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Biennial report for Permanent Supersite/Natural Laboratory

Marmara Region Supersite: May 2020 – April, 2022

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 North Anatolian Fault Zone (NAFZ) is one of the largest plate-bounding transform faults that separate the Anatolian and Eurasian plates and extends for 1600 km between eastern Anatolia and the northern Aegean. Along the eastern coast of the Sea of Marmara the Anatolian block is moving westward with respect to the collision zone between the Eurasian and Arabian Plates, at a rate of ~25mm yr^{-1}, activating major strike-slip and also N-S extensional normal faulting earthquakes south of the Marmara region. A series of large earthquakes that started in eastern Anatolia in 1939 near the city of Erzincan, propagated westward toward the Istanbul-Marmara region that is located in north-western Turkey and ended in 1999 with the devasting Izmit earthquake. West of the Izmit rupture a ‘‘seismic gap’’ exists along ~100 km long segment below the Sea of Marmara which connects the Ganos (1912, Mw 7.1) and Izmit (1999, Mw 7.4) ruptures. It is believed that the Central Marmara Segment is capable of generating an earthquake with a magnitude equal or larger than 7.1 that can rupture either as separate smaller events with normal faulting regime or as a single rupture (Armijo et al., 2002). The estimated 30-year probability for an event M ≥7 below the Sea of Marmara was 35– 70% (Parsons, 2004).

All the significant seismic sources in the Marmara Sea have the potential to generate damaging levels of ground motion in Istanbul which now 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, in 2014, the Marmara region has been designated a “Permanent Supersite” by the CEOS under the GEO Geohazard and Natural Laboratories Initiative (GSNL). In this framework, the surface displacements (mean deformation velocity maps and corresponding time-series) along the Marmara Region are calculated via the exploitation of SAR data acquired by different satellite systems. The achieved results were compared with the available independent in-situ measurements (e.g. GPS, strainmeter data) of the investigated areas (de Michele et al., 2017).

This initiative let researchers that investigate the seismic hazard in the Marmara Region to be able to access multiband SAR data sets thanks to the support of ASI/Italy, CNES/France, DLR/Germany, ESA/EU and JAXA/Japan, NASA/USA and USGS/USA. 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 (Diao et al., 2016).

In this report, firstly, we share the preliminary results of ongoing studies in the report period, related with the strain accumulation and release in order to obtain realistic hazard maps. Then, we introduce newly initiated studies, focusing on small scale secondary deformations, which are important for the sustainability of Istanbul under the threat of rapid development of infrastructures (e.g. new subway/metro lines), and uncontrolled groundwater problems in addition to natural hazards.

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 initial important findings of the multidisciplinary studies accelerated new SAR based studies with the contribution of national (e.g Boğaziçi University; Istanbul Teknik Univ.; Yıldız Teknik Univ.; Akdeniz Univ.) and international research groups (e.g GFZ, Germany; Univ. of Leeds, UK; Freie Universitat, Germany; BRGM, France; Standford University, US).

The 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 increase 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. The Turkish teams in collaboration with their international partners 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.

Marmara is under a serious earthquake threat and the continuous monitoring allows to the testing of new algorithms and interpretations to reduce potential hazards. Country scale deformation mapping of Turkey, including the Marmara region, has been carried out by the Leeds group based on their LicSBAS archive (Weiss et al., 2019). At the same time, new Turkish groups has focused on small-scale deformations with X-band data sets to understand the deformations along İstanbul's critical infrastructures, (e.g. metro lines). However, in this report period, there has been a reduction in the outcomes of new studies partly due to the COVID-19 pandemic.

Infrastructure monitoring opens up new means of establishing a "link" with decision-makers. Istanbul is rapidly expanding and the local authorities need inputs to improve their plans. Hence, the scientific teams can find the budget with the demonstration of our archive and the power of international collaboration.

