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INVESTIGATION OF HATAY-DEFNE EARTHQUAKE (20.02.2023) BY USING GNSS STATION

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Abstract. No studies have been conducted on the spatial changes related to the Hatay-Defne earthquake (20 February 2023) up to now. The reason for this situation is that the requested data cannot be accessed as a result of the power and internet interruptions caused by the earthquake. The southern Turkish city of Hatay had a 6.3 magnitude earthquake at 20:04 on February 20, 2023. Three minutes later, a 5.8 magnitude aftershock occurred, and 90 more aftershocks followed. These earthquakes, which were felt across the area, caused individuals who survived the horrific quakes on February 6, 2023, to experience new levels of dread. In the district of Hatay-Defne, the epicenter began. In its first assessment, the United States Geological Survey gave the earthquake a magnitude of 6.3 at a depth of 16 kilometers. In this study, firstly, GNSS data belonging to ARST station in 30 seconds recording interval were downloaded into CSRS-PPP. GNSS data was processed as static and then was processed as epoch to epoch by using kinematic method. The coordinate differences between the obtained coordinates by using the kinematic processing and the obtained coordinates by using the static processing were computed. According to the obtained results, a horizontal movement of approximately 8.30 cm in the south-west direction was observed at the ARST station, which is the closest to the earthquake center.

Keywords: GPS, GNSS, Hatay-Defne earthquake, deformation, displacements.

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1. Introduction

The Hatay area lies in a seismically active zone at the western end of the 1000-kilometer-long boundary created by the Arabic and Turkish plates. The region's tectonic activity exhibits complicated tectonic behavior as a result of faults stretching to the Dead Sea, Eastern Anatolia, and Cyprus. More than ten of the most devastating earthquakes in the last century (1937–2015) happened in this region, suggesting that ground shaking is heavily influenced by local site circumstances. Hatay and its environs are situated to the south of the Antakya-Kahramanmaraş graben, which formed as a result of the Dead Sea and Eastern Anatolian Faults, as well as the Cyprus Spring. The Dead Sea Fault shapes the graben to the south. The Arabian and African plates, on the other hand, migrate northward under the influence of mantle convection currents across the weakly resistive (fluid) upper asthenosphere. The slip vectors of the region's earthquakes, fault systems, and worldwide kinematic models based on oceanic spread all imply that the Arabian plate is moving north-northwest to Eurasia at a rate of 25 mm per year. In respect to Eurasia, the African plate is advancing northward at a rate of around 10 mm per year (Reilinger et al., 1997; Boulton et al., 2006; Boulton & Robertson, 2008; Büyüksaraç et al., 2014). Despite the fact that numerous devastating depressions have been uncovered throughout history, there has not been an earthquake in the region in 135 years. Every day, the probability of devastating earthquakes grows. The Otokton Arabian platform rocks are defined, with the main lines of the geology of the Amanos Mountains encompassing the great bulk of the area; Ophiolite nappes; and Neo-autoclaved sediments covering nappes and autochthonous units. The Amanos Mountains, situated at the southern edge of the Eastern Taurus Mountains, and the Kızıldağ ophiolite massif nearby, are also significant in the region's geology. In the past decade much studies have focused on city of Hatay-Antakya is located in the first degree seismic zone (Boulton et al., 2006; Boulton & Robertson, 2008; Büyüksaraç et al., 2014; Horoz, 2008; Reilinger et al., 1997; Över et al., 2004, 2011; Tarı et al., 2013) of Turkey which is on the Alp-Himalayan Seismic Belt known as one of the most active seismic belts.

