RESULTS AND ACHIEVEMENTS

This project has received funding from the European Union's Seventh Programme for research, technological development and demonstration under grant agreement N° [308417]

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MARsite ID card

Project acronym:	MARsite
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Key words:	Marmara Sea, Borehole Observation, Seismic Risk and Hazard
Coordinator:	Prof. Nurcan Meral Ozel - KOERI

Website: www.marsite.eu

Working plan

WP1 Consortium Management, assessment of progress and results obtained.

WP2 Data collection to detect the interactions and, thereby, to contribute to its seismic hazard assessment.

WP3 Long-term continuous monitoring of the crustal deformation.

WP4 Measure continuously the evolution of the state of stress of the fault

WP5 Real- and quasi-real-time Earthquake &Tsunami Hazard Monitoring, to be used in early warning applications will be implemented.

WP6 Improve the preparedness of those seismically induced landslide geohazards, through the using and the improvement of monitoring and observing systems in hydrogeotechnical and seismically well-constrained areas within the supersite.

WP7 Re-evaluation of the seismo-tectonics of the Marmara Region.

WP8 Monitoring seismicity and fluid activity near the fault using existing cabled and autonomous multiparameter seafloor instrumentation.

WP9 Early Warning and Development of the real-time shake and loss information for the supersite.

WP10 Integration of data management practices and coordination with ongoing research infrastructures.

WP11 Dissemination activities and public outreach strategy.

INTRODUCTION

To fulfil the requirements of the call, MARsite identifies a number of objectives that drive its implementation, the definition of the activities and the composition of the consortium.

The MARsite strategic objectives are to:

Achieve long-term hazard monitoring and evaluation by in-situ monitoring of: earthquakes, tsunamis, landslides, displacements, chemical-radioactive emission and other physical variables by the use of space-based techniques.

Improve existing earthquake early-warning and rapid-response systems by involving common activities, participants, competences, knowledge and experts from Europe.

Improve ground shaking and displacement modelling by the development/updating of source models and the use of probabilistic and deterministic techniques with real-time and time-dependent applications.

Pursue scientific and technical innovation by including state-of-the-art R&D in developing novel instruments and instrumentation.

Interact with end users and **contribute to the improvement** of existing policies and programs on preparedness, risk mitigation and emergency management.

Overview

In the last 12 years, Europe experienced destructive earthquakes such as 1999 Izmit (Turkey), 1999 Athens (Greece) and 2009 L'Aquila (Italy).

More destructive earthquakes happened earlier: Istanbul in 1509 and 1766, Izmir in 1688, Eastern Sicily in 1693 and Lisbon in 1755.

Such catastrophic event is now expected in the Marmara region, with a probability in excess of 65% in 30 years, due to the existing seismic gap and the post-1999 earthquake stress transfer at the western portion of the 1000km-long North Anatolian Fault Zone (NAFZ), passing through the Marmara Sea about 15 km from Istanbul.

Istanbul is fully aware of this impending problem and the authorities are in the process of taking all conceivable physical and social steps for preparedness and mitigation of the risk.

Nurcan Meral Ozel Project Coordinator for the MARsite Project. She is a is a member of the Geophysics Department at of Bogazici University –KOERI.

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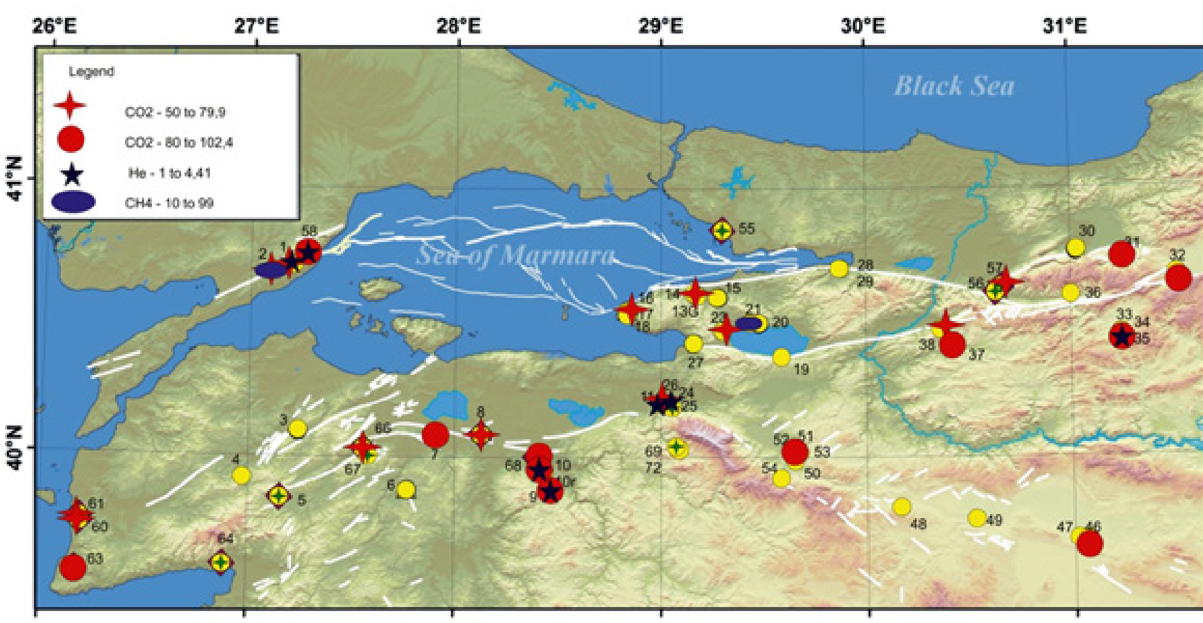
TABLE OF CONTENT

RESULTS OF THE FIRST MARSITE GEOCHEMICAL CAMPAIGN

Due to the close relationships between the movement of the Earth crust and the characteristics of circulating fluids (waters and gases) it was very important to gain an insight into the presence and composition of the fluids vented around the Sea of Marmara. To better understand what is going on in a seismic prone area, it is also of basic importance to intersect the information coming from different scientific disciplines that is, for the Marmara area, the geology, seismology, geodesy, fluids' geochemistry and the tectonic setting. The MARsite project has allowed us to build a comprehensive data set of fluids composition with an insight in the geochemical features of the fluids expelled from tectonic structures around the Sea of Marmara. A data server (MARsite Main Server) located at KOERI collects data from different disciplines including geodetic, geochemical data and the online seismic stations (71 in Marmara from KOERI, TUBITAK and KOU networks) at a rate of 50-100 samples per second.

The first results on the fluids' geochemistry of the area surrounding the Sea of Marmara allowed to gain a better insight on i) the geochemical features of the fluids expelled from tectonic structures around the Sea of Marmara, ii) the origin of the vented fluids, and iii) the occurrence of interactions processes. The data catalogue of 13 spring water and 21 soil radon gas stations in the Marmara region The data from the online spring water and soil radon probes are under evaluation.

Sampling of fluids from a natural hot spring (F. Italiano and C. Seyis, leaders of Task 1 and 3 in WP2 respectively)



Sites investigated for fluids expulsion around the Sea of Marmara

Francesco Italiano
senior scientist at INGV. Manger of several projects. He is carrying out investigations and monitoring in the shallow and deep sea, seismogenic faults and on active volcanoes.

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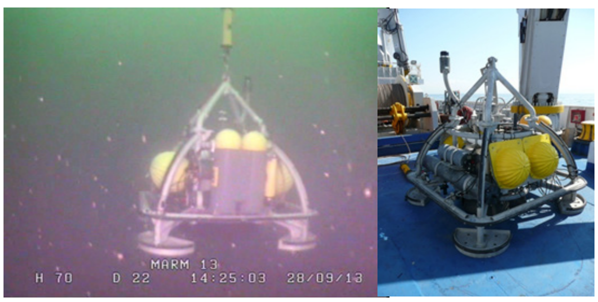
STUDY OF THE RELATIONSHIP BETWEEN FLUID SEEPAGE AND SEISMICITY

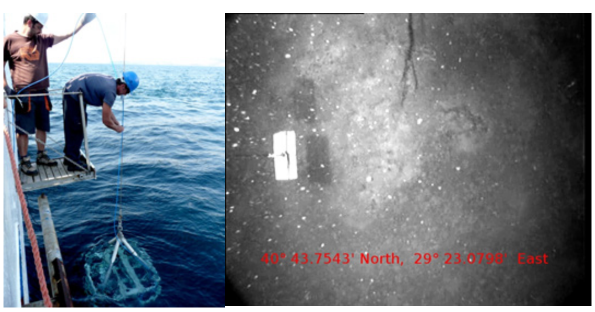
WP2&8

The evidence that the seafloor of the sea of Marmara shows clear clues of recent faulting related to the last destructive Izmit event and areas where fluids vents into the sea water, supports the possibility to gain a better insight of new faulting phenomena based on a monitoring activity carried out by both seafloor observatories and periodical observations of the venting fluids. A seafloor multiparametric observatory (SN4) was deployed and operated at the entrance of the Izmit Gulf to collect geophysical and geochemical data. SN4 data provides insight for methane emission and its relation with seismicity during the long term mission as well as data for sea state analysis (pressure, temperature, current direction and speed, dissolved oxygen concentration).

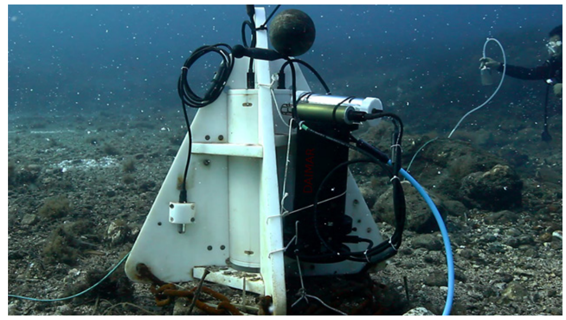


SN4 Seafloor observatory during the deposition operations (left) and on the vessel deck (right)

During the deployment cruise (r/v Urania, September 2013) a geophysical and visual survey in the area of seafloor observatory deployment was carried on in order to detect chemical (methane) vent on the seafloor using the vehicle "Medusa" . The picture below show the evidence of a seafloor fracture documented using the Medusa camera.

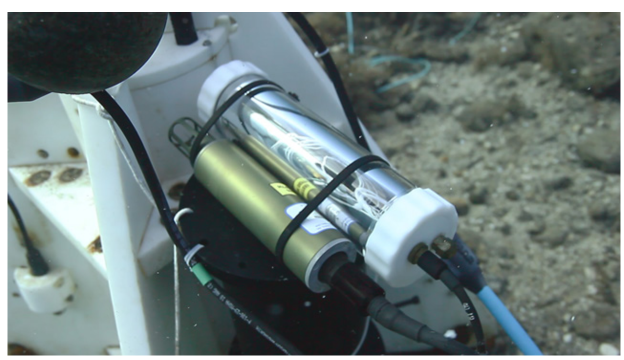


Marine operation for the Medusa survey in the area of observatory deployment (left) and a picture of the seafloor from Medusa camera, showing a fracture on the seabed (right).



