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Mass balance studies at Dome GRIP using GPS & gravity.

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INTRODUCTION.

In the GRIP field season of 1991, 1992 & 1993 extensive gravity-measurements and geodetic surveying have been made, using gravimeters and the Global Positioning System (GPS). The data have provided a detailed topographic map of the top of the icecap in an area of approx. 100 x 100 km. In the same area a gravity anomaly map was made (Ekholm & Keller, 1993). These data are used as a groundtruth control for the Greenland Aero-geophysical Project (Brozena, 1991) and for ERS-1 altimeter measurements (Tscherning et al. 1992; Ekholm, Forsberg & Brozena, 1993).

At eight points poles were put up as a strain net for measuring ice movements and a reference marker was set up 400 m away from camp area. This reference marker was fixed 80 m down in the icesheet. Repeated observations of these poles around GRIP (25-45 km) have given information about ice movements of the top of the icecap. Due to low accuracy of the data from 1991 they are not used here.

THE STRAIN NET.

In the table below positions and the measured movements are listed for the 8 poles. Also height measurements were made but due to very noisy data in 1992 these were left out. Point 47913 is the reference marker and this is kept fixed in the calculations.

position (WGS84)						horizontal movement in 1 year				
point	lat deg N	lon deg W	elev. m	dist km	az deg	ΔN cm	ΔE cm	Δr cm	err. est. cm	snow acc cm
47913	72,58	37,64	3240	0,0	-	-	-	-	-	-
47736	72,58	36,67	3210	32,1	89	8	159	159	± 20	55
47900	72,29	36,72	3189	44,6	135	-75	339	347	± 70	77
47807	72,38	37,20	3219	26,1	146	-86	152	175	± 15	68
47759	72,23	37,87	3219	39,4	192	-84	-58	102	± 50	56
47852	72,42	38,47	3210	32,2	238	-65	-196	206	± 15	54
47714	72,63	38,36	3215	25,1	284	1	-132	132	± 25	46
47828	72,80	38,32	3207	33,4	317	98	-95	136	± 15	56
47908	72,81	37,74	3216	25,7	351	118	-28	121	± 15	50

Table 1 : Position and movement of strain net, 1992-1993.

Compared to the surface, point 47913 (reference mark) has been moving 20 cm down in one year. The mean accumulation in the area is 23 cm of ice equivalent corresponding to 25 cm (pers. comm. S. Johnsen) at a depth of 80 m.

The measurements were obtained using geodetic GPS receivers (dual-frequency, P-code) and an observation time of 45 min. The observation time was limited by logistic constraints to 45 min. Later it appeared that our data from 1992 were very noisy and longer observation time might have increased the accuracy. The 1992 data are the main reason for the relatively low accuracy of 15-70 cm/year. The 1993 data's contribution to the accuracy is approx. 5 cm. In 1993 we have used better receivers (TRIMBLE 4000SSE L1PL2P instead of 4000SST L1L2P), and furthermore 6 more satellites were available. The data have been processed using standard software from TRIMBLE, GPSurvey, ver. 1.10d (released oct.93). The surface velocities show a nice regular pattern and, it is seen that towards North & South the movements are slower than towards East-West, where the slope is somewhat larger.

