Low-cost GNSS for Deformation and Geohazard Monitoring in the Swiss Alps

P. Limpach[(1,2)], A. Geiger[(1)]

[(1)] Institute of Geodesy and Photogrammetry, ETH Zurich, Switzerland

[(2)] BSF-Swissphoto, Regensdorf-Watt, Switzerland

Abstract. The Institute of Geodesy and Photogrammetry (IGP) of ETH Zurich is involved in several interdisciplinary projects and activities related to the monitoring of alpine mass movements. Within these projects, our major field of activities is the monitoring of displacements and deformations with continuously operated GNSS (Global Navigation Satellite Systems) stations, and the geodetic processing of the GNSS data. The GNSS data allows the precise monitoring of rock glaciers, slope instabilities and rock deformations. GNSS stations with a special design dedicated to geomonitoring applications were developed at IGP. The stations were designed to work as self-sustaining units under harsh environmental conditions. They are equipped with single frequency GNSS receivers. Power is provided by custom-made solar modules and data is transmitted by GPRS/UMTS. This paper focuses on the application within a project that aims to quantify seasonal ground deformations of bedrock around an active glacier, and to investigate long-term trends associated with ongoing ice retreat. This project is part of an interdisciplinary cooperation led by the Engineering Geology Group of ETH Zurich. Two GNSS stations are continuously operated at the Great Aletsch Glacier (Canton of Valais, Swiss Alps) since October 2013. In addition, two similar GNSS stations have been deployed in March 2015 at a slope instability in the direct vicinity of the Great Aletsch Glacier, in collaboration with the Swiss Federal Office for the Environment.

Keywords. GNSS, GPS, geohazard monitoring, deformation monitoring

1 Introduction

The Institute of Geodesy and Photogrammetry (IGP) of ETH Zurich is active in the field of geodetic monitoring with low-cost single-frequency GNSS receivers since 2009 (Limpach and Grimm D. (2009), Mautz et al. (2010), Limpach et al. (2011), Wirz et al. (2011), Wirz et al. (2013)). The IGP is involved in several interdisciplinary projects and activities related to the monitoring of alpine mass movements. Within these projects, our major field of activities is the monitoring of displacements and deformations with continuously operated GNSS (Global Navigation Satellite Systems) stations, and the geodetic processing of the GNSS data. The GNSS data allows the precise monitoring of rock glaciers, slope instabilities and rock deformations.

2 Method

2.1 GNSS monitoring stations

At our institute, we have developed special GNSS stations for geomonitoring applications in remote alpine areas (Fig. 1). The stations are a self-sustaining all-in-one unit, developed for harsh environmental conditions. They consist of a custom-made steel pillar containing all the electronic

Fig. 1 GNSS monitoring station MOO1 at the “Moosfluh” slope instability in the vicinity of the Great Aletsch Glacier.

equipment, e.g. GNSS receiver, data transmission device, solar charge controller, battery. The GNSS and data transmission antennas are mounted on the top of the pillar, covered by a radome. The battery is charged by custom-made solar modules, mounted around the pillar. The pillar has a diameter of 20 cm. The height of the pillar in Fig. 1 is 1.20 m. The pillars can be produced in various heights, e.g. depending on the excepted snow depths. They provide a stable geodetic monumentation, mandatory for long-term monitoring. The stations are designed in a way that no cables are located outside the station. It only has a small footprint, and is mounted to the ground (rock or concrete) with three treated bars.

2.2 GNSS receivers

The GNSS monitoring stations described above can be equipped with any GNSS devices. For monitoring applications, we have developed own GNSS devices with low power consumption. They consist of a low-cost L1 GNSS module from the Swiss manufacturer u-blox. They are equipped with internal data storage and a GPRS/UMTS modem for data transmission. In addition, they include a 3-axis accelerometer for inclination measurements.

