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Biogeosciences Discussions

Interactive comment on "The carbon budget of the Baltic Sea" *by* K. Kuliński and J. Pempkowiak

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The comments from the reviewer#2 are copied below, followed by our replies and changes in the manuscript.

The paper reports an improved and refined carbon budget for the Baltic Sea, a semi enclosed sea in NW Europe. Understanding and budgeting carbon fluxes in semienclosed system is crucial for our understanding of the overall global carbon budget, because semi-enclosed seas are located at the interface between the different compartments of the global carbon cycle, and thus play a key role in (re-)distributing carbon on Earth. The work by Kulinski and Pempkowiak substantially moves beyond earlier studies, by providing a much more detailed and comprehensive picture. To some degree unfortunately, the wealth of information is hardly shown. Thus, my general statement would be that, this paper is very concise and acceptable after a minor revision.

Still, I think that there is much more valuable information to show and discuss (which has been used anyway). From this discussion many interesting aspects will most likely arise, as I have tried to indicate at least some aspects below in my more detailed remarks. For example: -Please address and show (!) seasonal variability of the fluxes, if known/computed.

The carbon budget for the Baltic Sea presented in this manuscript was quantified on an annual timescale. However, some of the carbon fluxes used for the quantification were assessed with the temporal resolution better than one year. This was done e.g. for the quantification of carbon exchange between the Baltic and the North Sea, where results are presented with a weekly, and/or better, resolution. The results of these specific carbon fluxes are discussed in details in paper by Kulinski et al. (2011). On the other hand, some of the carbon fluxes were, due to their specificity, computed on the annual time scale. An example here might be carbon burial in the bottom sediments of the Baltic Sea (Kulinski and Pemkowiak, 2011). Carbon burial estimations are the result of difference between carbon accumulation in the bottom sediments and carbon return flux from sediments to the water column. Quantification of both these fluxes with resolution better than one year is unpractical or even impossible due to specificity of the methodology. When proceeding with the manuscript we were aware of these limitations and thus decided to present the whole carbon budget on an annual time scale in order to keep this manuscript clear. Additionally, one of the major goals of the study presented in the manuscript was the quantification of the net CO2 exchange through the Baltic seawater/atmosphere interface as a closing term of the carbon budget. This approach requires the assumption that steady state occurs, as a result of which all carbon sources and sinks balance one another. This approach is much more reliable for the temporal resolution not better than one year. Thus we would like to preserve the 'annual approach' used in the manuscript.

-If evident, is the seasonality the same for all rivers or would there be differences (Scandinavian, vs. continental European rivers)?

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The carbon input with rivers discharges was computed on the basis of the database created and provided by Baltic-C - a EU FP7 BONUS funded project. This database includes data of monthly means of both water flows and carbon concentrations obtained from the national monitoring programs. The seasonal variability of the carbon fluxes transported by rivers is highly dependant on the geological structure of the catchment as well as on the water flows. Both factors alter longitudinally and are directly related to biological activity, precipitation, temperature and time periods of freezing and melting of the drainage area. Hence the substantial differences occur in the seasonality of the carbon loads entering the Baltic Sea through different rivers. We admit that seasonality of the carbon input with rivers entering the Baltic Sea is of great importance and interests for the scientific community. However such detailed investigations of this flux were not the aim of our study. We consider separate manuscript should be dedicated to study this issue in details.

-Is there any consideration or information about alkalinity? Eventually, a parallel alkalinity budget, or an least some considerations about it could be used to constrain the closing term (CO2 air-sea flux).

Although, alkalinity is an important measure of the carbon cycling in the Baltic Sea (as well as in other water bodies), unfortunately we can not provide, at this stage, a parallel alkalinity budget for the Baltic Sea due to lack of data. There are some results, e.g. for the terrestrial input of alkalinity (provided with the river discharges database mentioned above), however insufficient to use them in the context of carbon budget for the Baltic.

-Please add a summary or conclusions.

The major conclusions are highlighted in the separate section of the revised manuscript as suggested by the reviewer (pages 12-13, lines 413-430 of the revised manuscript).

Some detailed comments: Page 4843, line 8-15. please rephrase (expand?) this section. For an introduction section, as it is here it is too short, and does assume too many prerequisites on the readers side.

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The paragraph with contents suggested by the reviewer was expanded and rephrased in the manuscript (page 2, lines 41-62 of the revised manuscript).

Page 4844, line 8: Wesslander et al. (2010) do not report pCO2 measurements. They report computed values. Please see also below comment for the discussion.

Indeed, the study by Wesslander et al. (2010) report computed, not the measured, values of the CO2 exchange through the Baltic seawater/atmosphere interface . This is corrected in the revised version of the manuscript (page 3, lines 72-76 of the revised manuscript). The sentences: “Although numerous measurements of pCO2 have been performed in the Baltic Sea in comparison with other shelf seas, there is no straightforward understanding of the part played by the entire Baltic Sea in CO2 air-sea exchange. There are discrepancies between reported results, even though they relate to the same area (Thomas and Schneider, 1999; Wesslander et al., 2010).” were replaced with: “Although numerous studies on CO2 exchange through the seawater/atmosphere have been performed in the Baltic Sea in comparison with other shelf seas, there is no straightforward understanding of the part played by the entire Baltic Sea in CO2 air-sea exchange. There are discrepancies between reported results, even though they relate to the same area (Thomas and Schneider, 1999; Wesslander et al., 2010)”.

Page 4846, 2.2: please mentioned first a brief overview over the fluxes considered for the budget

A brief overview of the considered carbon fluxes was added to paragraph 2.2 as suggested by the reviewer (page 4, lines 121-138 of the revised manuscript).

page 4846, line 11: please replace worse: finer? More/less coarse?