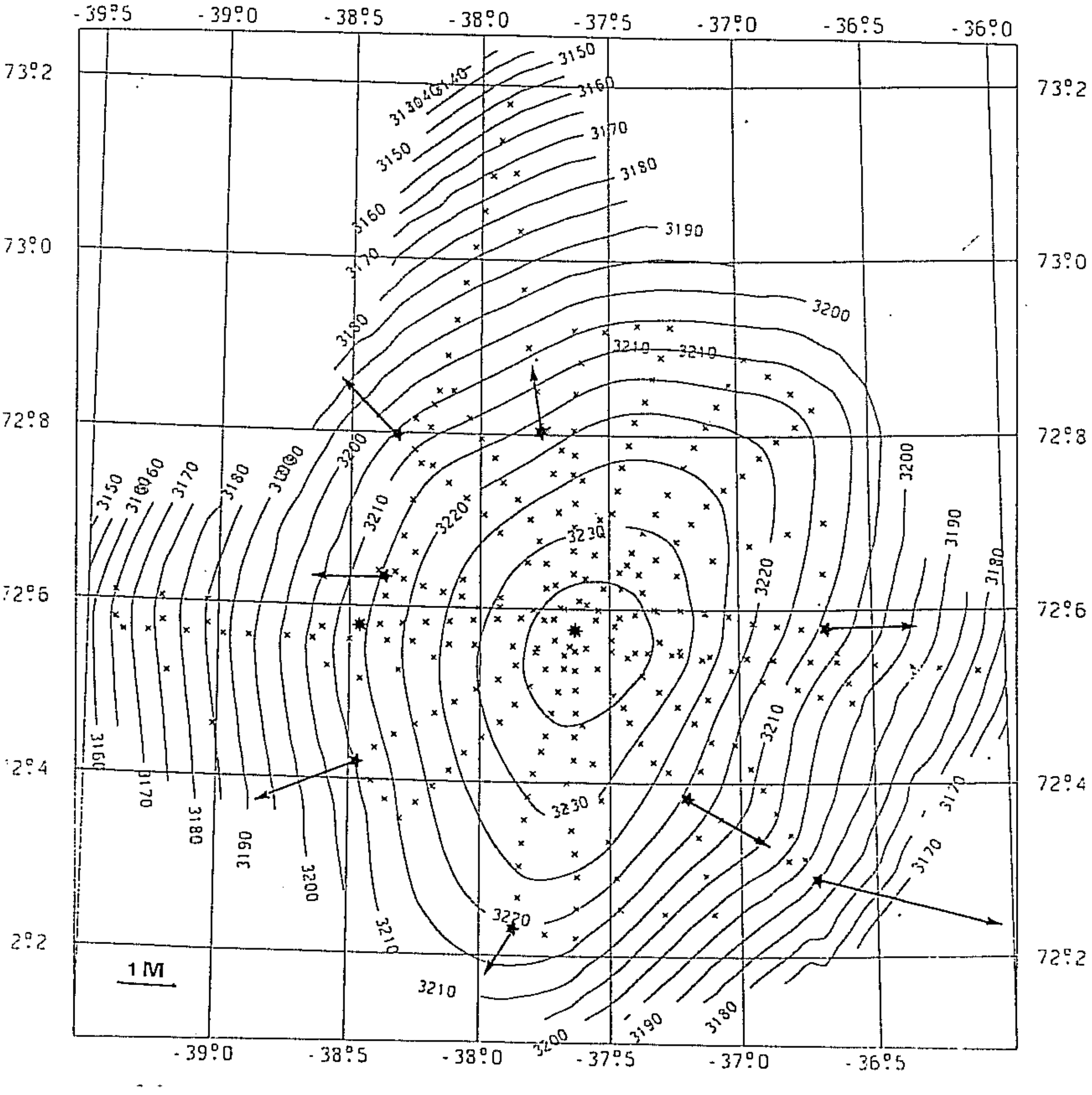

Figure 1: GRIP topography (c.i. 5 m) and ice velocities.

THE REFERENCE MARKER.

The GPS tie.

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 (Sondre Strom) is both a precise gravity station tied to the Greenland absolute network and a precise 3-dimensional benchmark - established by KMS and tied into the global ITRF92 system by the GAP project. Several observations were made both in 1992 and 1993.

The three sessions in 1992 shows a good accuracy using precise orbit information at approx 20-40 cm. When the broadcast ephemerides are used the accuracy decreases two or three times. In 1993 we have even higher precision as mentioned above. Using precise ephemerides this year as well, we are down to approx. 15 cm.

Even though not all the processing is finished, the results for such a long baseline (796.5 km) are quite satisfactory. As shown below the GPS-measurements indicates that the reference marker at GRIP is sinking. The expected sinking rate in the depth of 80 m is 25 cm/year.

year	latitude	longitude	ell.height	surface height
1992	72°34'31.2776" N	37°38'41.4390" W	3282.16 m	3279.63
1993	72°34'31.2801" N	37°38'41.4541" W	3281.83 m	3279.52
diff.	+ 8 cm N	+ 14 cm W	- 33 cm	- 11 cm

Table 2: Position(WGS84) and movement of the top of the reference marker at GRIP, 1992-1993. The geoid height at GRIP is approx. 42 m. Point 61338 in Kangerlussuaq is used as fixed reference: ITRF92 coordinates: 67° 00' 21.635" N, 50° 42' 11.465" W, h = 67.88 m

The Gravity tie.

