Referee #2

1. The authors present modelling results of lateral OC transfers based on an improved representation of POC and DOC transfer using the ORCHIDEE LSM model. Model outputs cover European catchments during the period from 1901 to 2014. The authors provide very interesting results on various OC budget component for the given period, which have not been published at the European scale (e.g. how much sediment/POC is stored in floodplains and exported to oceans). Furthermore, the authors compare the C budget with and without lateral C transfer and provide interesting information on the discussion of the net effect of lateral sediment transfer of the carbon budget. Overall, the study is of great interest and certainly the develop model provides a significant step forward on that topic (as far as I can judge this from a non-modeler point of view). I recommend this manuscript to be published in ESDyn after major revisions. Please consider the general and more detailed comments below to improve the submitted manuscript.

Kind regards

Thomas Hoffmann

Thanks a lot for your positive comments, as well as your suggestions and corrections below. Your comments are very helpful to improve our manuscript. We have carefully studied them and revised our manuscript accordingly. Please see our responses to your specific comments below.

2. General comments

It is very hard to understand the model setup as a non-model expert and the text is not very communicative to motivate and convince non-model experts to read the paper. I suggest that the authors should critically prove how they can motivate the linkages between the empirical evidences and the model setup. I had hard times to understand the general model approach and still do not fully understand how the authors define headwaters and whether they differentiate headwater sizes depending on the climate /lithology etc. But maybe I was

blind and unable to extract the relevant information. In any case, many assumptions/ approaches are not straight forwards and description should be improved.

Sorry for having not provided a detailed description on our model setup, especially regarding the scheme for simulating sediment and POC delivery from headwater basins to river networks, as this scheme has already been explained in detail in our previous paper by Zhang et al. (2020).

Our simulations are based on the well-established, simple but efficient MUSLE model. Note that this model is usually applied to small headwater basins, and high resolution geospatial data is needed to delineate single headwater basins and to parametrize the model. In order to use that approach in a land surface model (LSM) which runs at a coarse spatial resolution of 0.5 degree (~50km), we applied the following strategy: To simulate the sediment and POC deliveries from land soils to river networks, we first extracted the headwater basins and river networks from high-resolution DEM data (3″ (~ 90 m), Fig. S2a,d). Then the MUSLE model (Eq. 1) was applied to each headwater basin, parametrizing the model with information on topography and soil erodibility derived from similarly highly resolved geodata. For parameters related to vegetation cover, runoff and land management, which are variable over time, we applied freely chosen values which we applied as reference values to all headwater basins. The so obtained estimates of "reference net-soil erosion rates" were then aggregated to the 0.5 degree resolution used for our simulations with ORCHIDEE-Clateral (Fig. S2e). For the simulations of daily net-soil erosion in ORCHIDEE-Clateral, we took advantage of the fact that according to the MUSLE equation, changes in predicted net-soil erosion rates scale to changes in runoff and vegetation cover (Eq. 3, Fig. S2f). To that end, we use the rasterized predicted reference erosion rates as a forcing file for ORCHIDEE-Clateral, and use ratios between daily runoff and vegetation cover values simulated with that model and the reference values used to produce the forcing file to estimate the actual daily soil loss rate from land to river in each 0.5 degree grid cell of the model grid (Eq. 4, Fig. 2g). This upscaling scheme and the method for extracting headwater basins and river networks is described in detail in Zhang et al. (2020) , and for that reason we only provide a brief overview of the methodology in this manuscript.

We have thus revised the method section of this manuscript and added a supplementary figure (Fig. S2) to provide a more detailed explanation of the method for simulating sediment delivery from uplands to river channels. Please see "To give an accurate simulation of sediment delivery from uplands to river network and maintain computational efficiency, an upscaling scheme which integrates information from high-resolution (3″) topographic and soil erodibility data into a LSM forcing file at 0.5° spatial resolution, has been introduced (see details in Zhang et al., 2020, Fig.S2). With this upscaling scheme, the erosion-induced sediment and POC delivery from upland soils to the river network, as well as the changes in SOC profiles due to soil erosion had already been implemented in ORCHIDEE-MUSLE (Zhang et al., 2020). The sediment delivery from small headwater basins (which are basins without perennial stream and are extracted from high-resolution (e.g. 3″) digital elevation model (DEM) data, Figs. S2a&d) to the river network (i.e. gross upland soil erosion – sediment deposition within headwater basins) is simulated using the Modified Universal Soil Loss Equation model (MUSLE, Williams, 1975). As introduced in Zhang et al. (2020), "the daily sediment delivery rate from each headwater basin (S_{i_ref}, Mg day^{-1} basin^{-1}) is first calculated for a given set of reference runoff and vegetation cover conditions (Fig. S2e)" (lines: 216-227)

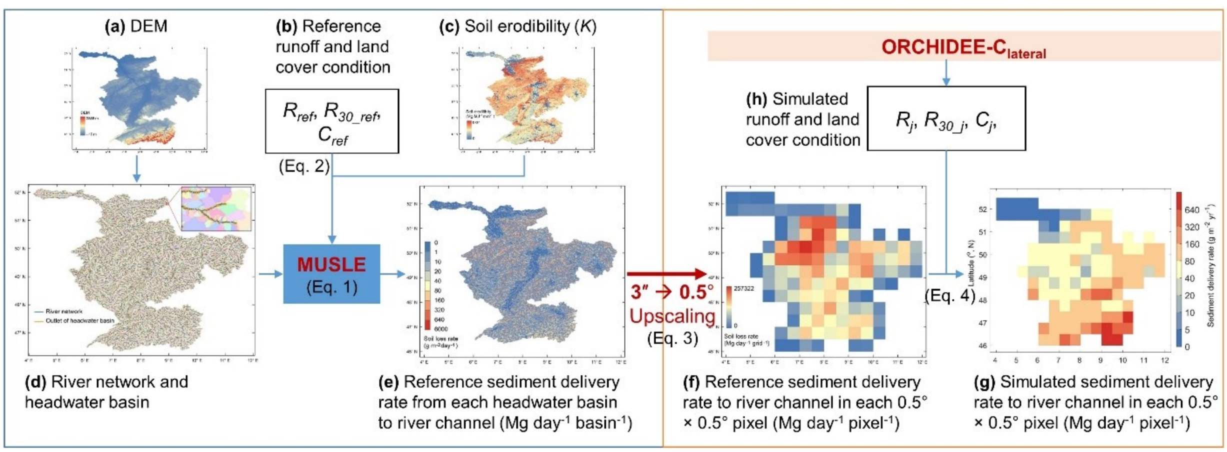

Figure S2 Upscaling scheme used in ORCHIDEE-MUSLE (Zhang et al., 2020) for calculating the sediment delivery rate from headwater basins to river networks. MUSLE is the Modified Universal Soil Loss Equation; DEM is the digital elevation model (m); *K* is the soil erodibility factor (Mg MJ-1 mm-1); R_{ref} is the assumed reference daily runoff depth (= 10 mm day^{-1}); R_{30_ref} is the assumed reference maximum 30-minutes runoff depth (= 1 mm 30-minutes^{-1}); C_{ref} (= 0.1, dimensionless) is the assumed reference cover management factor; R_{iday}, R_{30_iday} and C_{iday} are the simulated daily total runoff depth, daily maximum 30-minutes runoff depth and daily cover management factor, respectively.

Zhang, H., Lauerwald, R., Regnier, P., Ciais, P., Yuan, W., Naipal, V., Guenet, B., Van Oost, K., and Camino-Serrano, M.: Simulating Erosion-Induced Soil and Carbon Delivery From Uplands to Rivers in a Global Land Surface Model. J. Adv. Model. Earth Syst., 12, e2020MS002121, 2020.

3. The general concept, as depicted in Figure 1, draw an arrow (F_up2fld) from the upstream basin to the floodplain. I was wondering if this transport path is needed? The main transfer to floodplains steams from the main river channel that is passing the floodplain. The potential inputs from upstream basins is of academic nature and could be neglected.

