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Biennial report for Permanent Supersite/Natural Laboratory

Marmara Region Supersite: May 2018 – April, 2020

Status	*Permanent Supersite*
Proposal documents and previous documents	*http://geo-gsnl.org/supersites/permanent-supersites/marmara-region-supersite/*
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1. Abstract

The probability of the occurrence of a large earthquake within the Marmara Region (Turkey) has been estimated to be around 44±18% for the next 30 years. GPS observations and block modeling of secular strain around the Marmara Sea suggest an internally consistent set of fault slip rates for the major branches of the westernmost North Anatolian Fault (NAF) that cross the region. The deformation pattern indicates that those branches that have generated M>7 earthquakes in the past, are accumulating strain and are the most likely branches to generate future earthquakes. The geodetic results are consistent with historical earthquake studies that report multiple M>7 events along the Princess Island segment (5-6 km southeast of the metropolitan city center of Istanbul) and the Ganos Fault (~60 km west of the Istanbul). All the significant seismic sources in the Marmara Sea have the potential to generate damaging levels of ground motion in Istanbul which hosts a rapidly growing population of >15 million making it the cultural, financial, and industrial heart of Turkey. Because of Istanbul's proximity to NAF's offshore segments, Marmara has been designated a "Permanent Supersite" by the CEOS under the GEO Geohazard and Natural Laboratories Initiative (GSNL) of 2014. This initiative let researchers that investigate the seismic hazard in the Marmara Region to be able to access SAR data sets thanks to the support of ASI/Italy, CNES/France, CSA/Canada, DLR/Germany, ESA/EU and JAXA/Japan, NASA and USGS. The Supersite provided significant results from its beginning like the discovery and analysis of new creeping zones and shallow/fully locked segments in the region. Another unique finding is the observation of the ongoing postseismic movements due to the 1999 earthquake sequence making it one of the longest in the World, which is a significant finding that improves our understanding of the earthquake cycle.

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One of the significant developments that occurred within this report period, were the September 2019 events that occurred in the Marmara Sea. The September 26th, 2019 Mw 5.7 event was the biggest seismic event to occur in the last 56 years (previous one being the Mw6.3 event in 1963) in the Marmara Sea and stirred the attention of all researchers. However it was not possible to study it with the Supersite datasets due to its offshore location, 10 km away from the coast of Istanbul.

Another important development during the report period was the availability of freely available, open-source software like the one developed by COMET group from the University of Leeds that can help scientists with producing interferograms and line-of-sight (LOS) time series and velocities. These will open a new phase for identifying long-term behavior of seismic sources and will definitely help with long-term hazard mitigation plans.

The ongoing seismic quiescence along the Ganos segment of the NAF that last ruptured in 1912 with a moment magnitude of 7.4, raises the possibility of an ongoing aseismic fault creep. Within this report period a new study on the Ganos Fault is initiated that focuses on the Sentinel 1 A/B datasets available via the Supersite archive.

Aside from Istanbul and Kocaeli, another key industrial city in the Supersite region is Bursa. The ongoing deformation in the city is investigated by using the Supersite data which revealed that the subsidence is not due to a tectonic origin but instead due to uncontrolled usage of groundwater around the Bursa plain.

2. Scientists/science teams

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Scientists/science teams issues

In the first period of this initiative, the core team was based solely upon the consortium of the EU funded MarSite project (2012-2016). The members of the core team organized the roadmap of this GSNL Supersite and signed agreements with the aforementioned space agencies. Then all results and in-situ datasets were shared with the science community to serve other disciplines. The attractive results of the multidisciplinary studies accelerated new SAR based studies with the contribution of individual researchers and international research groups. In the second period of the initiative (2016-2018), there were four main research groups that have been actively working with the available satellite data:

1) Istanbul Technical University, Turkey (ITU) group, led by Ziyadin Çakır
2) Boğaziçi University Kandilli Observatory and Earthquake Research Inst. group, Turkey, led by Semih Ergintav (Point of Contact-PoC)
3) GFZ group, Germany, led by Thomas Walter
4) University of Leeds group, UK, led by Tim Wright and Andy Hooper

SAR data archive includes the pre-, co- and post-earthquake times of 1999 earthquake sequences (17 August Mw 7.6 İzmit; 12 November Mw 7.2 Düzce) and it is one of the unique data sets that cover the different phases of the earthquake cycle, with the contribution of rich in-situ data sets. Several MSc and PhD students within these research groups had the opportunity to use the Supersite data and develop new methodologies to estimate the response of fault systems to M>7 earthquakes. The international partnerships of each group increases the visibility and dissemination of the available datasets and scientific results.

The need for proper communication, between individual researchers and international groups, has been realized during project meetings, as well as special sections in international meetings. Turkish groups collaborate very well and are doing their best to create a center of excellence for the region. Other groups, generally, cooperate with Turkish researchers to investigate the tectonic problems of the region (e.g. GFZ group).

Following the example of the COMET-LiCS Sentinel-1 InSAR portal (https://comet.nerc.ac.uk/COMET-LiCS-portal/), we have started gathering feedback from unexperienced users (e.g. users from other disciplines and municipalities) about the potential use of a similar platform dedicated to the Marmara region. For example, civil engineers wish to use the correlation maps in rapid hazard assessment studies. We assume that, this will accelerate many SAR related studies in the near future and could initiate multidisciplinary studies.

Compared to the previous report period, the contributions from Turkish earth scientists are growing. Attention to SAR data has increased due to the January 24th, 2020, Mw 6.8 Sivrice-Elazığ (eastern Turkey) earthquake due to the lack of a surface rupture. As PoC, I advise them to focus on detecting local anomalies due to geological and tectonic problems. Hence, I also demonstrate them the rich X-band archive of Marmara region Supersite. However rapid SAR analysis requires important computational resources: we are searching for extra funds to increase capabilities of local clusters.

Marmara is under an important natural threat and the continuous monitoring allow the testing of new algorithms and interpretation to reduce potential hazards. Obviously, this scientific and social merits of the Marmara Region Supersite, with the momentum of open data sets, attract scientists to study in the region.

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3. In situ data

Type of data	Data provider	How to access	Type of access*
National GPS (30s,raw data) network data	*General Directorate of Land Registry & General Command of Mapping*	*http://rinex.tusaga-aktif.gov.tr*	*Public*
National GPS (1s,raw data) network data	*General Directorate of Land Registry & General Command of Mapping*	*https://www.tusaga-aktif.gov.tr/Web/DepremListe.html*	*Public*
Local GPS networks &daily solutions of national GPS network	*KOERI*	*MarSite ftp server*	*Public*
Geology	*KOERI*	*MarSite ftp server*	*Public*
Geochemistry	*KOERI*	*MarSite ftp server*	*Public*
Meteo	*KOERI*	*MarSite ftp server*	*Public*
Tide Gauge	*KOERI*	*Data Specific Service*	*Public*
	General Command of Mapping	*http://tudes.hgk.msb.gov.tr/tudesportal/*	*Public for Turkish Science Community*
Strainmeter	*UNAVCO*	*UNAVCO*	*public*
National Seismic network (Broadband, Accelerometer, OBS, borehole)	*KOERI*	*eida.koeri.boun.edu.tr*	*public*
Multinational/Local Seismic networks	*KOERI*	*eida.koeri.boun.edu.tr*	*Public*

- *without any registration through the EPOS portal, once the necessary authorization has been granted by the data provider*

In situ data issues

National level seismic monitoring institutions have opened the critical data sets to public without a registration mechanism. However, the national GPS network has a registration interface. Registration stage is very simple but was only open to the Turkish scientific community, until recently. However, if there is an earthquake, 1 Hz data will be opened to scientific community

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without any limitation. MarSite FTP server had been established under the EU supported MarSite project. MarSite database (DB) includes the data sets of more than 200 geophysical and geochemical stations, which were installed to monitor the critical branches of the North Anatolian Fault Zone in the Marmara Region. This DB is revised later in the EU supported EPOS-IP (Earth Plate Observation System-Implementation Phase) project as part of NFOs (Near Field Observation networks). This will be opened to the public without any registration mechanism, using standard services and metadata formats. However, to assure traceability, authorization will be required.

