# Effect of tropospheric delay estimation on GPS baseline accuracy:an application to a network along the Gulf of Suez, Egypt

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GPS is one of the most important innovations of the last century in the field of surveying and navigation. GPS observations produce very precise surveying results. The presence of water vapor in the earth's atmosphere is the limiting factor for the achievable baseline accuracy. Thus, one of the key tasks of geodetic GPS processing software is to account for the effect of water vapor. As water vapor varies greatly, it is very difficult to model the wet delay accurately. Geodesists have developed estimation techniques that determine the time varying wet delay using GPS data themselves. The use of GPS data to calculate the wet delay leads to a new application of the GPS in the field of meteorology. This paper focuses on the effect of using GPS to detect water vapor on the baseline accuracy. Three GPS sites forming a triangle from a network established for monitoring seismic and tectonic activity around the Gulf of Suez, Egypt were used to test the baseline length precision and biases after taking the tropospheric delay into account. The main results of this study are as follows. The tropospheric delay estimation does not affect baseline precision itself but it significantly reduces the solution biases. The change in the baseline in this area found to be varied in the range of 8.0 mm and 12.0 mm. However, the latitude and longitude components were not affected significantly. On the other hand, the change of the vertical component reaches about 80 mm.

يعتـبر نظـــام تحديـــد الموقع العالمى (GPS) واحداً من اهم المتغيرات فى نهاية القرن العشرين فى مجال الأعمال المساحية والملاحـــة والجيوديسيا البحرية. جيث يعطى نظام تحديد الموقع العالمى نتائج مساحية دقيقة جداً ويعتبر بخار الماء فى غلاف الأرض من العوامل المؤثرة على دقة قياس الأطوال. وهذا البحث يهتم بتحديد تأثير بخار الماء على دقة القياس بواسطة تحديد نظـــام تحديـــد الموقع العالمى حيث تم التركيز على تأثير استخدام نظام تحديد الموقع العالمى لتقليل تأثير بخار الماء على دقة القياســـات الطولـــية. وفى هذا البحث استخدمت ثلاثة محطات (GPS) مكونة مثلث من الشبكة التى انشئت عام ١٩٩٤ حول خلـــيج السويس بمصر وذلك للتبؤ بالتحركات الزلزالية والتاكتونية حول هذه المنطقة الهامة. وقد استخدمت هذه النقط لإختبار دقـــة القياســـات الطولـــية وانحـــرافاتها عند تقدير طبقة التروبوسفير. وقد أخذت البيانات فى هذا البحث من جهاز الاستقبال Trimble 4000SSI حيـــث اســـتخدمت بياناته لإختبار دقة الأطوال والإنحرافات عند تقدير تأثير طبقة التروبوسفير. وقد انـــتهى البحـــث الـــى ان تأثـــير طبقة التروبوسفير لا يؤثر على دقة الخطوط ولكت يؤثر تأثير مباشر فى تقليل الانحرافات (Solution biases) كمـــا أن التغـــير فـــى الاطـــوال يتراوح مابين 8 الى 12 ملليمتر كذلك فإن مركبات خطوط الطول والعرض لاتتاثر تاثيرا ملحوظا، كما أثبت البحث أن التغيير فى المركبة الرأسية يصل الى 80 ملليمتر.

**Keyword:** GPS observations, Water vapor, Tropospheric dely, Gulf of Suez network

## 1. Introduction

For a long time, the tropospheric delay of GPS signals was considered as a nuisance [1-4]. In practice, several models have been proposed and used to eliminate that delay. The accuracies and performance differ with the parameters used in the models. Analysis and assessment of such models show that many are not accurate enough for precise applications [5]. However, no assessment was performed for the Egyptian conditions (The authors plan to carry out that task in a future work).

Nowadays, geodesists use GPS data themselves to estimate the time varying site-specific tropospheric delay [6, 7]. The tropospheric delay is estimated simultaneously with the station coordinates as well as


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other parameters. The GPS estimated delay is utilized for meteorological analysis and GPS is considered a new meteorological sensor.

GPS produce a cost effective accurate water vapor estimate with good spatial and temporal resolution. Hence GPS is now used as a meteorological instrument [8, 9]. However, GPS is originally designed as a navigation and positioning system [10]. The effect of such an innovative application on the baseline accuracy is of great concern to geodesists. Many authors address the above problem but with analytical approach [11, 12]. Analysis of actual data is needed to investigate this problem.

Here a triangle (closed figure) is used to check the effect of using GPS for meteorology on both the precision and biases of GPS baseline solution. The data used here are a part of a network used to monitor seismic and tectonic activity around Gulf of Suez, Egypt. The results indicate that the GPS surveying precision is not affected significantly when estimating the tropospheric delay. The baseline solution biases are much reduced. The main improvements are observed in the vertical component of the baseline solution.

