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Modelling the long-term vertical dynamics of salt marshes

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Salt marshes are vulnerable environments hosting complex interactions between physical and biological processes with a strong influence on the dynamics of the marsh evolution. The estimation and prediction of the elevation of a salt-marsh platform is crucial to forecast the marsh growth or regression under different scenarios considering, for example, the potential climate changes. The long-term vertical dynamics of a salt marsh is predicted with the aid of an original finite-element (FE) numerical model accounting for the marsh accretion and compaction and for the variation rates of the relative sea level rise, i.e. land subsidence of the marsh basement and eustatic rise of the sea level. The accretion term considers the vertical sedimentation of organic and inorganic material over the marsh surface, whereas the compaction reflects the progressive consolidation of the porous medium under the increasing load of the overlying younger deposits. The modelling approach is based on a 2D groundwater flow simulator, which provides the pressure evolution within a compacting/accreting vertical cross-section of the marsh assuming that the groundwater flow obeys the relative Darcy's law, coupled to a 1D vertical geomechanical module following Terzaghi's principle of effective intergranular stress. Soil porosity, permeability, and compressibility may vary with the effective intergranular stress according to empirically based relationships. The model also takes into account the geometric non-linearity arising from the consideration of large solid grain movements by using a Lagrangian approach with an adaptive FE mesh. The element geometry changes in time to follow the deposit consolidation and the element number increases in time to follow the sedimentation of new material. The numerical model is tested on different realistic configurations considering the influence of (i) the spatial distribution of the sedimentation rate in relation to the distance from the marsh margin, (ii) the material heterogeneity (mineral vs organic), and (iii) different sequences and times of deposition. Additional experiments are performed to investigate the effect of a stochastic distribution of the material properties to account for the typical high variability of such ecosystems. The characteristic time spanned by the simulations is thousands of years, roughly corresponding to the Holocene.