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The Ice Deformation and Mass Balance at the Summit of Greenland as Determined by GPS and Gravity Measurements.

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Introduction.

During the Greenland Ice Core Project (GRIP) field seasons of 1991-1994, extensive gravity and geodetic surveying were performed on the summit of the ice sheet, using gravimeters and the Global Positioning System (GPS). The GPS data provided the background for the computation of a elevation model of the summit, covering an area of approx. 100 x 100 km. In the same area a gravity anomaly model was computed (Ekholm & Keller, 1993). In addition, the collected data are used as ground-truth control for the Greenland Aero-geophysics Project (Brozena, 1991), where airborne altimetry and gravimetry were collected, and for the validation of satellite altimetry (Tscherning et al. 1992; Ekholm et al. 1993).

The strain net.

At eleven points, poles were put up (whereof three were established by the University of Washington) as a strain net for measuring ice movements. A main reference marker was established 400 m Southwest of the GRIP camp area and was fixed 80 m down into the ice sheet. Repeated observations of these poles around GRIP (25-60 km distance from the camp site) have provided information about ice movements on the top of the ice sheet. Data from 1991 and 1992 were considered of insufficient accuracy and thus left out. In 1991, the observation time was too short and the high ionospheric activity corrupted the data. In 1992, the data was disturbed by a nearby placed STD-C telex transmitter. Furthermore, the instruments were replaced by new and improved models in 1993. Figure 1 shows the changes in position from 1993 to 1994. A regular pattern with the large velocities are seen in eastern and western direction, where the surface slope is steepest, and small velocities along the North-South ice divide, where the slope is more shallow.

Using the above mentioned velocities and a ice model by Reeh (1989), it is possible to determine the centre of the ice sheet. At each velocity point, the curvature and ice thickness were determined from figure 1. Furthermore, the accumulation rate was also calculated (Bolzan & Strobel, 1994) at each point. These data were then used, according to the elliptical ice flow model by Reeh, in a least squares determination of the ice centre. In the calculation, it is assumed that the flow line is along a straight line from the centre, e.g. the point is placed on the axis of an approximated ellipsoid (for further details see Reeh, 1989). According to this calculation, the centre is 1.4 km East of and 5.7 km North of the reference pole. This result is not satisfactory, but is probably due to the simplified flow model.

The reference marker.

The local gravity and GPS measurements are tied to the reference marker fixed at a depth of 80 m. This reference marker, in turn, is referenced to the global network using a reference benchmark (No.61388) in Kangerlussuaq (Søndre Strømfjord). This marker is both a precise gravity station tied to the Greenland absolute network, and a precise 3-dimensional benchmark established by KMS as well.

Even though all processing is not yet completed, the results (for this baseline of considerable length; 796 km) are quite satisfactory (using precise ephemerides and GPSurvey software).

In table 1, the GPS-measurements indicate that the reference marker at GRIP is sinking and is moving somewhat in the northwest direction, according to the present accumulation of 23 cm of ice, corresponding to an annual layer thickness of 25 cm at a depth of 80 m (S. Johnsen, Geophys. Dept, pers. comm.). This also confirms that the ice sheet is stable within the estimated accuracy of the GPS observations (15 cm).

	Annual Change in Position		
Year	Latitude	Longitude	Ell. Height
1992-1993	+ 7 cm N	+ 18 cm W	- 33 cm
1993-1994	+ 11 cm N	+ 23 cm W	- 17 cm
Mean	+ 9 cm N	+ 20 cm W	- 25 cm

Table 1: Movement of the top of the reference marker at GRIP, 1992-1993-1994. Point 61338 in Kangerlussuaq is used as fixed reference: 67° 00' 21.5426" N; 50° 42' 11.5802" W; h(ellip) = 67.056 m (W.B. Krabill, NASA/Wallops Flight Facility, pers. comm.) This leads to following position for the reference pole at GRIP (No. 47913): 72° 34' 31.2049" N; 37° 38' 31.2049" W; h(ellip) = 3280.5 m. The antenna height is 2.20 m and the geoid undulation is 48.2 m according to latest geoid model (GEOID93B) by R.Forsberg. Hence, the GRIP elevation above sea level is estimated to be 3230.1 m.

