GPS network measurements in the Kárahnjúkar area in 2006

Benedikt Gunnar Ófeigsson Erik Sturkell Halldór Ólafsson
Freysteinn Sigmundsson Páll Einarsson
Jón Thuy Xuan Búi

Institute of Earth Sciences
University of Iceland
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1 Introduction

As a part of a monitoring and research program by Landsvirkjun in the Hálslón area, an extensive network for crustal deformation research was established there in 2005 by the Institute of Earth Sciences, University of Iceland. The network was initially measured in 2005 [1]. The complete network was remeasured from August 8 until August 16 2006. A total of 35 benchmarks were occupied within a distance of 20 km from Kárahnjúkar. Ten of these stations were existing benchmarks including 3 benchmarks, used in the earlier ISNET campaigns (HATU, LAFE and GRUN). The GPS network was established in order to monitor the effect of reservoir filling. Processes that may be expected as a consequence of the filling of the Hálslón reservoir include crustal sagging due to the increased load, triggered earthquakes due to the increased pore pressure, and dilation of fractures by increased fluid pressure under low horizontal stress. Other crustal processes that are likely to be detected are crustal stretching due to plate movements, and uplift associated with decreasing load of the nearby Vatnajökull ice cap. In addition a seasonal variations have been observed in the contious GPS network [2] and modeled taking into account the seasonal snow load on Icelands four largest ice-caps [3].

2 GPS measurements in the Kárahnjúkar area

Currently three GPS networks have been established in the Kárahnjúkar area. One with continuous GPS stations and two networks of benchmarks measured in campaigns. Together these three networks form a coherent monitoring network for detecting spatial and temporal variations in crustal movements at Kárahnjúkar.

For resolving temporal changes in the Hálslón area in real time and monitoring seasonal variations, the Icelandic Meteorological Office established three continuously measuring GPS stations in the area (see Figure 3). Station SAUD located at Sauðárháls (N64°53′54.23″ W15°53′01.35″) was established in October 30, 2004. Station KARV located near the camps at Kárahnjúkar (N64°56′00.24″ W15°50′22.2″) was established September 17, 2005. Station BRUJ located near Brúarjökull (N64°49′45.48″ W16°05′19.8″) was established September 16, 2005. Detailed information about the continuous GPS sites can be found on the website of the Icelandic Meteorological Office [4]. In addition, a continuous GPS station was established in Heiðarsel (HEID) and run by the National Land Survey of Iceland (see Table 1), to be used as future reference.

Another network was also established in the Hálslón area by Hnit Ltd. and the Earthquake Engineering Research Centre of the University of Iceland. This network is confined to the area close to the dam sites and is focused on detecting fault movements in the immediate vicinity of the three dams [5].

The third network (Hálslón GPS Network) was established by the Institute of Earth Sciences and it was remeasured in August 2006.

3 The Hálslón GPS Network

The GPS network of the Institute of Earth Sciences can be divided into three parts

1. Benchmarks concentrated close to the dams (see Figure 1).
2. Benchmarks that are located within 20 km distance from Hálsón (see Figure 2).
3. Benchmarks in adjacent areas to widen the coverage of the network (see Figure 3).

In addition to the GPS measurements, precise leveling was performed between the benchmarks MISV and MISA (see Table 1 and Figure 1) which are established west and east of the Sauðárdalur fault, respectively.

4 Campaign summary

The Kárahnjúkar 2006 GPS campaign (KARA06A) took place from August 8 until August 16 and was carried out by the Institute of Earth Sciences in cooperation with Landsvirkjun. Overview of the campaign is given in Tables 1-2

Three groups on three jeeps participated in the campaign, one from Landsvirkjun and two from the Institute of Earth Sciences. A total number of 15 instruments were used: 3 pairs of Trimble 4000SSI receivers and (Micro NVI) TRM33429.20 antennas, 2 pairs of Trimble 4000SSI receivers and (Zephyr Geodetic) TRM41249.00 antennas, 2 pairs of Trimble 4400 receivers and (Compact L1/L2) TRM22020.00 antennas and 8 pairs of Trimble 5700 receivers and (Zephyr Geodetic) TRM41249.00 antennas. Four continuous GPS-stations were running nearby, The stations SAUD, BRUJ and KARV run by the Icelandic Meteorological Office, all close to the Hálslón area and one at Heiðarsel (HEID) near Egilstaðir which will be used as a reference station for deformation in the Kárahnjúkar area. Every benchmark was measured at least for 38 hours.

The processing of the data was done using Bernese 5.0. The analysis was based on double-difference processing where phase ambiguity fixing is attempted for baselines up to 2000 km length, based on quasi-ionosphere-free (QIF) resolution strategy. The final network solution is a minimum constraint solution, realised by no-net-translation conditions imposed on a set of ITRF2005 reference coordinates [6, Ch. 10.2.1 and 20.4.2]. The IGS stations used for reference are REYK, HOFN, ALGO, ALRT, ONSA, TROM, MADR and WES2. The uncertainty estimate from the processing for the calculated velocities have not been confined yet but the uncertainty arising from the setup of the instruments are used for preliminary values. By assuming setup uncertainty of ~ 1.6 mm the uncertainty of the vector between the two ephocs is ~ 2.5 mm. The uncertainty arising from the processing, then needs to be added. The uncertainty presented in Figures 3, 4, 5, 6, 7 and 8 are the 95 % confidence limit.

