

Accuracy Improvement of GNSS and Real Time Kinematic Using Egyptian Network as a Case Study

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Abstract

Differential Global Positioning system (DGPS) is an observation technique that can be used to reduce the ionosphere effects arising in ordinary GNSS. DGPS technique is used to increase the GNSS accuracy by reducing error associated with pseudo range but does not remove orbital ionosphere and troposphere errors. This paper investigates an integrated system for improvement the accuracy of differential GNSS and Real Time Kinematic (RTK) using Egyptian network as a case study. Three steps were used to reduce these errors. The comparison between DGPS observations and the treated observations used in determining the Egyptian network coordinate are presented. The resulting coordinate and of analysis of integrated system and computer programs are presented. The integration of use of precise ephemeris from International GPS Services (IGS) Network, Klobucher ionosphere model with Hopfield or Saastimoinen troposphere model improve the accuracy of DGPS to large extent.

Keywords: DGPS, RTK, Klobucher model, Hopfield, Saastimoinen and IGS.

1. Introduction

GPS (Global Positioning System) has become an important tool for any endeavor where a quick measurement of geodetic position is required .However GPS observations contains both systematic and random errors. Differential GPS (DGPS) and Real Time Kinematic (RTK) are observations technique that can be used to remove or reduce ionosphere effects arising in ordinary GPS observation. To reduce or eliminate the effect of some these biases and errors, GPS observable differencing technique, and/or linear combination between observables are formed. In addition, GPS-biases models can also be used as will be presented in the next two subsections. This current study investigates an integrated system for improving the accuracy of differential GPS and Real Time Kinematic (RTK) for the location which covers the great Cairo part of High Accuracy Reference Network “HARN” of Egypt. The study utilized three steps used to reduce the orbital error, the ionosphere error and the troposphere error [1]. A comparison study between DGPS and RTK solutions for Egyptian Network. The resulting analysis of this study is presented.

2. Errors of DGPS and RTK.

DGPS and RTK, Measurements are also biased by atmospheric refraction, clock errors, site and instrumental effects, Selective Availability effect. Phase is additionally biased by unknown ambiguity. Biases may be defined as being those effects on the measurements that cause the true range to be different from the measured range by a *systematic amount*, and which must be accounted for in the measurement model used for data processing. Additionally entering through incorrect or incomplete observation modeling, biases can also enter through imperfect knowledge of constants [1]. Hence, under the heading of "errors" are assembled all unaccounted for measurement effects, as well as any unmodelled or residual biases. These errors can be summarized as following:-

i. Ionospheric Delay

Ultraviolet and x-ray radiations coming from the sun interact with the gas molecules found in the atmosphere, which results in a large number of free negative charged electrons . This is called the gas ionization; such a region of the atmosphere where gas ionization takes place is called the ionosphere [2]. The ionosphere extends from an altitude of about 50 km to about 1000km the electron density within the ionosphere is not constant, it changes with altitude, therefore the ionospheric region is divided into sub regions according to the electron density. The refractive index (n) of microwaves is a function of frequency (and hence the ionosphere has the property of "dispersion") and the *density of free electrons*, and may be expressed as first-order approximation,

$$n = 1 \pm \frac{A \cdot N_e}{f^2} \tag{1}$$

A is a constant = 40.28

N_e is the total electron density (el/m^3), and

f is the frequency.

The sign in the above formula will depend on whether the **range** (+) or the **phase** (–) **refractive index** is required. The propagation speed v is related to the refractive index according to formula :

$$v = \frac{c}{n} \qquad (2)$$

Where (c) is the speed of electromagnetic radiation (EMR) in a vacuum. Equations (1) and (2) imply that the speed of the carrier wave (the "phase velocity") is actually increased, or "*advanced*". Hence the phase refractive index is less than unity. However, the speed of the ranging codes is decreased (the so-called "group velocity") and therefore the pseudo-range is considered "delayed", and hence the range (or group) refractive index is *greater than unity*. (The ranging codes modulated on the carrier waves are considered a "group" of waves because they have different frequencies) The implication is therefore that the distance as implied by the integrated carrier phase is *too short*, but the pseudo-range is *too long [3]*. The correction terms are, of course, quantities with a reversed sign, that is, the carrier phase correction is *positive*, while the pseudo-range correction is negative.

