TECHNISCHE UNIVERSITÄT DRESDEN

Technical Assistance during the 2010/2011 CryoSat Schirmacheroase Antarctic Validation Activity

Final Report
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Contents

1 Introduction

Following the successful CryoVEx 2008/2009 Antarctic campaign, this document reports the data acquisition of the CryoVEx 2010/2011 Antarctic campaign which was carried out in Dronning Maud Land from November 11, 2010 to February 20, 2011. The airborne part of the campaign was carried out by the Alfred Wegener Institute (AWI) using the AWI POLAR 5 (Basler BT-67) aircraft, whereas the GNSS ground measurements were carried out by TU Dresden.

Airborne and ground measurements were recorded in this campaign, which was the second CryoSat CalVal experiment supported by ESA in Antarctica. Both airborne and ground measurements were performed in the blue ice region close to Novolazarevskaya-Airbase (Fig. 1.1) and were carried out by scientists from TU Dresden and AWI. In general, the ground and airborne activities were very successful. All planned survey lines, including the survey test grids, could be measured.

The key objective of the ground measurements described here was to provide precise ground-based information on ice surface heights in the area of investigation. To obtain surface height changes it was essential to repeat the test areas observed during CryoVEx 2008/2009 within the blue ice region.
This report describes the ground-based field operations carried out by TU Dresden during the CryoVEx 2010/2011 Antarctic campaign, the obtained data, their analysis and the results including a sophisticated accuracy analysis.

The airborne operations of AWI belong to a separate contract with ESA. However, we add a few examples of intercomparison of our ground-based data with ASIRAS data provided by AWI.

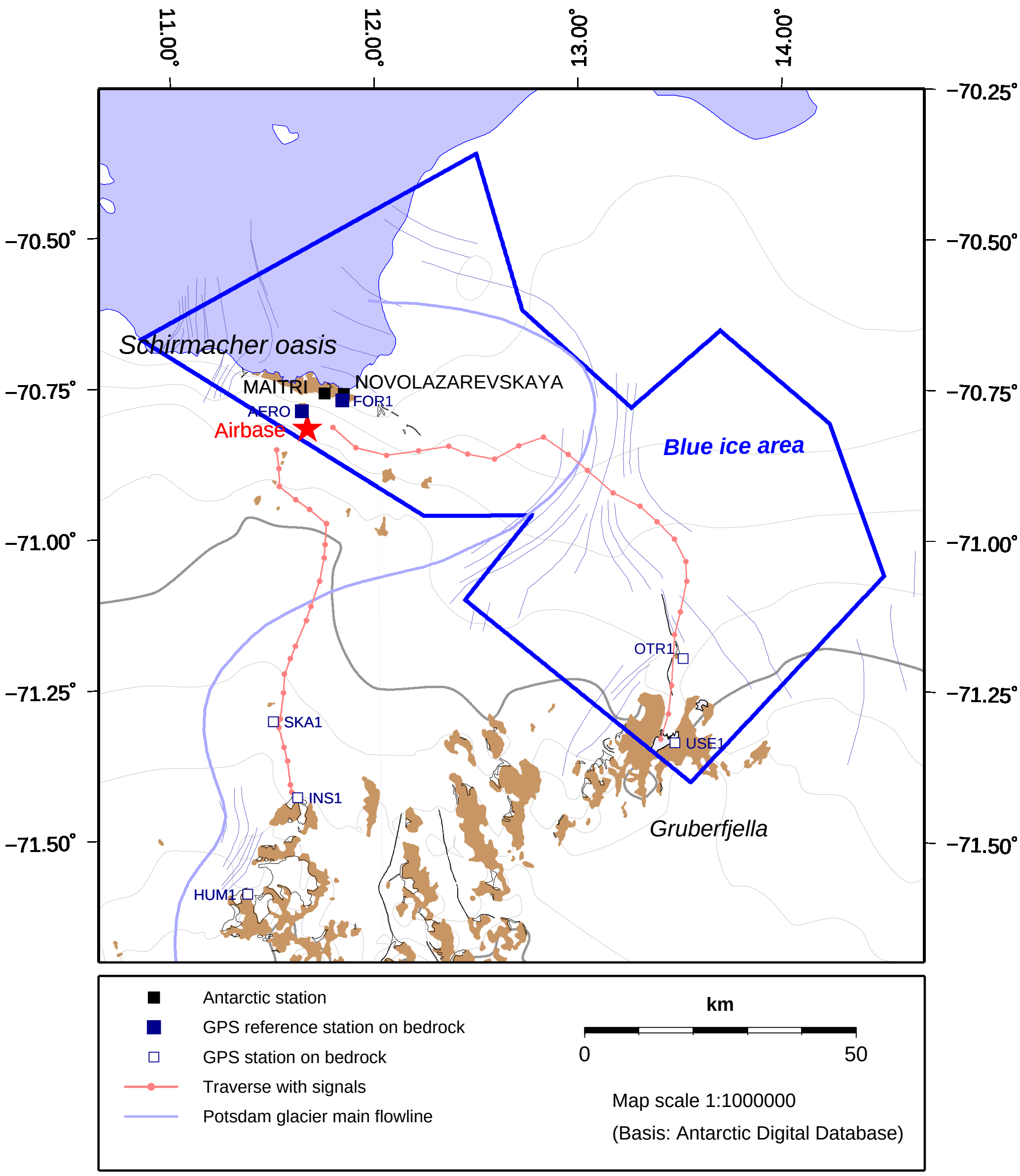

Figure 1.1: Schirmacher Oasis. General map with highlighted blue ice area.

2 Field party operations

2.1 Overview

The two geodesists forming the TU Dresden group flew on board an IL76TD aircraft from Cape Town to Antarctica on November 11, 2010. The Novolazarevskaya airfield is located south of the Schirmacher Oasis on an altitude of about 500 m. The group used the airfield camp about 12 km away from the Russian station Novolazarevskaya as the logistical base for the entire field campaign. This time, the focus was put on test areas in blue ice conditions, so a field camp (Fig. 2.9) close to the traverse waypoint U09 in the blue ice area about 85 km east of the Schirmacher Oasis was established on November 20 and 21 and finally occupied from November 30, 2010 to February 7, 2011. Due to severe technical problems of the snowmobiles type Bombardier Skidoo Alpine II initially provided by AWI, the stay had to be extended by about three weeks. On February 20, 2011 the group returned to Cape Town on board an IL76TD aircraft.

2.2 GNSS reference stations

In order to reduce systematic effects the kinematic GNSS data need to be analysed with respect to stable reference stations (differential GNSS). Tables 2.2 and 2.3 as well as Figure 2.1 summarizes the set-up of the reference stations on bedrock. During CryoVEx 2010/2011 two reference stations on bedrock were installed in the vicinity of Schirmacher Oasis: The stations FOR1 (Forster 1, Fig. 2.5) is located in the oasis itself, the station AERO (Aerodromnaya, Fig. 2.4) is located on the Aerodromnaya nunatak in a distance of about 3 km from the Airbase Camp. While the receiver at FOR1 tracked GPS satellite signals only, the Trimble R7 GNSS receiver and the geodetic TRM57971.00 antenna at AERO also provides observations of the Russian GLONASS system. FOR1 run without data loss over the entire observation time period whereas for AERO download of the complete data at the end of the field campaign failed due to malfunction of the flash memory card. However, all relevant daily observations files needed for processing of the individual kinematic profiles could be saved from previous data backups.

For backup reasons, additional static GNSS observations were carried out in the field camp U09. Here, a GNSS antenna was temporarily mounted on a tripod in the snow (Fig. 2.6). It has to keep in mind that the position change rates of ice-mounted stations are dominated by the ice movements. Therefore, such stations are suitable to only a limited extent to serve as a reference station for kinematic purposes. However, due to the continuous observation data of the GNSS reference stations on bedrock, the usage of the observations of the temporary field camp reference station during the data analysis was not necessary.

Table 2.1: Phases of CryoVEx 2010/2011 campaign with preparations

DATE	DESCRIPTION
07–08/09/2010	Delivering of cargo to Bremerhaven, prepare polar clothing at AWI
07–08/11/2010	Flight Dresden – Frankfurt/M. – Cape Town
08–11/11/2010	Stay in Cape Town, Ilyushin flight briefing
11–12/11/2010	Ilyushin flight D3 Cape Town – Novo
12–20/11/2010	Stay at ALCI Novo Airbase, reference stations AERO and FOR1, preparation of field camp
20–21/11/2010	Logistic trip to field camp, putting up two tents, return and breakdown of one snowmobile at signal U11
21–30/11/2010	Stay at Airbase, check of reference stations, recovery of snowmobiles in cooperation with Airbase authorities
30/11/2010	Trip to field camp
30/11–23/12/2010	Stay at field camp (1st phase), geodetic fieldwork around Camp U9
23/12/2010	Return to Airbase
23/12/2010–06/01/2011	Check and data backup of reference stations, blizzard
06/01/2011	Tried return to field camp, breakdown of one snowmobile at signal U20 and recovery
06–16/01/2011	Stay at Airbase, blizzard, negotiations and waiting for replacement snowmobiles
16/01/2011	Return to field camp
16/01/–07/02/2011	Stay at field camp (2nd phase), continuation and completion of fieldwork
07/02/2011	Shutdown of field camp and return to Airbase
07–20/02/2011	Stay at Airbase, dismount reference stations, data work, reports, preparation of return flight
20/02/2011	Ilyushin flight D11 Novo – Cape Town
20–28/02/2011	Stay at Cape Town due to shifted return flight
28/02–01/03/2011	Return flight Cape Town – Frankfurt – Dresden

2.3 Kinematic GNSS measurements

For the kinematic GNSS measurements two geodetic GNSS antennas TRM57971.00 without radomes were mounted on tripods on two Nansen sledges (rovers). Trimble R7 GNSS geodetic receivers and batteries were stored in aluminium boxes next to the tripods (Fig. 2.7). Besides GPS these receivers also tracked and stored GLONASS observations. The sledges were pulled by two-stroke Bombardier Alpine II snow mobiles, replaced by newer snow mobiles Alpine III in the second half of the campaign due to technical problems. The velocity was limited to about 10 km per hour on blue ice and about 15 to 20 km per hour on snow. All kinematic tracks were observed with a data sampling of 1 Hz. This yields to a resolution (along track) of about 3 m on blue ice and 4 to 6 m on snow. In order to assess the measurement accuracy cross over points were observed. In total more than 2400 km kinematic profiles were observed in the working area within 18 individual days which is an enormous

Table 2.2: Occupied GNSS reference stations during CryoVEx 2010/2011

Marker	Name	Latitude [deg min sec]	Longitude [deg min sec]	Height [m]
Forster 1	FOR1 66023M001	-70 46 40.58	11 49 30.23	152.9
Aerodromnaya	AERO	-70 47 39.71	11 37 13.68	514.9
Camp U9 temporary	CU09	-70 58 54.33	13 25 40.10	697.3

Table 2.3: Set-up and observations at GNSS reference stations

Station-ID	Receiver	Antenna	Data Sampl.	Observation-interval
Reference stations on bedrock				
FOR1	Trimble 4000SSI S/N 17687	TRM14532.00 NONE S/N 66181	5s	Nov 17 2010 - Feb 12 2009 10:321 - 11:043
AERO	Trimble R7 GNSS S/N 30139	TRM57971.00 NONE S/N 30403865	1s	Nov 14 2010 - Feb 11 2011 10:318 - 11:042
Reference station on ice				
CU09	Trimble R7 GNSS S/N 30135	TRM57971.00 NONE S/N 403822	1s	Dec 04 2010 - Feb 05 2011 10:338 - 11:036

extension compared to the previous campaign (see also 2.3.1). Figure 2.2 gives an overview of the main working area (green rectangle). A more detailed view of all observed kinematic GNSS profiles within the blue ice region is shown in Figure 2.3. A summary of all profiles is given in Tables 2.4, 2.6 and 2.5.

2.3.1 Kinematic GNSS test grids and CryoSat track profiles

The repeated observation and extension of the four test grids established near Camp U9 during CryoVEx 2008/2009 formed the mandatory part of the field measurements. Grid spacing of 50 m was kept, but without densification of the inner grid part. Furthermore, several options which can be classified in three stages became apparent while planning the

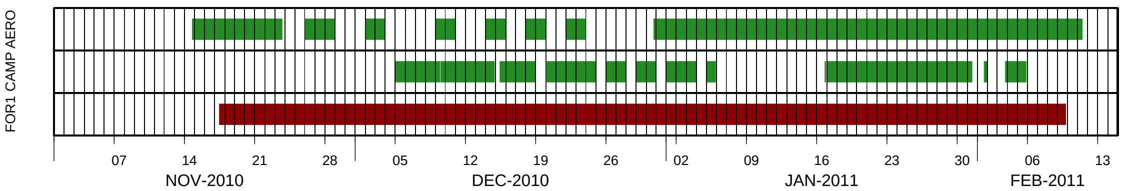

Figure 2.1: Observations at GNSS reference stations with indicated sampling rate. Green color: 1 sec sampling, red color: 5 sec sampling.

fieldwork.

First, the grids should be extended to 1.5 km border length which implies an increase by factor 2.25 in area (2 km^2) and 2.5 (100 km) in profile length. Because of the CryoSat profiles passing by very near, some grids (Grid 8 and Grid 9) could be designed to cover the precisely predicted satellite ground tracks. For this reason, Grid 9 was even planned to be extended to 2.2 km by 1.5 km size (more than 140 km profile length on two days of fieldwork).
At the second stage, CryoSat ground tracks crossing the working area within the scheduled period could beneficially be observed nearly synchronously. Depending on weather conditions, time and fuel, about three additional grids could be established on the satellite tracks. The final location of these grids had to be decided on in the field depending on latest precisely predicted satellite ground tracks provided by ESA and ice conditions. Grid N3 could even be placed on a CryoSat crossover (Orbits 3955 and 3224) located in the north-western part of the working area. The final option was to repeat the measurement of the satellite ground tracks and at least one grid to check for inter-annual variations, and thus, to ensure consistent comparison between GNSS and satellite observations. Despite of technical problems and unstable, stormy weather conditions (Fig. 2.10), all aforementioned stages could be accomplished. In the end, the four existing grids (220 km) were extended to 479 km profile length. Three new grids (320 km) were established, and grid G8 could be observed twice (120 km) as well as the CryoSat-2 ground tracks (110 km). In this season, larger parts of the blue ice area were covered with a snow layer (Fig. 2.7, bottom). The locations of the transition between the pure blue ice and the areas with partly snow coverage (snow borders) were surveyed as precisely as possible. Apart from Grid 7, the depth of the snow layer was taken at selected equidistant crossovers. A summary of the observed grid profiles within the area of main interest is given in Table 2.6. Table 2.5 shows a summary of the observed precisely predicted CryoSat ground tracks.

2.3.2 Kinematic GNSS measurements at Untersee traverse

Kinematic GNSS measurements were carried out along the glaciological traverse to Untersee. It covers a total length of about 120 km and leads from the Schirmacher Oasis in south eastern direction to the Gruber mountains and lake Untersee. The traverse is crossing an ablation area and is characterized by blue ice. Partly, the blue ice is covered by thin layers of snow up to a thickness of few decimetres. As the focus of CryoVEx 2010/2011 was on repeat measurements and extension of the test grids in this blue ice area, only the part of the traverse between Novo Airbase and Camp U9 was observed repeatedly. Single tracks were observed by two independent rovers, which allows a direct comparison of the determined ice surface heights. Due to loss of data caused by malfunction of the flash memory cards, the first of three observations could not be recovered. A summary of the profiles on Untersee traverse is given in Table 2.4.

2.4 Equipment

The scientific equipment was compiled and packed into Zarges aluminium boxes at IPG storage in Dresden. Logistic equipment for the field camp and snowmobiles were provided

Table 2.4: Summary of all kinematic GNSS profiles in the blue ice area of Untersee traverse.

GNSS Profile	Date	Description	Approx. Length
357A	10:357	Camp – Airbase without geodetic signals	75 km
357B	10:357	Camp – Airbase with geodetic signals	92 km
006A	11:006	Airbase – U20 (snowmobile breakdown)	17 km
006B	11:006	Airbase – U20	17 km
016A	11:016	Airbase – Camp	80 km
016B	11:016	Airbase – Camp	84 km

Table 2.5: Summary of all kinematic GNSS profiles following CryoSat-2 ground tracks

GNSS Profile	Date	Description	Approx. Length	Transfer
343A, 343B	10:343	Tracks 3644, 3224 North (cw)	53 km	45 km
344A, 344B	10:344	Tracks 3644, 3224 South (acw)	52 km	43 km
349A, 349B	10:349	Track 3955 (acw)	49 km	47 km
021A, 021B	11:021	Tracks 3644, 3224 (acw)	109 km	43 km
024A, 024B	11:024	Track 3955 (acw)	63 km	31 km

by AWI, Bremerhaven. Snowmobiles, clothing, tents, bamboo balises, jerry cans, fuel pump, generator and emergency kit were shipped to Cape Town from AWI storage together with the IPG cargo and provisions ordered from SVR Schiffsversorgung Rostock. Fuel for the snowmobiles (8 drums of 200 litres each) and four gas bottles for the field party were shipped from Neumayer station. Shortly before leaving to Antarctica, another box was sent to Cape Town by air.

After arriving at Novolazarevskaya Airbase, the equipment was sorted by destination and purpose and redistributed to the Zarges boxes, in particular the GNSS reference stations and the equipment for the field camp (Fig. 2.8).

Table 2.6: Summary of observed test fields (grids) in the working area. Profiles A and B refer to the used GNSS receivers.

Grid Number	GNSS profile	Remarks	Date	Profile length	
				grid	transfer
Grid 7	336A, 336B		10:336	108 km	7 km
Grid 7	337A, 337B	subsequent measurement	10:337	5 km	5 km
Grid 4	348A, 348B	grid + snow boundaries	10:348	129 km	35 km
Grid 7	352A, 352B	snow boundaries	10:352	33 km	5 km
Grid 8	353A, 353B	grid + snow boundaries	10:353	86 km	28 km
Grid 8	356A, 356B	subsequent measurement	10:356	65 km	34 km
Grid 9	018A, 018B		11:018	82 km	50 km
Grid 9	020A, 020B	subsequent measurement, snow boundaries	11:020	82 km	29 km
Grid N3	023A, 023B		11:023	96 km	30 km
Grid N3	024A, 024B	subsequent measurement, snow boundaries	11:024	39 km	3 km
Grid N2	031A, 031B	grid + snow boundaries	11:031	123 km	31 km
Grid 8	033A, 033B	repeated measurement	11:033	142 km	35 km
Grid N1	035A, 035B		11:035	84 km	34 km
Grid N1	036A, 036B	subsequent measurement	11:036	44 km	39 km

Table 2.7: Summary of scientific and logistic equipment provided by IPG and AWI.

Satellite positioning	2 GPS antennas TRM14532.00 NONE (Trimble L1/L2 Geodetic)
	4 GNSS antennas TRM57971.00 NONE (Trimble Geodetic Zephyr II)
	4 GNSS receivers Trimble R7 GNSS
	2 GPS receivers Trimble 4000 SSI CORS
	2 GNSS kinematic boxes with 28 Ah battery
	2 GPS navigation receivers (Garmin GPS III and II+)
	2 Garmin mounts and power cables
	1 GPS navigation receiver Garmin Oregon 450 (private)
	1 data logger
	1 Palmtop LX100 data logger
	diverse GNSS antenna and power cables
Fieldwork	1 optical plummet
	1 surveyor's tape 50 *m*
	1 levelling foot rule
Communication	2 Iridium satellite phones with supplies
	2 field notebooks HP Compaq nx7400
Logistics	2 snowmobiles Alpine II (later replaced by Alpine III)
	spare parts Alpine II
	4 Nansen sledges
	1 field party (kitchen)
	1 survival box
	1 emergency kit
	3 Scott tents
	1 hand-driven fuel pump
	4 propane gas bottles 12 *kg*
	8 drums of gasoline 200 *l* each
	8 jerry cans 20 *l* each, cone
	50 *l* two-stroke oil in bottles
	field toilet (bucket), trash bags, pegs
Power supplies	rechargeable batteries 1x80 *Ah*, 2x44 *Ah*, 2x28 *Ah*
	2 chargers 7A, 2 solar chargers 4 *A*
	4 solar panels 60 *W*, 4 solar panels 30 *W*
	2 generators 1kW (1x AWI, 1x ALCI)
	100 m power cable, cable reel and connectors, surge protector
	diverse NiMH rechargeable batteries and charger
Miscellaneous	2 tripods with wooden triangles
	1 levelling tripod
	adaptors for GNSS sites
	1 rigid backpack
	1 spade, shovel, saw
	toolbox, assortment of screwdrivers
	hammer, rubber mallet, wire
	all-purpose oil, two-component glue
	cable straps, tension belts, ropes, duct-tape, aluminium tape
	1 digital thermometer, 1 barometer, 1 wind speed meter
	field glasses
	1 set bar end heating for snowmobile
	2 camping seat cushions
	20 bamboo balises 3.60 *m*

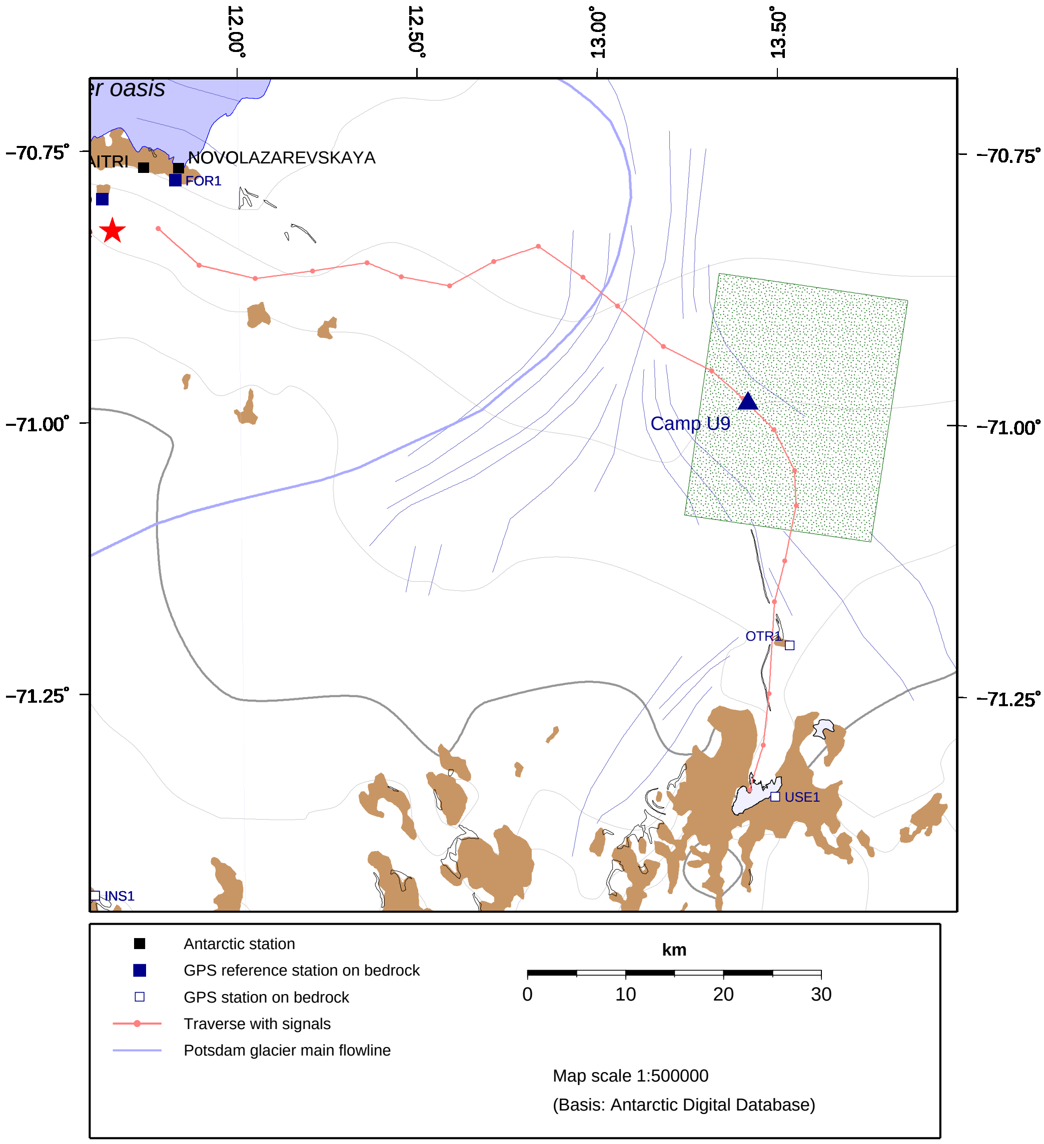

Figure 2.2: The CryoVEx 2010/2011 main working area is located east of the Schirmacher Oasis.

