C-CASCADES FACTSHEET

THE IMPORTANCE OF THE LAND-OCEAN AQUATIC CONTINUUM CARBON CYCLE FOR CLIMATE PROJECTIONS

Objectives of C-CASCADES

THE MOST RECENT INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE ASSESSMENT REPORT[1] (IPCC AR5, 2013) ACKNOWLEDGES THE TRANSPORT OF CARBON ACROSS THE LAND-OCEAN AQUATIC CONTINUUM (LOAC) AS A KEY COMPONENT OF THE GLOBAL CARBON CYCLE.

However, as of today, quantification of the role of the LOAC (inland and coastal waters) and its dynamics in the global carbon budget is still in its infancy:

- Earth System Models (ESMs) of the climate system and biogeochemical cycles used for the IPCC AR5 do not account for the lateral flows of carbon along the LOAC and associated CO_2 and CH_4 exchange with the atmosphere.
- Perturbations of the LOAC carbon cycle due to human activities (e.g. land-use, climate change, hydraulic management, industrial activities) have not yet been quantified.

This knowledge gap has major implications for assessing regional and global carbon budgets, climate projections and, thus, is crucial for climate policy. In order to make a breakthrough in the field, **the Marie Curie Innovative Training Network C-CASCADES aims to advance significantly the predictive capability of ESMs by integrating, for the first time, the transfer of carbon from land to ocean in analyses of the coupled carbon-climate system and its response to anthropogenic (human induced) perturbations.** This overarching objective is addressed across scales, from the local to the global.

1. Ciais, P., et al., 2013: Carbon and Other Biogeochemical Cycles, in: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

C-CASCADES

a Marie Curie Innovative Training Network

At the small catchment scale: the example of the Boreal Forest

By taking up roughly 5% of the anthropogenic CO_2 emissions (about 0.5 Gigatonnes of carbon per year ($GtC.yr^{-1}$) on average over the last decade), the extensive boreal forest ecosystems in the Northern Hemisphere are major contributors to the global terrestrial carbon sink. Quantification of the sequestration of atmospheric CO_2 by the terrestrial biosphere is mainly based on eddy-covariance Net Ecosystem Exchange (NEE) measurements (Fig. 1).

In simple terms, the NEE provides an estimate of the net flux between CO_2 fixed by photosynthesis (NPP) and CO_2 released back to the atmosphere by soil respiration, thus allowing quantification of the anthropogenic carbon sequestered in the living biomass and soils (ΔC). However, this approach does not account for the leakage of carbon from the plant-soil system into aquatic systems.

