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AMBIGUITY RESOLUTION IN PRECISE POINT POSITIONING TECHNIQUE: A CASE STUDY

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ABSTRACT:

Because of the dynamics of the GPS technique used in different domains like geodesy, near real-time GPS meteorology, geodynamics, the precise point positioning (PPP) becomes more than a powerful method for determining the position, or the delay caused by the atmosphere. The main idea of this method is that we need only one receiver – preferably that have dual frequencies pseudorange and carrier-phase capabilities – to obtain the position. Because we are using only one receiver the majority of the residuals that are eliminated in double differencing method, we have to estimate them in PPP. The development of the PPP method allows us, to use precise satellite clock estimates, and precise orbits, resulting in a much more efficient way to deal with the disadvantages of this technique, like slow convergence time, or ambiguity resolution. Because this two problem are correlated, to achieve fast convergence we need to resolve the problem of ambiguity resolution. But the accuracy of the PPP results are directly influenced by presence of the uncalibrated phase delays (UPD) originating in the receivers and satellites. In this article we present the GPS errors and biases, the zenith wet delay and the necessary time for obtaining the convergence. The necessary correction are downloaded by using the IGS service.

1. INTRODUCTION

The precise absolute positioning it is a term that nowadays it is associated with precise point positioning (PPP) it is a term (Wabbena, Schmitz, and Bagge 2005).

The development of the PPP it was made by the scientists from NASA's Jet Propulsion Laboratory which can provide around 1 cm accuracy with single receiver and without any ground control. But this method should not be confused with average point positioning in which we can obtain 5-10 m accuracy and it is performed in real time using pseudo ranges.

The full statistical information from each day improves the results and we can obtain reliable estimation of station coordinates as well as orbits of the satellites and none the less Earth rotation parameters (Ge et al. 2006). In this direction (Zumberge et al. 1997)(Héroux and Kouba 2001) demonstrate that Precise Point Positioning (PPP) is a reliable tool in application where the co-variances matrix between the parameters from different stations do not presents any interest, does being one of the factors that reduce the computation burden.

By using the Global Positioning System (GPS) and appealing the precise point positioning (PPP) method, we can determine a point's coordinates with high accuracy. The measurements from one receiver are used to determine the all three coordinates, but also other important parameters like: total neutral atmosphere delay, receiver clock error (Leandro et al. 2008). The characterization of the errors by implying the PPP the representation becomes much better and also closer to the physical error sources (Wabbena, Schmitz, and Bagge 2005).

Handling satellite and receiver clock errors represents the major difference between the two processing technique: relative processing and PPP. In the PPP method we use highly precise satellite clock estimates, otherwise for removing the satellite clock errors we would need to use in double differencing method. From a globally distributed network of GPS receivers we can derive use these satellite clock estimates which are then used in resolving the necessary parameters (King, Edwards, and Clarke 2002).

PPP presents interest not only in crustal deformation monitoring (Azúa, DeMets, and Masterlark 2002), (Savage et al. 2004), (Hammond and Thatcher 2005), (D'Agostino et al. 2005), (Calais et al. 2006) near real-time (Gendt et al. 2003), (Rocken et al. 2005) and orbit determination of low Earth orbiting satellites GPS meteorology (Bock, Hugentobler, and Beutler 2003), (Zhu, Reigber, and König 2004), but is also applied in the precise positioning of mobile objects (Gao and Shen 2002), (Zhang and Andersen 2006). It's importance was notice with the development of more and more dense GPS networks for the purpose of monitoring regional dynamics activity and meteorological information (Ge et al. 2007).

Because the ionospheric free linear combination is currently mandatory the accuracy PPP is limited. Information regarding the ionosphere aren't in general available. The integer nature of the ambiguities aren't preserve when using the ionospheric free linear combination because this isn't based on integer coefficients, and thus it isn't possible to resolve agreeably the ambiguities to the same value of accuracy with the GNSS carrier phase (Xu et al. 2012).

