

Observing and Predicting Changes in Greenland's Surface Mass Balance

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Box 1: SnowModel

The GrIS surface water balance components, with emphasis on precipitation, evaporation, sublimation, surface mass balance, and runoff, were simulated using SnowModel, a spatially and temporally distributed meteorological and snowpack modeling system, for present-day and future conditions [6,11]. SnowModel is composed of five submodels: 1) MicroMet defines the meteorological forcing conditions, 2) EnBal calculates the surface energy exchanges, 3) SnowPack simulates mass and heat transfer processes due to, e.g., retention and internal refreezing, 4) SnowTran-3D is a blowing-snow model that accounts for snow redistribution, and 5) SnowAssim is a snow-data assimilation model that adjusts the simulated snow distributions towards available snow observations.

The Greenland Ice Sheet (GrIS) is the Northern Hemisphere's largest terrestrial area with a perennial ice and snow cover. Complete loss of the ice sheet would raise global sea level by about 7m [1]. Climate models suggest that a regional temperature increase of 3°C or more, which is predicted to occur during this century under many greenhouse gas emissions scenarios, would be sufficient to melt most of the GrIS during a period of centuries to a few millennia [2]. Simulations by atmosphere-ocean models for areas north of 60°N project an increased mean surface air temperature of 2.5°C by the mid 21st century and 4.5°–5.0°C by the end of the century [3].

The GrIS gains mass from surface snow accumulation and loses mass by two main processes: (1) meltwater runoff (mostly as a result of summertime surface ablation), and (2) iceberg calving (associated with the flow of large outlet glaciers into the ocean). Recent observations indicate that the GrIS responds more quickly to climate perturbations than previously thought, especially near the margin in southern Greenland [4]. The ice sheet was close to equilibrium during the relatively cool 1970s and 1980s, but lost mass rapidly as the climate warmed in the 1990s and 2000s, with no sign of deceleration [5]. The GrIS is currently losing mass at a rate of nearly 300 Gt/yr [6, 7], enough to raise global sea level by about 0.8 mm/yr. Both surface melting and glacier outflow have accelerated during the past decade, likely in response to atmospheric and oceanic warming. Ice has thinned along the periphery (primarily in the south), while ice in the interior has thickened slightly because of increased snowfall [8].

In order to predict the impact of climate changes on the GrIS, it is essential to establish the present-day surface mass balance (SMB, the difference between annual accumulation and ablation) and

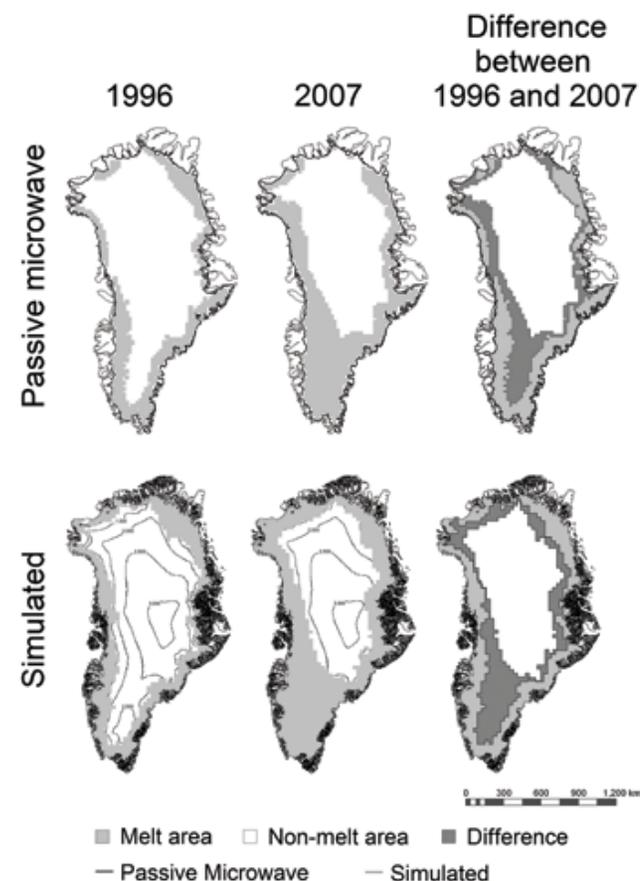


Fig. 1. Surface melt extent of the Greenland Ice Sheet based on passive microwave satellite-derived observations and SnowModel simulations for the years 1996 and 2007. The plots in the third column show the difference between the two years. The satellite-derived melt extent is based on data provided by the Cooperative Institute for Research in Environmental Sciences (CIRES), University of Colorado at Boulder.