The scheme used to simulate flooding flows in ORCHIDEE-Clateral is identical to that used in the ORCHILEAK model (Lauerwald et al., 2017). In the routing scheme of the model, all water coming from upstream lying cells of the modelling grid enter the mainstream of the river in a particular cell. If these inflows exceed the predefined bankfull flow, the excess water is flowing into the floodplains instead of into the river mainstream, while only the amount of water that equals the bankfull flow enters the mainstream directly. In a way, this model set-up represents the idea that most of the water and sediments entering the floodplains is coming from the mainstream. We realize that the name of the flux "F_{up2fld}" might have been a bit misleading here. Indeed, no water coming from the hinterland of the floodplains is actually entering these floodplains. We have changed the original "F_{up2fld}" to "$F_{riv2fld}$" in the revised MS to avoid this confusion. Please see:

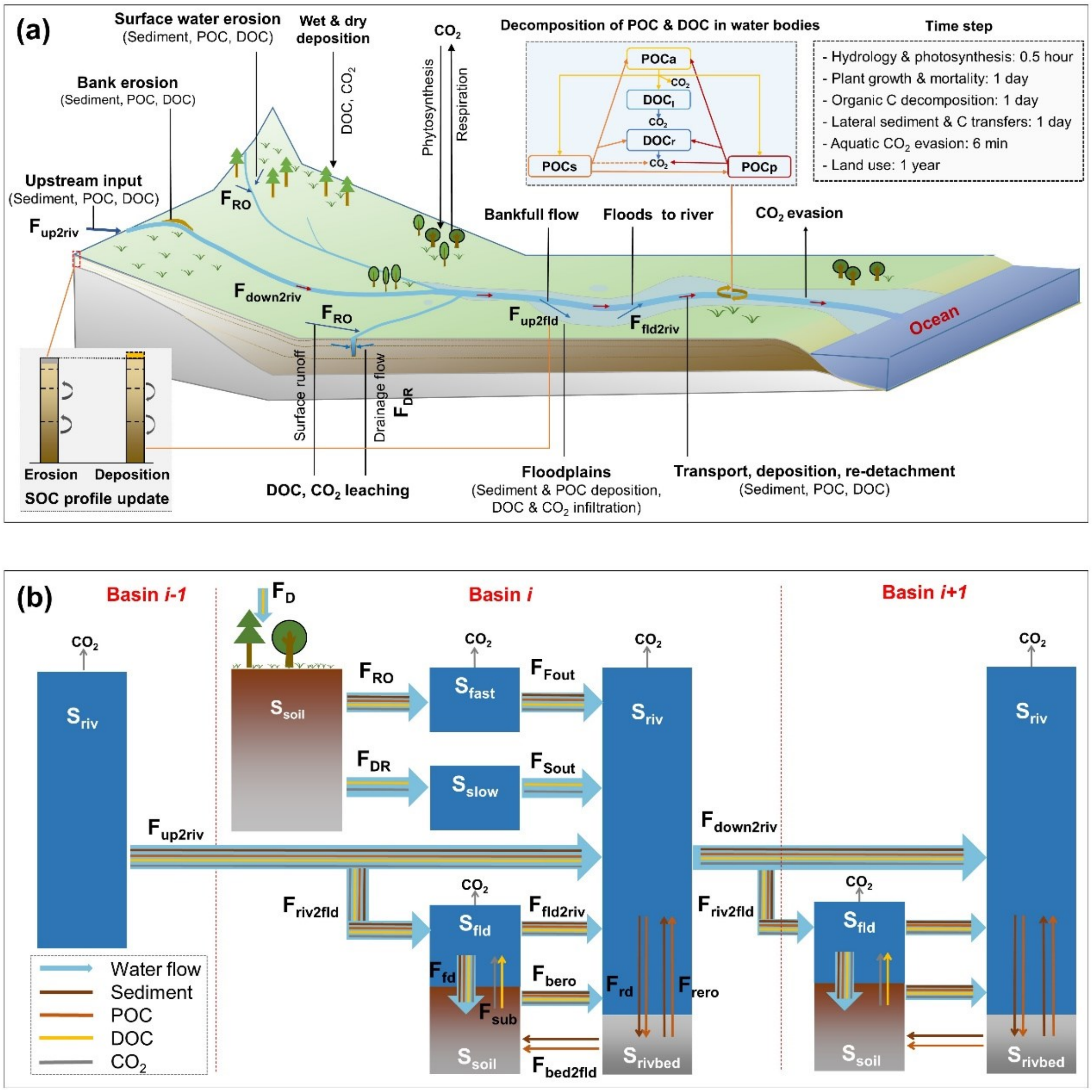

Figure 1 Simulated lateral transfer processes of water, sediment and carbon (POC, DOC and CO_2) in ORCHIDEE-$C_{lateral}$ (a) and a schematic plot for the reservoirs and flows of water, sediment and carbon represented in the routing module of ORCHIDEE-$C_{lateral}$ (b). S_{soil} is the soil pool. S_{rivbed} is the sediment (also POC) deposited in river bed. S_{fast}, S_{slow}, S_{riv} and S_{fld} are the 'fast', 'slow', stream and flooding water reservoir, respectively. F_{RO} and F_{DR} are the surface runoff and belowground drainage, respectively. F_{Fout} and F_{Sout} are the flows from fast and slow reservoir to the stream reservoir, respectively. F_{up2riv} and $F_{down2riv}$ are the upstream inputs and downstream outputs, respectively. $F_{riv2fld}$ is the outputs from river stream to the flooding reservoir. $F_{fld2riv}$ is the return flow from flooding reservoir to stream reservoir. $F_{bed2fld}$ is the transform from deposited sediment in river bed to floodplain soil. F_{bero} is bank erosion. F_{rd} and F_{rero} are the deposition and re-detachment of sediment and POC in river channel, respectively.

F_{sub} is the flux of DOC and CO2 from floodplain soil (originated from the decomposition of submerged litter and soil carbon) to the overlying flooding water. F_{fd} is the deposition of sediment and POC and the infiltration of water and DOC. F_D is the wet and dry deposition of DOC from atmosphere and plant canopy. DOC_l and DOC_r are the labile and refractory DOC pool, respectively. POC_a, POC_s and POC_p are the active, slow and passive POC pool, respectively.

4. Major parts of Europe are missing in terms of observations of suspended sediment loads (e.g. no observation for Spain, France GB, Italy), esp. Mediterranean rivers are not covered in this study. Due to the very different behavior of streams in south and north Europe, the study is strongly biased toward N-Europe. This becomes even more important by the comparison with the model output from WATEM/SEDEM for the two catchments of the Apennine Peninsula, which are simply ignored as 'outliers'.

Although the simulated sediment loss rates in the two catchments of the Apennine Peninsula is significantly lower than the estimates from WATEM/SEDEM, the simulated sediment loss rates in many catchments in southern and western Europe (e.g. France and Spain) are overall comparable to the estimates from WATEM/SEDEM. Moreover, the average sediment loss rate over all catchments is 40.8 g m^{-2} yr^{-1}, which is overall comparable to the estimate by the WaTEM/SEDEM (42.5 g m^{-2} yr^{-1}) (this result has been added to the revised manuscript, see lines: 545-546). Given this, our simulation result on sediment delivery rate from upland soils to river networks are, we believe, overall acceptable. Nonetheless, we recognize that further calibration of model using data from southern and western Europe would be very useful to decrease the uncertainties in our model andwe have stressed this aspect in our revised ms. Please see "Further model calibration, evaluation and development is necessary for improving our model. Due to the limitation of observation data, we calibrated the parameters controlling sediment transport, deposition and re-detachment (i.e. ω, c_{rivdep}, c_{flddep}, c_{ebed} and c_{ebank} in Table S1) in stream and flooding reservoirs only against the observed sediment yield. Even though our model can overall capture the lateral transfers of sediment and carbon in many rivers in central and northern Europe, more observation data are crucially needed to further evaluate the performance of our model, in particular in southern Europe. In addition, it is still unknown whether our model can satisfactorily simulate intermediate processes such as sediment deposition in river channels and floodplains, as well as the rate of river channel erosion. It is also unknown whether our model would perform satisfactorily in regions with very different climates than Europe such as the tropical region. Thus, in the future, an important aim will be to further calibrate our model against more detailed observation data (e.g. sediment deposition rate in river channels and floodplains) and extend the model application to regions of contrasting climate, vegetation and topography." (lines: 919-932)

5. The authors provide model runs with and without lateral C transport and find that SOC stock only marginally increase of lateral flux is turned on. This very low increase somehow contradicts the large amount of POC retention in floodplains. The authors somehow provide numbers with SOC stock decrease in mountains and SOC stock increases in floodplains, but does this mean that SOC retention in floodplains is more or less fully compensated by soil degradation at eroding sites? It was argued that at long-term (10^3a) OC retention in floodplains is more important than soil degradation, while at shorter terms (couple of years) degradation effect might dominate. I wonder what happens to the model if the authors considerer shorter and much longer time scales than those used in this study. Please discuss this in more detail.