Parts of the next generation of seafloor observatories (WP8) under test (offshore Panarea island, Italy; depth = 23 m)

The work carried out on the preparation of the next generation of seafloor observatories for geo-hazard monitoring produced new electronic devices (hi-tech, low power cards) and the plan for a new multidisciplinary observatory able to be deployed in hostile submarine environments where also fluids are released. The new electronics allow the contemporary collection of a large number of different sensors for physical, chemical and oceanographic parameters. The electronics as well as some probes and a new vessel are now under test in the hostile hydrothermal system located off the coast of the island of Panarea (Aeolian islands, Italy) where a marine infrastructure owned by INGV allows to communicate with the sensors installed on the observatory by the connection to a surface buoy.



Probes for temperature, CO2 and acoustics and the vessel (black container) under test at the sea-floor

Davide Embriaco
Researcher with a Degree and PhD in Physics. His major activity focuses on experiments with benthic observatories at deep sea.

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LONG-TERM CONTINUOUS GEODETIC MONITORING OF CRUSTAL DEFORMATION

Earthquakes continue to cause destruction around the world, including in the European region. In only the last twelve years, substantial damages and casualties were produced in 1999 Izmit (Turkey), 1999 Athens (Greece) and 2009 L'Aquila (Italy) to name just three damaging earthquakes. Earthquake records spanning two millennia indicate that, on average, at least one medium intensity (Io=VII-VIII) earthquake has affected Istanbul in every 50 years. The average return period for high intensity (Io=VIII-IX) events has been about 250-300 years, the last one of which was in 1766. Unfortunately, this type of catastrophic event is now expected in the Marmara region, with a probability in excess of 65% in 30 years, due to the existing seismic gap and the post-1999 earthquake stress transfer at the western portion of the 1000km-long North Anatolian Fault Zone (NAFZ), passing through the Marmara Sea about 15 km from Istanbul. The well-documented historical earthquakes in Marmara Region and the earthquakes occurred in the last century indicate that the segments of the NAFZ are seismically active and have the capability of generating destructive earthquakes.

The Marmara Region is fully aware of this impending problem and the authorities are in the process of taking all conceivable physical and social steps for preparedness and mitigation of the risk. Parallel to these efforts, local scientists have installed extensive on- and off-shore multi-disciplinary observation networks in the region. The Marmara Region has been monitoring by about 400 stations. Short period and broad-band seismology stations, strong-motion, GPS, soil radon, spring water and tiltmeter networks have already been installed in the study area. The city of İstanbul, one of the biggest cities in the World, has also earthquake early-warning and rapid-response systems.

Measurements, in the Marmara, provide one of the most complete geodetic records of deformation for any major continental earthquakes anywhere in the world with repeat GPS, InSAR, gravity, seismological observations. Hence, MARsite creates a link between the available and new data sets, comes from novel geo-hazard monitoring instruments including high-resolution displacement meters, novel borehole instrumentation and sea-bottom gas emission and heat-flow measurement systems.

Moreover, MARSite coordinates initiatives of important European partners focused on:

- To measure the tectonic strain accumulation across the metropolitan area and western section of the 1999 Izmit rupture by combining the InSAR and GPS data.
- To search for unknown faults to improve and spatially refine seismic hazard maps by using InSAR-derived maps.
- To image surface deformation caused by earthquakes and to constrain their focal mechanisms with greatest possible detail with the contribution of the continuous GPS and SAR data sets.
- To better determine the 4D postseismic deformation of Izmit earthquake with InSAR analysis in order to understand earthquake cycle processes with other relevant data sets and to constrain the seismic hazard models.

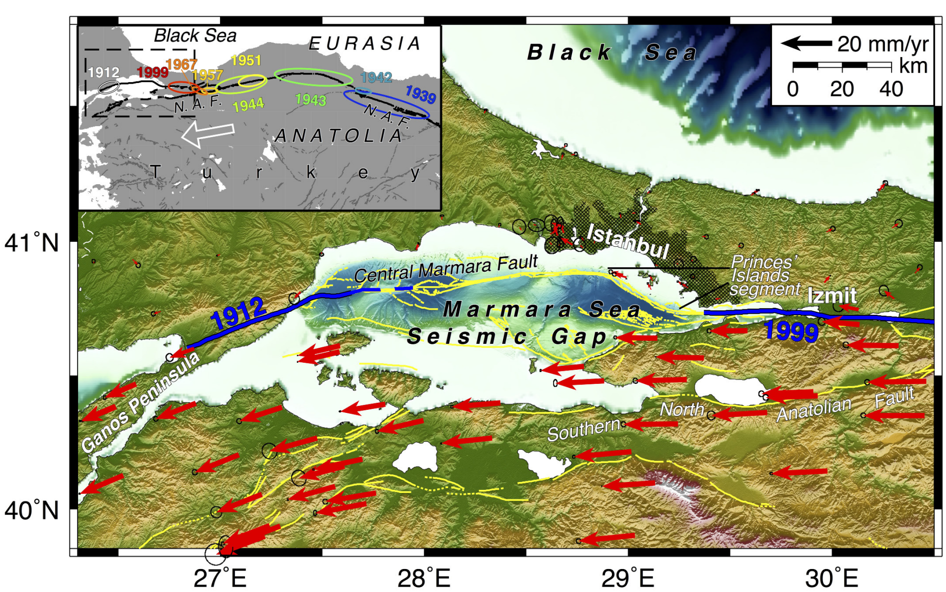

Figure 1. Sea of Marmara GPS velocities and 95% confidence ellipses plotted with respect to Eurasia. The inset shows the 20th Century, westward propagating sequence of major earthquakes on the NAF.

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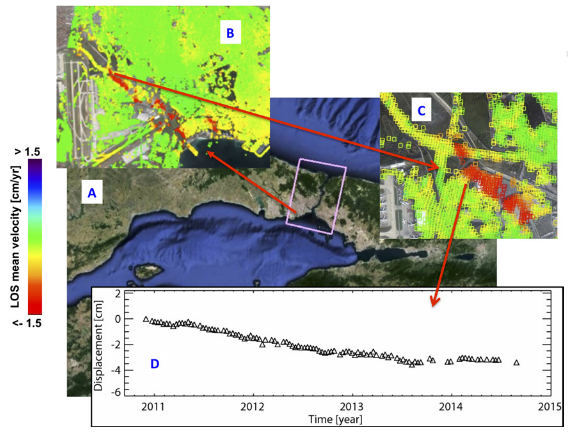

WP3

Figure 2. PSInSAR results, using X-band TerraSAR data. A) Marmara Region B) The sub-region, includes Ataturk Airport C) The sub-region, includes subsidence D) deformation rate in time of the sub-region in (C)

In this frame, we investigate the surface displacements affecting the Marmara Region via the exploitation of SAR data acquired by the different satellite systems, including the TerraSAR-X, Cosmo Sky-Med and Sentinel constellation. In particular, we benefit from SAR data archives already collected and to be acquired to generate, via the application of the Persistent Scatterers Interferometry (PSI) and of the Small BAseline Subset (SBAS) techniques, mean deformation velocity maps and corresponding time-series. The achieved results will be compared to the available independent ground displacement measurements (e.g. GPS data, Strainmeter) of the investigated areas.

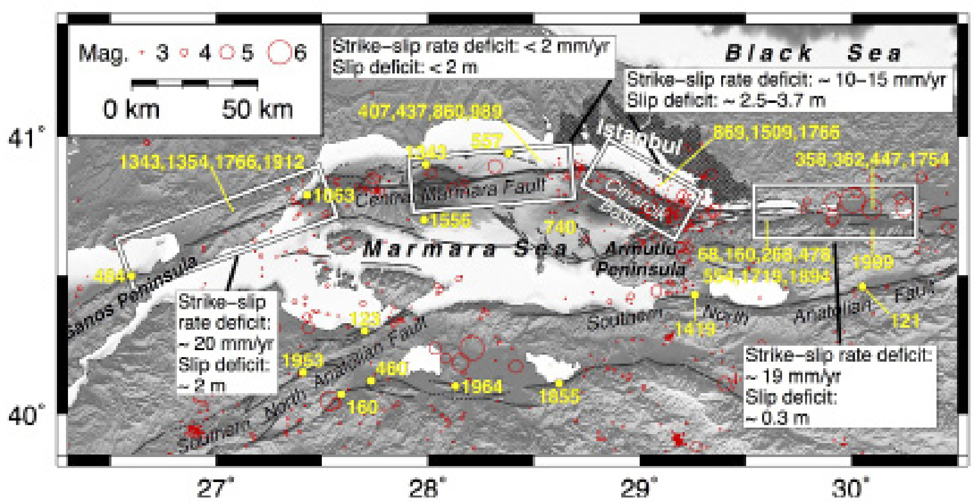

Figure 3. Map of historic earthquakes identified with particular fault segments in and around the Sea of Marmara. Faults and precisely located earthquakes, and estimated slip rate deficits and the total deficits accumulated since the last major earthquakes are also shown.

Such a long-term deformation analysis is crucial for the definition of the seismic hazard assessment. Indeed, the retrieved space-time information on the ground displacements can be properly exploited to better comprehend/model/ interpret the physical processes behind the observed deformation phenomena at different temporal and spatial scales.

The effectiveness of seismic hazard assessment in Marmara (including Istanbul) is directly linked to the knowledge on the parameters describing the rates of activity of the various seismic sources, as maximum magnitude earthquake, slip per event, slip rate, recurrence interval, time of last event. Some of these parameters can be estimated by inverting InSAR data via analytical or numerical fault models. Moreover, the availability of large SAR archives is strategic in case of a seismic event. Indeed, it assures the possibility to generate co-seismic interferograms for a rapid mapping of the co-seismic ground deformation during the first emergency phases, providing a clear picture of the occurred displacements by giving information about the spatial extension and the entity of the ground deformation field.

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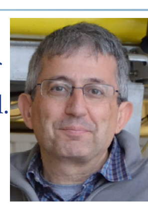

KOERİ , established in 1868 is the excellent institution of Bogazici University. Is operating as the Regional Earthquake – Tsunami Monitoring Center. Has a dense urban network in and around Istanbul.

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Project coordinator: N. Meral Ozel (KOERI)
Design: EMSC
Project manager: Meral Alguadis

ACHIEVEMENTS IN BOREHOLE SEISMOLOGY

Thousands of people lose their lifes and dwellings due to natural disasters (earthquakes, volcano eruptions, landslides, flooding etc.). In the last decades many challenging efforts have been setting out on the world to mitigate the hazards of the natural disasters. Especially technological developments make these efforts very effective. As one of these efforts, the Marsite Project aims to bring together scientists with complementary experience to discuss the analyses of long time series of high-resolution seismological, geodetic, geochemical, geological and geophysical data to identify and constrain tectonic processes, the identification of transient signals and slow deformation processes, the observations on earthquake initiation and propagation, triggering mechanisms, the analyses of seismicity patterns, repeaters and temporal changes in crustal condition and the underlying physics.

Faults are natural systems whose mechanical conditions evolve with time. Thus the understanding of the multi-scale physical and chemical processes controlling faulting and earthquake generation requires the availability of high-quality multidisciplinary data. Near-fault observatories are research infrastructures implemented worldwide to collect diverse data around active faults over long observational times. They are natural laboratories that promote multidisciplinary investigations.