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*	*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* *General Command of Mapping*	*Data Specific Service* *http://tudes.hgk.msb.gov.tr*	*Public* *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 up critical data sets to public access 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 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). To assure traceability, authorization is 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*

Number of [available/processed] images*						
Sensors	*ERS-1*	*ERS-2*	*ENVISAT*	*CSK***	*TSX****	*SENTINEL1*
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*
2020	-	-	-	*26/26***	*94/94*	*160/80*
2021	-	-	-	*20/20***	*187/100*	*160/140*
2022	-	-	-	-	*69/30*	*40/40*

** Estimated from papers and on-going projects*
***Data collected from ASI's archive*
**** We have experienced continuity problems in ordering due to local problems and limited manpower. These were resolved and regular orders commenced after 2019.*
***** frames of T036,T038,T131,T138 only*

Satellite data issues

Thanks to the organization of the GSNL supersites, access and demand to X-, C- and L-band SAR data has significantly increased, leading to new scientific researches.

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 extremely useful due to the high frequency of acquisition 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 is to order the data from a fixed ROI without any interruption in time. Within this frame, TSX data are being processed by French and Turkish groups, routinely, since 2017. But, due to the limited usage of CSK data in the previous report period, ASI only opened archive data sets, leading to gaps. This report reflects the usage of X-data, including CSK data sets and we hope that ASI's response will be similar to DLR. Obviously, to map the temporal evolution of the strain accumulation, it is important to have an uninterrupted data archive since large gaps in time hamper signal correlations.

ALOS-2 ScanSAR data have been received, archived and analyzed based on a specific JAXA call in 2017. Our first results are highly promising despite the limited data acquisitions. Similar to X-band data sets, we expect that JAXA will define a quota for the continued monitoring of the region with the ScanSAR mode.

CNES opened a part of their Pleiades archive. Unfortunately, we could not analyze it due to the limited human resources. However, we introduced the archive during scientific meetings to interested researchers that are interested in mapping the surface deformations of historical earthquakes. In February 2022, one group expressed their interest to study the Yenice-Gönen earthquake zone (18.03.1953, Mw 7.2) and we are waiting for their study plan. Hence, the continuity of CNES support in the next period is important for the Marmara Supersite. The archive presents an important opportunity to study the surface signatures of this earthquake in detail and the outputs of this study will be important for the geoscience community, as well as, decision makers.

The Geohazards Exploitation Platform (GEP) is one of the key interfaces to access the Supersite data sets (especially for CSK data sets). But, during the development phases, some data sets

cannot be accessed (or not visible). Regular feedbacks from GEP (or ASI) are very important to track these unaccessible data links. Also, the download permissions for registered users were not working in the past after the signing of ASI's license document. Unfortunately, one group started using different data sets, due to this type of download problems. We helped one of the groups to transfer the data from the Marmara Supersite to a local archive. Of course, this creates extra work load. For the sustainability of the Marmara Supersite, this kind of the support is essential.

5. Research results

Different research groups work at different map scales on hazard estimations and risk reduction measures for building stocks and critical infrastructures around and in Istanbul. In this section, we would like to summarize these on-going activities:

a) Studies on developing of a 3D fault locking model:

Generally, measuring fault mechanics offshore is a challenge in Marmara. To better constrain fault parameters along the offshore fault system, a joint work project has started between German and Turkish groups to create a new 3D fault locking model, using all available sensors (TSX; CSK and Sentinel 1 A/B). In addition to the multi-sensor SAR data sets we have rich local GNSS data sets from different CORS networks in the Marmara region. The InSAR measurements have been transformed to the common reference frame defined by the GNSS data w.r.t Eurasia. For Sentinel 1 A/B, we use images on 4 tracks, two in ascending and two in descending orbits. Overlapping with each other, we completely cover the northern and southern branches of NAF in the Marmara region. For TSX data, we have focused the rupture zones of the 1999 Izmit earthquake (Mw 7.6). To the east, we have processed the CSK data along the Ganos fault on which the last major earthquake took place in 1912 (Mw 7.1). We have processed the SAR data using the open-source software packages GMTSAR (Sandwell et al., 2011; Sandwell et al., 2016) and StaMPS [Hooper, 2008; Hooper et al., 2012] for calculating the interferograms and deformation time series. Shuttle Radar Topography Mission (SRTM) 90 m data were used for the removal of the topographic phase contribution. We have constructed a 3D fault model to infer the strain accumulation, aseismic slip release and slip deficit on it using a Bayesian approach with the BEAT code (Vasyura-Bathke et al. 2020). Examples of the data sets used in joint inversions are shown in Figure 1 and 2.

