Glaciological investigations on modern ice sheet response in South Greenland

GEUS

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Abstract

The reaction of the large ice sheets to global climate change is still in the focus of scientific debate. Recent investigations have shown pronounced thinning in the southern part of the Greenland Ice Sheet. In order to investigate the cause of the observed thinning in this area and to judge the sensitivity of this part of the ice sheet a combined field work, remote sensing and modelling project was designed. A glaciological transect was established in 2001 on one of the main outlet glaciers in South Greenland. This transect aims on monitoring the modern climatic conditions in an area of the ice sheet which is strongest affected by the recently observed thinning. A mass balance/elevation relation has been calculated from the field data, which is used as input to a regional ice dynamic model for investigating the dynamic conditions of this area. Results show that the sensitivity of the ice sheet to climatic changes varies considerably along the southern margin.
The history of the glacier variations in the same area during the last 40 years has been reconstructed on the basis of aerial photographs and satellite images. Comparing the development of the retreat in this area over the last decades with the maximum extent of the ice sheet from the 1890s indicates a strong increase in the recession of the margin. The estimated thinning from these observations is in good agreement with the recent laser altimeter measurements. The observed surface lowering is also responsible for the fast disintegration of several glacier tongues of tide water glaciers in the area.

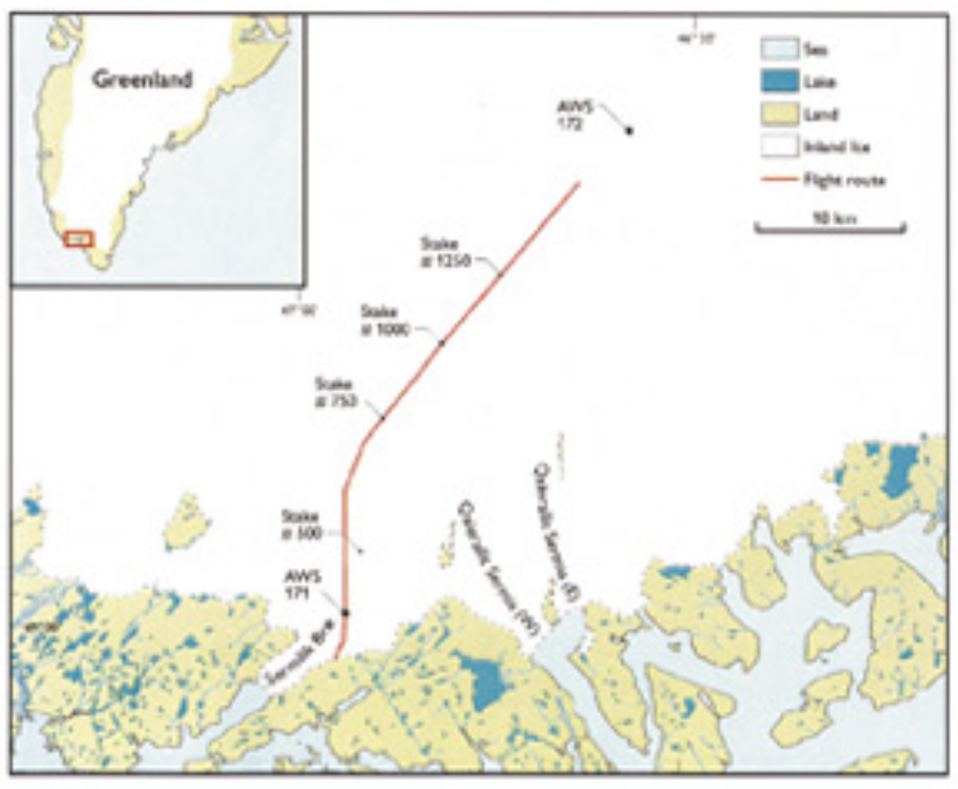


Fig. 1: A glaciological transect was established in May 2001 on one of the main outlet glaciers, Sermilik Bræ, in South Greenland and the first data are now available. In addition to the deployment of mass balance stations and ablation stakes, an airborne radar profile has been measured by NASA (red line).

