Airborne Lidar and Radar Measurements over Sea Ice and Inland Ice for CryoSat validation: CRYOVEX 2003 – Final Report

by

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1 INTRODUCTION

The CRYOVEX (CryoSat Validation EXperiment) 2003 campaign was a first comprehensive Arctic Ocean airborne and surface campaign, in support of the ESA satellite CryoSat, planned for launch late 2004. The primary goal of Cryovex-2003 was to provide coincident laser and 13.6 GHz interferometric radar measurements, in order to understand the penetration of CryoSat radar signals into polar sea-ice and continental ice caps. A secondary goal was to provide coincident sea-ice measurements of the radar/laser system and a helicopter-borne electromagnetic induction system ("EM bird") capable of direct measurement of sea-ice thickness.

The EM measurements, and associated surface ground truth measurements of snow- and sea-ice thickness, were made possible by a coordinated experiment with German research ice breaker R/V Polarstern, moored at a large ice floe in the Arctic Ocean north of Greenland and Svalbard at approx. 82 N, 10 W. The measurement campaign was additionally supported by comprehensive acquisitions of remote sensing data (Envisat and Radarsat).

The measurements and field activities were closely coordinated with activities related to two EU projects (GreenICE and SITHOS), and further supported economically by ESA and a Danish Natural Science Research Council grant for CryoSat preparative work.

This report primarily describes the fixed-wing aircraft operations and the results of the KMS scanning laser sea-ice freeboard measurements. A few examples will be given on comparisons between the different systems for sea-ice measurement, with more elaborate comparisons scheduled for future scientific papers.

The Cryovex-2003 campaign additionally measured continental ice cap profiles across the Greenland ice sheet (along the EGIG line), along the Northeast Greenland ice sheet margin, and over Nordaustlandet ice cap, Svalbard.

In general the objectives of the Cryovex-2003 campaign were met. Installation of the complex radar and lidar equipment in a small Twin Otter aircraft was successful, and the equipment operated with few problems, despite temperatures at –30°C and below. The actually flown patterns were close to the planned ones, despite several days during the campaign with poor weather, especially in Svalbard. Two coincident helicopter/Twin Otter flights were done, yielding useful operational experience for future CryoSat validation activities.

2 CRYOVEX 2003 - AIRBORNE KMS OPERATIONS

The airborne scanning laser (lidar) and radar measurements were carried out in the period April 1 to April 23, 2003 by Kort og Matrikelstyrelsen (National Survey and Cadastre – Denmark; KMS) in cooperation with Applied Physics Laboratory (APL) of Johns Hopkins University, USA. APL provided and operated the D2P 13.6 GHz interferometric Doppler radar, similar to the CryoSat radar system.

The airborne survey was performed using a chartered Air Greenland Twin Otter aircraft (registration: OY-POF), operating primarily from the military airfield at Station Nord, Greenland and the commercial airport in Longyearbyen, Svalbard.

Fig. 1. Air Greenland Twin-Otter at Station Nord, Greenland

The field operations of the KMS/APL airborne survey proceeded as follows:

April 1-5	Scientific equipment unpacked, checked and installed in the aircraft in Air Greenland hangar in Kangerlussuaq, Greenland. Set up automatically PC-logging reference GPS receiver. Test flight performed on April 5. Personnel involved: K. Keller and S. M. Hvidegaard, KMS, C. Leuschen and M. Jose, APL.
April 6	Bad weather at Kangerlussuaq.
April 7	Lidar/radar survey from Kangerlussuaq to Mestersvig (East Greenland) along EGIG line. Laser scanner stopped working after a few hours because of very low temperatures (-35ºC air temperature over the ice sheet). Science crew: K. Keller, S. M. Hvidegaard and C. Leuschen
April 8	No flight. Bad weather at Station Nord.
April 9	Flight from Mestersvig to Station Nord – survey of the East Greenland ice sheet margin and the 79-fjord glacier.
April 10	Two lidar/radar surveys out of Station Nord. Scanner too cold after 4 hours on first flight. Heated up in between trips and worked thereafter.
April 11	Flight from Station Nord to Longyearbyen, Svalbard. Survey of 100-km line near Polarstern coordinated with AWI helicopter. Fog from Polarstern to Longyearbyen and therefore no scanner data. Meeting additional personnel at Svalbard: R. Forsberg, KMS/Denmark; D. Wallis, UCL/UK; M. Jose, APL and M. Davidson, ESA-ESTEC/Holland.
April 12-14	No flights. Bad weather with fog and low clouds either at Polarstern or Longyearbyen or both. Heating pads mounted on laser scanner to prevent too much cooling.
April 15	Survey coinciding with helicopter flight from Polarstern and additional survey over Austfonna Glacier, Svalbard.
April 16	Bad weather, no flights possible.

April 17	Low clouds. Last day of R/V Polarstern drift mode. Flight to Polarstern and thereafter to Station Nord. Cloud base lifted enough around Polarstern to permit dense survey ("mow the lawn") of ice floe at an altitude of about 400 ft. Science crew on return leg to Greenland: K. Keller, S. M. Hvidegaard and C. Leuschen
April 18	Survey flight out of Station Nord.
April 19	Flight from Station Nord to Mestersvig with survey of ice sheet margin.
April 20	Flight out of Mestersvig. Survey of Geikie ice cap – repeat of previous survey.
April 21	Return to Kangerlussuaq with repeat of survey of EGIG line (since scanner failed the first time). Scientific equipment dismounted in Kangerlussuaq.
April 22	Scientific equipment shipped back to Denmark.

A total of 61 hr airborne hours was flown during Cryovex-2003, including the transits from and to the aircraft base at Kangerlussuaq, Greenland, cf. Table 1. The flown tracks are shown in Fig. 2 and Fig. 3.

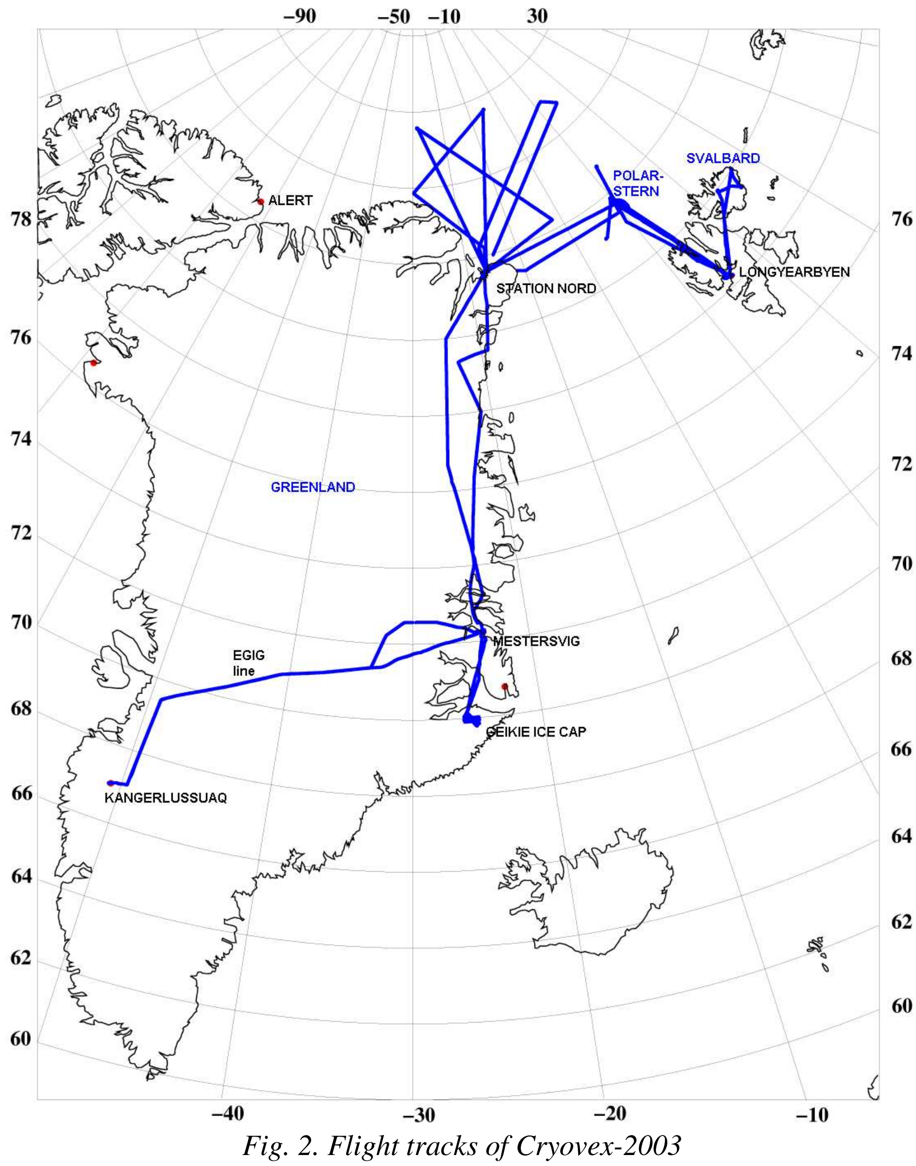


Fig. 2. Flight tracks of Cryovex-2003

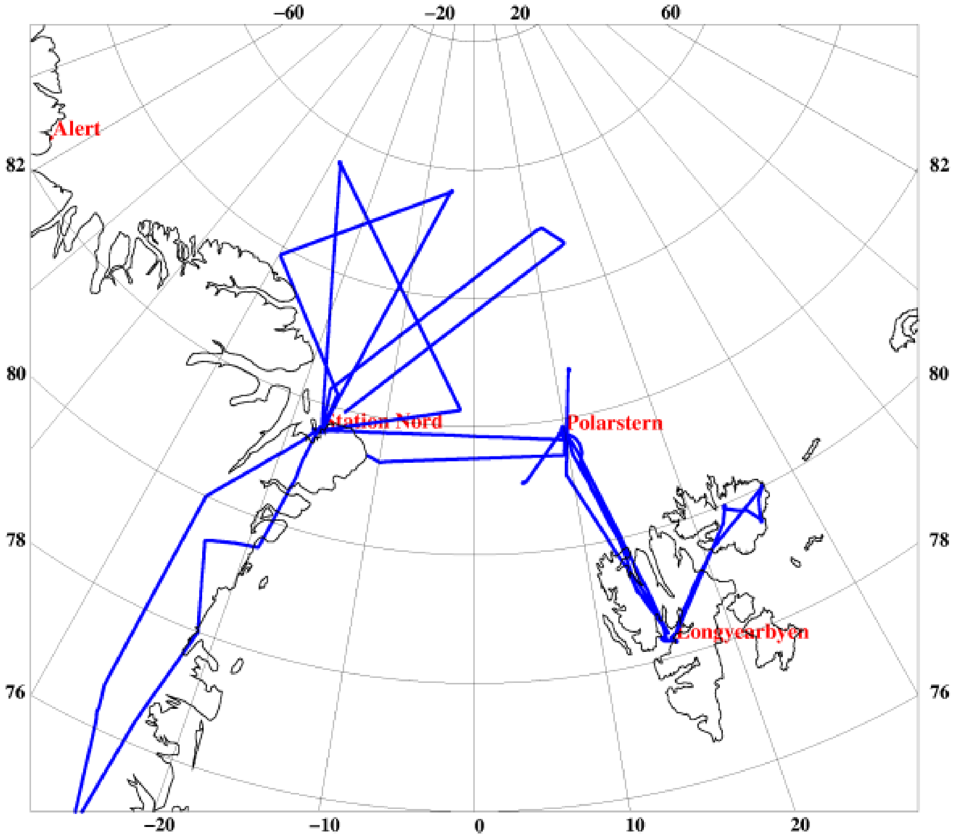


Fig. 3. Flight tracks of Cryovex-2003 over Arctic Ocean sea-ice region. Two tracks N and SE of Polarstern are the coincident helicopter EM - Twin-Otter laser flight.

Table 1. Flights of Cryovex-2003 by Julian day and date

Date/JD		Track	Take off UTC	Landing UTC	Airborne	Operator
April 5 / 95	SFJ-SFJ	test	2011	2056	0 h 45	KRK
April 7 / 97	SFJ-MRG	SFJ-EGIG	1306	1812	5 h 06	KRK
April 9 / 99	MRG-NRD	B	0949	1438	4 h 49	KRK
April 10 / 100a	NRD-NRD	D	1013	1529	5 h 16	KRK/SMH
April 10 / 100b	NRD-NRD	E	1618	2137	5 h 19	SMH/KRK
April 11 / 101	NRD-LYR	N-PST-P1	0910	1444	5 h 34	KRK
April 15 / 105a	LYR-LYR	PST-P2	0950	1451	5 h 01	KRK
April 15 / 105b	LYR-LYR	Austfonna	1552	1910	3 h 18	RF
April 17 / 107	LYR-NRD	Buoy-grid*	1227	1754	5 h 27	SMH
April 18 / 108	NRD-NRD	F	1021	1618	5 h 57	SMH
April 19 / 109	NRD-MRG	H	1031	1458	4 h 27	SMH
April 20 / 110	MRG-MRG	Geikie	1033	1431	3 h 58	SMH
April 21 / 111	MRG-SFJ	EGIG	1050	1710	6 h 20	SMH
TOTAL					61 h 17	

* “Mow the lawn”-survey of the ice floe next to R/V Polarstern.

3 HARDWARE INSTALLATION

The KMS laser scanner, GPS and INS equipment were installed in the aircraft in a similar fashion to the 2001 and 2002 installations, done in connection with airborne gravity projects (Forsberg et al., 2002). The installation of the APL D2P radar was prepared and finalized in cooperation with technicians from Air Greenland in Kangerlussuaq. The D2P radar was quite voluminous, and required two racks and an external antenna mount. All equipment was sent to the Air Greenland head office in Nuuk, South Greenland for tests and certification in advance of the actual installation in Kangerlussuaq.

The instruments were powered by 28 V DC of the Twin Otter aircraft, converted into 220 V AC by a specially designed power/conditioner system (including backup batteries), designed for KMS by Greenwood Engineering, Denmark.

Fig. 4. Installation of D2P radar racks (at right in pictures), KMS data logger (in back of pictures) and external ferry tank (at left in pictures) for extended 6 hr+ flight missions.

Fig. 5. D2P 13 GHz radar antenna

In general all instruments worked satisfactory, despite the very cold temperatures during part of the campaign – down to –28 ºC one morning at Station Nord. The laser scanner did fail during two tracks in the beginning of the campaign but mounting small heaters on the instrument solved this problem. In practice all equipment was kept warm on ground by hot-air blowers and by having power on at all time. Also one laptop PC was changed with a spare during the campaign without loss of data.

4 OPERATIONAL EXPERIENCES OF JOINT FLIGHTS

The Cryovex-2003 campaign was delayed for several days by poor weather at Svalbard. This limited the acquisition of measurements with the helicopter at Polarstern to two lines of 100 km where fog disrupted data from a small part of the first line. Low clouds and fog also limited the possibilities of acquiring useful laser scanner data on transits to/from Polarstern.

Coordination with Polarstern science crew and helicopter was done using e-mail, satellite telephones and VHF radio when airborne. Meteorological information, ship positions and flight plans as well as data after surveys were exchanged daily – even hourly at times. The joint Twin Otter and helicopter tracks were performed on April 11 and 15.

As can be seen on Figure 6 tracks were very close, within about 100 m for large parts, especially on the April 15 flight. For the April 11 flight waypoints were communicated to the helicopter when the Twin Otter was airborne. This was too close to the take off of the helicopter and caused some confusion, since it was not possible to communicate with the helicopter during the survey. For the April 15 flight pre-defined waypoints, adjusted for ice drift, were used without any problems. These waypoints were made with a small Fortran programme ("Cryovex.exe"), aligning Twin Otter and helicopter waypoints and departure times assuming a constant ice drift. It is concluded that careful planning and preceding agreements (e.g., which aircraft aligns to which aircraft?) is essential, and that it fundamental that both aircraft fly great circle trajectories as defined by the onboard GPS navigation systems which must include a 'cross-track-error' information on the display. Further it is more convenient to have several waypoints along the line.

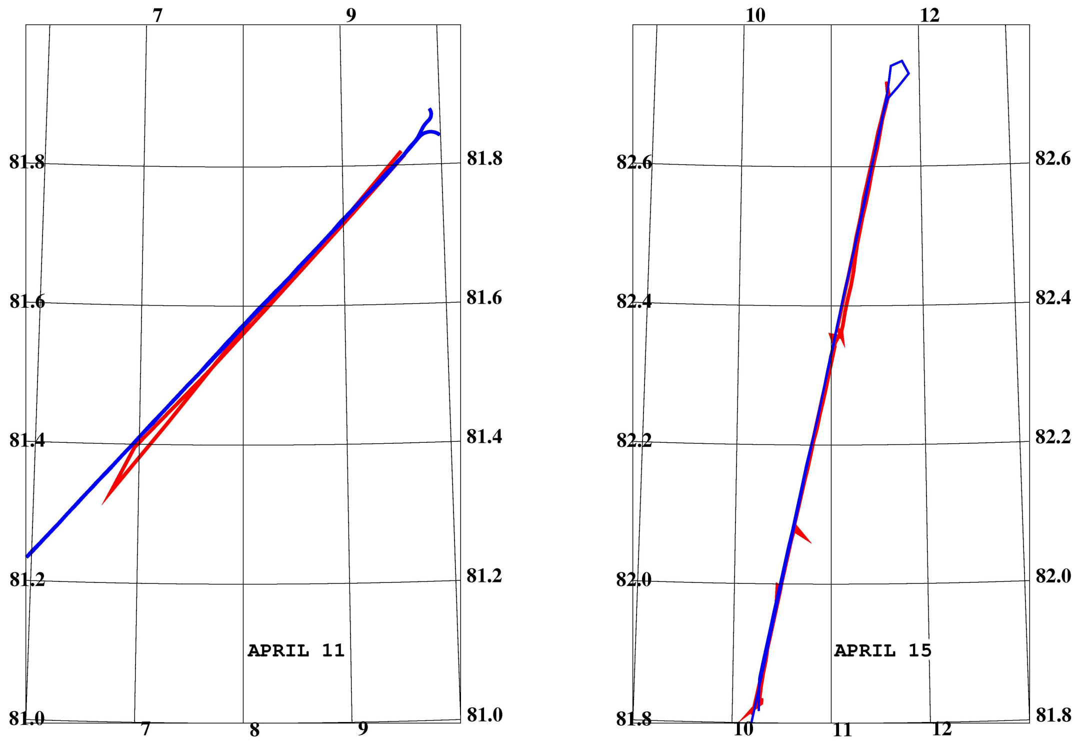


Figure 6. Tracks of the joint Twin Otter (blue) and helicopter (red) flights on April 11 (left) and April 15 (right).

5 OVERVIEW OF ACQUIRED KMS DATA AND PROCESSING

The basic principle of the measurement of ice free-board height, F, relies on laser measurements of range to the surface, r^{laser}, combined with precise kinematic GPS aircraft positioning, attitude determination by INS, and a geoid model; to first order, neglecting measurement errors and dynamic sea-surface topography, the freeboard is given by

$$F = h^{GPS} - r^{laser} \cos p \cos r - N \qquad (1)$$

The GPS height h^{GPS} of the aircraft is determined by diffential GPS relative to several ground base stations; the range r^{laser} from the aircraft to a ground point is measured by a scanning laser; pitch p, roll r by an inertial navigation system, and the geoid height N obtained from gravity measurements in other projects e.g. Arctic Gravity Project (Forsberg and Kenyon, 2004).

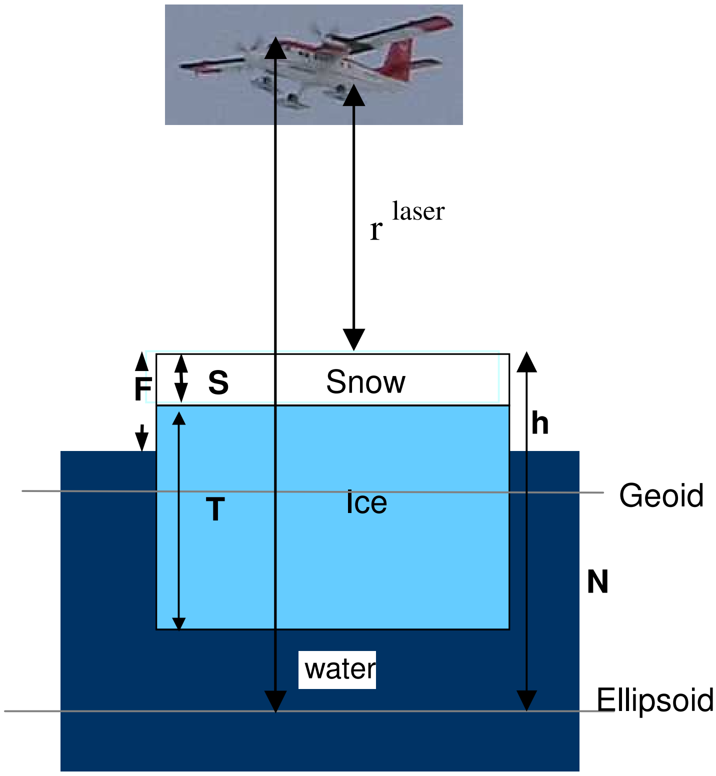


Fig. 7. Principle of freeboard determination. The conversion of freeboard, F, to thickness, T, is approximately a constant (~6.0 - Wadhams, 2000) depending on densities and snow depth, S.

