Investigation Ambiguity Resolution in GPS and the Effects of Ionospheric Modeling on Base Vector Components

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Key words: GPS, iono free solution, ambiguity, fixed solution, float solution

SUMMARY

The GPS technology has given many opportunities for the geodetic applications. Although GPS has many important advantages, there are many error sources that affect on GPS observations. In this study, the effects of initial phase ambiguity at GPS and modeling of ionosphere on base components were researched. Pseudorange observations and phase observations were done in the test network. The solutions that are related to frequency and solutions, which are unrelated to ionosphere, were done by using these pseudorange and phase observations. Fixed solution and float solution have been done for initial phase ambiguity solution. Suggestions about the solution parameters are made at the stage of GPS data analysis from obtained results.

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1. INTRODUCTION

Today, GPS is being used intensively for geodetic and geodynamics purposes. Particularly, the important improvements in the quality of the receivers and analysis of the data depending on great process in the computer technology caused the GPS technique to be widely used in many high precision engineering surveys. Related to these developments the demand for a better accuracy has required a deeper understanding of GPS positioning strategies, the related error sources and the methods to reduce or eliminate them.

There are many error sources, which affect on GPS observations. When it is taken into consideration that the GPS signals arrive at the receivers passing through the atmosphere.. There are two atmosphere layers, which affect the GPS observations. They are Ionosphere and Troposphere. These two layers therefore affect the GPS observations in different ways. Since their effects are different on GPS observations they are taken into consideration using different modeling and techniques in GPS processing.

In this study, the effects of initial phase ambiguity at GPS and modeling of ionosphere on base components were researched. For this aim, in Turkey, the test network that is located in Metropolitan Area of Konya was used. There were 7 points and 12 baselines that their distances change between 7 and 90 km in the test network. In this test network, pseudorange observations and phase observations were performed. The solutions that are related to frequency and solutions that are unrelated to ionosphere were done by using these pseudorange and phase observations. Fixed solution and float solution have been done for initial phase ambiguity solution. Suggestions about the solution parameters are made at the stage of GPS data analysis from obtained results.

2. ERROR SOURCES IN GPS

There are many numerous sources of error that will cause the rover unit’s position to be recorded erroneously. These errors include, but are not limited to: Atmospheric Error, “Multipath” Error, satellite and receiver clock errors, satellite orbit errors, receiver noise, and phase center variation. In this study, was especially focused on ionospheric error and carrier phase ambiguity.

2.1 Ionospheric Delay

The ionosphere is the portion of the atmosphere between on altitude of 50 kilometers and 1000 kilometers in which free thermal electrons are present. It is weakly ionized plasma depending primarily on the sun and its activity and affects radio wave propagation in various ways. Therefore the ionosphere becomes an important source of range and range-rate errors for user of GPS satellites who require high accuracy measurements (Klobuchar, 1996; Özlüdemir, 2003). In any medium, a carrier wave's propagation speed is less than or greater than that in a vacuum. However, in the ionosphere, GPS signals do not travel at the vacuum speed of light as they transit this region. This is because of free electrons in the ionosphere. The Total Electron Content (TEC) defines the number of free electrons. The Total Electron Content varies with a number of factors including the time of day, location and reason. However, one characteristic of the ionosphere is that the signals are affected proportionally to the signal frequency. As the GPS signals comprise two frequencies spaced by approximately 350 MHz, a combination of the L_1 and L_2 carrier phases can be generated which removes the ionospheric error. This ionosphere free observable suffer from an increase in random measurements error, however, should be used in periods of high ionospheric activity. In order to generate the ionosphere free observable, a dual frequency receiver is required. On short, baselines (<20~30 km) where the ionospheric errors cancel in between station (single) differencing, it is preferable to treat L_1 and L_2 as two independent observable, rather than from the linear combination. For long baselines (>50 km) it is better to use L_3 linear combination strategy with ambiguity fixed solutions.

