Determining glacier velocity with single frequency GPS receivers

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Introduction

A well-known phenomenon in glacier dynamics is the existence of a relation between the glacier velocity and available amount of melt water (Zwally *et al.*, 2002; Van de Wal *et al.*, 2008). This relation is of particular importance when estimating the reaction of glaciers and ice sheets to climate change. In order to better understand this relation, detailed flow velocity and mass balance information is crucial. For this purpose, the Institute for Marine and Atmospheric research Utrecht (IMAU) developed a low cost stand-alone single-frequency GPS unit to perform year round ice velocity observations.

The Instruments

The GPS units make use of the Global Positioning System (GPS) (United States Air Force, 1996; USA Department of Defence, 2008), to determine the location of an instrument at a preset time interval. GPS is available since 1973 and since in 2000 the selective availability (an artificial degrading of the signal) is turned off, the stand-alone system is commercially developed for navigational purposes. In 2003 IMAU started the development of a cheap and robust GPS receiver to monitor glacier velocities. Figure 1 presents the unit. It consists of a small chip containing the GPS receiver

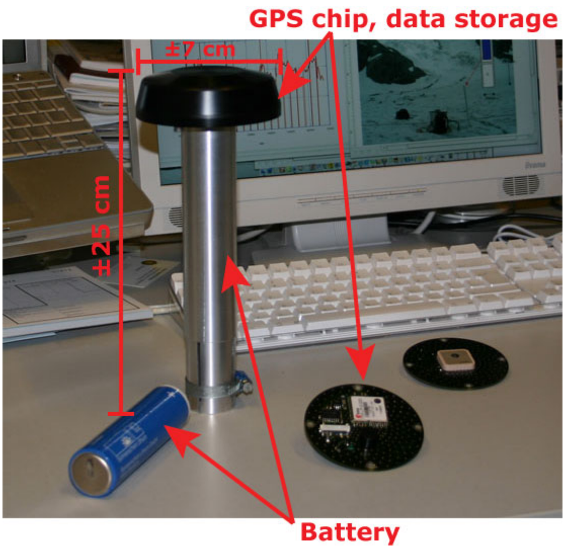

Figure 1. GPS unit.

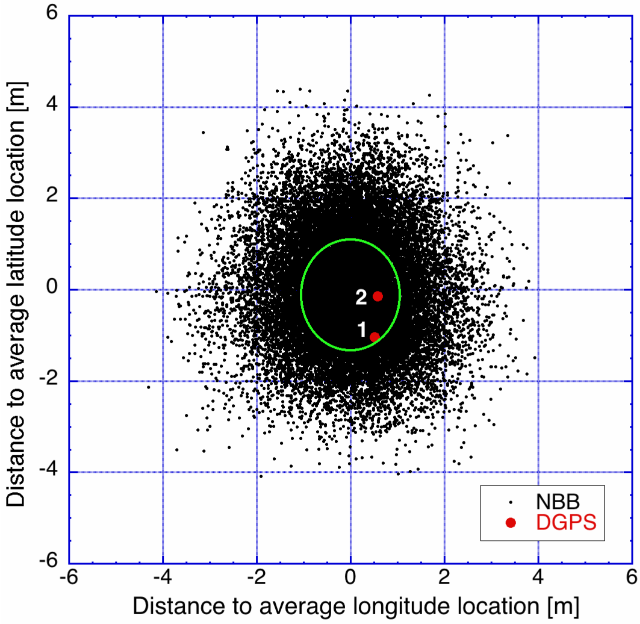

Figure 2. Scatter plot of three years of non-averaged data from a reference site on Svalbard (NBB). Observations are plot with respect to the average location, negative values denote the records to the south and/or west of the average position. The red dots indicate the location of the DGPS with respect to the averaged location, 1 = 2007, 2 = 2008. The green circle denotes one standard deviation of the non-averaged data.

and the data storage unit. The receiver uses 15 Ahr per year and when powered by one 3.6 V Lithium battery can run for over one year without servicing. The sample time is between 1 to 3 h and all data is stored locally. More details can be found in Den Ouden *et al.* (2010). First test with the system were carried out in 2004 on Breidamerkurjökull, and first year round deployment was in 2005 on the Kangerlussuaq transect, Western Greenland of which results are presented in Van de Wal *et al.* (2008). At present, about 60 IMAU GPS units are operational worldwide.

