Long Distance GPS Baseline Solutions Using Various Software and EPN Data

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Key words: GPS, positioning, processing software, baseline accuracy, engineering survey

SUMMARY

In this paper an experimental analysis is carried out in order to compare GPS baseline solutions obtained by various commercial processing software. GPS data was taken from the Data Centers of the Euref Permanent Network and the relative solutions are compared to the most accurate solution given by the ITRF2000 coordinates for the current epoch. The selected GPS permanent stations are distributed to the whole EPN area so that different atmospheric conditions and other GPS errors taken into account. Useful results about data handling and the ability of processing software packages for long baseline solutions are presented.

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1. INTRODUCTION

The Global Positioning System has dramatically changed the way that surveyors and other professional engineers measure positional coordinates. These experts can now measure spatial distances – baselines and estimate 3D coordinates of a new point relative to a reference located from a few to many tens of kilometers away. Control points are usually associated with permanent GPS receivers, operated by operational centers. A user can download via ftp the associated data after the GPS campaign. Data post processing, in most cases, is done using GPS commercial software packages purchased with the receivers. The present study was motivated in a big part of the EUREF Network using data from 15 stations, located under different atmospheric conditions in order to experimentally test the effectiveness of the GPS software in the processing of long baselines. The time duration of test data has covered 21 days from 11 until 31 of December 2005 (DOY: 345 to 365) and the processed baseline lengths varied from 63 to 492 Km. Using three different software packages the same Rinex files were independently evaluated in thirteen baselines.

2. EPN STATIONS AND DATA PROCESSING

In order to gain an insight into the variety of numerical results achieved by three different processing software, namely Leica Ski-pro v.3.0, Trimble Geomatics Office-TGO v.1.5 and Pinnacle v.1.0 of Topcon/Javad, the following experiment was applied. A total number of 15 EPN stations was selected forming 13 baselines varying from 63 to 492 Km (Table 1). Stations located in Belgium, Iceland, Italy, Netherlands and Switzerland are shown in Figure 1. Solving a baseline one of the two stations is considered the control point (fixed point) and the other one as the new unknown point. For each baseline data of 21 days gathered in December 2005 was processed. The coordinates of the control points were estimated in ITRF2000 at the midday of the observing campaign (21^{st} December), using the transformation parameters and site velocities given by the IERS (http://itrf.ensg.ign.fr). Using these EPN coordinates the “true” distance of each baseline was computed and used as a standard for comparison to the estimated one by means of the used software. Since the day to day ITRF coordinate differences of the control points were much less than a millimeter they were considered negligible.

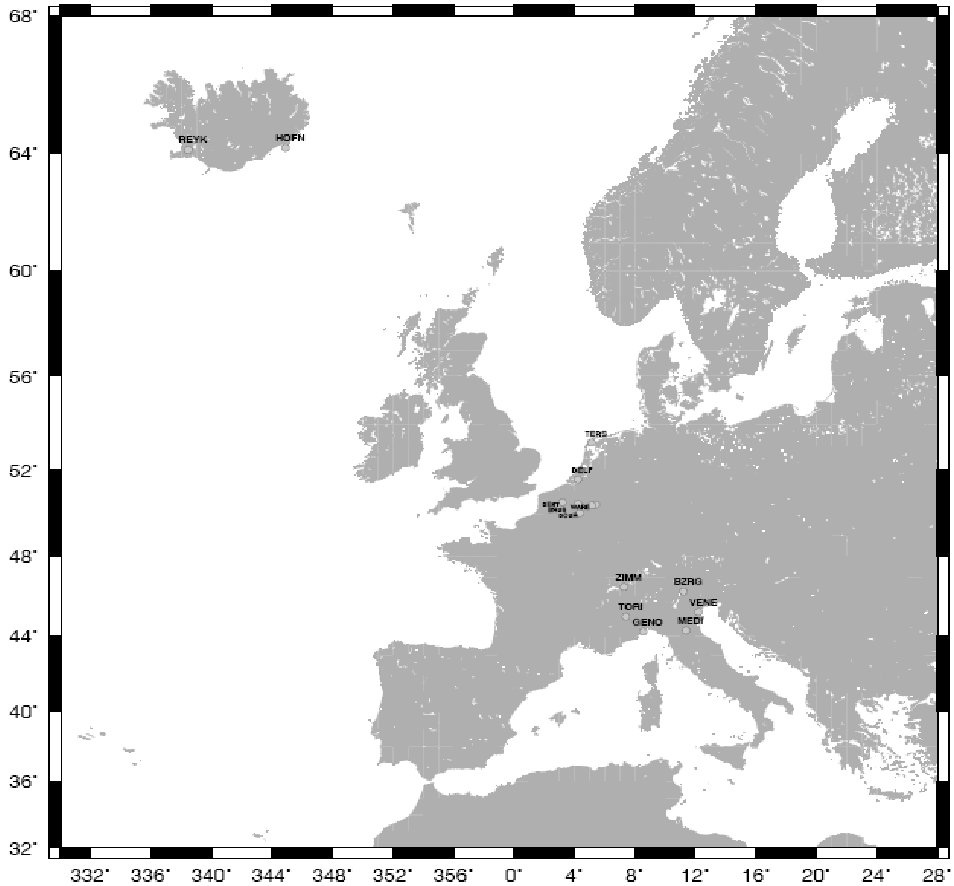

Figure. 1. The selected EPN stations

The IGS final precise orbits were used in all baseline solutions providing satellite positions with a standard error of about 5 cm. Due to mixing different antennas all the respective phase center offsets and variations were properly imported in the processing software. The selected baselines with the receiver's type are presented in Table 1.

