AIRBORNE GRAVITY SURVEY OF THE NORTH GREENLAND SHELF 1998

With additional measurements in Disko Bay

Survey and processing report (KMS Technical Report no. 10)

by

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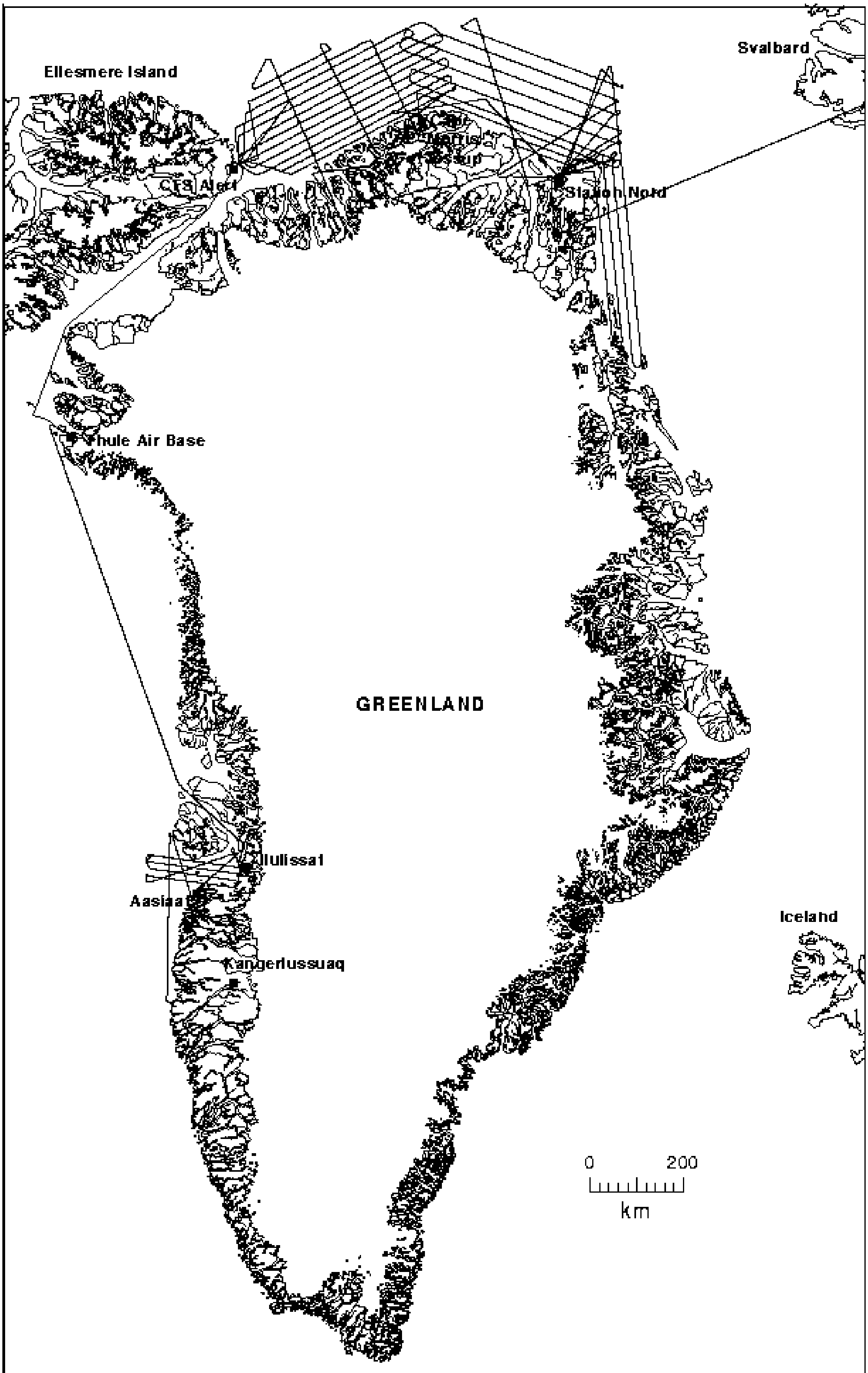

Fig. 1. Survey tracks of the KMS 1998 airborne gravity survey.

1. INTRODUCTION

This report describes the field operations, hardware setup, processing and results of the 1998 KMS airborne gravity survey of the North Greenland shelf region, and additional airborne gravity measurements in the Disko Bay and along the coast of western Greenland (Fig. 1). The measurements were made in a Danish-Norwegian cooperation, where similar measurements were carried out in Svalbard with the same system and airplane, immediately following the Greenland survey flights. The measurements were made with a Lacoste and Romberg marine gravimeter (S-99), provided by the University of Bergen.

The airborne gravity measurements represent the first phase of the offshore continuation of the 1991-97 Greenland Gravity Project, a US-Danish cooperation effort to complete the gravity coverage of Greenland, especially in order to satisfy the needs for improved global gravity field models. The project has included:

- Long-range airborne measurements over the interior of Greenland, carried out by the US Naval Research Laboratory and the US Naval Oceanographic Office 1991-92 in cooperation with NOAA and KMS (Brozena, 1991);
- A helicopter-based gravity and GPS survey of the ice-free parts of Greenland 1991-97, yielding a near-homogenous coverage of most areas with gravity station spacings of 12-18 km (Forsberg, 1994; and yearly internal survey and processing reports of KMS);
- Gravity measurements at the center of the Inland Ice (around the GRIP drilling site), in order to obtain ground truth for evaluating the airborne gravity measurements (Ekholm and Keller, 1992);
- A marine gravity survey of large areas off Western and North-Eastern Greenland, carried out by Nunaoil A/S in cooperation with KMS, as part of ongoing seismic measurements with the ice-strengthened Danish Naval Vessel "Thetis" (Strykowski et al., 1997).

The airborne and helicopter activities have been supported by the US National Imagery and Mapping Agency (NIMA). The gravity data from Greenland have provided significant improvements to the current state-of-the-art global model EGM96 (Lemoine et al, 1998), which has yielded major advances in e.g. satellite orbits, geoid models and ocean circulation studies, and is now used as a standard gravity field model on a global basis.

The 1998 KMS airborne gravity survey was primarily aimed at extending the Greenland gravity coverage into the permanently ice-covered Arctic Ocean. It is planned to continue the measurements in the coming years around the coast of Greenland, to provide a seam-less gravity coverage across the shelf regions into the satellite-altimetry derived gravity fields of the open ocean, with high-resolution aerogravity collected from "low and slow" flights.

Results of this first year of KMS flights were excellent, with an estimated r.m.s. measurement error of 2 mGal and resolution of 6 km, based both on cross-over comparisons and comparisons to independent surface gravity data.

2. THE KMS AEROGRAVITY HARDWARE SETUP

The hardware system for the airborne gravity measurements is based on experience gained in the AGMASCO (Airborne Geoid Mapping System for Coastal Oceanography) project, an EU-supported project under the MAST-III programme, carried out in a Norwegian-Danish-German-Portuguese cooperation, involving airborne gravity surveys for geoid determination in Skagerrak (September 1996), the Fram Strait (August 1997), and the Azores (October 1997), cf. Forsberg et al (1996) or Bastos et al (1997).

Fig. 2. OY-POF Twin-Otter at Station Nord

The KMS 1998 aerogravity system was mounted from scratch in a Greenlandair Twin-Otter (OY-POF), normally used as a freight/passenger charter airplane. The Twin-Otter is a well-suited airplane for aerogravity in Greenland, due to slow cruising speed (130 knots), and the ability to land on short, unprepared runways. The OY-POF airplane is especially well-suited for aerogravity due to the availability of an autopilot and the optional extra ferry tank, giving a flight endurance of 6.5 hr.

The gravity measurement is based on a Lacoste and Romberg marine gravimeter (S-99), modified for airborne use by ZLS Cooperation. S-99 is owned by the Institute of Geophysics, University of Bergen, Norway, and has been successfully used in the AGMASCO project, as well as in the earlier marine gravity measurements around Greenland by “Thetis”. The gravimeter sensor was mounted on pressurized vibration dampers, and placed inside a floor-mounted aluminum box.

The positioning of the aircraft was provided by two Trimble 4000 SSI GPS receivers, with antennas mounted forward and aft of the wings, respectively. The receivers had sufficient memory (10 MB), so that 1 Hz data recorded during flights could be stored internally, and downloaded onto laptop PC’s after landing.

Airplane heights above the sea-surface (mostly icecovered) were measured with an Optech 501 SX laser altimeter. The laser altimeter was mounted below the aft luggage compartment.

Roll, pitch and heading of the aircraft were determined with a prototype strapdown inertial sensor unit, manufactured by Greenwood Engineering, Copenhagen. The Greenwood INS consists of 3 μFORS fibreoptics gyros and 3 Schaewitz accelerometers, mounted in an

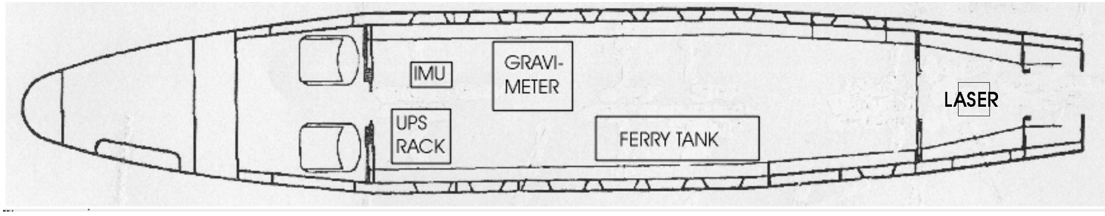

Fig. 3. Sketch of the gravity system installation in the Twin-Otter

Fig. 4. Internal view of aircraft installation looking forward in cabin. Ferry tank to the left, LCR gravimeter to the right, and electronics rack in background.

aluminum housing. The custom-made INS electronics digitize data internally at up to 2kHz, and records averaged measurements at 18 Hz.

Data from the INS and laser altimeter were logged together with GPS time tags and gravimeter data on a datalogger unit, which together with aircraft power converters, gravimeter control electronics and the GPS receivers were mounted in a single 19" rack.

A sketch of the aircraft installation is shown in Fig. 3. The offsets of the various sensors relative to a zero-point below the wings are given in Table 1. The total weight of the equipment was approx. 180 kg, and designed for 1-man operation.

The generous payload of the "POF" Twin-Otter thus gave a significant additional payload, which could be utilized in connection with combined survey and transit flights (allowing up to 4 additional passengers and all extra equipment), or space for tests of additional gravity measuring equipment. These tests included additional strap-down INS equipment (Honeywell) and a prototype INS gravity sensor, used in the survey flights of Disko Bay, in a cooperation with University of Calgary and the AGMASCO group. A succesful test of a tail-mounted ice-penetrating radar was also done, in cooperation with the Electromagnetics Institute, Technical University of Denmark.

Table 1. Sensor offsets (as measured by tape). Coordinates relative to zero point on centre of cabin floor, below wings, and with XY-plane along floor. Direct measured distance between GPS antennas: 280 cm.

