BaselineByCode: An Educational -Purpose Software Package for GPS Baseline Determination Using Code Measurements

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Key words: GPS, software development, code measurements, relative positioning, baseline determination.

SUMMARY

A complete software package has been developed for GPS baseline determination based on code data, and on double differences between simultaneous observations. It is a standalone windows application (entitled "BaselineByCode") with an educational user-friendly interface written on Delphi-5. Although the accuracy is comparable with the results obtained from commercial software, this package has the advantage of extended parameterization, allowing selection of input data types (C/A, P1, P2), ephemerides (broadcasted, precise), ionospheric and tropospheric models, optimum selection of reference satellite, signal-to-noise threshold level, cut-off angle, tolerance for the synchronization of observations, residual magnitude, time interval for all satellites, double differences for selected satellites, etc. In addition, the package displays and prints on demand all intermediate results (in textual or graphical form), exchanging data and results with other windows-based applications. The user may study the results obtained from adjustments with various parameterization criteria. Every solution is obtained with an 1-cm convergence limit.

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1. INTRODUCTION

A major objective of an educational package is a step by step analysis and presentation of the results during processing. Following this scope, the Department of Geodesy and Surveying has developed a windows-based software package written in Delphi programming language, which uses solely code GPS measurements. It has a user-friendly interface with extended parameterization for processing and displaying. It also prints and saves each type of results in textual or graphical form. Various models and useful options for the pre- and post processing of observations are selected by the user, so that helpful information and advanced analysis can be applied by an experienced user or a researcher using the intermediate results. Many types of graphical forms and report files can be saved and modified according to the user demands. The test solutions that were applied on baselines from 5 to 200 km and the results as compared to solutions using phase data (with fixed ambiguities), showed distance differences from 0.4 to 1.2 meters, as expected. Comparing with commercial software using only code measurements, the baseline differences are of the order of one dm. The package provides online help for (almost) every main panel option.

2. DATA IMPORT AND PROCESSING PARAMETERS

The main objective of the "BaselineByCode" software package is the baseline solution. Upon completion of a GPS survey, the collected data are imported for each receiver in RINEX format (Gurtner & Mader, 1990). Most of GPS data exchanges are based on this format, so that measurements from different receiver manufacturers can be used for processing. The software displays three main panels (*"data"*,*"results"*,*"utilities"*) and three auxiliary ones (*"info"*,*"print" and "help"*). Within the first panel ("data"), the user can select the processing parameters (see figure 1).

The upper *"data"* section displays the WGS84 cartesian coordinates, from both reference and rover receivers, as exported from the RINEX observation files (or altered by the user), the receiver type, the observing window, the total numbers of epochs with the observation rate, the post-processed coordinate corrections and the final baseline length with its associated rms.

In the middle *"data"* section there is a graphical representation of the satellite visibility for both sites during the observing period.

The lower section of the "data" is divided into six parts where the processing options are specified. The first selection is related to the type of satellite ephemeris being used. The program can use either broadcast or precise (in SP3 format) ephemerides. The precise ephemeris can be downloaded from a known data center (e.g. the Center for Orbit Determination in Europe) and the position vectors between the given epochs are obtained by Lagrange interpolation, based on polynomial base-functions is used (Hofmann-Wellenhof et al. 1997). The second selection refers to the choice of the code observations. The user may select C/A or P1, P2 on both frequencies. The next selection refers to the choice for the ionospheric refraction model. In addition to Klobuchar's iono-model with the eight coefficients (Klobuchar 1987), which included in the rinex navigation file, the program also uses the Single Layer Model (Georgiadou & Kleusberg 1988, Hugentobler et.al. 2001, Pikridas & Fotiou 2003). The determined parameters for this model can be imported by the user, since the program processes code measurements only, and not phase data in order to estimate the SLM parameters. The next atmospheric selection deals with the tropospheric models. Most of the well-known models, like Collins, Magnavox, Saastamoinen, Hopfield, Goad and Goodman and Marini, are included. The program also computes the atmoshperic components, like temperature, pressure and relative humidity for each site assuming a standard atmosphere. It should be pointed out that the user may modify these values if a better (local profile) model is available. The final two sub-sections are referred to restrictions on observations. Measurements with low signal-to-noise ratio, usually from satellites at low elevation, are subjected to high interference, so that the software has the option to select observations according to signal strength. Similar option is the change of the cut-off angle value for the collected data. Finally, the user may modify the selection of the observing window and the choice of the maximum residual value for the double differences.