The Work Package 4 (WP4) is one of the WP's of Marsite and the main objective of this WP is to install a multi-parameter borehole system and surface earthquake recording array as closest to the Main Marmara Fault (MMF) in the western part of the Marmara Sea and continuously the evolution of the state of stress of the fault zone surrounding the MMF and to detect any anomaly or change which may occur before earthquakes by making use of the data from the earthquake recording arrays running in the eastern part of the Marmara Sea. On the other hand, WP4 covers monitoring rupture nucleation and propagation using the data from these networks, identifying the presence of repeating earthquakes along the MMF, better understanding the existing seismically active structures (Figure 1) and their role in local tectonic settings and searching for low frequency events (non-volcanic tremor) from continuous recording.

In an attempt to understand where and when large earthquakes will occur, and the physics of the source process prior to large earthquakes, we proposed to install multi-parameter borehole instruments, capable of recording small deformations and tiny seismic signals near the active seismic zone of the North Anatolian Fault passing through the Marmara Sea, which should enable us to address these issues.

As an innovative part of the project, the objective of the WP4 is to design and build a multi-parameter borehole system and to observe slow deformation, low-frequency noise or tremors, and high frequency signals near the epicentral area of the expected Marmara earthquake.

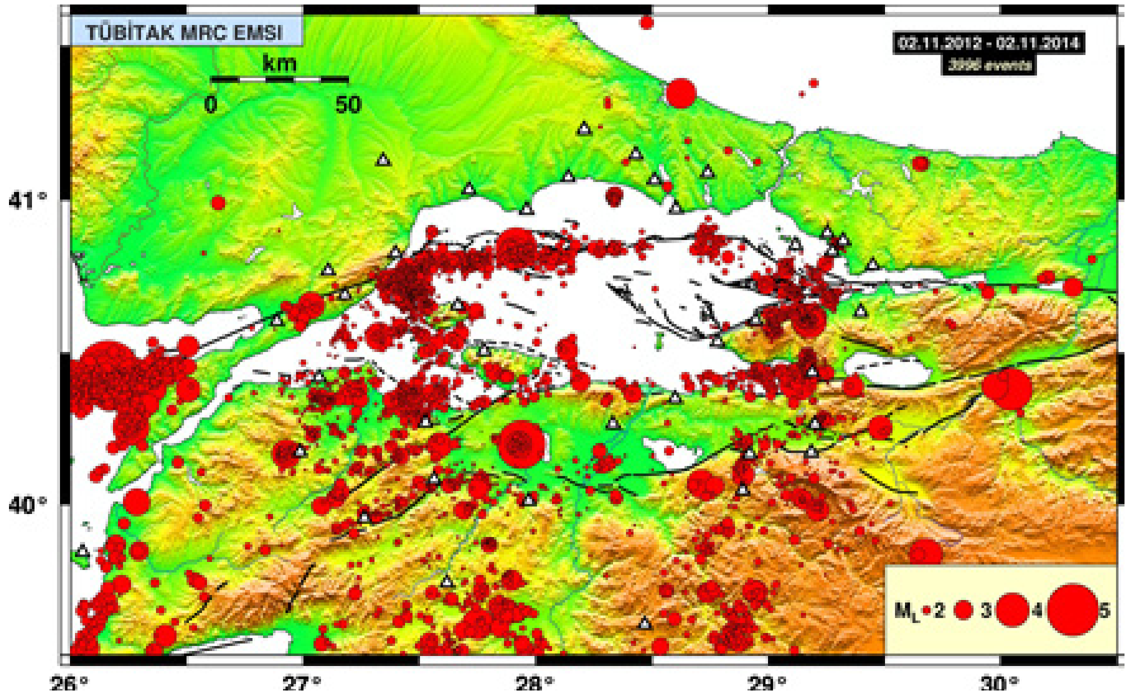

Figure 1.:Micro earthquake activity in western part of the Marmara Sea from the beginning of the project to the present.

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WP4

The proposed location of the borehole system is right on the Ganos Fault and in a low ambient noise environment in Gazikoy, where the Ganos Fault goes into the Marmara Sea (Figure 2). The proposed instrumentation consisted of broadband seismometer with very wide dynamic range, strain meter, tilt meter, hydrostatic pressure meter and thermometer. These instruments have been installed in 150m deep borehole.

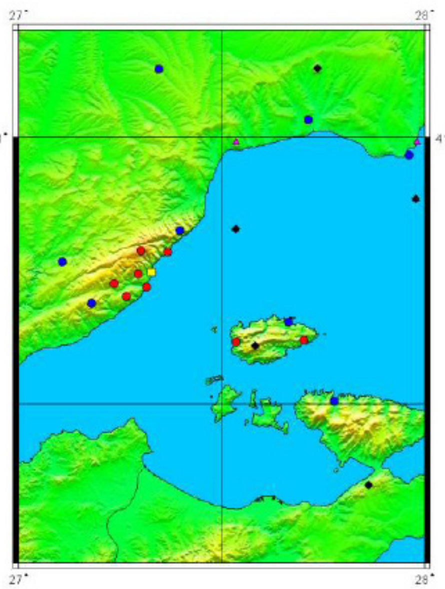

Figure 2. The location of multi-parameter borehole system (yellow rectangle) and surface array recording sites (red circles).

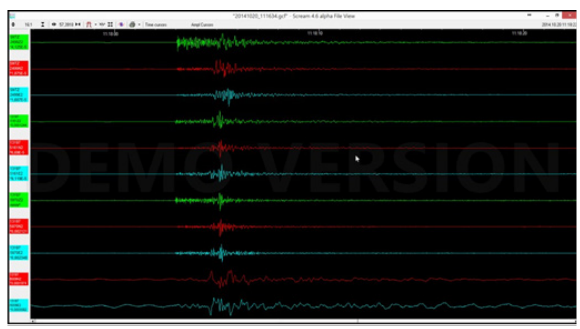

Figure 3: The event (M=1.9 on 20.10.2014) recorded by the borehole system. The top three channels belong to the broad band seismometer at the surface and following 6 channels are accelerometer's 3-component channels and very broad band seismometer's channels in the borehole, respectively, and the last two horizontal channels are from tiltmeter.

Figure 4: Scene from the multi-parameter borehole system installation

Additionally, a surface microearthquake observation array, consisting of 8-10 seismometers around the borehole have been established to obtain continuous high resolution locations of micro-seismicity and to better understand the existing seismically active structures and their roles in local tectonic settings.

The multidisciplinary borehole system data and surface array data are transmitted in real time to Kandilli Observatory and the data is available to all the members. The quality of the recorded local earthquake events both as strong motion and the broad band velocity sensors are exceptionally good. In a similar way the recorded long period tele-seismic signals are also good (Figure 3). However the very long period data extending in to 200 to 2000 seconds and beyond (longer) appears to have very long-term-drift associated signals which need to be investigated. Long period signal study requires extensive length of time to understand the nature of the signals.

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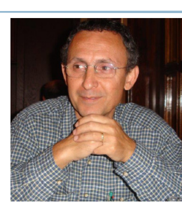

Istanbul University
Being established in 1453, Istanbul University has more than 5000 academics. Its educational activities range from bachelor to doctoral degree in 20 faculties and 18 institutes.

Project coordinator: N. Meral Ozel (KOERI)
Design: EMSC
Project manager: Meral Alguadis

REAL- AND QUASI-REAL-TIME EARTHQUAKE &TSUNAMI HAZARD MONITORING

Within WP5, 16 GPS sites have been updated and instrumented by strong ground motion equipment to make available the real-time data transmission from Marmara. The acquisition and harmonization of real time GPS and Strong Motion time series will provide excellent time resolution of real time earthquake monitoring and also provide to measurements of tectonic strain accumulation across the Marmara Fault zone.

Synthetic scenarios for the 1999 Duzce earthquake have been simulated and the variability of the ground motion have been investigated. For the Marmara region, various structural models in 1- and 3-D have been studied and simulated ground motions have been compared showing the significant improvements in the waveforms using the 3D model. Two different finite-fault techniques have been proposed and tested with the principal aim to assess the performance of the inversion codes in the Marmara configuration. The study showed how the proposed inversion techniques guarantee a reliable and accurate reconstruction of earthquake source rupture process on finite fault, in the Marmara tectonic and observational setting configuration.

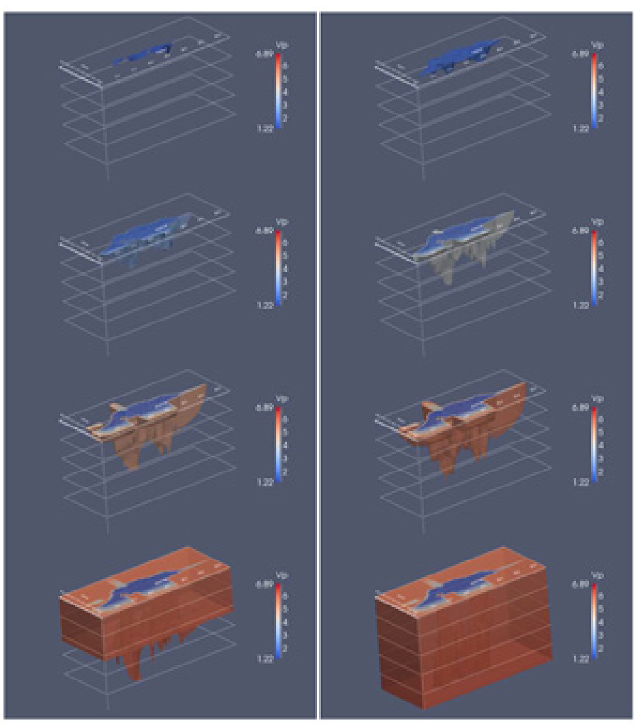

Figure 1: Representations of the 3D structural model of Bayrakci et al (2013). The horizontal planes in the each panel indicates every 2.5km along depth. The first panel represents the volume with Vp in the range 0 – 1.5 km/s. Similarly the following panels corresponds the volumes for a Vp equal or slower than 2, 3, 4, 5, 5.5, 5.9 and 6.1 km/s, respectively.

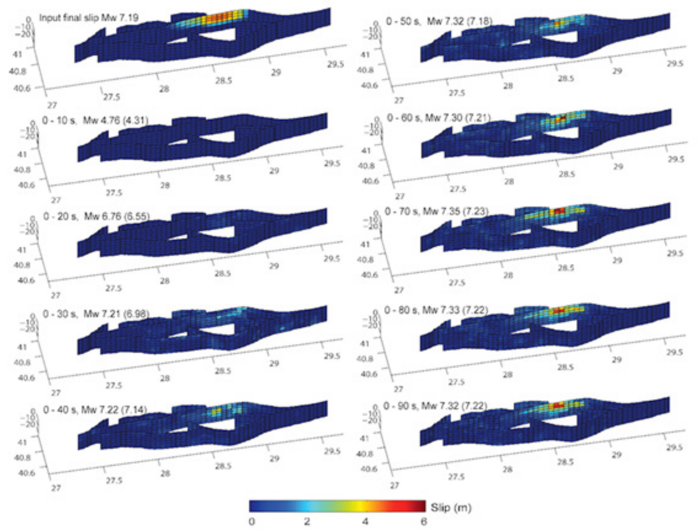

Figure 2: Comparison between the input (top left) and real-time reconstructed slip models. The moment magnitudes outside the brackets are inferred from the seismic moment distributed on the whole fault system, while that in the brackets corresponds to seismic moment located on the main rupture fault.

