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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 are copied below, followed by our replies and changes in the manuscript.

This ms provides a synthesis of C fluxes in the Baltic Sea. This paper arrives at different fluxes than those proposed by Thomas et al. Differences are discussed. Such box budgeting exercises are useful.

1. the authors should briefly mention the content of their recent papers Kulinski & Pempkowiak (2011) and Kulinski et al. (2011), so that reader can understand what is the originality of the present work and make sure there is no double publication.

The budget approach for the carbon cycling study in the Baltic, and in the other water bodies, requires precise data on carbon sources and sinks. The two most important

and difficult for quantification are explained in papers by Kuliński & Pempkowiak, (2011) and by Kuliński et al. (2011), related to assessments of carbon burial in Baltic Sea sediments and carbon exchange between the Baltic and the North Sea, respectively. In this study we used just conclusions from both papers and combined them with other sources and sinks to provide the full description of the carbon budget in the Baltic.

2. While box models are a useful tool to understand the main players in carbon cycling, I'm not sure that the CO2 exchange with the atmosphere as a closing term can be robust. A few percent error (5% ?) propagated on the all the bulk fluxes will lead to 100% error on the net flux. So I'm not sure that a box model approach can provide conclusive answers to the status as a source of a sink for atmospheric CO2. On the other hand as mentioned by authors there seem to be a few publications on the Baltic that provide divergent air-sea CO2 flux estimations.

The aim of the study described in this MS was to quantify most sources and sinks of carbon in the Baltic. This provides a useful background for assessment of the individual fluxes importance. The CO2 exchange through water-atmosphere interface is difficult to quantify in the sea of such diversified conditions. This is supported by the results of the pCO2 measurements in the Baltic described in the literature which are often divergent to one another (more detailed description can be find in chapters: 1. Introduction and 4. Discussion). Thus, we see the derived net CO2 flux as the indication that the Baltic is "neutral" in this respect with a slight indication that it is a source. The estimation of uncertainty, provided in the MS (last paragraph in chapter: 3. Results) indicate the Baltic as a weak source of CO2 is by far more realistic than Baltic as a sink of CO2. This by itself can be considered as a novelty, and supports results of studies by Chen & Borges (2009) on costal areas highly influenced by land.

Chen C.-T. A., Borges A. V., 2009, Reconciling opposing views on carbon cycling in the coastal ocean: Continental shelves as sinks and near-shore ecosystems as sources of atmospheric CO2. Deep-Sea Research II 56, 578-590.

3. In table 1, authors report TIC and TOC fluxes from rivers. I would be nice if the TOC fluxes could be broken down into POC and DOC fluxes. Although this is not necessary for the budget, such fluxes would be useful to others. Regarding TIC, it is unclear what it stands for. Is this the sum of DIC and PIC ? If so please break down the fluxes into the two components.

TIC and TOC fluxes from rivers are calculated as products of water flows and carbon (TIC and/or TOC) concentrations in water. Both hydrological (water flows) and geochemical (TIC, TOC concentrations) data are obtained from the national monitoring programs performed by the Baltic Sea countries. The measurements carried out within these programs do not support separate data on dissolved and suspended carbon species concentrations. Thus, it is unfortunately impossible to break down TIC and TOC fluxes into PIC/DIC and POC/DOC fluxes within presented database. Selected studies (Pempkowiak & Kupryszewski, 1980) indicated that proportion between POC and DOC in the Vistula River water is ca. 1:1.5. This might be looked as typical for rivers entering the sea from the south. On the other hand in Siikajoki River entering the Gulf of Bothnia the proportion is 1:1. Our own unpublished data indicate that at least 95% of TIC is DIC in river water entering the Baltic Sea from the south (Vistula and Odra Rivers).

Pempkowiak J., Kupryszewski G., 1980, The input of organic matter to the Baltic from the Vistula River. Oceanologia 12, 80-98.

4. There is a term in the budget missing, regarding PIC. PIC is also buried in sediments. There are benthic calcifiers (invertebrates (bivalves, etc. . .), coralline algae,. . .) in the Baltic Sea that should contribute to this flux. Also there are some reports of suspended PIC as well (Bernard and van Grieken 1989). This term might be minor, but since the authors attempted to be as exhaustive as possible (even estimating dry deposition of CO2) they should also attempt to provide a number on this.

Indeed, PIC export to the sediments was not included into the budget calculations.

However, PIC burial in the Baltic Sea sediments seems to be of minor importance. Bulk of the carbon buried in the bottom sediments is accumulated in the so called "depositional areas" of the Baltic constituting more than 1/4 of the sea surface. Large input of organic matter to these areas cause intensive mineralization of organic matter occurring there. Products of organic matter mineralization acidify the interstitial and benthic water. Such conditions prevent burial of PIC in bottom sediments. Dissolved inorganic carbon species (mostly CO2 (aq) and HCO3-) originating from organic matter mineralization in sediments occur in the interstitial waters. However, their contribution in total carbon exported to the sediments is ca. 250-300 times lower than organic carbon buried in the sediments. In the shallow areas where e.g. bivalves live, practically no accumulation of settled material is observed due to the near-bottom water currents that transport this material to the deep depositional areas.

