Reference Frame of GPS-PPP Solutions in Marmara Region-Turkey

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Key words: ISKI-CORS, relative positioning, PPP method, Eurasian plate, displacements.

SUMMARY

Monitored displacements/velocities consist of “rigid body displacement” and “deformation”. The rigid body part (rotation and translation) depends on the reference frame with which the coordinates are defined whereas the deformation part is independent from the frame definition. GPS Precise Point Positioning (PPP) has been important in positioning studies since it does not need simultaneously operating reference points on the field. It has been shown that the PPP is an alternative positioning technique in deformation analysis with respect to the relative positioning. To estimate the deformation parameters such as engineering strain and shear, it has been shown that the PPP technique gives similar results with the relative positioning. However, the rigid part of the monitored displacements/velocities from PPP is not clear since it is relative to a geocentric reference frame. In tectonic regions, the definition of a specific reference frame of the coordinates is important as much as monitoring the changes itself. In this study, we compared the GPS-PPP displacements with the Bernese v5.2 Eurasian-referenced displacements in 8 GNSS stations located at the central part of the Marmara Region belonging to the ISKI-CORS network in Turkey. For the period 2018-2021, four separate 7-day data sets were analyzed. The APPS online data processing service was used to perform the analysis. From the numerical results, we observed that the differences between both solutions were statistically insignificant in terms of north, east and up components. This result shows that the PPP can be performed directly to have Eurasian-referenced north, east and up displacement/velocity components as defined in nearly all tectonic studies of the region selected. However, it may not mean that this is valid for all parts of the Marmara Region. The reference frame of the PPP solution in this region will be fully examined in further studies having included long-term data of different points in different locations of the region.

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1. INTRODUCTION

The PPP (Precise Point Positioning) technique has been developed and has become the preferred method of analysis for several GNSS (Global Navigation Satellite System) research. This technique is commonly utilized in academic and engineering studies since it provides online processing services and a fast response. APPS (Automatic Precise Positioning Service), CSRS-PPP (Canadian Spatial Reference System-PPP), magic-GNSS, GAPS (GNSS Analysis and Positioning Software), AUSPOS (Australian Online Global Positioning System Processing Service) and OPUS (Online Positioning User Service) are all examples of online services that are used in applications. AUSPOS and OPUS are two of these services that use the relative positioning method to analyze data. Other services are run on a PPP technique.

There are several studies in the literature according to the PPP technique and comparisons are performed with the academic software. Some studies assess the accuracy of positioning methods, while others compare the position accuracies/velocities of different techniques (Tsakiri, 2008; El-Mowafy, 2011; Ocalan et al., 2013; Dawidowicz and Krzan, 2014; Yigit et al. 2016; Jamieson and Gillins, 2018; Aydin et al., 2019; Duman and Sanli, 2019; Gökdaş and Özlüdemir, 2020; Güneş and Demir, 2022) Apart from these studies, deformation analysis can use the PPP as an alternate positioning method in addition to the relative positioning. Due to the fact that GPS-PPP does not require the use of several reference points in the field at the same time, it has become increasingly popular in positioning research. The PPP method has been shown to be as good as the relative positioning method when it comes to estimating deformation parameters such as engineering strain and shear. Because the PPP technique uses precise satellite orbits as well as enhanced ionospheric and tropospheric modeling, the technique's accuracy improves. Displacement/velocity studies are constructed for rigid body displacement and deformation. The rigid body component (rotation and translation) is frame-dependent, whereas the deformation component is frame-independent. However, because the observed displacements and calculated velocity from PPP are relative to a geocentric reference frame, the rigid body component of the monitored displacements and velocity from PPP is not explicit. Defining a specific coordinate reference frame in tectonic regions is as important as monitoring the changes themselves. Consequently, GPS-PPP and relative positioning results can be compared to see if there is a link between the two methods when it comes to geocentric deformation or velocity frame definition.