2.2 Carrier Phase Ambiguity

Resolving the GPS carrier-phase ambiguities has been a continuing challenge for sub-centimeter level high precision GPS positioning. The GPS carrier-phase ambiguity represents the arbitrary counter setting (an integer value) of the carrier-phase cycle tracking register at the start of observations of a satellite (phase lock), which biases all measurements in an unbroken sequence of that satellite's carrier-phase observations. Once the integer ambiguities are fixed correctly, the carrier-phase observations are conceptually turned into millimeter level high-precision range measurements and hence it is possible to attain sub-centimeter level positioning solutions. However, fixing the integer ambiguities is a non-trivial problem, especially if we aim at computational efficiency and high performance (Kim, D. and Langley, B.R. 2000).

In general, algorithms for solving the integer ambiguities the algorithm have been developed for two different applications. The first group of the algorithms has been developed for applications using multi-reference stations in static model. Multi-reference stations are occupied for several hours or even several days. Inter-station distance can reach thousands of kilometers. The second group of the algorithms has been developed for rapid-static, kinematic and navigation applications. Only two stations are usually involved with at least one station moving. The maximum distance between the stations is a few tens of kilometers. Time of occupation is to order of seconds to minutes or even instantaneous. However, conceptually there are no differences between the two applications, and the researched directed to one application can benefit from research conducted for the other. Moreover, particular interests such as real time long-baseline kinematic applications integrate the two approaches.

In Table 1; according to IGSM (2002), the classification of horizontal control network is given. In addition to Table 1, in Table 2, evaluation parameters that are used for real time kinematic application are given.

Table 1: Classification of Horizontal Control Survey

CLASS	**ORDER**	**c (1 σ)**	**Typical applications**
3A	00	1	Special high precision surveys
2A	0	3	High precision National geodetic surveys
A	1	7,5	National and State geodetic surveys
B	2	15	Densification of geodetic survey
C	3	30	Survey coordination projects
D	4	50	Lower CLASS projects
E	5	100	Lower CLASS projects

Table 2: Processing Parameters Recommended in Real Time Kinematic Application

CLASS (Australia)	**3A**	**2A**	**A**	**B**	**C**	**D**	**E**
c value (1 sigma)	≤ 1	≤ 3	≤ 7.5	≤ 15	≤ 30	≤ 50	≤ 100
Base Distance	Recommended processing parameters						
< 8 km	D*, DD, FX	D*, DD, FX	S, DD, FX	S, DD, FX	S, DD, FX	S, DD, FT	S, DD, FT
8-25 km	D, DD, FX	D, DD, FX	D, DD, FX	D, DD, FX	S, DD, FX	S, DD, FT	S, DD, FT
25-50 km	D, DD, FX (25)-FT (50)	D, DD, FX (25)-T (50)	D, DD, FX-FT	D, DD, FX-FT	D, DD, FX-FT	D, T	D, T
50-90 km	D, DD, FT	DD or T, D, FT	DD or T, D, FT	DD T, D, FT	DD or T, D, FT	D, T, NCP	D, T, NCP
> 90 km	D, T	D, T	D, T	D, T	D, T	D, T, NCP	D, T, NCP

S	: single frequency
D	: dual frequency
DD	: double differences
T	: triple differences
FX	: ambiguity fixed solution
FT	: ambiguity floats solution
NCP	: Narrow correlation, C/A code or Pseudorange
*****	: L1 solution, If dual frequency is used, widelaning integer ambiguity solution

3. NUMERICAL APPLICATION

In this study, the effects of initial phase ambiguity at GPS and modeling of ionosphere on base components were researched. For this aim, in Turkey, the test network that is located in Metropolitan Area of Konya was used. There are 7 points and 12 baselines that their distances change between 7 and 90 km the test network. Test network is given in Figure 1. The static measurements were performed between 1.5 - 6 hours in 2002.264 and 2002.265 GPS days in test network. According to these measurements, the effects of ephemeris information on coordinate components were researched. During this research, Trimble Geomatics Office Software system was used. As a troposphere model, Saastamoinen standard troposphere model was used and a cut-off elevation angle 15^o was chosen. By the modeling of ionosphere and the solution of initial phase ambiguity were used ionosphere free fixed solution used as far as 30 km baselines. For the other baselines that are longer than 30 km, ionosphere free float was used.

