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Monitoring of the Timorion glacier (Aosta, Italy) surface using RTK-GPS measurements

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ABSTRACT: The technical use of real time GPS, is assuming a fundamental role in environmental applications. In this case study, some lines has been defined on the Timorion glacier (Aosta, Italy) using the RTK technique to create a DTM. This work has been done using double frequency GPS receivers, which are able to work under extreme conditions (low temperature). This kind of job requires some particular attention, for example the multipath effect caused by the snow cover, which in some cases has led to a difficult fixing of the phase ambiguity. The thus obtained DTM was compared with the available ones, drawn with other techniques in order to appraise its suitability. The relief phases of the and the obtained results are described in this paper.

1 INTRODUCTION

A glacier needs to be continuously monitored, because it is important to estimate the snow balance between summer and winter. The monitoring operation is composed of different parts; in particular the snow cover is measured twice a year using a specific auger. The aim of this work was to define the snow thickness and to evaluate whether the difference between the old value and new one is positive or negative. This is of fundamental importance to study the behaviour of a glacier. Geologists need a valid tool devoted to defining an accurate position, where to put the auger and make the measurement. The use of traditional instrument is not possible, because the environmental conditions are not particularly easy. Nowadays, technicians can use GPS methods to estimate where probing should be made or to identify where old points are on the snow cover. This permits a stake out to be made on the glacier and a probing to be made in the same point, with centimentrical precision.

Stake out is a real time approach therefore a network of known points where master station can be putted is necessary. A network of known points is usually materialized and estimated around the glacier area. The RTK methods, approaches and the obtained results of the research are described in this paper.

2 APPROACHES AND METHODS

A limited area on the glacier was measured, using a RTK approach. This technique was selected because it allows a good level of accuracy (centimetrical) to be obtained and because the area was not too large, therefore the number of unknown points was limited.

A RTK relief is made using two GPS receivers, positioned on two appropriate vertexes which are opportunely materialized. The coordinates of these unknown points are defined in a national reference system (WGS84-IGM95), by means a fitting using GPS raw data collected in situ and GPS raw data collected in two GPS permanent stations: Torino (TORI) and Biella (BIEL). Moreover, another GPS receiver was on a IGM point (n.° 41902), on the Nivolet hill, close to the Timorion glacier. These raw data were also used for the post-processing elaboration.

The unknown points are measured with a kinematic method, using two different approaches: RTK and PPK (post-processing kinematic) (Hofmann-Wellenhof *et al.* 1997). In the first one, the unknown position was defined in real time, while in the second one, the unknown position is defined using GPS raw data, applying a post-processing elaboration. RTK solutions were possible because a master station evaluated and transmitted the differential corrections on TIMO point, by radio modem using the RTCM format.

Two LEICA GPS/GLONASS receivers that are able to receive and apply differential corrections and collect GPS raw data were used on the glacier.

PPK solutions allow a centimetrical positioning to be obtainned, using a post-processing approach. In this way a relief efficiency can be evaluated, paying particular attention to some possible difficult situations (i.e. low satellite number, high DOP level, no RTK position).

This method uses raw data collected at the CIMA vertex and GPS raw data collected at the rover receiver. Four receivers were involved in this job: two in static occupation and two in kinematic.

First of all, the CIMA and TIMO point coordinates were estimated, using 2 permanent stations (TORI and BIEL), and the raw data collected on a IGM vertex.

Elaboration was done using the L1/L2 approach, GPS + GLONASS (where available), fixing all the known points, using a relative positioning method.

The static relative positioning permits the common bias to be removed in order to obtain a centimetric accuracy. This session lasts 6 hours, which is enough to solve the baseline with a length equal to 60 km. The new coordinates are defined in WGS84-IGM95 reference system.

All the baselines were estimated with fixed ambiguities and in the BIEL-CIMA and TORI-CIMA cases, the solution was iono-free because the length of the baseline was high (>30 km).

