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GPS Geodetic Measurements around Bárðarbunga Volcano, Central Iceland, in 1997

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1 Introduction

The sequence of events that culminated with a volcanic eruption beneath the Vatnajökull glacier in September to October 1996 and the jökulhlaup in November, see e.g. Einarsson et al. [1997] and Guðmundsson et al. [1997], is one of the most remarkable geological occurrences in Iceland in this century. An earthquake of M_W 5.6 near the boundary fault of the Bárðarbunga volcano (Fig. 1) on September 29 triggered an intrusion that propagated away from the caldera. The instrusion led to a subglacial eruption that began the following day on a N–S trending fissure south of the volcano. The fissure attained a length of 7 km and continued erupting for two weeks.

Most of the heat of the eruption went into melting the glacier ice, only one vent breached the surface of the glacier and erupted into the atmosphere. The volume of the erupted magma is estimated at 0.4 km^3 [Guðmundsson et al., 1997]. The melt water was channeled into the caldera of the neighbouring Grímsvötn volcano where it accumulated behind an ice barrier. The barrier was lifted by the rising lake level on November 4 and a total volume of 4 km^3 was released from the caldera lake in a catastrophic flood.

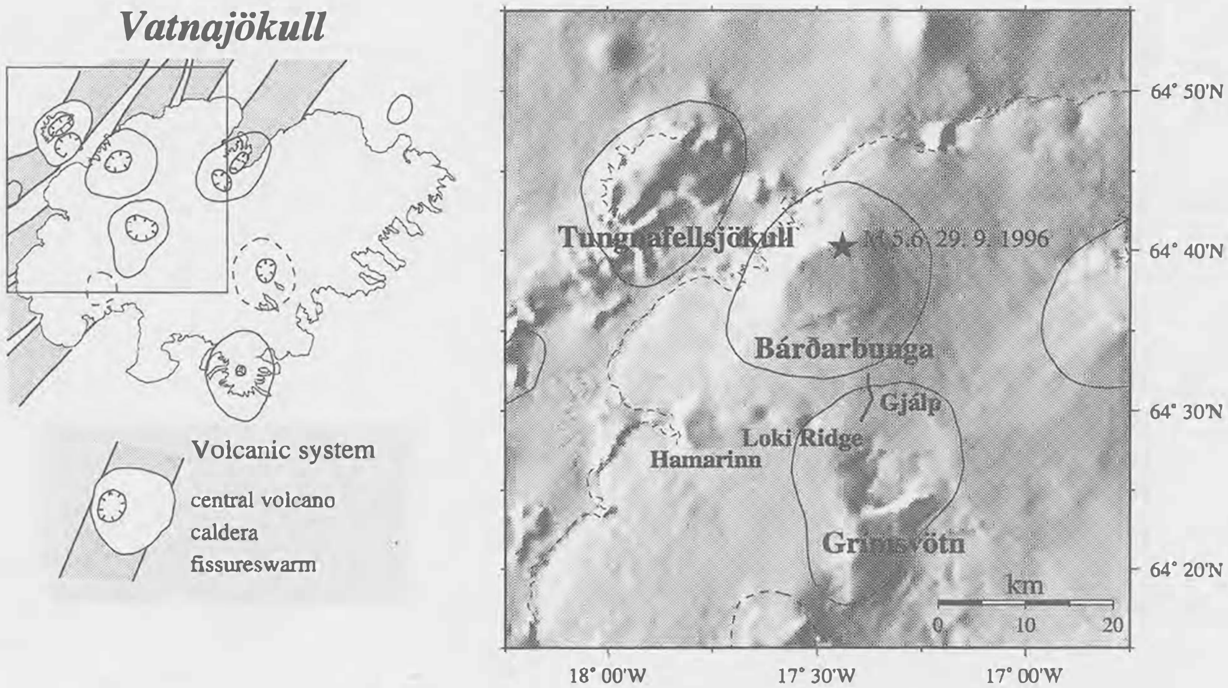

Figure 1: Vatnajökull glacier. The map shows the location of the earthquake that triggered an intrusion that led to a subglacial eruption in the N–S trending fissure, Gjálp.

The activity of 1996 was preceded by a long series of events that appears to have begun in 1974 with a magnitude 5 earthquake in the caldera region of Bárðarbunga. Several other events followed in the next years [Einarsson, 1991]. These earthquakes had focal mechanisms with a large component of reverse faulting. A component of non-double-couple suggests that the earthquakes originated on curved faults, presumably the caldera faults of Bárðarbunga [Nettles and Ekström, 1998]. The September 1996 event that triggered the magmatic activity had the same characteristics.

In addition to this increased seismic activity there is also evidence to suggest that sudden floodings from geothermal areas on the subglacial Loki Ridge are accompanied by magmatic activity, intrusion or extrusion of magma [Björnsson and Einarsson, 1990; Þorbjarnardóttir et al., 1997]. Continuous tremor of the type frequently observed in association with eruptive activity has been recorded during some of these floods. Direct ground check of this is, however, not possible because of the glacial cover. Floods accompanied by tremor occurred in 1986 (November), 1991 (August), 1995 (July), 1996 (August), and 1997 (August). An earthquake swarm in February 1996 at the Hamarinn volcano at the western end of Loki Ridge may be the expression of an intrusion there. For further description of these events and their geological framework, see Einarsson and Brandsdóttir [1997] and Einarsson [1997].

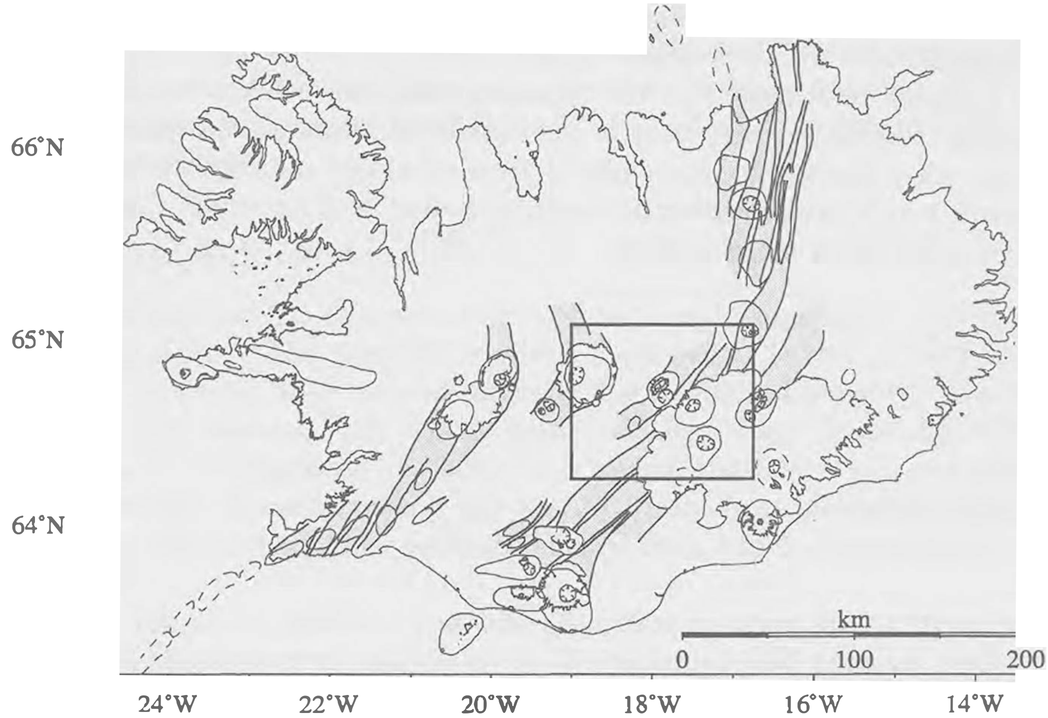

Figure 2: Map of Iceland. The box indicates the location of the GPS network measured in the Bárðarbunga campaign (the area shown in Figure 3). The plate boundary is marked by volcanic systems consisting of central volcanoes and fissure swarms (from Einarsson and Sæmundsson [1987]).

The 1997 GPS project reported here is a cooperative project between the Science Institute, University of Iceland, the Nordic Volcanological Institute and the National Power Company. It is a part of a general attempt to study and monitor the progress of the recent unrest of the Vatnajökull volcanoes. The movements of magma in the crust are accompanied by deformation at the surface that can be measured with accurate geodetic methods such as GPS-geodesy. The network measured consists of 25 points distributed around the NW edge of Vatnajökull, 15 of which were measured for the first time. The measurements were made 4th to 13th and 23rd to 26th of August 1997. The main objectives of the measurements were as follows:

- To establish a dense base network for future studies of crustal deformation in this part of the plate boundary, in the central area of the Iceland hotspot (Fig. 2).
- To establish a beginning of time series for the monitoring of pressure changes within the volcanoes Bárðarbunga, Grímsvötn, Tungnafellsjökull and Hamarinn.
- To determine displacements of previously measured points in this area.

The configuration of our network is less than ideal because of large parts of the area of interest being covered by the Vatnajökull glacier (Fig. 3). Only one point could be established on the Grímsvötn volcano, at the palagonite peak Saltarinn, on the caldera rim. Only three points are located near Hamarinn since that volcano is almost surrounded by glacial ice. The western and northern flanks of Bárðarbunga are reasonably covered by our network and Tungnafellsjökull is surrounded by it.

This report contains information on the measurements, the geodetic points used, and the data processing. Results are presented in the form of coordinates and compared to earlier measurements when applicable. Appendix B gives information on the 1992 Vatnajökull GPS-measurements which have not been documented before, and Appendix C gives descriptions of all points used in our measurements.

2 Measurements

2.1 Equipment and Participants

Four GPS receivers were used for the measurements; two Trimble 4000 SST GPS receiver (A and B) owned by the Nordic Volcanological Institute, one 4000 SST Trimble GPS receiver (H) provided by the Institut für Erdmessung, Hannover, (by Cristof Völksen) and one Trimble 4000 SSE GPS receiver (S) provided by The Icelandic Maritime Administration, Siglingastofnun (by Guðjón Scheving).

Two vehicle were used in the measurements from 4th to 13th of August. The Science Institute provided one jeep and the National Power Company, Landsvirkjun, provided another. The field work was done by Páll Einarsson and Sigrún Hreinsdóttir from the Science Institute, Sigurjón Jónsson from the Nordic Volcanological Institute, and assistant from Landsvirkjun, Geir Þ. Gunnarsson.

The measurements on Vatnajökull glacier, from 23rd to 26th of August, were performed in a trip with the Icelandic Glaciological Society which provided cars. For the measurements at the reference point, Háumýrar, the Science Institute provided one jeep. This field work was done by Páll Einarsson, Sigrún Hreinsdóttir and assistant from the Icelandic Glaciological Society, Freyr Jónsson.

2.2 General Information

Two types of Trimble GPS receivers were used in these measurements; three 4000 SST and one 4000 SSE receiver. The 4000 SST receivers measured at 15 second intervals but the 4000 SSE receiver measured at 30 second intervals due to limited memory. The measurements were divided into sessions, each session being 7:55 hour long. Each day was divided into three sessions; session 0 started at 00:00 GMT, session 1 at 8:00 GMT and session 2 at 16:00 GMT. The satellite elevation mask angle was 15°. Data from all visible satellite above that elevation were collected but their number changed from 4 to 9. No meteorological data were collected.

The point Háumýrar (HAUM) was used as a reference point during the measurements. It was chosen because it is in the middle of the Bárðarbunga GPS network, and it is also in the ÍSNET GPS network [Magnússon et al., 1997]. A 4000 SST receiver (A) was placed at that point during all the measurements, but the other three receivers were moved between points (see Table A.1 and A.2 in Appendix A). Each point was usually measured for two almost whole sessions and a part of the third. The shortest data set, 14 hours and 45 minutes, was collected at the point Kaldakvísl (KALD) but the longest data set, 38 hours and 35 minutes, was collected at the point Grímsfjall (GRIM).

2.3 The Bárðarbunga network

The Bárðarbunga GPS network consists of 25 points. Ten of the points have been measured before this campaign (Figs. 4–7). After the 1996 Gjálp eruption it was decided to begin systematic GPS measurements around Bárðarbunga volcano and neighbouring volcanos.

