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Some remarks on determining short-period changes in glacier surface velocity using GPS technique – case study of Hans Glacier example

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Abstract: Movement is one of the most spectacular phenomena involving glaciers. Determining glacier surface velocity is now a routine aspect of glaciological studies. These are geodetic methods, especially satellite positioning, that most frequently is applied in such work. Using the Hans Glacier (SW Spitsbergen) as an example, the presented paper is an attempt at defining the time resolution limit of changes in the velocity determined using GPS positioning technology.

A test network was established in the area of the examined glacier in order to define the size and variability of the main satellite positioning biases as well as to define their impact on determining position and the calculated velocity.

A discussion relating to achieved accuracy (differentiated from measurement precision) for baselines of a length of several kilometres in the high latitudes has also been presented.

Keywords: GPS, glaciology, glacier surface velocity

1. Introduction

The Hans Glacier is located near the Polish Polar Station of the Polish Academy of Sciences on the Hornsund Fjord on Spitsbergen. There are two dual frequency GPS receivers. The first one installed near the Polar Station operates continuously as a base station. The second one is permanently mounted on one of the ablation poles. It operates in pre-programmed sessions half an hour long every three hours in order to reduce the frequency of battery charge. Subsequently, the observations are processed and positions are determined for the relevant epochs. The distance between receivers amounts to approximately 5 km.

When looking at the processed data (Fig. 1), one can note that changes in position over the course of the day are regular, or rather that there is a certain similarity for various days. Moreover, the graphical presentation of the changes leads to the same conclusions[1]. However, if one specifies velocity changes with a diurnal resolution (by selecting positions determined at the same time over the course of the day for calculations), the results obtained for the various hours exhibit a very good mutual agreement. Differences in those velocities are smaller than in the case of the 3h resolution. This is obvious, however, it remains unsolved whether those irregularities are caused by measurement errors (additionally amplified due to the short time intervals, where long-term changes are significantly less sensitive to position determination errors) or if this is the effect of real, small changes in velocity that got "smoothed out" in diurnal determinations. Publications relating to the velocity of the described glacier do not look into changes in velocity at temporal resolution exceeding one day (Puczko et al., 2006; Vieli, 2001) or they present raw results that may lead to an over-interpretation or faulty conclusions. The further part of the paper is thus an attempt to define whether it is possible to determine velocity changes with a sub-diurnal resolution applying GPS technology for velocities in the range of 20–30 cm per day. For glaciers and ice shelves of surface motion velocities of 1 m per day the same problem is observed (King 2004, 2006) and a certain solution for improving reliability is given (King et al., 2000) but some artefact signals in results persist (King et al., 2003).

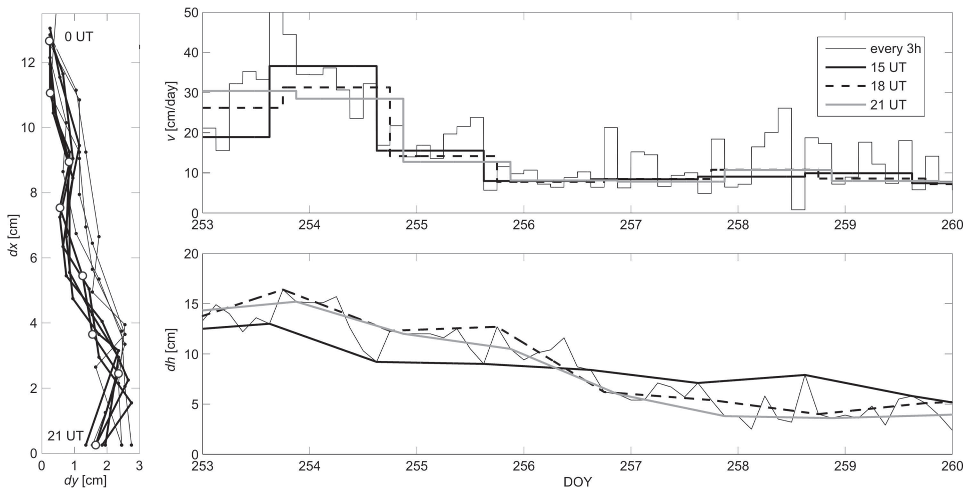

Fig. 1. Daily variations in UTM coordinates (*dx*, *dy*) at 3h intervals for several successive days (2–6 May 2007, left drawing). The surface velocity (*v*) and height variations (*dh*) during the autumn speed-up event in the year 2006 as calculated on the basis of all observations with resolutions of 3h and one day (on the basis of positions determined for the same hour)

[1] Glacier velocity was calculated on the basis of coordinates in the UTM projection. Due to the small slope of the glacier and minimal height above sea level, differences in calculated velocity and the real velocity are negligible.

