INSAR ANALYSIS OF AYVACIK 2017 (Mw 5.3) EARTHQUAKE SWARM (CANAKKALE, NW-TURKEY)

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ABSTRACT:

In this study, the deformation of Ayvacik Canakkale earthquake and aftershocks of 5.3 (Mw), which were observed on 6 February 2017 in Gulpinar Ayvacik and felt from the surrounding cities, were analyzed by InSAR and strain reduction technique. The earthquake is occurred at the Biga peninsula which is located at the south segment of North Anatolian Fault zone. The first shock (Ml = 4.8) started on 14 January 2017 in the region, and after the second shock (Ml = 5.4) on February 6, 2017, seismic storm continued with the large and small earthquakes. It was seen that 31 of these earthquakes have a size of 4 and above and occurred on the Tuzla fault. Since classical geodetic methods are not performed regularly and frequently, and are spatially provide point-based displacements, they are often insufficient to monitor sudden earthquakes. For this purpose, the deformation values were obtained along the line of sight (LOS) direction of Synesthetic Aperture Radar (SAR) sensor using Differential Interferometric SAR (DInSAR) method. For the geophysical analysis coulomb technique was applied and the continuity of the changes in the sea is determined.

1. INTRODUCTION

The right lateral strike slip on the Anatolian plate North Anatolian Fault Zone (NAFZ) is one of the most active faults due to movements of Eurasia, Africa and Arabian plates. This zone forms the northern border of the Anatolian block moving westward. In Turkey most of the biggest and destructive earthquakes occurred on this zone. The Balikesir earthquakes (1944 (Ms = 6.8), 1953 (Ms = 7.2) and 1964 (Ms = 7)) were formed on the southern branch of the NAFZ. The Biga Peninsula on the southern segment of the NAF is affected by this movement of the Anatolian plate (Sozbilir et al., 17a). The first shock (Ml = 4.8) started on 14 January 2017 in the region, and after the second shock (Ml = 5.4) on February 6, 2017 seismic storm still continues with large and small earthquakes. Lately, an earthquake occurred on February 20, 2019 with a magnitude of 5.0 (Mw).

After the Ayvacik earthquake occurred in 2017, General Directorate of Mineral Research and Exploration conducted the field observations and described the fault as Tuzla Fault which may be the source of the earthquake activity in the vicinity of Tuzla (Karacık and Yılmaz, 1998; Kürçer and Elmacı, 2017).

Sozbilir (2017a) described that Tuzla fault has an extension of NW-SE direction and it has an approximately 22 km length on land. It is also noted that, according to the seismological data of the earthquakes, these earthquakes did not occurred with a main shock and has a characteristic of earthquake swarm (Sozbilir 2017b). Ozden et al. (2018) studied earthquakes and indicated that the normal faulting stress regime at southern part and strike-slip stress regime from center to northern region of the study area. Ganas et al (2018) determined 6.2 cm maximum deformation at line of sight (LOS) direction using Sentinel-1A/B satellites images. The Sentinel results were used for the modeling of fault dislocation and yielded 6 km fault length and 6km fault width with a 0.28m fault slip.

It was determined that the energy released was smaller compared to the earthquakes on the NAF, but still 29 villages were affected and many buildings and structures were damaged (Livaoğlu et al., 2017). Due to fact that, extraction of earthquake related surface deformation and monitoring its spatial extension is crucial for local authorities to manage damage assessment and risk analysis.

In this context, space-borne satellite based Synthetic Aperture RADAR (SAR) data provides accurate movements of the surface from millimetres to centimetre level (Ding and Huang 2011). Differential SAR Interferometry (DInSAR) technique has demonstrated its powerful advantages over several phenomena in monitoring surface displacement monitoring including earthquakes, ground subsidence (Hu et al 2013), landslides (Raucoules et al. 2018) and volcanic activities (Lu 2007). One of the first successful study using was applied by Massonet et al. (1993) that extracted co-seismic deformation after The Landers earthquake using ERS-1 satellite data. The deformation pattern of Bam earthquake was extracted utilizing series of C-band ERS and Envisat data (Fialko et al. 2005).

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Wang et al. (2015) investigated the co-seismic and post-seismic deformation after Van earthquake using X-band and C-band satellite images.