This article discusses the displacements obtained from the ISKI-CORS (Istanbul Water and Sewerage Administration-Continuously Operating Reference Station) network, which was built for use in engineering studies in the central part of the Marmara Region. Data from selected points on this network was analyzed using both PPP and related methods.

Preliminary results show a link between the two strategies in terms of monitoring displacements and velocities.

2. DATA AND METHODOLOGY

Regardless of the purpose or analysis of GNSS data, the first knowledge that must be obtained is coordinate values. In terms of both quickness and accuracy, it is well recognized that online data processing services are quite convenient for users. Accordingly, what would happen if the results were derived from academic software? To address this issue for the PPP and relative positioning method, the ISKI-CORS network's eight GNSS stations listed in Table 1 were used.

Table 1. ISKI-CORS stations and schedule of observations used in this study

Stations	Lat (°)	Lon (°)	Schedule
BEYK	41.17672	29.09352	2018 to 2021 DOY 113-109 7-days time-series for each year
KCEK	41.00275	28.77975	
PALA	41.08633	28.96320	
SİLE	41.17900	29.61332	
SLVR	41.08022	28.08341	
TERK	41.30307	28.67358	
TUZL	40.82650	29.29245	
YALI	41.47335	28.29320	

The ISKI-CORS network consists of totally ten GNSS stations located throughout the province of Istanbul. This network has been established specifically for use in engineering studies (URL1). The positions of the eight ISKI-CORS stations chosen for this study are depicted in Figure 1.

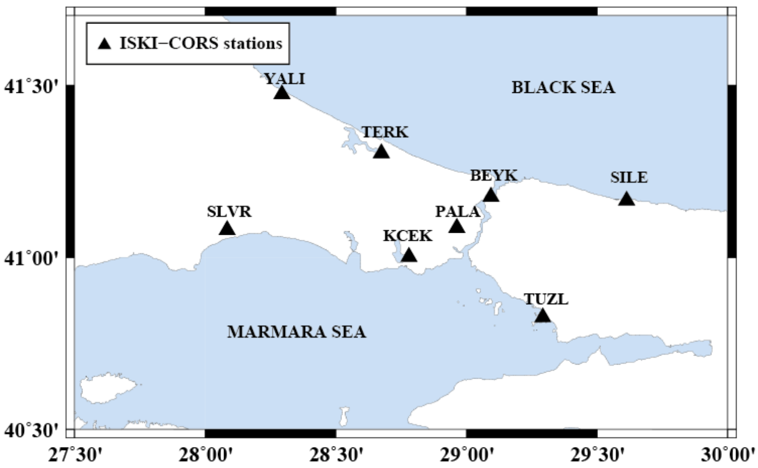

Figure 1. ISKI-CORS stations used in this study

For the period 2018–2021, four different seven-day data sets (day of the year-DOY 113–119) have been analyzed. The analysis carried out utilizing both the relative and PPP point positioning methods. For this purpose, in this study, BERNESE v5.02 and APPS are used.

APPS is a JPL (Jet Propulsion Laboratory)-operated online GNSS processing service (URL2). To process GPS measurements, this service utilizes JPL's GIPSY-OASIS II (GNSS-Inferred Positioning System and Orbit Analysis Simulation Software II) v6.4 academic software (Zumberge et al. 1997). As processing strategies, JPL's daily and weekly precise GPS orbit and clock data or real-time GPS orbit and clock products from JPL's Global Differential GPS (GDGPS) are used. To eliminate ionospheric and tropospheric effects on single-frequency GNSS data, APPS uses Global Ionospheric Map (GIM) and the Global Mapping Function (GMF) troposphere mapping function. Results obtained from the processing consist of three-dimensional coordinates (X, Y and Z) in the ITRF (International Terrestrial Reference Frame) 2014 system, as well as their one-sigma errors and correlation of two relevant coordinate components. Only GPS measurements in static and kinematic modes are supported by APPS. According to this, eight ISKI-CORS stations cartesian coordinates in the ITRF2014 system APPS processing were yielded for the time period 2018–2021 of each DOY.

