Hydrology and Earth System Sciences Discussions

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Interactive comment on "Global multi-scale segmentation of continental and coastal waters from the watersheds to the continental margins" *by* G. G. Laruelle et al.

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Authors reply to Interactive comment on "Global multi-scale segmentation of continental and coastal waters from the watersheds to the continental margins" by G. G. Laruelle et al.

Anonymous Referee #2 Received and published: 13 November 2012

The authors present a global multi-scale segmentation of continental and coastal waters from the watersheds to the continental margins.

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The paper is generally well written and follows a clear structure, although it is quite lengthy in many places and I would suggest more concise sections, especially section 3 is very long compared to the rest of the paper. Maybe have results and discussion as separate sections.

[1] We believe that separating the results and discussion would not make the manuscript easier to read. We did, however, take the reviewer's recommendation into account and condensed our text in several places (in particular sections 3.2 and 3.4, see below). The introduction and conclusion have also been largely re-written (see Comment #1, Reviewer #1).

When I read the abstract I got the impression that the authors were proposing a 'new' global scale segmentation composed of three different layers that "includes the wholeaquatic continuum with its riverine, estuarine and shelf sea components." However, when reading the paper more carefully it seems that the authors have used existing layer created in separate form previously and aggregated those to one single database.
This should be stated in the abstract.

[2] Our work largely uses already existing layers and the abstract has been modified to better reflect this. "*Our work delineates comprehensive ensembles by harmonizing previous segmentations and typologies in order to retain the most important physical characteristics of both the land and shelf areas.*"

Also it should be made clearer in the Introduction why each of the three levels are needed?

[3] The end of the 3rd paragraph now lists the databases that are required for budget and flux calculations. The 4th paragraph describes their integration into all 3 levels.

"*[...]Moreover, environmental databases gathering monitoring data, climatological forcings and average earth surface properties are available under various forms and at different spatial resolution. Some consists in gridded maps, files or model outputs at 0.5 or 1 degree resolution (World Ocean Atlas, DaSilva et al., 1994, Levitus et al., 1998, GLOBALNEWS, Mayorga et al., 2010, Seitzinger et al., 2005) while others are databases containing measurements from millions (SOCAT, Pfeil et al., 2012) to thousands (GLORICH) or just several dozen (Lonborg and Alvarez-Salgado, 2012, Laruelle et al., 2010, Seiter et al., 2005) of unevenly distributed sampling points. Thus, for environmental budgeting purposes, a multi-scale approach is required to integrate and combine this variety of databases.*

In this study, we present a harmonized multi-scale segmentation for the land-ocean continuum, from the watershed to the outer limit of the continental shelf. It is based on three increasing levels of aggregation and the inter compatibility of these levels not only allows to integrate a wide variety of databases compiled at various spatial resolutions, but also to compare and combine them with one another. The first level, at the finer resolution of 0.5 degrees, is based on the work of Vorosmarty et al., (2002) and resolves the watersheds and river routing. It also attributes an estuarine type to each watershed following the typology of Durr et al. (2011) which includes small deltas, tidal systems, lagoons and fjords. This spatial resolution allows for a realistic representation of the global river network and is compatible with many global databases (World Ocean Atlas, LOICZ, Buddemeier et al, 2008, Crossland, 2005). This level is also suitable for detailed regional analyses of coastal regions and their corresponding watersheds (Regnier et al., submitted). The second level is built on an updated version of the COSCAT segmentation (Meybeck et al., 2006) which distinguishes different segments of the global coastline based on a combination of terrestrial watershed characteristics and coastal geomorphologic features. It is extended here to include the relevant portions of the adjacent continental shelves. The highest level in the hierarchy is termed MARCATS (for MARgins and CATchment Segmentation) and consists of aggregated COSCAT units according to the main

climatological, morphological and oceanographic characteristics of the coastal zone. It is based on the recent synthesis by Liu et al. (2010) and allows for coarser regional analysis and upscaling calculations when datasets are limited. It nevertheless retains the major physical features of many different coastal regions and identifies a number of widely studied systems such as the main regional seas and some major coastal currents. It can be viewed as an analogue to the coarse segmentation of Takahashi et al. (2009) for the estimation of CO_2 fluxes in the open ocean."

Why is the MARCATS level needed? It is essentially an upscaling of the COSCAT units if I understand correctly.

