Modelling of carbon and nutrient transfers in French rivers: First step of a national generic land to sea modelling chain to fight against coastal eutrophication

Modélisation des transferts de carbone et de nutriments dans les rivières françaises : mise en place d'une chaîne de modélisation terre-mer pour lutter contre l'eutrophisation côtière.

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RÉSUMÉ

Face aux problèmes d'eutrophisation côtière, les outils de modélisation biogéochimiques des surfaces continentales doivent être portés à des échelles suffisamment grandes pour rendre compte l'ensemble de l'espace du bassin versant amont à l'origine des symptômes côtiers. Dans le même temps, ces modèles s'astreignent à des résolutions spatiales et temporelles de plus en plus fines, afin de décrire avec précision la transformation, l'élimination, la rétention du carbone et des nutriments durant leurs transferts dans les cours d'eau. Le modèle biogéochimique pyNuts-Riverstrahler permet de concilier une représentation mécaniste des processus microscopiques opérant dans le continuum aquatique, avec suffisamment de généricité pour être appliqué des domaines d'études nationaux et même continentaux. Ce modèle s'est en premier lieu appuyé sur des bases de données paneuropéennes pour modéliser tous les principaux fleuves européens de la façade Atlantique nord-est. Une nouvelle configuration du modèle est aujourd'hui proposée à l'échelle de la France métropolitaine, en utilisant des bases de données nationales plus fines spatialement, ainsi que les recherches les plus récentes permettant d'estimer les apports aux hydrosystèmes des bassins versants français. Ce travail constitue une première étape vers une chaîne de modélisation générique décrivant les transferts biogéochimiques de la terre vers les rivières et les estuaires côtiers français métropolitains (projet nuts-STeauRY sur financement OFB).

ABSTRACT

Biogeochemical watershed models are now prompted to reconcile the need to expand their spatial extent up to the regional scale where coastal damages are observed, and to increase their spatial and temporal resolution to accurately depict the transformation, elimination/immobilization of carbon and nutrients during their in-stream transfers. While regional modelling efforts are still greatly supported by statistical approaches, the biogeochemical pyNuts-Riverstrahler model rises up the challenge of a mechanistic representation of microscopic processes operating in the aquatic continuum, scalable and compatible with regional up to national or continental domains. This generic model was first successfully implemented using pan-European databases for all the north-east Atlantic rivers, including highly perturbed hydrosystems. A new set-up of the model is now proposed at the scale of metropolitan France, using more spatially refined databases and the most recent research available to support calculation of anthropogenic constraints. This work constitutes a first step toward a generic modelling chain describing biogeochemical transfers from land to rivers and estuaries down to the French metropolitan coastal areas (nuts-STeauRY project funded by the French Office of Biodiversity OFB).

MOTS CLES

Carbon and nutrients, Aquatic transfers, Biogeochemistry, PyNuts – Riverstrahler model, France

1 INTRODUCTION

The modelling of riverine exports in order to appraise coastal eutrophication problems at regional/national scales has long been supported by statistical regression models, input-output or partitioned retention approaches. Reproducing these terrigenous fluxes by being able to take into account the intensity of human activities in the watersheds, and at the same time, representing all aquatic processes involved in the transformation, the elimination or the retention of carbon and nutrients during their in-stream transfers, calls for more process-based approaches. The pyNuts-RIVERSTRAHLER model includes the biogeochemical RIVE module, and rises up the challenge of a mechanistic representation of microscopic processes operating in the aquatic continuums at pluri-regional scales. It belongs to a new generation of biogeochemical models capable of deepening the understanding of the functioning of man-impacted regional hydrosystems, and at the same time, being a tool to dialogue with water authorities to identify efficient mitigation measures to limit marine eutrophication problems.

2 MATERIALS AND METHODS

2.1 The RIVE biogeochemical aquatic model

The RIVE biogeochemical model has continuously evolved since 1994 (Garnier et Billen 1994) and aims at representing the biogeochemical functioning of aquatic systems, by simulating the cycling of nutrients (dissolved and particulate) and carbon (organic and inorganic), including interaction with micro-organisms (phytoplankton, zooplankton and bacteria). Most of the kinetic parameters involved have been determined through field or laboratory experiments under controlled conditions and are thus fixed *a priori*, without requiring additional calibration procedures. The RIVE code is still mobilizing several research teams. The code is available under the terms of the *Eclipse Public License 2.0* (see also: www.federation-fire.fr/rive/).

2.2 The RIVESTRAHLER drainage network modelling approach

RIVERSTRAHLER is a generic water quality model of the whole drainage network, idealized as a regular scheme of confluences of three types of objects: upstream sub-basin, main river-axis and hydraulic annexes (Billen et al., 1994). It incorporates the RIVE code and allows a Lagrangian description of the circulation of waterbodies and ecological function, according to constraints imposed by the morphology of the rivers, hydro-climatic conditions, urban point-sources, and all lateral inputs exported from terrestrial parts of the watersheds.

2.3 The pyNuts modelling environment

The pyNuts modelling environment is a python framework providing the information required by RIVERSTRAHLER when modelling the biogeochemical functioning of a water body along its journey from headwaters to its sea outlet. It basically includes the definition of simulation units, the processing of spatially explicit data describing natural and anthropogenic constraints, the piloting of the biogeochemical calculation, and the physical organization of the simulation in- and out-puts in a database-management system. Such infrastructure is essential to meet the challenge of mechanistic modelling of large-scale river networks (Thieu et al. 2017).

