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A statistical investigation on the effects of different GNSS systems

Farklı GNSS sistemlerinin etkileri üzerine istatistiksel bir araştırma

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Abstract

This study is to investigate the effects of various solutions of GPS only, GLONASS only, and combined GPS/GLONASS observations under different elevation angles on different GNSS days by using Magic GNSS software. Different elevation angles and measurement days were considered to investigate the increasing or decreasing number of satellites' effects on the measurement accuracy, and positioning accuracy affected by the solutions of GPS only, GLONASS only, and combined GPS/GLONASS observations, respectively. The assessment was based on statistical tests, namely ANOVA and Post Hoc tests. A test network, consisting of all the continuous stations of the ISKI CORS network in Istanbul city, was used to fulfill the aims of the study. The results showed that significant differences between positions of points obtained by GNSS in various elevation angles and with different satellite configurations were determined. Different satellite and measurement configurations affect position accuracy. In addition, the results showed that on the 136th GNSS day, significant differences in X and Z components were found while in Y components there were no significant differences encountered. In conclusion, combined GPS/GLONASS solutions produced better results under small elevation angles of 5° 10° or 15° than the solutions of GPS-only and GLONASS-only observations.

Keywords: ANOVA, Elevation Angles, GPS/GLONASS, magic GNSS, Post Hoc Test

Öz

Bu çalışma, Magic GNSS yazılımı kullanılarak farklı GNSS günlerinde farklı yükseklik açıları altında yalnızca GPS, yalnızca GLONASS ve kombine GPS/GLONASS gözlemlerinin çeşitli çözümlerinin etkilerini araştırmak içindir. Uydu sayısının artan veya azalan ölçüm doğruluğu üzerindeki etkilerini araştırmak için farklı yükseklik açıları ve ölçüm günleri dikkate alınmıştır. Değerlendirme, ANOVA ve Post Hoc gibi istatistiksel testlere dayanmaktadır. Çalışmanın amaçlarını gerçekleştirmek için İSKİ CORS ağının İstanbul ilindeki tüm sürekli istasyonlarından oluşan bir test ağı kullanılmıştır. Sonuçlar, GNSS ile çeşitli yükseklik açılarında ve farklı uydu konfigürasyonlarında elde edilen noktaların konumları arasında önemli farklılıklar olduğunu göstermiştir. Farklı uydu ve ölçme konfigürasyonları, konum doğruluğunu etkilemektedir. Ayrıca sonuçlar, 136. GNSS gününde X ve Z bileşenlerinde anlamlı farklılıklar bulunduğunu, Y bileşenlerinde ise anlamlı bir farkla karşılaşılmadığını göstermiştir. Sonuç olarak, kombine GPS/GLONASS çözümleri, yalnızca GPS çözümlerine ve yalnızca GLONASS gözlemlerine göre 5° 10° veya 15°'lik küçük yükseklik açıları altında daha iyi sonuçlar vermiştir.

Anahtar kelimeler: ANOVA, Yükseklik Açıları, GPS/GLONASS, Magic GNSS, Post Hoc Testi

1 Introduction

Over the last ten years, GLONASS observations have been combined with GPS observations to improve the positioning accuracy offered by GPS-only and GLONASS-only solutions of phase or code observations. Investigating the position accuracies of combined GPS/GLONASS observations to GPS only observations, several researchers drew slightly controversial conclusions. Steward et al. [1] investigated the internal and external precision of long baselines from GPS, GLONASS and combined GPS/GLONASS observations, and found that long baseline solutions of three cases were compatible with each other at a level of 0.01 ppm. However, larger error ellipses from combined least square solutions were interpreted as the availability of less number of observations of GLONASS for such thousands of kilometer baseline length at the time of the observations (1998-1999). Another study indicating results close to the former by Wang and Wang [2] was carried out to determine the effects of combined GPS/GLONASS observation in long baseline solution and found that the combining GLONASS with GPS observation for long baseline solution increased the baseline accuracy by utilizing two networks namely, four-station network in Australia and EUREF Permanent Network (EPN). While EPN network solution with combined GPS/GLONASS solution slightly improved the accuracy, the solution from the network in Australia presented equal magnitudes of Root Mean Square (RMS) errors with respect to GPS-only observations. Likewise, comparisons of solutions of GPS+GLONASS combination to GPS-only observations showed that combined solutions were compatible to European Permanent Network without degrading the accuracy [3]. Similarly, Cai

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and Gao [4] investigated the accuracy and reliability of combined GPS and GLONASS solutions by using 10° elevation cut off angle in processing the observations and stated that the combination of GLONASS with GPS-only observation increased the accuracy of PPP solution. Superior results from combined GPS/GLONASS observations compared to solutions of GPS-only observations were obtained by Azab, et al. [5]. Supporting the results of the study, Alcay et al. [6] concluded that adding GLONASS observations to GPS observations improved the results for short measurement time; typically, up to 4 hours of observations. However, due to Anquela et al. [7], solutions from combined GPS and GLONASS observations did not always improve the convergence of static PPP, but kinematic solutions of them produced more accurate results than that of GPS-only observations. Mohammed et al. [8], investigated achievable repeatability and accuracy from daily PPP solutions using GPS only, GLONASS only and combination of GPS and GLONASS for static positioning. Combined GPS and GLONASS solution produced low repeatability compared to GPS only and GLONASS only in Easting, Northing, and Up components. However, from the precision and accuracy point of view, little or no improvement was achieved compared to GPS only and GLONASS only. Abd-Elazeem, et al. [9], studied the effect of cut-off elevation angle (ranging from 5 to 30 degrees) on the accuracy of GPS positioning and found small standard deviations of the differences between GPS and total station coordinates for low elevation angles (10 to 20 degrees). Ning and Elgered [10] studied trend in atmospheric integrated water vapor for different elevation angles, concluded that systematic errors which were elevation angle dependent varied with time, and recommended more studies to be done.

