbelt: A sedimentary incinerator, Continental Shelf Res., 26, 2241–2259, 2006.

Aller, R.C., Blair, N.E., Xia, Q., and Rude, P.D.: Remineralization rates, recycling and storage of carbon in Amazon shelf sediments. Continental Shelf Res., 16, 753–786, 1996.

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.

Bianchi, T.S., Allison, M.A., Canuel, E.A., Corbett, D.R., McKee, B.A., Sampere, T.P.,Wakeham, S.G., and Waterson, E.: Rapid export of organic matter to the Mississippi Canyon. EOS 87 (50), 565, 572–573, 2006.

Bianchi, T.S., Galler, J.J., and Allison, M.A.: Hydrodynamic sorting and transport of terrestrially-derived organic carbon in sediments of the Mississippi and Atchafalaya Rivers. Estuarine Coastal Shelf Sci., 73, 211–222, 2007.

Bianchi, T.S.: The role of terrestrially derived organic carbon in the coastal ocean: A changing paradigm and the priming effect. Proc. Nat. Acad. Sci., 108, 19,473-19,481, 2011.

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.

Carter, L., Milliman, J.D., Talling, P.J., Gavey, R. and Wynn R.B.: Near synchronous and delayed initiation of long run-out submarine sediment flows from a record-breaking river flood, offshore Taiwan. Geophys. Res. Lett., 39, L12603, 2012.

Sampere, T.P., Bianchi, T.S., Wakeham, S.G., and Allison, M.A.: Sources of organic matter in surface sediments of the Louisiana Continental Margin: Effects of primary depositional/transport pathways and Hurricane Ivan. Cont. Shelf Res., 28, 2472–2487, 2008.