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Marmara Region Supersite: 2016 – April, 2018

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 over 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. This 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 south of the metropolitan city center of Istanbul) and the Ganos Fault (6~0 km west of the Istanbul). All the significant seismic sources have the potential to generate damaging levels of ground motion in Istanbul which hosts a rapidly growing population of >13 million making it the cultural, financial, and industrial heart of Turkey. Because of Istanbul's proximity to NAF's segments, Marmara has been designated a "Permanent Supersite" by the CEOS under the GEO Geohazard and Natural Laboratories Initiative (GSNL) of 2014. In this frame, researchers investigate the surface displacements affecting the Marmara via the SAR data sets, under 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 the beginning: like the discovery and analysis of new evidences of creeping zones and shallow/fully locked segments in the region. Another unique finding is the observation of the longest postseismic response in as a result of the 1999 earthquake sequence. These new findings will definitely help us improve our knowledge of the earthquake cycle.

Within this report period, aside from studies of the long-term behavior of seismic sources,

there were also significant results from studies that focus on the rapid and uncontrolled growth zones in cities with severe local deformation problems. A recent example is the observation of the reclaimed lands in both the European (Yenikapı reclamation area) and Asian (Maltepe reclamation area) coastlines of Istanbul which underwent significant subsidence up to 8±1.3mm/yr as a result of the primary consolidation process of the alluvial clay beneath of the filling material.

2. Scientists/science teams

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Scientists/science teams issues

In the first period of this initiative, the core team was based on 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 were shared with the science community to potentially serve the other disciplines with in-situ data sets. The attractive results of the multidisciplinary studies accelerated new SAR studies with the contribution of individual researchers and different international 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 (M~7.4, M~7.2) 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. Within these groups, mainly, MSc and PhD students use the Supersite data and develop new methodologies to estimate the response of fault systems to M>7 earthquakes. Also, each group has international partnerships with different countries like France, Italy, China, Japan, USA, this increases the visibility and dissemination.

The communication, between the individual researchers and international groups, has been realized during the project meetings, as well as special sections in international meetings. Turkish groups collaborate very well and create a center of excellence for the region. Other groups, generally, work with Turkish groups and use their experiences and knowledge about tectonic problems in the region.

However, while the international supersite users increase with each year, the contributions from Turkish researchers were very limited. To increase the national awareness, PoC (with the support of the ITU group) will try to organize regional SAR courses starting with Fall 2018.

In conclusion, the organization of scientific research was not a problem and new international users, from USA to Japan, are increasingly involved with the supersite. This shows that the scientific and social merits of Marmara Region Supersite are very important and this initiative works as planned with the momentum of open data sets.

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*
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/tudesportal/*	*Public* *Public for Turkish Scientists*
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 networks open 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 now. 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 will be modified in the EU supported EPOS-IP (Earth Plate Observation System-Implementation Phase) project as a part of NFOs (Near Field Observation networks). Then, it will be opened to the public without any registration mechanism, using standard services and metadata formats. However, authorization will be required, mainly, to assure traceability.

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 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. It will remain anyway accessible for the sake of reanalysis.

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*
RADARSAT-2	*CSA*	*POC requests access from CSA for a specific 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*

** PoC's project accepted in the end of 2016. It includes all key researchers in the Marmara.*

Number of [available/processed] images*						
Sensors ***Years***	*ERS-1*	*ERS-2*	*ENVISAT*	*CSK***	*TSX****	*SENTINEL*
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/na*	*11/11*	*24/na*	*4/4*	-
2012	-	-	-	*33/na*	*26/26*	-
2013	-	-	-	*102/na*	*42/42*	-
2014	-	-	-	*51/na*	*94/26*	*142/142*
2015	-	-	-	*69/30*	*143/8*	*401/401*
2016	-	-	-	*66/30*	*149/na*	*740/500*
2017	-	-	-	*42/20*	*110/na*	*1171 /640*
2018	-	-	-	*12/na*	*6/na*	*742/na*

** Estimated from papers and on-going projects.*

***Data collected from the GEP portal. We have noticed that some data are missing (of the 550 images ordered from ASI). Correct numbers will be provided when the database is updated.*

****DLR portal was under maintenance: data are from personal logs. We will provide the correct numbers, when the problem is fixed.*

Satellite data issues

Generally, in the Marmara Region Supersite, researchers study the long-term behaviour of the fault systems to understand the long-term strain accumulation, which have been loaded by the past earthquakes. Obviously, until the new earthquake, all efforts will be focused within this frame. Archive ERS and Envisat data sets are very important as long historical datasets. Besides, Sentinel-1 A/B data is getting very attractive due to the frequency of the sampling and consistency with other data sets. For example, Gökhan Aslan and his colleagues managed to generate the long time series (~25 yrs), using ERS, ENVISAT and Sentinel 1A/B. Then his team increased the spatial sampling with TerraSAR-X data on the pre-defined target zones. All of data sets successfully overlapped. As supplementary research outputs, subsidence areas of İstanbul were identified with X-band and C-band data sets. Without the multi-sensor support of this initiative, they could not have realized this study.

Handling and use of satellite data has been in agreement with guidelines provided by each of the space agencies providing data. Moreover, they accepted the new ideas. For example, in order to compare TerraSAR-X results on the creeping section of NAF in Marmara Region supersite, we decided to order new TerraSAR-X data along an another creeping section of NAF (which is outside of this supersite). DLR accepted our orders when we explained the requirements with a short email.

Ordering of TerraSAR-X data is very easy. In the meanwhile, surprisingly, we learned that DLR web page is not reachable from some of the French Research Organizations (e.g. ISTerre, CNRS). Our colleagues didn’t solve this problem, until now. Downloading Sentinel-1 data works very well. There are different website-based tools (e.g. Sentinel Hub, ASF). ASF’s interface is easier than ESA/Sentinel Hub and also the download speeds are higher than the ESA Sentinel Hub probably due to the fact that Sentinel Hub has a large number of users than ASF.

Canadian Space Agency (CSA) opened a very limited part of the archive data (120 frames). The PoC could not order Radarsat data from CSA since the archive did not have a sufficient number of images for InSAR time series processing. RADARSAT-2 loan agreement has now ended. During the discussion of the next signing period with CSA, we learned that the data quantity will not change and the products will be from the archive. The CSA quota can be used in the future when a request comes from an interested user or after an event to obtain the latest information. Hence, the signing of the Loan Agreement is one the important future tasks. As a last note, CSA's APT software runs only under MS Windows operating systems making the data selection a bit impractical.

To control the critical fault segments, Cosmo-SkyMed (CSK) data are ordered, until the end of

2020. This process was very smooth and feedbacks were very fast. To share the data with the scientific community, the Italian Space Agency (ASI) also decided to share the data via a common platform (ESA-GEP [1]). This was an excellent solution. All Supersite users can access the data via GEP using their "ESA Single-Sign-On account" and the tracking of the CSK data users will be easy for the PoC(s). We transferred all data to GEP (~426 frames) and the data sets will increase with time. The dataset itself is the biggest X-band dataset that was made available for the Marmara Permanent Supersite.

During the report period researchers managed to focus only on the L and C band radar data: only ¼ of the available CSK data (93 frames, between 2011-2013[2]) were processed during the report period. High resolution synthetic aperture radar satellites with short repeat time acquisitions are an essential part of strain accumulation studies: in the next period, the PoC will personally motivate the supersite researchers to focus specially on the already available X-band data.

Using the PoC's project, accepted by JAXA, ALOS-2 data sets are ordered. We will start processing these scenes once a sufficient number of images are accumulated in the archive.

We have decided to open an internal call to analyse the Pleiades data sets as a part of an MSc thesis. This will be very important during a destructive earthquake and can be useful for the mapping of the detailed morphological features.

Managing the orders of the satellite data sets and downloading and archiving of them requires a significant amount of time. Until now, we did these tasks with the contributions of the MSc and PhD students.

