Referee #2

Henry-Pinilla and colleagues introduce the LOAC-OCB model, a framework designed to simulate the transport and burial of particulate terrestrial organic carbon along the land-to-ocean aquatic continuum (LOAC) on a global scale. The model integrates rivers, lakes, reservoirs, floodplains, and coastal ecosystems to generate spatially explicit global estimates of organic carbon burial at high resolution. Using openly available datasets, the authors assess the model's performance by comparing simulated river discharge, sediment export, sedimentation rates, and organic carbon burial rates with global observational compilations. Their results provide a new framework for quantifying the relative contributions of different aquatic ecosystems to global organic carbon burial and for investigating how upstream processes influence carbon sequestration downstream. While I fully agree on the importance of improving quantitative estimates of OC transport and burial along the LOAC, and I appreciate the conceptual design and ambition of the model, the current implementation relies heavily on empirically derived parameterizations based on a relatively limited set of localized observations. I recognize that such compromises are often unavoidable in the development of global-scale models and that some degree of simplification is necessary. However, a more thorough evaluation of model sensitivity and uncertainty is needed to establish confidence in the results, clarify the conditions under which the model can be applied reliably, and identify priorities for future model development.

Given the limitations outlined below, particularly the lack of a quantitative sensitivity and uncertainty analysis, I am unfortunately unable to recommend publication of the manuscript in its current form in GMD. In my view, the manuscript would require at least a major revision before it could be considered for publication. I hope that the comments provided below will be helpful to the authors in strengthening the study.

We thank the referee for this thoughtful assessment of our work and for recognizing both the importance of improving quantitative estimates of OC transport and burial along the LOAC and the challenges inherent to developing a global-scale framework for these processes.

We agree that global models necessarily rely on empirical parameterizations and simplifications, particularly when observational constraints remain limited. We also appreciate the referee’s emphasis on the need for a rigorous evaluation of uncertainty and model sensitivity. Indeed, several of the concerns raised in this review relate directly to this aspect of the manuscript.

In response, we have made a substantial effort to strengthen the model evaluation framework. In particular, we implemented a global sensitivity analysis using the Morris screening method, requiring approximately 17,000 model simulations, and subsequently conducted a parameter uncertainty analysis based on 1,000 model realizations. These analyses allowed us to identify the most influential model parameters, quantify uncertainty in the principal output fluxes, and assess the robustness of the model conclusions. The resulting uncertainty estimates are now incorporated throughout the revised manuscript and discussed in the context of model assumptions and limitations.

We note that the absence of a quantitative sensitivity and uncertainty analysis was identified by the referee as one of the main limitations preventing publication. We therefore believe that the additional analyses conducted during the revision represent a substantial improvement to the manuscript and address a central concern regarding the confidence that can be placed in the model results.

We appreciate the referee's constructive suggestions and believe they have significantly improved the manuscript. Below, we address each specific comment individually.

Some specific methodological examples that I believe require either improvement or a more thorough discussion and evaluation of their associated uncertainties are:

1) The preservation/burial of organic carbon (OC) is simply calculated based on a burial efficiency which is a function of linear sedimentation rate. The underlying sigmoidal relationship is derived from 30 data points from only 13 lakes and reservoirs. Given the importance of this parameterization to the model, is there really no larger dataset available on which it could be based?

This relationship is then adapted for marine coastal ecosystems (here mangroves, saltmarshes, seagrass) by reproducing a similar relationship reported in Katsev & Crowe (2015). However, while this study may report a relationship for the marine environment more generally, it is not obvious that it is directly applicable to the specific coastal ecosystems considered here. The implications and uncertainties associated with this assumption should therefore be discussed in more detail.

We thank the referee for this thoughtful comment. We agree that the OCBE–LSR relationship is one of the key components of LOAC-OCB and therefore requires careful justification and evaluation.

The choice of OC burial efficiency (OCBE) rather than directly prescribing OC burial rates was intentional. OCBE represents the fraction of deposited OC that is ultimately preserved and therefore provides a direct link between sedimentation and burial while maintaining mass balance throughout the LOAC. In contrast, prescribed OC burial rates are not directly connected to the amount of sediment and OC entering a system, making their application to a globally connected framework considerably more challenging.

While more observations of OC burial rates are available than OCBE estimates, the existing datasets remain far too limited and heterogeneous to support the direct parameterization of OC burial rates across all ecosystem types represented in LOAC-OCB. Moreover, burial efficiencies provide a transferable and dimensionless metric that can be applied across systems with very different sediment and OC inputs. For this reason, we consider OCBE to be a particularly suitable variable for large-scale models seeking to preserve mass balance while representing spatial variability in sediment dynamics.

We have made this explicit in Section 2.4.5 of the revised manuscript:

“OCBE was selected as the key variable because it directly links OC deposition and burial while maintaining mass balance within the LOAC. Unlike prescribed burial rates, burial efficiencies can be applied across systems with contrasting sediment and OC inputs and therefore provide a transferable framework for representing spatial variability in OC preservation at the global scale.”

We acknowledge that the dataset used to establish the freshwater OCBE–LSR relationship is limited. However, the adequacy of the approach is not evaluated solely on the basis of the fitted relationship itself. The resulting model reproduces plausible burial rates and global burial fluxes across the LOAC, providing evidence that the relationship captures the dominant first-order controls on terrestrial POC burial at the global scale.

To address the uncertainty associated with this parameterization, we performed an additional non-parametric bootstrap analysis (1,000 iterations) of the sigmoidal fit. The resulting parameter distributions were used to derive a 95% uncertainty envelope around the OCBE–LSR relationship and were subsequently propagated through the broader model uncertainty framework. This analysis is now included in the revised manuscript and provides an explicit quantification of the uncertainty associated with the empirical burial-efficiency relationship.

Regarding coastal ecosystems, we agree that the adaptation of the relationship proposed by Katsev and Crowe (2015) introduces additional uncertainty. Nevertheless, both freshwater and marine observations support the same fundamental conceptual relationship: increasing sedimentation enhances OC preservation by reducing exposure to degradation processes such as reducing exposure to oxygen. Furthermore, the use of a sigmoidal OCBE–LSR relationship ensures that burial efficiencies remain constrained between 0 and 100% of the deposited OC, thereby avoiding physically unrealistic outcomes. This property is particularly advantageous in a global-scale model, where environmental conditions span a very wide range and unconstrained linear relationships may produce implausible burial efficiencies. Given the scarcity of OCBE observations currently available for mangroves, salt marshes, and seagrass meadows at the global scale, we considered this approach a reasonable approximation for representing the first-order controls on burial efficiency in coastal systems.

We nevertheless agree that future versions of LOAC-OCB would benefit from ecosystem-specific OCBE relationships. Expanding OCBE observations, particularly in floodplains and coastal ecosystems, remains one of the key research priorities identified by this study.

2) The approaches to estimate sediment trapping efficiency (TE) appear relatively simplistic and should be evaluated through a quantitative uncertainty analysis to assess their influence on model results. For lakes & reservoirs, it is unclear how many lakes were used to derive these relationships? For floodplains, a uniform TE efficiency is assumed everywhere, whereas for coastal ecosystems TE is also related to particle velocity and water depth. Is it reasonable to use these three rather different approaches together in a unified framework? It would be helpful to evaluate their performance against available observations and, where possible, compare the resulting TE estimates across environments. Such an analysis would provide greater confidence that the model predictions are not overly sensitive to the choice of parameterization.