[4] Correct. The MARCATS are an aggregation of COSCATs, in the same way that COSCATs aggregate single watersheds. The purpose of MARCATS is to design larger scale units accounting for coastal currents, regional seas and large climatic zones that are broader than the COSCATs. It provides a suitable scale at which meaningful regional analysis or data aggregation can be performed for given variables, processes or fluxes when data availability is scarce (Seiter et al., 2005, Laruelle et al., 2010, Lonborg and Alvarez Salgado, 2012). An example of such analysis based on the MARCATS units is given in the new section 3.5, which provides regionalized air-water CO_2 fluxes estimates in estuarine environments. In this example, the MARCATS segmentation allows to calculate fluxes from pCO2 data for about a third of the segments. The calculations also require values for estuarine surface areas, which are only available at that resolution (see table 3).

Was any of the listed parameter values in tables 1 to 3 validated or compared to other existing estimates, models or indeed observations, other than the relatively crude global estimates already stated in the text? Or is this the first time such numbers (such as freshwater residence times, watershed surfaces, freshwater discharge, etc) are presented? I imagine some alternative estimates or observations would exist for some of those parameters at least for some locations around the globe?

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[5] In a few of the best studied regions of the world (e.g. Western Europe, Eastern US), some data are already available but none of the parameter values in Table 1-3 have been synthesized at the global-scale. The purpose of our work precisely consisted in a systematic evaluation of these parameters for the entire world and this has been reiterated in the introduction. "*The COSCAT and MARCATS segmentation were used to calculate, for different isobaths, the surface area and volume of each segment of the coastal ocean. The surface areas of watersheds and estuaries are also reported at the same levels. These segmentations can be used in conjunction with biogeochemical databases (e.g. World Ocean Atlas, LOICZ, Hexacoral, GLORICH, SOCAT, and so forth) to establish regional budgets and, eventually, refine global assessments of the carbon and nutrient cycles.*"

Note that inconsistent geographic delimitations are often used among different studies, in particular for limit of the outer edge of the shelf. As a result, it remains difficult to relate the surface area of a coastal zone segment to its corresponding watershed. We believe that the data compiled in table 2 and 3 and supplementary material is useful in this respect as they provide comprehensive and consistent synthesis. We agree, however, that some validation for well surveyed regions is useful and we thus compared our results with published estimates for the North Sea, Baltic Sea, Hudson Bay and Persian Gulf (see new table and [7] below).

System	North Sea COSCAT 403	Baltic Sea MARCATS 18	Hudson Bay MARCATS 12	Persian Gulf MARCATS 29
Watershed Surface Area (103 km2)	**850** (1) *870*	**1650** (1) *1619*	**3700** (2) *3601*	n.a.
Shelf Surface Area (103 km2)	**573.3** (3) *592*	**374.6** (4) *383*	**1040** (5) *1064*	**239** (6) *233*
Shelf Volume (103 km3)	**42.3** (3) *36.3*	**20.5** (4) *20.1*	**100** (7) *105*	**8.8** (6) *8.3*

(1) OSPAR, 2010 (2) Dery et al., 2005 (3) Thomas et al., 2005 (4) Wulff et al., 2001(5) Macdonald and Kuzyk, 2011 (6) Pous et al., 2012 (7) Saucier et al., 2004

The authors should highlight some of the important implications their data could highlight (for the first time maybe?). For instance, with their data, can they allude to what implications there are on a global level for example of the different freshwater residence times?
Section 3.2 gives a little bit of assessment and compares some of the numbers obtained to previous estimations, which is very useful, but I feel the assessment of the proposed database is not as complete and insightful as it should be.

[6] Following Reviewer #2's suggestion, we have condensed the descriptive part of section 3.2 and elaborate further on the implications of our work. In particular, the second paragraph of the section now explicitly discusses the value of the newly calculated, better constrained, surface areas of continental shelf seas.

"*Most coastal ocean surface area evaluations yield values in the range 25-30 106 km2 (Laruelle et al., 2010; Walsh et al., 1988; Cai et al., 2006; Chen and Borges, 2005), which corresponds to 8% of the world's ocean. These values have been largely used in the literature to constrain global budgets and box models (Borges et al., 2005, Laruelle et al., 2010, Mackenzie et al, 1993, Rabouille et al., 2001, Ver, 1998, Wanninkhof et al., 2012) but the use of surface areas varying by 20% from one study to another has implications regarding the accuracy of the budgets calculated. The common definition of a single proper limit for the outer edge of the continental shelf remains a matter of debate in the literature (Borges et al., 2005, Laruelle et al., 2010, Liu, 2010) and the choice of this limit depends on various sedimentological and morphological criteria but also, to some degree, on convenience of use. Convenience is the main reason why the 200 m isobath has often been selected as it provides a consistent limit which is easy to manipulate and allows for inter-comparability between studies. However, the morphological heterogeneity of the coastal zone cannot be accounted for by such a*