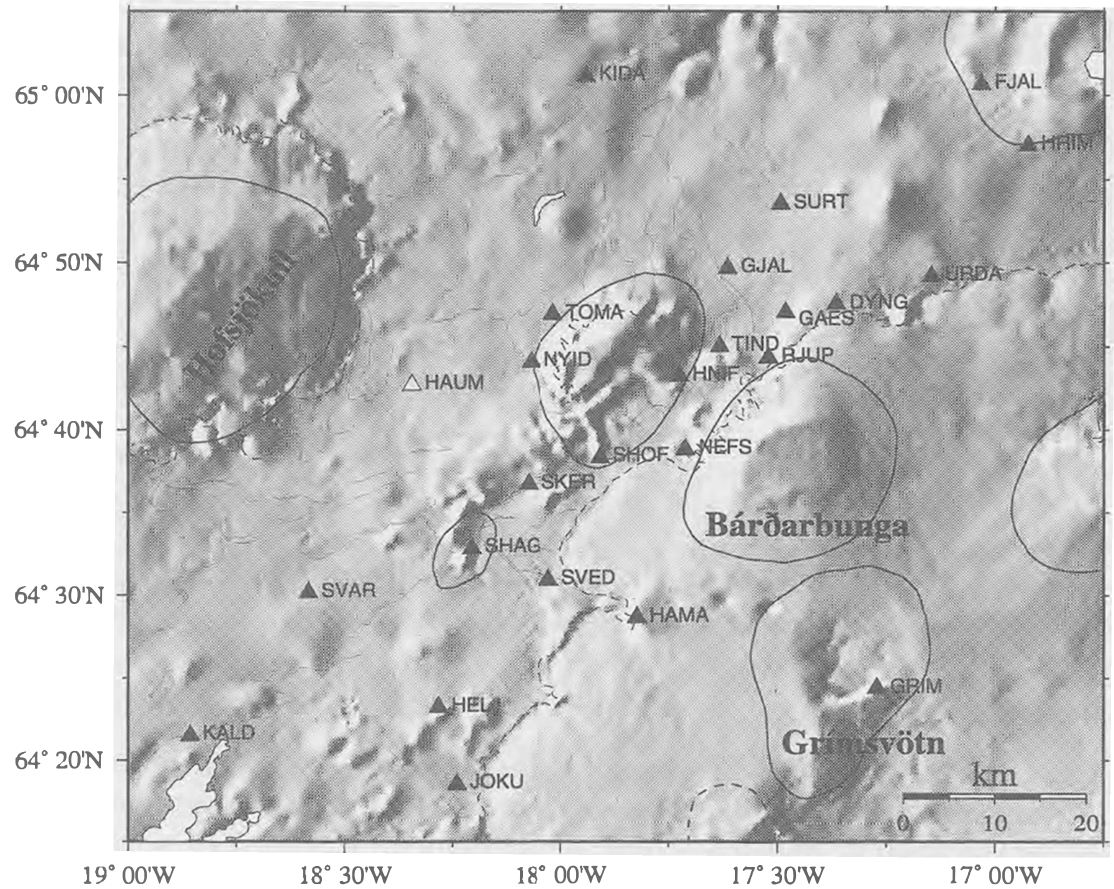

Figure 3: The Bárðarbunga GPS network. The triangles show the location of GPS points measured in August 1997. Háumýrar NA (HAUM) △ was a reference point in this campaign.

The oldest point in the network was first measured in the initial GPS survey in Iceland, July 1986. That is the point Jökulheimar (JOKU). In the 1987 ISNAC GPS campaign the points Gjallandi A (GJAL), Fjallsendi S (FJAL) and Kiðagilsdrög (KIDA) were measured for the first time and the point JOKU was remeasured. The point Kaldakvísl (KALD) was first measured in the year 1989 and the same year the points JOKU and GJAL were remeasured. In the 1990 ISNAC campaign the points Dyngjuháls (DYNG) and Hrímalda (HRIM) were measured for the first time, and the points GJAL and KIDA were remeasured. In the 1992 Vatnajökull GPS survey the points Hamarinn (HAMA) and Grímsfjall (GRIM) on Vatnajökull glacier and the point JOKU were measured, HAMA and GRIM for the first time. The same year, in the 1992 ISNAC campaign, the points KIDA, FJAL, GJAL and JOKU were remeasured. In 1993 the point Háumýrar NA (HAUM) was included in the Iceland GPS network in the ÍSNET93 campaign. In the same campaign the points JOKU, GRIM, KIDA, GJAL, and FJAL were remeasured. In the Askja 1993 campaign the points HRIM and FJAL were remeasured. They were remeasured again in the Askja 1994 campaign a year later. The same year the points KALD and JOKU were remeasured in the Eastern Volcanic rift campaign. In the 1995 ISNAC GPS campaign the points KIDA, JOKU, FJAL and GJAL were remeasured. Figures 4 to 7 show occupation of the Bárðarbunga network points from 1986 to 1995.

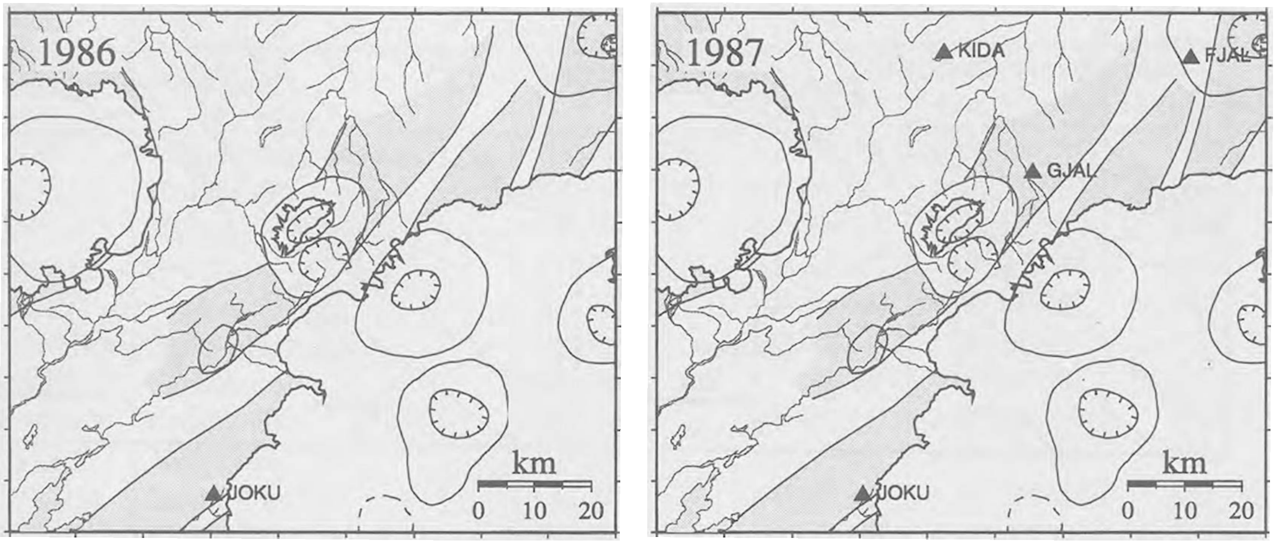

Figure 4: GPS points measured 1986 (left) [Guðmundsson and Einarsson, 1986; Foulger et al., 1993] and 1987 (right) [Guðmundsson and Einarsson, 1987; Foulger, 1987; Jahn, 1991]

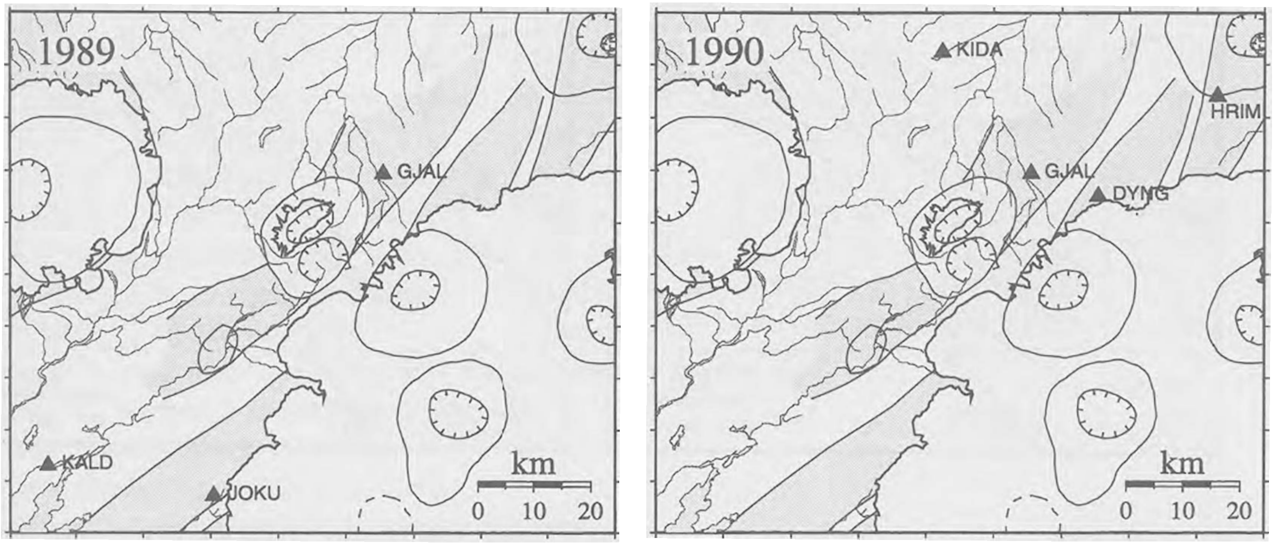

Figure 5: GPS points measured 1989 (left) [Hackmann, 1991] and 1990 (right) [Jahn, 1992; Camitz et al., 1995].

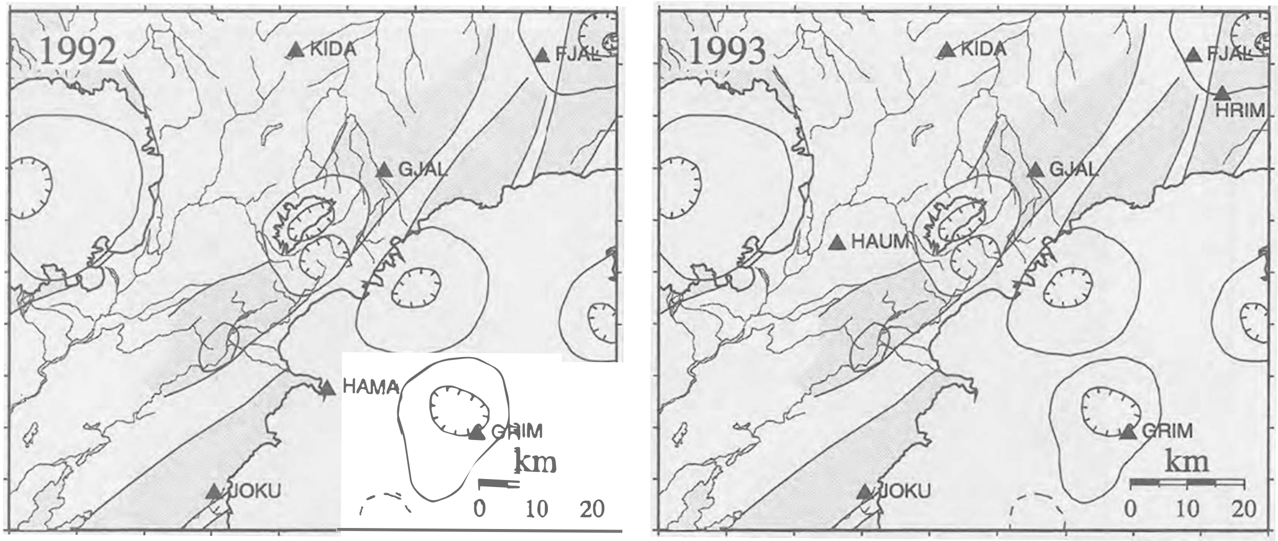

Figure 6: GPS points measured 1992 (left) [Appendix B; Völksen and Seeber, 1998] and 1993 (right) [Magnússon et al., 1997; Camitz et al., 1995]

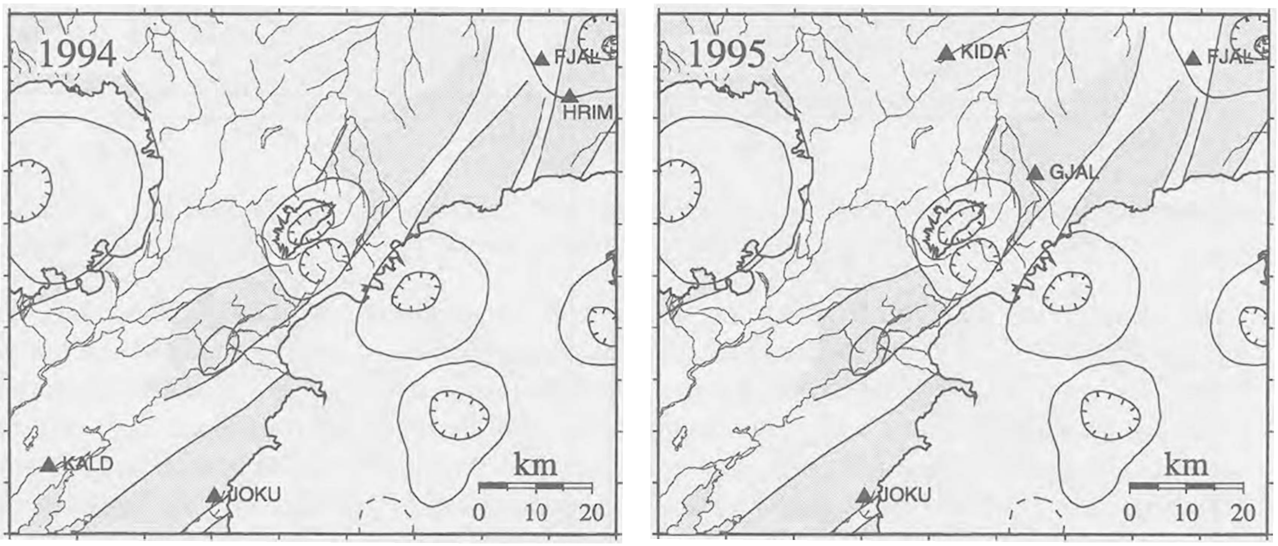

Figure 7: GPS points measured 1994 (left) [Jónsson et al., 1994; Sigmundsson, 1994] and 1995 (right) [Völksen and Seeber, 1998].

