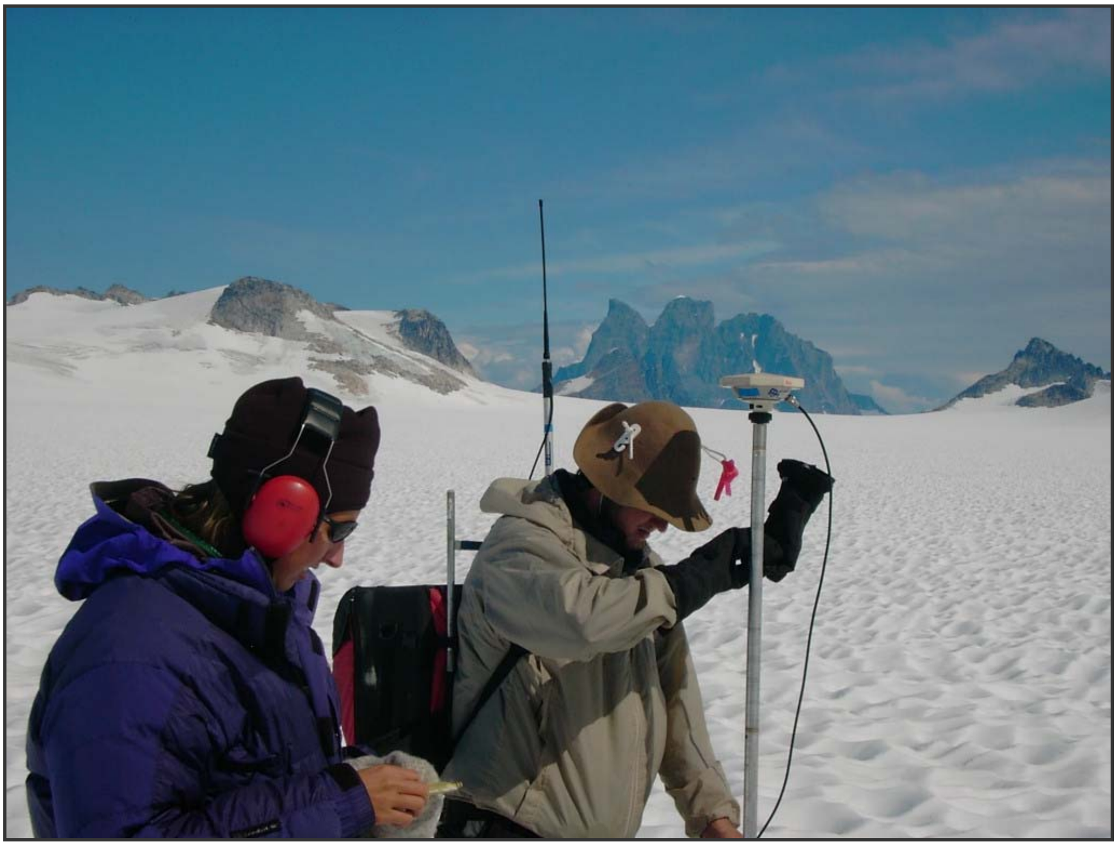

Foundation for Glacier and Environmental Research
Juneau Icefield Research Program
Seattle, Washington
and
Glaciological and Arctic Sciences Institute
University of Idaho
Moscow, Idaho

Technische Universität München

Universität der Bundeswehr

Penned by
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Geodetic Actives During the 2004 Juneau Icefield Research Program Field Season

by

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USA

The following data were collected from 1992 to 2004 by the Foundation for Glacier and Environmental Research, Juneau Icefield Research Program with additional support for the University of Idaho, National Science Foundation, NASA, the Army Research Office, the University FAF Munich and the Technical University of Munich.

Survey reports from the previous year may be obtained from the Foundation or the following web link:
http://crevassezone.org/Data/GPS/reports_frameset.htm

CONTENS

1. Summary

The geodetic observations of the glacier research projects in 2004 (Foundation for Glacier and Environmental Research, Juneau Icefield Research Program) were supported by the Technical University of Munich. They provided the necessary measuring equipment and expert support during the whole field season. As part of this field campaign, two independent measuring teams could be used for the first time over the entire period. As a result, 2004 could be described as a very successful year from a geodetic perspective. The focus of geodetic measurements was the observation of the longitudinal and transversal profile in order to determine changes in elevation and flow velocities as well as determining pressure and deformation. In addition to the Lemon Creek Glacier profile, the 2001 and 2003 GPS measurements at Gilkey Trench could be repeated; they precisely describe the ogives below the Vaughan Lewis Glacier. In addition, other projects for determining terrain information were supported, such as DTMs, localization of test pits and relative gravimeter measurements and developing geological maps. The 2004 measurement campaign also included creating two new GPS reference points in a defined JIRP system. The new GPS reference point on the Demorest Glacier made it possible to fully complete the B longitudinal profile. As a result, it was possible to cover the most important areas of the entire Juneau Icefield with GPS points. The new reference point at Camp 26 makes it possible to expand profile measurements in the direction of Atlin - that is, along the Llewellyn Glacier in a northern direction. During selection of the measurement program, attention was also turned in 2004 to possible referencing of new satellite missions - such as the ICESat Mission - through profile measurements in Juneau. These new types of satellites should make it possible to determine the height of glaciers from orbit in the future. In another project to determine flow velocities, magnets were installed on the entire ice field, which made it possible to establish an average annual movement vector for corresponding glacier surfaces. As in 2003, GPS raw data at selected reference points were measured to determine plate shifting. In 2004, geodetic measurements were evaluated for the first time using evaluation and visualization software developed as part of an master thesis.

2. Introduction

Geodetic measurements in 2004 were conducted using 5 Leica System (SR299 and SR399) GPS receiver units and good logistical organization over the entire period from the beginning of July to the middle of August. All geodetic observations on the icefield were made using a differential GPS method. Profile measurements were determined using the real time kinematic GPS technique, which involved sending a correction signal from the reference station to a mobile rover unit in real time. The new reference points and the GPS raw data used to determine plate shifting was previously conducted using a link to known GPS points through difference formation.

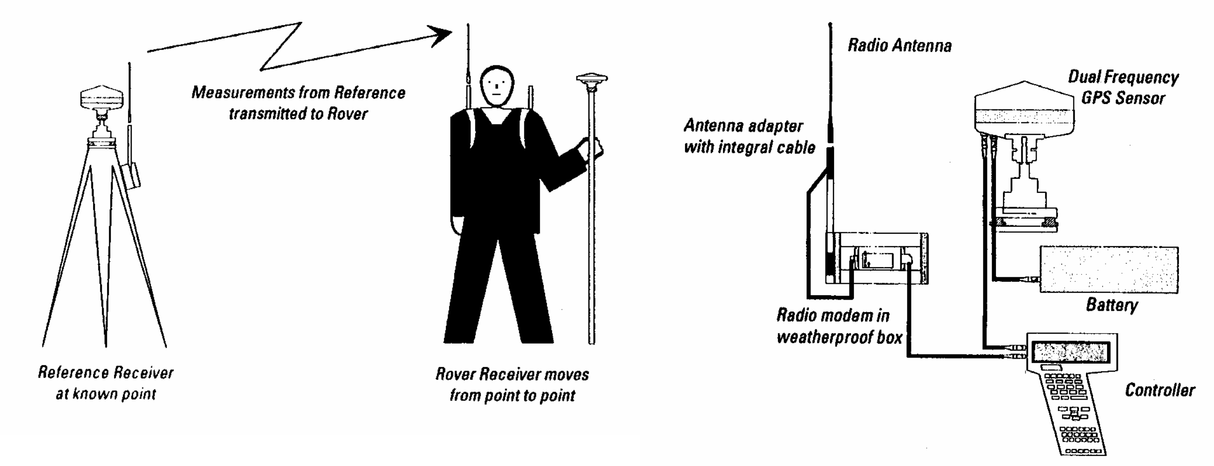


Fig. 1: Real Time Kinematic GPS Technology / GPS Receiver (Leica GPS System 300 Manuel)

An overview of all observations is shown in the next two figures and table 1.

As in previous years, measurements to determine glacier conditions focussed on the Taku Glacier (incl. Southwest und Northwest Branch), Matthes-, Demorest and Lemon Creek Glacier. In addition, projects involving relative gravimeter measurements (Profile 4) and at the F8/18 junction, mapping projects and localization of test pits were supported. An overview of all observations is shown in the next two figures and table 1.

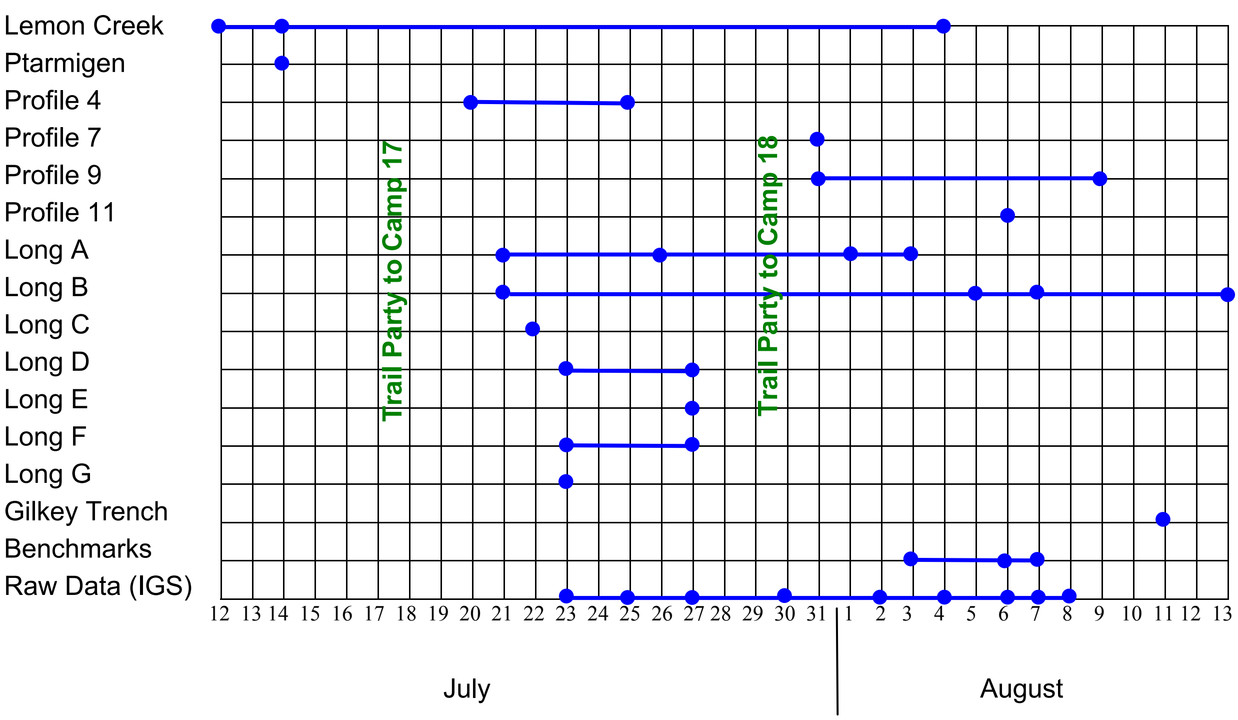


Fig. 2: Timetable of all Survey Projects 2004

The members of the surveying team in 2004 are:

- Scott McGee (U.S. Fish & Wildlife Service, USA),
- Dr. Werner Stempfhuber (Technical University of Munich, Germany),
- Susann Buettner (Student at the Technical University of Munich, Germany),
- Ronny Wenzel (Student at the University FAF Munich, Germany)
- Ryan Houdek (Student at the Indiana University, USA),
- Erin Whorton (Student at the University of Washington, USA) and
- Geir Moholdt (Student at the Universitetet for miljø- og biovitenskap, Norway)

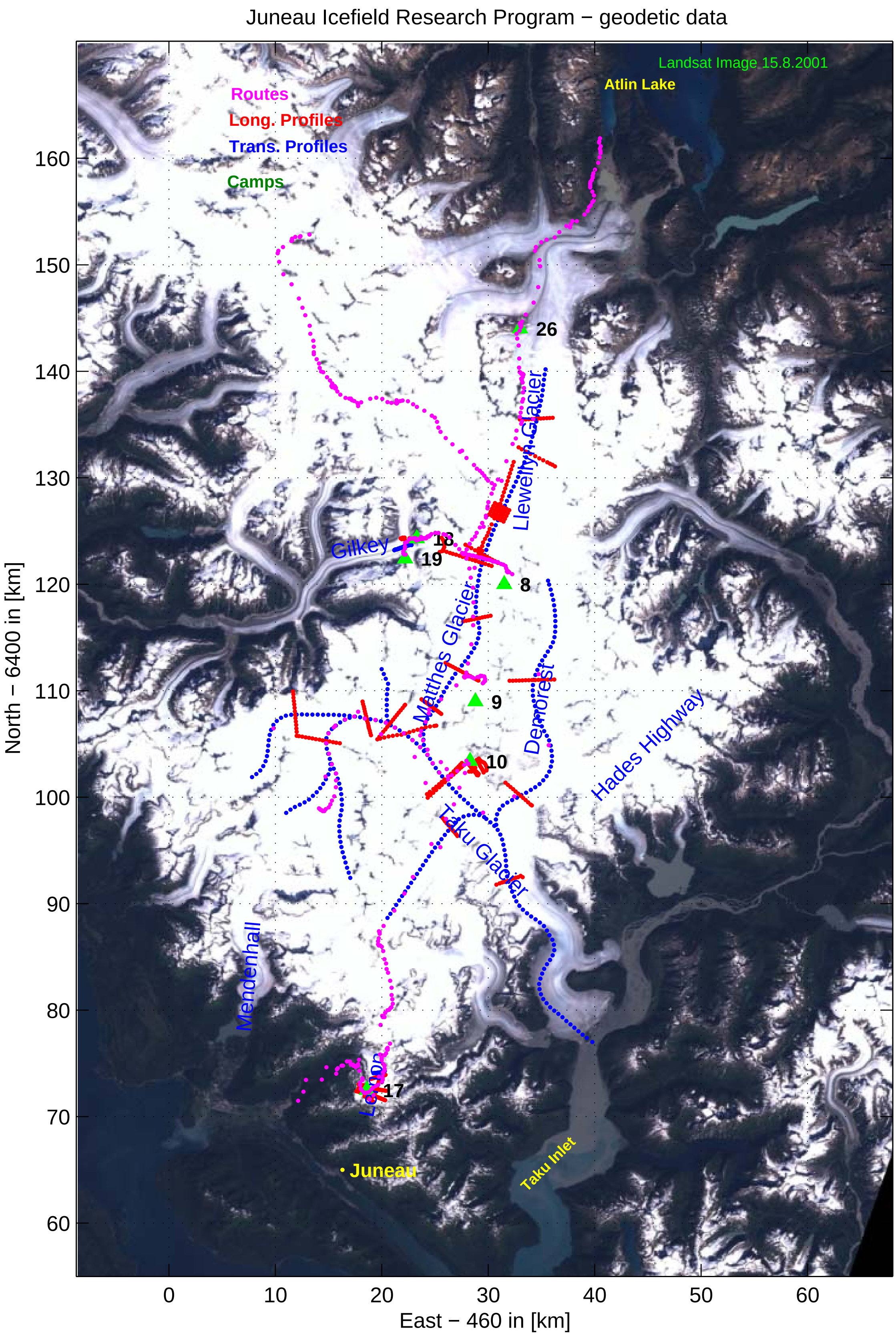


Fig. 3: Overview of the Geodetic Projects

Profile	Location	Survey Dates	Type	# of Flags
Lemon Gl.	Camp 17	July 12, 2004 July 14, 2004 Aug. 04, 2004	Profile Observation Velocity	129 29
Lemon Gl.	Camp 17	July 14, 2004	Setup new Profile	18
Ptarmigen	Camp 17	July 14, 2004	Profile Observation	14
Profile 4 upper & lower	Taku Gl.	July 20, 2004 July 25, 2004	Profile Observation Velocity	31 31
Profile 7	Matthes Gl.	July 31, 2004	Profile Observation	14
Profile 9	Vaughan Lewis Gl.	July 31, 2004	Profile Observation	8
Profile 11	Llewellyn Gl.	Aug. 06, 2004	Profile Observation	12
Long. A	Taku / Matthes Llewellyn Gl.	July 21, 2004 July 26, 2004 Aug. 01, 2004 Aug. 03, 2004	Profile Observation	123
Long. B	Demorest Gl.	July 21, 2004 Aug. 05, 2004 Aug. 07, 2004 Aug. 13, 2004	Profile Observation Velocity	41 20
Long. C	Southwest Branch	July 22, 2004	Profile Observation	6
Long. D	Northwest Branch	July 23, 2004 July 27, 2004	Profile Observation	39
Long. E	West Branch	July 27, 2004	Profile Observation	8
Long. F	West Branch	July 23, 2004 July 27, 2004	Profile Observation	26
Long. G	West Branch	July 23, 2004	Profile Observation	11
Gilkey Trench	Gilkey Gl.	Aug. 11, 2004	Profile Observation	100
Benchmarks	N1 – FFGR62 N1 – FFGR97	Aug. 06, 2004 Aug. 08, 2004	Raw Data Collection	2
GPS (Network) IGS-Station	Camp 17 (FFGR1) Camp 10 (Scott) Demorest Gl. - Camp 26 Taku Gl. - (Scott FFGR 81) Camp 10 - Camp 18 Camp 18 (N1) Camp 17 - Camp 18 Camp18 - Camp 26	July 10, 2004 July 23, 2004 July 27, 2004 Aug. 03, 2004 July 30, 2004 Aug. 02, 2004 Aug. 04, 2004 Aug. 08, 2004	Raw Data Collection	13
Magnets	Taku Gl. Camp 9 West Branch	July 31, 2004 Aug. 01, 2004 Aug. 03, 2004	RTKGPS accuracy	8
Support other Projects (Map-ping)	Camp 10 Profile 4 Camp 10 Mapping Taku Gl. Vaughan Lewis Gl. Camp18	July 25, 2004 July 26, 2004 Aug. 08, 2004 Aug. 09, 2004 Aug. 13, 2004	RTKGPS accuracy Strain DTM - Gravimetry DTM - Mapping DTM - Gravimetry	
Test Pits	Lemon Gl.	July 14, 2004	RTKGPS accuracy	4

Table 1: Details of the Geodetic Observations 2004

The master thesis on this topic written under supervision of the Chair of Geodesy could be used for the first time in 2004. This allowed all results not only to be collected in an integrated system, but also allowed all necessary results to be evaluated and calculated effortlessly on location during the field campaign. At the end of summer, all GPS observations could be discussed in relation to older observations as part of a final presentation in Atlin. Above all, this made it easier for new project participants to estimate the geodetic tasks required. The following figure illustrate an example of the GPS data processing with this tool [BUETTNER, 2005].