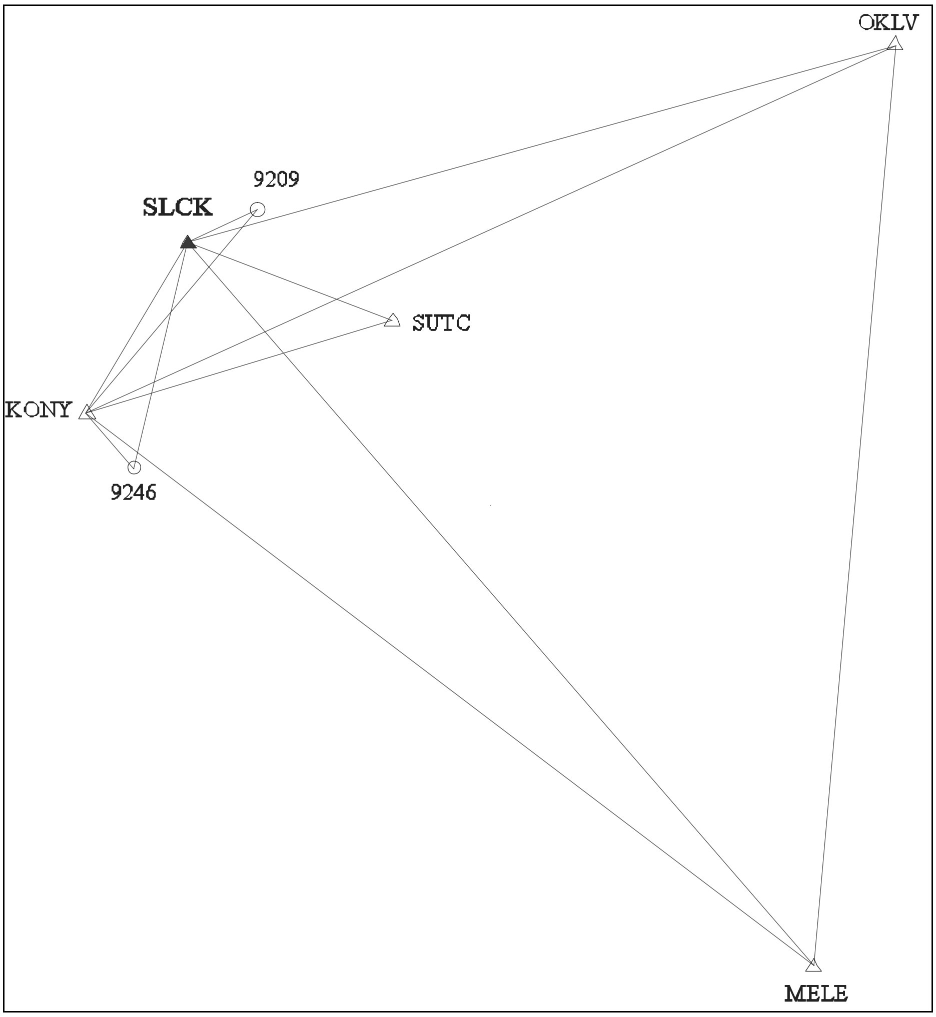

Figure 1: Test Network

Table 3: Base solutions in the end of process

Base Number	Point Number	Point Number	Base distance (m)	Solution type	Reference Variance	rms (m)
B1	SLCK	KONY	19649,077	Iono free fixed	0,910	0,010
B2	SLCK	SUTC	21184,084	Iono free fixed	1,062	0,011
B3	SLCK	9209	7507,089	Iono free fixed	0,694	0,009
B4	SLCK	9246	22969,709	Iono free fixed	0,687	0,009
B5	SUTC	KONY	30976,337	Iono free fixed	0,651	0,009
B6	9209	KONY	26222,023	Iono free fixed	0,295	0,006
B7	9246	KONY	7157,314	Iono free fixed	0,469	0,007
B8	SLCK	MELE	93689,767	Iono free float	1,519	0,013
B9	MELE	KONY	89051,645	Iono free float	1,258	0,014
B10	SLCK	KONY	19649,075	Iono free fixed	0,998	0,011
B11	OKLV	MELE	91455,790	Iono free float	1,096	0,012
B12	SLCK	OKLV	71019,985	Iono free float	1,139	0,012
B13	OKLV	KONY	86282,713	Iono free float	0,677	0,010

