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Discussions

Interactive comment on "Spatial and temporal CO_2 exchanges measured by Eddy Correlation over a temperate intertidal flat and their relationships to net ecosystem production" *by* P. Polsenaere et al.

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General comments: "With EC measurements, this paper presented spatio-temporal dynamics of vertical CO2 flux over a lagoon, and provided qualitative results of tidal effect. They found that the C flux exhibited seasonal pattern, which was related to the phenology and coverage of seagrass. They also showed that tidal flooding could easily turn the ecosystem from a C sink to a C source. However, with insufficient data points, the comparisons of different sites and different seasons were a little tricky; the discussion on the effect of seagrass coverage on the Fc-PAR relationship is not convincing. We would recommend a revision."

Working in muddy tidal flat is quite difficult in terms of logistics: soft floor where one sinks 50 cm deep or more, no electricity, immersion twice a day so little time to install material, need for a floating dry and safe place for electronics, etc... Each deployment, you are never sure if you will recover your material at the end. This is part of the reason why such data are so scarce. Indeed, as pointed out by Reviewer 1, our dataset is incomplete for the seasonal scale, as we could not deploy the system in winter. A deployment in December 2009 was attempted but failed due to the particular difficult weather conditions. This precludes an annual budget, as clearly stated in our submitted manuscript. However, the data obtained during the three other seasons, in particular during the most productive periods in the lagoon, provided very original findings about the ecological functioning of the flat at the tidal and diurnal time scales, as well as the relationships between the NEP and the CO2 fluxes. Previous Eddy Covariance measurements in tidal flats were restricted to the Wadden Sea and to the spring period (April 2008) and these fluxes have been extrapolated at the global scale and published in Geophysical Research Letters (Zemmelink et al., 2009). In our submitted manuscript, we are much more careful in our conclusions when considering global CO2 budget of tidal flats. We don't give any annual flux neither at the global scale, nor even at the scale of the flat. Instead we compare tidal flats with some other coastal systems in terms of CO2 fluxes and surface area.

"The most serious problem of the MS is what the scientific findings are by the authors. The MS is filled with descriptive data, lacking in targeted discussions on intertidal flat, neither on general conclusions."

We agree that a part of the submitted manuscript was a bit descriptive; so we will significantly shorten it in the revised version. However, we do not agree that our discussion was not targeted. These data are novel, so we try to describe and discuss them as a whole in the submitted manuscript. The main focuses enounced at the end of the introduction have been reached (focus 1, p.8 l.7 and focus 2., p8 l.10) with precise discussion: control of the primary producers on the vertical CO2 fluxes according to the season and the station at low tide (section 4.1.1., p.21 l.13-16; p.21 l.28-p.22 l.3; p.24 l.4-8; p.25, l.2-6), influence of the tide on the carbon status of the lagoon especially during the transition phases (section 4.1.2., p.25 l.22-26; p.26 l.1-10; p.27 l.8-17). Also, general conclusions have been drawn on the carbon budget of the flat compared to the others and the place of such intertidal ecosystems in aquatic carbon budget (section 4.2., p.30 l.6-18). The lack of data in the winter period and its impact on the confidence of this budget are carefully described.

Specific comments:

1. "The phenology of seagrass plays an important in shaping the seasonal pattern of Fc. However, no detail description of phenology information can be found in the Materials and methods. The phenology of the Zostera noltii seagrass in the Arcachon flat is described in the submitted manuscript (i.e. section 3.5. p.19 l.10 and l.18-22; section 4.1.1. l.9-15) but needs to be presented earlier and displaced in the Materials and Methods (section 2.1)."

We would like to point out that very little is known about seagrass metabolism, and for instance, there has been long discussion on the question of their NPP during the emersion versus during the immersion. See for instance Silva et al., 2005 (Journal of Experimental Marine Biology and Ecology, 317, 87-95), 2008 (Estuarine, Coastal and Shelf Science, 78, 827-830); Abril, 2009 (Estuarine, Coastal and Shelf Science, 82, 357-360); Silva and Santos, 2009 (Estuarine, Coastal and Shelf Science, 82, 361-362); Clavier et al., 2011 (Aquatic Botany, 95, 24-30). In the revised manuscript, we will briefly provide some information about the Zostera noltii phenology.

2. "Please provide a brief introduction of the weather condition and season definition at study site, and explain why chose these study period."