In this study, co-seismic surface deformation over Aycacik Canakkale was under investigation. New generation missions of Sentinel-1 SAR satellite images which are open source for research were utilized. The deformation of Ayvacik, Canakkale earthquake and aftershocks of 5.3 (Mw), which were observed on 6 February 2017 in Gulpinar Ayvacik and felt from the surrounding cities, were analyzed by InSAR and strain drop technique.

2. STUDY AREA

2.1 Tectonic structure

The earthquake occurred at the Biga peninsula which is located at the south segment of the North Anatolian Fault zone (Figure 1). According to the Bogazici University Kandilli Observatory and Earthquake Research Institute, and Earthquake Department of Disaster and Emergency Management Presidency between 14 January and 16 February 2017 around 1000 earthquakes were recorded. The first shock (ML, 4.8) started on 14 January 2017 in the region, and after the second shock (ML, 5.4) on February 6, 2017, seismic storm continued with the large and small earthquakes. It was seen that 31 of these earthquakes had a size of ML 4.0 and larger and occurred on the Tuzla fault. (Figure 2).

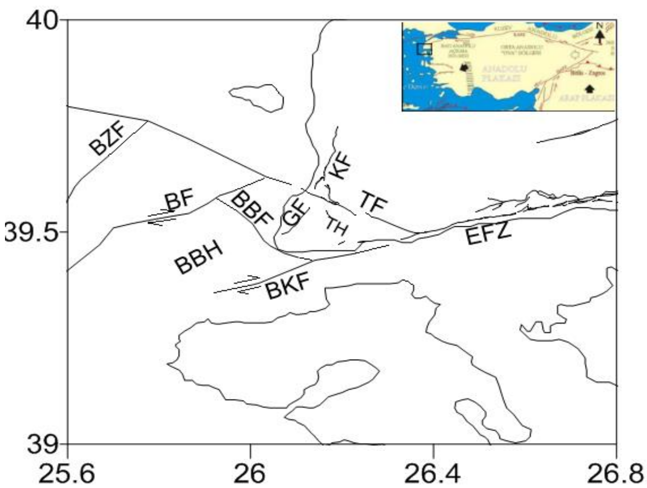


Figure 1. The active fault map of the vicinity of Canakkale-Ayvacik (MTA). TF, Tuzla Fault; BBF, Bababurnu Fault; BBH, Bababurnu Basin; BF, Biga Fault; BZF, Bozcaada Fault; GF, Gülpınar Fault; KF, KetanbolFat; BKF, Behramkale Fault, EFZ, Edremit Fault Zone, TH, Tuzla Basin

Tuzla fault has normal faulting feature. The focus mechanism solutions to the earthquakes that started in 14.01.2017 show that normal faulting has taken place. In Figure 2, the focusing mechanism solutions indicate that there is a very small percentage of right lateral strike besides normal faulting. In the general sense, the main shock was formed by movement of the block in the Tuzla basin along the direction of the slope of the Tuzla basin. However, a small block movement is observed right along the fault.

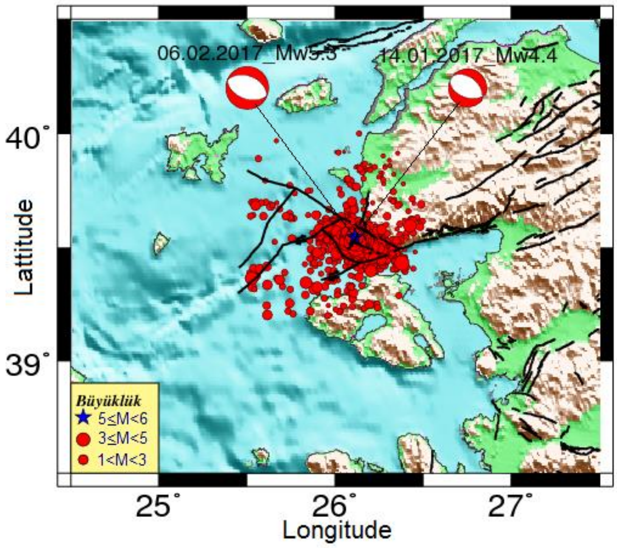


Figure 2. The focus mechanism solutions of earthquakes and epicenter in earthquakes between January 1, 2017 and August 31, 2018 in Canakkale Ayvacik.