5.1 GPS data and processing

Kinematic GPS is the key positioning method for the aircraft. GPS dual-frequency phase data were logged at 1 Hz using 1-2 reference ground receivers at one or more reference sites, and 3 aircraft receivers (Trimble, Ashtech and Javad type). The aircraft GPS receivers are named AIR1 (Trimble, 4000-SSI), AIR2 (Ashtech, Z-extreme) and AIR3 (Javad, Legacy). AIR1 and AIR2 share the front GPS antenna; AIR3 the rear GPS antenna. Antenna offsets were unchanged from earlier KMS installations in OY-POF.

Data were logged internally in receivers during flights, and downloaded upon landing on laptop computers. Nearly all data were recovered; only a few files were missing or incomplete due to operator errors or other malfunctions. Data were backed-up on CD-ROMs.

Reference GPS stations were mounted on roofs or on tripods in the field at Station Nord, Longyearbyen and Kangerlussuaq; the reference points were generally not marked. Available data are indicated in Table 2 and 3.

Fig. 8. GPS reference at Station Nord (left) and reference benchmark for control (right)

Table 2. GPS aircraft and reference data collected during Cryovex-03

JD/Date	AIR1	AIR2	AIR3	AIR4	EGI	SCANNER	PHOTO	LYR1	LYR2	NRD	SFJ	SCO
95/Apr. 5	X	X [1]	X		X [4]	X	X				X	
97/Apr. 7	X	X	X		X	X [2]	X				X	X
99/Apr. 9	X [3]	X	X		X	X	X				X	X
100/Apr. 10a	X [4]	X	X		X	X – txt[5]		X		X	X	X
100/Apr. 10b	X [3]	X[3]	X		X	X	X		X	X	X	X
101/Apr. 11	X	X	X		X	X – fog	X many err.	X	X	X	X	X
105/Apr. 15a	X	X	X	X	X	X	X	X	X	X	X	X
105/Apr. 15b	X	X	X	X	X	X	X	X	X	X	X	X
107/Apr. 17	X	X	X		X	X – only grd	X		X	X	X	X
108/Apr. 18	X [3]	X	X		X	X	X		X	X	X	X
109/Apr. 19	X	X	X		X	X – over ice				X	X	X
110/Apr. 20	X	X	X		n/a	X				X	X	X
111/Apr. 21	X	X	X		X	X	X				X	X

[1] first 15 min. aprox. only 20 sec. data

[2] scanner only worked for 2h 15, stopped because of too cold temp.

[3] ran out of memory before landing

[4] two files

[5] scanner stopped after 4 h because of too cold temp.

Table 3. GPS reference stations used for Cryovex-2003

Location	Name – site
Kangerlussuaq	SFJ - meteorological hut, Trimble
Scoresbysund	SCOB - KMS permanent GPS station in Scoresbysund, Trimble
Station Nord	NRD - antenna on roof of building 7, Javad ASTRO – concrete pillar used as common reference for surveys
Svalbard	LYR1 - antenna on Norsk Polar Institut building roof, Svalbard airport, Trimble LYR2 - antenna on Norsk Polar Institut building roof, Ashtech NPI1 - concrete benchmark in front of NPI bldg.

The reference positions of the GPS reference coordinates are computed in the ITRF2000 system relative to IGS international network, using the "Auto-GIPSY" service of JPL; this ensures GPS coordinates consistent with the global IGS coordinate system at an accuracy level of a few cm. The used GPS reference coordinate list is shown in Table 4.

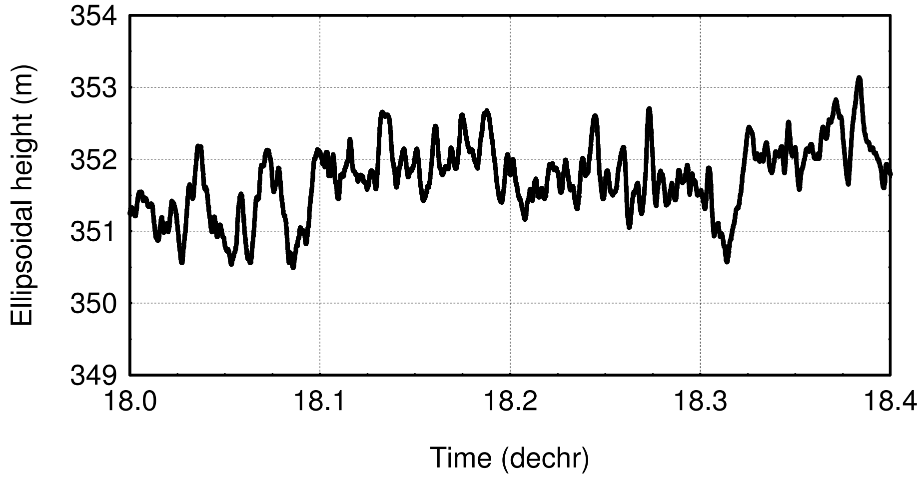


Fig. 9. Example of GPS aircraft height (JD 100), showing phugoid motion due to the autopilot feedback system. The regular phugoid motion is useful to check the timing calibration.

Table 4. GPS reference coordinates

Station	**Lat (dms)**	**Lon (dms)**	**h(el)**
Kangerlussuaq hut SFJ*	67 00 21.6422	-50 42 09.7107	72.001
Scoresbysund permanent GPS SCOB*	70 29 06.8436	-21 57 03.0301	128.715
Station Nord pillar 1001(nrd)	81 36 01.4627	-16 39 19.5929	68.380
Station Nord roof bldg. 9 NRD1*	81 36 05.0990	-16 39 43.5473	70.013
Longyearbyen NPI pillar (lyr)	78 14 51.8960	15 29 42.8984	49.260
Longyearbyen roof LYR1*	78 14 51.3999	15 29 41.4036	53.975
Longyearbyen roof LYR2*	78 14 51.3050	15 29 43.1396	53.941

* Position in IGS2000 reference system from auto-gipsy.

The GPS solutions for the aircraft antennas were done on a single baseline basis to available reference stations using the GPSurvey software, using precise IGS orbits. An example is shown in Fig. 9. Generally several solutions were made, and a "best" solution, with fewest dropouts and cycle slips, was selected as the basic GPS aircraft solution. These solutions are generally estimated to be accurate to the 20-50 cm level r.m.s. The accuracy is dependant on the distance from the reference station to the aircraft and on the number of satellites and their geometry. The number of satellites was usually quite high, often around 8-10, with some limited periods with fewer satellites.

5.2 Inertial attitude and position data

A Honeywell medium-grade inertial navigation system with embedded GPS (H764-G "EGI") was used throughout the flights to record inertially integrated position, velocity and attitude information. 50 Hz inertial data were logged on a laptop PC in binary format through a 1553 mil-spec communications bus. Both free inertial and Kalman filtered GPS-integrated inertial data were logged on most flights. Data volume per flight was typically 50 MB/hour. Nearly all EGI data were recovered, except for the April 20 Geikie flight, where data were not recorded due to an operator error.

The INS data processing consists of the following steps:

1) Reading and reformatting the original EGI binary 1553 data. The data are in this process averaged to 10 Hz to obtain more manageable file sizes (this has no impact on the final quality of the laser data). A specially developed Fortran programme "READEGI6" does this task.

2) Combination of the INS and GPS. "Draping" of the INS-integrated heights onto the GPS heights is done by modelling the function

$$\varepsilon = h^{GPS} - h^{INS} \tag{2}$$

by a low-pass filtered smooth correction curve, which is added to the INS results. In this way a smooth GPS-INS file is obtained, which will preserve the GPS solutions, but otherwise fill-in the gaps in data with INS information. The programme for this is "*readegi*".

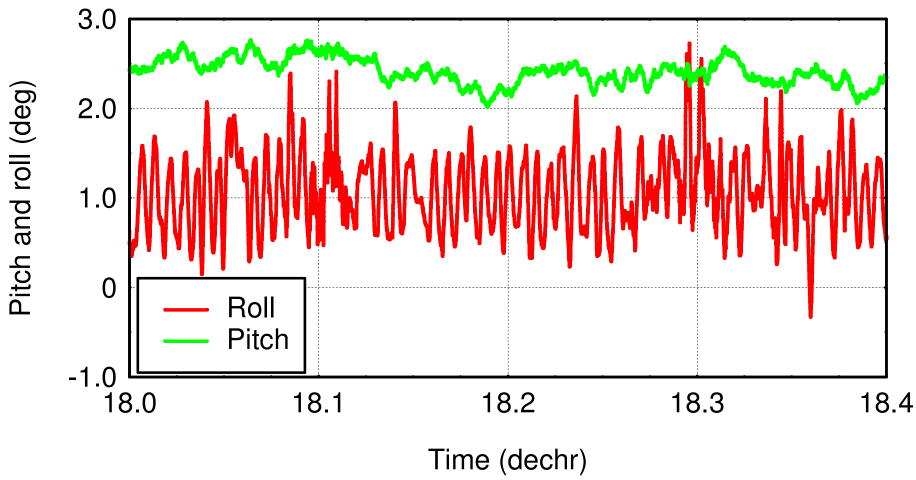


Figure 10: Example of pitch (green) and roll (red) from INS; JD100.

Figure 10 shows roll and pitch of a small part of a typical flight. The merged GPS-INS files are typically denominated ".pos"-files, and contain the following information:

thr, lat, lon, h, pitch, roll, heading where *thr* is the time, *lat, lon, pitch, roll* and *heading* in degrees. The raw INS files are typically in the data archives called names of form "0304151.ddk" where 030415 is date/time information (April 15th 2003).

The above principles for GPS-INS integration are far from optimal (a joint programme adopting multiple GPS files and doing rigorous INS integration has yet to be implemented in practice at KMS). However, with care, it represents a good practical solution, and is used for the subsequent lidar processing.

A practical note: Although it sounds relatively straightforward, the Cryovex-2003 processing was significantly delayed due to some UTC time tag problems in the EGI data. The UTC time tags were apparently not recorded properly in the inertial data packages of the H-764G. A special action was therefore necessary to recover the UTC time tag information from independent embedded GPS package information in the 1553-data bus. This was successfully implemented in a special programme version ("*readegi6*"), and results after the bug fix were fully compatible with the normal operation of the EGI (which has INS-UTC synchronization at the 50 μs-level). During a subsequent field campaign in April 2004 no problems with the EGI UTC time tag were encountered, and the problem was later identified as due to a faulty internal battery in the.

5.3 Scanning laser data and processing

During the Cryovex-2003 operations all laser measurements were done with a scanning lidar of type LMS-Q140i, which provides cross-track scans at a user selectable frequency, with range accuracy better than 5 cm. The laser operates in the near-infrared wavelength band, and has a scan angle of 60°, giving a swath width roughly identical to the flight elevation above ground (for the installation in the Twin-Otter a small fraction of the outermost scans were shaded by the fuselage due to a limited hole size in the Twin-Otter). The principle is outlined in Fig. 11.

The KMS Riegl laser scanner (lidar) data was logged as hourly files on a stand-alone laptop computer. The lidar files are time tagged by a 1 pps signal from the AIR1 GPS receiver, with start time of the scans given by the operator as a file name. Nominally files cover about 1 hr of data, at 40 scans/second and 208 measurements per scan. During changeover between files 1-2 min of data are typically lost. No data were taken in fog. Start and stop time of the lidar files acquired are listed in Appendix 2.

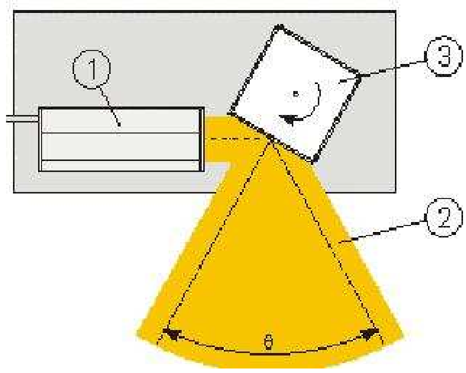


Fig. 11. Scanning lidar principle. A laser (1) provides a swath (2) by reflection in a rotating mirror (3)

Files were logged in text or binary (".2dd") formats, yielding file sizes of 200-300 MB. Data were written directly on CD's after the flights. The text-format logged files were converted into binary format as part of the processing, and no text-format files should be left in the raw data collections used for processing.

A note of caution: Unfortunately the Riegl logging system does not allow the recording of the integer seconds. There is therefore a risk of lack of synchronization between laser and GPS/INS at integer seconds, corresponding to translations at multiples of approximately 60 m on the ground. Usually these offsets have been detected in other KMS lidar surveys by comparisons to an independent Optech single-beam laser altimeter.

In the case of Cryovex-2003 the single-beam laser was omitted due to restrictions of space in the aircraft hole used for the scanner (a downward-looking camera and the D2P radar cables were mounted instead). Although care has been taken in the processing to detect any time shift, including using the phugoid motion characteristics, the assignment of correct 1 sec-shift can therefore occasionally be in error, typically at +/- 1 sec. In the comparisons with D2P radar data such a 60-m shift should readily show up.

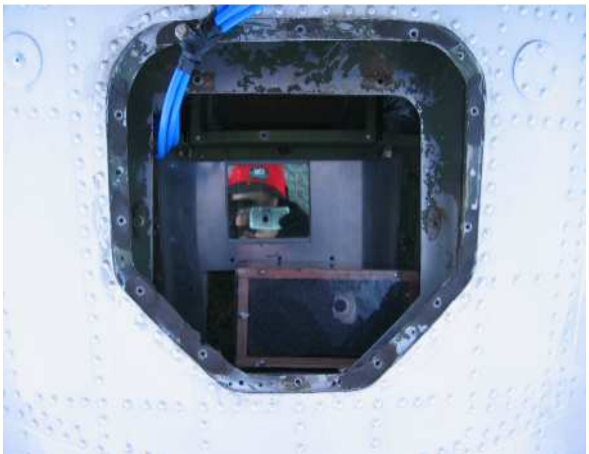


Fig. 12. Riegl laser scanner with attached heating pads (left) and aircraft hole photographed from below, with scanner mirror, Canon Ixus camera in insulated box and connecting cables to D2P radar (right).

The routine processing of the lidar data into ellipsoidal surface heights involves two steps:

1) Reading the raw Riegl scanner files, and recovering GPS time, laser mirror angle α and measured range r, and interpolating corresponding GPS coordinates and pitch, roll, heading (p,r,a) for the GPS-EGI output file.

2) Using three-dimensional geometry to compute coordinates of the ground laser reflection point by computing the coordinate vector (Δx, Δy, Δz) in a local-level system (N,E,U) from the aircraft GPS antenna position to the ground point position (not taken the misalignment into account):

$$\Delta x = cosa*cosp*dx_l + (cosa*sinp*sinr-sina*cosr)*dy + (cosa*sinp*cosr+sina*sinr)*dz$$
$$\Delta y = -sina*cosp*dx_l - (sina*sinp*sinr+cosa*cosr)*dy + (cosa*sinr-sina*sinp*cosr)*dz$$
$$\Delta z = sinp*dx_l - cosp*sinr*dy - cosp*cosr*dz \qquad (3)$$

where (dx,dy,dz) are the offsets in the aircraft body system:

x positive to the front of the aircraft	$dx = -sin(a)*r + dx_l$
y positive to the right of the aircraft	$dy = cos(a)*r + dy_l$
z positive down	$dz = sin(p)*r + dz_l \qquad (4)$

In the above equations the aircraft GPS antenna offset (dx_l, dy_l, dz_l) will depend on the GPS antenna used. The used offsets are listed in table 5a and the offsets from the GPS antennas to the radar antenna in table 5b, cf. Fig. 13.

Table 5a and 5b. The (dx, dy, dz) offsets

The lever arm from the GPS antennas to the origin of the laser scanner:

to laser scanner	dx (m)	dy (m)	dz (m)
from AIR1/AIR2 (front)	- 3.70	+ 0.52	+ 1.58
from AIR3 (rear)	+ 0.00	- 0.35	+ 1.42

The lever arm from the GPS antennas to centre of back side of radar antenna:

to radar antenna	dx (m)	dy (m)	dz (m)
from AIR1/AIR2 (front)	- 3.60	+ 0.48	+ 2.05
from AIR3 (rear)	+ 0.10	- 0.39	+ 1.89

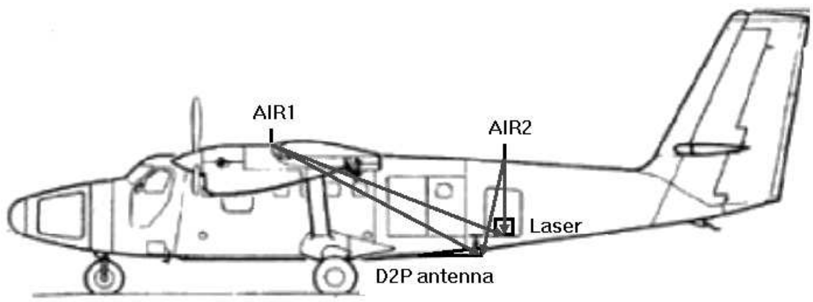


Fig. 13. GPS antenna offset vectors to laser and D2P radar

The laser scanner has an inherent unknown orientation when installed in the aircraft. Whereas the roll offset r_0 are easily found by regression over level surfaces (e.g. water), the determination of pitch and heading offsets p_0 and a_0 are determined by a 4-leaf-clover over flight of known GPS-positioned objects. Buildings of Kangerlussuaq and Svalbard were used for this purpose. The offset values

$$p_0 = +\ 0.80°,\ \ r_0 = -1.20°,\ \ a_0 = +1.10°$$

were used for all processed flights, based on an ad-hoc estimation from crossing overflights (4-leaf-clover test) over the Air Greenland Kangerlussuaq hangar building in Fig. 14.

At the last day of the field campaign, on the return leg to Kangerlussuaq, the test building was passed again twice in order to validate the misalignments. A similar test was performed at Longyearbyen in the middle of the survey, April 15th. All the passes showed that the misalignments were constant during the survey.

The basic outcome of the lidar processing is ellipsoidal heights in WGS84. For use in sea-ice freeboard estimation, a geoid model is subtracted from the computed ground heights. In the case of Cryovex-2003, a new geoid model, based on the Arctic Gravity Project and improved long-wavelength gravity field information from the GRACE satellite mission, has been used

(Forsberg and Kenyon, 2004). The geoid – computed across the entire Arctic region north of 64°N – was cut in a subgrid *"agpgeoid.gri"*, cf. Fig. 15, and used for all sea-ice flight processing. For the land ice, however, ellipsoidal heights were kept unchanged to ease comparisons with other GPS data and earlier acquired laser data. Fig 16 and 17 shows some examples of full-resolution sea-ice and land-ice lidar data.

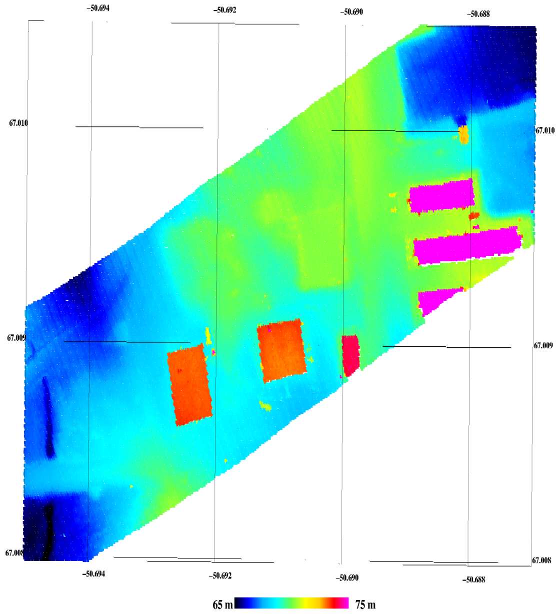


Fig. 14. Laser scan over Kangerlussuaq hangar, measured by GPS for calibration of offset angles.

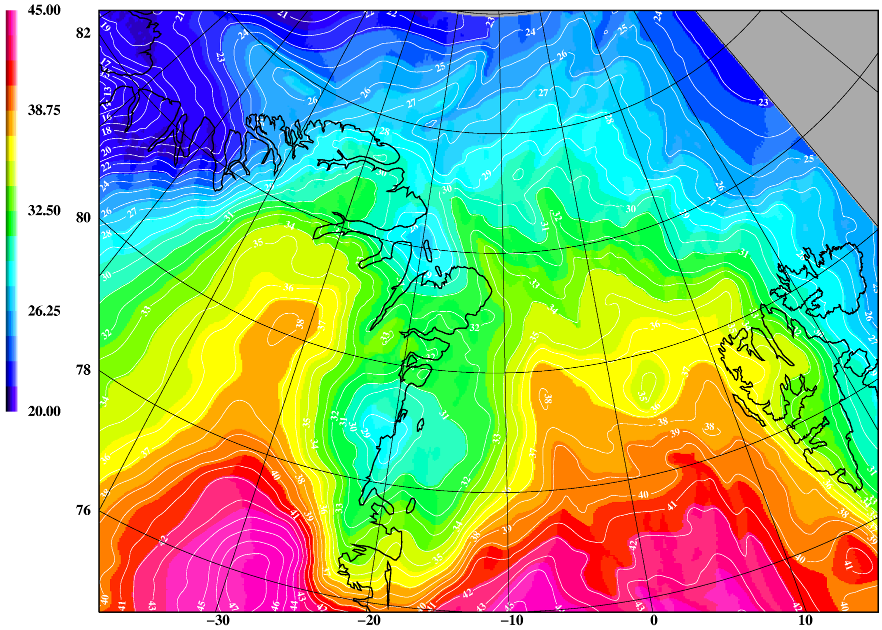


Fig. 15. Geoid of CRYOVEX area, derived from Arctic Gravity Project data and GRACE. Contour interval 1 m. Note: geoid is only used for sea ice flights; land-ice results are given as ellipsoidal heights.