In the Bárðarbunga 1997 GPS campaign, the following points were measured for the first time: Heljargjá (HELJ), Svartá (SVAR), Sveðja (SVED), Syðri-Háganga (SHAG), Skerðingur (SKER), Svarthöfði (SHOF), Nefsteinn (NEFS), Hníflar (HNIF), Nýidalur (NYID), Rjúpnabrekka (RJUP), Tindafell N (TIND), Tómasarhagi (TOMA), Gæsahnjúkur (GAES), Surtluflæður (SURT) and Urðarháls (URDA). The following points were remeasured: JOKU,

GJAL, FJAL, KIDA, KALD, DYNG, HRIM, HAMA, GRIM, HAUM.

The descriptions of all the GPS points in the Bárðarbunga GPS network are in Appendix C.

Abbr.	Name	Inscription	Approximate cooordinates		
			Latitude	Longitude	Height [m]
JOKU	Jökulheimar	OS 1986 7383	64° 18′ 34″	−18° 14′ 24″	740
KALD	Kaldakvísl	OS 1989 7491	64° 21′ 31″	−18° 51′ 26″	606
HELJ*	Heljargjá	RH 9707	64° 23′ 15″	−18° 16′ 55″	816
SVAR*	Svartá	RH 9705	64° 30′ 10″	−18° 34′ 58″	684
SVED*	Sveðja	NE 9706	64° 30′ 56″	−18° 01′ 43″	923
SHAG*	Syðri-Háganga	20"6"2-2	64° 32′ 51″	−18° 12′ 22″	898
SKER*	Skerðingur	NE 9704	64° 36′ 44″	−18° 04′ 29″	908
SHOF*	Svarthöfði	RH 9706	64° 38′ 21″	−17° 54′ 31″	991
NEFS*	Nefsteinn	NE 9705	64° 38′ 49″	−17° 42′ 46″	1126
HAUM	Háumýrar NA	LM 358	64° 42′ 42″	−18° 20′ 41″	727
HNIF*	Hníflar	NE 9703	64° 43′ 12″	−17° 42′ 37″	997
NYID*	Nýidalur	RH 9704	64° 44′ 04″	−18° 04′ 09″	867
RJUP*	Rjúpnabrekka	RH 9703	64° 44′ 20″	−17° 31′ 16″	1087
TIND*	Tindafell N	NE 9702	64° 45′ 03″	−17° 38′ 02″	983
TOMA*	Tómasarhagi	RH 9701	64° 46′ 56″	−18° 01′ 08″	872
GAES*	Gæsahnjúkur	NE 9701	64° 47′ 03″	−17° 28′ 53″	1063
DYNG	Dyngjuháls	RH 9006	64° 47′ 31″	−17° 21′ 57″	1198
URDA*	Urðarháls	NE 90011	64° 49′ 13″	−17° 08′ 50″	1078
GJAL	Gjallandi A (Vonarskarð)	(OS) 7470	64° 49′ 43″	−17° 36′ 50″	917
SURT*	Surtluflæður	RH 9702	64° 53′ 31″	−17° 29′ 34″	875
HRIM	Hrímalda	NE 90014	64° 57′ 01″	−16° 55′ 26″	898
FJAL	Fjallsendi	RH 8437	65° 00′ 40″	−17° 01′ 59″	920
KIDA	Kiðagilsdrög	OS 1987 7469	65° 01′ 09″	−17° 56′ 33″	934
GRIM	Grímsfjall (Saltarinn)	(LM) 500	64° 24′ 24″	−17° 16′ 15″	1781
HAMA	Hamarinn	(none)	64° 28′ 40″	−17° 49′ 19″	1634

Points marked with * are GPS points now measured for the first time.
Height the height above reference ellipsoid.
OS – National Energy Authority.
NE – Nordic Volcanological Institute.
RH The Science Institute, University of Iceland.
LM Iceland Geodetic Survey.

Table 1: GPS points measured in this campaign.

3 Data Processing

3.1 General Remarks

The GPS data from the 1997 campaign were analysed with the Bernese GPS software, version 4.0 [Rothacher and Mervart, 1996]. It uses differences between a pair of receivers (single difference), between a pair of receivers and a pair of satellites (double difference) and finally double difference observations from two different epochs t_1 and t_2 (triple difference) to reduce and eliminate biases in the measurements.

The point Háumýrar (HAUM) was kept fixed during the analysis and the coordinates from the ÍSNET93 GPS network [Magnússon et al., 1997] were used for that point.

The coordinates of the points were estimated using the orbit information from the Center for Orbit Determination in Europe (CODE). That minimizes the error due to satellite orbits in the measurements and also gives the result in the 1994 IERS Terrestrial Reference Frame (ITRF94) [Rothacher et al., 1997].

No meteorolocial data were collected during the measurements. A tropospheric refraction model, Saastamoinen, was used to estimate site troposphere values.

3.2 Data Transfer

Raw data from the Trimble receivers were first transferred into Receiver Independent Exchange format (RINEX format) with the program TRRINEXO. The rinex observation files were then transferred to Bernese format with the program RXOBV3.

Instead of broadcast orbits, precise orbits and earth rotation parameters from the IGS Global Data Center were used in this analysis.

3.3 Orbit Processing

Two programs, PRETAB and ORBGEN, were used to prepare the orbit files for the analysis. The precise orbit format (SP3 format) contains precise satellite clock information with 15 minutes sampling rate and precise orbit information. The SP3 file format is converted to Bernese format with the program PRETAB. It creates tabular orbit file in the system J2000.0 and (here) produces a satellite clock file by fitting the satellite clock with two degree polynomial within intervals of 12 hours.

ORBGEN generates one standard arc orbit for each day. It computes the standard orbits, using the satellite position in the tabular orbit files generated by PRETAB, with numerical integration.

3.4 Data Preprocessing

Three preprocessing programs, CODSPP, SNGDIF and MAUPRP, were used to check and prepare the data for the main estimation programs.

The main task of the first program, CODSPP, is to compute the receiver clock error with sufficient ($1\mu s$) accuracy, using the zero difference code measurements. The program also estimates the coordinates of the receivers. CODSSP uses standard least-square adjustment to compute the unknown parametes. It estimates the parameters iteratively, using ionosphere free (L_3) linear combination.

The next program, SNGDIF, creates the phase single difference between receivers at points measured simultaneously.

Finally the program MAUPRP detects and corrects cycle slips. First it checks for smoothing in the double difference phase observations to find time intervals that do not contain cycle slips. It uses those intervals to compute triple difference solution to estimate a fair approximation of the coordinates, using a standard least square adjustment for each baseline. Then MAUPRP computes the triple difference residuals for all the observations and saves them into a file. In the final step it first corrects large jumps, that usually originate from the receiver clock, on the single difference level. Then it uses the residual files, saved in previous step, to detect the cycle slips.

3.5 Parameter Estimation

The precise parameter estimation program, GPSEST, uses least square adjustment to calculate the coordinates, resolve the ambiguities, model the ionosphere and model the local troposphere. First GPSEST is used to check the quality of the data and save the residuals. In this first run it estimates the coordinates of the points, using the ionosphere free linear combination (L_3), and saves the result to get good a priori coordinates for the next step.

In the next run GPSEST keeps the estimated coordinates from previous run fixed and resolves the ambiguities. It uses the so called Wide-lane linear combination (L_5) on the double difference level for the phase obeservations.

In the third run the final coordinate solution for each point is calculated. The fixed wide lane (L_5) ambiguities are introduced and the ionospheric free (L_3) linear combination is used for solving the narrow-lane ambiguities.

The purpose of the fourth and the last run of GPSEST is to save Normal Equation files (NEQ) that are used in the final coordinate combination. In that run no point is kept fixed but constrains (default sigma per coordinate) are put on the reference point so it appears to be fixed.

Finally the program ADDNEQ combines the results from the GPSEST estimation into one multi-session solution. It uses statistically correct combination of the single session solution from the GPSEST estimation program to calculate accurate coordinates and their uncertainties.

4 Results

4.1 Uncertainties

To get good coordinates in the measurements each point was measured for at least one whole and part af two sessions. In the processing of the data each session was then processed separately. The combination program, ADDNEQ, was used to derive a final solution. That program uses least square estimation.

When processing each session the estimation program, GPSEST, gives a formal error that indicates the phase scatter. Systematic errors or mismodeled parameters have not been taken into account and the formal error may therefore be unrealistic. Experience shows it may be one order of magnitude too small. By looking at the weighted repeatability a better estimate of the error is gained (see scatter plot and repeatability plot in Appendix A, Figure 11 and 12).

In this campaing at least three sessions were processed for each point. However, to get a good estimation of the true error this is hardly enough. In the combination program, ADDNEQ, the scatter in the whole network solution is used to get more realistic error estimation. It calculates scaling factor for the formal errors from the estimation programs and calculates scaled sigma for the geocentric coordinates.

In the program package Bernese GPS software, version 4.0, ADDNEQ does not calculate the scaled sigma for the ellipsoid coordinates. It does though calculate unscaled formal uncertainty ellipsoids for each point. With the program DYNAP (Dynamic Adjustment Program) from the National Geodetic Survey, USA, the same method as in ADDNEQ is used to calculate the scaling factor and the scaled sigma for the ellipsoid coordinates. This scaling factor was applied to the unscaled formal uncertainty ellipse, to derive a more realistic final uncertainty ellipsoid. Figure 8 shows the 95 % confidence regions for the estimated coordinates in this campaign and Table 3, 4 and A.3 show the estimated scaled sigma of the coordinates of each point.

The scaling factor calculated used to scale the formal errors of the uncertainty ellipsoid was 12.58. In Table 2 the averages of the formal error, the repeatability error and the scaled error according to each coordinate component is shown. The repeatability for the geocentric coordinates was not calculated.

	X [mm]	Y [mm]	Z [mm]	lat. [mm]	long. [mm]	height [mm]
Formal error	0.32	0.16	0.73	0.15	0.10	0.84
Repeatability	–	–	–	2.61	2.07	8.69
Scaled formal error	2.04	1.50	3.71	2.25	2.04	9.58

Table 2: Unweighted average of the estimated error of each coordinate component in the Bárðarbunga GPS network.

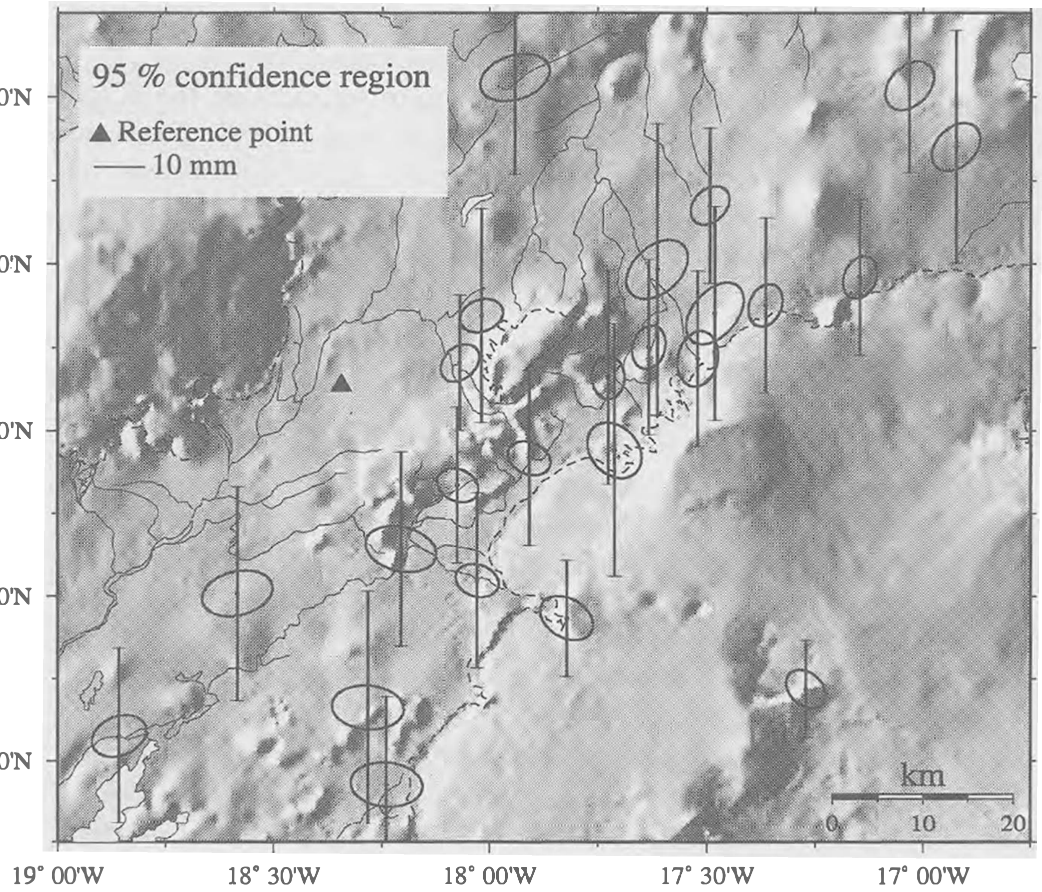

Figure 8: Uncertainty in the 1997 GPS measurements. The ellipses show 95 % confidence region for the horizontal coordinates and the vertical bars show the 95 % confidence region in the hight estimation.