For some kind of specific data (e.g. tide gauge) users will be directed to the data supplier's web page, which have the necessary information in order to obtain the data.

The open access data policy requested for European Union funded projects is modulated in the special case of civil security issues such as Marmara supersite for the priority of early warning and real time response. In case of a crisis, data access has to be delayed for actors outside the decision-making process.

4.   Satellite data

Type of data	Data provider	How to access	Type of access
ERS-1/ERS-2	*ESA*	*http://eo-virtual-archive4.esa.int*	*registered public*
ENVISAT	*ESA*	*http://eo-virtual-archive4.esa.int*	*registered public*
Pleiades	*CNES*	*https://spacedata.copernicus.eu/web/cscda/missions/pleiades*	*GSNL scientists*
TerraSAR-X	*DLR*	*PoC requests access from DLR for individual users, data then accessible via DLR web page*	*GSNL scientists*
Cosmo-SkyMed	*ASI*	*PoC requests access from ASI for individual user, data then made accessible for the specific user by POC*	*GSNL scientists*
SENTINEL-1A/B	*ESA*	*https://scihub.esa.int/*	*registered public*
ALOS-1/2	*JAXA*	*https:auig2.jax.jp/ips/home*	*Successful proposers*
ASTER, EO-1, MODIS	*NASA*	*https://lpdaac.usgs.gov/data_access/data_pool*	*Public*
Landsat-8	*USGS*	*https://landsat.usgs.gov/landsat-8*	*public*
NPP/Suomi	*NOAA*	*https://ncc.nesdis.noaa.gov/VIIRS/*	*public*

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Number of [available/processed*] images						
Sensors	ERS-1	ERS-2	ENVISAT	CSK**	TSX***	SENTINEL
Years						
1991	-	-	-	-	-	-
1992	9/9	-	-	-	-	-
1993	23/23	-	-	-	-	-
1994		-	-	-	-	-
1995	15/15	25/25	-	-	-	-
1996	7/7	15/15	-	-	-	-
1997	-	6/6	-	-	-	-
1998	-	6/6	-	-	-	-
1999	15/15	111/111	-	-	-	-
2000	-	115/115	-	-	-	-
2001	-	146/146	-	-	-	-
2002	-	21/21	28/28	-	-	-
2003	-	18/18	123/123	-	-	-
2004	-	11/11	298/298	-	-	-
2005	-	14/14	241/241	-	-	-
2006	-	21/21	118/118	-	-	-
2007	-	18/18	123/123	-	-	-
2008	-	20/20	122/122	-	-	-
2009	-	10/10	169/169	-	-	-
2010	-	-	92/92	-	-	-
2011	-	18	11/11	24	4/4	-
2012	-	-	-	33	26/26	-
2013	-	-	-	102	42/42	-
2014	-	-	-	51	94/26	142/142
2015	-	-	-	69/30	143/8	401/401
2016	-	-	-	66/30	149/45	740/500
2017	-	-	-	42/20	110/45	1171 /640
2018	-	-	-	139/80	6***	5481/940
2019				137/80	5***	5138/1020

* Estimated from papers and on-going projects

**Data collected from GEP portal.
*** We have experienced continuity problems in ordering due to local problems and limited manpower.
These were resolved and regular orders commenced after 2019.

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Satellite data issues

Researchers using the Marmara Region Supersite, generally focus on the long-term behavior of the fault systems that have been loaded by the past earthquakes to understand the long-term strain accumulation. ERS and Envisat data archives are therefore very important as they extend the time window for deformation monitoring studies. Besides, Sentinel-1 A/B data are very attractive due to the frequency of the sampling and consistency with other data sets.

Handling and use of satellite data have been in agreement with guidelines provided by each space agency.

To control the critical fault segments, our strategy was to order the data from a fixed ROI without any interruption in time. For example, Cosmo-SkyMed (CSK) data are ordered from the beginning of this supersite to end of 2020, along Ganos, and İstanbul (including the İzmit Bay). After the end of 2020, we may order data from new critical zones, identified in new studies.

For TSX data, we started to use the above strategy and ordered data from a specific profile along the eastern part of 1999 Izmit earthquake (Mw 7.6) rupture zone.

Similar to the previous report, since available workflows favor Sentinel 1 A/B data researchers tend to use this dataset more often. Few new researchers started on working on the available CSK and TSX data, but no results are published during this report period. One of these studies that utilize the X-band data in the Marmara Region is mentioned in the next section.

ALOS-2 data sets are ordered and archived using the PoC's project which was accepted by JAXA in 2017. Usage of the data is governed by similar rules like ASI and DLR.

The Pleiades data could be useful such as to extract high resolution DEM sets for improving the quality of SAR data. Until now, with the support of GEO GSNL Coordinator, discussions were initiated for very limited zones and we are still waiting for the final decision. Usage of Pleiades will be very important during a destructive earthquake and can be useful for the mapping of the detailed morphological features and seismic hazard in the . We hope that we can create a high-resolution DEM for the Marmara in a short time.

Marmara region Supersite, also, opens a gate for the scientific community to reach out to the space agencies in a short time frame: for example after the devastating Mw 6.8 event in Elazığ eastern Turkey) on January 24th, 2020, new Pleiades data was collected within hours upon our request. We would like thank the GEO GNSL Coordinator Stefano Salvi for his efforts

Managing the orders of the satellite data sets and downloading and archiving of them requires a significant amount of time due to the lack of APIs or command line utilities. Even with the

contribution of graduate students that work within the research groups we are continuing to have issues or continuity problems during ordering and downloading.

5. Research results

The largest seismic event in the Marmara region (Figure 1) during the report period had a magnitude of 5.7. This was the biggest to occur in the Marmara Sea since the Mw 6.3 event in 1963. Around 300 of the reported 3133 buildings are assessed as heavily damaged whereas various levels of damage are reported at several public buildings like schools and hospitals. The September 26th 2019 event that took place in the northern shelf of the Marmara Sea occurred 10 km away from the coast and was preceded by a Mw 4.9 event two days earlier on September 24th (Karabulut et. al, 2019). However preliminary InSAR results didn't provide a meaningful deformation signal, whereas a small amount of vertical deformation (< 1cm) could be observed at nearby GPS stations (Ergintav et al., 2020). Therefore, the Supersite users continued to focus on the study of deformations due to the interseismic movement of the North Anatolian Fault and local non-tectonic cases of subsidence observed in and around the mega-city of Istanbul.