2.3 GNSS data processing

The GNSS data is transmitted to a server at ETH Zurich, where it is processed in a fully automated processing chain. The core GNSS processing is done with the Bernese GNSS software (Dach et al. (2007)), based on differential carrier phase techniques. The processing chain allows the computation of daily static coordinates (24 h), subdaily static coordinates solutions over a time window with a length of a selectable number of hours and kinematic coordinates.

2.4 Accuracy

The accuracy of the GNSS positions strongly depends on the baseline length and the height difference with respect to the reference station, as well as on the length of the data time window used for the processing. In remote monitoring applications, power consumption is often an issue, making it sometimes it impossible to operate the GNSS receivers continuously 24 h per day. In such a case, the receivers are often duty-cycled, meaning that

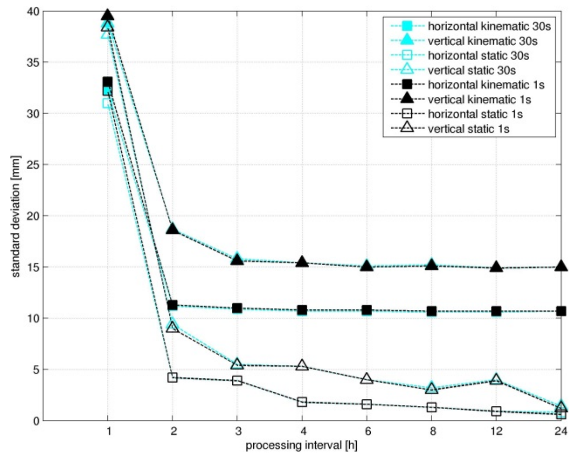

Fig. 2 Horizontal and vertical accuracy (standard deviation) as a function of the length of the processing window, for static and kinematic processing, and for sampling intervals of 1 s and 30 s.

they are operated e.g. only 1 h per day and put into sleep mode for the rest of the day. Depending on the length of the selected uptime window, the positioning accuracy can be considerably degraded.

Fig. 2 shows the accuracy as a function of the length of the processing window. The accuracy is expressed as the empirical standard deviation of the differences between the obtained GNSS positions and the known mean position. This analysis is based on *in situ* data over two weeks from a 300 m baseline in an alpine environment, with two low-cost single-frequency GNSS receivers. The height difference of the baseline is 50 m. It can be seen that the sampling interval (1 s or 30 s) has no influence on the accuracy. With a processing window of 24 h and static processing, the obtained accuracy is 0.8 mm in the horizontal and 1.5 mm in the vertical, hence similar to geodetic-grade dual-frequency receivers. With kinematic processing, the accuracy is 10 mm in the horizontal and 15 mm in the vertical, hence degraded by a factor of 10 with respect to the static processing. When the processing window is decreased, the accuracy is degraded, especially for windows below 2 h. In that case, the individual solutions not only become noisier, but they can contain outliers much larger than the standard deviations in Fig. 2.

The analysis of more than 30 baselines (not shown) confirmed the well-known fact that the accuracies are degraded with increasing baseline length and height difference. For baselines below 5-10 km, this is true for both single- and dual-frequency receivers, since the degrading factor are tropospheric delays, identically affecting single- and dual-frequency GNSS solutions. Hence, for short baselines, the accuracies obtained with low-cost single-frequency GNSS receivers are similar to dual-frequency receivers. In terms of accuracy, the advantage of dual-frequency receivers only becomes significant for baselines above 10-15 km, where ionospheric delays become a major degrading factor for single-frequency GNSS receivers.

3 Applications and results

3.1 Bedrock deformations at the Great Aletsch Glacier

This application aims at quantifying seasonal ground deformations of bedrock around an active glacier, and to investigate long-term trends associated with ongoing ice retreat. This project is part of an interdisciplinary cooperation led by the Engineering Geology Group of ETH Zurich. Two GNSS stations (AL01 and AL02) are continuously operated at the Great Aletsch Glacier (Canton of Valais, Swiss Alps) since October 2013. The stations are located on a cross-section of the glacier, on the bedrock at either side of the glacier (Fig. 3 and Fig. 4).