5. Research results

In the report period, the biggest seismic event in the Marmara region had a magnitude of 4.4 (25/06/2016, Yalova coast). Therefore the supersite users mainly focused on the study of deformations due to the interseismic movement of the North Anatolian Fault and local deformations observed in and around the mega-city of Istanbul.

In the following part, we have listed examples of recent research results, which benefited from

[1] Geohazard Exploitation Platform (https://geohazards-tep.eo.esa.int/geobrowser)

[2] Analyzed in EU supported MarSite Project (Contract no: 308417),

this supersite (study regions are shown in Figure 1).

a) Ganos Fault Zone (western part of Marmara Region)

The BRGM team published a paper on the Ganos Fault Zone (de Michele et al. 2017). The segmentation and creep distribution of this section, which last ruptured in 1912 to generate a moment magnitude (Mw) 7.3 earthquake, was poorly understood. de Michele et al. used L-Band SAR data from the Japanese Aerospace Exploration Agency's (JAXA) ALOS satellite (39 interferograms) to retrieve a ground velocity map for the near field of the Ganos section of the North Anatolian Fault zone to improve our understanding of this particular section. They estimated a robust near field velocity map from stacking L-band interferograms, combining both single and dual polarization SAR data. To improve the result, they developed a filtering strategy to remove the effect of RFI (Radio Frequency Interferences related with ionospheric noise) on the interferograms stack. Then, they characterized the spatial distribution of creep on shallow patches along multiple along-strike segments at shallow depths (Figure 2a).

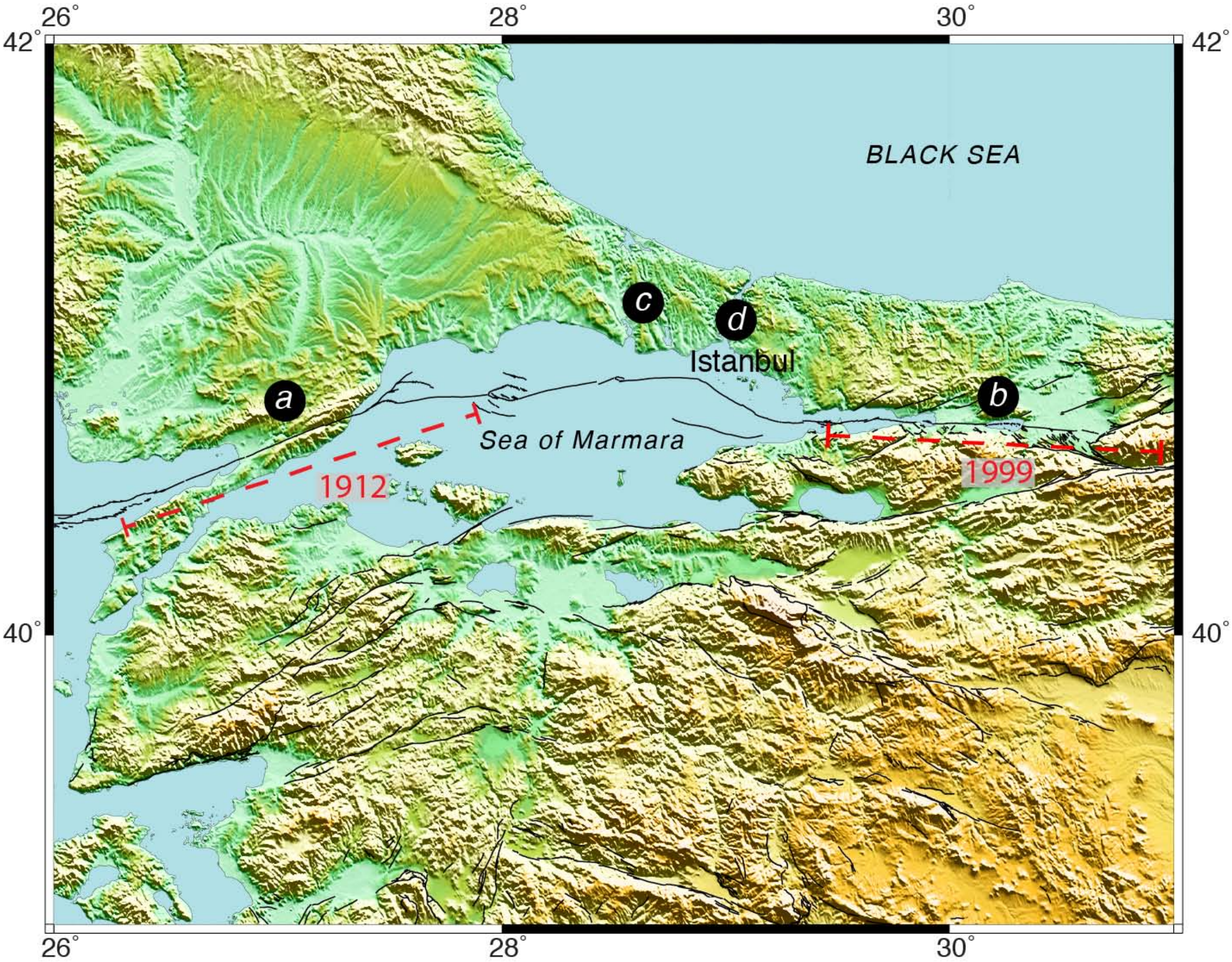

Figure 1. Map showing the locations of the outlined research results a-d. Black lines show the active faults (Fault database: Ö. Emre, Duman, T.Y., Özalp, S., Elmacı, H., Olgun, Ş. and Şaroğlu, F. 2013, Scale 1/1.250.000 Turkey Active Fault Map, General Directorate of Mineral Research and Exploration special publications series, Ankara, Turkey). The dashed lines represent the rupture zones of 1912 (Mw 7.4) and 1999 (Mw 7.6) earthquakes.

Their results suggest the presence of fault segmentation along strike as well as creep on the shallow part of the fault (i.e. the existence of a shallow creeping patch) or the presence of a smoother section on the fault plane. Data imply a heterogeneous fault plane with more complex mechanics than previously thought.

A second group, from the University of Miami was also working on the same area. They processed L-band ALOS data (101 interferograms between 2007 and 2011) and C-band Sentinel-1 data (550 interferograms between 2014-2017) using the PySAR software, which is the University of Miami version of the Small Baseline (SB) method (Figure 2b and 2c). Their initial results which were first made public at the 2017 AGU Fall Meeting (Havazli et al., 2017), indicate a maximum velocity of 15 mm/yr across the fully locked fault zone at the eastern part of Ganos. However, in the west, they observed a shallow creep zone, validating the results of de Michele et al. (2017).

The shallow creeping zone in the west can be related with unconsolidated sediments (the locking depth and the creep velocity are found out to be ~1 km and ~4-5 mm/yr, respectively, by both studies) or can be a marker of the shallow creeping patches under the continuous tectonic loading. The signature of the long-term response of the unconsolidated sediments could be correlated with seasonal oscillations in wet/dry seasons and could be decomposed from the signal in time. We believe that the answer will be given by the detailed time-series analysis of the long-term X-band CSK data acquisitions. Nevertheless, the current results had already improved our knowledge of the mechanisms underlying the Ganos fault, and will have implications for local seismic hazard assessment.

