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Greenland Ice Sheet surface mass balance under stratospheric sulfate aerosol injection geoengineering

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Changes in surface temperature have dramatically affected the mass budget of the Greenland ice sheet over the last few decades, but changes in precipitation and radiation budget have also been as important in controlling the extent of the ice sheet. Geoengineering by stratospheric sulfate aerosol injection could slow ice melting by reducing summer temperature and insolation, however such schemes would also reduce precipitation and affect large scale climate drivers such as the Atlantic Meridional Over-turning Circulation (AMOC). We examine the resulting changes on the Greenland Ice Sheet based on climates simulated by four Earth System Models (ESM) running the Geoengineering Model Intercomparison Project (GeoMIP) stratospheric sulfate aerosol injection experiment G4 and the RCP4.5 and RCP8.5 greenhouse gas scenarios. Both G4 and RCP4.5 have the same greenhouse gas forcing but G4 also includes injection of 5 Tg/year of sulphate aerosol into the lower stratosphere. We utilize runoff estimates from the ESM, from a degree-day model based only on surface temperature and precipitation changes, and from the surface energy and mass balance model SEMIC with 8 different surface albedo parameterizations. The SEMIC parameterizations frame the state-of-the-art results from the MAR model over the 1979-2004 period. There is a 20% reduction in runoff under G4 relative to RCP4.5, while under RCP8.5 it is increased by 17%. G4 produces reductions in mean near-surface air temperature by 1ºC, annual snowfall by 5 mm yr-1, and downward longwave radiation by 5 W m-2, relative to RCP4.5. The change in near-surface air temperature and downward longwave radiation contribute most to the change in SMB. The governing mechanism is through decreased low level clouds producing surface cooling by longwave radiation, as might be expected under the globally weakened hydrological cycle under G4 and increased Arctic sea ice concentration, which are not sufficiently counterbalanced by increases in AMOC. The impact on ice dynamics was estimated by running the three-dimensional BISICLES ice dynamics model of Jakobshavn Isbrae with parameterizations to represent the effects of ice mélange buttressing, crevasse-depth-based calving and submarine melting that reproduces its recent evolution. Dynamic ice mass loss is about a 10% lower under G4 than under RCP4.5 by 2070. Thus total sea level rise by 2070 from the Greenland ice sheet under G4 geoengineering is about 30% lower than under the RCP4.5 scenario it is designed to radiatively balance.