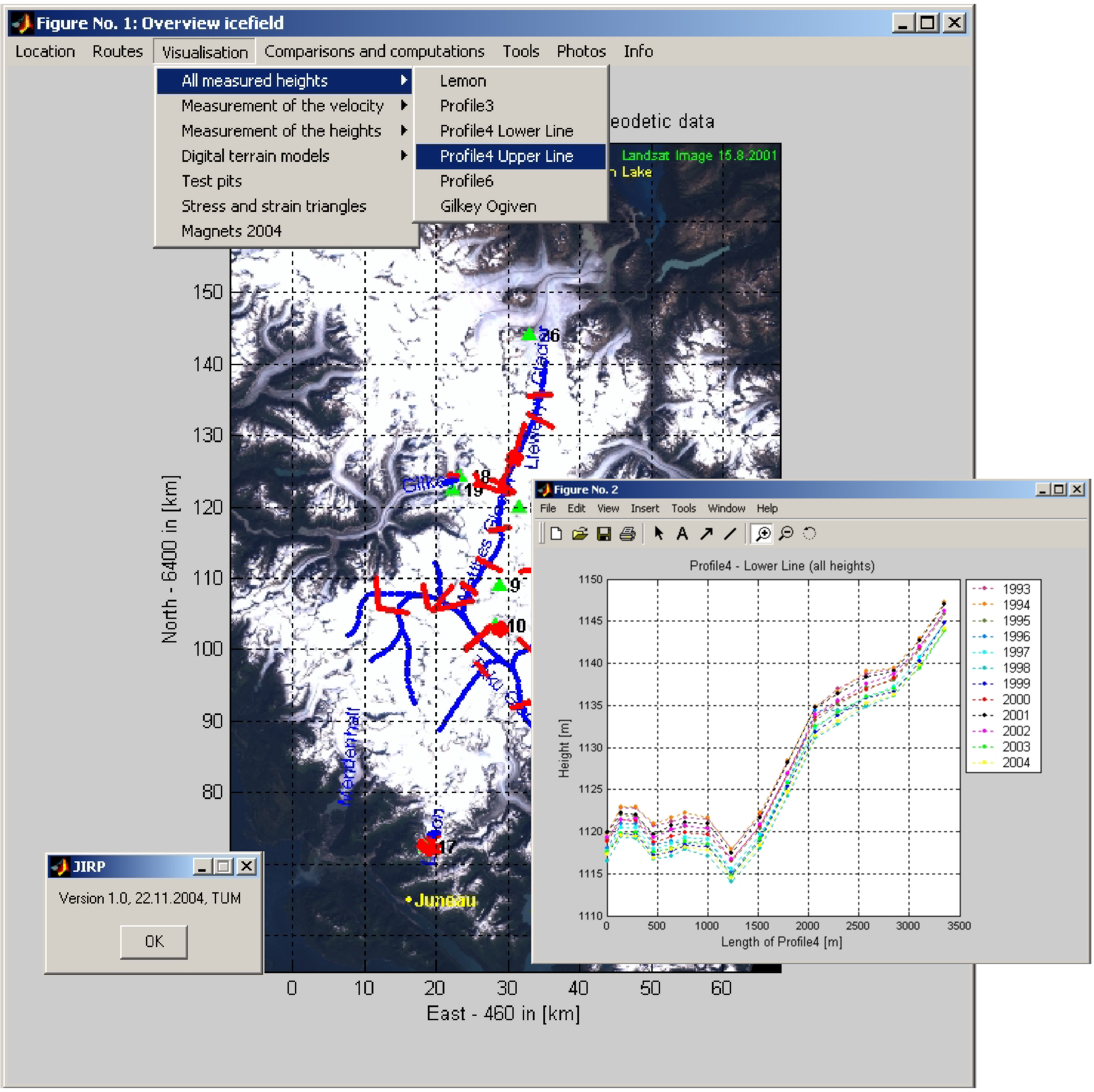


Fig. 4: Overview of the Software to visualize and process the Geodetic Data

In addition to management of geodetic measurements, all remaining information could be organized and managed. An example is shown with the temperature observations of Camp 10 (see Fig 5).

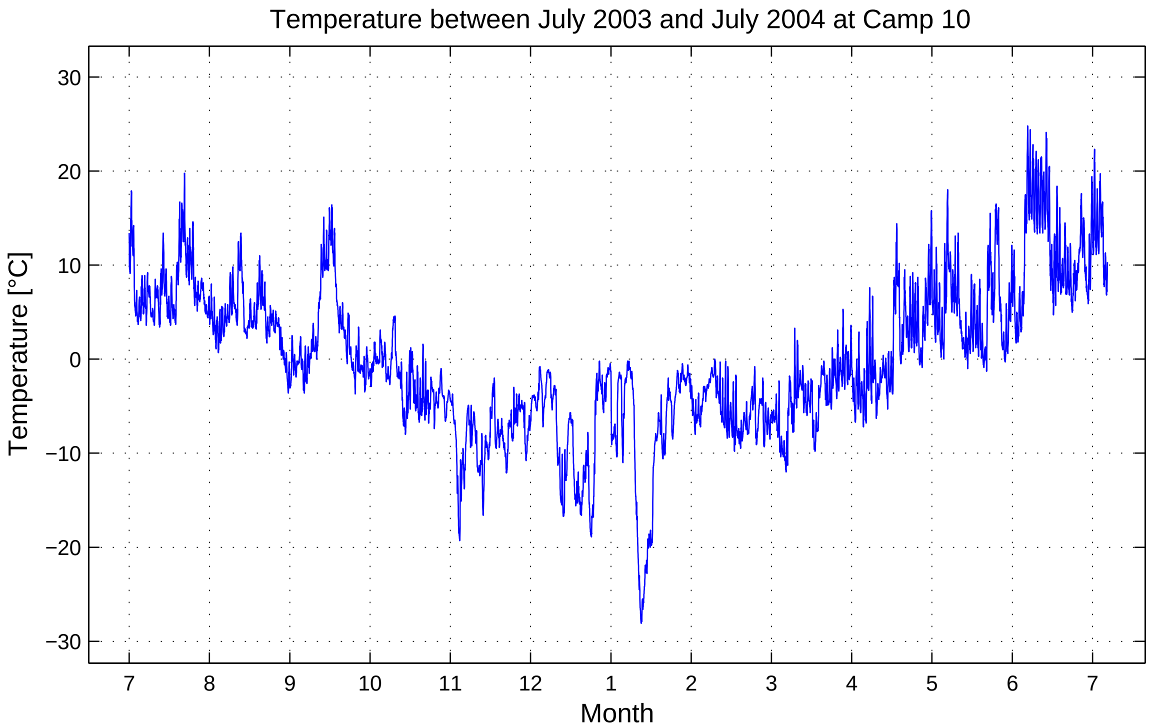


Fig. 5: Example of the temperature data, plotted with the geodetic program

To display all GPS observations the 3D coordinates of the WGS84 System have to be transformed into a plane system. To do this the followed transformation-set is used [Welsch et. al 1996]. An example of the stake-out points to find the precise location of the previous years is shown by the Profile 3B.

Parameter	Value
Projection	Transverse Mercator
Datum	WGS84
Ellipsoid	WGS84
Units	Meters
Central Meridian	134° 0' 0" West
Latitude of Origin	0° 0' 0"
Zone Width	3° 0' 0"
Central Meridian Scale	1.0
False Easting	500,000 meters
False Northing	0 meters

Profile 3B		
Flag	Easting (m)	Northing (m)
1	496,374.305	6,506,824.861
2	495,883.988	6,506,762.848
3	495,387.511	6,506,702.636
4	494,891.494	6,506,640.948
5	494,394.597	6,506,582.871
6	493,898.548	6,506,522.531
7	493,402.704	6,506,463.361
8	492,907.070	6,506,404.580

Fig. 6: Parameter of the JIRP-Projection and an Example of the GPS Stake Out Points

3. Survey Projects

As in previous years, the measurement plan's priority was determining changes in height and the flow velocitiy of the longitudinal and transversal profiles. As a result, the long-term study was expanded by one measurment period in 2004. At the start of field measurement activity, the profile of the Lemon Creek Glacier at Camp 17 was measured and evaluated.

3.1 Lemon Creek Glacier and Ptarmigan

Figure 7 illustrates both glaciers at the Camp 17 area. In 2004 an additional profile at the Lemon Creek Glacier in a northern direction was set up. The red profile points at figure 7 were setup in 1997 and annually measured since then using GPS. The interpolated elevations from the profile measurements allowed visualization with DTMs or annual changes in height (see figure 8). Figure 9 shows the profile from the point ID 1 to point ID 31. The points located west of Camp 17 (Ptarmigan) were once again observed and evaluated for the first time since 1997.

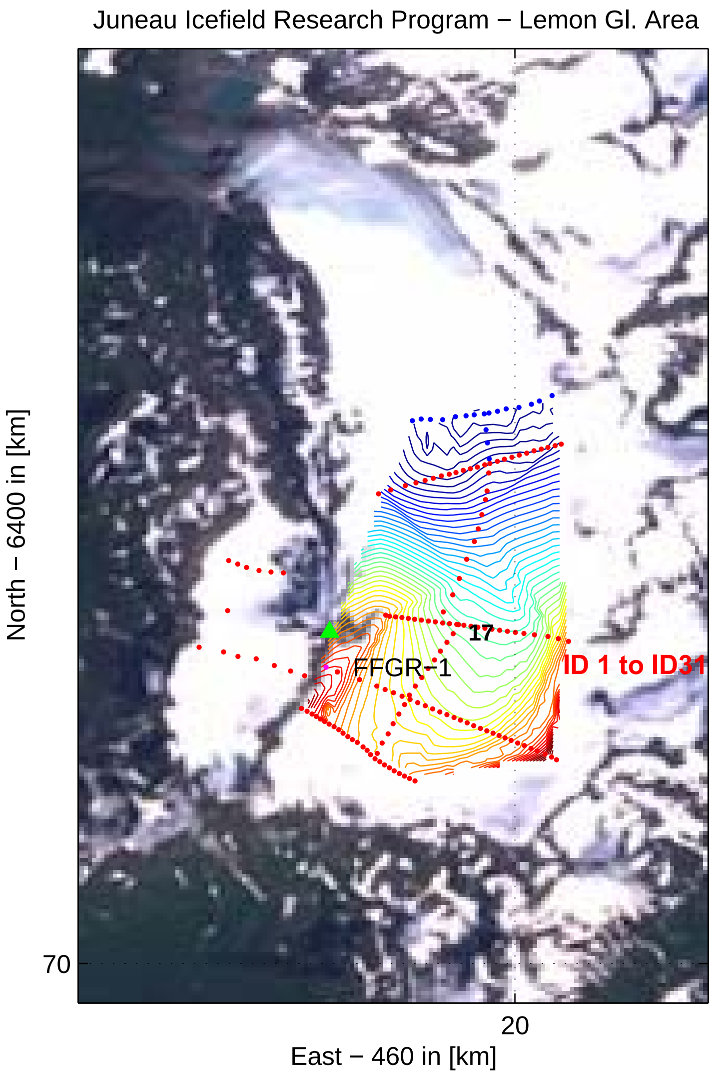


Fig. 7: Profiles Lemon Creek Glacier with the Ptarmigan (new setup in 2004, blue Profile)

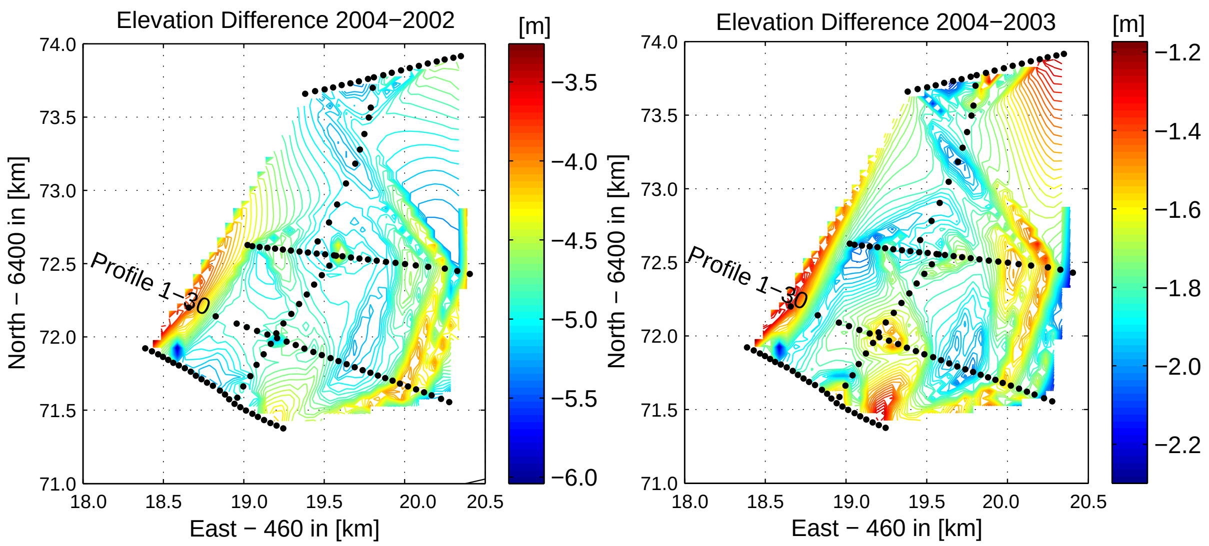
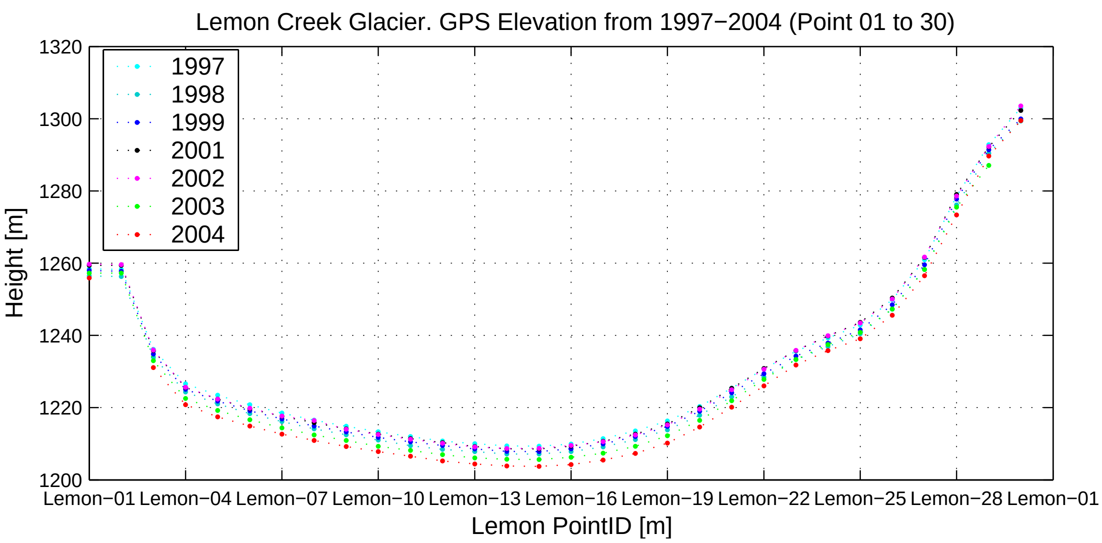