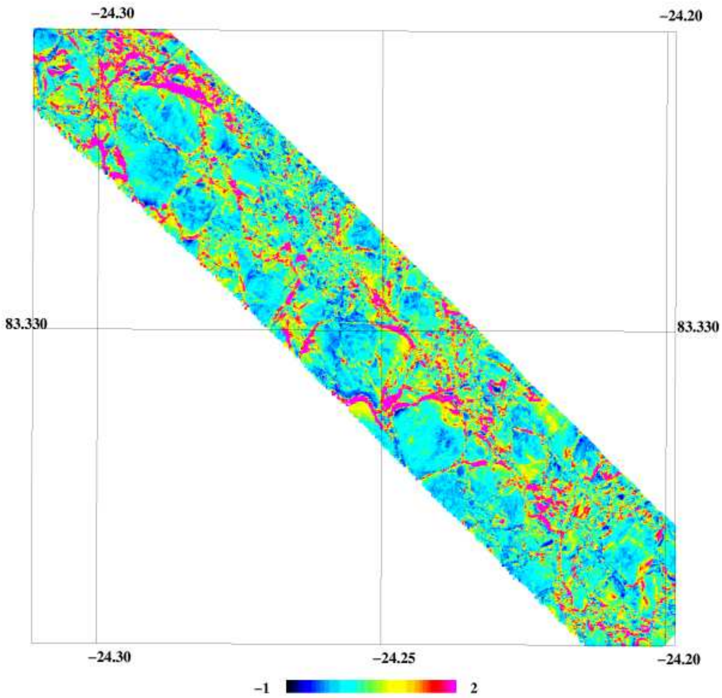
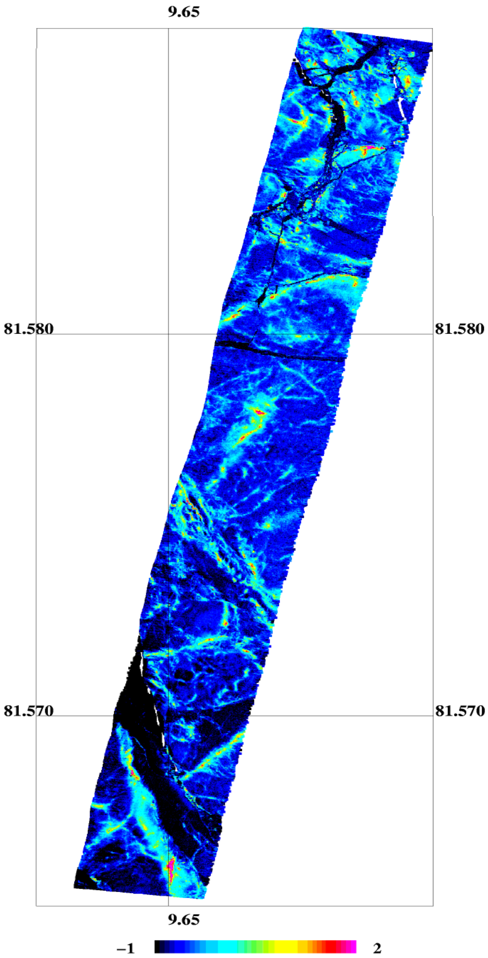


Fig. 16a. Example of section of sea ice with small floes and many pressure ridges (JD100). Heights are shown in meter above geoid, without fit to sea level. Width of scan approx. 300 m.



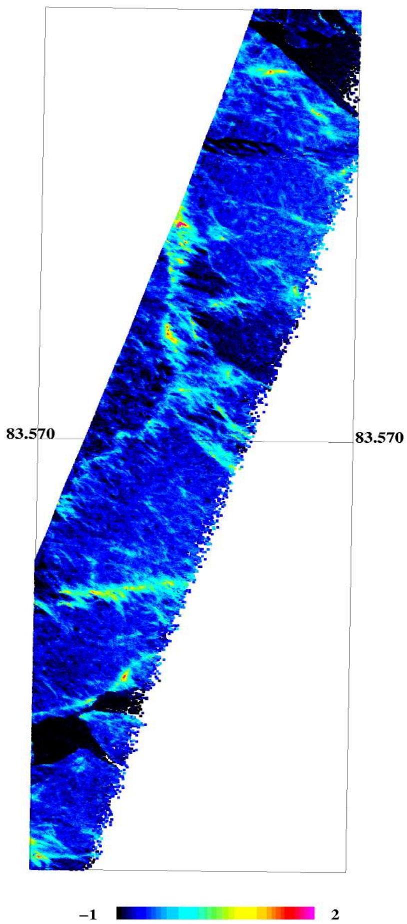


Fig. 16b. Examples of sea ice lidar data with larger floes. JD101 (left) and JD100 (right).

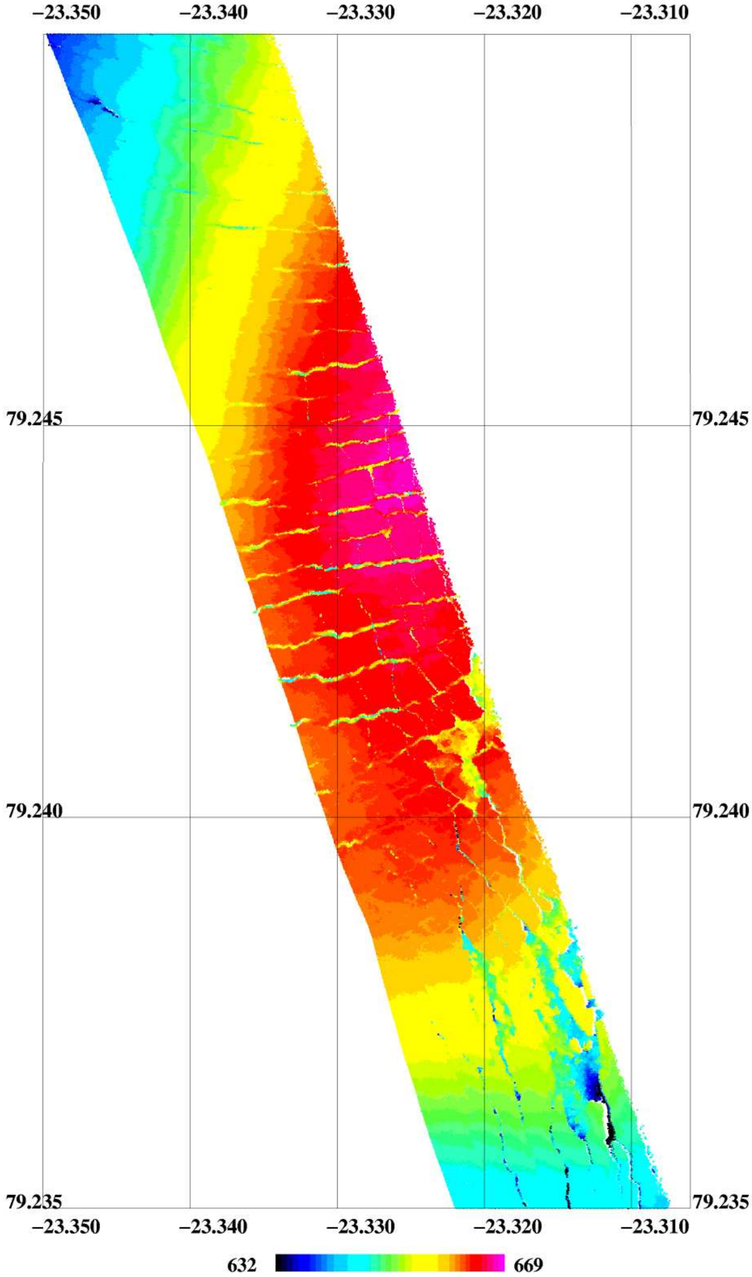


Fig. 17. Example of land ice heights by laser: Section of East Greenland ice sheet margin, showing crevasse field where lidar is seen to measure into crevasses. Ellipsoidal heights (meter).

5.4 Conversion of sea ice lidar results to freeboard heights

The lidar data over sea ice, processed as outlined in the previous section, are affected by systematic errors from GPS solutions, biases in geoid heights (in part due to different reference systems), and mean ocean dynamic topography, all of which implies that apparent freeboard heights F will be biased. This bias may be removed by "lowest-level" filtering. For the Cryovex-2003 a generalized collocation version of the lowest-level filtering scheme applied in Jacobsen and Forsberg (2002) has been used to routinely process thinned/averaged "level 2" lidar data into freeboard heights.

In the basic "standardized" method selected available lidar data – typically in a 1 hr segment – is subdivided into 0.02 hr intervals (corresponding to approx. 5 km). The minimal value in each interval is averaged over 0.04 hr intervals, and a "minimum surface" is fitted to the averaged minimal points by a trend surface

$$\Delta F = a + b*t + s \tag{5}$$

Here a and b are constants, and s a stochastic signal modelled by least-squares collocation

$$s = C_{sx} C_{xx}^{-1} \underline{x} \tag{6}$$

where $\underline{x}$ is the vector of minimal values, and C the covariance matrices. A second-order Markov model covariance model

$$C(t) = C_0 (1+\beta t)\, e^{-\beta t}, \quad \beta = 0.595\, t_{1/2} \tag{7}$$

was used throughout all Cryovex processing, with a correlation length ($t_{1/2}$) of 0.04 hr and an assumed apriori noise of 0.2 m. The computations were done with a specially developed Fortran programme *"fitlinc"*.

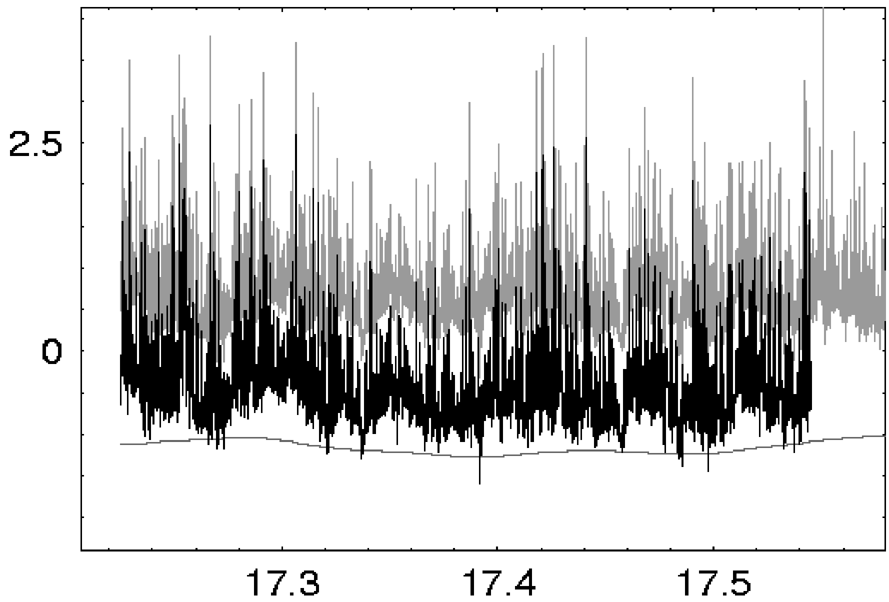


Fig. 18. Example of lowest level fitting of sea-ice lidar data. Black: lidar results; lower, smooth curve (grey): collocation minimum fit; grey (upper): freeboard heights. JD100.

The above principle corresponds to fitting a "smooth" curve to the lowest level. How to fit the curve, and the proper selection of covariance parameters are very much topics of ongoing research, and obviously a close function of ice properties, existence of outliers in the scanner data, and the nature of the local GPS and geoid errors. Fig. 18 shows a typical example of the lowest-level curve estimation, and Fig. 19 shows examples of the estimated freeboard heights with associated freeboard distributions on the JD101 flight from Greenland to Svalbard.

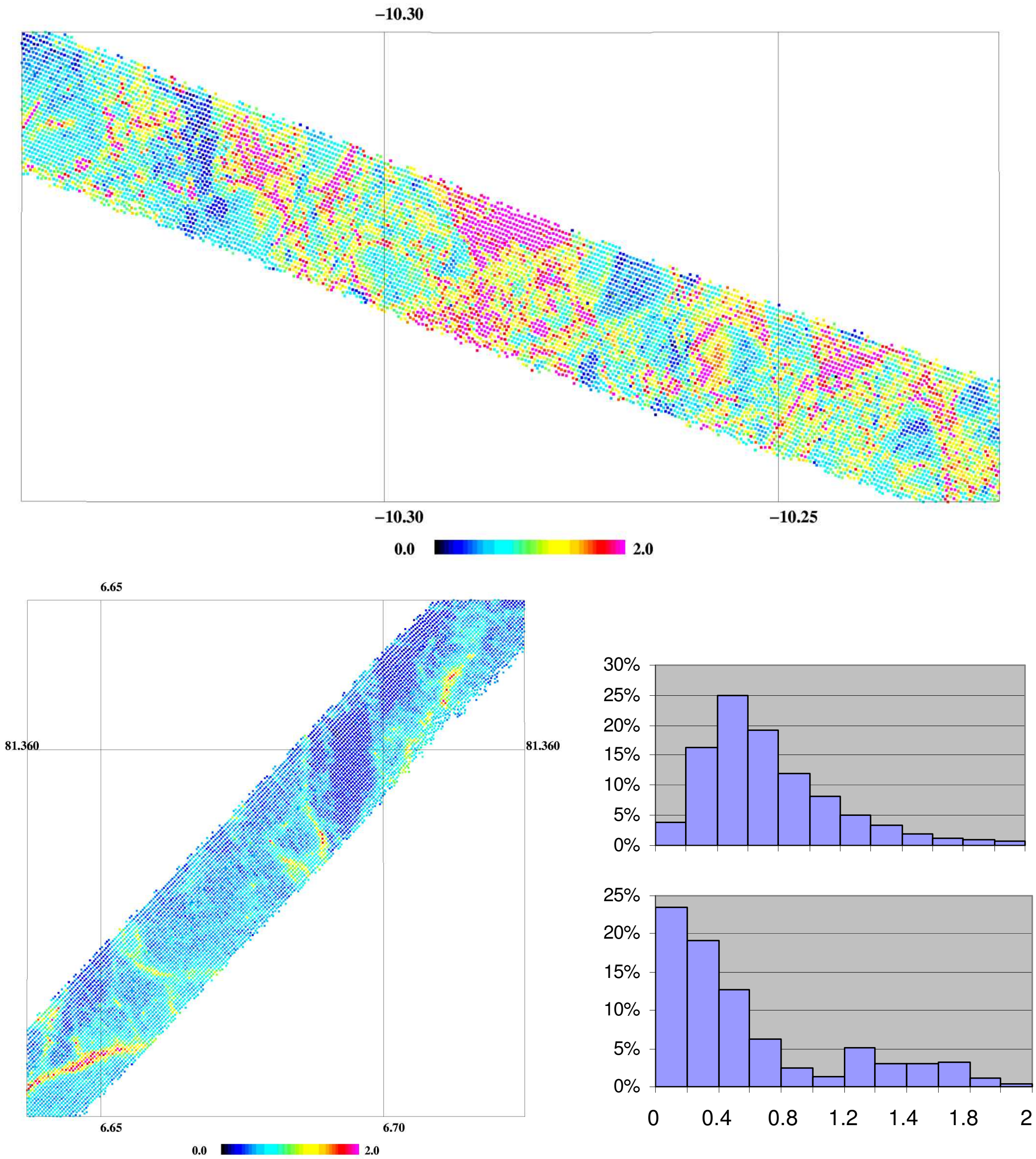


Fig. 19. Examples of "level-2" (5x5 mean) freeboard height data, and the associated freeboard height distributions for corresponding 1 hr segments around the plots (histogram unit: meter).

Average ice thickness may be derived from the freeboard heights, by multiplication by a climatology-determined factor (approximately 6.0 – Wadhams, 2000). Results for all data are shown in Fig. 21.

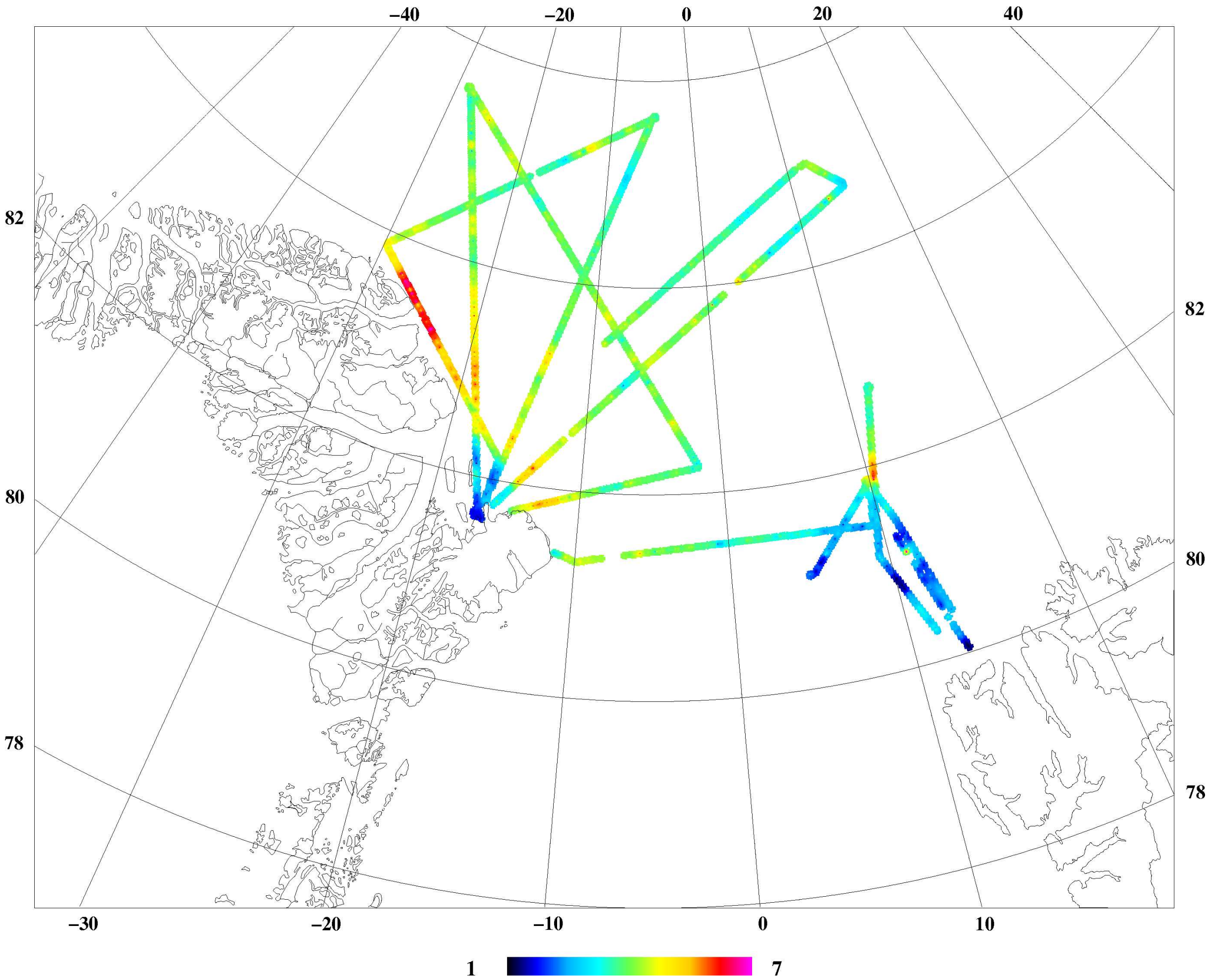


Fig. 21. Ice thickness from lidar measurements during Cryovex-2003. Unit: meter.

5.5 Auxiliary data: Digital photos and airborne video

A standard Canon Ixus digital camera was mounted (looking nadir) next to the laser scanner. This camera took images every 5 seconds and stored these directly on a laptop PC. Unfortunately the camera could not be mounted in the right (along-track) direction in the available hole in the aircraft, so a continuous sequence of imagery was not available. A photo example can be seen in Fig. 22, and a set of photos with associated laser scanning in Fig. 23. The vertical photos are given along with the lidar data as final results of Cryovex, and may be cross-referenced by the UT time.

Video scenes were additionally shot from right- and left-mounted cameras mounted with a roughly 45-degree look angle from the side of the aircraft. The videotapes hold about 1 hr and 1½ hr respectively, and only selected parts of the flights were recorded. The video data can be “grabbed” to mpeg-files on request for specific time intervals. It is otherwise not planned to copy the videotapes as part of the Cryovex-03 data delivery.