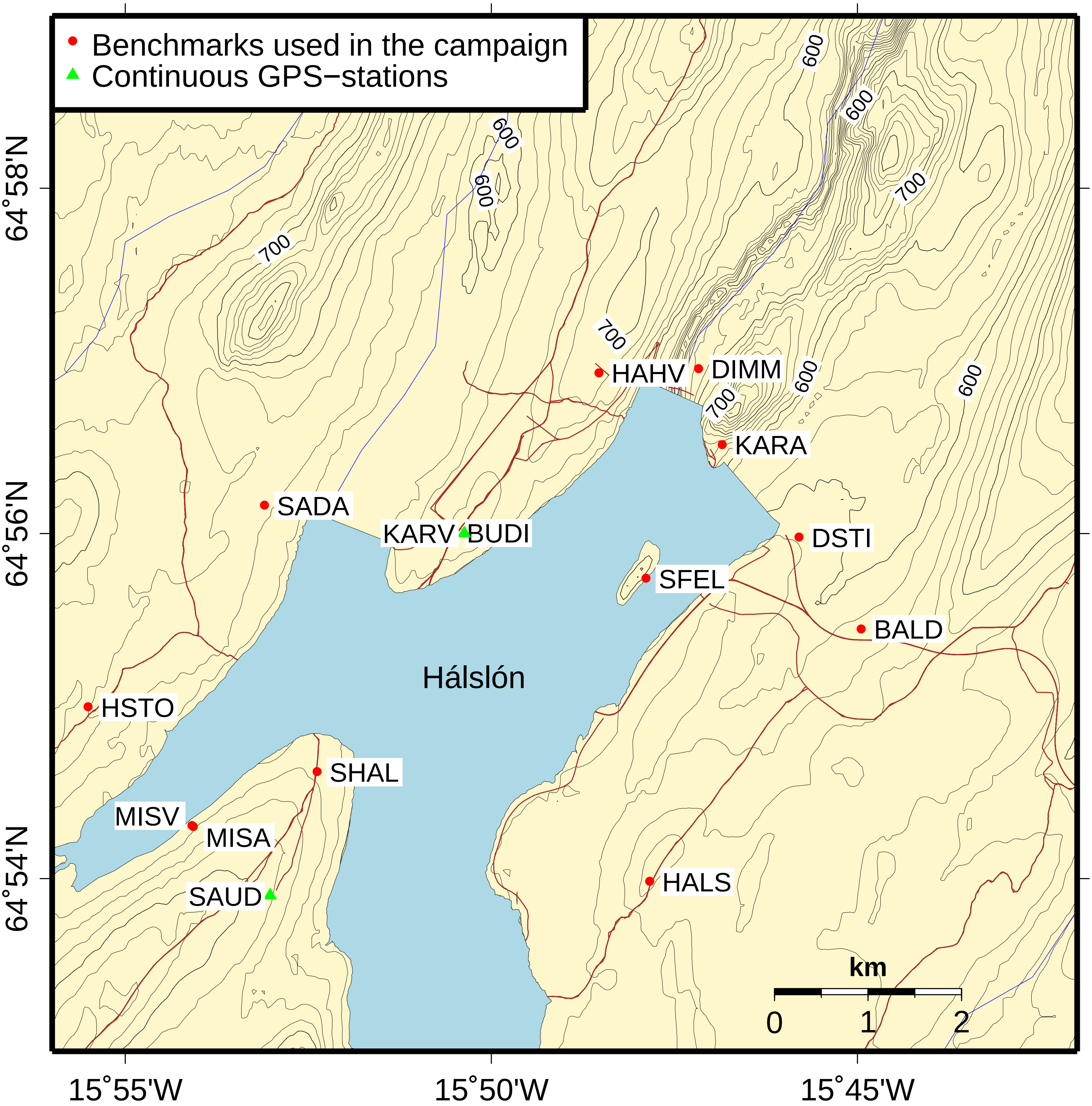

Figure 1: Benchmarks close to the dam area in the Kárahnjúkar 2006 GPS campaign. The figure shows Hálslón when filled to elevation of 625 m above sea level.