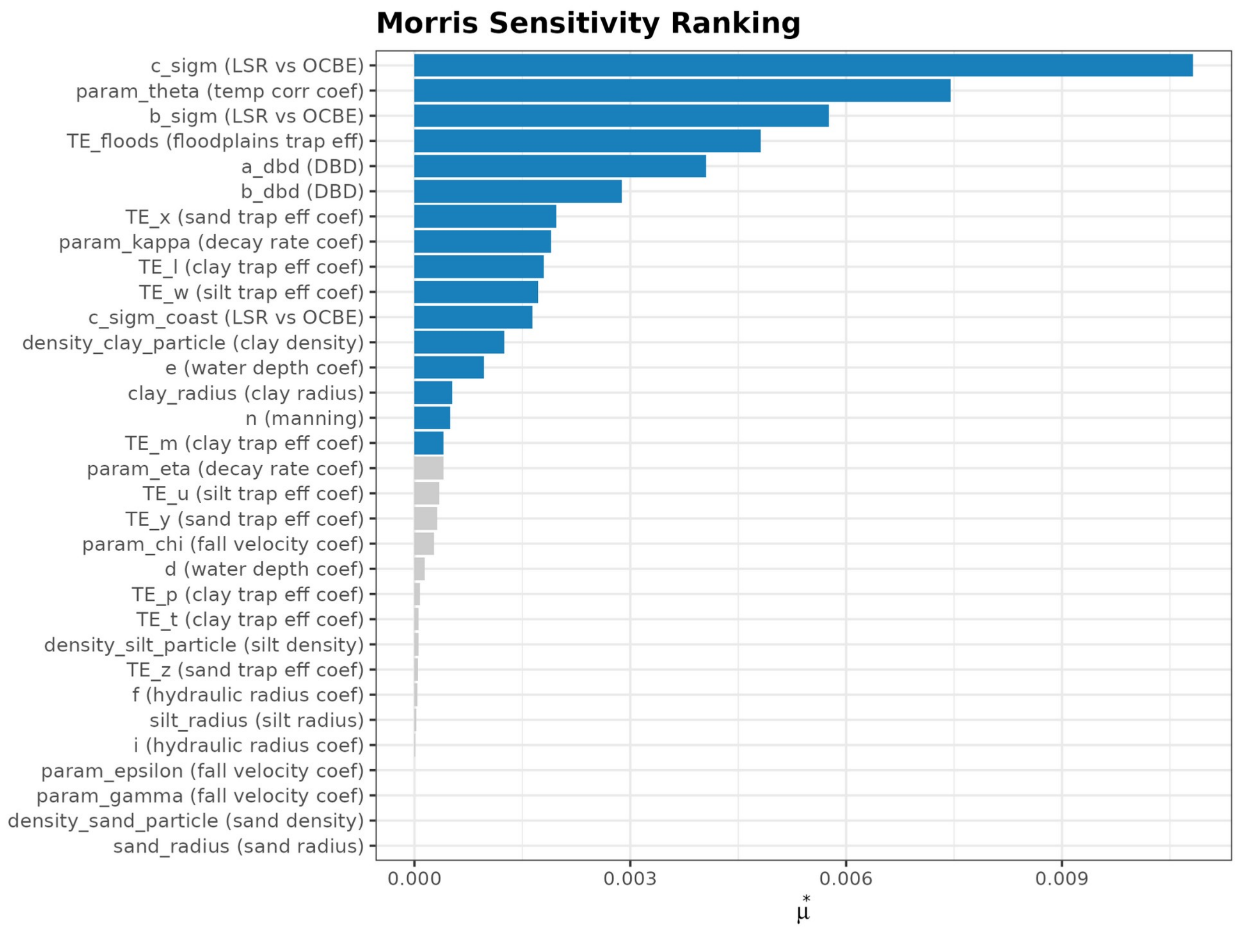
We thank the referee for this important comment. We respectfully disagree with the characterization of the trapping-efficiency (TE) formulations as simplistic. Rather, LOAC-OCB seeks to represent sediment retention using the most appropriate and best-supported formulation available for each ecosystem type, while maintaining a globally applicable framework.

For lakes and reservoirs, sediment retention is estimated using the empirical relationships of Brune (1953) and Gill (1979), which remain among the most widely used and extensively evaluated approaches for estimating sediment trapping efficiency at large scales. Recent assessments continue to identify these formulations as among the most reliable empirical methods for representing sediment retention in reservoirs (Tan et al., 2019). The use of long-tested and robust empirical approaches should not be considered simplistic merely because they rely on straightforward principles and mathematical formulations. We are therefore somewhat surprised by the characterization of these relationships as simplistic.

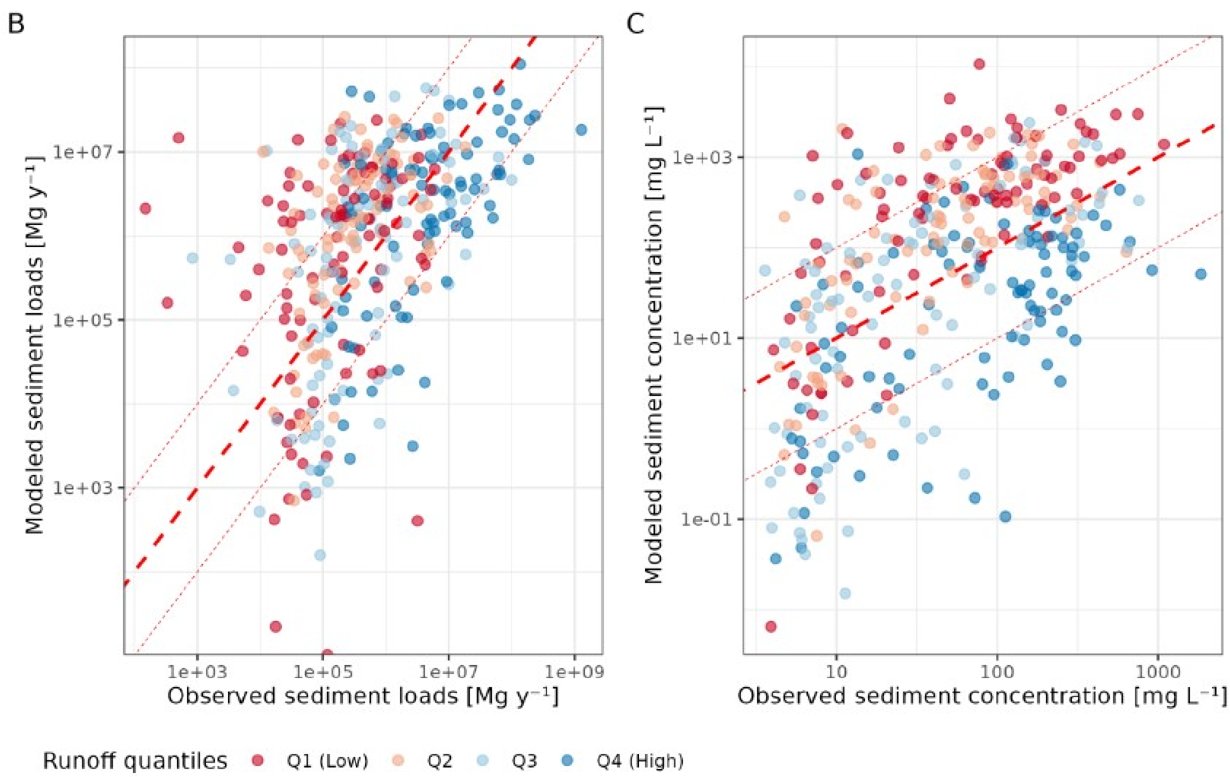
Tan, G., Chen, P., Deng, J., Xu, Q., Tang, R., Feng, Z., & Yi, R. (2019). Review and improvement of conventional models for reservoir sediment trapping efficiency. Heliyon, 5(9). DOI: 10.1016/j.heliyon.2019.e02458

We also respectfully disagree that a unified trapping-efficiency formulation across all ecosystem types would necessarily be preferable. Lakes and reservoirs, floodplains, and coastal ecosystems differ fundamentally in their hydrological and geomorphological functioning. Applying the same formulation to all components of the LOAC would therefore be difficult to justify physically. Instead, LOAC-OCB uses ecosystem-specific representations based on the best available literature and process understanding for each environment. We consider this flexibility a strength of the framework, as it allows the model to take advantage of the substantial differences in knowledge that exist among ecosystem types.