The words: "...no worse..." were replaced with the word "finer" (page 5, line 145 of the revised manuscript).

4847: Did the authors make assumptions about riverine input of particulate matter? Please discus this point here, if ignored or considered.

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Yes, particulate matter was included in the assessment of carbon input with river runoff. As it was already mentioned terrestrial carbon input estimations are based on the database provided by the Baltic-C - a BONUS funded project. This database contains water flows and carbon concentrations data obtained within the national monitoring programs of the Baltic Sea countries. Carbon concentrations there are provided as total inorganic (TIC) and total organic carbon (TOC). Thus, the computed carbon fluxes accompanying riverine discharges include suspended as well as dissolved fractions of both inorganic and organic carbon species. However, since the results are presented only as TIC and TOC, it is impossible to break down TIC and TOC fluxes into PIC/DIC and POC/DOC fluxes respectively.

Page 4850 equation 15: This does not appear to be the standard way to compute error propagation? Usually, it would be the square root of the sum of the squared errors?

Indeed, an error propagation should be computed as the square root of the sum of squared errors. This was recalculated and corrected in the manuscript (page 8, lines 256-261 and page 9, lines 302-303).

Page 4854, line 3 ...inconstancy...: This statement is not clear to me. How can one derive such information from a 1-box carbon budget?

Indeed this sentence is formulated ambiguously and did clarify little if anything. In order to avoid misunderstanding it was removed from the revised version of the manuscript.

Page 4854, line 13: I suggest to tone down the discussion/comparison with the Wesslander et al. (2010) study. When going back to Wesslander et al. (2010), they report an uncertainty for alkalinity of 5%, even there optimistic estimate of 2.5 % would yield an error in computed pCO2 on the order of a few hundred ppm, or 0.2 pH units (not considering the associated error in pH). In any case the pCO2 error is far larger than their assumed delta pCO2 signal, which defines the direction of the flux!! I leave it up to the authors to what degree this issue is addressed, but I think it needs to be addressed here.

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The results obtained by Wesslander et al. (2010) are opposite to other findings reported in the literature on CO2 exchange through the Baltic Proper seawater/atmosphere interface. However, the results should be discussed together with an uncertainty assigned to them. The uncertainty presented by the authors (Wesslander et al., 2010) and cited by the reviewer point at the wide range of the results computed by the authors. Thus, the discussion/comparison with the results obtained by Wesslander et al. (2010) was altered, and the following paragraph was removed from our manuscript: "However, these results become questionable when they are compared to the carbon budget obtained in this study. Assuming FCO2 values of -35.4 g C m-2 year-1 (Algesten et al., 2006) and -19.7 g C m-2 year-1 (Wesslander et al., 2010) to be representative of the Gulf of Bothnia and the Baltic Proper together with the Gulfs of Finland and Riga, the entire carbon budget would be unbalanced with 9.18 Tg C year-1. This corresponds to more than 84% of the river input, which is the largest source of carbon for the Baltic Sea reported in this study. In other words, an additional carbon source of 9.18 Tg C year-1 would need to be supplied to the Baltic Sea if the average carbon concentration in the Baltic Sea water did not change. Otherwise the carbon concentration of the Baltic Sea water would increase by an average of 0.4 mg dm-3 year-1 in the total water volume of the Baltic Sea (22 000 km3). This concentration change would correspond to about 10% of the DOC concentration or to almost 2% of the DIC concentration recorded in the surface water of the southern Baltic Sea (Thomas and Schneider, 1999; Schneider et al., 2003; Kuliński and Pempkowiak, 2008; Beldowski et al., 2010)."

Page 4855, line 11: It is unlikely...: This sentence is not clear to me. Please clarify.

Carbon fluxes considered as the Baltic carbon budget elements are quite sensitive to possible climate changes (temperature for example influences primary productivity patterns that influence both POC and DOC concentrations in seawater, precipitation changes will influence water flows and thus will alter carbon fluxes and so on) not to mention pCO2 increase in the atmosphere. Thus, "it is very unlikely that this carbon

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budget for the Baltic Sea will not evolve in the next few decades".

Page 4855, line 27: : : : by the increased carbon....

The correct version of the sentence reads: "Thus, some part of the additional terrestrial carbon load will be compensated by the increased carbon export to the North Sea and the reduced carbon import from the North Sea." It was corrected in the revised version of the manuscript (page 12, line 384 of the revised manuscript).

Figure 1 also should reveal the magnitude/values of the fluxes

Indeed, Fig.1 does not reveal the magnitude of the presented carbon fluxes. However, Fig.1 will be placed at the end of chapter 1 "Introduction" and present the scheme of the carbon sources and sinks included into the box model. Thus, we suggest to leave Fig. 1 as it is now.

Again, please add figures showing temporal variability of the fluxes.

We decided to present all the carbon fluxes of the box model on the time scale of one year. The justification of this approach was presented above. We admit that seasonality of some crucial carbon fluxes (e.g. carbon exchange between the Baltic and the North Sea) is very interesting and important for the Baltic Sea carbon cycling considerations. It has been appreciated in the manuscript by considering seasonality of water flows and carbon concentrations (e.g. in computing carbon loads exchanged with the North Sea and discharged with rivers). However, we consider study on this topic a task by itself, not to be combined with other issues. Thus, such results should be published separately (e.g. Kulinski et al., 2011) in order to enable an extended discussion on these issues. For the purpose of the Baltic carbon budget the carbon fluxes adjusted to the annual time scale were used.

Interactive comment on Biogeosciences Discuss., 8, 4841, 2011.