Final Report Summary - MARSITE (New Directions in Seismic Hazard assessment through Focused Earth Observation in the Marmara Supersite)

Executive Summary:
The development of the MARSite project in the Marmara sea region ensured the integration of data from land, sea and space and the processing of this composed data based on sound earth-science research has been shown as an effective tool for mitigating damage from future earthquakes. This has been achieved by monitoring the earthquake hazard through the ground-shaking and forecast maps, short- and long-term earthquake rate forecasting and time-dependent seismic hazard maps to make important risk-mitigation decisions regarding building design, insurance rates, land-use planning, and public-policy issues that need to balance safety and economic and social interests.

MARSite has demonstrated the power of the use of different sensors in the assessment of the earthquake hazard. A multidisciplinary innovative borehole seismic observatory and a dilatometer have been installed within MARSite where its data can be used for a range of seismic studies. Due to the encouraging results obtained from this experiment, it is likely that smaller number of stations will be required reducing the cost of national seismic networks. The technical infrastructure of the continuous GPS stations of MAGNET network has been updated. Improvement of Seismic Hazard Assessment for Marmara Region has been accomplished through improving the fault source model geometry and parameterization based on recent literature as well as outputs of different work packages of MARSite. A tsunami scenario database has been compiled in Marmara Sea showing that the tsunami hazard in the Marmara Region is primarily due to submarine landslides triggered by an earthquake and a Tsunami Early Warning System in the Marmara region has to be strongly coupled with the strong ground motion and existing Earthquake Early Warning System. The existing Earthquake Early Warning and Rapid Response system in the Marmara Region have been improved and the installation and test of a pilot seismic landslide monitoring system has taken place in the Avcilar-Beylikdüzü Peninsula, a large landslide prone area located in westward part of Istanbul and facing the North Anatolian Fault Zone (NAFZ). The evolution of the tectonic structure and the behaviour of the faults with time have been investigated and slip partitioning and slip rate on individual fault segments have been determined. The historical earthquakes have been revised in detail using the catalogues and the faults generating these earthquakes were tested and the historical catalogues and intensity maps were locally compared to better understand the impact of the historical earthquakes in the Marmara Region. An integrated approach based on multi-parameter seafloor observatories has been implemented in to continuously monitor the micro-seismicity along with the fluid expulsion activity within the submerged fault zone. Velocity models were developed to improve earthquake location in the Sea of Marmara to detect low magnitude earthquakes and improve the characterization of the near-fault micro-seismicity, particularly along the central part of the Marmara. All these accomplishments have contributed in the better understanding of the seismo-tectonic characteristics of the Marmara Region.

Strong integration and links have been established with major European initiatives focused on the collection of multidisciplinary data, their dissemination, interpretation and fusion to produce consistent theoretical and practical models, the implementation of good practices so as to provide the necessary information to end users, and the updating of seismic hazard and risk evaluations in the Marmara region. MARSite has shown that the the branches of NAFZ in the Marmara Sea is composed of fault segments of different properties and that each segments potential to produce an earthquake varies significantly. Furthermore, studies indicated that the Princess Island segment of the North Anatolian Fault Zone in Marmara Sea is actively accumulating strain and has not experienced a large event since 1766, making it the most likely segment to
generate an earthquake in the order of magnitude 7 and hence the most imminent seismic hazard to Istanbul and other cities around the Sea of Marmara, which requires continuous monitoring.

MARsite has an impact that is much greater than the sum of its parts. This is because the coherent collection, analysis and dissemination of the wide range of data types on all aspects of the geohazards (earthquakes, landslides and tsunamis) cycles from many different instruments that is envisioned in MARSite has enable a step change in understanding in hazard and risk in the Marmara region. This dramatic improvement in understanding would have not been possible without concentrating efforts on a single supersite and without bringing together all of these different data sources to create a synergy, where each overlapping piece of information reinforces another. The vast majority of previous studies on earthquake processes in the Marmara region have looked at simply a handful (or often fewer) of different aspects and, thereby, have had, at best, a partial, and in some cases a false, view of the tectonic cycle. MARsite has provided an opportunity to gain a fuller view of this cycle. Although, obviously, MARsite concentrated its efforts on a relatively small part of north-western Turkey, its scientific and technical impacts go far beyond this region since the scientific findings are likely to be applicable to other seismically-active areas in Europe and beyond and its technical developments (e.g. new instrumentation and processing techniques) will be able to be used globally. In addition, MARsite’s impact has gone far beyond the project’s consortium through, e.g. scientific papers, newspaper articles for the wider public, guidance and information for end-users (e.g. risk managers), but also thanks to the dissemination of the collected raw and processed data through easy-to-use and interoperable web portals.

Since very high technological earth monitoring system has been established during Marsite project in the Marmara Region, the impact of this project is expected to last far beyond the three and a half years of its duration...

Project Context and Objectives:
The devastating earthquakes and associated tsunamis in Japan, Indonesia, and Haiti, which killed more than half a million people, highlighted how mankind is still far away from a satisfactory level of seismic risk mitigation. Earthquakes continue to cause destruction around the world, including in the European region. In only the last twelve years, substantial damage and casualties were produced in 1999 Izmit (Turkey), 1999 Athens (Greece) and 2009 L’Aquila (Italy) to name just three damaging earthquakes. Fortunately none of these events was as catastrophic as earthquakes in, for example, Istanbul in 1509 and 1766, Izmir in 1688, Eastern Sicily in 1693 and Lisbon in 1755. Among the regions around the Mediterranean Sea for which earthquakes represent a major threat to their social and economic development, the area around the Marmara Sea, one of the most densely populated parts of Europe, is subjected to a high level of seismic hazard. For more than two millennia the Marmara region has been the crossroads between east and west. Being a continuously populated region and having as its centre Istanbul, the capital of both Eastern Roman and Ottoman empires, the historical seismicity record is continuous and relatively complete. 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. For this region the MARSITE project was proposed with the aim of assessing the “state of the art” of seismic risk evaluation and management at European level.

In particular, MARsite aims to harmonize geological, geophysical and geochemical observations to provide a better view of the post-seismic deformation of the 1999 Izmit earthquake (in addition to the post-seismic signature of previous earthquakes), loading of submarine and inland active fault segments and transient pre-earthquake signals, related to stress loading with different tectonic properties in and around Marmara Sea. Moreover, the results will be considered as earthquake/landslide triggering mechanisms along the Marmara Sea’s shoreline and they will support tsunami hazard modelling. These studies are planned to contribute to high-quality rapid source-mechanism solutions and slip models, early warning and rapid-response studies. The project outputs will also be adapted to improve various phases of the risk management cycle with the creation of a link between the scientific community and end users. In this context, MARsite will develop novel geo-hazard monitoring instruments including high-resolution displacement meters, novel borehole
instrumentation and sea-bottom gas emission and heat-flow measurement systems, in association with the relevant industrial sectors and SMEs.

