Meeting title	Experimental, typological and modelling approaches to evaluate at global and regional scales horizontal and vertical fluxes from land to the open ocean through rivers, estuaries and the coastal ocean			
Working Group	3			
Meeting convener	First name	Alberto	Surname	Borges
	Address	University of Liège, Institut de Physique (B5), B-4000 Liège, Belgium		
	E-mail	alberto.borges@ulg.ac.be		
	Telephone	+32.4.366.31.67	Fax	+32.4.366.33.67
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	Country	Belgium		

Meeting background and aims

Rivers and estuaries are conduits for material between the land biosphere and the oceans, but also reactive compartments leading to the transformation of land material before reaching the ocean. During transport through rivers and estuaries significant exchange with atmosphere can also occur. Hence, major biogeochemical elements such as carbon (C), nitrogen (N), phosphorous (P) and silica (Si) will be modified to during riverine and estuarine transit leading to different fluxes to the coastal ocean. Further, the transformation of C and P during riverine and estuarine transit can lead to the emission to the atmosphere of green house gases (GHGs) such as CO_2, CH_4 and N_2O. Finally, before reaching the open ocean, C, N, P and Si will be modulated by biogeochemical cycling in the coastal ocean further modifying land-ocean fluxes, and coupling with the atmosphere through air-sea exchanges of GHGs and other climatically active gases (DMS, COS, CS_2, …).

The aim of this workshop is to bring together a community of scientists working with different approaches ranging from field measurements to modelling, on fluxes from land to the ocean including vertical exchanges with the atmosphere. The major outcome expected from this workshop is to create synergies among this community to better constrain and evaluate transformation of matter and energy along the land-river-estuary-ocean continuum. Topics covered by the workshop are:

- estimates of fluxes of major biogeochemical elements from land through rivers and estuaries to the ocean based on typological approaches to derive regional and global estimates
- modelling with different degrees of complexity and scaling of transformations of major biogeochemical elements during riverine and estuarine transit and in the costal zone
- scaling of vertical fluxes (atmospheric exchanges) of GHGs and other climatically active gases in riverine, estuarine and coastal oceanic environments.

Summary of discussions

Arthur Chen provided an overview of C cycling in global continental shelves. Mass balance budgets suggest that the sink of atmospheric CO2 in global continental shelves is sustained by the export of DOC and POC to the open ocean. This export is sustained by new primary production mainly fuelled by inputs of nutrients at the continental margin (e.g. upwelling) and to a much lesser extent by river

inputs of nutrients. Data of CO2 in several Asian estuaries in particular 20 systems in Taiwan were briefly presented. Definition/delimitation of the coastal zone, estuaries and rivers was briefly discussed.

Jens Hartmann presented spatially explicit model for CO2-consumption resulting from silicate/carbonate weathering. It was discussed the difficulty of evaluating retention and remobilisation of silicate that will also modulate the net flux of silicate to the oceans. The impact of the resolution of global lithology maps on the computations of fluxes was also discussed. The GloRiCh (Global River Chemistry Database) was presented, and it was announced that the data base also banks data from estuarine zones. Results from Estucarb (Estuary Carbon Dynamics) project were presented among which a strong decrease of CO2 emissions in the Elbe estuary from the mid-1980's to present.

Hans Dürr presented the COSCAT typology and several applications such as the nitrogen and P retention based on a coupling of COSCAT and box-models, and evaluation of CO2 sinks and sources based on an estuarine surface area typology and a continental shelf typology.

Emilio Mayorga presented Global Nutrient Export from Watersheds (Global NEWS) and provided information on updates and novelties of recently released NEWS2 compared to previous version (NEWS1). These include the inclusion of a dissolved silica model, the representation of phosphorous from detergents, and better representation of dissolved inorganic nitrogen retention in the tropics. Uncertainties of estimates were compared by scale (regional versus global) and by element (C versus P and N). Future scenarios on DIN export to the ocean were discussed (Millennium assessment), and probably that direct drivers (dams, sewage, etc…) will have a stronger impact than climate change that will be anyway difficult to treat with the NEWS tools. A new evaluation of CO2 emission from freshwater systems was also briefly presented.

Gilles Billen and Josette Garnier provided an overview of modelling approaches of fluxes from watersheds to ocean : i) input/retention&transformation/output; ii) regression models; iii) deterministic models. Application of such models suggests a retention and elimination of N from watershed to the outlet of river between 50% to 90%. Deterministic models such as RIVERSTRAHLER have the advantage of providing seasonally resolved fluxes. An application of RIVERSTRAHLER was presented, the Indicator of coastal eutrophication potential (ICEP) that is based on Based on C/N/P/Si ratios of river loads and deviations from Redfield stoichiometry. Examples of the application of ICEP were presented such as the Seine and the Red River.