We agree, however, that the influence of these parameterizations on model predictions should be quantified. To address this concern, we conducted a global sensitivity analysis using the Morris screening method and a subsequent uncertainty analysis based on 1,000 model realizations. The results show that trapping-efficiency-related parameters are indeed among the most influential controls on modeled OC burial, especially those associated with clay, silt, and sand retention, as well as floodplain trapping efficiency (see Figure below). Consequently, uncertainty associated with these parameterizations is now explicitly incorporated into the revised model uncertainty estimates.



We acknowledge that comprehensive global datasets of trapping efficiency spanning lakes, reservoirs, floodplains, and coastal ecosystems do not currently exist, preventing a direct global-scale evaluation of TE across ecosystem types. Instead, the sediment-retention framework is evaluated indirectly through comparisons of modeled sediment loads and concentrations against independent observations, which show good agreement at the global scale (see Figure 5 below). Furthermore, the resulting burial estimates are consistent with observed ranges and global assessments, providing confidence that the framework captures the dominant first-order controls on sediment retention and burial.



Finally, we agree that additional TE observations and robust empirical studies, similar to the foundational work of Brune (1953) for reservoirs, would substantially improve future generations of the model. This need is particularly evident for floodplains and coastal ecosystems, where globally representative datasets remain scarce. We have expanded the discussion of these uncertainties and their implications in the revised manuscript.

3) More information is needed on the runoff that is used in "Input step 2". I was unable to find an article describing the output. In particular, it woluld be helpful to know whether the dataset represents surface runoff only, or also subsurface flow and groundwater discharge which together define the total river flow. Given the central role of runoff in transporting sediments and OC through the LOAC, it would also be useful to assess the sensitivity of the model results to this input.

We thank the referee for this comment. We agree that the description of the runoff dataset was insufficient and that additional information should be provided.

Runoff in LOAC-OCB is derived from the ISIMIP3a WaterGAP simulations (Gosling et al., 2025). We would like to clarify that this reference corresponds to the ISIMIP data product itself rather than to a dedicated publication describing the simulations. The dataset follows the ISIMIP3a protocols and model documentation and is distributed through the ISIMIP repository.

Additional information on the WaterGAP simulations is available at:

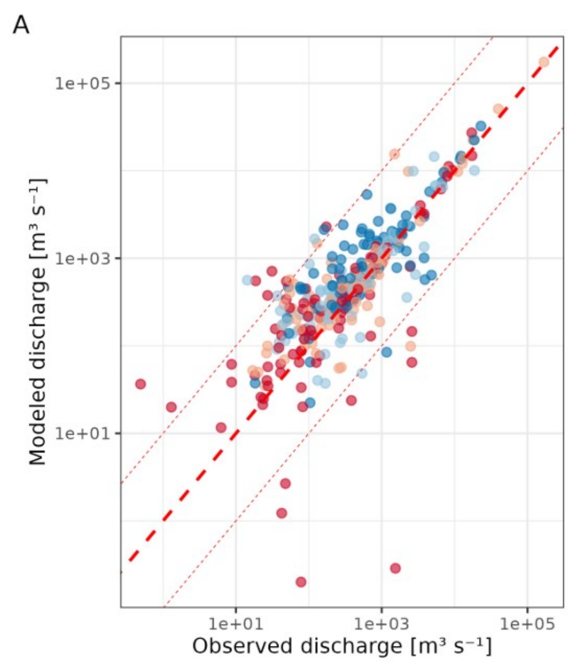
https://www.isimip.org/impactmodels/details/313/

Furthermore, the runoff variable represents the total runoff contributing to river discharge, including both surface and subsurface flow components. We now explicitly stated this in Section 2.5.2, the revised text now reads:

"Runoff, the climatic driver for discharge in the model, is obtained as monthly mean (kg m-2 s-1) from the ISIMIP3a data repository, using the WaterGAP simulations for the period 1901–2015 (Gosling et al., 2025). The runoff variable represents the total runoff contributing to river discharge, including both surface and subsurface flow components, and incorporates the effects of major water-use sectors represented in WaterGAP, including domestic, manufacturing, power-generation, livestock, and irrigation demands. [...] Maximum discharge is estimated from the 90th percentile of monthly runoff derived from the same WaterGAP time series (Gosling et al., 2025), using the Climate Data Operator (CDO) software."

Regarding the sensitivity of the model to runoff-related variables, this concern motivated part of the additional model evaluation developed during the revision process. Although runoff itself is an input forcing and was therefore not included as a parameter in the Morris screening analysis, the parameters directly dependent on discharge showed relatively limited influence on model outputs. The coefficients used to estimate water depth (parameters d and e) ranked 13th and 21st among the 32 evaluated parameters, while the hydraulic-radius parameters (f and i) ranked 26th and 28th.

In addition, the resulting discharge estimates were independently evaluated against global observations, with 94% of modeled discharge values falling within one order of magnitude of the observational dataset (see Figure 5 below). Together, the sensitivity analysis and validation results provide confidence that the runoff-driven hydrological component of LOAC-OCB adequately captures the large-scale patterns relevant for sediment and terrestrial POC transport.



4) Given the ambitious global scope of the model, it would be helpful to first demonstrate its performance in a well-studied regional setting where (ideally) a relatively dense observational dataset is available. Such an application could provide additional confidence in the model and help identify its strengths and limitations.

We thank the referee for this suggestion. We agree that applications in well-studied regional settings could provide valuable additional insights into model strengths and limitations and may represent an important future use of LOAC-OCB.

However, the primary objective of this study is the development and evaluation of a global-scale framework. Accordingly, model evaluation was performed against independent global datasets of discharge, sediment transport, sedimentation rates, and OC burial, allowing assessment across the full range of environmental conditions represented by the model rather than within a single regional setting. While the latter approach could improve geographical correspondence, it would also reduce the ability of the comparison to evaluate the global behavior of the model and would introduce additional sampling biases associated with the uneven spatial distribution of observations.

In addition, in response to the concerns raised by both referees, we substantially strengthened the evaluation framework through a global sensitivity analysis (~17,000 simulations) and a parameter uncertainty analysis (1,000 realizations), which provide an explicit assessment of model robustness and identify the parameters and processes exerting the strongest control on model outputs.

We agree that regional applications in data-rich systems could provide a useful complement to these analyses and could help identify opportunities for future model improvement. Nevertheless, we view such applications as a logical next step following the development of the global framework presented here, rather than a prerequisite for evaluating its global-scale behavior.

5) I don't find the comparison between model results and observations in Fig. 6 fully convincing. The number of observations is often orders of magnitude smaller than the number of modeled systems and may also come from only a limited number of locations. Therefore, I am not sure if this comparison provides a robust evaluation of model performance.