Two error sources have not yet been taken into account, a possible systematic errors due to the antenna position and the equipment type. The position of each antenna was measured accurately before and after the measurements to minimize errors due to antenna position. One point (SHOF) was measured twice, first with equipment S (Trimble SSE) and then H (Trimble SST). The measurements did not show any more session scatter than other points. This fact allows us to conclude that the equipment source of error is not significant. However there might still have been systematic errors due to the antenna position at other points in the network that were not tested.

4.2 Coordinates

The coordinates of the points in the Bárðarbunga GPS network were computed relative to the fixed point Háumýrar NE (HAUM). The coordinates used for HAUM were orginally calculated in the ÍSNET93 GPS campaign [Magnússon et al., 1997].

The main purpose of the ÍSNET93 campaign was to establish a new horizontal geodetic datum in Iceland. Orbits in ITRF93 system and four reference stations from the IGS network (in Norway, Sweden, England and Newfoundland), which coordinates and velocities were given in ITRF93 system, were used to compute the network. The computation was performed in the ITRF93.6 system and the new geodetic datum was named ISN93.

Orbits used in the processing of the Bárðarbunga network came in the ITRF94 system which differs insignificantly from the ITRF93 [Rothacher et al., 1997]. The coordinates of each point were calculated using the combination program, ADDNEQ. It uses the weighted coordinate repeatability of the whole network to estimate accurate coordinates of each point. The geocentric coordinates are shown in Table 3 and the ellipsoidal coordinates are shown in Table 4.

Point	X [m]	σ_X[m]	Y [m]	σ_Y[m]	Z [m]	σ_Z[m]
JOKU	2633520.812	0.005	-867895.731	0.002	5725425.851	0.006
KALD	2619302.982	0.002	-894604.908	0.002	5727671.619	0.002
HELJ	2625485.389	0.003	-867379.575	0.002	5729252.607	0.004
SVAR	2609831.161	0.001	-877427.716	0.001	5734687.767	0.001
SVED	2617085.005	0.002	-851788.813	0.001	5735508.974	0.004
SHAG	2611351.241	0.003	-858879.449	0.001	5737026.048	0.006
SKER	2607143.521	0.002	-850874.182	0.001	5740122.087	0.004
SHOF	2607052.143	0.001	-842486.811	0.001	5741484.227	0.001
NEFS	2609213.545	0.003	-833343.236	0.001	5741984.071	0.007
HAUM*	2593530.4831	–	-859971.2227	–	5744698.6253	–
HNIF	2602164.073	0.001	-830968.968	0.001	5745359.015	0.001
NYID	2595489.832	0.001	-846788.464	0.001	5745920.406	0.002
RJUP	2603129.704	0.001	-821818.184	0.001	5746331.316	0.004
TIND	2600323.934	0.001	-826558.350	0.001	5746803.046	0.001
TOMA	2591657.713	0.002	-843026.076	0.001	5748192.343	0.009
GAES	2599332.710	0.001	-818635.114	0.001	5748463.479	0.004
DYNG	2600277.000	0.001	-813174.016	0.002	5748957.822	0.005
URDA	2600584.302	0.004	-802386.026	0.001	5750193.451	0.004
GJAL	2593102.444	0.004	-823277.209	0.005	5750437.978	0.006
SURT	2588735.280	0.001	-815861.210	0.001	5753395.347	0.002
HRIM	2591055.414	0.001	-788407.494	0.002	5756184.922	0.002
FJAL	2583683.852	0.002	-791534.816	0.003	5759073.428	0.004
KIDA	2570035.329	0.003	-832199.653	0.001	5759459.885	0.003
GRIM	2638936.568	0.003	-820464.687	0.002	5731047.406	0.003
HAMA	2624038.187	0.001	-843590.454	0.001	5734343.913	0.004

* Coordinates from the ÍSNET93 GPS campaign [Magnússon et al., 1997].

Table 3: Geocentric X, Y and Z coordinates and their scaled sigma.

Point	Latitude [°]	dlat [m]	Longitude [°]	dlong [m]	Height [m]	dh[m]
JOKU	64.30955391	0.003	-18.24000760	0.002	740.201	0.009
KALD	64.35856055	0.002	-18.85724848	0.002	606.178	0.009
HELJ	64.38741370	0.003	-18.28196537	0.002	816.466	0.012
SVAR	64.50290220	0.003	-18.58269349	0.002	684.004	0.011
SVED	64.51551206	0.002	-18.02863649	0.002	923.428	0.009
SHAG	64.54763382	0.003	-18.20615473	0.002	897.873	0.010
SKER	64.61213093	0.002	-18.07474693	0.002	907.889	0.008
SHOF	64.63906279	0.002	-17.90859512	0.002	991.187	0.009
NEFS	64.64697111	0.002	-17.71269350	0.002	1126.411	0.013
HAUM*	64.71147073	–	-18.34465547	–	726.6618	–
HNIF	64.72020921	0.002	-17.71024040	0.002	996.767	0.011
NYID	64.73445880	0.002	-18.06911301	0.002	867.437	0.007
RJUP	64.73892635	0.002	-17.52110954	0.002	1086.717	0.009
TIND	64.75081524	0.002	-17.63376690	0.002	982.919	0.009
TOMA	64.78215836	0.002	-18.01890359	0.002	871.686	0.011
GAES	64.78421947	0.002	-17.48132531	0.002	1063.152	0.011
DYNG	64.79206545	0.002	-17.36581649	0.002	1197.629	0.009
URDA	64.82037027	0.002	-17.14712211	0.002	1078.352	0.008
GJAL	64.82860527	0.003	-17.61398458	0.003	916.922	0.015
SURT	64.89183515	0.002	-17.49267412	0.002	875.068	0.008
HRIM	64.95041021	0.002	-16.92397962	0.002	898.351	0.012
FJAL	65.01123808	0.002	-17.03291718	0.002	920.324	0.009
KIDA	65.01918809	0.003	-17.94240142	0.002	933.584	0.010
GRIM	64.40661683	0.002	-17.27085164	0.002	1780.624	0.005
HAMA	64.47788864	0.002	-17.82184966	0.002	1633.934	0.006

* The reference point. Coordinates from the ÍSNET93 GPS campaign [Magnússon et al., 1997].

Table 4: Ellipsoidal coordinates and their scaled sigma. The horizontal coordinates are presented in degrees and minutes in Table A.3 in Appendix A.

4.3 Crustal deformation

4.3.1 1992–1997

In the Vatnajökull campaign 1992 the points Hamarinn (HAMA), Grímsfjall (GRIM) and Jökulheimar (JOKU) were measured (see Appendix B). The coordinates from that campaign are published in the WGS-84 system (Wold Geodetic System 84). In this report the coordinates measured 1997 are represented in the ITRF-94 reference frame [Rothacher et al., 1997]. The estimated differences between the two reference frames are about 2 mm in the horizontal coordinates and 4 mm in the height [Jónsson et al,. 1995]. Taking that into account the displacement from 1992 to 1997 was estimated.

With Helmert transformation, without scaling and rotation about any axis, the points HAMA, GRIM and JOKU in the Bárðarbunga 1997 campaign were transformed so that

JOKU appeared to be fixed in time. The estimated displacement from 1992 to 1997 is shown in Figure 9.

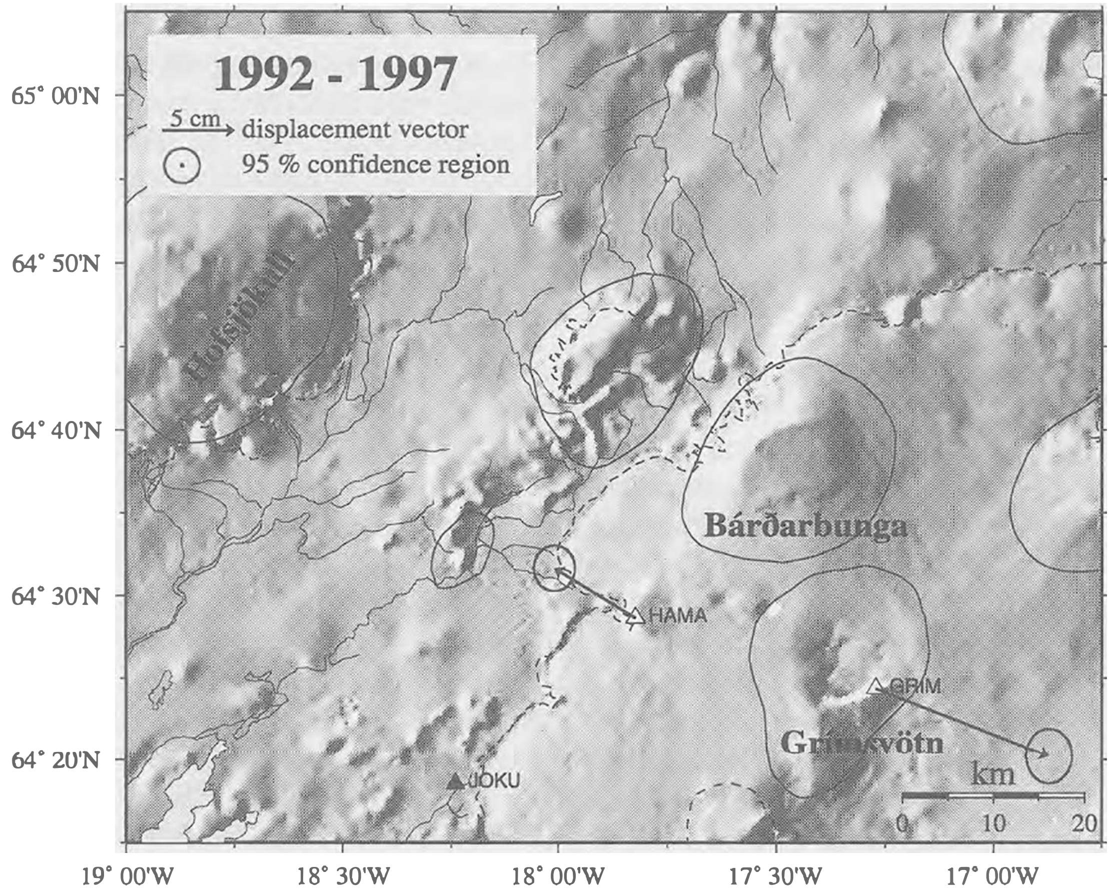

Figure 9: Horizontal displacement from 1992 to 1997 relative to the point Jökulheimar (JOKU).

The horizontal displacement, according to JOKU, is significant at both of the points. They move in opposite direction, as expected because of the eruption in Gjálp 1996. The vertical uplift measured at both of the points was also significant. GRIM has moved about 7 cm upward and HAMA about 4 cm.

4.3.2 1993–1997

Seven GPS points measured in this campaign were also measured 1993. In the ÍSNET93 campaign the points HAUM, GJAL, JOKU, GRIM, KIDA and FJAL were measured and FJAL and HRIM were measured in the ASKJA 1993 campaign. Here the coordinates from the ÍSNET93 campaign and this campaign are compared according to the fixed reference point, HAUM.

In the ÍSNET93 campaign a new horizontal geodetic datum was established for Iceland, ISN93. A network of 119 station were measured and their coordinates were given in system ITRF93.6. The processing of the data was done in two different software packages, Geonap and Bernese, and the difference between the solutions of the two programs was used to estimate the accuracy in the measurements. The uncertainties of about 4 mm in the horizontal coordinates and about 6 mm in the height [Völksen and Seeber, 1998] might therefore be underestimated. The difference between the two reference frames, ITRF93.6 and ITRF94, is not relevant as noted in Chapter 4.1.

The estimated displacement form 1993 to 1997 is shown in Figure 10.