Absolute positions of the two stations are computed with respect to a geodetic dual-frequency reference station operated by our institute, situated at approx. 5 km (not shown). The relative displacements time series between the two GNSS stations (station AL02 with respect to station AL01) is shown in Fig. 4. The baseline length between the two stations is 1 km. The vector from AL01 to AL02 is pointing in NW direction. The displacements are showing a distinct seasonal behavior with an amplitude of 1-2 cm (Fig. 5). During spring-time (April and Mai), the two stations are moving towards each other, while during the rest of the year, they are moving away from each other. The displacements also show inter-annual variations, e.g. a faster and larger movement during spring-time in 2015 than in 2014. The data is provided to the Engineering Geology Group of ETH Zurich for further geological investigations.

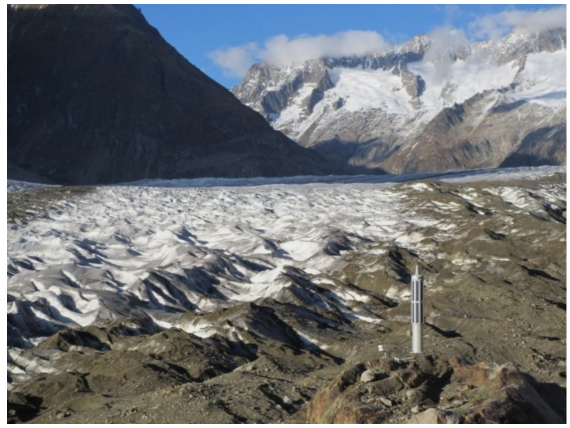

Fig. 4 GNSS station AL01 at the Great Aletsch Glacier.

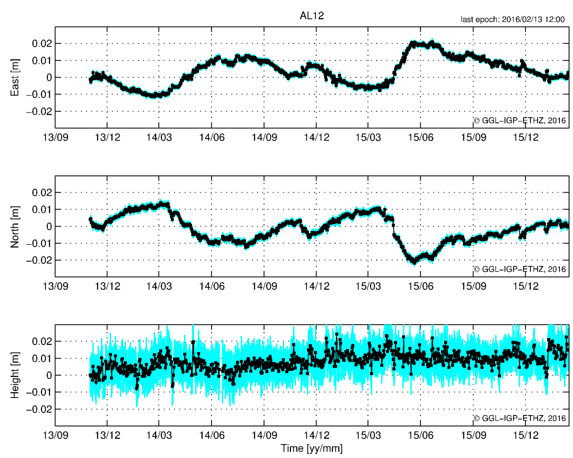

Fig. 5 Daily solutions of relative displacements in East, North and up directions, between the GNSS stations AL01 and AL02 (AL02 with respect to AL01). The blue bars indicate the uncertainty interval of 3 times the standard deviation.

Fig. 3 Location of GNSS stations AL01 and AL02 at the Great Aletsch Glacier (upstream view).

3.2 Slope instability at the Great Aletsch Glacier

Two GNSS stations (MOO1 and MOO3) have been installed in March 2015 at the “Moosfluh” slope instability close to the Great Aletsch Glacier, in collaboration with the Swiss Federal Office for the Environment. The same reference station as for the application in section 3.1 is used. The baseline lengths are 7 km. The location of the stations MOO1 (Fig. 1) and MOO3, as well as their mean horizontal velocity vector, are shown in Fig. 6.

Since the beginning of the monitoring, the total horizontal displacement of both stations is ~0.7 m over a time period of almost 11 months, corresponding to a mean velocity of ~2.2 mm/day (Fig. 7 and Fig. 8). The displacement rates of both stations are not constant over time, with e.g. a slow movement during winter and a faster movement during summer, with distinct accelerations during spring and summer, reaching e.g. 9 mm/day at station MOO3 in summer 2015 (Fig. 8).