We thank the referee for this important comment. We agree that the observational datasets are much smaller than the number of systems represented by the model and that the available observations are not evenly distributed geographically. This is an inherent limitation of current global OC burial datasets and one of the challenges motivating the development of models such as LOAC-OCB.

However, the objective of Fig. 6 is not to compare observed and modeled systems on a one-to-one basis, nor to perform a site-specific validation. Rather, the purpose is to evaluate whether the distributions and ranges of simulated LSR and OC burial rates are consistent with those currently reported in the literature for each ecosystem type and, where differences arise, to use them as a basis for understanding the strengths and limitations of the model, as well as potential biases and uncertainties in the observational datasets themselves.

We nevertheless agree that the limited size and uneven spatial distribution of the observational database introduces uncertainty into the comparison. This issue is especially relevant for floodplains, where observations remain particularly scarce.

Furthermore, the comparison shown in Fig. 6 is only one component of the overall evaluation framework. Model performance is also assessed through independent comparisons of discharge, sediment loads, sediment concentrations, global burial fluxes, and terrestrial POC export, and is now complemented by a global sensitivity analysis and uncertainty quantification. We therefore consider Fig. 6 as a useful but not standalone evaluation of model behavior.

6) 3.3 OCBE: This part would benefit from a comparison of the modeled results with existing theoretical expectations and observational constraints. Such a comparison would help readers assess the realism of the predicted OCBEs across the different environments.

We thank the referee for this suggestion. We agree that comparisons with theoretical expectations and observational constraints help assess the realism of the predicted OCBE.

As discussed in our response to comment 1, the OCBE–LSR relationship implemented in LOAC-OCB is based on the well-established conceptual expectation that increasing sedimentation rates enhance OC preservation by reducing exposure to degradation processes, and it is constrained by the available OCBE observations. The corresponding uncertainty has now been explicitly quantified through a non-parametric bootstrap analysis and propagated through the model uncertainty framework.

Beyond the calibration dataset itself, the realism of the OCBE formulation can also be evaluated through its implications for OC burial rates. Although independent OCBE observations are currently scarce, the resulting relationship between LSR and OCB produced by the model is broadly consistent with the observed patterns reported for lakes and reservoirs (Fig. A4), reproducing the expected increase in burial rates with increasing sedimentation. We therefore consider that the model captures the dominant first-order relationship between sediment accumulation and OC burial.

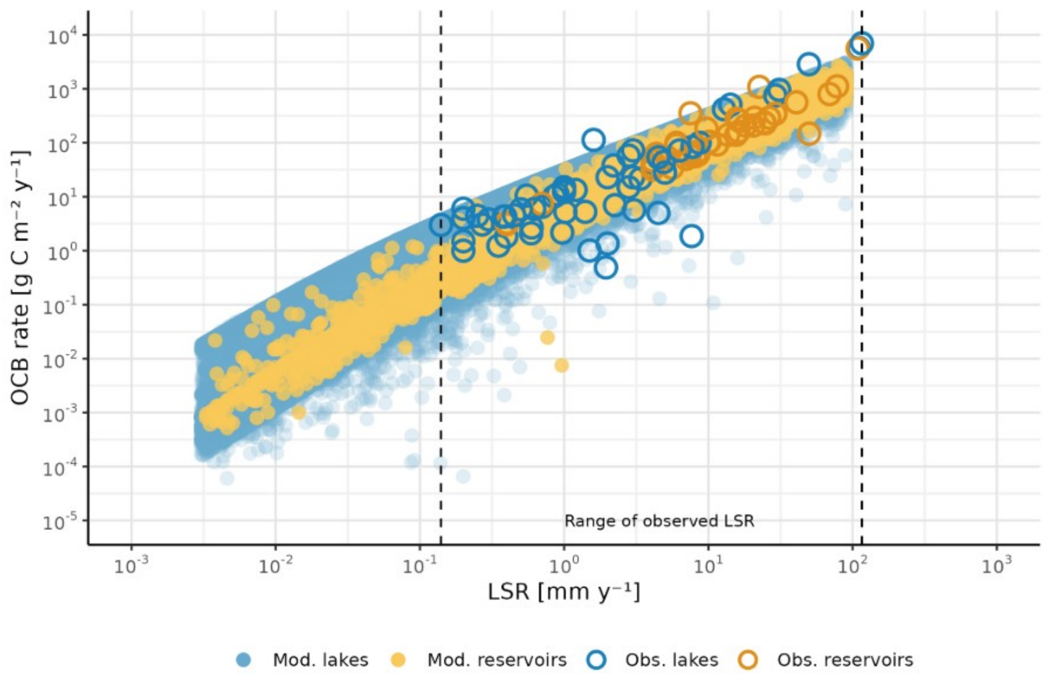


Figure A4. Relationship between linear sedimentation rate (LSR) and organic carbon burial (OCB) rate for lakes and reservoirs. Modeled data are shown as filled circles and restricted to the 5th–95th percentile range of LSR values, highlighting the central distribution of modeled conditions and minimizing the influence of extreme outliers that can obscure general trends. Observed data (open circles) are plotted in full for reference. Black dashed vertical lines indicate the observed LSR range across all lake and reservoir measurements. This percentile-based filtering focuses the analysis on the most representative range of modeled conditions while maintaining observed variability for contextual interpretation.

7) I am not sure that comparing median OC mineralization rates simulated by the model with CO_2/CH_4 emission rates from specific lakes or published estimates for coastal ecosystems is particularly informative. First, as the authors note, terrestrial OC is neither the sole nor always the dominant source of CO_2 and CH_4 emissions, especially in productive lakes and coastal ecosystems. Second, given the large variability in emission rates among lakes worldwide, observations from individual lakes are not directly comparable to median emission rates predicted by a global model. It would therefore be helpful to discuss the limitations of this comparison and its implications for model evaluation, or (if possible) compare specific lake estimates with the results of the model for the respective grids.

We thank the referee for this important observation. We agree that the comparison between modeled terrestrial POC mineralization and published CO_2/CH_4 emission estimates is not direct and should not be interpreted as a rigorous model evaluation.

As noted by the referee, terrestrial POC is only one of several carbon sources contributing to greenhouse gas emissions from aquatic ecosystems. Autochthonous OC, DOC, and other carbon pools can contribute substantially to total CO_2 and CH_4 emissions, particularly in productive lakes and coastal ecosystems. Consequently, we do not expect modeled terrestrial POC mineralization rates to match total ecosystem-scale greenhouse gas emissions.

Furthermore, we agree that comparisons between median mineralization rates produced by a global model and observations from individual lakes are of limited value, given the large variability in aquatic greenhouse gas emissions among systems worldwide. Our intention was simply to assess whether the simulated terrestrial POC mineralization rates fell within plausible ranges reported in the literature and to illustrate that the predicted values are generally located toward the lower end of total ecosystem emission estimates, as would be expected given the restricted carbon pool represented by LOAC-OCB.

We have revised the text to better emphasize these limitations and to clarify that the comparison is intended as a qualitative consistency check rather than a direct validation of the mineralization component of the model. The revised text now reads:

"Direct evaluation of these estimates remains challenging because observational studies generally report total CO_2 and CH_4 emissions, which integrate multiple C sources, including autochthonous production, DOC mineralization, and terrestrial OC inputs. In contrast, LOAC-OCB only represents the mineralization of terrestrial POC. Consequently, published ecosystem-scale greenhouse gas emissions are not directly comparable to the mineralization fluxes simulated by the model.