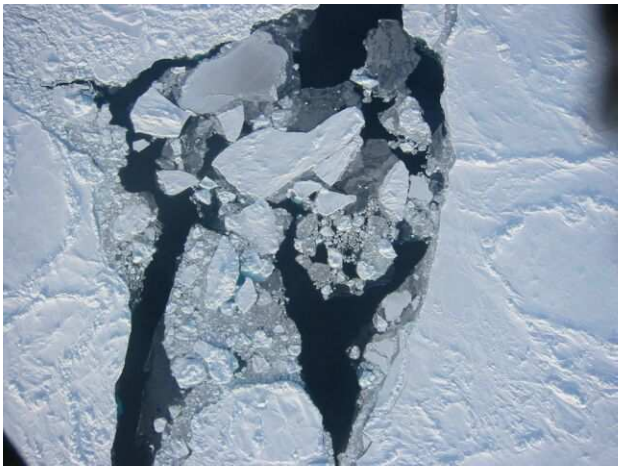


Fig. 22. Example of Cryovex-03 vertical photos. Size of image approx. 200 x 300 m.

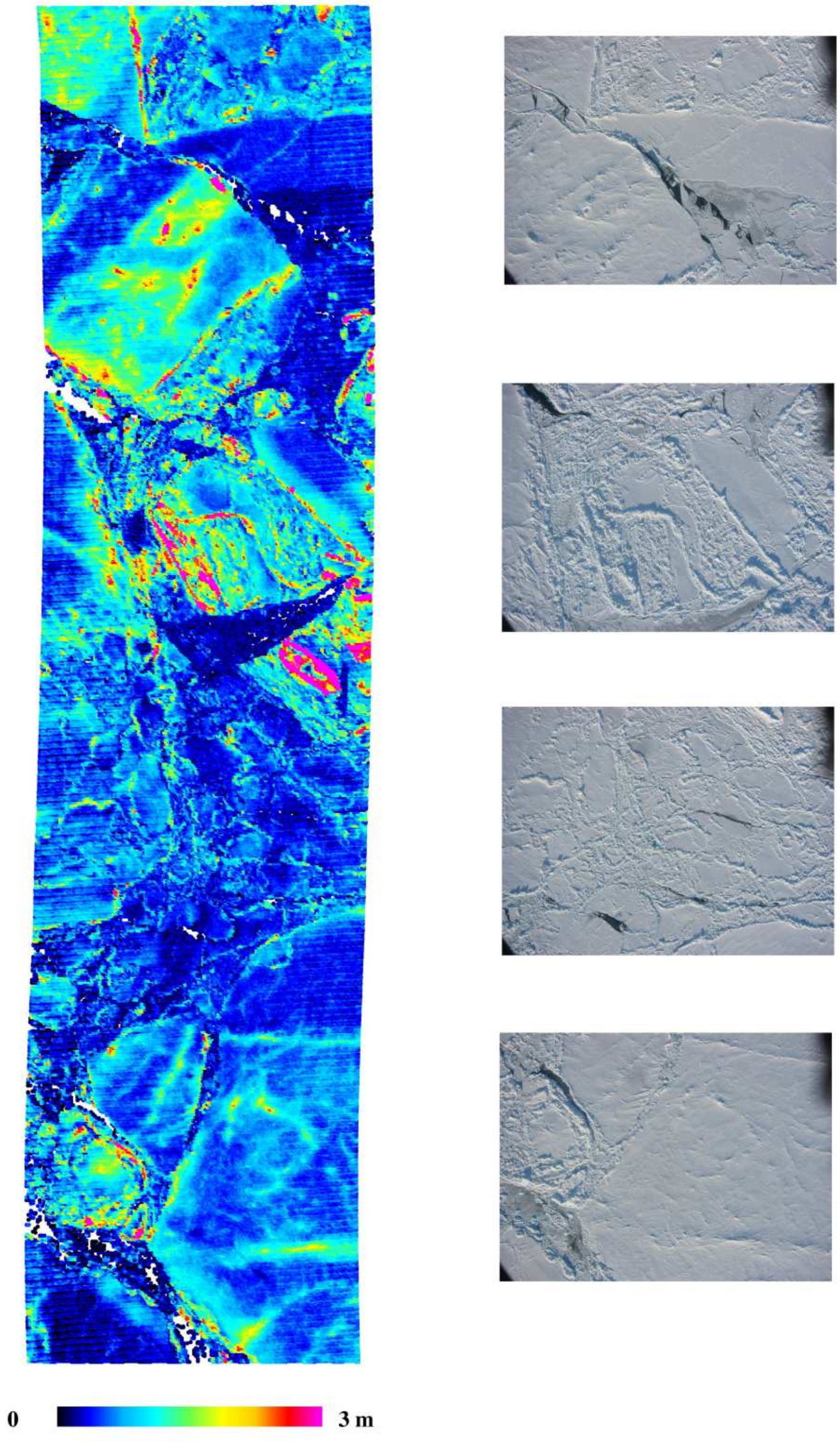


Fig. 23. Example of lidar scans and associated vertical imagery. JD105.

6 "MOW THE LAWN" SURVEY OF ICE FLOE NEXT TO POLARSTERN

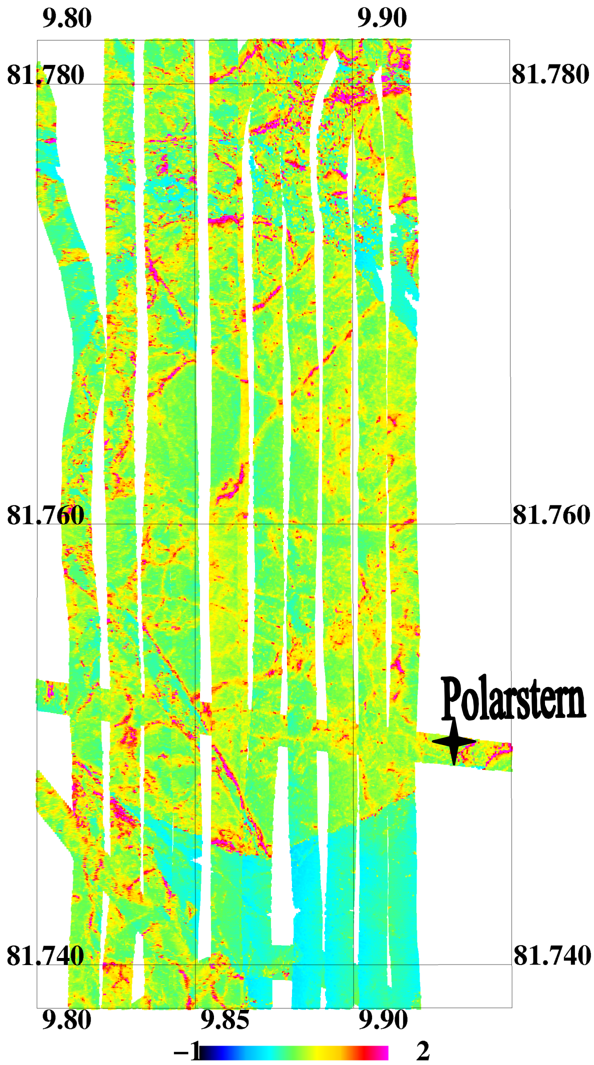


Fig. 24. Left: The freeboard from the "mow the lawn" laser survey of the ice floe next to Polarstern, which is marked on the plot. Data has been corrected for ice drift. Above: Polarstern anchored to the ice floe.

The large ice floe to which Polarstern was moored ("Tomato Island") was planned as a special survey target, making a "mow-the-lawn" survey for comparisons with ground truth drilling and EM measurements. This was done on April 15, the last possible day, on the return flight from Longyearbyen to Greenland. It was planned to do a coincident survey with the AWI EM-bird as well, but due to very bad weather (low clouds at 400 ft) the helicopter at Polarstern could not fly. Nevertheless, it was possible to do a low level Twin Otter survey of the ice floe in a very dense grid (cf. the flight track in appendix 4, day 107). The survey was almost completed when the aircraft had to ascend into dry air at 10.000 ft because of heavy icing. The gaps between the survey lines of Fig. 24 are caused by the flying altitude that was lower than planned, which made the laser swath less wide.

In order to make a map of the ice floe data had to be corrected for the ice movement during the 1.5-hour survey. This was done by a small programme "*icedrift.exe*". The programme corrects the positions using a geodetic projection to a fixed time frame determined by the user. The ice floe movements are obtained from the movements of Polarstern, (10 min. epochs) at that time fixed to the ice floe by ice anchors.

Ground truth ice thickness data from Polarstern has not yet been compared to the laser data, in part due to the lack of properly recorded GPS and time information of the ground data. Work is in progress to get the correct geolocation of the ground thruth data.

7 PRELIMINARY COMPARISON OF EM AND LASER RESULTS

The AWI electromagnetic ice thickness data is obtained from a combination of ice draft measurements (depth to conductor) and a laser elevation from a "bird" flown as a helicopter sling load. Resolution of the measurements is typically 10-15 m. The EM data for the comparison with the laser data were received from AWI as ASCII lat/lon/thickness data for the April 11 and April 15 coincident flights.

Before comparison of the laser and EM results, both data sets need to be corrected for ice drift that have taken place in-between the observations. Therefore all data are transformed back/forth to a specific epoch (11:30 on April 11 and 12:24 on April 15) using a linear ice drift model. The drift-correction is based on Polarstern positions and assumes that the whole ice-field moves as Polarstern did.

A comparison is done both for the April 11 and April 15 flights, in the following the comparison for the 11 is presented. The April 15 EM data did not produce a good comparison, and final comparisons for this day awaits reprocessed data. Unfortunately the April 11 flight did not produce a good flight alignment (cf. Fig. 25).

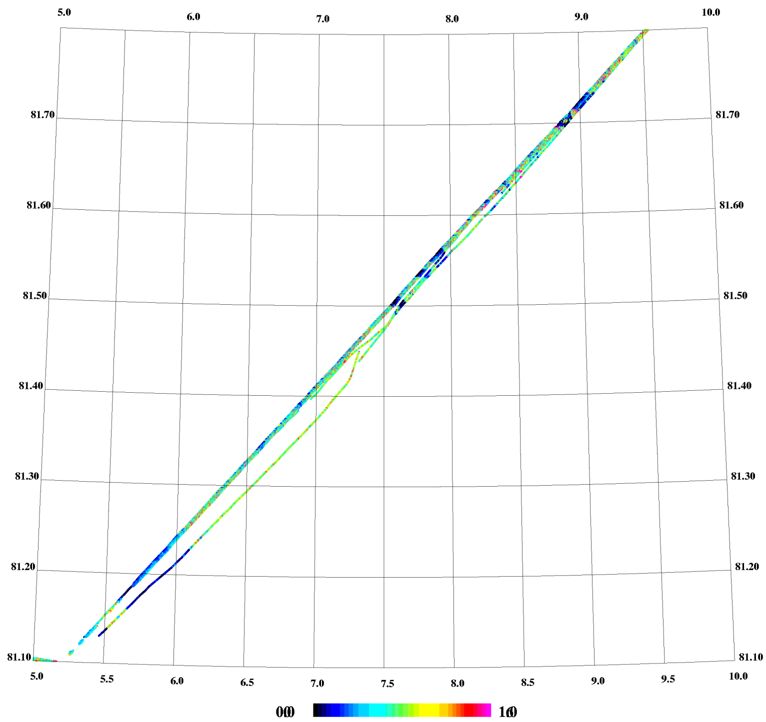


Fig. 25. Flight of helicopter (thin line) and lidar scan (thick line) on April 11.

The EM and laser data sets are compared by using weighted means (*"geogrid*") to predict the an interpolated laser-based thickness value at the location of each EM observation; only coincident observations within 15 m are compared. This results in more than 9000 coincident data points on April 11 (and approximately 25000 joint points on the better aligned flights of April 15). The comparison on the central part of the profile is shown in Fig 26. Note that on April 11 there is not more than one laser swath because of fog and low clouds on the return flight.

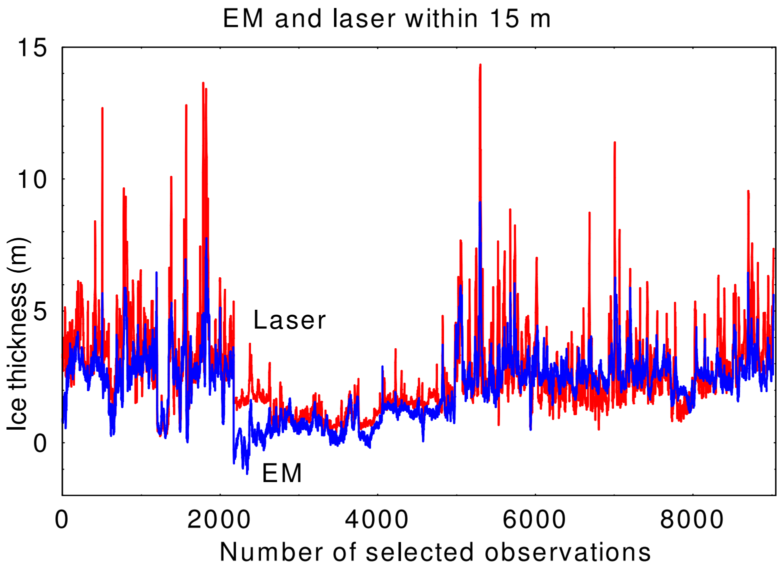


Fig. 26.Comparison of EM and laser measurements. Length of profile approx. 30 km. April 11 flight.

On April 11 the mean difference between EM and laser is 0.43m with a standard deviation of 1.0m. There are many similarities and the peaks coincide very well (not exactly in size but very much in space). The most pronounced difference near point 2100 corresponds to the southern-most observations and might reflect the calibration of the EM-sensor. The mean difference, also seen as larger peaks in the laser data, may be explained by e.g. difference in resolution, inadequate freeboard to thickness ratio and incorrect sampling of thickest ice by the EM system. Surprisingly the thickness distributions of the two data sets are not quite similar, and more research is required for understanding the differences between the EM and laser results.

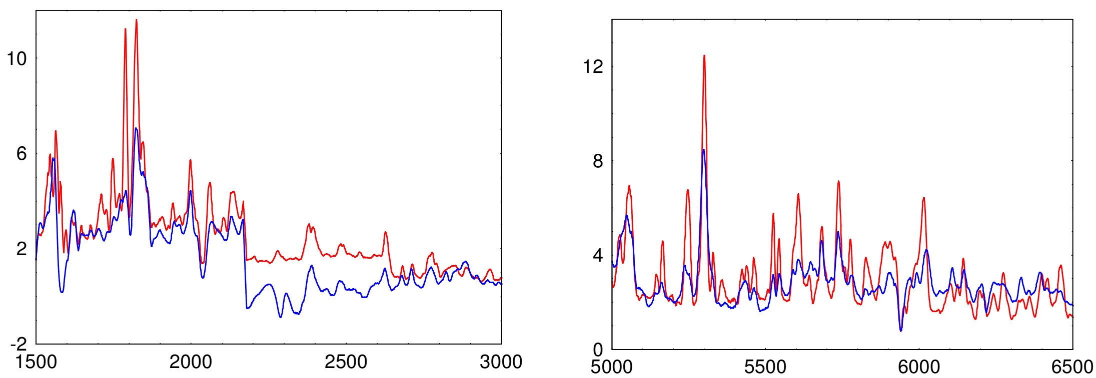


Fig. 27. Filtered EM (blue) and laser (red) measurements of the April 11 joint flight.

8 COMPARISON TO D2P RADAR ALTIMETRY

Examples of the comparison between the APL D2P radar and the KMS lidar have been made over four different types of surfaces, namely open water, inland icecap, sea ice and an iceberg. The 4 examples are taken from the two flights on the April 15.

Processed level-1b D2P data were acquired from APL's ftp server. In order to make the D2P data comparable to the lidar data, the amplitude of the complex waveforms were normalized such that 1.0 corresponds to the maximal amplitude (white in the plots) in the current waveform and 0.0 corresponds to no amplitude (black in the plots). The comparison of D2P to lidar data in sea ice covered areas showed disagreements in synchronization between the two datasets. Applying a 0.5 second offset to the D2P data solved the problem.

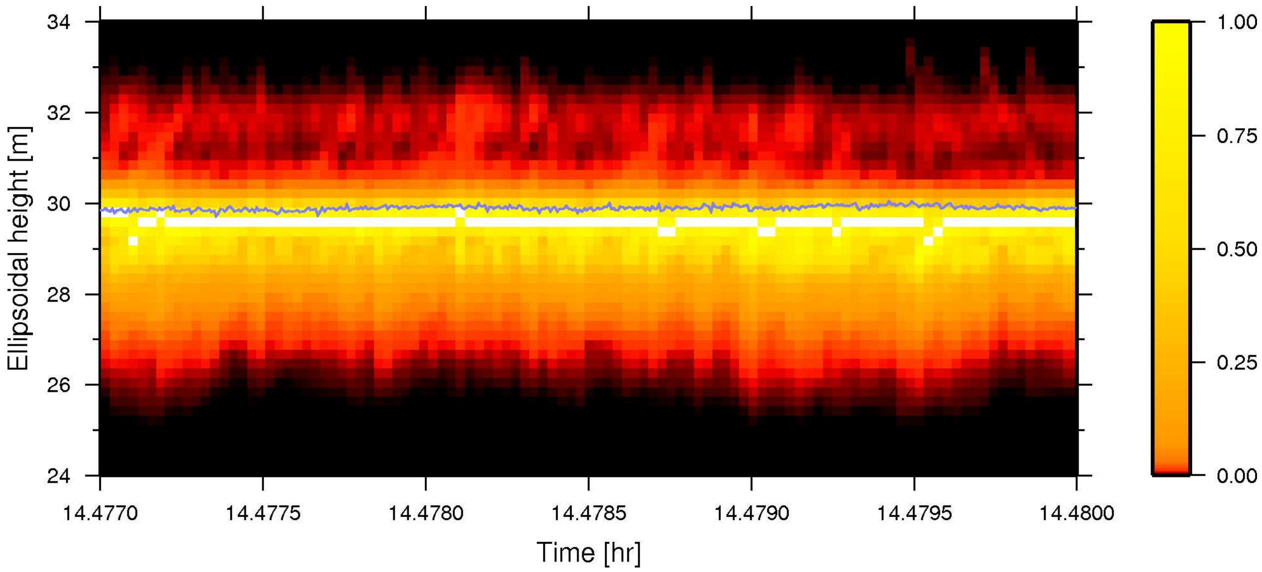


Fig. 28: Comparison of D2P signal power (color scale) and lidar (blue) over open water and thin ice in Isfjorden just north of Longyearbyen, Svalbard.

The first example (Fig. 28) shows radar and lidar data over an area of open water were the return pulses from the radar and the laser both are expected to originate from the water surface and therefore should show the same height. It is seen from Fig. 29 that there is no height bias between the lidar and the radar, as the lidar is coincident with 50% of maximally amplitude on the rising edge of the radar-return.

When comparing the two datasets over the top of the Austfonna icecap in Svalbard the picture is quite different, see Fig. 29. The lidar shows a smooth snow surface, opposed to the D2P radar that shows a varying maximal amplitude at various depths 1-2 meter below the surface. Another difference is the "peakiness" of the radar return pulse. Clearly the D2P radar peak signal is arising from reflectors (ice lenses?) within the upper layers of the snow pack. In the open water/thin sea-ice area (Fig. 28) the return power was concentrated within a depth band of about 8 meter; over the Austfonna icecap the power is distributed over a 16 meter deep region. Some internal layering is also apparent.

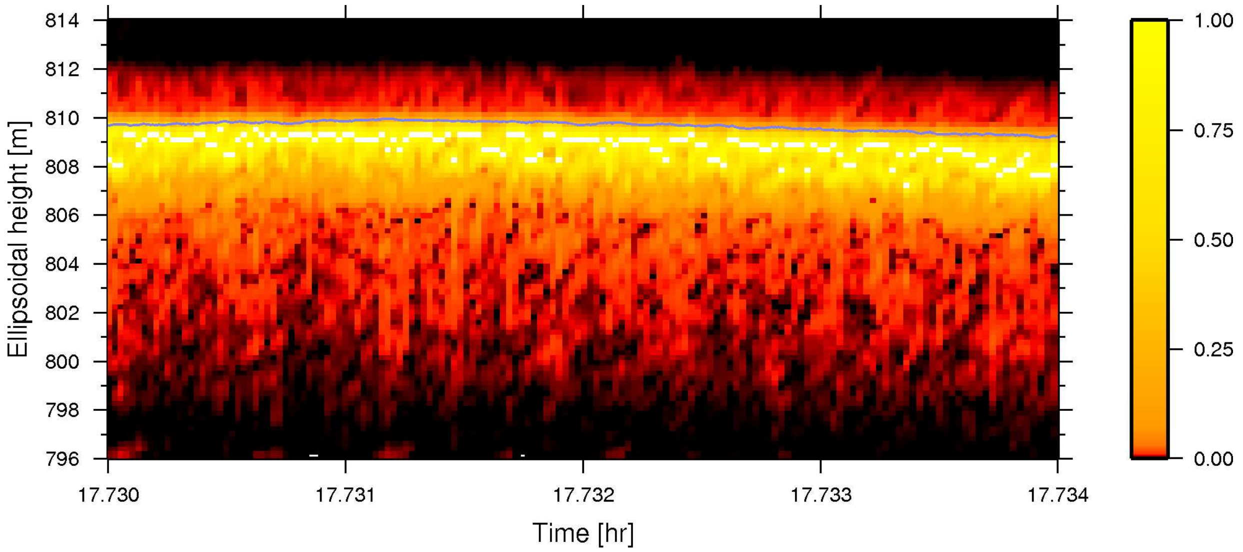


Fig. 29. D2P signal power (color scale) and lidar (blue) over Austfonna icecap.