Units: cm	X (pos. forward)	Y (pos. left wing)	Z (positive up)
Gravimeter sensor	77	-31	40
INS sensor	181	-34	10
Laser altimeter	-348	0	-15
GPS antenna #1	22	52	163
GPS antenna #2	-254	-20	157

3. GREENLAND 1998 SURVEY OPERATIONS

The installation of the equipment in the Twin-Otter was initialized in Kangerlussuaq Airport, Greenland (formerly named Søndre Strømfjord), on May 29. The installation period coincided with the International Workshop “Airborne Gravity and the Polar Gravity Field”, held on June 2-4 at the Kangerlussuaq conference centre, attended by 28 scientists from the US, Canada, Western Europe and Russia. During the installation period test flights was made with the TUD ice radar, as well as a ski flight to the centre of ice sheet, to remeasure a GPS site in the middle of the ice sheet (“Saddle North”) and do airborne laser altimetry in a small region around the site.

Fig. 5. Twin-Otter at Kangerlussuaq, returning from Inland Ice laser flight

Following the conference, a transfer flight to Ilulissat (Jakobshavn, JAV) on June 6 was used to measure a gravity profile along the coast, as well as profiling a local ice cap (Sukkertoppen Iskappe) with laser altimetry. These and the measurements at Saddle North were part of the ECOGIS (Elevation Changes of the Greenland Ice Sheet) project, funded by the Danish Research Councils Polar Research Programme.

On June 8-9 five gravity profiles in the Disko Bay were flown, along with the INS-gravity equipment from the University of Calgary and the “Q-flex” experimental accelerometer unit of the AGMASCO (results of comparisons to these sensors will be presented elsewhere). During this phase several workshop participants joined measurement flights.

Reference GPS stations for the Disko Bay flights were located at Ilulissat (2 sites) as well as in Kangerlussuaq and Aasiaat (Egedesminde, JEG, 2 sites). An additional GPS site at Qeqertarssuaq (Godhavn, JGO) failed due to laptop failures.

The KMS crew continued to Thule Air Base on June 11. This flight was GPS tracked from both Ilulissat and Thule. The survey flight to Thule crossed several marine gravity lines from the Nunaoil project, and provided an oppurtunity to test the use of isolated airborne gravity profiles to augment existing marine gravity data.

After being caught by a storm and weekend closure at Thule AFB, the full KMS survey crew of 4 finally reached CFB Alert on Ellesmere Island, Canada, on June 16. Alert was used as a base for the operations over the Lincoln Sea, which was covered in the period June 17-21 in a period with stable and sunny weather. The eastern half of the survey was completed on June 23, with two more flight days June 26-27 initiating the coverage of the North-East Greenland shelf to be completed in 1999 (these lines will first be processed when additional cross-overs are available). The details of the survey flights are shown in Table 2.

Table 2. Polargrav-98 flights in Greenland, showing time, track numbers and operator initials.

Date/JD	Flight	Track	Track integer identifier	Take off	Landing	Airborne	Operator
June06/157	SFJ-JAV	A, B, C	1, 2, 3	1642	2144	5h02	RF
June08/159	JAV-JAV	F, G	6, 7	1850	2040	1h50	AG
June09/160	JAV-JAV	H, D, E, G	8, 4, 5, 7	1440	1820	3h40	AG
June11/162	JAV-THU	J	9	1129	1601	4h32	RF
June16/167	THU-YLT	K, L		1259	1648	3h49	RF
June17/168	YLT-YLT	C, D	13, 14	1345	1802	4h17	RF
June17/168	YLT-YLT	F, E	16, 15	1900	2330	4h30	AVO
June18/169	YLT-NRD	G, P	17, 34	1306	1829	5h23	RF
June19/170	NRD-CMJ	S	37	0945	1231	2h46	RF
June19/170	CMJ-YLT	L	22	1307	1534	2h27	KRK
June19/170	YLT-YLT	T', AA, A, V, AB, AC, T", AE	23, 26, 11, 24, 27, 28, 123, 30	1630	2241	6h11	AVO
June20/171	YLT-YLT	H, I	18, 19	1252	1722	4h30	AVO
June20/171	YLT-YLT	J, K	20, 21	1815	2255	4h40	AVO
June21/172	YLT-CMJ	AD, B, Y	29, 12, 25	1458	1755	2h57	AVO
June21/172	CMJ-NRD	U, W	38, 39	1836	2052	2h16	AVO
June22/173	NRD-NRD	M, X	31, 40	0909	1400	4h51	RF
June22/173	NRD-NRD	Q, R	35, 36	1438	2000	5h22	KRK
June23/174	NRD-NRD	O, N, AF, AG	32, 33, 41, 44	0912	1602	6h50	RF
June26/177	NRD-NRD	AA, BB, AH	np, np, 43	0915	1427	5h12	RF
June27/178	NRD-NRD	CC, DD, AJ	np, np, 42	0911	1525	6h14	DS
June29/180	NRD-LYR		np	1004	1405	4h01	DS

np: not processed (to be included in 1999 data)

GPS tracking of the Arctic Ocean flights were made with Trimble 4000 SSI or Ashtech Z-12 receivers operating at CFS Alert (YLT), the military outpost at Station Nord, and a solar-powered GPS reference site at Cape Morris Jesup (CMJ), the north tip of Greenland. The GPS sites at Nord and Jesup were made in cooperation with the Alfred Wegener Institute, Germany, who did similar measurements (in different areas) with the "Polar-2" airplane.

Fig. 6. Twin-Otter taking off from Cape Morris Jesup GPS reference site

On June 29 the airplane left Greenland, on a combined survey and transit flight across the Fram Strait, to commence the flights of the “Svalbard Aerogravity Project” (SAG-98). The SAG-98 flights ended on July 6. SAG-98 was a cooperation project between Statens Kartverk, University of Bergen, Norsk Hydro and KMS, covering a gravity void over Nordaustlandet as well as flying some tests along satellite altimetry and seismic tracks south of Spitsbergen. After SAG-98 the airplane flew back to Greenland without gravimeter, to do iceprofiling and laser altimetry over the 79-glacier in a TUD/GEUS glaciology project.

Overall the KMS gravity operations went very well, and flight conditions were excellent in the Polar Sea north of Greenland, with only limited turbulence, and limited low clouds and fog (except the north-eastern ‘99 flights). All flights were flown with a 4-minute platform period for the gravimeter, with the measuring beam clamped during turns. On most flights the platform was relevelled manually after turns, to give a quicker stabilization of the platform gyro loops. A detailed operator flight log is given in Appendix 2.

Serious hardware problems were encountered in the first phase of the survey, resulting in occasional erronous system hang-ups and system “dumps”. These failures turned out to be due to a faulty power converter, and a new converter was found and delivered just in time for the Thule connection, and installed at Alert. The faulty power converter meant loss of all gravity data on the transit flight between Thule and Alert (a region with sufficient gravity data coverage, though). A similar “close call” of spare part delivery was a last-minute delivery of a malfunctioning gravimeter stepping motor, which was delivered from Texas to Ilulissat in less than two days, illustrating the importance of starting field surveys with new systems in areas with commercial air links.

4. DATA PROCESSING

4.1 GPS reference sites

A precise GPS reference network was computed, to serve as base coordinates for the airplane kinematic GPS solutions. The GPS reference network datum was ITRF-94, and the network is tied to the International GPS Service (IGS) permanent stations in Thule, Kangerlussuaq (Kellyville) and Ny Ålesund, Svalbard, as well as to the fundamental Greenland reference gravity network (REFGR). Computations were done using the Trimble GPSurvey software and precise orbits. The computed coordinates are shown in Table 3. Details of the reference stations are given in Appendix 2.

Table 3. ITRF-94 coordinates of GPS reference sites

Site	Lat	Lon	Ellips. h	AH	Comment
Kangerlussuak, KEL1	66 59 14.7031	50 56 1.4042	229.854		IGS station
Kangerlussuak, 61388	67 00 21.5448	50 42 11.5886	66.982	0.985	KMS ref.
Kangerlussuak, SFJhut	67 00 21.6502	50 42 09.6711	72.045		roof point
Ilulissat, JAV1	69 13 39.8870	51 05 45.7587	69.235	1.41	KMS ref.
Ilulissat, JAKX	69 13 01.5684	51 06 14.2225	82.330		temp roof point
Aasiaat, JEG1	68 42 21.5157	52 52 46.8450	30.680		temp tripod
Aasiaat, JEG2	68 42 10.3048	52 52 05.0019	60.465		do
Thule Air Base, THU1	76 32 14.4133	68 47 16.8209	54.983		IGS station
Thule Air Base, astro	76 32 28.6363	68 50 25.0673	23.782	0.58	KMS 3130

CFS Alert, YLT	82 30 41.5555	62 19 36.2949	56.114		roof ref (1995)
Kap Morris Jesup, CMJ	83 39 16.9702	33 22 33.4223	32.906		temp point
Station Nord, KMS 1001	81 36 01.4627	16 39 19.5927	68.383	0.97	astro pillar
Station Nord, AWI	81 35 49.4606	16 39 22.0634	67.060		temp roof point
Longyearbyen, Svalbard	78 14 51.8960	15 29 42.8984	49.262	0.801	NPI pillar

4.2 Gravity reference values

The reference gravity values used for the flights were based on gravimeter ties from nearby reference points, measuring to the aircraft parking spot on the airfield level. Table 4 gives the apron gravity values used for reference. These values have been based on absolute gravity measurements (Ilulissat, Thule, Alert and Ny Ålesund), using numerous relative gravimeter ties to Kangerlussuaq, Station Nord and Longyearbyen.

The apron ties were done using gravimeter G-867 of KMS. The adjusted standard deviation of the readings was 0.03 mGal.

Table 4. Reference gravity values of gravity base stations and 1998 apron values (mGal)

no.	g	location
805	982963.019	Longyearbyen Hangar (1997 ref.point)
909	983127.493	Alert Hilton (EMR point)
1351	983068.745	Station Nord bldg. 23
3130	982925.200	Thule Astro
58801	982486.930	Ilulissat airport
64227	982369.640	Sondrestrom Glace hangar (apron)
68202	982372.900	Sondrestrom Musk-Ox Inn
A1	982487.065	Ilulissat Apron
A2	982916.829	Thule apron at Hangar 3
A3	982913.671	Thule apron at Hangar 8
A4	983127.888	Alert apron
A5	983069.051	Station Nord apron, in front of bldg. 23
A6	982962.960	Longyearbyen apron, in front of garage

The apron gravity values were corrected by –0.4 mgal to account for the height of the gravimeter above the apron (1.3 m) in the airborne gravity processing.

4.3 Kinematic GPS solutions

Aircraft GPS positions were computed using commercial kinematic GPS software (mainly “GPSurvey”, with additional flights processed by “Flykin” or “Geotracer”). All packages use OTF ambiguity resolution techniques. Generally GPSurvey appears to give the best results, with fewer jumps due to changes in satellite constellations. Some flights could not be processed with some software packages, but gave good results with others. A single, short flight line from Station Nord on June 26 could not be processed at all due to unknown reasons (ionospheric disturbances?) and has been omitted completely.