Fig. 2: Surface conditions at Sermilik Bræ,top: crevasse zone within the descend of the glacier from the Inland Ice, left: modern ice fjord and glacier front, right: lower mass balance station close to the ice front.

Introduction

Over the past few years strong efforts have been undertaken to gain insight into the mass balance conditions of the Inland ice (e.g. Reeh & Starzer 1996; Van de Wal & Ekholm 1996; Ohmura et al. 1999; Van der Veen & Bolzan 1999; Janssens & Huybrechts 2000). One of the most comprehensive initiatives to obtain information on the state of the Greenland ice sheet is the Program for Arctic Climate Assessment (PARCA) co-ordinated by NASA. At lower altitudes of the Ice Sheet extensive thinning, but also minor areas of thickening, of the ice sheet seem to exist (Krabill et al. 1999). Specifically, strong thinning and recession is indicated for the ice margin in East Greenland, and over the south-western lobe of the Inland Ice in the study area (Fig. 1).
The study area in South Greenland is probably one of the most vulnerable areas of the Inland Ice in respect to climate induced thinning. The observed thinning rates seem to be due to a combination of variations in mass balance and the dynamic response of the ice flow to recent climatic changes (Krabill et al. 1999; Houghton et al. 2001). The main aims of the project initiated in 2001 are to improve estimates for surface mass balance from in situ observations and balance models, to improve modelling the dynamics of ice sheets (requiring combined studies of glaciological and satellite observations) and to establish a base line for long-term glacier/ice sheet observations.

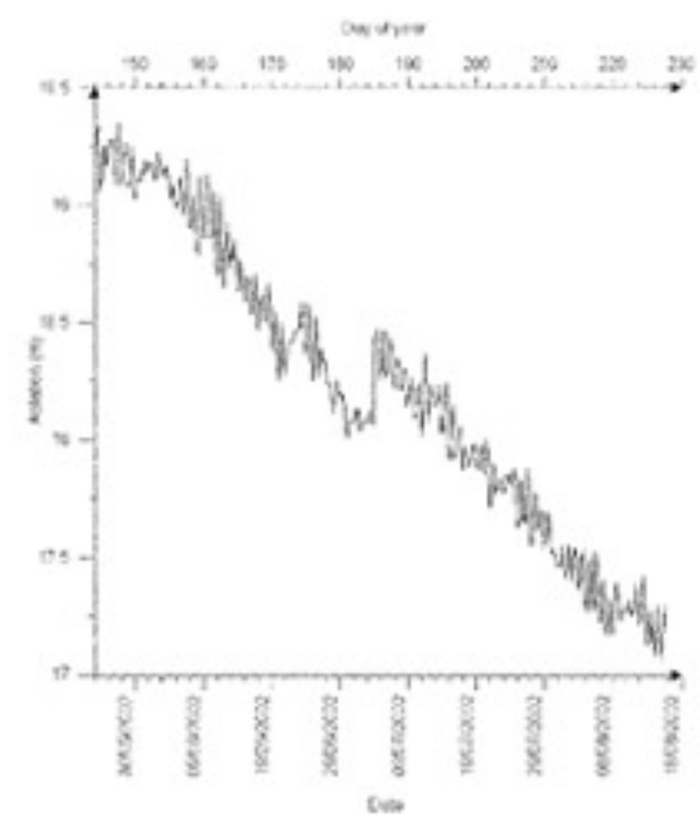
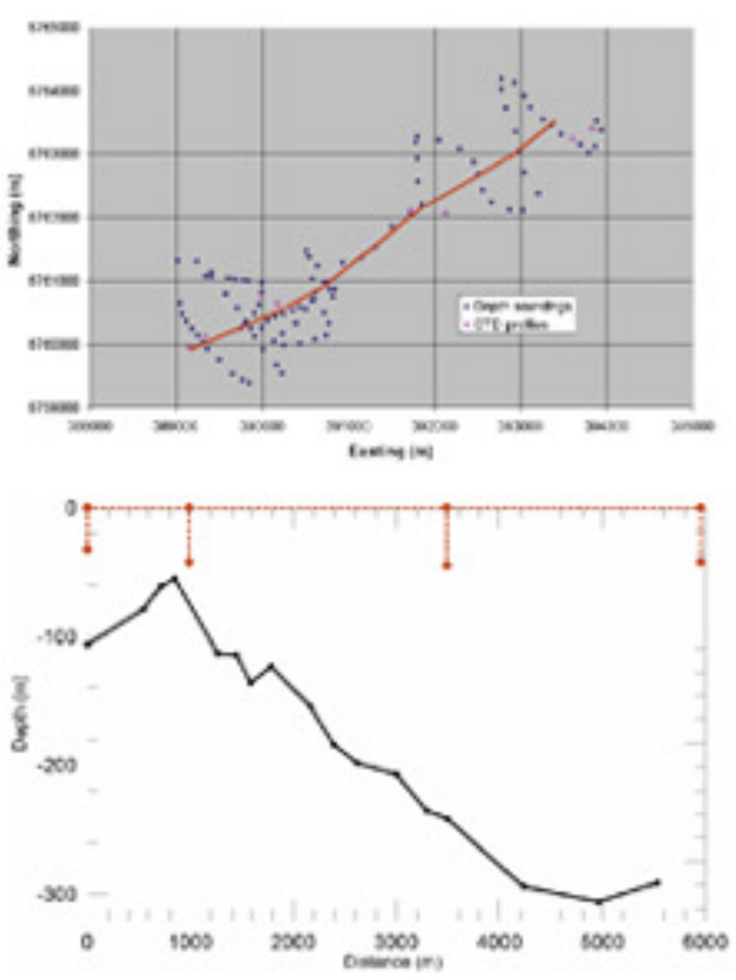