1.1. Satellite Positioning Biases

Satellite positioning biases are subdivided into three groups depending on the terrestrial segments (receiver, antenna, software, and observation station stability), the space sector (GPS satellite position and configuration), and environmental segment (ionosphere and troposphere).

The paper looks at differential measurements. The research is focused on the analysis of the differences between the determined positions. For this reason it is possible to neglect the biases of the first group, assuming their insignificance. Assessment of the size and variability characteristics of biases in the second group as well as their impact on the studies of motion is the main objective of this work. It is also important to bring to mind the fact that the GPS satellite configuration is repeated each sidereal day. The biases of the third group were of lesser importance. For small distances between points (5–6 km), the creation of differences in observation between two receivers operating simultaneously minimises the influence of environmental biases. However, the major variability of the terrain (tundra, glacier, mountains, and proximity of the ocean, especially in cases of a lack of snow cover) is unfavourable and results in significant differences in atmospheric conditions at various stations. The absence of circumzenithal GPS satellites at high latitudes has an unfavourable influence on estimating the impact of the troposheric delay.

2. Test Network

A test network (Fig. 2) was established in order to improve results as well as to make possible the estimation and analysis of the effect of various biases on the computed velocities. Additional observations were conducted during the campaign from 18 to 23 May 2007 (DOY 138–143). Apart from the receivers operating at the station (A) and on the glacier (H), two additional receivers were placed on the nearby mountains, i.e. Flatrygen (F) and Staszelisen (S). All dual frequency receivers operated continuously. The network geometry (Table 1) was not optimal due to the lack of appropriate, stable stations with a clear horizon near the glacier.

Table 1. Coordinate differences and ellipsoidal height differences for baselines in the test network

Vector	Δx[km]	Δy [km]	Δh [m]	Length [km]
AH	5.0	2.3	180	5.6
HS	4.5	-2.2	200	4.9
HF	-1.9	2.5	69	3.1

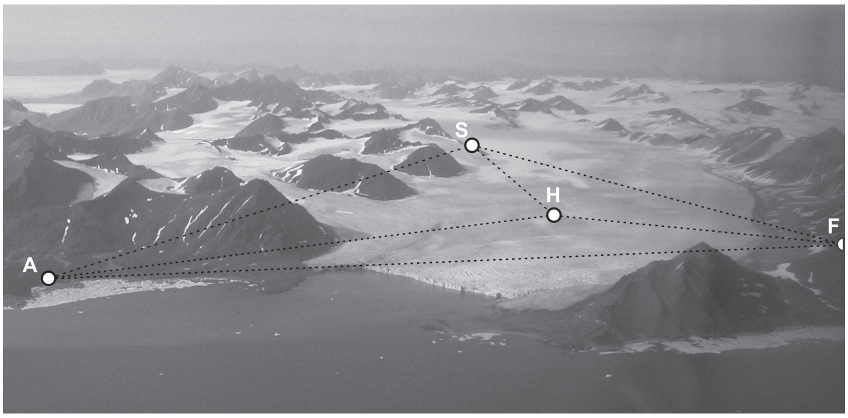

Fig. 2. The test network (drawing from ris.npolar.no/documents/Hans_gl_poster.doc)

3. Numerical Results and Analyses

In the studies presented, different software and processing strategies were applied. The scatter of results was similar for both commercial (Leica Geomatics Office) and scientific (Bernese) package. Different settings were checked finding that none of them is significantly better than others. Moreover, atmospheric delay modelling did not improve results, probably due to high correlation for such short baselines.

It seems important to present results showing "numerical noise" – non-univocal elements tied exclusively with the choice of numerical of processing parameters used (Fig. 3). A simple method setting the maximum values for the RMS for fixed phase ambiguity solutions was used for outlier rejection. This limit was selected empirically to prevent the rejection of too large number of observations. The number of rejected observations is presented in Figure 3, where the rejected observations are presented as an intermittent line, while the continuous line marks the remaining results used in successive analyses. It seems also important to stress that the *pq* parameter is not a measure of precision, but a measure of cohesiveness.