In terms of processing software, there have been a number of online PPP GNSS processing services available over the last decade. These services provide opportunities for users to obtain high precision results free of charge in International Terrestrial Frame. Martin et al. [11,12] compared Magic GNSS PPP results to those provided by online services namely; Canadian Spatial Reference System Online Global GPS Pro-cessing Service (CSRS-PPP), the automatic precise positioning service (APPS), GPS analysis and position software (GAPS), and BERNESE, and concluded good performance of Magic GNSS. Considering the above studies, solutions of combined GPS/GLONASS observations need more testing with different strategies.

The aims of this study were to statistically investigate the effects of various solutions utilizing GPS-only, GLONASS-only, and combined GPS/GLONASS observations under different elevation cut off angles on different GNSS days by using Magic GNSS service. Different elevation cut-off angles were considered to investigate the increasing or decreasing number of satellites' effects on the measurement accuracy, and taking observations on different GNSS days aimed at positioning accuracy affected by the solutions utilizing GPS only GLONASS only and combined GPS/GLONASS observations.

2 Material and methods

ISKI CORS network established in Istanbul city consists of eight continuously operating stations. All the stations (Beyk, Kcek, Pala, Sile, Slvr, Terk, Tuzl, Yali) from the ISKI CORS network were used to fulfil the aim of this study. GNSS measurements on the stations covered 24 hours of observations of the 136th, 164^{th}, and 166th GNSS days of the year 2012. Station names, satellite configuration and elevation angles were depicted in Table 1, and Figure 1 shows the locations of the stations. All the measurements from eight stations for three days were included in obtaining coordinates of the stations by using Bernese 5.0 software. In the processing, 13 IGS stations (Ankr, Bucu, Drag, Dubr, Glsv, Graz, Ista, Mat1, Nico, Not1, Polv, Ramo, Sofi) were used as reference stations.

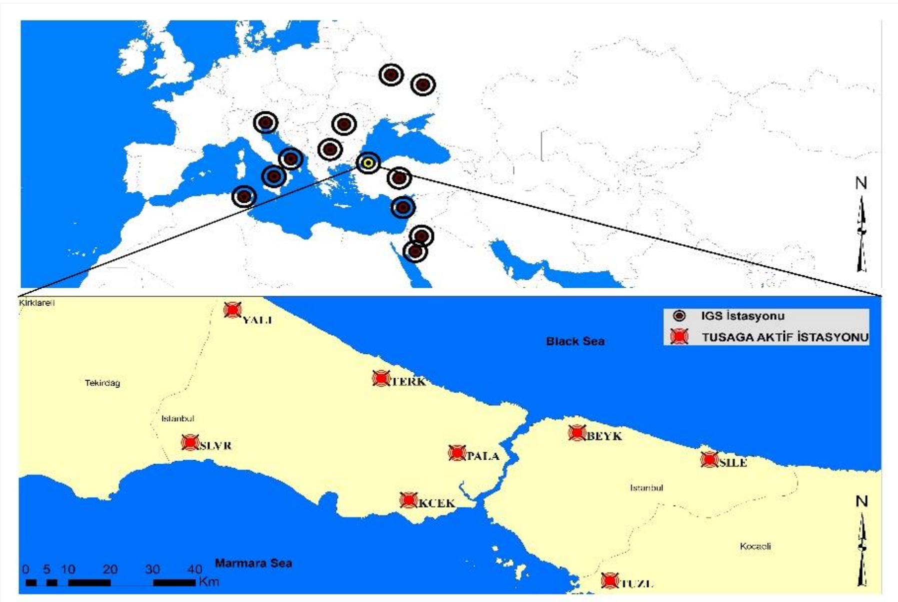


Figure 1. Station location

Table 1. Elevation angles, station names and satellite configurations of ISKI

Elevation Angle (degree)	Satellite Configuration GPS+GLONASS	GPS	GLONASS	ISKI UKBS CORS Configuration			IGS Stations		Measure Time
0^0	√	√	√	Coverage Area: Istanbul			SOFI	ISTA	2012 Year
5^0	√	√	√	Datum: ITRF 2008			ANKR	MAT1	
10^0	√	√	√	GNSS Stations : 8			BUCU	NICO	136. Day
15^0	√	√	√	BEYK	KCEK	PALA	DRAG	NOT1	164. Day
20^0	√	√	√	SILE	SLVR	TERK	DUBR	POLV	166.Day
25^0	√	√	√	TUZL	YALI		GLSV	RAMO	
30^0	√	√	√				GRAZ		

In this study, the datum of the coordinate is ITRF2008.00 (International Terrestrial Reference Frame, in 2008.00 epoch) and X, Y, Z are the Cartesian coordinates in meters throughout the study. The coordinates of the eight stations were estimated from the observations taken on three different GNSS days, and the average of these coordinates was taken as true coordinates. These measurements were processed by the web-based Magic GNSS software called MagicPPP which supports GPS, GLONASS, and GALILEO constellations performs static positioning as one of the processing modes, and accepts RINEX or RTCM format as input. Magic GNNS software claims that it can provide sub-cm level of accuracy for observations time around 24 hours [13].