Figure 3 demonstrates the slip deficit model, estimated from this rich data sets. Our first results support the heterogenous strain loading along the Main Marmara Fault and reduce the hazard in the near time or postpone the time of the expected earthquake. In the center of the Sea of the Marmara, strain loading appears to be very low, in contrast to its extension the east and west. This deformation pattern, adjacent to each of the major fault branches, indicates that those branches that have generated M> 7 earthquakes, are accumulating strain and are the most likely branches to generate future earthquakes.

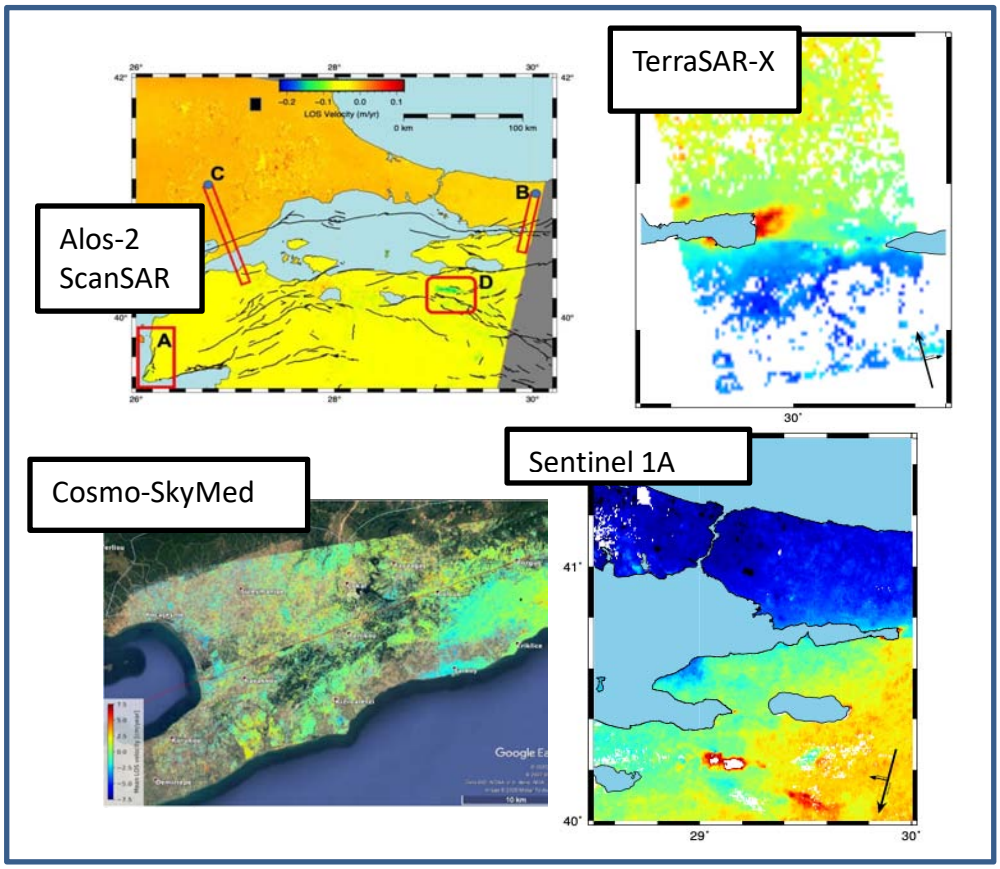

Figure 1. PSInSAR and SBAS velocity fields constructed from various SAR sensors.