Fig. 3: Example of field measurements from the transect at stake 500. The ablation was measured with a newly developed pressure transducer, which allows continuous measurements over a time period of several years.



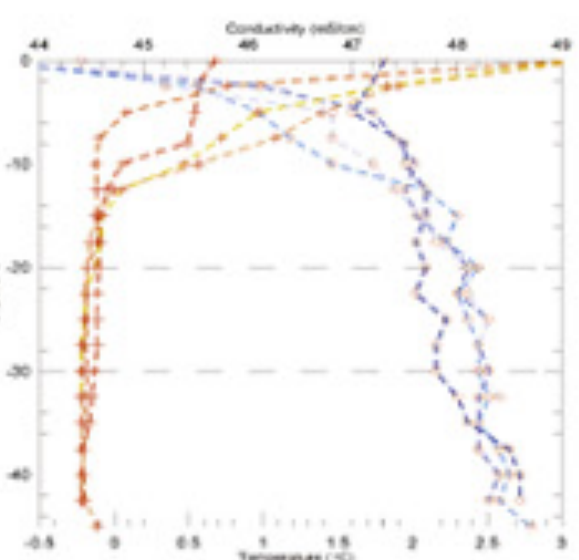


Fig. 4: Depth soundings and CTD measurements in the fjord of Sermilik Bræ. On top left a map is shown with all depth soundings. The red line displays the depth profile shown below. Distance is measured from the outermost point to the ice front, which is located at approx. 5800 m. The red dashed lines in the profile indicate the position and depth of the CTD profiles. CTD profiles are shown in the diagram to the top right.

