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REVIEW OF THE DEVASTATING SERIES OF EARTHQUAKES IN TÜRKIYE AND SYRIA IN FEBRUARY 2023. EARTHQUAKE ANALISYS USING SAR SATELLITE DATA: PRELIMINARY RESULTS

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Abstract. This article is dedicated to the earthquakes of February 6th, 2023 in Türkiye and Syria. The epicenters are located in seismically active region where the East Anatolian Fault is placed. Past and present seismicity is reviewed and together with the aftershock activity is shown as simplified map. The tectonic and geological features of the affected area are discussed in brief. Preliminary assessments of the consequences and damages are presented, according to the data we known up to now. In addition, the main shock generated tsunami waves that were registered by the mareograph network.

Using SAR satellite data, we made an estimation of the deformations in the Earth's crust after the earthquakes. The preliminary results show displacements above 2.5 m.

Keywords: earthquake; Türkiye; Syria; SAR satellite data

1. Introduction

Devastating earthquake struck southern and central Türkiye, as well as northern and western Syria on February 6th, 2023 at 01:17 UTC. The estimated moment magnitude is M_w7.8 and the maximum Mercalli intensity of XI, which refers to extreme scale level. The earthquake hypocenter was at a depth of 17.9 km according to USGS[1)] and 5 km according to KOERI[2)]. The epicenter is located 34 km west of Gaziantep and close to the border with Syria. Another strong earthquake (M_w7.5) occurred nine hours later near the province Kahramanmaraş. According to GEOSCOPE it had a depth of 13 km[3)], according to KOERI of 5 km[4)]. It was followed by two additional mb 6.0 aftershocks. Both of the earthquake epicenters are shown in Figure 1.

The main earthquake is the strongest earthquake in Türkiye since the Erzincan earthquake of 1939, with the same magnitude making it the second strongest in the country's history after the North Anatolia earthquake of 1668.

The earthquake is the deadliest in Türkiye since the Cilicia earthquake of 1268 and in Syria since the Aleppo earthquake of 1822. It has been felt as far away as Egypt, Israel, Palestine, Lebanon, Cyprus, and Türkiye‘s Black Sea coast.

Three days prior the mainshock, a foreshock of magnitude M4.4 occurred. The earthquakes were followed by more than 3 858 aftershocks[5)]. The seismic sequence was the result of a shallow strike-slip fault. By February 19, 2023, more than 47 400 deaths had been confirmed: more than 41 000 in Türkiye and more than 6,400 in Syria[6)]. A severe winter storm hampered rescue efforts, dropping snow on the ruins and lowering temperatures. Because of the freezing temperatures in the area, survivors, especially those trapped under the rubble, were at great risk of hypothermia. Overall, the earthquakes are estimated to have caused $84.1 billion in damage[7)], making them the fourth deadliest earthquakes since records began. It is the deadliest natural disaster in Türkiye's modern history.

For fully understanding and analyzing the consequences of these earthquakes, the presence of satellite data is crucial. The Copernicus Programme was established with the vision on one hand to enable continuous monitoring of the Earth environment and ecosystem for creating added value products, and on the other, to provide information for quick response in case of natural disasters[8)]. It relays on both, in-situ and satellite data to create its products and services. The satellite imagery with its good revisit time and spatial resolution can be implemented in planning and navigating hazard response, but also to evaluate the damage in timely manner and support humanitarian aid.

Radar images acquired by Synthetic Aperture Radar (SAR) can be utilized in estimating the ground motion and thus observing the land cover deformation. The Sentinel-1 satellite is equipped with a SAR antenna, which operates at C-band (approx. 5.5 cm wavelength and 5.405 GHz) and in the Inteferometric Wide (IW) swath mode its spatial resolution is 20 m in azimuth and 5 m in range[9)].

Information about changes in the terrain topography over an area of interest can be gained from the Interferometric SAR (InSAR) signal. This method makes use of the phase difference between two observations of the same area, obtained from different sensor position. After coregistration of the two images the terrain deformation can be mapped[10)].