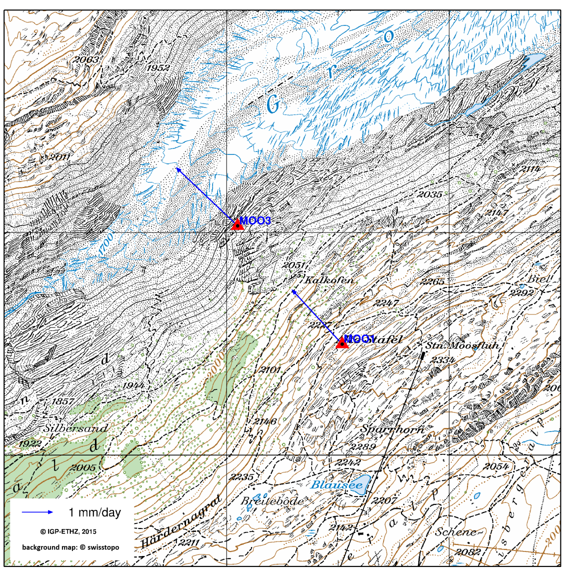

Fig. 6 Location of GNSS stations MOO1 and MOO3 at the Great Aletsch Glacier. The blue arrows indicate the mean horizontal velocity observed at the stations.

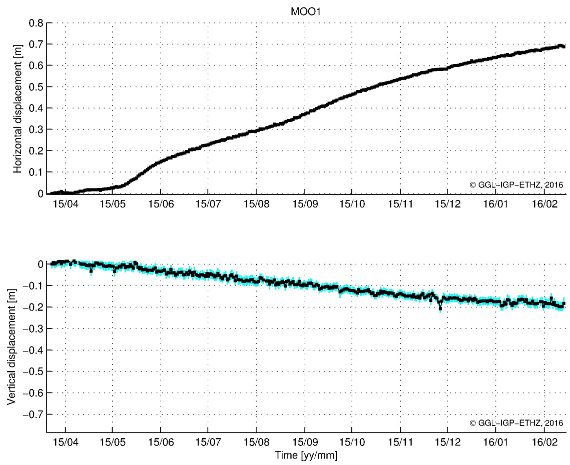

Fig. 6 Daily solutions of displacements of station MOO1 in horizontal and vertical directions. The blue bars indicate the uncertainty interval of 3 times the standard deviation.

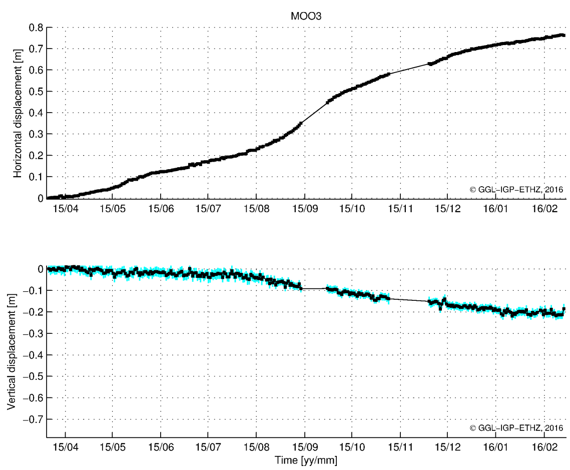

Fig. 7 Daily solutions of displacements of station MOO3 in horizontal and vertical directions. The blue bars indicate the uncertainty interval of 3 times the standard deviation.

4 Conclusions

GNSS can be an effective method for the precise monitoring of rock glaciers, slope instabilities and rock instabilities with a high temporal resolution. With continuous observations over several years, it is possible to analyze the temporal variations of the displacements and the displacement rates. In case of short baselines, low-cost single-frequency GNSS receivers can provide similar accuracies than geodetic-grade dual-frequency receivers.

Acknowledgements

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