ii. Tropospheric Delay

The troposphere is the electrical neutral atmospheric region that extends up to 50 km from the surface of the earth. The troposphere is a non-dispersive medium for radio frequencies below 15 GHz. As a result, it delays the GPS carrier and codes identically. Unlike the ionospheric delay, the tropospheric delay can't be removed by combining GPS waves L1&L2 observations. This is mainly because the tropospheric delay is frequency independent. Tropospheric delay depends on: Pressure, Temperature, Humidity and Signal path through troposphere, the tropospheric delay is minimized at the user's zenith and maximized at horizon. The tropospheric delay results in values about 2.30 m at zenith, 9.30 m for a 15^0 elevation angle, and 20-28 m for a 5^0 elevation angle [4].

Tropospheric delay is a function of the satellite elevation angle and the altitude of the receiver. However, a good starting point is to define it in terms of the refractive index, integrated along the signal ray path:

$$d_{trop} = \int (n-1).ds \qquad (3)$$

or in terms of the refractivity of the troposphere $N_{trop} = 10^6(n-1)$:

$$d_{trop} = 10^{-6} \int N_{trop}.ds \qquad (4)$$

The tropospheric refractivity can be partitioned into the two components, one for the *dry part* of the atmosphere and the other for the *wet part*:

$$\mathbf{N_{trop} = N_{wet} + N_{dry}} \qquad (5)$$

and the total tropospheric delay can be calculated according the following formula:

$$\mathbf{d_{trop} = d_{dry} + d_{wet}} \qquad (6)$$

The d_{trop} can then be estimated by separately considering its two constituents d_{dry} and d_{wet}. About 90% of the magnitude of the tropospheric delay arises from the dry component, and the remaining 10% from the wet component [5].

iii. GPS Orbital Biases.

As the forces of gravitational and non-gravitational origin perturb the motion of the GPS satellites, the coordinates of the satellites in relation to the WGS84 reference system must be continually determined through the analysis of tracking data [1]. The satellite Ephemeris bias is the discrepancy between the *true* position (and velocity) of a satellite and its *known* value. This discrepancy can be parameterized in a number of ways, but a common way is via the three orbit components: along track, cross track and radial as shown in figure (1). In the case of GPS satellites, the along track component is the one with the largest error.