The proposed analysis represents a useful tool to assess the performance of a finite-fault inversion code, by taking into account the actual or future planned stations configuration (strong motion, cGPS, GPS, BB) in the Marmara Sea and earthquake scenarios.

Another study group focused on the rapid determination of the most relevant earthquake source parameters, with special focus on their finite-fault characteristics, in case of large earthquakes in the Marmara region. For purposes of tsunami early warning and earthquake rapid response, time-dependent finite-fault source inversions are of great importance. To this goal, a blind test for kinematic source inversion have been performed. A synthetic dataset, by considering near-field strong-motion and high-rate GPS data, obtained by dynamic modelling of a single earthquake scenario, had been generated, to invert for the rupture process, by using the different codes. This approach allowed to assess the resolution and efficiency of the different inversion techniques, also in terms of the execution quickness, in the Marmara Sea configuration. The obtained result, for the blind test, show that, by inverting near-field strong-motion and high-rate GPS data in the Marmara Sea we are able to provide a rapid (CPU between 2 and 13 minutes) and reliable reconstruction of the rupture process of large earthquakes, by retrieving the most relevant earthquake source parameters. These analyses can be done in near real time and are particularly suited for capturing near- source large earthquakes.

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WP5

The proposed approach represents a helpful tool to improve rapid ground-motion simulations in case of large earthquakes in the Marmara region. Moreover, according to the test results, near real-time source characterization of large-scale earthquakes (Mw>7) under the Marmara Sea is feasible. Providing the real-time data acquisition for the current network and a good database of the active fault system, all key source parameters that are relevant for purpose of the rapid hazard assessment can be estimated without substantial uncertainties. The theoretical time delay between what can be resolved and what has been really occurred on the earthquake source is in the order of 10-15 s. The cause of this time delay is mainly physical, namely by the S wave propagation from the source to the network. In practice, a slightly larger time delay should be considered because of the time to be required additionally for the data transmission and inversion. The latter, however, can be generally reduced to a few seconds through parallelization of the IDS inversion technique.

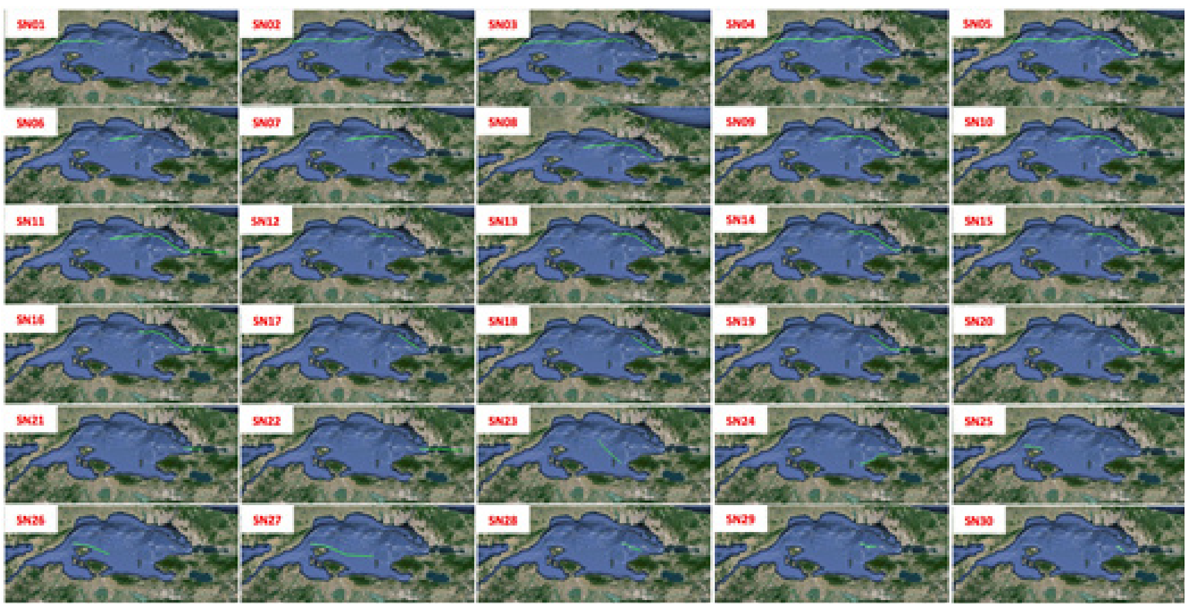

Figure 3: Map representation of the earthquake scenarios considered for the creation of the tsunami scenario database.

WP5 also aimed to introduce the dynamically simulated earthquake scenarios with weighting function in the deterministic ground motion simulations, where each simulation provides the estimation of the particular ground motion based on the hypothesis that assembling different simulations would allow to discuss statistically the probability and the variation of ground motion at selected sites.

Due to the very short travel times in Marmara Sea, a Tsunami Early Warning System (TEWS) cannot rely on real-time calculations and has to be based on a pre-computed tsunami scenario database to be queried in real-time, basing on the initial determination of earthquake hypocentre and Magnitude, but also on dislocation models calculated from real- time inversion of geodetic and seismic data similarly to e.g. the GITEWS in Indonesia. To address this problem, 30 different earthquake scenarios with maximum credible Mw values have been identified to produce a detailed scenario database for all possible earthquakes in the Marmara Sea with a tsunamigenic potential.

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BOĞAZİÇİ UNIVERSITY KANDİLLİ OBSERVATORY AND EARTHQUAKE RESEARCH INSTITUTE 1868

Project coordinator: N. Meral Ozel (KOERI)
Design: EMSC
Project manager: Meral Alguadis

A COLLABORATIVE EARTHQUAKE-INDUCED LANDSLIDES STUDY

As one of the three Supersite concept FP7 (EU's Seventh Framework Programme for Research) projects dealing with long term high level monitoring of major natural hazards at the European level, the MARsite project (Nov 2012-Nov 2015) assembles research groups in a comprehensive monitoring activity developed in the Sea of Marmara Region, one of the most densely populated parts of Europe and rated at high seismic risk level since the 1999 Izmit and Duzce devastating earthquakes.

Supersite is an initiative of the geohazard scientific community. The Supersites provide access to space borne and in-situ geophysical data of selected sites prone to earthquake, volcano or other hazards.

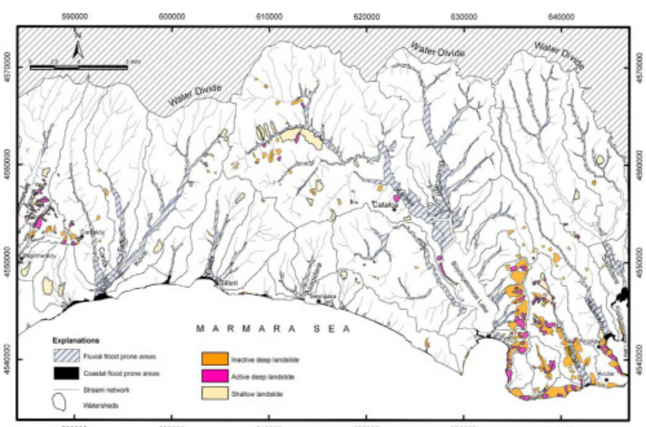

Figure 1: Landslide distribution map of the area (from Duman et al., 2005).

The 6th Work Package of MARSITE project gathers 9 research groups (INERIS, IU, ITU, TUBITAK, INGV, CNR, University of Pavia, IFSTTAR - University of "La Sapienza") to study earthquake-induced landslides, focusing on the survey and monitoring of two sub-regional areas of high interest.

The research aims to improve the preparedness of those seismically induced landslide geohazards, through the using of surveying, modelling and monitoring approaches.

First, the Cekmece-Avcilar peninsula, located westwards of Istanbul, is a highly urbanized concentrated landslide prone area (Fig.1), showing high susceptibility to both rainfalls while affected by very significant seismic site effects. Second, the off-shore entrance of the Izmit Gulf, close to the termination of the surface rupture of the 1999 earthquake, that shows an important slump mass facing the Istanbul coastline.

A multidisciplinary research program based on pre-existing studies has been designed with objectives and tasks linked to constrain and tackle progressively some challenging issues related to data integration, modeling, and monitoring.

For the on-shore area, this program included the refined analysis of the seismic site response, the installation of a permanent multi-parameter ground monitoring of a representative unstable slope as well as the in-depth slope stability analysis based on the stress-strain dynamic numerical modelling approach.

After refining the landslide inventory of the peninsula, one landslide (Beylikdüzü landslide) was chosen as pilot site (Fig.2) as it resulted the most dangerous due to the highest susceptibility to seismically-induced re-activation and to the highest exposition of buildings and infrastructures referred to the last decade (i.e. after the 1999 Izmit earthquake occurrence). In this landslide area were carried out geophysical campaigns and a field permanent multi-parameter observatory was set up, composed of GPS-RTK, borehole- and surface-seismometers thermometer, rain-gauge, moisture, etc.. Hyperspectral and Dinsar imagery technologies are also deployed to complete inventory and observational information.

Concerning, the modelling of the seismic response and displacements of the pilot landslide, the first step was to have an adequate engineering-geological model. A first engineering-geological model was reconstructed on the basis of extensive geological and geomorphological field campaign and a vast drilling program undertaken by the Istanbul Metropolitan Area.

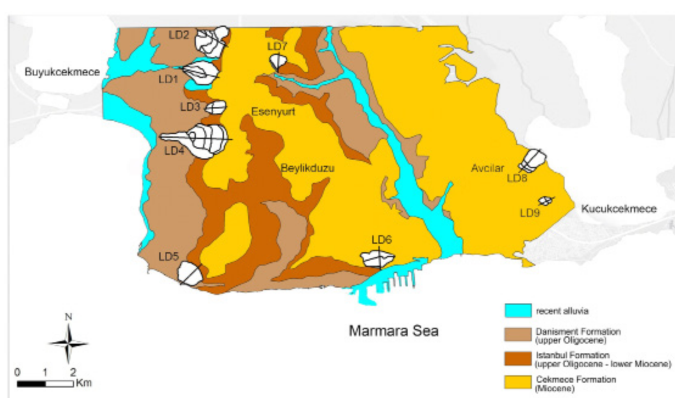

Figure 2 : Study area and inventoried rototranslational landslides. LD4 is Beylikdüzü landslide.

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WP6

Based on a detailed engineering-geological model of the landslide slope, a not-conventional pseudostatic slope stability analysis (Figure 3) was performed by considering a pseudostatic force distribution within the landslide mass according to a specific wave form instead of a conventional constant pseudostatic force. Numerical simulations of the seismic response in the landslide slope were also performed aiming at evaluating the role of geological and structural setting of the slope on the landslide displacements in case of expected earthquakes.

As regards the selected off-shore area, high resolution geophysical marine surveys are being conducted to complete its geomorphological description to help in mapping possible incipient mass movements. This provided better-constrained input for both laboratory testing and numerical modeling of tsunami scenarios thank to a unique lab-scale tsunami channel.

