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Monitoring the Continous Surface Motion of Glaciers by Low-Cost-GNSS Receivers

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Abstract

The motion of a glacier is usually monitored by episodic geodetic observations that are carried out during the summer. Realization of observations during winter is much more difficult due to harsh weather conditions and the remote location of glaciers in general. Based on such observations the glacier surface velocity is estimated as the mean displacement rate between the positions of the different observation epochs. The position estimation with Global Navigation Satellite Systems (GNSS) like GPS or GLONASS is today widely used in smart phones and many other devices. To keep the costs of these sensors at a minimum they usually provide only code observations. However, some of these cheap receivers deliver also phase data, which are the key for precise geodetic positioning and have been used in our experiment. Analyzing phase data of a Low-Cost GNSS sensor in combination with a nearby geodetic reference station allows the estimation of relative positions with an accuracy of a few centimetres.

Instrumentation

For the experiment we used *Denga10* USB-GNSS-Receivers (http://www.onetalent-gnss.com) that were connected to Raspberry Pi single-board mini-computers running on Linux. The Denga10 GNSS (Fig. 2) receiver is a single-frequency receiver (L1) and has the capability to track code and phase observations of GPS and GLONASS satellites. The devices consume less than 2 Watt and are powered by batteries (7 Ah). The battery is recharged by solar cells. Continuous operation is not intended due to the limited power supply. A python script synchronizes the computer with GPS time and initiates data logging and storage of the raw data on a SD-Card. The costs for an USB-GNSS receiver, Raspberry Pi and a quality single frequency antenna are about 300 €.

Fig. 1: Box with the mini-computer, Denga10, Raspberry Pi, Battery, Solar Charger, timer

Fig. 2: Denga10 GNSS receiver with GNSS-Chip from NVS

Analysis of GNSS data

The analysis of the GNSS data (GPS and GLONASS) requests a GNSS references station in a distance of up to 10-15 km as long as cm-accuracy is required. An alternative approach is based on a network of GNSS dual-frequency reference stations with spatial distance of up to 50 km. Corrections for the impact of the ionosphere and orbits errors can be estimated based on this network. Artificial observations of a *Virtual Reference Station* (VRS) located in the vicinity of the GNSS station with adapted ionosphere and orbit errors can then be generated (Wanninger, 2003). This concept of a VRS has been tested successfully with the Low-Cost-System. Table 1 shows the standard deviations derived from repeated baseline analysis (DD) and the concept of a VRS for different networks seen in Fig. 3 for the site STAF equipped with a DENGA10.