Fig. 8: Ellipsoid Height Difference Lemon Creek Glacier



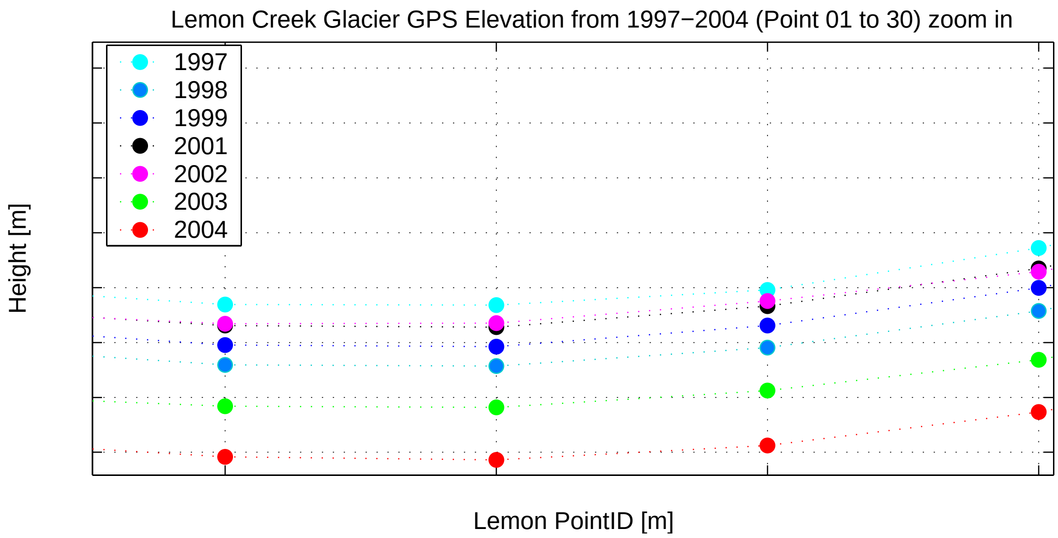


Fig. 9: Lemon Creek Glacier, second transversal Profile from south

In the next figure the elevation change is shown in an example of two transversal profiles. Over the last two years, the level of the glacier's surface has shrunk by 2 meters annually. This visualization of geodetic measurements presents a fundamental technique for determining balances of mass and help answer general questions on evaluating glacier conditions. The situation at the west part of Camp 17 is even worse. The north profile at the Ptarmigan hast a different to 1997 of 5 meter and at the south part of 12 meter.

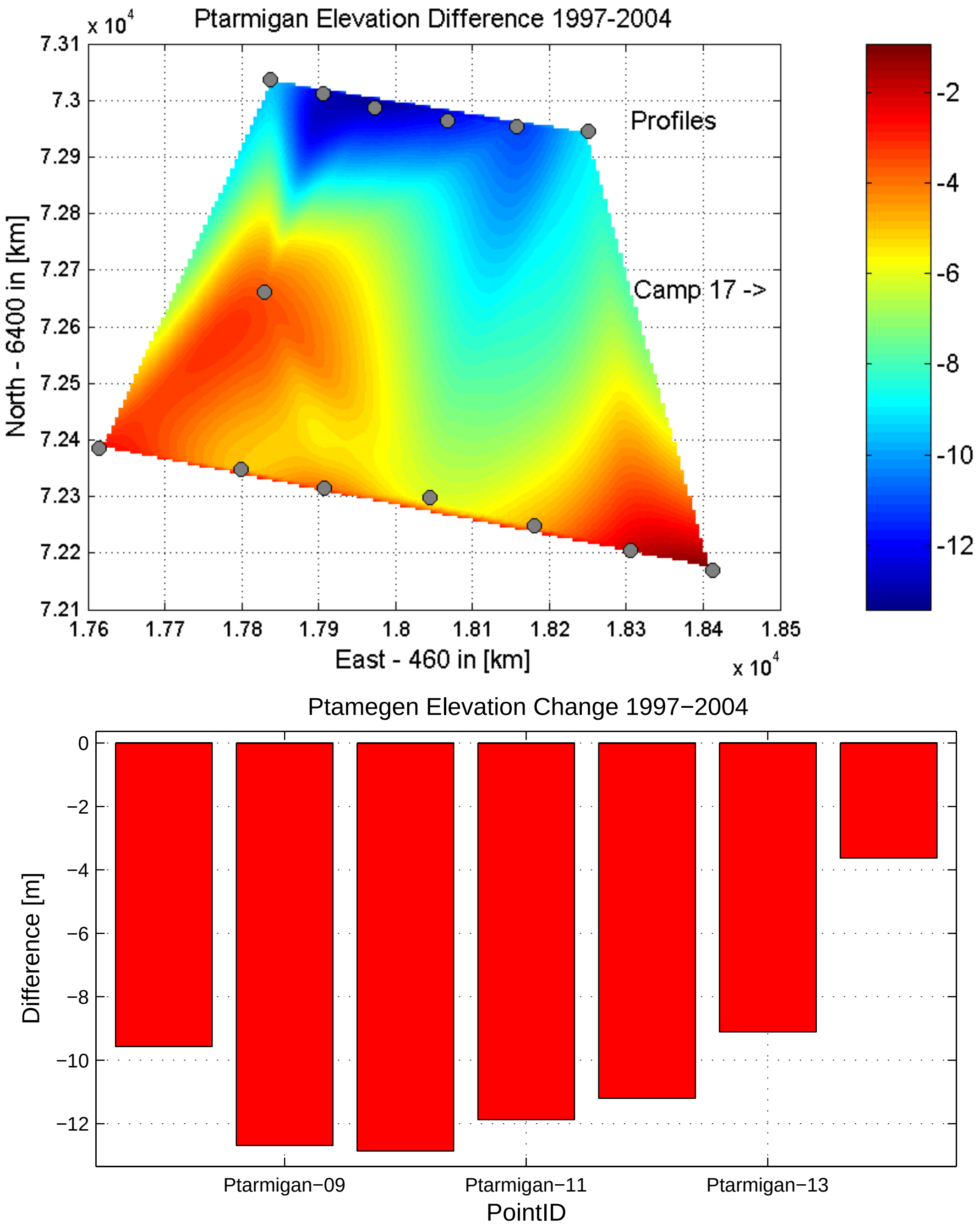


Fig. 10: GPS-Observation at the Ptamigan

Another important task is the preparation of precise information like digital terrain models (DTM) for glaciological scientists. The profiles of the Lemon Creek Glacier afford such a calculation of a DTM. By the comparison of a DTM with the precise test pit location (surveyed with RTKGPS) the explanation of the annual snow layer helps a lot (see Fig. 11).

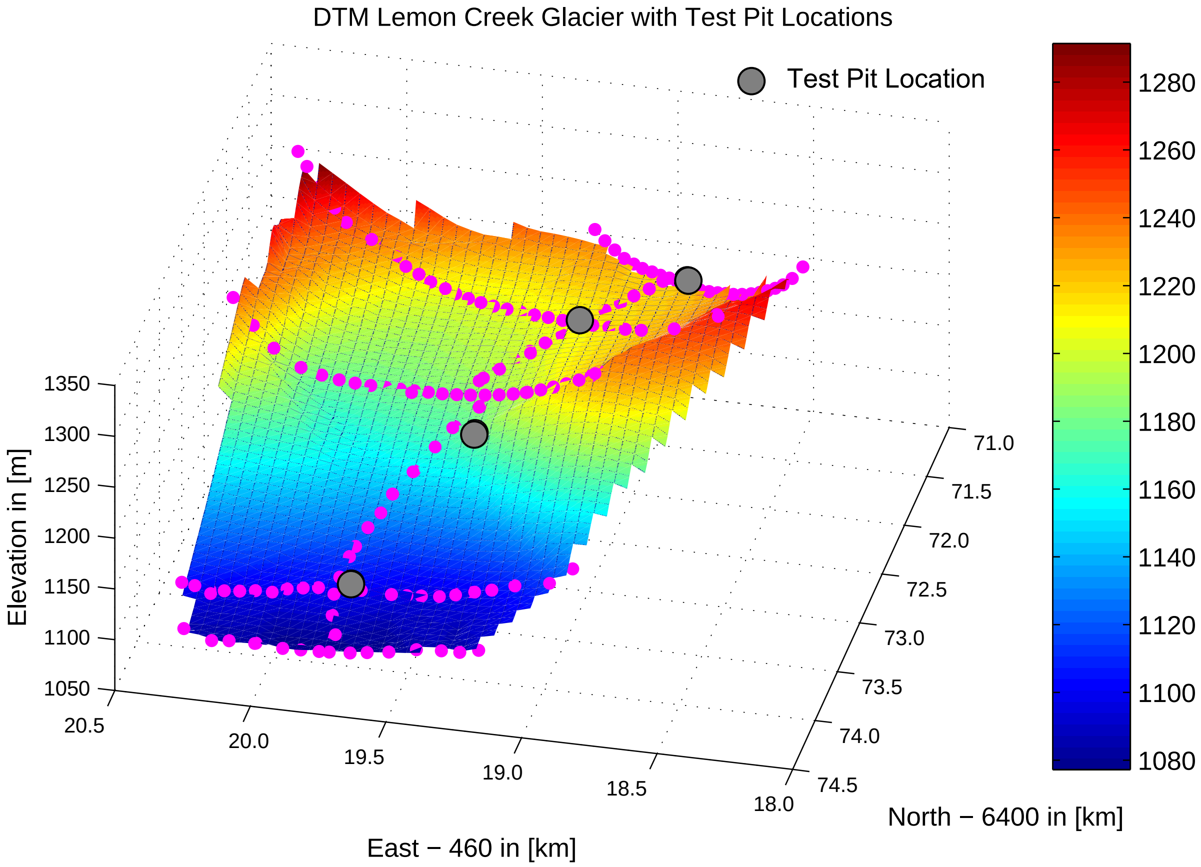


Fig. 11: Digital Terrain Model / Test Pits Location

3.2. Taku Glacier

Beside the longitudinal and transversal profiles of the lemon Creek Glaicer GPS Points are measured on the Taku-, Matthes-, Demorest- und Llewellyn Glacier. The blue points of figure 12 are only measured ones. The red points are measured two times to determine the velocity vector of the vector difference within a few days.

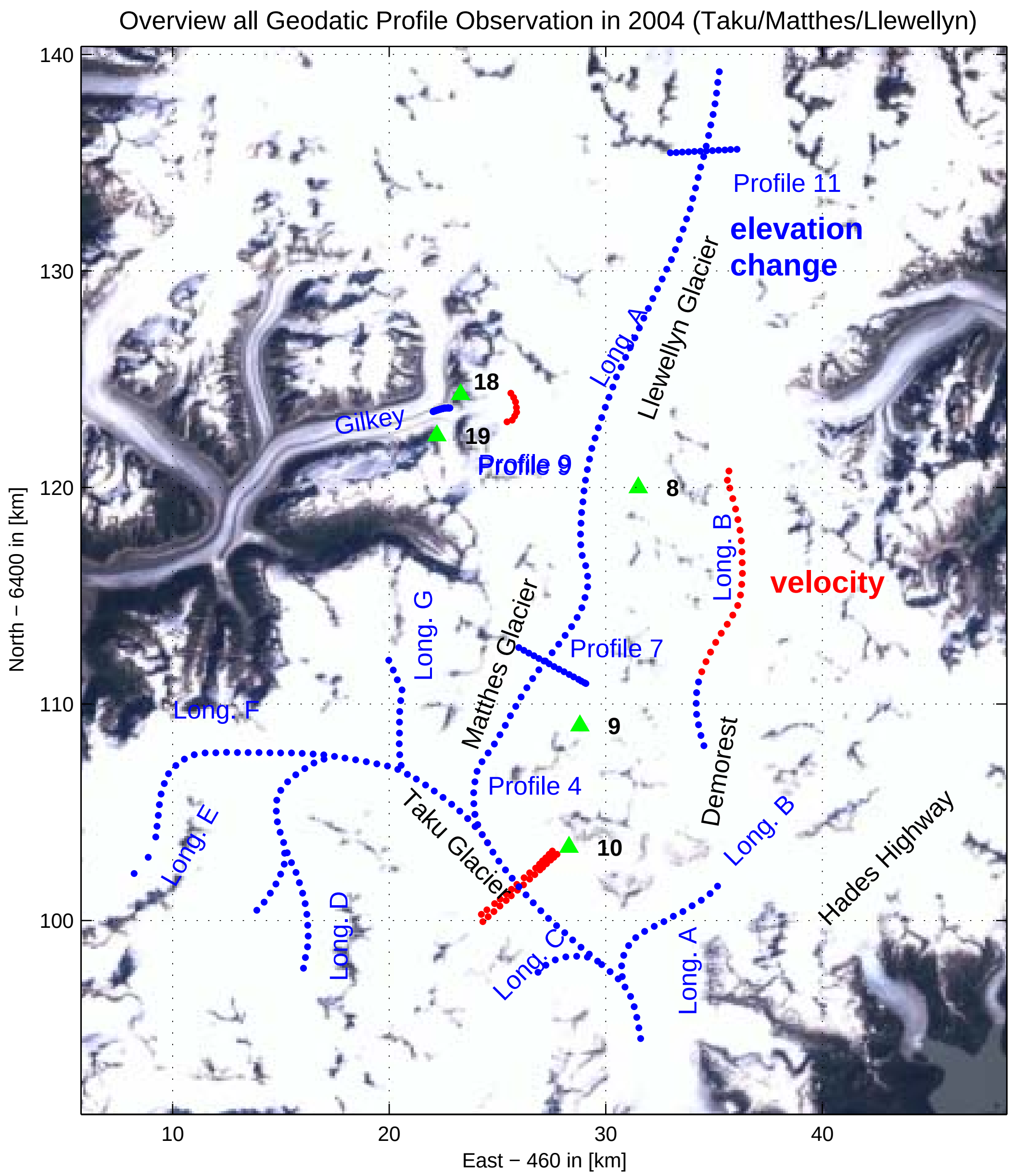


Fig. 12: Overview of all Profile Observation beside the Lemon Creek Glacier

3.2.1 Transversal Profile

Since the start of GPS measurements on the Juneau Icefield in 1992, 4 measurement data sets have been observed on both transversal profiles. Since 1993 measurements for the entire length are available. The following diagrams present the corresponding height for each measurement campaign.