The kinematic GPS solutions were produced as 1 Hz files with lat, lon, and ellipsoidal heights in ITRF-94. Solutions were checked by computing solutions for two aircraft antennas, or computing solutions from different reference stations to the same aircraft antenna. The typical agreement between the different solutions was at the 0.5 m level, with GPS reference baselines up to 500 km. Just one solution (subjectively judged “the best”) was used for the further gravity processing.

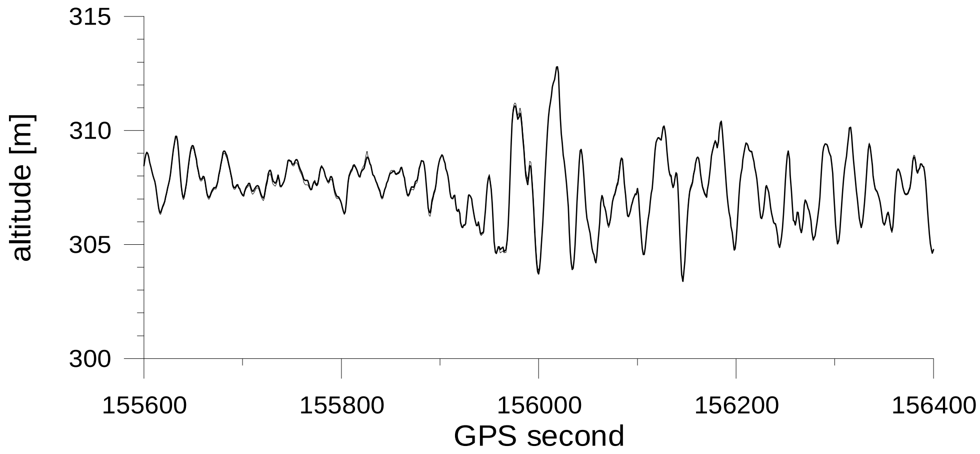

Fig. 7. Example of computed GPS heights during survey flight, showing phugoid oscillation.

The major problem in the GPS processing was to isolate spurious effects in the GPS solutions due to (mainly) changes in the visible satellite constellation during flight. Such spurios effects can yield filtered GPS accelerations up to the 10’s of mGal level. They may be detected by comparing different baseline solutions, inspection of gravity residuals and by comparisons to filtered vertical accelerations from the INS. The latter has been used routinely on all GPS solutions and has served as the main criterion in the evaluation.

The laser altimeter was used when tracking over ice and ocean to provide independent checks of GPS accelerations, but otherwise not used for the routine processing of gravity.

4.4 Airborne gravity processing

The Lacoste and Romberg “S” gravimeter use a combination of two internal measurements - spring tension and beam velocity - to obtain the relative gravity variations. The gravity sensor is mounted on a gyro-stabilized platform, kept horizontal by a feed-back loop with two horizontal accelerometers and two gyros. Details of the operation principle of the LCR gravimeter can be found in Valiant (1991).

The basic gravimeter observation equation for relative gravity y is of form

$$y = sT + kB' + C$$

where T is spring tension, s the scale factor, B´ the velocity of the heavily damped gravimeter beam, and the factor k the beam velocity/acceleration scale. A beam-type gravimeter like the S-meter is sensitive to horizontal accelerations even when the platform is levelled, and a cross-coupling correction C is computed in real time by the gravimeter control computer. For the S-99 the following factors were used: s = 0.997 mGal/CU and k = 27.4 mGal/(mV/s). The latter value was determined by an autoregression technique between measurements and GPS accelerations. The value is in good agreement with laboratory measurements.

Free-air gravity anomalies at aircraft level are (omitting second order terms) obtained by

$$\Delta g = y - h'' - \delta g_{eotvos} - \delta g_{tilt} - y_0 + g_0 - \gamma_0 + 0.3086\,(h - N)$$

where h'' is the GPS acceleration, δg_{eotvos} the Eotvos correction (computed by the formulas of Harlan, 1968), y_0 the basereading, g_0 the apron gravity value, γ_0 normal gravity, h the GPS ellipsoidal height and N the geoid undulation (EGM96 used throughout). The platform off-level correction δg_{tilt} is expressed as

$$\delta g_{tilt} = y - \sqrt{y^2 + A_x^2 + A_y^2 - a_x^2 - a_y^2}$$

where 'a' and 'A' denotes horizontal kinematic aircraft accelerations and horizontal specific forces measured by the platform accelerometers, respectively. Because of the potential high amplitude of horizontal accelerations, and the small difference between accelerations from accelerometer and GPS measurements, computed tilt effect is quite sensitive to the numerical treatment of the data. Calibration factors for the accelerometers have been determined by a FFT technique due to the frequency dependent behaviour of the platform, cf. Olesen et al. (1997).

Basereadings of the survey were very consistent, with negligible drift, allowing an independent check on the quality of basereadings before and after flights.

Lowpass filtering plays a fundamental role in airborne gravity processing. The objective of the filtering is both to account for the difference in filtering inherent from the data, and to remove the high frequency noise masking the gravity anomaly signal. The gravimeter data acquisition system uses a 1 sec. boxcar filter on internal 200 Hz data, whereas the inherent filtering of the accelerations derived from the GPS positions depends on the GPS processing software, and the algorithm applied for differentiation. This difference in filtering has little impact on the linear terms in our processing algorithm, because of the heavy final filtering. But the nonlinear terms, mainly represented by the tilt correction, are quite sensitive to the initial filtering.

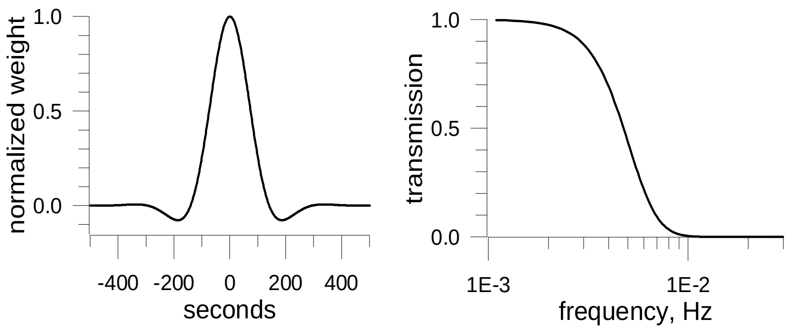

Fig. 8. Impulse response (normalized) and spectral representation of the filter.

All data were filtered with a symmetric 2nd order Butterworth filter with a half power point at 200 seconds, corresponding to a resolution of 6 km (half-wavelength). The impulse response and spectral behaviour of the used filter are shown in Fig. 8.

5. Final results and evaluation

The results of the processing resulted in more than 95% of all flights being succesful. Processing could be extended on the lines to within ca. 3 minutes of the line end. Some minor data gaps had to be left on some lines due to the earlier mentioned hardware problems (power failures and gravimeter-PC communication problems), and a few GPS problems. Data are presented in file format in the form

id, lat, lon, H, g, Δg, time (JD)

where *id = lineno*1000 + running no,* H the orthometric height, g absolute gravity and Δg the GRS-80 free-air anomaly. The numeric line numbers are indicated in Table 2. The tracks processed are shown in Fig. 9 and 10.

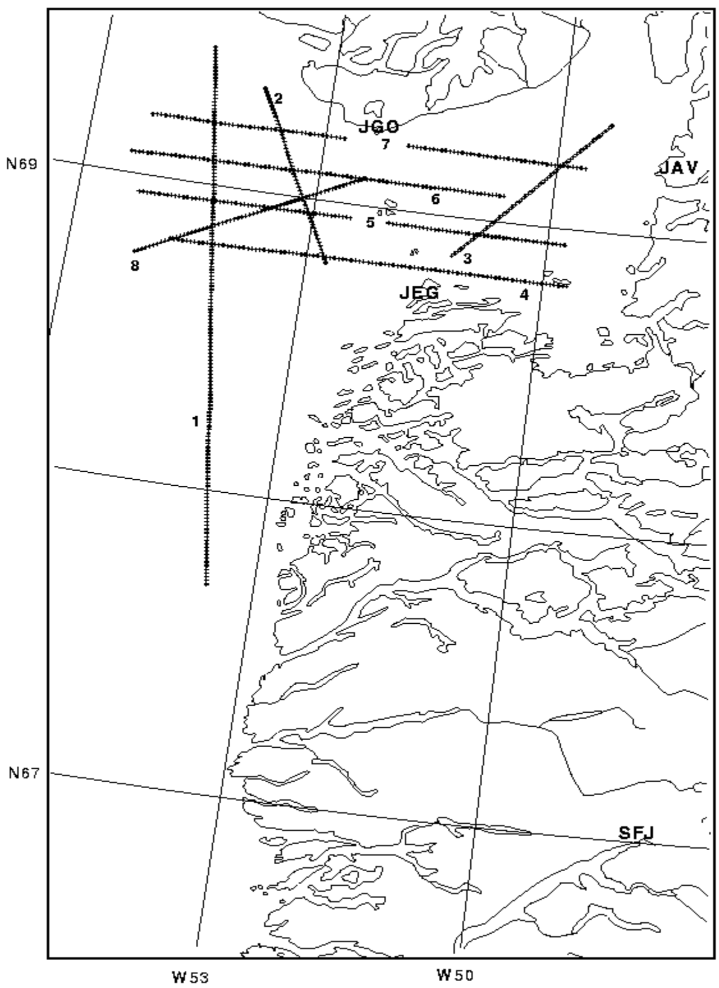

Fig. 9. Processed track data, Disko Bay.