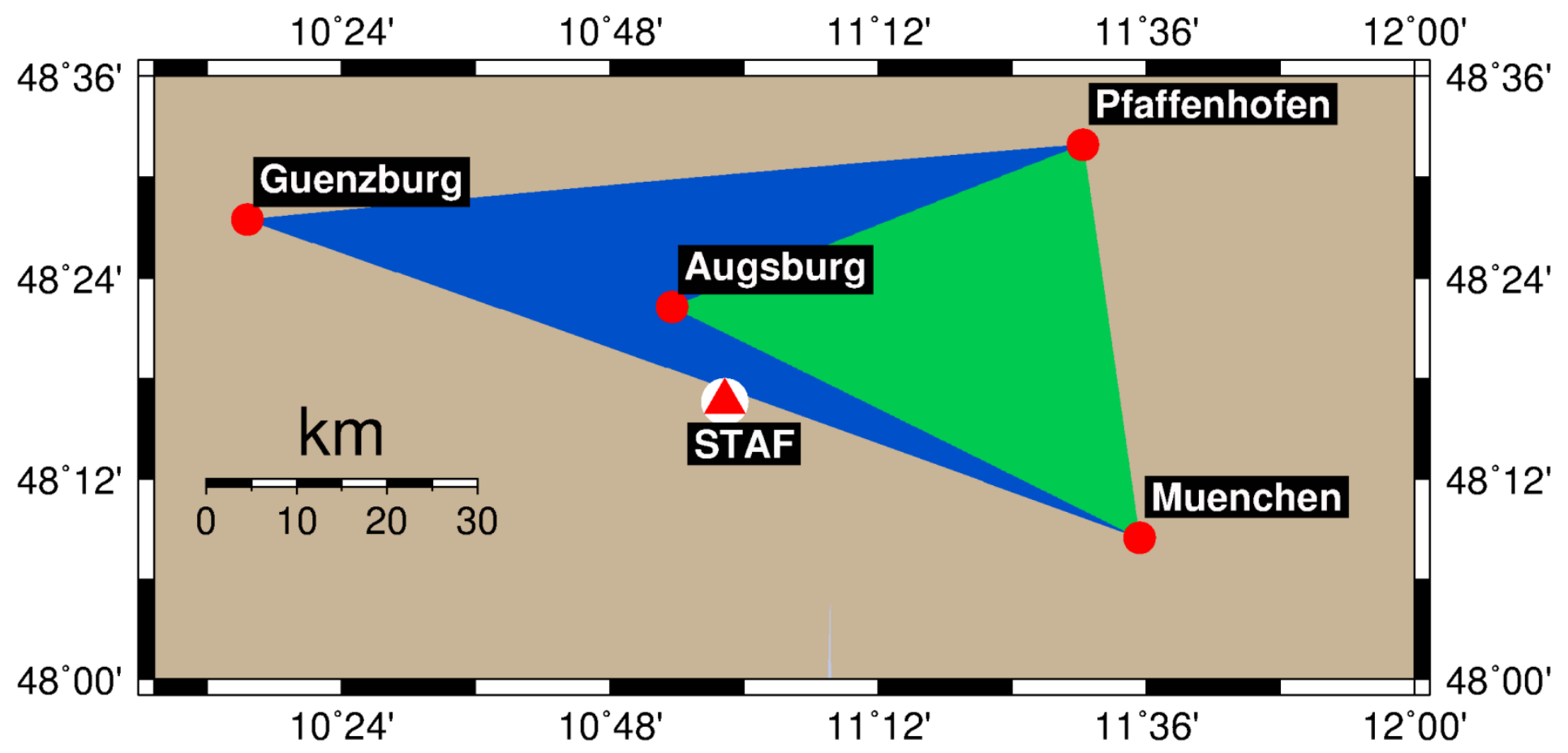

Fig. 3: Network of GNSS-Stations

Tab.1: Standard Deviation of coordinate components of the site **STAF** for different analysis strategies

Mode	REF	S_{East}	S_{North} [mm]	S_h
DD	AUG (b=15km)	4.5	5.1	11.6
DD	MUC (b=45km)	10.5	5.9	23.8
VRS	AUG-MUC-PFA	2.8	2.9	4.3
VRS	GUZ-MUC-PFA	3.1	3.8	9.8

Vernagtferner (Austria)

In the summer 2013 we started an experiment with two sensor systems on the glacier Vernagtferner in Austria. Each system was operating for two hours per day at noon to take advantage of the maximum solar radiation (solar cells). Observation times of two hours are also beneficial for the estimation of the height component due to the difference in the tropospheric delay between reference station and sensor. The coordinates for each day were estimated with accuracies better than one centimetre, while the coordinate time series are very consistent. One sensor was placed on a stake, which was drilled into the ice (Fig. 4 (left and right)). The second system was attached to a framework (Pyramid), which is placed on the surface of the glacier (Fig.4(center and right)).