Nevertheless, published emission estimates provide a useful order-of-magnitude context for interpreting the simulated terrestrial POC mineralization rates. For instance, individual lakes worldwide show CO_2 and CH_4 emissions ranging from 13.7 mg C m^{-2} d^{-1} in Lake Baikal to 435.6 mg C m^{-2} d^{-1} in Lake Kinneret (Sobek et al., 2009, 2011; Ferland et al., 2014), while the Mascarenhas de Moraes reservoir reports mean CO_2 and CH_4 emissions of 94.3 mg C m^{-2} d^{-1} (Mendonça et al., 2016). Regarding coastal ecosystems, Siikamäki et al. (2013) estimated total CO_2 emissions of 0.076 Pg C y-1 for mangroves, saltmarshes, and seagrasses. When averaged over their reported area (509,170 km^2), this corresponds to an approximate mean emission rate of 408.9 mg C m^{-2} d^{-1}.

The mineralization rates simulated by LOAC-OCB generally fall toward the lower end of these reported ranges, which is consistent with the fact that the model only accounts for the terrestrial POC component of ecosystem C processing. We therefore consider these comparisons as a qualitative consistency check rather than a direct validation of the mineralization component of the model. Future observational datasets specifically quantifying terrestrial POC mineralization would provide a more robust basis for evaluation."

8) Are there specific areas where the model shows large discrepancies with other models (e.g., compared to Li et al. (2022) for the reservoirs)?

We thank the referee for this comment. We agree that identifying and interpreting discrepancies among global modeling frameworks is important. To address this point, we substantially revised Section 3.5 and Table 2 to provide a more transparent comparison with previous studies. In the revised version, we explicitly identify the ecosystem types, carbon pools, and carbon sources represented by each study, allowing readers to distinguish between genuine model differences and differences arising from contrasting definitions, system boundaries, or processes represented.

The revised comparison shows that some discrepancies do exist, particularly for reservoir burial when compared with Li et al. (2022). However, many of these differences can be explained by differences in carbon pools and sources considered as well as ecosystem coverage. In contrast, our estimates of total LOAC burial, terrestrial POC input to the LOAC, export to the ocean, and burial within the different ecosystem types generally fall within the range of recent global assessments. We therefore consider that the revised comparison provides a more balanced and informative evaluation of where LOAC-OCB agrees with, and differs from, other available frameworks.

The revised Section 3.5 and Table 2 are reproduced below:

3.5 Global OC fluxes

When scaled to their total modeled surface areas, estimated global median OCB fluxes were 0.093 ± 0.010 Pg C y-1 for floodplains (8,363,169 km2), 0.070 ± 0.004 Pg C y-1 for reservoirs (253,404 km2), 0.050 ± 0.003 Pg C y-1 for lakes (2,061,552 km2), and 0.029 ± 0.003 Pg C y-1 in coastal ecosystems (873,923 km2). This yields a LOAC contribution of 0.243 ± 0.012 Pg C y-1 to the global OCB budget, highlighting the major role of floodplains, driven largely by their extensive spatial coverage despite relatively low areal OCB rates. Reservoirs, in contrast, represent a much smaller surface area and contribute disproportionately to global OCB due to their high sediment trapping efficiency and LSR. Overall, we estimated that the LOAC receives 34.55 Pg y-1 of sediment from the terrestrial systems through erosion, with the OC fraction corresponding to 0.482 Pg C y-1 (1.39%). Of this terrestrial POC load, 0.243 ± 0.012 Pg C y-1 is buried within the sediments, 0.166 ± 0.014 Pg C y-1 is mineralized, and 0.076 ± 0.004 Pg C y-1 is exported to the open ocean.

Many studies have reported global OCB estimates (Table 2), and most are broadly consistent with our assessment. Direct comparisons should nevertheless be interpreted with caution, as global studies often differ in the C pools considered and in the aquatic ecosystems included. A study that is particularly comparable to ours is Li et al. (2022), given the similarity in methodology and the OC sources and pools considered. They estimated a higher terrestrial POC input to the LOAC of 0.77 Pg C y-1. In comparison, Battin et al. (2023) estimated that soils and wetlands export 0.72 Pg C y-1 to the river network, a value lower than that reported by Li et al. (2022) but higher than our estimate of terrestrial POC input to the LOAC (0.48 Pg C y-1). However, their estimate includes both DOC and POC and represents C fluxes after passage through wetlands. They also estimated an export of 0.43 Pg C y-1 to the coastal ocean, whereas our estimate reflects the residual flux after accounting for burial and processing within coastal blue-carbon ecosystems. Similarly, Li et al. (2022) estimated a land-to-ocean POC export of 0.29 Pg C y-1, although their framework does not explicitly consider the role of floodplains and coastal ecosystems. Other comparable export estimates, which approximate even better with ours, were reported by Beusen et al. (2005), Liu et al. (2024) and Tian et al. (2026), who estimated that 0.2, 0.18, and 0.17 Pg C y-1 of terrestrial POC, respectively, but, again, this is the export that reaches the coastal ocean. Likewise, Regnier et al. (2022) estimated that inland waters, estuaries, and tidal wetlands collectively bury 0.25 ± 0.15 Pg C y-1, remarkably close to our estimate of total OCB across the LOAC. Their study, however, represented the broader aquatic carbon cycle and therefore included additional carbon pools such as dissolved organic carbon (DOC) and dissolved inorganic carbon (DIC). Consequently, they reported higher terrestrial carbon inputs (2.95 ± 0.55 Pg C y-1) and substantially greater mineralization *fluxes (1.85 ± 0.50 Pg C y-1) than those estimated here. Despite these methodological differences, the overall agreement among studies supports the robustness of our estimates and suggests that LOAC-OCB captures the dominant controls on the transport, processing, and long-term burial of terrestrial organic carbon along the aquatic continuum.*

Table 2. Global median terrestrial particulate organic carbon (POC) fluxes (Pg C y^{-1} ± SD) across LOAC ecosystems and comparison with previous studies. DIC: dissolved inorganic carbon; DOC: dissolved organic carbon; TC: total carbon; TOC: total organic carbon; allo: allochthonous; auto: autochthonous. (*) None of these studies accounts for burial and processing within coastal blue-carbon ecosystems. (**) The study is included for reference only, as it accounts for mineral-soil wetlands and boreal peatlands rather than riverine floodplains.

OC flux	LOAC-OCB	Other studies	C pool (source)	Reference
OC input to LOAC	0.482	0.72	DOC, POC (allo)	Battin et al. (2023)
		0.77	POC (allo)	Li et al. (2022)
		2.95 ± 0.55	DIC, DOC, POC (allo)	Regnier et al. (2022)
OC export to ocean*	0.076 ± 0.004	0.17	POC (allo)	Tian et al. (2026)
		0.18	POC (allo)	Liu et al. (2024)
		0.20	POC (allo)	Beusen et al. (2005)
		0.29	POC (allo)	Li et al. (2022)
		0.43	POC (allo)	Battin et al. (2023)
OCB LOAC	0.243 ± 0.012	0.25 ± 0.15	DIC, DOC, POC (allo)	Regnier et al. (2022)
OCB lakes	0.050 ± 0.003	0.09	TOC (allo)	Mendonça et al. (2017)
OCB reservoirs	0.070 ± 0.004	0.06	TOC (allo)	Mendonça et al. (2017)
		0.35	POC (allo)	Li et al. (2022)
OCB floodplains**	0.093 ± 0.010	0.096	TC (allo)	Bridgham et al. (2014)
OCB coastal ecosystems	0.029 ± 0.003	0.03 - 0.07	DOC, POC (allo, auto)	Lovelock and Reef (2020)
		0.07 - 0.22	DOC, POC (allo, auto)	Duarte et al. (2013); Ward et al. (2020)
		0.079 - 0.089	DOC, POC (allo, auto)	Breithaupt and Steinmuller (2022); Wang et al. (2021); Arias-Ortiz et al. (2026)
OC mineralization	0.166 ± 0.014	0.02	POC (allo)	Li et al. (2022)
		0.8 - 1.2	DOC, POC (allo)	Lal (2003)
		1.85 ± 0.5	DIC, DOC, POC (allo)	Regnier et al. (2022)