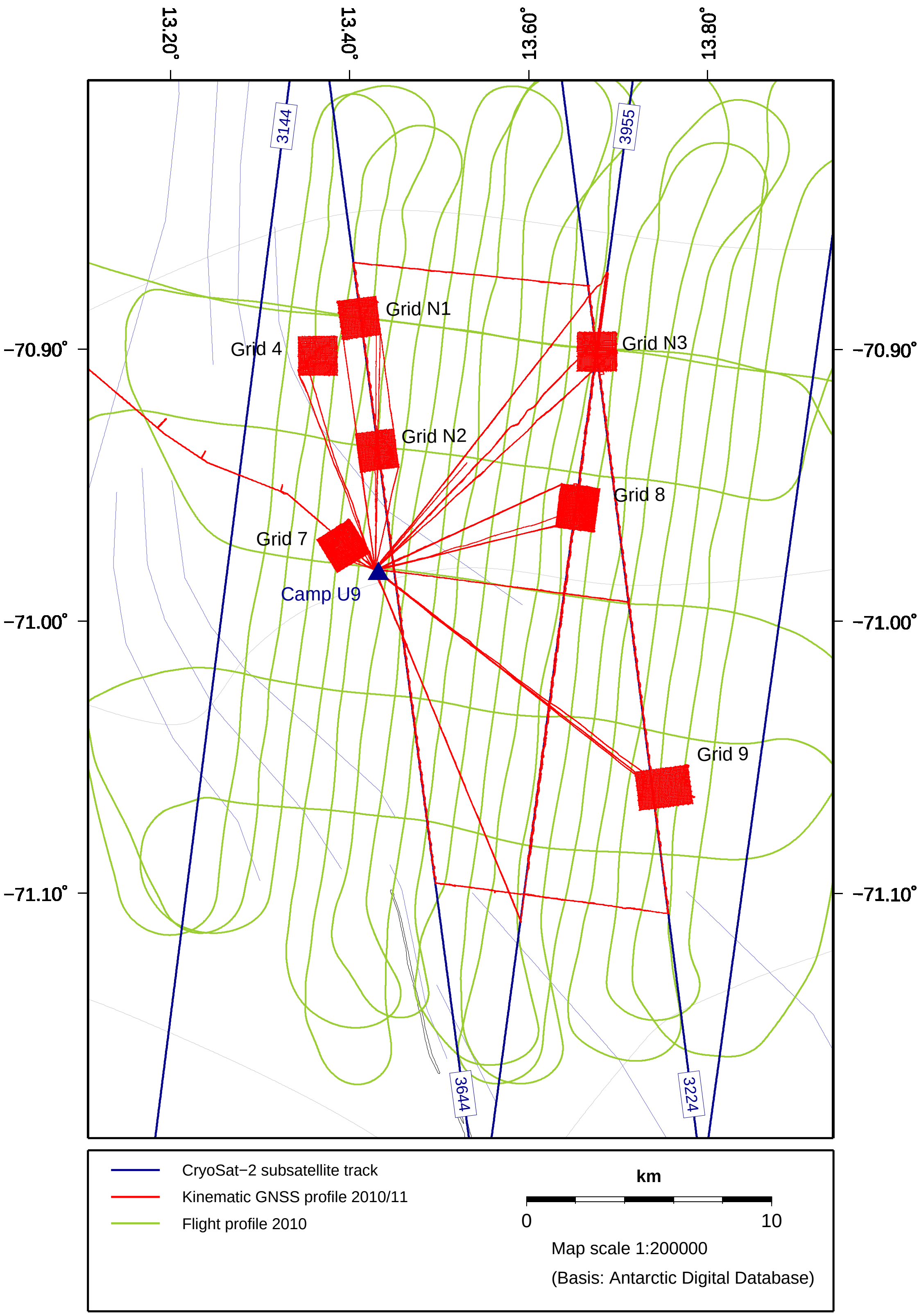

Figure 2.3: Overview of all observed kinematic GNSS profiles within the main working area during CryoVEx 2010/2011 including precisely predicted CryoSat ground tracks.

Table 2.8: Detailed expedition diary

	DATE	DESCRIPTION
Sun,	07/11/2010	Departure from Dresden
Mon,	08/11/2010	Arrival at Cape Town, Transfer to hotel, check of polar clothing, briefing at Meihuizen
Tue,	09/11/2010	Briefing at ALCI
Wed,	10/11/2010	Table Mountain, Ilyushin flight D3 Cape Town – Novo
Thu,	11/11/2010	Unload, sort provisions, preparation of first snowmobile
Fri,	12/11/2010	Tests Trimble R7 GNSS
Sat,	13/11/2010	Tests Trimble R7 GNSS, preparation of AERO
Sun,	14/11/2010	Installation of GNSS reference station AERO, weekly report
Mon,	15/11/2010	Change of living container, mounting of tripods on sledges, preparation of FOR1
Tue,	16/11/2010	Arrival and test of 2nd snowmobile Airbase – Novo
Wed,	17/11/2010	Installation of GPS site FOR1, change in weather
Thu,	18/11/2010	Novo – Airbase check of kinematic data, testing generator, mount GPS on 2nd snowmobile
Fri,	19/11/2010	Test setting-up Scott tent, prepare for logistic trip to field camp
Sat,	20/11/2010	Airbase – Camp U9, set-up of 2 Scott tents
Sun,	21/11/2010	Camp U9 – Airbase, break-down of snowmobile no. 76, weekly report
Mon,	22/11/2010	recreation
Tue,	23/11/2010	Test of corner reflector (Veit Helm, AWI), check and data download at AERO Airbase – AERO – CR – Airbase
Wed,	24/11/2010	Recovery of snowmobile no. 76
Thu,	25/11/2010	Change of living container, check AERO data
Fri,	26/11/2010	Airbase – Novo Check and data download at FOR1, hiking tour
Sat,	27/11/2010	Novo – Airbase smaller improvements of snowmobiles, prepare navigation for Unterseetraverse
Sun,	28/11/2010	Preparations of trip to field camp, weekly report, snowstorm
Mon,	29/11/2010	storm
Tue,	30/11/2010	Airbase – Camp U9 with geodetic signals (**Loss of data!**)
Wed,	01/12/2010	Set-up 3rd Scott tent, install kitchen equipment, charging kinematic boxes
Thu,	02/12/2010	Grid G7 (**Data gaps on box A!**)
Fri,	03/12/2010	Grid G7 (catch-up of missing profiles)
Sat,	04/12/2010	Wind >10 m/s, afternoon extension of camp, set-up reference station CAMPU9
Sun,	05/12/2010	Prepare camp for storm, afternoon wind >10 m/s, weekly report
Mon,	06/12/2010	Storm 30 m/s
Tue,	07/12/2010	Storm >20 m/s
Wed,	08/12/2010	Storm 15 m/s
Thu,	09/12/2010	CryoSat tracks 3224/3644 North
Fri,	10/12/2010	CryoSat tracks 3224/3644 South
Sat,	11/12/2010	Storm 30 m/s
Sun,	12/12/2010	Tidy-up camp after storm, technical work, weekly report

Table 2.9: Detailed expedition diary (continued)

	DATE	DESCRIPTION
Mon,	13/12/2010	Storm 20 m/s
Tue,	14/12/2010	Grid G4
Wed,	15/12/2010	CryoSat track 3955
Thu,	16/12/2010	Storm 30 m/s
Fri,	17/12/2010	Storm >25 m/s
Sat,	18/12/2010	Storm 15 m/s, afternoon snow cover grid 7
Sun,	19/12/2010	Grid G8 (**Failure of box A!**), weekly report
Mon,	20/12/2010	Storm (blowing snow, whiteout), check kinematic box A
Tue,	21/12/2010	Preparation of trip to Airbase and camp during leave, press photo
Wed,	22/12/2010	Grid G8 (catch-up), damages of snowmobile frames
Thu,	23/12/2010	Camp U9 – Airbase with geodetic signals
Fri,	24/12/2010	Negotiations with station chief, recreation (Christmas)
Sat,	25/12/2010	Recreation (Christmas)
Sun,	26/12/2010	Transport Airbase – Novo, check and download of data at FOR1, weekly report
Mon,	27/12/2010	Hiking tour to Maitri Base
Tue,	28/12/2010	Storm
Wed,	29/12/2010	Transport Novo – Airbase
Thu,	30/12/2010	Check and data download at AERO
Fri,	31/12/2010	Recreation (New Year)
Sat,	01/01/2011	Recreation (New Year)
Sun,	02/01/2011	Drifting snow, whiteout, weekly report
Mon,	03/01/2011	Storm >15 m/s
Tue,	04/01/2011	Blizzard
Wed,	05/01/2011	Blizzard
Thu,	06/01/2011	Airbase – traverse point U20 – Airbase, breakdown of snowmobile no. 66 and recovery
Fri,	07/01/2011	Blizzard >20 m/s
Sat,	08/01/2011	Blizzard >20 m/s
Sun,	09/01/2011	Blizzard >20 m/s, weekly report
Mon,	10/01/2011	Blizzard >20 m/s
Tue,	11/01/2011	Visit of White Desert Camp, report
Wed,	12/01/2011	Inspection of snowmobile no. 76, take-off GPS mount from irreparably damaged snowmobile no. 66
Thu,	13/01/2011	Wind 10-15 m/s, drifting snow, arrival and test of 2 snowmobiles Alpine III from Neumayer
Fri,	14/01/2011	Wind >10 m/s, afternoon installation of Garmin power cables to snowmobiles
Sat,	15/01/2011	drifting snow in the morning, afternoon check at AERO
Sun,	16/01/2011	Airbase – Camp U9 with signals U15 and U13, weekly report

Table 2.10: Detailed expedition diary (continued)

	DATE	DESCRIPTION
Mon,	17/01/2011	Tidy-up camp
Tue,	18/01/2011	Grid G9
Wed,	19/01/2011	Storm >15 m/s, data work
Thu,	20/01/2011	Grid G9
Fri,	21/01/2011	CryoSat tracks 3224/3644
Sat,	22/01/2011	Wind >10 m/s
Sun,	23/01/2011	Grid N3, weekly report
Mon,	24/01/2011	CryoSat tracks 3955, Grid N3, weekly report
Tue,	25/01/2011	Wind >10 m/s
Wed,	26/01/2011	Storm >15 m/s
Thu,	27/01/2011	Storm >30 m/s
Fri,	28/01/2011	Blizzard 25 m/s
Sat,	29/01/2011	Blowing snow weakening, in the evening tidy-up camp
Sun,	30/01/2011	Wind >10 m/s, drifting snow, weekly report
Mon,	31/01/2011	Grid N2
Tue,	01/02/2011	Wind >10 m/s, drifting snow, in the evening tidy-up camp, data work
Wed,	02/02/2011	Grid G8
Thu,	03/02/2011	Wind >10 m/s, drifting snow
Fri,	04/02/2011	Wind >10 m/s, drifting snow afternoon Grid N1
Sat,	05/02/2011	Wind >10 m/s afternoon Grid N1, dismount kinematic tripods and reference station
Sun,	06/02/2011	Preparation of return to Airbase, weekly report
Mon,	07/02/2011	Shut-down of camp, Camp U9 – Airbase
Tue,	08/02/2011	Recreation
Wed,	09/02/2011	Wind >10 m/s, recreation
Thu,	10/02/2011	Wind 10 m/s, unpacking of sledges, report
Fri,	11/02/2011	Dismount reference station at AERO
Sat,	12/02/2011	Transport Airbase – Novo, dismount FOR1
Sun,	13/02/2011	Blizzard >30 m/s, weekly report
Mon,	14/02/2011	Blizzard >30 m/s
Tue,	15/02/2011	Blizzard >20 m/s
Wed,	16/02/2011	Transport Novo – Airbase
Thu,	17/02/2011	Preparation of cargo
Fri,	18/02/2011	Preparation of cargo, personal baggage, weekly report
Sat,	19/02/2011	Shipping of snowmobiles Alpine III back to Neumayer, Ilyushin flight D11 Novo – Cape Town
Sun,	20/02/2011	Arrival at Cape Town, Transfer to accommodation
Mon,	21/02/2011	
Tue,	22/02/2011	
Wed,	23/02/2011	
Thu,	24/02/2011	
Fri,	25/02/2011	
Sat,	26/02/2011	
Sun,	27/02/2011	
Mon,	28/02/2011	Departure from Cape Town
Tue,	01/03/2011	Arrival at Dresden

Figure 2.4: GNSS reference station AERO on bedrock.

Top: Installation of setup and initialization of observations on Nov 14, 2010. The GNSS (GPS+GLONASS) antenna (TRM57971.00 NONE) is visible on top of the rock left of the historical geodetic tripod. GNSS receiver (Trimble R7 GNSS), two rechargeable batteries and solar charger are stored in the Zarges aluminium box which was protected from snow intrusion. Undisrupted power supply was ensured by three large solar modules oriented north-west, north and north-east.

Bottom: Scenic view from Aerodromnaya nunatak towards Schirmacher Oasis and Nivlisen ice shelf in northern direction.

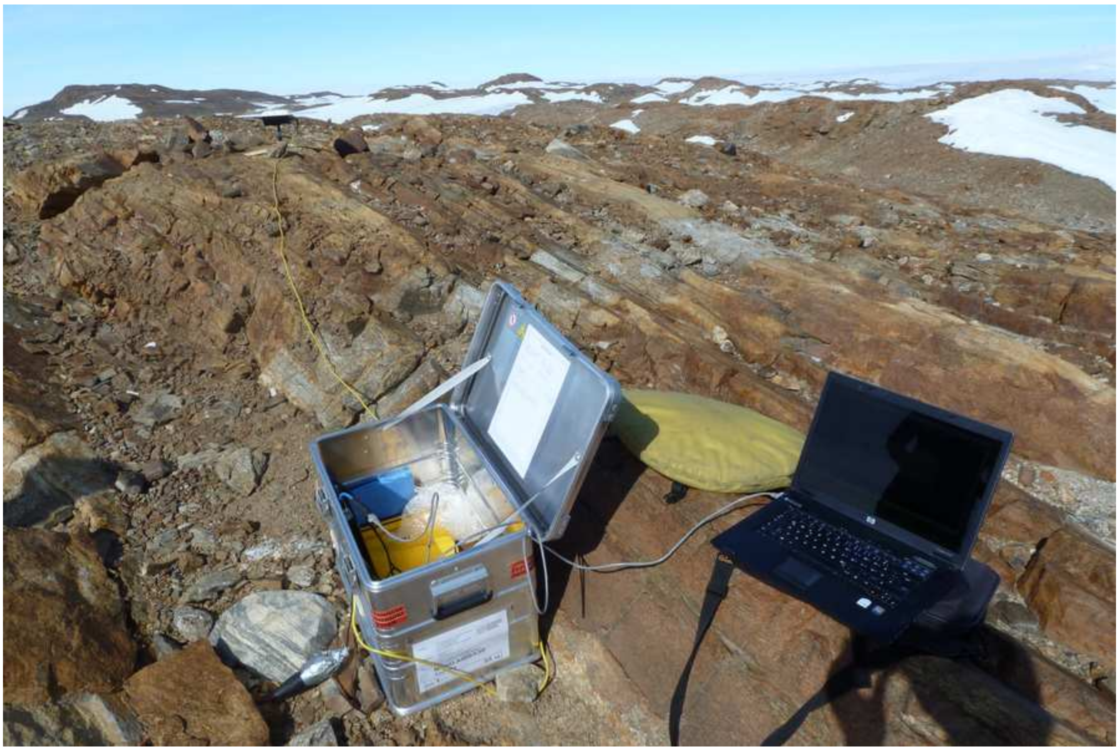

Figure 2.5: GPS reference station FOR1 on bedrock equipped with GPS antenna (TRM14532.00 NONE). The Zarges aluminium box stored a Trimble 4000 SSI CORS GPS receiver, a data logger, one small rechargeable battery and a charger device. Due to the embedded Linux system of the data logger, data download could be done by FTP with measurements ongoing. The site is located in vicinity of Novolazarevskaya station in Schirmacher Oasis, so power supply could be obtained from the nearby geophysical laboratory using a set of two 50 m power cables.

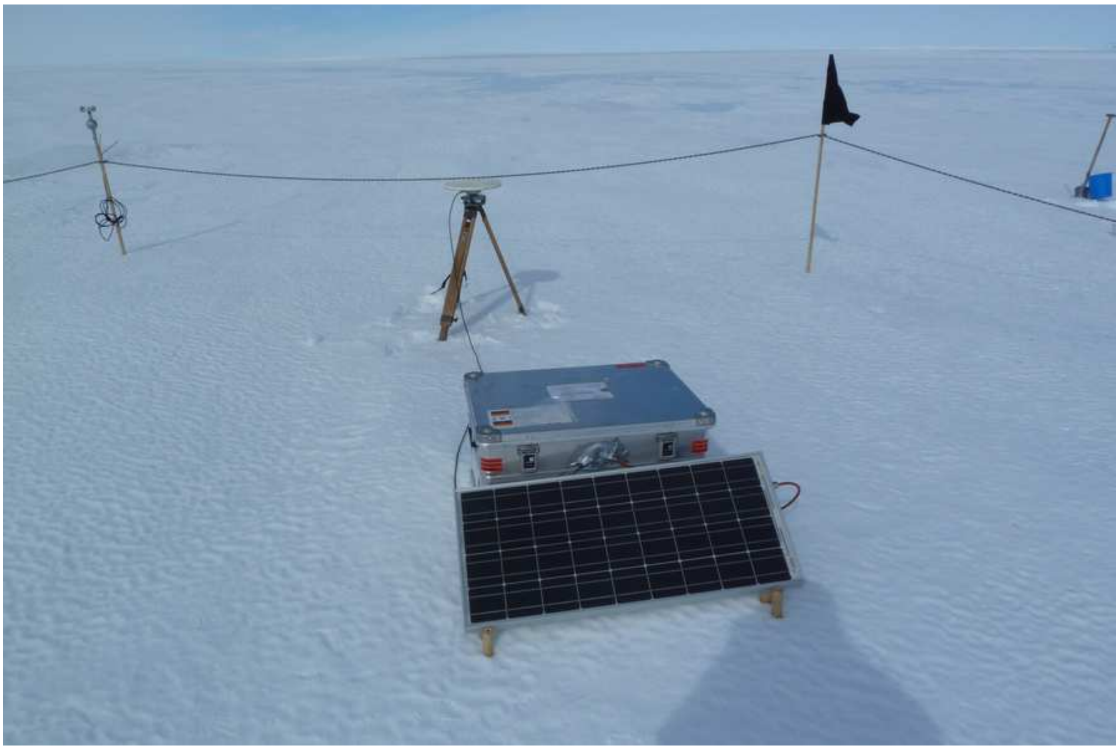

Figure 2.6: Setup of GPS reference station on ice (field camp U9) which served as a backup for AERO (same hardware configuration). The antenna is mounted on a tripod. To prevent the legs from melting out they were covered with fresh snow. Due to severe blizzards, no continuous observations were collected, but correct function was checked before leaving the camp for measuring kinematic profiles.

Figure 2.7: Kinematic GNSS observations in the field. Top: Setup of rover. The GNSS antenna (TRM14532.00 NONE) is mounted onto a Nansen sledge using a wooden triangle and tighteners specially designed at IPG/TU Dresden. Nansen sledges are flexible, support a lot of torsion and thus keep to the uneven ground surface very well. The red survival box was carried in the field at all times as well as an emergency kit. The sledge is pulled by a two-stroke snowmobile which carries also the small aluminium box containing GNSS receiver (Trimble R7 GNSS) and a small rechargeable battery. Alignment on the grid profiles and traverse accurate to some meters was ensured by handheld Garmin navigational GPS receivers. Bottom: Partly snow covered new grid N1 centred on CryoSat-2 track 3644, observed on February 04/05, 2011. Snowmobiles had to be changed to the newer model Alpine III at short notice for the second phase of the campaign.

Figure 2.8: Snowmobile trek, shortly before leaving Novolazarevskaya Airbase on November 20, 2011 to build up the field camp. Both snowmobiles and all four Nansen sledges are fully equipped with cargo, i.e. jerry cans with manually mixed two-stroke fuel, the first two drums of gasoline, gas bottles, field party, generator, tents (long gray bags), some food, personal bags. The 75 km trip took more than 12 hours due to slippery ice conditions.

Figure 2.9: View at the field camp.

Top: Tents are separated about 20 meters to prevent snow dunes. During this season, challenging conditions in the field camp were characterized by only a thin snow layer and heavy storms without snowfall in December, so the tents had to be fixed several times. In the second phase of the campaign, heavy blizzards and blowing snow occurred.

Bottom: 100 km/h storm and bad visibility. The bamboo balises and rope guaranteed orientation in case of a real whiteout when only the top of the next tent was visible.

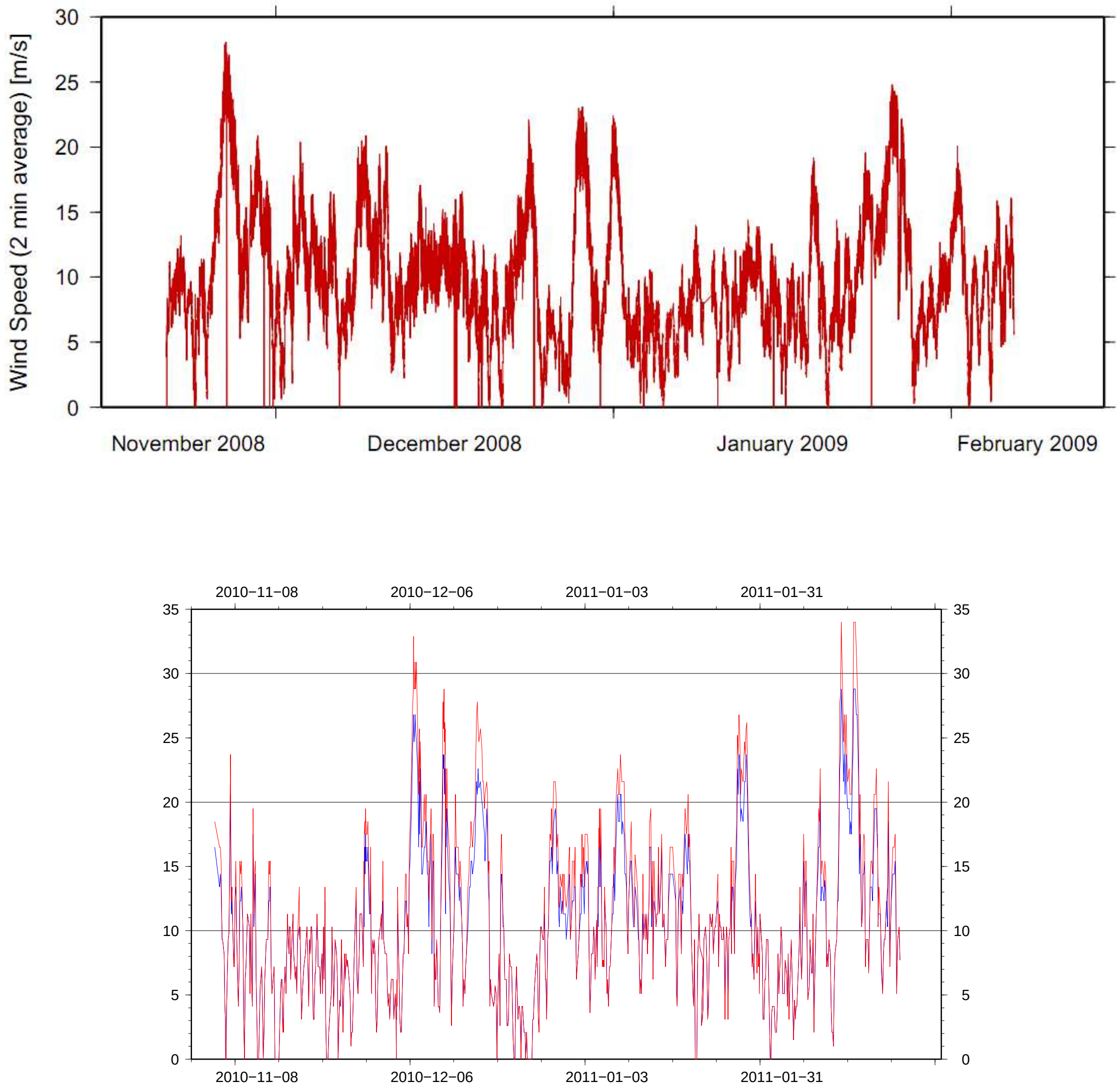

Figure 2.10: Wind speeds in $[m \cdot s^{-1}]$ at Novolazarevskaya Airbase during seasons 2008/09 (upper) and 2010/11 (lower). In the lower diagram, the red curve denotes maximum speed (gusts) while the blue curve shows mean values. In December, three severe storms occurred and allowed for only few days of fieldwork.