Moreover, the undertaken research in WP6 gained high profit of a vast drilling program (IBB project) undertaken by the Istanbul Metropolitan Area, aiming to yield a detailed geological and geotechnical characterization of the slopes throughout the west part of the Cekmece-Avcilar peninsula. Thanks to the TUBITAK partner it was possible to benefit of some of the important results of this field investigation program in this European project and, in addition, to use one borehole to set up the local seismic observational network on the very slow massive landslide (Beylikdüzü landslide - pilot site).

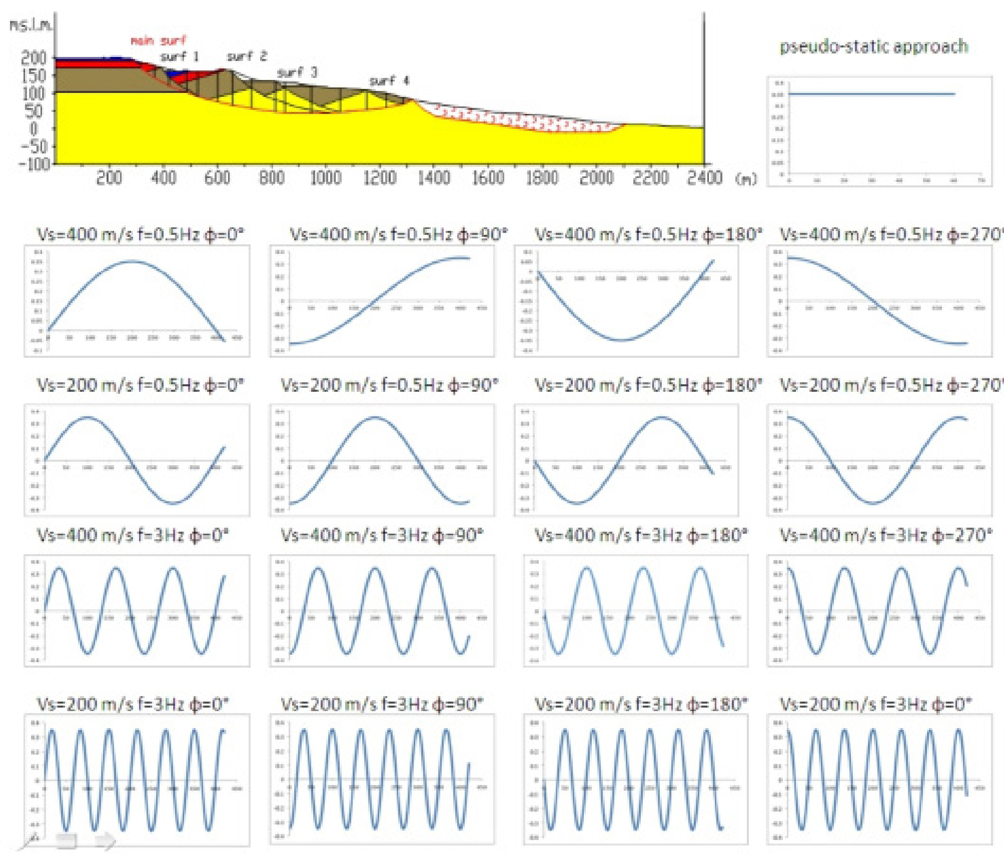

Figure 3: Conceptual sketch of the here performed not-conventional pseudostatic slope stability analysis.

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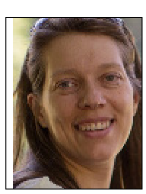

INERIS
Public institute; its mission is to provide expertise, scientific and technical assistance aimed at preventing risks.

INERIS
maîtriser le risque pour un développement durable

RE-EVALUATION OF THE SEISMO-TECTONICS OF THE MARMARA REGION

In the WP7, we aim to re-evaluate the seismo-tectonics of the Marmara Region in terms of revising the active fault map and establishing the history of the tectonic activity both since its origination in the medial Miocene and the historical times (past earthquake record).

Complex series of tectonic processes, related to the evolution of the Thrace Basin, The North Anatolian Shear Zone and the Sea of Marmara, create several basins within the Marmara Region. The Thrace Basin evolved during the early to medial Eocene as a fore-arc basin. Following the closure of the Intra-Pontide ocean, the basin converted into a remnant forearc and continued accumulating sediments with calc-alkaline volcanic rocks. This structure related to the paleotectonic era is superimposed with a dextral shear zone from medial Miocene onward. The evolution of a wide shear zone began in the medial Miocene and still continues with various tectonic structures, representing the pre-peak, peak, post-peak and pre-residual stages of classical shear zone evolution. The Sea of Marmara probably formed during the Pliocene to Pleistocene along a variety of Riedel and P-shears of the post-peak and pre-residual structure stages [Görür and Elbek, 2013].

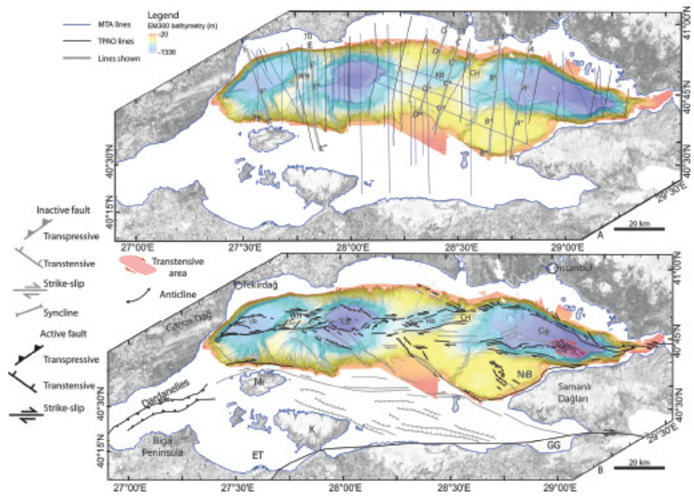

Figure 2: The revised active fault of the Sea of Marmara [Şengör et al. 2014]

In the frame of the MARsite project, all faults younger than Oligocene were mapped by using additional 210 multichannel reflection profiles, adding up to 6210 km profile length and high resolution bathymetry and chirp profiles reported in the literature for the Sea of Marmara. As the shear zone evolves, faults of all orientations become activated and deactivated in tendency where all movement has being confined to a narrower zone with time since the inception of the shear zone [Şengör et al., 2014].

The rich historical records clearly show high seismicity for the Sea of Marmara and the surrounding region especially for the last 2500 years. Paleoseismological studies increased significantly after 1999 İzmit and Düzce earthquakes. These two destructive events stimulated not only land-based "trenching" studies, but also sub-aqueous paleo-earthquake coring surveys. The Ganos Segment, the most western on-land segment of the northern branch of the North Anatolian Fault (NAF), was last ruptured during the 1912 Mürefte Earthquake (M 7.4). The trench studies revealed at least 6 paleo-events during the last 2250 years at multiple locations along this section of the NAF.

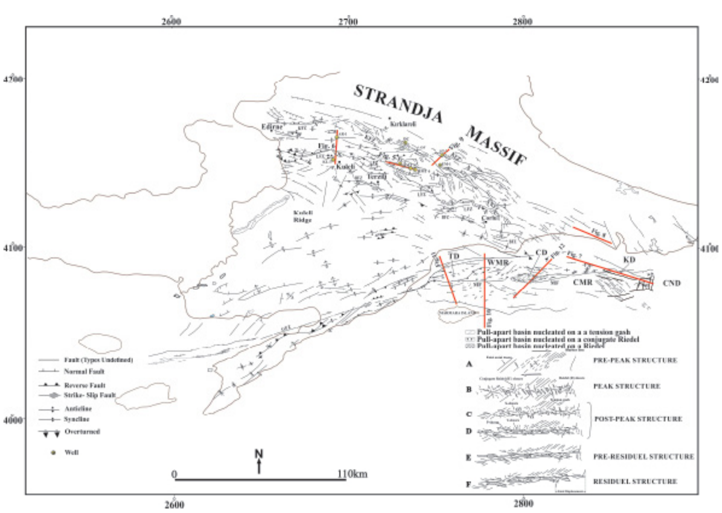

Figure 1: Structural map of the Thrace Basin (Görür and Elbek, 2013).

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WP7

In Sea of Marmara, the sediment cores yield a longer history, including up to about 13 paleoevents. The most significant result is the absence of any seismoturbidites in the cores, recovered from the Kumburgaz Basin for the last 15 ka, except a finding possibly related with the 1963 event. This is simply interpreted to be the supporting evidence of creeping processes for the central segment of the Main Marmara Fault (MMF).

The onland sections of the NAF last ruptured during the 1999 earthquakes in the eastern Marmara Region. Trench studies conducted on different locations revealed at least five surface-rupturing events in the last 2000 years. Although the AD 1719 event is thought to be identical to the 1999 İzmit earthquake (M 7.4), a prior one, the 1509 earthquake, was found to extend from the İzmit Bay towards the east as far as to the Sapanca Lake. Moreover, trenching and offset measurements show non-characteristic behaviour for the NAF section, crossing the Hersek Delta, where there was no significant displacement during the 1999 earthquake. A post-Justinian pipe was measured to have an offset about 10 metres in this location [Kozacı et al, 2012]. Contrary to the northern branch, there is relatively information on the paleoseismology of the southern branch of the NAF.

A single sub-aqueous study yields a single paleoevent (AD 368 or 447 or 460) from the sediment cores of the Manyas Lake. Trenches on the Yenice-Gönen Segment revealed at least two dated paleoevents (AD 1953 and 1440) for the southern parts of the fault zone. In order to have a better understanding on the seismic behavior of the poorly known southern branch, we conducted new paleoseismological trenching at various locations between the Gemlik Bay and Geyve. The preliminary results clearly show significantly longer interval of earthquake recurrence for the southern branch of the NAF.