For reservoirs, Li et al. (2022) estimated, using a process-based model, that 0.35 Pg C y-1 of terrestrial POC is trapped in reservoirs, approximately five times higher than our estimate of 0.07 ± 0.004 Pg C y-1. This discrepancy is particularly noteworthy given that their estimated sediment input to reservoirs (22.8 Pg y-1) is lower than ours (34.6 Pg y-1). In contrast, our estimate is more consistent with other global assessments. For example, Mendonça et al. (2017) reported a global reservoir OCB flux of 0.06 Pg C y-1, very close to the value obtained in this study. The agreement between these independent estimates suggests that the lower reservoir burial flux predicted by LOAC-OCB is within the range supported by current empirical evidence.

To our knowledge, floodplains have not been explicitly represented in previous long-term OCB modelling frameworks (Hoffmann et al., 2013), limiting direct comparisons with existing studies. One of the few relevant estimates is that of Bridgham et al. (2014), who revised the global C sequestration potential of wetlands originally reported by Mitsch et al. (2013) and obtained a value of 0.096 Pg C y-1. Notably, this estimate is remarkably close to our floodplain OCB flux (0.093 ± 0.010 Pg C y-1). However, their study included a broad range of wetland types, such as mineral-soil wetlands and boreal peatlands, treated as part of the terrestrial system, making it difficult to evaluate the degree of overlap with the floodplain systems represented in LOAC-OCB.

The absence of comparable global estimates highlights a major knowledge gap in current large-scale carbon assessments. One of the main goals of LOAC-OCB is therefore to provide a simple, process-based framework that explicitly incorporates floodplains into Earth System models and global carbon budgets. While we acknowledge the scarcity of global observations available for model validation, the agreement between our estimates and independent studies, together with the successful validation of the underlying hydrological and sedimentary processes, suggests that the framework provides a promising first-order approximation of floodplain OC burial at the global scale.

Finally, estimates of OCB in coastal ecosystems vary widely across studies. Lovelock and Reef (2020) reported a global burial flux of 0.03-0.07 Pg C y^{-1} in blue-carbon ecosystems, whereas Duarte et al. (2013) and Ward et al. (2020) estimated values ranging from 0.07 to 0.22 Pg C y^{-1}. Our estimate of 0.029 ± 0.003 Pg C y^{-1} lies at the lower end of these ranges. Other studies have also reported global estimates for mangroves (0.02 Pg C y^{-1}; Breithaupt and Steinmuller, 2022), saltmarshes (0.053 Pg C y^{-1}; Wang et al., 2021), and seagrasses (0.006 - 0.016 Pg C y^{-1}; Arias-Ortiz et al., 2026), which together amount to 0.079-0.089 Pg C y^{-1}. However, these estimates are not directly comparable because they represent total OC burial (i.e., DOC and POC) and generally do not distinguish between allochthonous and autochthonous sources of OC, whereas our estimate only accounts for terrestrially derived POC transported through the LOAC. The relative contribution of autochthonous biomass to long-term burial remains poorly constrained (Li et al., 2022). In many cases, autochthonous OC is expected to be more labile than terrestrially derived particulate OC, although exceptions exist, such as lignified plant materials. Consequently, a larger fraction of autochthonous OC may be degraded before long-term burial. The terrestrial POC flux represented in LOAC-OCB may therefore constitute a substantial fraction of the persistent OC ultimately buried within coastal blue-carbon ecosystems.

Global median POC mineralization fluxes were estimated at 0.166 ± 0.014 Pg C y-1, partitioned as follows: 0.104 ± 0.007 Pg C y-1 in floodplains, 0.020 ± 0.002 Pg C y-1 in lakes, 0.017 ± 0.010 Pg C y-1 in rivers, 0.012 ± 0.003 Pg C y-1 in reservoirs, and 0.010 ± 0.001 Pg C y-1 in coastal ecosystems.

As discussed in Section 3.4, direct comparisons between these estimates and the literature are challenging because most observational studies report total CO_2 and CH_4 emissions, which integrate multiple carbon sources, including autochthonous production, DOC mineralization, and terrestrial OC inputs. For example, Li et al. (2022) estimated that 0.02 Pg C y-1 of terrestrial POC is transformed into DOC, DIC, CO_2, and CH_4 along the LOAC, although they do not explicitly consider the role of floodplains and coastal ecosystems. Likewise, Lal (2003) estimated that 0.8 - 1.2 Pg C y-1 of terrestrial OC is emitted to the atmosphere due to lateral transport induced by erosion, a value substantially greater than our estimate, although the two quantities are not directly comparable because their assessment includes both dissolved and particulate terrestrial OC and does not account for *within-system processing. Similarly, Regnier et al. (2022) estimated atmospheric emissions of 1.85 ± 0.5 Pg C y-1 from inland waters, although this figure also includes inorganic carbon pathways involving DIC.*

The lower mineralization fluxes simulated by LOAC-OCB are therefore expected. First, the model does not represent inorganic carbon emissions, which are known to contribute substantially to global aquatic C fluxes (Marcé et al., 2015). Second, it exclusively tracks the mineralization of terrestrially derived POC, excluding autochthonous organic matter. Because autochthonous OC is generally more labile than terrestrial POC, it is more susceptible to degradation and can contribute disproportionately to aquatic CO2 and CH4 emissions. This distinction is particularly relevant in natural lakes, where autochthonous production represents an important fraction of total OC inputs (Fig. A5). Consequently, our estimates should be interpreted as atmospheric emissions associated with terrestrially derived particulate OC rather than total carbon emissions from aquatic ecosystems.

9) Figure 6: Is this truly an independent evaluation? My understanding is that the LSR–OCBE parameterization shown in Fig. 3 is also derived, at least in part, from the dataset of Henry et al. (2024). If so, the degree of independence between model calibration and evaluation should be clarified.