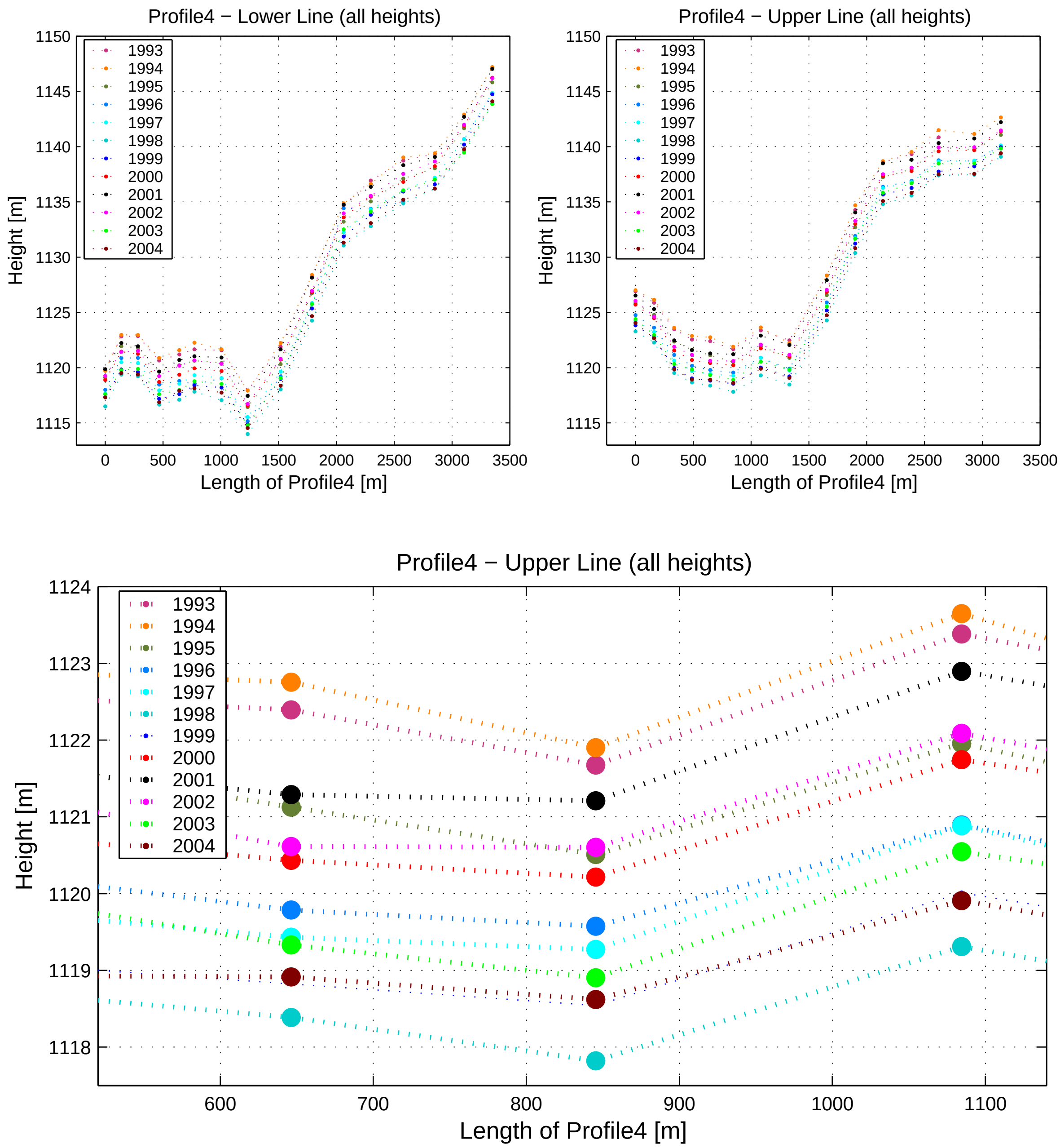


Fig. 13: Elevation at the Transversal Profile 4 from 1993-2004

Changes in height of both transversal profiles 4 are nearly identical, since there is a distance of less than 100 meters between both profiles. The zoom-in of the graphic section clearly shows the variation in height for the various measurement periods. The same figures be created for profile 7 or 9. In 2004 Profile 11 was measured for the first time as a georeference task with the ICESat and CryoSat-Data. These results are described in a second master thesis [WENZEL, 2005].

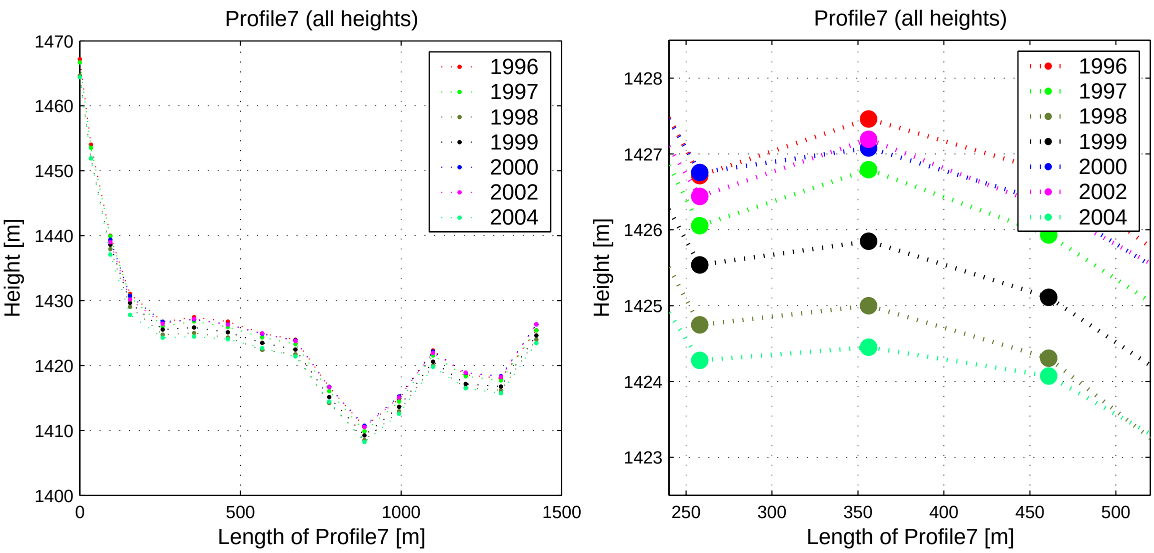


Fig. 14: Elevation at the Transversal Profile 7

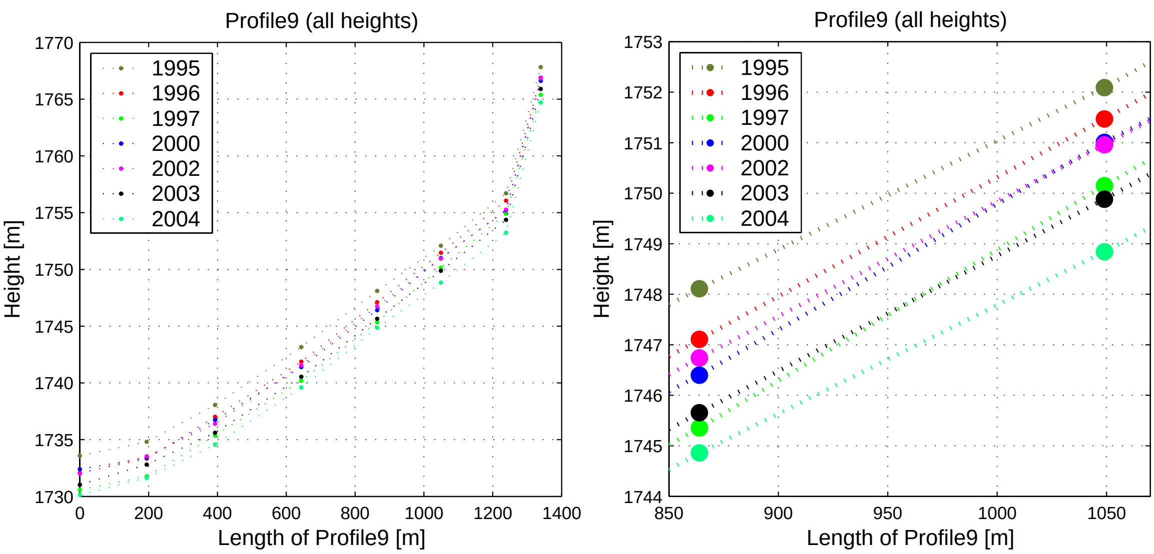


Fig. 15: Elevation at the Transversal Profile 9

3.2.2 Longitudinal Profile

When observing all longitudinal profiles, observations on elevation levels for the center of the glacier surface can be made. These graphics represent the glacier conditions for each measurement period; they are very precise for each observation year. Using this regional-scale geodetic information allows specialized fields of glaciology such as meteorological data collection i.e. precipitation measurements etc. to be combined and help answer global-scale paleoclimatology issues such as global warming. First, an overview of all longitudinal profile measurements using GPS is provided. In contrast to transversal profiles, longitudinal profiles have only been observed since 1999 (cp. table 2).

	Long. A	Long. B	Long. C	Long. D	Long. E	Long. F	Long. G
1999	Elev./Velocity	Elev./Velocity	Elev./Velocity	-	-	-	-
2000	Elev./Velocity	Elev./Velocity	Elevation	Elev./Velocity	-	Elev./Velocity	-
2001	Elev./Velocity	Elevation	Elevation	Elev./Velocity	Elev./Velocity	Elev./Velocity	Elev./Velocity
2002	Elevation	Elevation	Elevation	Elevation	Elevation	Elevation	-
2003	Elevation	Elevation	-	Elevation	Elevation	-	Elevation
2004	Elevation	Elev./Velocity	Elevation	Elevation	Elevation	Elevation	Elevation

Table 2: Overview – all Longitudinal Profile Observation with GPS

Longitudinal Profile A

This profile is straight from the Taku Inlet over the Divide and almost up to the Llewellyn Inlet. To compare this longitudinal profile with the location in the Icefield figure 12 is shown all the location in the LANDSAT satellite image.

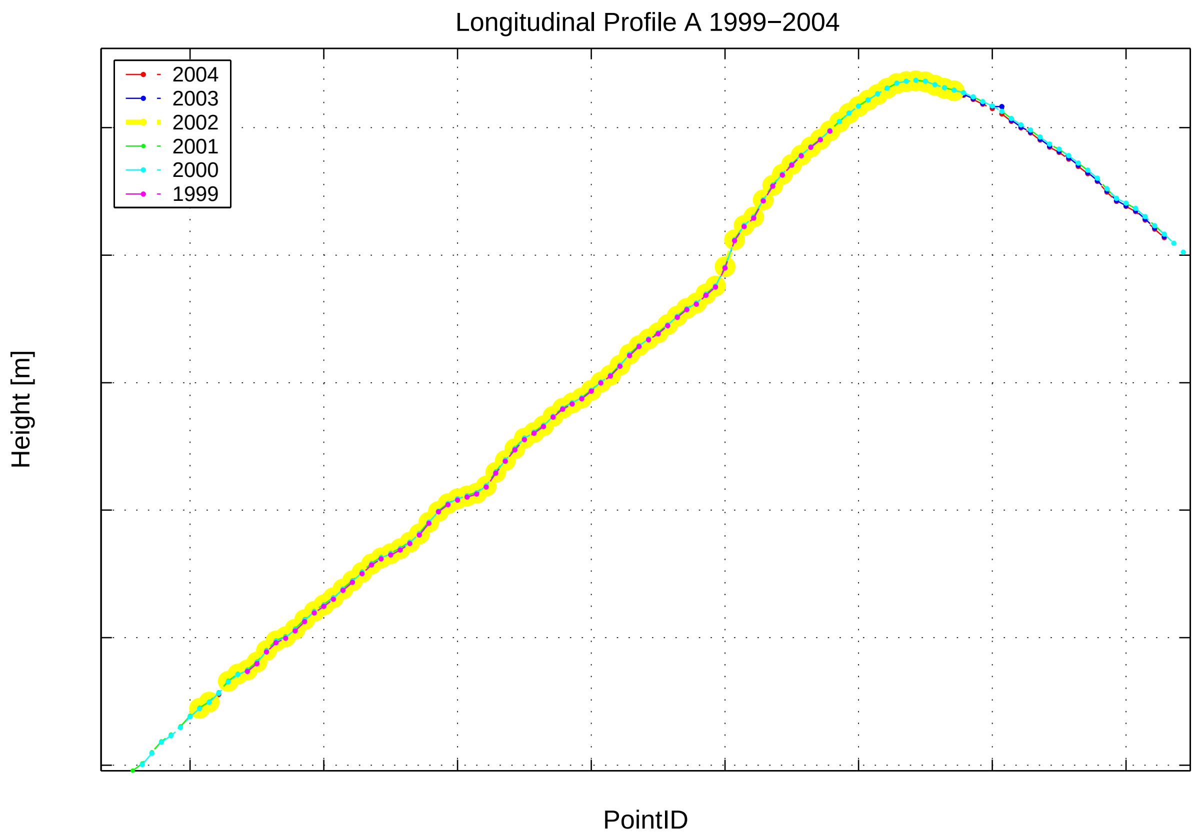


Fig. 16: Elevation at the Longitudinal Profile A

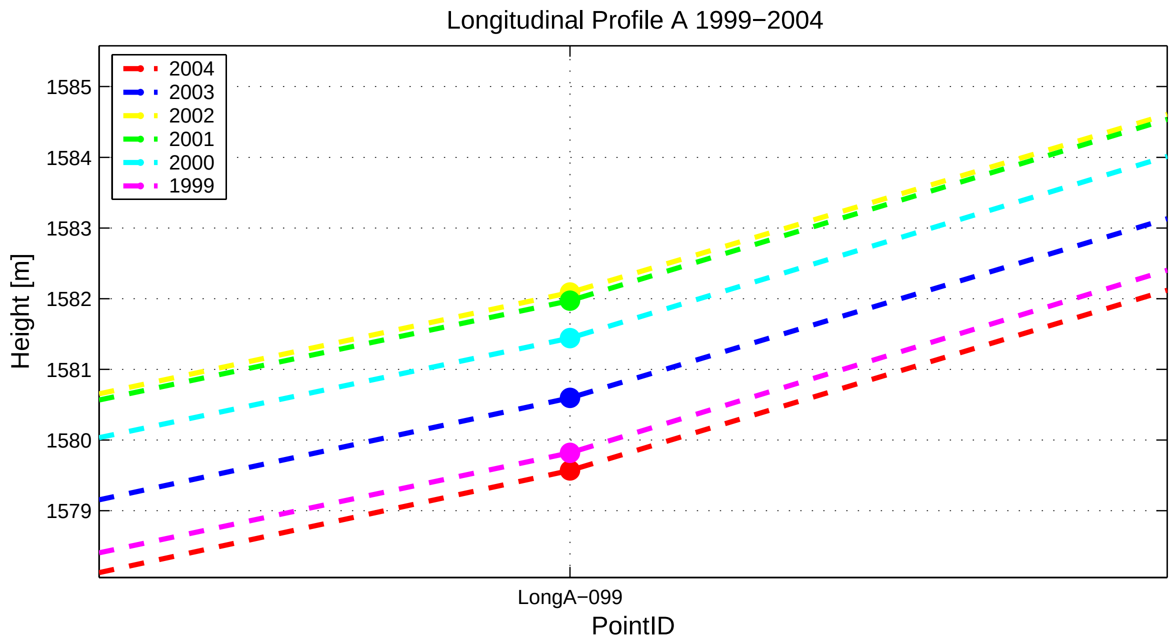


Fig. 17: Elevation at the Longitudinal Profile A, zoom in at Point 99

The following figure shows the height difference at the longitudinal profile A between 2004-2003. The Matlab tool can display each possible difference plot.

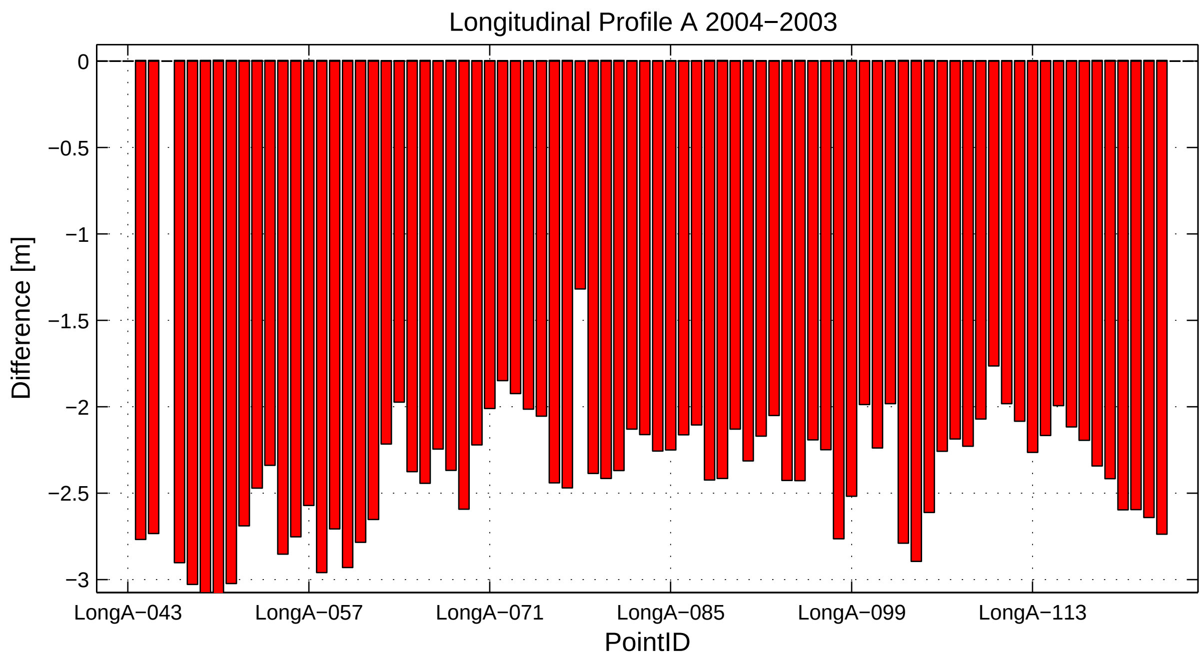


Fig. 18: Longitudinal Profile A Difference 2004-2003

Longitudinal Profile B

The longitudinal profile B describes the area of the Demorest Glacier.