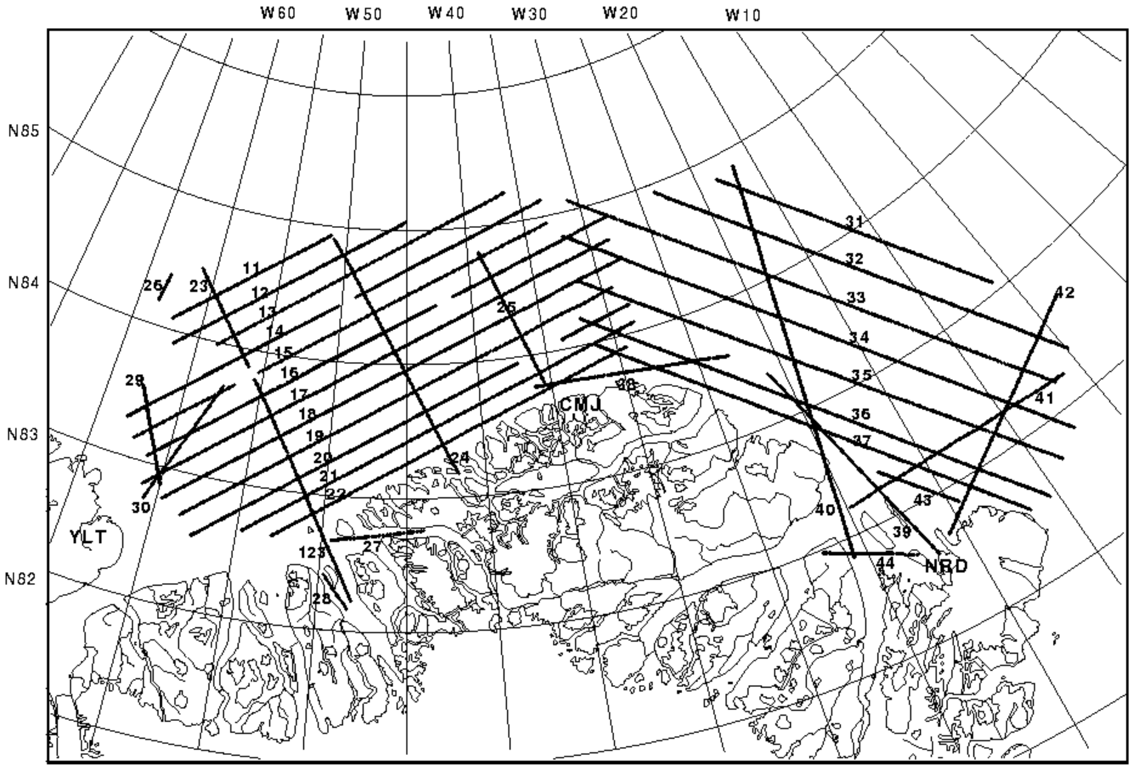

Fig 10. Processed track data, Northern Greenland.

5.1. Cross-over adjustment validation

The final track data were subjected to a bias-only cross-over adjustment. The results are given in Table 5 and Table 6. All available data have been used, except for the easternmost part of line 35 north of Station Nord, which was turbulent and subject to apparent large errors (cross-overs of 5 and 9 mgal, respectively). The eastern part of this line has been excluded from the cross-over adjustment, and was originally deleted from the processing. Because the line fills an important void, we decided to keep it though. If the 2 crossing points were included the cross-over error before adjustment would increase from 2.6 to 2.9 mGal.

Table 5. Results of cross-over analysis, North Greenland (69 cross-overs)

Units: mGal	R.m.s. cross-over error	Max difference
Before adjustment	2.6	6.0
After bias adjustment	2.1	6.0

Table 6. Results of cross-over analysis, Disko Bay (15 cross-overs)

Units: mGal	R.m.s. cross-over error	Max difference
Before adjustment	2.6	5.2
After bias adjustment	1.5	2.4

If the errors are assumed white noise, this corresponds to a point error less than 2 mgal (r.m.s. error divided by √2).

5.2 Comparisons to shipborne and ice-surface gravity data

The airborne gravity data have been evaluated to shipborne gravity data in the Disko Bay and Melville Bay (recent high-quality Nunaoil shipdata), and in the Arctic Ocean from Canadian ice gravity measurements in the Lincoln Sea. A single sea-ice profile, extending approx. 80 km north from Station Nord was surveyed by helicopter 1997, and overflown in 1998.

Statistics of the comparisons are given in Table 7. Comparisons in the Melville Bay are at crossings airborne/marine tracks (Fig. 12). In the Lincoln Sea and Disko Bay predictions of free-air gravity anomalies along the airborne tracks have been made from the available surface data using collocation (Fig. 11 and Fig. 13). Comparisons are only made for sufficiently close points (using only points were collocation aposteriori prediction errors were less than 3 mGal), and part of the error stated in Table 7 are thus due to the interpolation process.

A comparison of the short ground-truth Station Nord track is shown in Fig. 14. This is a direct comparison of data collected on the ice and data collected in the air. No downward continuation has been performed for the airborne data due to the low flight elevation (nominally 1000 ft).

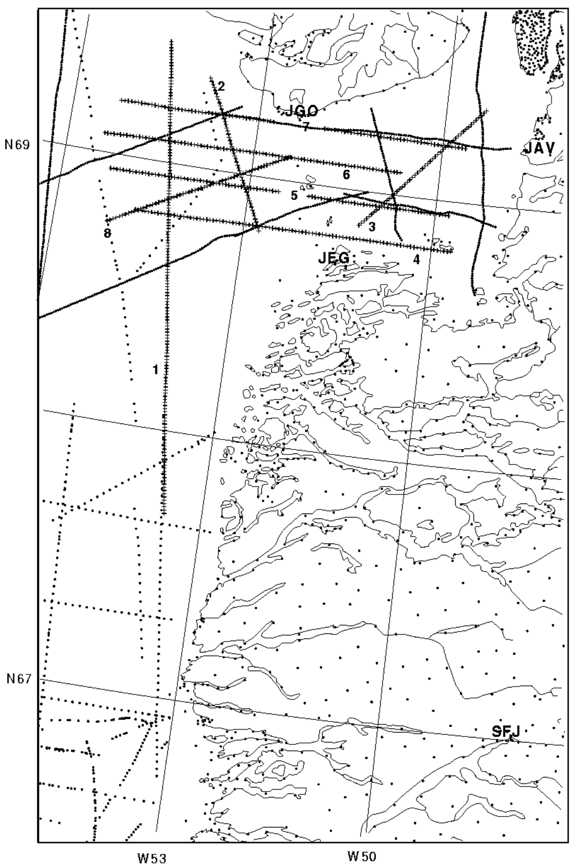

Fig. 11. Surface and airborne gravity data, Disko

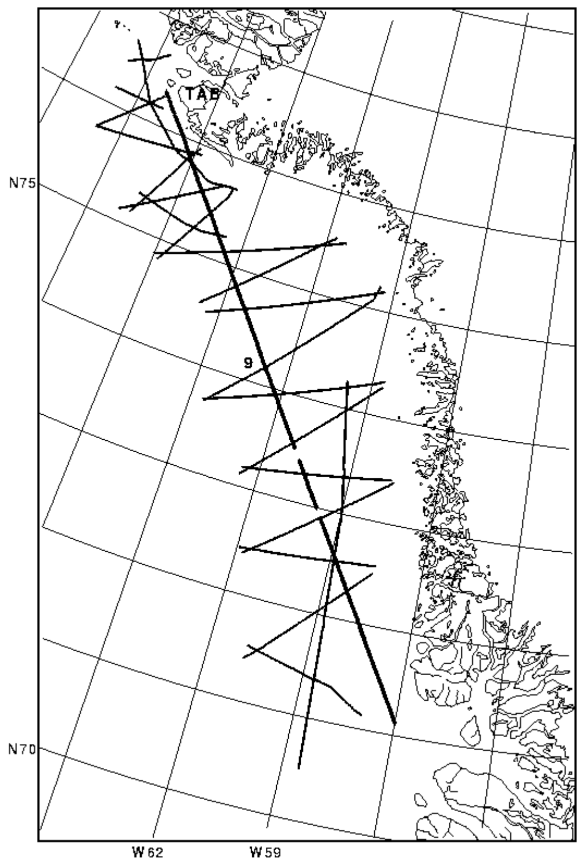

Fig. 12. Melville Bay. Nunaoil data and airborne data.

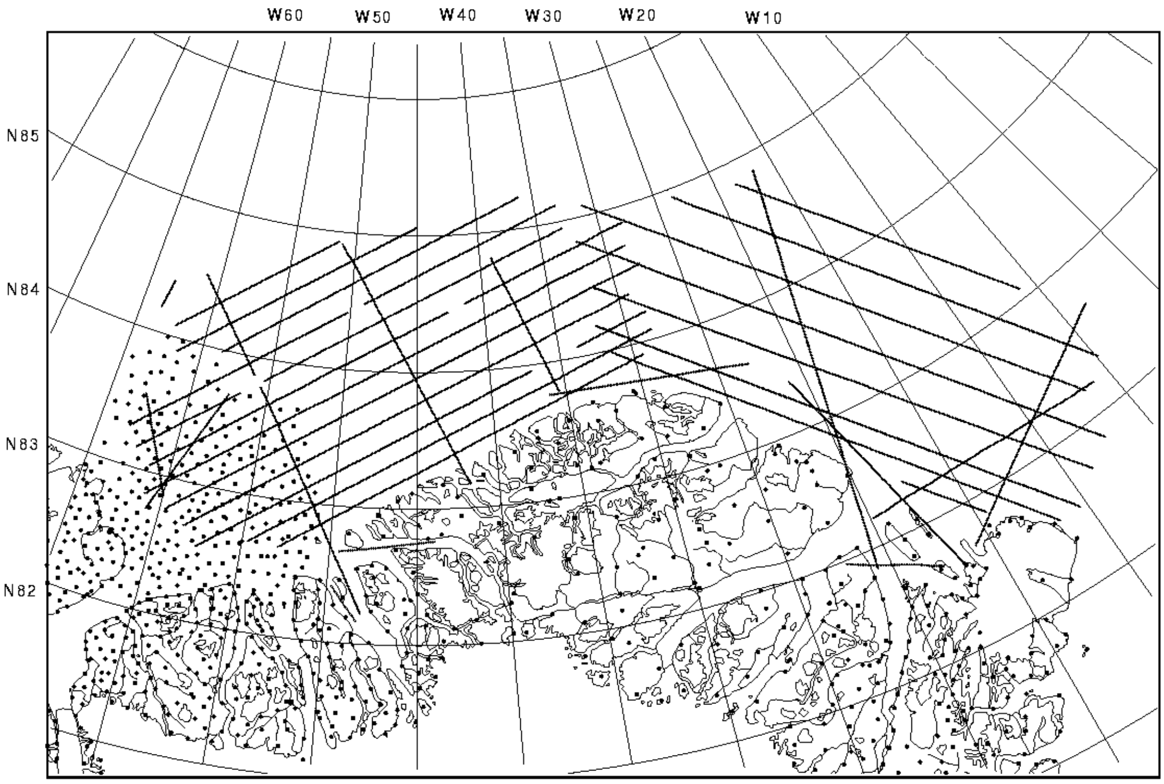

Fig. 13. Surface and airborne gravity data, North Greenland.

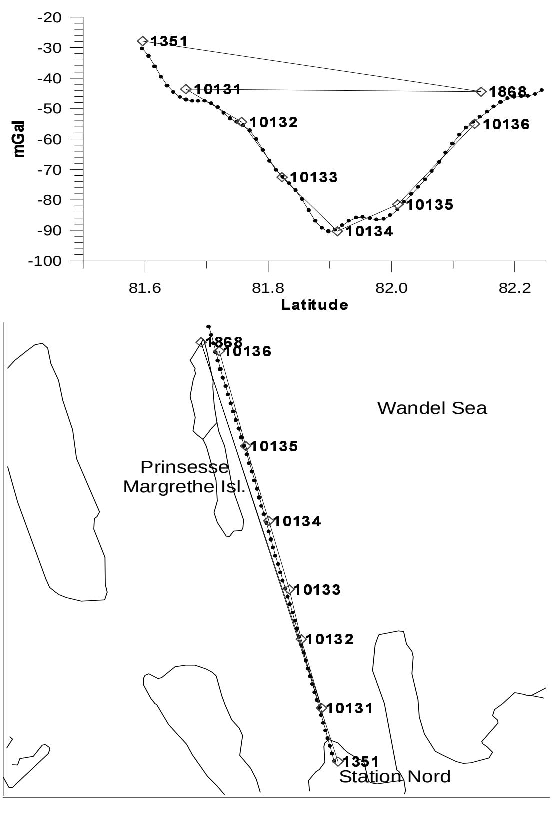

Fig. 14. Comparison between airborne (dots) and ice surface measurements (diamonds), Station Nord.

