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Biogeosciences Discussions

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

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Anonymous Referee #3:

Katrin Magin and colleagues presented a synthesis of >200 catchments examining the relationships between lateral carbon export and CO2 emissions and terrestrial net primary production (NPP) in southwest Germany. Inland waters have recently been recognized as important components in the global carbon cycle. While widespread studies have been conducted worldwide, most of these studies are based on individual catchments and a synthesis involving multiple catchments remains lacking. This manuscript is well-organized and quite timely, and will provide insights into the understanding of catchment carbon cycle (or budget) at regional scales.

We would like to thank the reviewer for her/his positive evaluation and the very helpful

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comments and suggestions. Below we reply on each specific comment.

- My first major concern after reading this manuscript is the carbon storage term which has not yet been considered when the authors evaluated catchment-scale carbon budget. Caron burial associated with soil erosion and sediment deposition within catchments is a quite important component in carbon budget assessments (e.g., Smith et al., 2001). If the traditional sediment delivery ratio of 10% is assumed (Harden et al.1999), 90% of the eroded POC from land may have been stored somewhere within the catchment and partly exposed to decomposition (thus evasion to the atmosphere). This missing term may affect the redistribution of carbon (downstream discharge vs. CO2 evasion) as well as the amount of total carbon input from land. Incorporating this term will thus refine the budget result.

Reply: See our response to your specific comment below.

- My second concern is the estimation of CO2 evasion. What are the resulting k600 values? Are they comparable to those based on field direct measurements (e.g., floating chamber or eddy covariance)? Estimation of the total areal extent of water surface by means of the parameters derived from USA catchments is probably problematic (see my specific comment below). In addition, can the available dataset suggest any seasonal variability in CO2 evasion?

Reply: The k600 values in our study range from 2.0 m d-1 to 20.6 m d-1 with a mean of 6.0±3.3 m d-1. These transfer velocities are comparable to k600 values based on direct field measurements by floating chambers from small headwater streams in Alaska (Crawford et al., 2013) and also to some short chamber deployments within the study area (Lorke et al., 2015). The pCO2 is higher in summer (mean±sd: 2780±2098 ppm) and autumn (mean±sd: 2848±2019 ppm) than in winter (mean±sd: 2287±1716 ppm) and spring (mean±sd: 2172±2343 ppm). In contrast, the relationship of catchment NPP and CO2 evasion is not influenced by the season. We will add the k600 values in Table 2 and discuss the seasonal variability of pCO2 in a revised version of the manuscript.

- Line 19: please clarify 'catchment-specific total export rate'. Is it the normalized carbon export by catchment area?

Reply: Yes, the catchment-specific carbon export rate refers to the carbon export per catchment area. We will clarify this in a revised version of the manuscript.

- Line 29-30: the latest CO_2 evasion from global rivers and streams is 0.65 Pg C/yr by Lauerwald et al., (2015).

Reply: We will include the reference in this section.

- Line 50: remove 'differ'.

- Line 71: the reference 'Strahler, 1957' should move to line 56.

- Line 77: remaining →retained

Reply: We will apply these corrections.

- Line 81-83. What's the data quality and what kinds of standards for water sampling and processing were used? Estimating pCO_2 from alkalinity and pH has been criticized for causing biases due to noncarbonate impacts (Abril et al., 2015). An uncertainty analysis should be provided here. I also suggest to provide the range of pH and alkalinity, possibly into Table 1.

Reply: The data are governmental monitoring data which are acquired according to DIN EN ISO norms ((DIN EN ISO 10523:2012-04;DIN EN ISO 9963-1:1996-02;DIN EN ISO 9963-2:1996-02)). The range of pH values of the investigated waters was 6.2 – 8.97 with a mean of 7.73±0.42 (mean±sd). The range of alkalinity is 0.08 – 9.88 mmol L^{-1} with a mean of 2.75±2.12 mmol L^{-1} (mean±sd). We would add pH values and alkalinity in Table 1. According to Abril et al. (2015), high uncertainties of pCO_2 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.

- Line 95-97: how was the site-specific pCO2 interpolated to the upstream catchments? And which interpolation technique was used?

Reply: The explanation is provided in the following sentence (Line 97-98): For this, the mean concentrations were averaged by stream order and assigned to all stream segments of the river network (Butman and Raymond, 2011). To clarify this, we would join the two sentences in a revised manuscript.

- Line 102-103: These arbitrary parameters derived from American rivers may not necessarily be representative of German rivers. See Leopold and Maddock (1953).

Reply: The coefficients we used were derived from various data sets obtained in North America, but have been applied also in global studies before, e.g. Raymond et al. (2013). Unfortunately, we are not aware of a comparably extensive data set of hydraulic geometry data derived for European rivers. A comparison of hydraulic geometry coefficients derived from various data sets, including data from England, Australia and New Zealand, is presented in Butman and Raymond (2011), who estimated that the error associated with uncertainties of hydraulic geometry coefficients is rather small, compared to uncertainties derived for C-fluxes. We will add these information to an extended discussion of uncertainties in the revised manuscript.