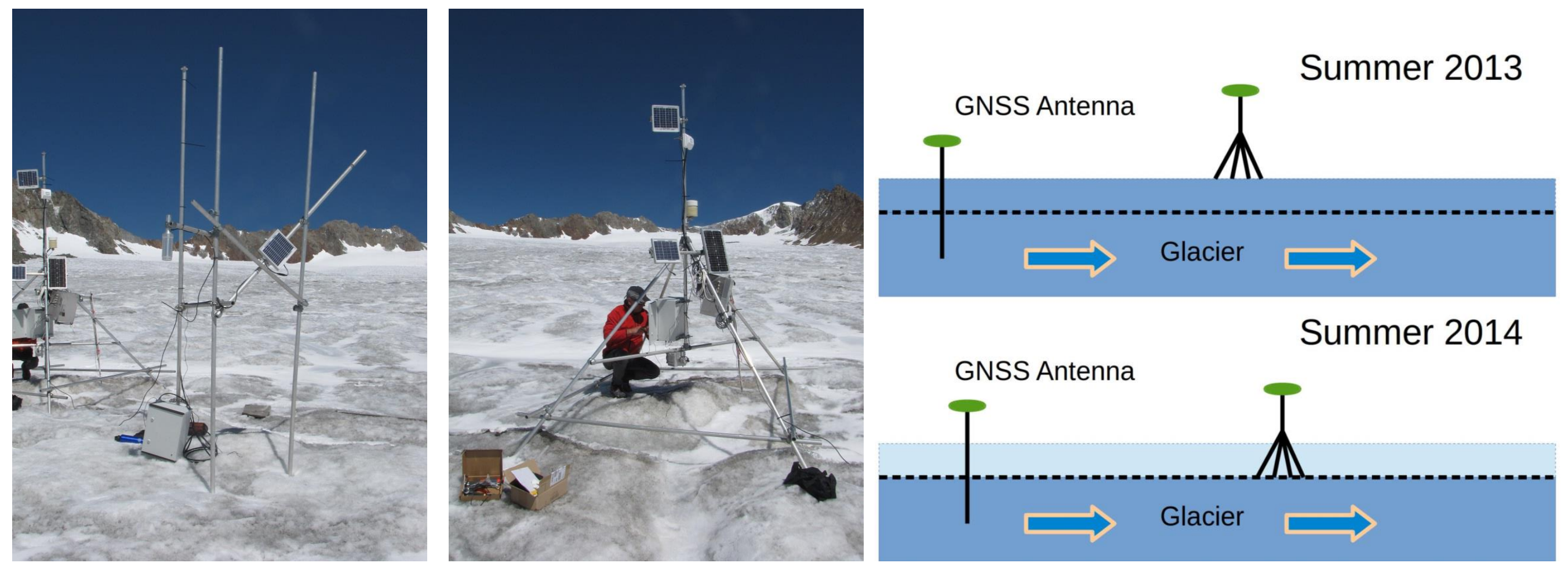

Fig. 4: (left) combination of stakes drilled into the ice; (center) image of the pyramid placed on top of the glacier; (right) sketch of the two set-ups on the glacier.

Set-Up 1 (Pyramid)

The construction is located on the surface of the glacier and therefore reflects the changes of it. Just after the installation we can still observe significant height changes of almost 35 cm (Fig.5). In Mid-October the melting of the surface stops and until the end of June no more significant height changes can be observed. The melting process starts again begin of July, probably after the reduction of the snow layer. From then on to the end of the recording we observe a further reduction of the surface of more than 2 m. Horizontal motion are much smaller and are also mixed with tilt signals of the "Pyramid".