MARsite was coordinated by the Bogaziçi University, Kandilli Observatory and Earthquake Research Institute (KOERI), Istanbul-Turkey. The Marmara region was identified as a ‘Supersite’ within European initiatives to aggregate on-shore, off-shore and space-based observations, comprehensive geophysical monitoring, improved hazard and risk assessments encompassed in an integrated set of activities in the MARSite Project. The project coordinated research groups with different scientific skills (from seismology to engineering to gas geochemistry) in a comprehensive monitoring activity developed both in the Marmara Sea and in the surrounding areas. It coordinated initiatives to collect multidisciplinary data, to be shared, interpreted and merged in consistent theoretical and practical models suitable for the implementation of good practices to move the necessary information to the end users.

The MARSite Project aims assessing the “state of the art” of seismic risk evaluation and management at European level to establish a starting point to move a “step forward” towards new concepts of risk mitigation and management by long-term monitoring activities carried out both on land and at sea. The project coordinates research groups with different scientific skills in a comprehensive monitoring activity developed both in the Marmara Sea and in the surrounding urban and country areas. The project outputs will also be adapted to improve various phases of the risk management cycle with the creation of a link between the scientific community and end users.

To fulfill the requirements of the EC-FP7 call, MARsite identified 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

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

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

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

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

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

vi) Build on past and on-going European projects by including their contributions and principal partners, avoiding duplication and using their successes and momentum to create a better understanding of geo-hazards.

The Project has 11 Work Packages dealing with Management (WP1), Research and Development (WP2-WP9), Data Integration (WP10) and Dissemination (WP11) activities. The aim of WP2 is the collection and integration of seismological, geochemical, and geodetic data to detect and model the interactions between fluids, crustal deformation and ruptures of the active tectonic structures. In WP3, long-term continuous monitoring of the crustal deformation will be investigated by exploiting the existing land and space based geodetic crustal deformation monitoring systems.

A multi-parameter borehole system and surface array as closest as to the main Marmara Fault (MMF) in the western Marmara Sea will be installed in WP4:

To measure continuously the evolution of the state of stress of the fault zone surrounding the MMF, WP5 will concentrate on...
real- and quasi-real-time Earthquake & Tsunami Hazard Monitoring, where an integrated approach by harmonizing geodetic and seismic data to be used in early warning applications will be implemented. The aim of WP6 is to 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. Re-evaluation of the seismo-tectonics of the Marmara Region will be conducted in WP7 and Monitoring seismicity and fluid activity near the fault using existing cabled and autonomous multiparameter seafloor instrumentation will be performed in WP8. WP9 will focus on Early Warning and Development of the Real-time shake and loss information for the supersite. Integration of data management practices and coordination with ongoing research infrastructures are the responsibilities of WP10, through which the data and the results will be exploited. Analysis of the target users and production of a communication plan for the dissemination and public outreach strategy of MARsite, together with the dissemination activities is the responsibility of WP11.

Project Results:

WORK PACKAGE 2: LAND BASED LONG-TERM MULTI-DISCIPLINARY CONTINUOUS MONITORING

Significant number of data has been collected by automatic seismic, geochemical and geodetic stations, by periodical measurements of soil degassing and by field works aimed to collect fluid samples and carry out in situ measurements on the fluid phases.

Geophysical, geodetic and geochemical time series including continuous and periodical soil radon gas and groundwater data have been analysed for possible changes related with seismic activity and/or crustal deformation. Due to the large amount of seismic events (about 6,000) recorded during MARsite project, various statistical methods were applied to identify possibly relationships between earthquakes and fluids behaviour during multiparameter data analysis.

MARSite project enabled us to collect enough data for the evaluation of the background values for the study area. It is worth of notice that the highest 3He/4He value which is possibly related to rock permeability changes and microfracturing induced by crustal deformations has been recorded in gases dissolved in a cold spring located over the area where seismicity was concentrated (Ganos).

As a general consequence, changes in geochemical parameters should be expected during the entire seismogenic cycle, even in the absence of a seismic energy release. The integration of the collected data bringing together the geochemical features indicated the existence of close relationships of the vented volatiles with the geological and structural setting of the Marmara area. The results represent a promising approach for further studies on the origin of the volatiles and their behaviour in coincidence of seismic events and episodes of crustal deformation and may provide new tools to gain a better insight into the evolution of the seismogenic processes over the Marmara area.

Due to the fluid monitoring in the context of earthquake research requires continuous, high-quality, long-term recording of relevant data, the critical evaluation of the existing time-series of continuous measurements based on the quality of the data first. In this framework, the online data have been added to the fluid monitoring database, routinely. A common fluid-monitoring dataset consisting of 21 soil radon sites and 17 groundwater sites (Figure 1) has been generated.

In the frame of MARSite, the network of both MAM and GFZ which operates fluid monitoring stations were jointly evaluated for the first time. The existing on-land continuous fluid monitoring network is composed of automatic stations equipped with different probes as a function of the specific features of the selected site.

The geochemical features of the waters and the gas phase from the monitoring stations of both networks indicated typical characters of deep-originated sources, coming either from the deep crust or/and from the shallow mantle. This was also validated by water-rock interactions responsible for the chemical composition of the ground waters.

The biggest problem with data quality that occurred at some of the radon soil measurements was artificial spikes, which are likely related to moisture on the detector surface. With respect to the groundwater monitoring, the main reasons for non-natural signals are related to man-made disturbances at some sites (pumping at the monitoring site or nearby), specifically in Bursa and Tuzla. All in all, our critical evaluation ranked 30% and 50% of the radon soil data and the groundwater data positive, respectively.
The results of data collection aimed to constrain the fluids geochemistry as well as the results of soil degassing measurements aimed to evaluate the amount of gases (CO2, CH4, Rn) released from the soil. During the activities carried out in the mainframe of MARSITE, a suite of 120 fluid samples from 61 sites in the Marmara region have been collected from thermal and mineral waters marking the Northern and Southern branches of the NAFZ (Figure 2). Samples of free bubbling gases were taken whenever feasible; additionally, water samples with dissolved gases were collected. 52 CO2 and CH4 soil degassing measurements were also carried out at 9 locations in the vicinity of thermal/mineral springs. A comparison between both CO2 and CH4 concentration and flux distribution maps highlights an overlapping of the highest values in the Adapazari area.