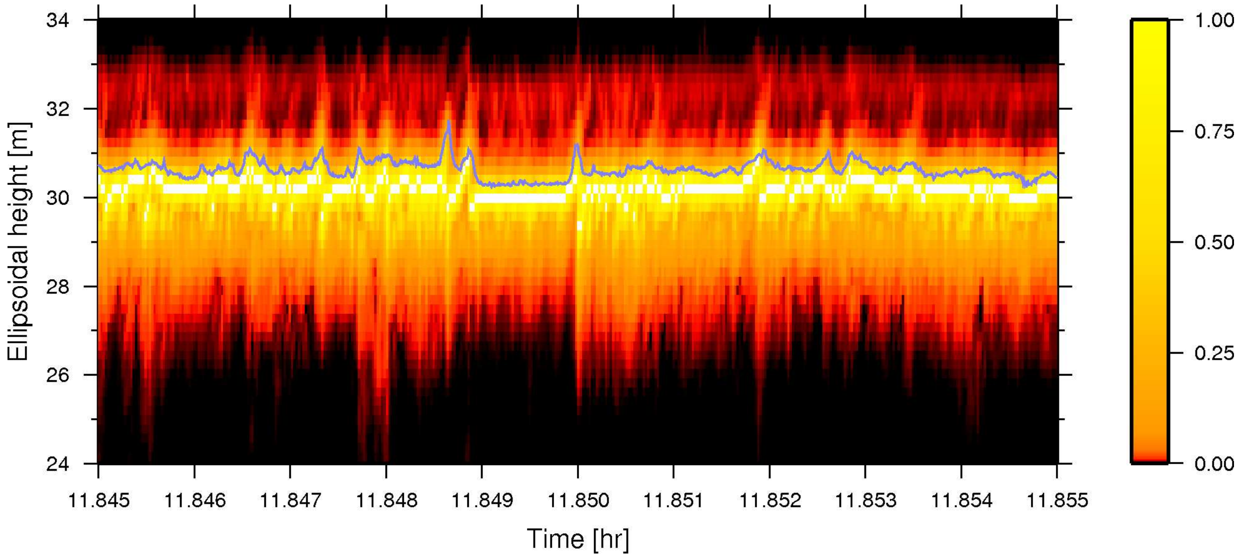


Fig. 30: D2P signal power (color scale) and lidar (blue) of sea-ice near Polarstern (April 15 flight)

Over sea ice any D2P vs. laser time synchronization problem becomes very clear, and data can readily be correlated by the ridges, cf. Fig. 30. Here again a 0.5 s offset was applied to the radar data. The excellent fit of the D2P radar and the sea-ice lidar data on April 15 is apparent; the example of Fig. 30 show a lead (at 11.849-11.850) which indicates that height biases between D2P and laser are very small.

Finally a comparison has been made of an iceberg flowing in open water/thin new ice, see Fig. 31. At the encounter of the first steep edge of the nearly 25 meter high iceberg (at time 18.3695) the radar fails to track the return pulse correctly and hence produces a signal that is placed 25 meters too high. After passing the first top of the iceberg (at 18.3719) the radar has troubles once again when tracking the steep edge. Besides the problems with the radar near the steep edges, the lidar and the radar are generally in good agreement.

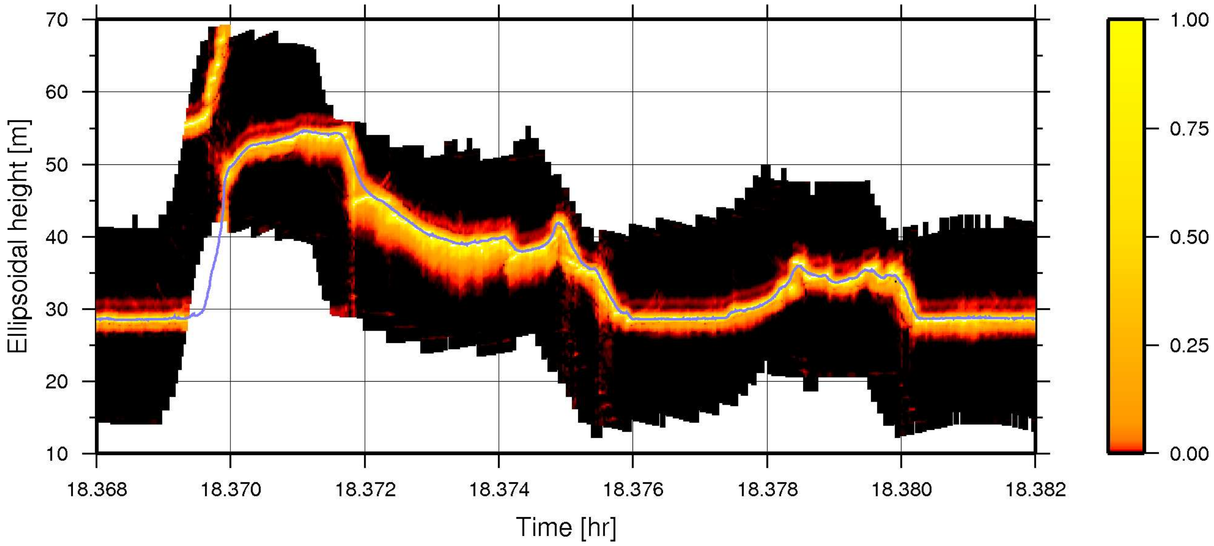


Fig.31: D2P signal power (color scale) and lidar (blue) of an iceberg in the strait between Spitsbergen and Nordaustlandet. April 15 flight.

9 CONCLUSIONS

The Cryovex-2003 airborne campaign was successful. Lidar and D2P radar data were acquired over essentially all the planned tracks, and only some minor parts of tracks did not yield useful laser scanner data due to fog and low clouds. Two coincident Twin Otter/helicopter flights, where ice thickness was measured directly with helicopter EM methods and freeboard with lidar/radar, was done with some success. The second of these joint flights demonstrated that it is possible to align to such aircraft, flying at different speeds over moving ice fields, and do measurements of the same ice features. It confirms the viability of this joint flight approach for the future post-launch calibration and validation activities of CryoSat, with first activity planned for spring 2005.

The lidar, imagery and radar data collected during Cryovex-2003 will provide important basic data for understanding the future CryoSat radar signals. All the data of Cryovex-2003 are made available on web and DVD/CDs. The very large high-resolution lidar data are made available through set-up streams to read directly the acquired raw data.

This report included some initial comparisons between lidar, D2P and EM data. Only one of the EM flights (JD101) yielded useful results; some problems are apparent in the EM data of the second flight. It is expected that the wealth of the Cryovex-2003 data will be an essential part of upcoming more detailed sea-ice scientific investigations in the region.

Acknowledgements

The European Space Agency and the Danish Natural Science Research Council provided economic support for the CRYOVEX 2003 campaign. Additional support for selected flights and remote sensing data acquisition was provided by EU projects GreenICE and SITHOS. Alfred Wegener Institute, Germany, provided support and infrastructure for the Polarstern coordinated flight experiments.

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April 15 typical sea-ice

Appendix 1. Airborne altimetry log CRYOVEX 2003

All times in UTC.

JD 95 5/4-03 Test flight SFJ

runway 1000 ft
fjord-ice
4-leaf-clover over calibration building in SFJ

1955	off bloc
1958	start INS, align
1959	start INS log file
2000	start 3 x GPS logging
2002	INS nav ready
200500	scanner file started
2011	take off
	INS's GPS bad
2013	INS's GPS OK
2015	very bumpy turbulence
2015	error at INS PC: 0218 000a
2018	do.
2020	new INS file started
2031	building -> East 500 ft
2034	building -> South
2037	building -> West
2040	building -> North
2045	Runway 1000 ft (too high for scanner) (black!)
2050	building at 1000 ft
2056	landing
2057	stop laser log
205x	on bloc

JD 97 7/4-03 SFJ - MVG (via jav and EGIG)

1255	off bloc
	GPS on and logging
	INS logging
130230	start scanner file
	GPS: only 6 SVs
1306	take off
1307	laser ok
1313	inland ice starts
1319	turn left to North
1320	cross VW-road
	GPS: 5 Svs! (Trimble)
140215	new scanner file
1423	turn right to East
1447	hazy
1450	clear
150058*	new laser file started at 150058 ** name: 150100
1515?	scanner stopped due to cold (-35C)
1556	EG4
1812	on ground
1818	on bloc

JD 99 9/4 03 MVG-B-NRD

MVG-B1-B2-B3-B4-B5-B6-NRD

0936	start engine
0938	power on
0939	start all, INS start align
0942	start log INS, start Trimble
0944	nav ready
0946	taxi
0949	take off
	laser, INS, GPS ok
105900	B1, scanner start
	Too low for radar
1147	B2
1157	stop scanner
115800	start scanner file
	beginning of Storstrømmen
1236	B3, climb
	stop scanner file
124300	start scanner file
1249-1250	passing over land
1315	B4, stop scanner file
131600	start scanner file
1330	B5
1340	B6
143200	start scanner file (-1 sec!)
143514	Cross runway in 1000ft
1438	on ground NRD
	close scanner file
1444	on bloc

JD 100 10/4-03 NRD-D-NRD

Very cold -28C!

0920	taxi to fuel
	INS PC failed, changed to KrK-PC
	INS failed to align (align/stat:10/111)
	3 GPS OK
	rear vertical camera failed
100630	new scanner file
1008	INS in NAV mode
1009	taxi
1013	take off
101840	x runway 1000ft
110300	new scanner file
1121	new tape KMS video left side
	large area without 'cracks' (leads?)
1153	new tape DTU video right
120300	new scanner file
1224	new tape KMS left
1242	fog, turn off videos
125901	new scanner file (1sec?)
1310	video on
135700	new scanner file
1400	Trimble stopped, started again
1405	fog/clouds - no scanner
1405	new tape DTU right video
1410	new tape on left KMS video
1416	descending to 1000ft

142330	new scanner file 142300.2dd rename it
1430	scanner too cold, stopped
1529	on ground
1533	on block,
	right engine idle during fueling
	heat blower on scanner
1540	new INS file, re-align
1610	INS nav mode

NRD - E - NRD

1618	taxi
1618	take off
161800	new scanner file
1625	tape 4? in right video started
171330	new scanner file
1725	new tape 5 left (KrK) KMS video started
181100	new scanner file
1757	new tape right DTU video
1905	new tape 6 left KMS video
191330	new scanner file
1930	new tape right DTU video
1950	Trimble mem full
2023	new scanner file
2026	new tape in (#7) in left video
2137	landing

<u>JD 101 11/4-03 NRD-N-PST-LYR</u>

Very cold -23C!

NRD-N1-N2-PS-WP-PS-LYR

0855	start engines
0856	power on
0858	all OK,GPS logging
	INS start align
0906	INS aligned, taxi
090700	new scanner file
0910	take off
091705	runway across
0923	turbulence
0950	new tape in right DTU video
0950	N1
0957	new tape (8 A) in left KMS video
0957	fog
1004	up to 1300 ft, fog, ice
100930	new scanner file
1101	new tape (9B) in KMS video
110700	new scanner file:'100700.2dd'
1110	down to 1100ft, fog
1117	new tape (8) in right DTU video
1125	passing PS (Polarstern)
112600	new scanner file
113125	PS line start to WP
1200	fog, no scanner data
1203	new tape (10) left video
120800	new scanner file
1208	turn around and back to PS
1210	fog no scanner data -> 1300
1312	little fog
1323	large lead, ice edge, prob. to the right side
1335	no ice left - open water near coast
1342	last sea ice before coast
1357	stop scanner file, climbing
144220	new scanner file
1444	on ground
	on bloc

<u>JD 105 15/4-03 Flight - 2nd Polarstern track</u>

0933	start engines
1055	open water, fog
1100	ice edge
1121	start camera, check of time: 12:26:18 pc = 11:26:31 UT
	13:50:56 pc = 12:56:06 UT
1145	over Polarstern, a little to left
1210	end of line
1244	oh Polarstern
1249	descend to 500 ft
1333	ice edge, wave direction azim 235 deg
1430	pitch/roll calibration
	over flight of runway
1451	on ground

Nordaustlandet

1547	INS nav, GPS on
1552	take off
15570	start laser
1610	up through pass, in clouds
162300	new laser file
1637	Nordaustlandet, solid ice in strait
1652	clouds, descend to 800 ft
181900	new laser file, over sea, climb to 1100 ft
1910	landing

<u>JD 107 17/4-03 GRID-track/mow-the-lawn</u>

LYR-PS-BOUY-1-20-PS-NRD

1215	start engine
1227	take off
	height above clouds
1331	descend to 1000 ft reached ca. 1340
134200	new scanner file
	small broken ice floes
1346	new tape in right video #11?
1355	new tape in left video #14?
	600 ft
	leads are covered with snow
1406	

100 m above ice surface

142600	new scanner file
1426	over PS towards buoy
1428	over buoy

	grid in approx. 450-500 ft
1433	grid start
1544	low pass over PS, grid end
1545	scanner file closed
	climb up over clouds
	no scanner, above clouds
1605	5500 ft
	thick cloud cover all the way to NRD
174300	new scanner file, for runway pass
175330	landing
1758	on block, fuelling

<u>JD 108 18/4-03 NRD-F2-F1-NRD</u>

1016	off bloc, start taxi
1021	take off
	cross over runway
102300	new scanner file
1026	new tape in right video #12
1027	new tape in left video #15
	no leads
	many spots without snow
	thick ice, many ridges
112200	new scanner file
1132	new tape in left KMS video
1202	new tape in right video
122300	new scanner file
1235	new tape in left video
1304	at F2
132300	new scanner file
1340	new tape in right video
1341	new tape in left video
1404	thin patches of fog
142300	new scanner file
	~100 kt NRD-F2
	~140+ kt F2-F1
1451	new tape in left video
	thin fog, still scanner data
1457	at F1
1513	new tape in right video
152300	new scanner file
1550	Trimble out of memory
	cross over runway
	pass over Dagmar cabin
1618	landing
1622	stop for fuelling

<u>JD 109 19/4-03 NRD-H1-H2-H3-MRG</u>

1027	start taxi
1031	take off
103300	start scanner file (maybe 103259)
	runway pass low and in 1000 ft
	climb above clouds
	scanner stopped ~1045
112600	new scanner file, ice edge
1131	at H1
	speed: 135-150 kt
122600	new scanner file
	at H2 about 1245
132600	new scanner file
1339	stop measurements, go higher cause of turbulence and reduced visibility
1458	landing
1501	stop engine

<u>JD 110 20/4-03 MRG-Geikie-MRG</u>

1031	start taxi
1033	take off
	could not start camera
103430	start scanner file, rename from
103330	
	runway pass in 1000 ft
1050	will do measurements through the valley
1127	climb, no scanner at 450-500 m
1128	scanner stopped
114400	new scanner file for Geikie survey
114655	video start right side #?
	Geikie survey pos. A-P
	ABDCEFGIJKLNMOP
1318	reached last point
	scanner file closed (1½ h)
	no measurement on way back
141600	new scanner file for runway pass
1426	scanner file closed
1431	landing
1435	stop engine

EGI not logged!

<u>JD 111 21/4-03 MRG-EGIG-SFJ</u>

1050	take off
	camera ok
105130	new scanner file (maybe 1 sec. late)
	runway pass in 1000 ft, also low pass along
1117	scanner file closed, high over mountains
112530	new scanner file
122700	new scanner file
132700	new scanner file
142700	new scanner file
1522	scanner pc full - delete files
152330	new scanner file
1525	new tape in right video #17
1545	Jakobshavn Isbræ, hardly any snow!
162100	new scanner file
1703 and 1707	low pass over blue building from two sides
1710	landing and straight into hanger

Appendix 2. CRYOVEX 2003 lidar data files

JD	File name	2dd format	Start (dechr)	Stop	Comments
95 – April 5	200500.2dd	T	20.0833	20.94737	Test flight
97 – April 7	130230.2dd	T	13.04167	14.02213	SFJ-EGIG-MVG
	1403750.2dd	T	14.03750	15.00304	
	150100.2dd	T	15.01667	15.26004	
99 – April 9	105900.2dd	T	10.98333	11.94859	MVG-B-NRD
	115800.2dd	T	11.96667	12.60977	
	124300.2dd	T	12.71667	13.25575	
	131600.2dd	T	13.26667	13.69357	
	143200.2dd	T	14.53333	14.65597	
100 – April 10	100630	Txt	10.10833	11.0	NRD-D-NRD
	110300	Txt	11.05000	12.97	
	125900	Txt	12.98333	13.94	
	135700	Txt	13.95000	14.53	
100 – April 10	161800.2dd	T	16.30000	17.20831	NRD-E-NRD
	171330.2dd	T	17.22500	18.17438	
	181100.2dd	T	18.18333	19.18055	
	191330.2dd	T	19.22500	20.37694	
	202300.2dd	T	20.38333	21.60062	
101 – April 11	090700.2dd	T	9.11667	10.14502	NRD-PST-LYR
	100930.2dd	T	10.15833	11.10669	
	100700.2dd	T	11.11667	11.41938	
	112600.2dd	T	11.43333	12.12185	
	120800.2dd	T	12.13333	13.12267	
	131200.2dd	T	13.20000	13.96026	
105 – April 15	110300.2dd	T	11.05000	11.71879	LYR-PST-LYR
	114400.2dd	T	11.73333	12.16884	
	121100.2dd	T	12.18333	13.12930	
	130900.2dd	T	13.15000	13.61325	
	142200.2dd	T	14.36667	14.84721	
105 – April 15	155700.2dd	T	15.95000	16.36879	LYR-Austfonna-LYR
	162300.2dd	T	16.38333	18.28873	
	181900.2dd	T	18.31667	19.19055	
107 – April 17	134200.2dd	T	13.70000	14.40558	LYR-PST-NRD
	142500.2dd	T	14.41667	15.75252	
	174300.2dd	T	17.71667	17.89334	
108 – April 18	102300.2dd	T	10.38333	11.34899	NRD-F-NRD
	112200.2dd	T	11.36667	12.37223	
	122300.2dd	T	12.38333	13.36748	
	132300.2dd	T	13.38333	14.37227	
	142300.2dd	T	14.38333	15.36016	
	152300.2dd	T	15.38333	16.30881	
109 – April 19	103300.2dd	T	10.55000	10.73965	NRD-H-MVG
	112600.2dd	T	11.43333	12.42066	
	122600.2dd	T	12.43333	13.42026	
	132600.2dd	T	13.43333	13.66904	
110 – April 20	103430.2dd	T	10.57500	11.46837	MVG-Geikie-MVG
	114400.2dd	T	11.73333	13.32040	
	141600.2dd	T	14.26667	14.43999	
111 – April 21	105130.2dd	T	10.85833	11.29379	MVG-EGIG-SFJ
	112530.2dd	T	11.42500	12.43607	
	122700.2dd	T	12.45000	13.43667	
	132700.2dd	T	13.45000	14.43902	
	142700.2dd	T	14.45000	15.36400	
	152330.2dd	T	15.39167	16.32332	
	162100.2dd	T	16.35000	17.16521	