Thanks for your thoughtful comment and suggestion. From 1901 to 2014, integrated erosion and leaching over Europe induced a loss of 3.03 Pg organic carbon (POC+DOC) from uplands to the river network, and only 0.65 Pg of this carbon flowed back to soils with flooding waters. The total stock of soil organic carbon in Europe thus should have decreased by 2.38 Pg C. However, due to the decrease in decomposition rate of the buried organic carbon (including in-situ and ex-situ carbon) in floodplain soils, the total stock of soil organic carbon in Europe only decreased by 0.91 Pg C. Floodplains in Europe have overall prevented 2.12 (= 3.03 - 0.91) Pg soil organic carbon from being transported to the sea or released back to the atmosphere in the form of CO_2. Although the sequestration of organic carbon in floodplains cannot make up for all of the soil organic carbon loss, the increased organic carbon stock in floodplains (2.12 Pg C) is much higher than the sole soil POC loss (0.86 Pg C) induced by soil erosion. We have added one paragraph to discuss this. Please see:

“Consistent with previous studies (Stallard, 1998; Smith et al., 2001; Hoffmann et al., 2013), our simulation results showed the importance of sediment deposition in floodplains with regard to the overall SOC budget. From 1901 to 2014, erosion and leaching over Europe totally induced a loss of 3.03 Pg organic carbon (POC+DOC) from uplands to the river network, and only 0.65 Pg of this carbon was redeposited onto the floodplains. The total stock of soil organic carbon in Europe thus should have decreased by 2.38 Pg C. However, due to the decrease in decomposition rate of the buried organic carbon (including in-situ and ex-situ carbon) in floodplain soils, the total stock of soil organic carbon in Europe only decreased by 0.91 Pg C. Floodplains in Europe have totally protected 2.12 (= 3.03 - 0.91) Pg soil organic carbon from been transported to the sea or be released to the atmosphere in forms of CO_2. Although the sequestration of organic carbon in floodplains cannot make up all of the soil organic carbon (POC+DOC) loss, the increased organic carbon stock in floodplains (2.12 Pg C) is much higher than the soil POC loss (0.86 Pg C) induced by soil erosion.” (lines: 789-801)
Moreover, we found that the effect of carbon retention in floodplains on the soil carbon budget is highly variable across regions. For example, in northern Europe where the soil is protected by densely growing forests, DOC leached from soil is the main source of riverine carbon, and soil and POC erosion rate is very low. Floodplains in northern Europe thus cannot store a large amount of organic carbon and the lateral carbon transfer in northern Europe generally results in a significant decrease in total soil organic carbon stock. However, in southern Europe, the soil erosion rates in uplands and sediment deposition rates in floodplains are both high. Floodplains in southern Europe are thus simulated to preserve a large amount of organic carbon. Accordingly, the lateral carbon transfer does not induce a strong decrease in the total soil carbon stock in southern Europe. In some catchments with large areas of floodplains and high sediment deposition, the lateral carbon transfer can even result in an increase in the total soil carbon stock.

In this manuscript, the main aims were to present the model developments and the comparison of model results against (limited) observational data and only cover a few key striking features of the lateral sediment and carbon transfers. Our subsequent, ongoing work now targets a model application study that explores in detail the spatiotemporal variation of the lateral carbon transfers over Europe during the period 1901-2014, as well as the impacts of the different processes of lateral carbon transfer on the regional terrestrial carbon budget. Therefore, we do not explore the effects of sediment and carbon deposition on the soil carbon budget for different time scales here, as this is beyond the scope of the present study. We agree that extending the simulations to the millennial timescale to explore the long-term effects of lateral carbon transfer on the land carbon budget is a great idea, and we will consider such simulations in the future.

6. Detailed comments

Line 38: 'but also leaching of DOC' → needs some more details, leaching from where?

We added 'soil' before DOC to more accurately describe the source of DOC. Please see "Erosion of soils and the associated organic carbon, but also leaching of soil dissolved organic carbon (DOC), represent a non-negligible leak in the terrestrial carbon budget and a substantial source of allochthonous organic carbon to inland waters and oceans" (lines: 37-40)

7. Line 45: I suggest to refer to a new review on OC sequestration in floodplains (https://doi.org/10.1016/B978-0-12-818234-5.00069-9)

Thanks for your suggestion. We have added this new reference in our manuscript. Please see "Meanwhile, the organic carbon that is redeposited and buried in floodplains and lakes might be preserved for a long time, thus creating a CO_2 sink (Stallard, 1998; Van Oost et al., 2007; Wang et al., 2010; Hoffmann, 2022)." (lines: 43-46)

8. Line 169ff: the many branches/modules etc. make it very hard to understand the model setup. Could you somehow visualize it?

Thanks to your suggestion. We have added a supplementary figure to visualize the difference between different branches of the ORCHIDEE model, as well as the developing history of these branches. Please see:

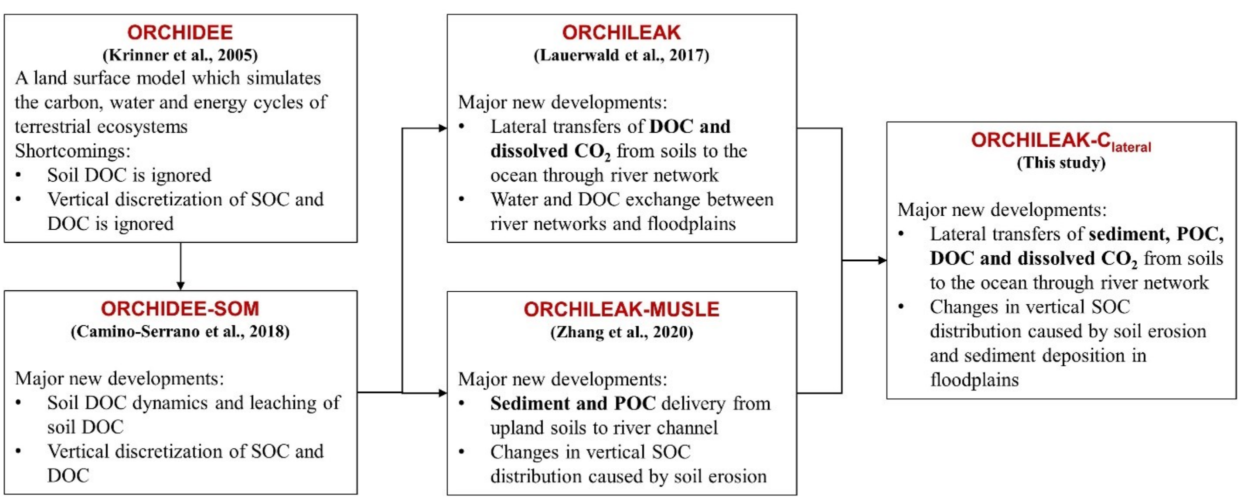

Figure S1. Properties and the developing history of the ORCHIDEE branches mentioned in this study.

9. Line 228: I suggest to avoid sediment delivery rate, as this might be confused with sediment delivery ratio. Please use sediment supply instead. How are headwater basins defined in this study?

The sediment delivery rate is very different from sediment delivery ratio, and we have provided the unit of sediment delivery rate to make the readers aware of that difference. In order to be consistent with our previous studies (e.g. Zhang et al., 2020), we prefer to keep using sediment delivery rate. For the explanation of headwater basins, please see our response to your comment #2.

10. Line 229: given set of runoff and vegetation cover conditions → could you specify them and motivate, why you refer to the reference runoff condition rather than actual runoff. This might be explained in the original reference. However, I highly recommend to give more details here, to ease the understanding of the approach.

The assumed runoff and vegetation cover conditions are used for our upscaling scheme. We introduce this upscaling scheme because it integrates high-resolution (3″) topographic and soil erodibility data into our simulation of sediment delivery from uplands to river channels at 0.5° spatial resolution while maintaining the computational efficiency of our model. As this upscaling scheme has been explained in detail in our previous study (Zhang et al., 2020), we only provide a brief description in this study. Nonetheless, we have revised our manuscript and added a supplementary figure (Fig. S2) to explain our method in more details. Please see our response to your comment #2 for more details.