A 6.3 magnitude earthquake hit Hatay in southern Turkey at 20:04 on 20 February 2023, followed by a 5.8 magnitude aftershock three minutes later and 90 consecutive aftershocks. These earthquakes were felt across the area, bringing increased anxiety for individuals who survived the February 6, 2023 earthquakes. The epicenter was located in Hatay-Defne district. The United States Geological Survey [USGS] first recorded a magnitude 6.4 earthquake at a depth of 16 kilometers. On 20 February, Mw 6.3 aftershock struck near Uzunbag in Hatay Province; the earthquake was caused by oblique-normal faulting. Based on the USGS fault model, preliminary analysis of the effects of stress changes caused by the Mw 7.8 earthquake on the Cardak-Sürgü Fault indicated up to 3 bars of added stress near the epicenter of the Mw 7.7 shock, sufficient to trigger rupture on that zone. Following the 6 February earthquakes, stress on the Hatay Fault, the cause of the 20 February Mw 6.3 aftershock, rose by 1 bar (USGS, 2023). The aim of this study consisted of processing (by using static/kinematic method) and analyzing data of ARST station that are part of the CORS-TR and is situated close to the epicenter of Hatay-Defne (20.02.2023) earthquake. The study region's three-dimensional displacements resulting from the earthquake were examined by analyzing the time series created from the daily solution by using the kinematic-static method (20.02.2023).

2. Materials and methods

2.1. CSRS-PPP Software

The static GNSS surveying method is favored for obtaining very precise three-dimensional coordinates on the stations. This method provides millimeter-level coordinates of ground points in both the horizontal and vertical components. Furthermore, the static technique allows for the correct measurement of azimuth, allowing the network's orientation with respect to the reference system to be determined. When compared to alternative surveying networks that use electromagnetic distance measuring devices, gravity fields, and geodynamic phenomena, building surveying networks using GNSS location offers the fundamental benefit of not needing inter-visibility. This includes polar motion, Earth tides, and crustal motion (Hofmann-Wellenhof et al., 2001; Wolf & Ghilani, 2002; Pırtı et al., 2023).

Kinematic surveying necessitates the work of two or more receivers at the same time. Methods comparable to Differential GPS (DGPS) may also be utilized with carrier phase-shift measurements to reduce errors. Throughout the whole observation method, all receivers must simultaneously acquire signals from at least four of the same satellites. Although single-frequency receivers may be used, dual-frequency receivers are preferred for kinematic surveying. The approach delivers positional accuracy to a few millimeters, making it suitable for the majority of stakeout, mapping, and surveying operations.

CSRS-PPP is a web-based tool for post-processing GNSS data. It determines exact user locations everywhere on the world by using precise satellite orbit, clock, and bias adjustments extracted from a global network of receivers, regardless of proximity to reference stations. Submit observation data in Receiver INdependent Exchange (RINEX) format from single or dual-frequency receivers operating in static or kinematic mode over the Internet to recover enhanced positioning precisions in the North American Datum of 1983 (CSRS) or the International Terrestrial Reference Frame (ITRF). The Precise Point Positioning (PPP) approach may reliably calculate the coordinates of a static point anywhere in the globe without the need for real-time adjustments or a nearby base station. A solo receiver determines its location alone using satellite data. Along with raw data, it receives navigation signals that include satellite clock offset, ionospheric and tropospheric corrections, and so on. Using this information, the receiver can compute its location with several-meter precision. The accuracy would be substantially poorer if there was no navigation data.

In contrast to these two approaches, PPP enables a single receiver to attain high levels of accuracy without relying on base station adjustments. PPP calculates coordinates using the same data as the navigation message supplied by a network of global reference stations. As a result, a single receiver may identify its location with centimeter-level precision using just its own raw data, accurate ephemerides, and clock offsets given by a PPP service. The PPP approach can establish the base location with absolute precision for future RTK and PPK surveys anywhere in the globe. The PPP approach does not need the use of a second receiver or the existence of an internet connection during the survey. Regarding the criteria, most PPP services can only function with GPS and GLONASS satellites.

The deformations that occur during and after an earthquake may be tracked quickly by using the kinematic processing method. It is obvious that the kinematic method should be run using 1–30 second data in order to correctly calculate the earthquake motion. Even if the accuracy obtained as a result of the kinematic process is on the centimeter level, it cannot be ignored that deformations in large earthquakes reach decimeter and meter levels (Reilinger et al., 1997; Hofmann-Wellenhof et al., 2001; Wolf & Ghilani, 2002; Pırtı et al., 2023).