simple boundary. Liu et al. (2010) proposed a definition based on the increase in slope of the continental shelf as an alternative which is also used here (see section 2.1) and, although our estimate of 30 106 km2 falls within the range of previously reported values, the method allows for a more rigorous regional analysis of the shelf area distribution around the globe. The shelf break depths for each COSCAT are provided in table 2. Furthermore, the surface areas and volumes between the calculated isobaths for all COSCAT segments are available as supplementary material as well as GIS files providing the exact geographic extend of each unit. This allows for comparisons between studies relying on different definitions for the boundary between the open and the coastal ocean. It also provides a clear boundary for oceanic studies which either exclude the coastal zone (Takahashi et al., 2009) or treat it differently from the open ocean (Wanninkhof et al., 2012).

The last paragraph of section 3.4 concerning the fresh water residence times has also been modified. It is now more concise and highlights the wide spatial heterogeneity of fresh water residence times in continental shelves and their potential use as indicator of strong riverine influence on coastal regions.

"For each COSCAT and MARCATS, the ratio between the shelf volume and the corresponding riverine discharge has been calculated (Fig 5a-5f). Globally, the comparison between the volume of continental shelf seas (3860 103 km3) and the annual fresh water input into the ocean (39 103 km3 yr-1) yields an average value of ∼100. However, this "fresh water residence time" is somewhat skewed by the very large contribution of Antarctic shelves to the total (figure 6). If they are excluded from the calculation, the fresh water residence time drops to ∼55 years which remains significantly higher than the average residence time of ∼8-10 years calculated on the basis of the exchange with the open ocean through upwelling fluxes (Brink et al., 1995; Rabouille et al., 2001; Ver, 1998). Therefore, our results reveal that the renewal of continental shelf waters by fresh water inputs is 5-7 times slower than through upwelling fluxes on average. It should however be noted that the globally averaged

*box-model calculations for upwellings fluxes do not account for the significant spatial
and temporal variability in intensity of upwelling processes which can locally renew
coastal waters in just weeks (Gruber et al., 2011). Furthermore, neither the box model
nor our calculations resolve the lateral transport by along-shore coastal currents. The
ratio of fresh water discharge to continental shelf volume varies significantly from
one region to the other, from 2 years (for COSCAT 1103 where the Amazon flows) to
several thousands of years in many arid regions. Only 17 of the 149 COSCATs have
fresh water residence times shorter than 10 years and the cumulative annual fresh
water input of these 17 COSCAT segment amounts to 16 103 km3, which corresponds
to 41% of the global water flux. These regions can be identified as coastal waters
under strong riverine influence and bear resemblance, in that respect, to the RiOMAR
which are defined as continental margins over which biogeochemical processes are
dominated by riverine influences (McKee et al., 2004).*"

Without any sort of validation/error characteristics, these numbers do not say
much and actually the suggested value of the created database as suggested by the
authors might not be entirely 'realistic' (such as regional analyses and for upscaling
and biogeochemical budgets and application in Earth System analysis).

[7] We understand the need for some sort of validation. The new table 4 (see [3]) and
the accompanying text at the beginning of the updated section 3.3 provides further
insights on the robustness of our estimates:

"*Table 3 summarizes the surface areas of watersheds, estuaries and continental
shelves for every MARCATS. The surface areas of watersheds and continental shelves
are also compared with published values for the North Sea, Baltic Sea, Hudson Bay
and Persian Gulf (Table 4). The consistency between our estimates and literature
data is fairly good and the discrepancy never exceeds 3%. Table 4 also provides
comparison between reported values and our estimates for the continental shelf
volumes. Only 2%, 5% and 6% deviation are obtained for BAL, HUD and PER,*

respectively. The discrepancy reaches 15% in the case of the North Sea (COSCAT 403) but this is likely due to the use of a slightly different geographic definition of the extent of the North Sea in Thomas et al., (2005), which includes a very deep trench located on the Eastern side."

On a related note, which regional analysis do the authors mean (see abstract)?