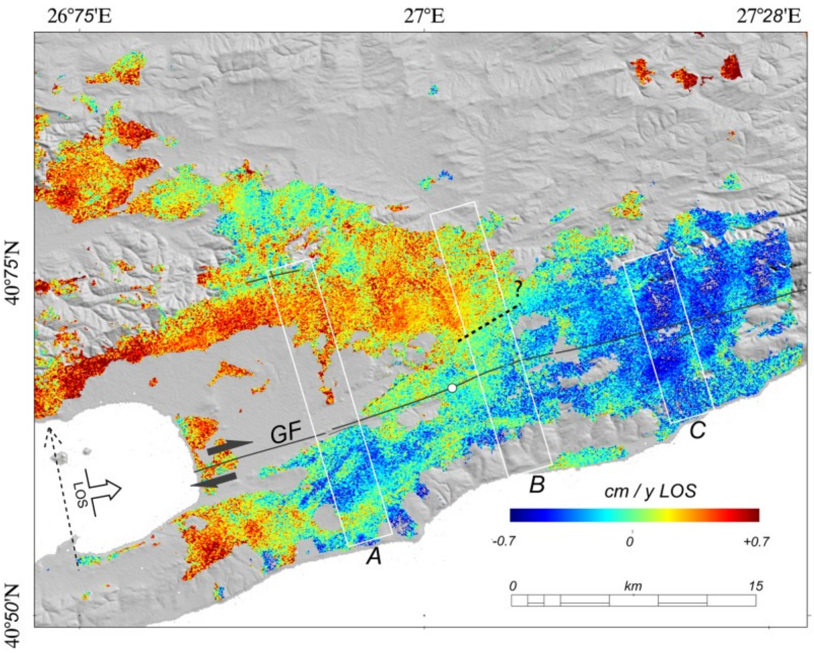

Figure 2a. The L-band InSAR velocity map that resulted from stacking 39 interferograms and showing LOS and flight directions (de Michele et al. 2017). The continuous black line represents the surface trace of the GF, black arrows indicate the sense of motion of the GF. Dotted black segments with the question mark represent possible active faults in the study area. The white circle represents the reference area for the stacking procedure.

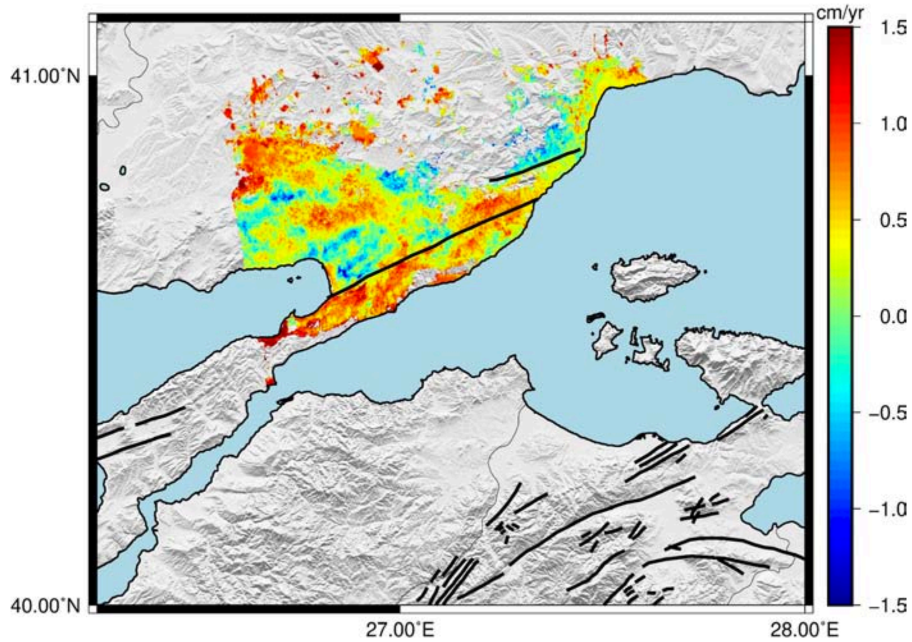

Figure 2b. The InSAR mean velocity map, obtained by PySAR software, which is the University of Miami version of the Small Baseline (SB) method (Havazli et al., 2017). The continuous black line represents the surface trace of the active faults. A total of 550 interferograms were generated, using 110 scenes from the C-band Sentinel 1 A/B satellites. Location of the Ganos section of the NAF is shown in Figure 1a.

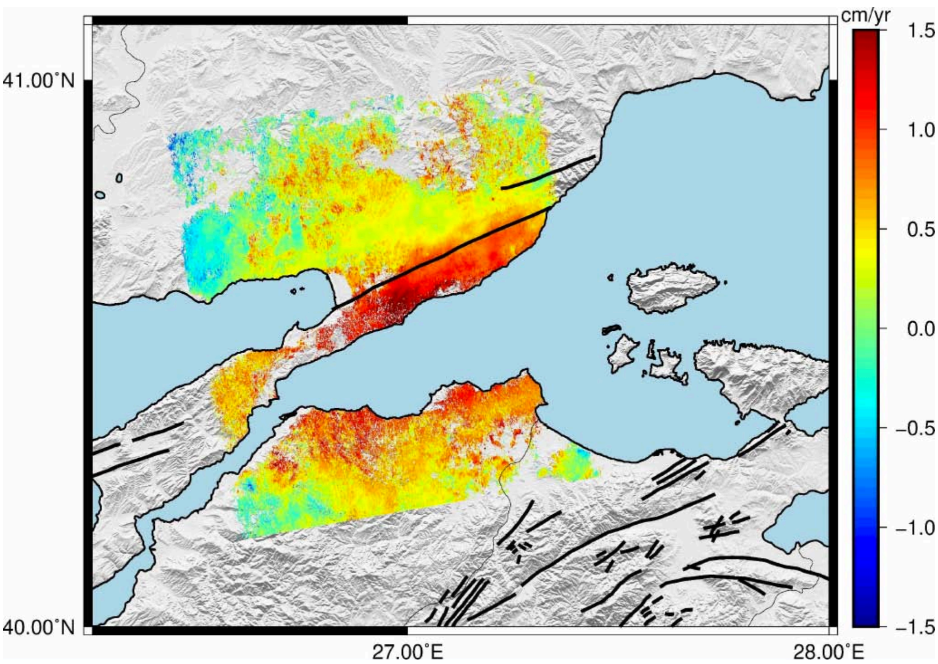

Figure 2c. The InSAR mean velocity map, obtained using the PySAR software, which is the University of Miami version of the Small Baseline (SB) method (Havazli et al., 2017). The continuous black line represents the surface trace of the Active faults. Total of 101 interferograms were generated, using 21 L-band ALOS scenes. Location of Ganos fault is shown in Figure 1a.

b) 1999 Izmit Earthquake Rupture Zone

ITU group published a paper (Aslan et al., 2018a) with the contribution of French scientists and Turkish scientists. They focused on the 1999 Izmit Earthquake rupture zone to monitor creep related phenomena, which started after 1999 earthquake. To monitor the surface creep behaviour along the Izmit rupture, they computed InSAR time series based on TerraSAR-X and Sentinel 1A/B radar images acquired over the period 2011-2017. The mean velocity field reveals that creep on the central segment of the 1999 Izmit fault rupture continues to decay but is still taking place, more than 20 years after the earthquake, in overall agreement with models of postseismic afterslip decaying logarithmically with time for a long period of time. The creep extends along the fault section that experienced supershear velocity rupture during the Izmit earthquake with a rate up to ~6 mm/year (Figure 3). A significant transient accelerating creep is detected in mid-November 2016 on the Sentinel-1 time series, near the maximum creep rate location, associated with a total surface slip of 10 mm released in one month only (Figure 4). Additional analyses of the vertical velocity field show a persistent subsidence on the hanging wall block of the Gölcük normal fault that also ruptured during the Izmit earthquake (Figure 5). These results demonstrate that afterslip processes along the North Anatolian Fault in east-southeast of Istanbul are more complex than previously proposed as they vary spatiotemporally along the fault.

c) Secondary deformations around Istanbul, related with fault activity

GFZ group published a paper (Diao et al., 2016) focusing on secondary deformations around the city of Istanbul. The team includes İtalian, Chinese and Turkish scientists. In this work, an advanced PSI technique named Persistent Scatterer Pair (PSP) was used to investigate crustal deformation and related the secondary fault activity southwest of Istanbul (Figure 6). They identified that a secondary fault near the Küçükçekmece Lake is now active with a dextral slip rate of ~ 5 mm/yr and a shallow locking depth of < 1.0 km (Figure 7). The paper provides the first geodetic evidence about the existence and present activity of secondary faults on north of the Marmara Sea, which has valuable implications for regional tectonic evolution and close seismic hazard assessment of the mega city Istanbul (Figure 8).