In the following part, we have listed a few examples in order to show the improvements on understanding of the deformation characteristics in the Marmara region, that emphasize the contribution of open SAR data sets of the Supersite.
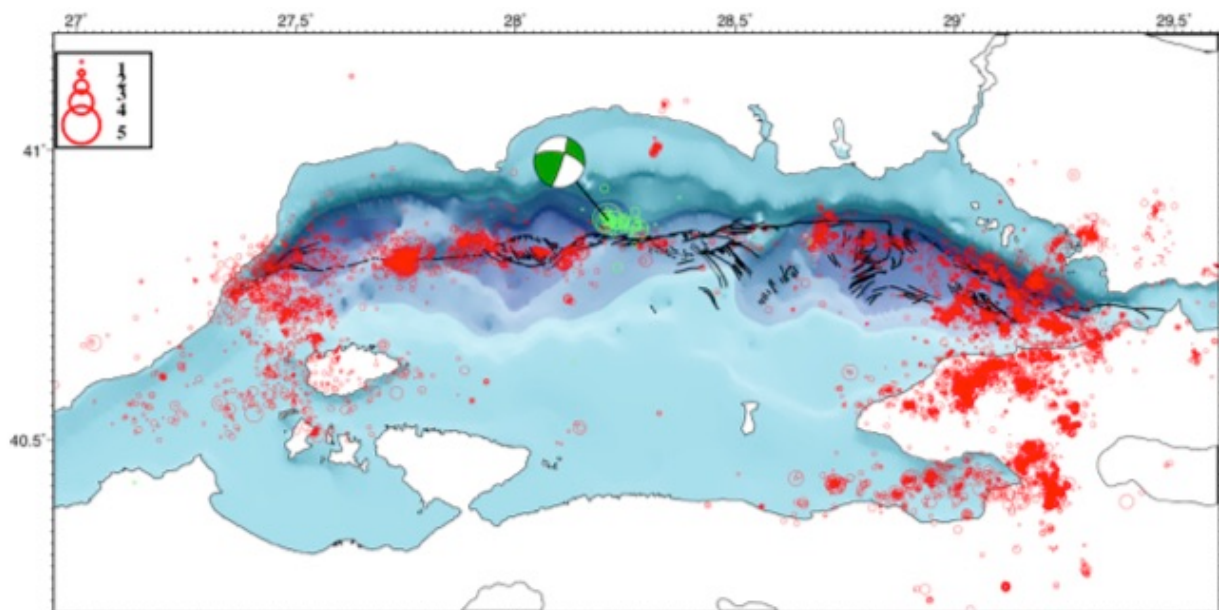
Figure 1. Map view of the seismicity in the Marmara Region during the period 2007–2015. Focal mechanism solution of the Mw5.7, 2019 Silivri earthquake (green beach ball) with aftershock seismicity (green circles) is also shown. Black lines show the active faults under the Marmara Sea (Simplified from Karabulut et al, 2019).

a) Demonstration of an automated workflows of SAR data: Anatolia (Weiss et al., 2020)

University of Leeds's COMET team developed an open-source package in Python (Morishita et al., 2020) that aim to make it easier for earth scientists to produce interferograms and line-of-sight (LOS) time series and velocities. We believe that similar availability of freely available software tools like MintPy[1] will open a new phase of research using SAR data.

The Leeds group also created an open web-based database to share their outputs (https://comet.nerc.ac.uk/COMET-LiCS-portal/). Figure 2 shows the estimated surface velocities calculated using this tool and the database (Weiss et al., 2020). Obviously, the production of the whole velocity of the Anatolian block (including the Marmara region) requires large computational resources but now anyone can study a specific region similar to a GPS velocity field in detail (the resolution is 250 m).

The group updates their database after every acquisition of Sentinel-1 A/B (every 6-days for Anatolia) and provides outputs like the coherence image of the interferometric pairs, the wrapped phase image in radians, the unwrapped phase image in radians and displacement time series and surface velocities.

This mechanism is different than of Geohazard-TEP (GEP, https://geohazards-tep.eu). The GEP, a public InSAR Browse service run by DLR, Terradue and ESA, processes data over predefined areas of interest, defined by registered users due to limited computational resources. In contrast, COMET_LİCS database provides all possible SAR products without any limitation. This opportunity may attract unexperienced researchers and an increase in SAR applications can be expected in the near future.

The database has a coarser resolution but nevertheless will be useful to identify the local anomalies in space and time. These zones can later be studied with X-band data or higher-resolution products of Sentinel 1 A/B that are available through the Supersite.

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[1] Yunjun, Z., H. Fattahi, F. Amelung (2019), Small baseline InSAR time series analysis: Unwrapping error correction and noise reduction, Computers & Geosciences, 133, 104331, doi:10.1016/j.cageo.2019.104331.
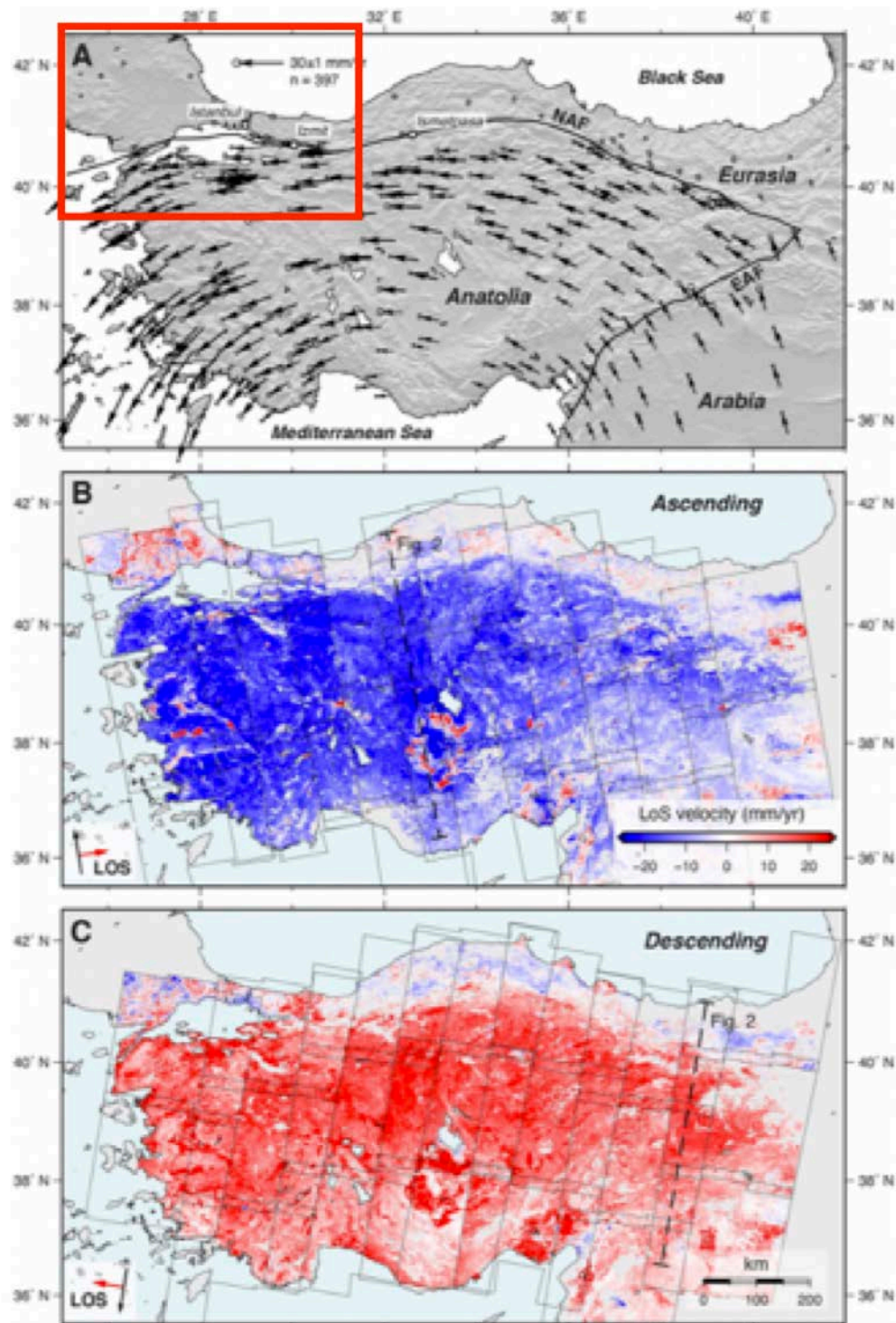
Figure 2. Tectonic setting of Anatolia and interseismic surface velocities in a Eurasia-fixed reference frame. (A) GNSS velocity vectors from England et al. [2016] and Nocquet [2012], illuminating the counter clockwise rotation of Anatolia and Arabia relative to Eurasia. Black lines indicate the main strands of the North Anatolian Fault (NAF) and East Anatolian Fault (EAF). (B) Ascending and (C) descending track Sentinel-1 line-of-sight (LOS) velocities with LiCSAR frame boundaries. Negative (blue) and positive (red) values indicate relative motion towards and away from the satellite, respectively. Colour scale is the same in (B) and (C). This figure copied from Weiss et al. (2029) without any modification. Red square in (A) shows the border of Marmara Region Supersite.