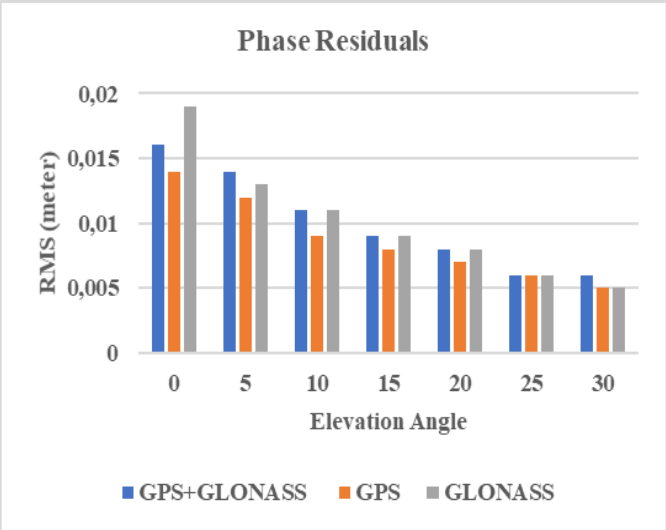
The software can utilize code and phase dual-frequency ionosphere-free combinations. It runs least-squares algorithm which minimizes measurement residuals to solve for GNSS satellite orbits and clock, phase ambiguities, tropospheric zenith delays [14]. The software can create orbit and clock files of GPS and GLONASS with a latency of 30 from GNSS stations distributed worldwide. If IGS products are available at the time of processing, it uses the available IGS files. If not, it uses the created GLONASS orbit and clock files in the process. So, solution of combined GPS and GLONASS observations was made possible [7].

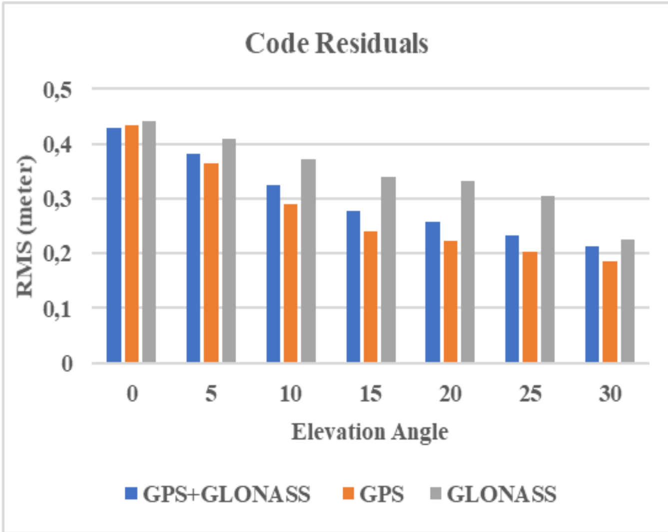
Differences between true coordinates (assumed as the average of these coordinates obtained by processing all the observations in three GNSS days) and those obtained through Magic GNNS processing were taken and used to test whether they were statistically significant or not. A common test for two mean comparisons is usually t-tests. It can be applied to paired means taken at a time but this increases the type 1 error possibility. Therefore, variance test with 95% confidence level was applied to the differences. In the test, the assumption of the each variance of the test groups being homogeneous and normally distributed was statistically tested so the assumptions were fulfilled. According to the test results, if there is any significant difference between the coordinates, then a Post Hoc test in terms of satellite configurations and different elevation angles may be applied to reveal factors that contribute to the significant differences. This test may allow one to analyse which satellite configurations and what elevation angle cause to affect the coordinate accuracy. For the entire statistical test applied SPSS 6.0 software (Statistical Package for the Social Sciences) was used.

In statistical analyses, the t-test is usually used to determine whether there is a significant difference between the two means. Analysis of variance is also used to determine whether there is a difference between more than two means. In the analysis of variance, dependent and independent variables are used. In general, the effect of independent variables (factors) on dependent variables is investigated. The type of analysis of variance varies according to the number of dependent and independent variables. In Analysis of Variance (ANOVA), each of the groups to be tested must be normally distributed and whether the variances of the groups are homogeneous should be tested before analysis. In this study, differences between groups were evaluated by applying the Tukey test if variance homogeneity was provided, and Tamhane's T2 test if variance homogeneity was not achieved. The ANOVA table generally tells whether there is a difference between the means of the groups. If there is a difference between the groups as a result of the analysis of variance, post-hoc tests are very important so that we can see which group the difference originates from. Tukey and Benferronni tests are commonly used in post-hoc tests. In the ANOVA table, it is tested whether there is a difference between the groups compared. If the value of F used in statistics is greater than the table value of F at the 95% significance level, the Ho hypothesis is rejected. For this, it is necessary to look at the tabular value of F. SPSS gave us the p-value (Sig). If this value is less than 0.05, the Ho hypothesis is rejected. This indicates that there is a difference between the groups. It can be said that there is a significant difference between the groups with significance levels below 0.05. Significance levels are determined by looking at the table values (sig.) obtained from SPSS. Accordingly, pairwise comparisons are made between the groups to determine whether there is a difference between which groups. In addition, SPSS creates subgroups according to the dependent variable. These subgroups are determined according to whether the variables show the same or different characteristics. In this study, the results were interpreted using these statistical analyzes and tests [15].