Because of the technological development only double difference (DD) ambiguities where able to be fixed until now, due to the fact that the UPD was canceled. Combination of simultaneously observed stations for the PPP solutions where, DD-ambiguities can be fixed and can be defined similar as for network solutions (Zumberge et al. 1997). The biggest problem that is arising is the computational burden, which can be solved by fixing ambiguities in sub-network mode (Savage et al. 2004) (Hammond and Thatcher 2005) (D'Agostino et al. 2005). The zero-difference (ZD) ambiguity of a satellite-receiver pair or the single-difference (SD) ambiguity between two satellites represents the major problem for the PPP ambiguity fixing, because there is not an integer value, which is generated by the existence of the uncalibrated phase delays (UPD) originating in the receiver and satellite (Blewitt 1989).

In the PPP the local phase biases are used as a constrain rather than fix, for linear combination of local phase biases for improving the compatibility with global phase bias estimates which represents one of the reason that way we not need the data from another receiver (Bertiger et al. 2010).

2. MATERIALS AND METHODS

Precise GPS point positioning (PPP), as an alternative to differential GPS Surveying that let us use only one GPS receiver – in our case we use dual frequencies receiver. However, the positioning accuracy is affected from global disturbances in addition to other unmodelled errors and biases. This is not the only type of source of errors.

In a PPP network we have the do the following: we need to form the undifferenced (UD) code and phase measurements and then to determine the integer ambiguities in widelane and narrowlane and also to factional-cycle biases (FCB) or uncalibrated phase delay (UPD) in phase measurements, and in the last part to use the clock corrections and orbit corrections that can be downloaded from different agency – for example IGS (Feng et al. 2013).

In the estimation process of the PPP, the clock errors are computed as part of the least squares solution that defines the coordinates, where in differencing between-satellite we can remove the clock errors. Consequently, precise absolute coordinates for a single receiver at an unknown location may be obtained without the need of a second receiver at a known location (King, Edwards, and Clarke 2002).

(Heroux et al. 2001) proved that point positioning solution could achieve accuracy that match DGPS solution by using ionosphere-free, undifferenced pseudorange with precise ephemeris and clock data.

Because of the main idea that stand for the definition of the precise point positioning (PPP) (Zumberge et al. 1997), where one GPS receiver it is used, for obtaining the resolution of the ambiguity, where we are interested in the integer nature, we cannot achieve this only by following the methodology for the network solutions. In the PPP processing the ambiguities aren't fixed to integers.

The PPP users are in need of clocks and Earth rotation parameters, orbits, which can be obtained from IGS or analyzing a permanent GNSS reference network. For ambiguity-fixing, wide- and narrow-lane uncalibrated phase delays have to be estimated (Ge et al. 2007). In the first case the estimation is done for every satellite pair which is considerate to be a constant for one day directly from pseudo-range and carrier-phase observations, resulting their independence from the analysis model. In the second one the representation is given by a set of tabular correction values in order to take into account the time dependent changes defined by the existence of modelling errors.

The dominant error source is defined by the ionospheric effect, after we are taking into account the precise orbit and clock products, which can be reduce by using dual frequencies observation our by using the ionospheric model offered by IGS or Berne University.

The measurements like the carrier-phase measurements are influenced from the nuisance ambiguities which have to be estimated along with the other parameters of primary interest (Geng et al. 2010). By obtaining integer ambiguity the results implying the position are improved, especially for the East component (Blewitt 1989). The problem is generated by the float ambiguities which can have a serious influence on the final solution by introducing amplified spurious signals into the long-term position time series (Tregoning and Watson 2009).

We shall present the concept of integer phase ambiguity and uncalibrated phase delays, as well as the ambiguity resolution using ionosphere-free solution.

2.1 The uncalibrated phase delay

The model defined by the dual-frequency carrier-phase and pseudo-range GPS observations from receiver k to satellite i, in unit of length, it is defined by:

$$L_{m_k^i} = -\lambda_m \phi_{m_k}^i = \varrho_k^i - \frac{\kappa}{f_m^2} + \lambda_m b_{m_k}^i \tag{1}$$