The calculated values demonstrate an uncertainty of several centimetres tied with various solution parameters. Such a dependence also points to a significantly poorer GPS satellite configuration at large latitudes. The relative error (or rather the relative uncertainty) sporadically reaches 30% (usually it is several percent). At a decreasing time resolution this problem disappears and does not exceed 0.5 cm in diurnal analyses.

The variation of GPS satellite configuration has the greatest impact on the determination of velocity at a sub-diurnal resolution. Again, this effect is amplified by a lack of GPS satellites at high latitudes as well as in the case of an obstructed horizon. The level of variability of determination for various baselines is presented in Figure 4. Moreover, the stressed difference between the RMS parameter and the real accuracy is observed. The precision for individual baselines is much better than for the adjusted solution obtained using least squares method considering all observed baselines.

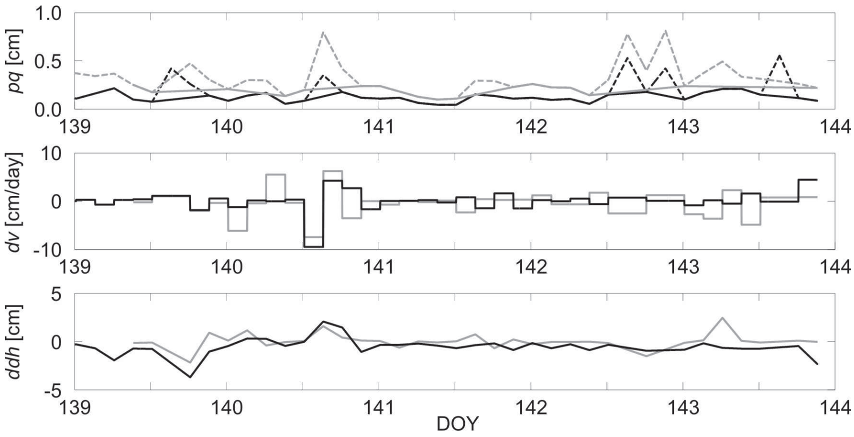

Fig. 3. Outliers rejection (intermittent line) by applying the RMS position quality indicator (*pq*). Differences in glacier velocity (*dv*) and change in height (*ddh*) dependent on both elevation mask and data logging (20° and 5 s, respectively – continuous black line; 10° and 30 s, respectively – continuous grey line) as compared with the solution for 10° and 5 s, respectively

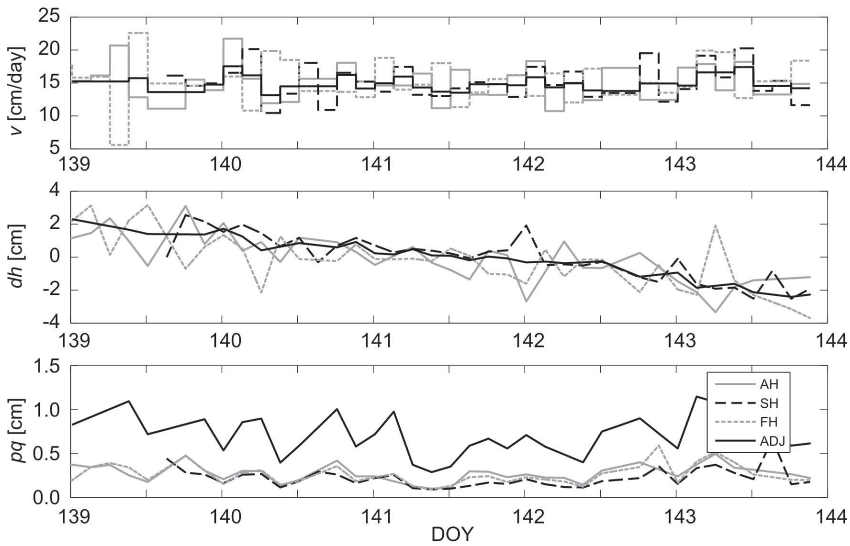

Fig. 4. The surface velocity and change in height of the glacier as calculated for various baselines and the adjusted solution (ADJ)

A better presentation of biases stemming from the variation of GPS satellite configuration (but inclusive the multipath bias and antenna phase centre variations) is found in Figure 5, which depicts solutions for static baselines linking fixed reference points.