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b) Ganos Fault Zone (western part of the Marmara Region) (Akoğlu et al., 2019)

The segmentation and the possibility of creep along the onshore segments of western extension of the Main Marmara Fault, which last ruptured in 1912 generating a Mw 7.3 earthquake, is yet to be understood. As we discussed in the previous report, Supersite researchers had tried to characterize this section using L-band ALOS 1/2 data sets. During this report period, the ITU and Kandilli groups started working on the available Sentinel 1 and Cosmo-SkyMed datasets which both record the movement of the fault starting from 2015. Initial results using the Sentinel-1 data are presented at the 2019 European Geosciences Union (EGU) meeting.
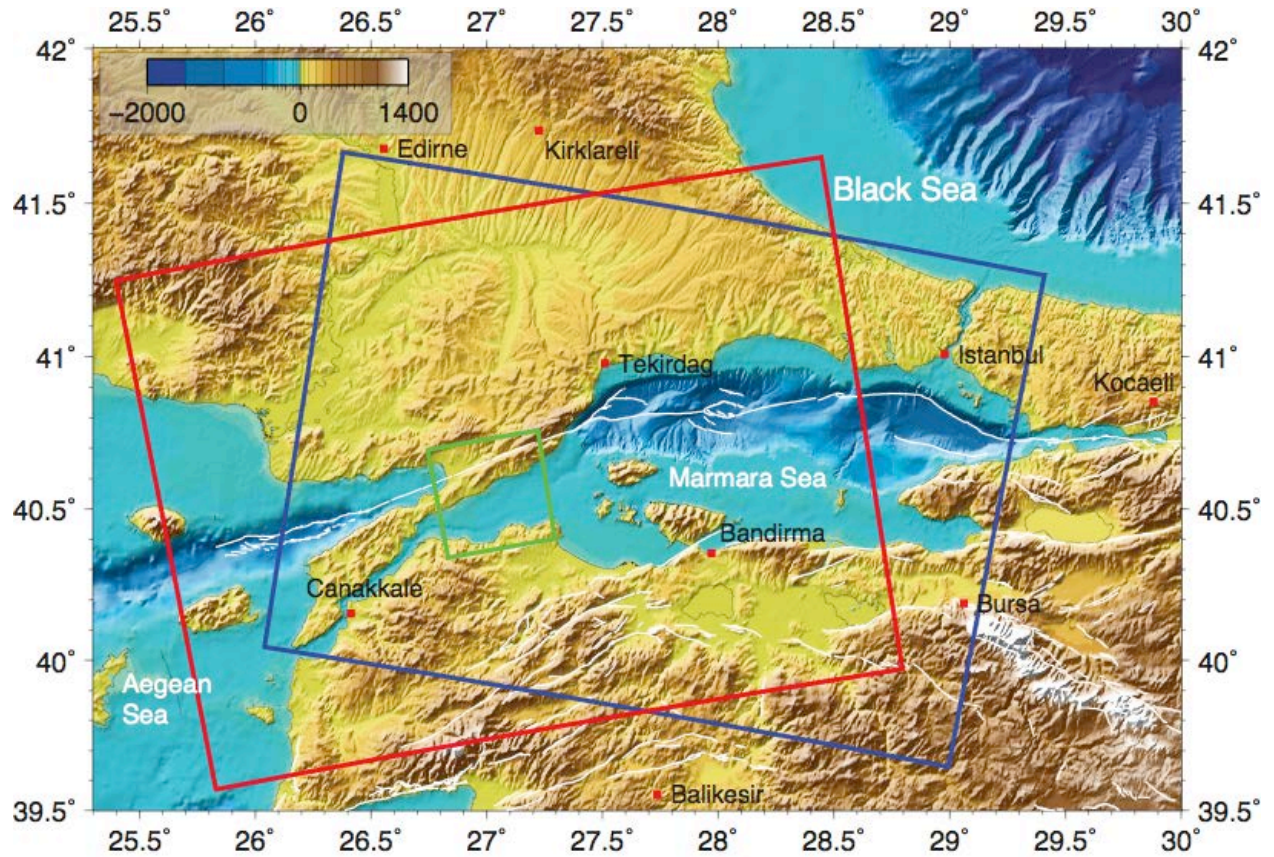
Figure 3. Study area in western part of Marmara. The westernmost segments of the North Anatolian Fault are shown with white lines (from Emre et al.,2013). The red and blue frames represent ascending (T131) and descending (T36) tracks of Sentinel-1 A/B radar satellites.
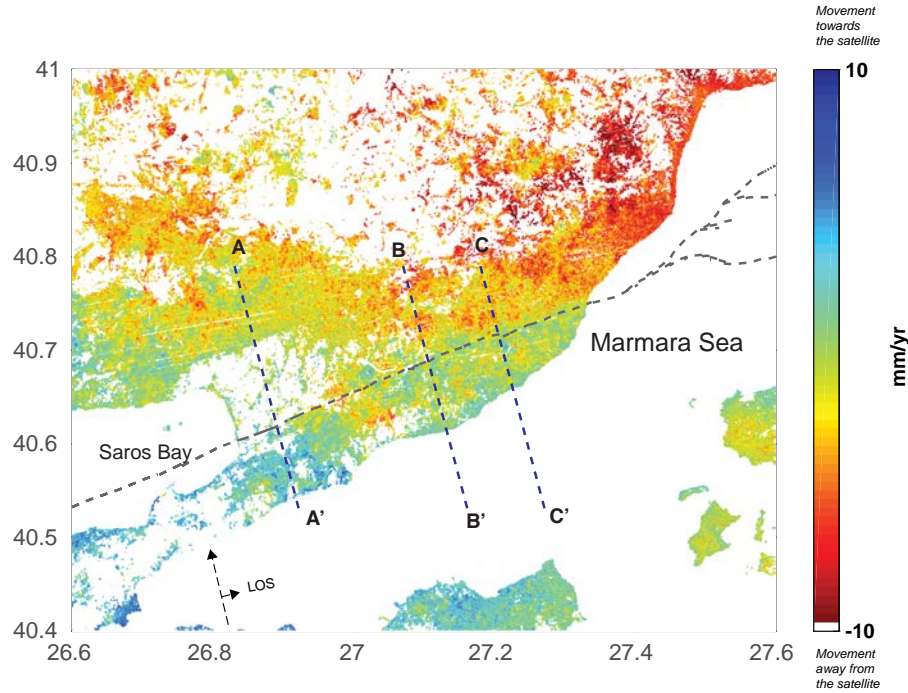
Figure 4. PS mean velocity map of Sentinel-1 data from the ascending orbit of T131 between October 2014 and February 2018. Warm colours represent movement away from the satellite, cold colours represent the movement towards the satellite. PSI methods implemented in StaMPS (Stanford Method for Persistent Scatterers; Hooper, 2008) are used in this study for the time-series analysis of SAR data. Sentinel interferograms are processed with GMTSAR (Sandwell et al., 2011).
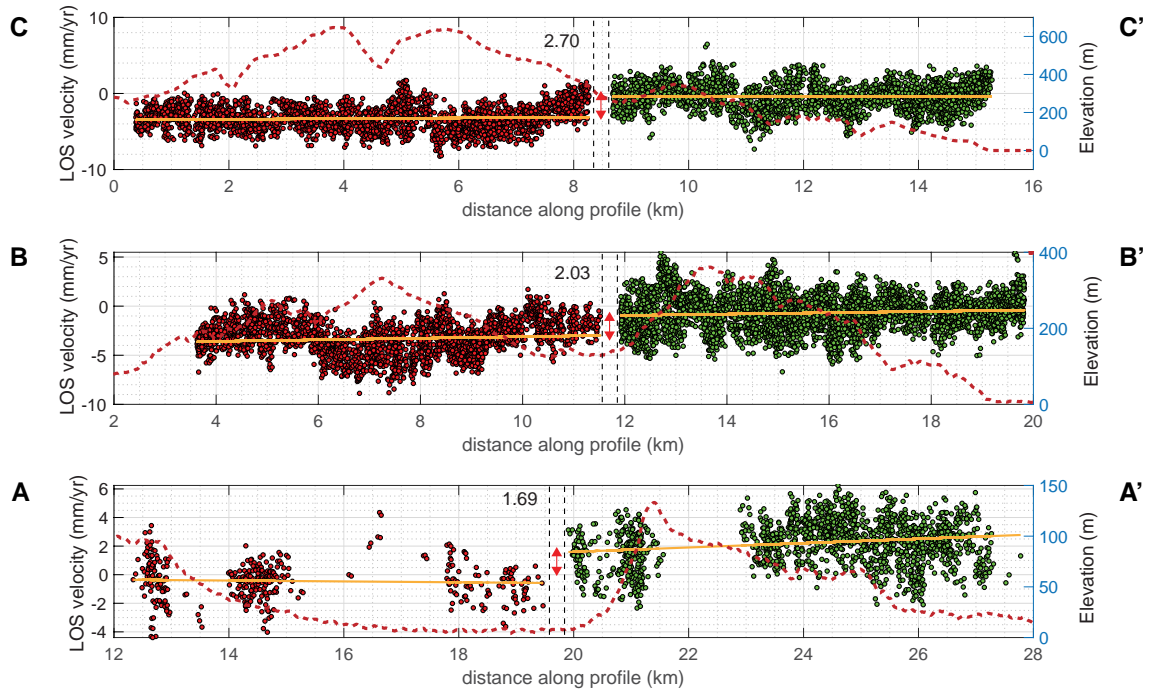