$$P_{m_k}^i = \varrho_k^i + \frac{\kappa}{f_m^2} \tag{2}$$

where $\phi_{m_k}^i$ and $P_{m_k}^i$ are carrier-phase and pseudo-range observations in frequency band m with corresponding wave-length λ_m and frequency f_m; $b_{m_k}^i$ is the ambiguity phase; ϱ_k^i is the non-dispersive delay, including geometric delay, tropospheric delay, clock biases and any other delay which affects all the observations identically; the second term on the right side is the ionospheric delay. The multipath effect and noise are not included for clarity (Ge et al. 2007). The receiver- and satellite-dependent pseudo-range biases (Schaer and Steigenberger 2006) are also ignored because the constant shifts have no substantial effect on the ambiguity fixing. The ambiguity for the carrier-phase is defined by the following terms:

$$b_{m_k}^i = n_{m_k}^i + \Delta\phi_m^i - \Delta\phi_{m_k} \tag{3}$$

where $n_{m_k}^i$ is the integer ambiguity, $\Delta\phi_m^i$ and $\Delta\phi_{m_k}$ are uncalibrated phase delays in the receiver and in the satellite transmitter, respectively. The uncalibrated phase delays are not integer values thus prevent the resolution of the integer ambiguities.

However, they are identical for common instruments, are stable to better than a nanosecond (Blewitt 1989) and are eliminated while forming DD ambiguities between two satellites

$$b_{m_{k,l}}^{i,j} = b_{m_k}^i - b_{m_k}^j - \left(b_{m_l}^i - b_{m_l}^j\right) = n_{m_{k,l}}^{i,j} \tag{4}$$

where the super index pair i,j is for the single-difference between satellites i and $,j$ while the sub index pair k,l is for the single-difference between receivers k and l.

2.2 Ionosphere-free solutions

In the PPP technique and also in large GPS networks, it can be used the ionospheric-free combination in order to reduce the ionospheric effect:

$$L_{c_k}^i = \frac{f_1^2}{f_1^2 - f_2^2} L_{1_k}^i - \frac{f_2^2}{f_1^2 - f_2^2} L_{2_k}^i = \varrho_k^i + \lambda_1 b_{c_k}^i \quad (5)$$

where $b_{c_k}^i$ is the related ambiguity and usually expressed as the combination of wide- and narrow-lane for ambiguity fixing:

$$b_{c_k}^i = \frac{f_1^2}{f_1^2 - f_2^2} b_{1_k}^i - \frac{f_1 f_2}{f_1^2 - f_2^2} b_{2_k}^i = \frac{f_1}{f_1 - f_2} b_{n_k}^i + \frac{f_1 f_2}{f_1^2 - f_2^2} b_{\omega_k}^i \quad (6)$$

where $b_{n_k}^i$ and $b_{\omega_k}^i$ are wide- and narrow-lane.

Denoting the epoch-dependent parameters, for example receiver and satellite clocks, with u, the estimated ambiguity parameters with b_c and all the others with x, the linear observation equations of Eq. (5) at epoch e with the weight matrix P_e reads:

$$v_e = A_e x + B_e b_c + C_e u_e + l_e, \qquad P_e \quad (7)$$

After the elimination of u_e his influence to the normal equation system is defined by:

$$\begin{bmatrix} A_e^T \bar{P}_e A_e A_e^T \bar{P}_e B_e \\ B_e^T \bar{P}_e B_e \end{bmatrix} \begin{bmatrix} x \\ b_c \end{bmatrix} = \begin{bmatrix} A_e^T \bar{P}_e l_e \\ B_e^T \bar{P}_e l_e \end{bmatrix} \quad (8)$$

With:

$$\bar{P}_e = P_e - P_e C_e (C_e^T P_e C_e)^{-1} C_e^T P_e \quad (9)$$

After accumulating all the observations the final normal equation system is:

$$\begin{bmatrix} N_{xx} N_{xb} \\ N_{bb} \end{bmatrix} \begin{bmatrix} x \\ b_c \end{bmatrix} = \begin{bmatrix} w_x \\ w_b \end{bmatrix} \quad (9)$$

2.3 Ambiguity fixing

The DD-ambiguity of satellites i and j from Eq. (6), and receivers k and l can be expressed as:

$$b_{c_{k,l}}^{i,j} = \frac{f_1}{f_1 + f_2} b_{n_{k,l}}^{i,j} + \frac{f_1 f_2}{f_1^2 - f_2^2} b_{\omega_{k,l}}^{i,j} \quad (5)$$

Due to the rank deficiency of the normal equation system the ambiguity for the wide- and narrow-lane cannot be estimated and fixed simultaneously. The first step is to fix the wide-lane using the corresponding carrier-phase and pseudo-range combination (Wübbena 1985)(Melbourne 1985). After its successful fixing, the narrow-lane and its related standard deviation (STD) are derived from the real-valued solution, and only then it can be used the ionospheric-free combination.