Appendix 3. Overview of GPS data processing

Date	JD	Flight	Ref.	Mobile	file name	start	end	var.rat.	ref. var.	Processing remarks	Comments
05-04-2003	**95**		**SFJ**	**1**	**ap05a1sf.p**	**20.0608**	**20.9994**	**2.7**	**2.024**	**Elev. 10, except sat #2**	**No gaps**
test flight				2	ap05a2sf.p	19.8278	21.0025	2.7	1.804	Elev. 10, except sat #2.17 20 sec data in beginning	Only data every 20 seconds!!
				3	ap05a3sf.p	20.0178	20.9981	2.0	3.614	Elev. 10, except sat #2,4	No gaps
07-04-2003	97		SFJ	3	ap07a3sf.p1	12.8736	18.2769	1.4	8.450	Elev. 15	2 gaps of in total 181 sec's
				1	ap07a1sf.p	12.8736	18.2778		1626234	Elev. 15, float	5 gaps of int total 288 sec's
				3	ap07a3sf.p2	12.8736	18.2769	2.8	6.124	Elev. 15, except sat #9, float	3 gaps of in total 1282 sec's
				3	ap07a3sf.p3	12.8736	18.2769	1.1	12.499	Elev. 10, except sat #9	No gaps
				3	ap07a3sf.p4	12.8736	18.3603	1.1	23.478	Elev. 10	No gaps
				3	**ap07a3sf.p5**	**12.8736**	**18.2769**	**1.1**	**21.377**	**Elev. 10, except sat #6,18,23**	**No gaps**
			SCOB	2	ap07a2sc.p	13.4892	18.2750	1.1	8.562	Elev. 15	1 gap of 123 sec's at 15,36 (141680)
				1	ap07a1sc.p	13.4892	18.2778		1869449	Elev. 15, float	3 gaps of in total 226 sec's
				3	ap07a3sc.p	13.4889	18.2769	1.1	6.381	Elev. 15, float	2 of in total 244 sec's
			SFJ	2	ap07a2sf.p1	12.8669	13.1786	24.6	1.267	Elev.15, except sat #9	No gaps
				2	ap07a2sf.p2	13.1803	18.2750	1.1	6.005	Elev.15, except sat #9	2 gaps of in total 183 sec's
09-04-2003	**99**		**SCOB**	**3**	**ap09a3sc.p1**	**9.6336**	**14.7619**	**1.1**	**28.860**	**Elev. 10**	**2 gaps of in total 1749 sec's**
				3	ap09a3sc.p2	9.6336	14.7619	1.1	29.400	Elev. 10, except sat #26	2 gaps of in total 1749 sec's
				2	ap09a2sc.p1	9.6503	14.7583	1.1	12.558	Elev. 15, float	4 gaps of in total 3224 sec's
				2	ap09a2sc.p2	9.6503	14.7583	1.1	23.852	Elev. 10	3 gaps of in total 1781 sec's
				1	**ap09a1sc.p**	**9.7069**	**14.1542**	**1.1**	**14.720**	**Elev. 15**	**2 gaps of in total 1701sec's**
				3/1	**ap0913sc.p**						**ap09a3sc.p1 filled in gaps with ap09a1sc.p**
10-04-2003	100	a	NRD	1	ap10a1n1.pa1	9.4589	13.9814	1.1	8.877	Elev. 15, del. In residuals, first part 9-14 (AIR1100)	4 gaps of in total 1310 sec's
				1	ap10a1n1.pa2	14.0031	16.2603	8.3	1.696	Elev. 15, except sat #1,28, last part (AIR11001)	1 gap of 120 sec's at 14,27 (396981)
				2	ap10a2n1.pa1	10.0364	16.1861	1.1	7.491	Del. In residuals	1 gap of2 sec's at 10,68 (384052)
				3	ap10a3n1.pa	10.0333	16.1825	1.1	6.086	Del in residuals, 10-16:10:57	No gaps
				2	ap10a2n1.pa2	10.0378	16.1861	1.1	6.024	Elev. 10, except sat #1,3,15,16,28, del in residuals	3 gaps of in total 13 sec's
				2	ap10a2n1.pa3	10.0364	16.1861	1.1	8.365	Elev. 10, except sat # 3,10,15,28	No gaps
				2	**ap10a2n1.pa4**	**10.0364**	**16.1861**	**1.1**	**5.848**	**Elev. 10, except sat # 3,15,28**	**No gaps**

		b	NRD	1	ap10a1n1.pb	16.2639	19.8614	1.1	13.993	Elev. 15	No gaps!
				2	ap10a2n1.pb1	16.2147	21.3528	1.1	6.231	Del. Outliers	One gap of 3 sec's at 20,576
				3	**ap10a3n1.pb**	**16.2061**	**21.6931**	**1.5**	**1.646**	**Elev. 10, except sat # 14,15,26**	**No gaps!**
				2	ap10a2n1.pb2	16.2147	21.3528	1.2	7.486	Elev. 10, except sat # 14,15,26, del in residuals	One gap of 2 sec's at 20,576
11-04-2003	101		MRD	1	ap11a1n1.p	8.9603	14.7753	1.1	46.223	Elev. 15	Many and big gaps (>1000)
				2	ap11a2n1.p1	8.9603	14.7736	1.1	13.468	Elev. 10, except sat # 2,5,6	Many and big gaps
				2	ap11a2n1.p2	8.9603	14.7736	1.1	24.479	Elev. 15	Many and big gaps
				3	ap11a3n1.p	8.9464	14.7728	1.1	32.715	Elev. 10, except sat# 2,5,6,10,13	Many and big gaps
			LYR1	**2**	**ap11a2l1.p**	**8.9536**	**14.7736**	**(1.1)**	**5.868**	**Elev. 10, except sat # 2.,5,6, float**	**GAP of 3003 sec's at 13,753 (481510)**
			NRD	2	ap11a2n1.p3	11.5803	12.7431	1.2	16.402	Elev. 10, except sat # 2,5,6, 11:15-12:45	Many gaps of 100's of sec's
				2	ap11a2n1.p4	11.5803	12.7431	1.1	3.179	Only sat # 3,15,18,23,26,28,31, 11:15-12:45	
				2	ap11a2n1.p5	10.2425	11.1086	1.1	1.425	Elev. 10, except sat # 2,5,6,16,26,28, 9:50-11:30	
15-04-2003	105	a	LYR1	1	ap15a1l1.pa	9.6869	14.9028	1.1	20.193	Elev. 10 except sat # 2,3,20	4 gaps of in total 31 sec's - many cycle slips!
				2	ap15a2l1.pa1	9.6586	10.5089	1.1	4.368	Elev. 10, except sat # 2,3,20	3 gaps of in total 24 sec's
					ap15a2l1.pa2	**10.5111**	**14.8397**	**1.1**	**15.976**		**one gap of 716 sec's at 14,6(225372)**
				3	ap15a3l1.pa1	10.2828	14.8950	1.1	15.704	Elev. 10 except sat # 2,3,20	one gap of 886 sec's at 10,6(211076)
				3	ap15a3l1.pa2	10.5108	14.8931	1.1	9.871	Elev. 10, except sat # 2,3,20,25 del in residuals	two major gaps of in total 1301 sec's
				4	ap15a4l1.pa1	11.5000	13.0000	1.1	6.829	Elev. 10, except sat # 2,3,20,25, 11:30-13	No gaps!
				4	ap15a4l1.pa2	12.5000	14.5000	1.2	9.835	Elev. 10, except sat # 2,3,20,25, 12:30-14:30	No gaps!
			LYR2	2	ap15a2l2.pa1	9.6586	10.5089	1.4	7.297	Elev. 10, except sat # 2,3,20,25, 711	3 gaps of in total 24 sec's
					ap15a2l2.pa2	10.5108	14.8931	(1.1)	49.841	Elev. 10, except sat # 2,3,20,25, 711 float	5 gaps of in total 215 sec's
				3	ap15a3l2.pa1	10.2828	14.8950	1.1	22.165	Elev. 10	one gap of 886 sec's at 10,6(211076)
				3	ap15a3l2.pa2	10.2828	14.8950	1.1	16.089	Elev. 10, except sat 20, del in residuals	3 gaps of in total 1243 sec's
		b	LYR1	1	ap15a1l1.pb1	15.6972	19.2819	1.1	13.134	Elev. 10	No gaps
				1	**ap15a1l1.pb2**	**15.6972**	**19.2819**	**1.3**	**9.282**	**Elev. 15**	**No gaps**
				2	ap15a2l1.pb	15.6981	19.2847	1.1	8.385	Elev. 15	No gaps
				3	ap15a3l1.pb	15.6872	19.2994	1.2	8.445	Elev. 10	No gaps
				4	ap15a4l1.pb	15.7161	19.3011	1.4	10.919	Elev. 15	One gap of 5 sec's at 19,17(241811)
			LYR2	1	ap15a1l2.pb	15.6972	19.2819	1.4	13.518	Elev. 15	No gaps
				2	ap15a2l2.pb	15.6997	19.2847	1.6	13.791	Elev. 15, except sat # 11,14	No gaps
				3	ap15a3l2.pb	15.6872	19.2994	1.1	6.184	Elev. 15	No gaps
				4	ap15a4l2.pb	15.7161	19.3011	1.3	13.308	Elev. 15	One gap of 5 sec's at 19,17(241811)

17-04-2003	107		NRD	1	ap17a1n1.p	12.3239	17.9936	1.1	73.801	Elev. 10, except sat # 25	21 gaps of in total 399 sec's
				2	ap17a2n1.p	12.2642	18.5042	(1.1)	10.412	Elev. 10, del in residuals, float	23 gaps of 2653 sec's (2085 sec's gap at 15,16)
				3	ap17a3n1.p1	12.2419	13.7608	1.3	1.847	Elev. 10, except sat #16 (+start 5,6), float	22 gaps of in total 1792 sec's
				3	ap17a3n1.p2	13.8386	17.9736	1.3	315.748	Elev. 10, except sat #16 (+start 5,6), float	2 gaps of in total 13 sec's
			LYR2	1	ap17a1l2.p1	12.6217	17.9936	1.1	24.449	Elev. 10	One gap of 37 sec's at 12,66 (391206)
				1	ap17a1l2.p2	12.2803	17.9936	1.1	30.083	Elev. 15	No gaps!
				2	**ap17a2l2.p**	**12.2503**	**18.5042**	**1.1**	**16.609**	**Elev. 10**	**No gaps!**
				3	ap17a3l2.p1	12.2369	13.7608	1.1	6.471	Elev. 10, float and fixed	3 gaps of in total 834 sec's
				3	ap17a3l2.p2	13.8386	17.9736	1.1	22.726	Elev. 10, float and fixed	One gap of 124 sec's at 12,66 (391206)
18-04-2003	108		NRD	1	ap18a1n1.p	10.3169	15.8458	(1.3)	9.230	Elev. 15, except sat # 11, float	62 gaps of in total 5390 sec's
				2	ap18a2n1.p1	10.3169	16.3639	1.1	11.379	Elev. 15, except sat # 11	61 gaps of in total 4517 sec's
				2	ap18a2n1.p2	10.4500	16.3639	1.1	11.216	Elev. 15, except sat # 11, del in residuals	52 gaps of in total 4295 sec's
				3	ap18a3n1.p	10.6425	16.3658	1.1	14.581	Elev. 10, except sat # 11,17,27, del in res.	56 gaps of in total 3488 sec's
				1	ap18a1n1.pa	10.3169	13.2625	1.1	2.639	Elev. 15, first part only	60 gaps of in total 4409 sec's
				2	**ap18a2n1.pb**	**13.0000**	**15.0000**		**2.080**	**Elev. 15, middle part only,float**	**1 gap of 6 sec's at 13,37(480164)**
				2	**ap18a2n1.pc**	**14.7500**	**16.3639**	**3.0**	**0.973**	**Elev. 15, last part only**	**No gaps**
			LYR2	1	ap18a1l2.p	10.2081	15.8458	1.1	30.618	Elev. 15,del in res. All sat#1, beg #20, end #28	1 gap of 146 sec's at 13,72(481396)
				2	ap18a2l2.p1	10.2172	16.3639	1.1	9.822	Elev. 15, except sat#1	1 gap of 1102 sec's at 13,56(480848)
				2	**ap18a2l2.p2**	**10.2172**	**16.3639**		**9.087**		**1 gap of 31 sec'c at 13,74(481471)**
				3	ap18a3l2.p	10.1958	16.3658	(1.7)	20.630	Elev. 15, except sat#1	3 gaps of in total 4432 sec's
			SCOB	1	ap18a1sc.p	10.2081	15.8458	1.2	17.074	Elev. 15, except sat#1	4 gaps of in total 397 sec's
				2	ap18a2sc.p	10.2172	15.6192	1.1	6.564	Elev. 15, except sat#1	4 gaps of in total 611 sec's
19-04-2003	109		NRD	1	ap19a1n1.p1	10.5850	15.0231	1.1	30.006	Elev. 15, except sat # 17,21,25	No gaps
				1	**ap19a1n1.p2**	**10.5850**	**15.0231**	**1.1**	**12.892**	**Elev. 10, except sat # 17,21,25**	**No gaps**
				2	ap19a2n1.p	10.5850	15.0194	3.6	1.070	Elev. 10, except sat # 17,21,25	1 gap of 44 sec's at 13,23(566043)
				3	ap19a3n1.p	10.5861	15.0156	1.7	2.336	Elev. 10, except sat # 17,21,25	2 gaps of in total 19 sec's
20-04-2003	**110**		**SCOB**	**1**	**ap20a1sc.p**	**10.4186**	**14.1117**	**1.3**	**3.264**	**Elev. 15, except sat # 21,29, del in res.**	**No gaps**
Geikie				2	ap20a2sc.p	10.3836	14.5736	1.2	7.172	Elev. 15, except sat # 21,29	2 gaps of in total 134 sec's
				3	ap20a3sc.p	10.6581	14.5725	1.2	4.047	Elev. 15, except sat # 21,29	3 gaps of in total 243 sec's
			NRD	1	ap20a1n1.p	10.5150	14.1117	1.1	5.496	Elev. 15, except sat # 21,29	No gaps
				2	ap20a2n1.p	10.5150	14.5736	1.1	9.195	Elev. 15, except sat # 21,29	3 gaps of in total 92 sec's
				3	ap20a3n1.p	10.5508	14.5725	1.1	5.662	Elev. 15, except sat # 21,29	4 gaps of in total 414 sec's

21-04-2003	111		SCOB	2	ap21a2sc.p	10.7086	17.2306	1.1	1 0.589	Elev. 15, except sat # 4,8,18	4 gaps of in total 1183 sec's
				3	ap21a3sc.p	10.6883	17.2331	1.1	16.307	Elev. 15, except sat # 4,8,18	5 gaps of in total 1192 sec's
				1	ap21a1sc.p	10.6992	17.2347	1.1	23.678	Elev. 15, except sat # 4,8,18	7 gaps of in total 1386 sec's
			SFJ	2	ap21a2sf.p	10.7086	17.2306	1.1	9.935	Elev. 10, except sat # 15, del in res. (sat 5)	2 gaps of in total 150 sec's
				3	**ap21a3sf.p**	**10.6883**	**17.2331**	**1.1**	**31.826**	**Elev. 10, except sat # 10,15, del start sat 8**	**2 gaps of in total 132 sec's**

Appendix 4. Overview of INS data processing

Date	JD	Flight	file name	GPS file	start	end	GPS antenna	Comments
05-04-2003	95		113005.pos	ap05a1sf.p			1	
test flight			230048.pos	ap05a1sf.p	20.0600	20.2400	1	
			232347.pos	ap05a1sf.p	20.3600	20.9700	1	
07-04-2003	97		030407.pos	ap07a3sf.p5	12.8990	18.2800	3	
09-04-2003	99		030409.pos	ap0913sc.p (comb.solution)	9.6336	14.7619	1/3	one gap of 59 sec's at 305750
10-04-2003	100	a	030410a.pos	ap10a2n1.pa4	10.1000	15.7000	1	No gaps
		b	030410b.pos	ap10a3n1.pb	16.2500	21.6300	3	No gaps!
11-04-2003	101		030411.pos	ap11a2l1.p	9.0000	13.7500	1	stopped at 13,75 - major gap in GPS file
15-04-2003	105	a	030415a.pos	ap1523l1.pa (comb. solution)	10.5200	14.8500	2/3	No gaps
		b	030415b.pos	ap15a1l1.pb2	15.8000	19.2000	1	No gaps
17-04-2003	107		030417.pos	ap17a2l2.p	14.3500	16.0000	1	No gaps!
18-04-2003	108		030418a.pos	ap18a2l2.p2	10.2200	13.1000	1	No gaps!
			030418b.pos	ap18a2n1.pb	13.0000	15.0000	1	One gap of 6 sec's at 13,38
			030418c.pos	ap18a2n1.pc	14.7500	16.3600	1	No gaps!
			030418.pos		10.2200	16.3600		Comb. solution (jumps at 13,00 and 15,00!!)
19-04-2003	109		030419.pos	ap19a1n1.p2	10.5800	15.0400	1	No gaps
20-04-2003 (geikie)	110		NO INS DATA!!					
21-04-2003	111		030421.pos	ap21a3sf.p	10.6900	17.2300	3	Two gaps of in total 132 sec's

<u>Appendix 5.</u> Overview of lidar data processing

JD	File name	2dd format	Start (dechr)	Stop	Route	Comments
95 – April 5	200500.2dd	T	20.0833	20.94737	Test flight	
97 – April 7	130230.2dd 1403750.2dd 150100.2dd	T T T	13.04167 14.03750 15.01667	14.02213 15.00304 15.26004	SFJ-EGIG-MVG	150100: Timeshift of -2 sec. 1403750: Name corrected to 140215
99 – April 9	105900.2dd 115800.2dd 124300.2dd 131600.2dd 143200.2dd	T T T T T	10.98333 11.96667 12.71667 13.26667 14.53333	11.94859 12.60977 13.25575 13.69357 14.65597	MVG-B-NRD	124300: Processing stopped at 13.206 due to gap in gps solution. 131600: Processing stopped at 13.676 due to gap in gps solution. Note: this file is processed with air1.
100 – April 10	100630 110300 120300 125900 135700	Txt Txt Txt Txt Txt	10.10833 11.05000 12.05000 12.98333 13.95000	11.00000 11.97000 12.97000 13.94000 14.53000	NRD-D-NRD	120300: Possible timeshift towards end of file 125900: Processed with a timeshift of 1 sec.
100 – April 10	161800.2dd 171330.2dd 181100.2dd 191330.2dd 202300.2dd	T T T T T	16.30000 17.22500 18.18333 19.22500 20.38333	17.20831 18.17438 19.18055 20.37694 21.60062	NRD-E-NRD	202300: Processed with timeshift of 60 sec.
101 – April 11	090700.2dd 100930.2dd 100700.2dd 112600.2dd 120800.2dd 131200.2dd	T T T T T T	9.11667 10.15833 11.11667 11.43333 12.13333 13.20000	10.14502 11.10669 11.41938 12.12185 13.12267 13.96026	NRD-PST-LYR	
105 – April 15	110300.2dd 114400.2dd 121100.2dd 130900.2dd 142200.2dd	T T T T T	11.05000 11.73333 12.18333 13.15000 14.36667	11.71879 12.16884 13.12930 13.61325 14.84721	LYR-PST-LYR	142200: Timeshift of -1 sec. Note: this file is processed with air3

105 – April 15	155700.2dd 162300.2dd 181900.2dd	T T T	15.95000 16.38333 18.31667	16.36879 18.28873 19.19055	LYR-Austfonna-LYR	155700: Out of range after 16.15 162300: Out of range before 16.45 181900: Out of range after 18.50
107 – April 17	134200.2dd 142500.2dd 174300.2dd	T T T	13.70000 14.41667 17.71667	14.40558 15.75252 17.89334	LYR-PST-NRD	134200 Too much fog to process 142500 Ice floe survey:OK 1545-1743 10.000 ft altitude because of icing on the aircraft
108 – April 18	102300.2dd 112200.2dd 122300.2dd 132300.2dd 142300.2dd 152300.2dd	T T T T T T	10.38333 11.36667 12.38333 13.38333 14.38333 15.38333	11.34899 12.37223 13.36748 14.37227 15.36016 16.30881	NRD-F-NRD	112200: Timeshift of -1sec. 122300: Timeshift of -1sec. Jump at 13.00 (~10cm) due to jump in combined GPSEGI solution 132300: Timeshift of -1 sec. 142300: Jump at 15.00 (~1 m) due to jump in combined GPSEGI solution.
109 – April 19	103300.2dd 112600.2dd 122600.2dd 132600.2dd	T T T T	10.55000 11.43333 12.43333 13.43333	10.73965 12.42066 13.42026 13.66904	NRD-H-MVG	103300: Timeshift of -1 sec. No positions calculation before 10.59. Out of range after 10.68. 122600: Out of range after 12.97.
110 – April 20	103430.2dd 114400.2dd 141600.2dd	T T T	10.57500 11.73333 14.26667	11.46837 13.32040 14.43999	MVG-Geikie-MVG	No data processed
111 – April 21	105130.2dd 112530.2dd 122700.2dd 132700.2dd 142700.2dd 152330.2dd 162100.2dd	T T T T T T T	10.85833 11.42500 12.45000 13.45000 14.45000 15.39167 16.35000	11.29379 12.43607 13.43667 14.43902 15.36400 16.32332 17.16521	MVG-EGIG-SFJ	105130: Out of range after 10.95 112530: Out of range before 11.57 122700: Started at 12.60 due to gap in gps data 162100: Timeshift of -1 sec.

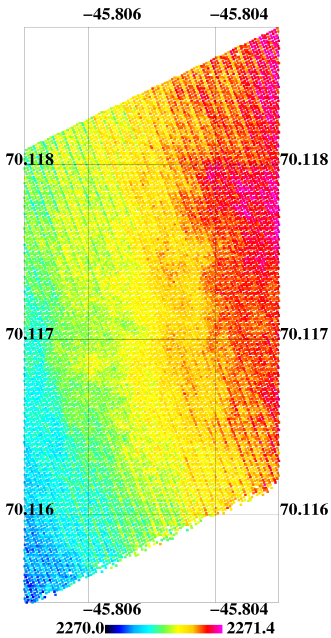
Appendix 6. Structure of data directories

The raw and processed data of CRYOVEX 2003 is provided on DVD's as the raw data files, and a "level 2" (5 x 5 average) lidar data of laser scanner heights and freeboard heights, produced by the methods outlined in Sect. 5.3.

It should be pointed out that the final, detailed processed lidar data are way too voluminous (around 40 GB) to make much sense in providing as files. Instead jobs are provided which allows the direct production of detailed lidar files for any period of the acquired lidar data (cf. Appendix 2) by a Fortran executable ("READSCA1 < RS.INP"). Examples of data and plots are given in the files for a short (36 sec) full-resolution section of the lidar data.