## 2. GPS Data

GPS data taken with Trimble 4000SSI receivers are used to test the baseline length precision and biases when estimating the tropospheric delay. Data used here are mainly the three baselines that connect three sites of a network established for monitoring seismic and tectonic activity around the Gulf of Suez, Egypt (fig. 1). The monuments of the stations are driven to bedrock nearby main roads in the area [13]

The network is observed on a yearly campaign basis since 1994. Between 1994 and 1998, the observation session was set to about 8 hours. Starting from 1999, the session was enlarged to 24 hours. Sampling rate is set to 30 second and the elevation mask angle is maintained at 5 degree. The data is downloaded manually using a personal computer. No surface meteorological data is available. Here, one day of the 1999 data is processed; day 125 (May 5th). The approximate coordinate of the used stations as well as the baselines lengths are given in tables 1. Fig. 1 shows the map of the area and location of points used.

## 3. Data analysis

Data of a full 24 hours session are used. GPS data are first transformed from the receiver format to the RINEX (Receiver Independent Exchange) format. Bernese software package version 4.0 is used to analyze the data. Both sites coordinates and the tropospheric delay are estimated.

IGS ephemerides downloaded from the Internet are used as the orbit information of GPS satellites. Double-difference ionospheric-free phase observation of L3 (Linear combination of L1 and L2 as defined in [14) are used for the calculations. Elevation mask angle is set to 5 degree and the sampling rate is set to 30 seconds.

The total tropospheric delay is estimated every 30 minutes along with sites coordinates. The mapping function used is the default Bernese one (cosec {elevation angle}). The phase ambiguity is resolved using the Bernese search strategy [14]. The analysis is carried out two times; one with no tropospheric delay estimation (using models to eliminate the tropospheric delay) and the other with tropospheric delay estimation. The changes in the baseline lengths and point coordinates as well as in the precision are used to measure the effect of estimating the delay on the GPS solution.

Table 1-a
Approximate coordinates of the GPS stations in WGS-84

| Coordinate / Site No. | Latitude | Longitude | Height (m) |
|---|---|---|---|
| 1 | $27^{o}$ 22'26.850386" | $33^{o}$ 37' 36.893024" | 54.2407 |
| 3 | $29^{o}$ 22'43.149999" | $32^{o}$ 33' 56.153563" | 27.8884 |
| 9 | $28^{o}$ 44' 52.32855" | $34^{o}$ 28' 1.920163" | 562.5598 |

Table 1-b
Baseline lengths (m)

| Baseline | 3-1 | 1-9 | 3-9 |
|---|---|---|---|
| Length | 245285.4878 | 173211.7209 | 197932.5191 |

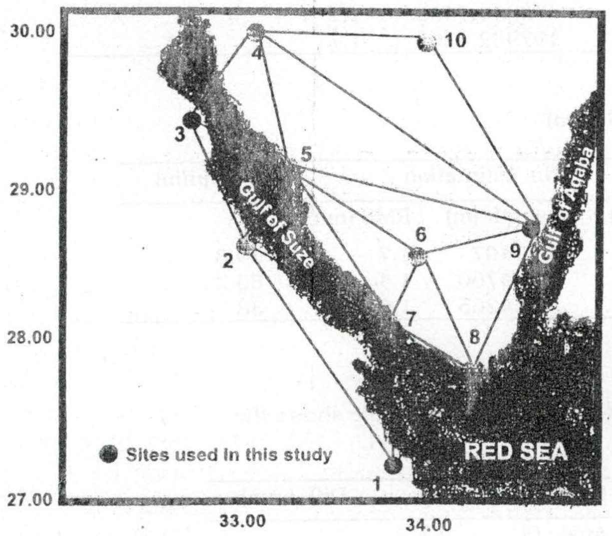


Fig. 1. Map showing the GPS network along the Gulf of Suez. The GPS sites numbers 1, 3, and 9 used in the present study are also shown.

## 4. Results and discussion

The analysis is carried out for two cases, in the first the tropospheric delay is not estimated while in the second that delay is estimated. The triangle connecting the three points 1, 3 and 9 of the Gulf of Suez network is used as a closed figure (fig. 1). Station 3 is held fixed and the coordinates of station 1 are estimated. The coordinates of point 9 are estimated two times, using the calculated coordinates of station 1 and the coordinates of point 3. The difference in the two sets of station 9 coordinates represents the closure error of the triangle. This closure error is a measure of the solution biases.

Tables 2 through 5 summarize the results. Table 2 shows the baseline length as well as their Root Mean Square error (RMS). It is readily seen from table 2 that the RMS of the three baselines change by 0.1 mm due to estimating the site-specific tropospheric delay. Thus the estimation of tropospheric delay parameters does not change the baseline precision significantly. However the change in the baseline lengths varies from 8 mm (baseline 3-9) to about 12 mm (baseline 3-1). The baseline length is shorter when estimating the tropospheric delay.