11. Line 232: Is this really a runoff or rather a precipitation reference (given the 10mm day-1)?

Yes, it is runoff with a unit of mm day^{-1}, that means it is a flux rate normalized by area. In ORCHIDEE, the runoff is calculated as: runoff = precipitation – canopy interception – evaporation – infiltration. The unit of all these variables is mm day^{-1}. We use water discharge (m^3 day^{-1}) to describe the water flow in river channels, and the amount of water discharge from land surface to river channel in each grid cell can be calculated as runoff×A_{grid}×10^{-3} (A_{grid} is the area of the target grid cell with a unit of m^2).

12. Line 237: DA^(dDA^c) → is that correct? Looks erroneous

Yes, it is correct. It represents the nonlinear impacts of drainage area to the peak flow rate at the outlet of a water basin.

13. Line 237: is assume that DA is drainage area (not defined)

We have added the definition of DA. Please see "q_{i_ref} was calculated from the reference maximum 30-minutes runoff (= 1 mm 30-minutes^{-1}) depth and drainage area (DA_i, m^2) according to the following equation" (lines: 233-235)

14. Line 238: same as above; (p.5-6) should be linked once more to the reference where this citation is taken from.

We have changed the position of (p. 5-6) from the end of the quoted contents to the place of the reference. Please see:

"As introduced in Zhang et al. (2020, p. 5-6), "the daily sediment delivery rate from each headwater basin (S_{i_ref}, Mg day^{-1} basin^{-1}) is first calculated for a given set of reference runoff and vegetation cover conditions (Fig. S2e):

$$S_{i_{ref}} = a\left(Q_{i_{ref}} q_{i_{ref}}\right)^b K_i LS_i C_{ref} P_{ref} \quad (1)$$

where Q_{i_ref} is the total water discharge (m^3 day^{-1}) at the outlet of headwater basin i for the daily reference runoff condition (R_{ref}) of 10 mm day^{-1}. In Eq. 1, q_{i_ref} is the daily peak flow rate (m^3 s^{-1}) at the headwater basin outlet under the assumed reference runoff condition. Similar to the SWAT model (Soil and Water Assessment Tool, Neitsch et al., 2011), q_{i_ref} was calculated from the reference maximum 30-minutes runoff (= 1 mm 30-minutes^{-1}) depth and drainage area (DA_i, m^2) according to the following equation:

$$q_{i\_ref} = \frac{R_{30\_ref}}{30\times60}\left(DA_i^{\left(d\,DA_i^{c}\right)}\right)1000 \quad (2)$$

where R_{30_ref} (= 1 mm 30-minutes^{-1}) is the assumed daily maximum 30-minutes runoff"." (lines: 225-237)

15. Line 247-249: not sure what the authors want to say here? I guess the model outputs should depend on these parameters.

In our upscaling scheme, the reference runoff (R_{ref}, R_{30_ref}) and vegetation cover (C_{ref}) conditions are only the intermediary for improving the computational efficiency of the model and reduce the usage of computer memory and storage space (these are important for global land surface modeling). They did not result in any change in the simulated result of sediment delivery. Below we provide the detailed process of mathematical transformation to explain why the assumed values of R_{ref}, R_{30_ref} and C_{ref} have no impact on the model output:

$$S_{\mathrm{j}} = \sum_{i=1}^{n} (S_{i\_j}) \times 10^6$$

$$= \sum_{i=1}^{n} \left(a(Q_j\, q_{\mathrm{j}})^b K_i LS_i C_j \right) \times 10^6$$

$$= \sum_{i=1}^{n} \left(a\left((R_{\mathrm{j}}\, DA_{\mathrm{i}}) \times \frac{R_{30\_j}}{30 \times 60} \left(DA_i^{(d\, DA_i^{c})} \right) 1000 \right)^b K_i LS_i C_j \right) \times 10^6$$

$$= \left(R_{\mathrm{j}}\, R_{30\_j} \right)^b C_j \sum_{i=1}^{n} \left(a\left(DA_{\mathrm{i}} \times \frac{1}{30 \times 60} \left(DA_i^{(d\, DA_i^{c})} \right) 1000 \right)^b K_i LS_i \right) \times 10^6$$

$$= \frac{\left(R_{\mathrm{j}}\, R_{30\_j} \right)^b C_j}{\left(R_{ref}\ \ R_{30\_ref} \right)^b C_{ref}} \sum_{i=1}^{n} \left(a\left((R_{\mathrm{ref}}\, DA_{\mathrm{i}}) \times \frac{R_{30\_ref}}{30 \times 60} \left(DA_i^{(d\, DA_i^{c})} \right) 1000 \right)^b K_i LS_i C_{ref} \right) \times 10^6$$

$$= \frac{\left(R_{\mathrm{j}}\, R_{30\_j} \right)^b C_j}{\left(R_{ref}\ \ R_{30\_ref} \right)^b C_{ref}} \sum_{i=1}^{n} (S_{\mathrm{i\_ref}}) \times 10^6$$

$$= \left(\frac{R_j\, R_{30\_j}}{R_{ref}\ \ R_{30\_ref}} \right)^b \frac{C_j}{C_{ref}} S_{\mathrm{ref}}$$

where n is the number of headwater basins in the target 0.5°×0.5° grid cell; i (=1-n) is the serial number of each headwater basin; S_{i_j} (Mg day^{-1} basin^{-1}) is the daily sediment delivery from land to river from headwater basin i on day j. S_{i_ref} (Mg day^{-1} basin^{-1}) is the daily sediment delivery from land to river from headwater basin i under reference runoff and vegetation cover conditions. S_j (g day^{-1} grid^{-1}) is the total daily sediment delivery from land to river in the target

0.5°×0.5° grid cell on day j; S_{ref} (g day^{-1} grid^{-1}) is the total daily sediment delivery from land to river in the target 0.5°×0.5° grid cell under reference runoff and vegetation cover conditions; R_{ref} (mm day^{-1}) is the assumed reference daily surface runoff; R_j (mm day^{-1}) is the simulated surface runoff on day j; R_{30_ref} (= 1 mm 30-minutes^{-1}) is the assumed daily maximum 30-minutes runoff; R_{30_j} (mm 30-min^{-1}) is the maximum value of the 48 half-hour runoffs on day j; C_{ref} (0-1, dimensionless) is the cover management factor and is set to 0.1 for the reference state; C_j (0-1, unitless) is the simulated cover management factor on day j; DA_i (m^2) is the drainage area of headwater basin i; K_i and LS_i is the soil erodibility factor and the slope length and steepness factor, respectively. a, b, c and d are model parameters.

As this upscaling scheme has been explained in detail by Zhang et al. (2020), we only give a brief overview in this study. Nonetheless, we have revised the method section of this manuscript and added a supplementary figure (i.e. Fig. S2) to give a better explanation on the method for simulating sediment delivery from uplands to river channels. Please see our response to your comment #2.

16. Line 250: ORCHILEAK Clateral → subscript lateral

We have revised this sentence following your suggestion. Please see "For the use of these reference sediment delivery estimates in ORCHIDEE-$C_{lateral}$, the values were first calculated for each headwater basin derived from high resolution geodata (Fig. S2e)" (lines: 249-250)

17. Line 251: was this done for various reference conditions?

The reference conditions have no impact on model outputs. We only need to calculate the sediment delivery under one reference condition, and the choice of the values for runoff, peak runoff and vegetation cover do not have an influence on the rescaled daily erosion rates simulated in ORCHIDEE $C_{lateral}$. Please see our response to your comment #15.

18. Line 254: awkward sentence; '…force the simulation of Then…' ?????

Sorry for that mistake. We have revised this sentence. Please see "This aggregated dataset is then used to force the simulation of the actual daily sediment delivery (S_j, g day^{-1} grid^{-1}) in ORCHIDEE-$C_{lateral}$," (lines: 254-255)

19. Line 260: Same b as in Eq.1? Where is S_iday located in Figure 1?

Yes, the b in Eq. 4 is same as that in Eq. 1. Please see our response to your comment #15 for detailed explanation. S_{iday} has been changed to S_j in the revised manuscript and it is represented by the F_{RO} in Fig. 1b (purple line, F_{RO_sed}). F_{RO} represents the surface water flux from land to river network. The eroded sediment flow from land to river network by following F_{RO}.

20. Line 262: R_30_k not in Eq. 3 and 4

Sorry for the typo. It should be R_{30_j}, the simulated maximum 30-minutes runoff on day *j*.

21. Line 304: Is F_{Fout_sed} identical with S_{iday}? Please remove sediment in this sentence, because this is confusing due to the fact that there is no storage in the fast water reservoir.