Baseline	Baseline Length (Km)	GPS Receivers
1.WARE – BRUS	63.6	Ashtech UZ12 – Z-XII3
2.DENT–BRUS	69.2	Ashtech UZ12 – Z-XII3
3.DOUR – BRUS	79.9	Ashtech UZ12 – Z-XII3
4.VENE – MEDI	115.3	Ashtech Z18 – Trimble 4000SSI
5.TERS – DELF	163.1	Trimble 4000SSI – 4700
6.EIJS – DELF	163.7	Trimble 4700 – 4700
7.GENO – MEDI	217.1	Trimble 4000SSI – 4000SSI
8.BZRG – MEDI	221.2	Leica GRX1200 – Trimble 4000SSI
9.TORI – MEDI	321.0	Trimble 4000SSI – 4000SSI
10.REYK – HOFN	328.3	AOA SNR8000 ACT – Trimble 4000SSI

11.MEDI – ZIMM	417.8	Trimble 4000SSI – NETRS
12.EIJS – ZIMM	450.9	Trimble 4700 – NETRS
13.BRUS – ZIMM	491.8	Ashtech Z-XII3 – Trimble NETRS

Table 1. Selected EPN baselines and receiver information

As noted above the 13 baselines were processed with three different commercial software packages. Identical processing strategies were applied for simplicity and compatibility reasons.

For each software package the following basic processing parameters were used: Cut-off angle: 15°, observation rate: 30 sec (nominally rate for EPN stations), orbits used: Precise, frequencies: L1 and L2, tropospheric model: Hopfield, solution type: Iono free fixed, observing session: one day. All the unknown phase ambiguities were fixed correctly to their integer values in all baseline solutions. We have to point out that for three baselines, No. 11, No. 12 and No. 13, longer than 400Km, no Pinnacle solution is included in the analysis. The reason is that the software proposes a solution based on a trivial triple-difference technique and therefore cannot be recommended for centimeter level accuracy for this type of baseline lengths. In addition it is interesting to note that for the baseline No. 10 (REYK – HOFN) TGO software gives a fixed solution only for 14 days out of 21, a problem that will be discussed later.

3. ANALYSIS OF THE RESULTS

Throughout the present study various statistics describing the estimations of baseline lengths will be used and discussed. As it is well known there is a problem concerning the proper stochastic model of GPS observations. Most of the commercial software packages give too optimistic values for the estimation of the reference variance due to the fact that physical correlation is ignored. Taking advantage of the observation period of the 21 days it is feasible to separate short term error sources. Usually some errors, such as those due to satellite orbits, ionospheric and tropospheric refraction site stability and multipath, may be highly correlated over a time span of a few days (3-4) or even a few weeks. These errors are long term errors and don't change significantly in a day-to-day observing session. In estimating long term precision measurements an observing period of at least three years should be used, a time-consuming problem for professional applications. Therefore they do not average out when combining estimates over several days (Davis et.al., 1989). In our case this assumption holds since the final IGS precise ephemeris were used and the multipath effect is almost the same realizing the permanent monumentation of the EPN sites.

Since site velocities were taken into account the correlation of atmospheric errors, especially the ionospheric refraction, should be of concern. Fortunately this effect is eliminated using the L_3 ionospheric–free linear combination (Hofmann-Wellenhof et.al 1997, Rizos 1999, Dermanis 1999, Fotiou and Pikridas 2006). Handling the tropospheric refraction effect no additional parameters were estimated as this option is not available in all software packages.

Professional engineers use data for short time periods, e.g. few hours or a couple of days, and the precision of the baseline solution results is affected by short term errors. Consequently, measures of this factor is of most importantance in usual applications.

A measure of the short term precision could be the repeatability R expressed by the weighted rms about the mean of daily estimates, determined from a 24 hour session or one day solution (Larson et.al., 1991). If there are *n* independent values of the computed baseline lengths, here $n = 21$, with estimated standard deviations $\sigma_1, \sigma_2, \ldots, \sigma_n$, then R is given by

$$R = \sqrt{\frac{\frac{n}{n-1}\sum_{i=1}^{n}\frac{(y_i - \bar{y})^2}{\sigma_i^2}}{\sum_{i=1}^{n}\frac{1}{\sigma_i^2}}}\ , \text{ where } \bar{y} = \frac{\sum_{i=1}^{n}\frac{1}{\sigma_i^2}y_i}{\sum_{i=1}^{n}\frac{1}{\sigma_i^2}} \text{ the weighted mean of } y_i\ . \qquad (3.1)$$

Short term precision R as computed by each one of the three software is plotted as a function of the baseline length and shown in Figure 2.

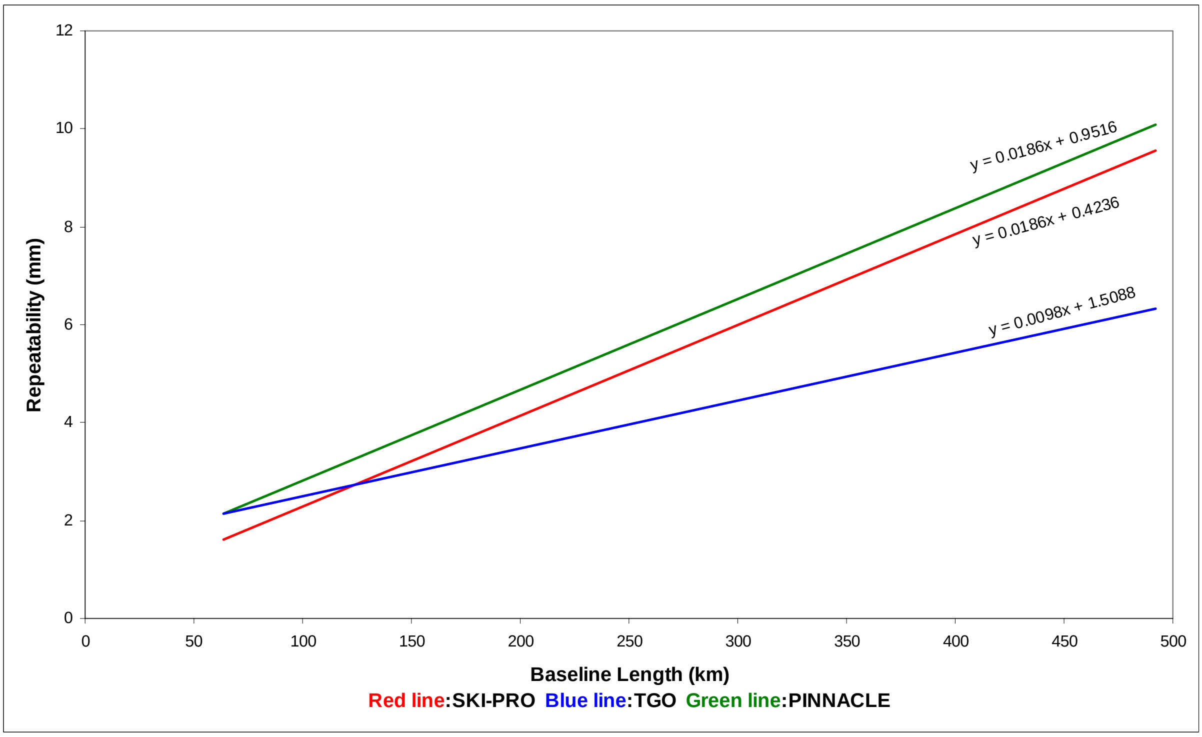

Figure 2. Best fitting lines on repeatability values according to baseline lengths for the test GPS software packages