Measurements

In 2001 a glaciological transect was established on Sermilik Bræ on the margin of the Inland Ice in South Greenland. The transect extends from an altitude of 270 m a.s.l. up to a height of 1150 m a.s.l. on the southern dome of the Inland Ice (Fig. 1) and consists of two automatic mass balance stations (AMS) and four ablation stakes placed along a flow-line.
Our new AMS concept consists of one mast, supported by wires, and set on a tripod (Fig. 2). They measure a variety of climatic and glaciological parameters at hourly intervals. In order to measure ablation automatically over several years, a new system was installed at several positions. This consists of a pressure transducer connected to a 20 m fibre reinforced PVC-hose filled with alcohol. A data example from this system is shown in Fig. 3. Surface velocitis increase from 0.4 m/day at the upper station to 1.4 m/day at the lower station
During the 2001 the NASA airborne laser altimetry system was used for investigations in southern Greenland within the PARCA project, where one flight track covers the GEUS glaciological transect (Fig. 1).
In the fjord the water depth was measured on several profiles using an echo-sounder, together with a number of CTD (Conductivity, Temperature, Depth) profiles (Fig. 4). The bathymetry can be used for the calculation of the former ice volume of the Sermilik glacier tongue. Vertical conductivity / temperature profiles enable an estimation of the melt water fluxes from the ice sheet. The water depth shows a typical situation of an over-deepened fjord, which reaches depths of more than 300 m close to the modern glacier front. The CTD profiles of the upper 50 m prove the existence of a shallow layer of warm water heated by the atmosphere. The low conductivity values of this water mass indicate that there is a strong amount of melt water from calf ice mixed into this surface layer.

Remote sensing analysis

During the past 50 years Sermilik Bræ has undergone significant variations in its dimensions. The retreat can be determined from aerial photography and satellite images. As an example, the pronounced retreat of Sermilik Bræ between 1953 and 2000 is illustrated in Fig. 5.
The resolution of all used images is better than 80 m, which allows a high-resolution determination of the glacier retreat over several kilometres. The earliest observations on Sermilik Bræ date from the mid-19th century, but there are insufficient records prior to 1947 to establish a continuous history of retreat or advance. The rate of retreat changed considerably between 1985 and 1993. Between 1995 and 2000 retreat events sum up to about 1900 m. The retreat over the entire ice sheet sector is shown in Fig. 6. The margin retreat is associated by a surface lowering of more than 100 m within the last 35 years.
Climatic effects, such as a general global warming, cannot account for the regional retreat of the glaciers in southern Greenland. Recent studies have shown that temperatures in western Greenland have experienced a slight cooling over the last half century, in contrast to the global trend (Chapman & Walsh 1993; Hansen et al. in press). However, relatively warmer periods have been noted between 1940 and 1950 and also during the 1980s and 1990s (Jorgensen 2001). The latter short-term temperature increases may have influenced the rapid disintegration of the floating glacier tongue.