Note on running the Fortran programmes: The "READSCA1" programme must be compiled with the Lahey F77L3 compiler, and will not work with GNU Fortran due to some compiler restrictions. The Lahey compiler requires a DOS-extender ("RUN386.EXE") in the path to run. This DOS-extender will not run under Windows XP (2000 and older are OK). KMS is currently making new scanner software ready avoiding these awkward Fortran constraints. A prototype of this software was used to run the land-ice results (which are processed as ellipsoidal heights only).

The first routine processing of Cryovex-2003 data showed patterns originating from a (manufacturer) miscalibrated mirror in the scanner. The problem was fixed by correcting all raw Riegl files with the programme "correct.exe". Mirror corrected scanner files are named c*.2dd, and those files thus make the basis for all Cryovex-2003 lidar processing. After the campaign the scanner was sent to Riegl and the mirrors were properly calibrated.



Description of delivered file types:

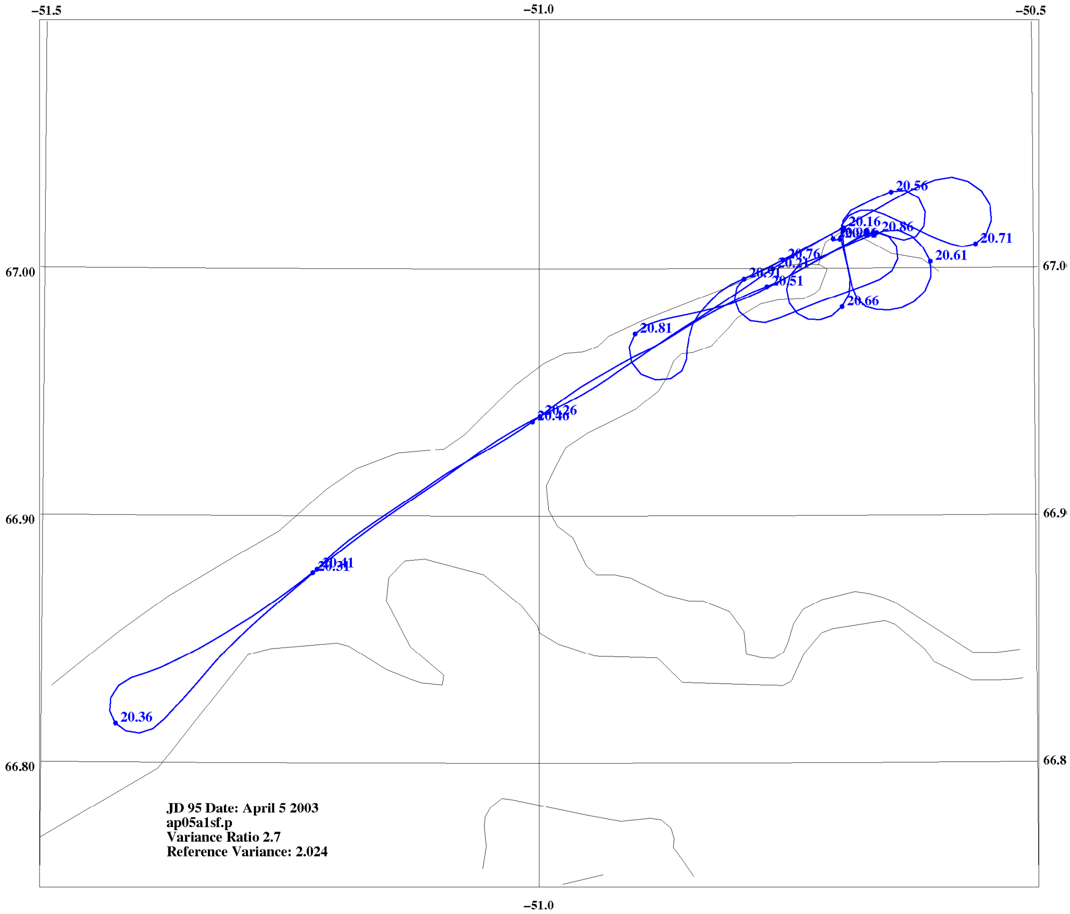
*.pos	Combination of GPS and INS data.
*.2dd	Raw scanner data in binary format.
*.scn	High-resolution processed scanner data in ASCII format.
*.ver	High-resolution vertical data in ASCII format.
*.ps	Postscript figure of high-resolution scanner data.
*_5x5.scn	Low-resolution processed scanner data in ASCII format.
*_5x5.ver	Low-resolution vertical data in ASCII format.
*_5x5.ps	Postscript figures of low-resolution scanner data.
*_5x5.frb	Low-resolution freeboard profile.
*_5x5.frs	Low-resolution freeboard scan.
*_frs.ps	Postscript figure of low-resolution freeboard scan data.
*.jpg	Pictures from the vertical mounted camera.
ver_photo.pos	Time and position for pictures taken with the vertical camera.
*.png	Plot of the flight.

Available files for each day

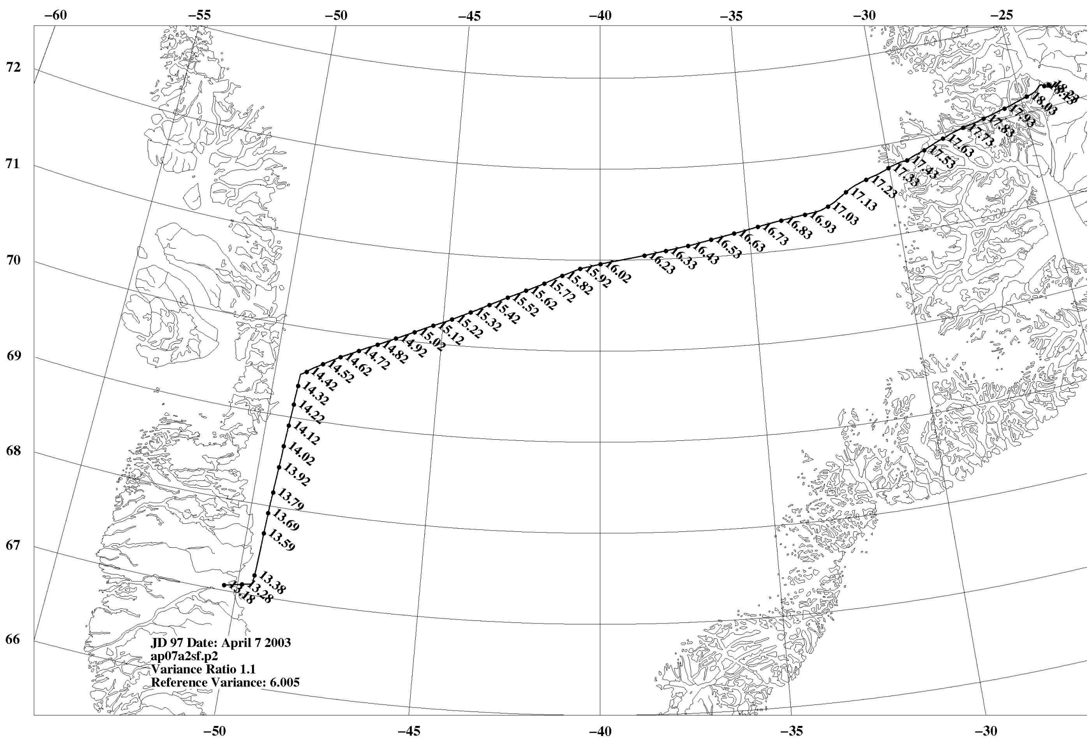
	*.pos	*.2dd	*.scn	*.ver	*.ps	*_5x5.scn	*_5x5.ver	*_5x5.ps	*_5x5.frb	*_5x5.frs	*_frs.ps	*.jpg	ver_photo.pos	*.png	Comment
095	X														
200500		X	X	X	X	X	X	X							
GPS														X	
097	X														
130230		X	X	X	X	X	X	X							
140215		X	X	X	X	X	X	X							
150100		X	X	X	X	X	X	X							
GPS														X	
ver_photo												X	X		
099	X														
105900		X	X	X	X	X	X	X							
115800		X	X	X	X	X	X	X							
124300		X	X	X	X	X	X	X							
131600		X	X	X	X	X	X	X							
143200		X	X	X	X	X	X	X							
GPS														X	
ver_photo												X	X		
100a	X														
100630		X	X	X	X	X	X	X	X	X	X				
110300		X	X	X	X	X	X	X	X	X	X				
120300		X	X	X	X	X	X	X	X	X	X				
125900		X	X	X	X	X	X	X	X	X	X				
135700		X	X	X	X	X	X	X	X	X	X				
GPS														X	
100b	X														
161800		X	X	X	X	X	X	X	X	X	X				
171330		X	X	X	X	X	X	X	X	X	X				
181100		X	X	X	X	X	X	X	X	X	X				
191330		X	X	X	X	X	X	X	X	X	X				
202300		X	X	X	X	X	X	X	X	X	X				
GPS														X	
ver_photo												X	X		
101	X														
090700		X	XX	XX	XX	XX	XX	XX	X	X	X				Both sea-ice and land-ice
100930		X	X	X	X	X	X	X	X	X	X				
110700		X	X	X	X	X	X	X	X	X	X				
112600		X	X	X	X	X	X	X	X	X	X				
120800		X	X	X	X	X	X	X	X	X	X				
131200		X	X	X	X	X	X	X	X	X	X				
GPS														X	
ver_photo												X	X		

105a	X														
110300		X	X	X	X	X	X	X	X	X	X				
114400		X	X	X	X	X	X	X	X	X	X				
121100		X	X	X	X	X	X	X	X	X	X				
130900		X	X	X	X	X	X	X	X	X	X				
142200		X	X	X	X	X	X	X							
GPS														X	
ver_photo												X	X		
105b	X														
155700		X	X	X	X	X	X	X							
162300		X	X	X	X	X	X	X							
181900		X	X	X	X	X	X	X							
GPS														X	
ver_photo												X	X		
107	X														
134200		X													Not processed due to fog
142500		X	X	X	X	X	X	X	X	X	X				"Mow the lawn"
174300		X													Runway, not processed
GPS														X	
ver_photo												X	X		
108	X														
102300		X	X	X	X	X	X	X	X	X	X				
112200		X	X	X	X	X	X	X	X	X	X				
122300		X	X	X	X	X	X	X	X	X	X				
132300		X	X	X	X	X	X	X	X	X	X				
142300		X	X	X	X	X	X	X	X	X	X				
152300		X	X	X	X	X	X	X	X	X	X				
GPS														X	
ver_photo												X	X		
109	X														
103300		X	X	X	X	X	X	X							
112600		X	X	X	X	X	X	X							
122600		X	X	X	X	X	X	X							
132600		X	X	X	X	X	X	X							
GPS														X	
110															Flight not processed due to missing
103430		X													inertial data.
114400		X													
141600		X													
GPS														X	
111	X														
105130		X	X	X	X	X	X	X							
112530		X	X	X	X	X	X	X							
122700		X	X	X	X	X	X	X							
132700		X	X	X	X	X	X	X							
142700		X	X	X	X	X	X	X							
152330		X	X	X	X	X	X	X							
162100		X	X	X	X	X	X	X							
GPS														X	
ver_photo												X	X		

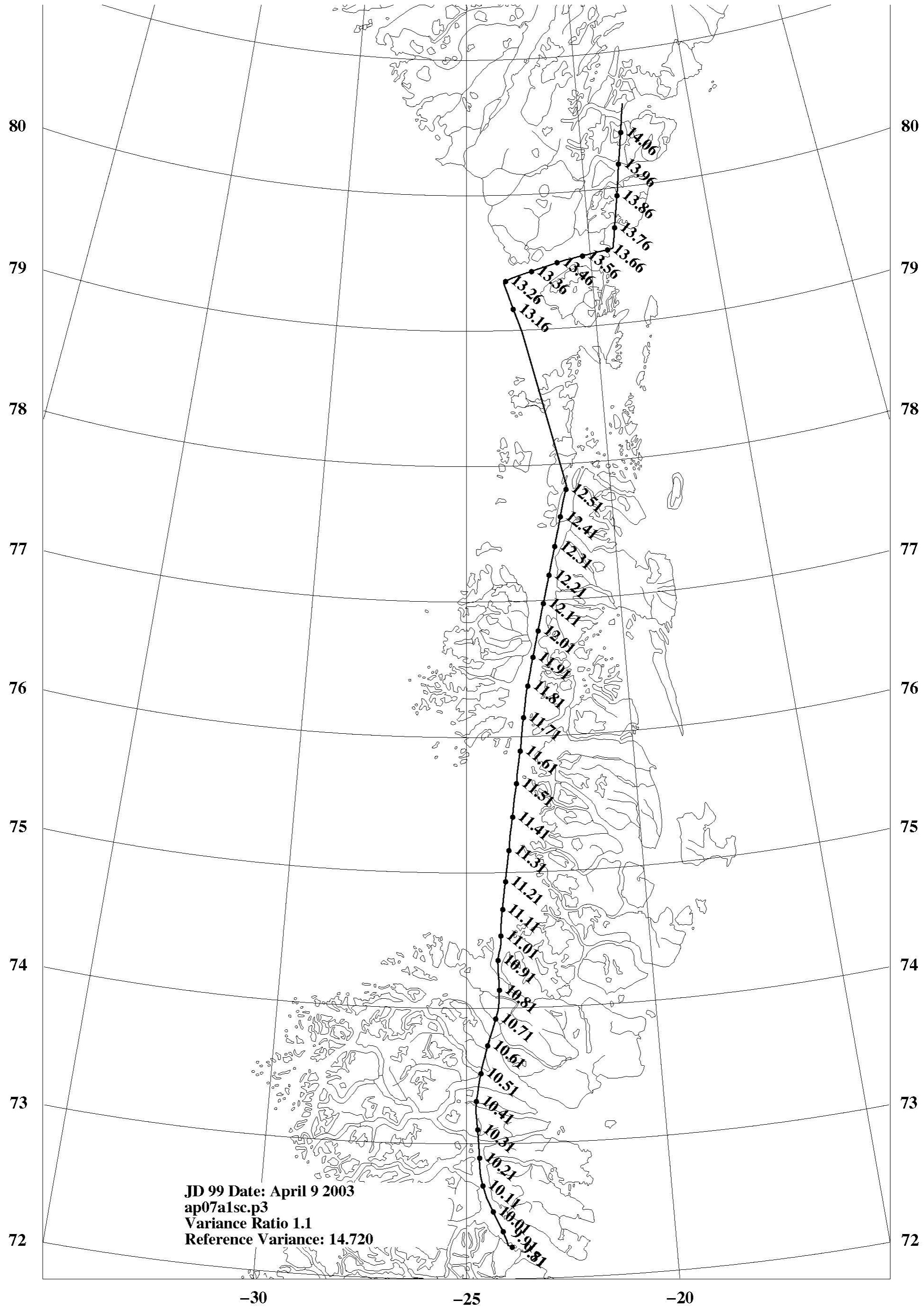
<u>Appendix 7.</u> GPS plots of daily flights
Time in UTC.



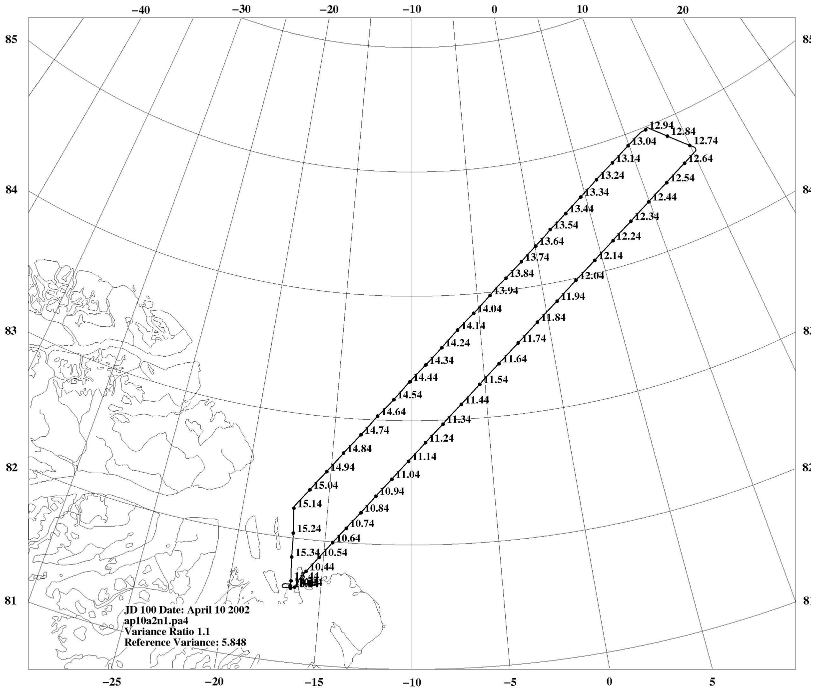
Flight track from April 5th, JD 95, Test flight in SFJ (Kangerlussuaq).

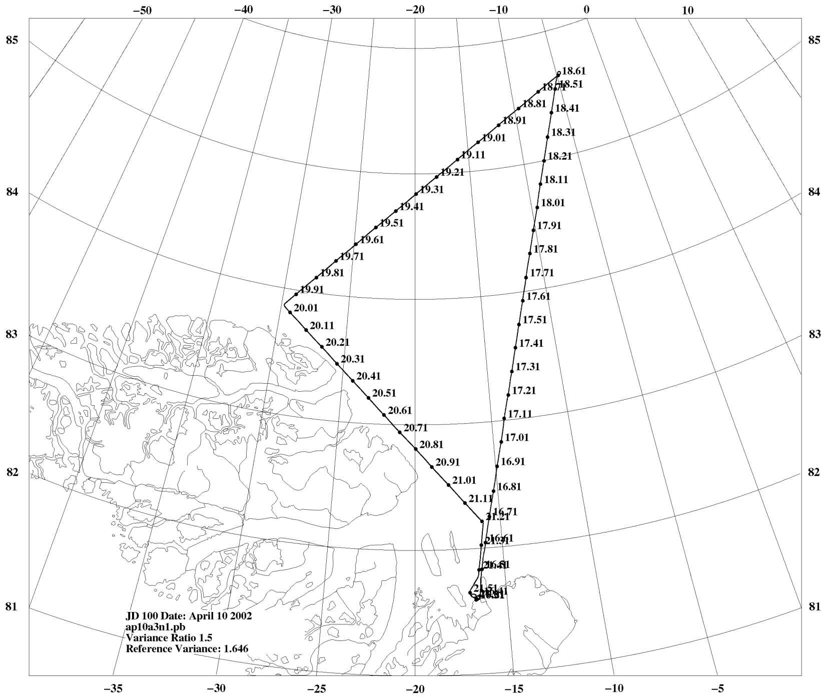


Flight track from April 7th, JD 97, SFJ – MVG.

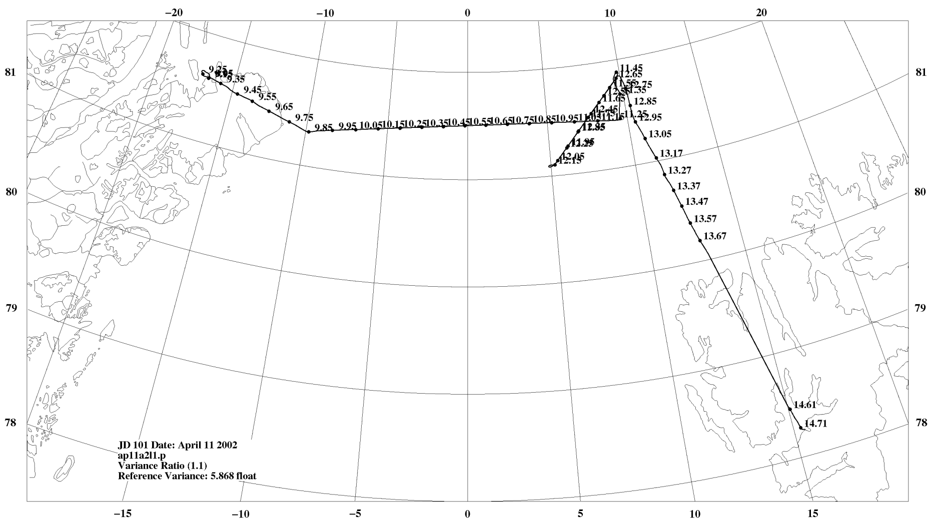


Flight track April 9th, JD 99, MVG – NRD.