Figure 1, shows the "data" panel and all the processing options of the BaselinebyCode package.

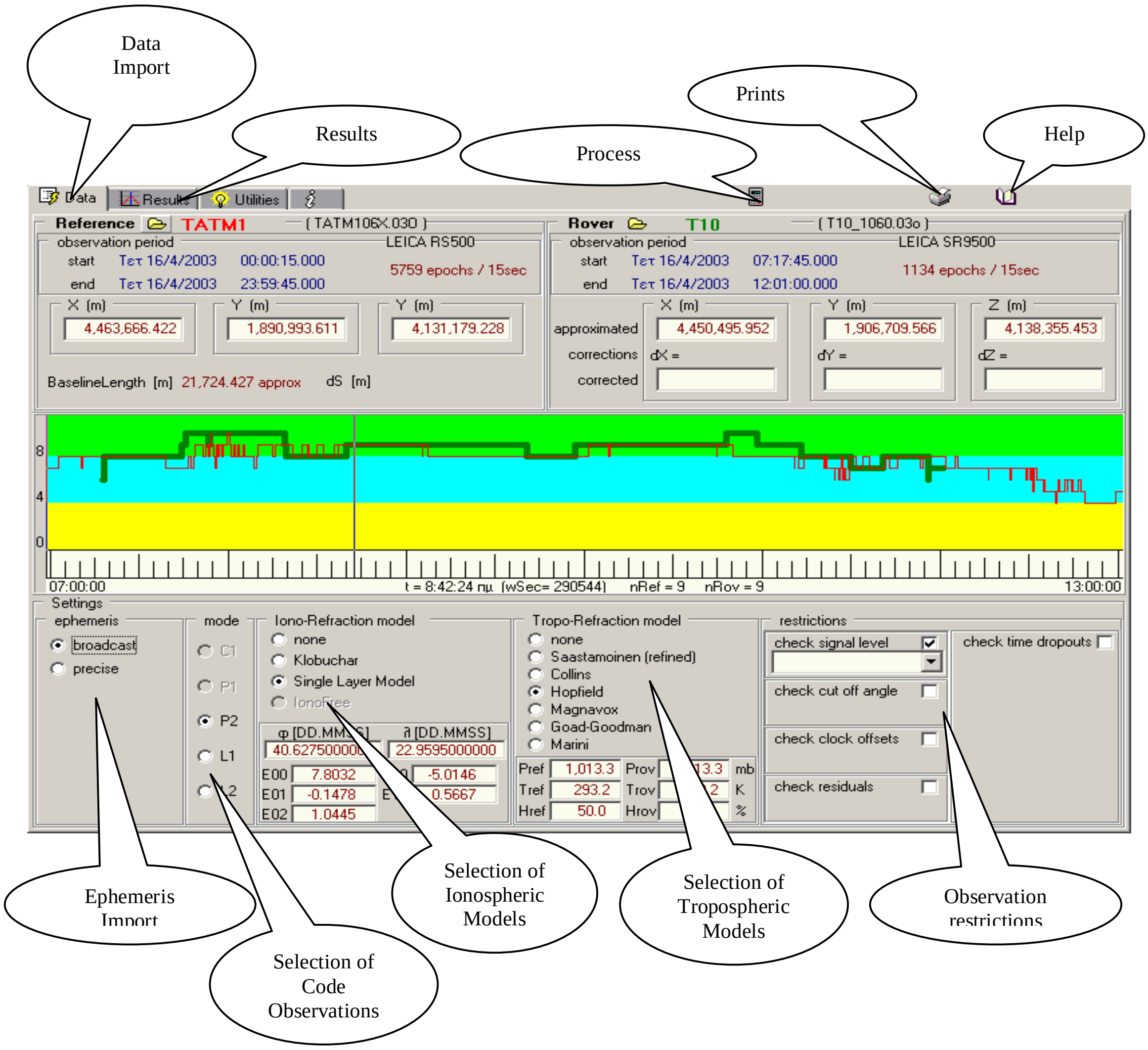

Fig. 1: The main panel of the program Baseline by Code

3. POSITIONING MODEL – SOFTWARE PHILOSOPHY

The code pseudorange for a satellite i and a point K (Hofmann-Wellenhof et.al. 1997, Fotiou & Pikridas 2002) can be modeled as