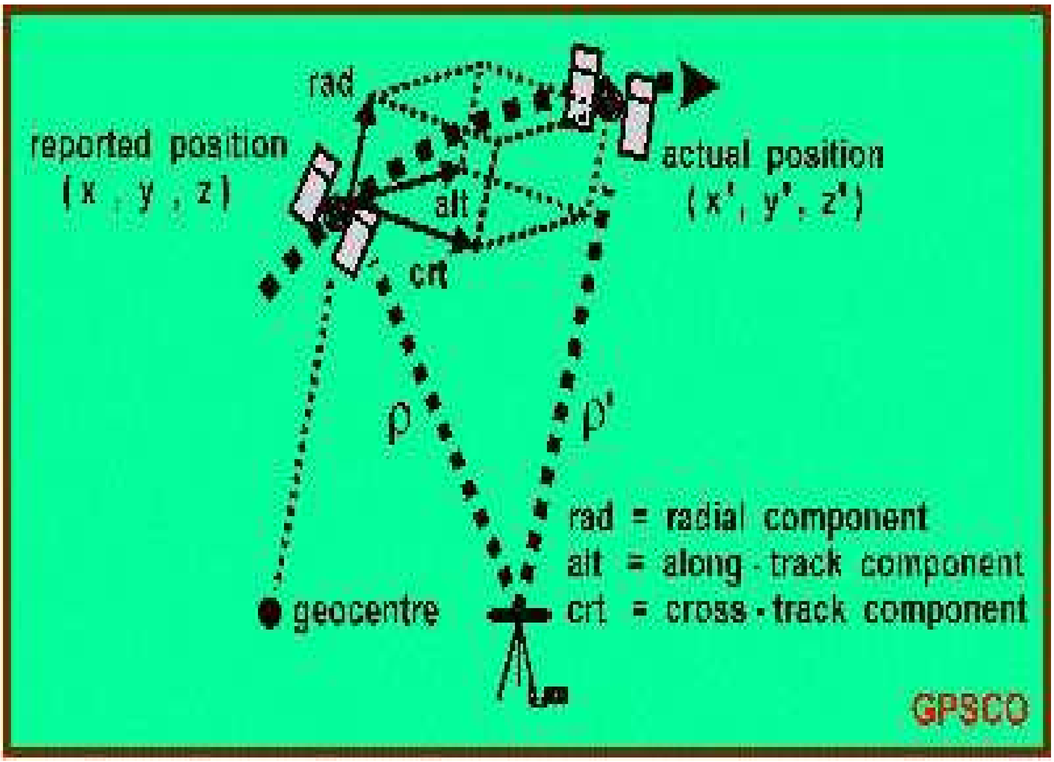


Figure 1: Satellite Ephemeris bias.

There are two basic classes of satellite orbit information:

- Ephemeris that are predicted from past tracking information, and are available to GPS users at the time of observation, available via the GPS Navigation Message. The Ephemeris computation takes place at the Master Control Station using tracking data acquired from the five monitor stations of the GPS Control Segment. Evidence suggests that the accuracy of the broadcast Ephemeris is below 10m for a single Navigation Message update per day, and better than 5m when three daily updates are performed.
- Post-processed Ephemeris, which are orbit representations valid only for the time interval covered by the tracking data. Obviously this information is not available real-time as there is a delay between collection of the data, transmission of the data to the computer centre, the orbit determination process and the subsequent distribution to GPS users. Post-processed Ephemeris are, in general, more accurate than predicted Ephemeris, with demonstrated accuracies well below the meter level.

iv. Carrier Phase Ambiguity.

As indicated in figure (2) below, the integrated carrier phase measurement at time T_j involving satellite i and receiver j consists of the three components:

- The fraction of a cycle.
- The arbitrarily assigned integer ambiguity at signal lock-on,
- A count of the whole cycles by the receiver.

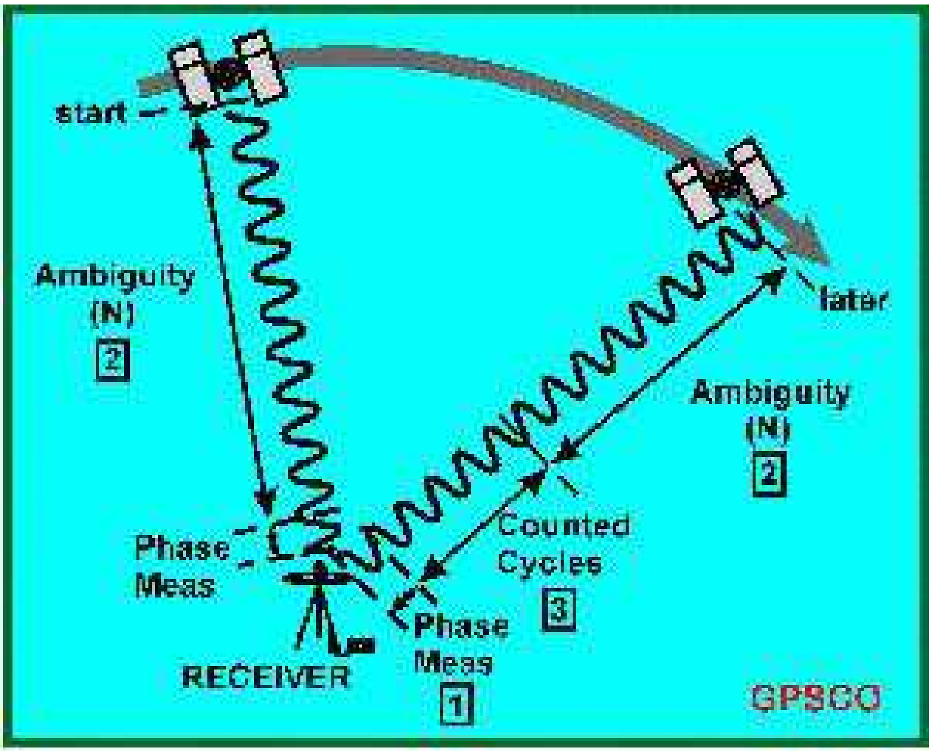


Figure 2: Components of the integrated carrier phase measurement.