3. RESULTS

For the simulation in this study we use the data from the permanent station in Oradea. The file that was process is a 24 h session with a logging interval of 5s. The model from antenna calibration was LEICA GRX1200+GNSS.
In fig.1 it is presented the sky plot.

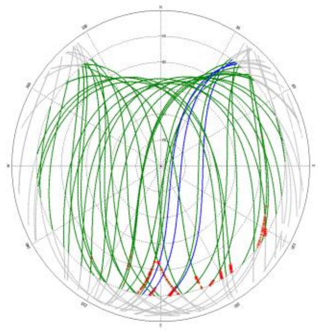

Fig. 1 Sky plot

To process the position we used the ionospheric free LC combination, precise satellite ephemeris, and the atmospheric delay model was VMF1. Also because of the location of the permanent station we used only solid tide correction, without the ocean tidal loading. The elevation mask was set to 10^0. The results are presented in fig.2

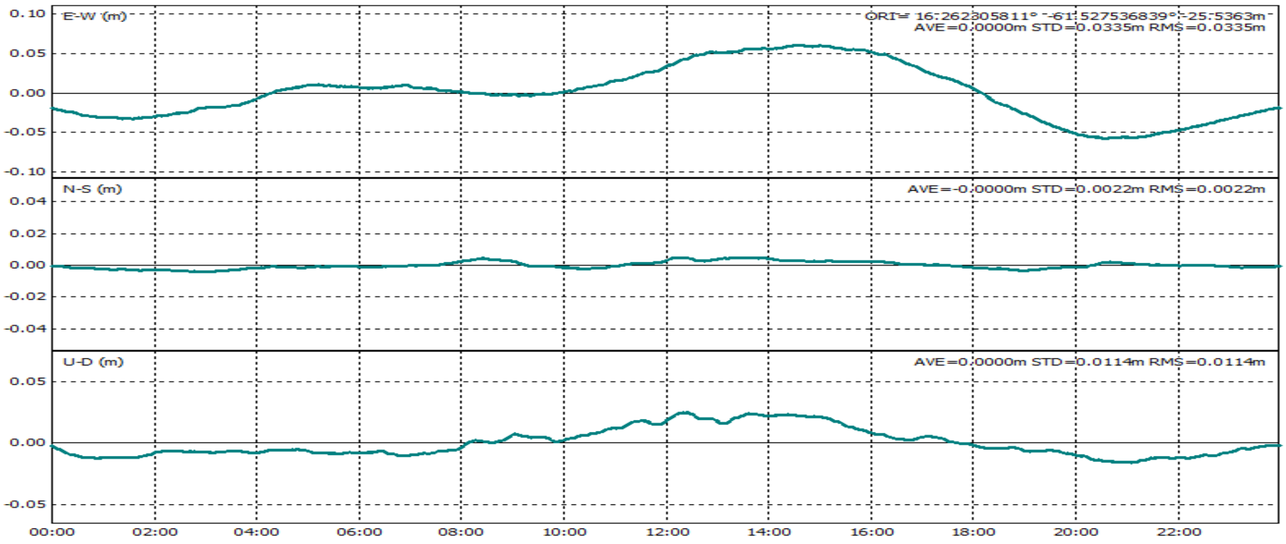

Fig. 2 Position variation in E-W, N-S and U-D direction

We ca see that the variation of the position along the time is taking values between ±0.055 m E-W part. In the N-S part the variation is between ±0.010 m and in the U-D part we face a variation between ±0.040 m. So, the major variation of the position is in the E-W part.

In fig.3 it is presented the SNR, multipath and the elevation dependencies on L1band.

