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A fully coupled 3-D ice-sheet - sea-level model: algorithm and applications

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Relative sea-level (RSL) variations during the late Pleistocene cannot be reconstructed regardless of the estimates of ice-volume fluctuations. For the latter, however, the knowledge of regional and global relative sea-level variations is necessary. Overcoming this problem of circularity demands a fully coupled system where ice sheets and sea level vary consistently in space and time and dynamically affect each other. Here we present results for the past 410,000 years from the coupling of a set of 3-D ice-sheet-shelf models to a global sea-level model based on the solution of gravitationally self-consistent sea-level equation. The sea-level model incorporates all the Glacial Isostatic Adjustment feedbacks for a Maxwell viscoelastic and rotating Earth model with variable coastlines. Ice volume is computed with four 3-D ice-sheet-shelf models for North America, Eurasia, Greenland and Antarctica. With an inverse approach, ice volume and temperature are derived from a benthic δ^{18}O stacked record. We show the dynamical response of the ice sheets to changes in RSL, the latter including both the deformation of the bedrock to ice and water loading and the geoidal deformations. Due to the self-gravitational pull of the ice sheet, RSL close to the ice sheets is higher than the eustatic sea level, and thus acts to stabilise ice sheets. Especially for the West Antarctic ice sheet, ice volume is lower during glacial periods relative to the uncoupled simulation. When using the Maxwell viscoelastic Earth model, the bedrock deformation due to ice loading is lower compared to the simple flexural Earth model used in the uncoupled experiments. Altogether, the coupled model results in lower ice volume during glacial periods relative to an uncoupled simulation that uses eustatic sea level derived from ice-volume changes only. The time dependent ocean function, however, accounts for the changes in the coastlines over the globe. This leads to a significant reduction of the ocean area during glacial maxima in the coupled simulation. Hence, eustatic sea level change for the coupled simulation is largely similar to the uncoupled simulation. Our simulated RSL changes are generally in good agreement with the RSL reconstructions derived from geological and archaeological paleo sea-level indicators from sites in Scandinavia, North America, the Caribbean and Antarctica.