

Velocity Estimation of Turkish National Permanent GNSS Network- Active Points Located at Central Anatolia Region

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Abstract: Turkey is located a region where Eurasia, Anatolia and Arab Tectonic plates intersect. The relative movements of these plates according each other cause that the locations of the geodetic points change in cm level per year. For this reason, the changes in the coordinates of the geodetic points should be monitored continuously and the velocities of these points should be determined.

In this study, the current coordinates and velocities of Turkish National Permanent GNSS Network- Active (TNPNGN-Active) points which are located at Central Anatolia Region have been determined at ITRF2008 reference frame and 2005.00 epoch. In the calculation, 11 IGS points have been selected as benchmark points and GNSS measurements which were obtained by selecting a day from every week with equal intervals from 2009 to 2015 have been evaluated with using Bernese v5.2 GNSS software. In addition, the coordinates and velocities of selected points have been obtained from General Directorate of Land Registry and Cadastre. These have been compared by the coordinates and velocities calculated by Bernese v5.2 GNSS software.

Keywords: Velocity estimation, GNSS, Bernese, TUSAGA-Active

1. Introduction

Nowadays, the coordinates of geodetic points are calculated in a specific reference epoch according to the points that are considered to be fixed. In the calculating of the points coordinates, it is accepted that there are relative movements of the points according to tectonic plates in which the points are located. The tectonic plates in which geodetic points are located are moving against each other and change the point coordinates at the cm level per year. Also, if it is considering that our country (Turkey) is located in the earthquake zone, earthquakes affect the positions of the geodetic points in large scale. It is possible to continuously monitor point coordinates with the help of GNSS measurements. With the help of the fixed GNSS stations in our country, geodetic points can be continuously monitored and current point coordinates and velocities can be calculated (Özdemir, 2016).

Turkey is located in the collision zone of the Eurasian, the African and Arab tectonic plates. The

boundaries of the tectonic plates in the region are shown in Figure 1 with the general outlines of lateral motion and normal faults and rupture zones.

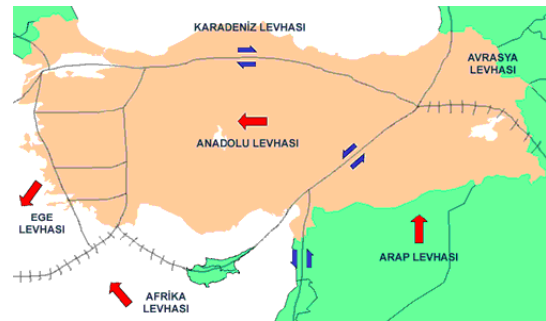


Figure 1. Tectonic plates on which Turkey is located and their movements

Tectonic plate movements in the region; according to the Eurasian plate of the Arabian plate, the movement of the East Anatolian region at a speed of 15-20 mm/year in the north-northwest direction and the rotation of the Anatolian plate to the west

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with the speed of 20-25 mm/year can be summarized as the northward movement dipping below the Anatolian plate and the extension of the Aegean block in the north-south direction due to withdrawal along the Hellenic arc (McKenzie, 1972; Jackson and McKenzie, 1988; McCluskey et al., 2000).

The velocities of Turkish National Permanent GNSS Network-Active (TNPNGN-Active) points in our country are calculated by Geodesy Office of General Command of Mapping and published by the General Directorate of Land Registry Cadastre (Tusaga, 2017a). In this study, the coordinates and velocities calculated by Bernese v5.2 GNSS software used in determining the point velocities were compared with the coordinates and velocities published by the General Directorate of Land Registry.

2. Turkish National Permanent GNSS Network-Active

The GNSS Stations Network (TNPNGN-Active/CORS-TR), which are making constantly observation, started on May 8, 2006, as the joint customer of General Command of Mapping (HGK) and General Directorate of Land Registry and Cadastre (TKGM) under the project of Istanbul Kültür University (İKÜ). It was completed as of December 2008. TNPNGN-Active consists of 146 reference GNSS stations and 4 of them are located in the Turkish Republic of Northern Cyprus (Figure 2). In the system of TNPNGN-Active, observations of GNSS receivers located at reference stations whose known coordinates cover the entire country are transmitted to a control centre; atmosphere and other errors are modelled in the control centre, the corrections are calculated in real time and sent to rover GNSS receivers for positioning.



Figure 2. TNPNGN-Active Stations

TNPNGN-Active system is frequently used by earth sciences and geographic information systems

researches, earthquake engineering, geophysics and seismology areas, prior knowledge of earthquakes and early warning studies, meteorological studies, and other studies in space and earth sciences (Eren et al, 2010).