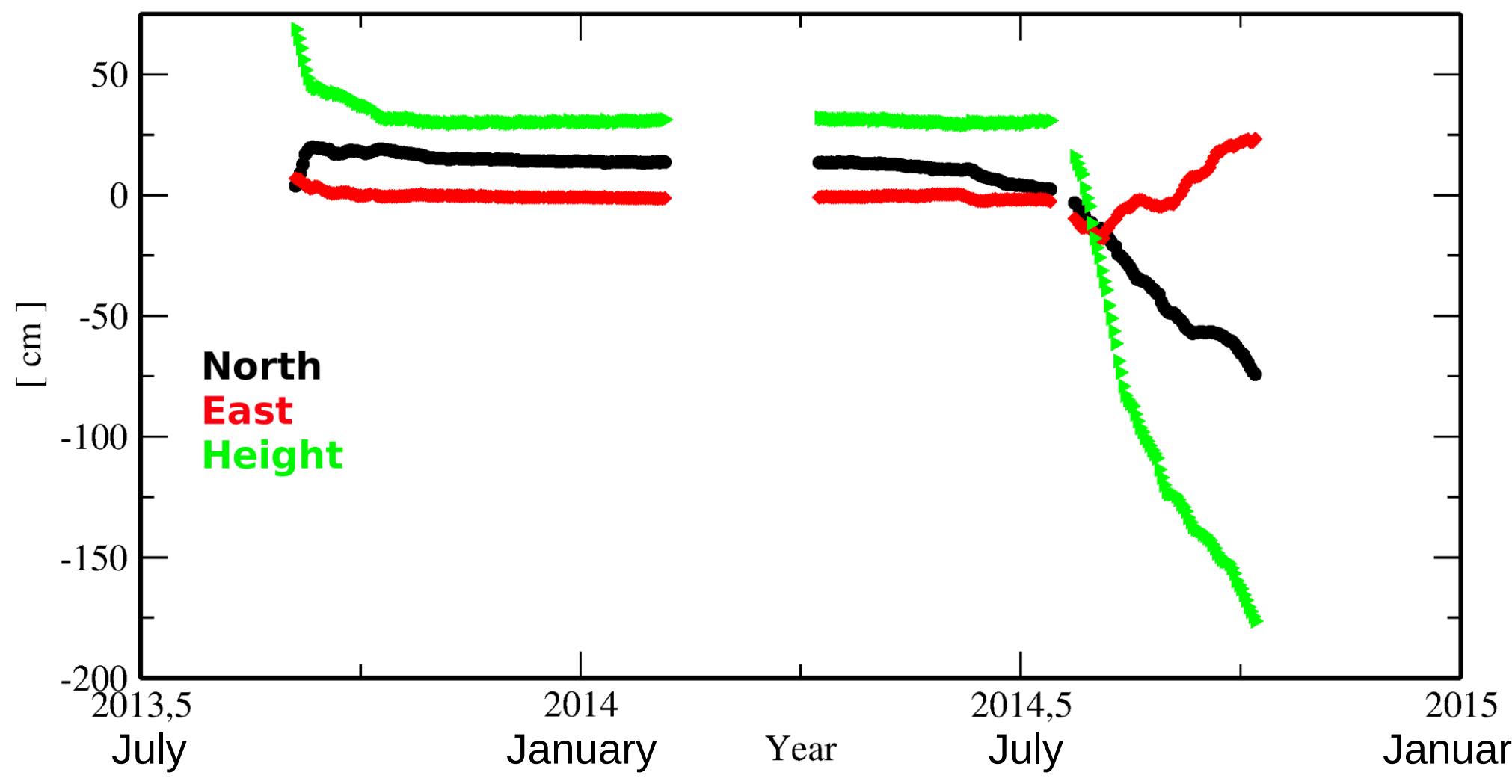

Fig. 5: Movements for the three coordinate components of the "Pyramid". Strongest signal is seen in the height reflecting the surface melting of the glacier.

Set-Up 2 (Ablatometer)

The second set-up called "Ablatometer" is drilled into the ice and therefore reflects the motion of the top layer of the glacier. In Fig. 6 the position changes for the three coordinate components are shown for the entire observation period. At this location of the glacier we observe very slow horizontal motion of about 0.3 m/a, while the height remains constant. The gap shown in Fig. 5 and Fig. 6 was caused by a power failure. After the gap we see an offset in the height component that was introduced by lowering the antenna.