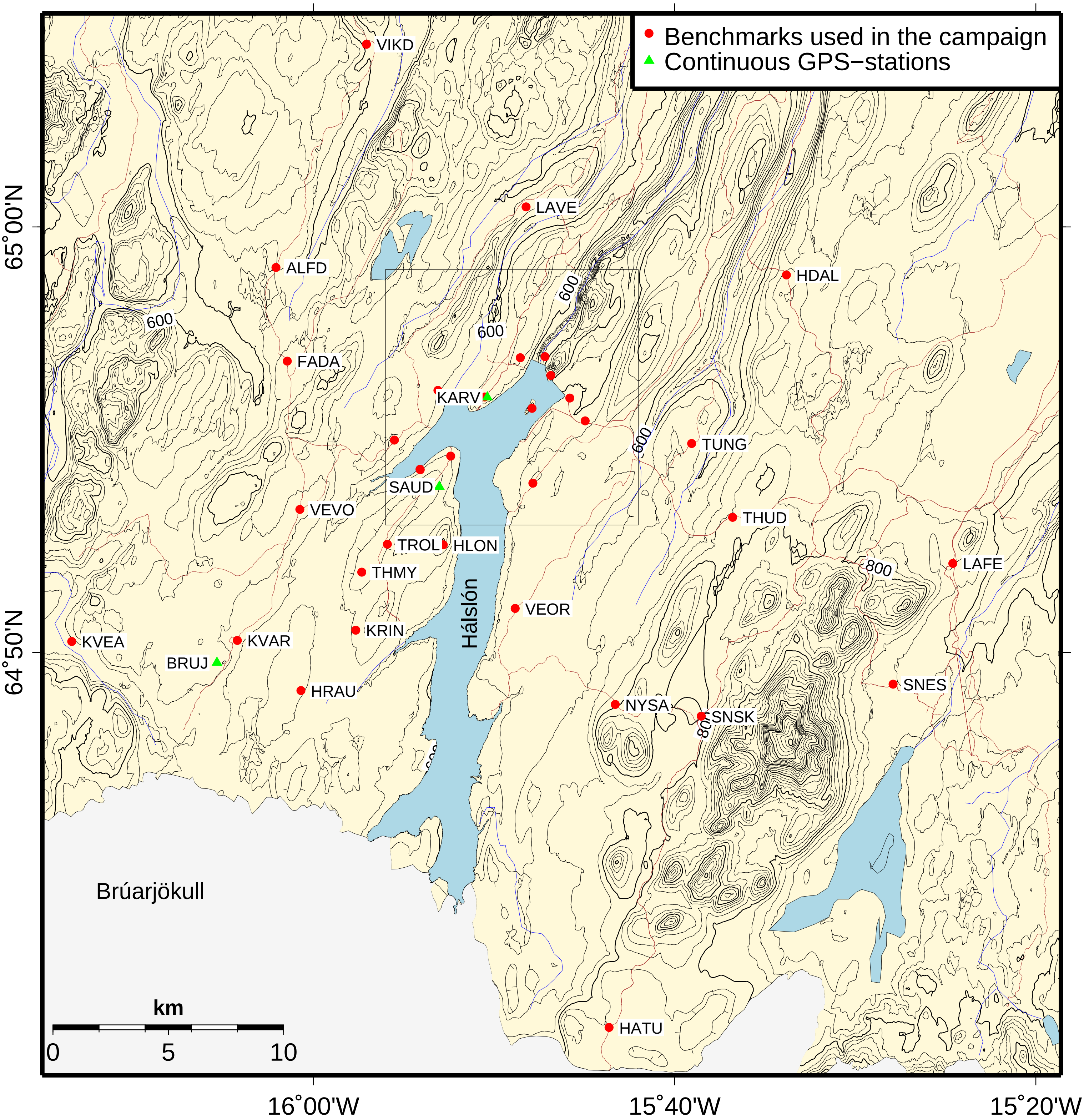

Figure 2: Benchmarks measured in the Kárahnjúkar 2006 GPS campaign. One additional benchmark, GRUN (see Table 1), was measured in the campaign but is not included on the map. It is located to the north of the map. The figure also shows the location of Hálslón when filled to elevation of 625 m above sea level. The box shows coverage of Figure 1

Table 1: Measured benchmarks in 2006.

Point	Long	Lat	Ant	ser	Height [m][1]
ALFD	16:02:03.5W	64:59:02.9N	TRM41249.00	612102	1.1523
BALD	15:44:57.0W	64:55:27.0N	TRM41249.00	020724	0.9407
BUDI	15:50:30.7W	64:56:00.5N	TRM33429.20	221333	1.1439
DIMM	15:47:10.3W	64:56:57.5N	TRM33429.20	171774	0.8664
DSTI	15:45:48.0W	64:55:59.0N	TRM33429.20	171774	0.8904
FADA	16:01:26.5W	64:56:51.1N	TRM41249.00	605840	1.0137
GRUN	15:32:21.0W	65:13:41.0N	TRM41249.00	634708	0.8679
HAHV	15:48:32.0W	64:56:56.0N	TRM41249.00	605840	0.8873
HALS	15:47:50.4W	64:53:59.2N	TRM41249.00	606552	1.0778
HATU	15:43:37.0W	64:41:08.0N	TRM33429.20	221333	0.7957
HDAL	15:33:48.3W	64:58:52.3N	TRM41249.00	101179	1.0424
HEID	14:32:27.4W	65:22:51.0N	TRM41249.00	108689	1.0010
HLON	15:52:48.2W	64:52:31.9N	TRM41249.00	606552	1.0060
HRAU	16:00:41.1W	64:49:06.0N	TRM22020.00	078192	1.0142
HSTO	15:55:30.5W	64:54:59.9N	TRM33429.20	168784	1.0609
KARA	15:46:50.9W	64:56:31.1N	TRM41249.00	534134	1.1135
KRIN	15:57:38.5W	64:50:31.3N	TRM22020.00	076635	1.3589
KVAR	16:04:12.2W	64:50:17.0N	TRM41249.00	612102	0.9333
KVEA	16:13:22.0W	64:50:15.4N	TRM41249.00	606552	1.2754
LAFE	15:24:35.3W	64:52:05.7N	TRM41249.00	482230	0.0680
LAVE	15:48:13.0W	65:00:28.0N	TRM22020.00	078192	1.0800
MISA	15:54:04.4W	64:54:18.2N	TRM22020.00	076635	1.1768
MISV	15:54:05.5W	64:54:18.6N	TRM22020.00	078192	1.2612
NYSA	15:43:16.8W	64:48:46.4N	TRM41249.00	101179	0.9093
SADA	15:53:06.0W	64:56:10.0N	TRM41249.00	612102	1.0809
SFEL	15:47:53.3W	64:55:44.6N	TRM41249.00	612102	1.0117
SHAL	15:52:23.0W	64:54:37.4N	TRM41249.00	605840	1.0350
SNES	15:27:54.1W	64:49:15.1N	TRM41249.00	634708	0.9143
SNSK	15:38:31.4W	64:48:29.6N	TRM33429.20	168784	0.8876
THMY	15:57:19.2W	64:51:53.4N	TRM41249.00	534134	1.1580
THUD	15:36:46.9W	64:53:10.9N	TRM41249.00	020724	0.8065
TROL	15:55:53.8W	64:52:32.9N	TRM22020.00	076635	1.0446
TUNG	15:39:02.8W	64:54:55.0N	TRM33429.20	171774	0.8815
VEOR	15:48:49.2W	64:51:02.3N	TRM41249.00	534134	1.1701
VEVO	16:00:44.1W	64:53:22.0N	TRM41249.00	605840	1.0316
VIKD	15:57:03.1W	65:04:16.3N	TRM41249.00	606552	0.9377

[1]Height from benchmark to antenna reference point (ARP).