3 Data analysis

3.1 GNSS reference stations on bedrock

In order to reduce systematic effects all kinematic GNSS observations need to be analysed with respect to reference stations (differential GNSS). The positions and velocities of the reference stations FOR1 and AERO have been determined with respect to the International Terrestrial Reference Frame (ITRF) using GNSS observations of several years. Due to technical reasons FOR1 stored the observation data with a sampling rate of 5 seconds. We used the WaRINEX module of the WaSOFT software package [1] to densify the observation interval to 1 second (Wanninger, 2000, 2003; Schüler, 2006). That has been necessary in order to consider as much as possible of the kinematically obtained datasets during data analysis. The interpolation algorithm used within the WaRINEX module increases the data sampling rate without a significant loss of accuracy (Wanninger, 2000).

To determine the positions and velocities of the reference stations FOR1 and AERO we used a modified version of the *Bernese GPS Software v5.1*. Double-differenced phase observations were the main observables. The models and strategies applied for this processing are state of the art (i.e. final orbits and Earth rotation parameters provided by IGS, absolute receiver/satellite phase centre variations and offsets, consideration of higher-order ionospheric effects). Table 3.1 shows the calculated coordinates of the appropriate reference stations.

Table 3.1: Coordinates of the GNSS reference stations.

Station	X [m]	Y [m]	Z [m]
AERO	2061472.157	423926.981	-6001259.379
FOR1 66023M001	2061522.473	431615.701	-6000314.492

3.2 Kinematic GNSS measurements

The analysis was performed using a modified version of the *Bernese GPS Software* in its latest version v5.1. As mentioned above, positions and velocities of FOR1 and AERO were determined in a global reference frame. After that, the positions of each kinematic GNSS profile were estimated with respect to these reference stations.

[1] http:\\www.wasoft.de

Then, the accuracy of the determined coordinate trajectories were evaluated using a crossover analysis. Figures 3.1 to 3.16 show the results of the crossover analysis. Each figure contains the specified kinematic GNSS profiles and the color-coded crossover errors at the trajectory intersections. Internal (within one track) and external (between two separate tracks) crossovers were computed. A histogram shows the distribution of the absolute crossover errors as well as the number of crossovers, RMS, Median and the number of outliers. The outlier threshold is set to 1 m. Table 3.2 summarizes the obtained crossover results. All of the analysed areas provide a Median better than 3 cm, most of them show a RMS better than 5 cm. The reason for higher values is well-founded in the strong and inhomogeneous snow covering and the resulting rough snow surface. Due to the simultaneously processed GPS and GLONASS observation data the crossover accuracy could be significantly improved. Figure 3.2 shows the results for a GPS only solution. It can be compared to Figure 3.1 which contains the combined GNSS solution. The improvement is about 2 cm in RMS and 0.5 cm in Median. Similar related enhancements can be found for the other regions.

The CryoVEx 2010/11 campaign activities involved also simultaneous airborne radar altimetry (ASIRAS) and laser data acquisition (ALS) over the blue ice region. The airborne part of the campaign was carried out by the Alfred Wegener Institute (AWI) using the AWI POLAR 5 aircraft. It was planned to compare the ground-based GNSS measurements to ASIRAS and ALS data. Unfortunately, the AWI laser scanner was out of order during the corresponding flights. Therefore, only the combined consideration of GNSS and ASIRAS could be carried out. Figure 3.17 presents a very preliminary crossover analysis of one ASIRAS flight following 2 CryoSat ground tracks and the corresponding GNSS profiles. The comparison of both datasets yields to a standard deviation of 0.85 m and a Median of -0.12 m. 15400 GNSS/ASIRAS crossovers could be found. The result shows the high quality of the obtained GNSS and ASIRAS datasets.

The kinematically observed test grids were partially covered by snow. Therefore, we additionally followed the snow boundary within the grid to separate blue ice parts from snow covered segments. The snow thickness at discrete points has also been measured during the kinematic survey. The Figures 3.18 to 3.24 show the particular kinematic GNSS profiles and the appropriate discrete values of the thickness of snow.

To obtain annual surface height changes of the grid test areas we compared the recent data with the results of CryoVEx 2008/2009. The output of this first comparison is preliminary and presented in Table 3.3 as well as in Figures 3.25 to 3.28. Furthermore the seasonal surface height change in the Grid 8 area can be provided comparing the both data sets obtained in November 2010 and February 2011. The results are illustrated in Figure 3.29.

The Untersee traverse has been ascertained, signalised and initially observed during the Antarctic season 1990/91 and connects the oasis with the Wohlthat massif crossing the main flowline of the Potsdam glacier (Fig. 2.2, Korth and Dietrich (1996)). Starting at Novolazarevskaya airbase the traverse runs about 75 km in an eastward direction up to signal U9 where the field camp was located. Thereafter, the route changes its direction to the south and ends in the Wohlthat massif.

During 1991–2000 the heights of the traverse signals have been observed several times by static GPS measurements (Korth and Dietrich, 1996; Korth, 1998). Since 2000 kinematic GPS/GNSS measurements along the traverse could be carried out three times (2000/01, 2008/09, 2010/11). Using these available datasets we determined the rates of the surface height change over different time spans:

1. 1991–2000: The rates of the surface height changes at discrete signal positions could be obtained using results of 5 observation campaigns. The values of some selected signal positions are presented in Figure 3.30 (bottom).

2. 2000–2008: The crossover comparison of the kinematic GPS measurements of the years 2000 and 2008 yields to height changing rates over 8 years (Fig. 3.30, second from the bottom).

3. 2008–2010: The crossover analysis of both CryoVEx campaigns yields to rates of the surface height change of the last 2 years (Fig. 3.30, second from top).

Whereas the changing rates of the surface heights show a negative trend up to year 2008, the rates determined over the last 2 years register positive trend values. It has to keep in mind that these results are very preliminary and have to be further inverstigated.

Table 3.2: Summary of crossover analysis. The observation of Grid 8 and the satellite ground tracks have been repeated (rep.). The outlier threshold is 1 m.

Grid / Profile	Number of crossovers	RMS [cm]	Median [cm]	Number of outliers
Grid 7	1595	6.8	1.8	8
Grid 7 snow	2753	7.2	2.5	10
Grid 4	2250	2.8	1.6	0
Grid 8	2819	3.2	1.8	0
Grid 8 rep.	2274	2.6	1.6	0
Grid 9	2322	3.3	1.6	0
Grid N1	2305	3.3	1.9	0
Grid N2	1973	3.9	1.7	0
Grid N3	2427	5.9	1.9	15
Profile Airbase - Camp	933	2.9	1.7	0
Profile Camp - Airbase	844	2.1	1.3	0
Track 3224	1294	8.1	1.7	0
Track 3224 rep.	476	2.6	1.4	0
Track 3955	112	2.5	1.3	0
Track 3955 rep.	3048	5.4	1.9	17
Mean	1828	4.2	1.7	

Table 3.3: Surface height changes of the observed kinematic test grids within a time interval of about two years (mean difference and mean rate).

Grid	Mean surface height difference [cm] $\Delta h = h(t_2) - h(t_1)$	Mean annual rate of height change [cm/yr] $\Delta\dot{h} = \Delta h \cdot \Delta t^{-1}$	Date of 1st observation (t_1)	Date of 2nd observation (t_2)	Time difference [days] Δt
Grid 4	+13.7	+6.9	Nov 28, 2008	Dec 14, 2010	746
Grid 7	+15.2	+7.6	Dec 6, 2008	Dec 2, 2010	726
Grid 8	+20.6	+10.3	Dec 7, 2008	Dec 19, 2010	742
Grid 9	+5.0	+2.5	Dec 18, 2008	Jan 19, 2011	762