d) Analysis of Secular Ground Motions in Istanbul

The identification and measurement of ground deformations in urban areas is of great importance for determining the vulnerable parts of the cities that are prone to geohazards, which is a crucial element of both sustainable urban planning and hazard mitigation. Interferometric synthetic aperture radar (InSAR) time series analysis is a very powerful tool for the operational mapping of ground deformation related to urban subsidence and landslide phenomena. Turkish and French researchers published a detailed study using long-term InSAR time series (1992-2017) (Aslan et al., 2018b). With an analysis spanning almost 25 years of satellite radar observations, they computed an InSAR time series of data from multiple satellites (ERS-1 and ERS-2, Envisat, Sentinel-1A/B) in order to investigate the spatial extent and rate of ground deformation in the megacity of Istanbul. By combining the various multi-track InSAR datasets (291 images in total) and analysing persistent scatters (PS-InSAR), they calculated mean velocity maps of ground surface displacement in selected areas of Istanbul (Figure 9). They identified several sites along the terrestrial and coastal regions of Istanbul that underwent vertical ground subsidence at varying rates, from 5 ± 1.2 mm/yr to 15 ± 2.1 mm/yr. The results reveal that the most distinctive subsidence patterns are associated with both anthropogenic factors and relatively weak lithologies along the Haramirede valley in particular, where the observed subsidence is up to 10 ± 2 mm/yr (Figure 10). They showed that subsidence has been occurring along the Ayamama River stream at a rate of up to 10 ± 1.8 mm/yr since 1992, and has also been slowing down over time following the restoration of the river and stream system. They also identified subsidence at a rate of 8 ± 1.2 mm/yr along the coastal region of Istanbul, which we associate with land reclamation, as well as a very localised subsidence at a rate of 15 ± 2.3 mm/yr starting in 2016 around one of the highest skyscrapers of Istanbul, which was built in 2010 (Figure 11).

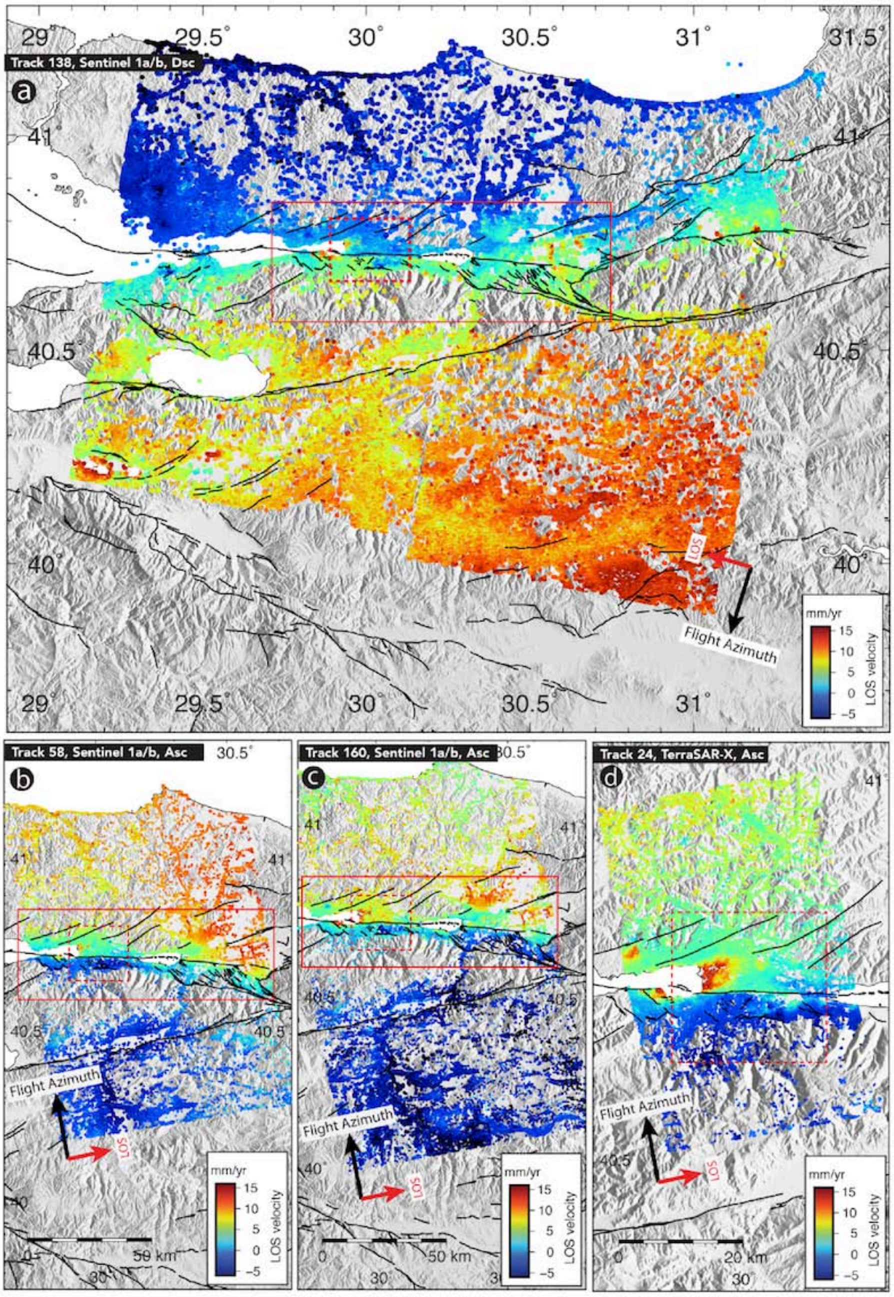

Figure 3. Mean line-of-sight (LOS) velocity fields for the period 2014-2017, form Sentinel 1/B tracks and for the period 2011-2015 form TerraSAR-X tracks, obtained from PS-InSAR time series analysis. LOS velocity fields along the Izmit earthquake rupture, with negative velocities (cold colors) representing motion of the ground toward the satellite and positive velocities (warm colors) motion away from the satellite. The change of motion direction across the NAF is attested by the warm/cold color contrast across the fault. Considering the different geometries of data acquisition (i.e., ascending or descending), it is consistent with right-lateral slip on the fault, due to the westward movement of the Anatolian plate

relative to the Eurasian plate. All LOS velocity maps show a very sharp velocity gradient along the central section of the Izmit rupture, in particular between the Izmit Bay and the Sapanca Lake.