2.2. Study site

The city is a sub-drainage basin of the Asi River and is situated in the Plio-Quaternary Hatay Graben (Boulton et al., 2006; Boulton & Robertson, 2008; Kaya & Kıyılı, 2009). On both sides of the Asi River, which is located on the bottom of the Hatay graben and runs northeast to southwest (NE-SW), the city's settlement area has grown. However, in recent years, the urban area has been mostly expanding toward the western Asi River's boundaries of neighboring areas. The city that the Macedonian King Selecus constructed in 300 B.C. has seen the greatest number of earthquakes since that time (Korkmaz, 2006). As a result, it is known as "The Sunken City" and has experienced several large earthquakes throughout its history (Horoz, 2008; Jenkins et al., 2013).

This property is a result of the region's geographic position, which is home to several big and diverse tectonic structures and a high concentration of tectonic activity. The region displays the general consequences of the relative motions of the Eurasian, Arabic, and African Plates. The city's location near the intersection of the Dead Sea, Karasu, and Cyprus-Antakya fault-lines (Över et al., 2001, 2004) has led to a tectonic regime that has given rise to diverse ground conditions within short distances. Antakya is situated in the 10–20 km wide Hatay Graben, which is NE–SW oriented. In ancient and modern times, hundreds of earthquakes struck Antakya and the surrounding area, which is at high risk for seismic activity. Both casualties and property damage were severe. Numerous research (Yüksel & Esnaf, 1993; Özşahin & Özder, 2011) have emphasized the presence of a consistent similarity between the magnitude of earthquakes and active fault lines. The province of Hatay is a region with high seismicity between the southern fault segment of the East Anatolian Fault Zone and the Dead Sea Fault Zone and in an area where the Cyprus Arc passing through the İskendurun Bay and the Southeast Anatolian Thrust Zone meet. As can be seen in the Turkey Active Fault Map prepared by the Mineral Technical Exploration Directorate in 2011, the North-East/South-West oriented Antakya Fault Zone and its fault segments are important tectonic elements in the region. There was a stress buildup at the south and north ends of the fault that ruptured after the two large earthquakes in Kahramanmaraş. This strain was too much for the Antakya fault to handle, and it snapped. The Antakya fault was set off by the significant earthquake (Figure 1) (Öztemir et al., 2000; Saban, 2010).

Since two earthquakes of magnitude 7.8 and 7.5, respectively, occurred southern Turkey on February 6 near the Syrian border, hundreds of structures in both countries have collapsed, confining or killing thousands of people. A different fault, the Cardak-Sürgü Fault Zone, which is a section of the northern strand of the East Anatolian Fault, is where the second M > 7 earthquake began. Along the northeast-southwest trending Doğanşehir Fault Zone, the rupture spread bilaterally along the Cardak section before moving eastward onto the Sürgü segment and then eastward to Malatya. Along the Cardak part, the rupture also moved southwestward. A 160 km overall rupture length was calculated. While the eastward-propagating rupture moved at a maximum speed of 2.8 km per second, the westward-propagating rupture moved at a maximum speed of 4.8 km per second. About 35 seconds passed