Nathalie Gypens presented how eutrophication can change food web structure with an impact on air-sea CO2 fluxes based on the results from the MIRO-CO2 model. It was discussed how simulations of eutrophication on C cycling and CO2 fluxes diverge at global scale from regional scale in particular with regards to the implementation of nutrient reduction policies.

Steven Bouillon provided an overview of available TSM, POC, DOC, δ^{13}C POC, δ^{13}C DOC in African rivers, and presented on-going measurement efforts. Several features of C in African rivers seem to diverge from global trends such as the %POC/TSM versus TSM patterns, as well as δ^{13}C POC versus %POC/TSM. Possible underlying explanations were briefly discussed although at present time still require verification with more data. Yet, there could be a specificity in the C fluxes from African rivers that could preclude the application (or would require the adjustment) of global models. CO2 data in African rivers was also discussed and the possible role of diurnal variability in modulating the fluxes. The possible role of reservoirs & floodplains in organic carbon retention and processing was discussed although not investigated/quantified so far in African Rivers.

Gwenaël Abril presented recent work on CO2 fluxes in the Amazon River, with a particular emphasis

on the different behaviour in the main stem and in the floodplain lakes, and seasonal variations in the relation to the high-low water cycle. During high waters floodplain lakes are over-saturated in CO2 but during ebbing high primary production due mainly to cyanobacteria leads to strong CO2 absorption. High biomass also leads to high diurnal variation in CO2 fluxes. Scaling of CO2 fluxes in the studied section of the Amazon suggests that previously published CO2 emissions from the Amazon could be over-estimated by 45%.

Christophe Bernard presented a study on the impact of silica river fluxes on ocean biogeochemistry using the HAMOCC5 model. Comparisons were also made of Si flux simulations over continental shelves with HAMOCC5 and more simple box models. Possible impacts of climate change on silica weathering due to temperature and precipitation changes were investigated. Results would suggest a increase export of opal in the North Atlantic due to enhanced inputs from the Amazon and a decrease in the Mediterranean Sea due to decrease precipitation on watersheds. It was discussed the usefulness of Earth System models to determine the change of nutrient fluxes due to precipitation changes. It was discussed how seasonally resolved Si fluxes from GLOBAL NEWS could improve model performance.

Pierre Regnier provided the conceptual frame to achieve a global tool to estimate the filtering capacity of estuaries. The underlying idea is that from basic geometry variables (shape and depth) coupled to physical forcing data (freshwater discharge and tidal prism) transport can be computed. With the use of a simple 1D biogeochemical model it should be then possible to compute transformation and retention. Application of such an approach was presented for salinity profiles in several small estuaries. Robustness of the approach was tested by comparison with a complex 2D model of the Scheldt estuary. It was discussed if an universal biogeochemical model could be achieved to describe the full range of processes. It was discussed that there was a need to compile and review all relevant processes in a range of several estuaries for a robust validation of such an approach. It was discussed the feasibility of coupling this approach with the COSCAT estuarine typology.

Filip Meysman provided an overview of bottom-up (O2 consumption) versus top-down (particle flux of organic carbon) estimates of organic matter degradation in continental shelf sediments. Both agree well except in deep-sea where there could be an under-sampling of O2 consumption measurements in sub-tropical gyres. The impact of fauna on sediment organic C processing was discussed in terms of bio-irrigation and faunal respiration. The relative role of faunal respiration seems particularly important in continental slopes compared to shelves and deep-sea sediments. Problems of undersampling and lack to deep-sea sediment digital maps were discussed.

Arthur Capet presented the 3D physical biogeochemical coupled model of the Black Sea with an emphasis on diagenesis on the continental shelf. Model reproduces well the main patterns of horizontal circulation and vertical temperature and salinity structures. Modell represents adequately the organic matter deposition and sediment-water fluxes of NH4, NO3, silica, oxygen, and denitrification, over inner, middle and outer continental shelf. The role of dentrification in sediments to remove nitrogen fluxes from the Danube was explored for the 1970's, late 1980's (maximum eutrophication) and late 1990's. It was discussed how to improve the model to represent sediment resuspension due to wind waves.

Thomas Bell presented a global surface-ocean dimethylsulphide (DMS) database and climatology. The data-base has now more than 47,000 measurements improving on previous climatology (<16,000 measurements). Procedure to achieve the climatology was presented (extrapolation, interpolation& substation, smoothing and correction with original data). New DMS emission estimates are about 20% higher than from previous climatology. Range in estimated flux due to uncertainty in seawater concentration data availability is similar to that due to uncertainty in parameterisation of the gas

transfer parameterization. Data on DMS in continental shelves represent about 30% of the whole data-base. It was discussed how to achieve a coastal estimate of DMS emission, covering the type of scaling tool (Longhurst biogeochemical provinces), type of gas transfer velocity parameterization, type of wind speed data sources. It was also discussed how if the C flux related to DMS fluxes would be significant in terms of C fluxes over continental shelves. Finally, it was also discussed how eutrophication could change species composition and DMS fluxes in coastal environments.

