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Insights into three-dimensional simulation of coastal flow dynamics using a fully coupled surface-subsurface approach

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Coastal aquifers are complex hydrologic systems because many physical processes interact: (i) variably saturated flow, (ii) spatial-temporal fluid density variations, (iii) tidal fluctuations, (iv) storm surges overtopping dykes, and (v) surface runoff of storm water. The HydroGeoSphere model is used to numerically simulate coastal flow dynamics, assuming a fully coupled surface-subsurface approach, accounting for all processes listed above. The diffusive wave approximation of the St. Venant equation is used to describe surface flow. Surface flow and salt transport are fully coupled with subsurfacial variably saturated, variable-density flow and salt transport through mathematical terms that represent exchange of fluid mass and solute mass, respectively. Tides and storm surges induce a time-variant head that is applied to nodes of the surface domain. The approach is applied to real cases of tide and storm surge events of the coastal catchment area of Unterweser, Northern Germany (ca. 2500 km2). To optimize the simulation and to reduce CPU cost, the actual simulation domain is only a part of the total catchment area: We selected a narrow strip of about 10 km width parallel to the coastline. The catchment area outside of that strip is not affected by saltwater intrusion and does therefore not need to be included in the numerical model. The seaside boundary condition of the reduced simulation domain is obtained from a 3D hydrodynamic-numerical flow model where changes in sea level are being simulated. The landside boundary condition is obtained from a 3D steady-state flow model of the total catchment area. The 3D model is calibrated using field data previously gathered at the study site. Results indicate that the fully coupled approach with a reduced simulation domain is effective in the simulation of 3D coastal flow dynamics.