Indeed, the choice of the seasons and sites are briefly described at the end of the section 2.1 of the submitted manuscript (p.9 l.8-14). These two contrasted stations have been chosen according to their differences in Zostera noltii density and in emersion

time (i.e. about four hours). Also, the different sampled seasons, i.e. summer, autumn and spring match with the most productive periods in the flat and imply the succession of different primary producers. To the contrary, weather conditions are described in the section 3 of the submitted manuscript for each season and site along with the Figures 3 to 6.

3. "I don't know why the authors deliberately overlooked the data collection in winter. The reviewer over interprets our submitted manuscript when he writes this was deliberate; for logistic reasons, working with Eddy Covariance in mudflats is not as easy as for instance in terrestrial systems where a lot of data have been published. A deployment in December 2009 was attempted but failed due to the extremely difficult weather conditions. The winter temperature in the study site is 6 ËŽC, which is not a very low temperature, assumed decomposition should happen undoubtedly. Further, as the authors have no C flux data for winter conditions, the conclusion tidal flat ecosystems are a modest contributor to the CO2 budget (p.4 l.11-12) is arbitrary."

It is true that decomposition happens undoubtedly in winter. It is not true however that because of the lack of winter data the conclusion that tidal flats are a modest contributor to the CO2 budget of the coastal zone is arbitrary. As discussed in our submitted manuscript (p.30 l.10-18), in comparison with other coastal systems, like for instance estuaries which emit CO2 all year round at rates much larger than here, tidal flat like the Arcachon lagoon absorb very small amount of CO2 in spring, summer and autumn. The largest measured fluxes (uptake or release) at our study site is 10 to 50 times lower than the degassing what was measured all year round for instance in the European estuaries, i.e. averaged values between 1.2 and 9.1 g m-2 day-1 (Frankignoulle et al. 1998) compared to averaged values close to 0.8 g C m-2 day-1 at maximum in autumn 2007 at Station 2 (p.30 l.13 in the submitted manuscript). In addition, as changes in CO2 flux direction occur with night/day and with the tide the net flux is even lower. This is for spring to autumn, but it is very improbable that the gap in data for the winter period would change this conclusion. During winter, the tidal flat would not emit enough amounts of CO_2 to significantly modify the annual budget and reach annual emissions of estuaries for instance. The amount of carbon fixed in situ from spring to autumn or delivered by the small rivers entering the lagoon is not enough to support such high winter degassing. Respiration rates have been measured in the Arcachon flat using benthic chambers in March 2005, May 2006 and September 2007 over sandy, muddy and seagrass stations (Davould et al., unpublished data). The lowest respiration rates were found in March 2005 with a maximum value close to 0.4 g m-2 day-1 for the seagrass station. Moreover, weak but positive NEP measured by benthic chambers on seagrass stations in the Morlaix bay (between 0.46 and 1.8 g C m-2 day-1) during an annual cycle (Ouisse et al., 2010) and carried out in the Arcachon lagoon in March 2005 (Davould et al., unpublished data) close to 0.52 g C m-2 day-1 suggest that these winter CO_2 emissions are modest and that the flat could remain net autotrophic. So we maintain our conclusion “tidal flats play a minor role in the CO_2 budget of the coastal zone” as their net annual CO_2 exchange with the atmosphere is probably much less than estuaries for instance. The reason for that is the possibility in intertidal areas of temporal net autotrophy in particular in the benthic compartment that (1) absorbs atmospheric CO_2 and marine DIC and (2) fuels heterotrophy and eventually export. This is what our data set shows and it is consistent with some other approaches like static chambers for instance. In our revised manuscript, we discuss these aspects with more details.

4. "The tidal activity is semi-diurnal, but how about the periodicity of spring and neap tide, did the Fc show pattern in this scale? In your analysis, you compared the Fc values in day/night and high/low tide condition, and why not try to understand the tidal effect with a time series perspective?"

Indeed, it would be interesting to study the influence of this periodicity on the CO_2 fluxes in the flat. Spring and neap tide cycles mostly influence the synchronicity between tidal and light cycles and so the intensity and direction of the CO_2 fluxes. A perennial Eddy Covariance station could provide getting longer time series and allow

answering such question. We have sampled neap tide and spring tide conditions, the twenty and thirteen days of CO_2 fluxes obtained respectively in September/October 2008 (25/09-17/10/2008) and April 2009 (1-13/04/2009) at Station 1. Our data did not show clear variations with water height amplitudes (Figures 5 and 6).