Fitting a line to the software scatter values a precision of 1.51 mm + 0.98 parts in 10^8 for TGO, 0.42 mm + 1.86 parts in 10^8 for Ski-pro and 0.95 mm + 1.86 parts in 10^8 for Pinnacle is derived. The scale factor for Ski-pro is equal with Pinnacle's and both of them are two times greater than TGO's. Figure 2 shows a significant correlation between the three solutions, especially for baseline lengths less than 150 Km whereas Ski-pro and Pinnacle have the same scale factors. For short baselines, as expected, the three software packages produce almost the same results.

A compatibility test between the repeatability values calculated from each software could be

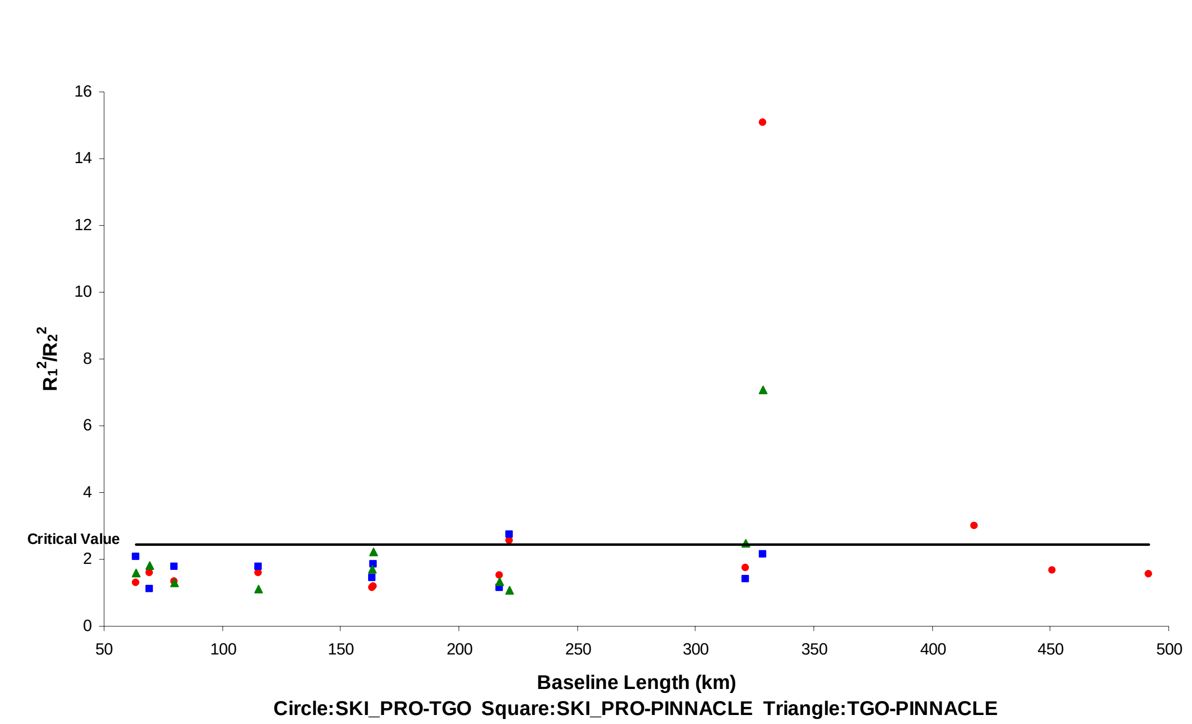

Figure 3. Repeatability compatibility test as a function of baseline length between pairs of GPS software

based on the ratio (σ_i^2/σ_j^2), which follows the F- distribution, for all computed baselines. The null hypothesis between each pair of software is formulated as $H_0: \sigma_i^2 = \sigma_j^2$ and tested against the alternative $H_a: \sigma_i^2 \neq \sigma_j^2$. For a significance level α=0.05, H_0 is accepted if

$$\frac{\sigma_i^2}{\sigma_j^2} \leq F_{n_{i-1},n_{j-1}}^{\alpha/2} \tag{3.2}$$

where $\sigma_i^2 = R_i^2, \sigma_j^2 = R_j^2$ and $F_{n_{i-1},n_{j-1}}^{\alpha/2}$ the critical value with $n_{i-1}=n_{j-1} = 20$ degrees of freedom. Test results are mapped in Figure 3. There is an obvious rejection of the null hypothesis for baseline Reyk–Hofn (328 Km) between Skipro-TGO and TGO-Pinnacle and marginally between Skipro-Pinnacle. The same conclusions are drawn if we use the results based on the formula (3.3) given below.

According to a different approach the precision given by each software and used in (3.1) can be ignored. Instead the new precision measure r, is computed for the same as above scheme by (Dermanis 1986, Andersen et.al., 1993)

$$r = \sqrt{\frac{1}{n-1}\sum_{1}^{n}(x_i - \overline{x}_i)^2} \quad , \quad \overline{x} = \frac{1}{n}\sum_{1}^{n} x_i \tag{3.3}$$

where x_i are the daily estimates of the baseline lengths using each software. This is another technique to determine the effect of the representative formal errors on the baseline length. Similarly to Figure 2, the corresponding best fitting lines are shown in Figure 4. Comparing Figure 4 to Figure 2 we can see that as far as the constant term is concerned, TGO, Pinnacle and Ski-pro show a degration of about 3.6, 2.6 and 1.2 times, respectively. The scale factor increases to 1.96 and 1.36 times for TGO and Ski-pro while for Pinnacle remained the same. It is obvious that the new results are similar to the previous ones and therefore the two approaches, using R or r, do not differ significantly. The same holds for the results of the statistical hypothesis testing as applied above.