In the laboratory, the chemical composition and the isotopic ratios of He and C of the bubbling and dissolved gases were determined using the same analytical equipment. The dissolved gases were extracted after equilibrium was reached at constant temperature with a host-gas (high-purity argon) injected in the sample bottle through the rubber septum. Chemical analyses were carried out by gas-chromatography (Perkin Elmer Clarus500 equipped with a double TCD-FID detector) using argon as the carrier gas. The isotopic composition of helium, always used to discriminate the origin of a gas phase, displays values in the range of 0.2-2.07 R/Ra (Ra is the isotopic ratio in air) showing a basically crustal origin with variable extents of mantle contribution at all the monitoring stations. This makes the monitored sites potentially useful to observe changes in the crust-mantle mixing ratios due to tectonic pulses.

Geochemical time series (continuous soil radon gas and groundwater), which contain data over several years, are analysed for any possible changes related with seismic activity. Positive or negative anomalies relative to normal variations could point to correlations with seismic activity.

Within the main frame of MARSITE project, a monitoring strategy focussed on the evaluation of potential indicators of the development of seismo-genesis and its impact on the circulating fluids has been followed. The seismic activity recorded during the time interval of the project is mainly located on the different branches of the NAFZ. The events marked by M>4 were extracted to carry out a preliminary check on the influence of ruptures on the fluids behaviour. A model of fluids circulation and interactions with the strike-slip NAF was proposed. The model accounts for the geochemical features of the fluids collected and analysed as well as for the information provided by the soil degassing and continuous monitoring activity.

The analytical results of the gases from 25 bubbling and 45 dissolved gases showed that the gases released at the monitoring sites are a mixture of two end-members: one dominated by N2 and the other dominated by CO2. All the gases collected at the monitoring stations, including dissolved and bubbling samples plot along a mixing line between the two gases at different extents.

A preliminary data analysis was performed on 34 stations of geochemical continuous monitoring belonging to the TUBITAK and ARNET networks installed around the Marmara Sea Region. Whereas the cross correlation diagrams between temperature and conductivity and autocorrelation diagrams of the temperature data show periodical patterns for many stations, autocorrelation diagrams of the conductivity data don’t show any periodical patterns.

The results of the investigations carried out on the fluids vented over the area of the Sea of Marmara show that crustal fluids are available along with mantle volatiles. The different geochemical features of the collected fluids (in terms of chemical and isotopic composition) associated to the evidence of an active natural degassing is a possible indication of different segments of the NAFZ cut crustal sections marked by variable geological and physical features (e.g. different rock types and permeability values). The composition of the circulating fluids was determined by the local geology (e.g. the hosting rocks where ground waters equilibrate or interact with gases); however, in the case of contributions of mantle fluids it is necessary that fractures or faults cut the whole crustal thickness allowing the volatiles of mantle origin to rise up and mix with crustal and other shallow fluids. In this case the composition of the deep fluids is a matter of tectonics.

High helium isotopic ratios and CO2 degassing indicate the presence of mantle volatiles through lithospheric faults. Evidence that fluids with a variable - although sometimes significant - mantle component are vented over the whole Marmara region implies a widespread lithospheric character of the various NAFZ branches highlighting the possibility of detecting changes in the fault behaviour from temporal and spatial changes in the mixing proportion of the deep and shallow fluid components.

A possible circulation and interaction model can be proposed following Doglioni et al. (2014) who indicates the Brittle-Ductile-Transition (BDT) zone as the area that ideally separates two layers with different strain rates and structural styles. This behaviour determines a stress gradient that is eventually dissipated during the earthquake. The two layers also represent two fluid domains with different geochemical features. NAFZ-like strike-slip fault displays coexisting, locked and unlocked segments.
with opposite evolution (tension and shortening). During an interseismic period, they perform opposite evolutions inducing different behavior in fluids circulation and changing both their geochemical features and flow rates. Before the rupture the proportion of mantle fluids is expected to increase within the dilated band in contrast to an increased fluid expulsion over the shortened area. The contribution of mantle fluids over the same area might decrease during the coseismic period due to the enhancement of shallow fluids expulsion induced by the sudden compression of the dilated band due to the fault movement. The crustal relaxation of the brittle crust will result in an increase of the mantle fluids upraise over the newly formed dilated band. Crustal deformation in dilating areas should be detectable by geodetic measurements.

**WORK PACKAGE 3: LONG-TERM CONTINUOUS GEODETIC MONITORING OF CRUSTAL DEFORMATION**

Long-term continuous monitoring of the crustal deformation was investigated by using the existing geodetic crustal deformation monitoring systems (Figure 3). GAMIT/GLOBK software developed by the Massachusetts Institute of Technology Department of Atmospheric and Planetary Sciences (EAPS MIT, USA) was used for processing data obtained from MAGNET (A Continuous GPS Network in Marmara Region with 22 continuous GPS stations). Daily loosely constrained solutions from GAMIT were identified by transformation with 7 parameters (3 translations, 3 rotations and 1 scale factor). Daily precise coordinates and repeated measurements at each period were joined by Kalman analysis and time series containing position variations of these points were obtained. Also, with the help of the Kalman filtering using trend analysis from the time series velocities for sites were determined. Time series of the stations and the velocity field respect to Eurasia were produced for 2002-2013 time period. As a consequence, the direct constraints on strain accumulation within the Sea of Marmara has been presented, showing that the Princes’ Islands fault segment that lies off shore and within 15 km of Istanbul, is accumulating strain at rates that are sufficient to produce a slip deficit since the last major earthquake in 1766 capable of generating an M>7 earthquake. In contrast, the Central Marmara fault, previously thought to represent the potential source for one or more M>7 earthquakes, shows no observable indication of accumulating strain, most likely due to aseismic fault creep to shallow levels. Furthermore, the low rate of strain accumulation on the Central Marmara fault provides a simple explanation for the low rate of historic M~7 earthquakes reported on this fault segment.