5. "The coverage comparison seems meaningless except when compared between Station1 and Station2."

It was not clear to us in what sense the reviewer used the term “meaningless”. Separating the different quadrants around the measurement point has a meaning. Then the different correlations between the Zostera noltii cover in each quadrant and CO_2 fluxes in Table 2 are tested statistically. Some are statistically significant, some other are not. For Station 1, in autumn, though with similar coverage, the average Fc differed a lot, which can’t be explained by coverage. Otherwise, it would be a good example to examine the interaction effect of coverage and tidal flooding. The author can grade the coverage, and choose the day/night and high/low tide values, and then present in a chart box. This is an important comment. The variations observed in the CO_2 fluxes especially in September/October 2008 cannot be explained by the seagrass covers alone but also by a combination of other environmental factors. In the submitted manuscript, the interaction effect of coverage and tidal flooding was not attempted; we chose on purpose to dissociate immersion and emersion cases and to remain only with coverage influence on CO_2 fluxes at low tide. The main reason of this choice was because during the emersion only benthic metabolism is active, whereas during the immersion, benthic and planktonic metabolisms are active and advection with water masses also contributes to the pattern in CO_2 flux. This was clearly evoked in our submitted manuscript in the introduction (p.6 l.25-29) and in the discussion section (4.1.2 p.26 l.1-10 and p.27 l.8-10).

6. "From the images in Fig.2 and the description about the study site, the footprint of EC seems strongly affected by tidal water. Therefore, compared to terrestrial ecosystem, the lateral mass flux in intertidal flat is very important and cannot be ignored (e.g., Yan

et al., 2008, GCB, 14: 1690.1702), and tidal activity shows significant effect on carbon flux (e.g., Guo et al., 2009, Agricultural and Forest Meteorology, 149: 1820.1828). In this MS, it seems the authors only give a superficial interpretation about the unique hydrological condition of intertidal flat. I hope the authors consider the issue more detailed and calculate the portion by tidal activity."

We could not understand what relation the reviewer suggests between footprint of Eddy Covariance and lateral mass fluxes. We are surprised when reviewer 1 writes that he "hope(s) the authors consider the issue (of lateral fluxes with water masses)"; indeed, in our submitted manuscript we referred on 3 occasions (p.6 l.25-29; p.26 l.1-10; p.27 l.8-10) on carbon advection with water masses. The whole section 4.1.2 (p.25 l.8-p.28 l.9) of the discussion was dedicated to water-air CO2 exchanges in relation with benthic and planktonic metabolism and also with advection. In the revised manuscript, we will put much more effort in discussing the effect of tidal water movements on the Carbon budget of the flat and we will integrate the suggested very relevant references to our revised manuscript. Although we do not exactly understand what the reviewer calls "the portion of tidal activity", we know that in the case of the Arcachon flat and with our available data, it is not possible to calculate the quantity of carbon exchanged laterally each tide between the tidal flat and the ocean. As commented by W.J. Cai in is open commentary of our submitted manuscript, very precise pCO2 monitoring at the mouth of the lagoon would be necessary for that. We have some unpublished water pCO2 data during 24h cycles in the main channel of the lagoon. These data show much more complex temporal patterns than expected from a simple enrichment during the immersion and export with the ebbing tide (the so called tidal pumping process). In fact, pCO2 drawdown by phytoplanctonic and Zostera noltii production combined with enrichment from porewaters pumping in the channels complicates the signal. In the present paper, we focus on net atmospheric exchange based on our Eddy Covariance data, and this is still a quiet and complex process to describe in a single paper. Another paper combining all data (also including river inputs) is in preparation and will benefit from the detailed description of atmospheric fluxes reported here.

Changes in footprint during tidal activity are mainly due to changes in measurement height. At low tide, we can investigate the vegetation cover influence at low tide as CO2 fluxes only come from the emerged flat. During the immersion, the footprint is smaller. However, because of the presence of waters, the gas exchange surface is more homogeneous than at low tide when the vegetation patchiness can create more heterogeneity in the fluxes.

Technical corrections: 1. "In Table 1, is this mean +- SE or SD? What's the difference between Average Fc and Daily Fc? Did you do gap-fill?"