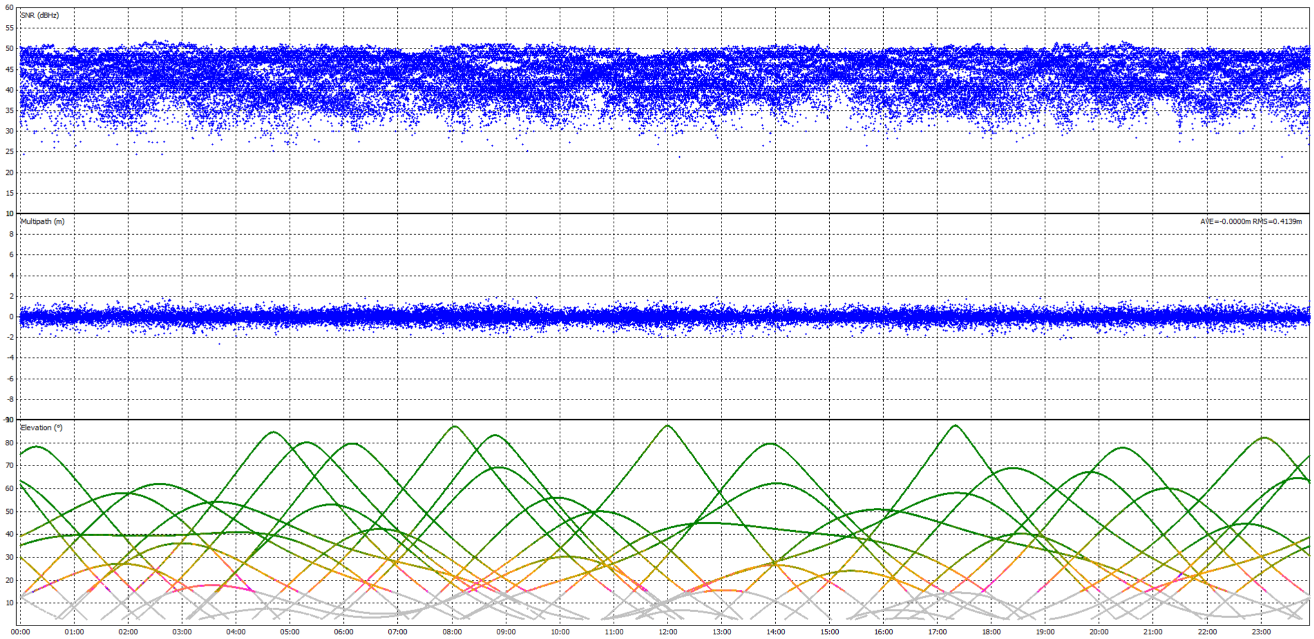

Fig. 3 In the upper part of the figure it is the SNR in dbHz, in the central part it is the multipath expressed in m, and in the lower part it is the elevation expressed in ^{0} on L1 band

The multipath effect has an influence of ±1.75 m with an RMS of 0.414 m. We will continue with analysing the same components but on L2 band. This is presented in fig.4. From the imagine we can see that on L2 band the SNR has a lower frequencies but in the multipath dominie there is not a noticeable change, the multipath having an RMS of 0.457 m. The SNR and multipath are presented together with the elevation because they are elevation dependent.