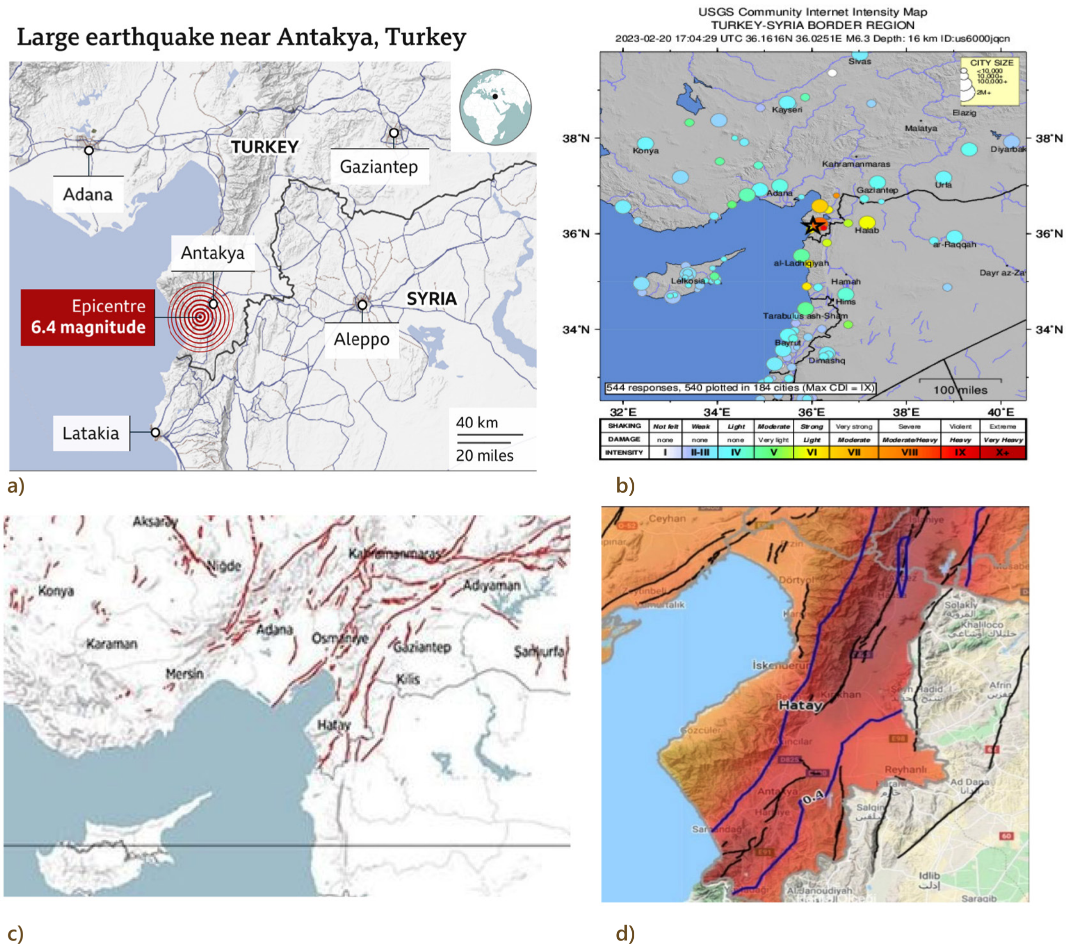

Figure 1. a – The epicenter of Hatay-Defne earthquake; b – USGS Community Intensity map of Hatay-Defne earthquake; c, d – The fault-lines of Hatay-Antakya region (USGS, 2023; AFAD, 2023)

after the rupture. Along the Hatay Fault, an aftershock measuring Mw 6.3 occurred on February 20. Normal faulting along a northeast-southwest striking fault was suggested by the focal mechanism (Karabulut et al., 2023; Afet ve Acil Durum Yönetimi Başkanlığı [AFAD], 2023; USGS, 2023).

3. Results

3.1. Static processing

Understanding the degree of displacement caused by the earthquake is necessary to understand the tectonic processes involved in the Hatay-Defne earthquake. Continuously Operating Reference Station CORS-TR station (ARST) near the earthquake epicenter provided data that is very useful in this situation. In this study, data were gathered and processed three GNSS stations that are near the epicenter of the Hatay-Defne earthquake (see Figure 2, Table 1). The stations' observation files (20.02.2023) were processed by using CSRS-PPP Software by using static and kinematic method. The coordinate results of CSRS-PPP Software were obtained. The coordinate standard deviations were computed with an accuracy of 2–4 mm in the horizontal components and 8–9 mm in the vertical components by using static method (20 February 2023, Table 1). These obtained data were examined on February 20, 2023, to investigate the seismic effects in the time series (17:00:00–17:59:00 UTC time). By examining the time series derived from this day (February 20, 2023) solutions, the displacements brought on by the earthquake were ascertained (Figure 3). Table 1 displays the coordinates and standard deviations of the three CORS-TR station.