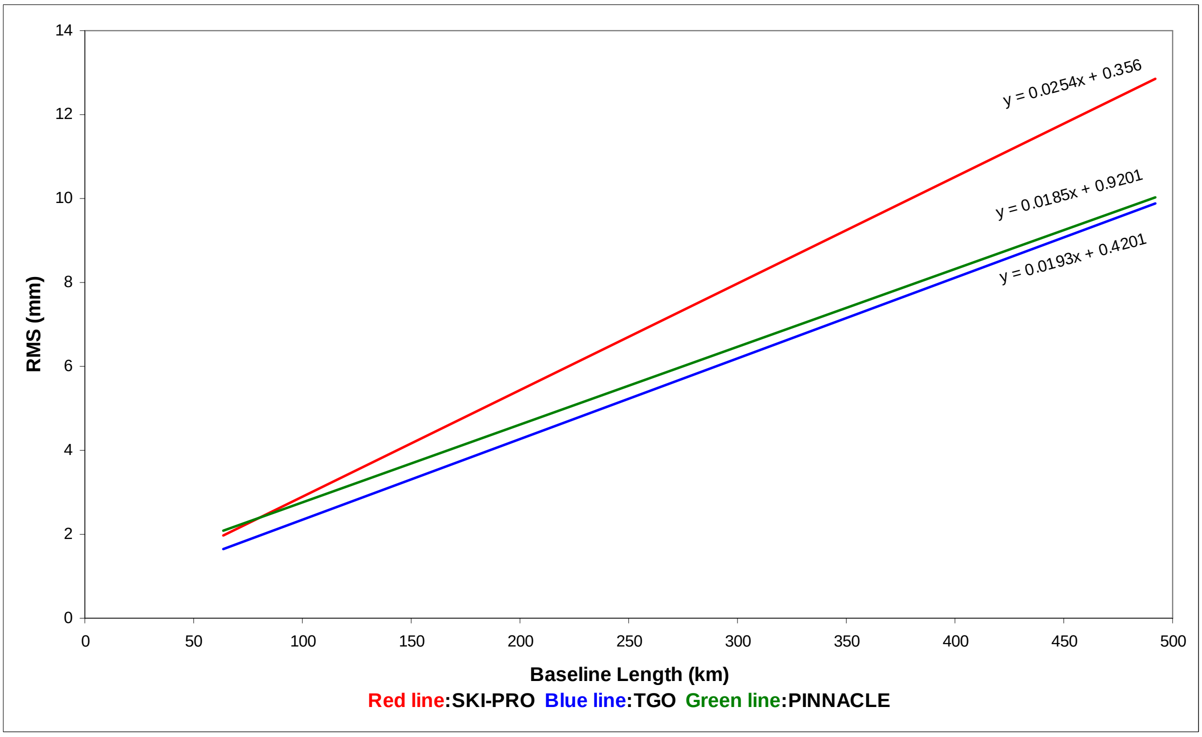

Figure 4. Best fitting lines on the derived rms values versus baseline lengths for the test GPS software's

A much more detailed insight into the accuracy relations can be gained by comparing the "true" distance of each baseline computed by the EPN network coordinate, to the mean distance and to the weighted mean distances derived by the same formulae (3.1 & 3.3). This test could be characterized as a check of external accuracy or reliability as the EPN coordinates are derived through network solution using more sophisticated software packages

like Bernese, Microcosm etc., with advance processing strategies on baseline determination (Hugentobler et. al., 2005).
For the new tests, differences for each baseline length, between EPN – Pinnacle (Figures 5a, 5b) marked by triangle, EPN – Ski-pro (Figures 6a, 6b) marked by circle and EPN – TGO (Figures 7a, 7b) marked by square, were computed. The respective differences in the relative Figures are marked by open and solid objects. Solid item means that the length difference is outside the rms interval (1-sigma) while open means inside. As noted almost all differences are of the order of a few millimeters and lie outside the respective intervals. For a 3-sigma confidence interval almost all differences are within the confidence intervals.

There is an exception for the REYK – HOFN baseline which shows few centimeter differences (up to 3 cm) and needs a detailed study given below. Based on these comparisons we conclude that the two statistics (3.1&3.2) are almost equivalent for describing the short term precision and the selected processing parameters. Perhaps in a long term analyses there would be some remarkable differences on precision and accuracy description.