Table 2: Measurement times of individual benchmarks in the Kárahnjúkar 2006 GPS campaign.

point	Aug, 8.	Aug, 9	Aug, 10	Aug, 11	Aug, 12	Aug, 13	Aug, 14	Aug, 15	Aug, 16
ALFD						—	—	—	
BALD			—	—	—				
BUDI				—	—	—			
DIMM					—	—	—		
DSTI			—	—	—				
FADA							—	—	—
GRUN				—	—	—			
HAHV	—	—	—						
HALS			—	—	—				
HATU		—	—	—					
HDAL				—	—	—			
HEID	—	—	—	—	—	—	—	—	—
HLON	—	—	—						
HRAU		—	—	—					
HSTO				—	—	—			
KARA				—	—	—			
KRIN		—	—	—					
KVAR					—	—	—		
KVEA					—	—	—		
LAFE	—	—	—	—	—				
LAVE						—	—	—	
MISA				—	—	—			
MISV				—	—	—			
NYSA		—	—	—					
SADA	—	—	—						
SFEL			—	—	—				
SHAL			—	—	—				
SNES		—	—	—					
SNSK		—	—	—					
THMY		—	—	—					
THUD	—	—	—						
TROL						—	—	—	
TUNG	—	—	—						
VEOR						—	—	—	
VEVO					—	—	—		
VIKD							—	—	—

5 Results

In order to evaluate eventual crustal deformation caused by the Hálslón reservoir it is first necessary to evaluate present ongoing crustal deformation in the area. The horizontal displacement field observed between 1993 and 2004 derived from the ISNET campaigns gives full spreading rate of 20-24 mm/yr across the plate boundary in Iceland [7]. Hálslón is located 40-50 km away from the central axis of the plate boundary in North Iceland which runs through the Askja caldera. The closeness of Hálslón to the spreading axis may lead to eventual deformation in the area due to the gradual increase in velocities over the plate boundary deformation zone.

Furthermore due to the location of Hálsón next to Vatnajökull ice cap in the central part of Iceland, uplift of the area is expected. Uplift relative to REYK (in Reykjavík) is observed near edges of Vatnajökull [8, 9]. The highest uplift rate is measured at Jökulheimar (JOKU) with average velocity of 28.4 mm/yr [10]. The continuous GPS stations SKRO, HOFN and ISAK also show present uplift of the area around the ice cap [2].

The inferred horizontal velocities of stations in the Hálslón GPS network from August 2005 to August 2006 are shown in Figures 3 to 5. The main process contributing to the displacement vectors shown in Figure 3 are the plate velocities relative to the ITRF2005 reference frame. When the plate movement has been subtracted from the velocitie vector, therfore fixing the Eurasian plate as in Figure 5, a small displacement is observed mostly within uncertainty limits. A general westward displacement is, however, observed especially in the western part of the area. This may suggest that full spreading rate has not been reached at this distance from the spreading axis. The westward displacement is however within the uncertainty of the measurements and therefore further measurements are needed to constrain it.

The vertical component (Figure 7) shows uplift of the area in the order of 10-30 mm/y which is consistent with the findings in [2, 12]. The vertical component though is uncertain due to high variability in the coordinate estimation. Longer time series are needed to constrain the uplift rate.