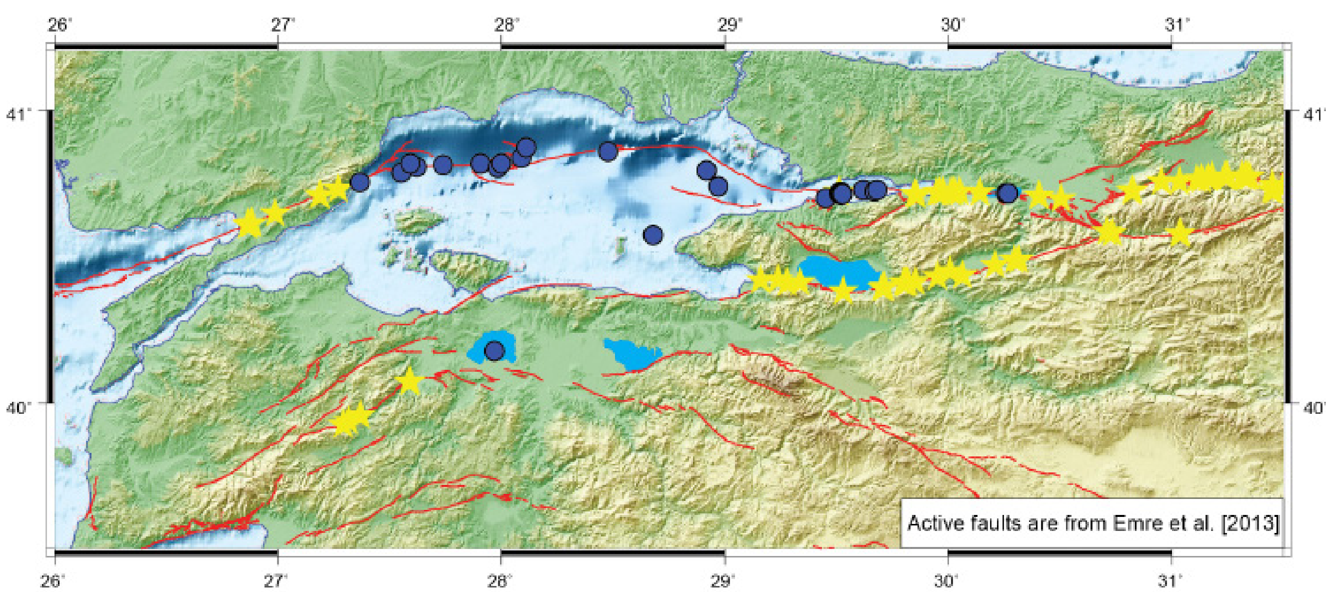

Figure 3: The paleoseismological studies conducted in the Marmara Region. Yellow stars are for onland trech studies, whereas blue circles represent sub-aqueous coring surveys

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GAS RELATED SEISMICITY WITHIN THE MARMARA SEISMIC GAP

The heavily populated Istanbul area, along the North Anatolian Fault, is considered to be collocated with an earthquake gap below the Sea of Marmara, which has not been filled for the last 250 years. Hence, the seismicity of the Main Marmara Fault (MMF) has been the subject of extensive studies since the devastating earthquakes 1999, with the objective to determine the mechanical behaviour of the different, submarine fault segments and to better assess the seismic hazard in the region. Both geological and geophysical, marine investigations have revealed the geometry of the submarine Main Marmara Fault (MMF) system. Seismological studies have shown that the seismicity along the MMF exhibits a strong lateral variability and concentrates in spatial and temporal clusters.

The western part has been shown to exhibit clusters of seismicity. Their origin has been interpreted only in terms of being tectonic-driven. The data collected during the Marsite Project has revealed that gas-induced, shallow seismicity should also be considered for interpreting these seismicity clusters. Our approach is guided by the recent discovery that the MMF in the Western Sea of Marmara cuts a hydrocarbon reservoir as part of the Thrace Basin. Special focus is given on the characterization of the aftershock sequence that followeda Mw 5.2 earthquake that occurred below a mud volcano-like, diapiric structure rising below the Western High, within less than 1 km away from the fault zone.

Three-dimensional high-resolution seismic imaging as well as heat flow data and geochemical indicators all indicate that this feature and the MMF provide gas migration pathways from a gas reservoir at ~3 km depth below seafloor. Using seismological data from a submarine sensor network deployed on the deep Marmara seafloor, we find that most of the events of the aftershock sequence are also located within the ~ 2-4 km depth-range.

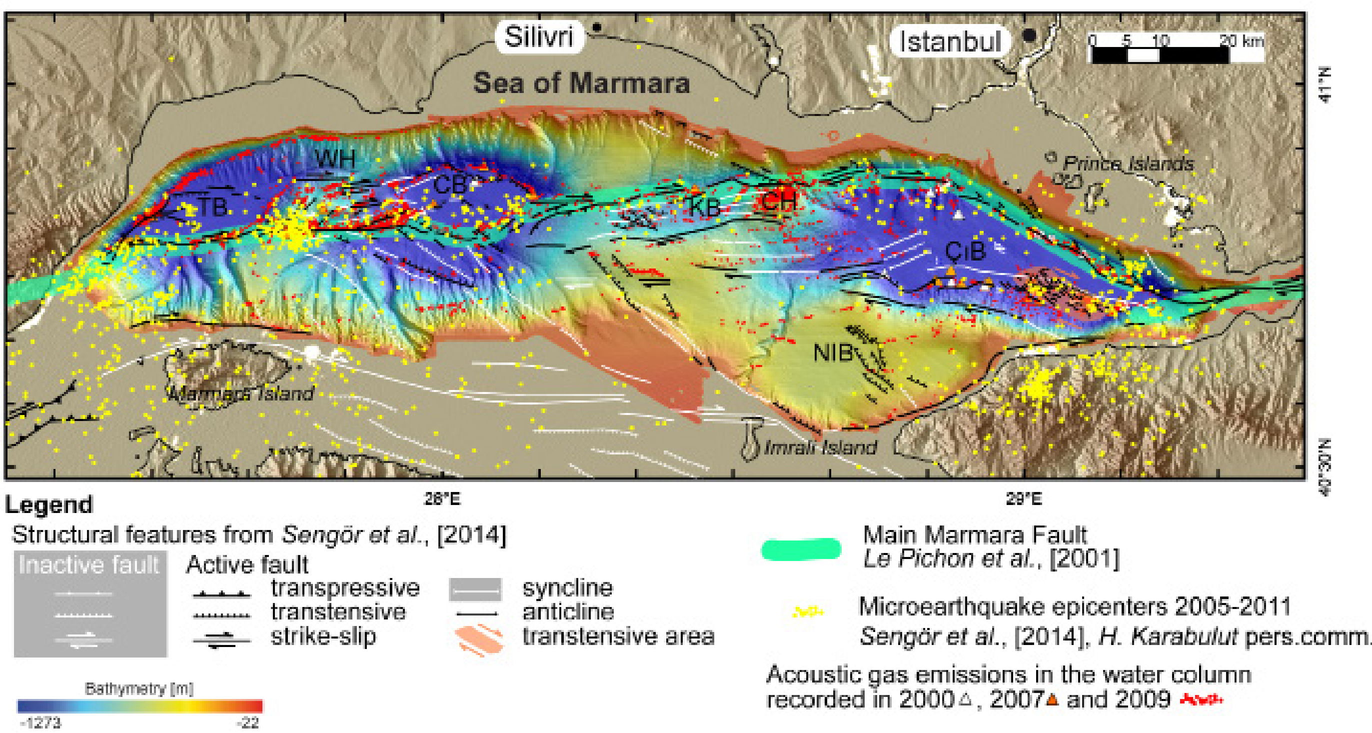

Figure 1 [after Dupré et al, 2014]: Fault networks from Şengör et al. [2014] with the offshore extent of the Eocene Thrace Basin from Le Pichon et al. [2014]. Yellow dots indicate microearthquake epicenters (yellow dots) recorded between 2005 and 2011 [Şengör et al., 2014; H. Karabulut, personal communication, 2014].White, orange, and redmarks stand for water column acoustic anomalies recorded in 2000, 2007, and 2009, respectively. The maps illustrate the 2009 seepage activity overmore than 1 month (from 4 November 2009 to 14 December 2009). Each of these acoustic anomalies is displayed as a 150m radius red dot. TB, Tekirdağ Basin; WH, Western High; CB, Central Basin; CH, Central; KB, Kumburgaz Basin; ÇıB, Çınarcık Basin; NIB, North Imrali Basin.

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WP8

The coincidence between the two independent observations supports the hypothesis that the shallow aftershock sequence occurred within the gas reservoir. This example strongly advocates for the need to discriminate shallow, gas-related seismicity from tectonic seismicity using permanent, deep seafloor observatories in the immediate vicinity of the fault, in order to properly characterize the Istanbul seismic gap.

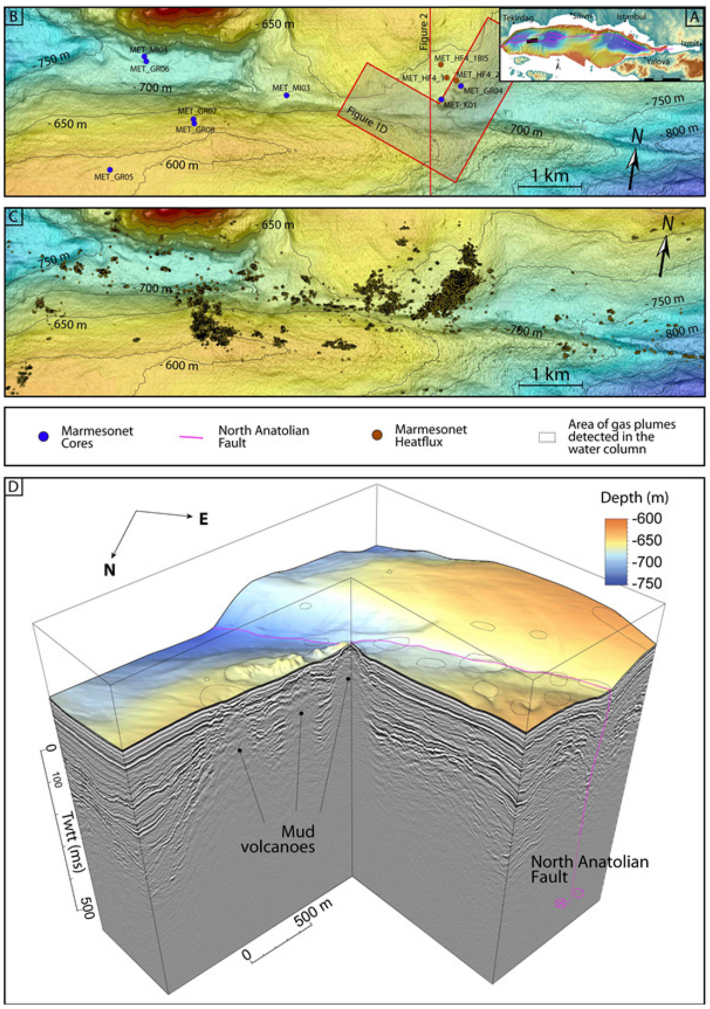

Figure 2: A) Inset indicates the location of the area surveyed with High-Resolution 3D seismics [Thomas et al, 2012]. B) Detailed bathymetry of the survey area, inferred from HR-seismics, with a lateral resolution of 5m. C) Same as 2D, with location of gas emissions sites (balck dots) detected during the Marmesonet cruise of R/V Le Suroit in 2009. D) Detailed 3D view showing the geometry of the mud-volcano complex relatively to the North-Anatolian Fault Zone (purple line).

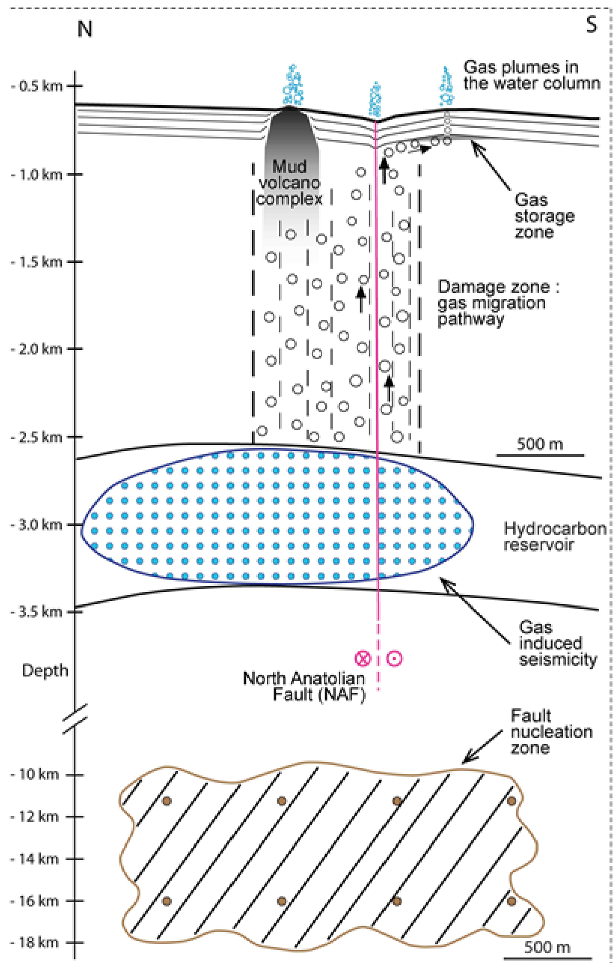

Figure 3 : Sketch summarizing our hypothesis to explain the seismicity pattern observed below the Western High, distributed in 2 zones, respectively located at shallow level (~2 to 4 km below seafloor) within the gas reservoir and at crustal (~10 km bsf) level.