In geodetic applications, essentially ambiguity fixed solution is used. In addition to this, initial phase ambiguity is calculated as a ambiguity float are used to eliminate ionospheric effects. It is necessary to perform observations in more than one frequency (for example L_1 and L_2) for iono free solution. By using L_1 and L_2 combination, ionospheric delay is removed.

To detect the effects of both ambiguity fixed solution and ambiguity float solution, just by changing to initial phase ambiguity, the same baselines were processed according to ambiguity fixed solution and ambiguity float solution. The results are given in Table 4.

The results of iono free fixed solutions in Table 4 show that the root-mean square values are less than 1 cm for short baselines (<30 km). The root-mean square values change between 3.2 cm and 4.7 cm for long baselines (>70 km). According to these results, it is clear that the root- mean square values increase related to the distance of baselines. In the and, it can be stated that ionospheric effects increase related to the distance of baseline when the results of L_1 fixed solutions examine, it is stated that the root-mean square value is less than 1 cm for about 7 – 8 km baselines. Also it can be seen that the reference variance value is about 3.8 cm. In the light of these results, it is stated that for short baselines, their distances chance between 7 km and 8 km, the results of single frequency observation can be used in geodetic network observations.

Table 4: The results of base solutions that obtained according to L_1 fixed, iono free fixed and iono free float

Ionosphere and initial phase ambiguity	Iono free float	Iono free fixed	L1 fixed
Ephemeris	Precise	Precise	Precise
Troposphere	Saastamoinen	Saastamoinen	Saastamoinen
Elevation Angle	15 ˚	15 ˚	15 ˚