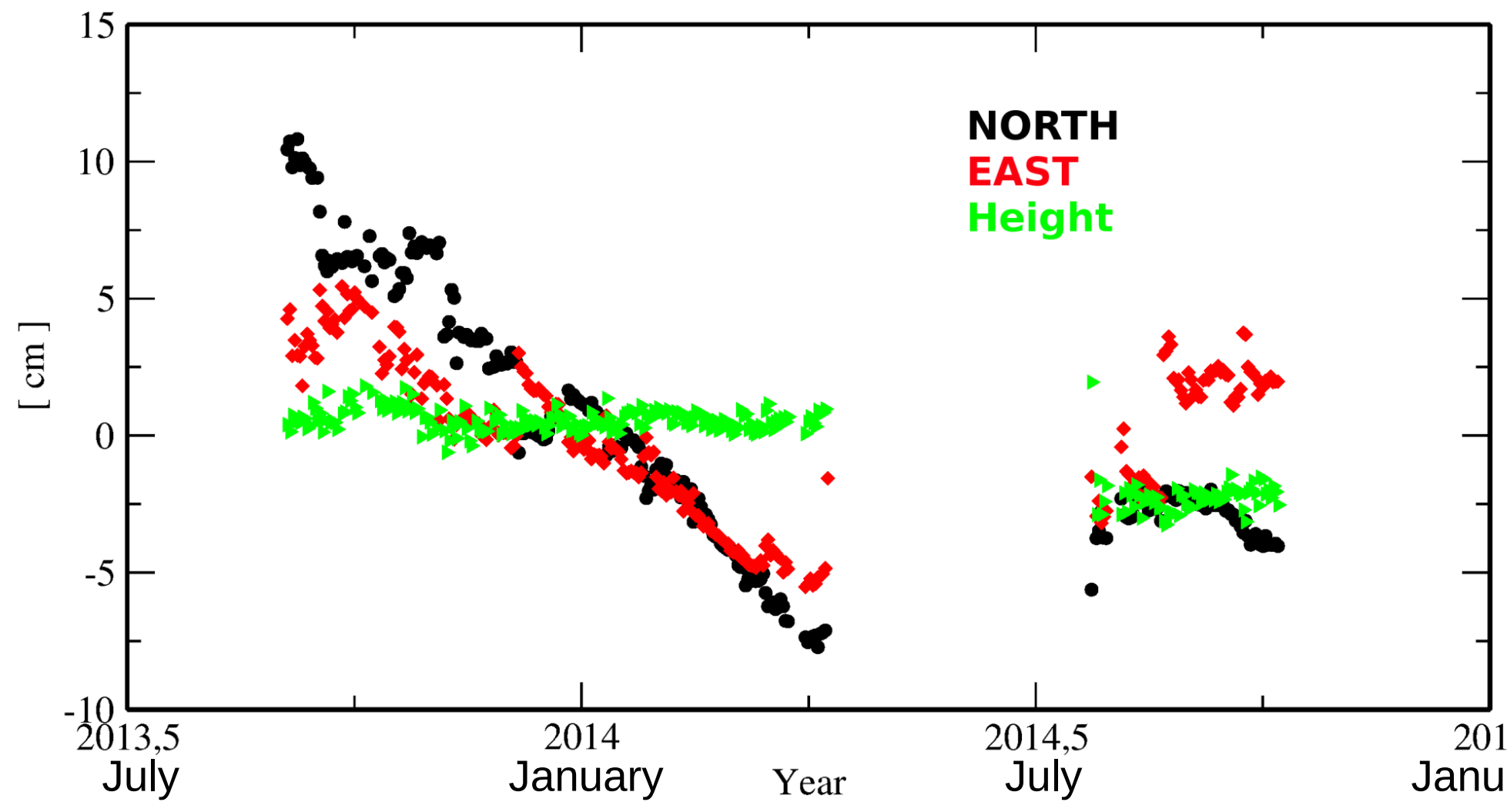

Fig. 6: Position changes for the three coordinate components for the "Ablatometer". This time the horizontal movements are larger than the vertical motion.

Myrdalsjökull (Iceland)

A similar experiment was conducted during the field campaign of the project ISVIEWS on the glacier Mýrdalsjökull in Iceland. Two sites were selected (LGNS and UGNS) and installed in the summer 2013 on the northern slope of the glacier. The location of the two sites with neighbouring GNSS reference stations of the ISGPS network are shown in Fig. 7 (Völksen, et al. 2009). Again, observation periods of two hours were chosen and stakes for the GNSS-antennas were drilled into the ice. Each stake was 3 m above the surface of the glacier. Due to the short daylight periods in the Icelandic winter we supplied each sensor with two large batteries (62 Ah). During the summer 2014 the sites had to be attended again in order to recover the data of the receivers. Unfortunately LGNS was damaged and we could only recover data for the first 33 days. We had also bad luck with the sensor UGNS, because the site was still covered by snow and was not locatable.

