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Basal conditions of the Rhine Glacier at the Last Glacial Maximum: insights from high-resolution transient numerical models

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Questions about the safety of nuclear waste repositories during future ice ages in previously glaciated landscapes have lent impetus to new numerical model simulations concerning past ice conditions. In Switzerland, all potential sites investigated for these repositories have been affected during LGM or earlier ice ages by large piedmont glaciers and/or peri-/subglacial permafrost under cold-dry conditions. First quantitative reconstructions and analysis using steady-state approaches were carried out in the 1980s. Recent advances in ice flow numerical models and code parallelization make it now possible to run transient thermo-mechanical full-Stokes models at high resolution. These models couple ice flow to temperature-dependent sliding at the bed and climate parameterization (temperature, mass balance gradients) at the surface. Starting from the reconstruction of the Alpine ice field in Switzerland, we model the transient flow of the Rhine Glacier from its source in the Alps to its terminus that formed a large polythermal piedmont lobe in the northern Swiss plateau and in southern Germany. Results indicate that basal conditions are strongly dependent on initial temperature parameterization and climate conditions that lead to the LGM. The models indicate that much of the substrate below the ice lobe was at the melting temperature, opening possibilities for fast erosion and overdeepening formation. Other areas in alpine valleys were also at the melting temperature when the basal ice originating from high up in the Alps had sufficient time to reach the melting temperature at the bed of thick valley glaciers. Cold climate conditions kept marginal ice and ice up valley cold. High sliding speed and basal shear stress, two other parameters that promote erosion, indicate that erosion was potentially high in some portions of the main trunks of the Rhine Glacier but less so in more marginal parts of the flat piedmont lobe. Results from these transient full thermo-mechanical models differ significantly from earlier steady-state calculations. The new model irons out unphysical ice surface topographic undulations present in the Swisstopo LGM glacial coverage map thereby eliminating hot-spots of basal shear stress and abnormally high surface velocity computed by two-dimensional steady state models using this map.