3 Results and discussions

Coordinates (X, Y, Z) of eight continuously operating reference stations from ISKI CORS in Istanbul acquired on different days (136th,164th, and 166th GPS days) under different elevation cut-off angles (0°, 5°, 10°, 15°, 20°, 25°, 30°) were statistically tested whether they were significant or not. Figure 2 shows the mean RMS residuals for the code and phase observations of GPS only, GLONASS only and the combination of GPS/GLONASS obtained through using Magic GNSS, depicting the precision of the raw data in the static position fixing.





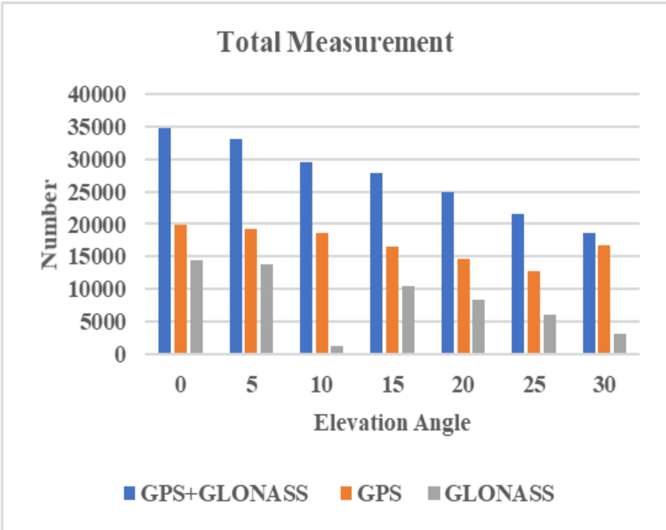


Figure 2. a) RMS of phase residuals, b) RMS of code, and c) RMS of total measurements with respect to elevation cut-off angles for GPS only, GLONASS only and the combination of GPS/GLONASS Observations.

In these results, it is clearly seen that RMS values of phase and code measurements decreased when the satellite elevation angle increased. On the other hand, GPS only solution presented smaller RMS values with respect to those of GLONASS-only solution of code and phase. Accordingly, the results of GPS/GLONASS combinations reflected average values according to the results obtained from GPS only and GLONASS only solutions. In the assessment regarding satellite elevation angles, the total number of observations, which provide useful advantages in GNSS solutions, were naturally decreased. As GLONASS observations provide less number of observations compared to that of GPS only, GPS/GLONASS combinations were improved in terms of number of observations.

Table 2 shows standard deviations of the coordinates from the measurements collected on different days under various elevation angles, and Figure 3 represents the standard deviations of coordinates on the 136th day only. The standard deviations of coordinates from the combination of GPS and GLONASS, GPS only and GLONASS only observations at 10° and 15° angles on the 136th and 166th days were small compared to those of different elevation angles (Table 2). However, the standard deviations of coordinates on 164th day did not follow the same pattern for the solutions of GPS-only observations while those of GLONASS-only observations illustrate compatible results. In terms of standard deviations of the coordinates, the combination of GPS and GLONASS observations produced 'best' results under 10° elevation angles.

True coordinates of the stations were assumed to be the coordinates obtained from the Bernese GNSS software version 5.0. The results of ANOVA (ANalysis Of VAriance) of the averaged coordinate differences between true values of coordinates and the coordinates obtained from Magic GNSS software on different GNSS days under different elevation angles showed statistically significant differences.

Table 2. Standard deviations of coordinates under different satellite configurations on different days (m).

GNNS Time	Elevation Angle (degree)	GPS+GLONASS x	GPS+GLONASS y	GPS+GLONASS z	GPS x	GPS y	GPS z	GLONASS x	GLONASS y	GLONASS z
	0º	0.006	0.005	0.004	0.009	0.004	0.006	0.020	0.010	0.016
	5º	0.005	0.005	0.005	0.005	0.004	0.004	0.010	0.004	0.009
	10º	0.002	0.003	0.002	0.003	0.002	0.003	0.005	0.004	0.005
136.DAY	15º	0.004	0.004	0.004	0.005	0.004	0.004	0.007	0.006	0.008
	20º	0.007	0.004	0.006	0.007	0.003	0.005	0.009	0.008	0.011
	25º	0.006	0.003	0.005	0.008	0.002	0.007	0.009	0.006	0.014
	30º	0.004	0.004	0.005	0.007	0.006	0.007	0.013	0.008	0.010
	0º	0.009	0.006	0.009	0.026	0.018	0.024	0.012	0.006	0.011
	5º	0.006	0.003	0.005	0.007	0.004	0.005	0.005	0.002	0.004
	10º	0.006	0.003	0.005	0.005	0.005	0.005	0.008	0.006	0.006
164. DAY	15º	0.005	0.002	0.003	0.006	0.004	0.004	0.009	0.002	0.007
	20º	0.003	0.002	0.002	0.003	0.006	0.003	0.009	0.004	0.008
	25º	0.004	0.003	0.004	0.005	0.005	0.007	0.013	0.007	0.011
	30º	0.003	0.004	0.003	0.005	0.009	0.004	0.009	0.007	0.013
	0º	0.008	0.009	0.009	0.010	0.010	0.009	0.016	0.009	0.018
	5º	0.004	0.008	0.007	0.005	0.007	0.006	0.010	0.006	0.012
	10º	0.003	0.008	0.004	0.005	0.009	0.005	0.004	0.006	0.004
166.DAY	15º	0.004	0.006	0.004	0.005	0.008	0.004	0.004	0.006	0.004
	20º	0.004	0.006	0.003	0.004	0.008	0.002	0.008	0.007	0.006
	25º	0.007	0.006	0.005	0.007	0.007	0.008	0.014	0.009	0.015
	30º	0.005	0.007	0.007	0.006	0.012	0.006	0.014	0.013	0.014