3. DATA AND METHODOLOGY

3.1 SAR Data Processing

In this study, multi temporal Sentinel-1 satellite images of the European Space Agency were used to determine the deformation of the Earth surface as a result of the earthquake. C-band Sentinel-1 data was used due to its free of charge and systematic frequent acquisition. Sentinel-1 SAR images were acquired in both ascending and descending orbit direction, Interferometric Wide swath (IW) mode Level-1 Single Look Complex product which contains phase and amplitude information. For both ascending and descending images only vertical-vertical (VV) acquired polarization bands are processed.

Specifications	**Description**
Sensor	Sentinel-1
Wavelength	C-band
Imaging mode	IW
Orbit	Asc & Des
Incidence Angle (˚)	43.7763 (Asc) 33.7812 (Desc)
Resolution (Rg x Az)	2.33 x 13.92 (m)
Polarization	Dual-Pol (VV-VH)

Table 1. Characteristics of data

Since classical geodetic methods are not performed regularly and frequently, and spatially provide point-based displacements, they are often insufficient to monitor sudden earthquakes. For that reason, for the deformation extraction using SAR data InSAR method was utilized. The method provides a powerful tool for remote detection of spatial surface displacement pattern, mapping and long term monitoring of several phenomena including earthquake related deformation. In this study, multi temporal Sentinel-1 satellite images of the European Space Agency were used to determine the deformation of the Earth surface as a result of the earthquake. C-band Sentinel-1 data was used due to its free of charge and systematic frequent acquisition. Sentinel-1 SAR images were acquired in both ascending (25 Jan 2017 and 18 Feb 2017) and descending (31 Jan 2017 and 12 Feb 2017) orbit direction, Interferometric Wide swath (IW) mode Level-1 Single Look Complex product which contains phase and amplitude information.

For both ascending and descending images only vertical-vertical (VV) acquired polarization bands are processed. The 3D decomposition of InSAR analysis were performed in Aydes Uzal product that is developed by TUBITAK BILGEM. During the processes the topographic phase effect was removed using 1Sec HGT SRTM data (30m x 30m). Using the Goldstein phase filter, the interferograms were filtered and noises were reduced. The deformation values and spatial distribution of the displacement were determined in both ascending and descending LOS direction.

Pre-event	25 Jan 2017	31 Jan 2017
Post-event	18 Feb 2017	12 Feb 2017
Orbit	Descending	Ascending
Bperp (m)	-89.70	55.73
Btemp (days)	24 days	12 days

Table 1. InSAR data set

3.2 Coulomb strain model

In this study, the relationship between the Coulomb stress change model originating from the Çanakkale-Ayvacık earthquake, and the relationship between aftershock activity in the region and the strain change on the fault plane was detected. This activity started with an earthquake of magnitude 4.8 (ML) on 14 January 2017 and continued with the second major shock on February 6, 2017 (ML) detected.

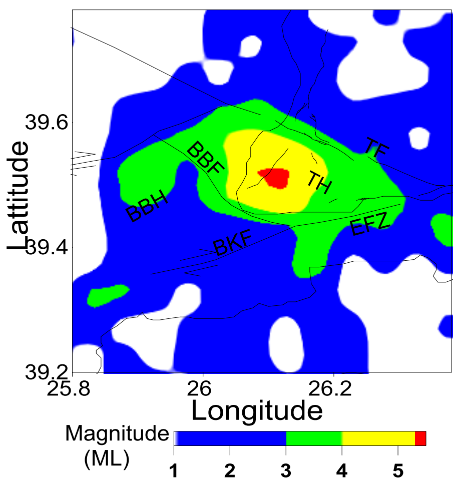


Figure 3. Spatial distributional pattern of mainshock-aftershock magnitudes (ML) (Contours show magnitudes).

4. RESULTS AND DISCUSSIONS

The deformation values and spatial distribution of the displacement was determined in both ascending and descending LOS direction.

Even the results of InSAR analysis indicated that the displacement is mostly dominated at vertical direction, ascending and descending results are combined for a detailed analysis. For the extraction of vertical and horizontal displacement decomposition was applied on LOS values of the ascending and descending results (Hu vd., 2014). Due to its low sensitivity the North component was ignored in this study. As a result of this study, the affected areas were determined over the study area. Approximately 9 cm displacement was determined in the vertical direction (Figure 3d).