3. Determining of The Velocities of TNPNGN-Active Stations

The analysis of the TNPNGN-Active stations is carried out by Geodesy Office of General Command of Mapping. The solution of RINEX data is running GAMIT / GLOBK v10.35 / v10.40 in Linux / MAC OS X operating system. As evaluation strategy, the following conditions have been selected.

- IGS precise orbit (sp3) and USNO_Bull_A orbit parameter (EOP)
- 16 IGS stations
- Reference frame: ITRF 2005
- Ocean loading effect: FES2004
- 9 parameters for Bern model to Radiation pressure parameters
- Zenith delay: Saastamoinen Troposphere model (2 hours, PWL)
- For dry / wet atmosphere: GMF reduction function
- Predictive Troposphere: Global Pressure Temperature Model (GPT)
- Ionospheric free L3 (L1, L2) linear combination
- Antenna phase center: Absolute and Azimuth + Height dependent model
- Phase ambiguities: Ambiguity-fixed and loose glx

Atmospheric loading effect is not brought (Özdemir et al. 2011).

4. Determining of The Velocities by Using Bernese GNSS Software

A reasonable time interval must be available so that the velocities of the points can be reliably estimated with Bernese v5.2 GNSS software (Dach et al, 2015). Where GNSS data is less than 2.5 years, annual signals can cause a significant bias in estimating station velocities. When it is over 4.5 years, the bias of velocities falls rapidly to negligible levels (Blewitt and Lavallee, 2002).

In order to be able to calculate the velocities with software, the obtained data must be analysed as a campaign. After the campaigns are solved, the normal equation systems (NEQ) are combined with software and the point velocities are estimated. In

estimating of the velocities in the Bernese v5.2 GNSS software, Menu>> Processing >> Combine normal equations system ready command is used (Figure 3).

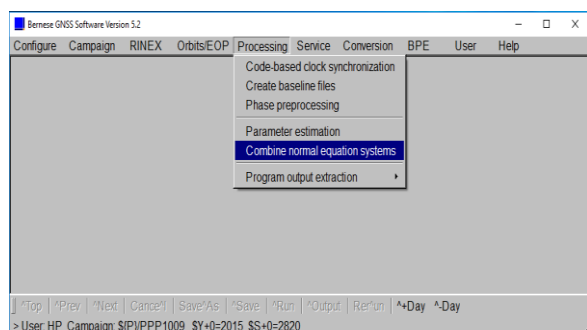


Figure 3. Velocity estimation by Bernese v5.2 GNSS software

5. Application

In the study, 11 stations from the TNPGN-Active points in the Central Anatolia region were selected as test points.

5.1. Obtaining data sets

In the study, the 30-second RINEX data of the test points was selected as one day per week which cover from 23.01.2009 to 25.12.2015 and evaluated based on the selected 11 IGS stations. (TUSAGA, 2017b; NASA, 2017a).

The necessary files to run Bernese v5.2 GNSS software;

- Ionosphere and troposphere data,
 - Differential code bias,
 - Clock correction data,
 - Earth rotation parameters
 - Satellite summary files (AIUB, 2017a ; AIUBb),
 - Precision orbit data for both GPS and GLONASS (NASA, 2017b ; NASA, 2017c),
 - Oceanic loading (Onsalo Space Observatory, 2017),
 - Tropospheric functions (GGOS)
- were obtained from related websites.

5.2. Analysis of data sets

The Bernese GNSS Software is a scientific, high-precision, multi-GNSS data processing software developed at the Astronomical Institute of the University of Bern (AIUB). The Bernese GNSS

Software, Version 5.2, continues in the tradition of its predecessors as a high performance, high accuracy, and highly flexible reference GPS/GLONASS (GNSS) post-processing package. Typical users of the software are;

- Scientists for research and education
- Survey agencies responsible for high-accuracy GNSS surveys (e.g., first order networks)
- Agencies responsible to maintain arrays of permanent GNSS receivers
- Commercial users with complex applications demanding high accuracy, reliability, and high productivity (Bernese, 2017)

The features and highlights of the software are;

- Available on Unix/Linux, Mac and Windows platforms
- User-friendly GUI with a built-in HTML-based help system
- Multi-session parallel processing for reprocessing activities
- Ready-to-use BPE examples for different applications:
 - PPP (basic and advanced versions)
 - RINEX-to-SINEX (double-difference network processing)
 - Clock determination (zero-difference network processing)
 - LEO precise orbit determination based on GPS-data
 - SLR validation of GNSS or LEO orbits
- All examples are designed for combined GPS/GLONASS processing.
- Some of them are prepared for an hourly processing scheme.
- Program for automated coordinate time series analysis (FODITS)
- Ambiguity resolution for GPS and GLONASS
- Flexible parameter handling on normal equation level
- Modern troposphere models (e.g., VMF1, GMF/GPT)
- Ionosphere modelling including higher order ionosphere corrections
- IGS and IERS 2010 conventions compliance
- Combination of different receiver and antenna types
- Galileo processing capability (URL-10).