- Line 105: Is a resolution of 10 m enough to estimate channel slope changes?

Reply: Zhang and Montgomery (1994) investigated the effect of digital elevation model (DEM) resolution on slope calculation and performance in hydrological models for spatial resolutions between 2 and 90 m. They found that while a 10-m grid is a significant improvement over 30 m or coarser grid sizes, finer grid sizes provide relatively little additional resolution. Thus a 10-m grid size presents a reasonable compromise between increasing spatial resolution and data handling requirements for modeling surface processes in many landscapes. We will justify the choice of DEM resolution in the revised manuscript. It should be noted, that similar studies have derived slope information from coarser DEM resolution, e.g. SRTM 90m Digital Elevation Data (Lauerwald et al., 2013), GMTED2010 with >250 m resolution (Raymond et al., 2013), NHDPlus with 30 m ground resolution (Butman et al., 2015).

- Line 125-126: Because the mean NPP for the period 2000-2013 is used here while the pCO2 data is for the period 1970-2011, it is better to explicitly indicate the distribution frequency of pCO2 data over the study period. For example, if the most of the pCO2 data were for the period 1970-1980, then using the NPP for 2000-2013 would be problematic.

Reply: The sampling frequency was increasing. There are nearly twice as much data from 2000-2011 than from 1977-1999. A comparison between DIC data from both sampling periods revealed no significant differences. We would add the sampling frequency distribution in a revised version of the manuscript.

- Line 135: Based on the given definition, the 'drainage rate' term should be 'runoff depth' in a formal way.

Reply: We would correct the term in our revisions.

- Line 146: Please quantify 'only a small fraction'.

Reply: On average 8.6% of the TOC consist of POC. The highest percentage of POC found in a catchment is 28.2%.

- Line 158: For the total C input, how about the POC term and the carbon storage term? See my major comment.

Reply: POC as suspended load in the rivers was estimated along with DOC and was only 8.6% of the TOC load (0.8 % of the total C-load) at the sampling sites. We agree with the reviewer that storage can make a significant contribution to the catchment-scale C balance. Estimates vary between 22% at a global scale (Aufdenkampe et al., 2011), 14 % for the Conterminous U.S. (Butman et al., 2015) and 39% for the Yellow River network (Ran et al., 2015). However, C storage in aquatic systems occurs mainly in lakes and reservoirs, which are virtually absent in the catchments studied here. Therefore we consider the bias caused by neglecting storage to be comparable in magnitude to remaining uncertainties (30%). We would add a more detailed discussion of the storage term and the associated uncertainty as part of a general uncertainty analysis (see comments above) in a revised discussion section. The neglect of storage, and potential high C loads during extreme discharge events, suggest that C-export from catchments estimated in the present study provides a lower bound of the aquatic C flux.

- Line 220-223: Are there peatlands within the studied catchments?

Reply: The fraction of peatlands in the area in really small (0.009%) and is restricted to 7 of the investigated catchments. For only 3 of these catchments DOC measurements were available and no influence of the peatland on the DOC was observable. We would add the information about the peatland in the study area in a revised version of the manuscript.

- Line 229-230: Is the absence of the carbon yield and NPP correlation due to failure to measure pCO2 during flooding periods? The short-duration carbon export during flooding events usually accounts for disproportionately a large share of the annual total carbon export.

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.

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- Line 238: please clarify the ‘surface area’. The global surface area?

Reply: No, this surface area refers to regions in the 2 studies cited in that sentence. We will clarify this in our revisions.

- Line 244-247: Could it also be because of chemical weathering and groundwater inputs? Rock weathering in carbonate-dominated catchments can be a significant contributor to DIC. I would suggest the authors to make a brief introduction about the lithology and mineralogy in the study area section (2.1).

Reply: 16% of the area investigated in our study contain calcareous bedrock. The DIC concentration in the water increased with the proportion of carbonate bedrock in the catchments ($R2=0.33$, $p<0.001$). We would add the information about the bedrock in the study area section and include the influence of chemical weathering in our discussion.

- Line 262: please summarize the study and make a short conclusion.

Reply: We would add the following conclusion to a revised version of the manuscript: Our analysis of the carbon budget in a temperate stream network on regional scale revealed a relationship of aquatic carbon export and terrestrial NPP. On average 2.7% of the terrestrial NPP were exported from the catchments by rivers and streams with CO2 evasion and downstream transport contributing equally to the export. A comparison of our regional scale study with other studies from different scales and landscapes showed a relatively narrow range of variability of carbon export per catchment area. Future research is needed to understand the processes that control the aquatic-terrestrial coupling and the role of inland waters in regional carbon cycling.

- Figure 2. It seems the top 2(?) data points far away from the majority are outliers. Please check and make the regression again, if necessary.

Reply: The apparent outlier is only 1 data point. It does not influence the regression.

- Table 1. pH could also be tabulated here. Is there any trend in pH from SO1 to SO4?

Reply: We would include pH in Table 1. There is no trend in pH from SO1 to SO4 but the variability of pH (e.g. standard deviation) is decreasing with increasing stream order.

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