In this context the InSAR technology can be very important in understanding and evaluating the impact of the devastating earthquake events in southern and central Türkiye and northwestern Syria from 6th February 2023. In this study we present preliminary results for the deformation of the Earth's crust based on InSAR image analysis.

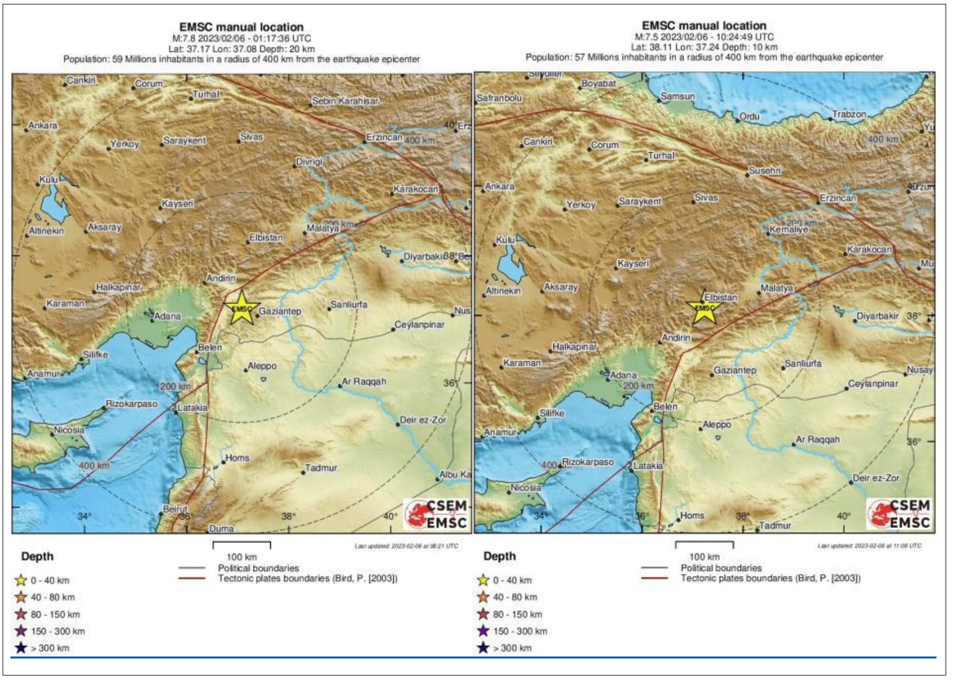


Figure 1. Location of the earthquake epicenters from February 6th, 2023.
The main shock M7.8 (left panel)[11] and the larger aftershock M7.5 (right panel)[12]

2. Geology, Seismicity and Tectonic Features

The East Anatolian Fault is a major strike-slip fault zone that runs from eastern to south-central Türkiye. The EAF is a 700 km long left-lateral fault between the Anatolian and Arabian plates and forms the transform tectonic boundary between the Anatolian Plate and the northward-moving Arabian Plate. The difference in the relative motions of the two plates is evident in the left lateral motion along the fault. The East and North Anatolian faults together accommodate the westward motion of the Anatolian plate, which is pushed out by the ongoing collision with the Eurasian plate. Figure 2. Represents the relative motion of the tectonic plates in the region. Several geological and geodetic studies have estimated the slip rates on segments along the EAF and its subparallel segments (McClusky et al. 2000; Reilinger et al. 2006). Geological and geomorphological studies show that the slip rate systematically decreases from ~10 mm per year^{-1} at Karlıova to ~4 mm per year^{-1} near Türkoğlu. Further west, the slip rate decreases to ~2.5 mm per year^{-1} on the main fault and to ~1 mm per year^{-1} on subparallel faults. Slip rates estimated from Holocene dislocations are compatible with geodetic fault slip rates (Güvercin 2022).