5. It is unclear in which zone the organic carbon burial estimates were made. We can imagine a situation where the organic carbon from rivers and the diffusive organic carbon inputs are deposited and buried near-shore and that these depositions areas were missed in the budget. The carbon burial estimates probably apply to the more open areas of the Baltic and not the near-shore areas.

Carbon burial was calculated as the difference between carbon accumulation in sediments and carbon return flux from sediments to water column (Kuliński & Pempkowiak, 2011). These study was performed for the deep depositional areas of the Baltic Sea, i.e. Arkona Basin, Bornholm Deep, Gdansk Deep, Gotland Deep and Gulf of Finland. Separately, for the Gulf of Riga and Gulf of Bothnia carbon burial data were adopted from the papers by Carman et al. (1996) and Algesten et al. (2006). As it was mentioned above, bulk of material settled to sediments in the shallow Baltic Sea areas is mineralized and/or transported due to near-bottom water currents to the deep depositional areas. Our own unpublished results indicate that organic carbon concentrations in the sandy sediments located in the shallow areas of the southern part of the Baltic (even these located close to river mouths) are somewhat 70-100 times lower than those observed in the sediments from the depositional areas. There are areas, mostly in the Gulf of Bothnia, where the deep zones are located close to river mouths and carbon burial is likely. However, in the case of the Gulf Bothnia the data adopted from paper by Algesten et al. (2006) took into account the whole sediments surface, together with the near-shore zones.

Algesten G., Brydsten L., Jonsson P., Kortelainen P., Löfgren S., Rahm L., Räike A., Sobek S., Tranvik L., Wikner J., Jansson M., 2006, Organic carbon budget for the Gulf of Bothnia. Journal of Marine Systems 63, 155-161. Carman R., Aigars J., Larsen B., 1996, Carbon and nutrient geochemistry of the surface sediments of the Gulf of Riga, Baltic Sea. Marine Geology 134, 57-76. Kuliński K., Pempkowiak J., 2011, Accumulation, mineralization and burial rates of organic carbon in the Baltic Sea sediments. Marine Chemistry, submitted.

6. Page 4849 Line 8 : justify the choice of temperature (10_C)

The temperature of 10°C was used as it is close to the annual mean temperature in the Baltic Sea region (von Storch & Omstedt, 2008). Because the inorganic carbon input due to wet deposition is related to rain, the low, winter temperatures were not taken into consideration.

von Storch H., Omstedt A., 2008, Introduction and Summary. [in:] The BACC Author Team [eds.], Assessment of Climate Change for the Baltic Sea Basin. Springer-Verlag, Berlin, 1-34.

7. Page 4849 Line 15 : If I understand this correctly, BOD should be a change of O2 concentration per unit of time (mol / m3 / time). How was this converted into a flux that should be expressed as a quantity per surface and per unit of time (mol / m2 / time) ?

Point sources are described as all the terrestrial carbon sources other than those entering the Baltic Sea from rivers. This carbon load was assessed on the basis of HELCOM (2004) data. However, the data were provided as BOD7 and expressed as an amount

of oxygen used by microorganisms in the water volume that enters the Baltic from the point sources per year. The conversion rate (k) was estimated using HELCOM (1983) data. In this paper the same organic carbon input from land was expressed in two ways: as an organic carbon load and as an amount of oxygen (BOD7). It enabled the calculation of conversion rate (k). When we analyzed once again paragraph "2.6 Point sources" in details we noticed a mistake in the equation 10 (page 4849, line 15). Now it is: Fp=BOD7*k and it should be: Fp=BOD7*k-1. We will correct this during the next upload of the files to the journal.

HELCOM, 1983, Seminar on review of progress made in water protection measures. Baltic Sea Environment Proceedings 14, 436 pp. HELCOM, 2004, The Fourth Baltic Sea Pollution Load Compilation (PLC-4). Baltic Sea Environment Proceedings 93, 189 pp.

8. It is a bit confusing to use a mix of units Gg/yr and Tg/yr.

All the total carbon fluxes in the presented carbon budget were expressed in Tg yr-1. However, the carbon loads entering the Baltic Sea from individual rivers were expressed in Gg yr-1. This is due to the fact that some of them are remarkably lower than the total carbon loads presented in the budget. We agree that this mix of units might be confusing. Thus, in the corrected version of the MS we will provide an explanation of the difference between both units in text and in the caption of Table 1.

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