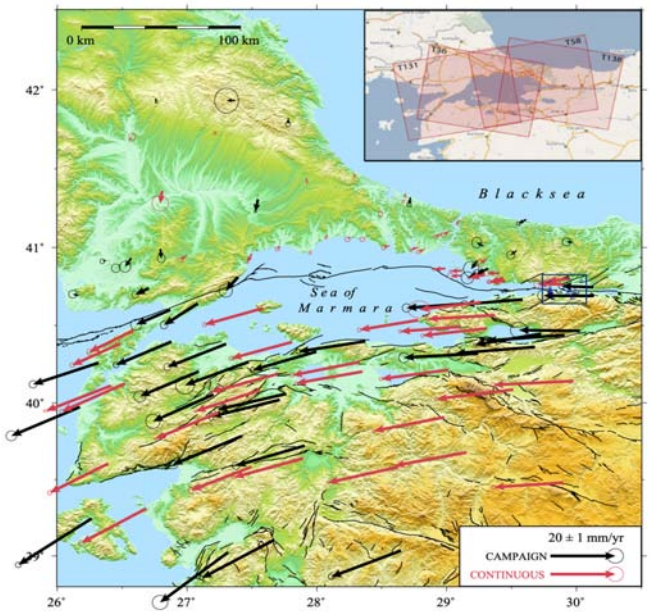

Figure 2. GNSS velocity vectors with respect to Eurasia. Inset shows the frames of Sentinel-1 data used in this study.

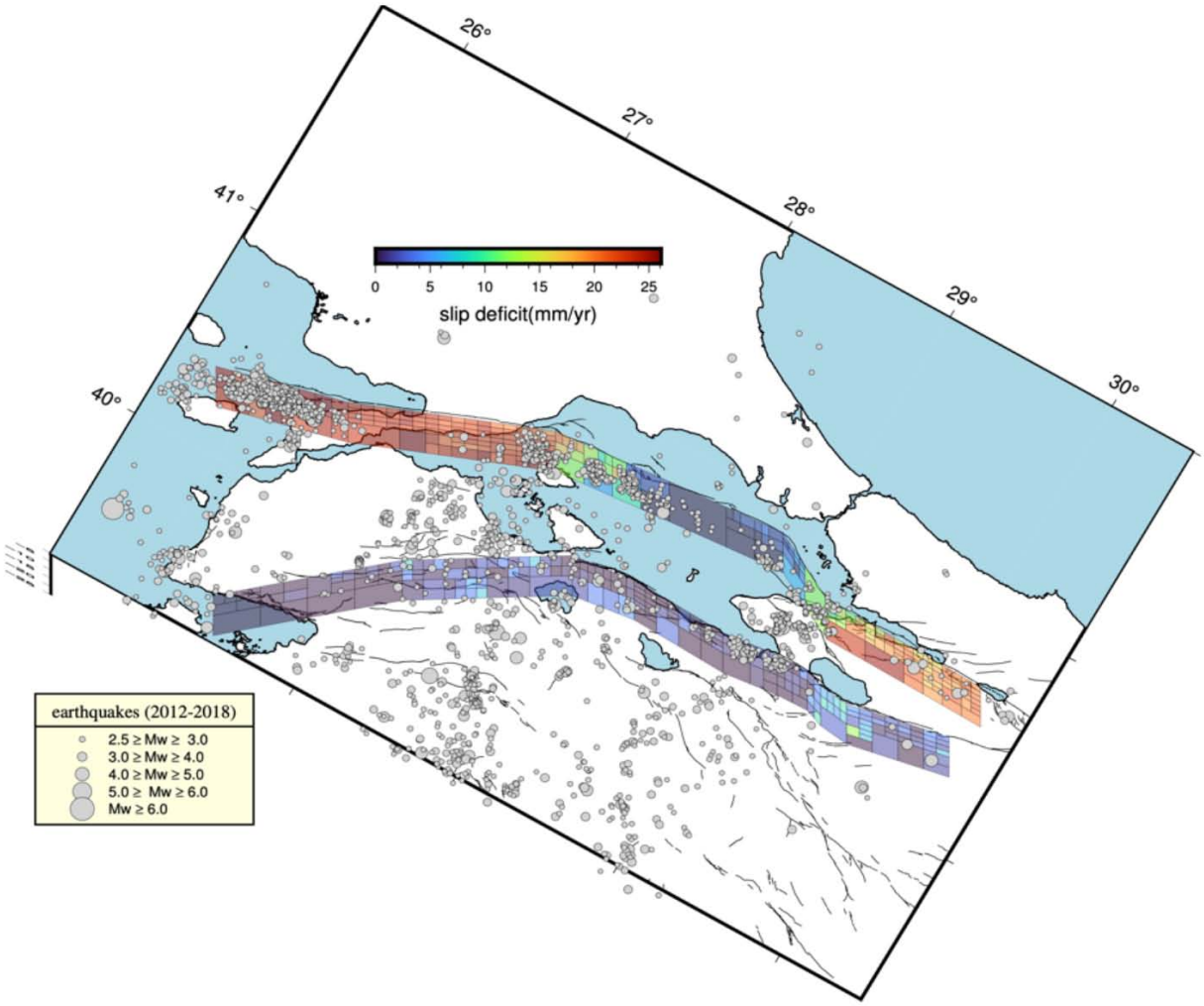

Figure 3. 3D slip deficit model (see the text for details).