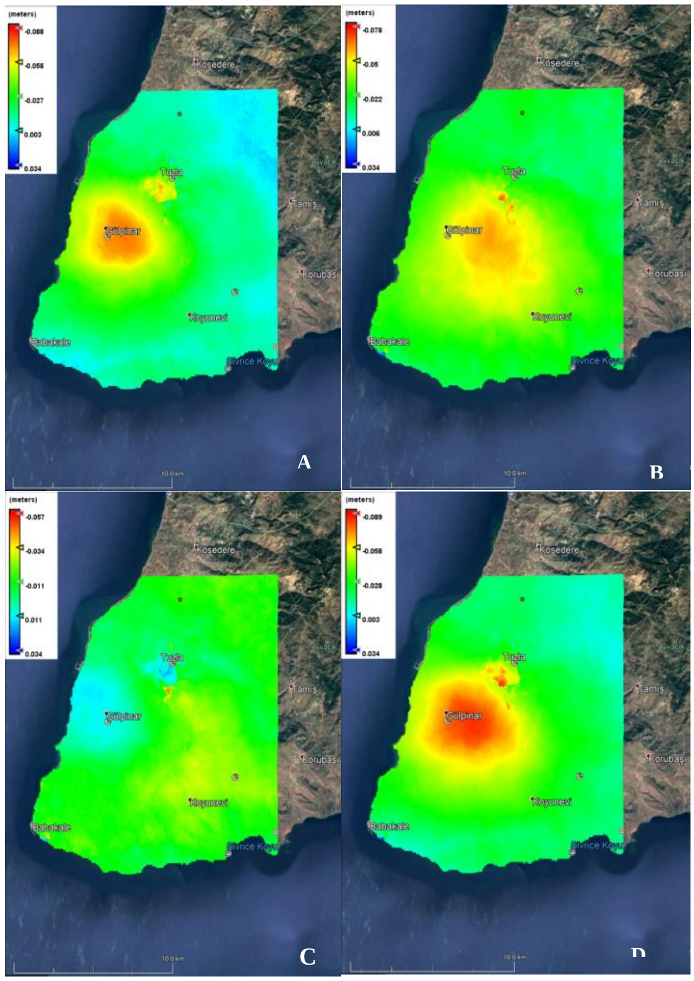


Figure 4. Sentinel-1 deformation results: a) ascending orbit, b) descending orbit, c) horizontal, d) vertical. (Background image is the Google Earth)

The continuity of the changes in the sea was determined by distributed seismicity and coulomb technique (https://pubs.usgs.gov/of/2011/1060/). The maximum changes in the Coulomb stress drop occur on the fault plane. Therefore, aftershocks are expected to occur on small faults around the main fracture forming the main slip plane where the main shock occurs. The distribution of aftershocks in the Ayvacik-Canakkale earthquake shows that the aftershocks occurred on small faults on the block moving in the direction of the slope of the Tuzla fault. In order to determine the stress change on the main fault Tuzla fault, the main stress values should be determined. The source parameters of the main fault plane of the Ayvacik-Canakkale earthquake are considered as follows; the strıke is 120°, the dip is 39° and the rake is -71° (Özden et al., 2018).

The vertical and horizontal displacement along the Tuzla fault were obtained and showed in Figure 4. The deformation occurred on the land with the Ayvacik-Canakkale earthquake continues at sea. It was determined that the deformation value was at the maximum level up to the coast and decreases from here. The deformation value in the horizontal direction is -4 cm (westward) and it is -8.3 cm in the vertical direction (Figure 4b, c).