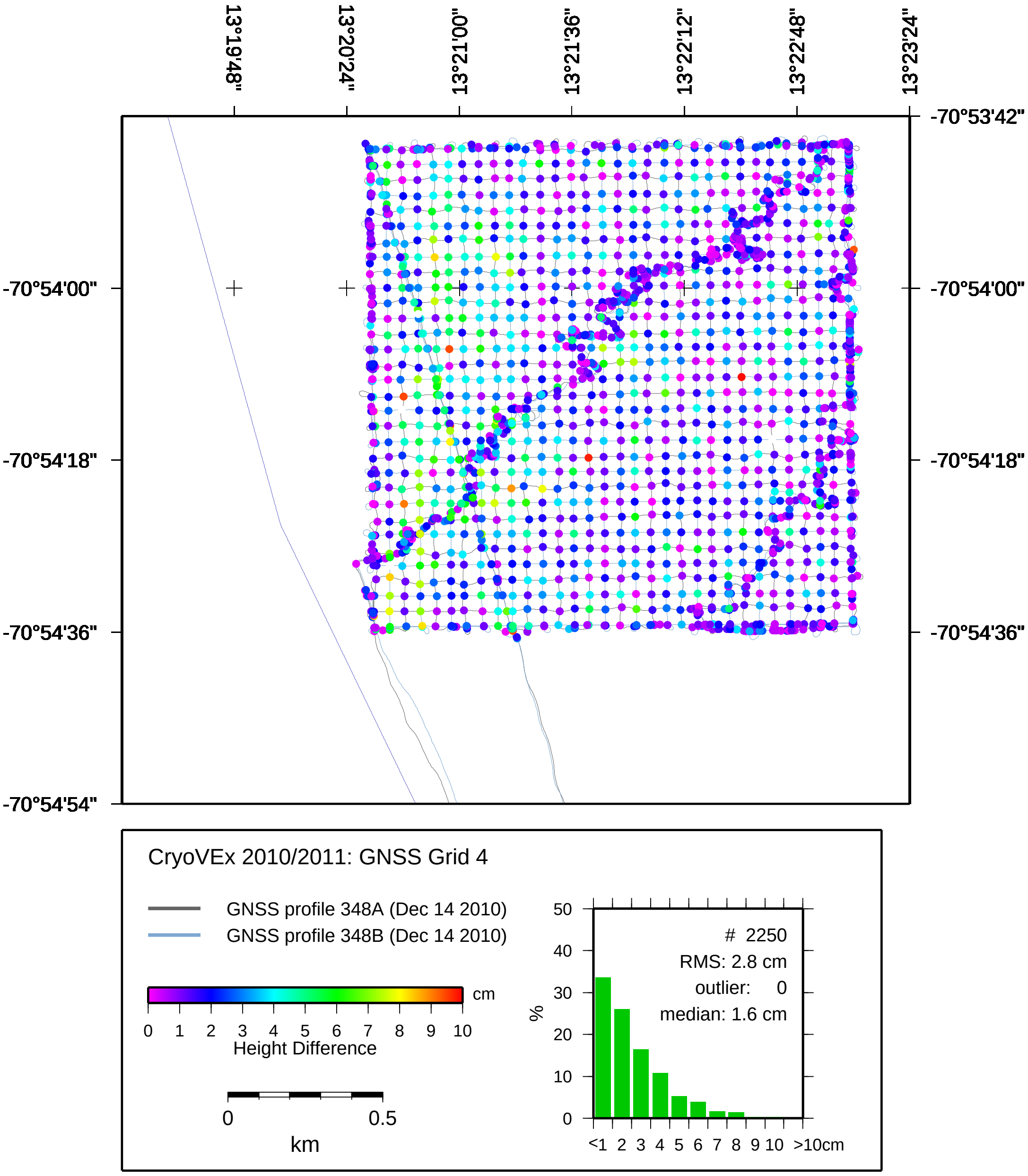

Figure 3.1: GNSS crossover analysis Grid 4

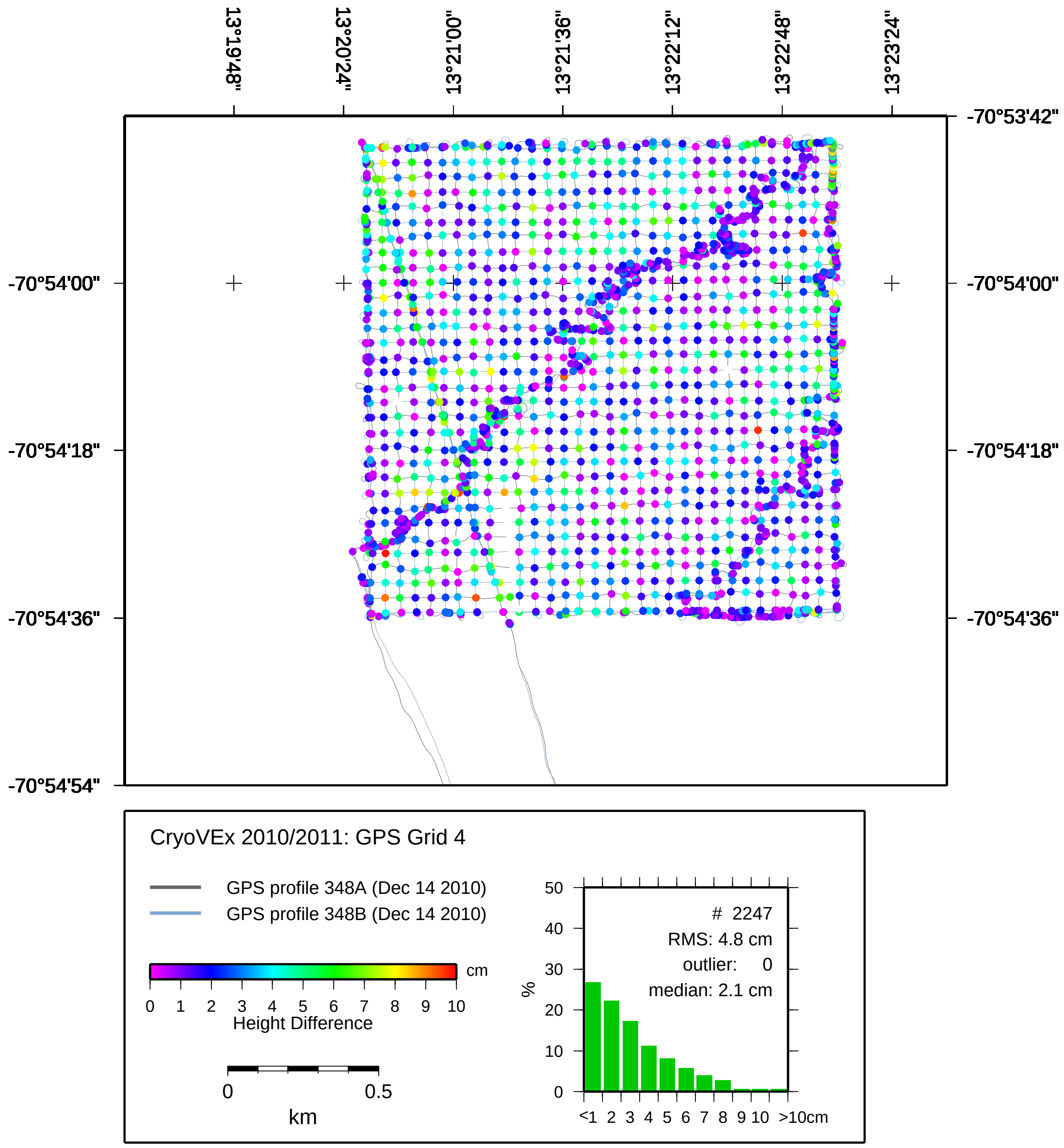

Figure 3.2: Crossover analysis Grid 4, GPS only solution

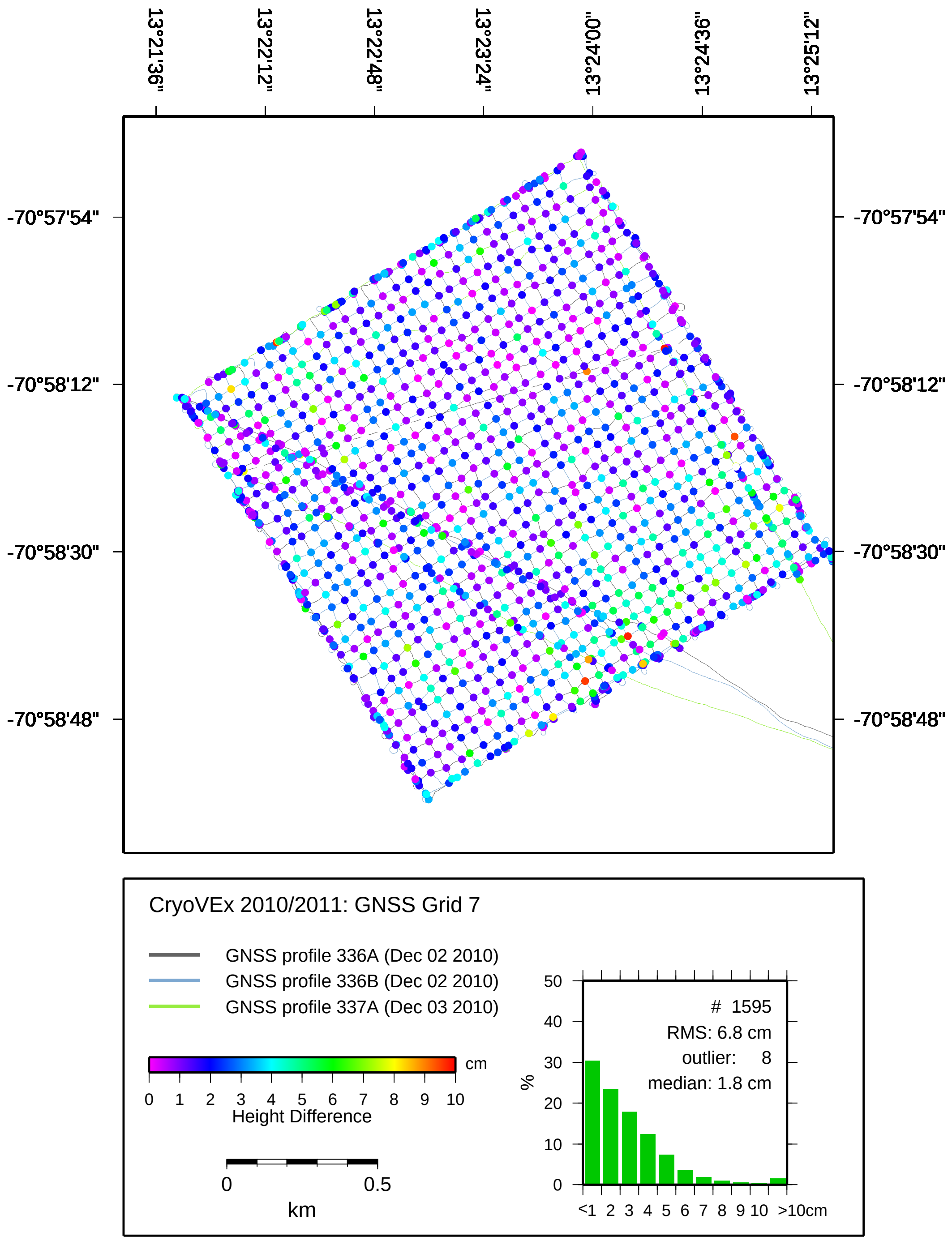

Figure 3.3: GNSS crossover analysis Grid 7

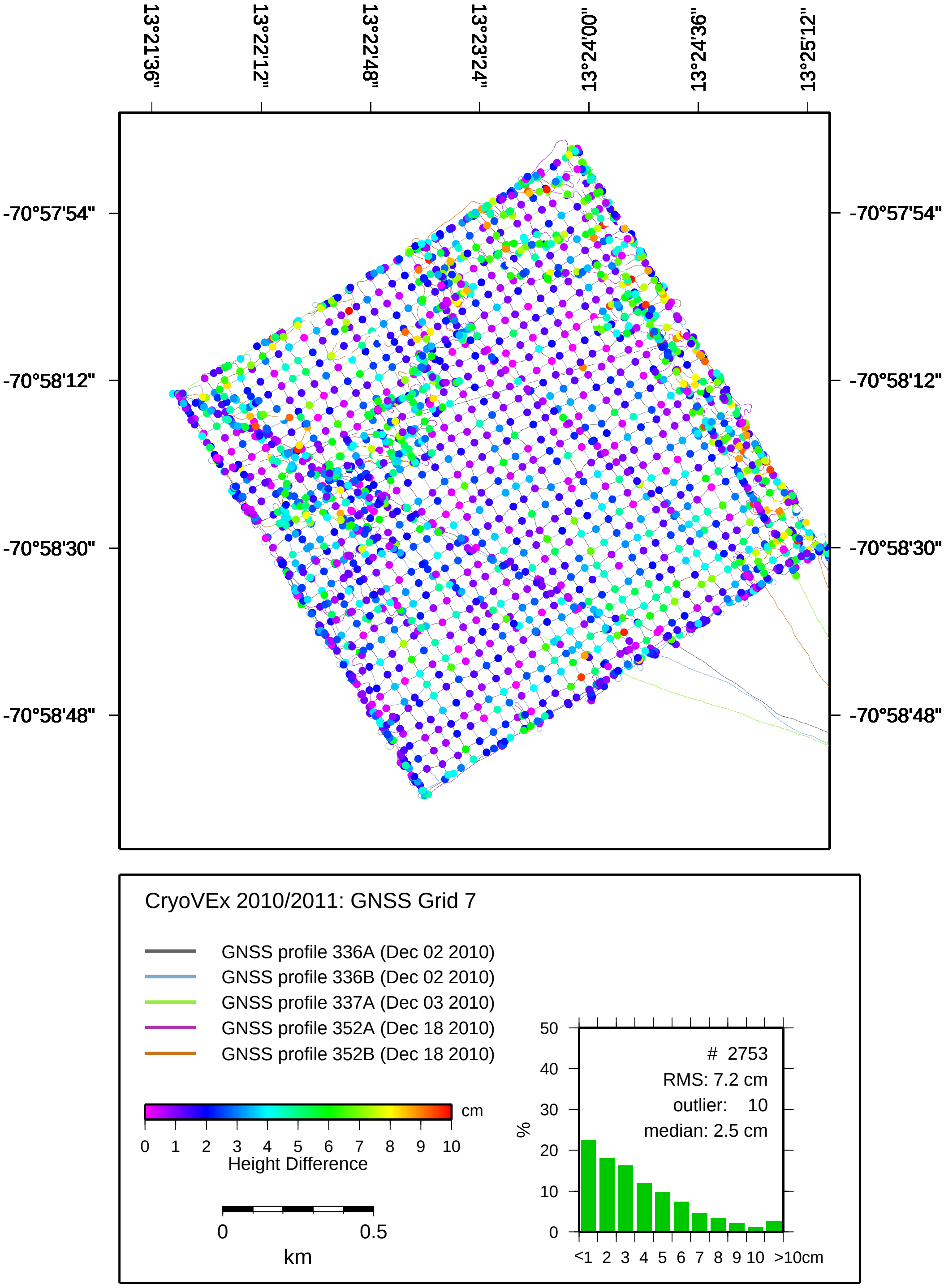

Figure 3.4: GNSS crossover analysis Grid 7 including snow borders

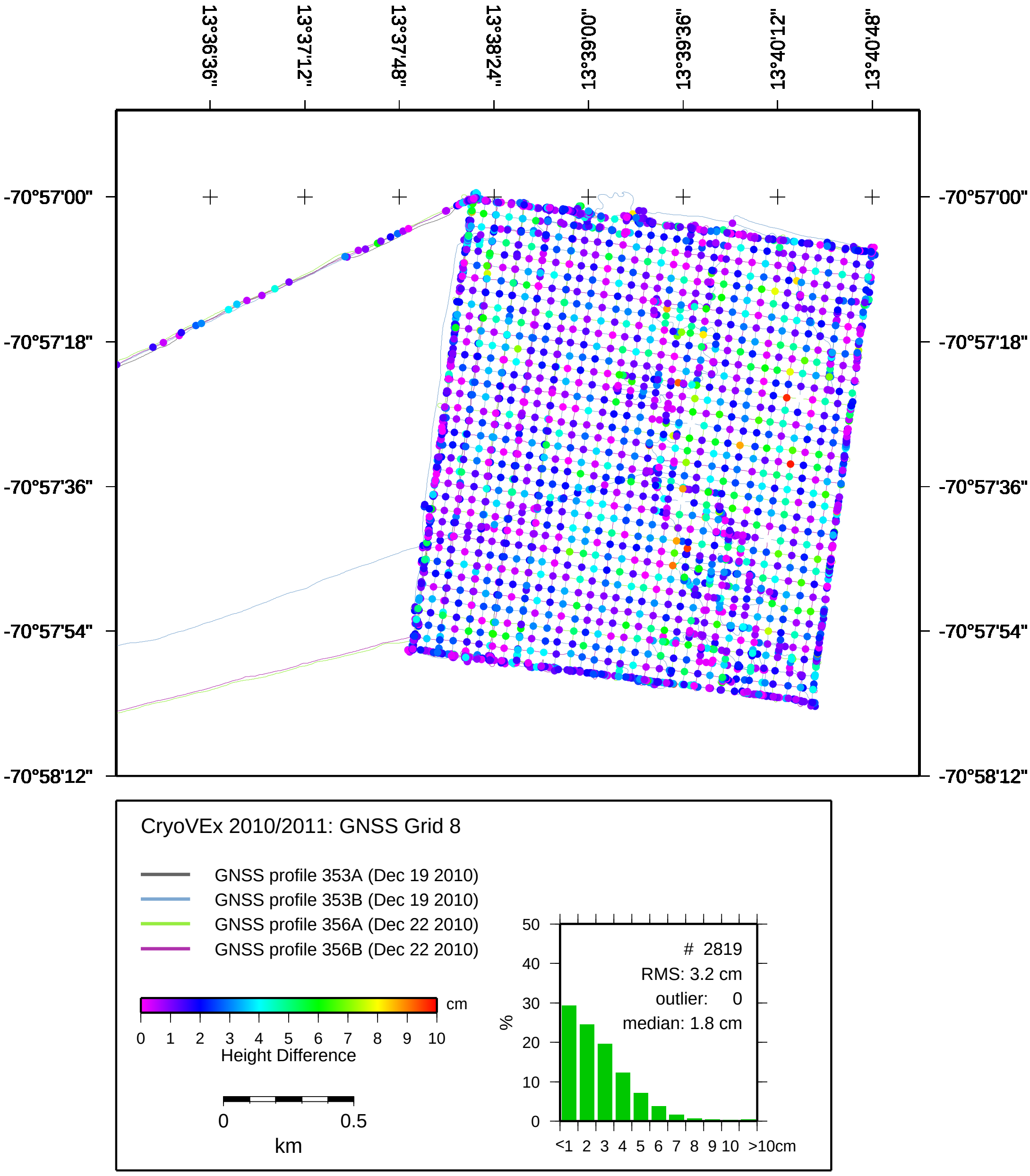

Figure 3.5: GNSS crossover analysis Grid 8

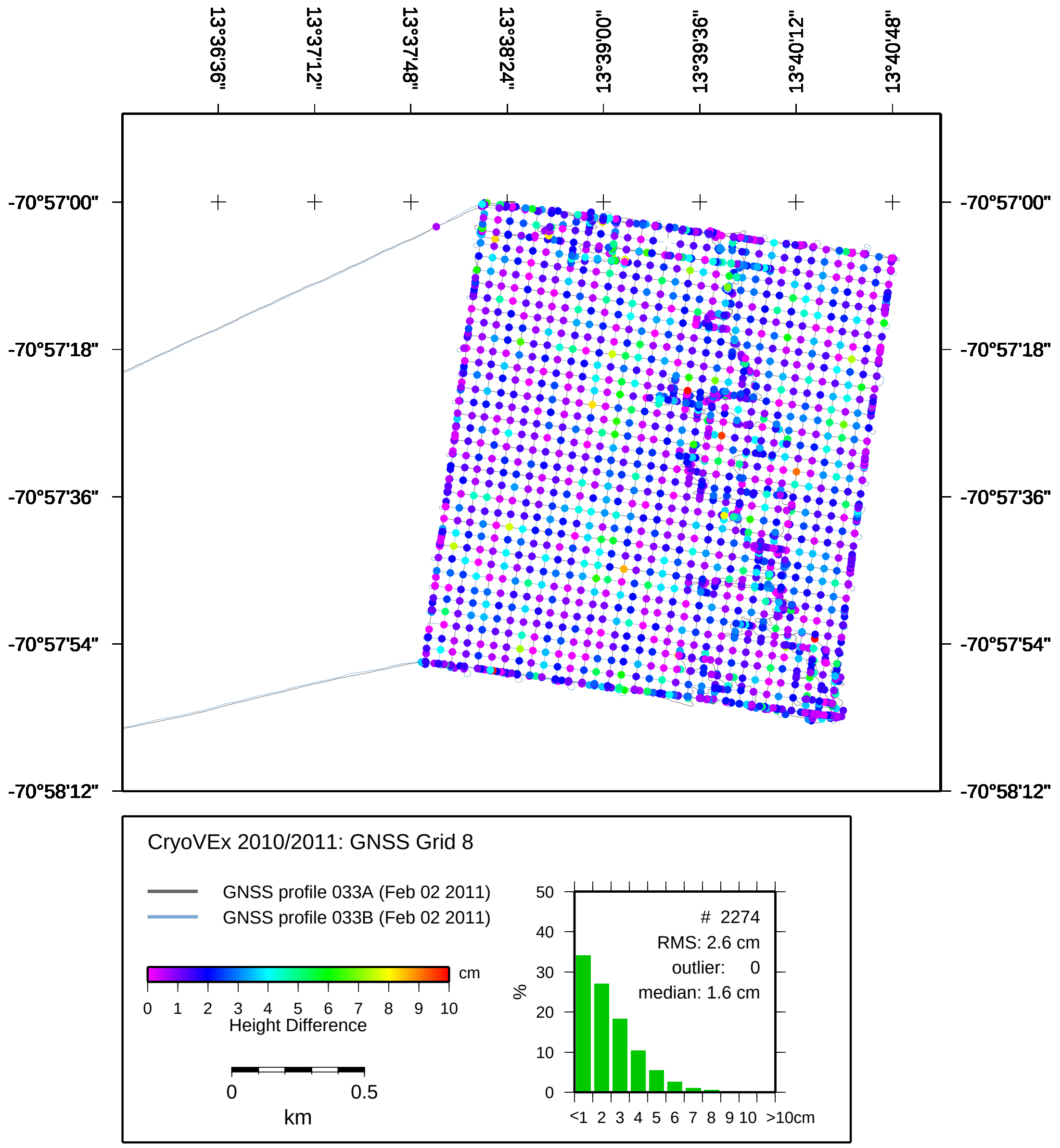

Figure 3.6: GNSS crossover analysis Grid 8, repeated measurement

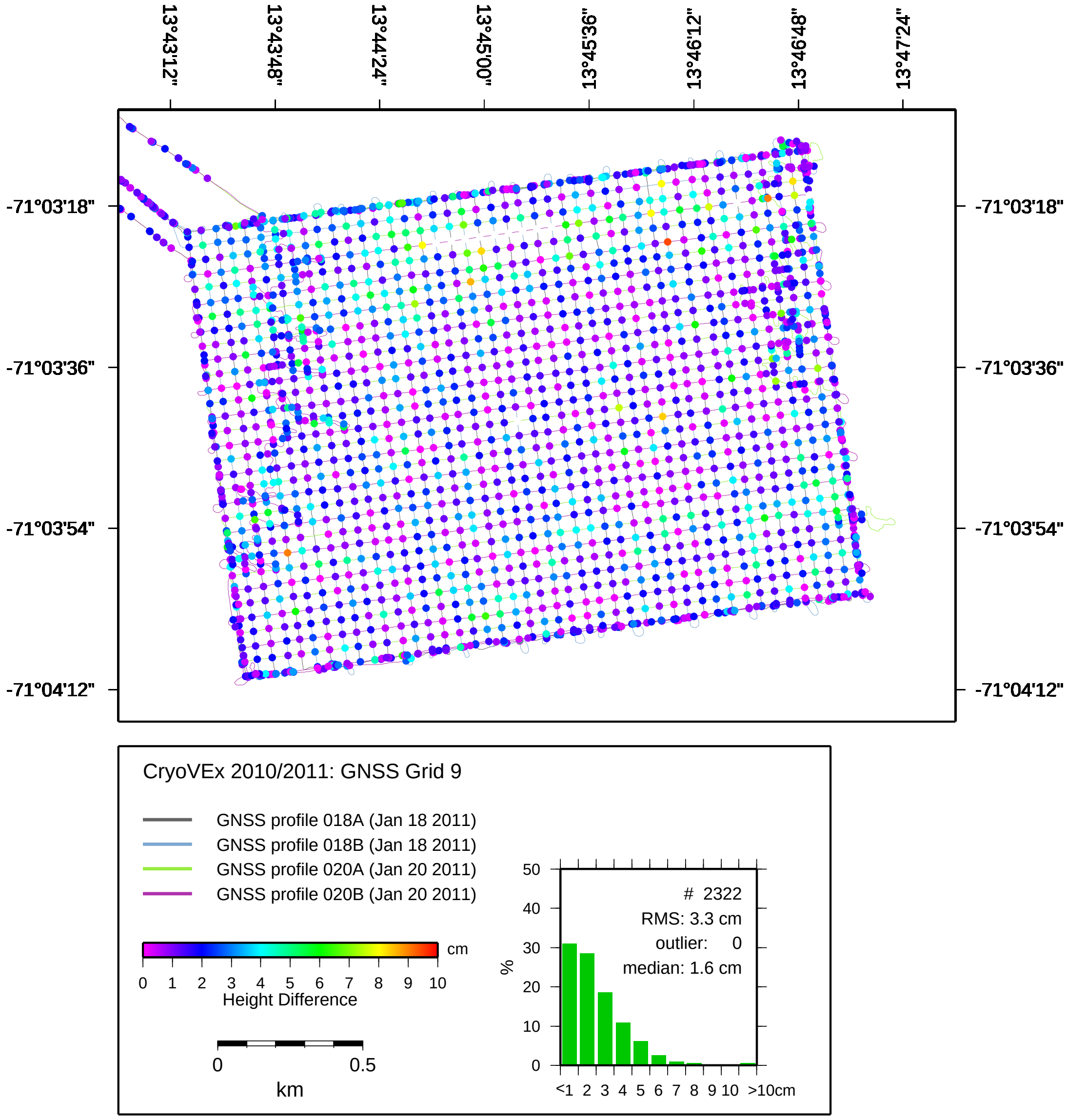

Figure 3.7: GNSS crossover analysis Grid 9

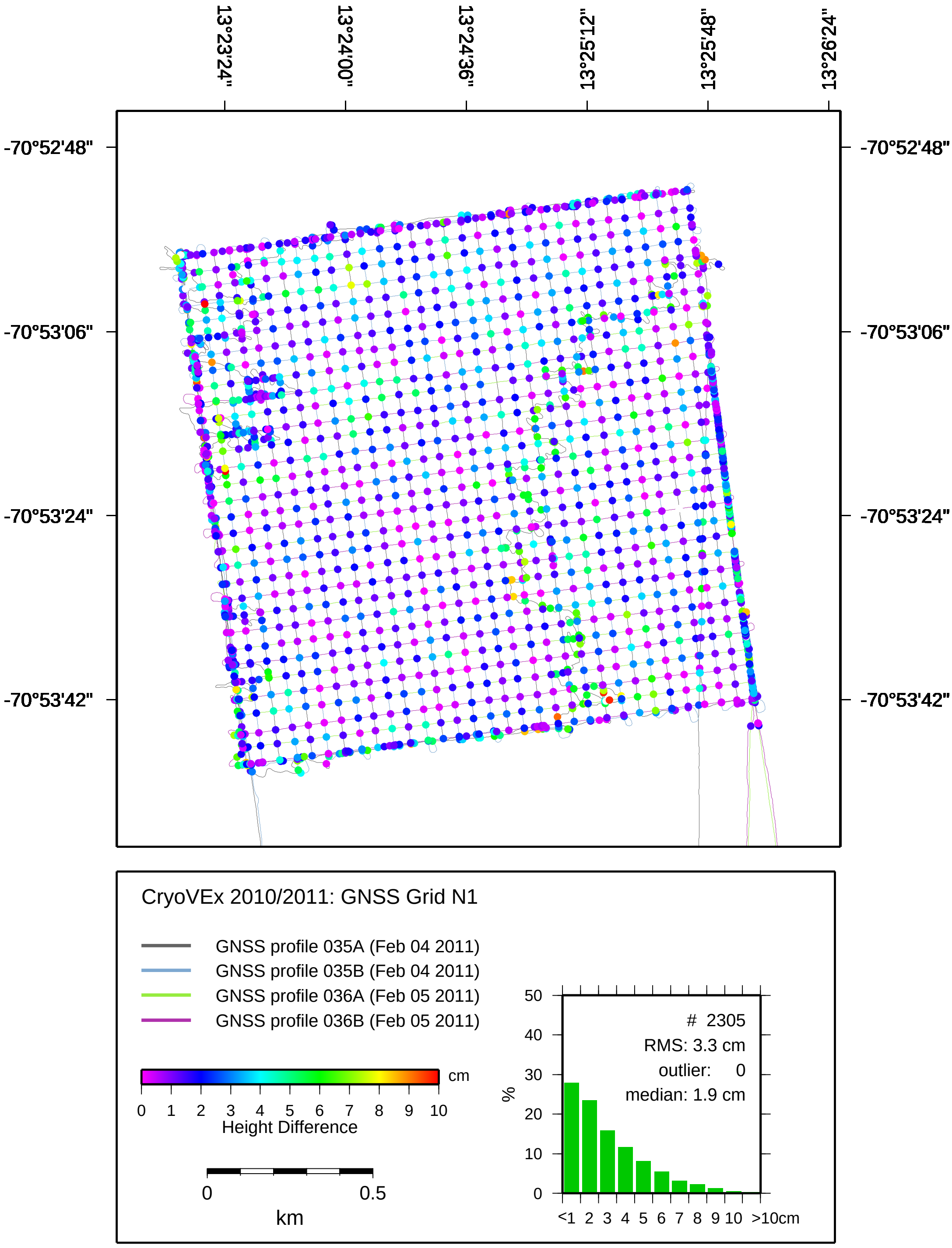

Figure 3.8: GNSS crossover analysis Grid N1

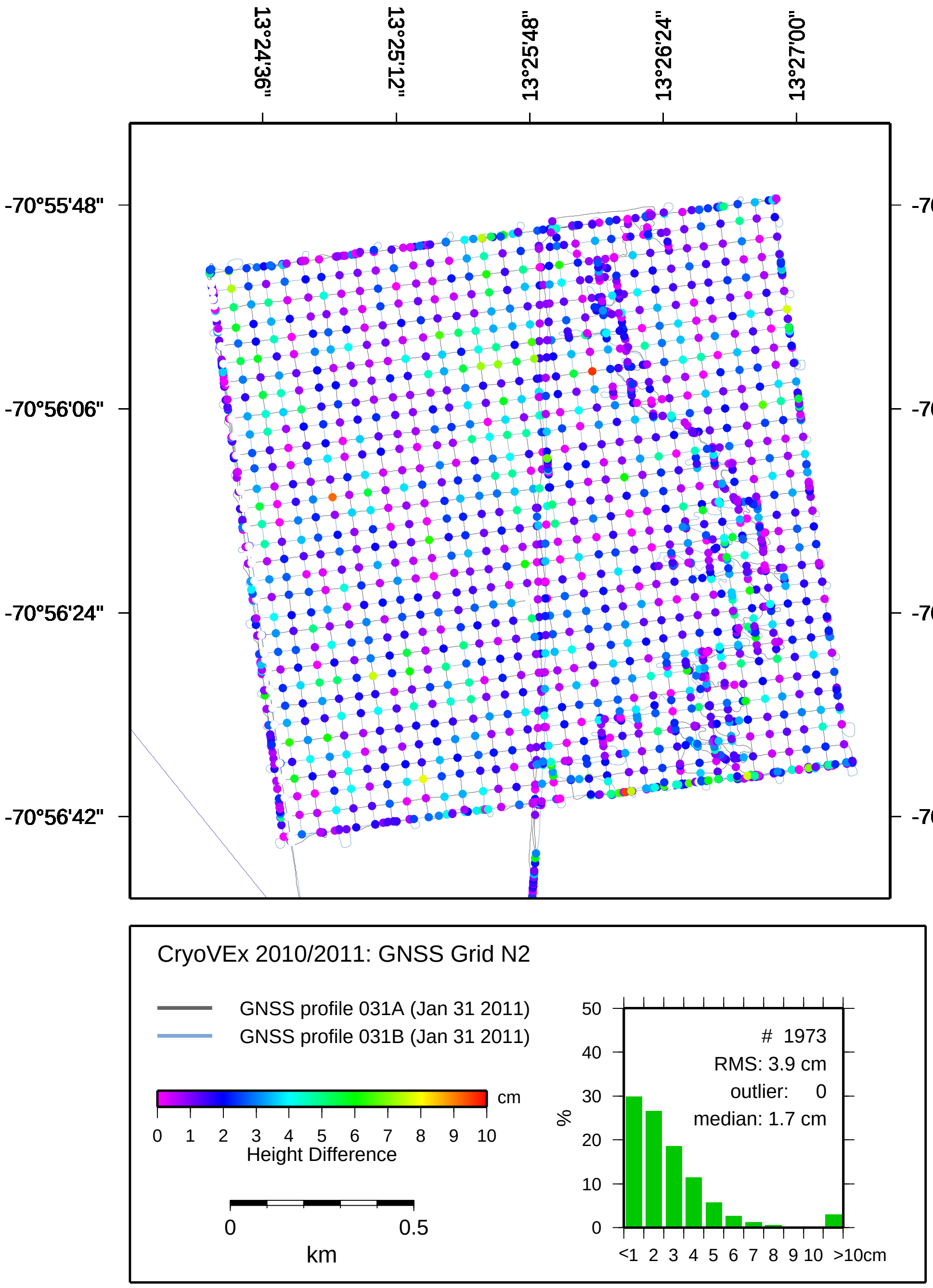

Figure 3.9: GNSS crossover analysis Grid N2

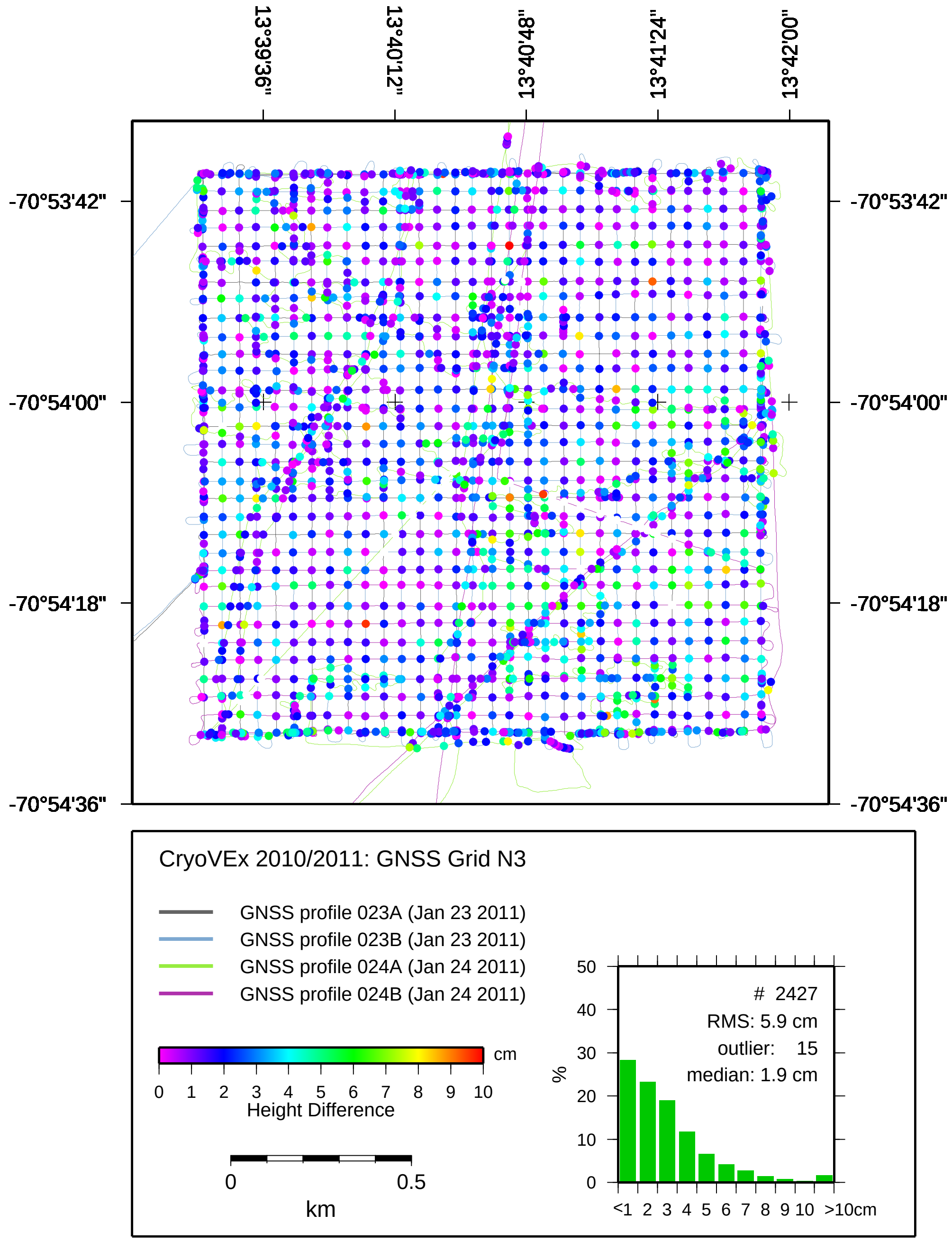

Figure 3.10: GNSS crossover analysis Grid N3