Synthetic Aperture Radar (SAR) data which is made available through the CAT-1 ESA (European Space Agency) archives, acquired by the C-band radar sensor Envisat ASAR, was processed to retrieve surface displacements map on selected areas of the Anatolian Fault Zone (AFZ). This exercise was based on testing if C band SAR signal coherence is high enough to allow us to map the spatial and temporal evolution of the present-day crustal deformation phenomena affecting the MARsite Area with high level of spatial details. The goal was to assess whether InSAR C-Band data can be useful to evaluate the long-term behaviour of the Ganos section of the NAFZ, complementarily to GPS measurements and other in-situ observations (Figure 4). Mid-term monitoring (4 - 10 years) of the crustal deformation in the MARsite area was investigated by using InSAR stacking approach for the purpose of providing the C-band data acquisition frame, the data processing strategy firstly, and the post-processing of the results and using them, if relevant, for characterizing the faults behaviour secondly. Due to InSAR signal coherence is very low in the study area and therefor just few coherent pixels could be analysed in the stacking procedure, the tectonic signal affecting the Ganos section of the NAFZ could not be retrieved from the Envisat InSAR velocity map. Unfortunately the results were not adapted to the purpose of tectonic studies whereas local subsidence sand landsliding were highlighted in the velocity map. The amount of coherent C-band InSAR data was not extraordinary. Due to 9 interferograms spanning more than 8 years are not so numerous to measure tectonic strain with high level of confidence, further processing were foreseen using the ESA Sentinel-1 to obtain more coherent InSAR signals in the study area. Additionally, L- band InSAR was recommended for the measurements of tectonic motions in the study area.

At the stage of concentrating on the Istanbul megacity area, where a large number of X-Band SAR data, acquired by the new radar systems onboard the TerraSAR-X (TSX) and COSMO-SkyMed (CSK) sensor constellations, good data spatial coverage as well as temporal continuity were already available (Figure 5). The selected SAR datasets were processed by exploiting the advanced multi-temporal and multi-scale InSAR techniques, known as Small Baseline Subset (SBAS) approach (Berardino et al., 2002) and StaMPS Persistent Scatterer Interferometry (PSI) method (Hooper et al., 2007), which provide new insights into the spatial and temporal pattern of the investigated phenomena.
The InSAR results relevant to the Eastern track consisting of mean deformation velocity map and corresponding displacement time series over about 145,000 coherent Persistent Scatterers were achieved. For the western track, instead, only some preliminary results relevant to more than 21,000 coherent Persistent Scatterers were achieved. Further analyses related to this track depending also on the availability of new data acquisitions over the same area were needed by dropping noisy interferograms and changing unwrapping parameters to improve topographic and atmospheric corrections.

The ground velocity field was calculated over two frames using STamPS method from COSMO-SkyMed InSAR data sets. The results show that the ground motions do not contain a clear tectonic signal; anyway, some local deformation signals are evident. The general accuracy of the results is however not always very good, mainly due to some temporal gaps in the datasets.

In order to investigate the occurred and on-going crustal deformation in the Istanbul Area, a set of SAR data, made available through the Supersites Initiatives archives, was processed, acquired from the TSX constellation (working on X-band) during the 2010-2014 time interval. To this aim, the Small BAseline Subset (SBAS) approach was applied, which allows us to generate mean deformation velocity maps and corresponding time series for the investigated area, with a centimeter to millimeter accuracy. As a main result, a generalized stability trend over the study area, except for some localized deformation phenomena (mostly related to subsidence and slope instability events), such as those in correspondence to the Istanbul airport and Miniaturk park was observed.

SAR data made available through the CAT-1 ESA (European Space Agency) archives, acquired by the L-band radar sensor ALOS PALSAR, was processed (Figure 6) to retrieve surface displacements map on selected areas of the Anatolian Fault Zone (AFZ).

The ALOS Palsar archived over the Ganos Section of the NAFZ was not extraordinarily rich concerning the number of SAR scenes acquired with the same viewing and polarisation mode. The tectonic signal within the velocity map retrieved from ALOS Palsar InSAR was unfortunately hidden beneath spurious phase contributions which are mainly due to residual orbital errors, a residual phase ramp, the presence of ionospheric disturbances or some data acquisition biases. The amount of L-band SAR data was not extraordinary. Besides, 13 frames spanning more than 3 years was not so numerous to measure tectonic strain with high level of confidence, considering that the expected tectonic motion, as seen by GPS. As a result, further processing was foreseen mainly consisting of better determination of the orbital parameters, defining a strategy for ramp removal, and assessing the influence of the ionospheric layer (or other Radio Frequencies Interferences) on the interferograms.

The velocity maps and time series were provided by applying the Persistent Scatterer Interferometry (PSI), the multitemporal interferometric technique used for SAR processing technique, with a huge dataset covering the time period 1992-2010. The region of interest was extended from the Metropolitan area of Istanbul far to the East beyond the epicenter of 1999 Duzce earthquake.

The PSIInSAR technique has been applied to two different areas in the Marmara region. The first one was related to the Metropolitan area of Istanbul and the PSIInSAR coverage has been obtained using 6 SAR frames. The overall number of SAR data was 180. Temporal coverage of ERS data spans from 1992 to 2000 while each Envisat analysis has covered 2003-2010 (Figure 7). The spatial extension ranges 800-4000 km² while the PS density is between 30 up to 220 PS/km². The second area of interest concerns the North Anatolian Fault System (NAFS). It has been observed by means of 14 portions of frames acquired by ERS1-2 and Envisat satellites. The overall number of SAR data was 137.

SAR Interferometry (InSAR) and advanced version as Persistent Scatterers (PS) and Small Baseline Subsets (SBAS) are widely exploited to evaluate the seismic phases of an earthquake cycle thus play an important role for the hazard mitigation in seismic areas. However, these techniques allow measuring movements occurring only along the satellite Line-of-Sight (LOS). The available GPS measurements which cover a time interval 2004-2009, have been expressed in yearly mean velocities and projected into the LOS (ascending and descending) directions to be compared with the SAR outcomes. The result shows some discrepancies probably ascribable to the non-homogeneous data available. In addition, the SAR time series of PSs have been analysed around selected GPS sites. The cumulative displacement was measured along the LOS from ascending orbit covering
the time span 2003-2009. In particular, two GPS sites, one (SISL) North of NAFS, one (SMAS) south of it has been considered. It was observed that detected displacements are in agreement with the GPS EW velocities where the GPS in the south sector of NAFS show a much larger movement than those to the north. Moreover, PS around SISL reaches a maximum displacement of about 7 mm in 2003-2009, while around SMAS PS move up to 32 mm in the same time span.

In the content of investigating various interfingered deformation processes based on GPS and InSAR data, a method to separate the regional and local deformation processes was developed. At a first glance, deformation occurrence along the Main Marmara Fault (MMF) is dominated by the interseismic strain. Consideration of a fault block model allows focusing on localized deformation occurrence and gradients, that for the first time reveal a significant complexity near the MMF. Although no secondary fault branches have been clearly identified, a proportion along the MMF close to the Princess Islands is shown to be subject to a strain gradient relevant for seismic hazard analysis. Therefore the results of the fault model can be used for further studies.

