Author comments on RC2

Interactive comment on "Spatio-temporal variations of lateral and atmospheric carbon fluxes from the Danube Delta" *by* Marie-Sophie Maier et al.
Anonymous Referee #2

Dear Anonymous Referee #2,

Thank you very much for your positive feedback, we highly appreciate the time and effort you invested to review our MS. In the following, you find our replies (black, indented) to the *individual comments* (blue, italic).

This paper reports results of a 2-year field study of carbon dioxide and methane fluxes from freshwater systems in the Danube Delta. The study focusses on 19 sites and provides insight in seasonally resolved fluxes and lateral carbon transport. This must have been an enormous effort. The authors find that lakes are the largest emitters of methane. Channels show a wide range of emissions and may be hotspots both for carbon dioxide and methane.
The paper is well-written and the results are well-presented. I do find the comparison to fluxes in other rivers rather descriptive. This is where a slightly more process-based comparison could increase the impact of the paper.

Thank you for pointing this out. We did discuss responsible processes in the manuscript, but we outline below for the discussion part (lines 565 ff) how to expand the processes-based comparison with other river systems.

I have only a few minor other comments, mostly editorial, see below.
Line 14. What is meant by "reference" systems in this sentence. Could you rephrase?

By «reference» system, we mean that the Danube River reaches can be used as a point of comparison: the water in the Danube Delta originates mainly from the Danube River, precipitation is only a minor water source. The river water can therefore act as a reference to establish concentration changes in the delta with respect to the water chemistry provided by the catchment. We will define this more clearly:

We plan to edit this as follows:

"In this paper, we use the river reaches that cross the delta as references systems. The water chemistry in the Danube River is defined by upstream processes in the catchment. The effects of biogeochemical processes of primary production and respiration in the lakes and reed stands imprint different chemical signatures on the water in lakes and channels. "

Line 94. Suggested change: "Station 16 was removed from the study because of limited access".

Accepted. We will slightly expand the statement: "Station 16 was removed from the study because of limited access during lower water level (clogged access channel)."

Line 170. Suggested change: "stored in the dark"

Accepted. The sentence now reads: "The other three bottles were stored in the dark at approximately in-situ temperatures and O_2 concentration was measured after 24 hours."

Line 172-173: Suggested change: "production rates"

Since the bottles were stored in the dark, we measured a decline in O_2, so it would rather be a "O_2 consumption rate". In our opinion using the term "production rate" here might be

misleading, since the same experimental set-up storing the bottles in light instead of dark conditions would indeed measure an O_2/primary production rate.

The sentence now reads: "The O_2 consumption rate was derived from the time and concentration difference, assuming a linear decrease over time."

Line 174. Suggested change: "are underestimating respiration rate" => "underestimate respiration rates"

Accepted. The sentence now reads: "Ward et al. (2018)argue that respiration rate measurements in BOD bottles underestimate respiration rate because microbial processes are limited by both the bottle size and the lack of turbulence and suggest a correction factor of 2.7 to correct BOD derived respiration rates for size effects only or a factor of 3.7 for size and low turbulence effects."

Line 177. Change to "rates"

Accepted. The sentence now reads: "Applying these correction factors did not change the main point of our comparison between fluxes and CO_2 production rates."

Line 235. Specify that you are referring to the width of the channels here. Is there no estimate of the number of these old meanders? I realize you discuss the uncertainty in the channel width later in the manuscript, but this ten-fold difference in width is still rather substantial.

There are two big old meanders along the Sulina branch, where stations 11 and 17 are located. They are now bypassed by the rectified, shorter branch of the Danube. Their area is about 4.5 km^2. We also calculated the area of the channels based on the length of all channels recorded in a publicly available shape file from mapcruzin.com (2016) and the area of these two meanders. With this approach, using the same average width, we arrive at a channel area of 31 km^2 (compared to 33 km^2 with the approach used in the paper). The main uncertainty lies in the width and number of the very small channels, that are very difficult to determine from areal photos, while the larger meanders can be measured comparably easy.

Changes for clarification: "Especially the old, cut-off meanders of the Danube River (Dunarea Veche), which we also consider as belonging to the channel category, do have a much larger width ranging in the order of 100–200 m."