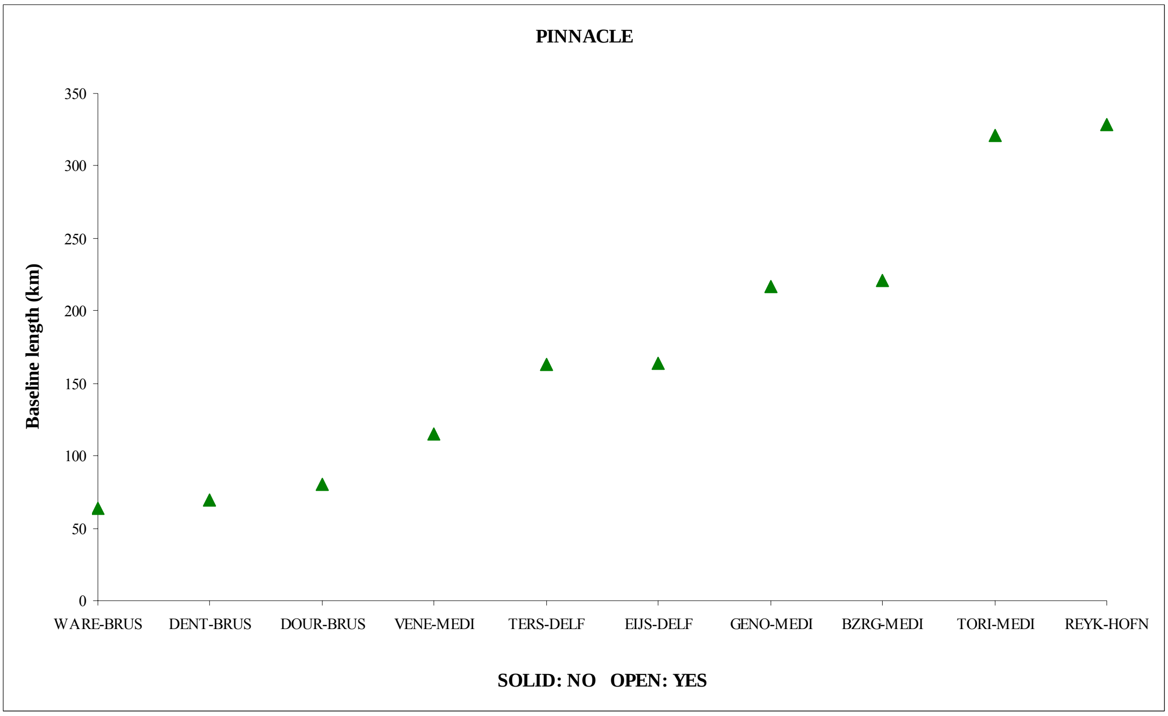

Figure 5a. Comparison between the weighted mean distances with their rms and EPN values for all the tested baselines using Pinnacle for 1-sigma confidence region. The solid triangle means that the true distance is outside the confidence region of the weighted mean (No). The open triangle means the opposite (Yes).

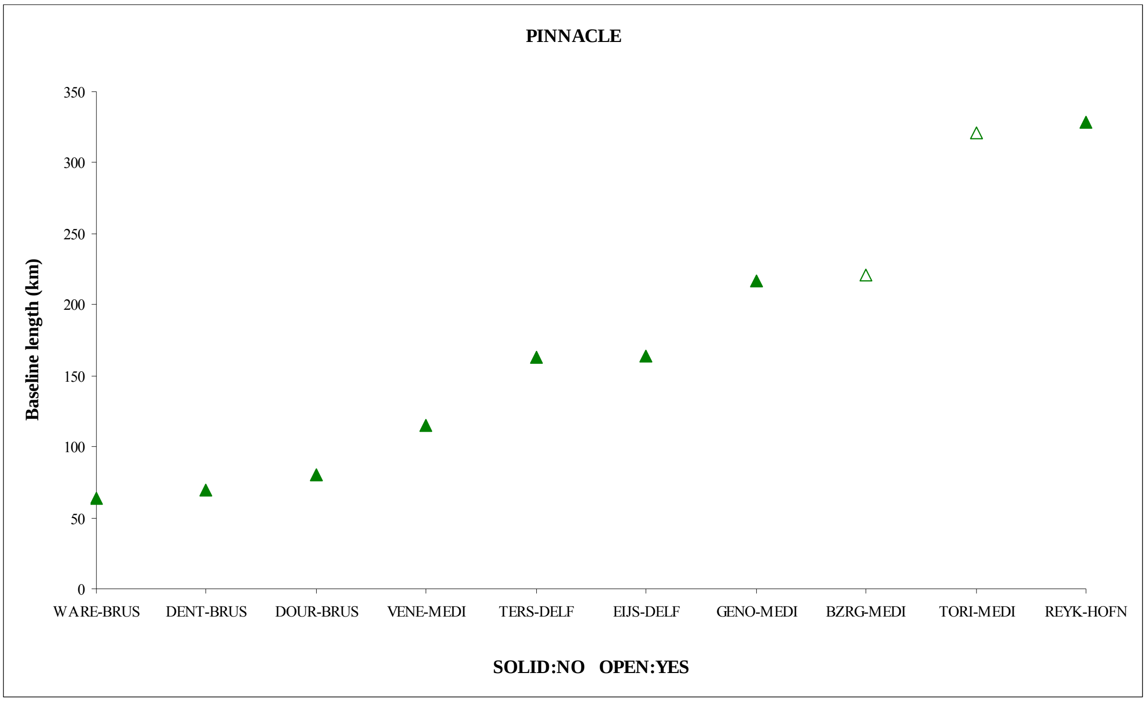

Figure 5b. Comparison between the mean distances with their rms and EPN values for all the tested baselines using Pinnacle for 1-sigma confidence region. The solid triangle means that the true distance is outside the confidence region of mean value (No). The open triangle means the opposite (Yes).

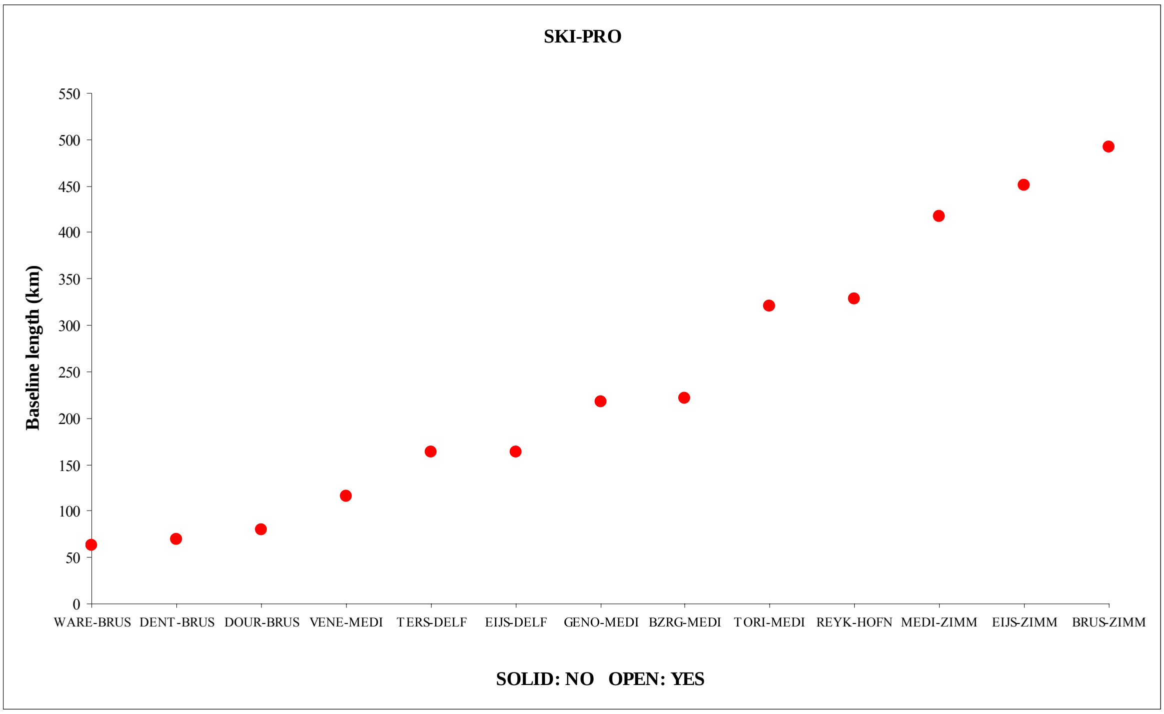

Figure 6a. Comparison between the weighted mean distances with their rms and EPN values for all the tested baselines using SKI-PRO for 1-sigma confidence region. The solid circle means that the true distance is outside the confidence region of weighted mean (No). The circle means the opposite (Yes).