In the study, the solution of RINEX data was run with Bernese v5.2 GNSS software in Windows operating system. As evaluation strategy, the following conditions were selected.

- IGS precise orbit (sp3) and USNO_Bull_A orbit parameter (EOP)

- 11 IGS stations
- Reference frame: ITRF 2005
- Ocean loading effect: FES2004
- 9 parameters for Bern model to Radiation pressure parameters
- Zenith delay: Saastamoinen Troposphere model (2 hours, PWL)
- For dry / wet atmosphere: GMF reduction function
- Predictive Troposphere: Global Pressure Temperature Model (GPT)
- Ionospheric free L3 (L1, L2) linear combination
- Antenna phase centre: Absolute and Azimuth + Height dependent model
- Phase ambiguities: Ambiguity-fixed and loose glx
- Atmospheric loading effect: Model calculated by using atmospheric tide model coefficients generated by point coordinates and atmospheric loading effect (Ray and Ponte, 2003) were selected.

In order to analyse the data with Bernese v5.2 GNSS software, firstly campaigns were created (Fig. 4).

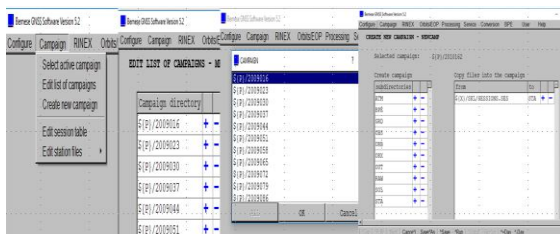


Figure 4. Creating of Campaign

7-character file names were used to create campaigns. For example, in creating the campaign named TZ10043, first 2 character (TZ) is the abbreviation of related processing, 10 is year and 043 is the day of year.

After the campaigns were created, NEQ used to obtain the velocities in the Bernese v5.2 GNSS software were obtained using the RNX2SNX.PCF automatic solution module (Figure 5).



Figure 5. Running of RNX2SNX.PCF

In RNX2SNX.PCF the automatic solution module respectively,

- Copying Required Files, Creating Preliminary Coordinates and Preparing Hourly Solutions
- Preparation of polar and orbital information
- Synchronization and transformation of observation files
- Obtaining the bases, pre-processing the phases and resolving without phase initial uncertainties
- Analysis of phase initial uncertainties
- Implementation of final solution and creation of NEQ, SNX and TRP files
- Creation of summary files, recording of results, deletion of completed files
- Termination of BPE

process steps are implemented An average of 330 campaigns were created in the analysis and the solutions were obtained in the measurement epoch (Figure 6).

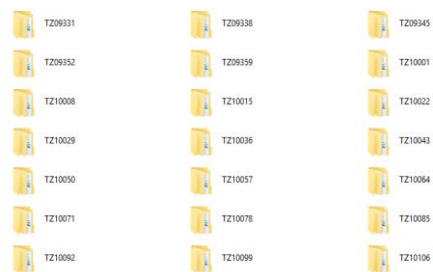


Figure 6. Part of the campaigns that were solved

6. Application

In order to be able to estimate velocities after NEQs are obtained, the main menu >> Processing >> Combine normal equations system was run. And NEQ's were combined with the automatic command and the point coordinates and velocities were obtained in the reference epoch (2005.00). The point coordinates and velocities obtained in the reference epoch are shown in Table.1.

Table 1. Point coordinates and velocities obtained in the 2005.00 epoch

Point ID	X (m)	Y (m)	Z (m)	Vx (m/y)	Vy (m/y)	Vz (m/y)
AKDG	3985177.05402	2881782.34504	4049905.34644	-0.01277	-0.00204	0.01431
ANRK	4119925.63959	2659815.33246	4066510.64897	-0.00829	-0.00181	0.01000
BEYS	4298980.59632	2659931.99080	3877883.30113	-0.00975	0.00372	0.00738
CIHA	4187342.46874	2711236.69936	3962713.17718	-0.01073	0.00000	0.00993
HYMN	4161311.86831	2650610.44941	4030510.17327	-0.00865	-0.00071	0.00786
KIRS	4098385.58734	2780607.91706	4007175.45520	-0.01119	-0.00098	0.01129
KKAL	4088935.95164	2708243.45912	4065148.10444	-0.01022	-0.00093	0.01133
KLUU	4155559.18035	2705396.67806	3999801.22778	-0.00957	0.00044	0.01086
NEVS	4103186.18254	2841492.92308	3959954.44751	-0.01276	0.00046	0.01356
YOZT	4028005.98932	2801198.41605	4063858.17392	-0.01119	-0.00152	0.01268
YUNK	4233095.37438	2617095.58405	3977555.57705	-0.00752	-0.00036	0.00692