Bernese v5.2 data processing software was used to obtain adjusted coordinate parameters from GPS data. It is possible to analyze data from GPS and other satellite systems using the Bernese V5.2 software, but the study analyzed only GPS data in order to adopt an assessment technique that was comparable with the APPS online data processing service. The IGS (International GNSS Service) provides earth rotation parameters and precise satellite orbits for use in analysis (URL3). The first order ionospheric delay was eliminated by using L3 frequency, and the phase initial uncertainty was solved by using the QIF (Quasi Ionosphere Free) technique. The GMF model was used to derive the Zenit delay time parameters (Dach et al., 2015). For the relative positioning utilizing Bernese v5.2, the BUCU, GLSV, GRAZ, POLV, and WTZR IGS stations located on European plates were fixed in the ITRF 2014 reference system. Figure 2 illustrates the locations of the selected IGS reference stations.

Their coordinates were retrieved from the Scripps Orbit and Permanent Array Center (SOPAC) (URL4). As a result of the network adjustment, the cartesian coordinates of the eight ISKI-CORS stations were calculated for each DOY.

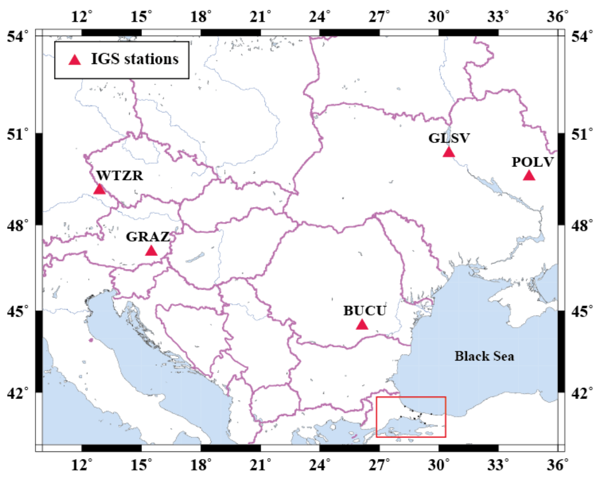

Figure 2. IGS stations used as a reference for the relative point positioning (red rectangle represents the study area)

After getting the coordinate components with Bernese v5.2 and APPS, a new subject was set up to examine how the PPP reference frame, or relative point positioning reference, affects the velocities. For this, the Least Squares Estimation method was used to calculate the velocity values for each point using the linear velocity model given in Eq. (1) (Nocquet and Calais, 2003).

$$x_i(t) + \upsilon_i(t) = x_i(t_0) + \dot{x}_i(t - t_0) \quad (1)$$

In Eq. (1), x_i represents the position of the point *i*, t is the period of time, t_0 is the reference epoch, $\dot{x}_i$ denotes the velocity of the point *i*, and υ_i refers to the residuals of the point *i* at the specified time. For each period, the average of the 7-day data sets was calculated. The velocity model mentioned in Eq. (1) is used to estimate the velocities derived from both APPS and Bernese v5.2 for all stations. Comparisons were made between the horizontal velocities. The most critical distinction is between the different approaches' underlying reference frames. As noted previously, five IGS stations located on the Eurasian plate fix were used to determine the Bernese v5.2 solutions. However, because the reference point set is unknown in the PPP solution, no plate definition can be provided for the magnitudes of the horizontal velocities. In summary, comparing the directions of horizontal velocities resulting from the PPP results is critical for understanding the GPS-PPP solutions reference frame. The comparison of horizontal velocities in the ISKI-CORS network in the Istanbul Marmara region is analyzed for this purpose, and the details are given in the next section.

3. RESULTS AND DISCUSSIONS

Bernese v5.2 results were accepted as true, and coordinate differences between Bernese v5.2 and APPS results were derived in the Cartesian coordinate system (X, Y, Z) for the time-span. Figure 3 shows the obtained differences. The maximum differences between the X, Y and Z coordinate components at all time-span were 16.2, 12.4 and 21.3 mm, respectively, while the minimum differences were -13.5, 4.4 and -7.8 mm.