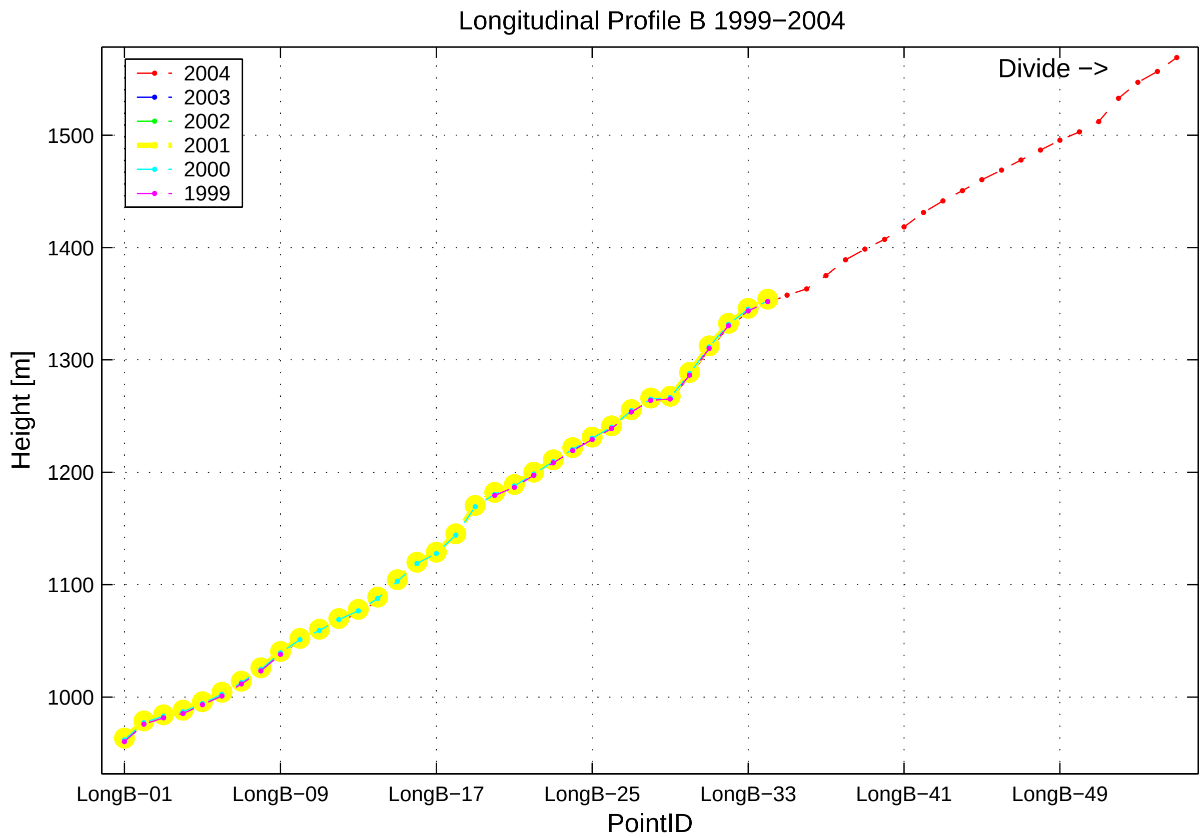


Fig. 19: Elevation at the Longitudinal Profile B

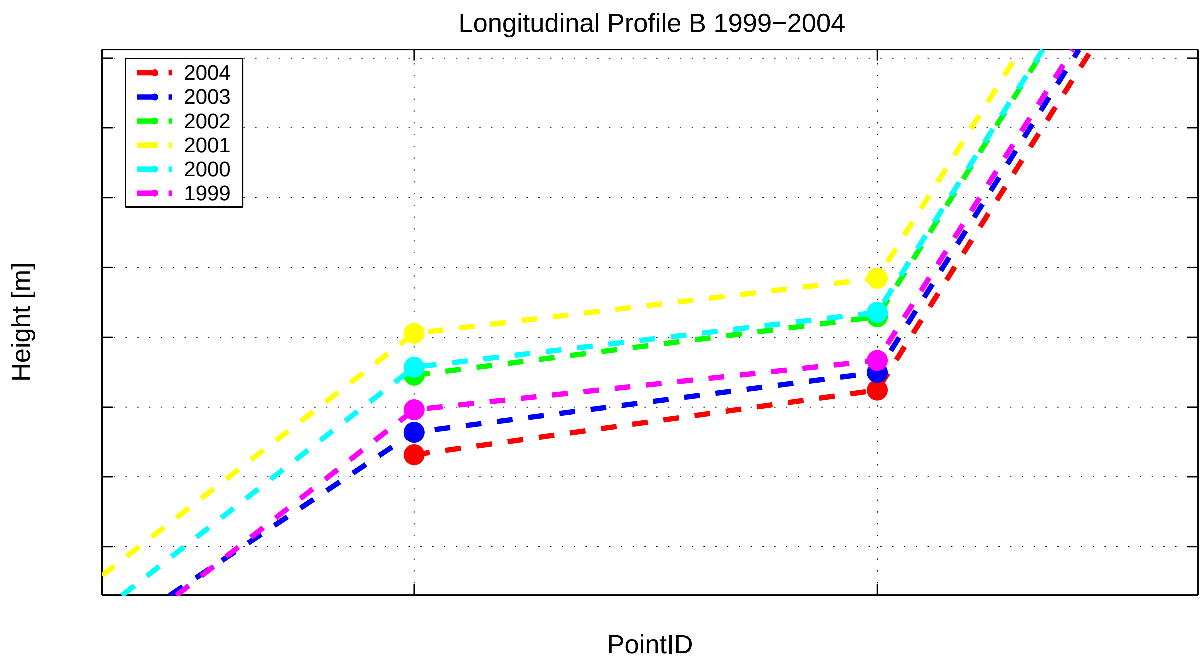


Fig. 20: Elevation at the Longitudinal Profile B, zoom in at Point 27 and 28

Longitudinal Profile C

The longitudinal profile C specifies the South-West Branch up to the Norris Icefall.

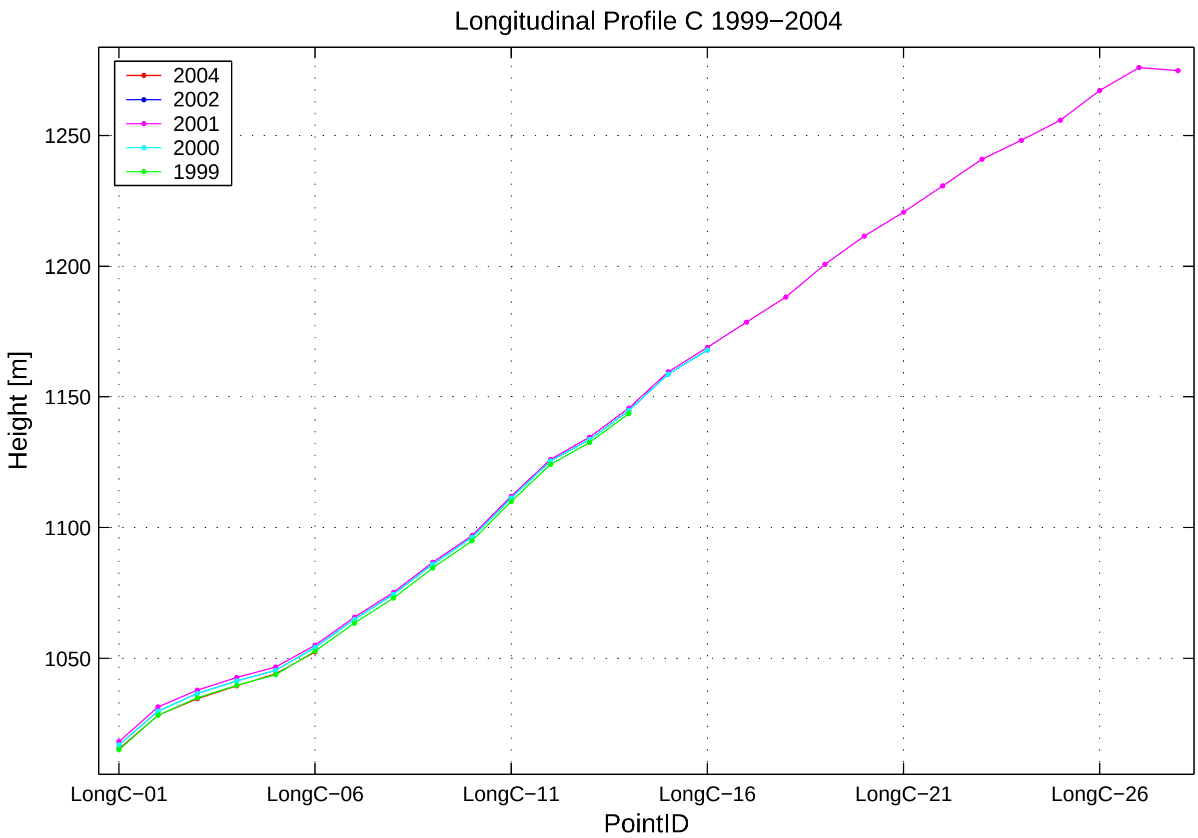


Fig. 21: Elevation at the Longitudinal Profile B

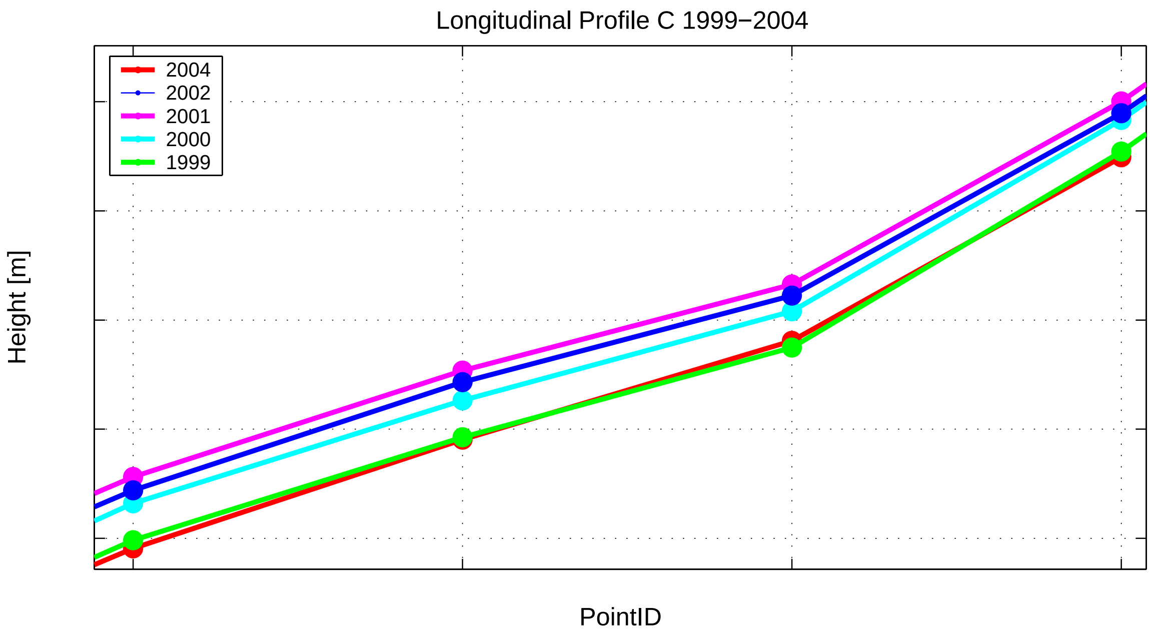


Fig. 22: Elevation at the Longitudinal Profile C, zoom in

The next figure represents an incorrect offset at the Point ID 4 to17. After 2 years, it is no longer possible to find the cause of error and correct the data set. The only way to correct it is to eliminate faulty measuring points. By using the Matlab tool all GPS observations can be controlled very fast in the field.

Longitudinal Profile D (North-West Branch Part 1)

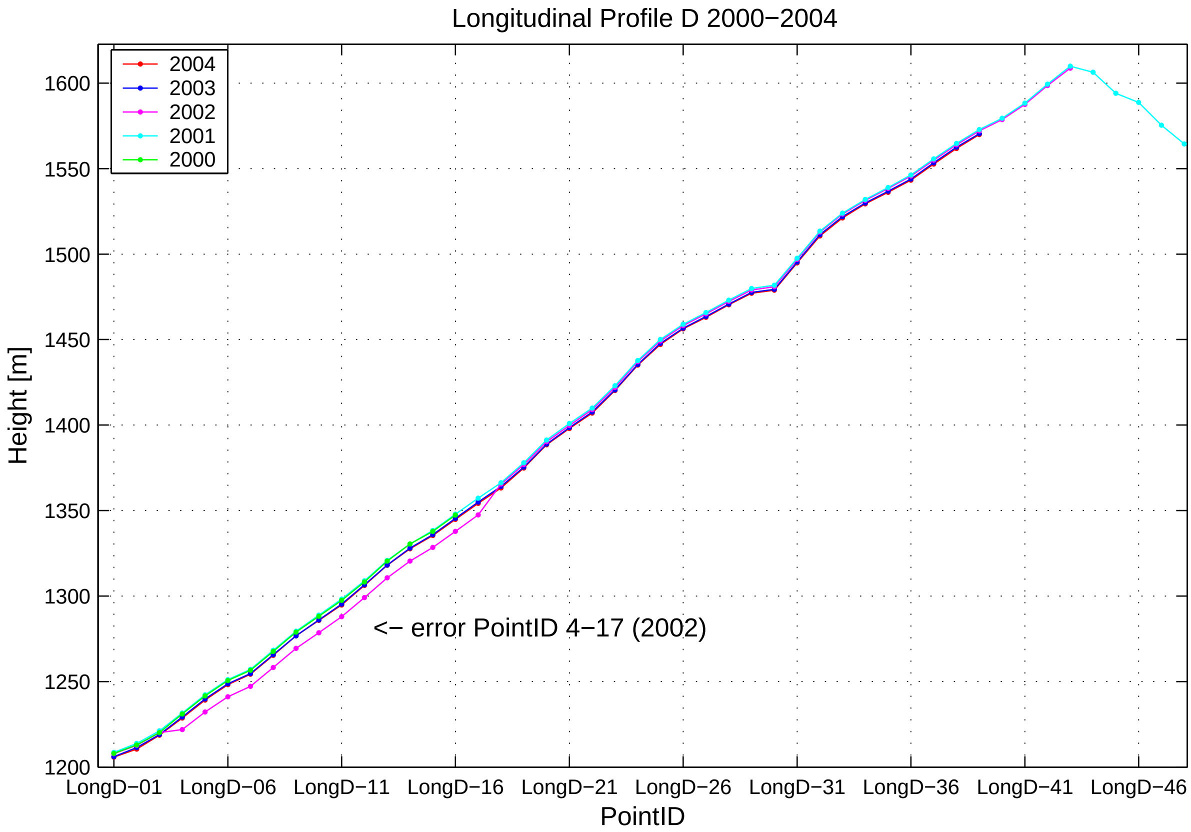


Fig. 23: Elevation at the Longitudinal Profile D

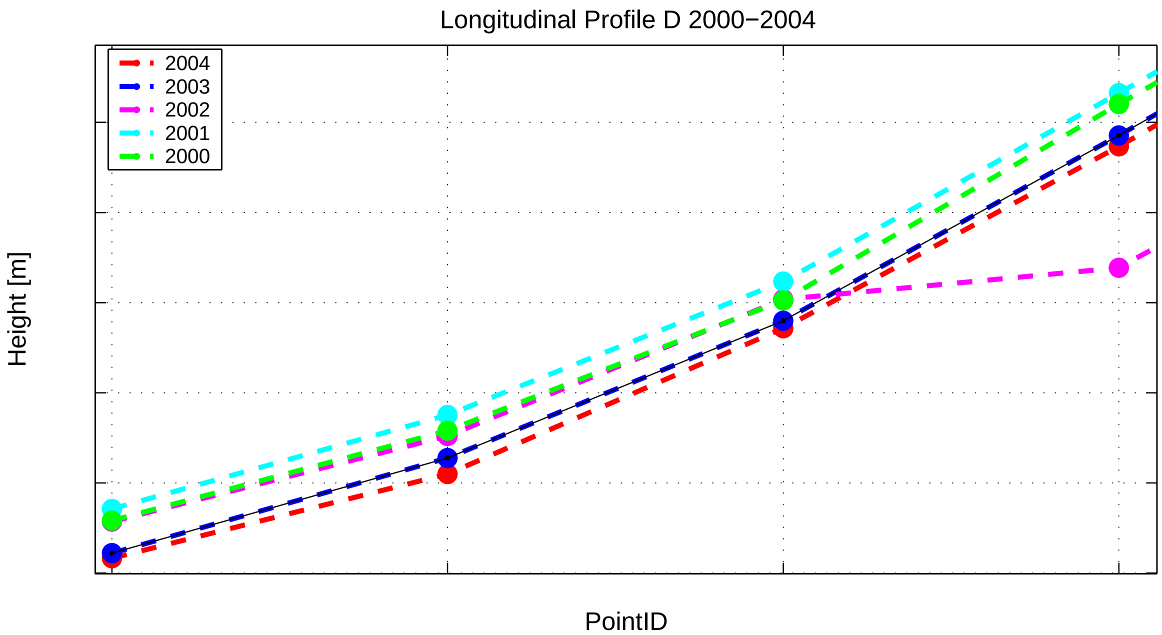


Fig. 24: Elevation at the Longitudinal Profile D, zoom in

Longitudinal Profile E

(North-West Branch Part 2)