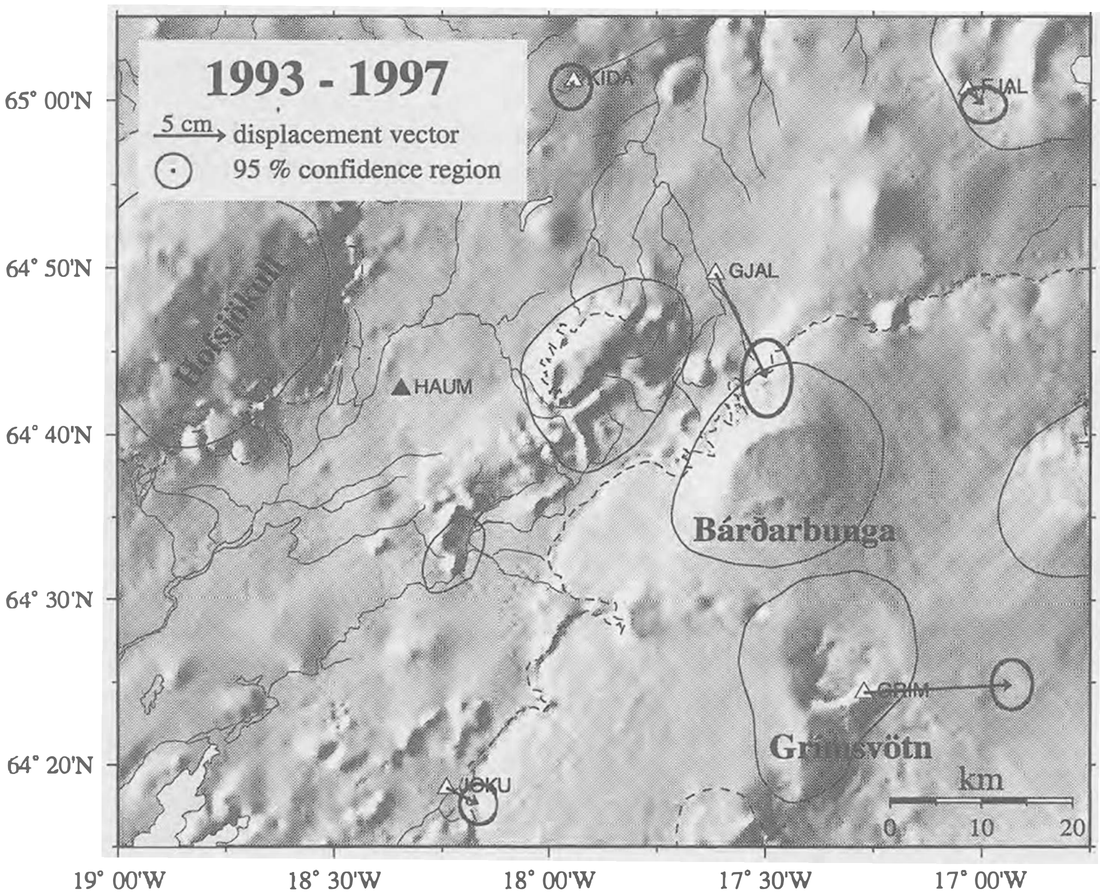

Figure 10: Horizontal displacement from 1993 to 1997 relative to the point Háumýrar NE (HAUM).

The horizontal displacement of the points GJAL, GRIM and JOKU according to HAUM is significant for this period but the vertical movement is not significant.

Acknowledgements

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A Tables and plots

A.1 Observations

Date:	4. 8.			5. 8.			6. 8.			7. 8.			8. 8.			9. 8.			10. 8.			11. 8.			12. 8.			13. 8.		
Day:	216			217			218			219			220			221			222			223			224			225		
Point	0	1	2	0	1	2	0	1	2	0	1	2	0	1	2	0	1	2	0	1	2	0	1	2	0	1	2	0	1	2
JOKU																										B	B	B	B	
KALD																								B	B	B				
HELJ																											S	S	S	
SVAR																		S	S	S										
SVED																											H	H	H	H
SHAG					H	H	H	H																						
SKER																				B	B	B	B							
SHOF																				S	S	S	H	H	H	H				
NEFS																					H	H	H							
HAUM	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
HNIF															S	S	S													
NYID																		B	B	B										
RJUP															H	H	H													
TIND															B	B	B													
TOMA		H	H	H	H																									
GAES												S	S	S																
DYNG												B	B	B																
URDA								B	B	B	B																			
GJAL			S	S	S																									
SURT												H	H	H																
HRIM									S	S	S																			
FJAL									H	H	H																			
KIDA		B	B	B	B																									

A and B – TRIMBLE 4000 SST receivers from the Nordic Volcanological Institute. (15 sec. measurements interval)
H – TRIMBLE 4000 SST receiver from The Institut für Erdmessung, Hannover. (15 sec. measurements interval)
S – TRIMBLE 4000 SSE receiver from the Siglingastofnun. (30 sec. measurements interval)

Table A.1: Occupation of GPS-receivers in the Bárðarbunga campaign, 4. – 13. August 1997.

Date:	23. 8.			24. 8.			25. 8.			26. 8.		
Day:	235			236			237			238		
Point	0	1	2	0	1	2	0	1	2	0	1	2
HAUM			A	A	A	A	A	A	A	A	A	
GRIM						B	B	B	B	B	B	
HAMA			B	B	B	B						

A and B – TRIMBLE 4000 SST receivers from the Nordic Volcanological Institute.

Table A.2: Occupation of GPS-receivers in the Bárðarbunga campaign, 23. – 26. August 1997.

The Trimble receiver marked A in the Tables was a combination of the antenna C and the receiver A owned by the Nordic Volcanological Institute and therefore not the orginal A combination that has been used in previous measurements. This should not affect the results.

A.2 Plots of Repeatability

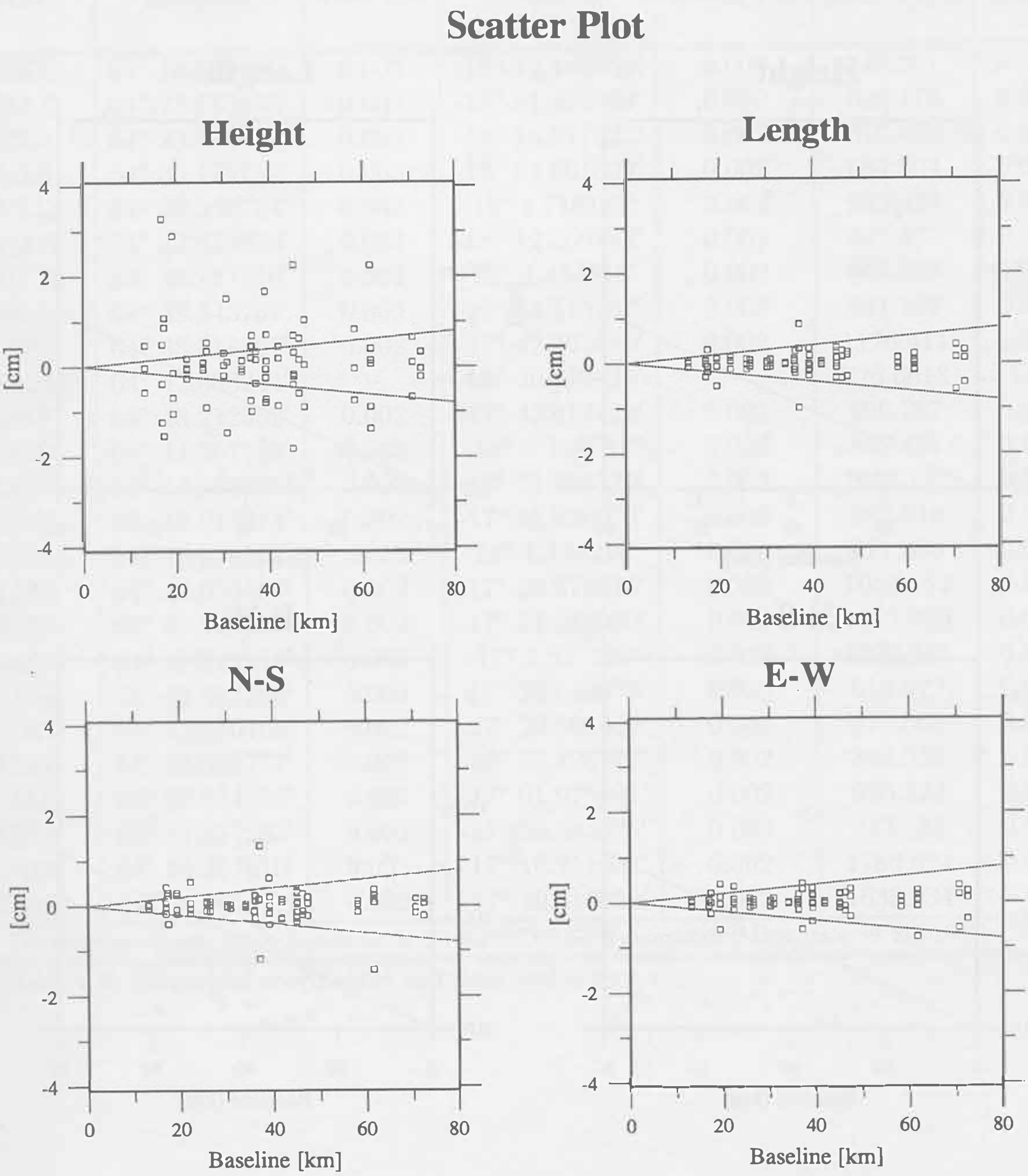

Figure 11: Plots of session scatter as a function of baseline length in the Bárðarbunga 1997 GPS measurements. Each session is marked with one square and the lines correspond to 0.1 ppm.

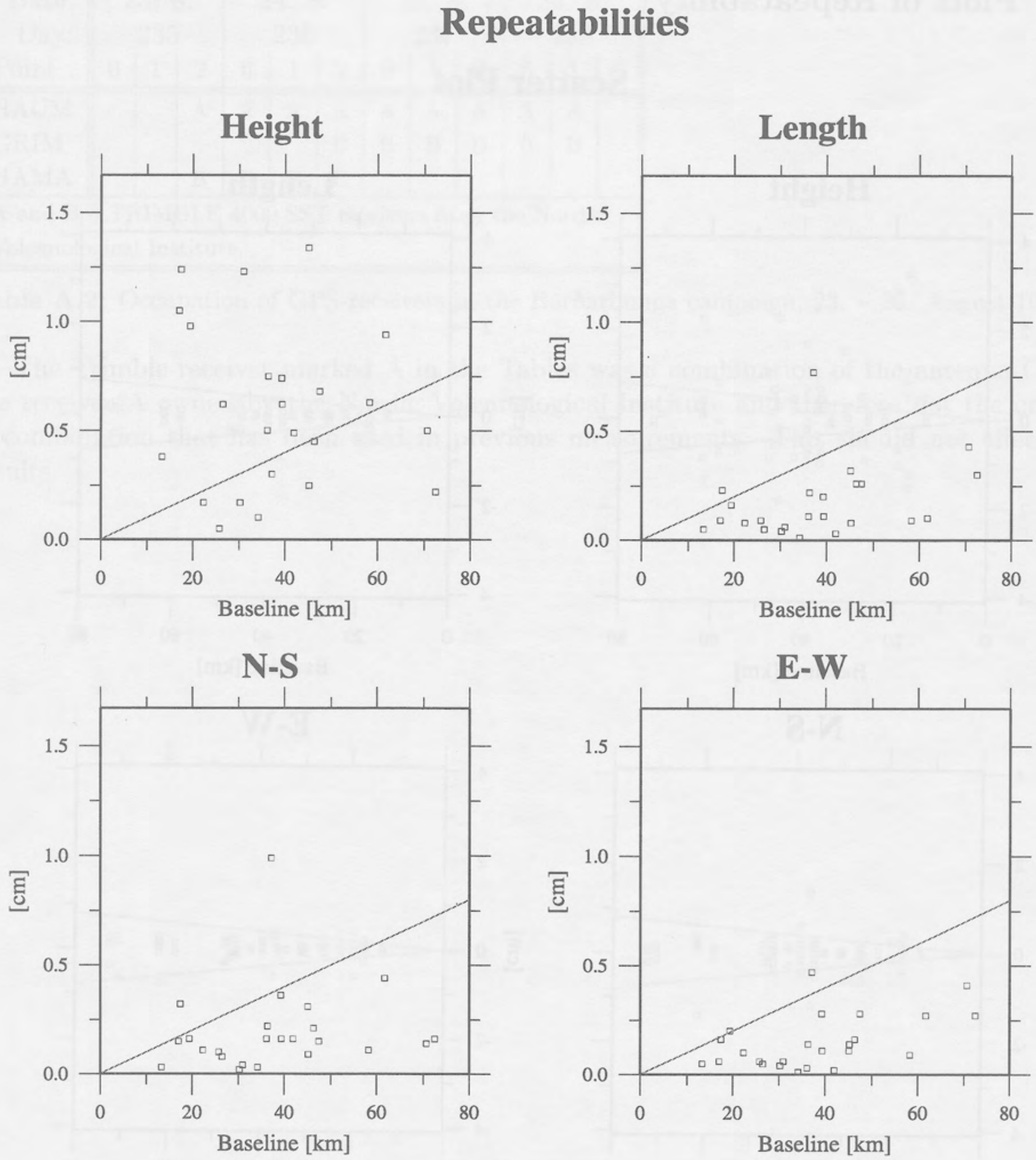

Figure 12: Plots of repeatability as a function of baseline length in the Bárðarbunga 1997 GPS measurements. Repeatability of each point is marked with square and the lines correspond to 0.1 ppm.