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EARLY WARNING AND DEVELOPMENT OF THE REAL-TIME SHAKE AND LOSS INFORMATION

Istanbul is a metropole city with an high seismic hazard and risk. The close location of the Main Marmara Fault line to the city center increases the seismic hazard and risk for the city. It is known that the potential consequences of seismic events can be reduced by some real-time monitoring actions. After the 1999 Marmara Earthquake sequences in the region the Earthquake Early Warning (IEEWS) and Rapid Response System (IERRS) was deployed in Istanbul city in 2002 in order to take immediate action after an event. Within the MarSite Project WP9, the existing IEEWRRS has been improved with new algorithms, technologies and data.

Istanbul Earthquake Early Warning (IEEWS) – Threshold Based

Considering the complexity of fault rupture and the short fault distances, the IEEWS applies a simple and robust Early Warning algorithm, based on the exceedance of specific threshold time domain amplitude levels (band-pass filtered accelerations and the cumulative absolute velocity) named as CAV is implemented.

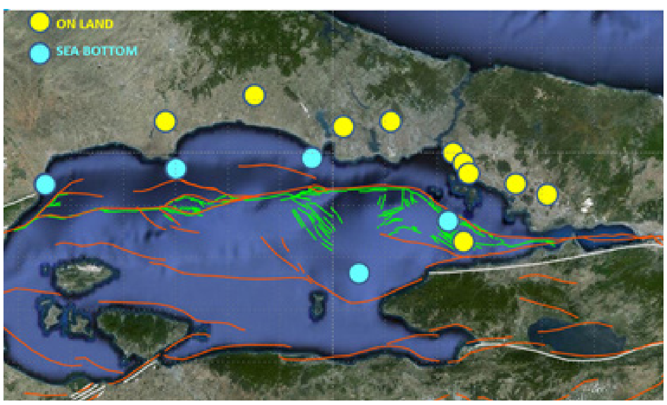

Figure 1: On Land Stations (Yellow dot), Sea Bottom Stations (Blue dot).

The existing IEEWS with 10 on-land strong ground motion stations has been improved with additional 5 sea bottom seismic observation stations as shown in the figure above

The communication system of the IEEWS with the main server in KOERI has been improved with additional fiber-optic cable data transmission in addition to existing Satellite data transmission.

Istanbul Earthquake Rapid Response System (IERRS)

The existing IERRS with 110 strong motion stations has been improved with additional strong motion data provided from Istanbul Natural Gas Distribution Company (IGDAS).

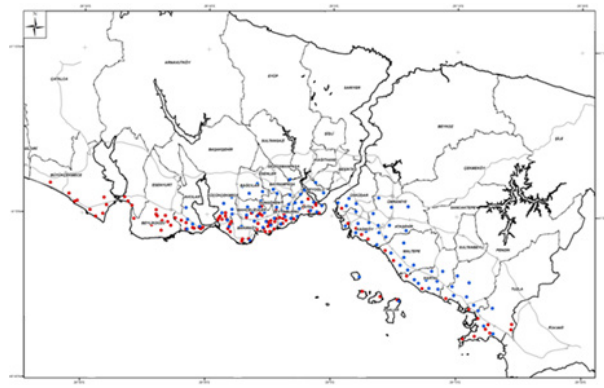

Figure 2: The improved IERRS ground motion stations. KOERI network (red dots), IGDAS network (blue dots)

The overall number of strong motion stations distributed throughout the city has been increased to 220 serving the real-time ground motion data for rapid estimation of the ground shaking, damage and loss.

The IERRS uses Earthquake Loss Estimation Routine (ELER) algorithm. The application provides real-time ground motion distribution by utilizing the regional ground motion prediction equations developed for Marmara region. The adjustment on ground motion distribution is provided by the ground motion data obtained from IERRS stations. The grid based shake mapping is provided in Modified Mercalli Intensity (MMI), PGA, PGV and Spectral parameters in certain periods. The grid based soil information with regard to Vs30 information is taken into account in the estimation of ground motion distribution. The damage estimation module of the algorithm uses grid based demography and building inventory data. The spectral acceleration-displacement-based vulnerability assessment methodology is applied. The IERRS generates a simulation every day in order to check the operability of the system and transmits the simulation results to related agencies.

Building Inventory Extraction

In order to keep updated building inventory a tool for building inventory extraction has been applied with the use of remote sensing technologies. This work has 3 stages: Coregistration (preprocessing), Built up extraction and Age of built up. High resolution multispectral data is necessary in order to carry out the developed methodology.

This project has received funding from the European Union's Seventh Programme for research, technological development and demonstration under grant agreement N° [308417]

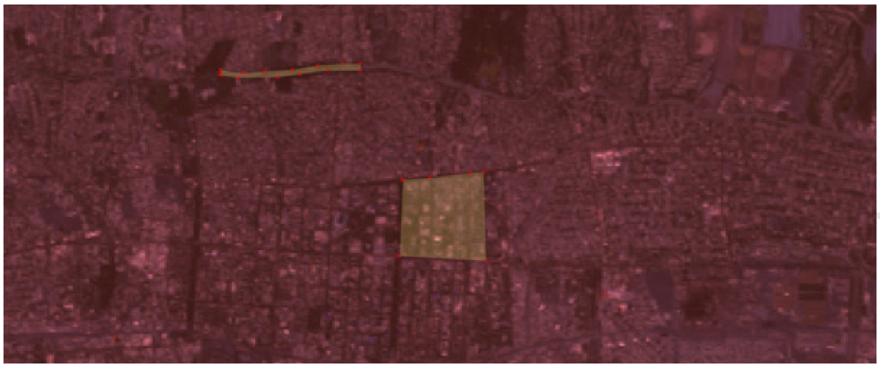

Figure 3: A sample of the coregistration method

Figure 4: A sample of the built up extraction

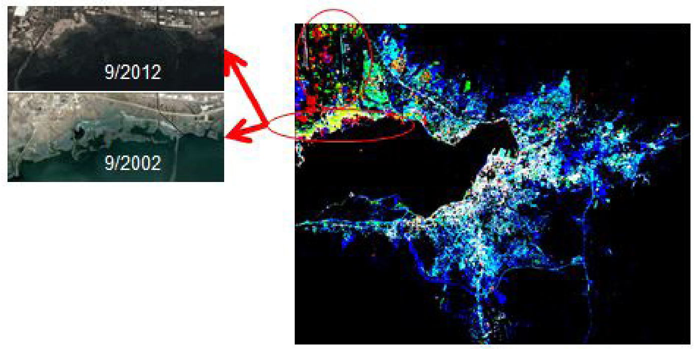

Figure 5: Using the satellite data from different periods in the region the estimated built up area is generated

Regional Earthquake Early Warning Applications in Marmara Region

In addition to IEEWS and IERRS, the present number of the broadband seismic stations in Marmara region is about 40 and the number of the strong motion stations is about 30. This dense seismic network provide an opportunity to implement regional early warning algorithms like Virtual Seismology and PRESTo with the use of seismological software SeisComP3. Currently, the EEW information is utilized in Istanbul Natural Gas Distribution Network and Bosphorus Railway Tube Crossing (Marmaray) in order to mitigate the potential risk.

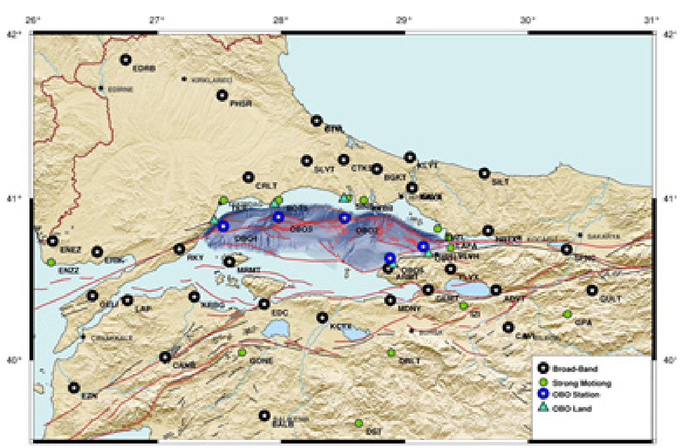

Figure 6: Seismic networks in Marmara region

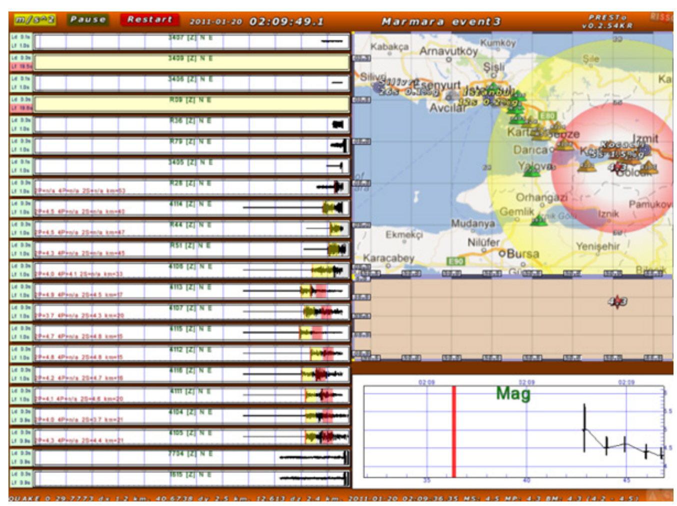

Figure 7: The snapshot of the PRESTo simulation for the 1999 Mw7.4 Kocaeli event

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KOERİ , established in 1868 is the excellent institution of Bogazici University. Is operating as the Regional Earthquake – Tsunami Monitoring Center. Has a dense urban network in and around Istanbul.

BOĞAZİÇİ UNIVERSITY KANDİLLİ OBSERVATORY AND EARTHQUAKE RESEARCH INSTITUTE 1868

Project coordinator: N. Meral Ozel (KOERI)
Design: EMSC
Project manager: Meral Alguadis

GROUND MOTION SIMULATIONS FOR SCENARIO EARTHQUAKES (MAGNITUDE 7) IN THE MARMARA REGION

Estimating the ground shaking level for a large earthquake (which may happen in the next decades) in the Marmara region is one of the priority tasks of seismic risk prevention. In particular, guessing a possible earthquake scenario is a scientifically challenging, difficult question, as the earthquake process is controlled by many factors such as fault geometry, tectonic stress and rupture criterion. The progress in our knowledge in the Marmara region and the North Anatolian fault (See Figure 1, newly constructed 3D structure model in the Marmara region) as well as in our understanding of earthquake mechanics since more than a decade allows us to explore the possibility of the future earthquake scenarios based on the geological and mechanical points of view. Furthermore we make full use of the high-performance computing for tacking this problem.