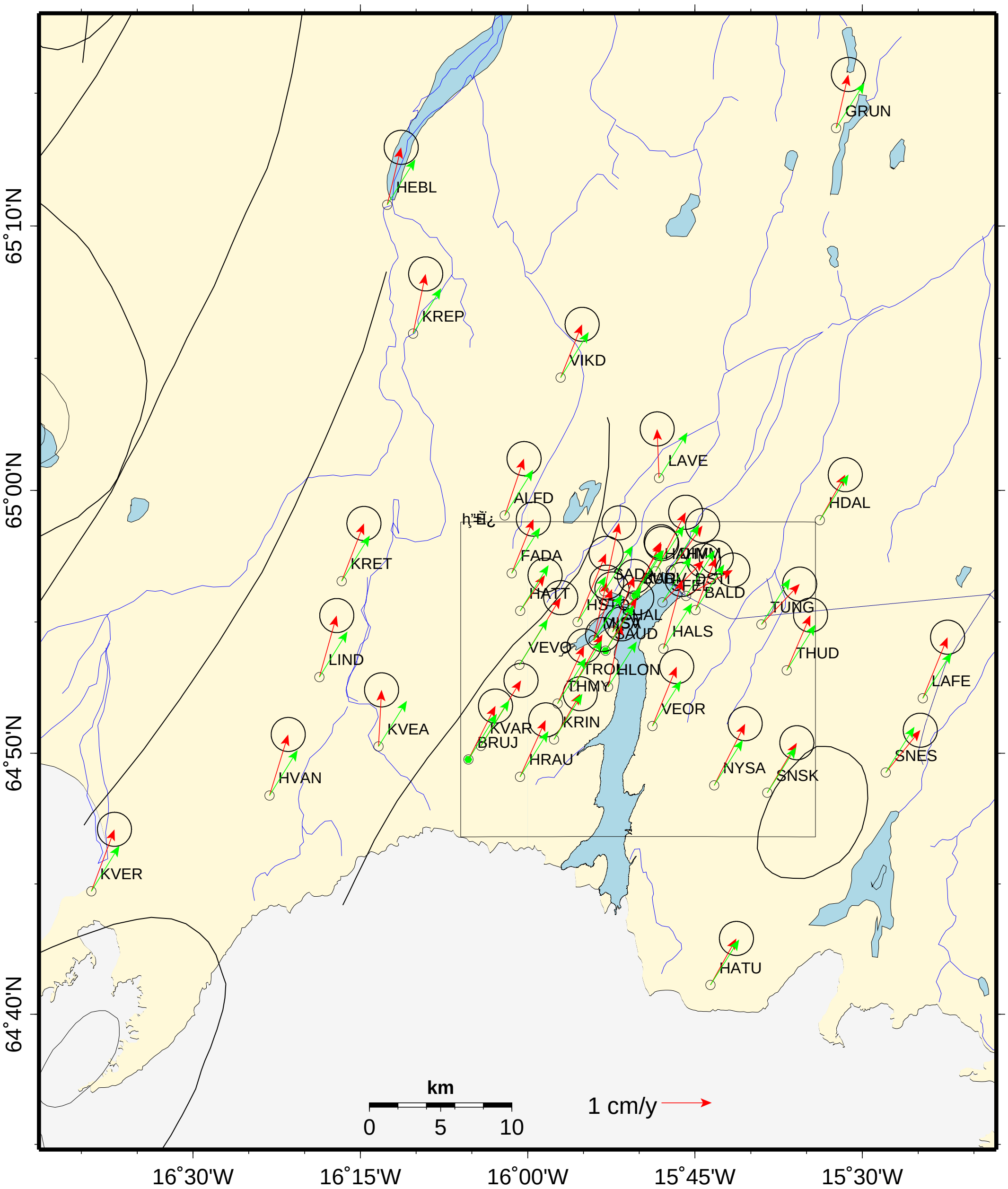

Figure 3: Horizontal velocities 2005-2206 relative to ITRF2005 reference frame. The red arrows are derived from the 2005 and 2006 GPS-campaigns. The green arrows are derived from the Nuvel-1A model [11]. The area inside the box is zoomed up in Figure 4.

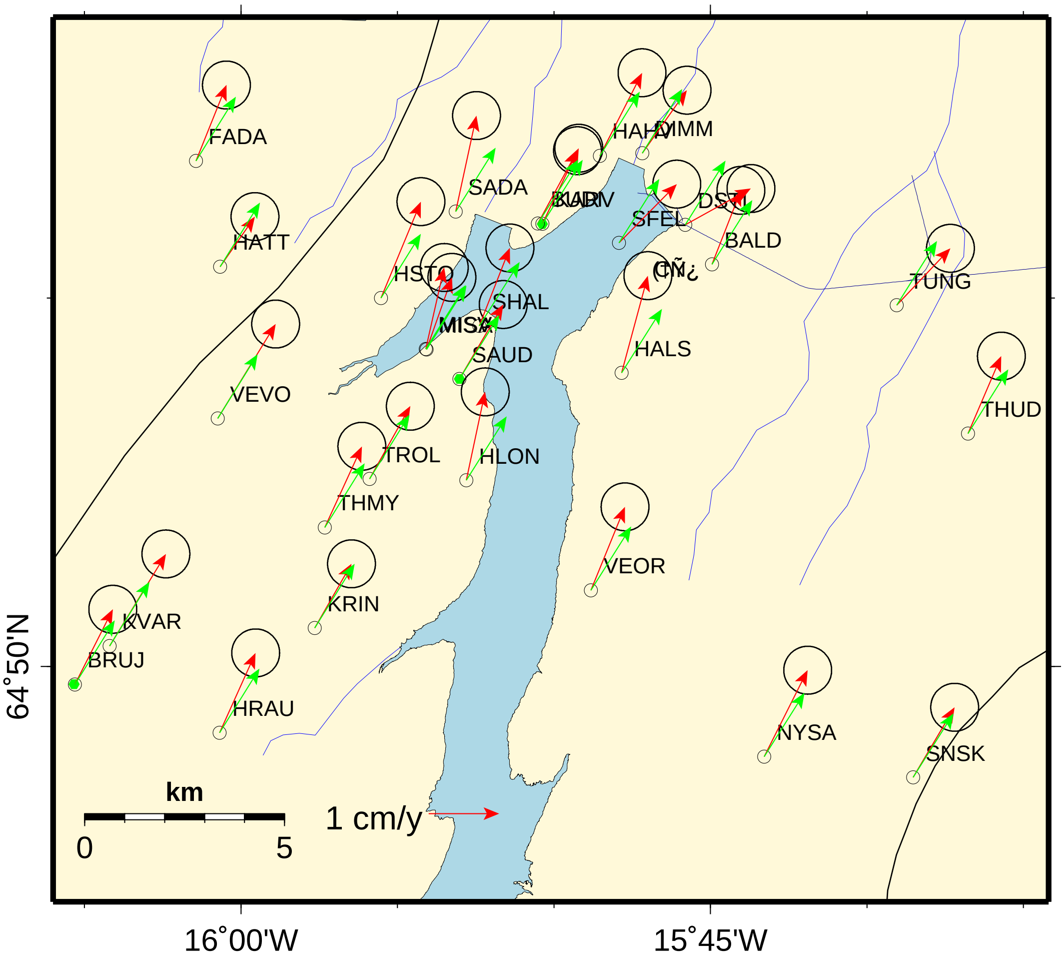

Figure 4: Benchmarks close to dam area. Horizontal velocities 2005-2006 relative to ITRF2005 reference frame. The red arrows are derived from the 2005 and 2006 GPS-campaigns. The green arrows are derived from the Nuvel-1A model [11].