As mentioned in the paragraph before, this study was processed and analyzed ARST station by using kinematic and static method. It is obvious that the earthquake significantly affected the horizontal coordinate data on DOY 051. The position discrepancies (X and Y) between the two CORS-TR stations were acceptable throughout, with mean and standard deviation values of less than 1 cm, with the exception of the time period of the earthquake. The mean and standard deviation values of height differences were 1.6 cm and 9.3 cm, respectively (Figure 3). For the horizontal (X and Y coordinates), Figure 3 depicts time series of ARST station, which exhibit considerable movement owing to their closeness to the earthquake's epicenter. When detecting the displacement values, the earthquake's timing is crucial. These tests establish the horizontal discrepancies between static and kinematic method, which range from a few millimeters to seven centimeters. Additionally, the height component at ARST station varied among static and kinematic method by up to 10 cm, as seen in Figure 3. According to Figure 3, during the earthquake period (17:04 UTC time), the Northing (X) and Easting (Y) components exhibit substantial values, with variations ranging from 5.1 cm to 6.6 cm at ARST station, respectively.

The effect of the Hatay-Defne centered earthquake on ARST point is shown in Figure 4. It seems that the motion of ARST point is in the south-west direction during the earthquake period (about 8.3 cm), see Figure 4. Using

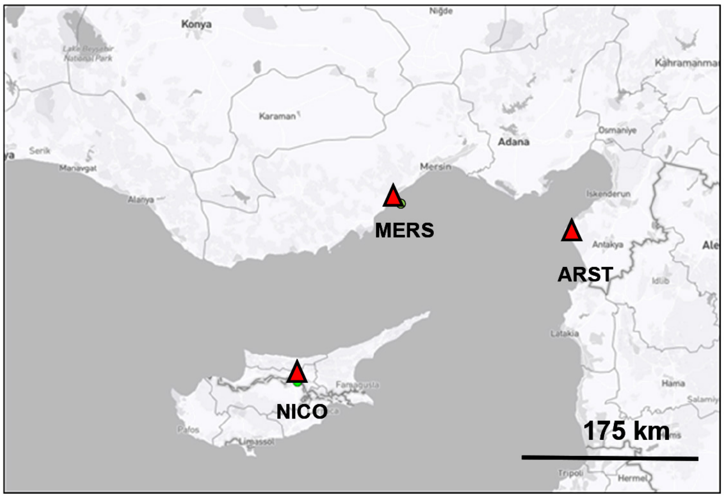

Figure 2. The station (ARST) near the earthquake region

Table 1. Standard deviations and ITRF20 2023.1 Epoch coordinates of three stations in the region of the Hatay-Defne earthquake

Point	φ_{ITRF}	λ_{ITRF}	h_{ITRF} (m)	Std (φ) [mm]	Std (λ) [mm]	Std (h) [mm]
MERS	36°33′59.00795″	34°15′21.07893″	38.469	2	2	8
NICO	35°08′27.55998″	33°23′47.21908″	190.015	2	4	8
ARST	36°24′56.13076″	35°53′ 06.52143″	31.140	2	4	9
h: Ellipsoidal Height (GRS80 reference ellipsoid-ITRF)						

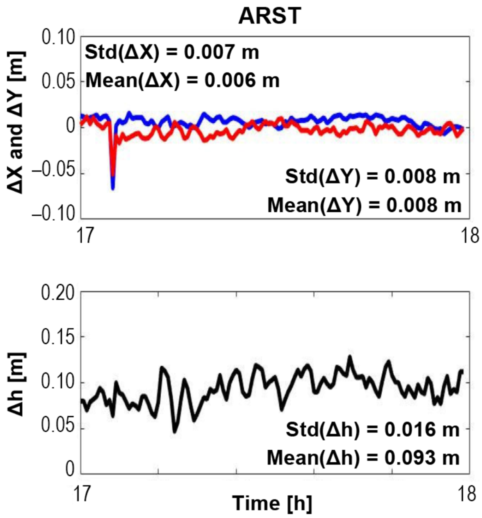

Figure 3. Horizontal coordinates (17:00:00–17:59:00 UTC time) time series (interval: 30 sec) acquired from ARST station during the monitoring Hatay-Defne earthquake period (17:04 UTC time) – (20:04 Local time)