The response of the eastern MMF to the loading of adjacent the 1999 Izmit and Duzce earthquakes were investigated and the deformation signals derived from InSAR and GPS recording were decomposed (Figure 8). InSAR observations were processed to get the pre- and post-seismic deformation using the SBAS technique. As a result, deformation velocity maps and time series of the Istanbul metropolitan area spanning the past 17 years was obtained. The InSAR results show several ongoing deformation phenomena that were studied in modelling approaches. Inversion results indicate that the PI segment along the MMF began to slip with a decreasing rate since the 1999 earthquakes, which may partially release the strain accumulated on this segment and delay the possible rupture of the eastern MMF. Additional hidden fault structures could not be revealed parallel to this segment of the MMF. The reasons might be various, such as due to the limited resolution in the offshore fault segments, or due to a spatial proximity that does not allow such additional constraints. Nevertheless, the decomposition of the signal reveals an activity along the MMF that might dramatically affect future hazard assessment and modelling in the region. In the region close to the Princess Island segment, a significant strain gradient was found that almost perfectly agrees in space with the localization of microearthquakes.

Fault segments may experience different states during a seismic cycle: co- and post-seismic slip, aseismic creep or interseismic locking, which change the loading condition along faults and associated hazards. The status of a fault is routinely recorded by geodetic and seismic techniques, which allow for estimations of the location and magnitude of the fault slip, creep or slip deficit. These parameters are essential for the assessment of potential earthquake hazards.

The fault-locking status at the the Princes’ Islands fault (PIF) segment was investigated by using Interferometric Synthetic Aperture Radar (InSAR) and GPS observations, and modelling techniques for such data set was improved. Because deformation signals are influenced by other processes, such as the post-seismic viscoelastic relaxation of the adjacent 1999 Izmit/Düzce earthquakes, model-based signal decomposition was performed and then the decomposed data was studied to determine the fault-locking status near Istanbul. In order to investigate deformation occurrence and also overlapping processes (e.g. coseismic, postseismic), interpretation of data based on GPS and InSAR technologies was improved. Postseismic, coseismic and other deformation processes were evaluated separately, in an attempt to further identify and model the wanted compartments of observed displacements. Modelling routines to investigate the structure of the elastic and viscoelastic earth and the nature of fault slip associated with coseismic ruptures are investigated (Diao et al., 2016).

Furthermore, the post-seismic deformation processes following earthquakes were investigated and two different inversion modelling strategies were explored by simulating (i) pure afterslip and (ii) the combined effect of afterslip and viscoelastic relaxation. The inversion code, SDM (Steepest Descent Method), developed by Wang et al. (2013) was used to derive the afterslip distribution (http://www.gfz-potsdam.de/sektion/erdbeben-und-vulkanphysik/daten-produkte-dienste/downloads-software/).

As a result, a clear strain accumulation at the eastern main Marmara fault in the vicinity of the Princes’ Islands has been found. However, the uncertainties of the results are large due to the limited data coverage. Therefore, improved data
SARscape software which supports data type of SLC (Single Look Complex) and GRD (ground range) has been updated in order to fully support Sentinel-1 data from version 5.2 on forward: stripmap and TOPSAR mode. The first update was the new SARscape tool for the automatic data download which allows performing a query and download Sentinel data from the ESA scientific Hub (https://scihub.copernicus.eu/). The second update was the SARscape interferometry (InSAR-DInSAR) module. The third update was the SARscape interferometric stacking (PS and SBAS) module which is also capable to reduce atmospheric artifacts before the phase to height and phase to displacement steps.

As a consequence, a kind of tutorial for the software usage with Sentinel Data and some demonstrative result were provided. Moreover, some key issues and hints on specific tuning were given to have a simple data processing and to obtain more reliable result. In particular, InSAR and Stacking SBAS tools exploitation were highlighted and the displacement maps over part of Marmara region obtained by the SBAS were presented.

SARscape has been updated with automatic data support for MERIS, MODIS and the ECMWF datasets and it is now capable of importing and processing a stack of geocoded atmospheric phase delays matching the SAR acquisition dates. Moreover, the SARscape stacking processing has been updated to exploit these new layers during the interferogram generation phase. The goal was to extract the atmospheric phase delay deformation from external and independent sources such as optical satellites (MODIS or MERIS), GPS, or global numerical weather forecasts (ECMWF).

The first update was about the standard SARscape interferometry module. The second update was the SARscape interferometric stacking module. In this case, a new tool for the geocoded Zenith Path Delay (ZPD) generation was introduced, where the user can automatically create a stack of ZPDs that can be used in the SBAS or PS processing steps.

The ZPDs are extracted over one same area covered by the SAR acquisition at the same time. The user shall provide the list of SAR acquisitions and specify which sensor must be used for the ZPDs extraction. When the MERIS sensor is used, the data gathered through optical acquisitions matching the corresponding ASAR acquisitions must also be provided. When OSCAR or ECMWF sensors are used, the software requires an Internet connection to automatically download the necessary parameters and information from the Web. The result consists of a stack of raster files at different resolutions, depending on the selected sensor. The software performs the download, the geocoding, the mosaicking of the water vapour, and eventually the conversion to ZPDs.

A dataset of images were processed by using the improved SARscape processing pipeline that uses different sources for automatically applying APS correction which is an interesting and useful feature that can provide a concrete improvement in the quality of the image processing. However, some problems related to the idiosyncrasy of the SAR and APS data were observed in this work: since the two pieces of information are acquired in two distinct time lapses, and because of the highly dynamic nature of atmospheric phenomena, the automatic correction risks, more often than not, to decrease quality. In addition, such dataset, due to its very low resolution (of about 3 km) and to the speculative nature of the model used, never provided an improvement in quality when used as source for our APS correction.

WORK PACKAGE 4: ESTABLISHMENT OF BOREHOLE OBSERVATION SYSTEM AND HIGH RESOLUTION SEISMIC STUDIES IN THE MARMARA SEA

Deploying a borehole seismometer in Marmara Island or eastern of Ganos Fault Zone has been thought as an effective way in terms of monitoring the last stages of the preparation stage of major rapture. In that case, geophysical measurements were performed (MASW, seismic reflection and microtremor measurements) to determine the S-wave velocity structure and the depth of the seismological bedrock and the depth of borehole. The deeper results were obtained by SPAC method (Spatial Auto Correlation Method) as the engineering bedrock lies at a depth range of 60m-200m.

