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Improved Mass-balance Estimates of Eastern Antarctic Inland Ice/Ice Shelf Systems by combining Modeling and Remote Sensing

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Antarctic inland ice/shelf ice systems can be regarded as cryospheric indicators of climate change that react particularly sensitively to variations of global to regional climate parameters. Changes in ice-shelf regimes will have consequences for climate through their role for the radiation budget and the global freshwater budget. Increased melting of Weddell Sea shelf ice will result in freshening of water masses with impact on the global thermohaline circulation. Increases of ice export from ice sheets, and in particular possible disintegrations, will strongly affect global sea levels.

Despite recent advances in the understanding of polar ice sheets, their current mass balance is still unknown. The major obstacle for mass budget studies is poor coverage by in-situ measurements. The state of the balance is assessed by estimating the individual mass balance terms (accumulation and ablation.) Accumulation rates have been measured from stakes and shallow ice cores, but these are logistically demanding and only exist for a limited number of locations. Accumulation distributions have also been determined by atmospheric moisture flux convergence analysis from meteorological data, remotely-sensed brightness temperatures of dry snow or a combination of several methods. Considerable uncertainty for determining the mass balance results from the difficulty to define the position of the grounding line, its ice thickness, and the need for assumptions about the vertical distribution of ice velocity. The grounding line is a natural boundary for calculating ice discharge because the entire ice volume that crosses it eventually melts into the ocean.

Flow modeling of big natural ice bodies is based on geometry, flow movement and temperature distribution as described by the laws of mass, energy, and momentum conservation. A numerical formulation of the partial differential equations expressing these conservation laws, in conjunction with a formulation of stress-strain relationships governing the rheological behavior of the ice (flow law), comprises the basis of the numerical ice flow model.

Of special importance is the ability to model the transition between an ice regime with large basal shear stress (inland ice) and a regime with no basal shear stress and vertically constant velocities (ice shelf.) In order to be able to model this transition region realistically, we solve the equations for momentum and energy three-dimensionally on a horizontally regular, and vertically shape-following grid (sigma coordinates) using finite differences. All relevant stress terms are taken into account (i.e., vertical resistive stress to include bridging effects that are important for grounding line flow dynamics.) This gounding-line module links the components of an existing finite-difference thermo-mechanical ice sheet/ice shelf model (Sandhäger, 2000). Combining 3-D modeling of ice flow in grounding-line regions and remotely-sensed forcing in adjacent inland-ice and shelf-ice areas is expected to provide more realistic mass balances estimates.

The behavior of ice sheets is controlled by the dynamics of the grounding line zones, and areas of concentrated flow in outlet glaciers and ice streams. We derive estimates of ice topography from a combination of laser and radar altimeter data, and ice velocity by means of SAR repeat pass interferometry, such as tandem mission interferometry. Cryosat SIRAL altimeter data will lead to considerable improvements in spatial resolution for key ice areas, mainly the steep-slope grounding line regions.

The development of crack structures presents the most important mechanism to increase the velocity of ice streams. Ice shelves lose their stability by summer melt water penetrating into these cracks, before a total collapse can take place. Deformation and stress conditions are modeled and stress limits are adjusted before cracks can develop. This is done iteratively until results are coherent with remotely-sensed observations (like from SAR or AVHRR.) Because of the availability of topography and ice velocity ground truth data, we concentrate on Eastern Weddell Sea ice stream/ice shelf systems, such as the Jutulstraumen, Schirmacher Oasis, Ekströmisen, and Riiser-Larsenisen (25°E – 15°W, 70° – 75°S).