Figure 5. Cross-sections across the Ganos Section of the NAF showing the PS mean velocities from the Sentinel-1 ascending track T131 (Fig. 3). The creep rate is quantified as the offset of the y-intercepts of the two linear functions (orange lines) that are fitted to select windows (8 km) of data on either side of the fault zone. A buffer zone of 200m is used to represent the fault zone. The topography is shown with red dashed lines.

As can be seen in Figures 4 and 5, there is a clear contrast across the fault zone in the ascending Sentinel-1 dataset owing to the fact that it's look angle is almost parallel to the fault. Obviously, profiles show hints of possible fault creep near Kavakköy, Gölcük, Yörgüç and Mursallı but all below 3 mm/yr (in LOS). Work on the processing of T36 (descending) frame is still ongoing. This result matches earlier L-band results and support the evidence of the creeping zone with a low creep rate (de Michele et al. 2017; Havazli et al., 2017). As we discussed in the previous report, the source of the creep can be tectonic or the unconsolidated soil within the fault zone. Hence, time series analysis is required to characterize the behavior of creep. If deformation is not oscillating in time, creep can be accepted as having a tectonic origin. In this case, hazard estimation studies should be improved due to the aseismic behavior of the Ganos fault.

c) Subsidence in the Bursa Plain, Turkey (Aslan et al., 2019)

The industry in Turkey is mostly developed in the Marmara Region: apart from İstanbul and Kocaeli, Bursa is one of the key industrial cities of Turkey, especially known for its role in the automotive industry. It is now the 4th populous city in the country with a population of > 3 million people.