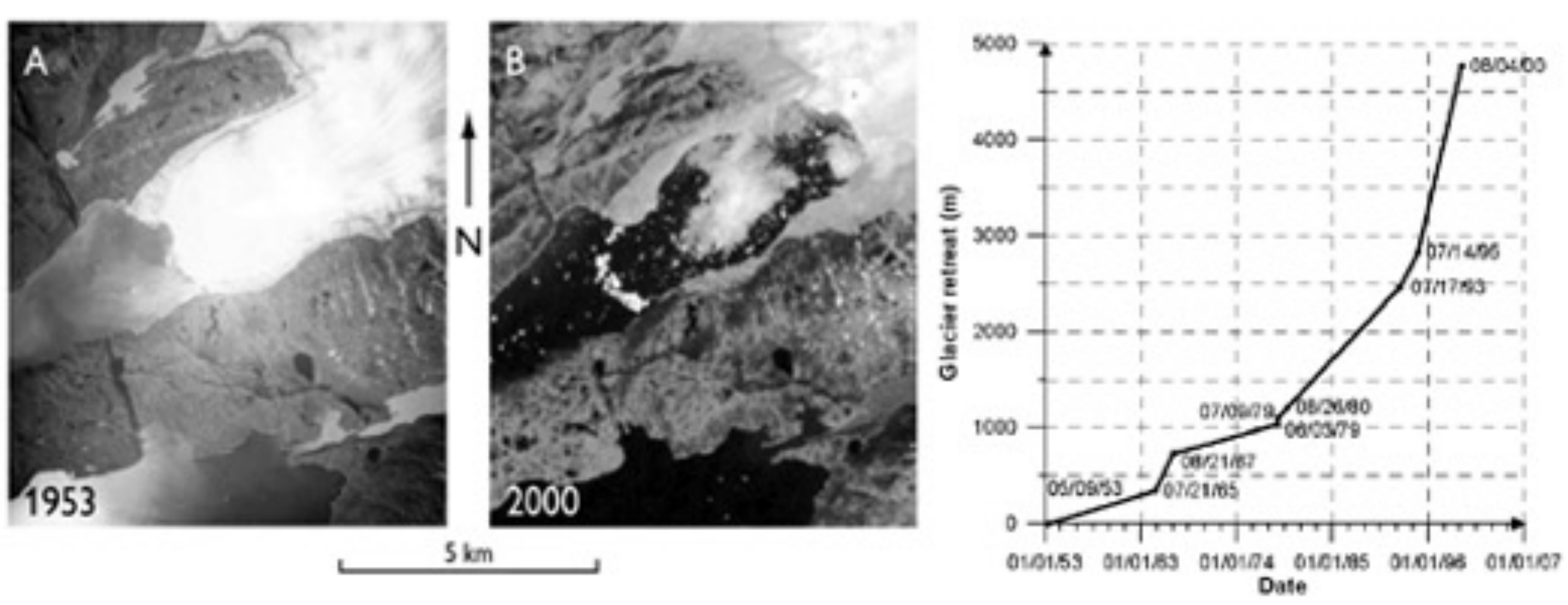
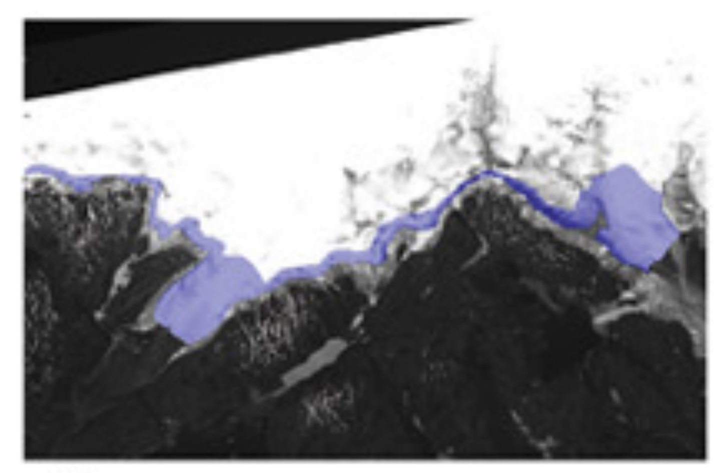


Fig. 5: Retreat of the Sermilik glacier tongue between 1953 and 2000, documented by an aerial photograph (A) and a Landsat 7 image (B). The shallow bedrocj sill is visible in the Landsat image by grounded ice bergs. The temporal development of the retreat is displayed in the left panel.