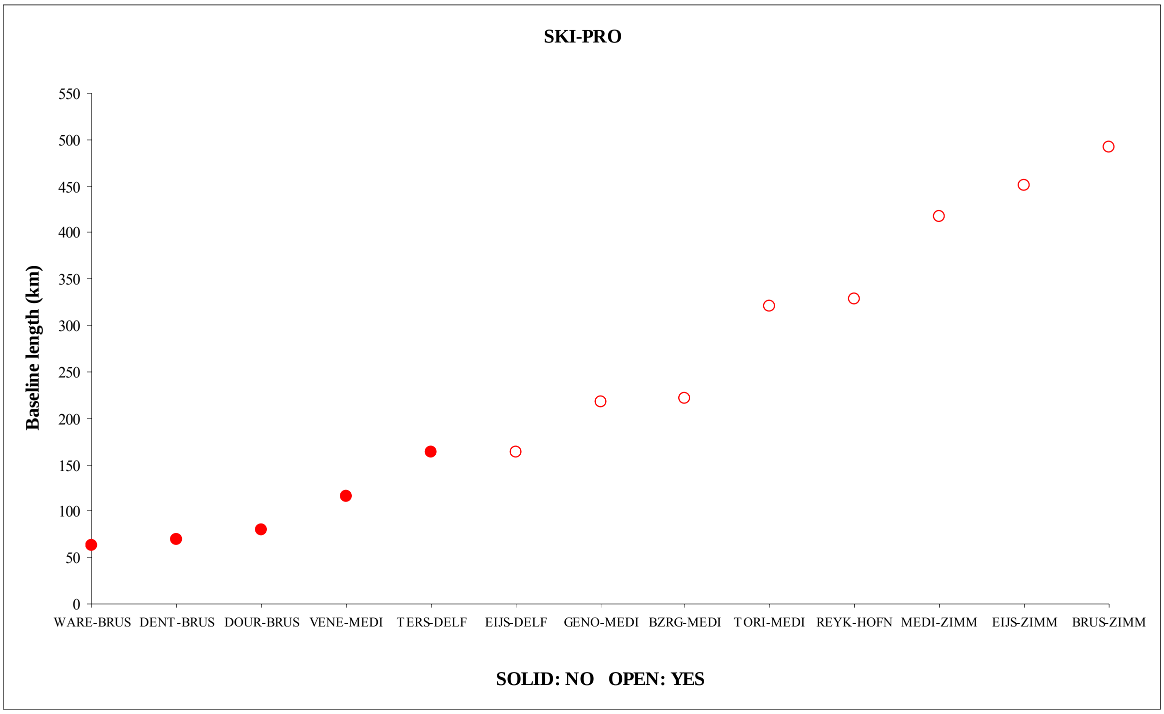

Figure 6b. Comparison between the mean distances with their rms and EPN values for all the tested baselines using SKI-PRO for 1-sigma confidence region. The solid circle means that the true distance is outside the confidence region of mean value (No). The open circle means the opposite (Yes).

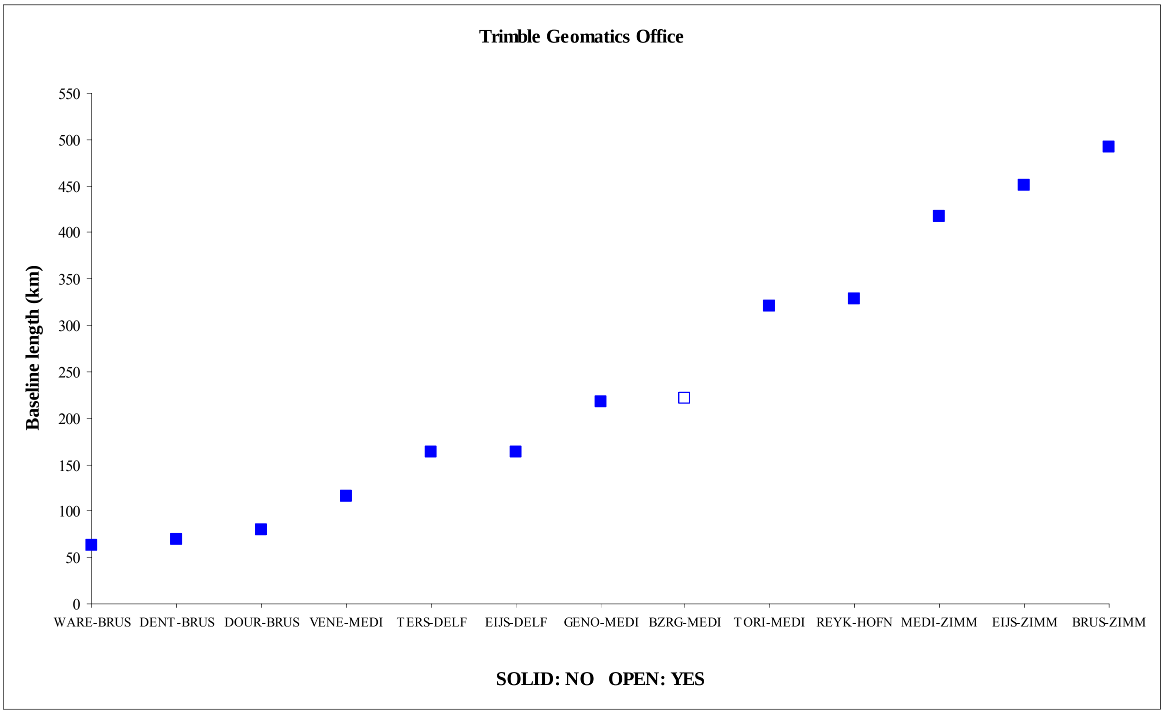

Figure 7a. Comparison between the weighted mean distances with their rms and EPN values for all the tested baselines using TGO for 1-sigma confidence region. The solid square means that the true distance is outside the confidence region of weighted mean (No). The open square means the opposite (Yes).

