Reply on RC1

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We thank the reviewer for her/his overall positive assessment of our work.

- OC in the soil is represented by four different litter and three different SOC pools with different turnover rates. The SOC is subdivided into active, slow and passive pools (Figure 1). I understand that such a complex model is needed to describe the turnover of OC in the soil. However, one can critically question whether NPP and the amount of SOC in the catchment are significant criteria in determining how much DOC enters the river (see statement line 401). The proportion of DOC export relative to terrestrial NPP is low (on average 0.6%, line 630), but highly variable (~0.02% to 2%) and strongly related to runoff (Figure 12). This seems to suggest that NPP is likely not the rate limiting step and that hydrology is the key factor governing the transport of DOC to the stream, as also mentioned in the manuscript (lines 645-647). I would like to see a sensitivity analysis added to show how much the variability of the modeled parameters NPP, SOC, and pore water DOC as well as the input parameters determines the final result and if the parameters are significant. The multiple regression (equation 13) makes a step in this direction. But it would be more convincing if NPP was tested independently, not as a ratio DOC leaching / NPP.

We agree with the reviewer that it would be interesting to directly compare the impact of NPP vs. hydrology on DOC leaching. For that, we will add a table showing the partial correlations of DOC leaching vs. NPP, runoff, drainage, temperature. The analysis of this table indeed highlights that DOC leaching is mainly controlled by hydrology, while temperature and NPP have only a limited impact on the spatial variability of DOC leaching across Europe. We normalized DOC leaching to the NPP because our was to highlight that once, surface runoff, drainage (and their ratio) alone can explain most of the spatio-temporal variability in DOC leaching fluxes, temperature only playing a subordinate role. Performing a sensitivity analysis of DOC export to NPP is nevertheless not straightforward because in our model several modules are coupled and changing NPP may have indirect effects that are not easy to isolate from the direct effect.

PARTIAL CORRELATION	DOC leaching

Runoff	**0.43**
Drainage	**0.54**
Temperature	**-0.17**
NPP	**0.18**

- It is well documented that the near-stream (riparian) areas are the main source areas of stream DOC (Inamdar and Mitchell 2006, Grabs et al. 2012), while large parts of the catchment remain hydrologically disconnected from the stream during most of the time. The upslope areas will be connected to the stream only occasionally during events (Stieglitz et al. 2003, Ocampo et al. 2006). In line with this, field investigations showed that the largest part of the DOC flux originated from only a few decimeters thick organic soil layer in the riparian wetland zones (Ledesma et al. 2015), which are near-infinite sources of DOC (Raymond and Hopkinson 2003). With this in mind, it seems questionable to assume the entire watershed as the source of the DOC in the model. It would be interesting here to see what the authors' views are on this issue. Should future models focus on riparian zones?

We agree with the reviewer that riparian zones are a main source of DOC to the stream-network. Note that the impact of riparian zones on DOC leaching through runoff to the river network is implicitly represented in the model (as described in Lauerwald et al. 2017). For this, a distinction is made between the riparian zones around smaller streams (stream order 1 to 3), which are not explicitly represented in the model because of the coarse spatial resolution, and the riparian zone along larger river stretches. For the small streams, it is assumed that the extent of the riparian zones, from which most of the DOC stems, scales linearly to the surface area of these small streams, both in time as well as in space (i.e. between different grid cells of our model grid). While the surface area of these small streams is not directly represented, Lauerwald et al. 2017 assumed that spatial and temporal variations in this stream surface area scale to the square root of discharge that is flowing through these streams (eqs. 1 and 2 below), roughly in line with empirical scaling laws (e.g. Raymond et al. 2012).

$DOC_{leaching\ RO} = RO * r_{gen} * r_{con} * C_{DOC,top}$ (eq. 1)

$r_{con} = f((RO+GW)^{0.5})$ (eq. 2)

With:

$DOC_{leaching\ RO}$ leaching of DOC with runoff

RO   runoff

GW   ground water outflow

r_{gen} general reduction factor that implicitly accounts for the fact that some of the runoff represents excess throughfall that never entered the soil

r_{con} reduction factor accounting for the connectivity

between small streams and catchment

C_{DOC_top} concentration of C in the top soil (here to 4.5cm)

Note that this connectivity issue only affects the leaching of DOC through runoff. Leaching of DOC through drainage is assumed to occur everywhere and is thus simply calculated as the product of DOC concentration in the last soil layer and drainage (see Lauerwald et al. 2017 for details).

