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A Late Pleistocene ice-sheet model for Scandinavia: combining surface geological evidences and non-linear plastic and viscoplastic ice rheologies

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Geological and instrumental observations record long-term crustal and geoid deformations which stem from the direct response of mantle minerals to a surface forcing of glacial origin. A spatio-temporal discretization of the Late Pleistocene ice coverage is therefore necessary to constrain the upper mantle rheology of the Scandinavian shield. The expansion and retreat of ice-sheets is testified by the occurrence of geological surface marks that come in form of depositional and erosive features. In particular, the dated and calibrated end moraines and pro-glacial lake deposits provide unique evidences of the position and migration through time of the ice-sheets margins. In this work we take advantage of extensive databases available from literature and combine the dated and georeferenced surface geological evidences to infer the time-dependent ice-sheets margins for the time range 21 to 8 kyrs BP. By adopting plastic and viscoplastic ice rheologies we find analytical solutions for the steady-state form of ice-sheets and fill the inferred boundaries with ice mass assuming steady state for each individual time slice. The ice volume through time, which is the same for both the plastic and viscoplastic ice rheologies, does not depend on the ice mass balance but only on (i) the area of the ice covered region, (ii) the basal shear stress. We test the performance of the ice reconstruction by first solving the gravitationally self-consistent Sea Level Equation for a linear viscoelastic deformable Earth, and then comparing the observed and predicted Holocene relative sea-level changes and present-day rates of crustal and geoid deformation at different sites. For both ice rheologies a general satisfactory agreement is found. Since the ice model is independent from any assumption about the mantle rheological profile, it provides a unique opportunity to study the presence of lateral rheological heterogeneities and non-linear Earth rheologies without any bias and to show their impact.