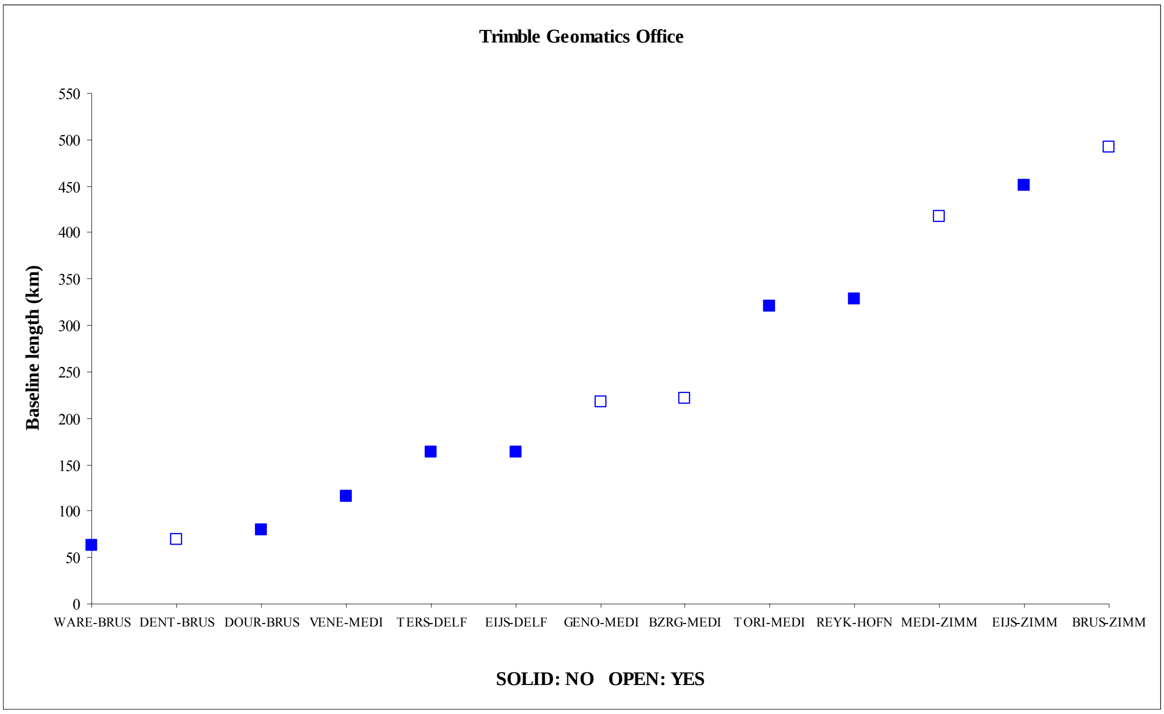

Figure 7b. Comparison between the mean distances with their rms and EPN values for all the tested baselines using TGO for 1-sigma confidence region. The solid squares mean that the true distance is outside the confidence region of mean value (No). The open square means the opposite (Yes).

3.1 Quality check of the raw data for the Reyk-Hofn baseline

The differences for the Reyk-Hofn baseline between EPN and software solutions are about three to four times bigger than all other baseline differences. It is known that the precision of differential GPS surveys on such scales is several millimeters in the horizontals and almost twice that in the vertical component. The accuracy of these surveys may be depend on which GPS receivers are used and how the software analyzes the measurements (Larson et.al, 1991). It is interesting to note again that only for 14 days (21 total) the ambiguities resolved using TGO, for 20 days using Ski-pro and 21 days using Pinnacle. In addition the statistical F-test (3.2) has failed for this baseline.

A quality check on GPS measurements using the GNSSQC (Leica) was applied. It is a stand-alone software that can perform quality checking and reporting of the logged Rinex data. Based on the quality check results we focus on some basic topics relative to the quality of the GPS raw data. The first topic is about the data completeness and their tracking performance on L_1 and L_2 frequencies. For both receivers, AOA SNR8000ACT in Reykjavik and Trimble 4000SSI in Hoefn, these values were almost 100% for all the test period. As far as the multipath is concerned both values of this bias for L_1 and L_2 code measurements were less that the threshold set by the software. Another critical factor is about the number of cycle slips. On this point the program reports many cycle slips for Hoefn receiver, more than a marginal value and throughout the observing period. For Reyk station the same situation happened but only for six days.

Next quality indicator was the receiver clock offset. It is known that the offset between the receiver clock and the GPS system clock ensemble is allowed to change with time without any significant constraints, though some receiver manufacturers control its size by adjusting or steering the receiver clock. A change in receiver clock bias changes the observations. Figures (8a & 8b) show the behavior of Reykjavik and Hoefn receiver clocks during the test campaign without a trend removal. Our purpose is to draw attention to frequency stability of the different clocks rather than to provide specific quantitative results. We can note that the clock bias of Trimble receiver is indeed predictable and swing widely constant in the observing period. On the contrary, the Rogue receiver presents big changes for several days and this not so robust behavior may have an influence on the quality of GPS data. Reprocessing this baseline, without those observing windows characterized by big clock offset variations the baseline was successfully resolved with fixed ambiguities (now resolved with TGO). Nevertheless the difference from the EPN solution has changed only a few millimeters. Almost the same results derived when all the days with big amount of cycle slips and clock offset variations were excluded. We cannot explain this result with a satisfactory way. Obviously these clock jumps are eliminated when forming double differences of phase observations. The magnitude of differences is bigger than the site velocities and for this kind of product estimation, like site velocities, orbit determination, earth rotation parameters etc., and especially for smaller time periods, the use of more sophisticated software is mandatory.