If satellite signals are obstructed by objects or interfered by other signals, a loss of lock on the satellite signal will occur. On the resumption of lock to the satellite(s), the accurate fractional part of the phase observable can again be measured [6]. However the integer part will be re-initialized and the initial integer ambiguity will no longer have a valid connection between the ambiguous fractional cycle measurement and the satellite-receiver range.

3. Observation Sites and used Instruments

The plan of this study was in two phases, **First :** five stations ***OZ95 , A6 , OZ97 , OZ88 and E7*** from Egypt network will be taken . The distances between these stations are approximately 30-40 km interval, these stations are selected from a High Accuracy Reference Network (HARN), the coordinates of these stations are shown in table (1), **Second:** GPS (Trimble 4000SSE dual frequency) is used to observe approximately 20 km with RTK .

Table 1: The HARN network point coordinates

Point	E (m)	N (m)	H (m)
0Z88	309898.5549±0.002	3303157.7225±0.004	137.729±0.004
A6 (control point)	340016.9413	3304353.5077	134.981
E7	268216.4468±0.005	3302823.7931±0.004	230.875±0.005
0Z97	333921.048±0.002	3323219.2644±0.005	219.776±0.005
0Z95	350276.5655±0.002	332842.0164±0.004	230.5272±0.004

4. Analysis of Observations

Leica Geostationary Office programme (LGO) was used for analysis the data. The results and analysis of observations will be introduced into three steps as following:

4.1 orbital errors

This step is used to show the differences between the broadcast orbit which available for all GPS users and the precise orbit which obtained from IGS at the same day of observation with fixation all other factors. The results is presented below.

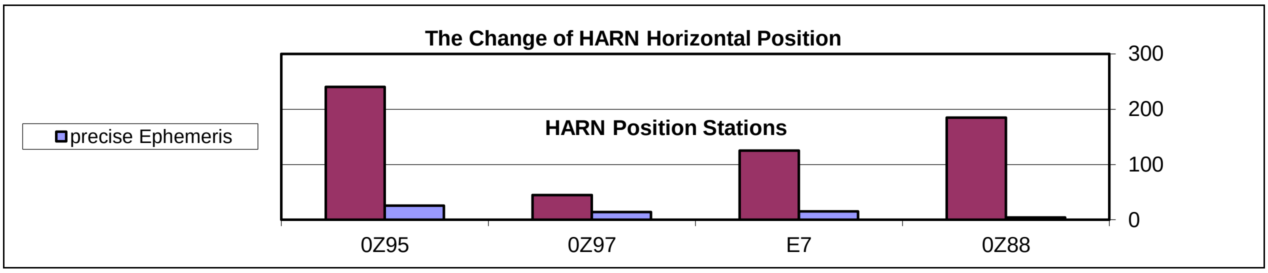


Figure 3: Precise Ephemeris VS Broadcast Ephemeris (Horizontal Position)

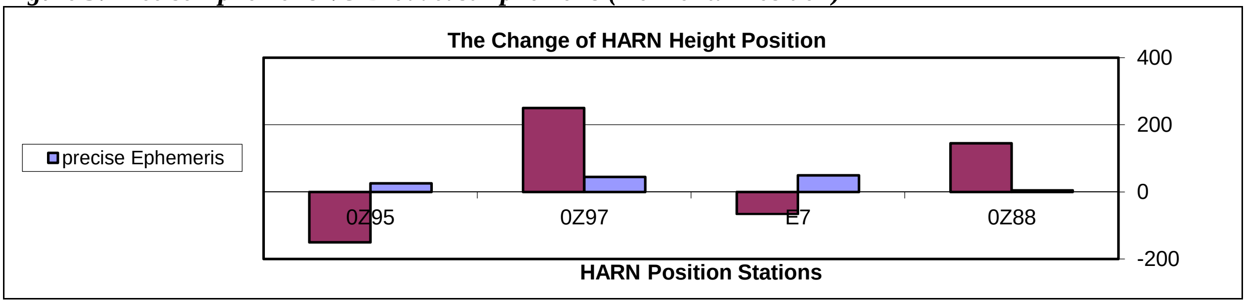


Figure 4: Precise Ephemeris VS Broadcast Ephemeris (Vertical Position)