Yes, the amount of F_{Fout_sed} is identical to S_j (i.e. the S_{iday} in the last version of our manuscript). In our model, S_{fast} is the reservoir fed by surface runoff. Therefore, sediment, POC, DOC and dissolved CO_2 in the surface runoff will first enter the S_{fast} (i.e. the erosion process), and then enter the river streams. Given this, we prefer to keep the sediment in this sentence.

22. Figure 1a: Not sure what the direction of arrows indicates. I suggest that they point from the text to the feature in the graphic (if this is not related to vertical fluxes; unlikely for sediment). S_river and S_flood is used in Figure caption but not within the Figure itself.

In Fig. 1a, we have deleted the arrows which do not represent flow directions. S_{river} and S_{flood} read be S_{riv} and S_{fld}, respectively, and we have corrected this error. The revised Fig. 1 is:

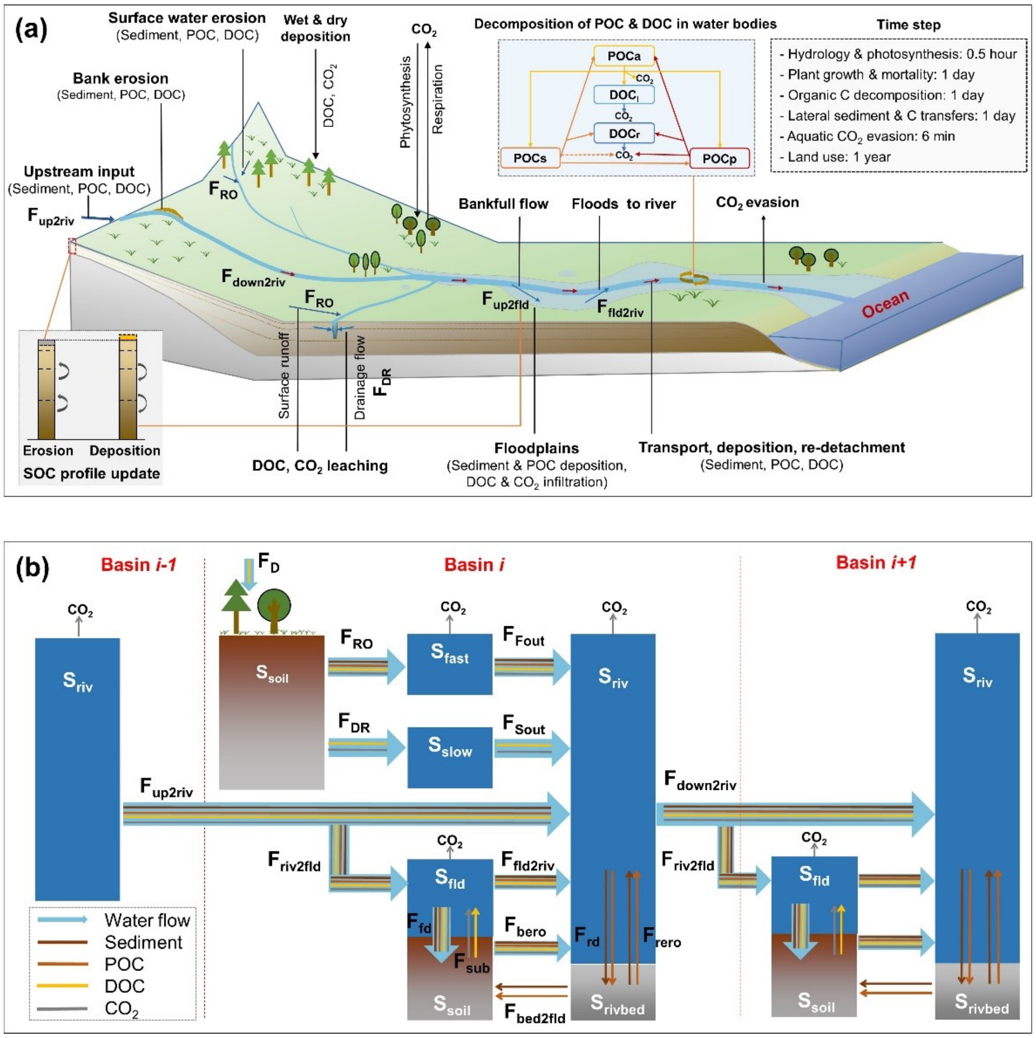

Figure 1 Simulated lateral transfer processes of water, sediment and carbon (POC, DOC and CO_2) in ORCHIDEE-$C_{lateral}$ (a) and a schematic plot for the reservoirs and flows of water, sediment and carbon represented in the routing module of ORCHIDEE-$C_{lateral}$ (b). S_{soil} is the soil pool. S_{rivbed} is the sediment (also POC) deposited in river bed. S_{fast}, S_{slow}, S_{riv} and S_{fld} are the 'fast', 'slow', stream and flooding water reservoir, respectively. F_{RO} and F_{DR} are the surface runoff and belowground drainage, respectively. F_{Fout} and F_{Sout} are the flows from fast and slow reservoir to the stream reservoir, respectively. F_{up2riv} and $F_{down2riv}$ are the upstream inputs and downstream outputs, respectively. $F_{riv2fld}$ is the outputs from river stream to the flooding reservoir. $F_{fld2riv}$ is the return flow from flooding reservoir to stream reservoir. $F_{bed2fld}$ is the transform from deposited sediment in river bed to floodplain soil. F_{bero} is bank erosion. F_{rd} and F_{rero} are the deposition and re-detachment of sediment and POC in river channel, respectively. F_{sub} is the flux of DOC and CO2 from floodplain soil (originated from the decomposition of

submerged litter and soil carbon) to the overlying flooding water. F_{fd} is the deposition of sediment and POC and the infiltration of water and DOC. F_D is the wet and dry deposition of DOC from atmosphere and plant canopy. DOC_l and DOC_r are the labile and refractory DOC pool, respectively. POC_a, POC_s and POC_p are the active, slow and passive POC pool, respectively.

23. Line 323ff: I wonder if the author mix up several things. In rivers, suspended sediment (esp silt and clay which are transport agents of POC) is transported as wash load. The transport of the wash load is not transport capacity limited but supply limited. Whether changes in the channel bed need to be considered depends on the target time scale. Therefore, I am not sure if it is required to discuss Eq. 7 in detail. If the authors specify the relevant scales much earlier in their paper, the lengthy discussed could be reduced.

The scheme used in our model to simulate sediment transport and deposition in river channel is similar to that in many previous sediment transport models such as SWAT (Neitsch et al., 2011), WEPP (Nearing et al., 1989) and ROTO (Arnold et al., 1995). These previous models all assume that suspended sediment in river flows will deposit to river bed when the amount of suspended sediment (including clay and silt sediments) exceeds the sediment transport capacity of the water flow. Moreover, observations also show that clay and silt sediment can deposit in river channels.

The target time scale is decades to a few hundreds of years. Thus, we did not consider the evolution and diversion of river channels. We have added a sentence explaining this important point. We have added a sentence to explain this. Please see "Moreover, as our model mainly aims to simulate the lateral transfer of sediment and carbon at the decadal to centennial timescale, rather than covering the past thousands of years or even longer time periods, we did not consider the evolution and diversion of river channels in our study." (lines: 382-385)

Arnold, J. G., Williams, J. R., and Maidment, D. R.: Continuous-time water and sediment-routing model for large basins. J. Hydraul. Eng., 121, 171-179, 1995.

Nearing, M. A., Foster, G. R., Lane, L. J., and Finkner, S. C.: A Process-Based Soil Erosion Model for USDA-Water Erosion Prediction Project Technology. Transactions of the Asae, 32, 1587-1593, 1989.

Neitsch, S. L., Williams, J. R., Arnold, J. G., and Kiniry, J. R.: Soil and Water Assessment Tool Theoretical Documentation Version 2009. Texas Water Resources Institute, College Station, 2011.

24. Line 357: what is e1 in Eq.8?

Line 361: Drainage area in Eq 1 was defined with DA. Use same symbols!