b) Studies on the understanding of the deformations within İstanbul's critical infrastructures

Risk reduction of building stocks and the deformations on the dams and along the metro lines have been investigated by various researchers using the Supersites SAR data. Deformations on the dams have been estimated using Sentinel-1 data (Figure 4) by Çakır et al. (in prep). Deformations along the metro line constructions are estimated by Halicioglu et al. (2021) (Figure 5).

In a newly initiated study covering the last two years, slow moving landslides in western Istanbul are detected using Sentinel-1 data (Figure 6). Seismic fragility and landslide sensitivity (including triggering possibility of them by earthquakes) are also taken into account. Figure 7 shows landslides triggered by the 26.09.2019 (Mw 5.8) offshore event near the coast of the Silivri district

of Istanbul using CosmoSky-Med data. Only two pairs could be analyzed. First one covers the pre-earthquake period (07.02.2019-12.04.2019) and the other one includes the coseismic period (12.04.2019-19.07.2020). After the correlation of them, several anomalies along landslide-prone areas are identified. Unfortunately, post-earthquake acquisitions following the event were not available.

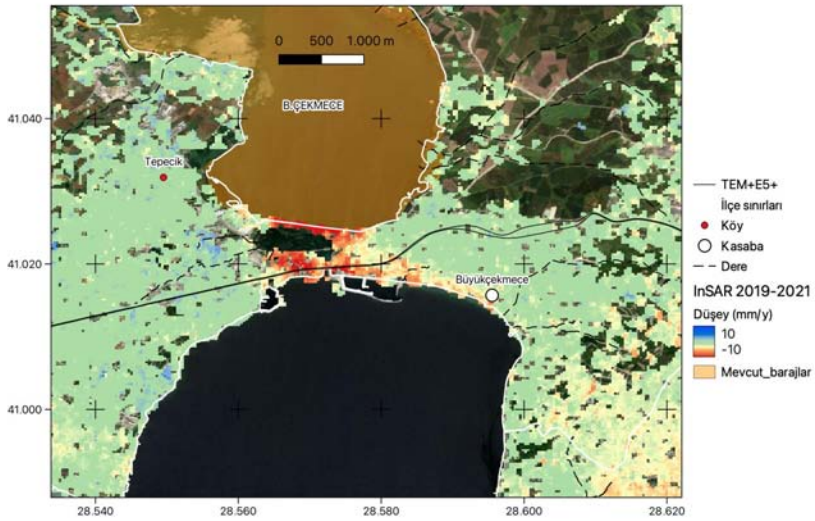

Figure 4. PSInSAR velocity map (Data: Sentinel 1 A/B) on the Büyükçekmece Dam in Istanbul (2019-2021) (Cakir et al., in prep)