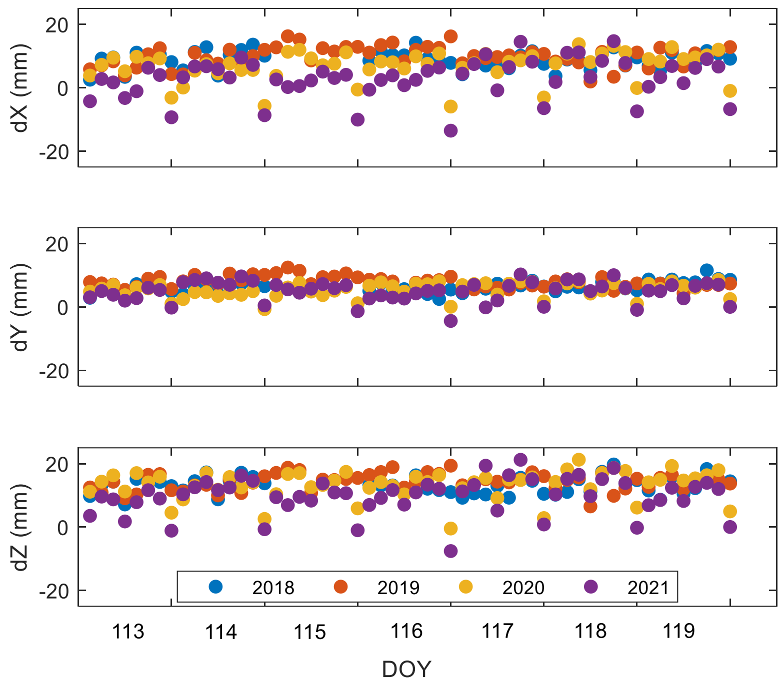

Figure 3. Differences in Cartesian coordinates of the stations over the years (mm)

Due to the fact that the X, Y and Z coordinate components are geocentric coordinates, topocentric coordinates (neu system) were calculated for each station to actually understand the deformations. For all stations, we analyzed the time-series of topocentric coordinates derived from two alternative positioning techniques. As an example, Figure 4 shows the time-series of PALA and YALI stations. From the numerical results, we noted that the differences in the north, east, and up components between the two solutions were insignificant. In other words, both positioning techniques yielded the same displacements. While the average difference between the horizontal position components is 0.4 mm, the up component is -1.2 mm. The maximum displacement difference was found from the up component of the YALI station in 2021 and was determined to be -24 mm, as can be shown in Figure 4.