Line 361: In Eq. 8 the term F_down2riv_h20 is used, here in the text you use F_down2riv_sed but talk about water discharge. I am confused. I assume you refer to the Psi-equation of Cohen et.al. If this is true

Sorry for the mistakes. We have revised the manuscript according to your comments. In the revised manuscript, we provided the explanation of e_1 and changed symbol for drainage area to *DA*. Please see: "

$$TC = \frac{\omega\, {q_{ave}}^{0.3}\, A^{0.5} \left(\frac{q_{iday}}{q_{ave}}\right)^{e_1} (24\times60\times60)}{F_{down2riv\_h20}} \tag{8}$$

$$e_1 = 1.5 - max(0.8, 0.145\log_{10} DA) \tag{9}$$

where ω is the coefficient of proportionality, q_{ave} ($m^3\ s^{-1}$) is long-term average stream flow rate obtained from an historical simulation by ORCHILEAK (Table 1), q_j ($m^3\ s^{-1}$) is stream flow rate on day *j*, e_1 is an exponent depending on the upstream drainage area (*DA*, m^2), $F_{down2riv\_h20}$ (m^3 day^{-1}) is the daily downstream water discharge from the stream reservoir." (lines: 331-336)

25. Line 371: Assuming that channel bank erosion only occurs if no sediment is left at the channel bank is not a meaningful assumption. Many rivers migrate without changing their channel bed.

For a global scale land surface model, it is very hard to simulate in detail the erosion of river channel, as well as the evolution of the river channel, due to the coarse resolution as well as important limitations associated with fragmented forcing data and calibration data. Thus, we have introduced a very simple scheme to simulate the transport and deposition of riverine sediment, and the erosion of the river channel. The geomorphic properties of river channel in our model are assumed to be fixed. To avoid too much sediment deposition and/or too high erosion rate of the river channel, we assumed that bank erosion only occurs when all of the previously deposited sediment is eroded. We recognize that this assumption might not hold true for all rivers. However, as there is still no well-tested algorithm to simulate river channel erosion at continental/global scales (to our knowledge) to date, we believe that relying on this simplifying assumption is the best we can do for now. Nevertheless, following the reviewer's comment, we now discuss this shortcoming in the revised ms.. Please see "In the present version of ORCHIDEE-$C_{lateral}$, the lateral transfers of sediment and carbon is simulated using a simplified scheme, due to the fragmented nature of large-scale forcing (e.g. geomorphic properties of the river channel) and validation data (e.g. continuous sediment and carbon concentration data in river streams and deposition/erosion rates inriver channels). We recognize that this simplification induces significant uncertainties in model outputs, especially regarding changes in lateral sediment and particulate carbon transfers under climate change and direct human perturbations." (lines: 803-809)

"Overall, we encourage future studies to produce large-scale databases on the geomorphic properties of global river channels (e.g. river depth and width) and to develop large-scale sediment transport models capable of producing more realistic simulations of sediment deposition, re-detachment and transport processes, including the exchanges of water, sediment and carbon between river streams and floodplains." (lines: 835-840)

26. Line 387: F_up2fld_sed not needed in my point of view. Why was this introduced and and why is there no F_riv2fld?

Please see our response to your comment #3.

27. Line 390: sum in text but negative sign in Eq. 16 → furthermore, I don't understand the approach here. Why does evaporation and infiltration contribute to sediment deposition? Please explain.

Sorry for the mistake in Eq. 16. The total sediment deposition in floodplain is calculated as the sum of a natural deposition + the deposition due to evaporation (E_{h2o}, m^3 day^{-1}) and infiltration (I_{h2o}, m^3 day^{-1}) of the flooding waters. We have changed the negative sign to plus sign (+).

$$F_{fd\_sed} = c_{flddep}\, S_{fld\_sed} + S_{fld\_sed} \frac{E_{h2o} + I_{h2o}}{S_{fld\_\mathrm{h2o}}} \quad (16)$$

In our opinion, it is reasonable to assume that the evaporation and infiltration of flooding waters can contribute to sediment deposition (Fig. R1 below). For example, when 10% of the flooding water is infiltrating into soil, the sediment in this part (10%) of the flooding water will be deposited onto floodplains. Similar to infiltration, evaporation also results in decrease in the amount and depth of flooding water, thus can contribute to the sediment deposition.

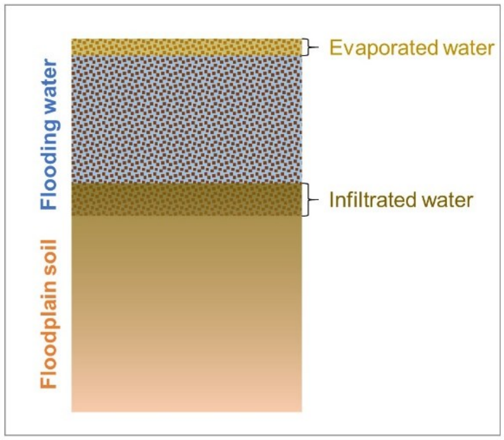

Figure R1. Schematic diagram for the impacts of infiltration and evaporation on sediment deposition in floodplains.

28. Line 400: Same f_topo as on hillslopes? How was this calculated? I am confused!

The f_{topo} is calculated from the slope steepness of river channel using the method in Vörösmarty et al., 2000. We have included some more explanation in the text before this line and in Table 1. Please see "Daily water (F_{Fout_h2o}, m^3 day^{-1}) and sediment (F_{Fout_sed}, g day^{-1}) flows from fast water reservoir to stream reservoir are calculated from a grid cell-specific topographic index f_{topo} (unitless, Vörösmarty et al., 2000) extracted from a forcing file (Table 1) and a reservoir-specific factor τ which translates f_{topo} into a water residence time of each reservoir (Eqs. 5, 6)." (lines: 303-307)

In addition, we have added '(Table 1)' behind the f_{topo} in this line to point the readers to more information. Please see "where τ_{flood} is a factor which translates f_{topo} (Table 1) into a water residence time of the flooding reservoir." (lines: 375-376)

29. Line 485: I guess that you run in the problem of equifinality of you simple calibrate five parameters against one observation (sediment yield). Please discuss this problem.

Agreed and we have now added some discussion around this. Please see “Further model calibration, evaluation and development is necessary for improving our model. Due to the limitation of observation data, we calibrated the parameters controlling sediment transport, deposition and re-detachment (i.e. ω, c_{rivdep}, c_{flddep}, c_{ebed} and c_{ebank} in Table S1) in stream and flooding reservoirs only against the observed sediment yield. Even though our model can overall capture the lateral transfers of sediment and carbon in many rivers in central and northern Europe, more observation data are crucially needed to further evaluate the performance of our model, in particular in southern Europe. In addition, it is still unknown whether our model can satisfactorily simulate intermediate processes such as sediment deposition in river channels and floodplains, as well as the rate of river channel erosion. It is also unknown whether our model would perform satisfactorily in regions with very different climates than Europe such as the tropical region. Thus, in the future, an important aim will be to further calibrate our model against more detailed observation data (e.g. sediment deposition rate in river channels and floodplains) and extend the model application to regions of contrasting climate, vegetation and topography. Moreover, the GLORICH database (Hartmann et al., 2019) only provides instantaneous observations of riverine organic carbon concentrations and it is therefore difficult to evaluate the model’s ability to reproduce temporal trends. Therefore, future modelling efforts should be combined with data mining efforts targeting the collection of continuous (e.g. daily) and long-term observational data of organic carbon content and fluxes in streams and rivers.” (lines: 919-936)

30. Line 509: Major parts of Europe are missing (e.g. no observation for Spain, France GB, Italy), esp. Mediterranean rivers are not covered in this study.

Please see our response to your comment #4.

31. Line 517: Indicate which stations in Rhine were used. POC is strongly discharge dependent, please indicate how many measurements at which discharge are used.

We have added the specific stations of the observed riverine POC data used in this study, as well as the number of POC measurements at these three stations. Please see “POC was measured at only two sites (Bad honnef (51 measurements) and Bimmen (78 measurements)) in the Rhine catchment and one site (Rheine, 36 measurements) in the Ems catchment (Fig. S4d).” (lines: 500-502)

The discharge at these three sites are added to the caption of Fig. 6. Please see:

Figure 6 Comparison between the observed (instantaneous measurement) and simulated (monthly average value) riverine POC concentrations at three gauging sites. In figure (b), (d) and (f), the histogram and error bar denote the mean and standard deviation of POC concentrations, respectively. Long-term average water discharge rates at Bad Honnef, Bimmen and Rheine during the observation periods are 2023, 2100 and 80 m^3 s^{-1}, respectively.

32. Line 606: It seems that the model underestimates the observed DOC variability (Fig. 4b), however, this is in contrast to the Figure S8. Please explain this discrepancy.

Fig. 4b shows the spatial variation of DOC concentrations across 314 gauging stations. However, in Fig. S8 and Fig. 5 show the temporal variation of DOC concentrations at each of the 15 gauging stations (with relatively long-term observation data) of major European rivers. In addition, the number of measurements of DOC concentrations at many of the 314 gauging stations is very limited (less than 20 or even 10). The calculated seasonal variation in DOC concentrations based on these limited DOC measurements at these sites is highly uncertain and may be smaller than the value calculated based on simulated DOC concentrations.