In Table 1, it is the Standard Deviation (as in Tables 2 and 3). Average Fc values have been obtained computing the average over the whole data set (all the values obtained every 10 min) for each of the four periods (September/October 2007, 2008, July 2008 and April 2009). Daily Fc values represent the average over the averages obtained for every entire days of each period (i.e. in July 2008, five mean values were obtained for the five entire days and then the daily average was computed over these five values). The percentage of data used to compute daily averaged fluxes will be added in the revised manuscript. No gap-filling was made.

2. "In Table 3, I would suggest a wind-weighted coverage for Zostera noltii."

This wind-weighted coverage won't be able to be done in the revised manuscript because we can solely take into account the wind direction for the seagrass cover calculations and not the wind intensity or the footprint change.

3. "Under unstable condition, the ratio of height: fetch hardly exceeded 1:100. Considering study site is intertidal flat, I would assume a strong turbulence mixing, and thus a fetch of 500m is enough. If possible, can author launch a footprint analysis and give more precise coverage values?"

Indeed, it is a relevant comment, CO2 fluxes came only from the emerged tidal flat from a fetch of 1000 m at maximum. It is due to the unstable prevailing atmospheric conditions and also the measurement heights used for each deployment along with the surface roughness of the flat. Satellite image analysis in a radius of 500 m has been performed to have more precise values for each deployment especially for Station 2 where the measurement height was 4.20 m at low tide. No clear differences between a fetch of 500 and 1000 m were seen in average and also per wind sectors for each deployment and where Fc values are available (see Table below). Moreover, for all the deployments at the Station 1, the measurement heights were above 5 m at low tide and the very low surface roughness of the flat, suggest a footprint rather between 0 and 1000 m than between 0 and 500 m. The choice of 1000 m was then retained as the most adapted and homogeneous radius between all the deployments/stations and atmospheric conditions. In the revised manuscript, the seagrass covers in a radius of 1000 m will be solely presented.

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		NNE 0–45°	ENE 45–90°	ESE 90–135°	SSE 135–180°	SSW 180–225°	WSW 225–270°	WNW 270–315°	NNW 315–360°	Average ± SD
Station 2 Autumn 2007	*Zostera noltii* cover (13/09/2007) - 1000 m	19%	25%	27%	17%	4%	14%	15%	51%	22 ± 14 %
	- 500 m	44%	28%	45%	8%	4%	7%	3%	12%	19 ± 17 %
	F_c (µmol m^{-2} s^{-1})		-0.9 ± 0.7	-2.1 ± 1.4	-2.1 ± 4.4	-0.7 ± 0.6	-0.7 ± 0.7			
Station 1 Summer 2008	F_c (µmol m^{-2} s^{-1})			-1.1 ± 0.9	-1.4 ± 0.3	-1.4 ± 0.6	-0.9 ± 0.9	-2.0 ± 1.4	-0.7 ± 0.2	
Station 1 Autumn 2008	*Zostera noltii* cover (17/10/2008) - 1000 m	98%	93%	86%	70%	95%	99%	99%	98%	92 ± 10 %
	- 500 m	92%	86%	75%	82%	97%	96%	96%	97%	90 ± 8 %
	Zostera noltii cover (08/09/2009) - 1000 m	97%	95%	87%	69%	94%	98%	99%	98%	92 ± 10 %
	- 500 m	91%	89%	77%	82%	97%	96%	97%	97%	91 ± 8 %
	F_c (µmol m^{-2} s^{-1})	-0.5 ± 1.5	-0.7 ± 1.3	-0.1 ± 0.9	-0.9 ± 1.0	-1.5 ± 2.6	-2.2 ± 2.0	-2.0 ± 1.1	-1.5 ± 1.2	
Station 1 Spring 2009	*Zostera noltii* cover (24/06/2009) - 1000 m	90%	89%	74%	62%	94%	97%	96%	94%	87 ± 13 %
	- 500 m	78%	83%	64%	66%	95%	92%	91%	89%	82 ± 12 %
	F_c (µmol m^{-2} s^{-1})			-3.8 ± 3.6	-1.0 ± 1.6	-1.6 ± 1.0	-4.5 ± 2.6	-3.0 ± 1.5	-3.1 ± 1.2	

Fig. 1.