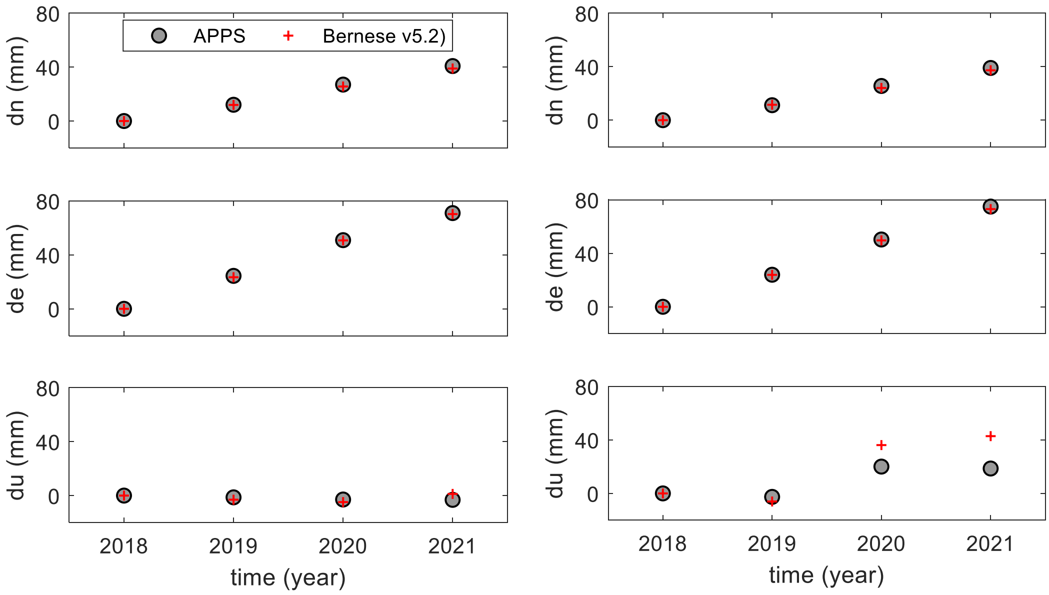

Figure 4. Time series of topocentric coordinates for the stations of PALA (left panel) and YALI (right panel)

After comparing the differences in displacements, horizontal velocities for both techniques were computed using Eq. (1). The horizontal velocities generated from the APPS analysis and their differences between the Eurasian-referenced Bernese velocities are given in Figure 5.

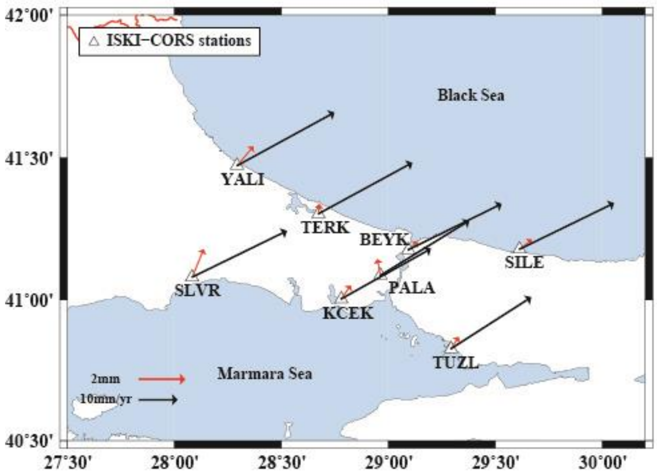

Figure 5. Velocity field for ISKI-CORS stations (Black arrows show the horizontal velocities obtained from APPS, while red arrows show the differences vectors from Bernese v5.2)

When the obtained velocities were analyzed, it was found that each positioning technique provided identical results. The average values for the north and east components of the horizontal velocity are 0.8 and 0.4 mm. Upon averaging the differences, the SLVR station has the highest variation, with a value of 1.5 mm. The magnitude and direction of the velocities are consistent when the results are summarized. This result demonstrates that the PPP may be used directly to obtain Eurasian-referenced north and east displacement/velocity components as defined in practically all tectonic investigations of the selected region. However, this does not always imply that it is true for all areas of the Marmara Region.

4. CONCLUSIONS

In this study, analyses were carried out on a network consisting of eight points in the ISKI-CORS network for a 7-day time series selected in 2018–2021. This network, which is located in the district of Istanbul in the Marmara region, was analyzed using both relative positioning and PPP techniques. For this, Bernese v5.2 academic software was used for relative positioning, while the APPS online processing service was used for PPP. The results were initially assessed in terms of the cartesian coordinate components. After that, topocentric coordinates were used to better understand the displacements. Both techniques provided similar results for displacements. The ISKI-CORS station velocities were then estimated by least-squares adjustment using the linear velocity model for the period 2018–2021. Based on five selected IGS stations on the Eurasian plate, velocities were computed using Bernese v5.2 academic software and the APPS online processing service. When the coordinate differences and velocity values obtained from the two methods are compared, it is found that there is no significant difference between them. With the velocities obtained by the PPP technique, it is not possible to address any reference frame definition. A comparison of the displacements and velocities from both methods tells us about the GPS-PPP reference frame for the restricted study area. These initial findings are included within the scope of the study's objective. Further research, which will include long-term data from various points in the region, will be thoroughly examined in the context of the PPP solution in this region. This will give us an understanding of how the PPP solution works in this region.

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BIOGRAPHICAL NOTES

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