33. Line 649: How does this number relates to empirical sediment budgets? Is that in the order of observations? Please discuss. Line 679: are there any empirical values to compare with?

To our knowledge, many studies have investigated the sediment delivery ratio from upland soils to river network (i.e. the ratio of sediment entering river network to gross upland soil erosion) using empirical soil erosion models or observation data. However, to our knowledge, no study has investigated the fate of the sediment entering the river network (e.g. the fraction of deposited sediment in river channels and floodplains) at continental scale of Europe, mainly because the amount of sediment entering river network is hard to measure at large spatial scale. In this study, although we cannot directly evaluate the simulated deposited fraction of riverine sediment, we have evaluated the simulated sediment discharge rates against observations at 221 gauging sites (Fig. 3). As our model can overall capture the sediment discharge rates in many rivers, in particular the sediment delivery rates from upstream to downstream of some rivers (Fig. S4c), we infer that the simulated deposited fraction of riverine sediment should overall be reliable too. Nonetheless, we acknowledge that more observation data on the sediment and carbon deposition rate in floodplains would be very useful to further calibrate and evaluate our model. We have discussed this in the revised manuscript. Please see: "In addition, it is still unknown whether our model can satisfactorily simulate intermediate processes such as sediment deposition in river channels and floodplains, as well as the rate of river channel erosion. It is also unknown whether our model would perform satisfactorily in regions with very different climates than Europe such as the tropical region. Thus, in the future, an important aim will be to further calibrate our model against more detailed observation data (e.g. sediment deposition rate in river channels and floodplains) and extend the model application to regions of contrasting climate, vegetation and topography." (lines: 925-932)

34. Line 661: any idea what causes this decline?

We now do and these results are actually part of a follow-up manuscript in preparation. By running our model under different climate change and land use scenarios, we found that the decrease in sediment delivery from land to river during the past century is mainly caused by land cover change (afforestation), followed by atmospheric CO_2 increase (which increases plant canopy and root biomass and litter cover, then induces the decline in upland erosion), and temperature increase. Of course, in different regions of Europe, the contributions of land use change and climate change to the changes in lateral sediment and carbon transfers can be very different.

35. Fig. 10: Does C_riv2land represent the transport from river channels to floodplains? If yes, I suggest to consider floodplains not at 'land'.

In our model the floodplain is indeed regarded as a part of the land, and the carbon deposited (POC) or infiltrated (DOC and dissolved CO_2) to floodplains is added to the soil carbon pool. Moreover, flooding generally occurs occasionally in most regions in Europe. During most of the time, the floodplains are not inundated. To give a more accurate definition of the $C_{riv2land}$, we clarified that $C_{riv2land}$ denotes the transport of carbon from river streams to floodplains. Please see "$C_{land2riv}$, $\underline{C_{riv2land}}$ and $C_{riv2sea}$ are the average annual carbon fluxes from land to inland waters, from inland waters to floodplains and from inland waters to the sea, respectively. SD is the standard deviation." (lines: 717-719)

36. Line 753: flooding decreases SOC stored in floodplain soil???? This is total contradicting our expectation and needs discussion

You might have misunderstood this sentence. We are saying "Accounting for flooding thus decreases the decomposition rate of litter and SOC stored in floodplain soils.". Flooding decreases the decomposition rate of litter and SOC in floodplain soils, thus favors an increase in the SOC stock.

37. Line 747: can you account for the soil-wettness driven changes in soil temperature? Is this effect significant?

Yes, the effects of ecosystem water cycle on land surface and soil temperatures are represented in ORCHIDEE model. By comparing the soil moisture and temperature simulated by ORCHIDEE-Clateral with activated and deactivated lateral water and C transfers, we find that the lateral water transfer, in particular flooding waters, can slightly but significantly change the soil moisture and temperature at grid cells with a large area of floodplains (Fig. S15).

38. Line 754: any number how this influences the C budget. Many empirical studies argue that this effect is important and strongly increases the OC retention in floodplains. Could this somehow be quantified?

It is still very hard to quantify the changes in land C budget caused by the changes in vertical SOC distribution alone. By comparing the SOC stocks simulated by ORCHIDEE-Clateral with activated and deactivated lateral C transfer process, we can quantify the changes in SOC stock caused by lateral C transfer. However, lateral C transfer can affect SOC stock at a specific location through several different mechanisms: 1) soil erosion or deposition can directly increase or decrease the SOC stock; 2) lateral water transfer can affect SOC decomposition rate by altering soil moisture; 3) lateral water transfer can affect vegetation productivity, which is the dominant C source of SOC; 4) soil erosion and deposition can affect SOC decomposition by altering vertical SOC profile, as the soil moisture and priming effect in different soil layers are different. To estimate the influence of each of these four mechanisms on the changes in SOC stock, the other three mechanisms would have to be cknown. However, it is still very hard to evaluate each of the 4 mechanisms individually in ORCHIDEE-Clateral. In particular, the changes in vertical SOC profile are directly determined by the amounts of eroded or deposited sediment and carbon.

39. Line 793: this very low increase somehow contradicts the large amount of POC retention in floodplains. You somehow provide numbers with SOC stock decrease in mountains and SOC stock increases in floodplains, but does this mean that SOC retention in floodplains is compensated by soil degradation at eroding sites?

Please see our response to your comment #5.

40. Line 811: Please cite Hoffmann 2013 (GBC): they present results for hillslope and floodplain storage of OC for the Rhine basin.

Thanks for your suggestion. We have added Hoffmann et al. (2013) as one of our references. Please see "For example, many studies suggest that a substantial portion of the eroded sediment and carbon is deposited downhill at adjacent lowlands as colluviums, rather than exported to the river (Berhe et al., 2007; Smith et al., 2001; Hoffmann et al., 2013; Wang et al., 2010)." (lines: 863-866)

41. Line 826ff: Considering NP might not only decrease NPP at eroding site but also increase NPP at depositional site. Correct? If yes, leave some words in the paragraph on depositional sites as well. Certainly, a worthwhile action to link NP here.

Indeed, we have indicated that both soil erosion and sediment deposition can affect vegetation productivity by modifying soil nutrient availability. Please see "many studies have indicated that the soil erosion and sediment deposition can affect vegetation productivity by modifying soil nutrient (e.g. nitrogen (N) and phosphorus (P)) availability (Bakker et al., 2004; Borrelli et al., 2018; Quine, 2002; Quinton et al., 2010)." (lines: 884-887)

42. Line 839: Hoffmann et al (2020, ESurf) provides a way to differentiate exsitu and insitu OC in rivers. This paper also offers more infos on POC in the Moselle and Rhine rivers.

Thanks for your suggestion. Findings in Hoffmann et al (2020, ESurf) are very interesting and should be very helpful for our further model development and evaluation. In addition, we have cited Hoffmann et al (2020, ESurf) as reference for the fact that river-borne phytoplankton can contribute to the riverine organic carbon. Please see "Although soils are the major source of riverine organic carbon, domestic, agricultural and industrial wastes, as well as the river-borne phytoplankton can also make significant contributions (Abril et al., 2002; Meybeck, 1993; Hoffmann et al., 2020)." (lines: 892-894)

43. Line 849: Could the routing be done using DEMs with better spatial resolution to overcome limitations of the routing on low-res DEMs?

Yes, some of our colleagues are developing a routing scheme at higher spatial resolution. We will implement the rouging scheme in the future version of our model after their development is finished.