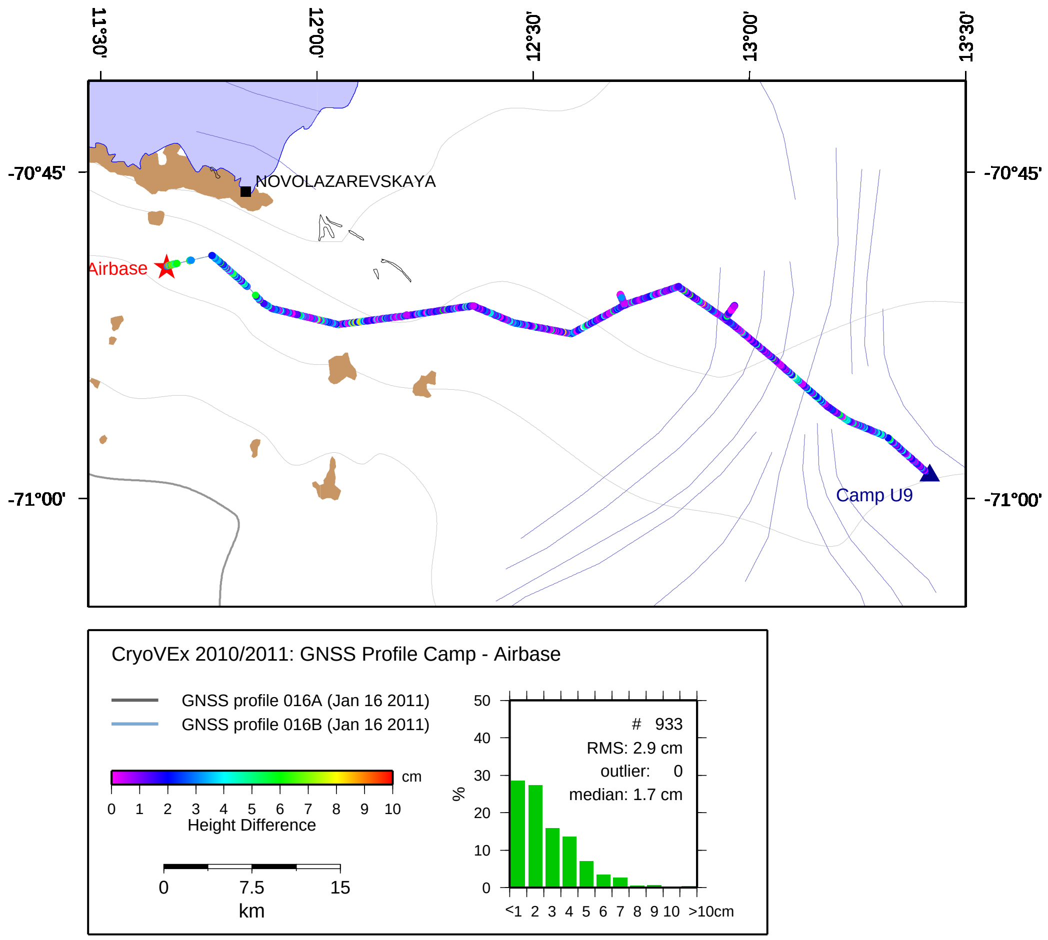

Figure 3.11: GNSS crossover analysis profile Airbase - Camp

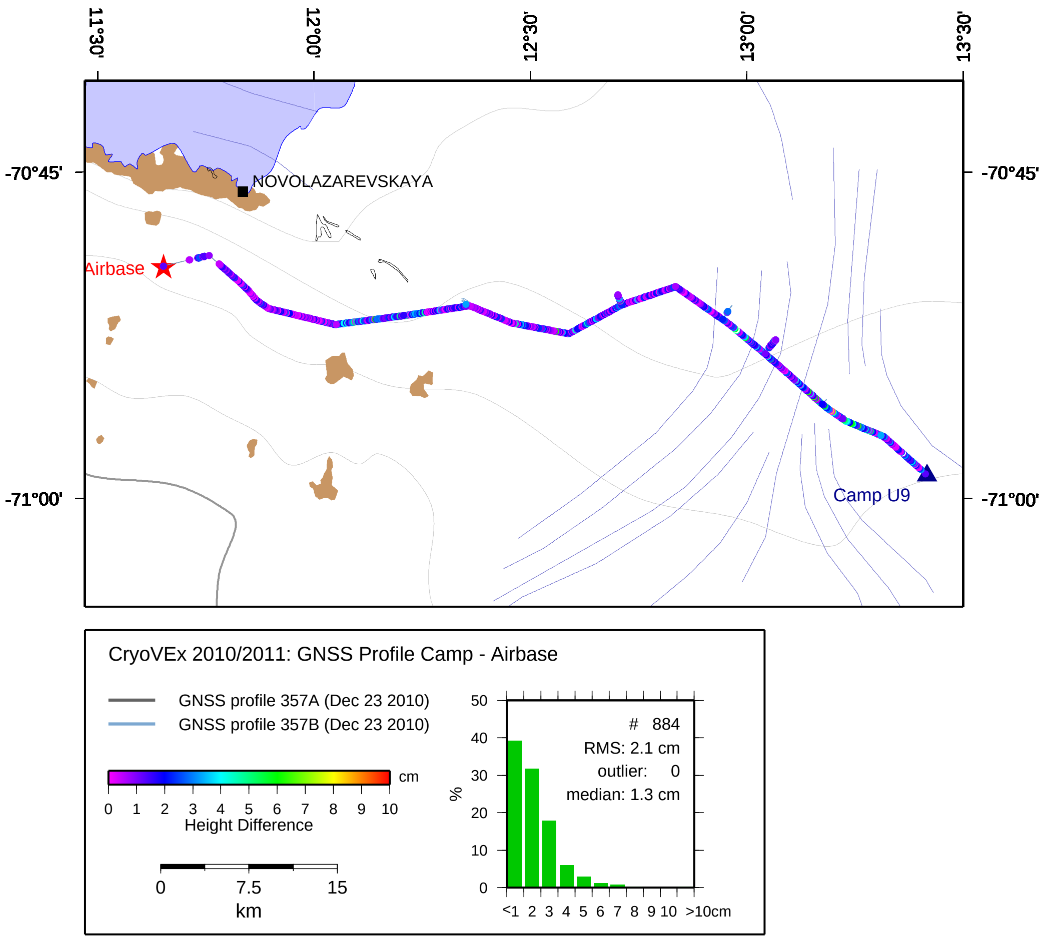

Figure 3.12: GNSS crossover analysis profile Camp - Airbase

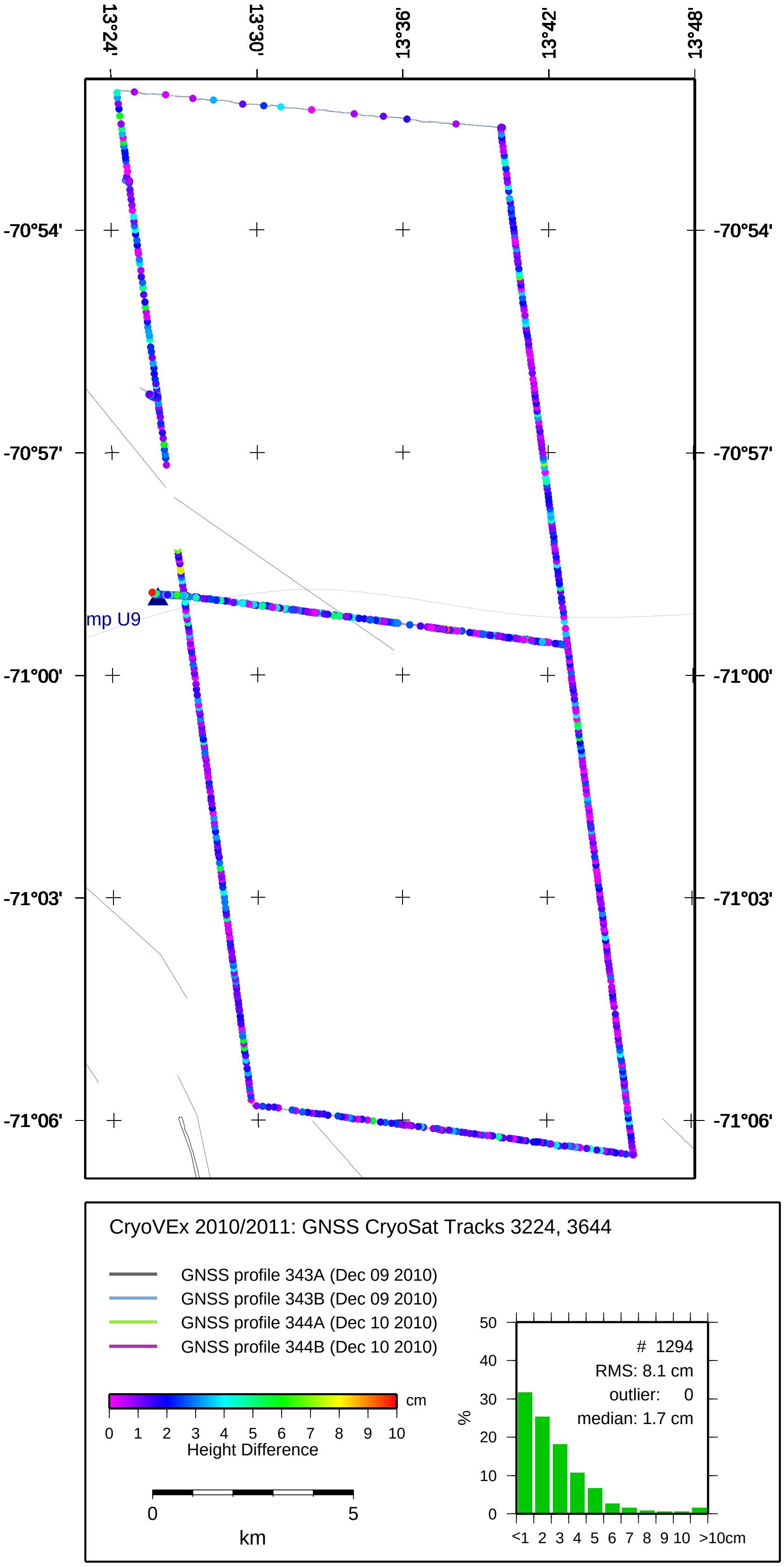

Figure 3.13: GNSS crossover analysis CryoSat ground track 3224

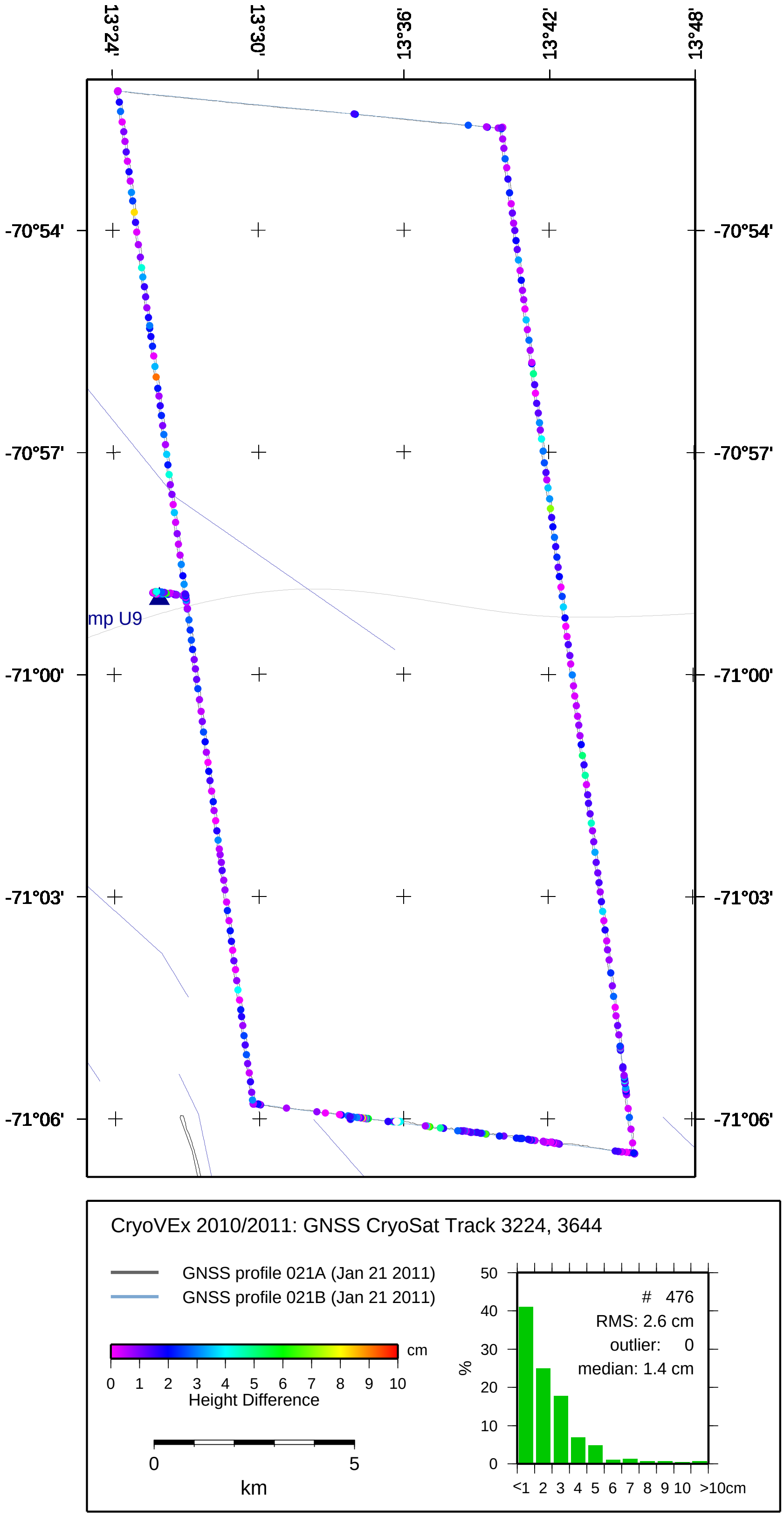

Figure 3.14: GNSS crossover analysis CryoSat ground track 3224, repeated

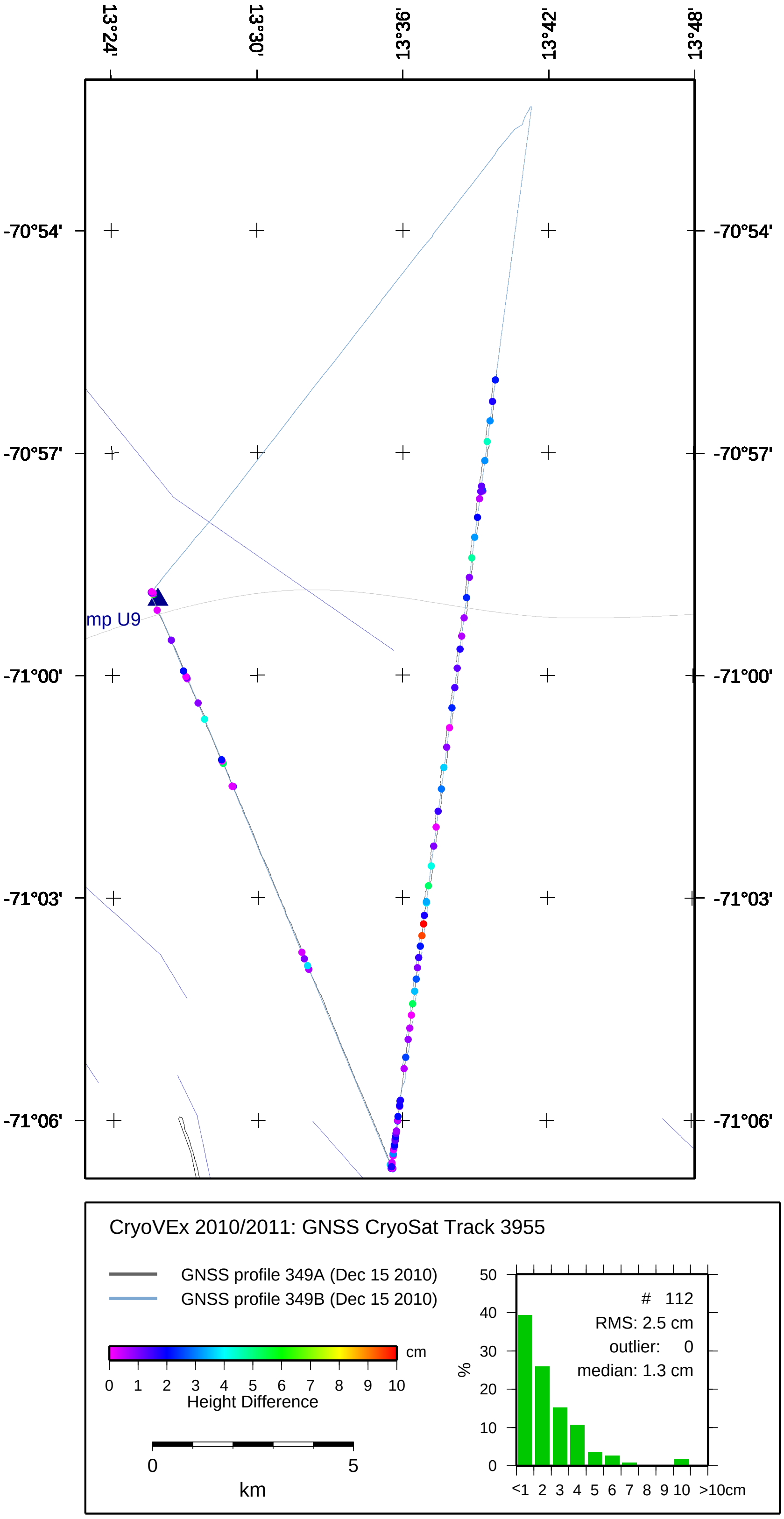

Figure 3.15: GNSS crossover analysis CryoSat ground track 3955

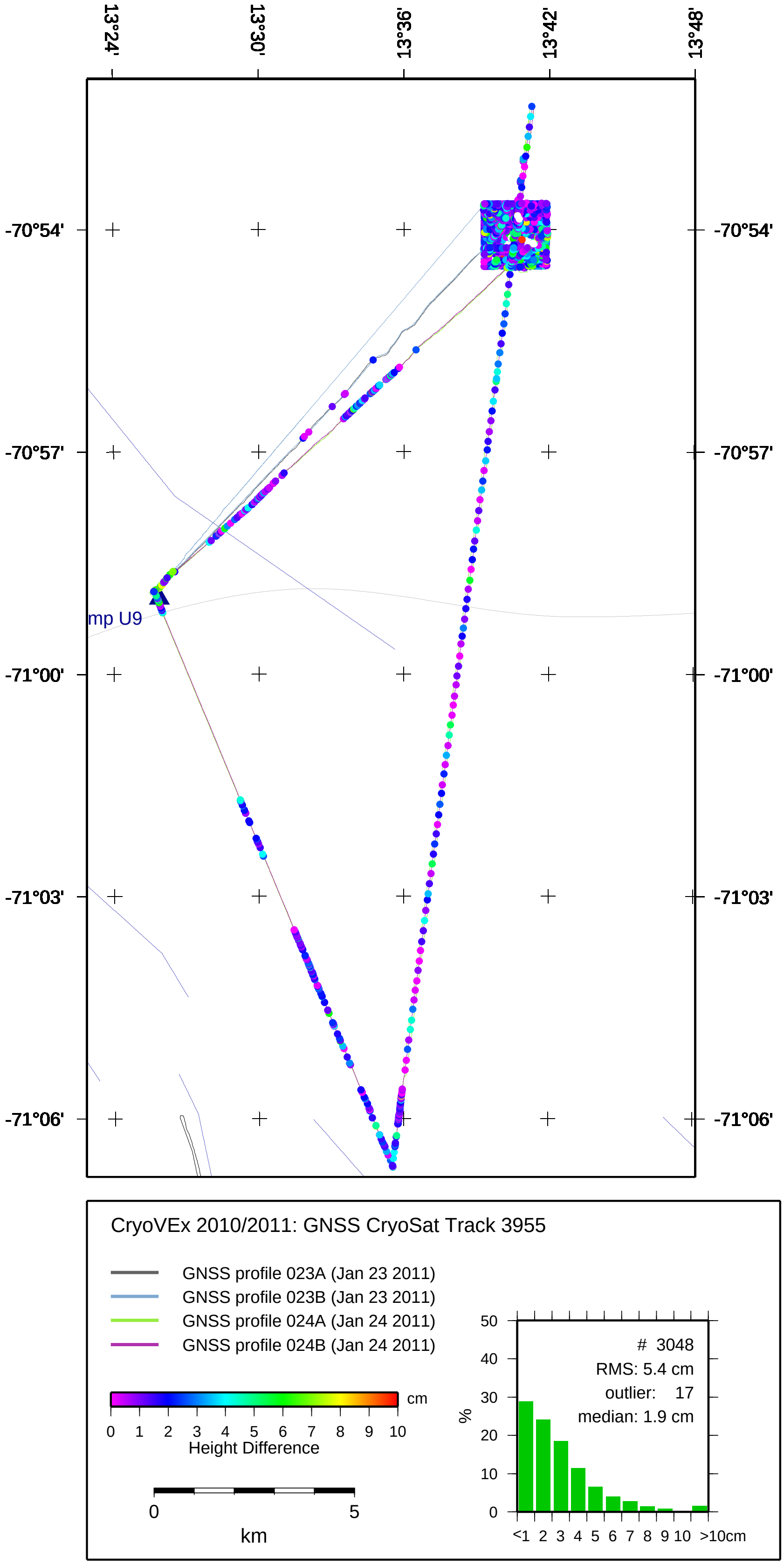

Figure 3.16: GNSS crossover analysis CryoSat ground track 3955, repeated

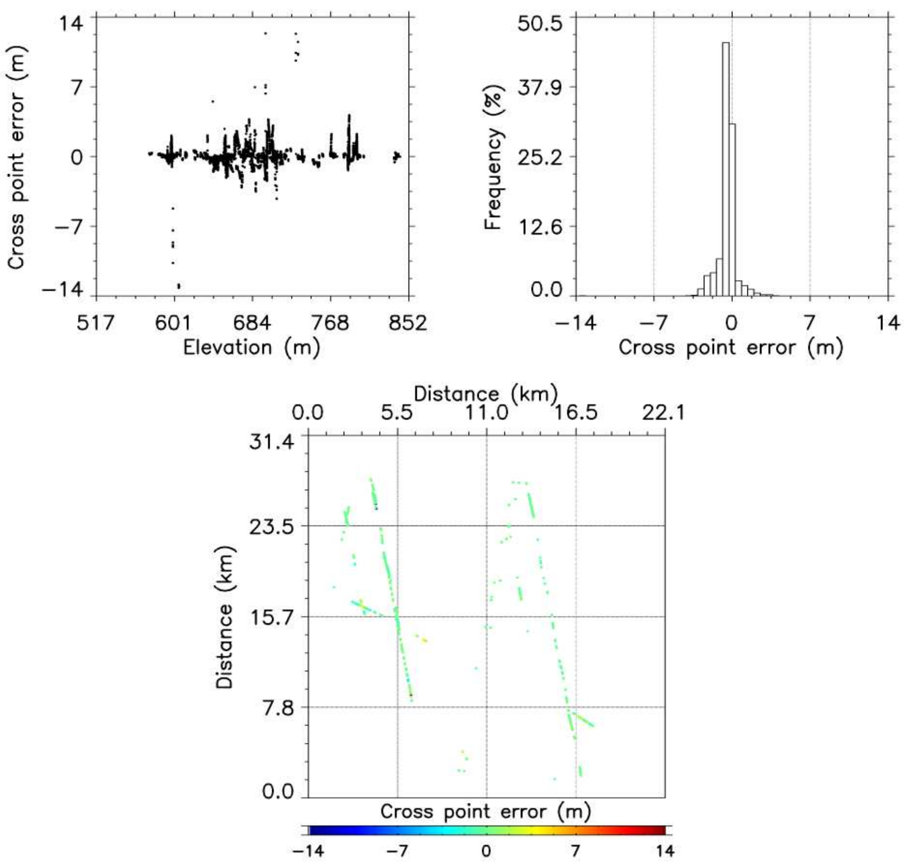

Figure 3.17: GNSS/ASIRAS crossover analysis provided by AWI. Comparison of one ASIRAS flight and the corresponding GNSS profiles.

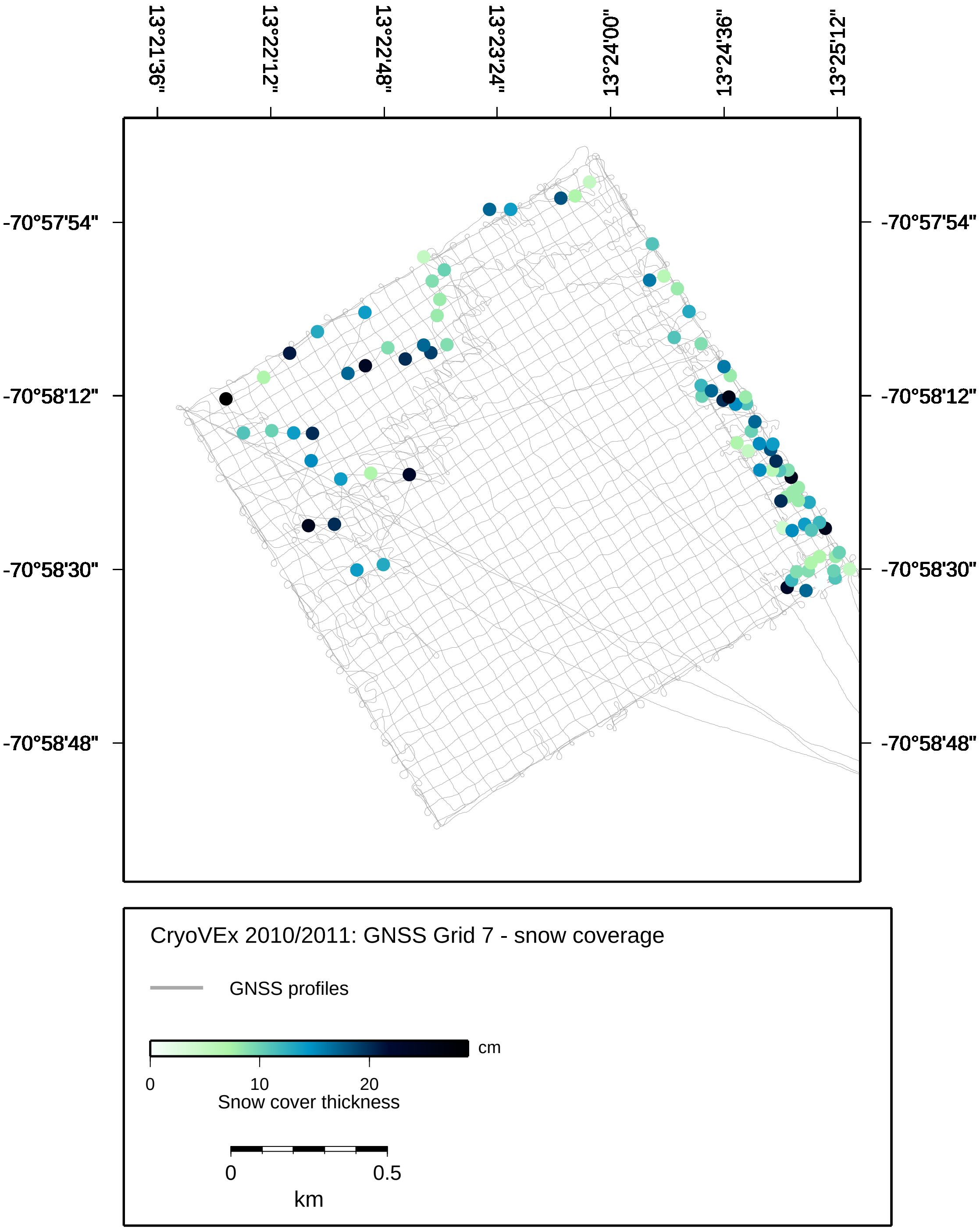

Figure 3.18: Measured thickness of snow at discrete points of Grid 7. The values are colour-coded.