The vertical components of the baselines are given in table 3. Again, the RMS of the vertical component does not change significantly (the change is in the range of 0.2 – 0.3 mm). On the other hand, due to estimating the tropospheric delay, the vertical components are reduced by about 3.8 cm (point 9 as estimated from station 3) to 8.3 cm (point 9 as estimated from point 1) (table 3). Comparing the vertical coordinates of site number 9 as calculated from site 1 and 3 respectively, reveals that the biases are reduced when estimating the tropospheric delay. When no troposheric delay is estimated, the difference is about 49 mm. Estimation of the tropospheric delay reduces the above biases to only 4.3 mm only. This remaining biases may be due to errors in mapping function. This result agree totally with the theoretical stipulation that there are a high correlation between errors in the tropospheric delay and those errors in the vertical components of the GPS solution [4].

Tables 4 and 5 show the improvements of the other two baseline components (latitude and longitude) due to tropospheric delay estimation in the solution. The two tables indicate that no visible changes are observed. The difference does not exceed few parts per thousand of seconds.

No results were given here about the values of the estimated tropospheric delay as it is not the point of interest in the current study. Also, analysis of the meteorological parameters connected with the tropospheric delay needs more data. The current results are based on one campaign only, but it indicates clearly that estimation of a site specific tropospheric delay greatly improve the GPS solution biases, specially in the vertical components.

Table 2
Baseline Lengths (m) along with their RMS (mm)

| Baseline | Estimation of delay | | No. estimation | | Diff. (mm) |
|---|---|---|---|---|---|
| | Length (m) | RMS (mm) | Length (m) | RMS (mm) | |
| 3-1 | 245285.4785 | 1.7 | 245285.4878 | 1.6 | 9.3 |
| 1-9 | 173211.7319 | 1.3 | 173211.7439 | 1.2 | 12 |
| 3-9 | 197932.5183 | 1.7 | 197932.5265 | 1.7 | 8.2 |

Table 3
Vertical components (m) along with their RMS (mm)

| Point | Estimation of delay | | No. estimation | | Diff. (mm) |
|---|---|---|---|---|---|
| | Length (m) | RMS (mm) | Length (m) | RMS (mm) | |
| 1 (from 3) | 54.2009 | 2 | 54.2407 | 1.7 | 39.8 |
| 9 (from 1) | 562.3928 | 1.6 | 562.4760 | 1.4 | 83.2 |
| 9 (from 3) | 562.3885 | 1.8 | 562.4265 | 1.6 | 38 |

Table 4
Latitude components (") along with their RMS (mm), the table shows the seconds only

| Point | Estimation of delay | | No. estimation | | Diff. (mm) |
|---|---|---|---|---|---|
| | Angle (") | RMS | Angle (") | RMS | |
| 1 (from 3) | 26.851463 | .9 | 26.850775 | 1.0 | 0.000688 |
| 9 (from 1) | 52.465474 | .8 | 52.465114 | .8 | 0.000360 |
| 9 (from 3) | 52.464841 | 1.0 | 52.464692 | .9 | 0.000149 |

Table 5
Longitude components (") along with their RMS (mm), table shows the seconds only

| Point | Estimation of delay | | No. estimation | | Diff.(mm) |
|---|---|---|---|---|---|
| | Angle (") | RMS | Angle (") | RMS | |
| 1 (from 3) | 36.893101 | 1.7 | 36.893141 | 2.3 | 0.00003 |
| 9 (from 1) | 1.920162 | 2.1 | 1.919754 | 2.2 | 0.000408 |
| 9 (from 3) | 1.920221 | 1.8 | 1.919936 | 1.8 | 0.000285 |

## 5. Conclusions

Nowadays, GPS is used as a meteorological sensor to provide information about the time varying water vapor in the lower atmosphere. This means it use to estimate parameters that describe the tropospheric delay besides the station coordinates. The effect of this new GPS application on baseline accuracy is investigated in this study.

A closed triangle formed by three GPS from a network established for monitoring seismic and tectonic activity around the Gulf of Suez, Egypt is used to test the above effect. The results showed that estimation of the tropospheric delay does not affect GPS baseline precision. However, the solution biases are reduced significantly. The baseline always assumes shorter length when estimating the tropospheric delay. In the current analysis, the baseline shorting is in the range of 8.0 to 12.0 mm.

To investigate how much the baseline components are affected, the changes in the stations coordinates due to the estimation have been studied. The latitude and longitude components were not affected significantly. Even though, the effect on the latitude is one order of magnitude higher than the longitude, both were affected by less than 0.0006". On the other hand, the change of the vertical component is found to be very big. It reached about 80.0 mm as for the case of baseline connecting sites 1 and 9 (about 173.2 km). The vertical coordinate of point 9 is estimated from the other two points showed 4.3 mm biases after estimating a tropospheric delay parameter compared to 49 mm for the normal processing case.

Based on the above conclusions, it is highly recommended to estimate a tropospheric parameter when processing GPS data in order to reduce the biases especially with the vertical components.

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