The display of all of the coordinates obtained from the adjustment result takes up too much space. Therefore, the graphs obtained by opening the coordinates (X, Y, Z) of the adjustment result of

the Ankara station (ANRK) to the time series is shown in Figure 7-9.

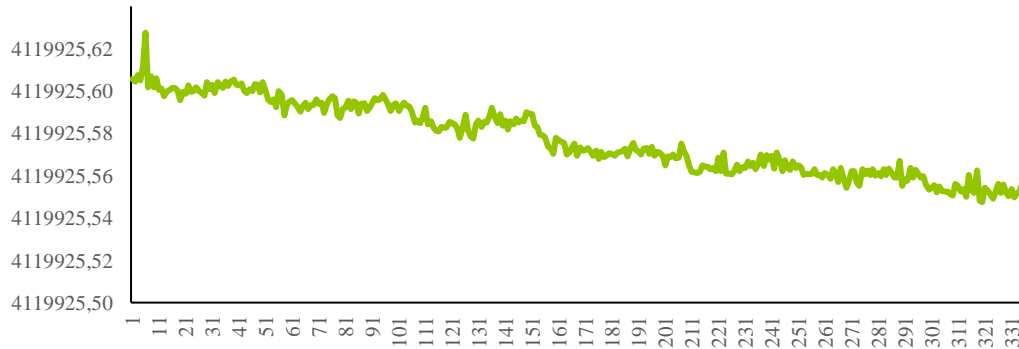


Figure 7. Expansion of the X coordinate of the ANKARA station into time series



Figure 8. Expansion of the Y coordinate of the ANKARA station into time series

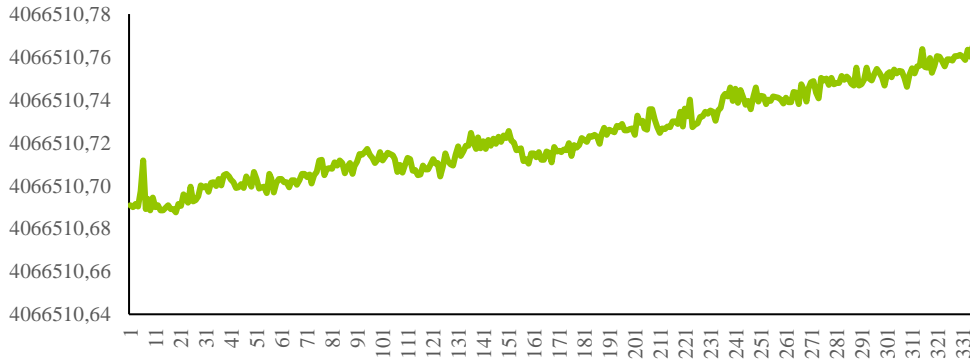


Figure 9. Expansion of the Z coordinate of the ANKARA station into time series

When figure 7-9 are investigated, it seen that the coordinates of ANRK station have a movement and that in the directions of X and Y axis, the movements is negative and in the direction of Z axes, the movement is positive. When calculated

velocities are compared with figure 7-9, it is seen that the movements are similar with each other's. Coordinates and velocities of the TNPGN-Active stations which are continuously updated and loaded are shown in Tables 2.

Table 2. point coordinates which are published at 2005.00 reference epoch

Point ID	X (m)	Y (m)	Z (m)	Vx (m/y)	Vy (m/y)	Vz (m/y)
AKDG	3985177.07014	2881782.35537	4049905.31060	-0.01256	-0.00148	0.01149
ANRK	4119925.65215	2659815.33773	4066510.60688	-0.00773	-0.00095	0.00774
BEYS	4298980.61314	2659931.99914	3877883.26147	-0.00950	0.00428	0.00462
CIHA	4187342.48310	2711236.70890	3962713.14115	-0.01042	0.00038	0.00696
HYMN	4161311.88079	2650610.45934	4030510.13163	-0.00823	-0.00038	0.00549
KIRS	4098385.60160	2780607.92625	4007175.41611	-0.01080	-0.00062	0.00868
KKAL	4088935.96101	2708243.46828	4065148.07311	-0.00931	-0.00044	0.00784
KLUU	4155559.19598	2705396.68516	3999801.18637	-0.00942	0.00125	0.00845
NEVS	4103186.20042	2841492.93445	3959954.41146	-0.01276	0.00075	0.01061
YOZT	4028006.02230	2801198.42496	4063858.13620	-0.01050	-0.00290	0.00950
YUNK	4233095.40544	2617095.59200	3977555.53260	-0.00660	-0.00200	0.00470