$$P_K^i = \rho_K^i + c\delta_K - c\delta^i + I_K^i + T_K^i + e_K^i \tag{3.1}$$

where P_K^i is the measured code pseudorange between the observing site K and the satellite i, ρ_K^i is the geometric distance, c is the speed of light (c=299792458 m/s) I_K^i, T_K^i are the ionospheric and tropospheric biases, $c\delta_K, c\delta^i$ the satellite and receiver clock errors accordingly, e_K^i the random error and ignoring multipath effect.. The point coordinates to be estimated are implicit in the distance ρ_K^i, written as

$$\rho_K^i = \sqrt{\left(X^i - X_K\right)^2 + \left(Y^i - Y_K\right)^2 + \left(Z^i - Z_K\right)^2} \qquad (3.2)$$

where X^i, Y^i, Z^i are the components of the geocentric position vector of the satellite and X_K, Y_K, Z_K the three unknown point coordinates of the observing point all expressed in the ECEF (Earth Centered Earth Fixed) system.

The objective of relative positioning is the determination of the coordinates of the unknown (rover) point with respect to a known (reference) one. Assuming two points *A* and *B*, and two satellites *j* and *k*, the corresponding pseudoranges can be formulated as

$$P_A^j = \rho_A^j + c\delta_A - c\delta^j + I_A^j + T_A^j + e_A^j \quad , \quad P_B^k = \rho_B^k + c\delta_A - c\delta^k + I_B^k + T_B^k + e_B^k \qquad (3.3)$$

Forming the double difference for specific epoch,

$$P_{AB}^{jk} = \rho_{AB}^k - \rho_{AB}^j = (\rho_B^k - \rho_A^k) - (\rho_B^j - \rho_A^j) + I_{AB}^{jk} + T_{AB}^{jk} + e_{AB}^{jk} \qquad (3.4)$$

the canceling effects of the receiver and satellite are obvious and the other biases are reduced as well. Equation (3.4) is used for the solution of the GPS baseline.

According to the least squares adjustment (Dermanis and Fotiou, 1992) and using the method of observation equations (method of parameters), the above equation (3.4) has to be linearized with respect to the coordinates of the unknown point which could be point A or B or generally point K. Assuming a set of approximate coordinates (X_0 , Y_0 , Z_0) for the unknown point K (imported from the rinex observation file) an approximate distance can be calculated. The partial derivatives are given by

$$\left.\frac{\partial \rho_K^i}{\partial X_K}\right|_0 = -\frac{X^i - X_0}{\rho_0^i} = \alpha_X^i$$

$$\left.\frac{\partial \rho_K^i}{\partial Y_K}\right|_0 = -\frac{Y^i - Y_0}{\rho_0^i} = \alpha_Y^i \qquad (3.5)$$

$$\left.\frac{\partial \rho_K^i}{\partial Z_K}\right|_0 = -\frac{Z^i - Z_0}{\rho_0^i} = \alpha_Z^i$$

so that

$$\rho_K^i = \rho_0^i + a_X^i \delta X_K + a_Y^i \delta Y_K + a_Z^i \delta Z_K \tag{3.6}$$

Finally, with the help of (3.6) the system of linear observations equations is formed and the estimation of the unknown point coordinates is obtained by the well know least squares adjustment.

4. UTILITIES AND RESULTS PRESENTATION

As has been stated in the introduction, "BaselineByCode" publishes all intermediate results. This option is easily activated from the *"results"* panel. There are two types of presentation, text files and graphical forms.