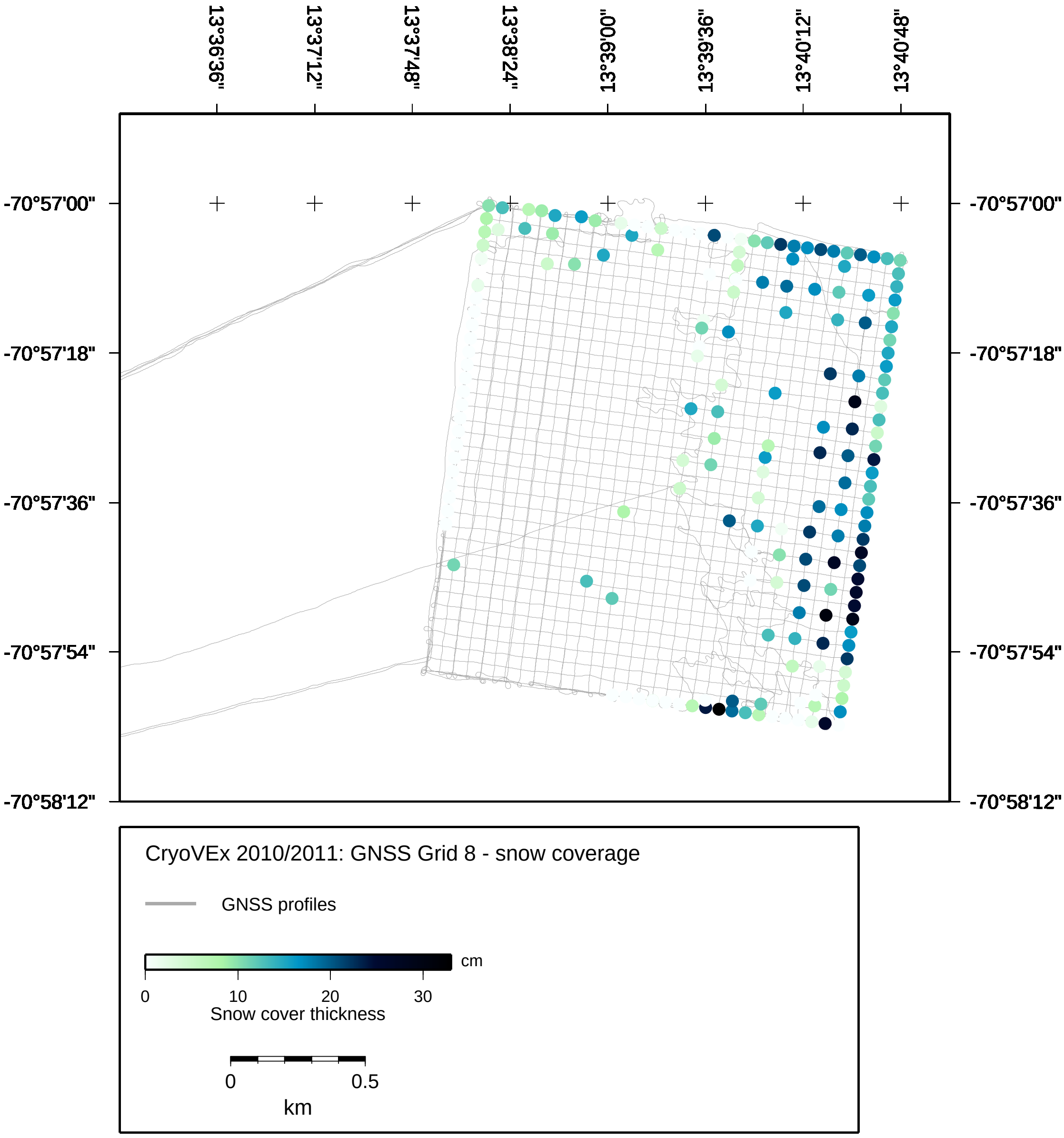

Figure 3.19: Measured thickness of snow at discrete points of Grid 8. The values are colour-coded.

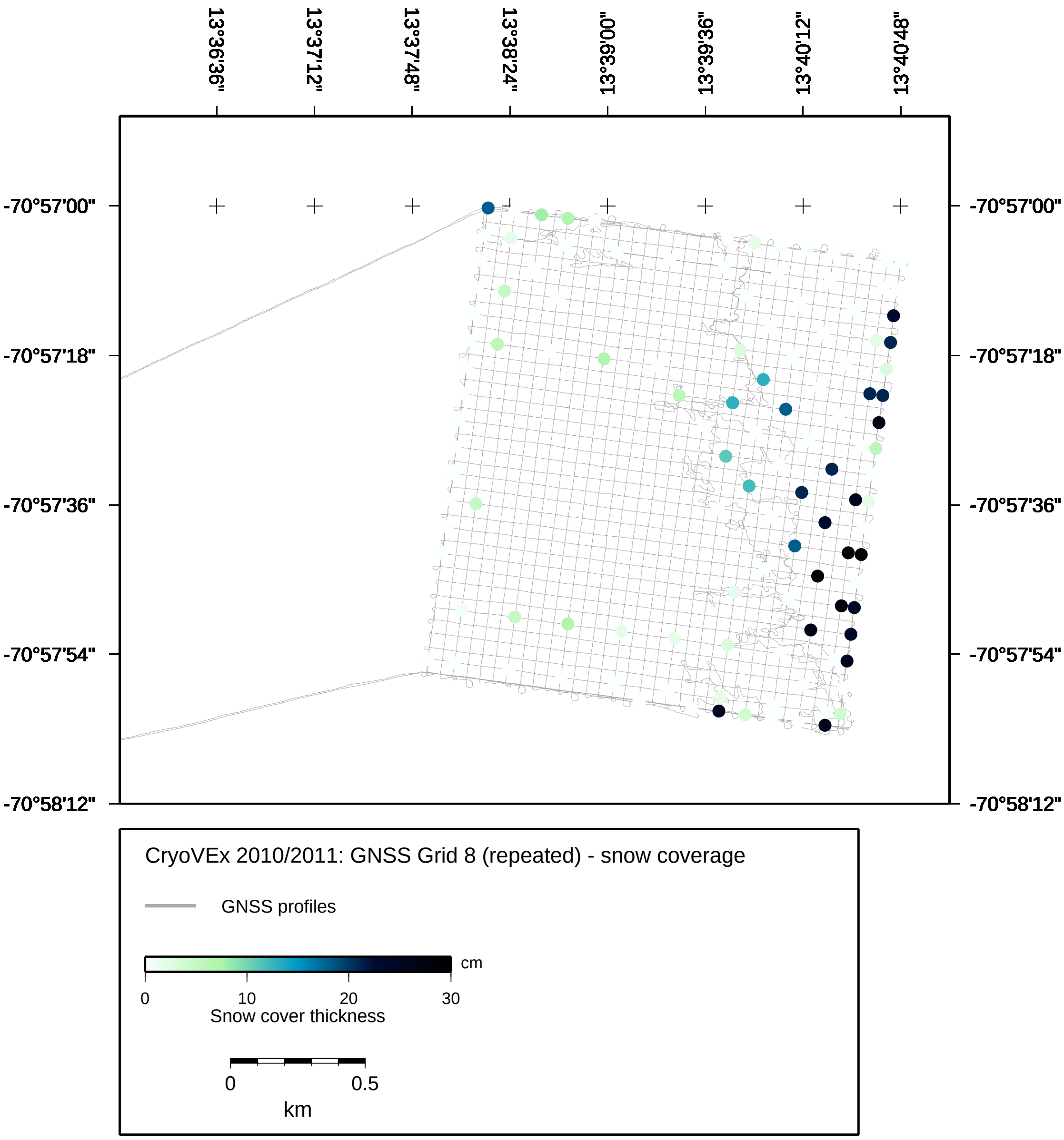

Figure 3.20: Measured thickness of snow at discrete points of Grid 8 (second observation). The values are colour-coded.

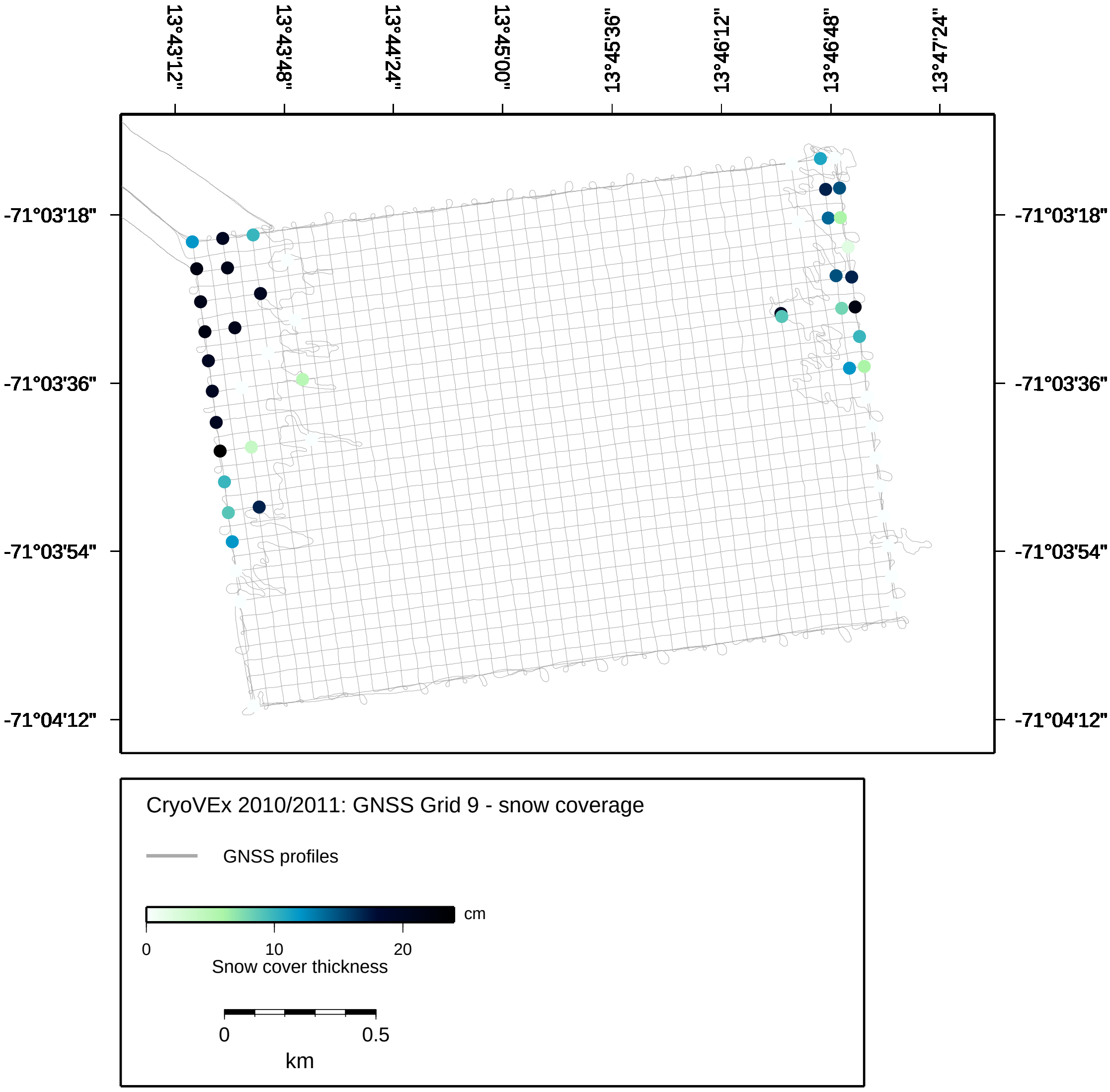

Figure 3.21: Measured thickness of snow at discrete points of Grid 9. The values are colour-coded.

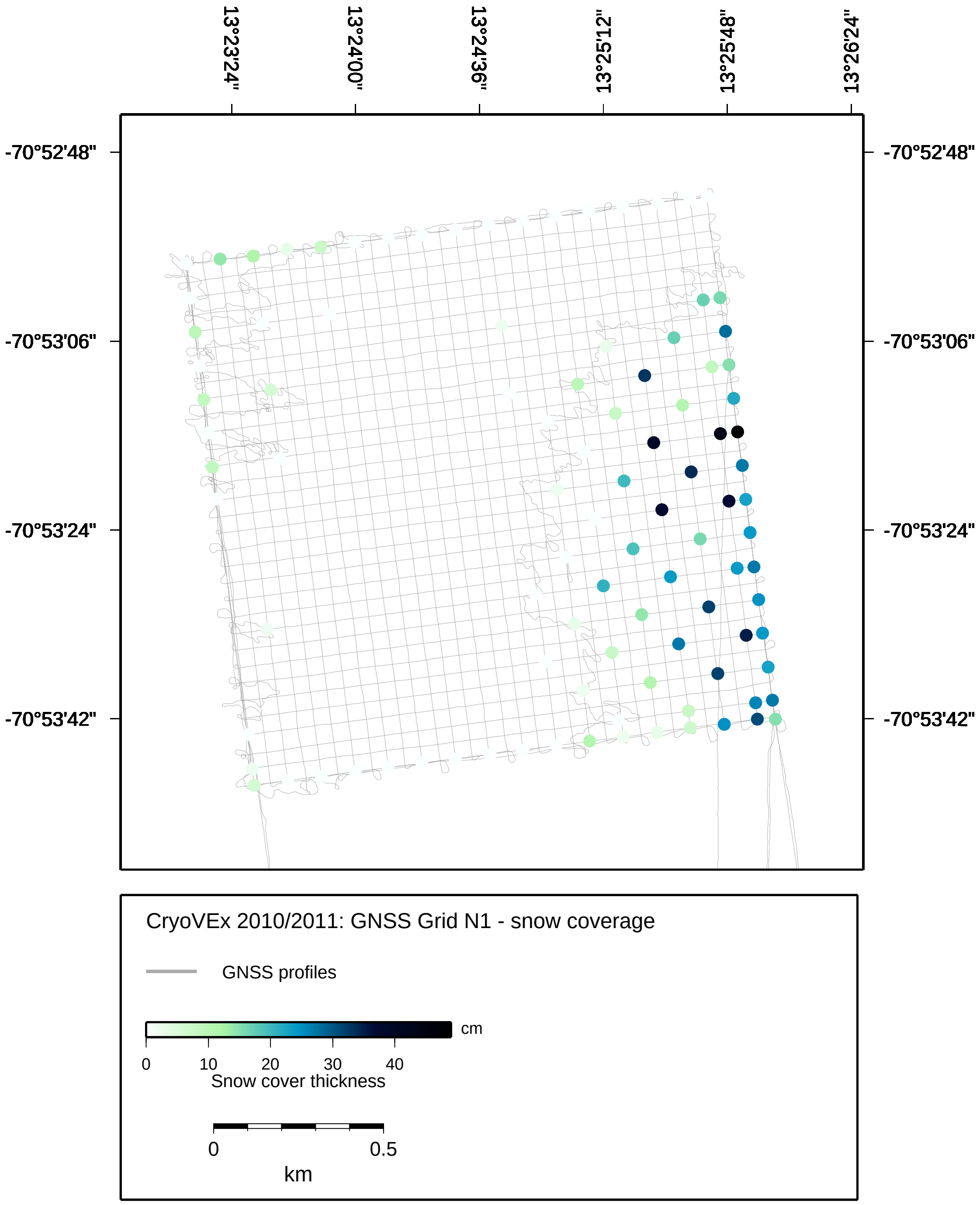

Figure 3.22: Measured thickness of snow at discrete points of Grid N1. The values are colour-coded.

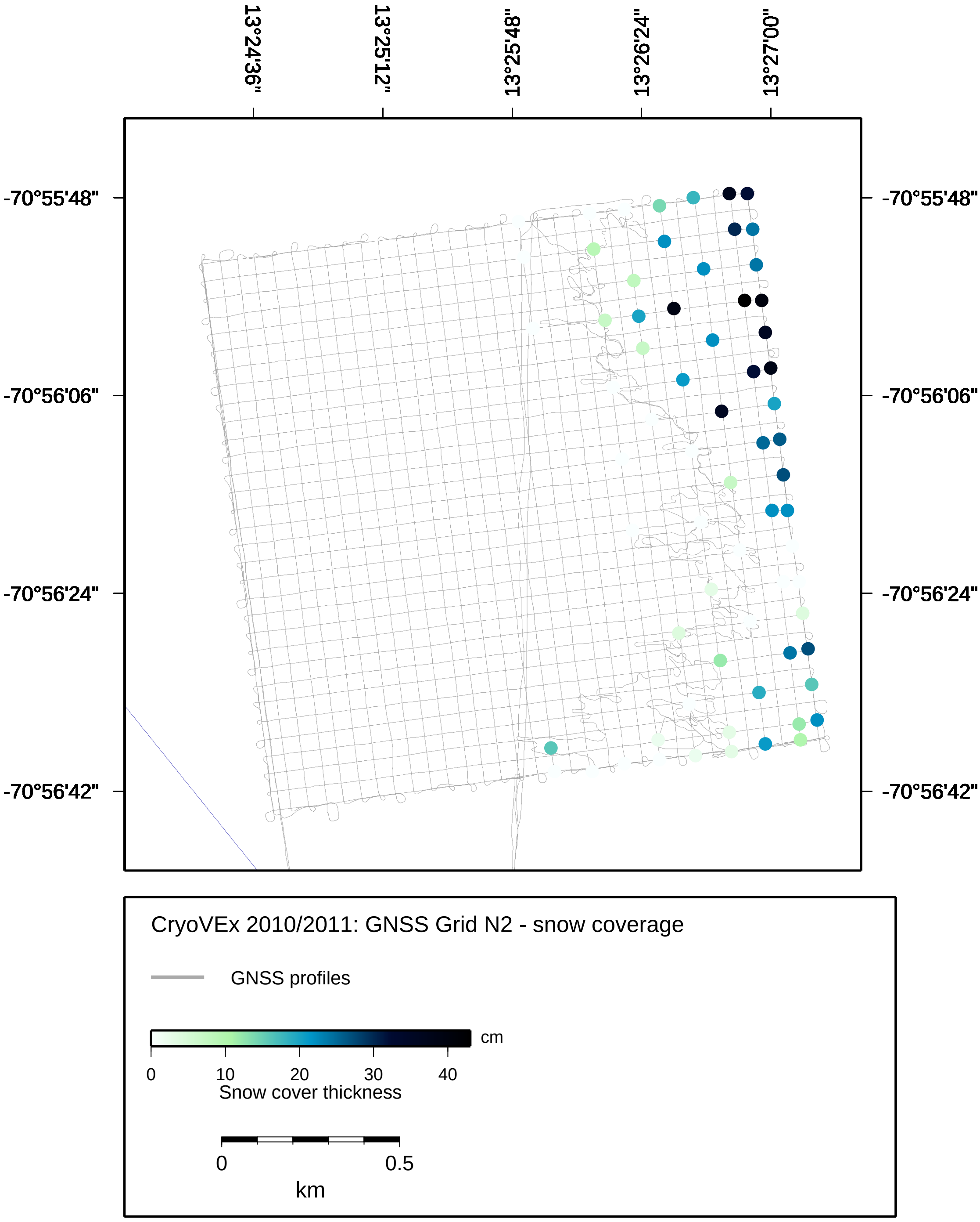

Figure 3.23: Measured thickness of snow at discrete points of Grid N2. The values are colour-coded.

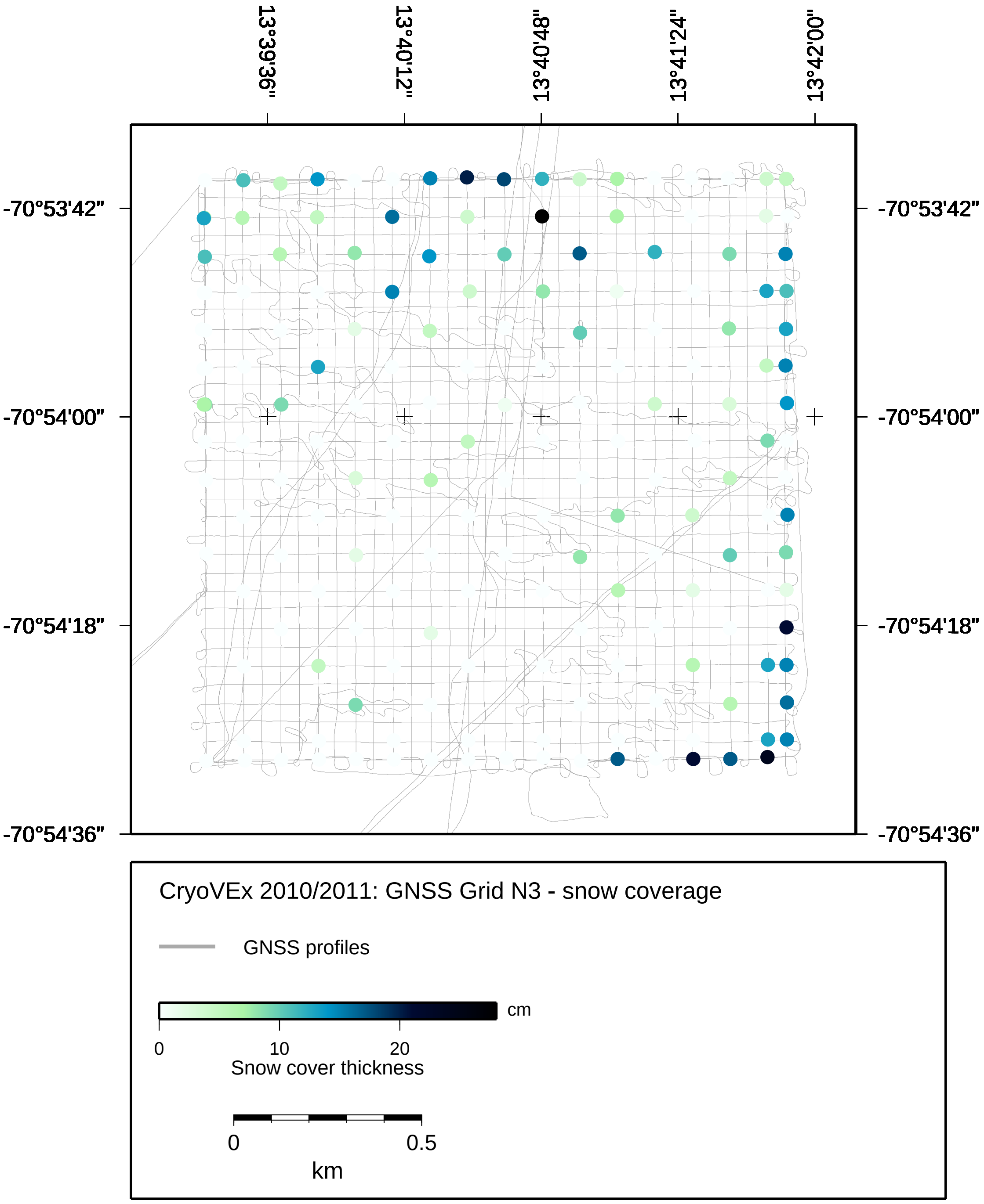

Figure 3.24: Measured thickness of snow at discrete points of Grid N3. The values are colour-coded.