A.3 Coordinates

Point	Latitude	dlat. [m]	Longitude	dlong. [m]	Height [m]	dh [m]
JOKU	64° 18.573235′	0.003	-18° 14.400456′	0.002	740.201	0.009
KALD	64° 21.513633′	0.002	-18° 51.434909′	0.002	606.178	0.009
HELJ	64° 23.244822′	0.003	-18° 16.917922′	0.002	816.466	0.012
SVAR	64° 30.174132′	0.003	-18° 34.961609′	0.002	684.004	0.011
SVED	64° 30.930724′	0.002	-18° 1.718189′	0.002	923.428	0.009
SHAG	64° 32.858029′	0.003	-18° 12.369284′	0.002	897.873	0.010
SKER	64° 36.727856′	0.002	-18° 4.484816′	0.002	907.889	0.008
SHOF	64° 38.343767′	0.002	-17° 54.515707′	0.002	991.187	0.009
NEFS	64° 38.818267′	0.002	-17° 42.761610′	0.002	1126.411	0.013
HAUM*	64° 42.688244′	–	-18° 20.679328′	–	726.6618	–
HNIF	64° 43.212552′	0.002	-17° 42.614424′	0.002	996.767	0.011
NYID	64° 44.067528′	0.002	-18° 4.146781′	0.002	867.437	0.007
RJUP	64° 44.335581′	0.002	-17° 31.266573′	0.002	1086.717	0.009
TIND	64° 45.048914′	0.002	-17° 38.026014′	0.002	982.919	0.009
TOMA	64° 46.929502′	0.002	-18° 1.134216′	0.002	871.686	0.011
GAES	64° 47.053168′	0.002	-17° 28.879518′	0.002	1063.152	0.011
DYNG	64° 47.523927′	0.002	-17° 21.948990′	0.002	1197.629	0.009
URDA	64° 49.222216′	0.002	-17° 8.827327′	0.002	1078.352	0.008
GJAL	64° 49.693209′	0.003	-17° 36.839075′	0.003	916.922	0.015
SURT	64° 53.510109′	0.002	-17° 29.560447′	0.002	875.068	0.008
HRIM	64° 55.428777′	0.002	-16° 55.428777′	0.002	898.351	0.012
FJAL	65° 00.674285′	0.002	-17° 01.975031′	0.002	920.324	0.009
KIDA	65° 01.151285′	0.003	-17° 56.544085′	0.002	933.584	0.010
GRIM	64° 24.397010′	0.002	-17° 16.251098′	0.002	1780.624	0.005
HAMA	64° 28.066997′	0.002	-17° 49.310980′	0.002	1633.934	0.006
* The reference point. Coordinates from the ÍSNET93 GPS campaign [Magnússon et al., 1997].						

Table A.3: Ellipsoidal coordinates and their scaled sigma.

Point	Minor axis [mm]	Major axis [mm]	Angle [°]
JOKU	1.8	2.9	174.9
KALD	1.6	2.3	22.0
HELJ	1.8	2.9	175.3
SVAR	1.8	2.9	14.4
SVED	1.3	1.8	161.2
SHAG	1.8	2.9	166.0
SKER	1.3	1.8	154.9
SHOF	1.3	1.8	157.0
NEFS	1.9	2.5	130.7
HNIF	1.3	1.8	91.7
NYID	1.3	1.8	39.8
RJUP	1.6	2.3	78.3
TIND	1.3	1.8	74.2
TOMA	1.3	1.8	20.3
GAES	1.8	2.9	50.7
DYNG	1.3	1.8	67.5
URDA	1.3	1.8	67.6
GJAL	1.9	2.9	43.2
SURT	1.3	1.8	46.6
HRIM	1.6	2.3	44.6
FJAL	1.6	2.3	46.1
KIDA	1.8	2.9	19.2
GRIM	1.3	1.8	137.3
HAMA	1.6	2.3	148.9

Table A.4: 1 σ minor and major axis of uncertainty ellipsoids in the 1997 measurements. The fourt column gives the counter-clockwise angles from the horizontal axis to the major axis of the ellipses.

B The 1992 Vatnajökull GPS survey

B.1 Introduction

The first GPS measurements on Vatnajökull glacier were conducted in June 1992 by Páll Einarsson (Science Institute, University of Iceland) and Erik Sturkell (Nordic Volcanological Institute). The measurements were a part of the 1992 Vatnajökull expedition of the Icelandic Glaciological Society.

B.2 Measurements

The 1992 Vatnajökull GPS survey was conducted during June 14th to 20th. Three Trimble 4000SST GPS receivers of the Volcanological Institute were used. One instrument was operated almost continuously during the whole survey at a fixed reference point, Jökulheimar (0S20), near the glacier edge. The second receiver was operated in a static mode at an old geodetic point, Hamarinn (HAMA), on a the Hamarinn volcano at the western edge of the glacier. The third instrument was used mostly for kinematic surveying, but also in a static mode at a new point, Saltarinn (SALT), on the caldera rim of the Grímsvötn volcano in the middle of the glacier. These points are listed in Table B.1, and their location is shown in Figure 13.

Abbreviation	Name	Inscription	Approximate cooordinates		
			Latitude	longitude	Height [m]
0s20	Jökulheimar	OS 1986 7383	64° 18′ 34″	−18° 14′ 24″	740
HAMA	Hamarinn	(none)	64° 28′ 40″	−17° 49′ 19″	1634
SALT	Grímsfjall	500	64° 24′ 24″	−17° 16′ 15″	1781

Table B.1: Vatnajökull GPS control points measured in 1992.

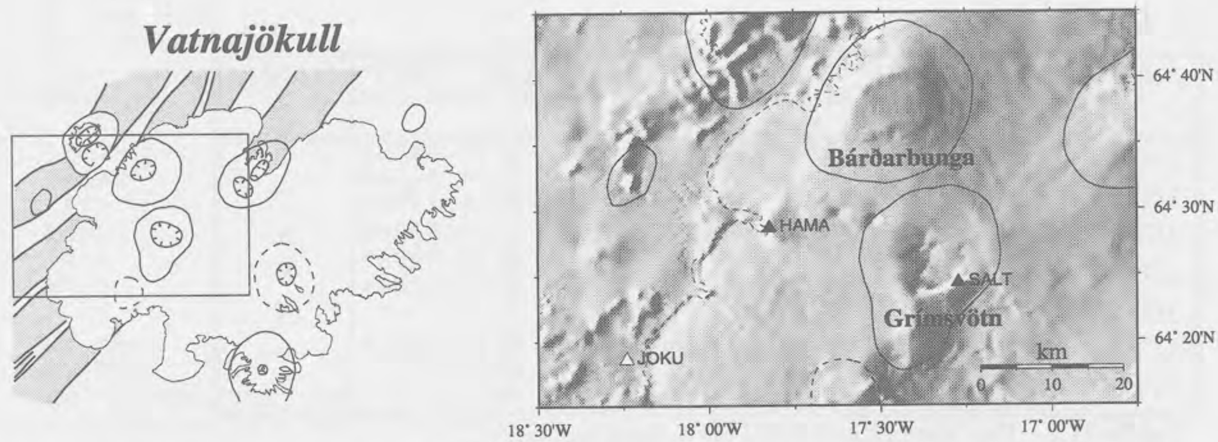

Figure 13: The Vatnajökull glacier GPS network. The triangles show the location of GPS points measured in June 1992. Jökulheimar (0s20) was a reference point in this campaign.

B.3 Data analysis

The GPS data were analysed with the Bernese GPS software, version 3.2. The coordinates of the point Jökulheimar were held fixed in the data processing using values obtained by Jahn [1991]. Both L_1 and L_2 data were collected. Cycle ambiguity resolution was successful for this data set, 143 out of 169 or 85% of the cycle ambiguities could be resolved to integers. The resulting point coordinates are presented in geocentric coordinates in Table B.2 and in ellipsoidal coordinates in Table B.3. The coordinates are presented in the WGS-84 geodetic system.

Point	X [m]	d_X[m]	Y [m]	d_X[m]	Z [m]	d_Z[m]
0s20	2633518.2020	–	-867888.1410	–	5725418.9250	–
HAMA	2638933.8499	0.0001	-820457.1889	0.0001	5731040.4339	0.0003
SALT	2624035.6070	0.0001	-843582.8156	0.0001	5734336.9356	0.0003

Table B.2: Geocentric coordinates for points measured in June 1992 and their formal errors.

Point	Latitude [°]	d_{lat} [m]	Longitude [°]	d_{long} [m]	Height [m]	d_h [m]
0s20	64.30956622	–	-18.23987554	–	731.8555	–
HAMA	64.40662882	0.0001	-17.27071991	0.0001	1772.2537	0.0003
SALT	64.47790048	0.0001	-17.82171491	0.0001	1625.5713	0.0003

Table B.3: Ellipsoidal coordinates for points measured in June 1992 and their formal errors.

The estimated error of the coordinates in the Tables are the formal errors given by the Bernese programs. The session-to-session scatter suggest that the true uncertainty for the east and north component and the baseline length is about 5 mm and the uncertainty for the vertical component is about 10 mm, see Tables B.5 and B.6.

B.4 Tables

Session	Start time	End time	Hours	0s20	SALT	HAMA
166-9	14. 6. 12:11	14. 6. 22:00	10.0	X	X	
166-1	14. 6. 22:30	15. 6. 10:04	11.5	X	X	
167-1	15. 6. 22:43	16. 6. 21:52	23.0	X	X	X
168-1	16. 6. 23:00	17. 6. 13:50	14.0	X	X	X
168-2	17. 6. 13:51	17. 6. 21:53	8.0	X		X
171-1	19. 6. 13:40	19. 6. 22:00	8.5	X	X	
171-2	19. 6. 22:02	20. 6. 09:36	11.5	X	X	

Table B.4: The Vatnajökull 1992 GPS measurements.

Session	Latitude	Formal unc. [sec]	Deviation [m]
1661	64. 24. 23.864101	0.000011	0.01037
1669	64. 24. 23.863780	0.000007	0.00044
1671	64. 24. 23.863685	0.000008	-0.00250
1681	64. 24. 23.864176	0.000011	0.01269
1711	64. 24. 23.863550	0.000010	-0.00667
1712	64. 24. 23.863617	0.000007	-0.00460
w. mean	64 24 23.863766		
w. RMS [sec]	0.000220		
w. RMS [m]	0.006799		
av. Formal unc. [m]	0.000278		

Session	Longitude	Formal unc. [sec]	Deviation [m]
1661	-17. 16. 14.591793	0.000024	-0.00029
1669	-17. 16. 14.591983	0.000014	-0.00284
1671	-17. 16. 14.592246	0.000014	-0.00636
1681	-17. 16. 14.590974	0.000025	0.01068
1711	-17. 16. 14.591703	0.000017	0.00092
1712	-17. 16. 14.591429	0.000013	0.00459
w. mean	-17 16 14.591771		
w. RMS [sec]	0.000403		
w. RMS [m]	0.005403		
av. Formal unc. [m]	0.000239		

Session	Heigth [m]	Formal unc. [m]	Deviation [m]
1661	1772.2642	0.0010	0.01109
1669	1772.2663	0.0005	0.01319
1671	1772.2547	0.0006	0.00159
1681	1772.2492	0.0009	-0.00391
1711	1772.2501	0.0007	-0.00301
1712	1772.2388	0.0005	-0.01431
w. mean [m]	1772.2531		
w. RMS [m]	0.0116		
av. Formal unc [m]	0.0007		

Session	L from Base [m]	Formal unc. [m]	Deviation [m]
1661	48068.9707	0.0003	0.00277
1669	48068.9661	0.0002	-0.00183
1671	48068.9617	0.0002	-0.00623
1681	48068.9815	0.0004	0.01357
1711	48068.9678	0.0002	-0.00013
1712	48068.9715	0.0002	0.00357
w. mean	48068.9679		
w. RMS	0.0052		
av. Formal unc. [m]	0.0007		

Table B.5: Session-to-session scatter of the point Saltarinn, SALT.