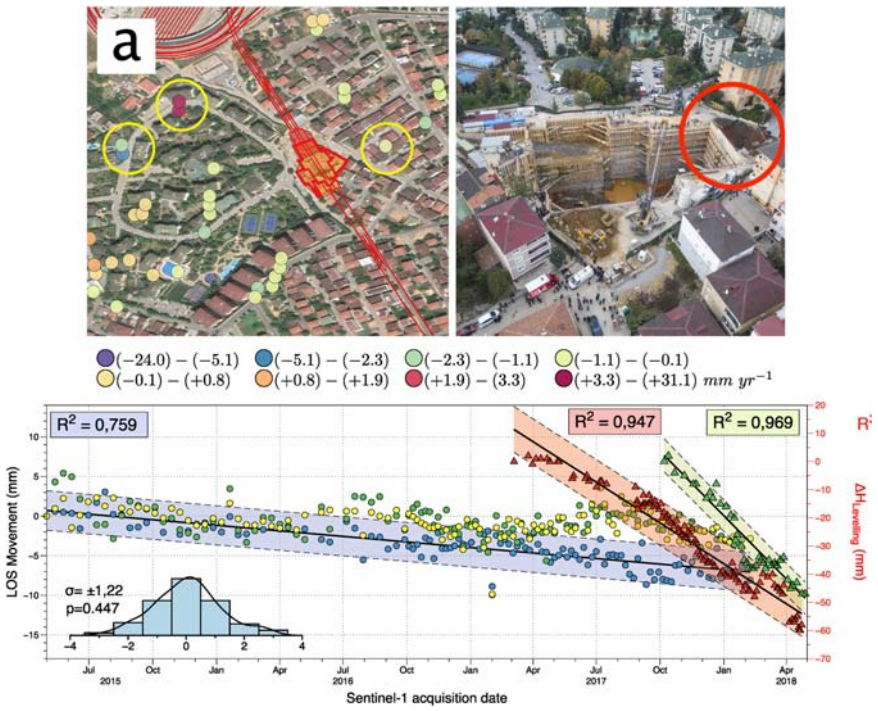

Figure 5. Optical imagery of a station of the underground metro line constructed in the Asian part of Istanbul Turkey, and the time series of the surrounding area (Sentinel 1 A/B data). Orange area covers the ground construction site, and the red area is the collapsed region in November 2018. Yellow circles on the satellite image indicate the plotted time series, and the red circle on the photograph shows the collapsed region. The red and green triangles are the ground measurements performed at the construction site at two separate elevations (Halicıoğlu et al., 2021).