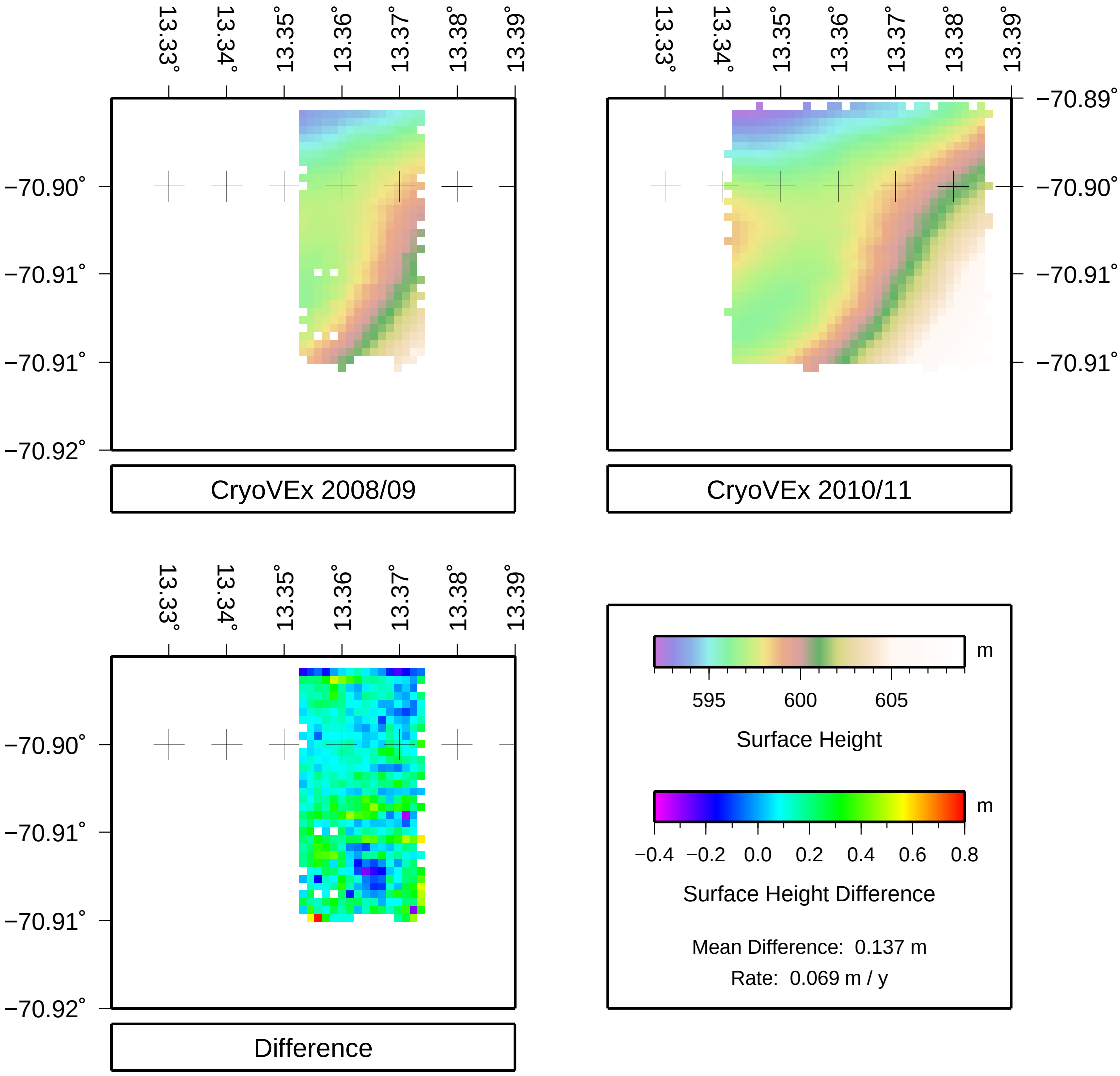

Figure 3.25: Surface height changes Grid 4

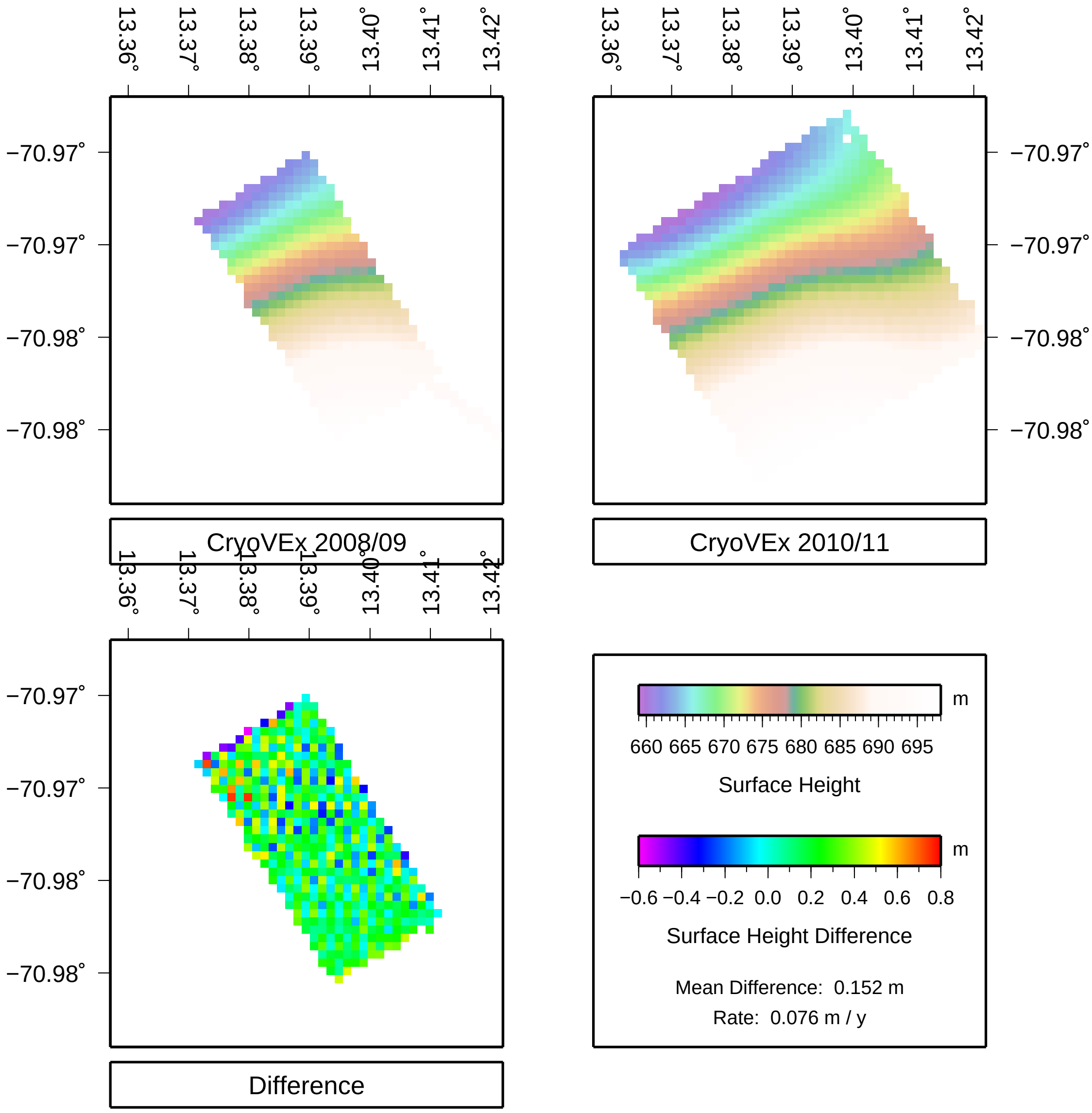

Figure 3.26: Surface height changes Grid 7

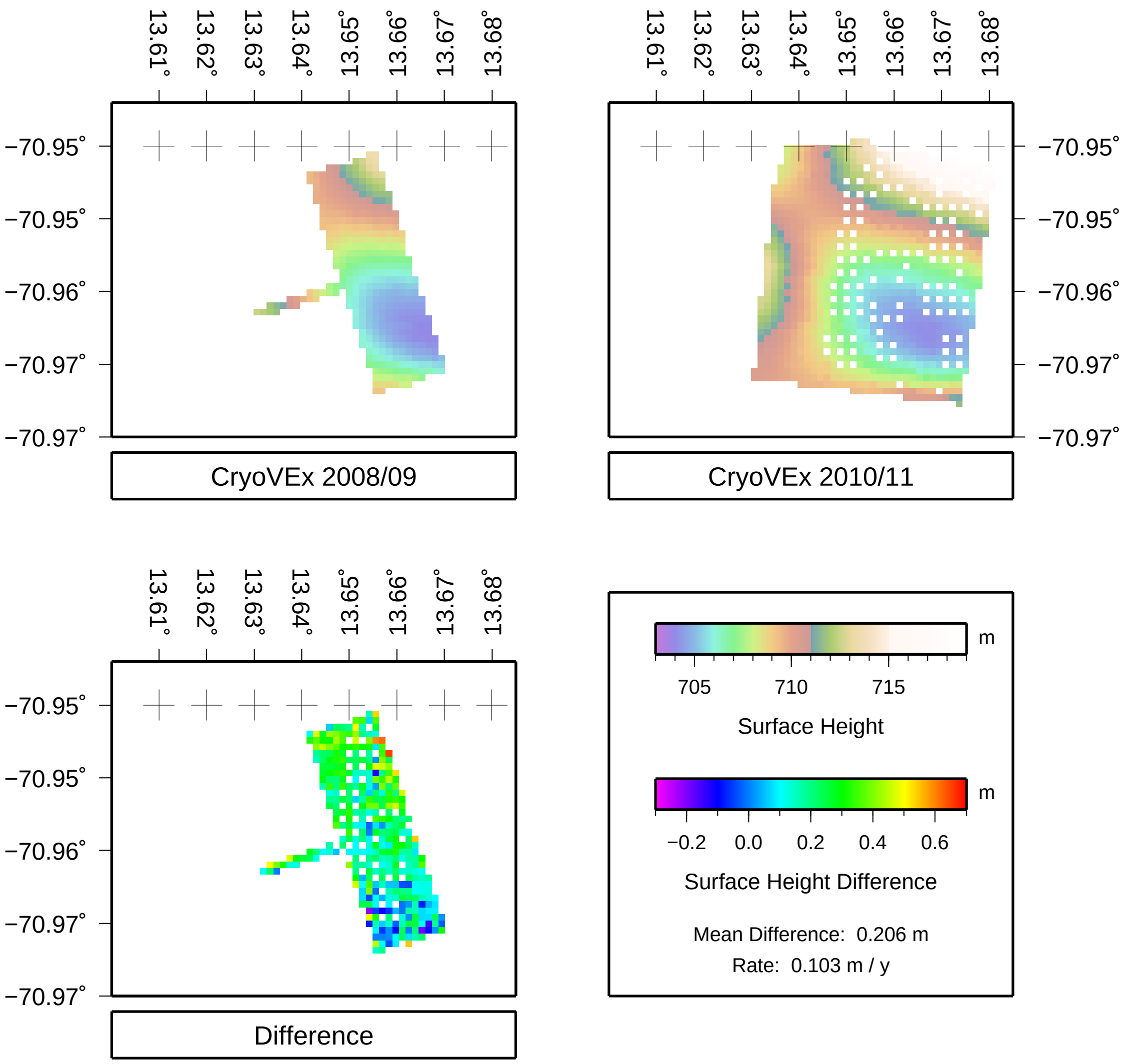

Figure 3.27: Surface height changes Grid 8

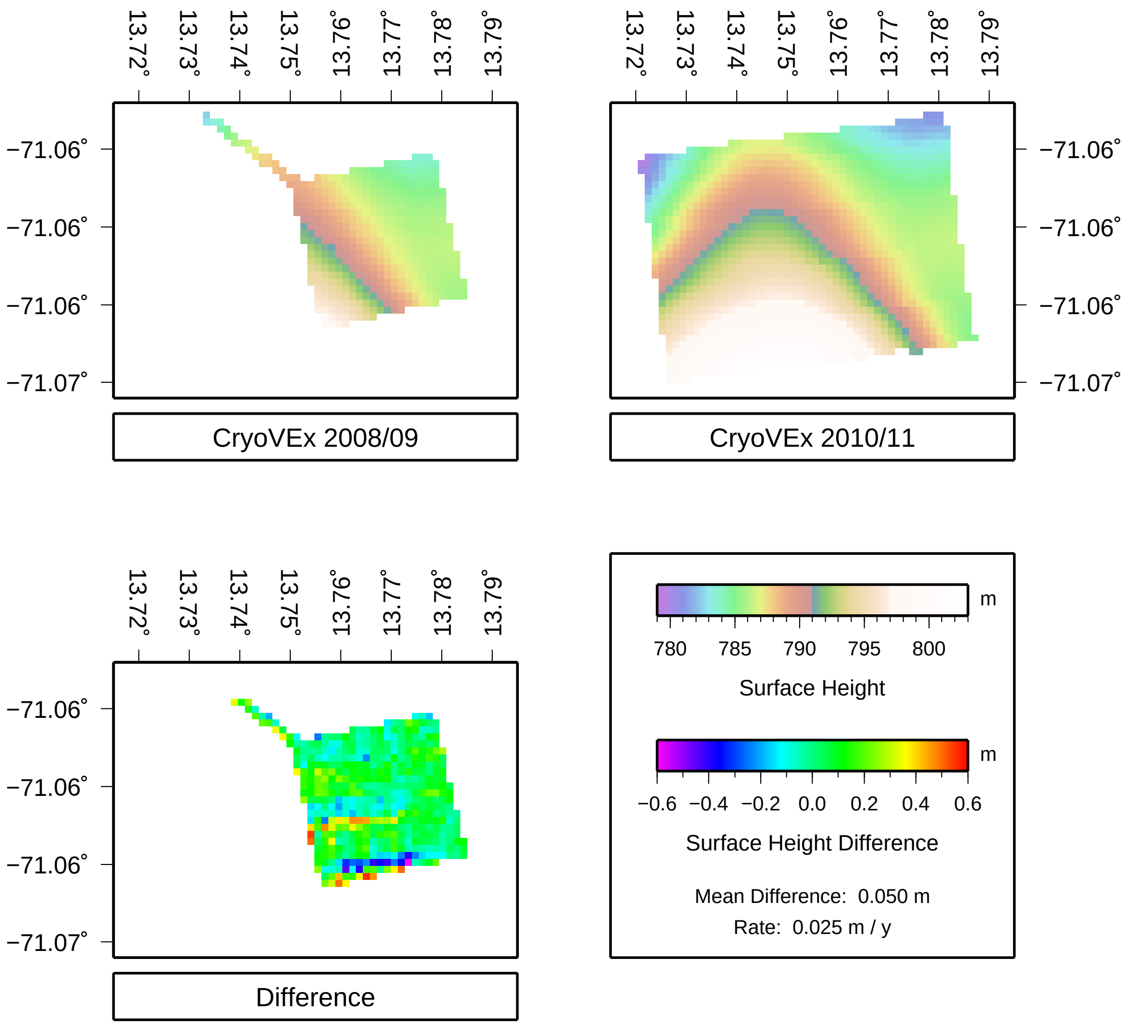

Figure 3.28: Surface height changes Grid 9

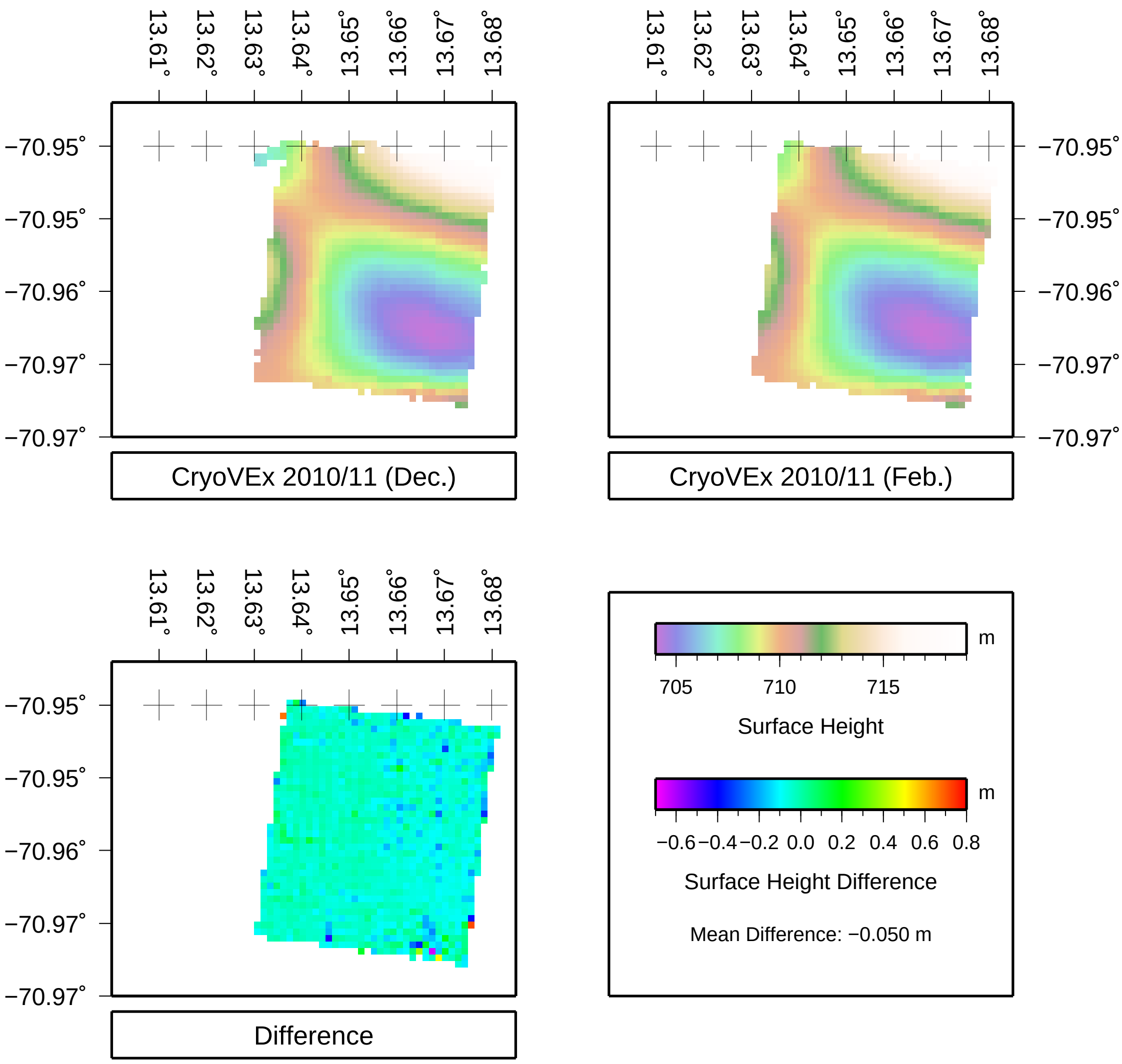

Figure 3.29: Seasonal surface height changes Grid 8

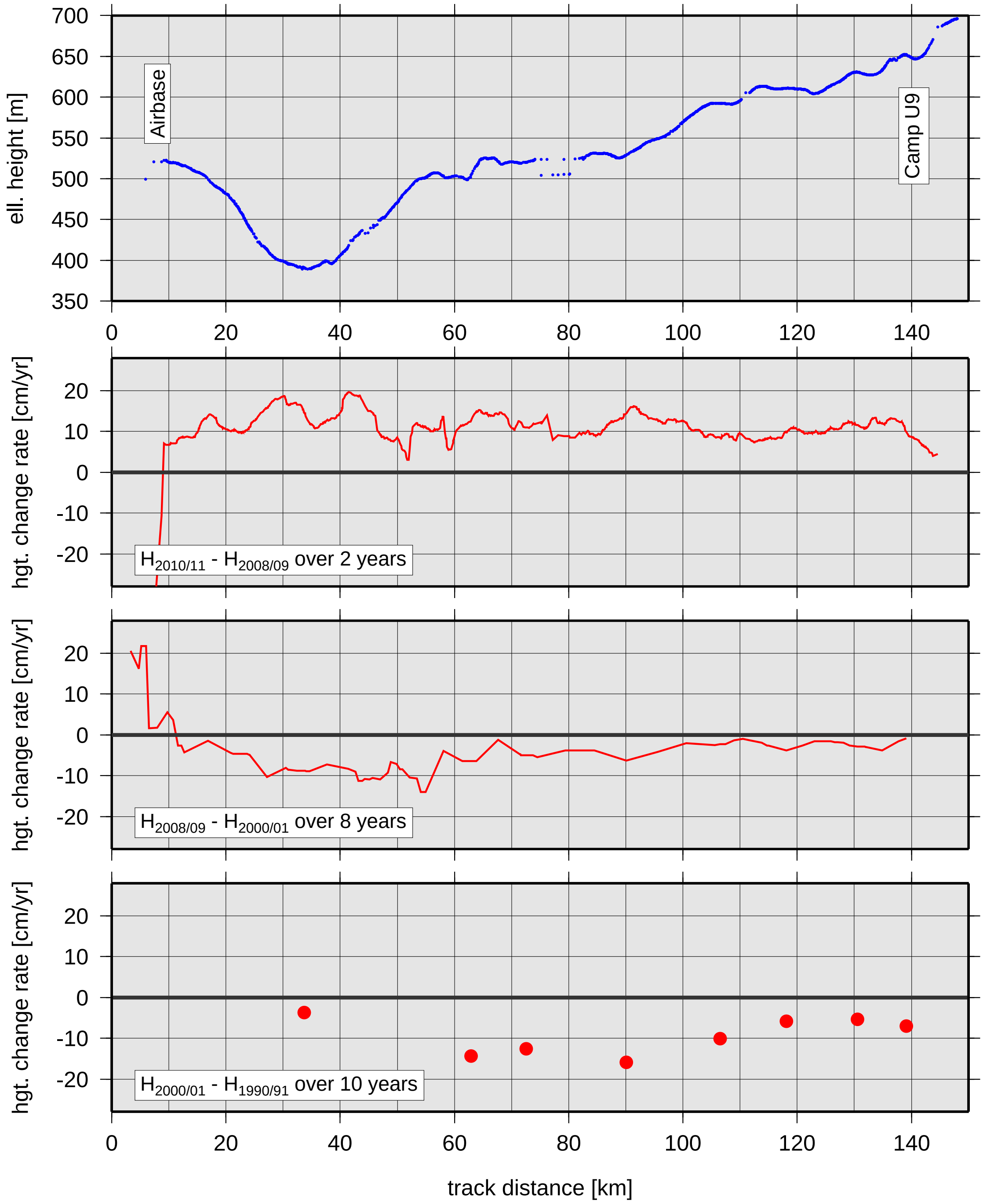

Figure 3.30: Long term changing rates of surface height of the Untersee traverse. Top: Vertical height profile of the Untersee traverse from the Airbase (left) to the field camp at U9 (right). Bottom: Rates of surface height changes at discrete signal positions between year 1991 and 2000. Second from bottom: Rates of surface height changes over 8 years (2000-2008) obtained by crossover comparison of kinematic measurements. Second from top: Rates of surface height changes over 2 years (2008-2010) also obtained by crossover comparison of kinematic measurements. In any case the rate is determined by $(h(t_2) - h(t_1)) \cdot \Delta t^{-1}$, whereas t_2 refers to the later one of dates.

4 Products to be delivered

- Kinematically obtained surface height profiles (positions and elevations in 3..5 m distance) of altogether 2400 km of length including 7 grids (spacing between lines 50 m) covering an area of about 2 km^2 per grid. The data will be delivered in form of kinematic coordinate files (Bernese GPS software format).
- Measured thicknesses of the snow in the grid regions.
- Format descriptions of all delivered file formats (see appendix).

5 Summary

The ground based GNSS observations carried out by TU Dresden were focused on the blue ice area east of the Schirmacher Oasis. Four test grids - observed for the first time during CryoVEx 2008/2009 - were observed again and extended to a nominal profile length of about 110 km per grid. Additionally, three new test grids were established, mainly located in CryoSat ground tracks or crossovers of CryoSat ground tracks. The Untersee traverse with a total length of 120 km was surveyed by four independent profiles. Furthermore, the trajectories following precisely predicted CryoSat ground tracks within the working area were observed. In summary a total amount of about 2400 km of kinematic GNSS profiles were obtained. Additionally the snow boundaries of the grids which were partly snow covered as well as the thickness of snow at discrete points within the test grid areas have been measured.

The crossover analysis yields to several thousands of intersection points with very good error statistics. A first comparison between ASIRAS airborne data provided by AWI and surface heights obtained with GNSS shows promising results. As a second result we provide a first comparison of the test grids observed during CryoVEx 2008/09 and CryoVEx 2010/11. Furthermore, we obtained preliminary changing rates of the surface height along the Untersee traverse using measurements of the last 20 years.