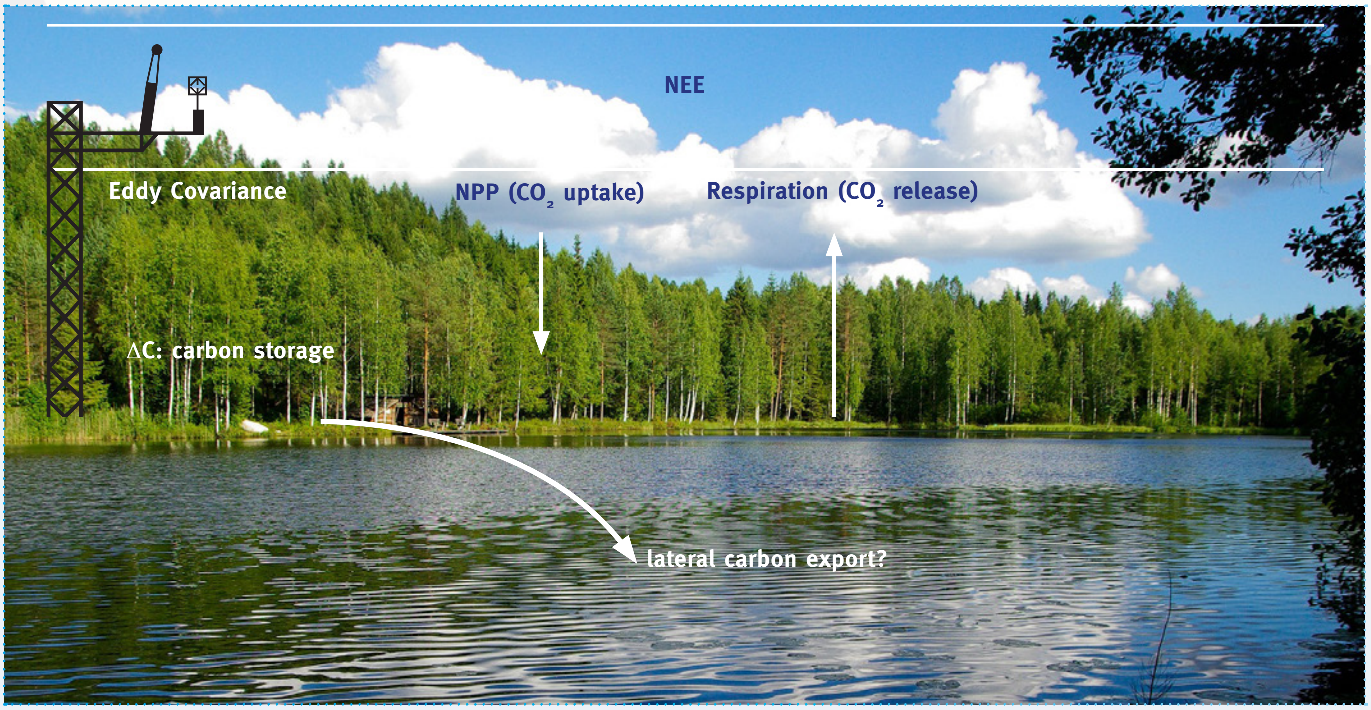

Fig.1 - Assessment of net ecosystem exchange (NEE) by eddy-covariance measurements. The lateral export of carbon to aquatic systems is excluded in the carbon budget analyses.

How large is the lateral carbon export in a small boreal catchment and what are the implications for estimates of the terrestrial carbon sink?

Recent studies[2] from a small boreal catchment in Sweden demonstrated that the amount of carbon export along the LOAC was significant compared to the NEE (between 4 and 28 %), leading to an overestimation of the land carbon sink at the catchment scale. In other words, a fraction of CO_2 absorbed by the forest and measured as NEE is not sequestered in the ecosystem, but transferred to the nearby inland waters as shown in Fig.1. Considering that many political decisions and carbon management strategies are based on estimates of the terrestrial carbon sink, such overestimation is substantial and needs attention.

How will the lateral carbon export in small boreal catchments change in future and how will this affect the terrestrial carbon sink?

The lateral carbon export is strongly influenced by precipitation, reaching maximum values during wet years. The NEE shows the opposite pattern with lowest values during wet years. Thus, overestimation of the terrestrial carbon sink will likely be higher with increasing precipitation. As a wetter climate has been predicted for large parts of the boreal region, we can expect boreal ecosystems to become less efficient terrestrial carbon sinks in near future.

HOW WILL C-CASCADES ADDRESS THIS ISSUE?

C-CASCADES will provide an improved understanding and quantification of the lateral carbon transfer at the catchment scale across a wide range of environmental settings. These include all major aquatic systems of the LOAC, from alpine streams to alluvial estuaries. In addition, new measurement technologies will be developed, a crucial step for better understanding the LOAC carbon cycle and its human perturbation.

2. Öquist MG, Bishop K, Grelle A, Klemedtsson L, Kohler SJ, Laudon H, Lindroth A, Lofvenius MO, Wallin MB, Nilsson MB. 2014. The Full Annual Carbon Balance of Boreal Forests Is Highly Sensitive to Precipitation. Environmental Science & Technology Letters 1: 315-319.

At the regional scale: the example of the EU region

The LOAC transports carbon away from where CO_2 is withdrawn from the atmosphere (NEE) and induces large uncertainties when assessing policy-relevant carbon budgets at regional scales. For instance, a recent estimation[3] showed that the lateral transfer of carbon for the EU-25 region is comparable in magnitude to the carbon accumulation in European forests (ΔC) (Fig. 2).

In addition, a significant fraction of the carbon which leaks from the plant-soil system into the LOAC is decomposed in streams, rivers, lakes and estuaries and re-emitted back to the atmosphere as greenhouse gases before reaching the ocean. This implies that the storage capacity of anthropogenic CO_2 by European terrestrial ecosystems is likely overestimated.