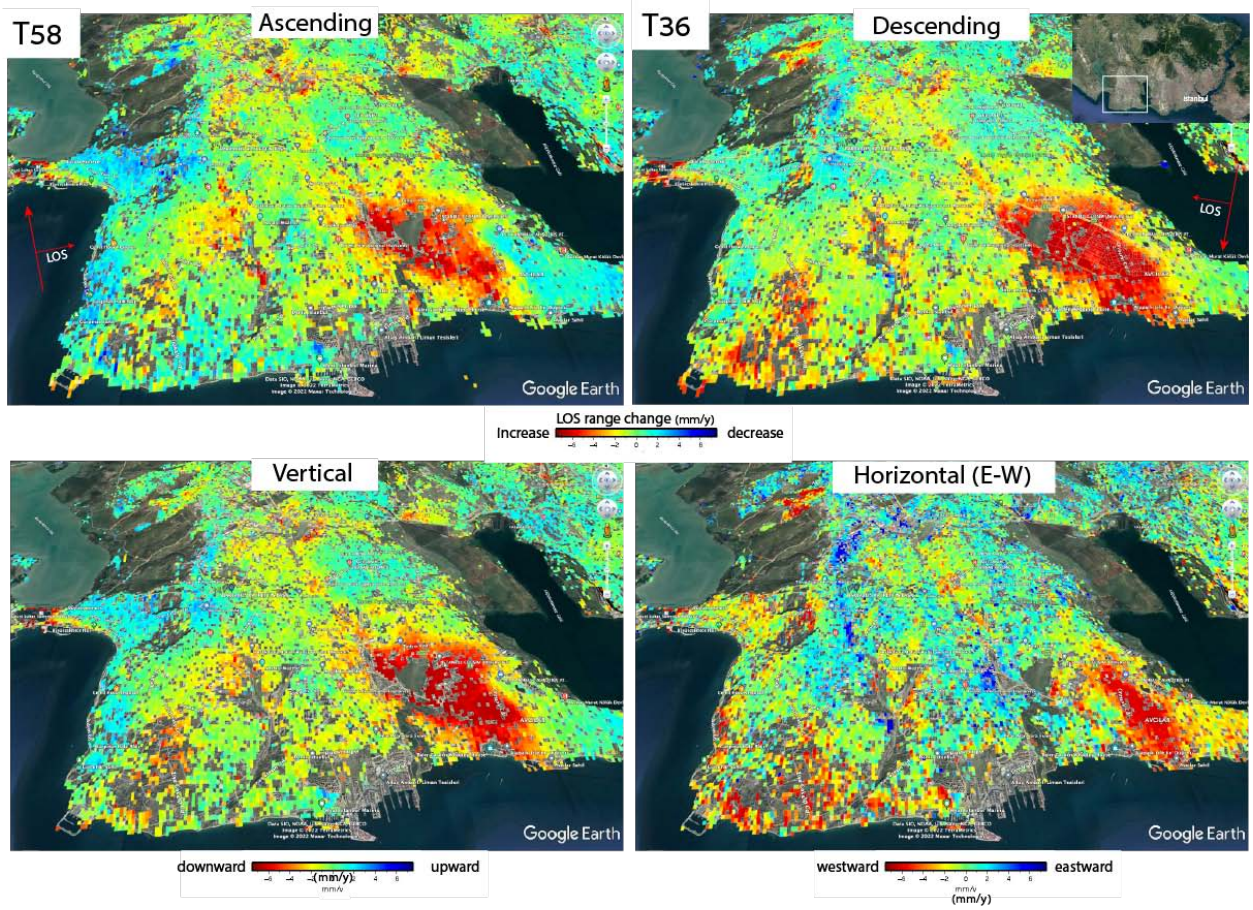

Figure 6. Perspective view of slow-moving landslides between Küçükçekmece and Büyükçekmece Lakes (western Istanbul) captured by time series of Sentinel-1 ascending (T58) and descending (T36) data between 2019 and 2021 (Cakir et al., in prep).