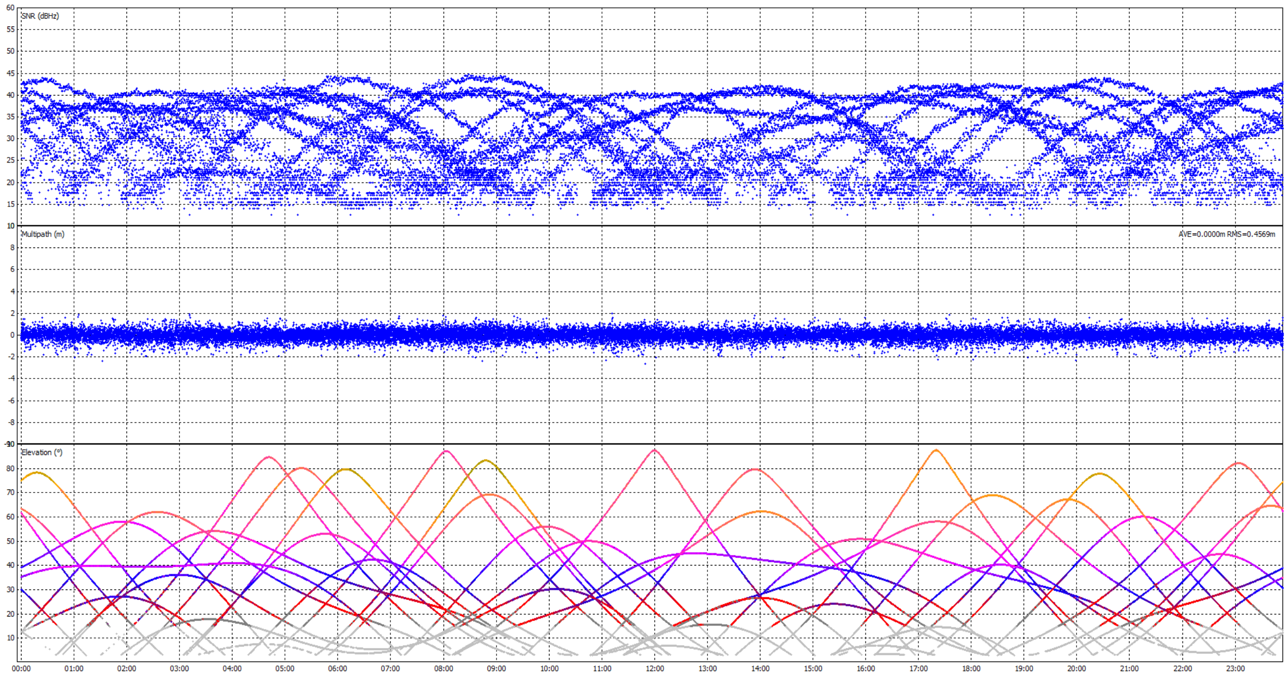

Fig. 4 In the upper part of the figure it is the SNR in dbHz, in the central part it is the multipath expressed in m, and in the lower part it is the elevation expressed in ^{0} on L2 band

One of the main concerns related to PPP is the convergence time required to produce meaningful estimates. Even though the final accuracies that can be achieved with this technique are certainly very good, as shown here, the time required to achieve them (usually around several tens of minutes) is currently a bit of an impediment in the use of PPP for real-time applications (Leandro, Santos, and Langley 2010).

The position error convergence derived from all solutions in latitude, longitude and height are presented in fig.5.