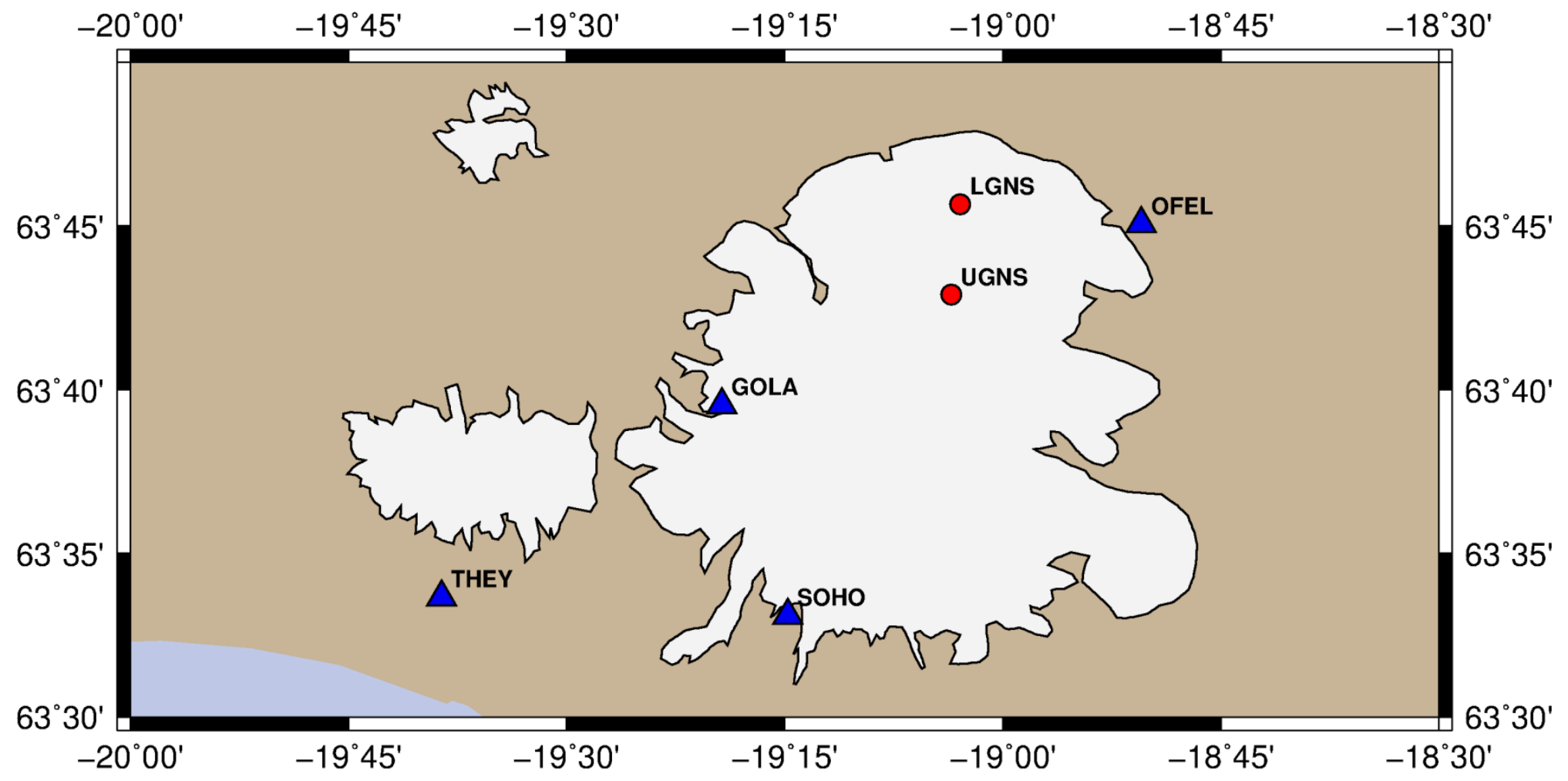

Fig. 7: Location of the two sensors LGNS and UGNS with GNSS reference station of the ISGPS network.

First results

The positions of the sensor LGNS were estimated using the VRS approach and the position changes are shown in Fig. 8. Clearly a motion in the horizontal components is visible. Again, the precision of the estimated positions is very good and gives a reliable estimate for the horizontal velocity of 21.7 m/a (azimuth: 19.4º) for these 33 days only. While revisiting the station again in the summer 2014 the position of the stake has been estimated with a second GNSS-Receiver. Comparing this position with the estimates from summer 2013 gives a horizontal velocity of 13.4 m/a (azimuth: 13.2º) for the entire year. Obviously the motion during the summer is by a factor of approx. 1.5 faster than during the entire year, while the direction of the motion is similar. The vertical motion amounts to 1.2 m/a for the 33 day period and 3.7 m/a for the entire year.