From 1939 to 1999, a series of earthquakes occurred westward along the North Anatolian Fault. However, since 1998, there has been a series on the East Anatolian Fault. This began with the 1998 Adana-Ceyhan earthquake and includes the 2003 Bingöl earthquake, the 2010 Elâzığ earthquake, the 2020 Elâzığ earthquake, and the 2023 Türkiye-Syria earthquake. Türkiye has been hit by 21 earthquakes of magnitude 7 or higher since 1900 (see Figure 3). Aleppo, in Syria, was devastated several times historically by large earthquakes, though the precise locations and magnitudes of these earthquakes can only be estimated. Aleppo was struck by an estimated magnitude 7.1 earthquake in 1138 and an estimated magnitude 7.0 earthquake in 1822. Fatality estimates of the 1822 earthquake were 20 000 – 60 000.

Figure 4 depicts the seismicity[13)] in the period between 1st and 13th February 2023. The earthquakes have magnitude equal to or larger than 3.5. The size of the circles is scaled according the magnitude of the earthquakes. The black lines show the seismic faults according the European Database of Seismogenic Faults (Basili et al. 2013).

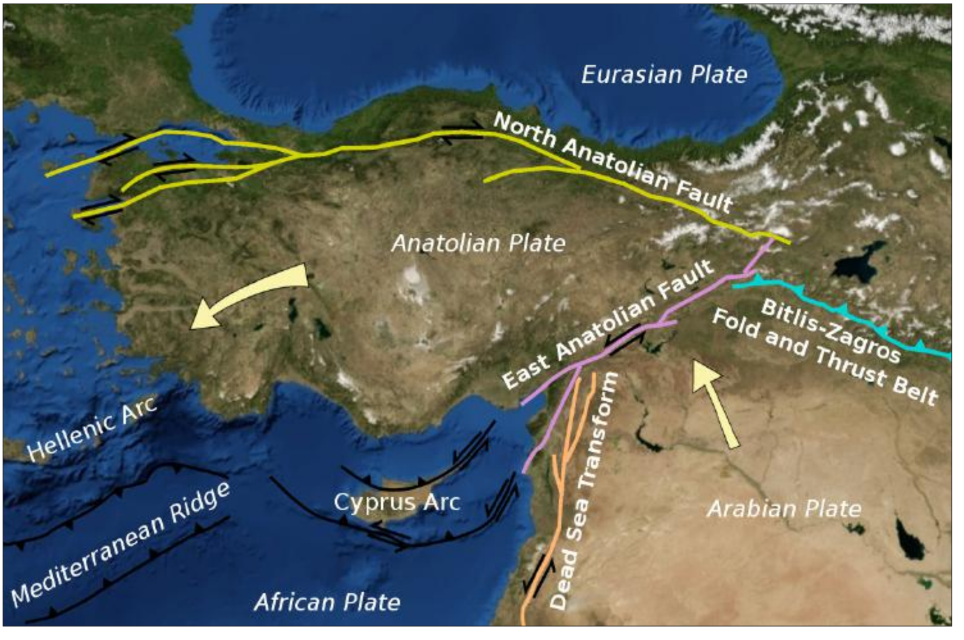


Figure 2. Relative motion of Anatolian and Arabian plates and major faults[14)]

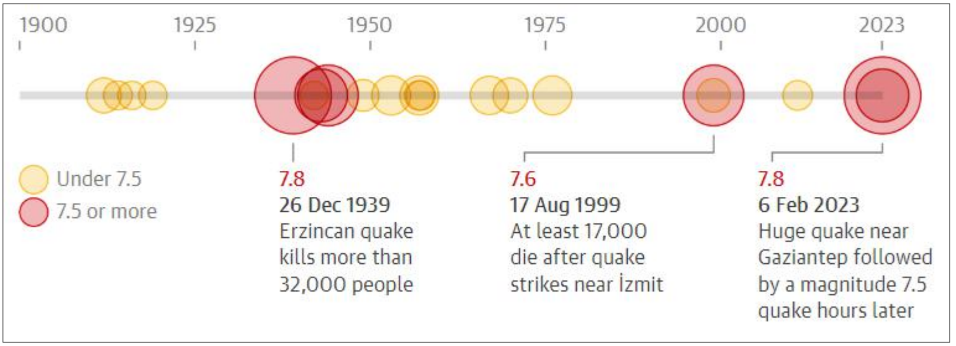


Figure 3. Strong earthquakes in the past 100 years in Türkiye[15)]