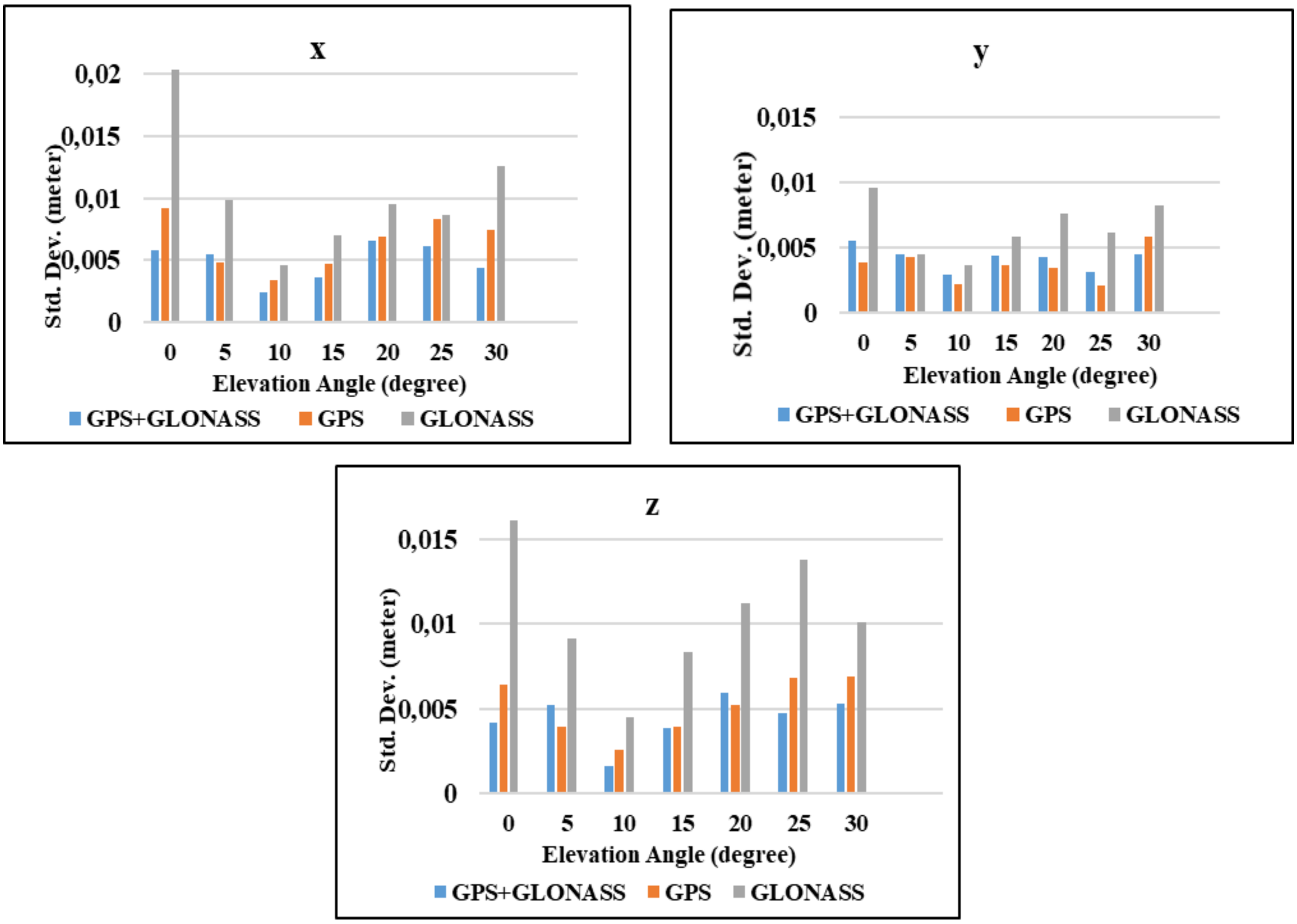


Figure 3. Standard deviations of coordinates on the day of 136th

Therefore, Post Hoc test were applied to mean differences to reveal which satellite constellations were causing the significant differences. This was done by comparing mean coordinate differences obtained from paired combinations of GPS/GLONASS, GPS only and GLONASS only observations, and Table 3 shows the significant differences found.When the table above is examined, it shows that there is a statistically significant difference between the groups whose (Sig.) value is less than 0.05. In Table 3, grey highlighted rows represent statistically significant differences. Clearly, on the 136th GNSS day, significant differences in X and Z components were determined while in Y components there were no significant differences encountered. This may be because of the degrading GLONASS observations. On the other hand, GNSS days of 164 and 166 didn't represent any significant differences.

Table 4 shows the subgroups obtained from different satellite configurations. From Table 4, the coordinates obtained through the combination of GPS and GLONASS and GPS only observations on 136th and 164th GNSS days were included in the same group while the coordinates from GLONASS-only observations were assigned in a single group. This indicated that both results of the combined GPS/GLONASS and GPS only observations showed similar properties. However, for the 166th GNSS day, all the coordinate components were included in one group. One can generalize this as the results of the combined GPS/GLONASS and GPS-only observations show similar solutions.