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------------------------------------------------------------------------
Session              Latitude          Formal unc. [sec]   Deviation [m]

1671          64. 28. 40.441773           0.000006           0.00246
1681          64. 28. 40.441709           0.000006           0.00048
1682          64. 28. 40.441479           0.000009          -0.00663

w. mean       64  28  40.441693
w. RMS [sec]           0.000129
w. RMS [m]             0.003981
av. Formal unc. [m]    0.000216
------------------------------------------------------------------------
Session              Longitude         Formal unc. [sec]   Deviation [m]

1671         -17. 49. 18.173432           0.000013           0.00074
1681         -17. 49. 18.173731           0.000012          -0.00326
1682         -17. 49. 18.173045           0.000018           0.00591

w. mean      -17  49  18.173487
w. RMS [sec]           0.000312
w. RMS [m]             0.004168
av. Formal unc. [m     0.000192
------------------------------------------------------------------------
Session                 Heigth [m]       Formal unc. [m]   Deviation [m]

1671                  1625.5700           0.0005            -0.00479
1681                  1625.5837           0.0005             0.00891
1682                  1625.5667           0.0007            -0.00809

w. mean [m]           1625.5748
w. RMS [m]               0.0090
av. Formal unc. [m]      0.0006
------------------------------------------------------------------------
Session            L from Base [m]       Formal unc. [m]   Deviation [m]

1671                 27571.7151           0.0002             0.00037
1681                 27571.7150           0.0005             0.00027
1682                 27571.7138           0.0003            -0.00093

w. mean [m]          27571.7147
w. RMS [m]               0.0007
av. Formal unc. [m]      0.0006
------------------------------------------------------------------------
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Table B.6: Session-to-session scatter of the point Hamarinn, HAMA.

C Point descriptions

All descriptions start at route #F26, beside the Hrauneyjarlón reservoir. Drive route #1, Suðurlandsvegur, past Selfoss and ~ 15 km farther east on that road. Turn left on road #30, Skeiðavegur, and drive ~ 18 km further. Then turn right on road #32, Þjórsárdalsvegur, and drive past Árnes and Búrfellsvirkjun power station and continue on route #F26 past Hrauneyjarlón reservoir. Numbers in parantheses are point numbers used for the respective point in the surveys of 1986 [Foulger et al., 1993], 1987 [Foulger, 1987; Jahn et al., 1991], 1989 [Hackmann, 1991], 1990 [Jahn. 1992; Camitz et al., 1995], 1992 [Völksen and Seeber, 1998; Appendix B], 1993 [Magnússon et al., 1997; Camitz et al., 1995], 1994 [Jónsson et al., 1997; Sigmundsson, 1994], 1995 [Völksen and Seeber, 1998] and 1997.

OS 1986 7383 Jökulheimar

64° 18.56′ N
18° 14.39′ W

The point is at Jökulheimar west of Tungnaárjökull glacier (Vatnajökull glacier). Drive route #F26 past Hrauneyjarlón reservoir. Turn east at a signpost marked Jökulheimar and drive 21 km to a signpost marked Jökulheimar–Veiðivötn. From the post turn to northeast and drive about 35 km towards the huts owned by The Icelandic Glaciological Society, JÖRFI, in Jökulheimar. The point is at the top of a massive lava outcrop, 5 m above and 20 m west of the parking area. It is marked with a cairn. Brass bolt and a plate with the inscription OS 1986 7383.

Description: 1986
Surveys:
1986: GPS (S20)
1987: GPS (57)
1989: GPS (S20)
1992: GPS (0S20, 57)
1993: GPS (OS 1986 7383)
1994: GPS (JOKU)
1995: GPS (57)
1997: GPS (JOKU)

OS 1989 7491 Kaldakvísl

64° 21.51′ N
18° 51.40′ W

The point is near the bridge across the river Kaldakvísl, north of the lake Þórisvatn. Drive route #F26, Sprengisandsleið, past Hrauneyjarlón reservoir and continue past the lake Þórisvatn. From the intersection to Þórisós, continue 600 m on route #F26 to the Kaldakvísl bridge. Cross the bridge and turn east on a track and drive about 120 m. The point is in bedrock, south of the track on the north edge of the Kaldakvísl canyon. It is marked with a cairn. Brass bolt and a plate with the inscription OS 1989 7491. (The marker was installed in september 1989 by Freysteinn Sigmundsson, after the 1989 GPS measurements. At the

time of the measurements there was only a painted mark. The installed bolt is within 4 mm horizontally from the measured painted mark, and 1.5 cm higher.)
Description: 1989
Surveys:
1989: GPS (S49)
1994: GPS (KALD)
1997: GPS (KALD)

RH 9707 Heljargjá

64° 23.25′ N
18° 16.95′ W

The point is in Heljargjá in Gjáfjöll west of Jökulheimar and Tungnaárjökull glacier (Vatnajökull glacier). Drive route #F26, Sprengisandsleið, past Hrauneyjarlón reservoir and 3 km further on the same road. Turn east at a signpost marked Jökulheimar and drive 21 km to a signpost marked Jökulheimar-Veiðivötn. From the post turn to the northeast and drive about 35 km towards the huts owned by The Icelandic Glaciological Society, JÖRFI, in Jökulheimar. 1.8 km west of the huts (64° 18.79′ N and 18° 16.21′ W) you turn on a track to north (64° 18.79′ N and 18° 14.33′ W). (Two radar satellite mirrors are placed near the track.) Drive along this track for about 10 km, first to N and then to W, towards a funny looking palagonite peak, Dórinn, on a mountain end in Gjáfjöll mountains (you can see it from far away). There the track splits in two (64° 22.94′ N and 18° 14.81′ W). Follow the track to the west, that lays between the lava (Tröllahraun) and hill.·for about 0.6 km. Then (64° 23.26′ N and 18° 15.09′ W) you turn away from the lava and drive up the hill. Drive for about 1.3 km, until you come to a lava (64° 23.55′ N and 18° 16.24′ W). There you have to drive between the lava and hill (NB very narrow in parts!) for about 0.9 km. Then you drive upp a hill SW from the lava (64° 23.33′ N and 18° 16.76′ W). The point is on a palagonite outcrop at the top of the hill, about 21 m east of the track. It is marked with two cairns, one beside the track and other 1 m west of the point. Brass bolt and a plate with the inscription RH 9707.
Description: 1997
Surveys:
1997: GPS (HELJ)

RH 9705 Svartá

64° 30.17′ N
18° 34.99′ W

The point is beside the river Svartá which crosses the route Sprengisandsleið between the hills Þveralda and Hnöttóttaalda. Drive route #F26, Sprengisandsleið, past Hrauneyjarlón reservoir past Versalir and over the hill Þveralda. Cross the river Svartá and turn off the road to west about 15 m north of the river. The point is about 160 m from the road and about 14 m north of the riverbank on a palagonite outcrop. The point is marked with a cairn. Brass bolt and a plate with the inscription RH 9705.
Description: 1997

Surveys:
1997: GPS (SVAR)

NE 9706 Sveðja

64° 30.95′ N
18° 01.70′ W

The point is in the hills Mókollar, west of Hamarskriki, west of Vatnajökull, beside the river Sveðja. Drive route #F26, Sprengisandsleið, past Hrauneyjarlón reservoir and past the hill Skrokkalda. Turn east on the road towards Hágöngur and drive to the mountain Syðri-Háganga. Cross the Hágöngur dam east of Syðri-Háganga and drive towards Mókollar if possible. The point is on the first hill in the hill province and is marked with a cairn. If the track goes under water it should be possible to drive from Jökulheimar to north on a track that leads to Mókollar. Brass bolt and a plate with the inscription NE 9706.
Description: 1997
Surveys:
1997: GPS (SVED)

20"6"2-2 Syðri-Háganga

64° 32.85′ N
18° 12.39′ W

The point is located NNE of Syðri-Háganga, about 200 m north of the road to the Hágöngur dam. Drive route #F26, Sprengisandsleið, past Hrauneyjarlón reservoir and past the mountain Skrokkalda. Turn east on a track towards Hágöngur and drive 11.4 km to Syðri-Háganga. The point is about 1.1 km west of the westenmost Hágöngur dam. It is on a 5×5 m outcrop with a nice view over the Hágöngur reservoir and is marked with a cairn. The point has the inscription 20"6"2-2.
Description: 1997
Surveys:
1997: GPS (SHAG)

NE 9704 Skerðingur

64° 36.72′ N
18° 04.48′ W

The point is northwest of the mountain Skerðingur southwest of Vonarskarð and west of Köldukvíslarjökull glacier (Vatnajökull glacier). Drive route #F26, Sprengisandsleið, past Hrauneyjarlón reservoir and past the mountain Skrokkalda. Turn east on a track to Hágöngur and drive about 7 km towards the mountain Syðri-Háganga. Turn left onto a track that leads up a hill. Drive 13 km on this track into a valley and up a palagonite hill. There may be changes in this track due to changing water level in the Hágöngur reservoir. The point is in a palagonite outcrop, 15 m west of the track. It is marked with a cairn. Brass bolt and a plate with the inscription NE 9704.

Description: 1997
Surveys:
1997: GPS (SKER)

RH 9706 Svarthöfði

64° 38.34′ N
17° 54.52′ W

The point is south of Kolufell and southwest of Svarthöfði where Kaldakvísl river runs out of Vonarskarð. Drive route #F26, Sprengisandsleið, from Sigalda power station past the mountain Skrokkalda. Turn east on a track to Hágöngur and drive about 7 km towards the mountain Syðri-Háganga. Turn left onto a track that leads up a hill. Drive on this track past the mountain Nyrðri-Háganga to the mountain Kolufell. There you stop before the track goes down a hill where Kaldakvísl river takes a U–turn. The point is on a palagonite ridge beneath Kolufell and is marked with a cairn. Brass bolt and a plate with the inscription RH 9706.
Description: 1997
1997: GPS (SH●F)

NE 9705 Nefsteinn

64° 38.82′ N
17° 42.75′ W

The point is in a small valley between the mountains "Nefsteinn" (actually the mountains name is not Nefsteinn but has been wrongly marked on many maps. The real mountain Nefsteinn is between the mountain Systrafell in Vonarskarð and the (subglacial) mountain Bárðarbunga) and Fremsta-Bálkafell in Vonarskarð. Drive route #F26, Sprengisandsleið, from Sigalda power station past the mountain Skrokkalda. Turn east on a road towards Hágöngur and drive about 7 km in direction to the mountain Syðri-Háganga. Turn left onto a track that leads up a hill. Drive on this track past the mountains Nyrðri-Háganga and Kolufell. You have to cross the Kaldakvísl river twice to pass the mountain Svarthöfði and then drive past the mountains Skrauti and Deilir. There the track disappears in a sandy riverbasin. Turn east and cross the riverbasin (beware of quicksand) towards a noname mountain ($\sim$ 1014 m high). South of the mountain you have to cross a small man-made dam. Then you drive up a riverbed north of Fremsta-Bálkafell as far as you can towards the mountain "Nefsteinn". Drive up the valley between "Nefsteinn" and Fremsta-Bálkafell. The point is on the most eyecatching palagonite outcrop in the walley. It is marked with a cairn. Brass bolt and a plate with the inscription NE 9705.
Description: 1997
Surveys:
1997: GPS (NEFS)

LM 358 Háumýrar NA

64° 42.70′ N
18° 20.66′ W

The point is 3 km east of Þjórsá and 13 km WSW of Nýidalur, beside an old route north of Háumýrarkvísl. Drive route #F26, Sprengisandsleið, past Hrauneyjarlón reservoir and to Versalir. Drive past Versalir on the route "Kvíslaveituvegur" and continue on that route for about 31 km. Cross a bridge over kvíslaveitu reservoir and continue on a the route for about 4 km more, towards Háumýrarkvísl. There you turn east on an old route. Drive about 2.8 km on this track. The point is on a concreted pillar on a $\sim$ 0.3 m high bedrock, about 110 m north of the track. Brass bolt with the inscription LM 358. A tribrach screws directly on the bolt. (A bolt LM 0533 is 4 m south of the pillar.)
Description: 1997
Surveys:
1993: GPS (LM 0358)
1997: GPS (HAUM)

NE 9703 Hníflar

64° 43.22′ N
17° 43.59′ W

The point is northeast of the mountain Valafell in Vonarskarð between Tungnafellsjökull glacier and Vatnajökull glacier. Drive route #F26, Sprengisandsleið, past Hrauneyjarlón reservoir to Nýidalur east of Tungnafellsjökull glacier. About 6 km north of the Ferðafélag Íslands hut, Nýidalur, is a crossroad and a signpost marked Askja. Take the road to the east, Gæsavatnaleið (route #F98), and drive 19.5 km. Turn right towards south and drive 11.9 km towards the mountain pass "Gjósta" in Vonarskarð. Then you pass a small brook where the track splits in two. You take the one on the left that leads to two palagonite cliffs called Hníflar. Continue about 700 m on the track. The point is in a palagonite outcrop, about 25 m west of the track and about 1 km before you get to the cliffs. A cairn is beside the marker. Brass bolt and a plate with the inscription NE 9703.
Description: 1997
Surveys:
1997: GPS (HNIF)