After several data processing steps, it was found that average velocity changes laterally from 1050 m/s to 1150 m/s corresponds to 137.5 m depth. Therefore, the borehole depth was determined as about 150m. The SPAC measurements was
also pointed out a velocity discontinuity between 100m and 150m (about 130m), that was compatible with the seismic reflection result. As a result of these studies, 146-meter deep borehole has been drilled and cased. Then, cementing of the cased borehole was accomplished with tubing inserted in between the drilled borehole and the borehole casing. Additionally, very high sensitivity two-axis borehole tilt-meter design completed, manufactured and installed (Figure 9). A dilatometer attached to a borehole casing, strong motion and weak motion 6-axis borehole Very Broad Band (VBB) seismometer design has also been completed, manufactured and installed. Surface borehole hut has been built over the wellhead as protection and to house the complete surface seismic station. For the period of years 2013 and 2014, the micro-earthquake activity in the western part of the Marmara Region has also been continued to monitor by TUBITAK MRC seismological broadband stations together with surface array stations. 1327 events in 2013 and 2460 events (4.5 ≥ ML ≥ 0.5) in 2014, totally 3996 events were located.

In conclusion, after drilling the hole, firstly calliper log was performed for determining the radius of the hole. The result of calliper test shows that the drilled bore is consistent with the initially set out specification. Then, SP log, gamma log and sonic log were performed to determine the geological formations. All log results showed that the lithology does not change so much down to the depth of about 500 feet. Moreover, the magnetic properties of the formations from the samples taken by 1m in the borehole were determined and compared with the log results. The magnetic susceptibility results also showed that lithology does not change in the borehole.

Reliable predictions of ground-motion that may arise from future earthquakes can only be obtained by a combination of realistic source, wave propagation and site-response models. In that content, deconvolution interferometry has been applied separately to recordings of sensors installed in buildings to study wave propagation through the structure arising from earthquakes, synthetic sources and ambient vibration (e.g. Picozzi et al., 2009, Newton and Snieder, 2012, Rahmani and Todorovska, 2013, Nakata et al., 2013, 2015, Nakata and Snieder, 2014, Cheng et al., 2015) and to earthquake recordings of borehole sensors (e.g. Mehta et al., 2007a, 2007b, Parolai et al., 2009, 2010, 2012, 2013 Oth et al., 2011) to investigate the wave propagation in shallow geological layers in the past. However, the joint application to systems including both soil and structure has so far received limited attention. Therefore, waves traveling from the soil to the building and the wavefield radiated back from the building to the soil can only be analyzed if the recordings of sensors installed in both, i.e. in a borehole and in nearby buildings, are available and jointly analyzed.

For that purpose, two vertical arrays and borehole systems were installed. The installation of a multi-parameter borehole system in Gaziköy, Turkey, next to the main Marmara fault, consists of a tiltmeter (at -145 m), two broadband seismometers (-143.6 m and 0 m) and two strong-motion accelerometers (at -142.3 m and 0 m). The data used in the studies was acquired from a downhole array and building (B22) pair (the distance apart being around 30m) located in the Ataköy district, Istanbul, Turkey.

Numerical simulations are performed using the approach of Wang (1999) to better understand the wave propagation through the building-soil structure and finally, to identify the peaks of the deconvolved wavefield. To better understand the results, the deconvolved wavefield of the synthetic seismograms was compared with the results obtained after stacking of the deconcolved wavefield of the 5 analyzed earthquakes.

As a result, analysis of the wave propagation through the building, the soil or the building-soil structure, including transmitted waves and waves reflected at the different layers, the surface and the top of the building, was performed. Moreover, quantification of the amount of energy radiated back from the building to the soil even for complicated underground velocity structures and without a priori knowledge of velocity and quality factor Q was possible. Results showed that waves radiated back from the structure are not negligible and possible interactions between nearby buildings should be considered.

The PIRES network includes 17 stations of weak motion velocity transducers installed on Prince Islands stations by joint cooperation of GFZ and KOERI. The stations were distributed over 7 islands, with two arrays of 5 stations each installed on the islands of Yassiada and Sivriada. The data transfer from the stations was initially was done by off-line approach and then converted to on-line during the first year of the project.
The whole of the collected data was stored at MARSite database. It consists of 3-components waveforms, all sampled with 200 Hz. Two of the stations have broadband data, where else the remaining are short period data with 4LC sensors of 1 Hz natural frequency. The data was stored both in terms of the raw data and also in sac format. The sac data for the end user were arranged in files of 1 hour, for each component and for each station.

The study of receiver functions for teleseismic waves recorded at all 17 PIRES stations were also performed by adding other local stations that are operated by KOERI. All recordings of teleseismic events above moment magnitude Mo>5.5 located at a distance between 300-900 have been collected. The receiver functions were calculated in time domain using iterative deconvolution technique suggested by Ligorria and Ammon (1999). It was clearly seen that most seismic sources are located in Japanese subduction (400-700) and Java-Sunda subduction (1000) zones.

A high-resolution analysis of the seismicity distribution along the MMF during the 2007-2012 period has been performed and linked to the geodetic observations (Figure 10). In this frame, the extent of the seismogenic zone both in time and space was shown and it was compared to the geodetic locking depth. Moreover, the lateral variations of statistical properties of micro-seismicity were studied: background seismic rate, b-values, and seismic slip distribution.

The results showed that the low level of seismicity on the Kumburgaz segment at the center of the MMF with very sparse seismicity. To the west, in the Tekirdag basin (TB) and Central Basin (CeB), seismicity is abundant and distributed over a wide depth range (from surface to 17 km). This segment exhibits a fully locked behaviour similar to the Ganos segment, which hosted the 1912 earthquake. In the Cinarcik basin, the situation looks intermediate with seismicity mostly at the geodetic locking depth of about 10km. Furthermore, the Main Marmara Fault is a major seismic gap. In this context, the estimate of the locked segment area provides an estimate of the magnitude of the main forthcoming event assuming that the rupture will not enter significantly within creeping domains. The two adjacent domains (the Central basin segment and the Princes Island segment) could be at the seat of moderate earthquakes or could rupture with the Kumburgaz segment. Moreover, the simple geometry and the very poor activity along the Kumburgaz segment are the signature of very little stress heterogeneities along the fault plane, making it a good candidate for supershear rupture. If repeating foreshocks were expected to develop, they should emerge at depth below or at the boundaries of the segment, possibly along the vertically extended deep observed swarms.

The applicability of continuous monitoring for the purpose of detecting any possible variations in seismic wave velocity has been investigated using data provided by the PIRES Network (Prince Islands Realtime Earthquake Monitoring System). Two types of seismic sources: the local quarry blasts and the teleseismic events, have been tested in this case.