Additional comment: we noticed a typo in Table 1 concerning the calculation of the channel area: Instead of 10 m width, we actually used 19 m width for the calculation and will correct this in the revised version: 1753 km * 19 m = 33 km^2

Line 350 "at 0.69" instead of 'with 0.69"

Accepted. The sentence now reads: "Median k_{600} was lowest in in the river branches and in the channels at 0.69 m d^{-1} and 0.74 m d^{-1}, respectively (see Table S1)."

Line 362: suggested change: "cause the" => "contributed to the"

Accepted. The sentence now reads: "It is likely that the different hydrological conditions triggered different amounts of lateral inflow from the reed-covered wetlands and cause the large variability in CO2 fluxes."

Line 363: suggested change: "seems to be" => "appears to be"

Accepted. The sentence now reads: "For CH_4, this effect appears to be much smaller."

Line 371: this sentence needs rephrasing: "A look into the contribution from the different waterscapes shows that the river branches the main source of CO_2 to the atmosphere were in both years"
Line 371: use past tense: "switched"

Corrected sentence: “Considering the contributions from the different waterscapes shows that the river branches were the main source of CO_2 to the atmosphere in both years”.

Line 388: It’s not clear what “it” refers to in “It mainly relates to”

Rephrased sentence: “The slightly higher load mainly relates to increased DOC levels reaching the main branches from the delta, especially during the spring flood.”

Line 397: change to “in the case of”

Accepted. The sentence now reads: “In the case of DOC, only the rivers differ significantly from the other two groups, while in the case of POC, only channels are significantly different.”

Line 415. Change to “do not see”

Accepted. The sentence now reads: “At all sites, O_2 is slightly undersaturated most of the times, but we do not see a strong influence of the delta close to the Black Sea.”

Line 442. Longer when compared to what? Please specify

Results from the Sobek model simulation showed that the residence times of the lakes we studied mostly surpassed the travel time of the water to the individual lake (Oosterberg et al., 2000), so the combined time spend in channels and rivers on the way to the lake. This is where the “longer” came from in this sentence. However, we do acknowledge that the water might be spending longer time in stagnant channels (albeit in connection with the wetland) and therefore propose to remove the “longer”.

Changed sentence: “In the lakes, residence times of 10–30 days allow primary production and local decomposition of organic matter to become important factors driving carbon cycling.”

Line 445. “Seems to be reoccurring” raises the question what evidence there is for that. You might consider rephrasing to “This pattern may be due to the eutrophic state. . . .” unless you can be more specific.

Tudorancea and Tudorancea (2006) report reoccurring algal blooms in the period from 1977 to 1999 without mentioning the month of occurrence. Two studies (Coops et al., 2008; Coops et al., 1999) based on data from 1996-1998 indicate the timing of the algal blooms was also around July and occurred simultaneously with a decrease in macrophyte abundance.

E.g. Coops et al. (2008): “Comparison between early and late summer vegetation showed a distinct seasonality of the vegetation in the large lakes: these lakes were almost entirely covered by Potamogeton spp. vegetation in June, and devoid of macrophytes in late summer. Concomitantly a strong decrease in transparency had occurred with the development of algal blooms.”

The observations of these studies date several years before our study and nutrient levels in the Danube River reduced since then, therefore the phrasing “seems to be reoccurring” - still.

Line 514. “data. . .are treated”

The corrected sentence now reads: “For the Danube Delta, CO_2 flux estimates decreased when considering spatial heterogeneity and seasonality, because the channel data, which showed the most pronounced seasonality and the higher fluxes, are treated independently and assigned to a comparably small area.”

Line 553: “and thus is the”

Corrected sentence: “Since the Danube River is providing more than 50 % of the total discharge and thus is the largest freshwater contributor to the Black Sea …”

Line 565. The Black Sea has only a limited connection to the open sea. Is it meaningful to include it in the estimate of the DOC and POC flux to the ocean?

Although the Black Sea is a marginal sea, it is included in studies concerning global riverine carbon or nutrient export to the ocean (e.g. M. Dai et al., 2012; Li et al., 2017; Ludwig et al., 1996). We therefore considered it reasonable to compare our estimates of the organic carbon export flux of the Danube River to the estimated carbon fluxes of European rivers, especially since the Danube is Europe's second largest river.

Line 565-570. In this section, you are comparing your DIC, POC and DOC fluxes to those of other rivers, but you are not providing any explanations for the observed differences. Adding that would make the comparison more useful.

For the comparison of the different rivers our intention is to look at the carbon yield of the respective river catchments, which we summarized in the following. We will add this information to Table 3 and expand the discussion as presented below.