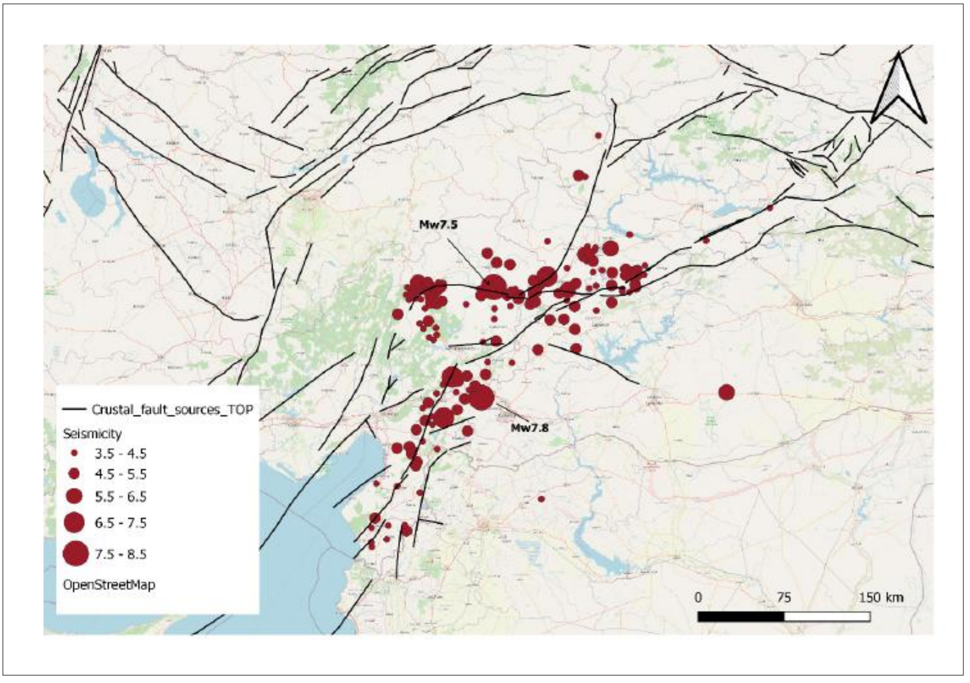


Figure 4. Foreshock and aftershock activity in the period 1 Feb. 2023 – 13 Feb. 2023

3. Earthquake Damages

One of the most powerful earthquakes ever recorded in Türkiye killed thousands of people and devastated a densely populated region of southern Türkiye and northern Syria. The area was particularly vulnerable to a large earthquake. Older concrete-framed buildings are common, and thousands were destroyed. The infrastructure in northern Syria was already very fragile after years of airstrikes and bombings during the country's civil war. While the full extent of the damage is not yet known, collapsed homes, hotels and other buildings have been spotted in dozens of towns near the epicenter on both sides of the border. More than 5 600 buildings were destroyed across Türkiye. In Syria, the earthquakes hit the country's war-ravaged north. More than a thousand were dead and thousands more were injured, according to the Syrian Health Ministry. As of 9th February 2023, the casualties in different Turkish provinces are shown in Table 1. As of 17th February 2023, the total number of live affected and some statistics are collected in Table 2. Figure 5 and Figure 6 depicts destroyed buildings in Türkiye and in Syria. Damage extension according the level of the shake intensity of the main shock if presented in Figure 7.