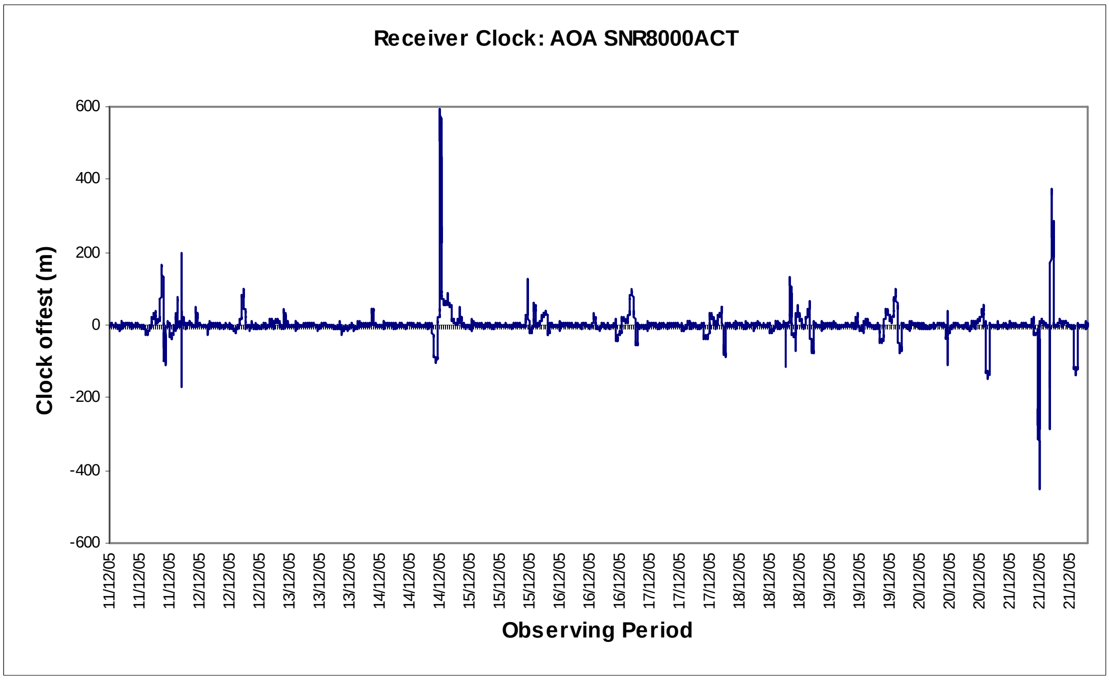

Figure 8a. The clock offset of Reykjavik station receiver for the test period.

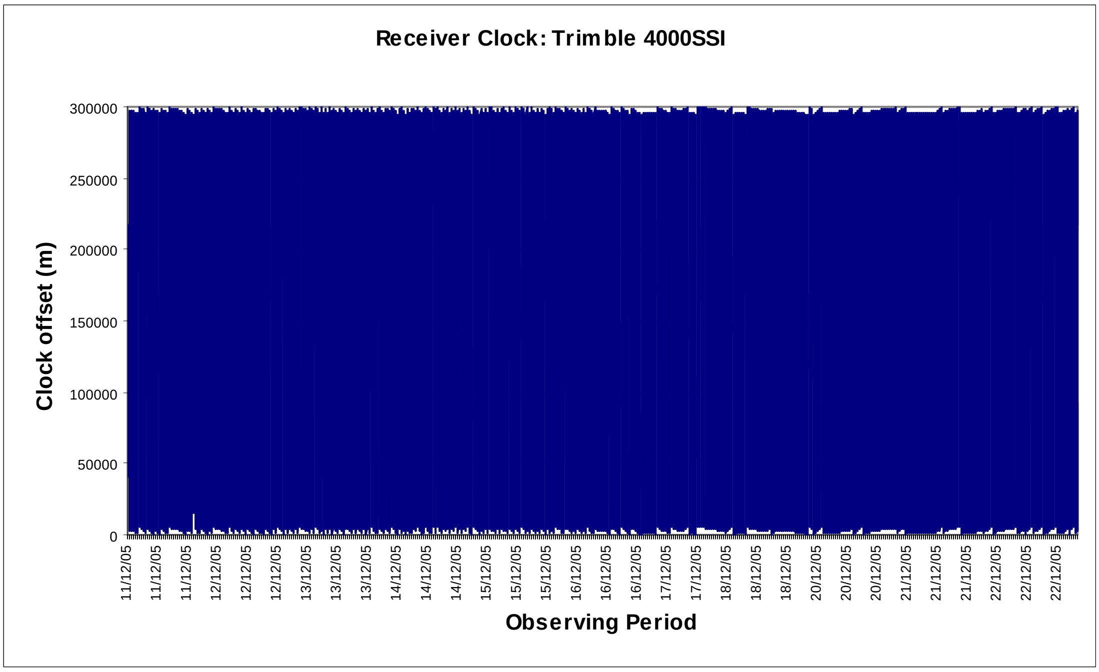

Figure 8b. The clock offset of Hoefn station receiver for the test period

4. CONCLUSIONS

Several sets of GPS data for 13 baselines of the Euref Permanent Network are processed in order to evaluate the quality (precision and reliability) of GPS baselines using the commercial software packages of Leica (Ski-pro), Trimble (TGO) and Javad (Pinnacle). The study was restricted to lengths ranging from 63 to 492 km. The test data are spanned in 21 consecutive days of observation and therefore the short term measure of precision can be determined. We have used two different statistic formulae in order to compute the repeatability for each baseline processed by each one of the software packages and a hypothesis testing on the variance compatibility as well. The best fitting lines on the repeatability scatter show a length dependence of 0.35-1.5 mm for the constant term and 0.98-2.54 parts in 10^8 for the scale factor. The obtained precision is too optimistic and all the commercial software solutions have almost the same behavior under the same processing parameters. The same conclusions derived by means of hypothesis testing.

An accuracy investigation of the estimated baseline lengths by comparing them to those derived from EPN coordinates was carried out. In all cases all the length differences except one are at the level of few millimeters (2-7), being within the formal accuracy intervals. The examined commercial software passed the tests successfully and therefore can produce reliable results in almost any professional project. For long baseline solutions, usually over 500 Km, or for precise products like site velocities, orbit determination, earth orientation parameters, more sophisticated analysis on data processing is needed, offered usually by scientific software packages, in order to avoid some lack of the preferable accuracy.

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