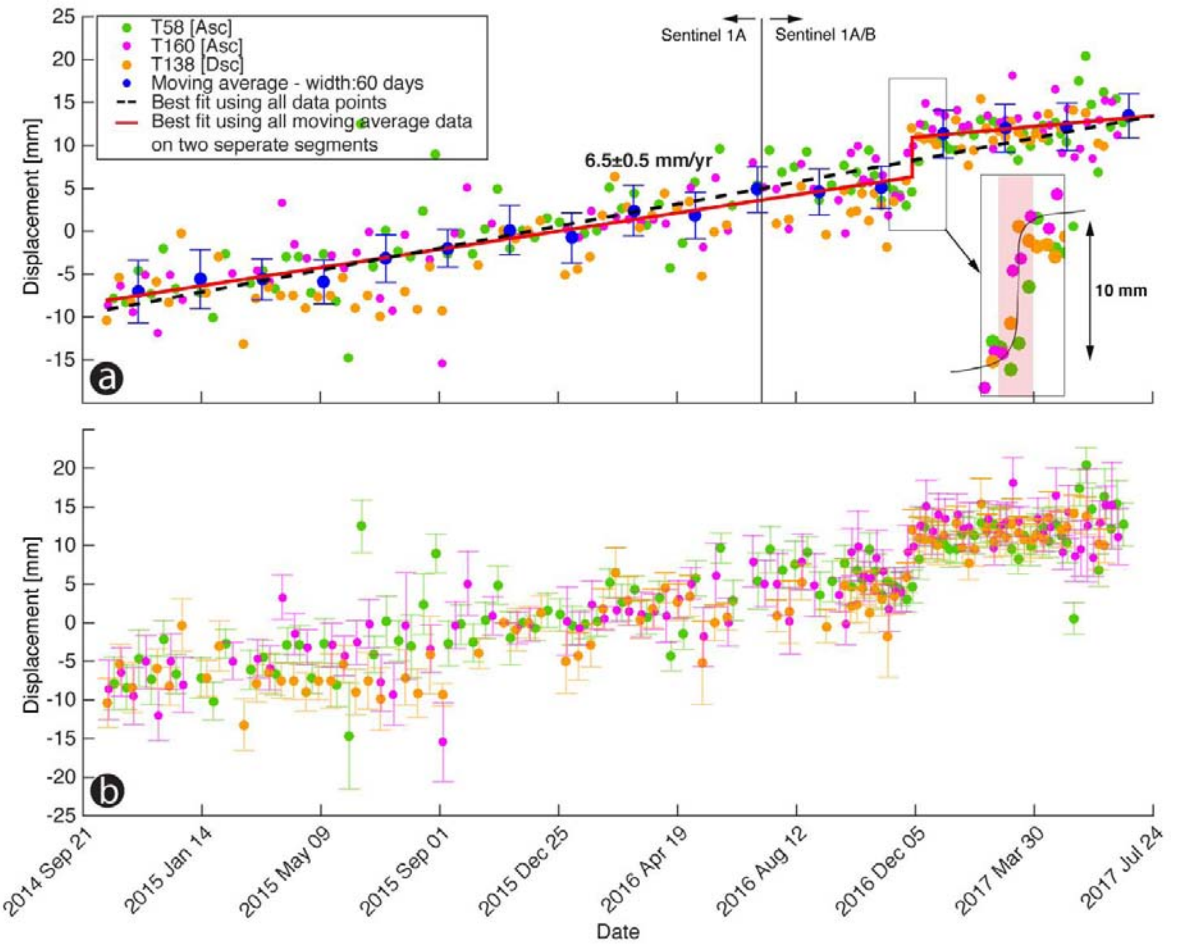

Figure 4. Time series of horizontal creep estimated along a fault perpendicular profile using all Sentinel data sets and assuming pure horizontal motion parallel to the fault. (a) Blue dots are the binned averages every 60 days. Error bars show one standard deviation of the distribution of the points within each bin. A transient event is seen around November 2016 (see inset). Red lines are fitted to the two separate segments of the bin-averaged data before and after this month. The vertical red line shows the transient creep event amplitude calculated from the offset of the two red lines. Black dashed line is the best fitting line for the entire data set points that represent the mean rate (~6 mm/yr). The period of transient creep, from mid-November to mid-December 2016, is highlighted by the transparent red background in the inset. (b) Raw data showing estimated creep rates with error bars that indicate the standard deviation of the measurements.

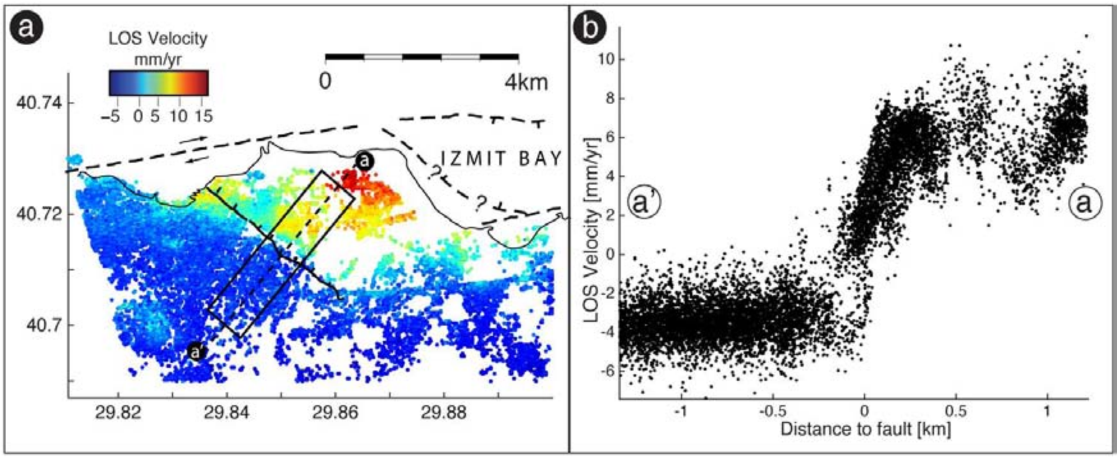

Figure 5. (a) Close-up view of line-of-sight velocities across the Golcuk normal fault calculated from TerraSAR-X ascending track 24 for the period of 2011-2015. Fault location is indicated by black solid line inland and dashed lines offshore, inferred from fault geometry inland and bathymetry and shallow seismic profiles in the Sea of Marmara (b). Line-of-sight velocity profile along profile a-a' shown in (a).

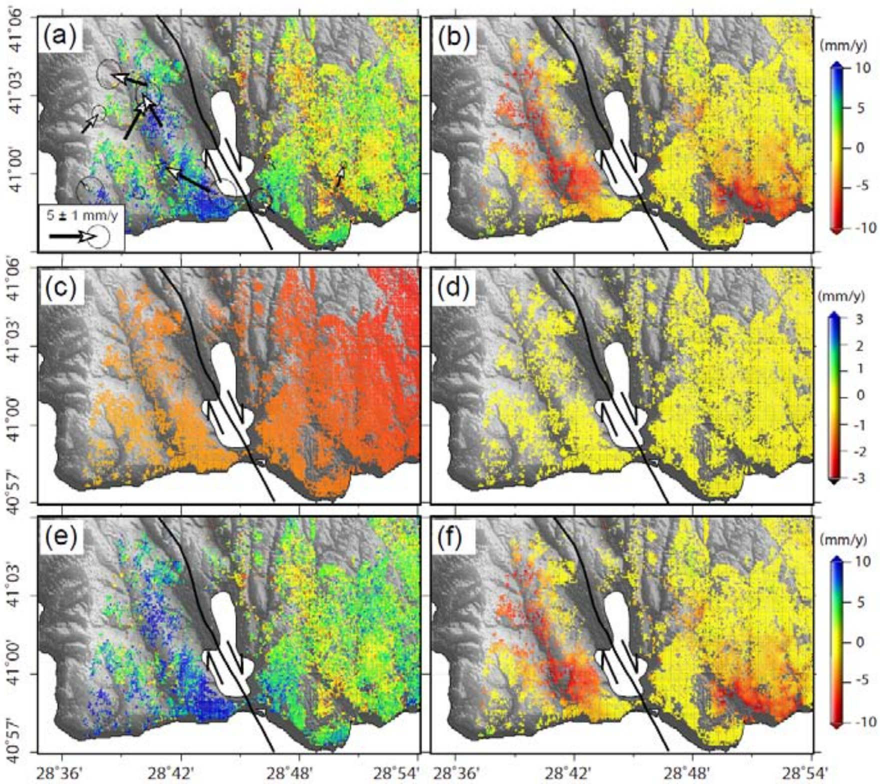

Figure 6. Decomposed InSAR velocity in horizontal (positive means that points move in N30°W) (a) and vertical direction (b). (c) and (d) are horizontal (N30°W) and vertical crustal velocity that induced by the post-seismic viscoelastic relaxation of the 1999 İzmit/Düzce earthquakes. (e) and (f) are fault-parallel and vertical velocity after removing the post-seismic viscoelastic relaxation effect of the İzmit/Düzce earthquakes. Black arrows in (a) show GPS velocity in this area.