River	Q_km3/yr	Source	Area [10^6 km2]	source	calculated yields [gC/m2/yr] DOC	POC	DIC
Amazon	5444	A. Dai et al. (2009)	6.4	Meybeck and Ragu (1997)	5.9	0.95	3.8-4.7
Mississippi	552	A. Dai et al. (2009)	3.0	Meybeck and Ragu (1997)	0.31-0.63	0.37-1.0	5.3
Danube	213	ICPDR (2018)	0.82	Tudorancea and Tudorancea (2006)	0.74	0.39	9.5
Zambezi	119	"av lit value" as cited by Teodoru et al. (2015)	1.3	Meybeck and Ragu (1997)	0.20	0.24	2.8
Nile	55.5	Badr (2016)	2.9	Meybeck and Ragu (1997)	0.10	0.14	4.3

"The comparison of our lateral DOC and POC fluxes with available estimates of lateral carbon transport of European rivers to the ocean (M. Dai et al., 2012; Ludwig et al., 1996), indicates that about 3% and 4% of the POC and DOC could be exported by the Danube River alone. On a global scale, the lateral export of POC compares to the amount exported by the Zambezi River (Teodoru et al., 2015) but is about 20 % lower than the export from the Nile, despite the much higher discharge (Meybeck & Ragu, 1997). Absolute DOC export on the other hand is about twice as high in the Danube compared to Zambezi and Nile (Badr, 2016; Teodoru et al., 2015). Differences in DOC and POC export are strongly correlated to catchment area or river discharge, while depending on climate, factors such as forest cover, population density or seasonality also affect the respective export fluxes (Alvarez-Cobelas et al., 2012; Hope et al., 1994). Looking at the organic carbon export yields (see Table 3), we observe that this general trend also prevails for the selected rivers, yet the DOC yield of the Danube's catchment surpasses the one of the Mississippi. This might be due to the lower population pressure and lesser agricultural usage of the Danube Delta, potentially resulting in a better connection of the floodable land to the river.

DIC yield, however, is strongly influenced by the lithology of the catchment via silica and carbonate weathering (Gaillardet et al., 1999). The DIC yields of the Mississippi and the Danube catchment, where siliciclastic and carbonate rocks are abundant are also highest, especially in comparison to the Amazon, where a Precambrian basement covers a large part of the heavily weathered catchment. This might explain why the Danube is transporting as much as 1/3 of the

Amazon's DIC load, while only having 3% of its discharge (Druffel et al., 2005; Moquet et al., 2016)."

Lines 572-575: This is again very descriptive. Are there any possible explanations for the observed differences between rivers?

CO_2 concentrations in large rivers positively correlates with DOC concentration (Borges & Abril, 2011), which can be explained both by simultaneous lateral inputs and by terrestrial organic matter degradation in these net heterotrophic systems. For the selected rivers, the positive correlation also roughly holds for the CO_2 fluxes. The CO_2 fluxes per unit area from the Danube are much smaller than the ones from the Amazon, but they are closer to those observed in the Mississippi, the Zambezi and the average deduced for estuarine systems (Borges & Abril, 2011; Jiang et al., 2019). Based on this correlation we would expect the CO_2 fluxes per unit area for the Nile to be somewhere between the ones from the Amazon and the Zambezi.

Sites with high CO_2 concentrations are also likely to have large CH_4 content. However, the relation is more complex and not always straightforward (Borges & Abril, 2011). The CH_4 fluxes per unit area in the Danube Delta were comparable with those of the Zambezi River but exceeded the fluxes of the large Amazons' inner estuary reported by Sawakuchi et al. (2014).

Line 585. Change to "we therefore assess the potential role". Your intentions are not relevant.

Corrected sentence: "In the following, we therefore assess the potential role of the wetland in this complex hydrological system."

Line 599. What does "decal" refer to?

"decal" is a typo in this context and was supposed to be "decadal" and refers to the estimate carbon storage/sedimentation rate. The corrected sentence reads: "In the Mississippi Delta, DeLaune et al. (2018) found long-term storage of wetlands up to one order of magnitude lower than expected from the decadal sedimentation rate."

Table 3: typo in the heading of the right column "water-air flux from delta"

Thanks!

Line 632: change to "these"

Corrected sentence: "The export surpasses these inputs with the net carbon source from the delta to the Black Sea amounting to about 160 GgC yr^{-1}."

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