The locations which were provided by UDIM (Kandilli Observatory Earthquake Research Institute, National Earthquake Monitoring Center) are in general distributed around four main clusters: the Uskumruko quarries (most northern close to Black Sea coast), the Sultangazi quarries (the most western sources, close to Istanbul metropolitan area), Cekmekoy quarries (east of Bosphorus, on the Asian side), and the Gemlik quarries (south of the Marmara Fault, east Gemlik Bay). All of these clusters have been investigated.

A total of 243 blasts were recorded from Sultangazi Source area during the year of 2013. The source area was located at a distance of 25 km from the PIRES arrays at an azimuth of 3100. This was closest of all sources and expected to provide the best SNR. Although the locations were scattered within a circle of 3.5 km of radius, in reality the quarries are located within a distance of 1-1.5 km within each other.

The waveforms of quarry blasts from POWD (Sivriada), were aligned with respect to time of blasts again as estimated using conventional earthquake location procedures. The waveforms have been cross correlated to detect if a reflection from basin boundary exist. Quarry blasts from Cekmekoy, recorded at station PIER on Yassiada, which is the closest to the source location, showed that there is a strong emphasis on the second arrival on both three components, which strongly asserts that it corresponds to a shear energy production at the source site. This observation is contradictory of what it knows from the general modeling of explosive sources. However it can be a useful tool for investigating the dilatency. Finally, the blasts from the southern side of the Marmara Fault namely those from Iznik-Gemlik quarries were also analysed. Surprisingly it was noted that for all explosive sources coming from the southern side the second arrival has not been observed as in the case of northern blasts. This may be due to the strong attenuation of S-waves as it crosses the deep unconsolidated sediments of the
Seismic repeaters were searched along the Main Marmara Fault (MMF) to detect the possible creeping segments of the fault. Initially, earthquakes were searched manually on the continuous recordings of the permanent OBS stations deployed by KOERI and operated between 2011-2013. The main reason to start the search with the OBS station was that they are the closest stations to the fault therefore small magnitude events have better S/N compared to the land stations located at distances > 25km. Then the manually detected events from the OBSs were used as templates and perform a more extensive search by cross correlation using the same OBS recordings. This allowed detecting lower magnitude events and possible undetected events. This process was repeated for the 4 OBS sites and we observed several long term repeating earthquakes in the central Marmara basin but none in the Kumburgaz Basin or Cinarcik Basin.

The second step of the search has involved the land stations. The origin times of the events detected from the OBS recordings are used to extract waveforms from the recordings of land stations. The seismic repeaters have been observed from 2008 to 2015 with different recurrence times: from 5 minutes to 9 months. Due to the location accuracy of the repeaters is important to claim that the same asperity is ruptured during each occurrence, the events have been cross correlated with a reference waveform. The reference waveform was chosen as the one with the highest S/N. In the frame of spectral analysis, the waveforms have been analysed assuming the earthquakes have source regions defined by circular cracks (Brune, 1971).

Furthermore, the geophysical observations have shown that earthquakes can trigger other earthquakes, raising the possibility that earthquake interaction plays an important role in the earth’s deformation. Seismicity catalogues have been used to study the spatial and temporal variations of seismicity s in the Marmara region. The seismic catalogue, was more uniform and had a completeness of magnitudes ~2.0 after 2009. Both the temporal and spatial distribution of the clusters appears to be quite stable throughout the years. The major change on the seismicity occurs during 2014 following the earthquake in Saros.

**WORK PACKAGE 5: REAL AND QUASI-REAL-TIME EARTHQUAKE & TSUNAMI HAZARD MONITORING SEISMIC STUDIES IN THE MARMARA SEA**

In October 2014, 16 GPS stations have been updated in order to establish real time data transmission and installation of strong ground motion instruments. For this purpose the power systems for cGPS stations operating with electricity and stations without electricity were improved and 3G GPRS modems were got into use for high-rate data transmission. Processing of High Rate GPS data (1Hz) has been studied with Professor Semih Ergintav. And an algorithm using TRACK/TRACKRT software as a part of routine daily GPS processing with GAMIT/GLOBK was developed and tested with 1s GPS data sets of Van earthquake (Mw7.2) 2011.

The ground motion simulations around the Marmara Sea has been performed by collecting available structure models of this region and using a new version of simulation code (finite difference scheme parallelized using GPU. A moderate earthquake was tested to check the model parameters before providing the reliable ground motion simulations of scenario large earthquakes.

After several preliminary simulations, a model with dimension of 200 km (EW) x 120 km (NS) x 40 km (depth) covering the whole Marmara Sea and the surrounding area has been prepared. The topography has not been considered, as the main purpose of the ground motion simulations were rather on the northern coast of the Marmara Sea. However in some extended model, the bathymetry has been considered so as to introduce one layer of water, because it is important to explore the observations at the bottom of the Sea. For the rapidity under the current test study, a finite difference method was used with 500m-grid size.

In this frame, two different models were used. Firstly, the 1D model used in Karabulut et al. (2002) was used as the reference for study. This model was calibrated for the analyses of the aftershocks of the 1999 Izmit earthquake. Secondly, a 3D model, which was the result of a tomography campaign in the Sea of Marmara region Bayrakci et al. (2013), was used (Figure 11). It was considered that the basin characteristics under the Sea of Marmara are well established. Finally, the ground motions were compared at several selected stations for the 1D and 3D models. In general, a good agreement of the first pulse (P-wave) was
Two different finite-fault techniques have been proposed and tested in order to assess the performance of the inversion codes in the Marmara configuration. Zhang et al. (2014) proposed a new kinematic inversion scheme, called the iterative deconvolution and stacking (IDS) method. In the IDS method which aims at robust and rapid estimation of the main character of the rupture process, synthetic Green’s function deconvolution was applied to the waveform data to obtain apparent subfault source-time-functions from different stations. Results of IDS method have indicated that the input four asperities are clearly identified. Based on the data processing approach used in that study, inversions were carried out by using the three different corner frequencies (0.05 Hz, 0.10 Hz and 0.20 Hz). The inverted results have been showed that the input asperities can be well captured, although different corner frequencies were used for the inversions. Moreover, it was not surprising to find a better resolution by using higher corner frequencies.