The data processing (data elaboration, baseline processing and adjustment) was carried out with the Leica Geo Office (LGO) v.5.0 commercial software. The kinematic tracks were defined using the PPK method and the following schema was obtained:

The PPK tracking was calculated using raw data collected in a nearby station (CIMA ~1 km) and in a distant station (i.e. CAST ~38 km). The elaboration was made only considering GPS data and GPS + GLONASS data and the results were compared.

The results obtained using the different permanent station were compared, and the difference between the local coordinates were in particular analysed.

An attempt was then made to evaluate a solution using only code measures and the results also in this case were compared.

3 RESULTS

All the results and comparisons were obtained using raw data collected at the CIMA and CAST.

These data were processed with the kinematic data collected on the glacier.

First of all, the solution obtained using only GPS data was compared with the combined GPS + GLONASS data.

In both case (CIMA and CAST), solutions obtained using only GPS coincide with solutions estimated with combined data (GPS + GLONASS). In this case, the low number of GLONASS satellites does not give any benefit to the improvement of accuracy.

The second step was to evaluate the difference between the solutions estimated considering CAST and CIMA. In this analysis, the first result was that the number of points estimated in PPK with ambiguity fixing was different when the elaboration was made using CIMA or CAST.

It is possible that some baselines were not fixed, when the length of the baseline increases.

In the CIMA case, 247 points were estimated, instead in the CAST case only 158 points were calculated. Comparing the PPK solutions, the behaviour of the differences is shown in the following figure:

The PPK solutions were defined in WGS84-IGM95 and the differences were coherent with the accuracy of the IGM95 reference system.

Another analysis concerned a comparison between the solution obtained using the permanent station defined in IGM95 and the solution obtained with the permanent stations defined in another referent system. Today the CAST station belongs to a testing network of permanent stations and it is defined and described in a particular reference system called IGb00. This reference system is commonly used to define GPS permanent station, because it is more congruent than IGM95, in particular IGS product (ephemerids, pole motion, etc.)

When a differential corrections is transmitted, the reference system also received in the rover. It is very important to known the reference system on which the permanent station is defined because if this aspect is not considered problems can arise.

The PPK solutions was defined raw data belonging to CAST station, but using a different reference system to define its coordinates.

Table 1. Accuracy of CIMA coordinates.

	East [m]	North [m]	Up [m]
Standard Dev.	0.016	0.010	0.027

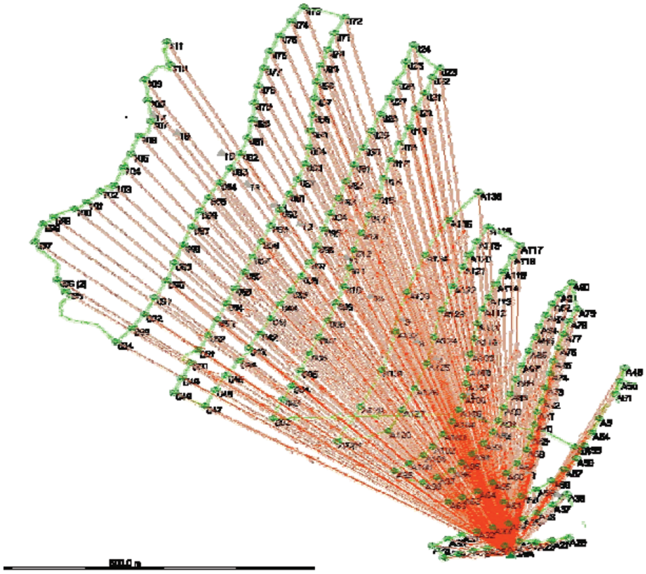

Figure 1. Points in RTK.