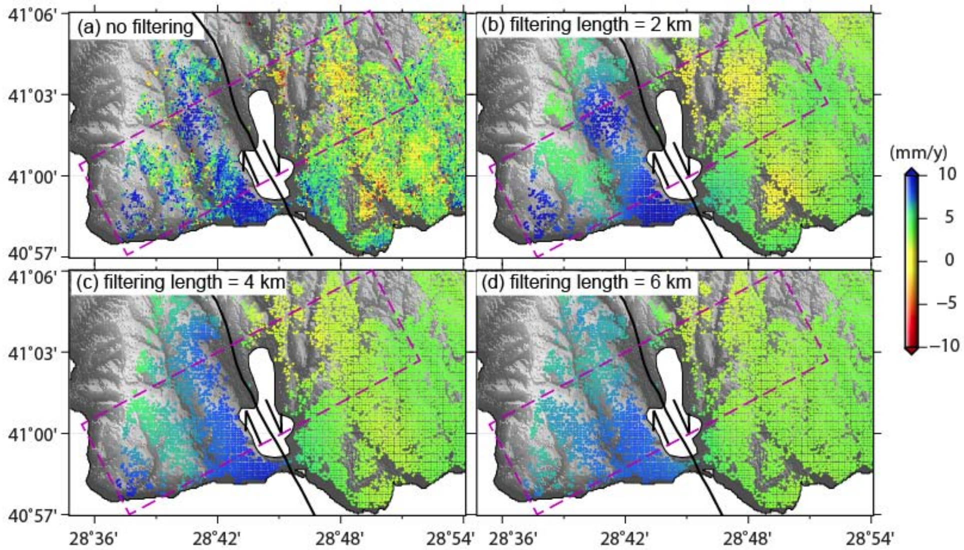

Figure 7. Horizontal velocity field near the Küçükçekmece Lake: (a) without spatial filtering, (b) – (d) show filtered data with different spatial filtering length. Purple boxes show the location of the velocity profile shown in figure 8.

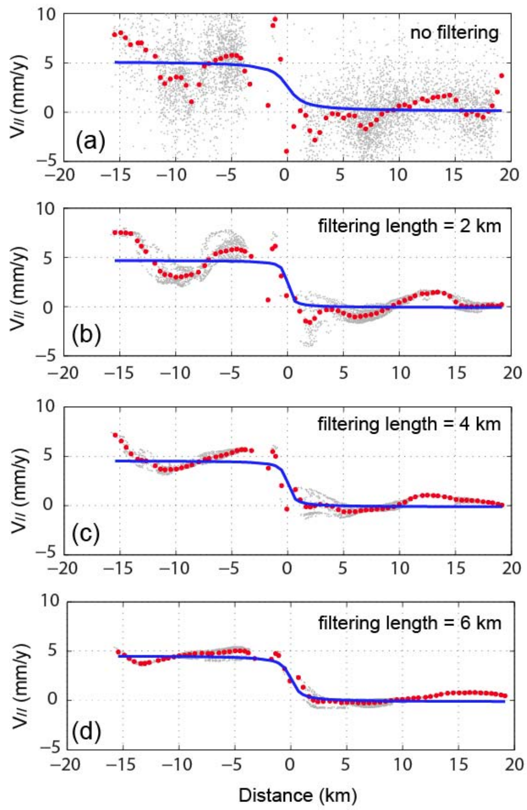

Figure 8. Decomposed horizontal velocity (N30°W) on profiles perpendicular to the orientation of the fault and comparisons with the model predictions: (a) original fault-parallel velocity without spatial filtering. (b), (c) and (d) are velocity profiles obtained from low-pass filtered data. The blue lines in each subfigure are the forward predictions based on the inverted optimal fault parameters.

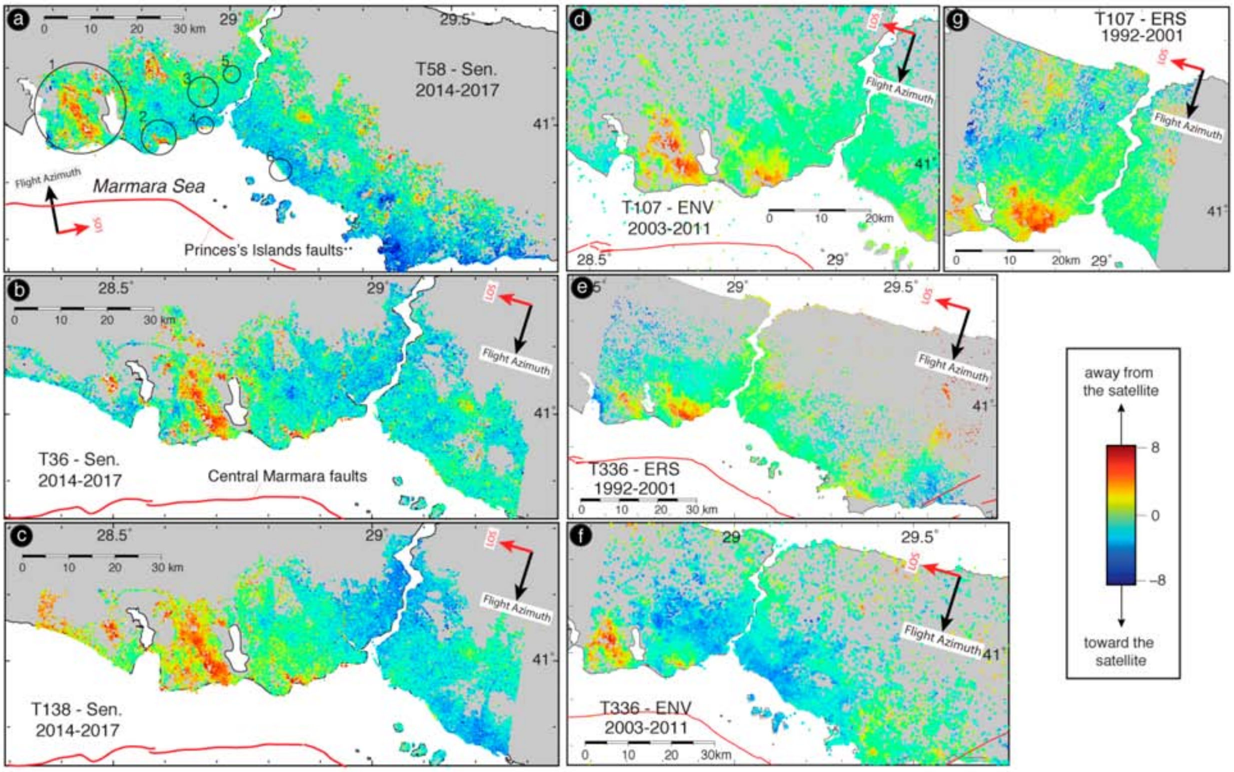

Figure 9. Averaged line-of-sight velocity maps of the Istanbul metropolitan area from an interferometric synthetic aperture radar (InSAR) time series analysis, with varying time spans depending on the sensor. Negative velocities (cold colors) represent the displacement of the ground toward the satellite and positive velocities (warm colors) indicate the displacement away from the satellite. Red lines in the Sea of Marmara indicate the submarine branches of the NAF.