2.4 The French river network domain

An idealized description of the river network is provided by the Catchment Characterization Model (CCM 2.1) database, which includes a hierarchical set of river segments and catchments based on the Strahler ordination. In total, 80 sea outlets have been identified as contributing to the French metropolitan marine domain, considering a minimum size of 300 km². They drain a terrestrial domain of 486 039 km^2 covering a wide gradient of climate, population density, land use and hydrological conditions and cumulate 174 183 km of river network.

3 RESULTS AND DISCUSSION

The pyNuts modelling environment (Figure 1) is built on PostgreSQL database-management system in tandem with PostGIS spatial database extender for processing geographic objects and calculating the required input at the scale of the modelling units. Following the pyNuts data access strategy, data used for rapid access during simulation runs are stored in a binary format as python pickles files, while final simulation results are consolidated in a relational database-management system to enable a

thorough exploration of simulation results using SQL language. Raw data and databases describing natural and anthropogenic constraints within river basins are stored in compressed archives preserving their original data structure and a calculation method is thus created for each model input calculation. Management of the model runs, is based on a simulation roadmap describing one or multiple simulation sequence(s), each of them containing reference to annual simulation scenarios corresponding to a set of specific input calculation methods.

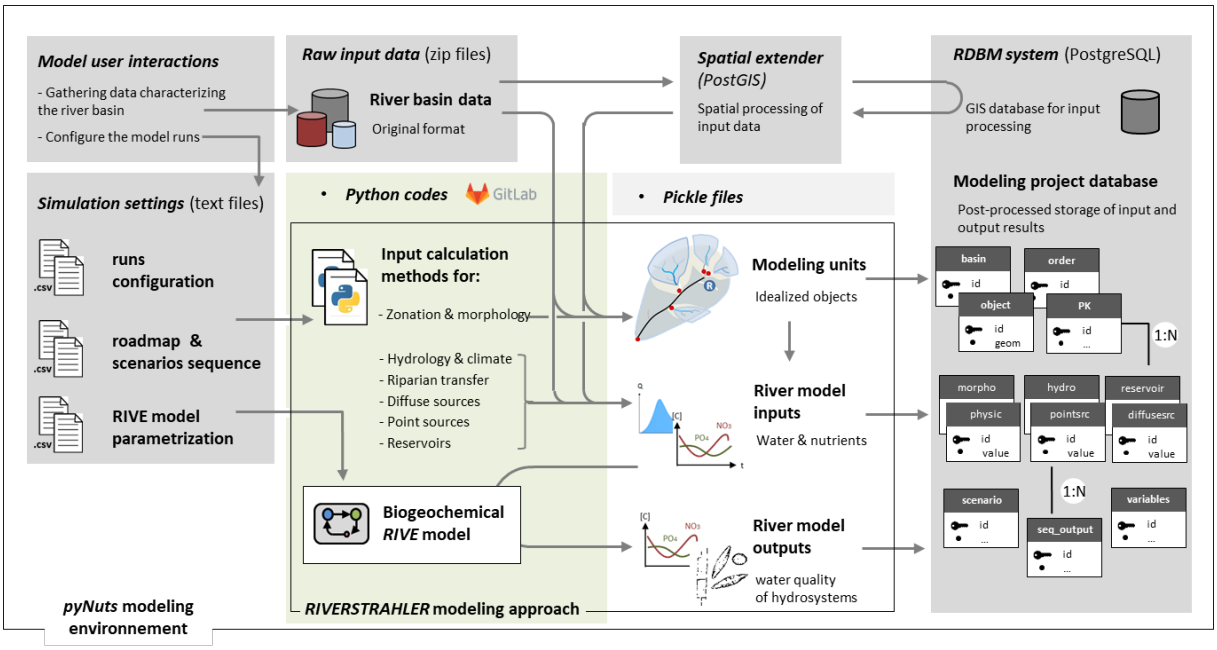

Figure 1: schematic representation of the integrative pyNuts modelling environment including a flowchart of the different processing and simulation stages with associated data format and access

For French rivers, specific methods are developed for calculating point and diffuse inputs according to multiple regional databases describing land uses, soil properties and human activities in watersheds. Land-based nutrient emissions are validated using water quality times series available for upstream monitoring station. An interactive atlas, scaling and mapping these terrestrial exports to rivers, was developed for the whole French domain https://nuts-steaury.cnrs.fr/les-resultats/. Simulation of water quality can be provided for the time period 2016-2020 with a 10-day time step at each kilometer of the French drainage network. Nutrients exported to coastal areas can be calculated for each sea outlet and then aggregated by coastal water bodies where eutrophication indicators will be also estimated. The pyNuts-RIVERSTRAHLER model, by mechanistically linking human pressures in watersheds and nutrient fluxes exported to coastal areas, constitutes a valuable tool for integrated water quality management services. It can promote efficient dialogue between researchers and managers, in order to better integrate territorial peculiarities and concerns into the ecological functioning of regional hydrosystems, and thus succeed in ultimately reducing coastal eutrophication issues in France.

BIBLIOGRAPHIE

Billen, G., Garnier, J., Hanset, P., 1994. Modelling phytoplankton development in whole drainage networks: the RIVERSTRAHLER Model applied to the Seine river system. Hydrobiologia 289, 119–137. https://doi.org/10.1007/BF00007414

Garnier, J., Billen, G., Coste, M., 1995. Seasonal succession of diatoms and Chlorophyceae in the drainage network of the Seine River: Observation and modelling. Limnol. Oceanogr. 40, 750–765. https://doi.org/10.4319/lo.1995.40.4.0750

Thieu, V., Silvestre, M., Garnier, J., Billen, G., 2017. Introducing the biogeochemical pyNuts-Riverstrahler model to assess prospective scenario impact along the aquatic continuum in western EU-rivers, in: Mountains to the Sea. Honolulu, Hawai.