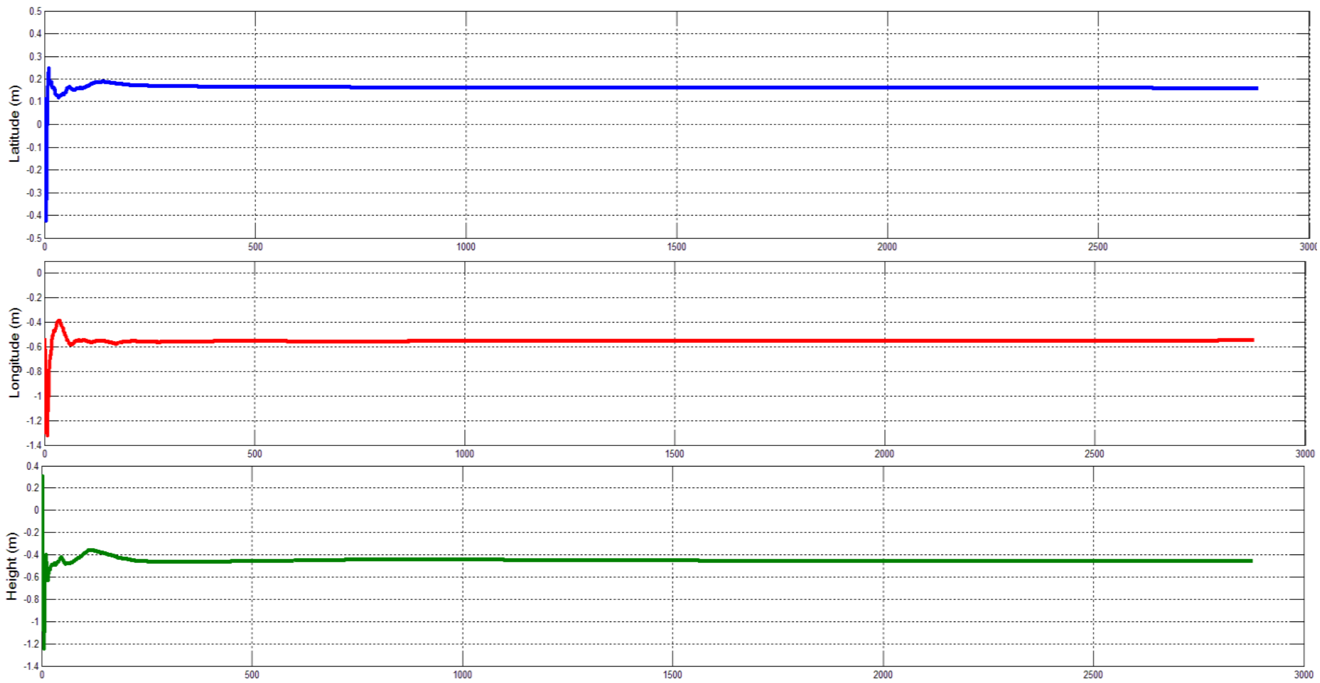

Fig. 5 Convergence of the latitude, longitude, height and the necessary time to obtain a reliable estimate

In the atmospheric zenith delay modelling that it is presented in fig.4 we used a random walk process with a noise of 5.0 mm/sqrt(h). The elevation cut-off angle was set to 10^{0} but this setting could generate a pour de-correlation.

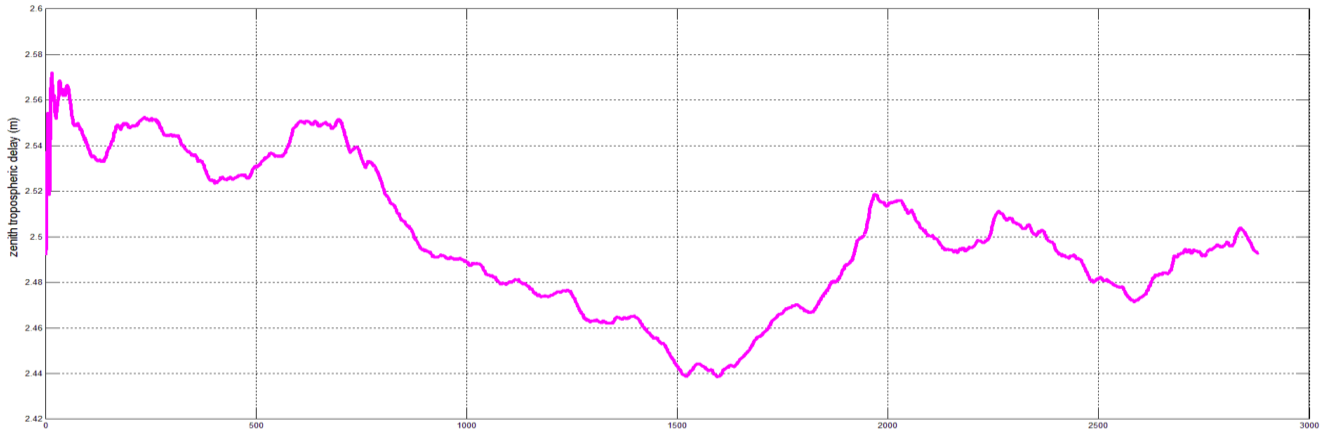

Fig. 6 Zenith tropospheric delay

The carrier-phase and pseudorange residual are presented in fig.7. The residuals from carrier-phase it is in the middle of the figure and has values usually within ± 0.1 m resulting a reasonably stable spread of the residuals. The red line indicates the presence of the cycle slips.

The residuals from the pseudorange has values usually within ± 2 m which is also a reasonably stable spread of the residuals.