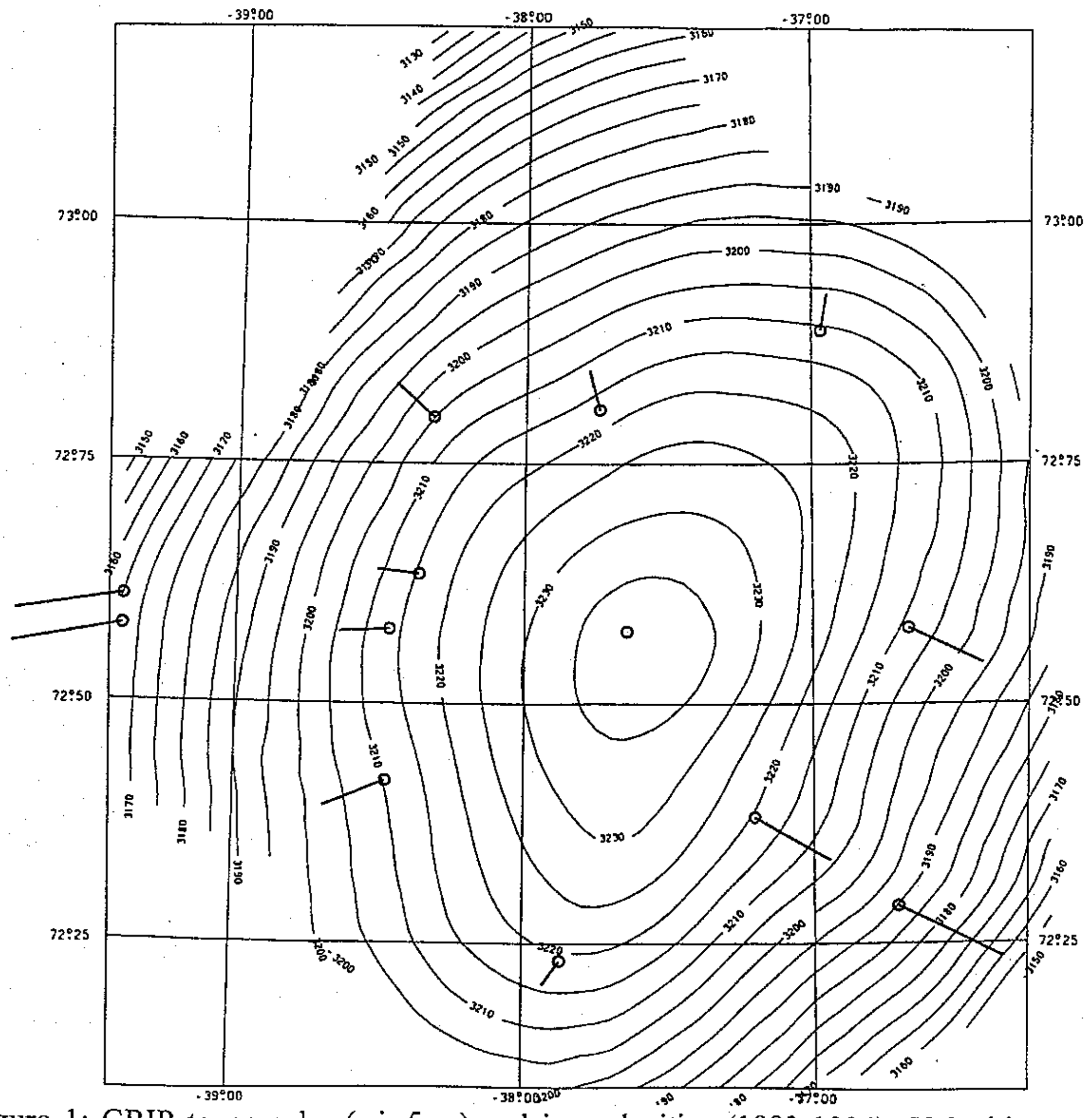

Figure 1: GRIP topography (c.i. 5 m) and ice velocities (1993-1994). Velocities are indicated by the vectors. 1 cm = 2 meters/year.