In the textual form, the software outputs (upon user request) the clock offsets file for each epoch, the single and double difference residuals, the design matrix and its transpose, the weight matrix, the excluded observations, and for each observation point (reference and rover), the satellite positions as a series of time-tagged Earth Center Earth Fixed (ECEF) coordinates (see Figure 2), as well as all the necessary information for the selected atmospheric models.

As long as the graphical form is concerned, the program illustrates the satellite elevation, dilution of precision factors, ionospheric and tropospheric refraction for each satellite according to its elevation during the observing window and the estimated satellite residuals. Figure 3, shows a representative residuals diagram for a selected satellite, where, the blue dots are the residuals values and the red line is the satellite elevation. It must be emphasized that for the graphs of the atmospheric refraction there are active options like the geographical location, (latitude and longitude) of the receiver, the satellite elevation and azimuth, the reference atmospheric values and all atmosphere-related critical parameters. The user has the option to alter these values in order to monitor the corresponding disturbance. Figure-2 is an orbit information text file, which includes all the necessary information for each common epoch (e.g. satellite position, elevation, azimuth, satellite clock offsets, etc). This information is made available to the user for further research.

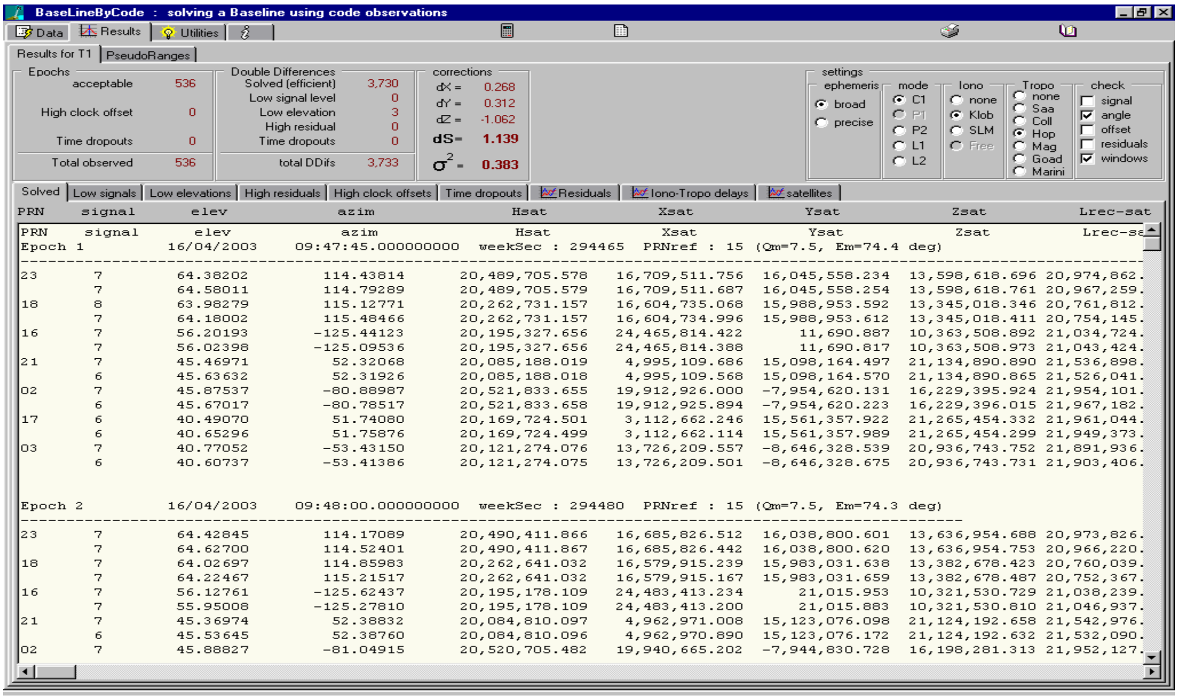

Fig. 2: The orbit information text file of the program Baseline by Code

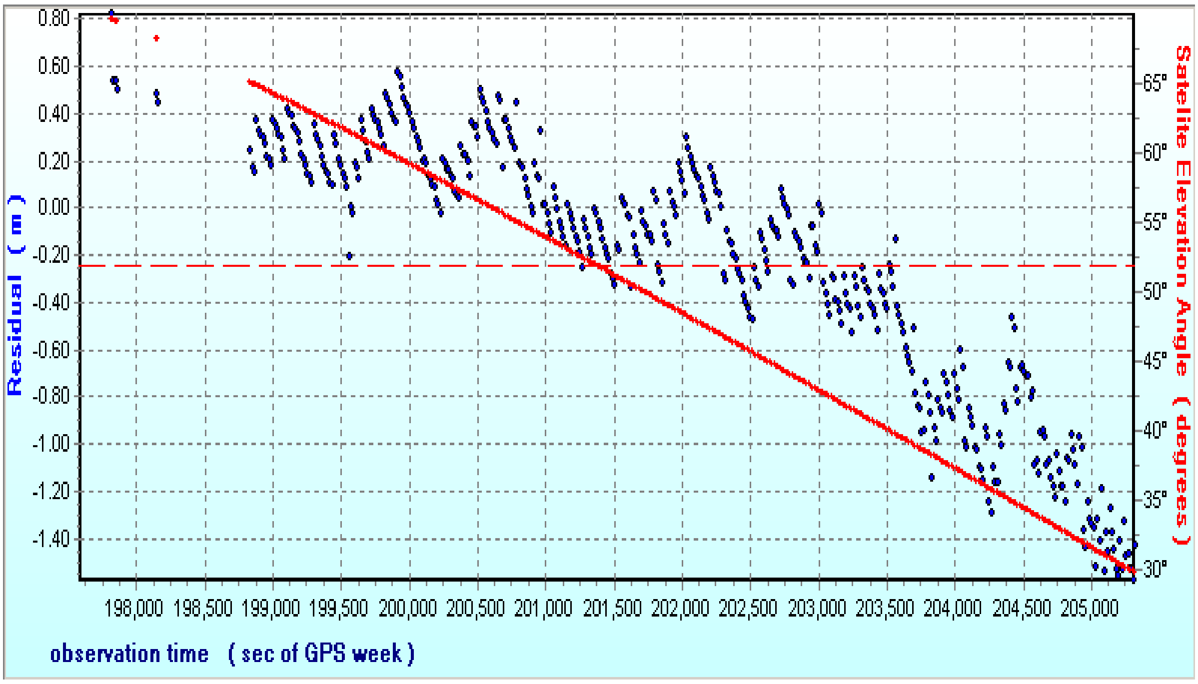

Fig. 3: The satellite residual panel of the program Baseline by Code

In figure 4 the tropospheric refraction using all the available models (using different color lines) according to satellite elevation is plotted. This diagram can be easily viewed from the *"utilities"* panel. Same options are also available for the ionospheric models and appear in figure 5.