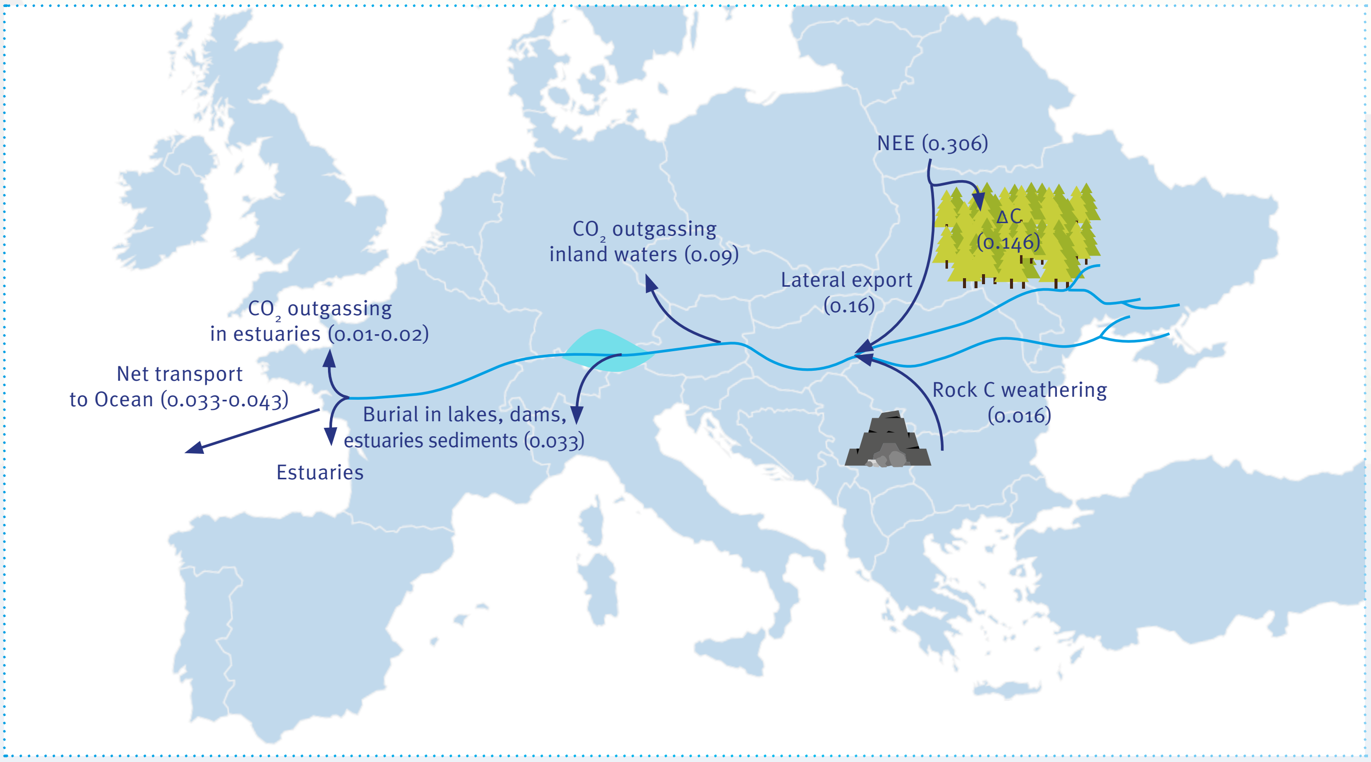

Fig. 2 - European-scale carbon cycle loop involving lateral transport by the LOAC (fluxes are in GtC.yr-1). The decomposition of this loop into natural background and human induced perturbation fluxes is not known.

In addition, the LOAC carbon cycle has been profoundly modified by human activities (e.g. erosion enhanced by agriculture, untreated waste water poured in the aquatic network, river damming and irrigation) and will further be altered in the decades to come. Therefore, it is crucial to understand how the regional-scale lateral carbon flows along the LOAC and associated CO_2 and CH_4 exchange with the atmosphere are impacted by environmental and climate change.

HOW WILL C-CASCADES ADDRESS THIS ISSUE?

C-CASCADES aims to better understand, quantify and model the carbon transport and transformation processes along the LOAC in several large regions with contrasting climate and environmental conditions: the Seine and Danube catchments, the Amazon river and plume system and the pan-Arctic land-ocean continuum. These efforts will not only lead to more accurate regional carbon budgets, but will also allow quantification of past and future changes in natural and anthropogenic LOAC carbon fluxes, and their attribution to climate and environmental drivers.

3. Ciais, P. et al.: The impact of lateral carbon fluxes on the European carbon balance. Biogeosciences, 5, 1259–1271, 2008. doi:10.5194/bg-5-1259-2008.

At the global scale

The perturbation of the global carbon cycle caused by human activities (fossil fuels, industry and land-use change emissions) commonly neglects the contribution of the LOAC[1,4] (Fig. 3). This is an important knowledge gap as it has been shown that the incorporation of the LOAC carbon fluxes could significantly modify the anthropogenic CO_2 budget[5] (Fig. 4). However, it is important to recognize that much of the quantification of the role of LOAC and its dynamics in the global carbon budget entails large uncertainties.

