The Cryosphere Discuss., 4, C990–C997, 2010
www.the-cryosphere-discuss.net/4/C990/2010/

The Cryosphere
Discussions

Interactive comment on "Stand-alone single-frequency GPS ice velocity observations on Nordenskiöldbreen, Svalbard" *by* M. A. G. den Ouden et al.

M. A. G. den Ouden et al.

c.h.tijm-reijmer@uu.nl

Received and published: 26 October 2010

Author response

We would like to thank both referees and M. Pelto for their constructive comments to our manuscript. Below are our responses to all issues raised by the anonymous referee, M. King and M. Pelto.

Response to comments from Anonymous referee #1

It is correct that the main goal of this paper is to present a method to measure ice flow velocities. In the description of the aims and scope of The Cryosphere, we could not find any comments suggesting that a methods paper is not appropriate for this journal. Furthermore, the method is developed specifically for the application on glaciers and its applicability is illustrated using several years of observations on a glacier on Svalbard. We therefore feel that this manuscript is in its present format appropriate for The Cryosphere.

However, we agree with the referee that the presented observations can be described and discussed in more detail. We will therefore extend the discussion on the temporal and spatial velocity variations in sections 4.2 and 5, also following the comments by M. King and M. Pelto.

Specific comments

- We will add more information about the GPS system following the comments by M. King. Please read our response to his comments for more details.
- The term stand-alone refers to the fact that our system operates autonomous, it does not use differential techniques in order to improve the accuracy. We will add a comment to clarify this in the Introduction.
- By smoothening the time series all noise, including atmospheric, with periods shorter than the averaging window are removed. We choose a time window of 240 hours. This removes e.g. the daily cycle from our series. However, variations on longer time scales remain in the series and we can not completely rule out that variations present in the time series are caused by atmospheric noise. This will be discussed in more detail in section 4 also following the comments by M. King.
- 982-22 We will rephrase the sentence in the revised manuscript.

- 985-5 This will be corrected in the revised manuscript.
- 985 1st para: Yes, in section 4.1 we discuss periodicities found in the observations, which makes it necessary to know what type of periodicities are present in the GPS system itself. The orbital information is necessary in order to understand that the satellite distribution over the sky may not be ideal in polar regions and may result in extra uncertainty in the observations, as discussed in section 4.1. The frequency information is also necessary because the fact that we only use the L1 band has large impact on the accuracy of our system as well.
- 987-8 Yes, vector summed is meant here, we will rephrase the sentence.
- 992-17 This will be corrected in the revised manuscript.
- 995-14 We have checked the costs. It should be €000,- which includes materials (stakes and housing), battery, GPS chip and labour. Furthermore, we agree with the reviewer that at present more reasonably cheap options to measure flow velocities are available. We will therefore remove the comment from the manuscript.

Response to comments from M. King

1. - We agree with the reviewer that the effect of the ionosphere on out system should be explained in more detail. We will therefore add a paragraph and several comments in section 4.1 about the variations in the signal resulting from the delay in the signal in the ionosphere and its influence on the accuracy of the system following the comments of the reviewer. Since we do not apply any ionospheric correction, the absolute error is indeed considerable. It is also correct that we cannot apply the double differencing approach since the coordinates are computed in the receiver and the only information stored is time, location and height.
2. - The way the GPS coordinates are calculated is very basic. We use the C/A signal to determine the location, without the carrier phase information. No corrections or models were applied on the data. Thus, we do not apply a model of the tropospheric

delay in order to reduce the tropospheric errors. We do not apply the ionospheric model from the navigation message. We do not apply between satellite differencing to reduce receiver clock errors. And we do not apply elevation dependent weighting. We do use the broadcast orbits with the WGS84 reference frame. Thus basically all errors are stil in the determined location. The only error addressed in the design is the multipath error, which is reduced by using a patch antenna in combination with a smart design of the housing. Furthermore, the sampling procedure is such that it minimizes the error caused by the signal arrival timing.
- The whole design of the system is focused to keep the system as simple as possible in order to keep it cheap and operational for longer time periods in harsh conditions. The design is therefore small, only essential data is stored and as a result the power consumption is kept to a minimum which makes it possible to run the system on one 3.6 V battery for over a year.
- The GPSs on Nordenskioldbreen were installed as part of a IPY project to study the relation between meltwater and flow velocity of a glacier. We were therefore interested in the temporal and spatial variations in the mass budget and flow velocity on the lower parts of the glacier. The receivers were therefore placed as close as possible to the central flow line of the glacier, with the lowest instruments as close as possible to the calving front. On Nordenskioldbreen the GPSs were placed on an elevation interval of about 100 m spacing the instruments evenly over the flow line to above the equilibrium line. In addition, a reference station was placed on rock in order to be able to asses the accuracy of the system and possible correcting the stations on the glacier.
- Based on the above comments we will rewrite section 2.1. of the manuscript.
3. - The power spectrum presented in figure 5 is a Lomb periodogram. The 95% line indicates how important the different peaks are. We will rephrase the caption. The period of the 15 day peak is significant between 14.55 and 14.7 days with the max at 14.66 days, thus likely not of tidal origin.
- We have applied differencing to our data sets and will change tables 4 and 5, and figures 6 and 7, accordingly. Note that, the changes in resulting average velocities

and uncertainty estimates are very small compared to the old values. It does remove some of the variability on time scales of weeks. The 15 day period however, remains in the signal and is not removed from the figures presented. We will remove the remark relating the 15 day period to satellite repeat period.

4. - As suggested we will add a figure to illustrate the unsmoothed data.