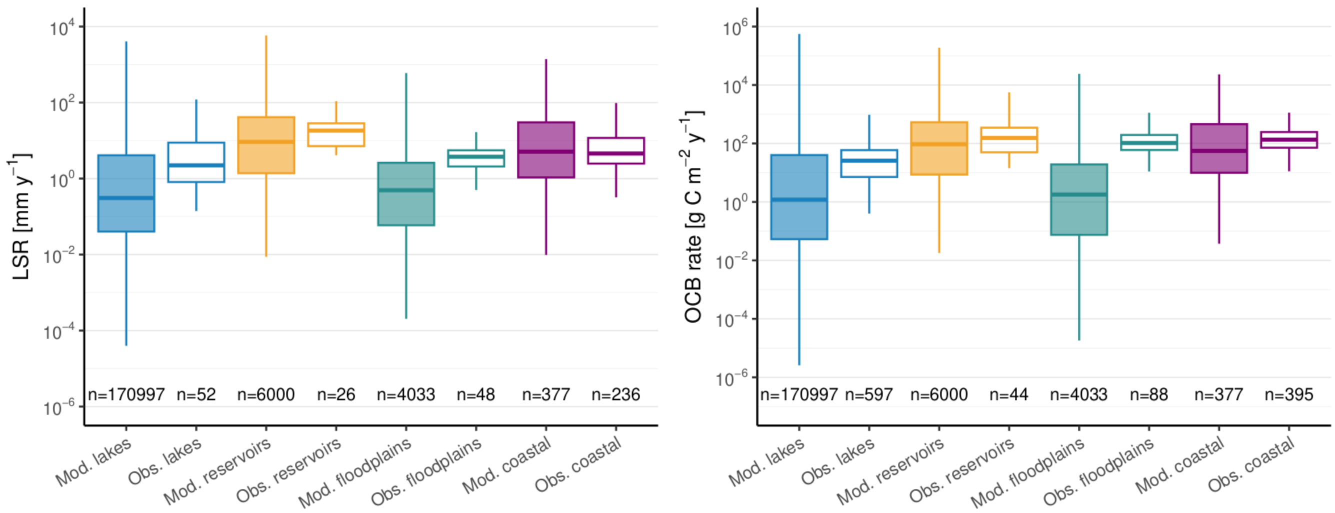
We thank the referee for identifying this issue. The referee is correct that the 30 data points used to derive the LSR-OCBE sigmoidal relationship (Fig. 3) were also included in the original comparison shown in Fig. 6 for lakes and reservoirs. Therefore, the evaluation was not fully independent as originally presented.

To address this concern, we removed these 30 observations from the Fig. 6 analysis and recalculated all reported statistics. The resulting changes are minor because the remaining sample size is sufficiently large. The median values reported in Section 3.2 remain unchanged, while only the uncertainty estimates (standard deviations of the medians) change slightly. Figure 6 and the corresponding text have been updated accordingly.

The revised paragraphs and figure are:

For LSR: "*Observed values follow a similar pattern: highest medians in reservoirs (10.80 ± 3.00 mm y-1) and coastal systems (4.55 ± 0.55 mm y-1), and lowest in lakes (2.00 ± 0.62 mm y-1) and floodplains (3.75 ± 0.41 mm y-1).*"

For OCB rates: *"Observed values are about one order of magnitude higher, with highest medians in coastal systems (134.0 ± 10.3 g C m-2 y-1), followed by floodplains (104.0 ± 12.3 g C m-2 y-1), reservoirs (101.0 ± 28.3 g C m-2 y-1), and lakes (25.0 ± 1.3 g C m-2 y-1)."*



We have also clarified in the revised manuscript which datasets were used for model calibration and which were used for evaluation to avoid ambiguity regarding the degree of independence between these analyses:

"To evaluate model performance, we compared values and distributions of LSR and OCB generated by LOAC-OCB with those from the global observational dataset (Fig. 6) compiled in a previous work (Henry et al., 2024). ***To ensure independence of this evaluation, the subset of 30 lake and reservoir observations used to calibrate the LSR-OCBE relationship shown in Fig. 3 was excluded from the comparison presented in Fig. 6.****"*

In addition, the simulated LSR (and, consequently, OCB) appears to be systematically lower than the observations. It would be helpful to discuss possible reasons for this bias. One potential explanation could be that the model represents only clay, silt, and sand fractions, while other particle classes that contribute to sediment accumulation (such as plant debris, algal biomass, biogenic silica, carbonates, or organic-mineral aggregates) are not explicitly represented. Could the omission of such materials contribute to the discrepancy?

We thank the referee for this observation. We agree that the lower modeled LSR and OCB values warrant further discussion. As now discussed more explicitly in Section 3.2, several factors may contribute to these discrepancies, including observational datasets being biased toward systems with high sedimentation and OC burial rates, differences in spatial scale between site-based observations and the large ecosystem units represented by the model, and the exclusion of small lakes.

We also agree that the omission of certain materials not explicitly represented in the sediment module may contribute to the observed differences. LOAC-OCB represents the transport and deposition of clay, silt, and sand fractions and calculates burial from terrestrially derived POC associated with these particles. Consequently, sediment accumulation associated with autochthonous biomass production, plant debris, biogenic silica, carbonates, organic-mineral aggregates, and other non-terrestrial components is not explicitly represented. In systems where these components contribute substantially to sediment accumulation, observed LSR and OCB values may therefore exceed those predicted by the model.

This explanation is consistent with another important distinction between the model and many observational estimates: LOAC-OCB specifically represents the fate of terrestrial (allochthonous) POC, whereas observed sediment accumulation and OC burial generally integrate both allochthonous and autochthonous contributions. We have expanded the discussion of these potential sources of discrepancy in the revised manuscript. The revised text in Section 3.2 (current L396-398) reads as follows:

"The observed distributions of LSR and OCB for reservoirs and coastal ecosystems fully overlap with the modeled distributions, showing strong agreement. For lakes, observed distributions also overlap with modeled distributions but primarily at the upper end of the range. Several factors likely contribute to these differences: (i) observational datasets are biased toward systems with high sedimentation and OC burial rates, (ii) observational estimates generally include both allochthonous and autochthonous OC whereas LOAC-OCB only represents terrestrial OC, and (iii) the exclusion of small lakes and the large spatial units used to represent floodplains tend to reduce modeled rates relative to many site-based observations. These factors are discussed in more detail below."

Furthermore, the possibility of observational bias is supported by ecosystem types for which substantially more data are available. For example, in lakes and reservoirs, the observational dataset appears biased toward systems with high OC content and elevated burial rates, as illustrated by the concentration of observed systems within the upper range of OC contents and OCB rates relative to the much broader distribution represented by the model. Such a bias is expected because sediment studies are often preferentially conducted in systems known or presumed to exhibit substantial organic carbon accumulation and are therefore not necessarily representative of the global population of aquatic ecosystems. Therefore, a similar effect may also contribute to the apparent discrepancy observed for floodplains, where observational data are considerably more limited.

In particular, the largest deviations occur for floodplains, where modeled values are lower than observations. We attribute this mainly to (i) the limited amount of observational data available for these systems, which may bias the literature toward sites with particularly high sedimentation and OC burial rates; (ii) the large differences in spatial scale between modeled units and field measurements, as observational studies typically focus on relatively small depositional hotspots whereas the model represents much larger floodplain units; and (iii) the lack of a globally consistent definition of floodplain boundaries, which introduces additional uncertainty in both observed and modeled estimates. These factors are expected to increase the likelihood of observing higher LSR and OCB values in the literature than those obtained when averaging across the much larger floodplain areas represented by the model. The observed discrepancies are therefore indicative of differences in definitions, scale, and data availability.

We added a clarification in Section 3.2 of the revised manuscript (current L418-420):

“These large discrepancies in spatial scale between modeled units and field observations likely influence their comparability. Because field studies often target depositional hotspots, whereas LOAC-OCB represents average conditions across much larger floodplain units, such scale mismatches are expected to yield higher observed LSR and OCB values than modeled estimates. This should not be interpreted as a shortcoming of either approach but as a consequence of their intrinsic differences in scale and methodology.”

Some detailed/technical comments:

line 186: Please provide a reference for this equation and/or the parameters used. Are they specifically for terrestrial OC?

We thank the referee for pointing this out. We have now added the appropriate reference (Maavara et al., 2017). The mineralization formulation is not specific to terrestrial POC, but rather represents a generic first-order decay model for organic carbon mineralization in aquatic systems. In Maavara et al. (2017), the approach is applied to both allochthonous and autochthonous organic carbon pools, with mineralization rates controlled by temperature and residence time. We therefore considered it appropriate for representing the mineralization of terrestrial POC during transport through the LOAC.