Accuracy

The IMAU GPS unit is a stand-alone single-frequency system. The accuracy of a single measurement of such a system is on the order of 13 - 23 m depending on ionospheric conditions (HSAT value, USA Department of Defence, 2008). A number of methods and models are available to improve the accuracy of this type of system (King *et al.*, 2002). However, in order to limit power consumption only time and positional information is stored and almost no in situ computations are carried out. Therefore, none of these corrections can be applied due to lack of information. As a result, the accuracy of our system is variable in space and time, largely determined by ionospheric conditions. Figure 2 illustrates the accuracy of a reference system placed on solid rock on Svalbard. The standard deviation (std) in three years of data is 1.65 m, which is much better than the HSAT values given above. This is due to the sampling strategy in which for every measurement the system is turned on for 3 minutes until a stable signal is reached.

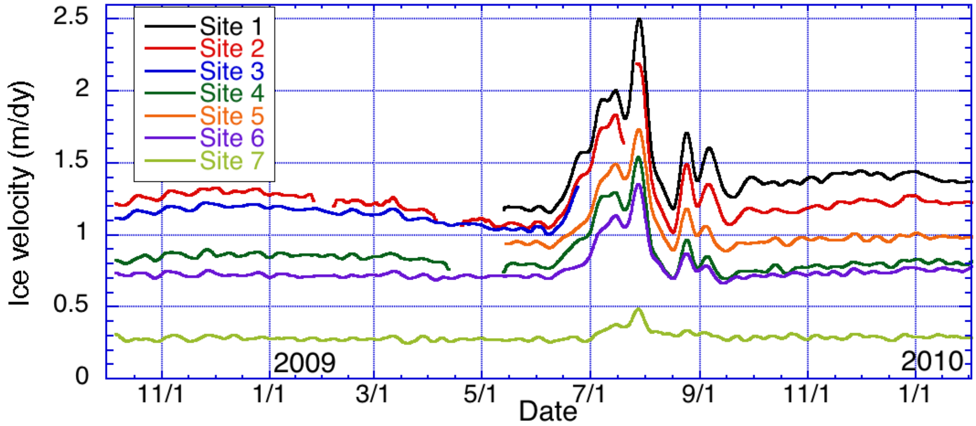

Figure 3. Scatter plot of three years of non-averaged data from a reference site on Svalbard (NBB). Observations are plot with respect to the average location, negative values denote the records to the south and/or west of the average position. The red dots indicate the location of the DGPS with respect to the averaged location, 1 = 2007, 2 = 2008. The green circle denotes one standard deviation of the non-averaged data.

Glaciers show a wide range of velocities from slow (order m/yr) to very fast flowing glaciers (order km/yr). To better distinguish signal from noise, especially for slower moving glaciers, the signal must be averaged. Unfortunately, this reduces the temporal resolution. The std in the averaged observation reduces with 1/sqrt(n) with n being the number of measurements in the running average. With a sample time of 1 hour, averaging over n = 168 hours results in a reduction of the std to 0.20 m. As a result, applicability of this system is limited to faster flowing glaciers (> 30 m/yr). An example of observed velocities after averaging is given in Figure 3.

Challenges

Besides the accuracy of the system posing a limit to its applicability, the harsh environment on glaciers also provides challenges. Moisture is a major problem for all electronic equipment on glaciers. The housing of the unit is constructed such that fortunately no moisture problems are encountered. Furthermore, the system is not opened in the field for data collection ensuring that no moisture can enter the system in situ.

Ice formation around the instrument may cause the stake on which it is mounted to break, which may result in burial of the instrument. To prevent loss of the system through burial, a RECCO reflector is attached to the unit (Link). RECCO is a system used for finding and rescuing avalanche victims. The RECCO transmitter uses a directional radar signal to locate a RECCO reflector. It works up to 200 m through air and depending on moisture content of the snow up to 20 m through snow. Since using this system we found 5 units out of 6 that would otherwise be lost.

In very crevassed areas systems are placed using helicopters instead of snow mobiles or hiking. In order to ensure data collection, the IMAU GPS are now equipped with Argos transmitters, broadcasting data every few days. Note that this type of IMAU GPS uses more than one 3.6 V lithium battery.

Conclusions

The IMAU GPS system is a very robust system with low power consumption. Main issue of this system is its accuracy (order 1.5 - 2 m). As a result averaging is necessary to improve signal to noise ratio limiting the temporal resolution to several days, and applicability of the system to faster flowing glaciers (> 30 m/yr). Recent developments include a type that transmits data using the Argos satellite system and applying DGPS techniques to improve the accuracy. As a side result, the RECCO has proven to be very useful in finding buried equipment.

References

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