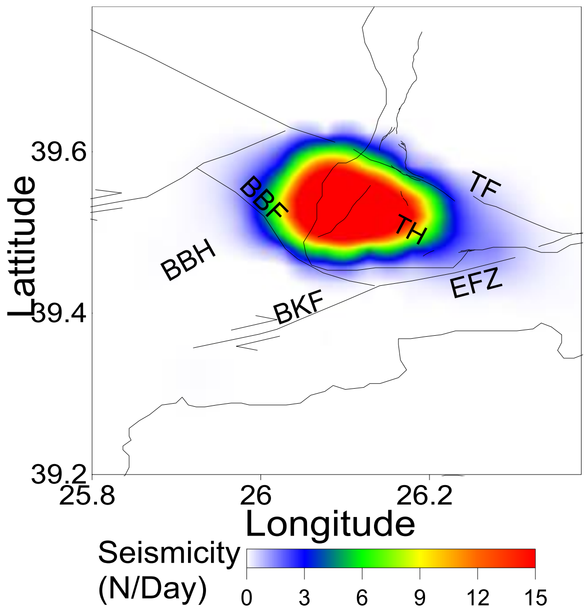
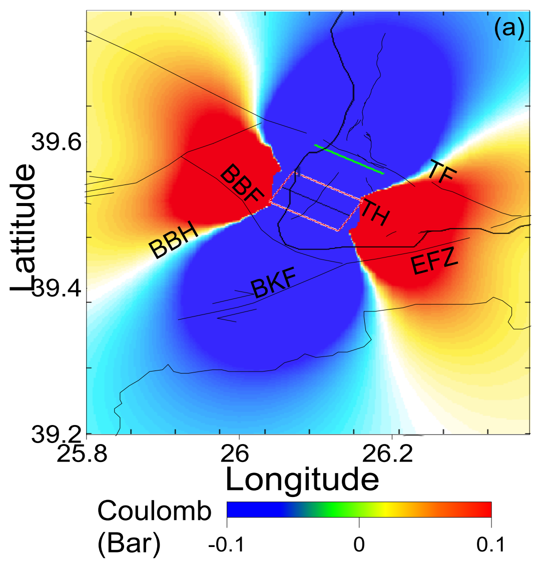


Figure 6. The seismicity in a day between February 06, 2017 and February 28, 2017 in the studying region. N denotes the number of earthquakes.



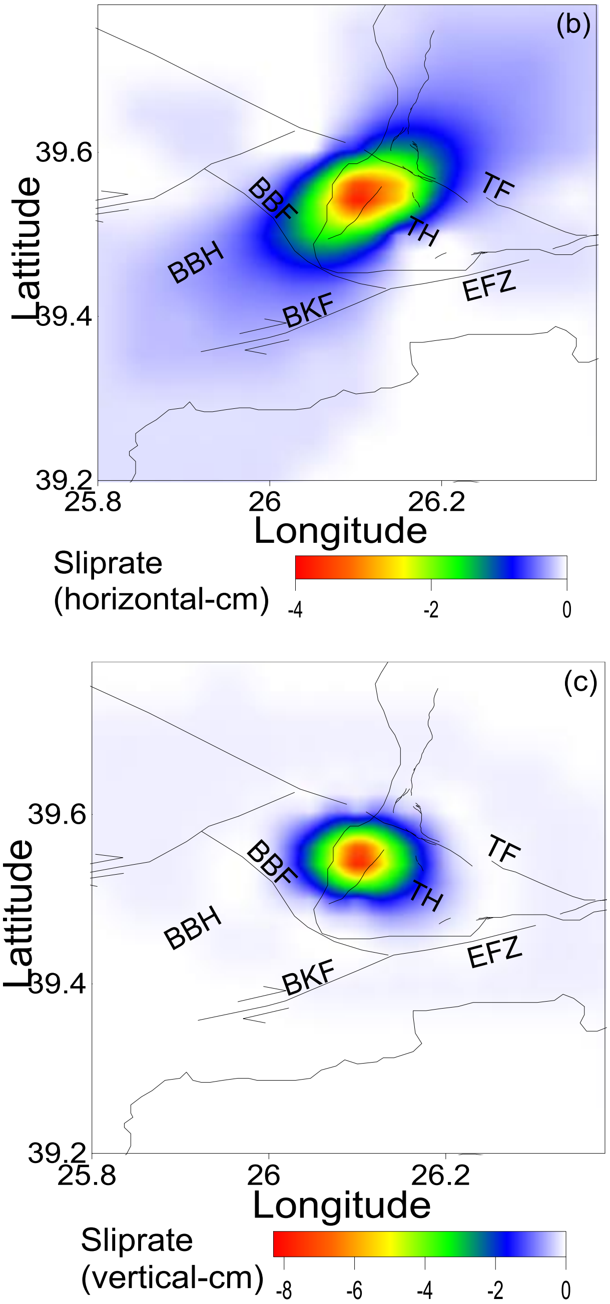


Figure 7. (a) Coulomb stress changes (Bar), (b) Horizontal sliprate (cm) and (c) Vertical sliprate (cm).

5. CONCLUSION

As a result of the study, the affected areas were determined over the study area. Approximately 9 cm displacement was determined in the vertical direction. The continuity of the changes in the sea determined by seismicity and coulomb technique. It was observed that the deformation determined on land continued in the sea depending on the Tuzla fault mechanism.