44. Figure S2: bad quality, can't read the text

We have changed revised the original Figure S2. The new figure is:

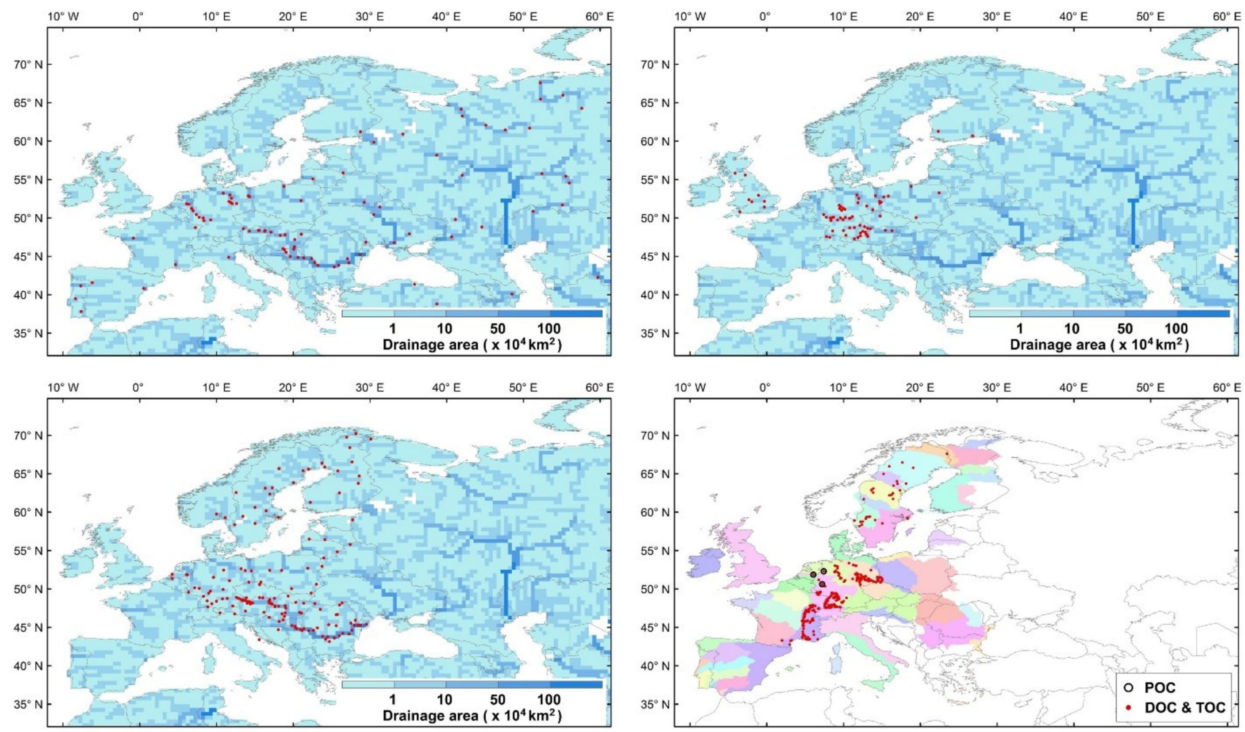

Figure S4 Geographical location of the gauging stations for river discharge (a), bankfull flow (b), sediment discharge (c) and riverine organic carbon discharge (d) used in this study. Figure (d) also shows the spatial distribution of 57 catchments in Europe. The simulated average net soil loss rates (g m^{-2} yr^{-1}) of these 57 catchments were compared to the average net soil loss rates extracted from the sediment delivery data provided by the ESDAC (see section 2.3 of the main text).

45. Figure S4: give names of gauging stations

We have provide the names of the gauging stations in the original Figure S4. Please see:

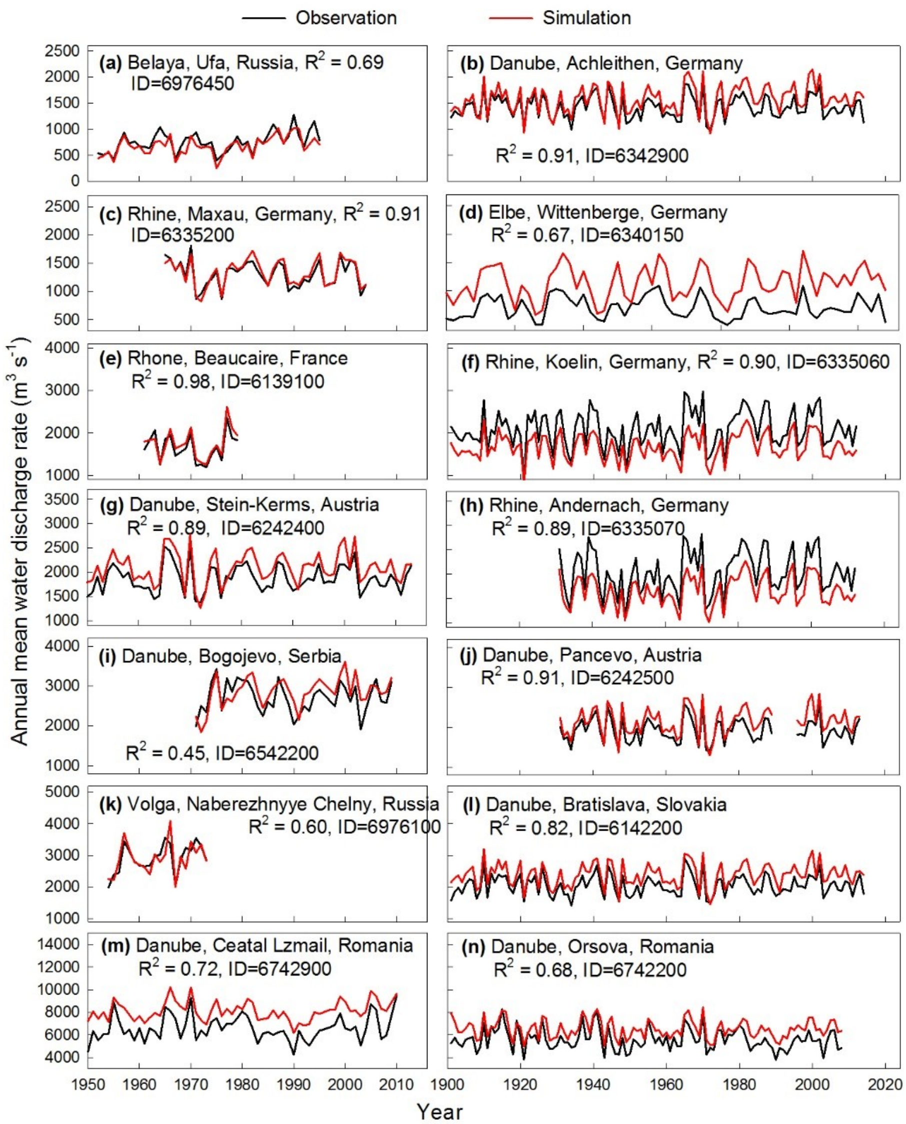

Figure S6 Comparison between the simulated and observed time series of mean annual water discharge rates at 14 gauging stations.

46. Figure S5: bad quality of left map

We have revised the original Figure S5. The new figure is:

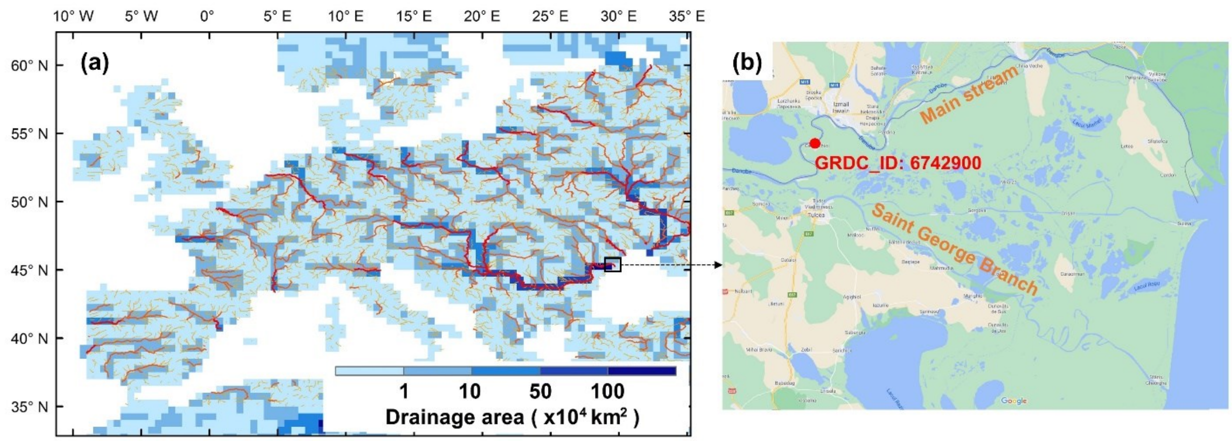

Figure S7 (a) Comparison between the river network extracted from the STN-30p database at 0.5° resolution (blue) (i.e. the forcing data of stream flow directions used in this study) and the river network derived from the HydroSHEDS DEM data at 3″ resolution (red); (b) the real river network in the estuary region of the Danube River (obtained from © Google Maps). GRDC_ID denotes the identify number of the gauging station in the GRDC database (Table 1).