surface melt extent (the area that experiences some melting in a given year). Relatively modest temperature changes can bring about large changes in melt volume and extent. Since 1995, the year with the minimum GrIS surface melt extent was 1996, while the most extensive melting occurred in 2007 (Fig. 1). The 2007 melt extent was 20% greater than the average for 1995–2006. In regional

modeling simulations [9], the year-to-year variability in melt extent was in excellent agreement with observations. The year 2007 had the highest simulated surface runoff (approximately 520 Gt/yr) and the lowest surface mass balance (close to zero). Through the simulation period, the SMB varied from -5 (2007) to 310 Gt/yr (1996), averaging 124 (± 83) Gt/yr (Fig. 2).

Scientists in the Climate, Ocean and Sea Ice Modeling (COSIM) project are using global and regional models to predict future changes in Greenland's surface mass balance. Mernild and collaborators [10] have used projections from a regional atmosphere model to force SnowModel, a state-of-the-art meteorological and snowpack modeling system. (See **Box 1** for further information). The GrIS surface mass balance was simulated to decrease by ~ 300 Gt/yr between 1950 and 2080, with negative values by the final decade of the simulation. (When the SMB is negative, the ice sheet melts inexorably, even in the absence of iceberg calving.) The end-of-summer melt extent nearly doubled during this period, with the greatest changes in the southern and eastern parts of the ice sheet.

These simulations are now being extended to the Community Climate System Model (CCSM), a fully coupled global climate model. COSIM scientists have recently coupled the Glimmer ice sheet model to CCSM in order to simulate changes in ice sheet dynamics. Glimmer is forced with the surface mass balance computed by the CCSM land and atmospheric models. The global atmosphere model is run at relatively coarse grid resolution (~ 100 km), which may not be sufficient to obtain an accurate SMB in regions of steep topography. To improve the estimated mass balance, we are taking part in coupled global climate-change simulations with an atmosphere grid resolution of ~ 25 km over Greenland. We are also coupling surface processes to the dynamic ice-sheet model in order to simulate melt-induced increases in ice flow. The coupled models will be validated against recent observations and then applied to various greenhouse forcing scenarios on decade-to-century time scales. These simulations will constitute a unique contribution to ice-sheet and sea-level

projections in the next Intergovernmental Panel on Climate Change (IPCC) assessment report, AR5.

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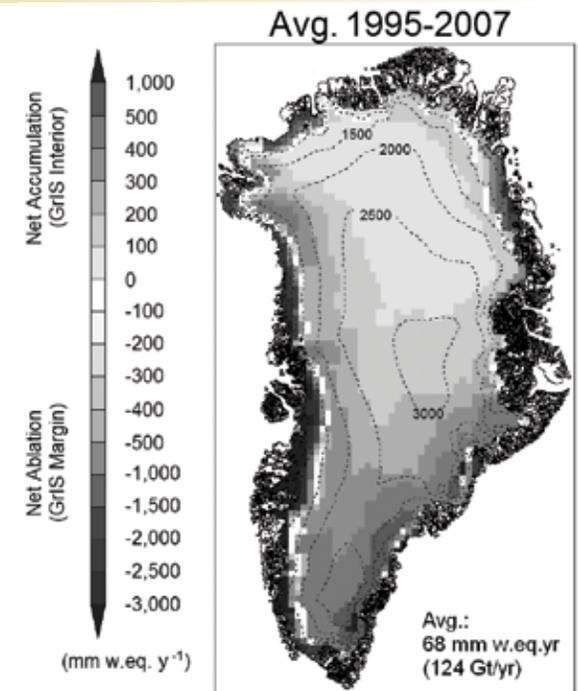


Fig. 2. The 1995–2007 average annual surface mass balance as modeled for the Greenland Ice Sheet (in mm w.e./yr and Gt/yr). Dotted lines show surface elevation with a 500-m contour interval.

Funding Acknowledgments

- LANL Institute for Geophysics and Planetary Physics
- DOE Office of Biological & Environmental Research (OBER), Climate Change Prediction Program
- DOE Scientific Discovery through Advanced Computing Program (SciDAC)