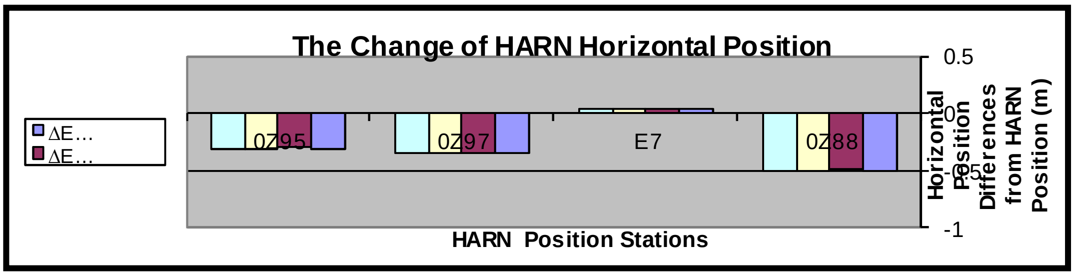
From figure (3) horizontal Position varies from 45 mm to 240 mm with respect to broadcast Ephemeris but for precise Ephemeris, it ranges from 4mm to 25 mm. The range for height decreased with respect to precise Ephemeris. The rang is from -64 mm to 250 mm in the case of broadcast Ephemeris but when using precise Ephemeris the range was from 5 mm to 50 mm. Then the use of precise ephemeris rather than broadcast ephemeris would give an appreciable improvement

4.2 Ionosphere errors

This step is used to show the differences between using the different ionosphere models and select the model which gives the best solution where all other factors are constant. The ionosphere models in this case are computed model using Klobucher model, Standard model, and Global/Regional model [7]. The results are shown in figure (5 and 6).

From figure (5 and 6), the coordinates vary in a clear range from 215 mm to 561 mm with respect to all types of ionosphere models but for Klobucher model, the ranges varies from 206mm to 511 mm. Then the use of Klobucher model rather than other ionosphere models would give an appreciable improvement.

Figure 5: HARN Vertical Position



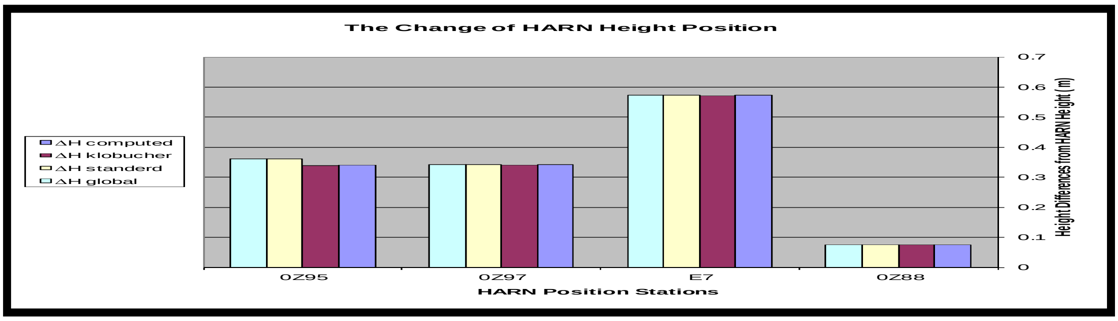


Figure 6:HARN Horizontal Position

4.3 Troposphere errors

This step is used to show the differences between using the different troposphere models and select the model which gives the best solution where all other factors are constant. In this case, Hopfield, Simplified Hopfield, Saastimoinen, Essen and Froome troposphere models were used [8]. The results are presented below. The analysis of observations carried out using troposphere models are;

- Static code & phase solution.
- Kinematic code & phase solution.