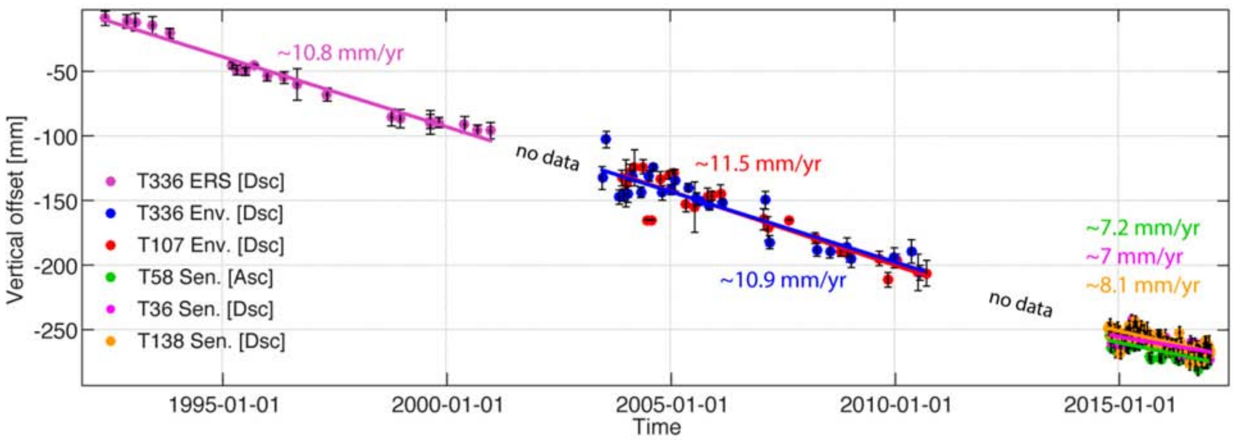

Figure 10. Time series of the vertical displacement at the selected PS points around Haramidere. Details can be given in Aslan et al. (2018).

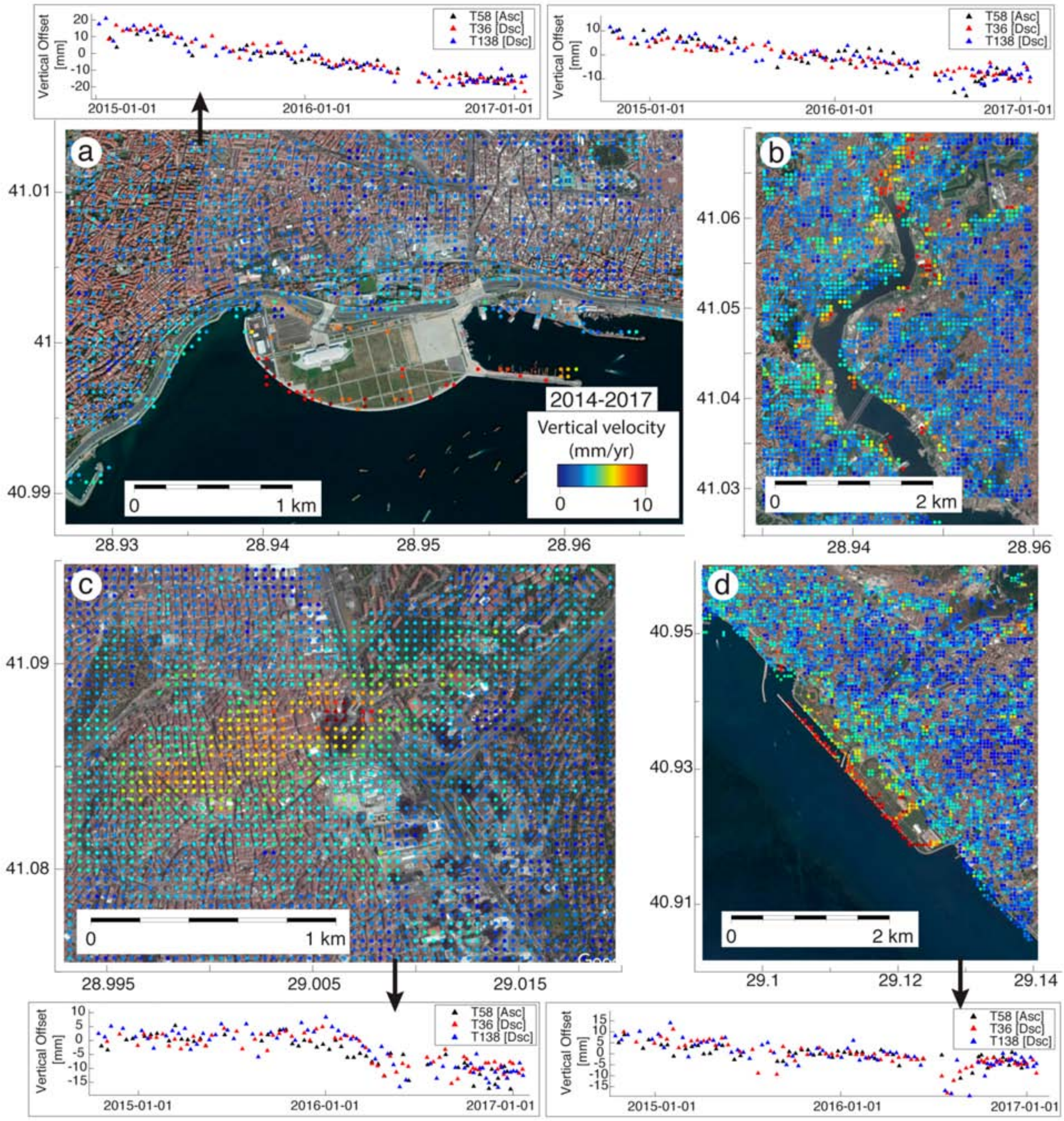

Figure 11. Vertical velocities obtained by the decomposition of mean velocity fields of Sentinel 1 data (T58 ascending track and T138 descending track) superimposed on a Google Earth image of Istanbul, and the relevant time series of the vertical displacement. Black, red, and blue triangles represent the ascending T58, descending T36, and descending T138 tracks, respectively. (a) Yenikapi coastal and land reclamation area (circle 4 in Figure 9a). The colour scale represents the vertical displacement of the surface; (b) Golden Horn area (circle 3 in Figure 9a); (c) Highly urbanised area of Istanbul, with subsiding persistent scatterer points clustered around the highest skyscraper of Istanbul (circle 5 in Figure 9a) (d) Maltepe reclamation zone (circle 6 in Figure 9a).

Publications

Peer reviewed journal articles
de Michele M, Ergintav S, Aochi H, Raucoules D (2017) An L-band interferometric synthetic aperture radar study on the Ganos section of the north Anatolian fault zone between 2007 and 2011: Evidence for along strike segmentation and creep in a shallow fault patch. PLOS ONE 12(9): e0185422. *https://doi.org/10.1371/journal.pone.0185422*
Diao, F., Walter, T. R., Minati, F., Wang, R., Costantini, M., Ergintav, S., ... & Prats-Iraola, P. (2016). Secondary Fault Activity of the North Anatolian Fault near Avcilar, Southwest of Istanbul: Evidence from SAR Interferometry Observations. *Remote Sensing*, *8*(10), 846.
Aslan G, Cakır Z, Ergintav S, Lasserre C, Renard F. (2018a) Analysis of Secular Ground Motions in Istanbul from a Long-Term InSAR Time-Series (1992–2017). Remote Sensing. 2018, 10(3), 408, doi:10.3390/rs10030408.
Aslan G, Lasserre C, Cakir Z, Renard F, Ergintav S. (2018b) Shallow creep along the 1999 Izmit earthquake's rupture (Turkey) from high temporal resolution interferometric synthetic-aperture radar data (2011-2017) (Submitted)
Conference presentations/proceedings
Solaro, G., Bonano, M., Manzo, M., 2016, InSAR analysis of the crustal deformation affecting the megacity of Istanbul: the results of the FP7 Marsite Project as a GEO Supersite Initiative, EGU General Assembly
Havazli, E., Wdowinski, S., Amelung, F., 2017, Title, Interseismic Strain Accumulation of the Gazikoy-Saros segment (Ganos fault) of the North Anatolian Fault Zone [G43B-003] presented at 2017 Fall Meeting, AGU, New Orleans, LA, USA
Aslan, G., Cakir Z., Lasserre, C., Dogan, U., Cetin, S., Renard F., Ergintav, S., Surface Creep along the 1999 Izmit Earthquake's Rupture (Turkey) from InSAR, 05 - 09 June. 2017, Fringe 2017 meeting, Helsinki, Finland.
Emilie Klein, E., Duputel, Z., Masson, F., Yavasoglu, H., and Agram, P., 2017, Aseismic slip and seismogenic coupling in the Marmara Sea: What can we learn from onland Geodesy?, 23-28 April 2017, EGU General Assembly, 2018, Vienna, Austria.
Ozel,N. M., Necmioglu O., Ergintav, S., Ozel, A. O., Italiano, F., Favali, P., Bigarre, P., Cakir, Z., Geli, L., Aochi, H., Bossu, R., Zulfikar, C., and Sesetyan, K., 2017, MARSite–MARMARA SUPERSITE: Accomplishments and Outlook, 23-28 April 2017, EGU General Assembly, 2018, Vienna, Austria.
Aslan G, Cakır Z, Ergintav S, Lasserre C, Renard F. Identification of secular ground motions in Istanbul by longterm time-resolved InSAR analysis, 8-13 April 2018, EGU General Assembly, 2018, Vienna, Austria.
Aslan G, Lasserre C, Cakir Z, Renard F, Ergintav S, 2018, Surface creep along the 1999 Izmit earthquake's rupture (Turkey) from high temporal resolution interferometric synthetic-aperture radar data, 8-13 April 2018, EGU General Assembly, Vienna, Austria.
Yılmaz, Z., Konca, A. O., Ergintav, S., 2018, Interseismic Behavior of the Main Marmara Fault in the Marmara Region of Turkey, 8-13 April 2018, EGU General Assembly, 2018, Vienna, Austria.
Yamamoto, R., , Kido, M., Ohta, Y., Takahashi, N., Yamamoto, Y., Ozener, H., Kalafat, D.,