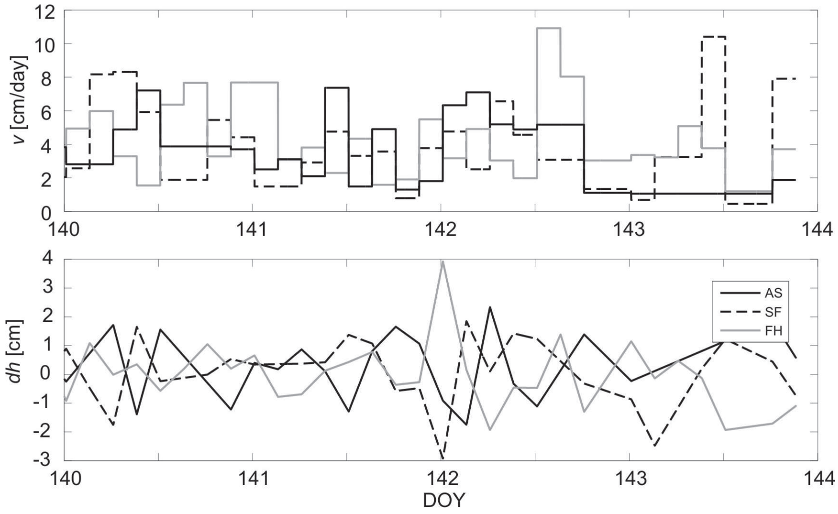

Fig. 5. The "motion" of static baselines – impact of the biases of the space segment

3.1. Overlapped Sessions

Kryński and Zanimoniskiy (2001) used observations from a mini-network in order to indicate the magnitude and character of biases caused by a variable GPS satellite configuration at medium latitudes. The work presents the benefits of using overlapped observation sessions. The idea involves the use of longer periods subject to processing, where random errors disappear and biases are averaged. The number of results may be freely generated by appropriately selected overlap lengths. However, this does not increase the resolution, which is limited to the length of the observation session. Moreover, the results are smoothed out. This method may be compared with a moving average.

Overlapped observation sessions are used in this case to isolate biases caused by the variation of GPS satellite configuration and to demonstrate the influence of other non-modelled errors. It may be assumed that for all diurnal sessions the influence of biases from the second group is identical. When using position differences (movement determination), the problem of those biases cancels out. This method makes it possible to present the biases of the third group. The results presented in Figure 6 are probably underestimated and smoothed out. They are small, but significant.

A successive effort at differentiating changes in velocity at a resolution of less than a day is made by looking at longer observation sessions. In the case of this method, the session may be as long as the desired temporal resolution, but on the other hand,

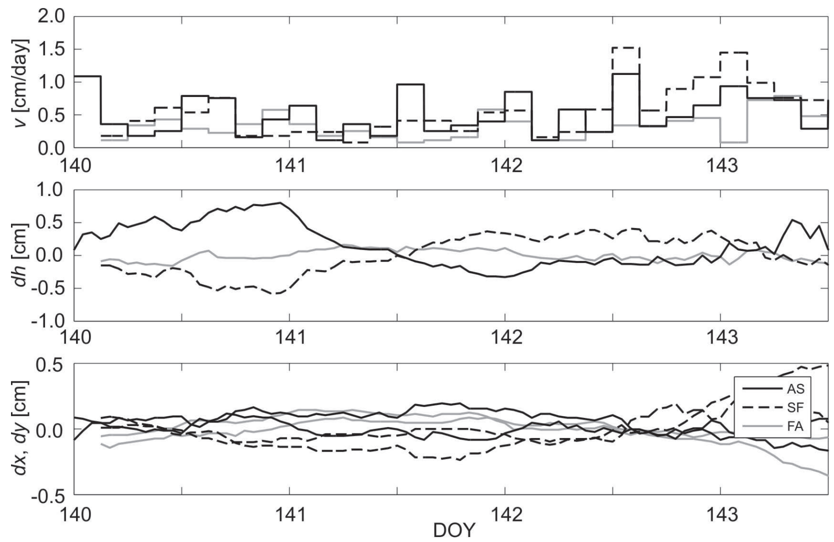

Fig. 6. The “motion” of network static baselines – the impact of environmental effects. 24h sessions with a 1h overlap