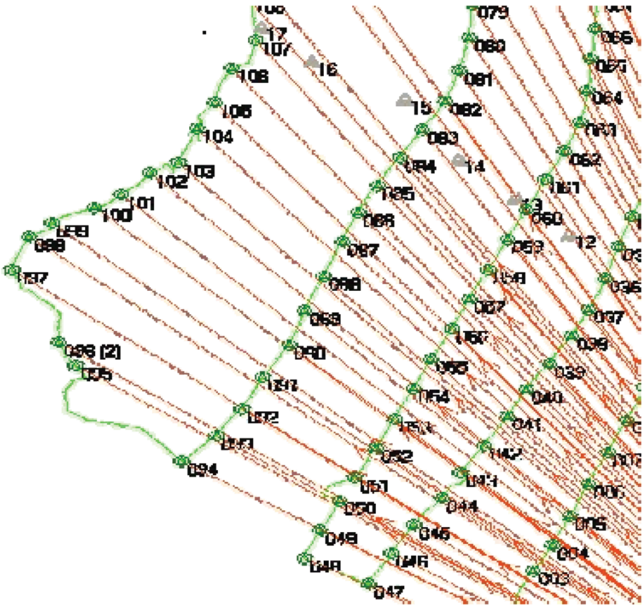

Figure 2. PPK tracks.

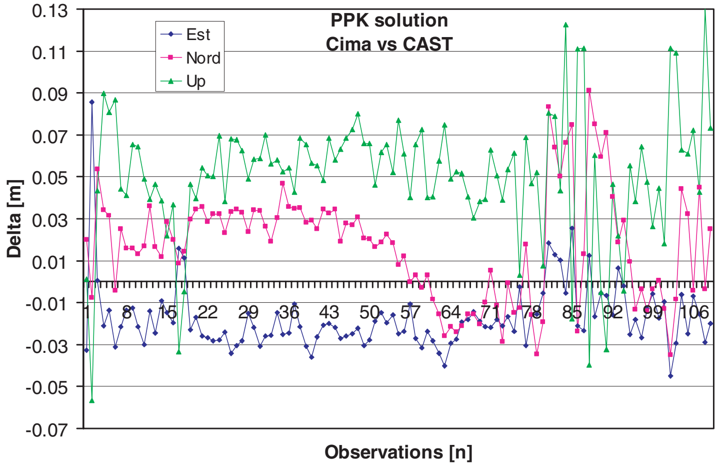

Figure 3. PPK solution comparison.

Table 2. Accuracy of PPK solutions.

	East [m]	North [m]	Up [m]
Average	−0.017	0.017	0.051
Standard Dev.	0.016	0.026	0.031

Comparing the results, it is possible to evaluate the discordance between IGM95 and IGb00, in particular in the planimetric component.

The following figure shows the difference between the PPK solutions obtained using the same master station, but defined in two different reference systems: IGM95 (national RS) and IGb00 (international RS).

The height component is congruent because it is less affected by reference system translation. The East and north components are instead affected by this phenomena, therefore the single coordinates suffer from a translation, which has a mean value equal to 30 cm.

The last analysis concerns the PPK solution obtained using only pseudorange measures. This problem is particularly interesting for GIS applications, where the level of accuracy is not centimetric.

In this case, the PPK tracks were defined in a similar way as to that described before, but using only pseudorange measures. CAST was used as master station and the PPK solutions obtained with carrier phase and pseudorange were compared. The results show that the quality of positioning obtained from the pseudorange positioning is not very bad, because the difference between the couple of point are not high. When CIMA was used as the master station, the accuracy improves, because the baselines were shorter and the bias removal was easier. In this case, the accuracy defined differencing the RTK position and the PPK position were comparable with accuracy obtained using LGO processing.

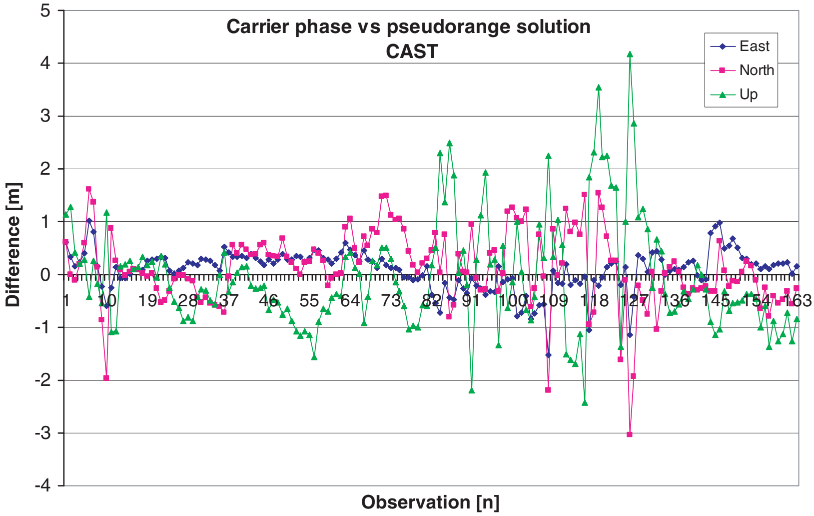

Figure 4. PPK solution comparison in CAST.