In the results, the displacements along the fault show irregular decreases. This situation shows that the faulting behavior is discrete and therefore faulting occurs by oblique mechanism. Even though the faulting of the focal mechanism solutions is found to be normal faulting with slope displacement, it is seen that it is oblique because of the right-handed throw.

The irregular and discrete position of the displacement supports the fact that the circular geometry in the interferogram is not the complete circle and the faulting is oblique, that is, direction component. If it is assumed that the possible secondary faults are very small, it will be difficult to estimate the displacements. For this reason, displacements at cm level are formed by vertical component (normal faulting) and direction components (strike-slip faulting).

It is seen that the deformation values obtained from DInSAR data and the deformation values obtained by Coulomb strain method are very close to each other and overlap in space. From this point of view, it is observed that deformation in the sea continues for 5-6 km from the coast in the area limited by Biga Fault.

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REFERENCES

Ding, X., Huang W., 2011. D-InSAR monitoring of crustal deformation in the eastern segment of the Altyn Tagh Fault. *International Journal of Remote Sensing*, 32, 7, 1797–1806.

Fialko Y., Sandwell D., Simons M., Rosen P., 2005. Three-dimensional deformation caused by the Bam, Iran, earthquake and the origin of shallow slip deficit, *Nature*, 435, 295-299.

Ganas, A.; Kourkouli, P.; Briole, P.; Moshou, A.; Elias, P.; Parcharidis, I. Coseismic Displacements from Moderate-Size Earthquakes Mapped by Sentinel-1 Differential Interferometry: The Case of February 2017 Gulpinar Earthquake Sequence (Biga Peninsula, Turkey). *Remote Sens.* 2018, *10*, 1089.

Hu Z., Ge L., Li X., 2013. An Underground-Mining Detection System Based on DInSAR, *IEEE Transactions on Geoscience and Remote Sensing*, 51, 1, 615-625.

Livaoğlu R., Timurağaoğlu M.Ö., Serhatoğlu C., Döven M.S., 2017. Damageduringthe 6–24 February 2017 Ayvacık (Çanakkale) earthquake swarm. *Nat. Hazards Earth Syst. Sci*., 18, 921–934.

Lu Z., 2007. InSAR Imaging of Volcanic Deformation over Cloud-prone Areas – Aleutian Islands, *Photogrammetric Engineering & Remote Sensing*, 73, 3, pp. 245–257.

Massonnet, D., Rossi, M., Carmona, C., Adragna, F., Peltzer, G., Feigl, K., Rabaute,T., 1993, The displacement field of the Landers earthquake mapped by radar interferometry.
Nature, 364, pp. 138–142.

Ozden S., Over S., Poyraz S.A., Gunes, Y., Pinar A., 2018. Tectonic implications of the 2017 Ayvacık (Çanakkale) earthquakes, Biga Peninsula, NW Turkey, Journal of Asian Earth Sciences 154, 125–141.

Roucoules D., Michele M., Aunay B., 2018. Landslide displacement mapping based on ALOS-2/PALSAR-2 data using image correlation techniques and SAR interferometry: application to the Hell-Bourg landslide (Salazie Circle, La Réunion Island). *Geocarto International*, doi: 10.1080/10106049.2018.1508311.

Sozbilir H., Sümer Ö., Uzel B., Softa M., Tepe Ç., Eski S., 2017a. 14 OCAK - 28 ŞUBAT 2017 Çanakkale - Ayvacık Depremleri Ve Bölgenin Depremselliği, Dokuz Eylül Üniversitesi Deprem Araştırma ve Uygulama Merkezi Diri Fay Araştırma Grubu Raporu (In Turkish).

Sozbilir, H., Uzel, B., Sumer, Ö., Eski, S., Softa, M., Tepe, Ç., Ozkaymak, C., Baba, A. 2017b. Çanakkale-Ayvacık Deprem Fırtınasının (14 Ocak-20 Mart 2017) Sismik Kaynakları, 4rd International Conference on Earthquake Engineering and Seismology (4ICEES) Oct 11-13 2017 – Anadolu University – Eskisehir/Turkey (In Turkish).

Wang C., Ding X., Li, Q., Shan X., Zhu, W., Guo, B., 2015. Coseismic and postseismic slip models of the 2011 Van earthquake, Turkey, from InSAR, offset-tracking, MAI, and GPS observations. *Journal of Geodynamics*, 91, 39–50.