Aslan et al. (2019) characterized and monitored the subsidence of the Bursa Plain (Figure 6), which had been previously interpreted as tectonic motions in the region. They quantified the subsidence using Interferometric Synthetic Aperture Radar (InSAR) time-series analysis. The Stanford Method for Persistent Scatterers InSAR package (StaMPS) is employed to process series of Sentinel 1 A-B radar images acquired between 2014 and 2017 along both ascending and descending orbits (Figure 6). They obtained the vertical velocity field after decomposition of line-of-sight velocity fields on the two tracks that revealed that the Bursa plain is subsiding at rates up to 25 mm/yr (Figure 7). They showed that the most prominent subsidence signal in the basin forms an east-west elongated ellipse of deformation in the east, and is bounded by a Quaternary alluvial plain undergoing an average vertical subsidence of ~10 mm/yr (Figure 8). They marked that another localized subsidence signal is located 5 km north of the city, following the Bursa alluvial fan, and is subsiding at velocities up to 25 mm/yr (Figure 9). The comparison between temporal variations of the subsiding surface displacements and variations of the water pressure head in the aquifer allows estimation of the compressibility of the aquifer, α. They estimated that it falls in the range of 0.5×10^{-6} – 2×10^{-6} Pa^{-1}, which corresponds to typical values for clay and sand sediments.
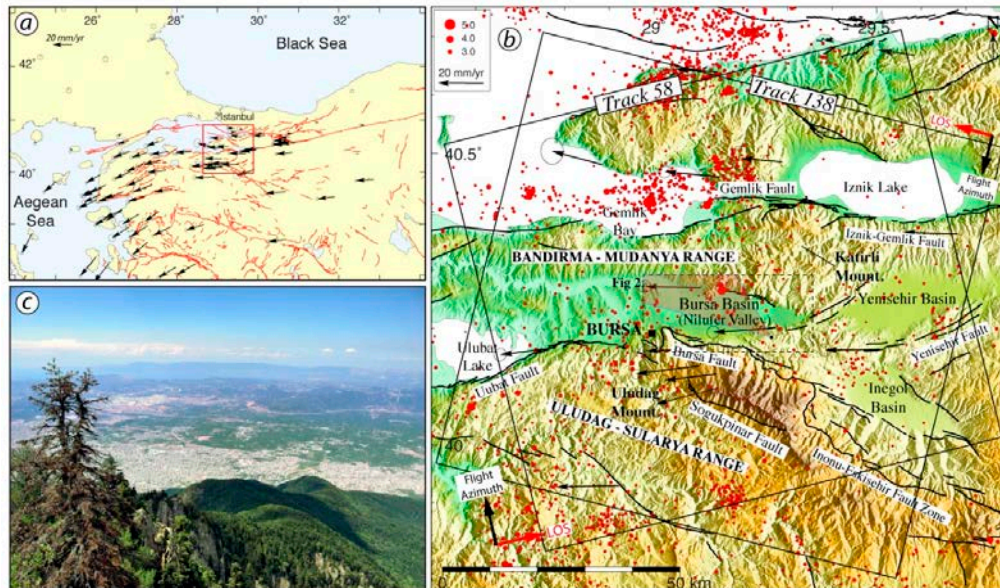
Figure 6. Study area and Sentinel 1 SAR data converge used in Aslan et al. (2019)'s study. (a) Map of northwestern Turkey with active fault zones (red lines) and GSP vectors w.r.t Eurasia. The plain red box highlights the study area. (b) Rectangles with track numbers indicate the coverage of SAR data on SRTM data. Blacklines Show active fault zone (Emre et al., 2013). Red and black arrows at the bottom left indicate the satellite's line-of-sight look and look and flight directions, respectively. Red dots depict the seismicity of the region since 2005.
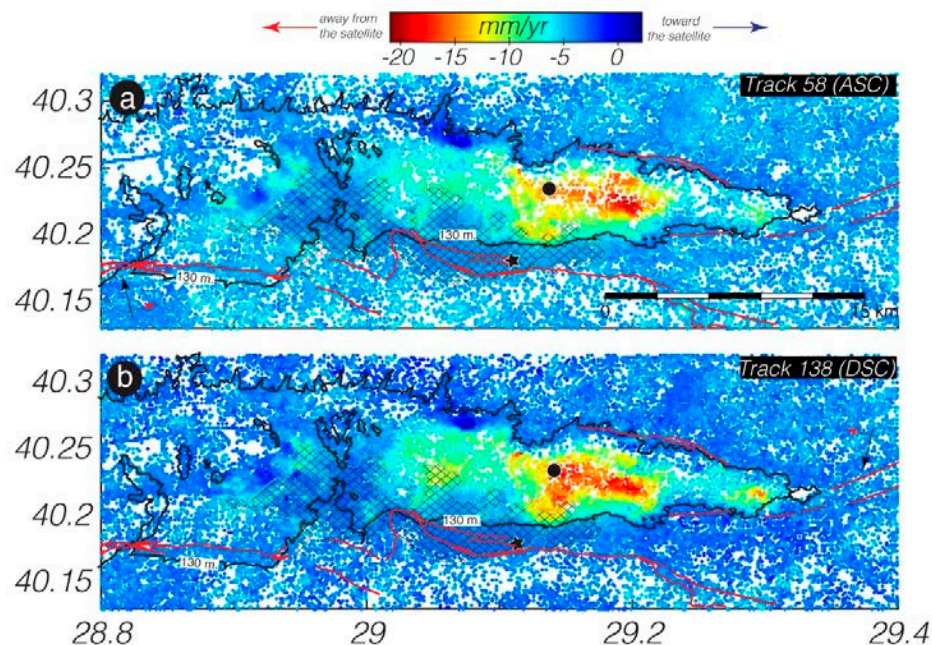