Table 3. Comparisons of mean coordinate differences obtained from paired combinations of GPS/GLONASS, GPS only and GLONASS only observations in terms of satellite configurations (m)

Dependent Variable	Satellite (I)	Satellite (J)	x Mean Diff. (I-J)	x Sig.	y Mean Diff. (I-J)	y Sig.	z Mean Diff. (I-J)	z Sig.
136. DAY	GPS+GLONASS	GPS	-0.003	0.681	0.002	0.167	-0.001	0.962
		GLONASS	0.009	0.005	0.001	0.635	0.007	0.027
	GPS	GPS+GLONASS	0.003	0.681	-0.002	0.167	0.001	0.962
		GLONASS	0.012	0.000	-0.001	0.970	0.008	0.007
	GLONASS	GPS+GLONASS	-0.009	0.005	-0.001	0.635	-0.007	0.027
		GPS	-0.012	0.000	0.001	0.970	-0.008	0.007
164.DAY	GPS+GLONASS	GPS	0.001	0.965	-0.001	0.988	0.001	0.934
		GLONASS	-0.003	0.631	-0.003	0.242	-0.002	0.794
	GPS	GPS+GLONASS	-0.001	0.965	0.001	0.988	-0.001	0.934
		GLONASS	-0.004	0.459	-0.002	0.517	-0.004	0.532
	GLONASS	GPS+GLONASS	0.003	0.631	0.003	0.242	0.002	0.794
		GPS	0.004	0.459	0.002	0.517	0.004	0.532
166.DAY	GPS+GLONASS	GPS	-0.003	0.760	-0.001	0.918	-0.002	0.832
		GLONASS	-0.001	0.994	-0.002	0.702	-0.002	0.746
	GPS	GPS+GLONASS	0.003	0.760	0.001	0.918	0.002	0.832
		GLONASS	0.002	0.872	-0.001	0.972	0.000	0.999
	GLONASS	GPS+GLONASS	0.001	0.994	0.002	0.702	0.002	0.746
		GPS	-0.002	0.872	0.001	0.972	0.000	0.999

Table 4. Subgroups created according to different satellite configurations (m)

	Tukey HSD (Subset for alpha = 0.05)													
	x					y				z				
Satellite	136.DAY		164.DAY		166.DAY	136.DAY	164.DAY		166.DAY	136.DAY		164.DAY		166.DAY
	1	2	1	2	1	1	1	2	1	1	2	1	2	1
GPS+GLONASS	-0.004		-0.001		0.000	-0.001	-0.010		-0.006	-0.002		0.005		0.000
GPS	-0.001		-0.003		0.002	-0.003	-0.010		-0.005	-0.001		0.004		0.002
GLONASS		-0.013		0.002	0.000	-0.002		-0.007	-0.004		-0.010		0.008	0.003
Sig.	0.171	1.000	0.714	0.179	0.198	1.000	0.897	0.100	0.473	0.741	1.000	0.599	0.341	0.265

Means for groups in homogeneous subsets are displayed

Similarly, Post Hoc test were applied to the mean differences to reveal which elevation angles contributed to the significant differences resulting from the variance test. The test results in Y, X and Z components were tabulated in Table 5, 6, and 7 correspondingly. In the tables, only those of insignificant differences were given to save space.

Table 5. Comparisons of mean coordinate differences of Y component in pair of the results of combined GPS/GLONASS, GPS only and GLONASS only observations in terms of elevation cut-off angles

136.DAY				164.DAY				166.DAY			
Angle (I)	Angle (J)	Mean Diff. (I-J)	Sig.	Angle (I)	Angle (J)	Mean Diff. (I-J)	Sig.	Angle (I)	Angle (J)	Mean Diff. (I-J)	Sig.
0º	5º	-0.003	0.710	0º	5º	-0.006	0.353	0º	10º	-0.007	0.122
0º	10º	-0.005	0.103	5º	0º	0.006	0.353	5º	0º	0.004	0.924
0º	15º	-0.005	0.181	10º	15º	-0.001	1.000	5º	10º	-0.003	0.949
0º	20º	-0.007	0.017	10º	20º	-0.003	0.905	5º	15o	-0.006	0.125
5º	0º	0.003	0.710	15º	10º	0.001	1.000	10º	0º	0.007	0.122
5º	10º	-0.002	0.982	15º	20º	-0.002	0.584	10º	5º	0.003	0.949
5º	15º	-0.001	0.999	20º	10º	0.003	0.905	10º	15º	-0.002	0.998
5º	20º	-0.003	0.396	20º	15º	0.002	0.584	10º	20º	-0.004	0.726
10º	0º	0.005	0.103	25º	30º	-0.005	0.160	15º	5º	0.006	0.125
10º	5º	0.002	0.982	30º	25º	0.005	0.160	15º	10º	0.002	0.998
10º	15º	0.000	1.000	0º	5º	-0.004	0.924	15º	20º	-0.002	1.000
10º	20º	-0.002	0.974					15º	25º	-0.005	0.280
15º	0º	0.005	0.181					20º	10º	0.004	0.726
15º	5º	0.001	0.999					20º	15º	0.002	1.000
15º	10º	0.000	1.000					20º	25º	-0.003	0.922
15º	20º	-0.002	0.986					25º	15º	0.005	0.280
20º	5º	0.003	0.396					25º	20º	0.003	0.922
20º	10º	0.002	0.974					25º	30º	-0.006	0.517
20º	15º	0.002	0.986					30º	25º	0.006	0.517
20º	25º	-0.004	0.274								
25º	20º	0.004	0.274								
25º	30º	-0.003	0.907								
30º	25º	0.003	0.907								