Table 7. Comparisons between surface gravity data and airborne data (unadjusted)

Unit: mGal	Mean diff.	R.m.s.	Max
Disko Bay (114 points)	-0.5	3.1	9.1
Melville Bay (16 crossings)	-1.5	2.2	4.8
Polar Sea (288 points) - Before cross-over adjustment - After cross-over adjustment	 -0.1 0.6	 2.4 2.9	 8.8 9.5
Station Nord ice profile (6 points)	-0.8	1.7	3.5

It is evident from Table 7 that the introduction of a bias adjustment makes the fit to the surface data worse, in spite of the improvement in r.m.s. cross-overs (Table 5). In fact, with proper line processing and reliable base readings there appears to be no physical justification for a cross-over adjustment, at least with the present survey geometry with relatively few tie-lines. The final results have thus been based on the *unadjusted* data set. The proof of good results without bias adjustment also means that single lines can be used with advantage to densify marine gravity measurements, as indicated in the Melville Bay comparison.

6. Conclusions

A high-quality airborne gravity survey has been performed, with an accuracy around 2 mGal r.m.s. No cross-over adjustment has been used on the data. The final anomalies are shown in Fig. 15 and 16 (incorporating available land and marine data). The anomalies show a.o. a new, previously unknown marginal high in the Lincoln Sea, and a very disticnt gravity gradient

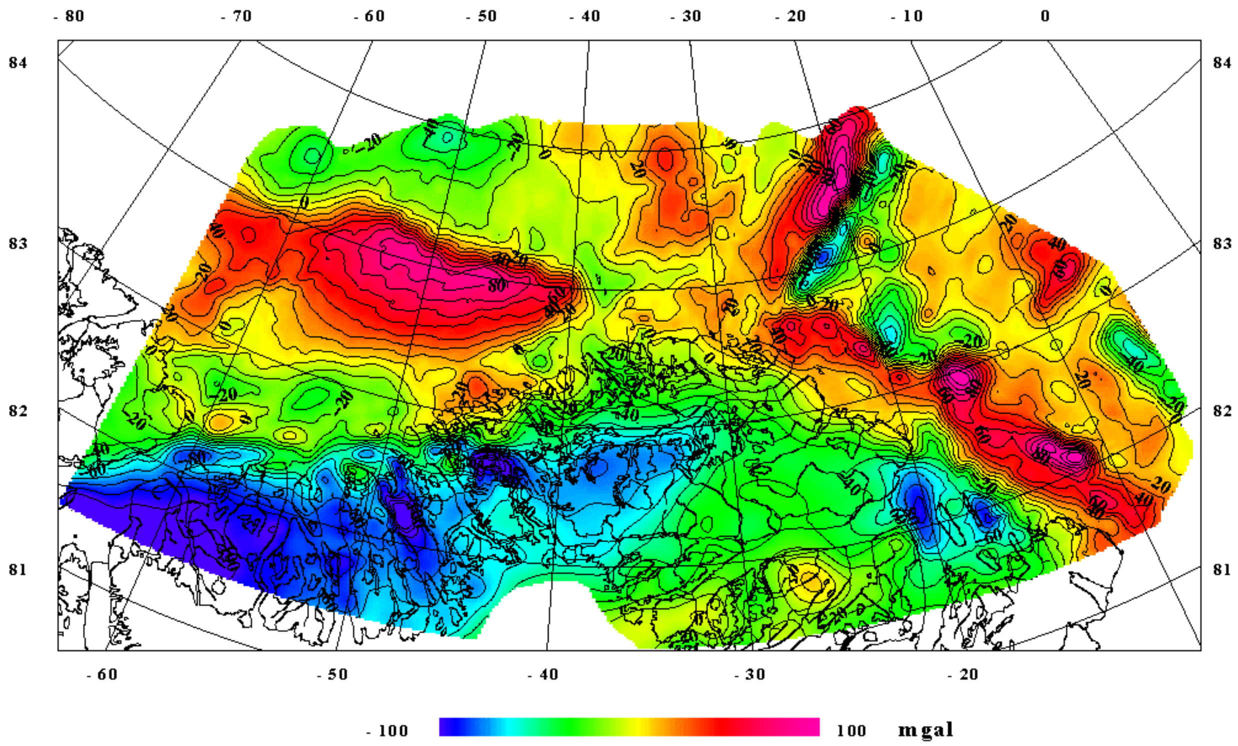

Fig. 15. Gravity anomalies off North Greenland (free-air at sea, Bouguer at land), 10 mGal contour interval.

associated with the eastern edge of the Morris Jesup Rise, a bathymetric feature north of Greenland of uncertain geological origin.
The new gravity anomalies of the North Greenland shelf will be a contribution to the Arctic Gravity Project, an ongoing international cooperation to compile and release an Arctic-wide gravity grid by year 2001, see http://164.214.2.59/GandG/agp/index.htm.

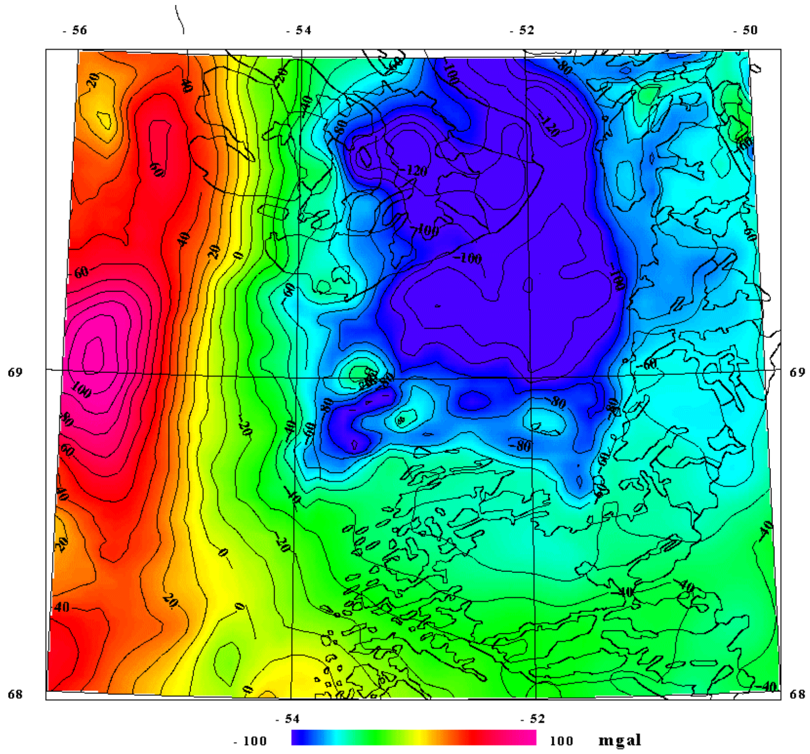

Fig. 16. Gravity anomalies around Disko Bay (free-air at sea, Bouguer at land), 10 mGal contour interval

Acknowledgements

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References

Bastos, L., S. Cunha, R. Forsberg, A. Olesen, A. Gidskehaug, U. Meyer, T. Boebel, L. Timmen, G. Xu, M. Nesemann, K. Hehl: An Airborne Geoid Mapping System for Regional Sea-surface Topography: applications to the Skagerrak and Azores areas. In: Forsberg (Ed.): Geodesy on the Move, IAG proceedings 119, pp. 30-36, Springer Verlag, 1997.

Brozena, J. M.: The Greenland Aerogeophysics Project: Airborne Gravity, Topographic and Magnetic Mapping of an Entire Continent. In: Colombo (Ed.): From Mars to Greenland: Charting Gravity with Space and Airborne Instruments, IAG Proceedings Series 110, pp. 203-214, Springer Verlag, 1991.

Ekholm, S., K. Keller: Gravity and GPS survey on the summit of the Greenland ice sheet. Kort og Matrikelstyrelsen Technical Report 6, 1993.

Forsberg, R.: Gravity and GPS surveys in Greenland. Proc. Nordic Commission of Geodesy Gen. Assy., Ullensvang, pp. 198-209, published by Statens Kartverk, Norway, 1994.

Forsberg, R., K. Hehl, L. Bastos, A. Gidskehaug, U. Meyer: Development of an Airborne Geoid Mapping System for Coastal Oceanography (AGMASCO). In: Segawa et al. (eds.): Gravity, Geoid and Marine Geodesy, IAG proceedings 117, pp. 163-170, Springer Verlag, 1996.

Harlan, R. B.: Eotvos corrections for airborne gravimetry. J. Goephys. Res., 73, 4675-4679, 1968.

Lemoine, F. G., S. Kenyon, J. Factor, R. Trimmer, N. Pavlis, D. Chinn, C. Cox, S. Klosko, S. Luthcke, M. Torrence, Y. Wang, R. Williamson, E. Pavlis, R. Rapp, T. Olson: the Development of the joint NASA GSFC and National Imagery and Mapping Agency (NIMA) Geopotential Model EGM96. NASA Technical Publication TP-1998-208261, 1998.

Olesen A V, R Forsberg, A Gidskehaug: Airborne gravimetry using the LaCoste & Romberg gravimeter – an error analysis. In: M.E. Cannon and G. Lachapelle (eds.). Proc. Int. Symp. on Kinematic Systems in Geodesy, Geomatics and Navigation, Banff, Canada, June 3-6, 1997, Publ.Univ. of Calgary, pp. 613-618, 1997.

Strykowski, G., R. Forsberg, M. D. Larsen: Acquisition and Processing of High Precision Greenland Marine Gravity Data. Phys. Chem. Earth, 21, pp. 353-356, 1996.

Valliant, H: The LaCoste & Romberg air/sea gravimeter: an overview. In: CRC Handbook of Geophysical Exploration at Sea, Boca Raton Press, 1991.

Fig. 17. Arctic sea ice north of Peary Land

Appendix 1. Airplane operator log file.

LOG FILE for KMS AEROGRAVITY 1998

All times in UT. See laseraltimeter notes JUN12.
Ultrasys screen listings: G-filt, ST, CC, beam and TC.