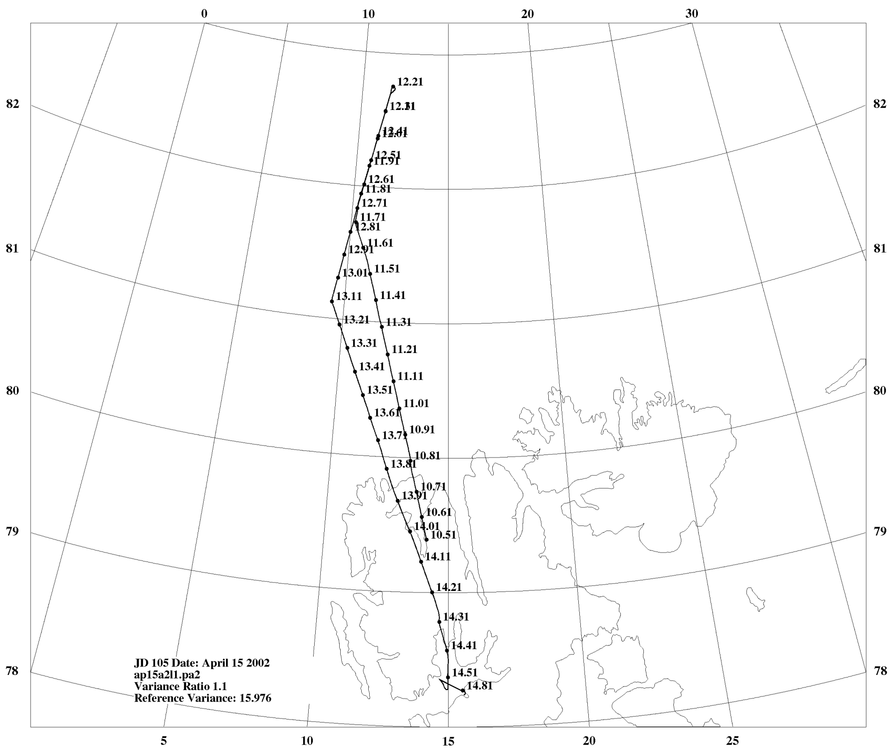




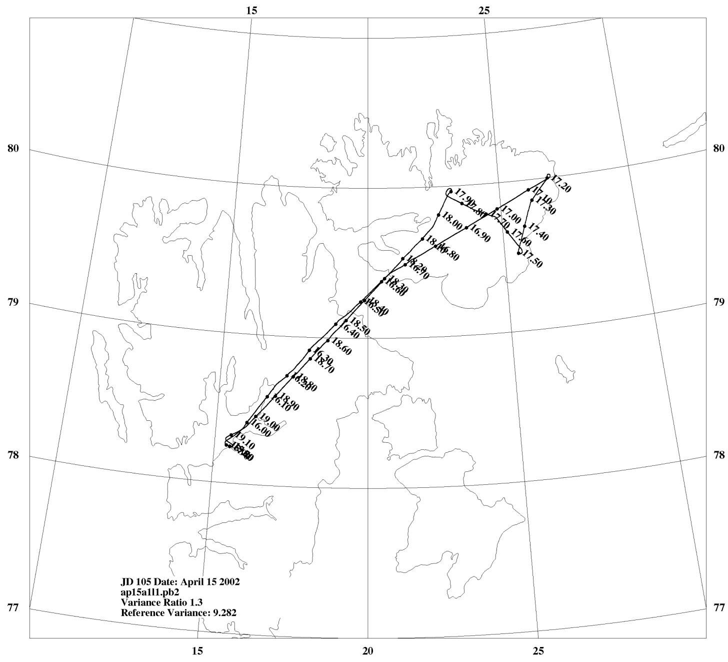
Flight tracks from April 10th, JD 100, top is flight 100a, lower is flight 100b.



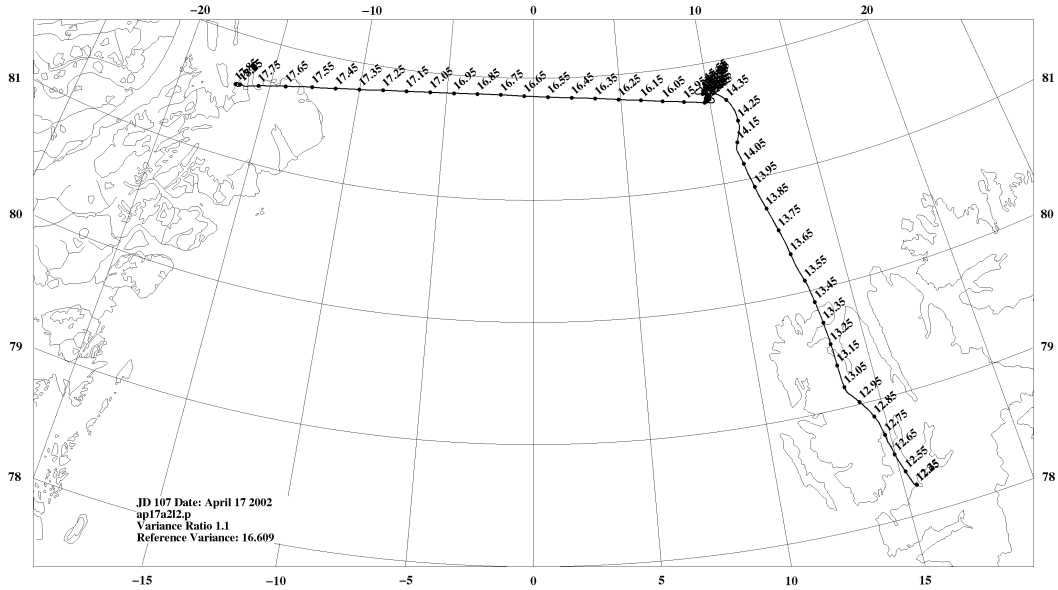
Flight track April 11, JD 101, NRD – LYR. On the way to LYR a coincident flight was made with the helicopter from Polarstern, located just South of 82N; 10E.



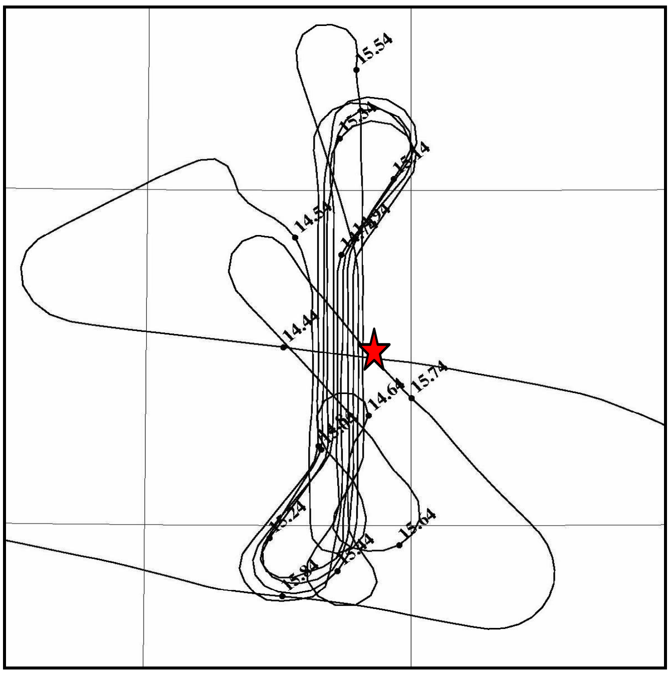
Flight track from April 15, JD 105, LYR – Polarstern – LYR. The second coincident flight with the helicopter from Polarstern, located just South of 82N; 10E.



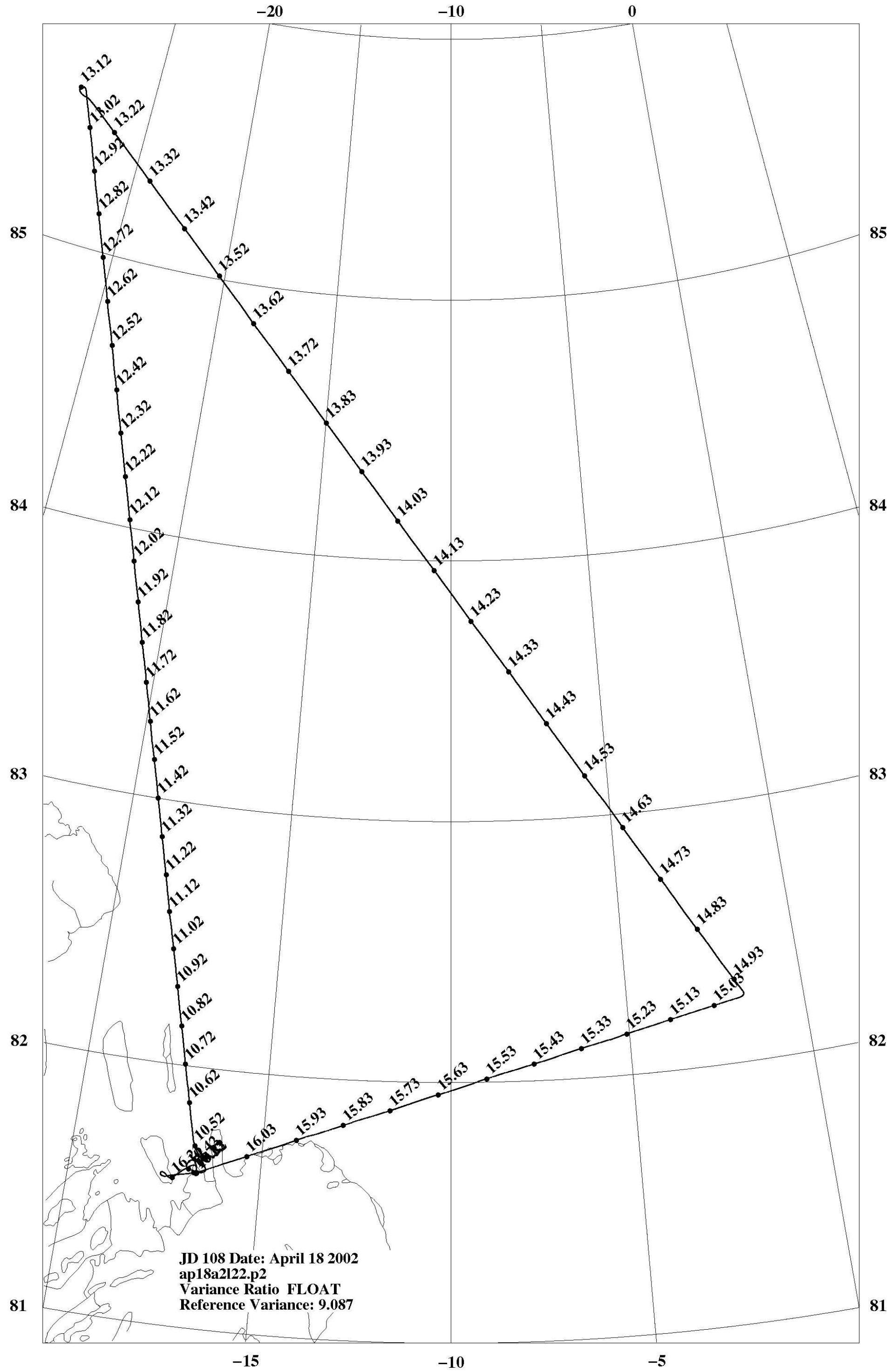
Flight track from April 15th, JD 105, afternoon flight 105b, LYR- LYR.
Nord Austfonna is a small ice cap North East of LYR.



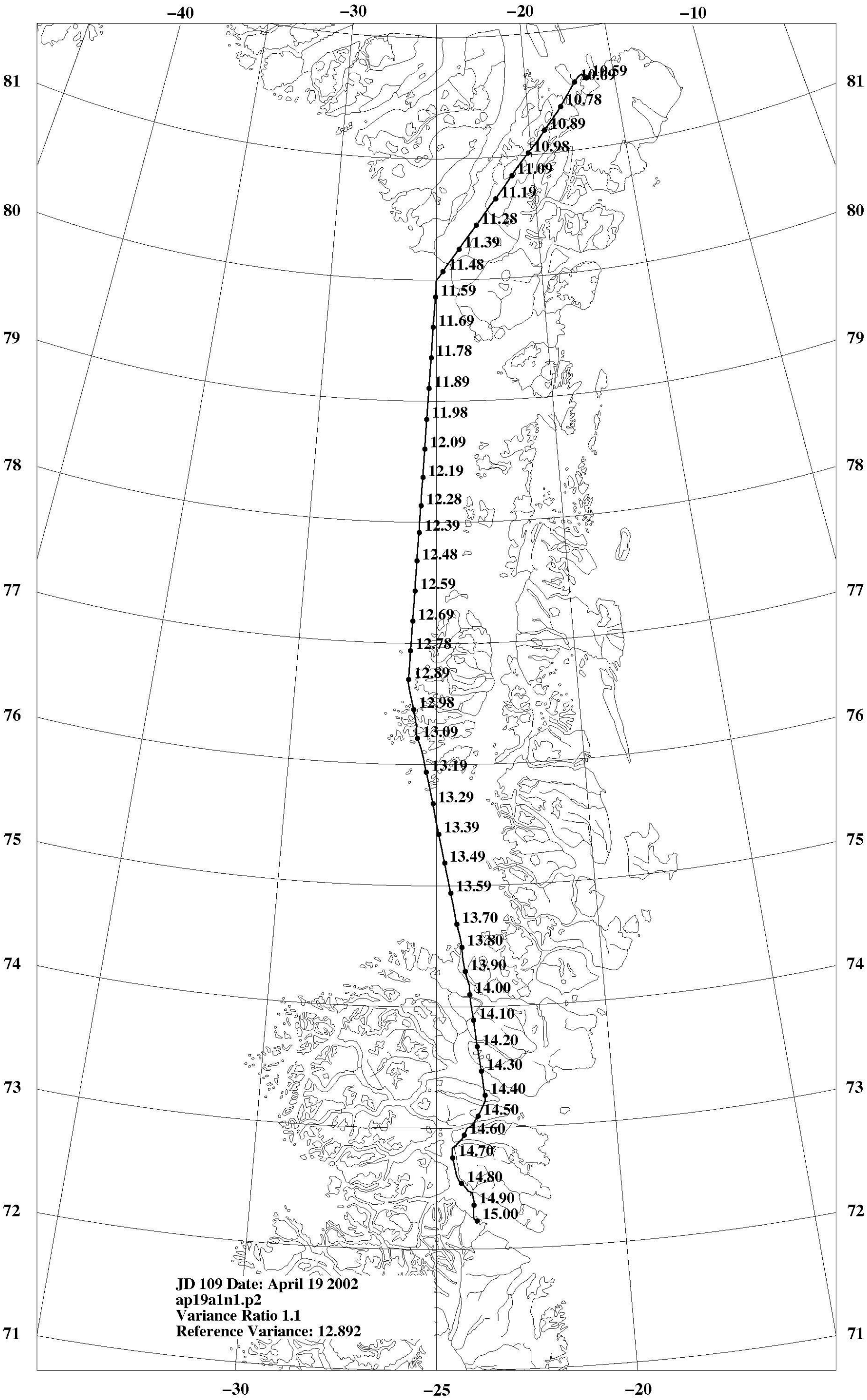
Flight track from April 17th, JD 107, LYR – Polarstern – NRD. At Polarstern's position a very dense "mow the lawn" survey were completed in order to survey the "Tomato" ice floe.



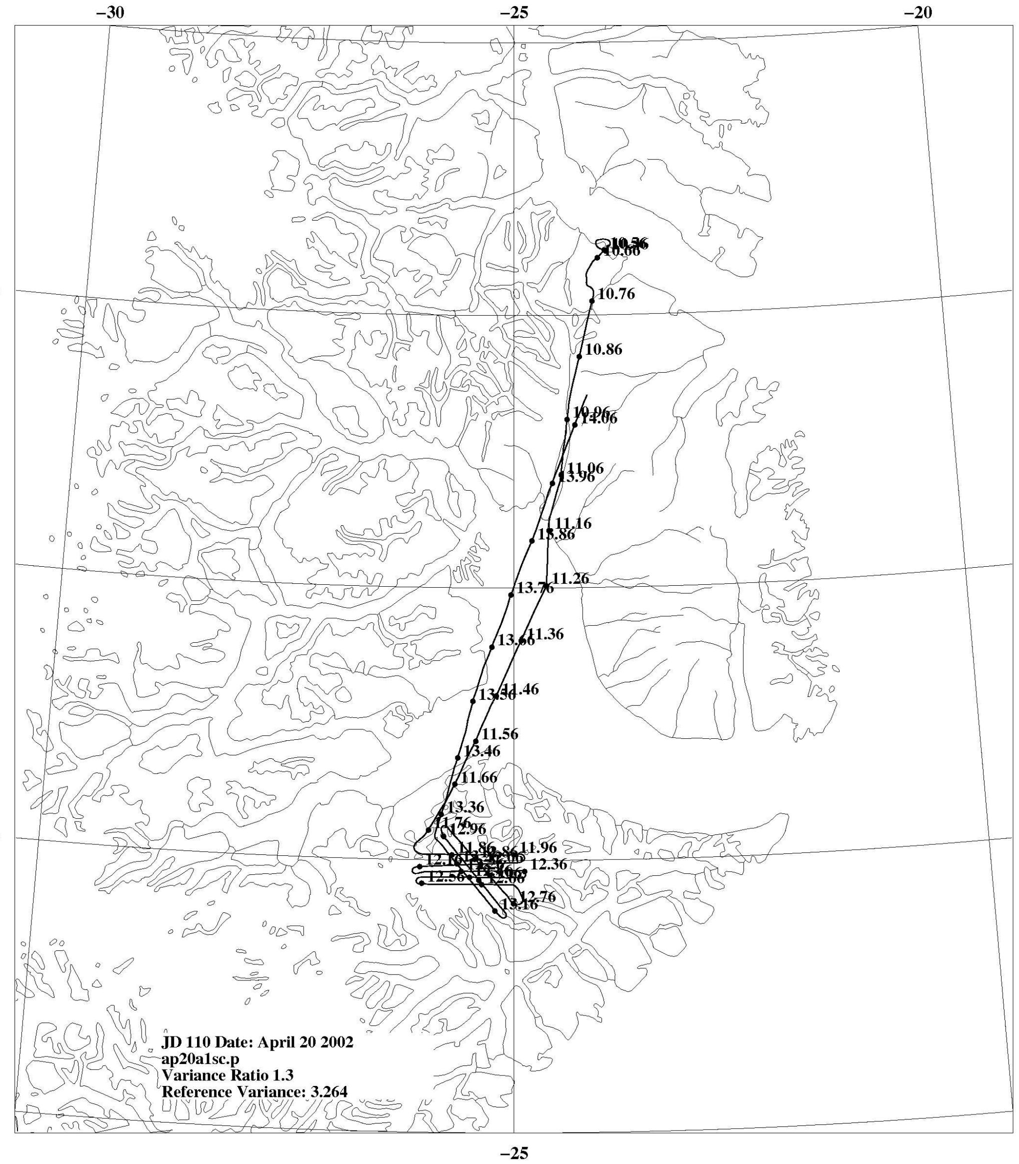
The track plot of the" mow the lawn" survey of the "Tomato" ice floe next to R/V Polarstern, indicated by the red star.



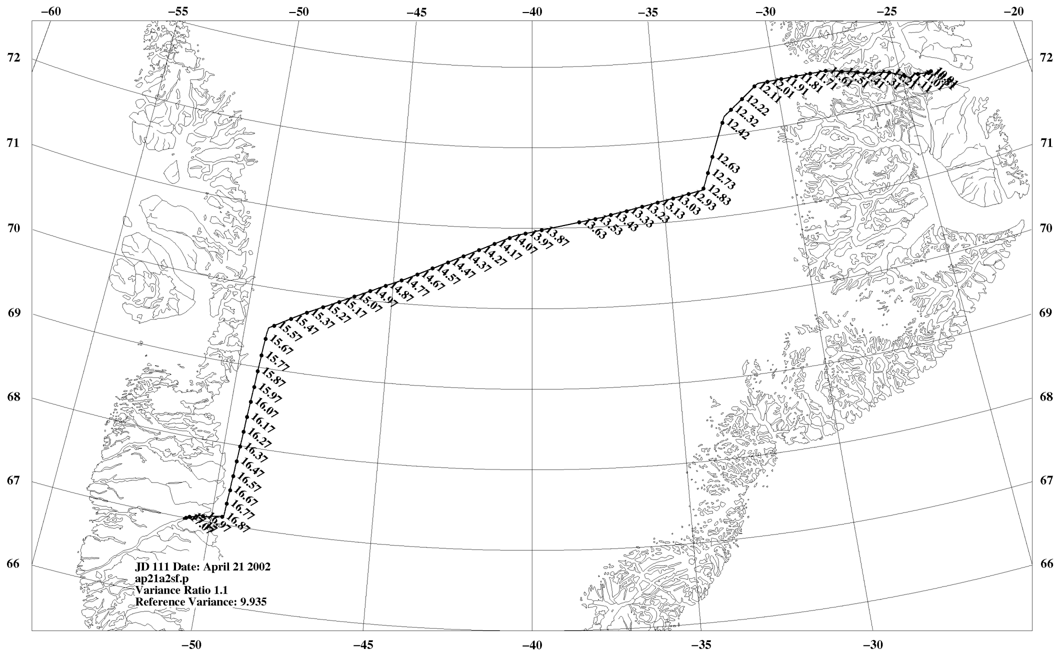
Flight track from April 18th, JD 108, NRD – NRD.



Flight track from April 19th, JD 109, NRD – MVG



Flight track from April 20th, JD 110, MVG – Geikie Ice Cap – MVG.



Flight track from April 21st, JD 111, MVG – SFJ, last day of surveying.

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25. K. Keller, S. M. Hvidegaard, R. Forsberg, N. S. Dalå, H. Skourup, L. Stenseng*: Airborne Lidar and Radar Measurements over Sea Ice and Inland Ice for CryoSat validation: CRYOVEX 2003 – Final Report*, 58 pp, 2004.

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