Assessing the fate of dissolved inorganic phosphorus in global watersheds using process-based models

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Key words: phosphorus, surface freshwaters, global scale, process-based modelling

Introduction
Phosphorus (P) is a key element for all living species, typically acting as the limiting nutrient for primary productivity in freshwater bodies. Over the past century, human activities have drastically amplified and accelerated P transport to global surface freshwaters [1]. This has led to widespread eutrophication, constituting threats to human and ecosystem health not just in rivers and lakes, but also in the coastal ocean. Designing future strategies to reverse this trend requires a thorough understanding of large-scale interactions between human activities, climate, and P cycling, notably in river networks, the main pathways for P transfer from land to oceans. Beusen et al. [2] recently estimated global total P (TP) delivery to watersheds, transfer in river networks, and export to the coasts over the 20th century, by coupling global nutrient and hydrology models, and using the spiralling method to estimate TP retention (IMAGE-GNM). However, eutrophication risks are, to a great extent, linked to the presence of soluble reactive nutrient forms, which can be directly uptaken by algae for primary production [3]. Moreover, even if global freshwaters may retain large amounts of P on the long term, this accumulated P can be re-mobilized locally at shorter timescales and hinder local remediation efforts. It is therefore crucial to distinguish between different P forms in global biogeochemical models, and assess their ability to be retained and re-mobilized. In the present study, we therefore refined the IMAGE-GNM model by including 3 P forms (dissolved and particulate inorganic P, and organic P, noted DIP, PIP and OP, respectively) and mechanistically simulating processes of the P cycle within global river networks. We present here results on DIP, since it is most likely to affect algal proliferation.

Scientific approach
Monthly water stores and fluxes in the hydrosystem were quantified with the spatially explicit, mechanistic model PCR-GLOBWB at a half degree spatial resolution [4]. TP flows entering the river network from various natural and anthropogenic sources (i.e., aquaculture, sewage, chemical weathering, runoff, soil loss and vegetation scouring in floodplains) were assessed at a yearly time step with the Integrated Model to Assess the Global Environment (IMAGE), which simulates the interactions between the Human and Earth systems [5]. We split these loads between the 3 studied forms, based on a literature review on sources’ composition. We furthermore implemented physical (sedimentation, erosion, sorption) and biotic (primary production, mineralization) processes affecting the P cycle (Fig. 1). We used a lumped representation of biotic processes to adapt the complexity of the model to large scale simulations and to the resolution of available forcing data. We estimated DIP, PIP and OP concentrations, together with the rates of the different biogeochemical processes, globally over the 20th century.

Figure 1: Modelled processes (ero.=erosion, sed.=sedimentation, min.=mineralization, desorp.=desorption).
Simulation of river DIP concentrations
First tests of the model were performed on the Mississippi River basin, where concentration measurements of different P forms are available over decades at several monitoring stations (USGS database). The model provides realistic yearly results, showing that a mechanistic approach can be adapted to simulate large basins (Fig. 2).

Figure 1: Preliminary results for the Mississippi River basin. Comparison of measured and simulated DIP concentrations at the USGS monitoring station of St Francisville, closest to the river mouth.

Effect of human activities, hydrology, and in-stream transformations on DIP exports to global oceans
By using spatially explicit outputs from IMAGE, our results account for the effect of both large scale and local interactions of climate and human activities. The effect of natural and anthropogenic inputs, hydrology and in-stream physical and biogeochemical transformations on DIP exports to global coasts can be assessed. Thanks to the high spatial resolution of the model, further distinction can be made between the individual contributions of rivers, lakes and reservoirs. The model can be used to explain observed trends, and highlight locations of high P accumulation that can constitute significant future sources of DIP, e.g., if desorption from the bottom sediments occurs due to reductions in the inputs to the water column.

References