The Gravity tie.

From measurements of gravity at the top of the reference marker in successive seasons, the vertical movement of the ice at a depth of 80 m can in principle be observed. The expected annual sinking rate of the pole is 25 cm, sufficiently in order to be observed in the gravity measurements under ideal conditions.

During the project (1992-1994) two LaCoste & Romberg gravimeters were used each year, altogether there were four different gravimeters used in the survey. Each gravimeter has it's own individual scale and scaling factor. The scaling factors are estimated from an adjustment including only the ties between the absolute gravity stations in Copenhagen, Søndre Strømfjord and Jakobshavn, thus making the procedures of the gravity adjustment more complex than normal. This fact plus the rough transportation are the likely reasons for a rather low accuracy (approx. 100μGal). Figure 2 presents the gravity at the top of the reference marker at GRIP.

In spite of the rather noisy data, we observed a signal of gravity increase of approx. 72 μgal in the data adjustment, equivalent to 23 cm descent of elevation, using the free-air gravity gradient of 0.3086 mgal/m.

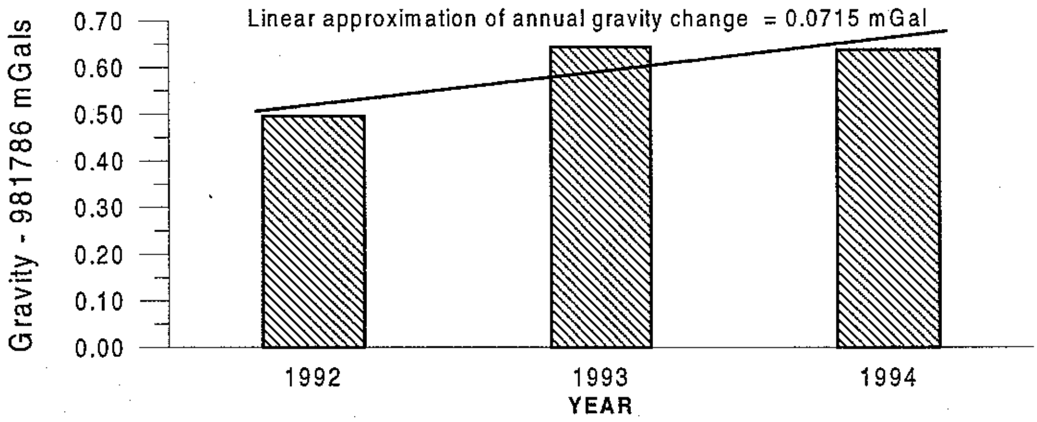

Figure 2. Gravity at the top of the reference pole at GRIP in the years 1992, 1993, and 1994

Conclusion.

Local gravity and surface topography were measured in a 50 km network around GRIP. The accuracy of the surface topography model is comparable to the height of a sastruga (30cm).

Repeated GPS observations at the eleven pole strain net 50 km around GRIP has provided surface velocities in the area. The estimated error of the velocity is approx. 10 cm/year.

Long GPS baselines from GRIP to Kangerlussuaq has indicated an ice sinking rate in agreement with the present accumulation, which shows that the ice sheet is stable within the observation accuracy.

This has also been confirmed by means of repeated gravity measurements.

Further measurements in 1995, and in the future, will provide a considerable accuracy improvement.

More advanced ice models will be applied in future calculations of the ice centre.

Acknowledgements.
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