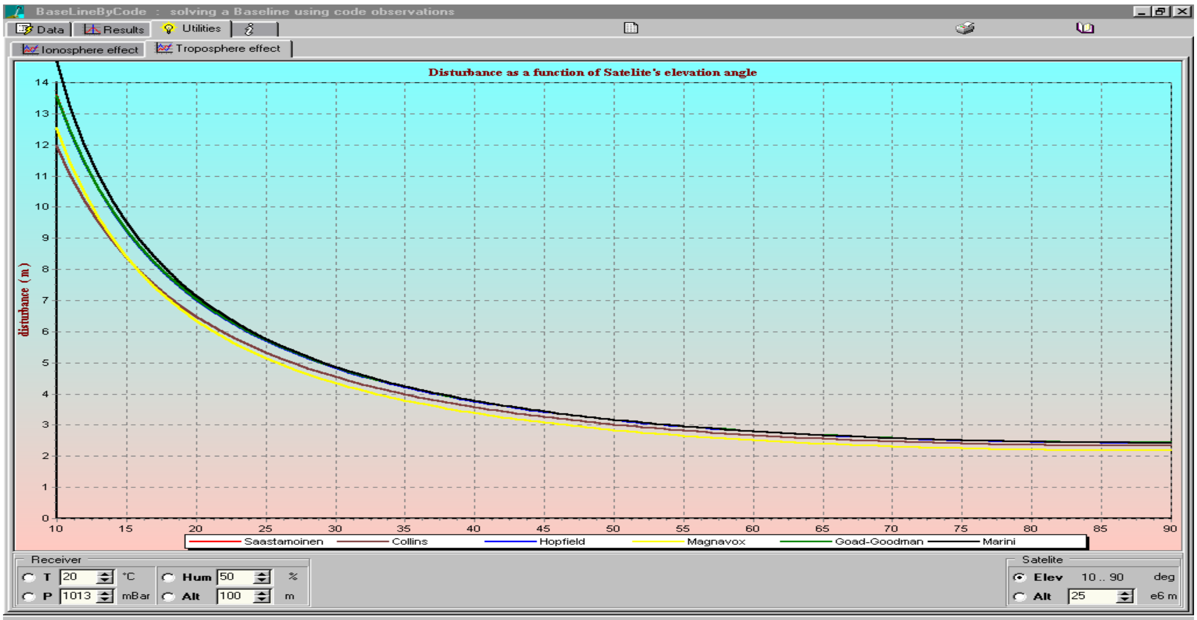

Fig. 4: The computed tropospheric refraction Vs satellite elevation.

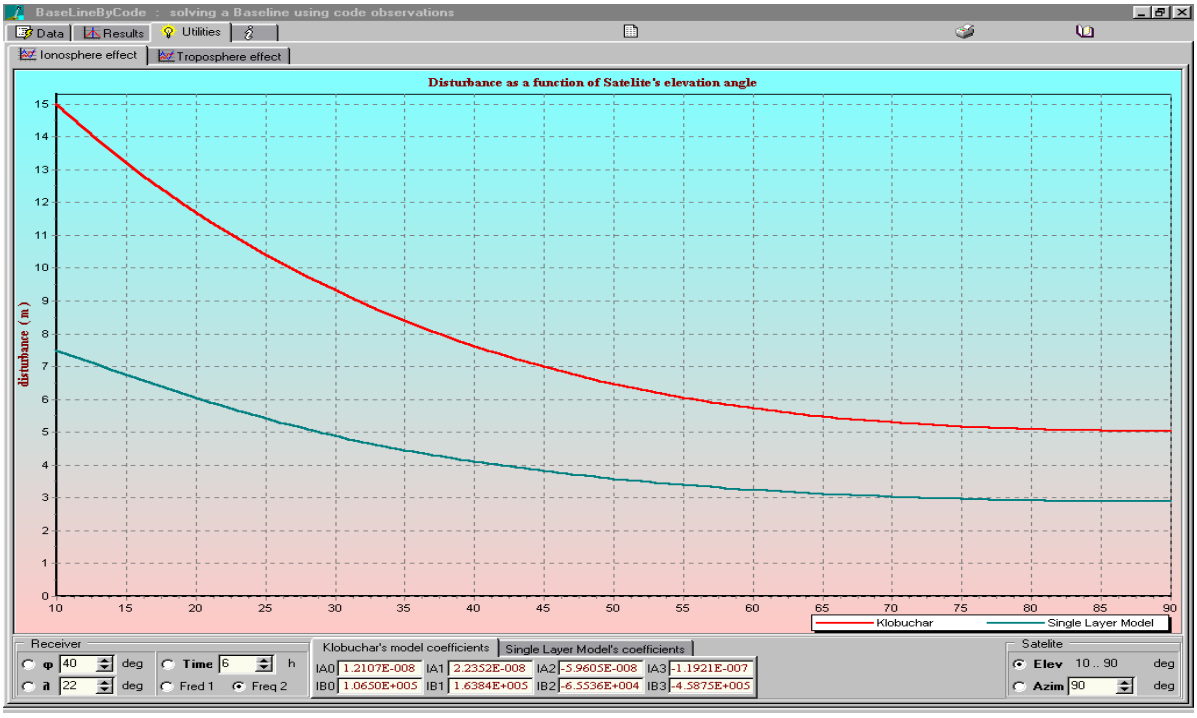

Fig. 5: The computed ionospheric refraction Vs satellite elevation

4. COMPARISONS WITH COMMERCIAL SOFTWARE PACKAGES

In order to evaluate "BaselineByCode" and to assess the reliability of its results, we re-processed the same data using the receiver manufacturer's software, choosing the same parameters. Figure 6 shows the baselines differences for the above process using C/A or P code measurements for various baseline lengths. An interesting remark is that using the P code data for baselines below 50 Km the baseline differences are greater than when using the C/A code. This point needs to be further investigated.