BASE										
		Length **Variance** **rms**	**N** **E** **H**	**σ N** **σ E** **σ h**	**Length** **Variance** **rms**	**N** **E** **H**	**σ N** **σ E** **σ h**	**Length** **Variance** **rms**	**N** **E** **h**	**σ N** **σ E** **σ h**
KONY	9246	7157,295	-5402,088	0,001	7157,314	-5402,091	0,001	7157,298	-5402,079	0,001
		0,295	4682,093	0,004	0,459	4682,120	0,000	3,885	4682,108	0,000
		0,006	-324,884	0,005	0,007	-324,867	0,004	0,007	-324,885	0,003
SLCK	9209	7507,090	3277,558	0,002	7507,089	3277,563	0,001	7507,073	3277,557	0,001
		0,619	6751,668	0,002	0,672	6751,665	0,000	3,812	6751,649	0,000
		0,008	-104,326	0,006	0,008	-104,319	0,004	0,007	-104,324	0,004
SLCK	KONY	19649,076	-16960,289	0,001	19649,077	-16960,289	0,000	19649,002	-16960,228	0,001
		0,822	-9912,399	0,001	0,852	-9912,400	0,000	23,832	-9912,358	0,000
		0,010	207,742	0,003	0,010	207,747	0,002	0,017	207,693	0,004
SLCK	SUTC	21184,076	-7829,510	0,009	21184,075	-7829,525	0,001	21184,022	-7829,512	0,002
		1,267	19679,773	0,013	1,072	19679,754	0,001	44,044	19679,701	0,001
		0,013	-161,848	0,020	0,012	-161,823	0,008	0,021	-161,809	0,010
SLCK	9246	22969,711	-22362,386	0,002	22969,709	-22362,383	0,001	22969,642	-22362,319	0,001
		0,538	-5230,267	0,006	0,674	-5230,276	0,000	15,877	-5230,254	0,001
		0,008	-117,125	0,007	0,008	-117,103	0,005	0,014	-117,145	0,007
KONY	9209	26222,015	20237,843	0,001	26222,022	20237,849	0,000	26221,929	20237,780	0,001
		0,233	16664,063	0,001	0,270	16664,067	0,000	26,489	16664,007	0,001
		0,005	-312,054	0,004	0,006	-312,057	0,003	0,017	-311,976	0,008
KONY	SUTC	30976,331	9130,762	0,003	30976,335	9130,758	0,001	30976,477	9130,808	0,004
		0,493	29592,154	0,007	0,630	29592,161	0,000	201,991	29592,294	0,003
		0,008	-369,534	0,008	0,009	-369,514	0,004	0,080	-369,497	0,022
		71019,987	19459,095	0,001	71020,064	19459,062	0,002			
SLCK	OKLV	1,108	68289,804	0,002	15,940	68289,892	0,001			
		0,011	-172,545	0,004	0,044	-172,421	0,011			
		86282,715	36419,381	0,001	86282,708	36419,350	0,002			
KONY	OKLV	0,653	78202,204	0,001	19,100	78202,210	0,001			
		0,010	-380,305	0,003	0,047	-380,331	0,012			
		89051,645	-54675,099	0,001	89051,724	-54675,120	0,001			
KONY	MELE	1,260	70268,456	0,002	10,401	70268,539	0,001			
		0,014	-54,234	0,004	0,040	-54,197	0,009			
		91455,792	91094,481	0,001	91455,816	91094,504	0,001			
MELE	OKLV	0,978	7933,750	0,002	7,374	7933,775	0,001			
		0,011	-326,058	0,004	0,032	-326,113	0,008			
		93689,767	-71635,385	0,001	93689,836	-71635,417	0,001			
SLCK	MELE	1,466	60356,051	0,002	8,814	60356,118	0,001			