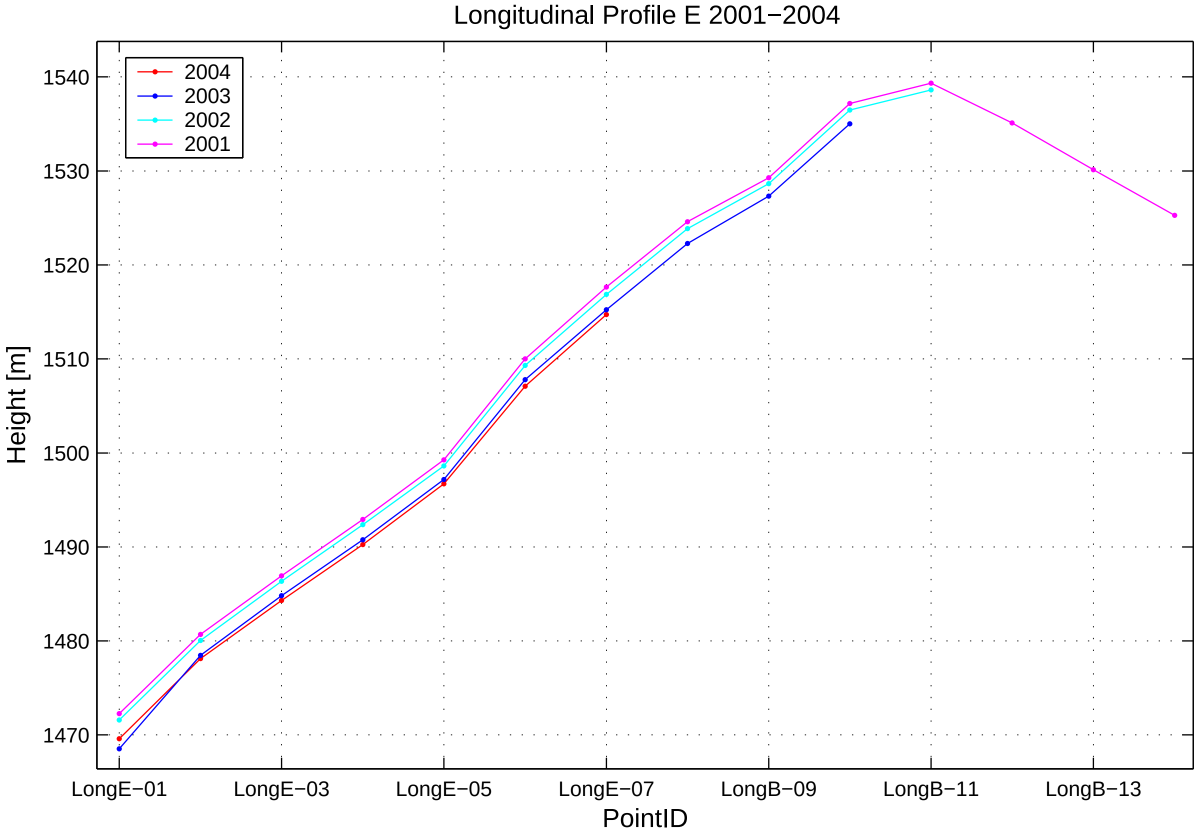


Fig. 25: Elevation at the Longitudinal Profile E

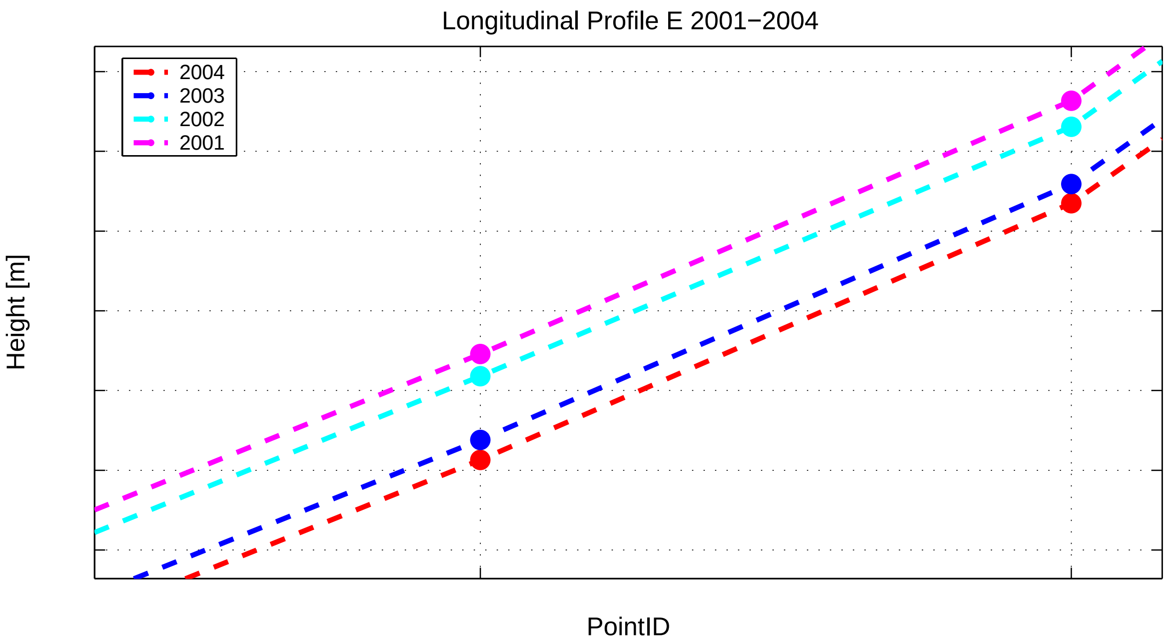


Fig. 26: Elevation at the Longitudinal Profile E, zoom in

Longitudinal Profile F
(North-West Branch Part 3)

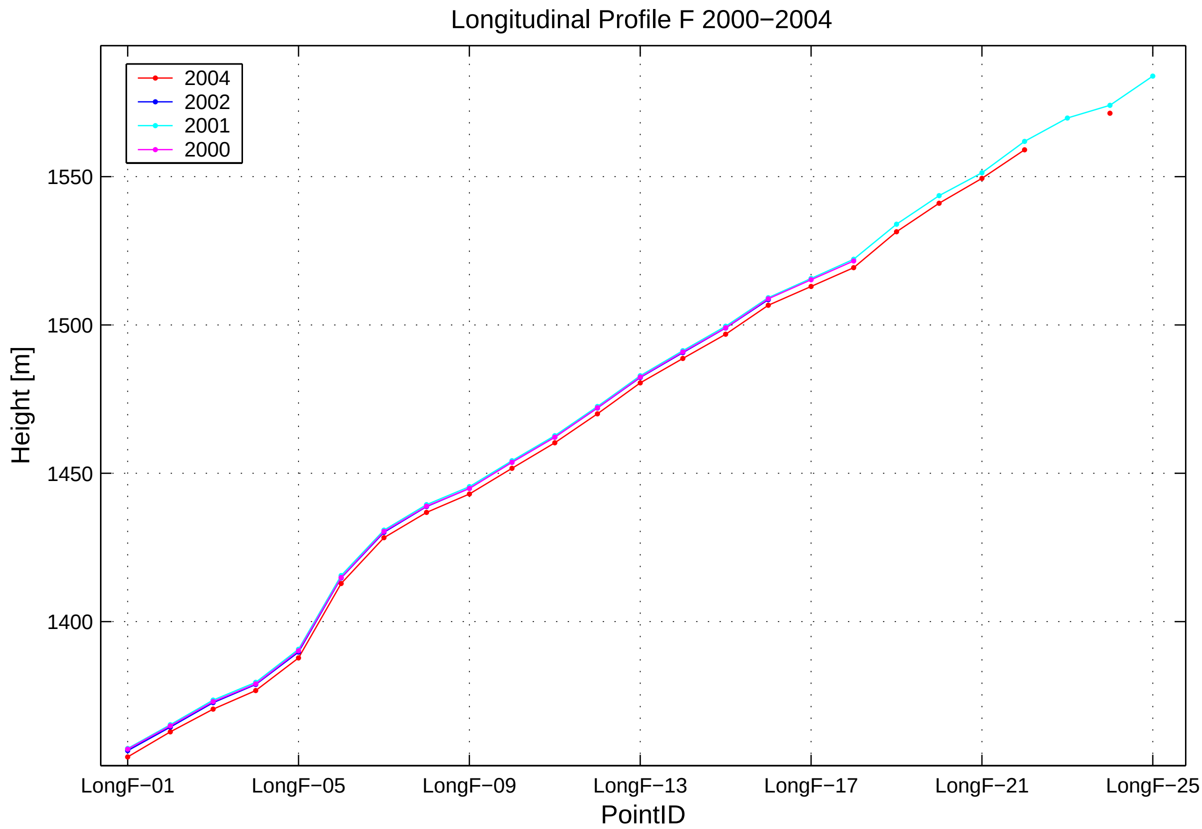


Fig. 27: Elevation at the Longitudinal Profile F

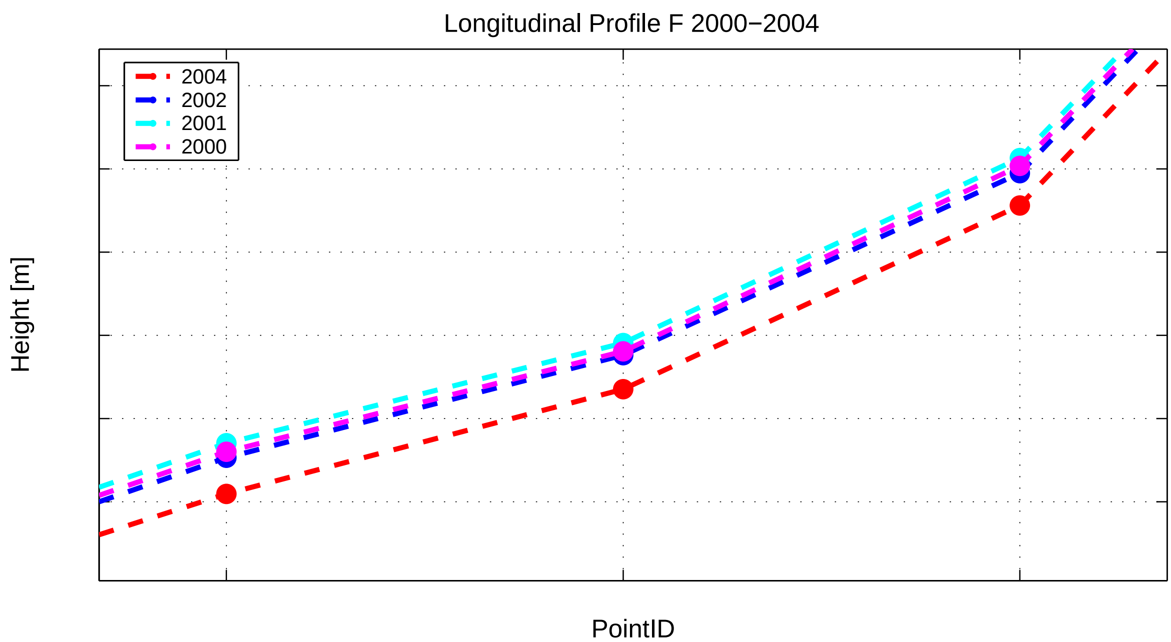


Fig. 28: Elevation at the Longitudinal Profile F, zoom in

Longitudinal Profile G
(North-West Branch Part 4)