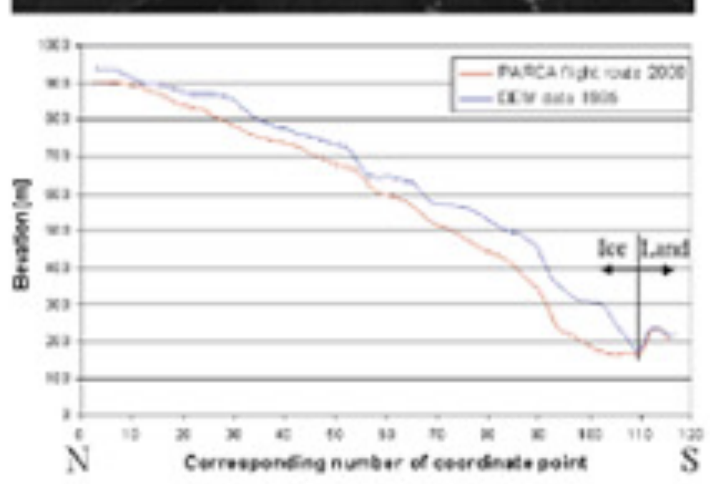


Fig. 6: Upper panel: Comparison of the S-Greenland ice margin from a Corona image of 1965 (background image) and a Landsat image of 2000 (detection of modern ice margin). The blue shaded area shows the retreat of the ice sheet during this time.
Lower panel: Comparison surface elevation for the laser altimeter profile (2000) and a DEM from 1985. The ice thickness shrinks by more than 100 m close to the margin over this time.

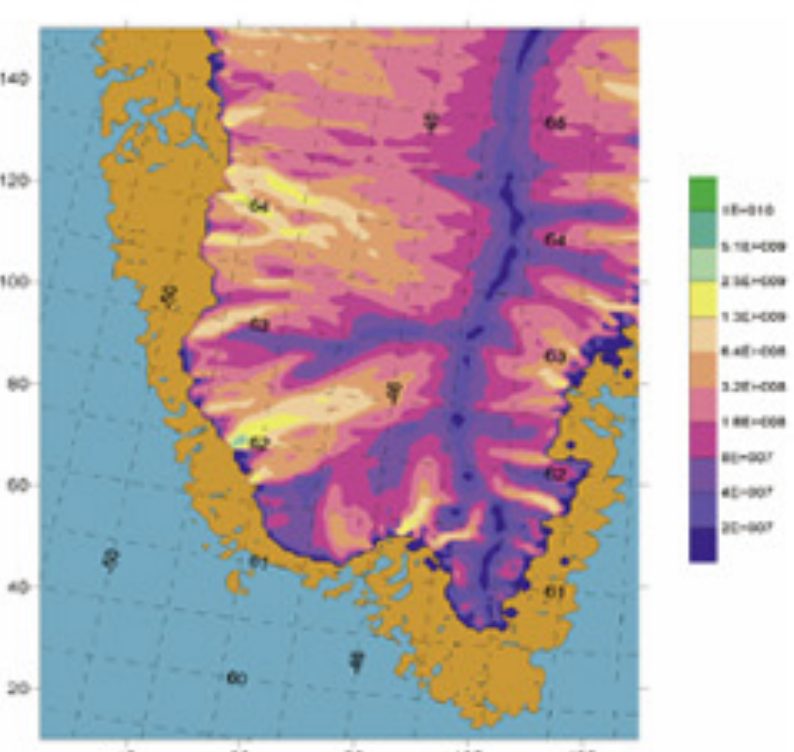
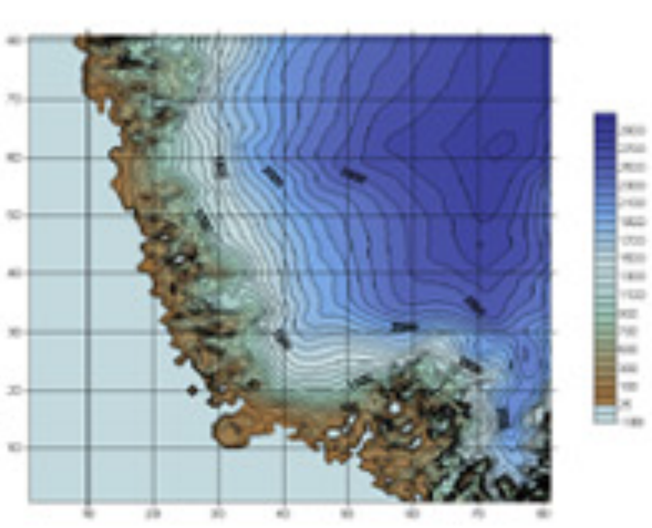


Fig. 7: Map of ice fluxes on the S-Greenland ice sheet. Several of the main glacier systems are easily detected by the high flux values (flux is given by m3/(year * grid size)). Topographic data basis is Bamber (2001) and Bales (2001).