		0,013	153,505	0,005	0,034	153,681	0,008			

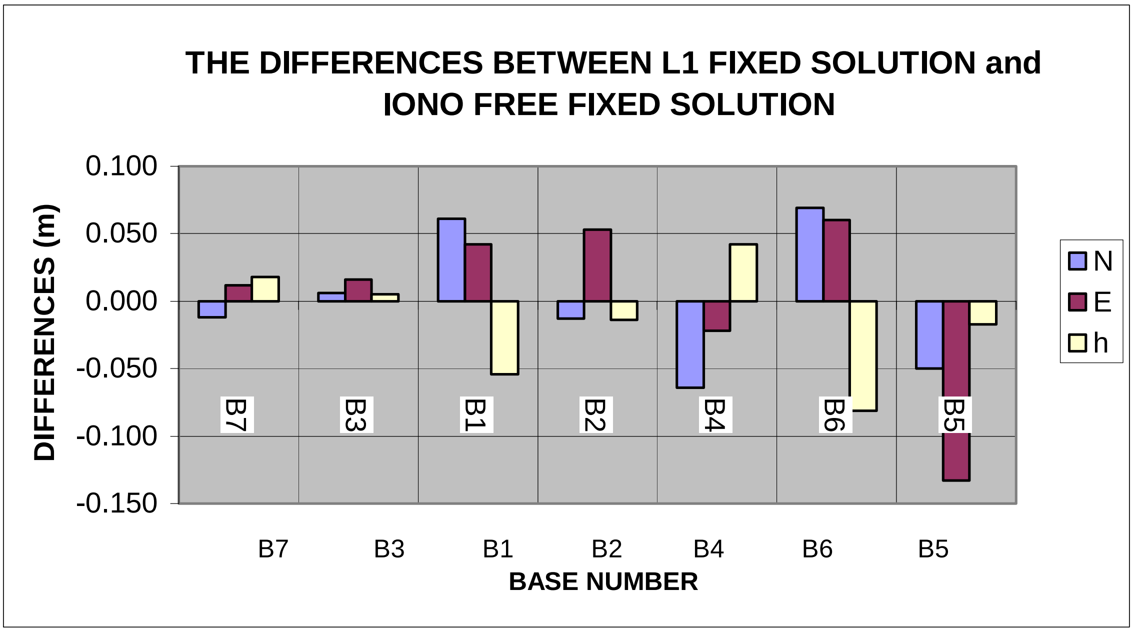

Figure 2: The differences between L1 fixed solution and Iono free fixed solution

In figure 2, when the results of iono free fixed solutions are compared with the results of L_1 fixed solutions, it is stated that the differences between these two solutions are larger than 5 cm for about 20 – 30 km baselines. Also it is seen that the differences change between 1.3 cm and 13.3 cm in base components (N, E, h).

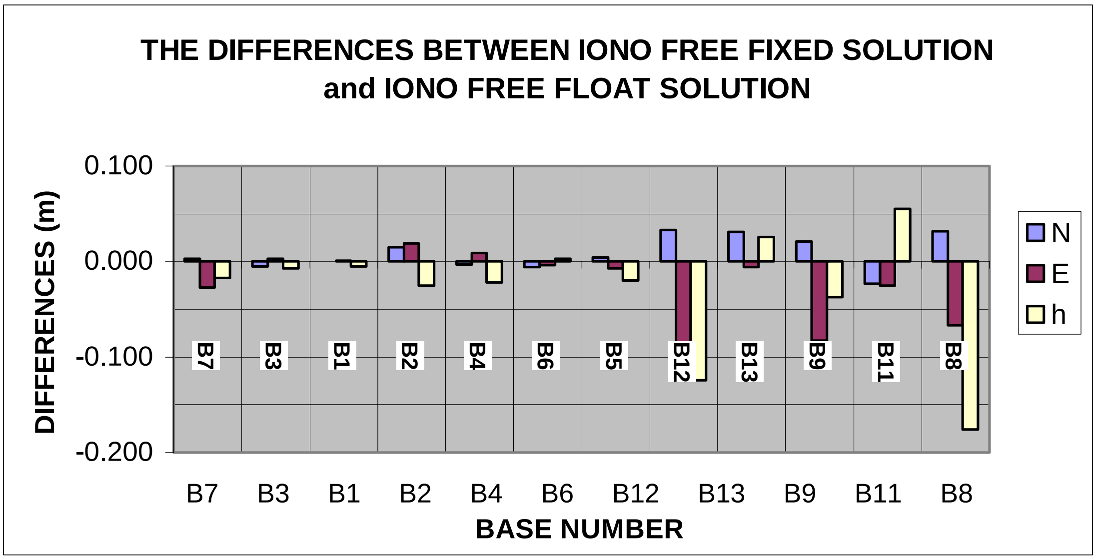

Figure 3: The differences between the iono free fixed solution and iono free float

In the figure 3, it is demonstrated the differences between the iono free fixed solution and iono free float solution. According to this figure, the differences between these solution are stayed less than 3 cm for shorter than 31 km baselines. For longer than 70 km baselines, these differences change between 3.1 cm and 17.6 cm in base components (N, E, h).

4. CONCLUSIONS

In engineering application, to get the essential accuracy criterion, in GPS measurements, pseudurange observations and carrier phase observation are used together. In the phase measurements, initial phase ambiguity fixed resolution is fundamental. In this study, it is concluded that, while ambiguity fixed solution is preferred for short baselines (<30 km), for long baselines (>30 km) the chosen of ambiguity float solution will be more convenient in GPS data processing by commercial software packages. In addition to this, according to result of both iono free fixed solution and L_1 fixed solution, it is stated that for shorter than 10 km baselines the same results are obtained in the end of these two solutions. For baselines that are longer than 20 km, it is obtained that the differences of these solutions are larger than 5 cm in baselines. Finally, in engineering application, by using of single frequency by this way in GPS observation for shorter than 10 km baselines, it is possible to obtain necessary accuracy criterion. Also, it is possible to get more economical solutions in geodetic applications.

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