Pinar, A. and Kaneda, Y., Partial creep revealed by seafloor geodetic observation along the North Anatolian Fault, beneath the Sea of Marmara, 8-13 April 2018, EGU General Assembly, 2018, Vienna, Austria.

Kopp H., , Lange, D., Petersen, F., Royer, J., Sakic, P., Ballu, V., Çakir, Z., Ozeren,S., Henry, P., Ergintav, S. and Géli, L., 2018, 8-13 April 2018, EGU General Assembly, 2018, 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.*

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 products of the supersites are the scientific publications in the international literature (see list above). Normally, in academic communities, where publishing is emphasized, there is little reward for making research products accessible. Obviously, this needs extra manpower for the re-formatting of the products and sharing with scientific community from a web server.

There are no common formats available in InSAR software. In EPOS-IP, 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 the 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 very important efforts of Stefano Salvi (Chair of SAC) on the Supersite specific website organization. We are sure that it will be very important platform to share the data sets and the outputs in the future.

6. Dissemination and outreach

As a nature of the hazard related studies, we informed decision-makers at every appropriate opportunity. Within the Marmara Region Supersite, end users are defined as:

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

The outputs of the SAR related studies were shared with them in many public lectures, briefings and interactive project meetings.

The expected Marmara earthquake is an important matter of debate for the Turkish public. Supersite has provided a unique opportunity of research: the results of recent work using supersite data are also shared directly with the public using news networks and TVs.

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 Programme. 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.

A new project called *DISCREATE* (Discovery of Creeping Zones: towards to the realistic hazard map for Marmara, Turkey) will be funded (starting in May 2018) under the DFG (Germany) - TÜBİTAK (Turkey) bilateral cooperation program. The main task of the project will be to process all available data sets (Figure 12), 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. They will serve to the targets of EPOS-IP project on integrating and opening research infrastructures of European interest.

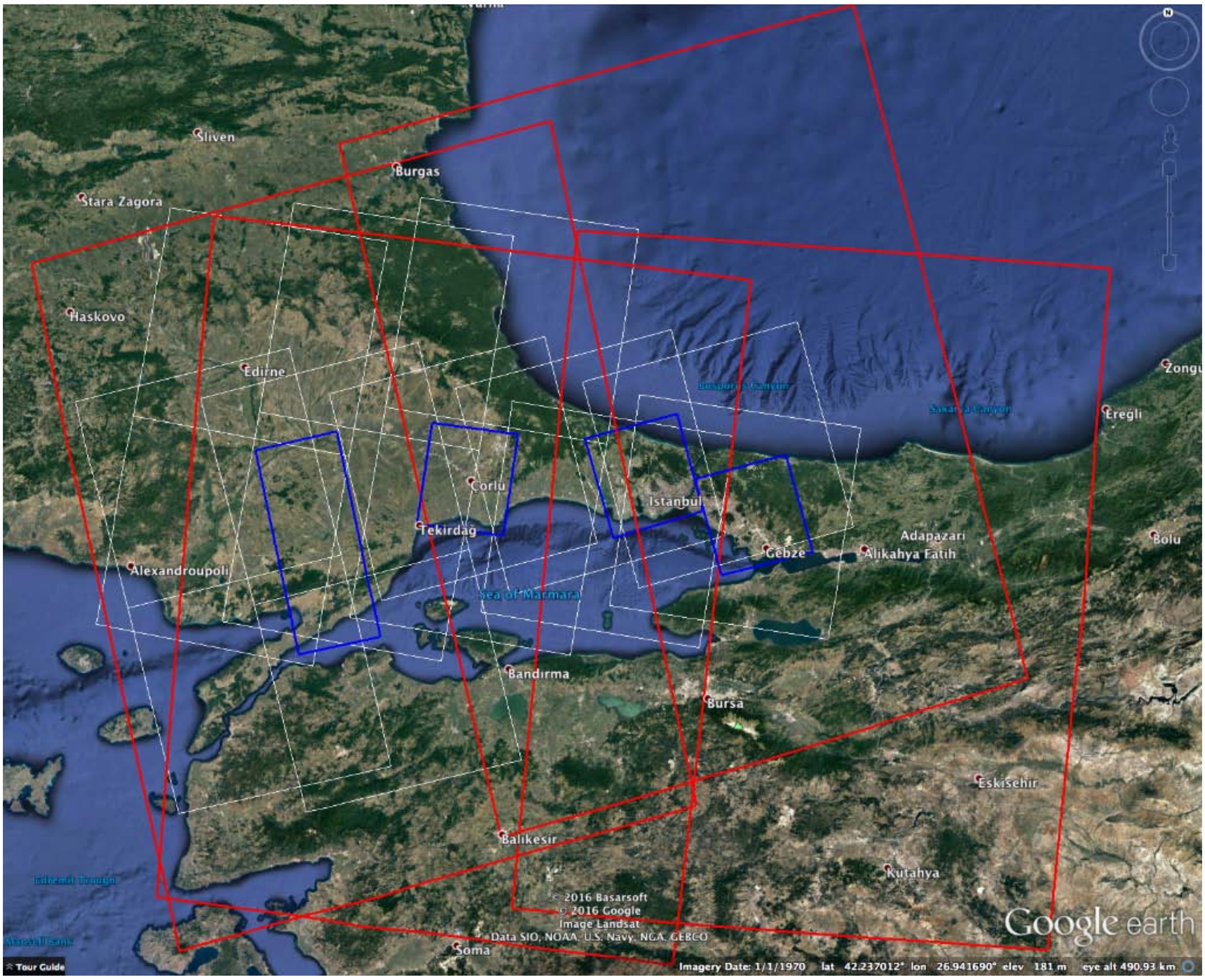

Figure 12. ENVISAT (white), Cosmo Sky-Med (blue) and SENTINEL 1A/1B (red) frames are shown in order to introduce some part of SAR data (to reduce the complexity, all SAR data frames are not shown) in Marmara Region Supersite and to demonstrate the SAR coverage around the Marmara.

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 controls 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 (<mm/year). The results can be regularly presented to the decision-makers in order to compare them with other data sets and interrupt the current state/changes in any local deformations (substances, landslides) and earthquakes. Then, decision-makers could be ready for the emergency management, via a rapid generation of critical information relevant to the co-seismic deformation event, using pre- and post-event imagery.

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, to Supersite SAR data in space agencies, 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. 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.

Supersites need a specific address to demonstrate the importance of a GSNL Supersite, to fund agencies in order to obtain the long-term sustainability. 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.