Table 1. Casualties by Turkish province (as of 9th February 2023)[16), 17)]

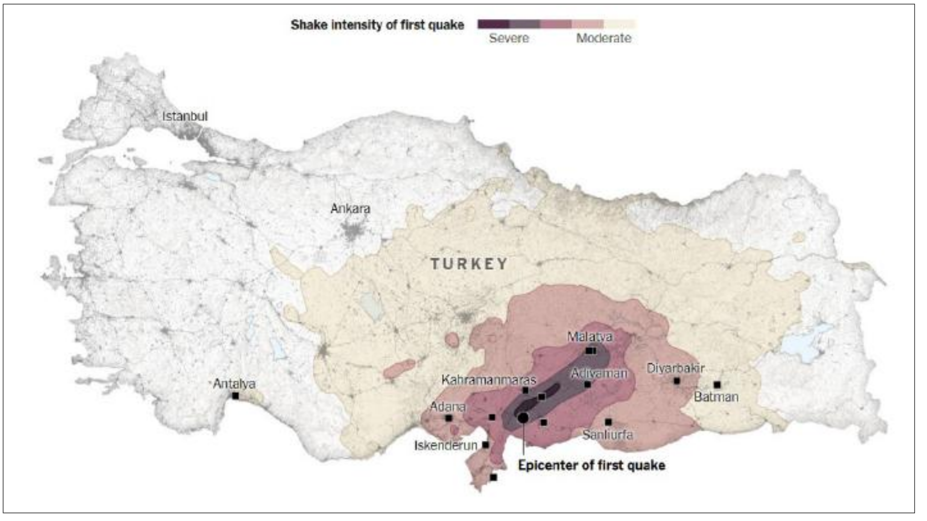
Province	Deaths	Injuries
Hatay	21,000	24,000
Kahramanmaraş	5,323	9,243
Gaziantep	3,273	13,325
Adıyaman	3,105	11,778
Malatya	1,386	7,300
Osmaniye	878	2,224
Adana	454	7,450
Şanlıurfa	304	4,663
Diyarbakır	255	901
Kilis	22	518
Elazığ	5	379
Mardin	1	0
Batman	0	20

Table 2. Lives affected and statistics as of 17th February 2023[18)]

Deaths	Non-fatal injuries	Displaced	People affected	Buildings destroyed	Property damage
43 858	114 926	2.4 M	24 M	6589	50 – 85 B

Figure 5. Destroyed building in Diyarbakir, Türkiye[19)]

Figure 6. The town of Jandaris, near Afrin, Syria[20)]



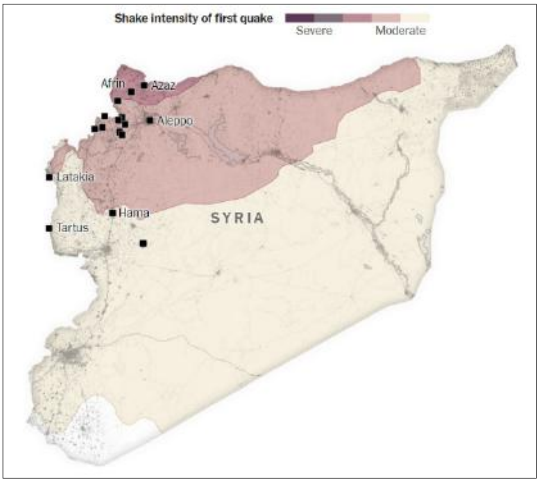


Figure 7. Damage extension in Türkiye and Syria according to the shake intensity of the main earthquake[21)]

4. Earthquake Analysis Using SAR Satellite Data: Preliminary Results

The satellite data used in our analysis is from the space segment of the Copernicus Programme. The images are freely available for download at the Copernicus Open Access Hub after short registration[22)]. The pre-processing steps which need to be applied are described in Braun & Veci 2021. The images are processed with the software SNAP (Sentinel Applications Toolbox)[23]. All satellite images are selected to cover as short period as possible before and after a given earthquake. A condition for using the SAR data is that the earthquake has a magnitude greater than 5.5 or 6; presence of vegetation or complex topography may lead to bad results because of the strong interference. The interferometric maps are represented by interferometric fringes (colour-coded from blue to purple) each of them equals to 28 mm, half the wavelength of the instrument. After unwrapping the phase, the deformation map is obtained. It is important to note that the deformation is in Line-of-Sight (LoS) direction of the satellite antenna and not vertical displacement. Both ascending and descending orbits over the given region are used to calculate the vertical displacement, and after calculating the total deformation along the direction of the satellite antenna and using information about the angle of incidence between the radiation and the perpendicular to the base, we can calculate the vertical displacement in the up-down direction and the horizontal displacement in the east-west direction.

