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Antarctic ice-sheet hysteresis in a three-dimensional hybrid ice-sheet model

Marisa Montoya[1,2], Jorge Alvarez-Solas[1,2], Alexander Robinson[1,2,3], Javier Blasco[1,2], Ilaria Tabone[1,2], and Daniel Moreno[1,2]
[1]Universidad Complutense de Madrid, CIF: Q2818014-I, Facultad de Ciencias Fisicas, Física de la Tierra y Astrofísica, Madrid, Spain (mmontoya@ucm.es)
[2]Instituto de Geociencias (UCM-CSIC), Madrid, Spain
[3]Potsdam Institute for Climate Impact Research, Potsdam, Germany

Ice sheets, in particular the Antarctic Ice Sheet (AIS), are considered as potential tipping elements (TEs) of the Earth system. The mechanism underlying tipping is the existence of positive feedbacks leading to self-amplification processes that, once triggered, dominate the dynamics of the system. Positive feedbacks can also lead to hysteresis, with implications for reversibility in the context of long-term future climate change. The main mechanism underlying ice-sheet hysteresis is the positive surface mass balance-elevation feedback. Marine-based ice sheets, such as the western sector of the AIS, are furthermore subject to specific instability mechanisms that can potentially also lead to hysteresis. Simulations with ice-sheet models have robustly confirmed the presence of different degrees of hysteresis in the evolution of the AIS volume with respect to model parameters and/or climate forcing, suggesting that ice-sheet changes are potentially irreversible on long timescales. Nevertheless, AIS hysteresis is only now becoming a focus of more intensive modeling efforts, including active oceanic forcing in particular. Here, we investigate the hysteresis of the AIS in a three-dimensional hybrid ice-sheet--ice-shelf model with respect to individual atmospheric forcing, ocean forcing and both. The aim is to obtain a probabilistic assessment of the AIS hysteresis and of its critical temperature thresholds by investigating the effect of structural uncertainty, including the representation of ice-sheet dynamics, basal melting and internal feedbacks.