Below is the effect of troposphere model with phase solution for static code and phase solution

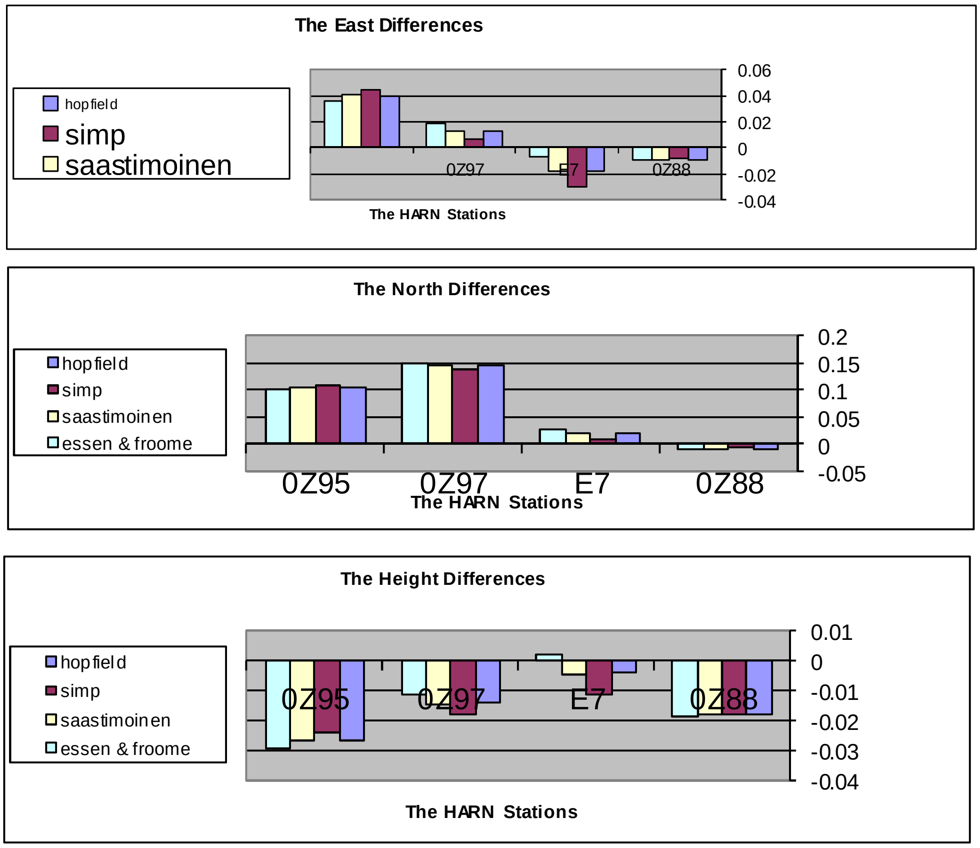
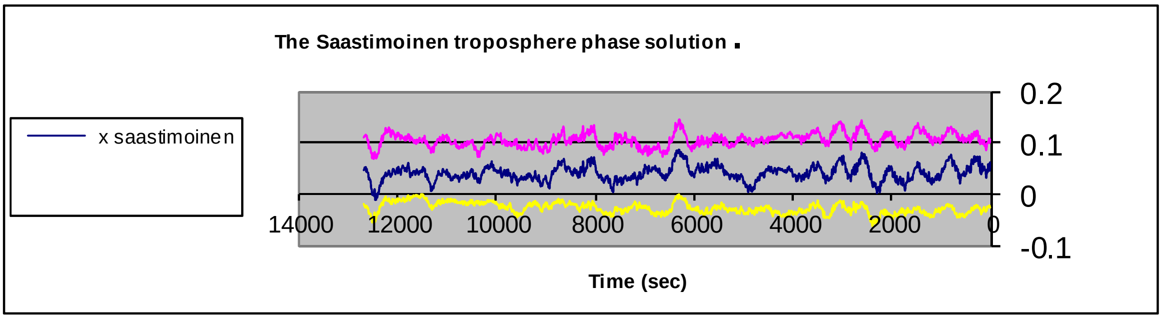