Figure 7. Line-of-sight (LOS) velocity maps from Sentinel 1A/B time-series analysis for the time period of 2014-2017 (Aslan et al. 2019). Positive velocities (cold colors) represent stable areas and displacement of the ground of 2014-2017. Positive velocities (cold colors) represent stable areas and displacement of the ground toward the satellite while negative velocities (warm colors) indicate displacement away from the toward the satellite while negative velocities (warm colors) indicate displacement away from the satellite. Average line--of--sight velocity (**a**) on ascending track 58;; and (**b**) on descending track 138.. Elevation contours at 130 m around the subsiding Bursa Plain are shown in black solid lines. Shaded area shows the location of the city. Major active faults are drawn in red (Emre et al., 2013)
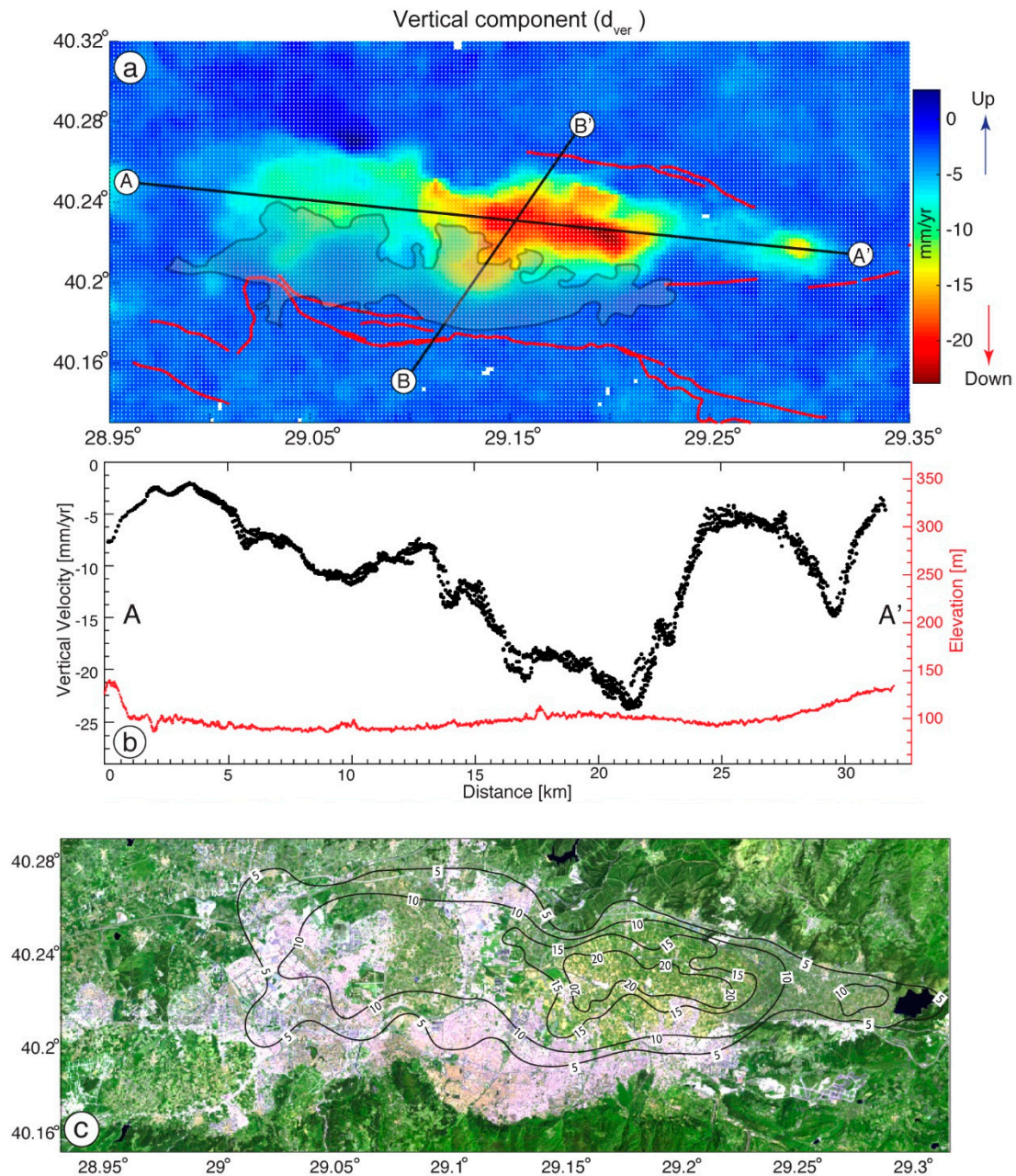
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Figure 8. Decomposition of LOS velocities into vertical component for Sentinel-1 data during the time period of 2014–2017 (from Aslan et al., 2019). (**a**) Vertical mean velocity map. The warm colors represent the land subsidence relative to the reference area. The shaded area shows the Bursa city. AA' profile is shown in (**b**), BB'profile in Figure 9. (**b**) East-west AA' profile showing vertical displacement rates in black altitude in red. (**c**) 5 mm/yr interval contour maps superimposed onto Landsat 8 image of 23 April 2018, in RGB combination of bands 7, band 6, and 4. Agriculture areas appear in shades of light green and yellow during the growth season and are located where the subsidence is the highest. Urban areas are in white, gray, or light purple colors
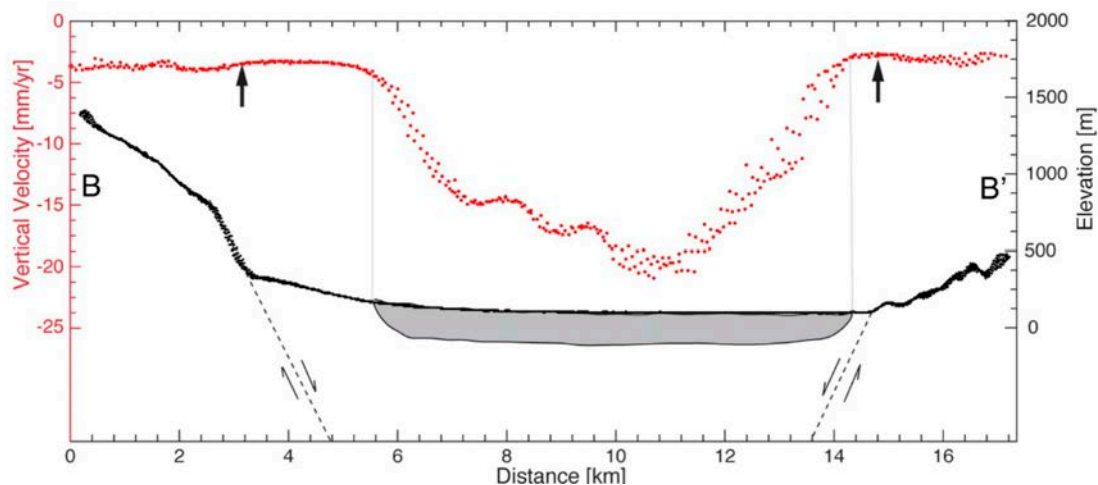
Figure 9. Cross section showing vertical deformation rates in red and altitude in taken from b-b' profile shown in Figure 8a

All these observations indicate that the subsidence in Bursa plain is due to excessive groundwater extraction, not tectonic motions. This study demonstrates the capability of InSAR time series, combined with geological and hydrogeological data, to detect and monitor subsidence and identify potential control factors in the Bursa Province. Further work, complementary to InSAR, would be required to better monitor and assess the hazard related to land subsidence, using continuous GPS time-series in combination with in-situ measurements, including piezometric and geophysical data, such as borehole extensometers. In order to predict the future development of the land subsidence along the basin and differentiate the tectonic and anthropogenic contribution to the subsidence signal, further research should be performed to investigate elastic and hydraulic characteristics of the aquifer system. Because the entire Bursa basin is affected by land subsidence, and elaborate and orderly use of land is necessary to secure the infrastructures of the urban areas.

Publications

Peer reviewed journal articles
Aslan, G., Lasserre, C., Cakir, Z., Ergintav, S., Özarpaci, S., Dogan, U., et al. (2019). Shallow creep along the 1999 Izmit earthquake rupture (Turkey) from GPS and high temporal resolution interferometric synthetic aperture radar data (2011–2017). Journal of Geophysical Research: Solid Earth, 124, 2218– 2236. https://doi.org/10.1029/2018JB017022   Aslan, G., Cakir, Z., Lasserre, C., and Renard, F. Investigating Subsidence in the Bursa Plain, Turkey, Using Ascending and Descending Sentinel-1 Satellite Data. Remote Sensing, 11(1):85, 2019.

Karabulut, H., Güvercin S. E., Eskiköy, F., Kocan, A.Ö., Ergintav, S., (2020). The Moderate Size September 2019 Mw 5.8 Silivri Earthquake Unveils the Complexity of the Main Marmara Fault Shear Zone, accepted by GJI.

Weiss, J., Walter R., Morishita, Y., Wright, T. Lazecky, M., Wang, H., Hussain, E., Hooper, A.J., Elliot, J.R., Rollins, C., Yu, C., Gonzales, P.J., Spaans, K., Li, Z, Parsons, B. (2020). High-resolution surface velocities and strain for Anatolia from Sentinel-1 InSAR and GNSS data, submitted to Geophysical Research Letters, doi:10.31223/osf.io/8xa7j.

Conference presentations/proceedings

Akoğlu, A., Çakır, Z., Ergintav, S.(2019) Questioning the Possibility of Aseismic Movement along the Ganos Section of the North Anatolian Fault with InSAR, EGU General Assembly, Vienna, Austria.