Table 3. Comparison between carrier phase solution and pseudorange solution in CAST.

	E [m]	N[m]	U [m]
Average	0.086	0.108	−0.050
St. dev.	0.373	0.697	1.025

These differences could be due to the different values of the tropospheric effect. The master stations used were positioned at different heights (hCAST = 410 m, hCIMA = 3500 m), therefore troposphere bias had different influences on the PPK solution.

What does it happen if residuals between carrier phase solutions and pseudorange solutions are compared with the accuracy provided by LGO?

These values are concordant as is described in Table 4, where average values of deviation standard are similar to residuals with respect to known tracks.

Studying the troposphere bias in the CAST and CIMA vertexes, it is possible to define its different impact. Troposphere delay could change around some meter at the zenith, if height difference is equal to 3000 m. The variation of temperature has a smaller influence on the troposphere variation.

When DGPS is applied with a remarkable gradient, it is necessary to estimate a good model of tropospheric delay. Height difference cannot be neglected. This could be explain the low quality of pseudorange solution obtained with CAST raw data. Low cost receiver could obtain submetric accuracy, but this effect already influences the measures of pseudorange, causing a worsening of solution. To explain better the dependence between tropospheric delay and temperature difference and height difference, we have considered

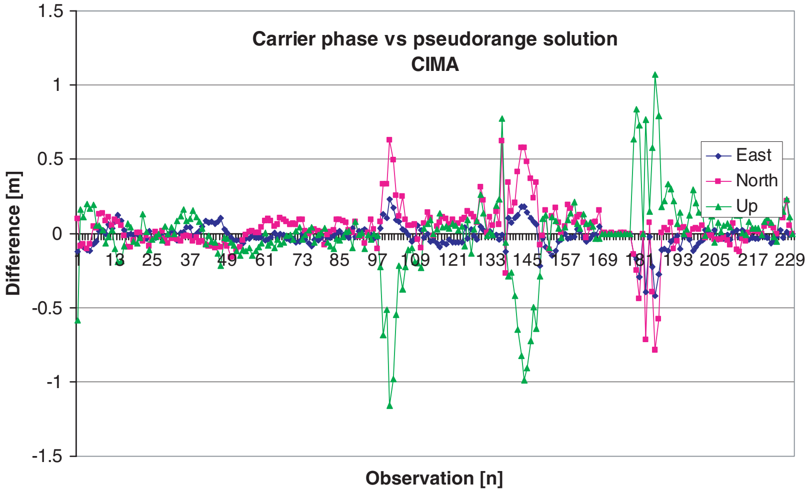

Figure 5. PPK solution comparison in CIMA.

Table 4. Comparison between carrier phase solution and pseudorange solution in CIMA.

	E [m]	N [m]	U[m]
Average	−0.018	0.032	−0.006
St. Dev.	0.076	0.160	0.260

Table 5. Accuracy evaluated by LGO.

	East [m]	North [m]	Up [m]
Average	0.110	0.210	0.333
Standard Dev.	0.092	0.184	0.300

two different cases. We have used the Goad & Goodman model. Comparing each tropospheric delay, the following result is obtained:

Tropospheric delay changes of few decimeters in the first case (changing temperature and h = cost) and about some meters in the second one (changing height and T = cost).

The comparison between PPK solutions and other surveying techniques was made. A LIDAR profile devoted to evaluating snow cover one year ago was made on the Timorion glacier one year ago. Comparing the cloud points defined by LIDAR and PPK solutions, any significant difference can be defined, so this shows that PPK solution has a high accuracy. Figure 7 shows the overlapping between the LIDAR profile and the PPK solution.