Table 3. Main parameters of the selected products

Swath	Slice Number	Master	Slave	Orbit	Pass
IW1, IW2, IW3	8	28.01.2023	9.02.2023	14	Ascending
IW1, IW2	13, 14	29.01.2023	10.02.2023	21	Descending

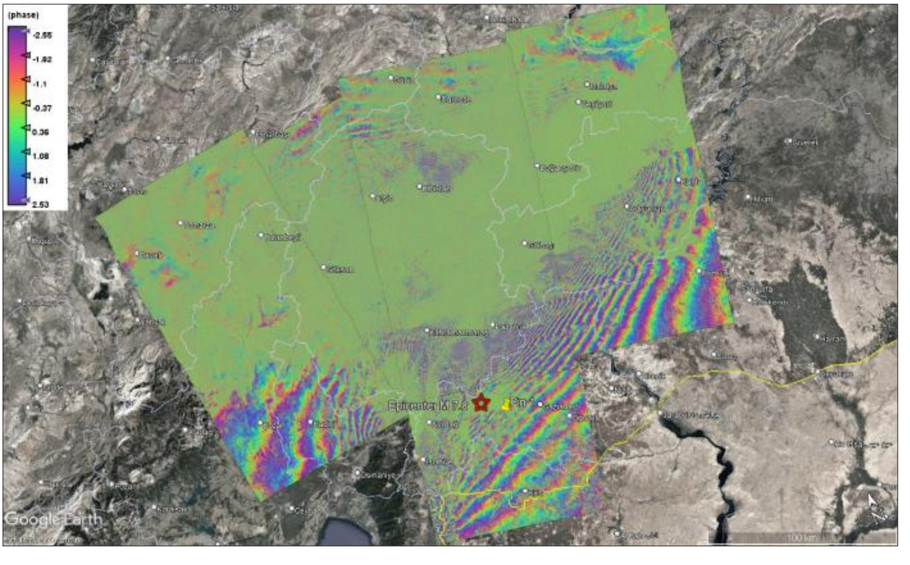


Figure 8. Interferogram formed by Orbit 14 and Orbit 21

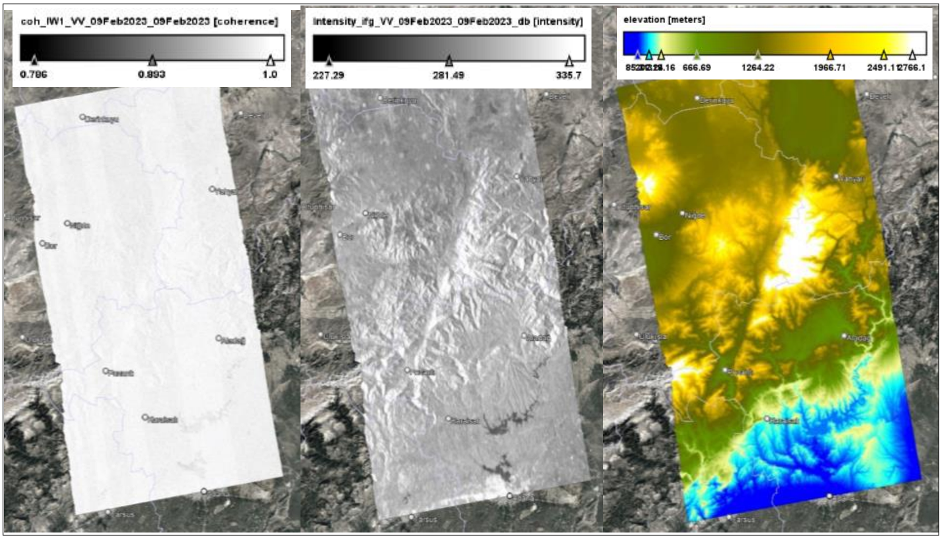


Figure 9. Coherence (left panel). Intensity (central panel). DEM (right panel) Orbit 14: 28.01.2023-9.02.2023