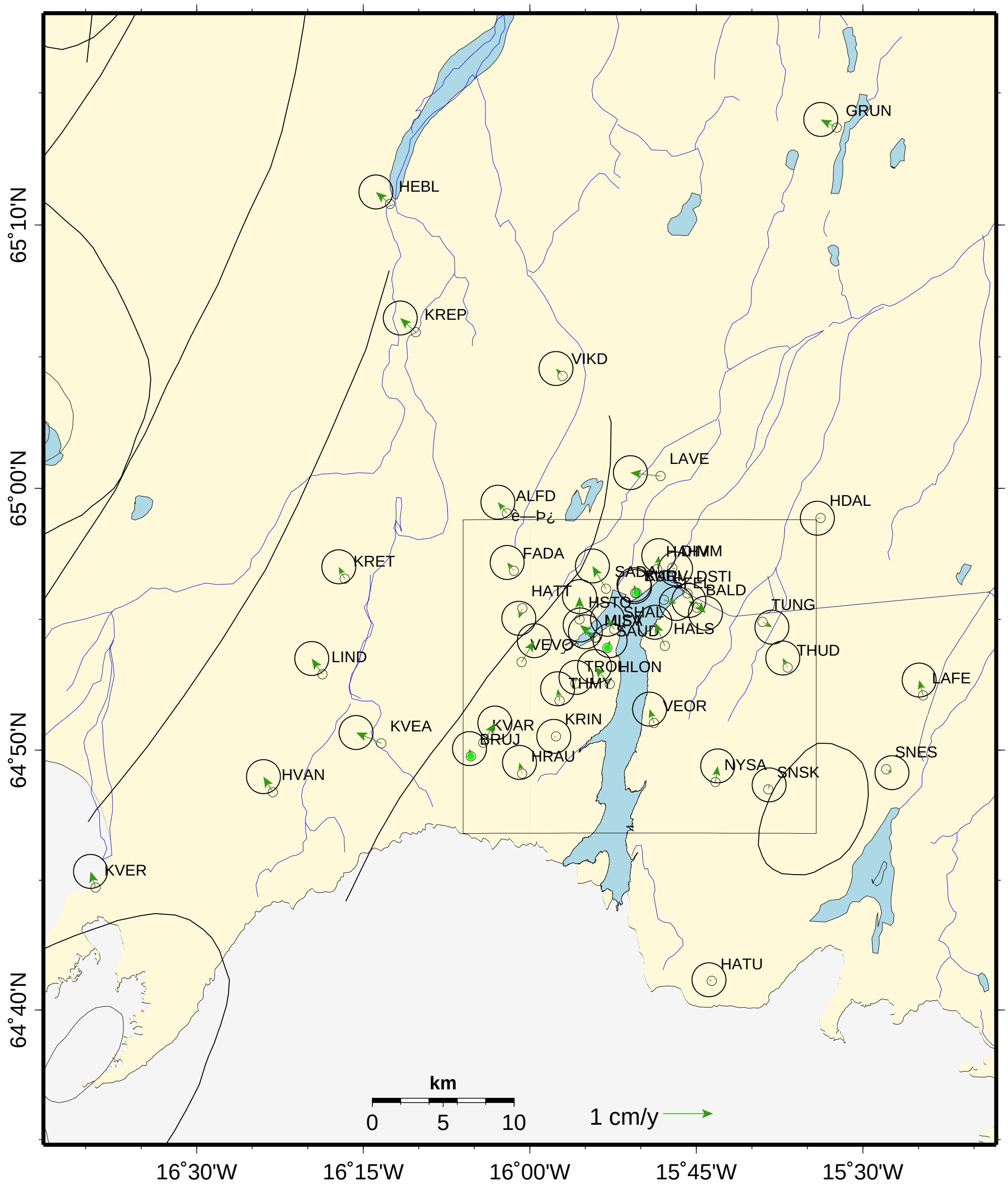

Figure 5: Horizontal velocities 2005-2006 after the Nuvel-1A velocities have been subtracted. see Figure 3. The network is stationary relative to the Eurasian within uncertainty limits but a general westward displacement can bee observed in the western part of the network. The area inside the box is zoomed up in Figure 6.