Line 204: why is the depth of the river needed

We thank the referee for this question. River depth is required to estimate the hydraulic radius used in Eq. 6, which is needed to calculate water residence time in river nodes. Because residence time directly influences OC mineralization during downstream transport, an estimate of river depth is necessary even though sedimentation and burial are not calculated within river nodes. To clarify this point, we have added a short explanation in Section 2.4.3 after Eq. 6 of the revised manuscript:

“... where RT is the water residence time (s); l is the length of the stream segment (m) which varies depending on whether flow occurs between horizontally, vertically, or diagonally connected cells; n = 0.044 is the Manning coefficient (s $m^{1/3}$) (Font et al., 2019); R is the hydraulic radius (m) that is estimated from channel width and depth relationships; and s the channel slope (m m^{-1}).”

Line 209 – 211: reference needed

We thank the referee for pointing this out. The estimation of floodplain inundation depth as the difference between water depths under maximum and mean discharge conditions is not derived from a previously established approach but rather from a modeling assumption adopted within LOAC-OCB. Because the model operates in a steady-state framework at annual timescales, it requires a single representative inundation depth for each floodplain system rather than an explicit simulation of transient flood dynamics. We therefore approximated floodplain depth as the additional water depth associated with high-flow conditions relative to average-flow conditions. We have clarified this assumption in the manuscript.

We have clarified this in the manuscript.

"Given the absence of globally consistent floodplain water-level observations, floodplain inundation depth is approximated as the additional water depth occurring under high-flow conditions relative to average-flow conditions. This simplified representation provides a representative inundation depth, as LOAC-OCB operates at annual timescales and does not explicitly simulate transient flood dynamics."

line 218: "that depends on the flow direction": unclear

We thank the referee for pointing this out. The original wording was ambiguous. Here, the length of the stream segment depends on the flow direction because raster cells connected diagonally have a longer flow path than cells connected horizontally or vertically. We have clarified this in the revised manuscript as you can see in the answer of the previous comment for Line 204.

Eq. (14): how is SED_{bur} different from $Oc_{bur\text{-}ws}$ in eq. (2)?

We thank the referee for pointing this out. We believe the confusion originated from a typographical error in Eq. 14, where OC_{depo} was mistakenly written instead of SED_{depo}. We apologize for this oversight. The corrected equation is:

$SED_{bur} = SED_{depo} - OC_{min\text{-}sed}$

We also agree that the distinction between sediment burial (SEDbur) and organic carbon burial (OCbur) was not sufficiently clear. SEDbur represents the sediment mass remaining after sediment mineralization and is used to estimate LSR and OCBE, whereas OCbur represents the amount of organic carbon permanently buried in the sediments. We have corrected Eq. 14 and clarified this distinction throughout Section 2.4.5 of the revised manuscript.

In Section 2.4.5, current L267: *"The first iteration starts with the assumption that the sediment burial rate (SED_{bur}, in kg m^{-2} y^{-1}), representing the mass of sediment ultimately buried within the sediment column after accounting for OC mineralization, and its OC content ($\%OC_{bur}$) are equal to SED_{depo} and $\%OC_{depo}$, respectively."*

In Section 2.4.5, current L280: *"Note that SED_{bur} represents sediment burial and not OC burial, which is represented separately by OC_{bur}."*

Eq. (15) OC_{ws} is only mentioned here

We thank the referee for identifying this typographical error. The variable name OC_{ws} in Eq. (15) should be $OC_{bur\text{-}ws}$, consistent with the notation introduced in Eq. (2). We have corrected this typo in the revised manuscript. The revised equation is:

$\%OC_{bur} = OC_{bur\text{-}ws} \cdot 100/SED_{bur}$

Section 2.5 Input data: I suggest changing the titles of the subsubsections (2.5.1 – 2.5.3) to something more descriptive

We thank the referee for this suggestion. To improve clarity, we have revised the subsection titles as follows:

2.5.1 Input step 1: Hydrological forcing
2.5.2 Input step 2: Geospatial and ecosystem datasets
2.5.3 Input step 3: OC and sediment inputs

These titles better reflect the content of each subsection while maintaining the stepwise structure of the methodology.

line 311 – 313: unclear

We thank the referee for pointing this out. We agree that the original description was too brief. We have revised the manuscript to clarify that, following Golub et al. (2022), when multiple water bodies occurred within a pixel, the representative water body was selected using a depth-weighted median criterion, with lake area used as the weighting factor.

"The HydroLAKES database contains approximately 1.4 million water bodies, and at the model's spatial resolution, multiple systems may occur within the same pixel. To address this, we selected a single representative water body per pixel following the approach of Golub et al. (2022), whereby, when multiple lakes were present within a pixel, the representative water body was chosen based on the depth-weighted median lake depth, using lake area as the weighting factor."

line 320 – 324: please rewrite, I found this a little unclear

We thank the referee for pointing this out. We agree that the original explanation was unnecessarily detailed and could be difficult to follow. We have revised the text to clarify that the issue arises when a lake or reservoir located on a tributary is assigned to the main channel because both features occur within the same model pixel, potentially leading to an overestimation of contributing discharge. The revised text is shown below:

"This version of LOAC-OCB considers one representative lake or reservoir per node and, conceptually, assumes that it is located along the main river channel, since each node receives all upstream runoff as a single unit. Although the model operates at a relatively fine spatial resolution and isolated systems are already excluded, some potential mismatches in discharge assignment can still occur due to the working spatial scale. ***For instance, when a lake or reservoir is located on a tributary very close to its confluence with the main channel, the spatial resolution may prevent the model from distinguishing whether the water body belongs to the tributary or the main channel. In such cases, the water body may be incorrectly assigned to the main channel and receive a substantially larger contributing discharge than it would in reality.*** *To avoid this kind of spatial mismatch…"*

line 338 – 339: unclear

We thank the referee for pointing this out. We agree that the original wording was unclear, as "maximum discharge" is not derived from the absolute maximum runoff value. Instead, it is approximated using the 90th percentile of the monthly runoff time series. We have revised the text to clarify this point:

“Maximum discharge is approximated by the 90th percentile of monthly runoff values derived from the same WaterGAP time series (Gosling et al., 2025), calculated using the Climate Data Operator (CDO) software.”

line 354: GloSEM, is this a typo? I couldn’t find the abbreviation in the paper.

We thank the referee for pointing this out. The acronym GloSEM was introduced in a later development of the modelling framework, but it is not explicitly used in the original dataset publication on which this study is based (Borrelli et al., 2017). To avoid confusion regarding the specific product used, we have removed the acronym from the manuscript:

“Local sediment input at each node is estimated as the amount of soil displaced by water, expressed in Mg ha^{-1} y^{-1}, based on global soil erosion estimates derived using a RUSLE-based modeling framework (Borrelli et al., 2017).”

Line 356 – 358: unclear what is meant by “A separate sediment and OC mass balance are performed for each particle fraction”

We thank the referee for pointing this out. We agree that the original wording was unclear. The intention was to indicate that clay, silt, and sand fractions are tracked independently throughout the model because their different settling velocities influence sediment retention and burial. We have revised the text accordingly to clarify that separate sediment and OC flux calculations are performed for each particle-size fraction before aggregating them into total loads.

“Separate sediment and OC mass balances are calculated for each particle-size fraction, accounting for differences in settling velocity that affect sedimentation and burial at burial nodes. The resulting fluxes are then aggregated to obtain total sediment and OC loads.”