First, BRGM worked on the numerical simulations of the earthquake rupture process along the North Anatolian fault in the part of the Marmara Sea. In fact, it is known that the fault system has some geometrical irregularities such as bends and segmentations along its strike. These affect significantly the generation of a large earthquake.

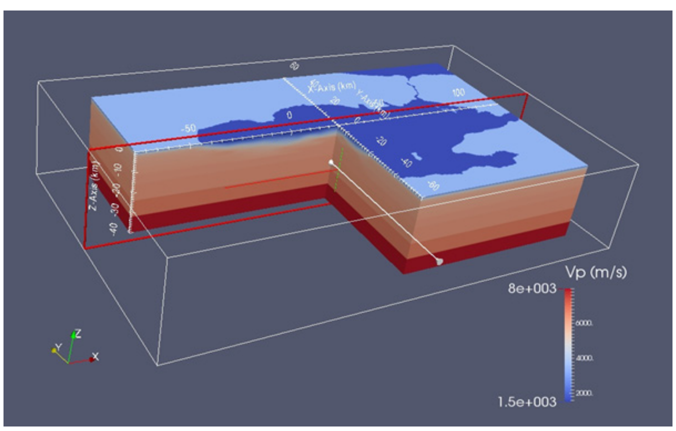

Figure 1: View on the constructed 3D structure model around the Marmara Sea.

Figure 2 illustrates a snapshot of the earthquake process simulated by a 3D boundary integral equation method on a super computer. High slip velocity propagating eastward in the figure radiates strong seismic waves. This is why it is important to estimate how the rupture scenario could be. We find that an earthquake might easily tends to be enlarged along the fault system until a moment magnitude

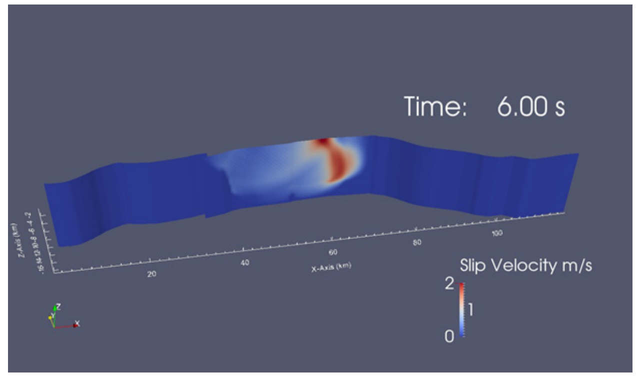

Figure 2: View of simulated earthquake scenario along the North Anatolian fault (Mw7.3).

of 7.2-7.3 once it started, while a moderate earthquake of magnitude between 6 and 7 is hardly expected. The ruptured area expands mainly along the northern end of the Marmara sea (say, main Marmara fault).

Next, BRGM has been working on the ground motion simulations in the Marmara region based on the 3D structure model newly constructed. The new simulations of the ground motion in the area take into account of the Marmara basin structure (about 7 km depth) and the sea water layer (1.5 km depth at max.). We use a 3D finite difference method also on a super-computer. The scenarios of a future large earthquake previously calculated above are implemented to assess the ground shaking in the region. The ground shaking significantly varies according to the scenario, in particular, its hypocenter location, the rupture directivity, the rupture velocity and the ruptured area. We also carried out a series of the parameter studies to quantify the ground motion level. Figure 3 shows a result of the ground shaking, on a portal site created in WP10 (http://marsite.brgm-rec.fr). One can see how the ground motions propagate from the North Anatolian fault with time.

These works directly contribute to the quantitative estimation of earthquake scenario and ground motion in the region. We are also working on the variability of ground shaking from the statistical point of view. Furthermore, these simulation results are provided to the MARSite partners as the synthetic data base for the further analyses.

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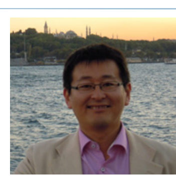

Thomas Ulrich
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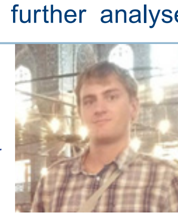

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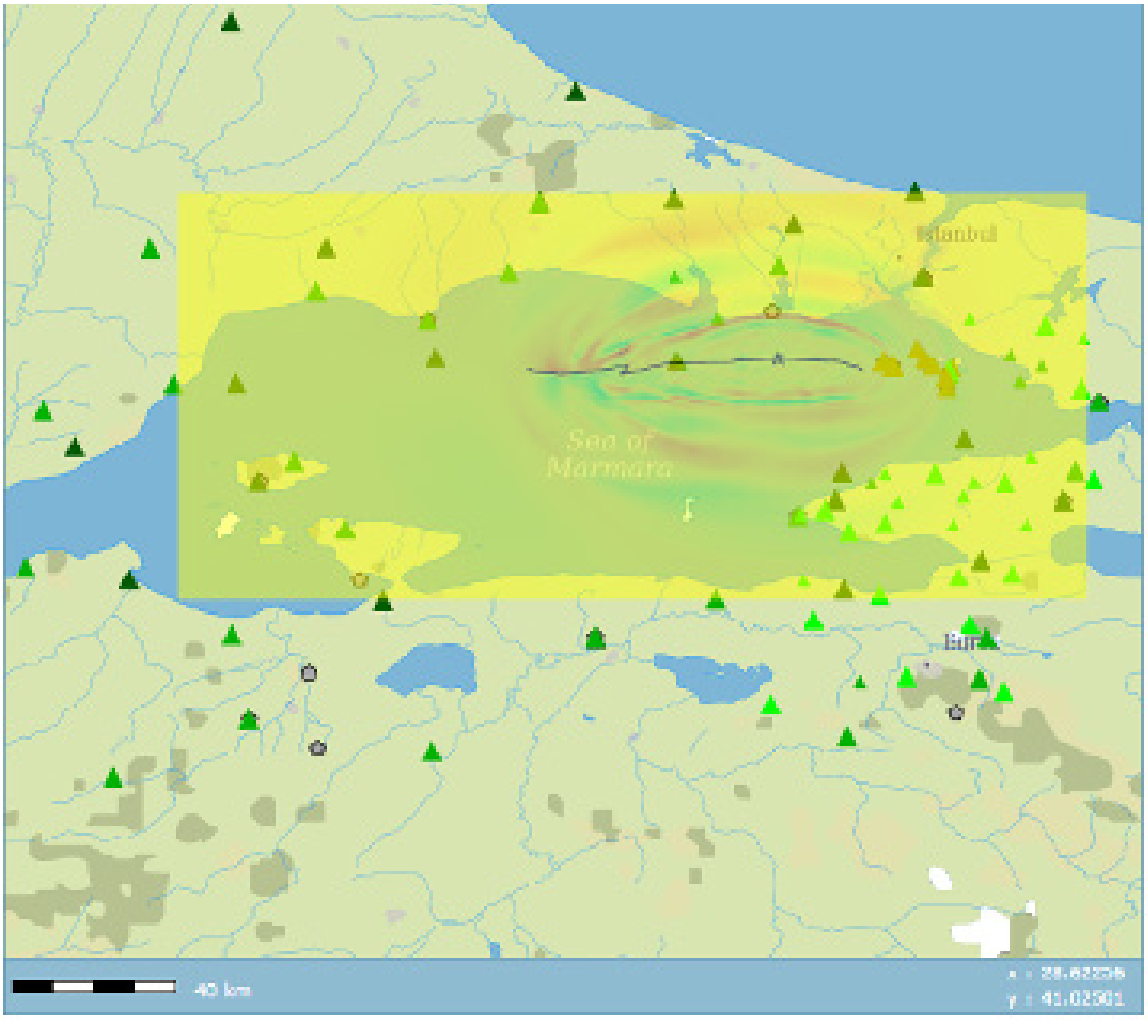
WP10



Please note that the geographical scope of the data layers is limited to the Marmara Sea region.

Figure 3 : Ground motion snapshot from a simulation for the M7.3 scenario earthquake.

Another important task in the WP5 is a rapid and reliable estimation of the earthquake parameters in the current observation network. For this purpose, the synthetic scenarios are applied, because there is no large earthquake observation in the target area yet. The different approaches of the partners show the reliable results with respect to the given scenario. This assures the performance of the seismological analysis as well as the deployment of the current observation networks. The synthetic ground motion data are to be used for the other associated risk such as landsliding and tsunamis.

By the way, new insights are to be discussed further and introduced in the models. In particular, recent geodetic and seismological studies propose laterally heterogeneous seismic coupling along the North Anatolian fault. This means that the stress loading is laterally heterogeneous, while our modeling is based on the hypothesis of the homogeneous loading along the fault system. The seismicity mapping might tell us the level of the fault heterogeneity, which is the indication for possible rupture velocity and strong ground motion generation. In conclusion, the progress in geological and geophysical understanding continues improving the quantitative assessment of seismic risk in the region so as not to see any unexpected result in the coming large earthquake.

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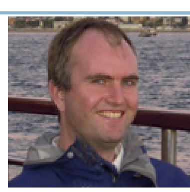
expert in seismology, currently lecturer at University of Strachcylde



BRGM
(French Geological Survey) is a French public institution for Earth Science applications in the management of surface and subsurface resources and risks.

Géosciences pour une Terre durable
brgm

Project coordinator: N. Meral Ozel (KOERI)
Design: EMSC
Project manager: Meral Alguadis

Partners

21 partners from 6 nations of the Euro-Mediterranean area.
The partners include universities, research institutes and agencies:

KOERI	Kandilli Observatory and Earthquake Research Institute - Bogazici Universitesi
KOU	Kocaeli University Geophysical Department
UNIPV	Engineering School of University of Pavia
IU	Istanbul University Department of Geophysics
ITU	Istanbul Technical University Eastern Mediterranean Center for Oceanography and Limnology
CNR	Consiglio Nazionale delle Ricerche
CNRS	Centre National de la Recherche Scientifique
EUCENTRE	European Centre for Training and Research in Earthquake Engineering
EMSC	European-Mediterranean Seismological Centre
GFZ	Deutsches GeoForschungs Zentrum
TUBITAK	Marmara Research Center Earth and Marine Sciences Institute
IFREMER	French Research Institute for Marine Studies
INGV	Istituto Nazionale di Geofisica e Vulcanologia
BRGM	Bureau de Recherches Géologiques et Minières
INERIS	National Institute of Industrial Environment and Risks
AMRA	Center of Competence in the Field of Analysis and Monitoring of Environmental Risk
IFSTTAR	French Institute of Sciences and Technology for Transport, Development and Networks
ESA	European Space Agency
GURALP	Systems Ltd
DAIMAR SRL	National Council of Researches
SARMAP SA	Earth Observation Gateway

Beneficiaries

Wider scientific community
Stakeholders and decision makers in the Marmara Sea region
Industrial domains
Members of the consortium

Design and formatting

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