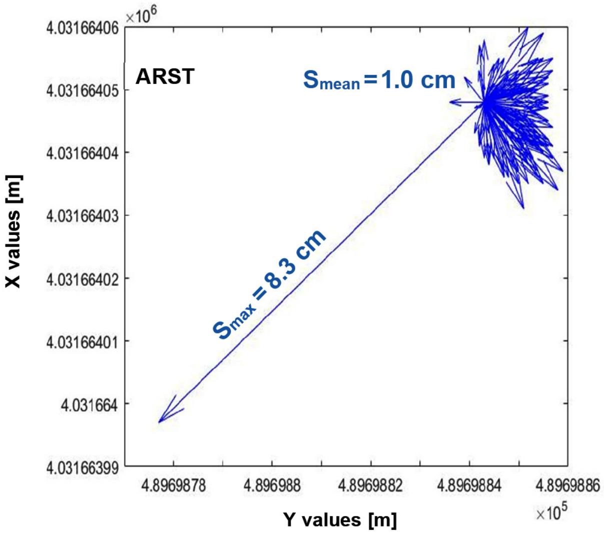

Figure 4. Horizontal displacement vectors caused by an earthquake on February 20, 2023 (17:00:00–17:59:30 UTC time) for ARST (Arsuz) station

kinematic and static processing method, the co-seismic displacements were estimated by comparison of the coordinates of ARST station before and after the Hatay-Defne earthquake (February 20, 2023, Day of the Year 051). As shown in Figure 5, Xpost, Ypost, hpost, Xpre, Ypre, and hpre denote the mean GNSS-based positions determined prior to and following the earthquake, where Xcos, Ycos, and hcos represent the co-seismic displacements. Figure 5 displays the co-seismic displacement values that were collected for ARST station by using the aforementioned method. The three-dimensional displacement directions of ARST point observed by GNSS, as illustrated in Figure 5. The height differences were shown in Figures 3 and 5 totally found to be approximately 5–12 cm of swell at the period of the earthquake.

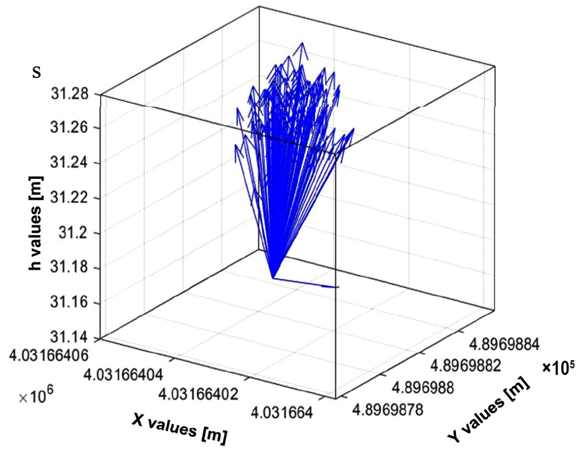

Figure 5. Comparison of the 3D coordinates of ARST station among the results of static and kinematic method

4. Conclusions and discussion

After two major earthquakes (06.02.2023), stress accumulation occurred at the southern and northern ends of the fault that broke. The Antakya fault could not withstand this stress and broke (20.02.2023). Major earthquakes triggered the Antakya fault. Using relative GNSS analysis, co-seismic displacements caused by the Hatay-Defne earthquake on February 20, 2023, were efficiently determined. For this, one station (ARST) close to the epicenter was selected. Using the daily coordinate time series (20.02.2023), it was possible to compute X, Y and h coordinate displacements with accuracy of sub-mm and sub-cm. The horizontal displacement values were reported at the ARST station, which is about 35 kilometers from the epicenter. As can be seen from the obtained data, the effect of the earthquake on the horizontal, vertical and height coordinates was approximately 5–10 cm. These differences show the displacements and deformations that occur on the earth as a result of the analysis of time series created from the daily solution by using the kinematic-static method (20.02.2023). In addition, they have emerged as a result of movements such as tension, fracture or uplift in the earth's crust due to the effect of the earthquake.

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