Global carbon dioxide budget without LOAC (GtC.yr-1) - 2004-2013

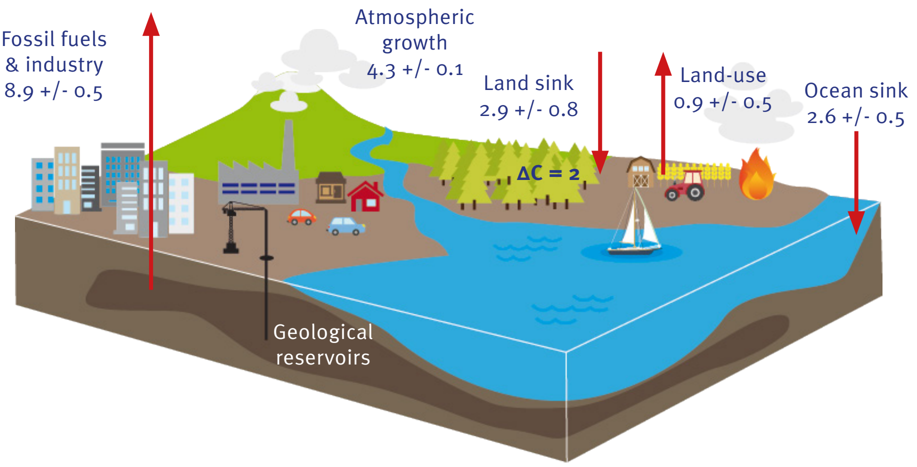

Fig. 3 - Schematic representation of the overall perturbation of the global carbon cycle caused by anthropogenic activities, averaged globally for the decade 2004-2013. The arrows represent emission from fossil fuels and industry, emissions from deforestation and other land-use change, the growth of carbon in the atmosphere and the uptake of carbon by the "sinks" in the ocean and land reservoirs. Source: Le Quéré et al., 2015[4].

Accurate representation of carbon fluxes and feedbacks within the LOAC in modern earth system models (ESMs), based on model parameterizations and empirical evidence is essential to address this gap. This will improve the accuracy of the global carbon budget and help to inform climate policy.

Global carbon dioxide budget with LOAC (GtC.yr-1) - 2004-2013

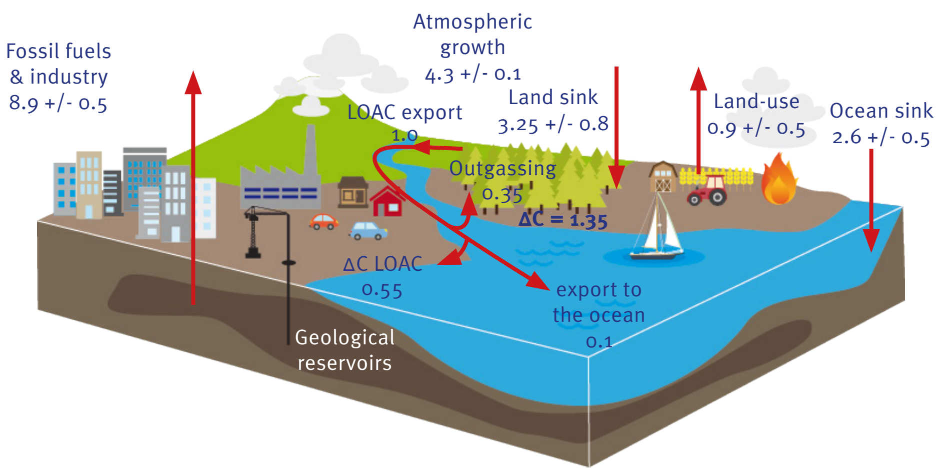

Fig. 4 - Global budget of anthropogenic CO_2 in GtC. yr-1, represented as perturbation of natural fluxes in presence of 'boundless' carbon cycle processes, which includes the land–ocean aquatic continuum (LOAC) fluxes. Source: Regnier et al., 2013[5]. Note that due to lateral carbon export, the storage of anthropogenic carbon on land (ΔC = 1,35) is significantly smaller than in the traditional analyses (ΔC = 2 in Fig. 3).

HOW WILL C-CASCADES ADDRESS THIS ISSUE?

C-CASCADES will address essential processes, such as the contributions of terrestrial soils and their connected rivers, lakes and dams, aquatic sediments, and the coastal - open ocean interface, that determine the role of the LOAC in the global carbon cycle. Representation of these processes in ESMs will help to reduce uncertainties and make progress towards a comprehensive global carbon budget which includes the LOAC dynamics. These issues are essential for accurate future climate projections and thus for climate-policy.

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4. Le Quéré, C. et al.: Global Carbon Budget 2014. Earth Syst. Sci. Data, 7, 47-85, 2015.
5. Regnier P. et al.: Anthropogenic perturbation of the carbon fluxes from land to ocean. Nature Geoscience, 6, 597–607, 2013.

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