JUN 6 - JD157
=============
SFJ-JAV transit flight and Sukkertoppen Iskappe. GPS bases in JAV and SFJ.
Sondrestrom Hangar: Beam zero -1; beam gain 9000.
1632 Basereading 14019.4 14019.5 -6 -.3
1633 clamp beam for take-off
1643 at cruise alt out of SFJ
1645 ST on, unclamp
1718 First line of ECOGIS Sukkertoppen glacier profiles
1720 Fog patches, clear after 3 min over ice cap
1900 Platform dump and restart, CTRL U+D used to move beam, unstable
1916 14052 13874 n/a 2847 224
2021 End of line, select space stable mode
2026 4 min period
2028 unclamp
2056 End of line, set space stable
2104 ST on, 4 min period
2132 Clamp beam for landing in JAV

JUN 7 - JD158
=============
Test on JAV apron. Beam zero +1 (-24 before adj.), beam gain 9001.
St. sensor 14141.4, monitor 14171.9 - problems with ST. P4 set ST.
Pressure 26.6

JUN 8 - JD159
=============
Survey flight Disko Bay. Ref GPS at JAV, JEG and JGO (power failures).
Beam zero -1; beam gain 9005.
Base reading ST 14145.0, monitor 14145.1
1521 Basereading G 14137.7 ST 14137.8
K check: ST+30 14136.3 14167.8 0 214 -30.2
ST-60 14137.6 14107.8 0 -60 29.7
1839 Baserdg apron 14137.5 14137.2 0 -2 0
1850 take-off
1852 icebergs
1858 new line, beam unclamped, ST on.
1903 clouds
1924 SAGS reset
1942 end of line
1952 new line, beam unclamped
2020 error 25401 (data glitch)
2028 ultrasys stopped and started again
2033 end of line
2045 landing
2123 base reading 14137.7 14137.6 0 -4 0

JUN 9 - JD160
=============
Survey flight Disko Bay. Ref GPS at JAV, JEG and JGO (power failures).
Beam zero 3, beam gain 9002. Time sync 0 sec.
1425 base reading 14137.7 14136.6 0 15 1.6
1433 engine start
1440 airborne
1459 on line H, beam unclamp, platform tilts after spacestable test
1515 restart ultrasys
1542 end of line
1552 line D, beam unclamp
1625 some turbulence
1632 end of line
1639 line E
1659 system hanging?
1722 end of line
1726 Trimble AIR1 lost lock - antenna cable error
1734 line G
1815 end of line
1819 on ground
1826 engines off
1859 base reading 14137.6 14137.2 0 -2 0.2

JUN 11 - JD162
==============
Transfer flight JAV-THU. GPS in JAV and THU.
Beam zero -3, beam gain 9003 (not adj.). Set ST 14143.3 (+0.5).
Clock offset GPS - S99 = -5 sec
1110 base reading 14137.5 14136.6 0 19 1.0
ultrasys stopped, 1998_12.162 -> apron11.dat
1125 taxi to runway
1129 takeoff
1149 line I, low fog
1157 communication error
1200 restart ultrasys, ST OK
1228 end of line, continue without clamping due to small turn
1232 beam clamped
1235 line J
1244 altitude change
1350 line error
1432 HF radio used
1510 14552 14549 .0 -12 34
1536 14589 14605 .1 -105 -31
1546 end of line
1813 base reading (uncomplete) - completely wrong value (14230.4),
ST must have slipped around base reading.

NB: aircraft moved to new position after basereading

JUN 12 - JD163
==============
Test in THU hangar. Change stepper motor.
1120 start, ST set 14230.1 -> 14230.6.
1530 base reading after new motor 14564.1, ST set to new value
1612 new base reading 14565.0

Laser altimeter readjustment:
Slope of airplane floor: 1.2 cm/20 cm.
Airplane slope in air: 0.7 cm/20 cm.
Laser found to be rather loose and point too much aft (0.5/20)
Adjusted 1.0/20 to point forward of nadir by 0.5/20 (i.e., nadir at flight).
Correction at 1000 ft: 0.37 m, to be added to laserheights before JUN12.

(Weatherbound/Weekendclosed in Thule Air Base JUN 13-15)

JUN 15 - JD166
==============
Base reading in Hangar 8, TAB
1015 Start
1630 Basereading 14565.0 14565.0 0 0 .2

JUN 16 - JD167
==============
Flight from TAB to Alert. GPS ref at Astro, TAB.
0955 Start ultrasys, ST PC 14570.0, grav 14560.0.
1203 Basereading 14565.1, ST sync OK
1250 Ultrasys start, power failure in acft, restart.
1257 Taxi and take-off
1306 set ST 14597.0. Slew to 14630.
1324 On line, manual platform level, unclamp, ST on
1330 14596 14342 1.1 724 -20
1331 Platform dumped, restart, dumped again. Power/EM problems?
After numerous attempts abort gravity system. Laser profiling only.
1615 End of laser line near Joe Is, direct to Alert
Change power supply unit.
ORIGINAL VERSION OF ULTRASYS RELOADED FROM ZLS DISCS.
2150 Basereading Alert apron 14780.3 14780.5 .0 2.0 -.4

JUN 17 - JD168
==============
Double flight pattern over Lincoln Sea from Alert. GPS ref in Alert.
1330 Start. ST set 0.5.
1335 Baserdg 14781.8 - not complete
1339 Start engine
1347 Take-off
1359 Unclamp beam for 4 min, clamp again for turn
1413 Unclamp, on D1 1414, ST OK
1426 14628 14641 .6 -10 -94, ST OK, UT(GPS) = UT(grav)-25 sec
1609 end of line, clamp beam, 4 min period in turn
1617 on line, unclamp 1621
1723 line error until 1728, ST OK
1653 14704 14686 .0 -356 8 ST OK
1736 end of line, clamp
1739 unclamp for Alert transit, somewhat turbulent
1757 Beam clamped
1802 Landed. platform dumped.
1900 Take-off for lines F+E
1913 Unclamp, ST OK
2128 end line F, beam clamp, slew st 14700, ST OK
2139 On line E, unclamp, ST on
2146 Platform dump, restart ultrasys. ST sync OK.
2216 ST grav 14738.2 pc 14737.7
2316 end of line, clamp, shut down system after 5 min
2330 landing
0102 base reading 14779.9 14780.7 0 1 -.8
0109 base reading 14779.9

JUN 18 - JD 169
================
Survey flight from Alert to Nord. GPS at Alert.
1015 ultrasys startet
1126 14780.1 14779.9 .0 1. .2 - basereading 14780.1 ST sync OK
1130 beam zero + gain adjust
1228 base reading 14779.8 ST OK
1250 reboot+reheat due to pwr fail
1306 airborne
1316 unclamp, on heading for G1
1324 UT(Grav) = UT(GPS) + 28 sec
1333 low fog
1516 clamp beam, ST off, end of line G2, ST OK
1544 unclamp, begin of line P1
1646 ST OK. Low ground fog.
1733 In clouds, turbulence
1746 end of line, stop ultrasys
1829 landed
1930 base reading Nord (lumber shop)
grav ST
14720.7 14723.9

JUN 19 - JD 170
================

first flight part 1.
WP: NRD-S2-S1-CMJ

0931 baserd 14721.1 14721.1 0 0 -.3
power fail, restart.
0945 take off
G 14821 PC 14820.9

1028 unclamp line S
1029 ST on, turbulence
1033 set beam
1236 end of line S, clamp

first flight, part 2.
WP: CMJ-L1-L2-YLT

1305 take off, UTC(grav)= UTC(GPS)+30sec
1332 start ultrasys
1337 L2
1339 unclamp
1341 ST on
1342 ST sync pc14770.2 gr14770.5
1420 pc14744.1 gr14744.4
1455 pc14714.6 gr14714.9
1504 end of line, clamp, ST off

second flight.
WP: YLT-G1-T3-T1-AA1-AA2-A1-A2-V1-V2-AB1-AB2-AC1-AC2-T2-T3-YLT

1630 take off
1644 pc=14541.0 gr=14541.8
1646 ST synch=14541.8
1647 line G1-T3, beam uncl
1708 pc14600.4 gr14600.4
1714 end line, beam clamp
1717 slew ST +150
1721 line T3-T1, uncl beam
1751 end line, beam clamp, ST off
1752 pc=gr=14695.4
1753 slew ST -40
1755 line AA, beam uncl, ST on
1808 end AA, beam clamp, ST off
1809 slew ST -95
1810 pc14575.8 gr14575.7
1812 line A, beam uncl
1816 ST on
1845 pc 14562.7 gr 14562.5
1856 end A, beam clamp, ST off
1857 slew ST 25
1858 pc 14566.8 gr 14566.6
1905 line V, beam uncl
1910 ST on
1939 pc 14681.7 gr 14681.5
2007 end V, beam clamp, ST off
2008 slew ST +170
2009 pc 14725.3 gr 14725.2
2018 line AB beam uncl
2020 ST on
2043 end AB, beam clamp, ST off
2044 ST slew -200
2045 pc 14502.7 gr 14502.6
2046 line AC, beam uncl, ST on
2050 fog, no laser
2051 ST on
2102 end AC, beam clamp, ST off
2103 slew ST 150
2104 pc 14477.2 gr 14476.9
2105 line T1-T3, beam uncl
2109 ST on
2141 pc 14722.9 gr 14722.5
2200 end T1-T3, beam clamp
2201 slew ST +30
pc 14807.4 gr 14807.2
2203 home line, beam uncl
2208 ST on
2235 end home line, beam clamp, ST off, ultrasys shut down
2241 touch down
0041 base reading: gravity spring tension raw beam corr
pc 14780.3 14782.5 -26 -2.2
gravimeter 14781.7
base reading=14781.7-2.2=14799.5

JUN 20 - JD171
=============
980620 gravimeter log, first flight.

WP: YLT-H1-H2-I2-I1-YLT

1252 take off
1258 pc 14782.1 gr 14781.2
synch pc=gr=14780.5
1300 slew ST 14490
1301 line H, beam uncl
1303 ST on
fog, no laser
1335 pc 14621.2 gr 14621.2
1405 pc 14669.1 gr 14669.0
1452 pc 14624.2 gr 14624.1
1508 end H, beam clamp, ST off
1510 slew ST 160
1512 pc 14762.4 gr 14762.3
1516 line I, beam uncl
fog no laser
1540? laser ok
1603 pc 14815.6 gr 14815.5
1625 fog, no laser
1707 end I, beam clamp, ST off
1708 pc 14735.6 gr=14735.5
1709 ultrasys closed
1722 touch down

second flight
YLT-J1-J2-K2-K1-YLT

1815 take off
1827 slew ST 14500
1828 synch ST pc=gr=14500
ultrasys stopped and started
1835 line J beam uncl
fog, no laser
1840 ST on
1855 pc=14527.5 gr=14527.1 !!
2007 climb to 1200 ft due to ice
2009 pc 15027.6 gr 15027.2
2043 end I, beam clamp, ST off
slew ST 140
pc 15063.1 gr 15062.6
synch ST pc=gr=15062.6 !!
climbs to 1500 ft to avoid ice problems

2051 line K, beam uncl
fog no laser
2053 ST on
2136 pc 14680.0 gr 14680.0
2215 ? datalogger runtime error 200 at
1909:000A
reboot
2217 datalogger locked
2219 reboot seems to be OK, but all data from
this
flight are lost.
2221 pc 14662.1 gr 14662.1
2229 end K, beam clamp, ST off
2231 home line, beam uncl
2233 ST on
2248 end home line, beam clamp, ST off
ultrasys stopped
2255 touch down
0105 base reading
pc 14778.9 147789 .0 7. (-.2)
gravi 14779.5
basereading=14779.5

JUN 21 - JD 172
===============
980621 gravimeter log, first flight.