For the larger rivers, for which the surface area is explicitly represented in the model, it is assumed that the riparian zone can temporally make up to 10% of the river water surface area, depending on the temporal variability of discharge. In the model, we simulate a direct input of DOC produced in the temporally inundated topsoils (assuming reduced SOC decomposition and DOC production due to inundation) into the river channel. For details, see Lauerwald et al. 2017.

We admit that these important issues have not been very clearly described in our original submission. In the revised version, we will add the necessary information to the method section, and, moreover, we will add a paragraph to the discussion (in a new subsection on model limitations) addressing the importance of the riparian zone, which is only implicitly taken into account in the model. We think that this indeed remains a major shortcoming of large-scale land surface models such as ORCHILEAK. Moreover, we will discuss this issue as an important challenge for future model development, considering the useful references the reviewer kindly provided.

- Figure 5 shows that DOC pore water concentrations decrease nonlinearly with depth, which is a reasonable result. However, the DOC in the topsoil was overestimated by 100% compared to reference sites. This can be a problem as the annual DOC exports are largely generated during events, when groundwater tables are high and the OC-rich topsoil layers become the main source of water and DOC to the stream (lines 590-595). The transmissivity feedback predicts that lateral hydraulic conductivities increase nonlinearly with increasing distance from the soil surface (Kendall et al. 1999, Bishop et al. 2004). Are there different lateral hydraulic conductivities assumed for different soil layers to connect the pore water DOC with the stream? In addition to Figure 5, I recommend including a graph showing the relationship between discharge and predicted DOC concentration in the stream. Typically, DOC concentration increases exponentially with discharge.

The representation of leaching processes in ORCHILEAK is highly simplified. Leaching occurs either from the topsoil, which in our configuration represents the top 4.5 cm of the soil column, or from the bottom soil, i.e. the lowest 50 cm of the 2 m soil profile.

The DOC leaching via runoff is calculated as described above in eqs. 1 and 2 (see also Lauerwald et al., 2017) for more details. The leaching is controlled by two reduction factors, a general reduction factor r_{gen} and a reduction factor r_{con} that represents the connectivity between streams and their catchment through the extent of the water saturated riparian zone. The general reduction factor r_{gen} accounts for the fact that some of the runoff represents excess throughfall that never entered the soil and thus corrects for the overestimated DOC concentration in the topsoil through . Note that the "runoff" is simulated as excess throughfall that is not infiltrating into the soil. ORCHILEAK is

representing flows of water from land to the stream network only through surface runoff and drainage from the bottom soil. In other words, there is no representation of interflow, which is however of importance with regard to lateral solute transfers from catchment to the river network. For the implementation of DOC leaching in ORCHILEAK, it was thus assumed that the surface runoff exports the DOC from the topsoil (here defined as the top 4.5 cm), which we believe is reasonable as in reality the surface runoff, in particular in the riparian zone, contains some amount of interflow that exfiltrates where soil is saturated. This simple approach helps to overcome the limitation in the hydrology scheme which does not represent interflow.

We will describe the representation of DOC leaching more clearly in the method section, as this is a process which is very central to our study. We will further add a subsection on model limitations where we discuss the potential importance of the process-details that are not represented in the model and how they might affect model performance.

The figure below reports the DOC concentration against discharge for the entire simulation period (one point for each month during 1979-2006) at the mouth of the Elbe and the Rhone rivers, model and observation. No clear correlation between the two variables can be observed (pearson correlation coefficient between 0.1-0.2) and this result is to be expected because DOC concentrations do not necessarily increase with discharge (flushing effect), another common response being just the opposite (dilution effect).

- In the late 1980's the DOC concentrations started to increase in many European streams and rivers. Often the concentrations have doubled over the last decades. As possible causes a decrease of soil pH and ionic strength leading to a higher solubility of DOC (Monteith et al. 2007) and a decreasing stability of iron minerals and an accompanying release of formerly adsorbed OC are discussed (Ekström et al. 2016, Musolff et al. 2017). Is the model sensitive to the parameters discussed?

We agree with the reviewer that those are important processes. Unfortunately, these parameters and processes are not represented in our model, as there are still no reliable methods and forcing data to simulate the dynamics of soil pH and ionic strength at large scale. While the model accounts for the effect of soil pH on adsorption of DOC in the soil, soil pH is prescribed from a forcing file and does not change over time. We will add some discussion regarding these processes and the potential bias related to the fact that we do not represent the role of soil pH and ionic strength dynamically in our model. Note that we will add a new subsection on model shortcomings.