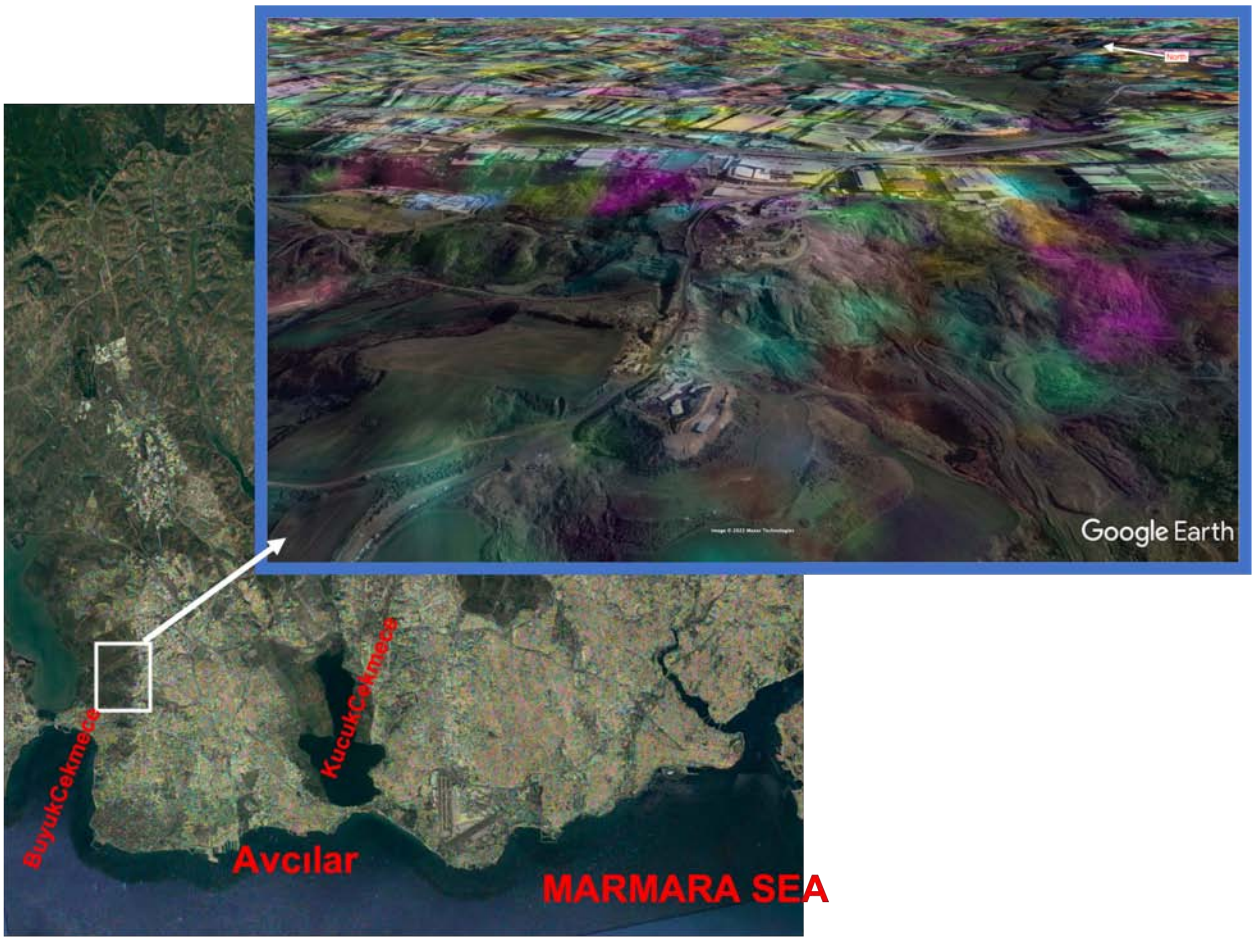

Figure 7. Landslides triggered by the 26.11.2019 (Mw 5.8) off-shore Silivri earthquake. Data is from the CSK archive. Details are given in the text.

Peer reviewed journal articles

Halicioglu, K., Erten, E. & Rossi, C. Monitoring deformations of Istanbul metro line stations through Sentinel-1 and levelling observations. Environ Earth Sci 80, 361 (2021). https://doi.org/10.1007/s12665-021-09644-0

Ergintav et al., (in prep), Estimation of 3D slip deficit along the Main Marmara Fault, Turkey

Çakır et al., (in prep), Monitoring of the deformations of critical infrastructures of Istanbul, Turkey.

Çakır et al., (in prep), Mechanisms of landslides in western Istanbul, Turkey.

Conference presentations/proceedings

Nozadkhalil, T., Ergintav, S., Cakir, Z., Dogan, U., and R. Walter, T.: Investigation of Land Subsidence in Eastern Thrace (Turkey) using Multi Temporal InSAR, EGU General Assembly 2021, online, 19–30 Apr 2021, EGU21-11343, https://doi.org/10.5194/egusphere-egu21-11343, 2021.

Özbey, V., Özeren, M. S., Henry, P., Cavalié, O., Le Pichon, X., Klein, E., Tarı, E., and Galgana, G.: Kinematics of the Sea of Marmara using GPS, InSAR and underwater geodetic data: Possible Influence

of Crustal Heterogeneity, EGU General Assembly 2021, online, 19–30 Apr 2021, EGU21-13441, https://doi.org/10.5194/egusphere-egu21-13441, 2021.

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.*

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). Unfortunately, in academic communities, there is little reward for making research products accessible.

Research products (PSInSAR velocity maps, deformation fields) highlighting the problems along critical infrastructures are shared with municipalities and decision makers in GeoTIFF format, compatible with their institutional GIS archives.

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 is 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 started a project with the IBB to increase the awareness about the seismic hazard and to improve the related risk plans. The project is based on the systematic analysis of PSInSAR deformation time series for Istanbul.

In addition, research teams have attended local and international online meetings during the COVID-19 pandemic to disseminate the outputs of SAR related studies. These meetings and presented studies are often covered by news organizations; due to increased awareness in the public following a seismic event. Core research teams also started experimenting with the automatic estimation of coseismic deformations due to earthquakes using Sentinel-1 data (M>5). These initial results are shared on social media using the Twitter account of the Turkish Active Tectonics Research Group (@aktiftektonik) to increase the visibility of the Supersite among the researchers and the public.

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.

7. Funding

The core team, post-docs and PhD students working on the data sets are mostly funded by national and international fellowship mechanisms & projects. Generally, we have limited resources from the local projects.

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.

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.

As outlined above during the report period, the Supersite scientists continued to share recent research results and inform the public regarding their recent findings either through interviews with reporters or attending national TV shows and also through their personal social media accounts like Twitter.

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 our 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, 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 topographical information. This data set is essential to improve the resolution of SAR results. DLR opens some part of this data upon the acceptance of proposals. But, the usage of the data is restricted to the owners of these proposals. It is not an open data set.

Communication and the fostering of common research goals are important between the Supersites. Regular scientific meetings can be a means to create synergy between them. We believe that a special session should be organized at the biennial FRINGE meetings.

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.