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C-GEM (v 1.0): a new, cost-efficient biogeochemical model for estuaries and its application to a funnel-shaped system

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Abstract. Reactive transport models (RTMs) are powerful tools for disentangling the complex process interplay that drives estuarine biogeochemical dynamics, for assessing the quantitative role of estuaries in global biogeochemical cycles and for predicting their response to anthropogenic disturbances (land-use change, climate change and water management). Nevertheless, the application of RTMs for a regional or global estimation of estuarine biogeochemical transformations and fluxes is generally compromised by their high computational and data demands. Here, we describe C-GEM (Carbon-Generic Estuary Model), a new one-dimensional, computationally efficient RTM that reduces data requirements by using a generic, theoretical framework based on the direct relationship between estuarine geometry and hydrodynamics. Despite its efficiency, it provides an accurate description of estuarine hydrodynamics, salt transport and biogeochemistry on the appropriate spatio–temporal scales. We provide a detailed description of the model, as well as a protocol for its set-up. The new model is then applied to the funnel-shaped Scheldt estuary (BE/NL), one of the best-surveyed estuarine systems in the world. Its performance is evaluated through comprehensive model–data and model–model comparisons. Model results show that C-GEM captures the dominant features of the biogeochemical cycling in the Scheldt estuary. Longitudinal steady-state profiles of oxygen, ammonium, nitrate and silica are generally in good agreement with measured data. In addition, simulated, system-wide integrated reaction rates of the main pelagic biogeochemical processes are comparable with those obtained using a high-resolved, two-dimensional RTM. A comparison of fully transient simulations results with those of a two-dimensional model shows that the estuarine net ecosystem metabolism (NEM) only differs by about 10%, while system-wide estimates of individual biogeochemical processes never diverge by more than 40%. A sensitivity analysis is carried out to assess the sensitivity of biogeochemical processes to uncertainties in parameter values. Results reveal that the geometric parameters LC (estuarine convergence length) and H (water depth), as well as the rate constant of organic matter degradation (k_{ox}) exert an important influence on the biogeochemical functioning of the estuary. The sensitivity results also show that, currently, the most important hurdle towards regional- or global-scale applications arises from the lack of an objective framework for sediment and biogeochemical process parameterization. They, therefore, emphasize the need for a global compilation of biogeochemical parameter values that can help identify common trends and possible relationships between parameters and controlling factors, such as climate, catchment characteristics and anthropic pressure.

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