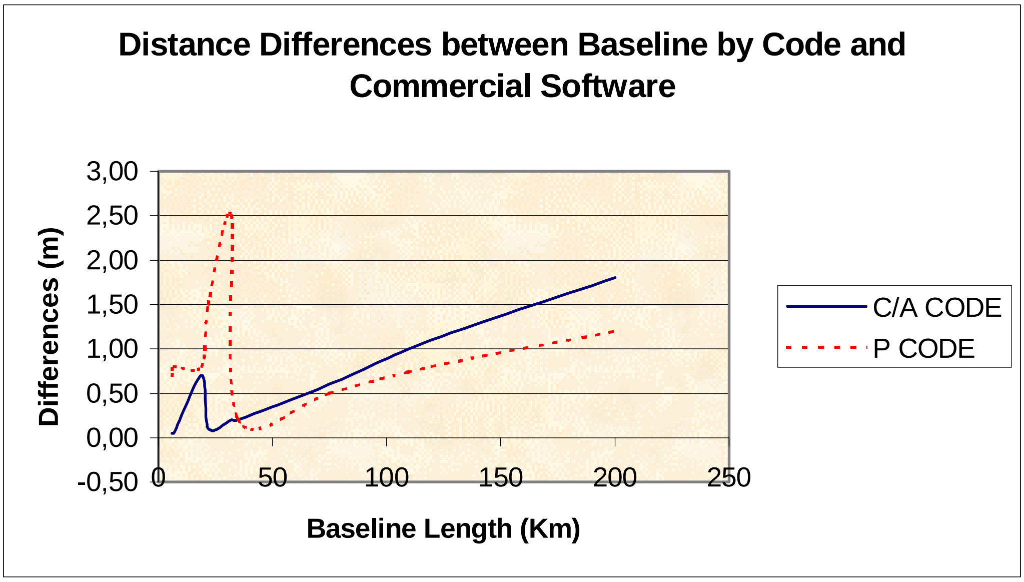

Fig. 6: The baseline distance differences between BaselineByCode and commercial software using C/A and P code measurements

5. CONCLUDING SUMMARY

As an educational - purpose software, "BaselineByCode" has been developed for the determination of a baseline using solely code GPS measurements. All tests that have been contacted, lead to the following useful remarks.

The final results depend upon a number of initially selected processing parameters. Sometimes, these parameters may play a critical role for the final accuracy and many of them are not well known to the inexperienced user or to a student. It is essential for these users to study the effect of certain parameters on the final results. For this reason, the user may change or adjust critical factors (like, cut-off angle, signal quality, maximum zero, single and double difference residual, etc.) to their proper values in order to achieve the highest possible accuracy.

The monitoring of each atmospheric model according to the satellite elevation or to its characteristics is supported from within the *"utility"* panel.

All of the intermediate results are extracted to graphical or textual forms. Advanced analysis and useful educational examples can be produced from these results. The program uses the RINEX observations and navigation files in order to determine the baseline. The solution results are compared with GPS receiver manufacturer software on different baseline lengths in order to evaluate its reliability. The differences are varying from 0.2 to 2.5 meters, so that the program can easily work for low accuracy GPS applications (e.g. GIS projects) using low cost handheld receivers.

6. SOFTWARE AVAILABILITY -ROYALTIES

"BaselineByCode" has been developed as an educational package. Colleagues from academic institutions may download the self-extracted software from the following URLs, provided that they will give proper credit to the authors.

http://www.softwaypro.gr/Files/Other/GPS/instBLBC.EXE
http://users.auth.gr/kvek/BaselineByCode/

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