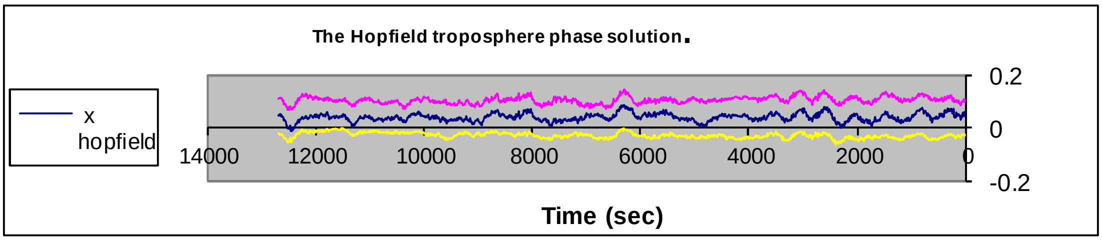
Figure 7: The difference from the HARN coordinates and the solution with changing the troposphere model

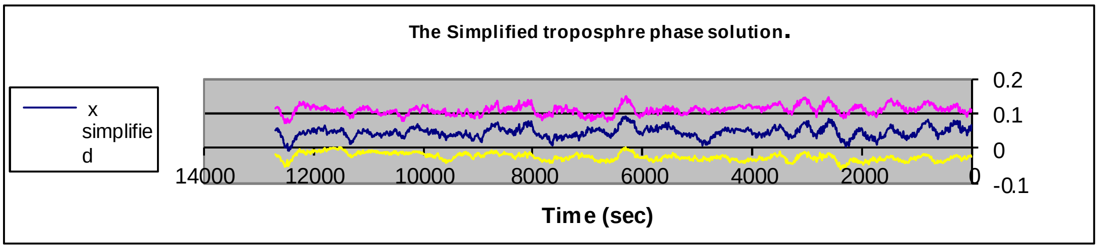
Figure 7: The difference from the HARN coordinates and the solution with changing the troposphere model

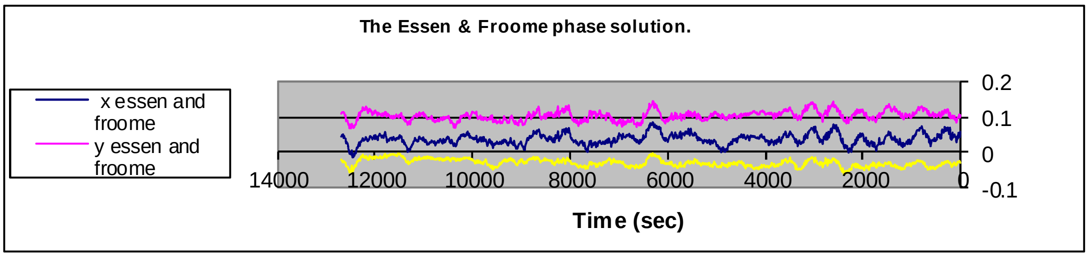
Figure (7) showing that the Hopfield and Saastimoinen give the same values and the results were middle from the Essen & Froome model and Simplified model .The differences between solutions by troposphere models with code solution were equal the differences between solutions by troposphere models with phase solution with the same mask angle [9].

For Kinematic code & phase solution, figure (8) is the solution. Figure (8) shows the variation between using troposphere models in all component of coordinates with time. The result indicates small variation and can be neglect.









5- Conclusions

1. The use of precice ephemirace rather than broadcast ephemirace would give an apperciable improvement for all baselines.
2. The troposphere models have the same effect on the all observation teqniques, the Hopfield model give the same results with the Saastimoinen model as addition of midel result values between the Simplified Hopfield model and Essen & Froome model.
3. The troposphere effect on the height component can be neglect in both east and north component .
4. The use of Klobucher ionosphere model would give an apperciable improvement for all baselines.
5. DGPS and RTK techniques accuracy improvement would be assured using precise ephemirace with Klobucher ionosphere model with Hopfield or saastimoinen troposphere model with code & phase solution.

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