Table 6. Comparisons of mean coordinate differences of X component in pair of the results of combined GPS/GLONASS, GPS only and GLONASS only observations in terms of elevation cut-off angles

136.DAY				164.DAY				166.DAY			
Angle (I)	Angle (J)	Mean Diff. (I-J)	Sig.	Angle (I)	Angle (J)	Mean Diff. (I-J)	Sig.	Angle (I)	Angle (J)	Mean Diff. (I-J)	Sig.
0º	5º	-0.010	0.073	0º	5º	-0.008	0.533	0º	5º	-0.006	0.583
5º	0º	0.010	0.073	5º	0º	0.008	0.533	5º	0º	0.006	0.583
5º	10º	-0.002	0.996	10º	15º	-0.004	0.776	20º	25º	-0.004	0.799
10º	5º	0.002	0.996	15º	10º	0.004	0.776	25º	20º	0.004	0.799
20º	25º	-0.007	0.145	15º	20º	-0.005	0.205	25º	30º	-0.007	0.615
20º	30º	-0.011	0.095	20º	15º	0.005	0.205	30º	25º	0.007	0.615
25º	20º	0.007	0.145								
25º	30º	-0.004	0.999								
30º	20º	0.011	0.095								
30º	25º	0.004	0.999								

Table 7. Comparisons of mean coordinate differences of Z component in pair of the results of combined GPS/GLONASS, GPS only and GLONASS only observations in terms of elevation cut-off angles

136.DAY				164.DAY				166.DAY			
Angle (I)	Angle (J)	Mean Diff. (I-J)	Sig.	Angle (I)	Angle (J)	Mean Diff. (I-J)	Sig.	Angle (I)	Angle (J)	Mean Diff. (I-J)	Sig.
0°	5°	-0.009	0.089	0°	5°	-0.008	0.374	0°	5°	-0.006	0.640
5°	0°	0.009	0.089	5°	0°	0.008	0.374	5°	0°	0.006	0.640
5°	10°	-0.003	0.917	10°	15°	-0.004	0.497	5°	10°	-0.006	0.057
10°	5°	0.003	0.917	15°	10°	0.004	0.497	10°	5°	0.006	0.057
10°	15°	-0.005	0.072	15°	20°	-0.004	0.116	20°	30°	-0.005	0.411
15°	10°	0.005	0.072	20°	15°	0.004	0.116	25°	30°	0.009	0.089
15°	20°	-0.007	0.021					30°	20°	0.005	0.411
20°	30°	-0.007	0.082					30°	25°	-0.009	0.089
25°	30°	0.005	0.961								
30°	20°	0.007	0.082								
30°	25°	-0.005	0.961								

In general, pairwise comparison became significant as the difference of elevation angle increased and vice versa. It is noted here that the results of comparisons in Y components as compared to the other components showed more statistical insignificance. The effect of elevation angle on coordinate accuracies was determined by creating subgroups similar to the ones created for different satellite configurations. The results of the Y, X, and Z components are given in Table 8, 9, and 10 correspondingly.

Table 8. Sup groups of elevation angles for Y components

Tukey HSD (Subset for alpha = 0.05)														
Elevation	136. DAY				164. DAY					166. DAY				
Angle	1	2	3	4	1	2	3	4	5	1	2	3	4	5
0°	-0.01				-0.02					-0.01				
5°	0.00	0.00				-0.02				-0.01	-0.01			
10°		0.00					-0.01			-0.01	-0.01	-0.01		
15°		0.00					-0.01				0.00	0.00	0.00	
20°		0.00	0.00				-0.01	-0.01				0.00	0.00	
25°			0.00	0.00				0.00	0.00				0.00	0.00
30°				0.01					0.00					0.01
Sig.	0.25	0.23	0.14	0.54	1.00	1.00	0.72	0.09	0.08	0.06	0.24	0.62	0.37	0.19

Means for groups in homogeneous subsets are displayed.

Table 9. Sup groups of elevation angles for X components

	Tukey HSD (Subset for alpha = 0.05)															
Elevation	136. DAY					164. DAY						166. DAY				
Angle	1	2	3	4	5	1	2	3	4	5	6	1	2	3	4	5
0°	-0.03					-0.02						-0.02				
5°		-0.02					-0.01					-0.01				
10°		-0.01	-0.01					-0.01					0.00			
15°			-0.01					0.00	0.00				0.00	0.00		
20°				0.00					0.00					0.01	0.01	
25°				0.01	0.01					0.01					0.01	0.01
30°					0.01						0.02					0.02
Sig.	1.00	0.97	0.22	0.06	0.59	1.00	1.00	0.72	0.53	1.00	1.00	0.16	0.05	0.12	0.42	0.07

Means for groups in homogeneous subsets are displayed.