- Application of manure was included (lines 216-226). Is there observational evidence that manure can contribute to stream DOC, except for cases when manure was applied on frozen ground or snow? On the other hand, discharge from wastewater treatment plants was not considered as a carbon source (lines 93-94). This can be questioned as the DOC concentrations in wastewater effluent are as high as in the streams (Griffith et al 2009) and, in contrast to manure this source is directly released to the stream. For

the Sacramento River, Sickman et al. 2007 estimated that urban sources contributed 20% to total OC discharge. It can be assumed that wastewater-derived OC is also significant in other rivers with densely populated catchment areas.

There are indeed a couple of studies that have shown an increase in DOC flux with runoff and of DOC concentration in the river that is related to manure application (e.g., Royer et al., 2007; Delpla et al., 2011 ; Singh et al., 2014; Humbert et al., 2020). These studies have shown as well that the frequency and intensity of storm events in spring directly after manure application and exert an important control on the amounts of additional DOC leached to the river network. We will briefly summarize and discuss these findings in the revised version of our ms.

These processes are as well represented in ORCHILEAK. Note that the manure derived DOC is first entering the topsoil. There, a part of the DOC is decomposed, another part is transported to deeper parts of the soil column with percolating water, and finally a variable part of this DOC is flushed out of the topsoil with the runoff. Also in our model, runoff occurs mainly during storm events. The less of this manure added DOC is flushed out of the topsoil through runoff, the more of it will infiltrate deeper into the soil profile, and will be decomposed into CO2 and or contribute to the formation of particulate SOC.

To show that our model reproduces the behavior observed in the field studies mentioned above, we will further investigate in how far manure application affects DOC export in runoff vs DOC export in drainage, and we will further show during which months the manure increased DOC leaching is most intense. These findings will as well be added to the discussion in section 3.1.6.

We agree with the reviewer that sewage water injection may be another significant source of DOC to the river network, which we do unfortunately not represent in our model due to the lack of forcing data related to the sewage water (e.g. time, place and amount of the sewage discharge, and the DOC concentration in the sewage). However, Meybeck (1986) showed that DOC from sewage is very labile and only affects the concentration within short distances downstream of water processing plants. We will again discuss briefly the possible implications introduced by this shortcoming in our new section dedicated to model limitations, in particular with regard to the potential biases that this omission might introduce in our model-data comparison.

Further comments

DOC is also produced by autochthonous photosynthesis in the stream. How important can production be compared to the terrestrial DOC modeled here. Or can we assume that the DOC is readily available and therefore most of it is quickly decomposed in the river itself?

Yes, most of the autochthonous DOC has a short turnover time within the river (Frajalla et al., 2009; Fonte et al., 2013), and thus won't contribute much to the net-C budget. Meybeck (1993*a,b*) found that soils were the major source of organic carbon, followed by rocks, with river-borne phytoplankton being negligible at the global scale. Autochthonous DOC would be important if river C cycling was represented in more detail. But in ORCHILEAK, we focus more on the role of fluvial DOC fluxes for the terrestrial C budget. We will make that point clear in the model description, and shortly discuss that shortcoming in the discussion section.

If the manuscript aims to provide an estimation of riverine organic carbon transport, particulate organic carbon (POC) cannot be ignored. Compared to DOC, concentrations are smaller, typically ranging between 10% and 30%. May briefly discuss the potential contribution of POC to OC flux.

We agree with the reviewer that fluvial POC transfers contribute to the terrestrial C budget, and should not be ignored. Building on the recent work by Zhang et al. (2018; 2021), we will give a short review of recent model developments and applications investigating the role of lateral POC fluxes in the terrestrial C budget and highlight the challenges that persist to implement these fluvial OC fluxes into a model like ORCHILEAK.

Figure 9: DOC export is the product of DOC concentration and discharge. What is the variability of DOC concentration compared to the variability of discharge? Figure 9 suggests that the exports largely depend on discharges. Would a similar result be obtained if a mean constant DOC release were assumed?

Of course discharge is the main contributor to inter-annual variability (IAV). But to fully answer the question of the reviewer, we will quantify the interannual variability in discharge, DOC concentration and DOC fluxes as coefficient of variance, which will allow to directly compare the variability in relative terms.

Table 1: May briefly explain 'topographic index' and the context of 'Floodplains and swamps'.

We agree that this needs clarification. Topographic index is an index controlling the flow velocity in each cell. "Floodplains" is defined as the maximum areal proportion of a grid cell that can be flooded when the river exceeds its bankful flow. "Swamps" represent groundwater fed wetlands in the the floodplain of a river. Depending on the areal extend of these swamps, a proportion of stream flow is simulated to feed into the soil moisture storage of the grid cell considered. Both parameters have an effect on the simulated river discharge and soil hydrology in the floodplains. Both parameters are prescribed by the forcing file.

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