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Discussions

Interactive comment on "Regional-scale lateral carbon transport and CO_2 evasion in temperate stream catchments" *by* Katrin Magin et al.

Katrin Magin et al.

magi6618@uni-landau.de

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Anonymous Referee #1 :

- Rivers and streams are an important link in the global C cycle and C export via aquatic systems has repeatedly been concluded to make a significant proportion of catchment C budgets at different spatial scales and in different climate zones. This is an interesting paper that will make a good contribution to the understanding of regional-scale carbon export via streams with stream order 1-4 in the temperate zone. The authors observed a narrow range of variability of C export per catchment area and conclude that other processes than water surface area or location of mineralization of terrestrial derived C control the aquatic-terrestrial coupling and the role of inland waters in regional C cycling. However, the final version of the paper would benefit from more details about lateral C export calculations. It is not clear if extreme runoff events are covered appropriately. The lack of extreme event data would of course lead to a much narrower range of variability of C export.

We would like to thank the reviewer for her/his positive evaluation and the very helpful comments and suggestions. Below we reply on each specific comment.

- Ln 20. Explain "catchment-specific"

Reply: Catchment-specific carbon export refers to the carbon export per catchment area. We will explain this in a revised version of the manuscript.

- Ln 53. Why is the fluvial C load dominated by DIC? Are there carbonates? Please also state why you neglected methane.

Reply: 16% of the study area contain carbonate bedrock. The weathering of the carbonate rock can be an additional source of DIC in the streams. In our study area, the DIC concentration in the water increased with the proportion of carbonate containing bedrock in the catchment ($R2=0.33$, $p<0.001$). We would add the information on bedrock in a revised version of the manuscript. On average, DIC in the stream water was composed of 91.2% bicarbonate, 0.4% carbonate and 8.4% CO2. Alkalinity ranged between 0.02 – 13.5 mmol L-1 for the individual measurements and between 0.08 – 9.88 mmol L-1 for the averaged seasonal mean values. Measurements of methane concentration or fluxes are not available for the present study. According to a recent meta-analysis, the dissolved methane concentration in headwater streams varies mainly between 0.1 and 1 μmol L-1, with streams in temperate forests being at the lower end (Stanley et al., 2016). The methane makes up only a small fraction of total carbon (in comparison to the mean DIC concentration in the present study (500 μmol L-1)) and we assume that methane makes a rather small contribution to the catchment scale carbon balance. We would add these information, together with an upper bound of methane evasion (based on the published meta-analysis), to the revised manuscript.

- Ln 56. Strahler stream order?

Reply: Yes, Strahler stream order. We will add this information to the revised manuscript.

- Ln 61-66. What about the geology? Is there C-containing bedrock in the catchments?

Reply: See our comment above - 16% of the study area contain carbonate bedrock. The weathering of the carbonate rock can be one additional source of DIC in the streams. In our study area, the DIC concentration in the water increased with the proportion of carbonate containing bedrock in the catchment ($R2=0.33$, $p<0.001$). We would add the information on the bedrock in a revised version of the manuscript.

- Ln 70. "15 800" do not separate numbers

- Ln 71. Delete "order"

Reply: We will correct this.

- Ln 82. How are pH values of investigated waters? The pCO2 calculation with alkalinity was found to high uncertainties for low pH values (Abril et al. 2014).

Reply: The range of pH values of the investigated waters is 6.2 – 8.97 with a mean of 7.73 ± 0.42 (mean$\pm$sd). According to (Abril et al., 2015), high uncertainties of pCO2 estimates from pH and alkalinity measurements occur at pH values <7, while the median and mean relative errors were 1% and 15%, respectively for pH>7. Only 7% of the pH values in our study were <7. We would add a discussion of the expected uncertainties to a revised manuscript.

- Ln 89. How exactly did you aggregate annual means? Did you calculate a (discharge) weighted average?

Reply: pCO2_annual=(pCO2_spring+pCO2_summer+pCO2_autumn+pCO2_winter)/4 (seasonal values are averaged over all available samples). Discharge was not measured during the water sampling and no time-resolved discharge data are available for the sampling sites. We used annual mean discharge data, which were derived from data-driven regionalization of discharges from 125 gauging station from the period of 1979-1998 for the entire fluvial network. Application of discharge-weighted averaging was therefore not possible.

- Ln 128. Name the program used for statistics

Reply: All statistical analyses were performed with R. We will add this information to the revised manuscript.

- Ln 145-148. Discuss variance of organic C. How about peaty areas?

Reply: There are no pronounced regional or temporal differences of organic carbon. The fraction of peatland in the study area is small (0.95 km2 ; 0.009% of the study area) and only seven of the investigated catchments contain peaty areas. As organic C was measured only in three of these catchments, an investigation of the influence of peat on organic C was not possible. We would add the information about the variance of organic C and the peatland in the study area in a revised version of the manuscript.

- Ln 152. Specify which value is meant: mean NPP or mean specific NPP?

Reply: Mean specific NPP is meant. We will clarify this.

- Ln 169. In Figure 3 some of the data points (mostly stream order 1 and one of stream order 2) scatter more. Please discuss reasons for these outliers.