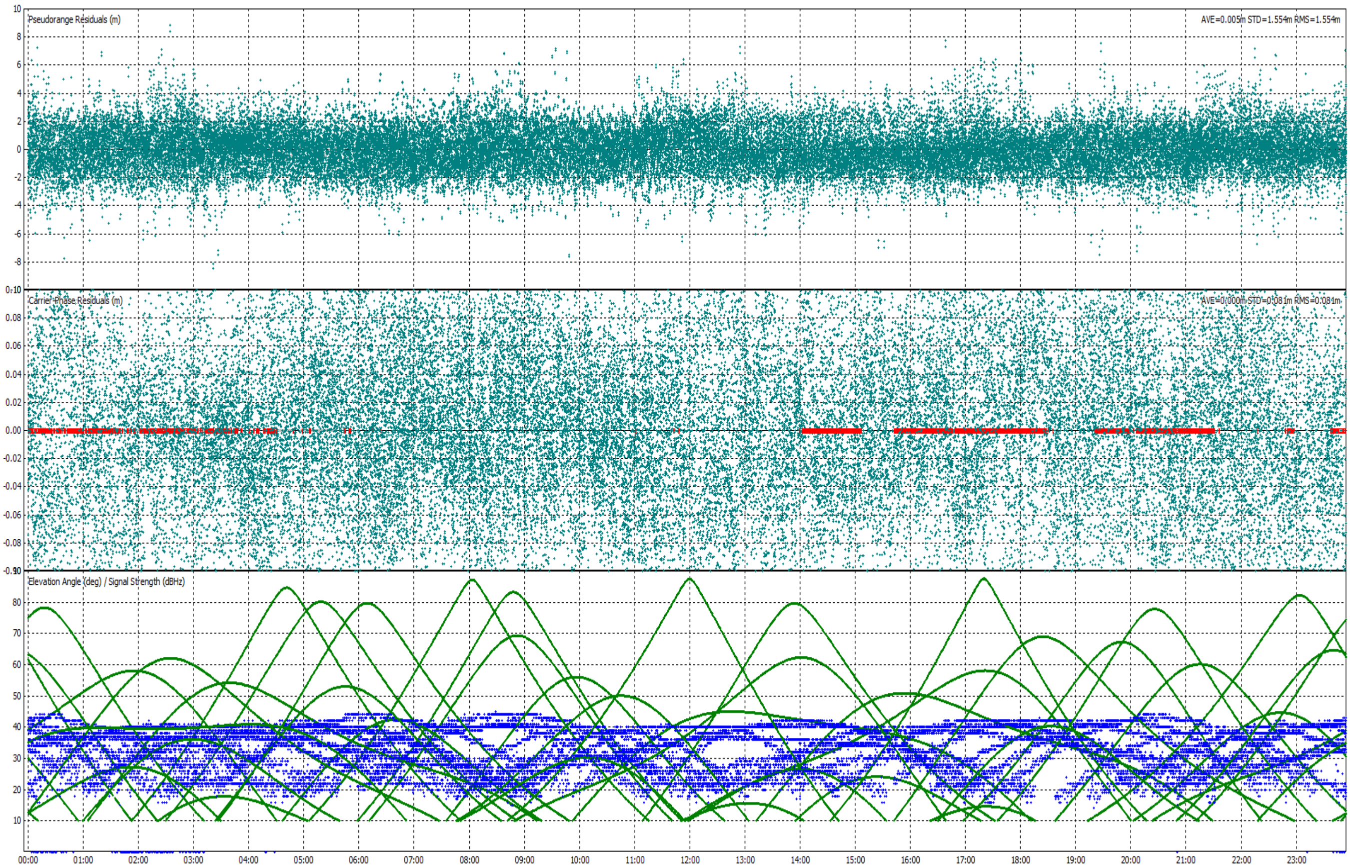

Fig. 7 Pseudorange, carrier-phase residual and elevation angle/signal strengths

4. CONCLUSIONS

The precise point position technique it is a method that is integrating the GPS precise orbit and clock products from which we can derive a variety of circumstance like geodesy, geodynamics, near real-time GPS meteorology in which to use only one receiver.

By using static receiver and involving the PPP technique we can conclude from the presented results that this method it is competitive with traditional bias fixing method like the double-difference ambiguity resolution.

The major problem in using the PPP method, for obtaining centimeter level accuracy by using dual frequency receivers is that it requires at least 30 min of continuous measurements, but in recent years with the development of ambiguity resolution methods we can expect a decrease for the necessary required time for obtaining centimeter accuracy.

By comparing the PPP method with the relative position it has the advantages of high computational efficiency, flexible operating mode, and it has no limitation concerning the distance between the reference station and the receiver.

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