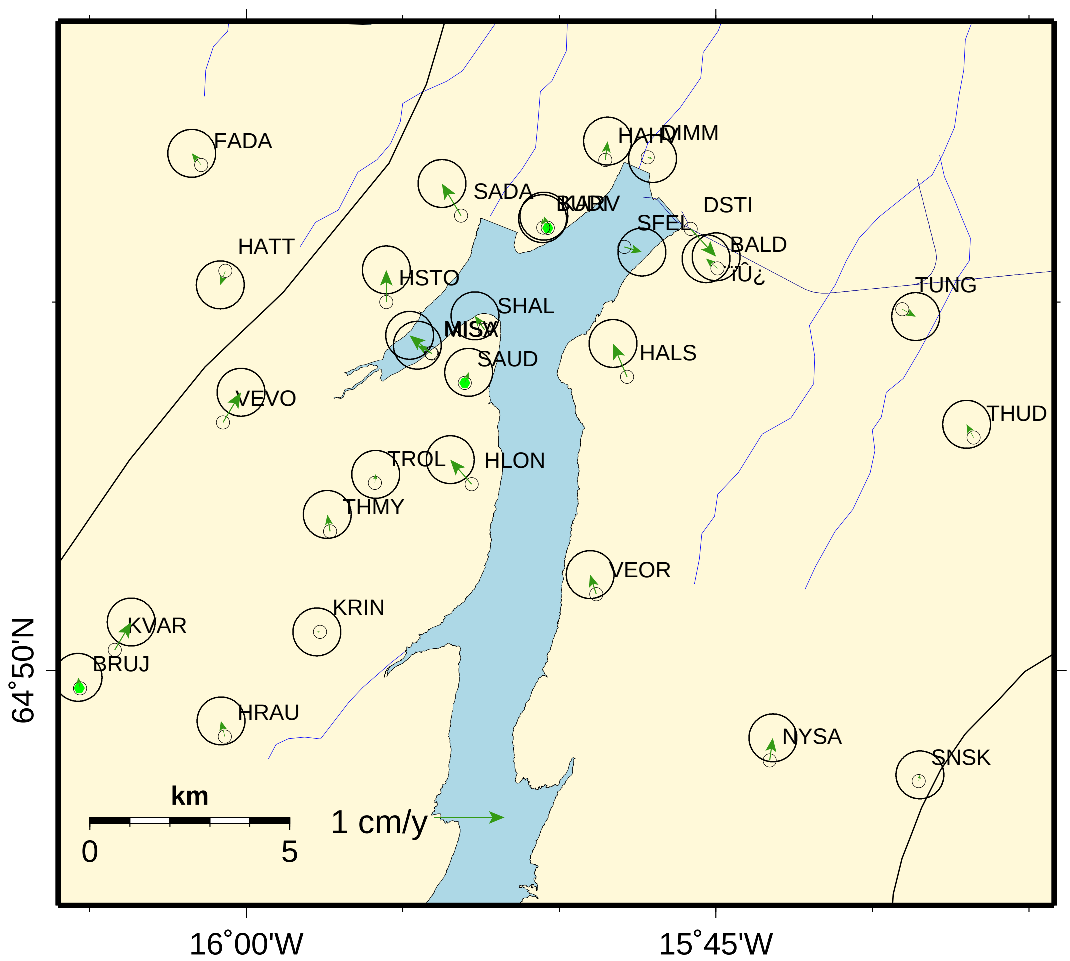

Figure 6: Benchmarks close to dam area. Horizontal velocities 2005-2006 after the Nuvel-1A velocities have been subtracted. see Figure 3. The network is stationary relative to the Eurasian within uncertainty limits but a general westward displacement can bee observed in the western part of the network.

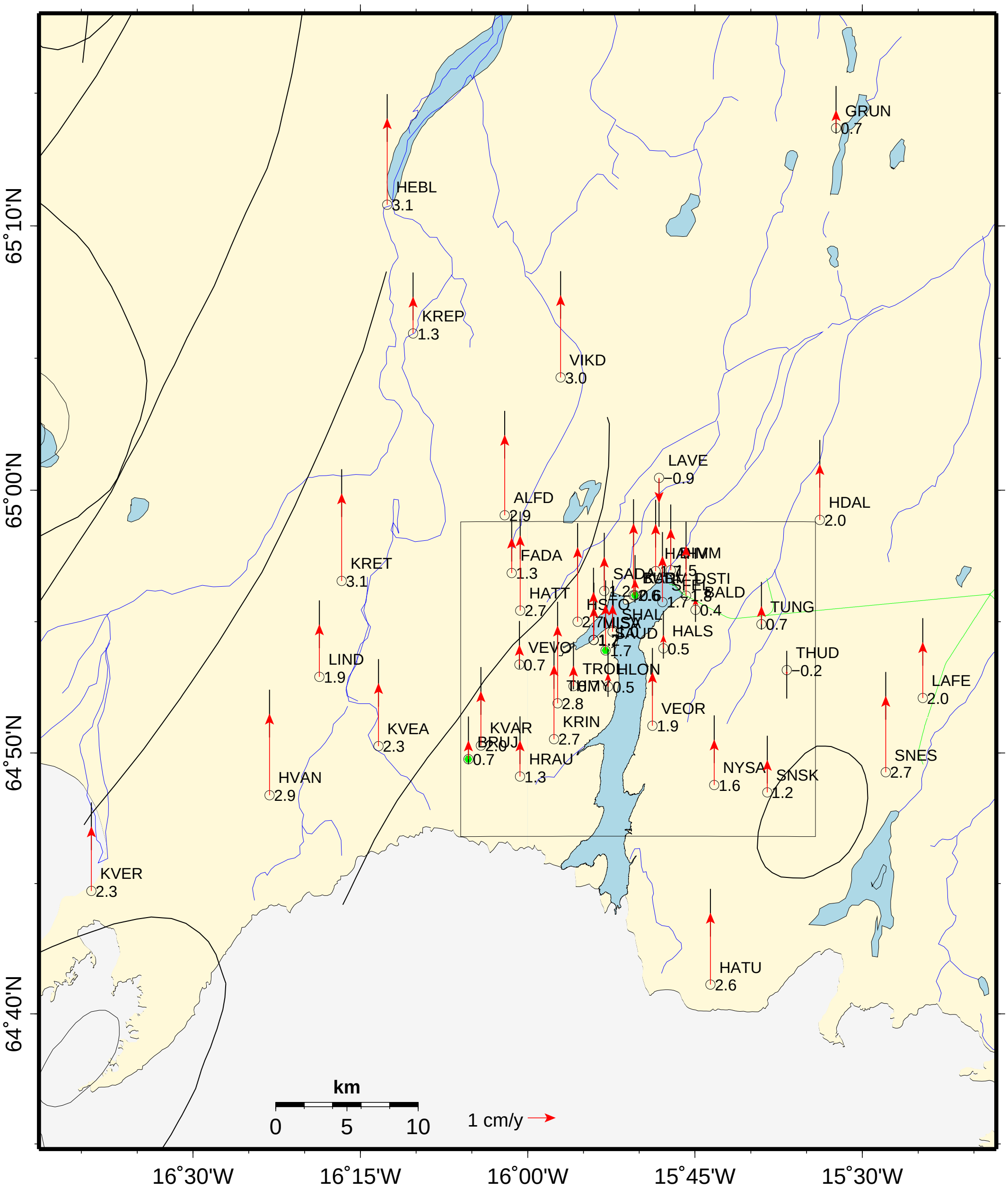

Figure 7: Vertical velocities 2005-2006 relative to ITRF2005 reference frame. The numbers at each benchmark are in units of cm/y. A general uplift of 20-30 mm/y is observed. The area inside the box is zoomed up in Figure 8.