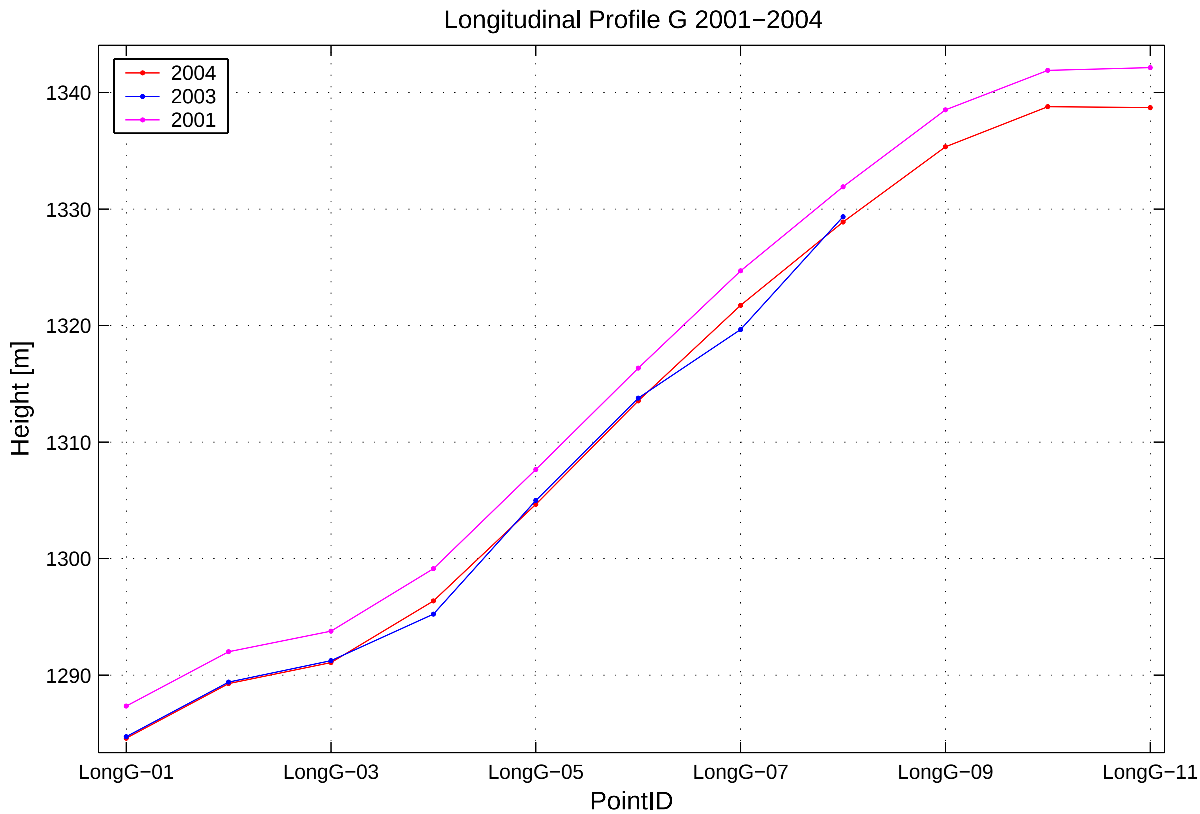


Fig. 29: Elevation at the Longitudinal Profile G

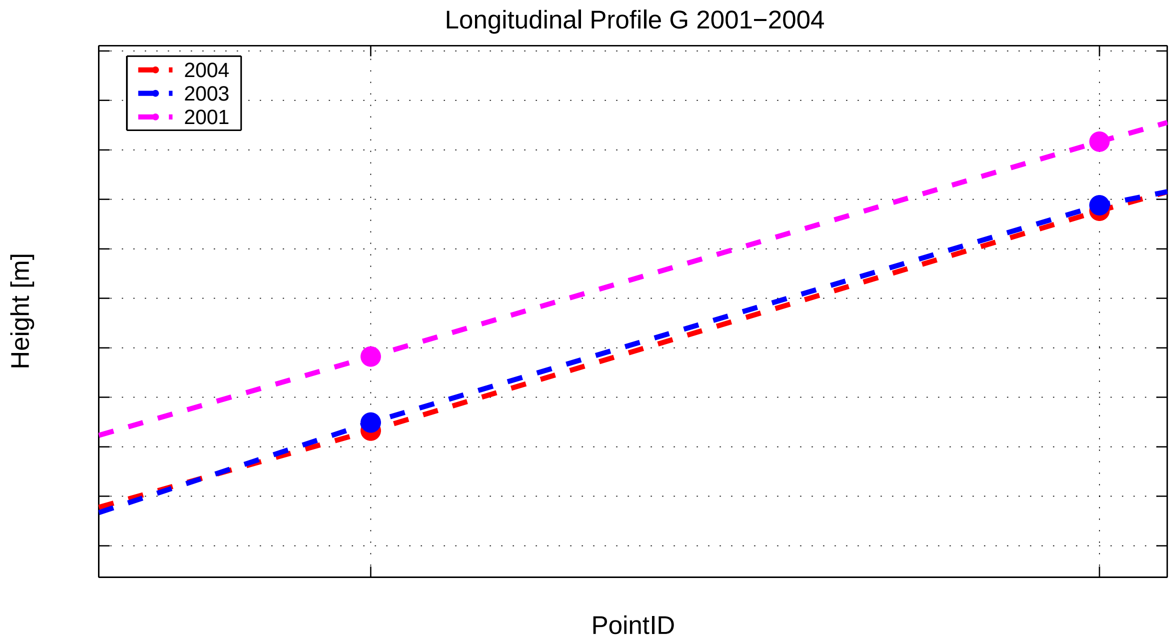
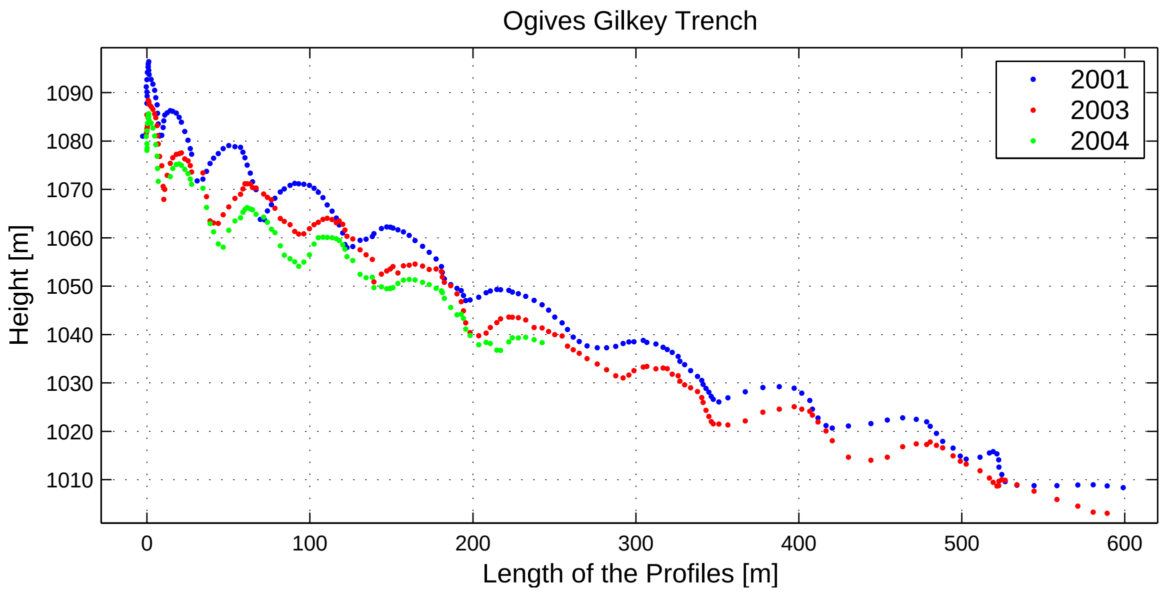


Fig. 30: Elevation at the Longitudinal Profile G, zoom in

In 2004, an additional longitudinal profile could be measured for the third time. This required considerably more logistical efforts, since all measuring equipment had to be transported across a steep cliff. The ogives that occurred yearly in the Vaughan Lewis Icefall could be measured with GPS in 2004 and visualized with the evaluation software. This also revealed a clear reduction of glacier surface. By zooming in the figure each ogvie can be determined.



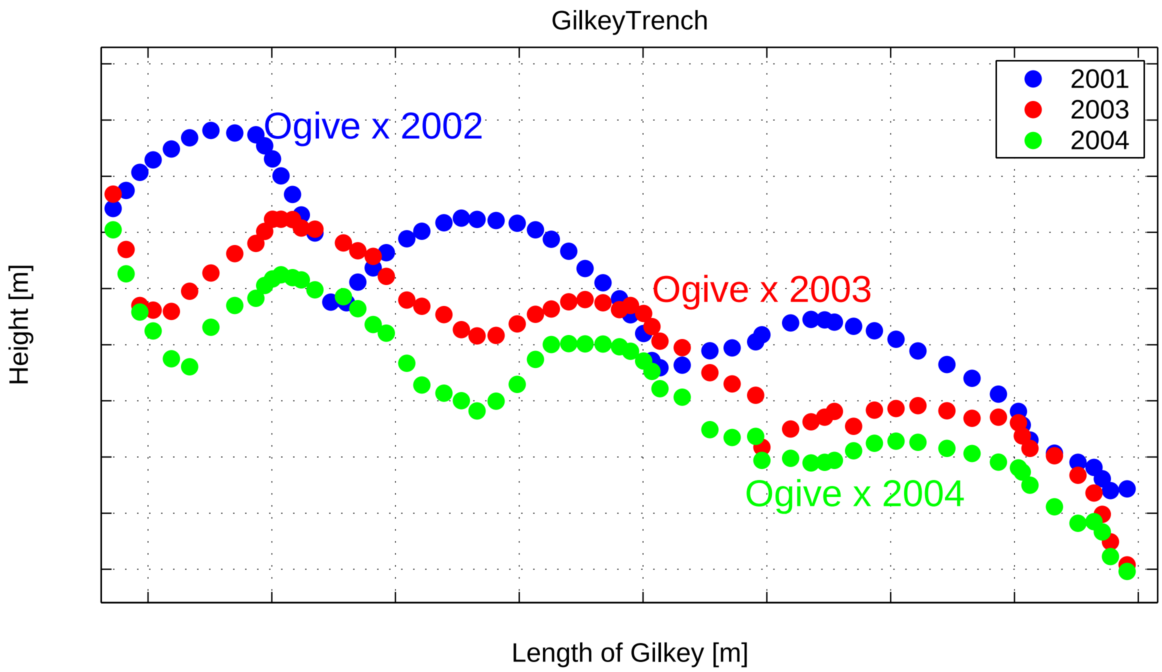


Fig. 31: Longitudinal Profile at the Gilkey Trench, Ovigen of the Vaughan Lewis Icefall

3.3 Velocity Observation

As you can see in table 2 a few profile were resurveyed to determine the velocity of the glacier surface. The time period is normally between 1 to 2 weeks.

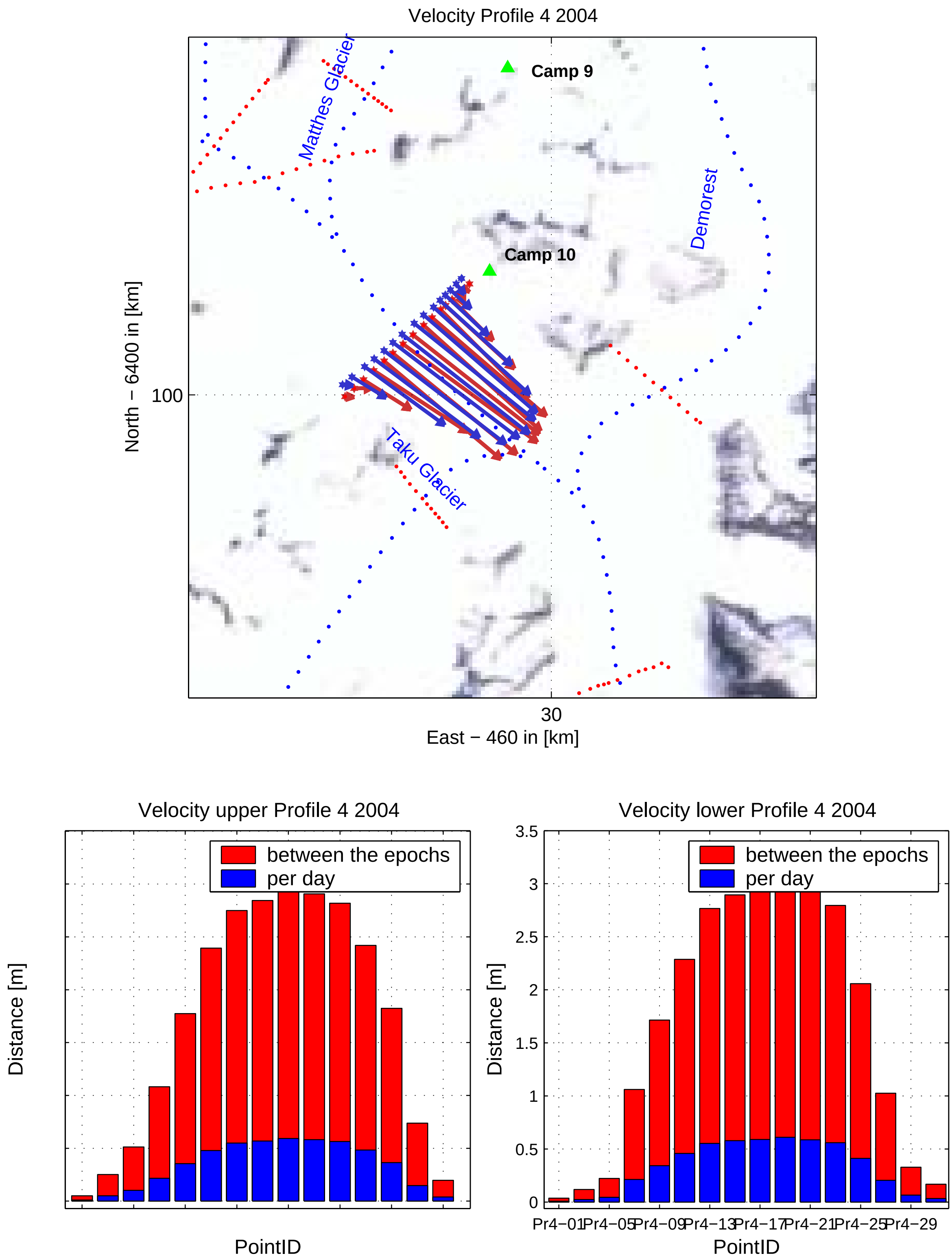
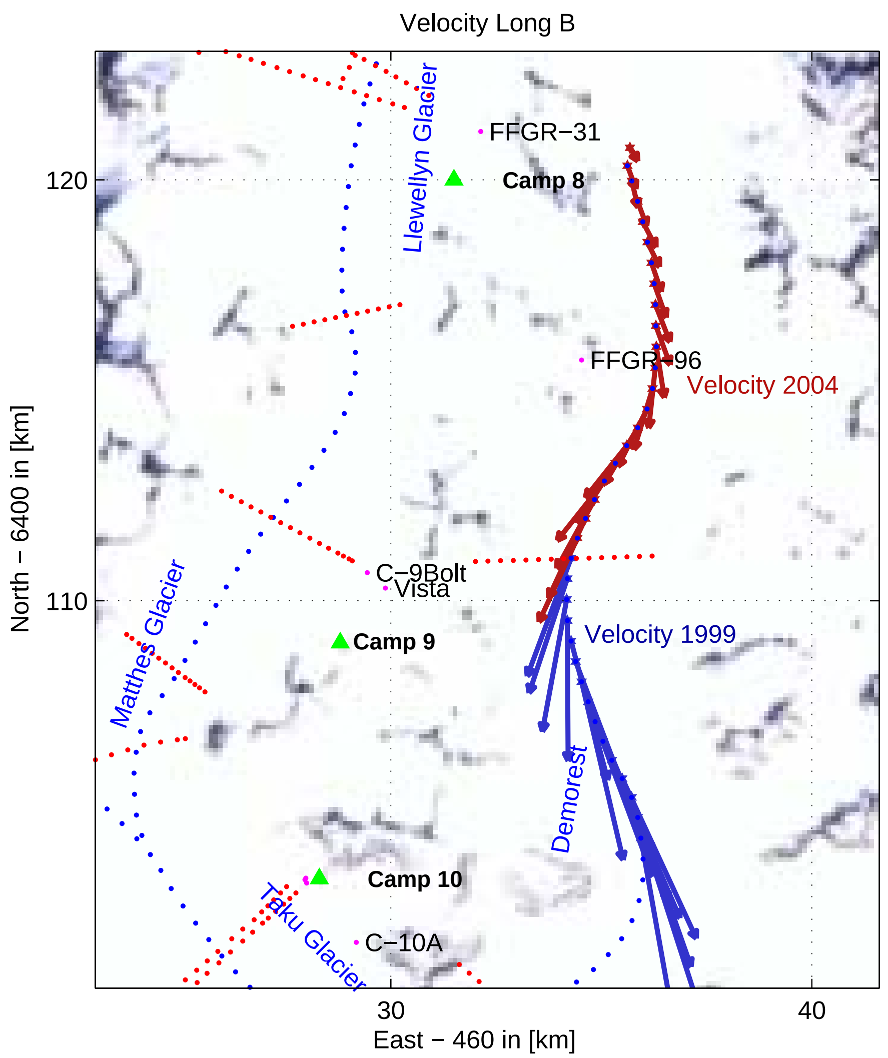


Fig. 32: Velocity at Profile 4



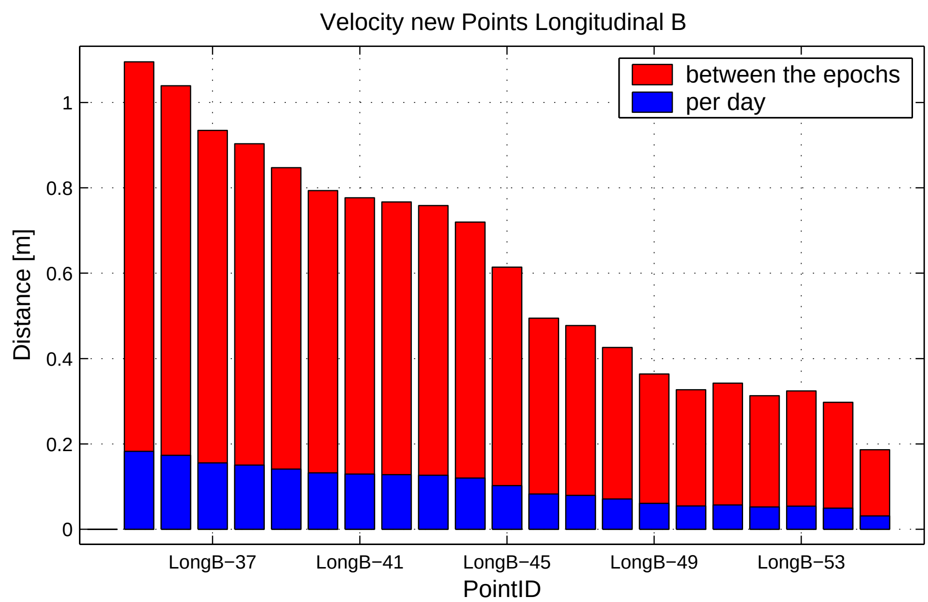


Fig. 33: Velocity at Longitudinal B – new Stake Out Points at the Divide of the Demorest Glacier

The results of the flow velocity measurement on profile 9 showed an average movement vector of about 10 cm per day. These are comparable to the results of 1995, 1996, 1997, 2002, 2002 and 2003.