Ergintav, S., Doğan, U., çakır, Z., Walter, T., Diao, F., Wang, R: Özarpacı, S., Karabulut, H., Konca, Ö., Floyd, M., King, R:, Reilinger, R., Slip Variability along Main Marmara Fault, EGU General Assembly, Vienna, Austria

Ergintav, S., Özdemir, A., Erkoç, H., Ayruk, E. T., Doğan, U., Karabulut, H., Kocan, A.Ö, Walter T., Vasyura-Bathke, H., (2020). Analysis of the complexity of the Mw 5.8, 26 September 2019 Silivri Eq. in the Sea of Marmara, Turkey, constrained from geodetic datasets, EGU General Assembly, Vienna, Austria

Gokhan A., Lasserre, C., Çakır, Z., Ergintav, S., Özarpacı, S., Doğan, U., Bilham, . Renard, F., (2019). Characterizing interseismic aseismic slip along the 1999 Izmit earthquake rupture (Turkey) from GPS, InSAR and creepmeter measurements, EGU General Assembly, Vienna, Austria.

NOTE: *The list of the papers and presentations above are prepared after a formal internet search. The PoC is not aware of others studies which use the ESA data sets: these are being downloaded from UNAVCO or ESA and unfortunately researchers do not acknowledge the Marmara Region Permanent Supersite in their papers.*

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Research products

Type of product	Product provider	How to access	Type of access
Ground deformation maps, time series, interferograms	Authors *of the publications (see list above)*	*…web address of the journals and the web sites of the researchers*	*public, registered*

Research product issues

The main research product of the supersites are the scientific publications (see list above). Normally, in academic communities where publishing is emphasized, there is little reward for making research products accessible.

As of 2020 there are no common formats for the sharing of InSAR products. In EPOS, one of the main targets is to define standard formats to share the results. This can solve large parts of the problem. Others are related with funding. Until common format and manpower issues get addressed, interested users have to communicate directly with the authors of the studies, in order to use the outputs in their studies.

We closely follow the efforts of Stefano Salvi (Chair of SAC) on the Supersite specific website organization. We are sure that it will be an important platform to share the data sets and the outputs in the future.

6. Dissemination and outreach

As it's the nature of all hazard related studies, we inform decision-makers at every appropriate opportunity. Within the Marmara Region Supersite, end users are defined as:

- The Istanbul Metropolitan Municipality (IBB)
- Disaster and Emergency Management Authority of Turkey (AFAD)

During the report period we had the opportunity to present the benefits of time-series SAR data to the newly elected officials of the IBB. We believe that, within the municipality, the visibility and usage of SAR data will increase in the next report period. The importance of SAR data and the supersite is also emphasized during a special two-day Marmara earthquake workshop organized by IBB in December 2019.

The 23rd meeting of the Turkish Active Tectonics Research Group (ATAG) was also held in Istanbul to commemorate the 20th anniversary of the 1999 İzmit-Düzce earthquakes. The meeting hosted by the ITU research group led by Ziyadin Çakır provided an important opportunity to disseminate the outputs of SAR related studies in Turkey and neighboring countries with the government officials and the public. The meeting and presented studies are widely circulated in the news media.

As expected the Marmara earthquake is an important matter of debate for the Turkish public. Turkish scientists are doing their best to keep the public informed by summarizing the results of recent studies that use the supersite data via highly watched TV news programs and also newspaper articles.

In 2019 our colleagues started an initiative to share early SAR analysis of M>5 events in Turkey using the Twitter account of the Turkish Active Tectonics Research Group (@aktiftektonik), which we hope will also increase the visibility of the Supersite among the researchers and the public.

7.   Funding

As mentioned above, in the beginning of this initiative researchers were supported under the MARSite project which was funded by the European Commission's FP7 program. After the end of MARSite (April, 2017), the associated funding required some reorganization of the personnel working with the satellite data provided by CEOS, as well is in other research activities. The core team, post-docs and PhD students working on the data sets are mostly funded by national and international fellowship mechanisms & projects.

DISCREATE (Discovery of Creeping Zones: towards to the realistic hazard map for Marmara, Turkey) project, funded by the DFG (Germany) - TÜBİTAK (Turkey) bilateral cooperation program, provide support for the researchers processing the SAR data. The main task of the project will be to process all available data SAR sets (see previous report for 2016-2018), that are open to the scientific community in Marmara Region Supersite. Then, the main deliverable will be to assess the ground velocity and strain rate maps around the northern part of Marmara region, using SAR and GPS data.

Individual users, of course, used research funding from different sources but since there are no reporting requirements, the PoC is not aware of those projects.

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8. Societal benefits

This initiative develops innovative methods for earthquake hazard assessment and improvement of our knowledge. These observations have the fundamental importance for a wide range of the studies, perhaps most especially for probabilistic seismic hazard analysis. All hazard models should be modified based on the SAR results, which provide information over a wide area with high sampling rate in space and time.

SAR data constitute a critical resource for this monitoring and research. In a short time (<1 week), a large area (>150km) can be mapped with high precision (<cm/year) and rapid generation of critical information is possible. The results can be regularly presented to the decision-makers in order to be compared with other data sets in case of local deformations (subsidences, landslides) and earthquakes.

The January 24th, 2020 Mw 6.8 Sivrice-Elazığ (eastern Turkey) case is a recent example to the rapid applicability of InSAR datasets. Due to a lack of surface rupture the co-seismic pattern deduced from interferograms help the identification of the rupture zone and is shared with decision makers and rescue teams in the field.

As outlined above the Supersite scientists shared recent research results with the public through news networks and continued to inform the public regarding their recent findings during the report period.

9. Conclusive remarks and suggestions for improvement

Under the GSNL initiative, joint interpretation of satellite and in-situ data is now much easier and new interpretations of fault kinematics/dynamics and local deformations in the cities could now be carried out. This is a major scientific challenge. A group of graduate students, junior and senior researchers, at a number of research institutions are working on various aspects of the SAR data provided by CEOS. This is the best demonstration case of the global scale science networks under the power of CEOS. During the studies, the interaction with the space agencies has been excellent.

However, the procedure for accessing the Supersite SAR data should be standardized. Currently it is difficult to know who is working with the Supersite data, thereby complicating the efforts to coordinate work and to report results. Generally, PoC controls the data transfer between space agencies and researchers. But, in some cases, PoC may be unaware about the usage of data,

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results and teams. This is critical when it comes to demonstrate the importance of the Supersite to the scientific community and to the public.

There is a lack of supporting data, like digital elevation information (DEM). Tandem-X data (from DLR) can provide high-resolution topography. This data is essential to improve the resolution for SAR results. DLR opens some part of this data to the accepted proposals by their system. But, the usage of the data is restricted to the owners of the proposals. This is not an open data set.

Another important data set is Pleiades optical data (CNES). This is very important for creating high resolution DEMs and tracking the morphological characteristics of the study area. Unfortunately, this also is not an open data set.

Supersites need a specific address to demonstrate the importance of a GSNL Supersite. Therefore, we support the invaluable efforts of Stefano Salvi (Chair of SAC) on the Supersite specific website organization.

10.   Annex with dissemination material

In section 5, the main scientific results of the Supersite, including figures and citations, are summarized.