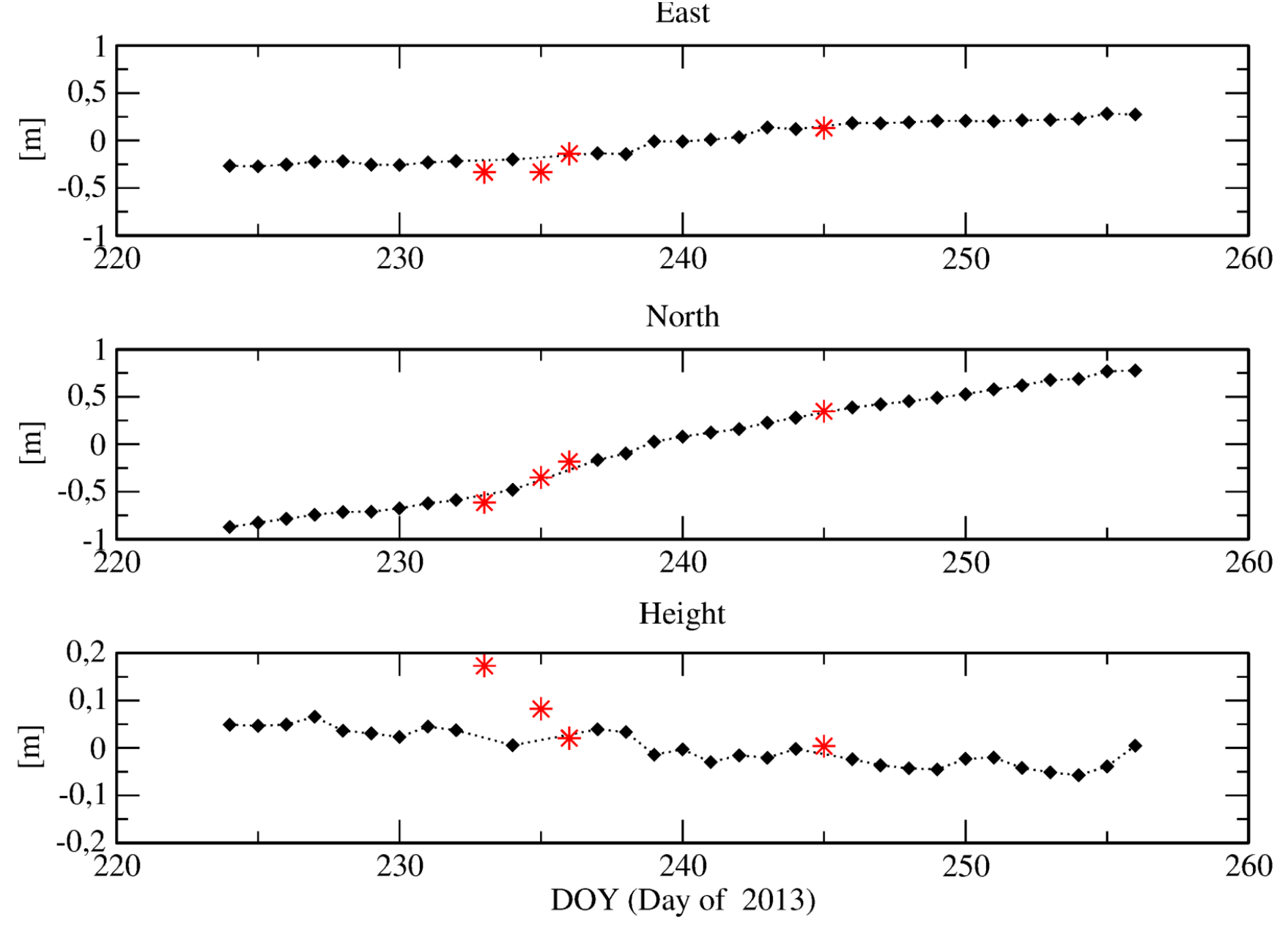

Fig. 8: Movements of the station LGNS for the first 33 days before destruction. Red stars indicate "float solution" with lower accuracy.

Conclusions

LOW-COST GNSS receivers offer the possibility to monitor deformations at the one centimetre-level. Due to the continuous observation the variations of the velocities will give a better understanding of the seasonal ice dynamics. They cannot only be used on glaciers but also for other monitoring purposes like landslides or volcanoes. This precision requires phase observation of the sensor, a GNSS-Reference station or a network of GNSS-stations in order to generate data of a VRS. Still, it is necessary to improve the reliability of the set-up and providing the data in real-time would be desirable. Not only to control the operation of the system but also to develop an early warning system.

References:

Völksen, et al. (2009): Present day geodynamics in Iceland monitored by a permanent network of continuous GPS stations. Journal of Geodynamics, Volume 48, Issue 3, p. 279-283.

Wanninger, L. (2003): GPS on the Web: Virtual reference stations (VRS). GPS Solutions, 7, p.143-144.