Measuring the gravity at top of the reference marker in successive seasons, could resolve the vertical movement of the ice at a depth of 80 m. The expected sinking of the pole is 25 cm, just large enough to be seen in the noise of the gravity surveys under ideal conditions.

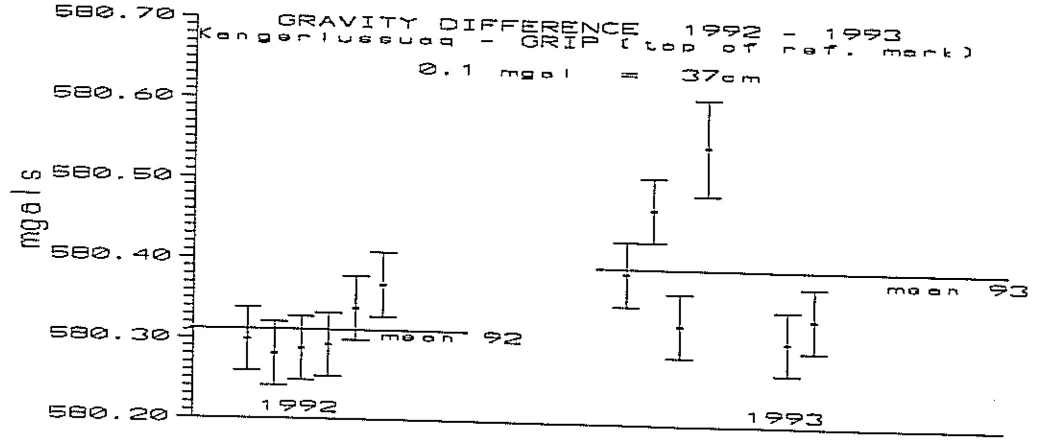

Figure 2: Gravity difference (raw measurements), Kangerlussuaq - GRIP, 1992 & 1993.

The change of gravity is due to ice movements of the reference marker relative to sea level. The free-air gradient due to height change is 0.3086 mgal/m. Because of accumulation of snow this gradient has to be reduced with a Bouger plate with a density of 0.920 g/cm^3 which gives a reduction of 0.0385 mgal/m. This gives a total gravity gradient at the ice cap of 0.270 mgal/m. This formula for the vertical gradient is then used to determine height changes due to that fact that gravity is considered constant in time.

Both in 1992 and 1993 two LaCoste & Romberg gravimeters were used. In 1992 10 observations were made but because of a big 'bump' all four observations from instrument G-69 were out of range and not used at all. In 1993 6 observations were made, all are used. The figure shows the gravity differences between Kangerlussuaq and GRIP in 1992 and 1993. It shows that even though the data are noisy there is a signal of gravity increase of approx. 96 μgal (result of adjustment) which is equivalent to a 35 cm descent.

Successive gravity observations have also been performed at the strain net points, however these data are much too noisy due to the 'bumpy' transportation (plane or skidoo) of the gravimeters.

CONCLUSION.

Local gravity and surface topography has been measured in a 50 km network around GRIP. The accuracy of the surface topography is comparable to the height of a sastruga.

Repeated GPS observations at the eight pole strain net 45 km around GRIP has provided surface velocities in the area. The accuracy of the latest observations is ± 5 cm and the estimated error of the velocity is approx. 25 cm/year.

Long GPS baselines from GRIP to Kangerlussuaq has indicated an ice sinking rate in agreement with the present accumulation.

The vertical ice velocity has also been measured by gravitational means. The gravity results confirm the GPS measured sinking rate, although the gravity measurements are somewhat more noisy than the GPS measurements.

Repeating the measurements in 1994 will further improve the accuracy of the result.

ACKNOWLEDGEMENTS.

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