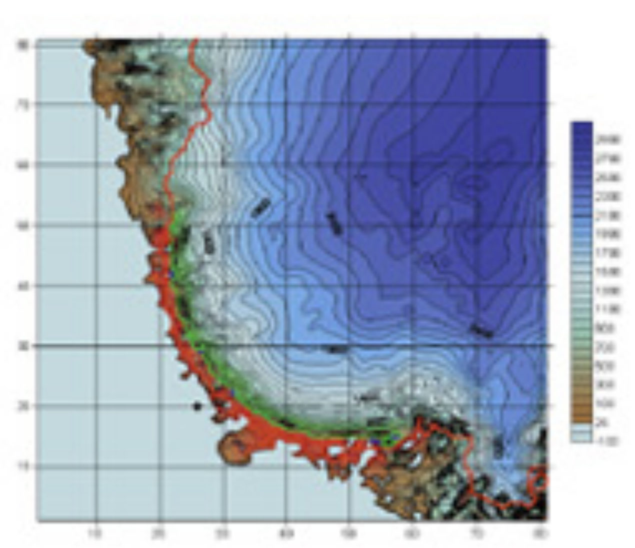


Fig. 8: Original ice sheet topography (top right) and steady state surface from the numerical model using modern mass balance values (bottom right). The green and red lines in the left picture show the ice margin for a rise (green) or lowering (red) of the equilibrium line of 100 m.

Model approach

Balance velocities are calculated under the assumption that ice transport is always directed down along the steepest surface slope (Fig. 7). For each grid element in the model the influx from upslope grid elements and the local accumulation will be distributed to the downslope grid elements. This means the divergence of the ice flux equals the local mass balance (Budd and Warner, 1996). As input information about ice thickness, surface elevation, precipitation and ablation is required. As forcing the mass balance conditions over the area need to be known.
Dynamical aspects have been investigated with an ice dynamic model, based on the laminar flow theory. The flow in this model is driven only by vertical shear stresses originating from the surface slope of the ice sheet. The model steady state is approximated to the modern ice sheet geometry by adapting suitable and realistic parameter values for e.g. the flow factor. This initial model steady state is used for sensitivity studies with different parameter sets and mass balance conditions (Fig. 8). The results are furthermore compared to the flux distribution from the balance velocity model in order to assess the dynamic state of the ice sheet.

Conclusions

This analysis of the terminal position in the fjord and the adjacent ice margin from remote sensing data reveals that the quiet margins of the Qassimiut lobe have retreated about 400 m horizontal distance since 1964. The glacier tongue in the fjord experienced a retreat of 4.5 km in the same period, where the disintegration rate increased during the last 15 years.
The developed modelling tools focussed on the investigation of s ice flow in different areas in SW Greenland, the deformation history and the sensitivity of different sectors of the ice sheet.
From balance velocity considerations the approximate age of the ice is older than 5000 years in all of these areas and for the southern part the marginal ice is very likely of holocene origin. Evaluation of ablation gradients and ice velocity observations suggests that the southern part of the ice sheet is not in balance. A further retreat of the ice margin is therefore very likely. The rates of retreat will, however, not exceed the recent magnitude. A retreat of several kilometres is not unlikely to occur also at other outlets of the ice sheet with a similar setting as Sermilik Bræ. The ice dynamic model results have shown that the sensitivity of the glaciers to climatic changes differ considerably.

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