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Evolution of a Coupled Marine Ice Sheet – Sea Level Model

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An instability mechanism is widely predicted for marine ice sheets resting upon reversed bed slopes whereby ice-sheet thinning or rising sea level is thought to lead to irreversible retreat of the grounding line. Previous analyses of marine ice-sheet stability have considered the influence of a sea-level perturbation on ice-sheet stability by assuming a geographically uniform, or eustatic, change in sea level. However, gravitational, deformational and rotational effects associated with changes in the volume of grounded ice lead to markedly non-uniform spatial patterns of sea-level change. In particular, a gravitationally self-consistent sea-level theory predicts a sea-level fall in the vicinity of a shrinking ice sheet that is an order of magnitude greater amplitude than the sea-level rise that would be predicted assuming eustasy.

We highlight the stabilizing influence of local sea-level changes on marine ice sheets by incorporating gravitationally self-consistent sea-level changes into a steady state model of ice sheet stability (Gomez et. al., Nature Geoscience, 2010). In addition, we develop a dynamic coupled ice sheet – sea level model to consider the impact of this stabilizing mechanism on the timescale of ice sheet retreat. The coupled system combines a sea-level model valid for a self-gravitating, viscoelastically deforming Earth to a 1D, dynamic marine ice sheet-shelf model. The evolution of the coupled model is explored for a suite of simulations in which we vary the bed slope and the forcing that initiates retreat. We find that the sea-level fall at the grounding line associated with a retreating ice sheet acts to slow the retreat; in simulations with shallow reversed bed slopes and/or small initial forcing, the drop in sea level can be sufficient to halt the retreat. The rate of sea-level change at the grounding line has an elastic component due to ongoing changes in ice-sheet geometry, and a viscous component due to past ice and ocean load changes. When the ice-sheet model is forced from steady state, then on short timescales ($< \sim 500$ years) viscous effects may be ignored and grounding-line migration at a given time will depend on the local bedrock topography and on contemporaneous sea-level changes driven by ongoing ice-sheet mass flux. On longer timescales, an accurate assessment of the present stability of a marine ice sheet requires knowledge of its past evolution. We end with a discussion of the first results of simulations in which post-glacial sea-level physics is coupled to a 3D, dynamic model of the Antarctic Ice Sheet.