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A new free surface stabilization algorithm for steep slopes

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The surface of the Earth is typically modelled as a free surface in numerical geodynamic modelling, letting both horizontal and vertical velocities along the surface be solved during each time-step. Accurate modelling of the top free surface is important since it allows to generate topography, which partially controls the body force conditions at the beginning of each time-step. Furthermore, including realistic modelling of the top surface helps to better compare numerical results with observations, and allows better evaluations of eustatic effects due to the studied processes and modelling of superficial processes such as erosion or sedimentation. However, even for relatively small time-steps (e.g. <20Kyr for large-scale regional flow), free surfaces usually present stability problems due to overestimations of the calculated velocities at the top of the model. Here we present a new algorithm for stabilizing free surfaces for large time steps based on an Eulerian penalization of the body forces at the top nodes of the model. The algorithm first calculates the body force penalization by using the initial velocities and slopes at each of the nodes of the free surface, at the beginning of each time step, to solve the system using the corrected body forces. A similar algorithm is described by Kaus, Mühlhaus and May (2010) where they use the velocities normal to the free surface at the beginning of each time step to calculate the body force penalization. We are also including a horizontal velocity term into our penalty load which makes the resulting corrected Stiffness matrix asymmetric. In applied practice, we turn the problem into an iterative symmetric problem by moving the horizontal-velocity penalty terms to the right-hand side of the system in order to achieve better numerical performance. Rayleigh-Taylor, sinusoidal-topography, and steep-slope tests are being explored in order to test the efficiency and accuracy of this algorithm. In general, these show small differences with previous approaches in accuracy and in the maximum time step we can choose for stable forward evolution. However, for the steep-slope test where the horizontal component of the correction is most significant, our algorithm accuracy is slightly better in the steep slope regions and allows a bigger time step without mesh or instability problems than the algorithm previously published by Kaus, Mühlhaus and May (2010).