WP: YLT-AD1-AD2-B1-B2-Y2-Y1-CMJ

1458 take off
slew ST 14650
pc=gr=14650.6
1512 line AD, beam uncl
1521 end AD, beam clamp, ST off
ST slew -130
pc 14549.3 gr 14549.4
1544 line B, beam uncl
1547 ST on
1640 pc 14538.8 gr 14539.0
1652 end B, clamp beam, ST off
slew ST 40-55=-15
pc 14595.4 gr 14595.6
descent to 500 ft
slew ST 60
1702 line Y, beam uncl
1707 ST on
1738 pc 14675.1 gr14675.3
1746 end Y
system shut down
1755 touch down
CMJ
1836 take off
1847 slew ST -60
pc 14602.6 gr 14602.8
ST synch 14602.8
1853 line U, beam uncl
1856 ST on
1921 pc 14606.6 gr 14606.7
1942 end U, beam clamp, ST off
1944 line W, beam uncl
pc 14740.1 gr 14740.3
1947 ST on
2015 pc 14612.2 gr 14612.3
2048 end line W, beam clamp
system shut down
touch down
base reading
pc 14720.1 14720.1 .0 7. 0.1
grav 14720.4

base reading=14720.4

22 JUN 98 - JD 173
==================

980622 gravimeter log, first flight.

WP: NRD-Z1-Z2-M2-M1-X2-X1-NRD

GPS air1 and air2, plane taxis in static mode
0909 take off
slew ST 14580
pc 14580.1 gr 14580.3
GPS air2 no power
0919 line Z, beam uncl
0920 ST on
1011 end Z, beam clamp, ST off
slew ST 160
pc 14661.6 gr 14661.7
descent to 280 ft
1033 line M, beam uncl
1044 ST on
turbulence
1117 pc 14811.7 gr 14811.9
200 ft
1153 end M, beam clamp, ST off
slew ST -40
pc 14808.5 gr 14808.8
synch pc=gr=14808.8
1205 line X, beam uncl
1208 ST on
1253 pc 14610.3 gr 14610.3
1341 end line X
slew ST -100
1343 line home, beam uncl
pc 14481.0 gr 14481.0
1349 ST on
1357 end home, beam clamp
system shut down
1400 touch down

23 JUN 98 JD 174
========================

NRD-O2-O1-N1-N2-AE1-AE2-NRD

0913 Take off
0915 ultrasys on
0916 ST slew pc14470.0 gr14469.9
0920 unclamp, ST on
0922 turbulence for next 10 min.
0935 clouds, no laser
0941 ST pc14459.7 gr14459.5
0954 ST off clamp

1002 O2, torque off + on,
1002 ST slew 14578, pc14577.9 gr14577.5
1002 height 1300 ft, 155 knots
1003 unclamp
1029 ST pc14692.9 gr14692.5
1051 boot datalogger,
1054 datalogger OK
1055 UTC(GPS)=UTC(gravPC)-40 sec
1146 end of line
1149 ST pc14634.5 gr14634.3
1200 start line N1 - N2, 1300 ft, 125 knots
1204 unclamp
1206 ST pc14651.6 gr14651.5
1315 ST pc14564.7 gr14564.5
1315 turbulence next 20 min
1357 end of line, ST off, clamp
1359 slew ST 238
1401 start of line AE1 - AE2 torque off + on
1402 unclamp
1410 ST pc14759.1 gr14758.9
1415 turbulence next 15 min.
1502 small corrections in heading and height !
1507 AE2
1513 end of line, ST off, clamp
1514 slew -220
1515 pc14436.9 gr14436.5
1517 new line AE2-NRD, torque off + on
1518 ST on, unclamp
1531 ST pc14378.4 gr14378.2
1545 end of line, St off, clamp, ultrasys terminated
1550 3 times passing runway, 1000ft, 500ft, 100ft
1725 basereading pc14719.9 gr14719.6
1743 14720.2 14719.9 .0 5 .3 basereading 14720.2
ST set to 14719.6

JUN 26 - JD177
===============
First flight towards south along coast. GPS at Nord.
0905 basereading 14720.5 14720.5 0 0 -.3
0915 take off. Short move before "rove" pressed on GPS.
UT(Grav) - UT(GPS) = 49.5 sec
0936 hand level platform after turn. Fog.
0937 unclamp, flight altitude 2000 ft
1105 end of line, clamp beam, ST OK
1112 unclamp, on line. Some turbulence. Altitude 400 ft.
1250 end of line, clamp, slew to 14730, ST OK
1307 unclamp, hand level platform
1340 clamp, end of line, slew to 14650
(turn over low land, not ocean)
1347 unclamp, on UU1. ST OK.
1416 end of line
1418 ultrasys stopped
1427 landing, extra funflight
1547 base reading 14719.5 14719.4 0 -3. .3
ST ej sync - g:14720.0, pc:14719.4
ST reset to 14720.0 - new baserdg 14720.0

JUN 27 - JD178
===============
gravimeter log 980627, NRD-NRD CC, DD and EE

0911 take of
pc=14720.4 gr =14720.4
0921 on line, beam uncl
no pps signal, could not find the menu, sorry
0924 ST on
0943 end line, beam clamp, ST off
0946 slew ST 14680
pc=14680 gr 14680
0953 line CC, beam uncl
0955 ST on
1143 end line, beam clamp, ST off
slew ST -180
1144 pc 14435.9 gr 14435.9
1150 line DD beam uncl
1154 ST on
1418 end line, beam clamp, ST off
slew ST
1420 pc=14734.2 gr=14734.1
1421 beam uncl
1425 ST on
1519 ultrasys shut down
1525 touch down

JUN 29 – JD180
===============
Flight from Nord to Svalbard
1004 take-off
1007 slew ST
1014 adjusted ST, PC=14425.7, Gr = 14425.7
1100 on-line, beam unclamped
1104 ST on
1313 slowly increasing height
1351 Ultrasys shotdown. Datalogger, laser, gravPC off
1405 Touch down, Longyearbyen

Appendix 2. Reference station descriptions.

Kort & Matrikelstyrelsen

GPS STATION: SFJ-hut

Coordinates (° ' "): 67 00 21.6502 N   Elevation (m): 72.045 ell.

50 42 09.6711 W

Monumentation: none

GPS point on former meteorological hut, Kangerlussuaq, Greenland.
Used repeatedly for ice sheet GPS reference.

See photo.

Operated by KMS June 1998.

Kort & Matrikelstyrelsen

GPS STATION: JAV1

Coordinates (° ’ ”): 69 13 39.8870 N   Elevation (m): 69.235 ell.

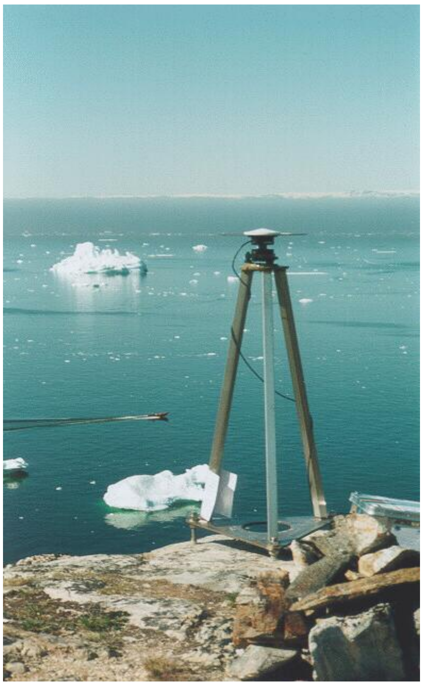
51 05 45.7587 W

Monumentation: Bronze plate

KMS reference point with permanent tripod near Arctic Hotel, Ilulissat, Greenland.

See photo.

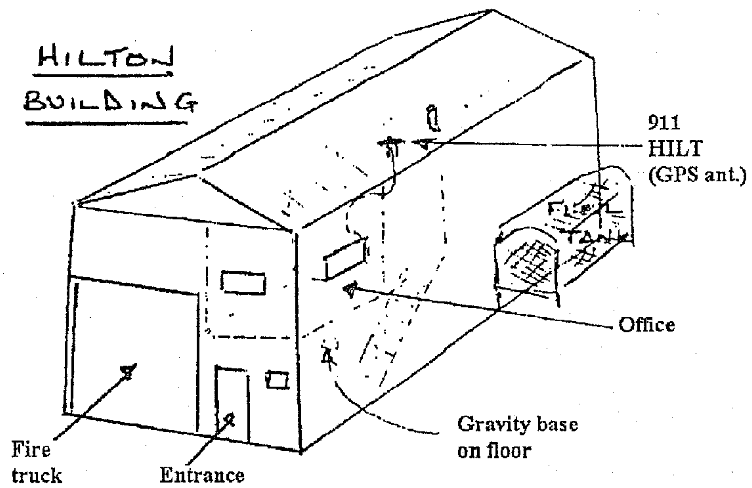
Operated by KMS, June 1998.

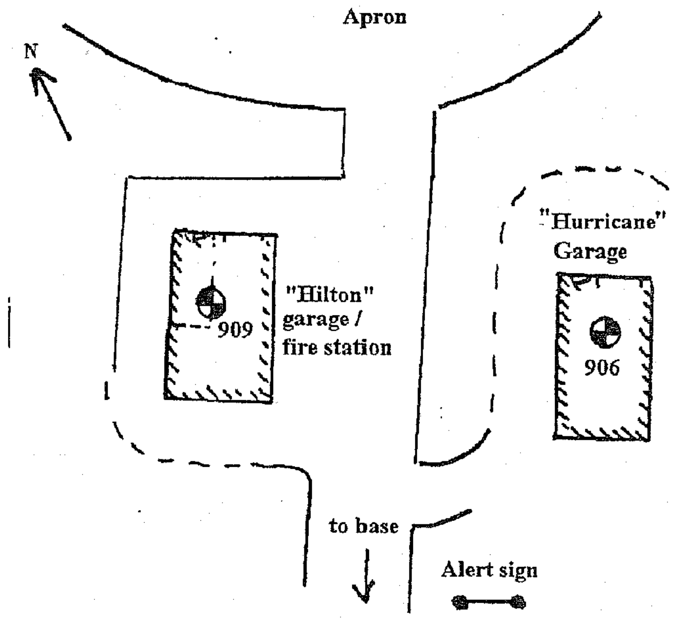


GPS STATION: 911 Alert Hilton

Coordinates (° ' "): 82 30 41.56 -62 19 36.31 Elevation (m): 85.1 ellipsoidal

Temporary GPS antenna location, on top of "Hilton" building (fire station at apron).