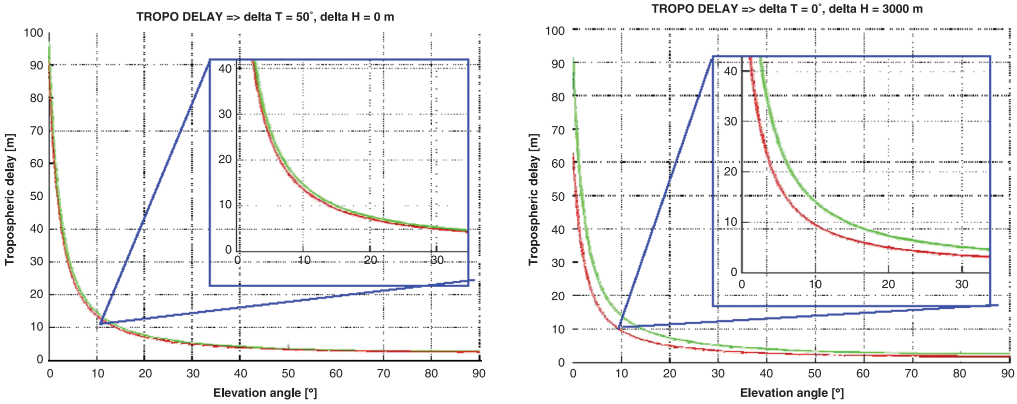

Figure 6. Tropospheric delay.

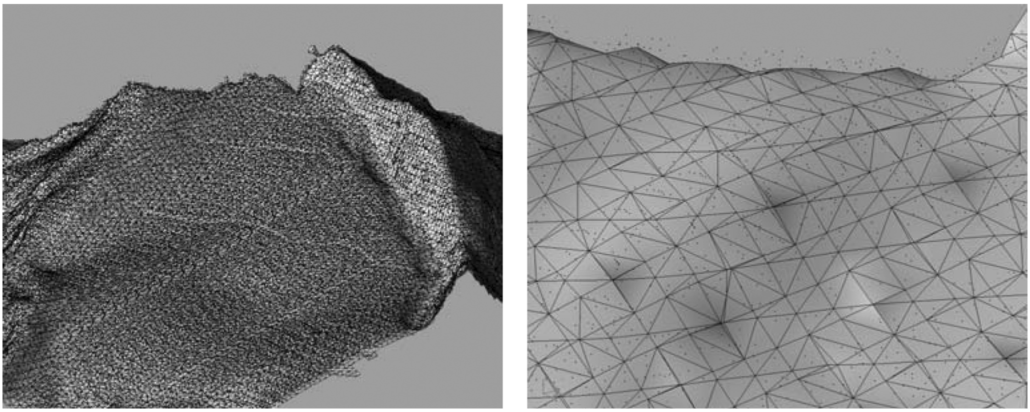

Figure 7. LIDAR profile and PPK solution.

4 CONCLUSIONS

First of all, the research was conditioned by the particular environmental conditions; the overall multipath caused some difficult operational conditions. In some parts of the glacier, it was not possible to apply a differential correction or to collect clean raw data. The glacier was a good reflector surface and the possibility of having a multipath was very high.

A second aspect is the tropospheric delay that has conditioned our results, in particular the quality of PPK solutions. It is possible to obtain high accuracy, using a distant master station (CAST), but obviously, if a master station nearby is used, the accuracy of the solutions increases. The height difference is important as the distance between master and rover.

In the code approach, it was also possible to obtain an acceptable solution, but a height difference can cause different tropospheric behaviour.

Moreover, the PPK solution is a good solution compared to other solutions made with other techniques when overlapping LIDAR solution with PPK solution, no asperity was noticed.

In the case of the PPK or the RTK solution, it is very important to know the reference system to which the raw data are referred. If this information is neglected, the different solutions can be translated up to 30 cm. In the RTK case this effect is more serious because the solution is defined in real time and there no possibility to checking the solution quality.

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