Differences between coordinates which are calculated via Bernese v5.2 GNSS software and

published by TKGM are calculated;

$$\begin{aligned}
 DX &= X_{\text{Bernese}} - X_{\text{TNPGN-Active}} \\
 DY &= Y_{\text{Bernese}} - Y_{\text{TNPGN-Active}} \\
 DZ &= Z_{\text{Bernese}} - Z_{\text{TNPGN-Active}}
 \end{aligned}$$

$$\begin{aligned}
 DV_X &= V_{X_{\text{Bernese}}} - V_{X_{\text{TNPGN-Active}}} \\
 DV_Y &= V_{Y_{\text{Bernese}}} - V_{Y_{\text{TNPGN-Active}}} \\
 DV_Z &= V_{Z_{\text{Bernese}}} - V_{Z_{\text{TNPGN-Active}}}
 \end{aligned} \tag{1}$$

Obtained differences are shown in Table 3.

Table 3. Differences of coordinate and velocities between Bernese v5.2 and TNPNGN-Active

Point ID	DX (cm)	DY (cm)	DZ (cm)	DV _X (cm/y)	DV _Y (cm/y)	DV _Z (cm/y)
AKDG	-1.612	-1.033	3.584	-0.021	-0.056	0.282
ANRK	-1.256	-0.527	4.209	-0.056	-0.086	0.226
BEYS	-1.682	-0.834	3.966	-0.025	-0.056	0.276
CIHA	-1.436	-0.954	3.603	-0.031	-0.038	0.297
HYMN	-1.248	-0.993	4.164	-0.042	-0.033	0.237
KIRS	-1.426	-0.919	3.909	-0.039	-0.036	0.261
KKAL	-0.937	-0.916	3.133	-0.091	-0.049	0.349
KLUU	-1.563	-0.710	4.141	-0.015	-0.081	0.241
NEVS	-1.788	-1.137	3.605	0.000	-0.029	0.295
YOZT	-3.298	-0.891	3.772	-0.069	0.138	0.318
YUNK	-3.106	-0.795	4.445	-0.092	0.164	0.222

When Table 3 is investigated, maximum coordinate differences in direction of X, Y and Z axes are 3.298 cm, 1.137 cm and 4.445 cm, respectively. It can be said that the reason why the differences of the Z coordinates are bigger than the other coordinate components is due to the determination of the heights with GNSS techniques. When Table 3 is investigated, in the comparison of the velocities, maximum velocities differences in direction of X, Y and Z axes are -0.092 cm/y, -0.164 cm/y and 0.349 cm/y, respectively.

7. Conclusion

The geodetic points that are considered as constant on earth are subjected to displacements because of the earthquakes, the movement of the earth, the intervention of mankind, etc. at cm level per year, even m level per year. As a result of these effects, it can be seen that in the geodetic studies the points are not fixed points and their locations are changing. For this purpose, it is important to determine how much the point movements change annually.

In the determining of the velocities of point with GNSS measurements, the existence of the continuously observed GNSS stations provides great convenience to investigate this subject. Long-term observations are crucial in determining the point velocities with GNSS data. For this purpose, it is necessary to analyse the minimum 2.5-year data and determine the point velocities. In the studies carried out, it is seen that if GNSS data

have a time interval which are longer than 4.5 years, it removes the misconceptions that may raise in estimation of the point velocities.

The velocities of 11 stations which are located at Central Anatolia Region were calculated with Bernese v5.2 GNSS software and compared the velocities published by TKGM. It is showed that there is no significant difference between calculated and published velocities because there is a similarity at mm-below level. because of that, at measurement epoch, if the point coordinates are calculated with the velocities calculated with Bernese v5.2 GNSS software or published by TKGM, it is caused no different at significant level.

The reasons why the point coordinates and velocities which are obtained by Bernese v5.2 GNSS software and published by TKGM are different from each other can be caused processing algorithm and IGS points selected as reference.

Acknowledgment

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This study was both presented as an oral presentation and published at ISMSIT 2017 (1st International Symposium on Multidisciplinary Studies and Innovative Technologies). Also, it was found appropriate to be directed to “Bilge International Journal of Science and Technology Research” by scientific committee of ISMSIT 2017.

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