Overview map

Kort & Matrikelstyrelsen

GPS STATION: Cape Morris Jessup temp. point. AWI

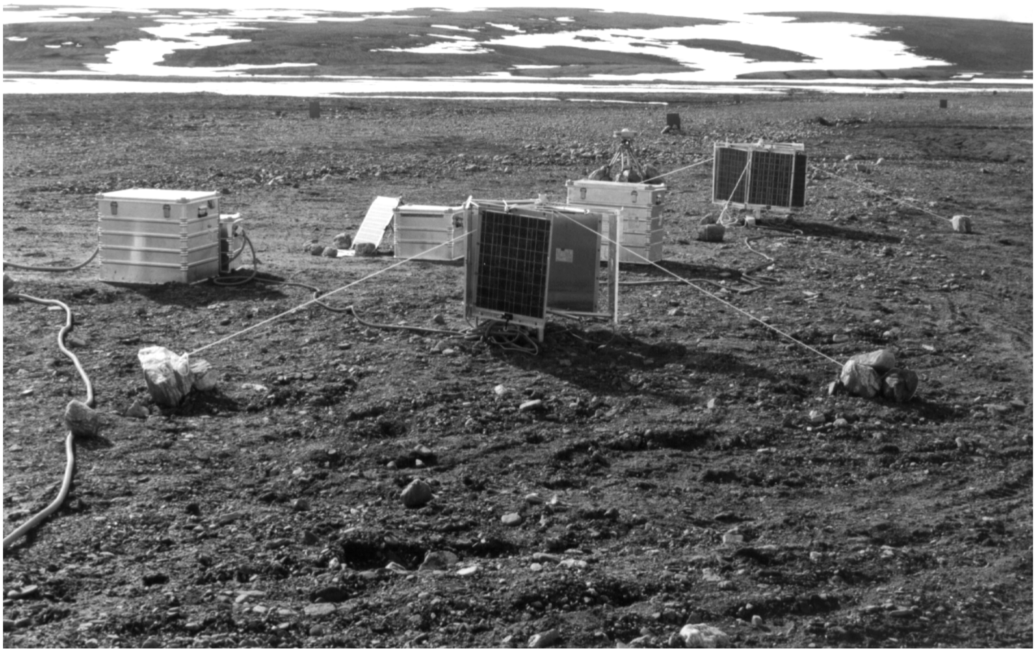
Coordinates (° ' "): 83 39 15.3141 N   Elevation (m): 34.195 ell.

33 22 21.5729 W

Monumentation: none

Temporary GPS point at Cape Morris Jessup.
Established in cooperation with AWI
See photo.

Operated by AWI, June 1998.



GPS STATION: AWI-Nord

Kort & Matrikelstyrelsen

Coordinates (° ' "): 81 35 49.4606 N
16 39 22.0634 W

Elevation (m): 67.060 ell.

Monumentation: none

GPS point on house (no. 19 ?), Station Nord, Greenland.
Established by AWI, june 1998.

See photo.

Operated by AWI june 1998.

Kort & Matrikelstyrelsen

GPS STATION: LYR

Coordinates (° ' "): 78 14 51.8960 N Elevation (m): 49.262 ell.

15 29 42.8984 W

Monumentation: Bronze bolt

Temporary tripod on NPI pillar, ant. height 0.801 true vert.

See photo.

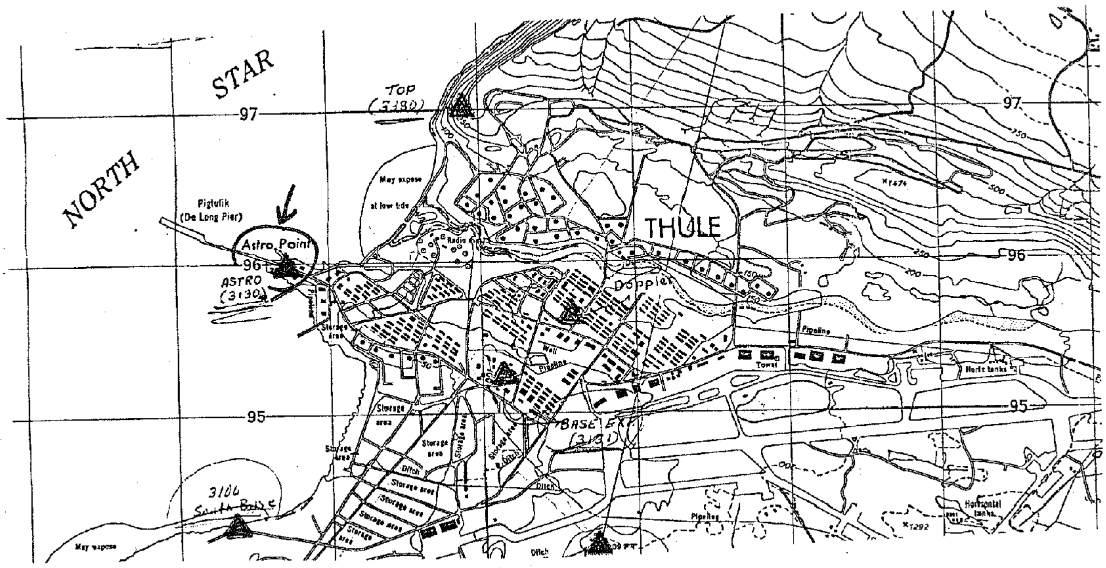
Operated by KMS July 1998.

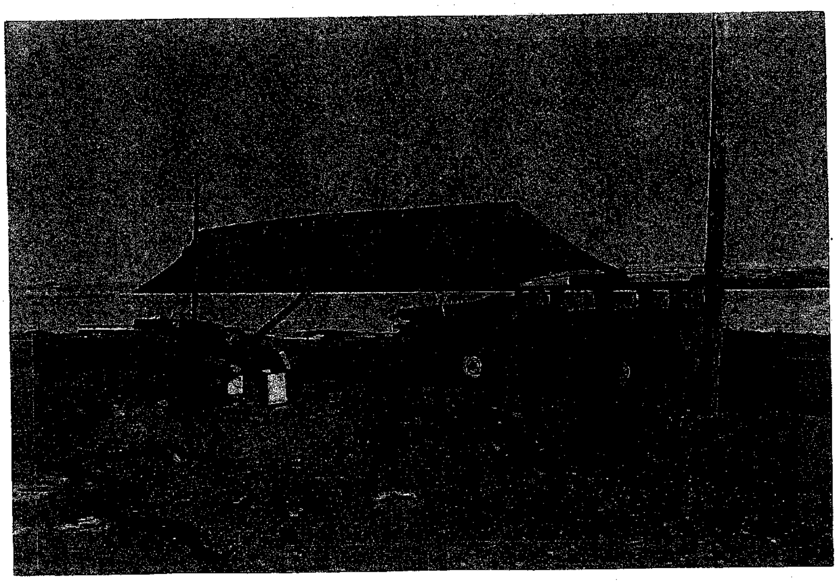
GEODETIC STATION: 3130 Thule Air Base - Astro

Coordinates (° ′): 76 32.48 N 68 50.42 W | Elevation (m): 8.25

Gravity value (mGal): 982 925.14 | Monumentation: bronze plate

On big, yellow-painted boulder to the left of the road to the main pier, Thule Air Base. Established 1946 by american surveyors.





Station Nr. 1001 Station Nord astro

Beliggenhed: Geografiske koordinater (hele sek.).

Bredde: 81°36'04" N. Længde: 16°39'20" W. Kote: 39.8 m.

Journalside: 21308-311

Måleår: 1952, 1978, 1979, 1980

Observator: Sinding

Afmærket på foto

		rute	billede		rute	billede
Lodfoto	1:150 000			Skråfoto		
—	—			—		
—	1:50 000	259 H 009		—		
—	—					
—				Terr. foto	nr.	
—				—		

Etableringsform:

Bronzeplade	☐
Bolt	☒
Boret hul	☐
Anden:	
Ingen	☐

Naturligt fixpunkt:

Signalering:

Varde	☐	m
Pille	☒	0.7 m
Stang	☐	m
Terrænsignal	☐	
Anden:		
Ingen	☐	

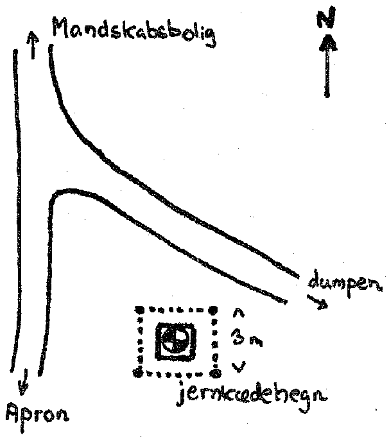
Observationer:

Astro ☒ Doppl ☒ Trig ☒ Baro ☐ Grav ☒ Vandst ☐ Niv ☐

Supplerende oplysninger (skitser, opstigning etc.):

Station Nord, top af astronomisk pille.
Omhegnet af jernkæde.

Station Nord, north-east Greenland.
70 cm high concrete pillar, fenced by
a low iron chain fence. Monumented by
bronce plug. Gravity station on top
of pillar.

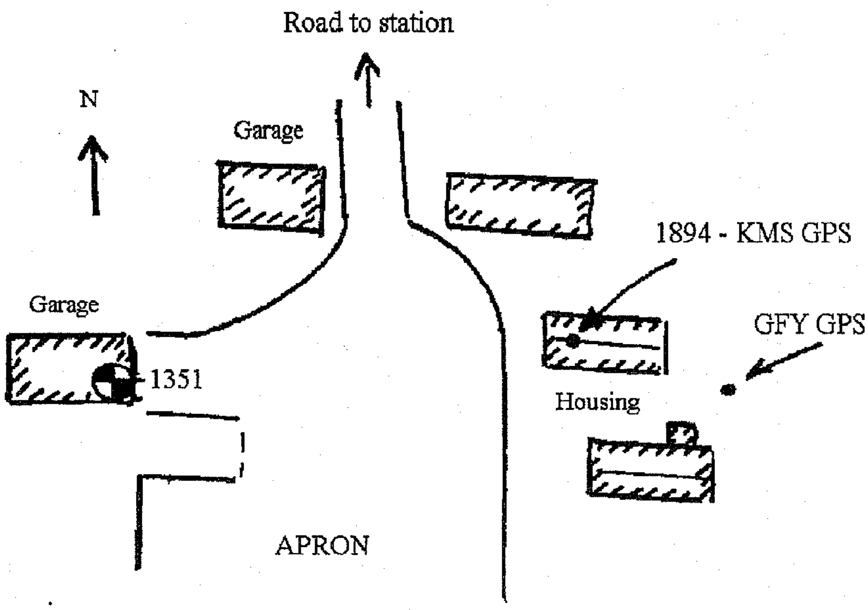


GRAVITY STATION: 1351 Station Nord

Coordinates (° ' "): 81 35.78 -16 39.58 Elevation (m): 35.0

Gravity value (mGal): 983068.74 Monumentation: None

Station Nord, Building 23, old garage at apron. Gravity point is located just inside door to the left of the main door. On concrete floor, 50 cm to the door, 50 cm to the S-wall.



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