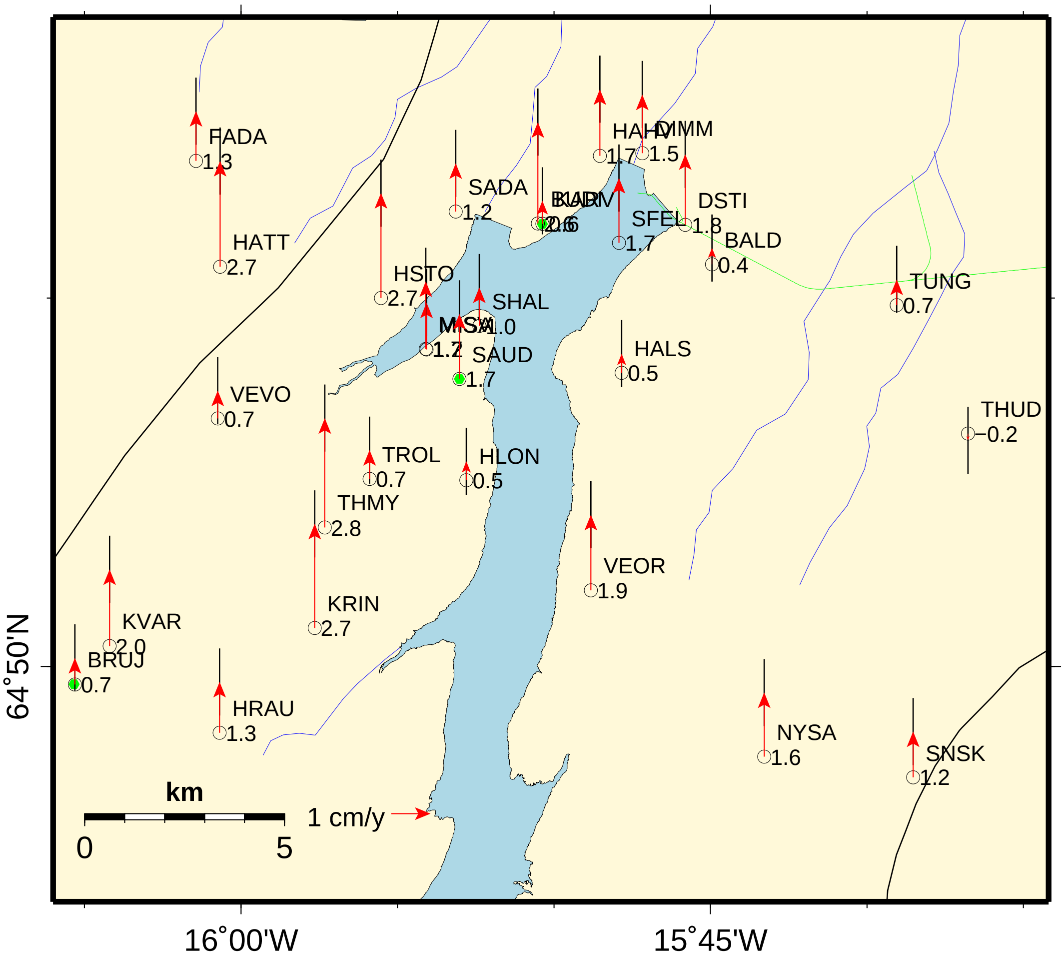

Figure 8: Benchmarks close to dam area. Vertical velocities 2005-2006 relative to ITRF2005 reference frame. The numbers at each benchmark are in units of cm/y. A general uplift of 20-30 mm/y is observed.

Table 3: Estimated velocities of GPS-stations derived from the August 2005 and August 2006 campaigns. The velocities are relative to ITRF2005 reference frame. The data obtained at KARA benchmark was inadequate and is therefore excluded.

Point	Long	Lat	East [mm/y]	North [mm/y]	Up [mm/y]
ALFD	-16.034188	64.984149	6.9	20.4	28.9
BALD	-15.749234	64.924263	7.4	18.9	4.2
BUDI	-15.841859	64.933482	10.1	18.6	25.9
DIMM	-15.786258	64.949339	11.4	16.1	15.0
DSTI	-15.763460	64.933168	16.8	9.3	18.0
FADA	-16.024008	64.947595	7.8	19.4	12.7
GRUN	-15.539170	65.228133	4.4	19.2	6.5
HAHV	-15.808957	64.948773	10.8	21.2	17.0
HALS	-15.797303	64.899787	6.7	24.8	4.9
HATU	-15.726922	64.685431	9.3	16.7	25.8
HDAL	-15.563452	64.981194	9.1	16.3	20.1
HEID	-14.540947	65.380845	6.2	17.5	-8.0
HLON	-15.879944	64.875461	4.8	22.6	4.9
HRAU	-16.011335	64.818318	9.2	20.4	13.0
HSTO	-15.925429	64.916686	10.2	24.6	26.8
KARV	-15.839507	64.933424	9.3	19.3	5.9
KRIN	-15.960746	64.842042	9.4	16.4	26.6
KVAR	-16.069980	64.837986	14.4	23.5	19.6
KVEA	-16.222903	64.837597	1.1	20.3	22.7
LAFE	-15.409803	64.868260	8.9	21.9	20.1
LAVE	-15.803647	65.007849	-0.7	17.6	-9.0
MISA	-15.901223	64.905056	6.5	18.4	12.0
MISV	-15.901565	64.905170	4.7	20.8	17.3
NYSA	-15.721364	64.812883	11.1	22.1	16.4
SADA	-15.885622	64.936198	5.3	24.5	12.3
SFEL	-15.798788	64.929113	14.8	15.0	16.6
SHAL	-15.873043	64.910375	7.8	19.9	9.8
SNES	-15.465185	64.820974	12.4	15.2	27.4
SNSK	-15.642082	64.808212	10.6	17.9	11.7
THMY	-15.955429	64.864835	9.5	20.7	27.9
THUD	-15.612837	64.886023	8.5	19.8	-1.7
TROL	-15.931515	64.875762	10.4	18.6	7.4
TUNG	-15.650794	64.915076	13.7	14.5	6.6
VEOR	-15.813634	64.850601	8.7	21.3	19.3
VEVO	-16.012372	64.889467	14.8	24.1	7.1
VIKD	-15.950772	65.071227	7.7	19.1	29.6

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