Reply: Small streams of low stream order can be directly influenced by local peculiarities which can increase the scatter of the data points while larger streams represent more average conditions over larger spatial scales. The scattering points in Figure 3 belong, e.g. to ditches or outflows from ponds which might differ in their characteristics to other rivers and streams. Based on the available data, however, there are no particular properties of all the scattering points, which would justify special treatment: the catchments are completely included, pH values are in the range of 7.1-8.3, and no urban areas around these catchments

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Discussion paper

Ln 186. You talk about average fluxes, but what happens during floods/ extreme events? Do measurement intervals cover extreme events?

Reply: Since we do not have time-resolved discharge data we cannot account for extreme events. Moreover, no information are available if the governmental monitoring included sampling during floods. Given the stochastic nature and short duration, we expect that such samples are at least underrepresented. Since it has been observed that high-discharge events can make a disproportionally high contribution to annual mean carbon export from catchments, we consider our estimates as a lower bound – in accordance with other uncertainty estimates, see below. We would add this information to the discussion in the revised manuscript.

- Ln 205. ": : :wetlands covering up to 16 % of the land surface area." Add a reference.

Reply: The 16% was taken from (Richey et al., 2002). However, in the revised version we would rather refer to a fraction of 14%, which was estimated in the study of (Abril et al., 2013). This reference is cited earlier in that sentence and will be moved to the end of the sentence in our revisions.

- Ln 226. Expected for temperate zones? In dry regions such as deserts this can be different.

Reply: We would change the sentence as follows: As expected for temperate zones, large streams and rivers with large surface area have larger catchments.

- Ln 235. Discuss "uncertainty of the various estimates"

Reply: For a comparable methodological approach, Butman and Raymond (2011) estimated the uncertainty in the calculation of the aquatic carbon flux to be 33% (based on Monte Carlo simulation). Raymond et al. (2013) estimated uncertainties from comparisons of estimates obtained using similar approaches as we with direct measurements of CO2 concentration on streams. For a density of sampling locations of 0.02 sites per km2 (corresponding to our study) they derived an uncertainty of 30%. In addition to errors associated with sampling and interpolation, our estimates are subject to a number of systematic errors. The neglect of carbon burial in sediments, carbon export and evasion as methane and unresolved flood events can be expected to result in an underestimation of the carbon exported from the catchments in our study. We will discuss these uncertainties at greater detail in the revised manuscript.

- Ln 236. Name potential controlling factors

Reply: Here we refer to the potentially controlling factors listed in Table 3, including catchment NPP, fractional water coverage as well as size and climatic zone of the study area. In the revised manuscript, we would list these factors in the text.

- Ln 244-247. How do you know that? In regions with corresponding geology also weathering of C-bearing minerals can be a large source of stream DIC. Respiration in soils is more likely the dominant DIC source in catchments that lack carbonate rocks. Is that true for catchments in Rhineland-Palatinate? Can you give an example for cases with predominance of aquatic respiration? I would expect predominance of aquatic respiration in warmer climates where large DOC concentrations prevail.

Reply: We agree. 16% of the study area contain carbonate bedrock and the observed association between DIC and the proportion of carbonate containing bedrock in the catchment ($R2=0.33$, $p<0.001$) indicates, that weathering can be one additional source of DIC in the streams. We will add these results and revise the discussion accordingly. We will mention that both mineral weathering and soil respiration contribute to DIC in stream water and discuss the relative contributions of both sources observed in other studies (Hotchkiss et al., 2015;Lauerwald et al., 2013;Humborg et al., 2010;Jones et al., 2003). Examples for cases with predominance of aquatic respiration can not only be found in the tropics, but also in the boreal zone and in peat-draining streams. We would refer to (Duarte and Prairie, 2005;Jonsson et al., 2007;Lynch et al., 2010;Richey et al., 2002) as examples. (Hotchkiss et al., 2015) observed an increased CO2 emissions from internal production for increasing stream size.

- Ln 249. How is the range of discharge? The study by Hotchkiss et al. covers values from 0.0001 to 10,000 m3 s-1. Can the lower range in your study be the reason that you do not observe findings in Hotchkiss et al.?

Reply: The range of discharge in our study is 0.003 - 12.2 m3 s-1 which is indeed a lower range compared to the study by Hotchkiss et al. We would add this in the discussion.

- Ln 252. Does "small number of observations" relate to this study?

Reply: No, at this point we refer to the meta-analysis presented in Table 3. We will make this clearer in the revised manuscript.

- Ln 255-257. This section summarizes the paper well but it could go further. It might be speculative but can you say what these other, poorly explored processes could be?

Reply: We would speculate, that hydrology plays a major role for C-cycling at larger scale. Precipitation controls not only terrestrial NPP but also, drainage density, export of OM from land to water and retention time of OM in soil and in surface waters respectively. Since our hydrological data base is rather weak (annual discharge only, no precipitation), we think that these speculations would be not well supported by the presented results.

- Ln 267. I think it is preferable to provide data as supplement material.

Reply: We will provide information about the investigated streams (stream order, water surface area, discharge, pH), catchment size and catchment NPP, DIC, DOC and TOC, pCO2 and the seasonality of pCO2, gas exchange velocity and total stream evasion as supplemental material.

- Table 1 and Table 2 would be more informative if you could add ranges. Please also add calculated gas transfer velocity values to Table 2.

Reply: We will add the information to the tables.

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