List of Figures

List of Tables

Bibliography

Dach, R., Hugentobler, U., Fridez, P., and Meindl, M. (eds.) (2007). *Bernese GPS Software Version 5.0*. Astronomical Institute, University of Bern, Switzerland.

Korth, W. (1998). *Bestimmung von Oberflächengeometrie, Punktbewegungen und Geoid in einer Region der Antarktis*. Number 505 in Reihe C. Deutsche Geodätische Kommission, München.

Korth, W. and Dietrich, R. (1996). *Ergebnisse geodätischer Arbeiten im Gebiet der Schirmacheroase / Antarktika 1988–1993*. Number 301 in Reihe B. Deutsche Geodätische Kommission, München.

Schüler, T. (2006). Interpolating Reference Data: Kinematic Positioning Using Public GNSS Networks. *Inside GNSS*, 1(7):46–52.

Wanninger, L. (2000). Interpolation von GPS-Beobachtungen. *Allg. Vermnachr.*, 107:360–363. Heft 10/2000.

Wanninger, L. (2003). Permanente GPS-Stationen als Referenz für präzise kinematische Positionierung. *Photogrammetrie Fernerkundung Geoinformation*, 4:343–348.

A Product format description

A.1 Kinematic coordinate files

The kinematic coordinate files created by the *Bernese GPS Software* contain epochwise geocentric station coordinates of one kinematic station of one session. The given local geodetic datum does not mean that the coordinates below are referring to this datum. The geodetic datum is only used to compute ellipsoidal coordinates in the processing programs if necessary.
File format description:

`STATION`	Full station name (`%16s`)
`WEEK`	GPS week (`%4d`)
`SECONDS`	GPS seconds of the week (`%8.0f`)
`X (M)`	Geocentric coordinate in X-direction, given in meters (`%15.4f`)
`Y (M)`	Geocentric coordinate in Y-direction, given in meters (`%15.4f`)
`Z (M)`	Geocentric coordinate in Z-direction, given in meters (`%15.4f`)
`F`	Flag to indicate the quality of the coordinate solution (`%s`). **Please only consider epochs with flag 'K'!**. Flag 'S' indicates too few observations for that epoch, flag 'X' indicates an interpolated coordinate.
row format (FORTRAN)	`FORMAT(1X,A16,1X,I4,1X,F8.0,1X,3F15.4,1X,A1)`

File naming conventions:

Nomenclature: `<kinematic_rover>_<solution>_<session>.KIN`
e.g. `336A_PC_10336.KIN`

`<kinematic_rover>`	Specifies the name of the 'kinematic station', consists of DOY followed by character 'A' or 'B' which refers to both kinematic GNSS receivers respectively.
`<solution>`	Specifies the type of the coordinate solution. Here, we only provide the 'Phase cluster solution' (PC), which is the final result of the kinematic data processing.
`<session>`	Specifies the session the kinematic coordinate file refers to (`<year><doy>`). In our case one session is defined to be one day.

For further information we refer to Dach et al. (2007).

A.2 Files with values of snow thickness

The thickness of the snow covered parts of the test grids were measured at discrete points during the kinematic GNSS observations. Each filename contains the number of the appropriate test grid. The file format is simply given as

```
<longitude [deg]> <latitude [deg]> <thickness [cm]>
```

separated by spaces.

B Classification of kinematic GNSS profiles

Typically each kinematic coordinate file contains data of a full session (in our case one session is defined to be one day). To only consider data regarding to a defined area (e.g. Grid N1 only) we identified all subtracks within each coordinate file. The following Table B.1 gives detailed information about the identified subtracks and their corresponding time windows as well as the respective kinematic coordinate files. It is sorted in chronological order.

Description of columns of Table B.1:

ID	...	Sequential number
DOY	...	Day of year (YY:DDD)
START	...	Start time of the subtrack
STOP	...	Stop time of the subtrack
.KIN FILE	...	Corresponding kinematic coordinate file without extension .KIN (A and B refer to both kinematic GNSS receivers respectively.)
FLAG	...	Subtrack description flag, see below
DESCRIPTION	...	Further explanation of the subtrack, see below

Description of flags in column FLAG:

D	...	Route to or from a destination area
G	...	Observation of a grid
S	...	Observation of the snow boundary within the test grid area
C	...	Observation of a CryoSat ground track
T	...	Observation of the Untersee traverse
U	...	Observation of the ancient signal positions of the Untersee traverse

Within the column DESCRIPTION the following keywords are used:

continued	...	subsequent measurement on the same day
follow up	...	subsequent measurement another day
repeated	...	repeated measurement (in 2011)

Table B.1: Classification of kinematic GNSS profiles. See page 69 for further information on the content of the columns.

ID	DOY	START	STOP	.KIN FILE	FLAG	DESCRIPTION
001	10:336	13:45:31	14:06:34	336A_PC_10336	D	to Grid 7
002	10:336	13:45:23	14:07:17	336B_PC_10336	D	to Grid 7
003	10:336	14:06:35	22:28:16	336A_PC_10336	G	Grid 7
004	10:336	14:07:18	22:30:21	336B_PC_10336	G	Grid 7
005	10:336	22:28:17	22:37:33	336A_PC_10336	D	back from Grid 7
006	10:336	22:30:22	22:37:21	336B_PC_10336	D	back from Grid 7
007	10:337	18:04:57	18:18:09	337A_PC_10337	D	to Grid 7 - follow-up
008	10:337	18:18:10	18:50:22	337A_PC_10337	G	Grid 7 - follow-up
009	10:337	18:50:23	19:06:30	337A_PC_10337	D	back from Grid 7 - follow-up
010	10:343	13:18:48	13:26:59	343A_PC_10343	D	to CS track 3644
011	10:343	13:18:56	13:27:11	343B_PC_10343	D	to CS track 3644
012	10:343	13:27:00	14:06:10	343A_PC_10343	C	CS track 3644 - north
013	10:343	13:27:12	14:05:57	343B_PC_10343	C	CS track 3644 - north
014	10:343	14:06:11	14:39:05	343A_PC_10343	D	to corner reflector 7
015	10:343	14:05:58	14:38:58	343B_PC_10343	D	to corner reflector 7
016	10:343	14:39:06	15:19:23	343A_PC_10343	C	CS track 3644 - north - continued
017	10:343	14:38:59	15:19:11	343B_PC_10343	C	CS track 3644 - north - continued
018	10:343	15:19:24	15:34:29	343A_PC_10343	D	to corner reflector 4
019	10:343	15:19:12	15:34:24	343B_PC_10343	D	to corner reflector 4
020	10:343	15:34:30	15:50:37	343A_PC_10343	C	CS track 3644 - north - continued
021	10:343	15:34:25	15:50:27	343B_PC_10343	C	CS track 3644 - north - continued
022	10:343	15:50:38	17:16:41	343A_PC_10343	D	to CS track 3224 (from 3644)
023	10:343	15:50:28	17:16:56	343B_PC_10343	D	to CS track 3224 (from 3644)
024	10:343	17:16:42	19:05:22	343A_PC_10343	C	CS track 3224 - north
025	10:343	17:16:57	19:05:20	343B_PC_10343	C	CS track 3224 - north
026	10:343	19:05:23	20:04:12	343A_PC_10343	D	back from CS track 3224
027	10:343	19:05:21	20:04:55	343B_PC_10343	D	back from CS track 3224
028	10:344	09:57:35	10:02:42	344A_PC_10344	D	to CS track 3644
029	10:344	09:57:31	10:02:45	344B_PC_10344	D	to CS track 3644
030	10:344	10:02:43	12:07:03	344A_PC_10344	C	CS track 3644 - south
031	10:344	10:02:46	12:07:06	344B_PC_10344	C	CS track 3644 - south
032	10:344	12:07:04	13:42:20	344A_PC_10344	D	to CS track 3224 (from 3644)
033	10:344	12:07:07	13:42:12	344B_PC_10344	D	to CS track 3224 (from 3644)
034	10:344	13:42:21	15:36:50	344A_PC_10344	C	CS track 3224 - south
035	10:344	13:42:13	15:36:37	344B_PC_10344	C	CS track 3224 - south
036	10:344	15:36:51	16:42:15	344A_PC_10344	D	back from CS track 3224
037	10:344	15:36:38	16:40:49	344B_PC_10344	D	back from CS track 3224
038	10:348	08:37:34	09:43:14	348A_PC_10348	D	to Grid 4
039	10:348	08:37:44	09:44:09	348B_PC_10348	D	to Grid 4
040	10:348	09:43:15	17:31:40	348A_PC_10348	G	Grid 4

Continued on next page

Table B.1 – continued from previous page

ID	DOY	START	STOP	.KIN FILE	FLAG	DESCRIPTION
041	10:348	09:44:10	17:33:38	348B_PC_10348	G	Grid 4
042	10:348	17:35:27	18:41:33	348A_PC_10348	S	Grid 4 - snow surface
043	10:348	17:34:30	18:43:41	348B_PC_10348	S	Grid 4 - snow surface
044	10:348	18:41:34	19:17:30	348A_PC_10348	D	back from Grid 4
045	10:348	18:43:42	19:40:00	348B_PC_10348	D	back from Grid 4
046	10:349	10:13:30	11:56:54	349A_PC_10349	D	to CS track 3955
047	10:349	10:13:09	11:56:59	349B_PC_10349	D	to CS track 3955
048	10:349	11:56:55	14:34:46	349A_PC_10349	C	CS track 3955
049	10:349	11:57:00	14:34:39	349B_PC_10349	C	CS track 3955
050	10:349	14:34:47	15:32:01	349A_PC_10349	D	to old corner reflector
051	10:349	14:34:40	15:32:13	349B_PC_10349	D	to old corner reflector
052	10:349	15:32:02	16:47:25	349A_PC_10349	C	CS track 3955 - continued
053	10:349	15:32:14	16:47:20	349B_PC_10349	C	CS track 3955 - continued
054	10:349	16:47:26	18:53:39	349A_PC_10349	D	back from CS track 3955
055	10:349	16:47:21	18:53:55	349B_PC_10349	D	back from CS track 3955
056	10:352	17:01:31	17:14:17	352A_PC_10352	D	to Grid 7 - snow surface
057	10:352	16:53:50	17:13:16	352B_PC_10352	D	to Grid 7 - snow surface
058	10:352	17:14:18	19:45:08	352A_PC_10352	S	Grid 7 - snow surface
059	10:352	17:13:17	19:53:42	352B_PC_10352	S	Grid 7 - snow surface
060	10:352	19:53:43	20:19:14	352B_PC_10352	D	back through Grid 7 - snow surface
061	10:353	08:54:08	09:51:16	353A_PC_10353	D	to Grid 8
062	10:353	08:54:28	09:51:55	353B_PC_10353	D	to Grid 8
063	10:353	09:51:17	11:33:38	353A_PC_10353	G	Grid 8
064	10:353	09:51:56	19:23:42	353B_PC_10353	G	Grid 8
065	10:353	19:25:30	20:14:00	353B_PC_10353	S	Grid 8 - snow surface
066	10:353	20:14:01	20:29:15	353B_PC_10353	D	through Grid 8
067	10:353	20:29:16	21:12:49	353B_PC_10353	S	Grid 8 - snow surface - continued
068	10:353	21:12:50	22:16:57	353B_PC_10353	D	back from Grid 8
069	10:356	09:56:05	11:02:00	356A_PC_10356	D	to Grid 8 - follow up
070	10:356	09:55:57	11:02:31	356B_PC_10356	D	to Grid 8 - follow up
071	10:356	11:02:01	16:30:55	356A_PC_10356	G	Grid 8 - follow up
072	10:356	11:02:32	16:41:05	356B_PC_10356	G	Grid 8 - follow up
073	10:356	16:30:56	17:41:07	356A_PC_10356	D	back from Grid 8 - follow up
074	10:356	16:41:06	17:41:22	356B_PC_10356	D	back from Grid 8 - follow up
075	10:357	07:55:52	22:36:01	357A_PC_10357	T	Traverse - Camp to Airbase
076	10:357	07:56:41	08:08:36	357B_PC_10357	T	Traverse - Camp to Airbase
077	10:357	08:08:37	08:22:37	357B_PC_10357	U	Signal U 9
078	10:357	08:22:38	09:15:56	357B_PC_10357	T	Traverse - Camp to Airbase - continued
079	10:357	09:15:57	09:32:14	357B_PC_10357	U	Signal U 10

Continued on next page

Table B.1 – continued from previous page

ID	DOY	START	STOP	.KIN FILE	FLAG	DESCRIPTION
080	10:357	09:32:15	10:01:10	357B_PC_10357	T	Traverse - Camp to Airbase - continued
081	10:357	10:01:11	10:11:27	357B_PC_10357	U	Signal P 10/1
082	10:357	10:11:28	10:28:05	357B_PC_10357	T	Traverse - Camp to Airbase - continued
083	10:357	10:28:06	10:41:57	357B_PC_10357	U	Signal U 11
084	10:357	10:41:58	11:31:49	357B_PC_10357	T	Traverse - Camp to Airbase - continued
085	10:357	11:31:50	12:22:22	357B_PC_10357	U	Signal U 12
086	10:357	12:22:23	12:54:32	357B_PC_10357	T	Traverse - Camp to Airbase - continued
087	10:357	12:54:33	13:24:28	357B_PC_10357	U	Signal U 13
088	10:357	13:24:29	14:51:14	357B_PC_10357	T	Traverse - Camp to Airbase - continued
089	10:357	14:51:15	15:35:49	357B_PC_10357	U	Signal U 15
090	10:357	15:35:50	18:08:42	357B_PC_10357	T	Traverse - Camp to Airbase - continued
091	10:357	18:08:43	18:59:54	357B_PC_10357	U	Signal U 18
092	10:357	18:59:55	19:36:03	357B_PC_10357	T	Traverse - Camp to Airbase - continued
093	10:357	19:36:04	19:45:50	357B_PC_10357	U	Signal U 19
094	10:357	19:45:51	20:27:31	357B_PC_10357	T	Traverse - Camp to Airbase - continued
095	10:357	20:27:32	20:38:47	357B_PC_10357	U	Signal U 20
096	10:357	20:38:48	22:33:56	357B_PC_10357	T	Traverse - Camp to Airbase - continued
097	11:006	10:11:20	10:41:50	006A_PC_11006	T	Traverse - Airbase to Camp
098	11:006	10:10:48	10:42:06	006B_PC_11006	T	Traverse - Airbase to Camp
099	11:006	10:41:51	11:03:43	006A_PC_11006	U	Signal U22
100	11:006	10:42:07	11:03:40	006B_PC_11006	U	Signal U22
101	11:006	11:03:44	12:11:19	006A_PC_11006	T	Traverse - Airbase to Camp - continued
102	11:006	11:03:41	12:12:02	006B_PC_11006	T	Traverse - Airbase to Camp - continued
103	11:006	12:11:20	12:30:05	006A_PC_11006	U	Signal U20 - repeated
104	11:006	12:12:03	12:30:12	006B_PC_11006	U	Signal U20 - repeated
105	11:006	12:30:06	14:07:31	006A_PC_11006	D	Skidoo transport
106	11:006	12:30:13	15:18:19	006B_PC_11006	D	Skidoo transport
107	11:016	09:34:21	13:42:25	016A_PC_11016	T	Traverse - Airbase to Camp
108	11:016	09:34:29	13:43:06	016B_PC_11016	T	Traverse - Airbase to Camp
109	11:016	13:42:26	14:14:59	016A_PC_11016	U	Signal U15 - repeated

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Table B.1 – continued from previous page

ID	DOY	START	STOP	.KIN FILE	FLAG	DESCRIPTION
110	11:016	13:43:07	14:15:15	016B_PC_11016	U	Signal U15 - repeated
111	11:016	14:15:00	15:08:15	016A_PC_11016	T	Traverse - Airbase to Camp - continued
112	11:016	14:15:16	15:08:39	016B_PC_11016	T	Traverse - Airbase to Camp - continued
113	11:016	15:08:16	15:48:28	016A_PC_11016	U	Signal U13 - repeated
114	11:016	15:08:40	15:48:30	016B_PC_11016	U	Signal U13 - repeated
115	11:016	15:48:29	17:56:09	016A_PC_11016	T	Traverse - Airbase to Camp - continued
116	11:016	15:48:31	17:56:30	016B_PC_11016	T	Traverse - Airbase to Camp - continued
117	11:018	12:39:03	13:47:26	018A_PC_11018	D	to Grid 9
118	11:018	12:58:54	13:47:22	018B_PC_11018	D	to Grid 9
119	11:018	13:47:27	19:04:54	018A_PC_11018	G	Grid 9
120	11:018	13:47:22	19:04:56	018B_PC_11018	G	Grid 9
121	11:018	19:04:55	20:13:16	018A_PC_11018	D	back from Grid 9
122	11:018	19:04:57	20:13:12	018B_PC_11018	D	back from Grid 9
123	11:020	09:25:28	10:35:17	020A_PC_11020	D	to Grid 9 - follow up
124	11:020	09:25:48	10:34:29	020B_PC_11020	D	to Grid 9 - follow up
125	11:020	10:35:18	15:15:03	020A_PC_11020	G	Grid 9 - cross profiles
126	11:020	10:34:30	15:18:19	020B_PC_11020	G	Grid 9 - cross profiles
127	11:020	15:18:57	15:31:59	020B_PC_11020	D	through Grid 9
128	11:020	15:15:04	15:50:00	020A_PC_11020	S	Grid 9 - snow surface
129	11:020	15:32:00	16:10:50	020B_PC_11020	S	Grid 9 - snow surface
130	11:020	15:52:35	16:08:56	020A_PC_11020	G	Grid 9 - cross profiles - continued
131	11:020	16:08:57	17:23:37	020A_PC_11020	D	back from Grid 9 - follow up
132	11:020	16:10:51	17:24:30	020B_PC_11020	D	back from Grid 9 - follow up
133	11:021	08:47:57	08:53:01	021A_PC_11021	D	to CS track 3644
134	11:021	08:48:01	08:52:29	021B_PC_11021	D	to CS track 3644
135	11:021	08:53:02	10:07:55	021A_PC_11021	C	CS track 3644 - south - repeated
136	11:021	08:52:30	10:07:44	021B_PC_11021	C	CS track 3644 - south - repeated
137	11:021	10:07:56	11:59:14	021A_PC_11021	D	to CS track 3224 (from 3644)
138	11:021	10:07:45	11:59:46	021B_PC_11021	D	to CS track 3224 (from 3644)
139	11:021	11:59:15	15:12:58	021A_PC_11021	C	CS track 3224 - repeated
140	11:021	11:59:47	15:12:38	021B_PC_11021	C	CS track 3224 - repeated
141	11:021	15:12:59	16:29:13	021A_PC_11021	D	to CS track 3644 (from 3224)
142	11:021	15:12:39	16:29:09	021B_PC_11021	D	to CS track 3644 (from 3224)
143	11:021	16:29:14	17:54:42	021A_PC_11021	C	CS track 3644 - north - repeated
144	11:021	16:29:10	17:54:20	021B_PC_11021	C	CS track 3644 - north - repeated
145	11:021	17:54:43	17:59:01	021A_PC_11021	D	back from CS track 3644

Continued on next page

Table B.1 – continued from previous page

ID	DOY	START	STOP	.KIN FILE	FLAG	DESCRIPTION
146	11:021	17:54:21	17:58:40	021B_PC_11021	D	back from CS track 3644
147	11:023	10:04:17	10:37:39	023B_PC_11023	D	to Grid N3
148	11:023	11:22:17	18:22:49	023A_PC_11023	G	Grid N3
149	11:023	11:22:14	18:23:30	023B_PC_11023	G	Grid N3
150	11:023	18:22:50	19:28:39	023A_PC_11023	D	back from Grid N3
151	11:023	18:23:31	19:29:01	023B_PC_11023	D	back from Grid N3
152	11:024	08:56:16	10:25:59	024A_PC_11024	D	to CS track 3955
153	11:024	08:56:18	10:27:00	024B_PC_11024	D	to CS track 3955
154	11:024	10:26:00	14:42:33	024A_PC_11024	C	CS track 3955 - repeated
155	11:024	10:27:01	14:42:29	024B_PC_11024	C	CS track 3955 - repeated
156	11:024	14:53:25	15:14:15	024A_PC_11024	C	south part of CS track 3955 - repeated again - with offset
157	11:024	14:53:20	15:13:08	024B_PC_11024	C	south part of CS track 3955 - repeated again - with offset
158	11:024	15:29:31	17:34:52	024A_PC_11024	S	Grid N3 - snow surface
159	11:024	15:33:49	18:11:18	024B_PC_11024	G	Grid N3 - cross profiles - follow up
160	11:024	17:34:53	17:55:37	024A_PC_11024	D	through Grid N3
161	11:024	17:55:38	18:05:22	024A_PC_11024	S	Grid N3 - snow surface - continued
162	11:024	18:05:23	19:26:39	024A_PC_11024	D	back through Grid N3 - follow up
163	11:024	18:13:19	19:34:07	024B_PC_11024	D	back through Grid N3 - follow up
164	11:031	08:49:04	09:26:19	031A_PC_11031	D	to Grid N2
165	11:031	08:49:09	09:27:09	031B_PC_11031	D	to Grid N2
166	11:031	09:26:20	11:01:12	031A_PC_11031	G	Grid N2
167	11:031	09:27:10	18:58:56	031B_PC_11031	G	Grid N2
168	11:031	11:07:13	13:07:50	031A_PC_11031	D	back to Camp (skidoo problems)
169	11:031	13:07:51	19:01:40	031A_PC_11031	G	Grid N2 - continued
170	11:031	19:11:18	19:58:15	031A_PC_11031	S	Grid N2 - snow surface - only snow
171	11:031	19:11:10	20:05:48	031B_PC_11031	S	Grid N2 - snow surface - few snow/snow patches
172	11:031	20:14:54	20:42:28	031A_PC_11031	D	back through Grid N2
173	11:031	20:14:52	20:42:35	031B_PC_11031	D	back through Grid N2
174	11:033	07:29:20	08:20:33	033A_PC_11033	D	to Grid 8 - repeated
175	11:033	07:29:31	08:21:27	033B_PC_11033	D	to Grid 8 - repeated
176	11:033	08:20:34	16:09:55	033A_PC_11033	G	Grid 8 - repeated
177	11:033	08:21:28	18:04:24	033B_PC_11033	G	Grid 8 - repeated
178	11:033	16:20:20	17:44:21	033A_PC_11033	S	Grid 8 - snow surface - repeated
179	11:033	17:44:22	17:51:14	033A_PC_11033	D	through Grid 8 - repeated

Continued on next page

Table B.1 – continued from previous page

ID	DOY	START	STOP	.KIN FILE	FLAG	DESCRIPTION
180	11:033	17:51:15	18:33:34	033A_PC_11033	S	Grid 8 - snow surface - only snow - repeated
181	11:033	18:33:35	19:15:31	033A_PC_11033	D	back through Grid 8 - repeated
182	11:033	18:04:25	19:15:56	033B_PC_11033	D	back along Grid 8 - repeated
183	11:035	13:02:53	14:00:34	035A_PC_11035	D	to Grid N1
184	11:035	13:03:04	14:08:40	035B_PC_11035	D	to Grid N1
185	11:035	14:00:35	16:38:05	035A_PC_11035	G	Grid N1
186	11:035	14:08:41	19:44:29	035B_PC_11035	G	Grid N1
187	11:035	16:38:06	16:38:59	035A_PC_11035	D	through Grid N1
188	11:035	16:39:00	17:48:35	035A_PC_11035	G	Grid N1 - continued
189	11:035	18:12:49	19:41:46	035A_PC_11035	S	Grid N1 - snow surface
190	11:035	19:41:47	21:11:18	035A_PC_11035	D	back through Grid N1 - follow up
191	11:036	13:05:31	14:01:10	036A_PC_11036	D	to Grid N1 - follow up
192	11:036	13:05:37	14:01:13	036B_PC_11036	D	to Grid N1 - follow up
193	11:036	14:01:11	17:13:19	036A_PC_11036	G	Grid N1 - follow up
194	11:036	14:01:14	17:01:04	036B_PC_11036	G	Grid N1 - follow up
195	11:036	17:07:58	17:15:41	036B_PC_11036	G	Grid N1 - continued - follow up
196	11:036	17:13:20	18:11:11	036A_PC_11036	D	back from Grid N1 - follow up
197	11:036	17:15:42	18:11:25	036B_PC_11036	D	back from Grid N1 - follow up

C Cited papers