Specific comments

- 981-3 The sentence will be rephrased.
- 984-5 This will be corrected in the revised manuscript.
- 985-12 The value of 6 is based on the UERE values presented in table A4-2 of the cited document. More correct would be to present the HSAT value which would in this case be 13.6 m expressed as rms value (or 26.7 m 95%). This value is based on the best estimate of Ionosperic delay model. Based on the range of Ionospheric delay the HSAT range would be 13.6 - 22.7 m (or 26.7 - 44.5 m 95%). We will change this in the manuscript.
- 985-18 Following the comments per 2., we will rewrite section 2.1 and include more information about dual frequency and its (dis)advantages.
- 986-1 The combination of the patch antenna and the specific design of the housing of our GPS results in an even larger reduction of the reception from below than when using only a patch antenna. We will rephrase the sentence.
- 986-7 The system uses about 15 Amp hour per year and is powered by a 3.6 V lithium battery that is under normal conditions capable of providing 30 Amp hour. We will add a comment in section 2.1.
- 986-17 This will be corrected in the revised manuscript.
- 986-23 We will add a comment.
- 987-13 The technique we use is differential carrier phase (L1,L2). We will add a comment in section 3, and when appropriate rephrase the sentences where DGPS is

mentioned.
- 989-12 We will rephrase this sentence.
- 989-21 This will be corrected in the revised manuscript.
- 990-2 We have experimented with different sample intervals. As a result the 3 minute time interval to stabilise the system was chosen. Furthermore, the sample frequency should be high enough to resolve the diurnal variations. Furthermore, Figure 4 shows the dependency of the standard deviation in the NBRef data set on the number of samples in the running average window. Thus, an increase in number of samples also reduces the standard deviation, although an optimum value is present. Based on these and power consumption considerations a 1 hour sampling interval was chosen. A comment will be added in section 2.1.
- 990-17-22 The paragraph will be revised based on these and similar comments.
- Section 4.2.1 We will add a comment in this section about the velocity at NBRef.
- 992-3 We do not think that variations in ionospheric activity can explain the differences between determined velocities. If there was a significant difference in ionospheric activity it would be visible in variations in standard deviation of the NBRef site, Tab 2., which is not the case.
- 992-16 We will add a comment about the ionospheric impact on the found standard deviation in section 4.1.
- 992-20 Yes, 'detectable period is' meant, the sentence will be changed accordingly.
- 992-25 We are not sure what you mean by clearer. The summer period is dominated by the melt water related peak in late spring, early summer. In the winter period, other variability is not obscured by such a large peak. We will add a comment allong these lines.
- Figure 6. We have not added a velocity figure for NBRef similar to Figure 6. Since in this figure the velocity in latitude and longitude direction are combined, directional information is lost and the velocity will not be varying around 0 and the figure would not illustrate that NBRef is indeed stationary.
- 993-17 The comment will be removed.

- 996-4, 18-19. The sentences will be rephrased.
- Table 3-4 We will add height in Table 3. We will not add height in tables 4 and 5 because due to the movement of the stakes, the height changes.
- Figure 7. The height changes in this figure are not from a GPS but from a sonic height ranger. We will add a comment in the caption to make this more clear. The units on the RHS are correct. Note that the surface height changes are not absolute height changes but relative changes due to melt of the surface.

Response to comments from M. Pelto

The motivation to utilize the described system is the desire to measure on several location for longer time period but to keep the costs as low as possible. Logistics is important in both considerations, since it determines where we can place our system and how often we can visit the sites. Given the size of the GPS system itself (20 by 8 cm, dimensions will be added in figure 1.) the logistics are mainly determined by the accessibility of the locations. The different transport means include hiking, snow mobiles and helicopters. Type of transport is determined by the glacier itself.
- Following the comments by the two reviewers we will extend the discussion on the temporal and spatial velocity variations in sections 4.2 and 5.
- 986-3 All the GPSs on the glaciers were placed on mass balance stakes. The reference GPS on Terrierfjellet was placed on a tripod. In the accumulation area stakes are the best option, since they can more easily be extended. On this glacier we use in the ablation area stakes, which is possible since the ablation at the lowest locations is max about 2 m ice per year. In areas where melt is large positioning the GPS on a stake would result in too much movement by wind, therefore tripods are used in these situations. This choice also depends on how often it is possible to visit the site. We will add a general comment in section 2.1 and site specific comment in section 3.
- 988-1 The sonic ranger was mounted on a construction of 3 stakes. The initial height

on installation in March/April of each year is between 0.5 and 1.m, the average annual mass budget at this site is about -1. m w.e.. The used sonic ranger is a Cambell SR50 with a specified accuracy of 1 cm. The largest problem is ice formation on the instrument, which results in spurious readings. The remaining data is reasonable reliable. The data refered to in 994-1 and figure 7 is indeed from this instrument. A comment will be added in section 3 and section 4.2.2.
- 993-12 Based on the mass balance data obtained from stake measurements on the same sites as the GPS observations the ELA varied from: 655 m (2006), 585 m (2007), 585 m (2008), 595 m (2009). Only for site 5 there is some information on snow removal in time, no information is available on changes in transient snow line. Since the ELA in 2007 and 2008 are at about the same elevations, it can not explain the difference in velocity at NB8 and NB9 from 2007-2008. The difference is likely related to the second peak in velocity in September 2008, which is related to reasonably high temperatures and high amounts of rain. The mass balance and ELA observations presented in WGMS GMBB 10 for Svalbard (2006 and 2007) show variable changes in ELA. All ELAs presented in that report are lower than the ELA on Nordenskiöldbreen, which is due to the location of the presented glaciers, west of Nordenskioldbreen.

Interactive comment on The Cryosphere Discuss., 4, 981, 2010.