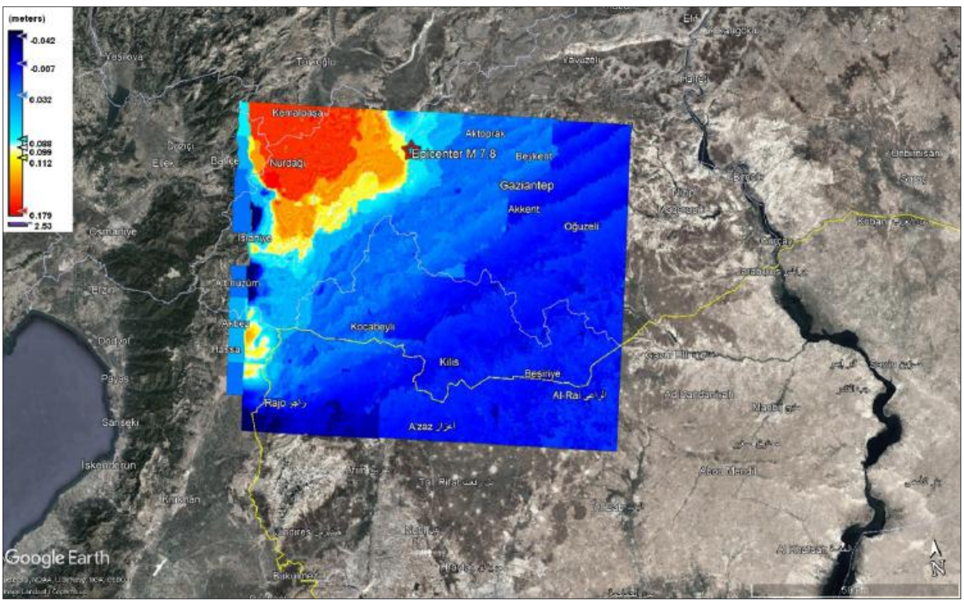


Figure 10. Deformation map using images from Orbit 21. The earthquake epicenter is denoted as red star

In total we selected, downloaded and processed 3 pairs of available images. The results are exported as .kml files and visualized via Google Earth Pro software[24]. The final interferogram composed by different images is presented in Figure 8.

Coherence is used to verify the legitimacy of the derived phase data. When creating the interferogram an important part is to check the coherence of the master and slave images. Usually, the threshold is 0.3. In the case of this huge earthquake for some of the pairs we get a minimum coherence of 0.8. Figure 9 shows the coherence, the intensity and the digital elevation model (DEM) from Orbit 14, master image of 28 January 2023 and slave image of 9 February 2023.

An example of deformation map is presented in Figure 10. We can see that at some areas the displacements reach values greater than 2.5 m. These are preliminary results, thus when more images from different orbits are available, we will combine all the data and create more complex image of the different scenes.

5. Conclusions

An overview of the destructive series of earthquakes in Türkiye and Syria was described in this paper. The number of casualties is not final as the rescuers are still struggling to find many of the people under the collapsed buildings.

The analysis of earthquakes using the data from SAR leads to a better understanding of the generation mechanisms and complements the geophysical and geological information. Using SAR satellite data, we analyzed a series of images and produced interferometric maps. The differences in the values from the different orbits confirm the need, when studying deformations obtained after earthquakes, to prepare interferogram images from both types of orbits in order to get a better idea of them and their subsequent comparison with field measurements or results from other sources.

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NOTES

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2. Kandilli Observatory KOERI: http://www.koeri.boun.edu.tr/new/en

3. GEOSCOPE: http://geoscope.ipgp.fr/index.php/en/catalog/earthquake-description?seis=us6000jlqa

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