RH 9704 Nýidalur

64° 44.07′ N
18° 04.17′ W

The point is west of Tungnafellsjökull glacier. Drive route #F26, Sprengisandsleið, past Hrauneyjarlón reservoir to the turist huts in Nýidalur owned by the Ferðafélag Íslands (The touring club of Iceland). The point is on an outcrop east of the huts and south of a horse-fence. It is marked with a cairn. Brass bolt and a plate with the inscription RH 9704.
Description: 1997
Surveys:

1997: GPS (NYID)

RH 9703 Rjúpnabrekka

64° 44.33′ N
17° 31.26′ W

The point is in Rjúpnabrekka, north of Rjúpnabrekkujökull glacier (Vatnajökull glacier) 4.4 km south of Gæsavötn (line of sight). Drive route #F26, Sprengisandsleið, past Hrauneyjarlón reservoir and past Nýidalur west of Tungnafellsjökull glacier. About 6 km north of the turist huts, Nýidalur, is a crossroad and a signpost marked Askja. Drive Gæsavatnaleið, route #F98, to Gæsavötn. Drive from Gæsavötn to south along track west of the small brook west of Gæsavötn hut. The track is unclear. It leads you up a steep hill, across a lava flow and then it crosses a riverbed where it disappears. The point is on a waterfall edge in a gully north of a prominent moraine. It is marked with a cairn. Brass bolt and a plate with the inscription RH 9703.
Description: 1997
Surveys:
1997: GPS (RJUP)

NE 9702 Tindafell N

64° 45.04′ N
17° 38.01′ W

The point is about 2 km north of the mountain Tindafell in Vonarskarð between Tungnafellsjökull glacier and Vatnajökull glacier. Drive route #F26, Sprengisandsleið, past Hrauneyjarlón reservoir to Nýidalur. Drive about 6 km north of the turist huts in Nýidalur, to a crossroad and a signpost marked Askja. Drive Gæsavatnaleið, route #F98, about 19.5 km. Turn on a track towards south and drive until you see a signpost marked Gjóstur. There you turn left towards east. Drive until you pass a ford on Skjálfandafljót river. Caution: This ford is frequently unusable, it is dangerous. Drive 0.5 km from the ford and turn right towards south on an unclear track. Drive the faded track 1.6 km, the last few hundred meters are on river sand. The point is on a 20 m high hill in a pillow lava outcrop, about 100 m west of the river sand. It is marked with a cairn. Brass bolt and a plate with the inscription NE 9702.
Description: 1997
Surveys:
1997: GPS (TIND)

RH 9701 Tómasarhagi

64° 46.91′ N
18° 01.13′ W

The point is in Tómasarhagi west of Tungnafellsjökull glacier. Drive route #F26, Sprengisandsleið, past Hrauneyjarlón reservoir and past Nýidalur, west of Tungnafellsjökull, and

about 7 km further. The point is on a flat outcrop of palagonite breccia in a dry river bed 35 m north of the road and 1 km from the crossroads toward Gæsavötn. It is 1 m from the west edge of the riverbed and is marked with a cairn. Brass bolt and a plate with the inscription RH 9701.
Description: 1997
Surveys:
1997: GPS (TOMA)

NE 9701 Gæsahjúkur

64° 47.05′ N
17° 28.89′ W

The point is NNW of the mountain Gæsahnjúkur west of Dyngjujökull glacier, Vatnajökull glacier. Drive route #F26, Sprengisandsleið, past Hrauneyjarlón reservoir and past Nýidalur, west of Tungnafellsjökull glacier. About 6 km north of the turist huts in Nýidalur, is a crossroad and a signpost marked Askja. Take the route to east, Gæsavatnaleið (route #F98). and drive past Gæsavötn. Drive about 1.9 km from the hut at Gæsavötn to east and continue 350 m past a steep gravel slope. The point is 10 m south of the track in a lava that has slightly lighter color than the surrounding lava. A cairn is close to the point. Brass bolt and a plate with the inscription NE 9701.
Description: 1997
Surveys:
1997: GPS (GAES)

RH 9006 Dyngjuháls

64° 47.53′ N
17° 21.90′ W

The point is near the route Gæsavatnaleið, #F98, on the eastern slope of the ridge Dyngjuháls, south of the mountain Trölladyngja. Drive route #F26, Sprengisandsleið, past Hrauneyjarlón reservoir and past Nýidalur, west of Tungnafellsjökull glacier. About 6 km north of the Ferðafélag Íslands huts in Nýidalur, is a crossroad and a signpost marked Askja. Take the route to east, Gæsavatnaleið (route #F98), and drive past Gæsavötn. Drive about 9.8 km to east from the hut at Gæsavötn. The point is on the eastern slope of Dyngjuháls where the track has a N–S orientation, 16.5 km west of the large crater on Urðarháls. The marker is in a flat, polished, pahoehoe lava, 25 m west of the track. Two cairns mark the site, one is 10 m west of the track and another, smaller one, 2.5 m SW of the marker. Bolt and plate with the inscription RH 9006. (Beware of a second marker installed by OS in 1995 about 200 m south of RH 9006.)
Description: 1990
Surveys:
1990: GPS (77)
1997: GPS (DYNG)

NE 90011 Urðarháls

64° 49.24′ N
17° 08.80′ W

The point is on the hill Urðarháls north of Dyngjujökull glacier (Vatnajökull glacier). Drive route #F26, Sprengisandsleið, past Hrauneyjarlón reservoir and past Nýidalur, west of Tungnafellsjökull glacier. About 6 km north of the turist huts in Nýidalur is a crossroad and a signpost marked Askja. Take the route to east, Gæsavatnaleið (route #F98), and drive past Gæsavötn and over the Dyngjuháls ridge. Drive along the track up the hill Urðarháls. The point is S of the big crater at the top of Urðarháls, about 40 m north of the track. The point is on a flat outcrop about 130 m west of a signpost on Urðarháls. It is marked with cairn. Brass bolt and a plate with the inscription NE 90011. (The point was installed in 1990 but it was not measured until 1997.)

Description: 1997
Survey:
1997: GPS (URDA)

OS 7470 Gjallandi A (Vonarskarð)

64° 49.72′ N
17° 36.85′ W

The point is on a small hill (854 m high) east of the river Skjálfandafljót and north of the gorge Fossagljúfur. Drive route #F26, Sprengisandsvegur, past Hrauneyjarlón reservoir and past Nýidalur, west of Tungnafellsjökull glacier. About 6 km north of the turist huts in Nýidalur is a crossroad and signpost marked Askja. Take the route to east, Gæsavatnaleið (route #F98) and drive to the bridge on the river Skjálfandafljót. Cross the bridge and turn towards south 200 m east of the bridge. Drive 1 km along that track and then turn northwards on a track just south of a small hill (854 m) and drive 500 m to the point at the top of the hill. The marker is in a tuff outcrop, 14 m SSE of a cairn. Brass bolt and a plate with the inscription (OS) 7470.

Description: 1987
Surveys:
1987: GPS (54)
1989: GPS (N54)
1990: GPS (54)
1992: GPS (54)
1993: GPS (OS 7470)
1995: GPS (54)
1997: GPS (GJAL)

RH 9702 Surtluflæður

64° 53.52′ N
17° 29.57′ W

The point is in Trölladyngja lava west of the mountain Trölladyngja. Drive route #F26, Sprengisandsleið, past Hrauneyjarlón reservoir and past Nýidalur, west of Tungnafellsjökull glacier. About 6 km north of the turist huts in Nýidalur is a crossroad and a signpost marked Askja. Take the route to east, Gæsavatnaleið (route #F98), and drive to the bridge on the river Skjálfandafljót. Cross the bridge and turn to north on route #F910, Austurleið, towards Askja. Drive about 40 km along the track. The point is about 50 m south of a kipuka and about 30 m east of the track on a pahoehoe lava field. The best way of finding the point is to use a GPS positioning equipment! The point is marked with a cairn. Brass bolt and a plate with the inscription RH 9702.

Description: 1997
Surveys:
1997: GPS (SURT)

NE 90014 Hrímalda NE

64° 57.02′ N
16° 55.46′ W

The point is south of the Dyngjufjöll massif, slightly NW of the northern end of a small palagonite ridge wich extends N–S, north of the crossroad where route #F98, Gæsavatnaleið joins the route #F910. Austurleið. Drive route #F26. Sprengisandsleið. past Hrauneyjarlón reservoir and past Nýidalur, west of Tungnafellsjökull glacier. About 6 km north of the turist huts in Nýidalur is a crossroad and a signpost marked Askja. Take the route to east, Gæsavatnaleið (route #F98), to the bridge on the river Skjálfandafljót. Cross the bridge. Then you come to a crossroad where you can choose between two routs, to continue on route #F26, Gæsavatnaleið, or turn to north on route #F910, Austurleið. If you choose to continue on Gæsavatnaleið then you drive past Gæsavötn and past the crater on Urðarháls. You continue your drive along that track in east direction until you come to a sandy river-basin. There the track may disappear. You drive north along the track/riverbed (beware of quiksand) and turn towards west from the riverbed on a signpost (with no sign left). There you have to drive along the lava in the sand towards north. past the mountain Hrímalda and on until you come to a crossroad where route #F910 takes over and continues in both northeast and northwest direction. You take the western track and drive for just few meters past a palagonite ridge with the N–S direction. The point is NW of the northern end of the palagonite ridge and is marked with a cairn.

If you choose route #F910, Austurleið, you drive past the palagonite ridge Þríhyrningur and past the palagonite ridge Dyngjufjöll ytri and along the same track in SE direction. You drive past a track that leads to Dyngjufjalladalur (north direction) and on until you see a small palagonite ridge with a S N direction. Then the point is, as before, NW of the northern end of the palagonite ridge and is marked with a cairn. Brass bolt and a plate with the inscription NE 90014.

Description:
Surveys:
1990: GPS (75)
1993: GPS (HRIM)
1994: GPS (HRIM)
1997: GPS (HRIM)

RH 8437 Fjallsendi S

65° 00.68′ N
17° 01.96′ W

The point is southeast of Fjallsendi, the southernmost end of the palagonite ridge Dyngjufjöll ytri. Drive route #F26, Sprengisandsleið, past Hrauneyjarlón reservoir and past Nýidalur, west of Tungnafellsjökull glacier. About 6 km north of the turist huts in Nýidalur is a crossroad and a signpost marked Askja. Take the route to east, Gæsavatnaleið (route #F98) and drive to the bridge on the river Skjálfandafljót. Cross the bridge and turn to north on route #F910, Austurleið, towards Askja. Drive past the palagonite ridge Þríhyrningur and towards Fjallsendi. The point is on a 20 m high palagonite ridge south of Fjallsendi. The ridge extends E–W and has several small peaks where pillow lava is exposed. The marker is on the second small peak from east. Brass bolt and a plate with the inscription RH 8437.
Description: 1997
Surveys:
1987: GPS (48)
1992: GPS (48)
1993: GPS (RH 8437, FJAL)
1994: GPS (FJAL)
1995: GPS (48)
1997: GPS (FJAL)

OS 1987 7469 Kiðagilsdrög

65° 01.16′ N
17° 56.52′ W

Drive route #F26, Sprengisandsleið, past Hrauneyjarlón reservoir and to Nýidalur, west of Tungnafellsjökull glacier. From Nýidalur you drive 37 km on the road past Tómasarhagi and the lake Fjórðungsvatn to a crossroad with a signpost marked Eyjafjörður/Skagafjörður/Laugafell. Turn west and drive 1.5 km uphill along route #F881 to Laugafell. As the road begins to slope downhill again, turn towards north on a track and drive 70 meters up the hill. The point is marked with a cairn. Brass bolt and a plate with the inscription OS 1987 7469.
Description: 1997
Surveys:
1987: GPS (47)
1990: GPS (47)

1992: GPS (47)
1993: GPS (OS 1987 7469)
1995: GPS (47)
1997: GPS (KIDA)

LM 500 Grímsfjall (Saltarinn)

64° 24.39′ N
17° 16.26′ W

The point is on a palagonite peak called Saltarinn on the mountain Grímsfjall, Vatnajökull glacier. Saltarinn is NW of the huts owned by The Icelandic Glaciological Society, JÖRFI. The point is 231 m NW of the corner of the younger hut. Brass bolt and a plate with the inscription 500. The bolt is cemented on a 90 cm long pipe which is drilled about 60 cm into the palagonite.
Description: 1997
Surveys:
1992: GPS (SALT)
1993: GPS (LM 500)
1997: GPS (GRIM)

Hamarinn

64° 28.67′ N
17° 49.33′ W

The point is on the palagonite peak Hamarinn in western Vatnajökull glacier. It is on the higest peak of the mountain, under a cairn. The point is a rod (no inscription) which is driven into the palagonite. It is bent in SSW direction (about 5 mm displacement to SSW).
Description: 1997
Survey:
1992: GPS (HAMA)
1997: GPS (HAMA)