Table 10. Sub groups of elevation angles for Z components

	Tukey HSD (Subset for alpha = 0.05)																
Elevation	136. DAY					164. DAY						166. DAY					
Angle	1	2	3	4	5	1	2	3	4	5	6	1	2	3	4	5	6
0°	-0.02					-0.01						-0.02					
5°		-0.01					-0.01					-0.01	-0.01				
10°		-0.01	-0.01				0.00	0.00					0.00	0.00			
15°			-0.01					0.00	0.00					0.00	0.00		
20°				0.00					0.01						0.01	0.01	
25°					0.08					0.02						0.01	
30°					0.01						0.03						0.02
Sig.	1.00	0.90	0.31	1.00	0.34	1.00	0.09	0.70	0.59	1.00	1.00	0.15	0.13	0.12	0.33	0.37	1.00

Means for groups in homogeneous subsets are displayed.

In the tables above, in the subgroups created for the elevation angle, groups with the same or different characteristics ranging from 4 to 6 were found. In each group, elevation angles showed similar properties. The elevation angles of 5°, 10° and 15° were grouped together while the elevation angle 25° and 30° were grouped into another. It is noted here that as the difference of elevation angles in degrees increased, they didn't present similar properties. In another word, significant differences between various elevation angles and satellite configurations became obvious. Rising and setting satellites affected the accuracy of the coordinates.

In addition to these, the effects of satellite configurations and elevation angles as the dependent variables in determining the coordinate components of eight stations were investigated. This was done by carrying out Multivariate test. The Wilk's Lambda test results were given in Table 11**.** In Table 11, it can be seen that the effect of elevation angles in positioning was more than that of the solutions of GPS/GLONASS, GPS-only, GLONASS-only observations. The magnitude of the effect can be seen in the column of Partial Eta Squared, and the significance of the effects of independent variables to dependent variables can be seen in the sig column. Here only satellite*angle in Y components were found to be insignificant, and the effects of different satellite configurations and different elevation angles together to independent variable were obtained to be small.

Table 11. Multiple comparisons

	Effect	Value	F	df	Error df	Sig.	Partial Eta Squared
x	Intercept	0.566	37.114	3	145.000	0.000	0.434
	Satellite	0.600	14.067	6	290.000	0.000	0.225
	Angle	0.148	21.973	18	410.607	0.000	0.471
	Satellite * Angle	0.594	2.301	36	429.146	0.000	0.160
y	Intercept	0.277	125.984	3	145.000	0.000	0.723
	Satellite	0.912	2.266	6	290.000	0.037	0.045
	Angle	0.281	12.904	18	410.607	0.000	0.345
	Satellite * Angle	0.744	1.255	36	429.146	0.153	0.094
h	Intercept	0.420	66.798	3	145.000	0.000	0.580
	Satellite	0.689	9.884	6	290.000	0.000	0.170
	Angle	0.158	20.960	18	410.607	0.000	0.459
	Satellite * Angle	0.685	1.628	36	429.146	0.014	0.118

4 Conclusions

This study was to investigate the effects of various solutions of GPS only, GLONASS-only and combined GPS/GLONASS observations under different elevation angles on different GNSS days by using Magic GNSS service.

Coordinates (X, Y, Z) obtained from ISKI CORS in Istanbul acquired on different days (136th,164th, and 166th GPS days) under different elevation cut-off angles (0°, 5°, 10°, 15°, 20°, 25°, 30°) compared to the assumed true coordinates, and were statistically tested whether they were significant or not.

The results showed that RMS values of phase and code measurements decreased when the satellite elevation angle increased. On the other hand, GPS only solution presented smaller RMS values with respect to those of GLONASS-only solution of code and phase. Accordingly, the results of GPS/GLONASS combinations reflected average values according to the results obtained from GPS only and GLONASS-only solutions. In the assessment regarding satellite elevation angles, the total number of observations naturally decreased. As GLONASS observations provide less number of observations compared to that of GPS only, GPS/GLONASS combinations were improved in terms of number of observations.

The standard deviations of coordinates from the combination of GPS and GLONASS, GPS-only and GLONASS-only observations at 10° and 15° angles on 136th and 166th days were small com-pared to those of different elevation angles. However, the standard deviations of coordinates on the 164th day did not follow the same pattern for the solutions of GPS-only observations while those of GLONASS-only observations illustrate compatible results. In terms of standard deviations of the coordinates, the combination of GPS and GLONASS observations produced 'best' results under 10 ° elevation angles.

The results of ANOVA of the averaged coordinate differences between true values of coordinates and the coordinates obtained from Magic GNSS software on different GNSS days under different elevation angles showed statistically significant differences

Post Hoc test were applied to mean differences to reveal which satellite constellations were causing the significant differences. The results showed that there were statistical significant differences of the mean coordinate differences obtained from paired combinations of GPS/GLONASS, GPS only and GLONASS-only observations. The results showed that on the 136th GNSS day, significant differences in X and Z components were determined while in Y components there was no significant differences encountered. This may be because of the degrading GLONASS observations. On the other hand, GNSS days of 164 and 166 didn't represent any significant differences.

Similarly, Post Hoc test were applied to the mean differences to reveal which elevation angles contributed in the significant differences resulted from the variance test. It was found that significant differences between various elevation angles and satellite configurations were detected. Rising and setting satellites effected the accuracy of the coordinates.

It is concluded that better results from GPS/GLONASS combinations in comparison to GPS and GLONASS-only solutions might be obtained under small elevation cut-off angles of 5° 10° or 15°.

This research was conducted using all the continuously operating stations of ISKI CORS in Istanbul. The stations extend 10-30 km baseline length. Results from larger CORS network should be carried out.

Conflict of interest

The authors declare that there is no conflict of interest.

Similarity rate (iThenticate): 12%

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