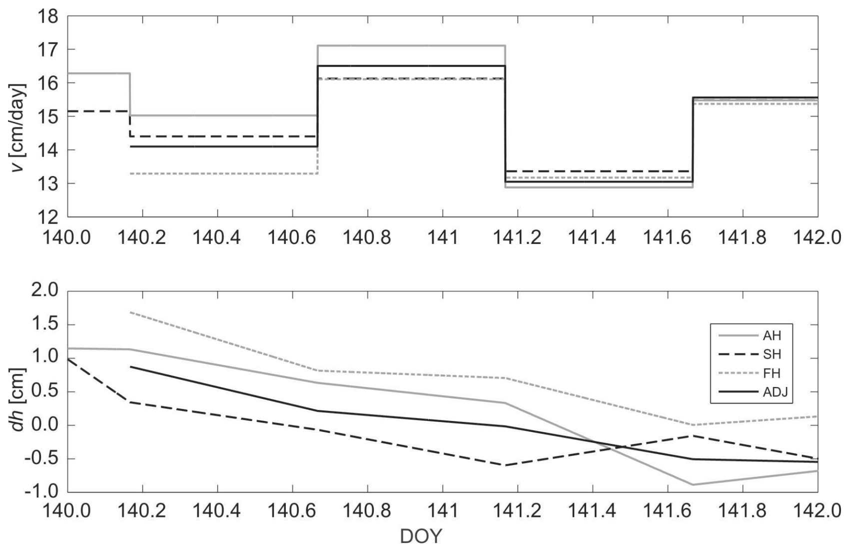

Fig. 7. Velocity and changes in height as calculated for various baselines on the basis of a 12h observation session

changes in position during measurement cannot be fully neglected and that is why the sessions should be referred to as being pseudo-static. The calculated position is thus an average over the whole session and makes the calculation of the average velocity possible[2]. In the case of long sessions, the solution for all baselines and the adjusted solution are very close to each other (Fig. 7). They are also similar to the results for the adjusted solution for short static observations. Unfortunately, on the basis of the presented analyses, it is still not possible to determine whether the changes in velocity as presented in Figure 7 stem from real changes in position or whether this is the effect of the average influence of the variation of GPS satellite configuration (more probable). The only method for verification would be to compare the results with terrestrial techniques, e.g. tacheometry, what in this specific case (difficulty in finding a suitable site) is impossible.

4. Conclusions

The presented results lead to the conclusion that the sub-diurnal changes in surface velocity of a glacier as well as changes in height cannot be definitively differentiated using GPS positioning technology. Due to various biases, mainly caused by the variation of GPS satellite configuration, changes in position of a scale less than a day are encumbered by uncertainty that is too large for the results to be used in glaciological interpretations. It seems that the only advantage of frequent observations is the control aspect, but this has no impact on improving the temporal resolution. What is more, although this may seem strange, better results are achieved when determining glacier surface motion velocity on the basis of diurnal position changes (or multiples of a day), rather than e.g. 1.5 day position changes.

An opportunity to improve results is the increasingly better modelling of individual effects, including the continuous growth in the number of satellites within various Global Navigation Satellite Systems – GPS, GLONASS, Galileo.

The presented analysis pertains to a specific case, the case of the Hans Glacier. For glaciers demonstrating more movement, in the case of smaller distances between the reference station and the rover, or at different latitudes, separate studies should be conducted.

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[2] In all cases the velocity of a glacier is calculated on the basis of determined positions at the assumed temporal resolution. It is the average velocity only under the assumption of unidirectional simple motion between successive measurements.

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Wyznaczanie krótkookresowych zmian prędkości powierzchniowej lodowca z obserwacji GPS na przykładzie lodowca Hansa

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Streszczenie

Jednym z najciekawszych i najbardziej spektakularnych zjawisk dotyczących lodowców jest ich ruch. Wyznaczanie powierzchniowej prędkości lodowców jest obecnie czynnością rutynową w pracach glacjologicznych. Do tych celów stosuje się najczęściej metody geodezyjne, głównie pozycjonowanie satelitarne. W niniejszej pracy przedstawiono próbę określenia granicznej rozdzielczości czasowej przy wyznaczaniu krótkookresowych zmian prędkości z obserwacji GPS na przykładzie lodowca Hansa na południowym Spitsbergenie. W tym celu została założona sieć pomiarowa, składająca się z jednego odbiornika na lodowcu oraz trzech odbiorników odniesienia w bezpośrednim sąsiedztwie lodowca. Na podstawie zebranych obserwacji zostały przedstawione rozważania dotyczące wpływu wybranych błędów pomiarowych technologii GPS oraz ich wpływu na określanie sub-dobowych zmian prędkości na dużych szerokościach geograficznych. Błędy pomiarowe, mimo krótkich wektorów, głównie związane ze zmienną konfiguracją satelitów GPS nie pozwoliły w tym przypadku na określanie zmian prędkości z rozdzielczością czasową większą niż doba.