[8] Basically, we aim at regionalized budget and flux analyses for biogeochemical variables. This has now been clarified in the abstract, introduction and conclusion. The new section 3.5 in which MARCATS units are used to calculate regionalized estuarine CO_2 fluxes while still relying on the level 1 segmentation for the allocation of estuarine types within each segment should clarify our objectives.

The results and discussion section is very descriptive in many places and there is not much detail on the actual value these data might provide.

[9] In the revised manuscript, sections 3.2 and 3.4 are now better balanced between description and analysis (see [6]). The new section 3.5 also focuses more on the implications of our multi-scale segmentation, being also now relevant for the study of biogeochemical processes (i.e. CO_2 fluxes).

In the conclusion, the authors need to clarify what they mean by:
- "The 0.5 degree resolution of our level I compares to the highest resolution globally available". This is interesting and useful but 50 km resolution is still very coarse and I'm unsure whether stating that at this resolution, "the majority of river networks are properly represented" is adequate?

[10] This resolution was used because it is the resolution at which numerous global and regional databases are available and this allows a coupling between these databases and our segmentation (LOICZ, hexacoral, World Ocean Atlas...). It is that compatibility which allows combining the global estuarine typology of Durr et al. (2011) with the

global fresh water discharge of Fekete et al., (2002) and the COSCAT and MARCATS units. "the majority of river networks are properly represented" means that most watersheds produced at a 0.5 degree display a proper river routing and the water discharge calculated by terrestrial GIS models are realistic for watersheds larger than ten 0.5 degree grid cells. This has been checked by previous studies (Vorosmarty and al., 2000, Beusen et al., 2005) and by calculations of the authors. Our statement has been made more explicit now in the conclusion section:

"*At this resolution, the routing amongst the vast majority of river networks is properly represented and terrestrial GIS models are able to produce reliable riverine discharge estimates for large and medium sized rivers (watersheds> ten terrestrial cells, Beusen et al., 2005).*"

- "The multi-scale segmentation of the Land-Ocean-continuum provides an appropriate support for the progressive integration of global databases for carbon, nutrients and green house gas characteristics into lateral land-ocean matter flux budgets"; How?

[11] Again, our new section 3.5 should now illustrate how our segmentation can be applied to establish budgets of biogeochemically relevant variables such as CO2 fluxes in spite of the limited available measurements. The purpose of our segmentation is to integrate, combine and compare various databases by, for example, calculating average properties for any given segment (watershed, COSCAT or MARCATS) depending on the data density and availability. This is, for instance, what is being performed in section 3.4 in which fresh water discharges extracted from the Global NEWS database are compared to the estuarine typology of Durr et al. (2011), each at 0.5 degree resolution, and fresh water residence times are calculated for each COSCAT segment using continental shelf volumes. Based on these average properties per COSCAT, extrapolation to other regions or upscaling to the entire world is possible as illustrated in the new section 3.5, and allows for a new set of studies on biogeochemical element

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cycling based on a harmonized database, allowing to compare uncertainties due the approaches chosen while minimizing the effects of the application of different geodata-products.

- "robust regional and global budgets of relevance to environmental and climatic research"; how would research communities use these?

[12] Constraining regional and global air-water CO2 flux for estuaries has been the object of intense research over the past decade (Abril and Borges, 2004, Borges 2005, Borges et al., 2005, Chen and Borges, 2009, Laruelle et al., 2010, Borges and Abril, 2011, Chen et al., 2012, Cai, 2011). Similar applications can be ambitioned for the other compartments of the Land-Ocean continuum such as inland waters and the coastal ocean. Other biogeochemically relevant gas or chemical components could be covered too (e.g. the fate of organic carbon or silica impacting the biological cabon pump). This work fits within the broad target of constraining better the natural and anthropogenic carbon cycle and thus complements the work currently carried out on the source and sinks for terrestrial ecosystems and the open ocean (see e.g. RECCAP analysis in Special issue of Biogeogeosciences Discussion 2012: REgional Carbon Cycle Assessment and Processes (RECCAP), Editor(s): J. Canadell, P. Ciais, C. Sabine, and F. Joos). In this context, the contribution of the aquatic continuum remains poorly constrained, especially its role in the global anthropogenic CO2 budget and climate perturbation. Thus the dataset can be used to improve the knowledge about the carbon cycle, but also about other relevant elements influencing feedback mechanisms of the Earth's system like N, P or Si.

NB: The updated sections of the manuscript (introduction, section 3.5, conclusions and outlook) are available in a PDF as supplementary material to this letter.

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