Based on a hypothesis of Guy W. Adema (National Park Service's glaciologist at Denali National Park and Preserve), magnets were attached at selected pointed along the longitudinal profile on the glacier's surface. By locating these magnets again, this should allow measuring average flow velocities at these points over the next years. Figure 34 shows the exact position of the points on the Landsat satellites.

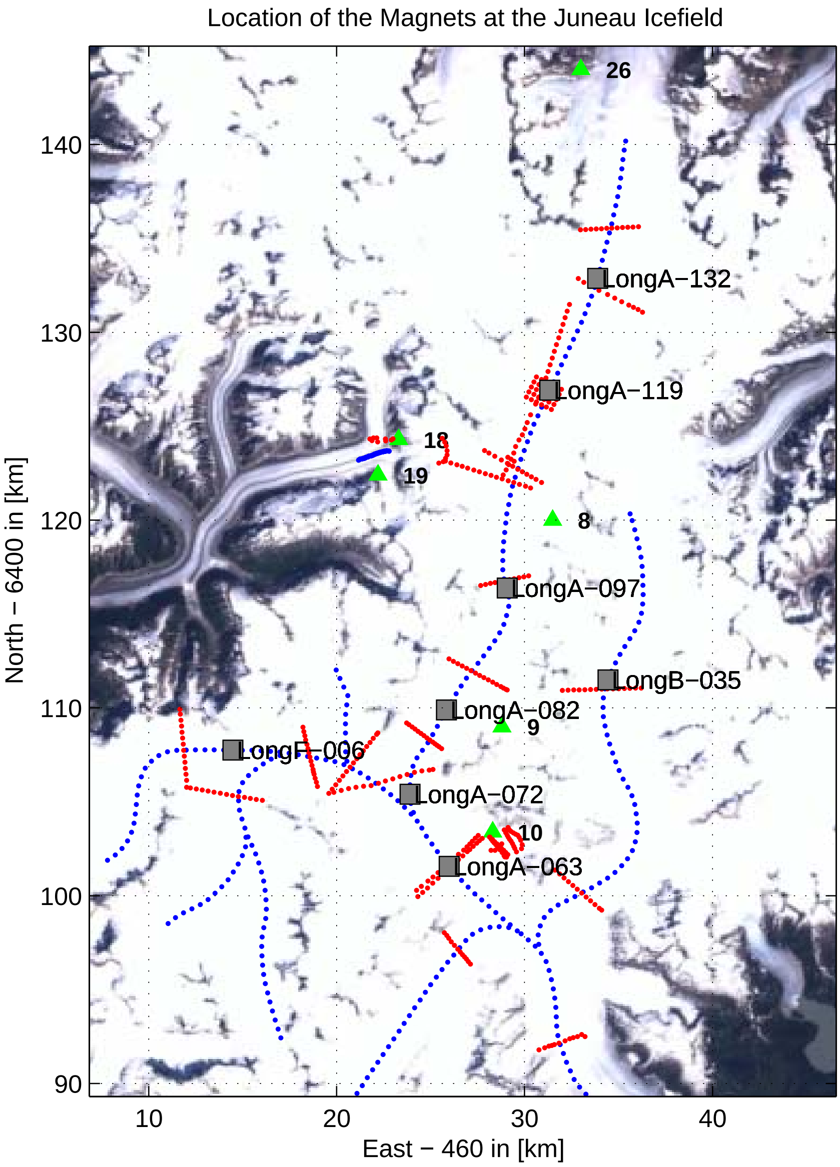


Fig. 34: Position of the Magnets

The coordinates of the point for this new project in the JIRP-System are:

Flag	Easting in [m]	Northing in [m]	elli. Height in [m]
LongF-006	474484.836	6507748.642	1412.383
LongA-063	485985.001	6501559.627	1124.266
LongA-072	483904.815	6505405.860	1220.030
LongA-082	485843.863	6509889.781	1357.411
LongA-097	489072.279	6516388.388	1536.761
LongA-119	491337.988	6526913.103	1871.205
LongA-132	493894.921	6532868.698	1780.813
LongB-035	494433.974	6511487.584	1357.486

Table 3: Coordinates of the Magnets in the JIRP System (accuracy a few cm)

The two new reference points to continue the longitudinal profile were setup. The positions of the new benchmarks are post processed with the raw GPS data in SkiPro (GPS Post processing Software of Leica Geosystems). The results of the dataprocessing are:

Flag	Easting in [m]	Northing in [m]	elli. Height in [m]
FFGR96 (Demorest Gl.)	494531.122	6515717.135	1562.521
FFGR97 (Camp 26)	493094.441	6544549.841	1438.350

Table 4: Coordinates of the new Benchmarks (JIRP System)

Flag	West	North	elli. Height in [m]
FFGR96 (Demorest Gl.)	134° 05’ 40.16286’’	58° 45’ 28.84223’’	1562.521
FFGR97 (Camp 26)	134° 07’ 12.74518’’	59° 01’ 00.58034’’	1438.350

Table 5: Coordinates of the new Benchmarks (WGS84 System)

The position in the whole satellite image is plotted in figure 3.

3.4 Strain

In conjunction with the monitoring of surface elevation and mass balance change at profile 4, strain rates have been analyzed annually. This is accomplished by determining the change in the geometry of the triangles formed by the dual line setup of profile 4. Calculation of strain rates is based on the method described by Welsch (1987), which evaluates the changes in the elements (interior angles and the length of sides) of a triangle. The strain regime at profile 4 has been relatively consistent since 1993.

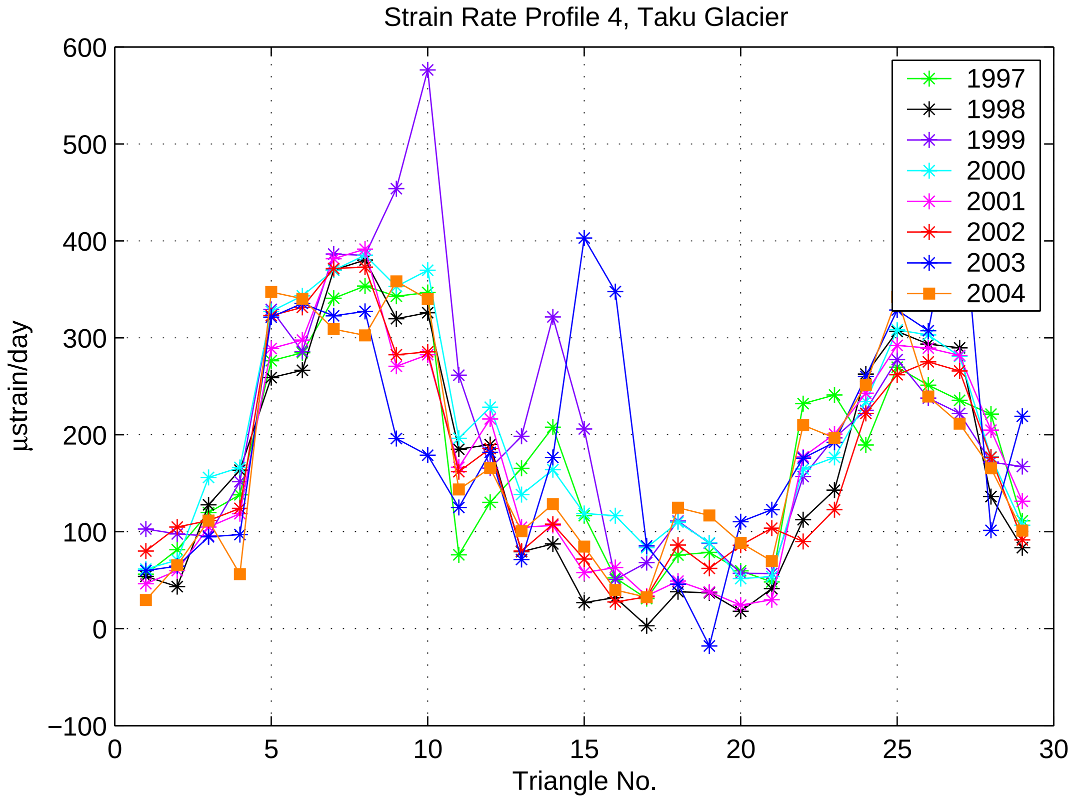


Fig. 35: Strain Rate at Profile 4, 1997 - 2004

3.5 Gravimetry and Mapping Projects

In addition, other projects dealt with measuring the relative gravimetry on profile 4 and at the F8/18 intersection, and developing geological maps. Here GPS positions with centimeter precision were made available. Results were also graphically visualized using the evaluation software program. Furthermore the results are plotted with the new visualization tool (see Figure 36 and 37).

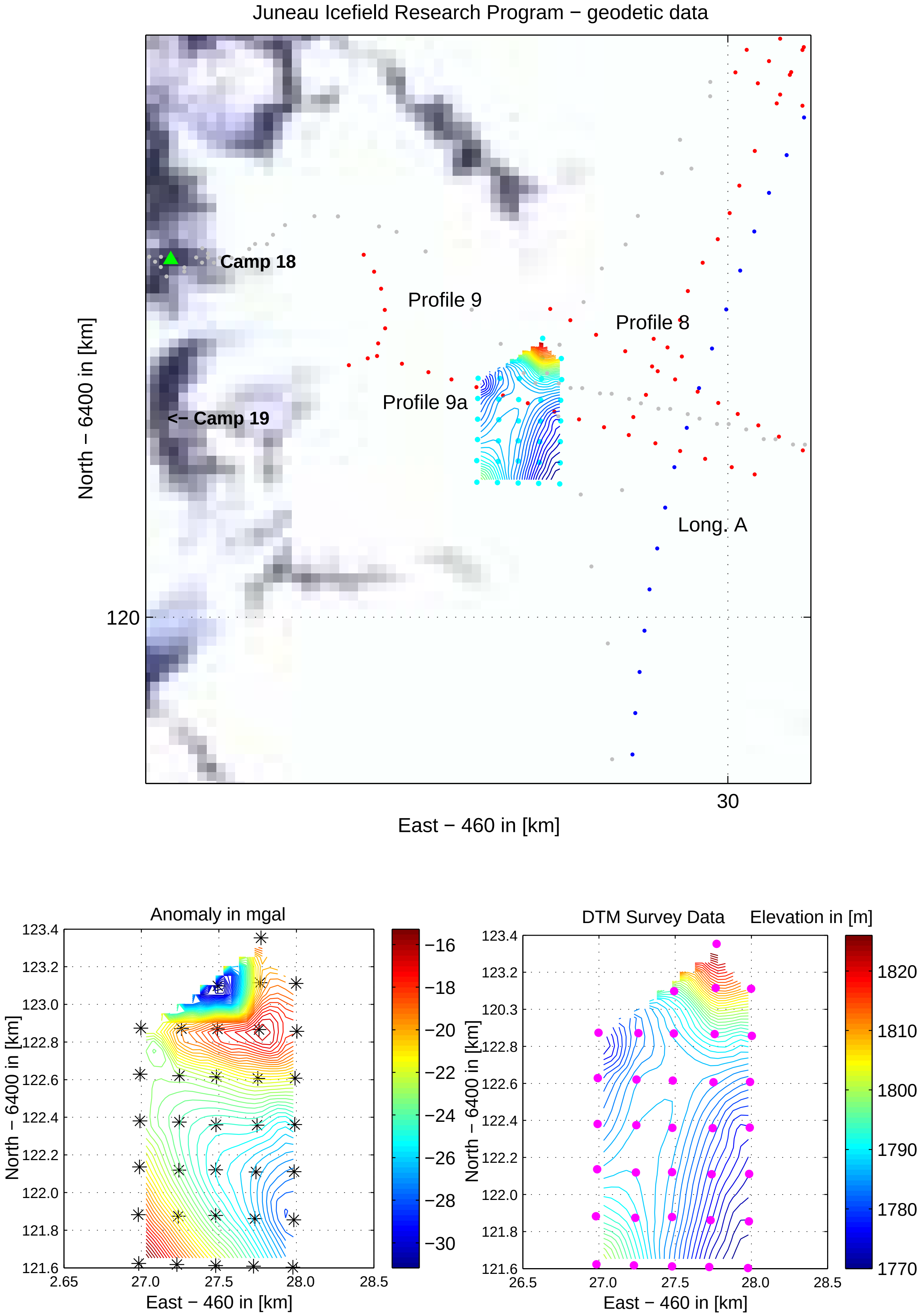


Fig. 36: Gravimetry Observation at the F8/18 Junction

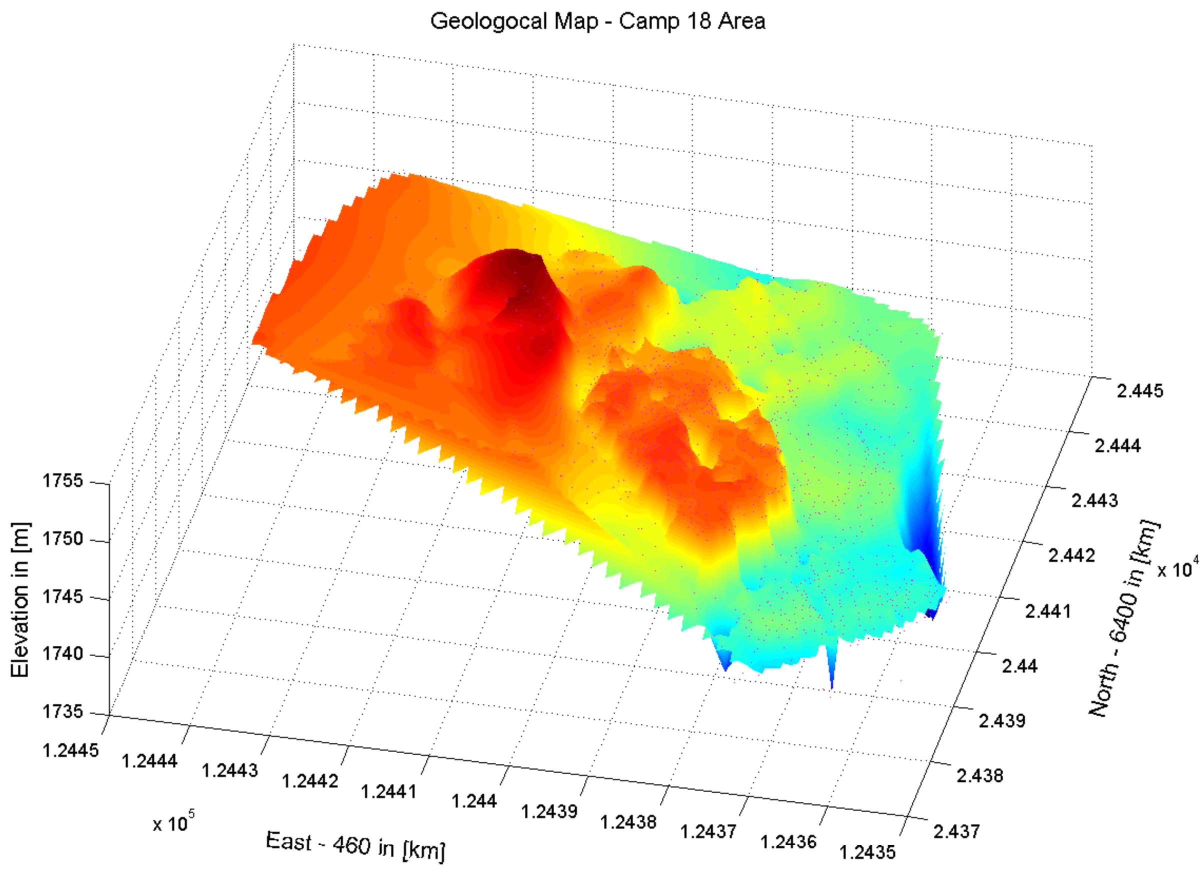


Fig. 37: Mapping Project at the Camp 18 Area

4. Conclusion and Outlook

Over the next few years, continuing to measure longitudinal and transversal profiles can continue existing geodetic data sets. Determining changes in height must continue to play a central role here. Analysis showed relatively constant flow velocities which was observed using GPS measurements. As a result, the Juneau Icefield project as a long-term study provides an important contribution in answering scientific questions about regional and global climate change with respect to greenhouse effects. Geodesy provides vital basic data in this regard. In addition, over the next few years further projects can be linked, such as investigating plate tectonics or the combination of terrestrial and satellite data.

5. Acknowledgment

As usual, the survey work detailed in this report could not have been accomplished without the financial, logistical, and field support of the Foundation for Glacier and Environmental Research, Juneau Icefield Research Program. Financial support from

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All Coordinates are stored at this Matlab tool.
For more details, please contact *www.geo.bv.tum.de*.