Helmuth Thomas presented carbon dioxide fluxes in Scotian Shelf and Amudsen Gulf based on high resolution sampling. Differences in air-sea CO2 fluxes, source versus sink and underlying mechanisms were discussed. The Scotian Shelf acts as a source of CO2 to the atmosphere due to upwelling of deep waters and rapid stratification that limits phytoplankton blooming in time. The Amudsen Gulf acts as a sink for atmospheric CO2 due to biological activity under-ice and a during ice-free zones, and due to the presence of sea-ice during winter-time. It was discussed how calcium carbonate precipitation could contribute to the CO2 fluxes, and how seaice-atmospheric CO2 fluxes would impact the overall budget.

Hermann Bange presented MEMENTO (Marine Methane and Nitrous Oxide database). A first round of data archiving was successfully achieved, and another round is planned. Existing data-sets not yet included achieved in MEMENTO were briefly discussed. It was discussed if and to which extent estuarine data-sets should be included in MEMENTO. While the objective main objective is to use MEMENTO to evaluate open ocean fluxes, it was suggested that estuarine data could be deposited in MEMENTO. Additional data-sets held by scientists in the audience were also identified.

Alberto Borges provided an overview of available fluxes in continental shelves and limitations of these various estimates. Novelties of latest scaling study of CO2 fluxes in coastal environments was also presented with emphasis on differentiation of upwelling systems among ocean basins and underlying rational. Overview of quality control procedures and status of surface ocean carbon dioxide atlas (SOCAT) was presented. Overview of existing and planned observatories for carbon in coastal environments was also presented. It was discussed how denitrification and oxygen minimum zones could explain the different behaviour of air-sea CO2 fluxes in different coastal upwelling systems.

Jonathan Barnes presented N_2O data in U.K. estuaries and underlying mechanisms suggesting a major role of nitrification in generating N2O contrary to common believe that denitrification generates N2O in estuaries. In highly polluted estuaries such as Adyar (India) denitrification actually leads to a removal and under-saturation in N2O. A re-evaluation of N2O emission from European estuaries provides lower values than previous estimates.

Goulven Laruelle presented the evaluation of CO2 fluxes in estuaries and continental shelves using a spatially explicit typology based on the COSCAT coastal segmentation combined to Smith and Sandwell topography to delineate the continental shelf break. The new estimates indicate a lower source of CO2 from estuaries and weaker sink of atmospheric CO2 for continental shelves than previous estimates. It was discussed on reliability of extrapolation for some estuarine types like fjords where data is scarce. It was discussed if CO2 fluxes scaled equated with organic carbon inputs from the COSCAT typology. It was discussed how volume of systems could be implemented in the existing typology to be compatible with the modelling approach of Pierre Regnier. It was discussed how the typology could also be used to scale estuarine emissions of N2O and CH4 using data compiled in MEMENTO.

Meeting Outcomes

- Discussion of feasibility of coupling a the RIVERSTRAHLER model with a simplified forcing

field with the GLOBAL NEWS to provide more robust estimates of fluxes from rivers, at European and possibly global scales.

- Discussion of feasibility of using the estuarine typology of University of Utrecht to scale estuarine N2O and CH4 fluxes using MEMENTO and other data-bases.
- It was noted that a recent mangrove GIS data-base has recently been developed and could be used to upgrade the University of Utrecht estuarine typology, to include inter-tidal areas.
- Discussion of feasibility of using COSCAT continental shelf typology of University of Utrecht to scale DMS emissions from continental shelves.
- Some participants expressed willingness to contribute CH4 and N2O data-sets to MEMENTO.
- Some participants expressed willingness to contribute carbon data-sets to GloRiCh in particular in the tropics. This will be highly valuable to calibrate/adjust the GLOBAL NEWS DIC model outputs. These carbon data-sets to be banked in GloRiCh will also contribute to on-going synthesis efforts on riverine fluxes in the REgional Carbon Cycle Assessment and Processes (RECCAP) initiative.
- Arthur Chen proposed that discussions and outcomes during the workshop could the subject of a paper in *Current Opinion in Environmental Sustainability*

Goals and plans for future activities

It was highlighted that further interaction between WG3 with WG2 would be necessary to decide on best gas transfer velocity parameterization, wind speed products, and gridded gas transfer velocity to computed the CH4 and N2O fluxes based on the data compiled in MEMENTO.

Other comments

All participants agreed that the workshop was stimulating and successful.

Most presentations were circulated among workshop participants through a server of the University of Liège.