The inversion methodology was a two-stage nonlinear technique (Piatanesi et al., 2007, Cirella et al., 2012), which involves the joint inversion of strong motion records and geodetic data. To account for rupture complexity, the model was described by four spatially variable fault parameters - peak slip velocity, slip direction, rupture time and rise time. The final slip distribution was derived by the inverted parameters. The inverted models were similar to the target one; the positions of the asperities were correctly imaged and the slip values were well estimated. In order to quantify and to compare the obtained results, inversion the cost function values associated to the waveforms’ comparison and the ‘SLIP-FIT’ comparison were shown for each performed.

Consequently, the obtained results have been 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. The proposed analysis represented 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.

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 has been investigated. In this frame, a blind test for kinematic source inversion was performed (Figure 12). The obtained result, for the blind test, showed that, it is possible to provide a rapid (CPU between 2 and 13 minutes) and reliable reconstruction of the rupture process of large earthquakes, by inverting near-field strong-motion and high-rate GPS data in the Marmara Sea and by retrieving the most relevant earthquake source parameters. The proposed approach represented 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 was 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 was 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.

Methodology of ground motion simulation was demonstrated and adjusted for the Sea of Marmara (Figure 13). In particular, the available data about the structure models for constructing heterogeneous medium was assembled and the earthquake scenarios were adopted dynamically and stochastically simulated with weighing functions. The regional PGV map for each simulation has ben created and then the ground motion estimations has been analysed statistically. Each earthquake scenario has been attributed a probability ranging from 0.5 to 7.5 %. The PGV was smaller than 0.1 m/s for all the simulated earthquakes of magnitude smaller than 6, while values up to 1.4 m/s were observed for the events of magnitude larger than 7. Besides, the strong-ground-motion simulations were presented from selected earthquake scenarios using a stochastic finite-fault model with a dynamic corner frequency approach Motazedian and Atkinson (2005).
To sum up, for selected fault model the synthetics were computed at 180 sites for this rupture scenario, obtained by the combination of slip model. The largest peak ground value for the selected scenario reach 1.0 g for PGA and 80-90 cm/sec for PGV. The position of the maximum shaking area is located close to the southwestern coast of the European side of Istanbul close to the Bakirkoy and Avclar districts. In addition, simulated ground acceleration and velocity values with those calculated using two different slip distributions, uniform and random weighted slip distributions on the same fault were compared. In both cases the maxima is related to the directivity effects. The computed values clearly depend on the position of nucleation point, whereas the slip model modifies the maxima distribution at the sites close to the fault and according to the asperity location. The maximum PGA and PGV is lower for the uniform and random slip distribution models with right lateral nucleation point varying from about 0.6 g and 40-45 cm/sec for uniform slip model and 0.7 g and 55-60 cm/sec for random slip model, respectively. The maximum value is obtained for the LP slip distribution model where the slip asperity is located in the middle of the fault that could generate PGA values up to 1 g and 90 cm/sec.

A set of earthquake scenarios has been identified to constitute a basis for tectonic origin tsunami scenario database for the Marmara Region. 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 GI-TEWS in Indonesia. Initially, it was decided to divide the Marmara region in grid areas of fixed size 0.1°x0.1° and to develop tsunami scenarios for each bin, where the bin centre will be characterized as the epicentre location. Based on the database provided, simplified fault segments have been identified, where each segment correspond to a rectangular area with an associated uniform slip (Figure 14). All parameters required for the identification of the segments, such as geographical coordinates for the start- and end-points of the segments, hypocentre, type of fault, strike, dip, rake, length and width of the segment, focal depth, corresponding displacements according to empirical relations provided by Leonard (2010) and Wells and Coppersmith (1994), have been provided in.

Tsunami numerical analyses in Marmara Sea have been performed using the earthquake scenarios. In this frame, a tsunami scenario database has been compiled in Marmara Sea referring to 30 different earthquake scenarios obtained with the combinations of 32 fault segments. Tsunami numerical modeling has been carried out by the modeling code NAMI DANCE (NAMIDANCE, 2011). The sea surface at the moment of fault rupture for each segment has been calculated using Okada (1985) formula. The segments were combined according to the earthquake scenario as if all faults were ruptured at the same instance and the final sea surface was obtained as the tsunami source of each scenario. Tsunami hydrodynamic parameters were calculated through Marmara basin and at the total number of 1333 numerical gauge points selected along the coasts of Marmara using tsunami sources of each earthquake scenario. The bathymetric and topographic data used in tsunami modeling is in 90m grid size and a compilation of bathymetric and topographic measurements, GEBCO and ASTER data, digitized coastline and sea structures, and DEM data on land. The evaluation of the modeling results for all earthquake scenarios showed that the maximum wave amplitudes for Kadikoy and Silivri coasts, Bayramdere and Kursunlu districts along the coasts of Bursa province and Halic coasts would be more than 2m. The estimated maximum water levels at Bostanci, Pendik, Cinarcik, Bandirma and Buyukkada coasts and at the entrance of Izmit Bay would reach up to 2m. Tekirdag coasts especially M. Eregli, B. Cekmece and Bakirkoy coasts in Istanbul and Yalova coasts would experience maximum tsunami wave amplitudes around 1.5m. The waves reach up to 1m at Izmit and Gemlik Bays, Erdek Peninsula and Marmara Island (Figure 15).

The fact that a submarine landslide triggered by an earthquake could be the primary cause of a tsunami in the Marmara Sea, as indicated by the historical catalogues and previous studies, shows the importance of an earthquake early warning-coupled tsunami warning system without waiting for any focal mechanism parameter determination that may lead to an underestimation of the tsunami risk in the case of a strike-slip fault earthquake, which sets the dominant seismotectonic characteristic of the Marmara Sea. Through a tsunami warning system directly coupled with the Istanbul earthquake early warning system and based on system-to-system communications, an effective tsunami warning could be made within 3 min to ensure that citizens of the coastal areas would stay away from the direct coastline for at least 2 h after the earthquake has
Despite all recent efforts, in the absence of such awareness in the Marmara region, a possible earthquake-generated tsunami may increase the number of casualties simply due to the fact that, in the absence of post-disaster assembly areas inland, the residents of the coastal areas may storm to the shoreline, especially to Maltepe and Yenikapı landfill assembly areas, in an attempt to save lives from the structural damage due to the earthquake.

Following the seismic hazard modeling study conducted by Erdik et al. (2004) for the Marmara region, and with the purpose of updating the model, the earthquake hazard in the region has been assumed to be the result of the contributions, computed in following two steps: (1) Ground motions that would result from the earthquakes in the magnitude range from 4.3 to 6.6. (2) Ground motion that would result from larger events in the magnitude range 6.8 and higher. First step is termed as “background source activity”. The undelineated fault sources and small areal sources based on spatially smoothed historic seismicity have been used as the background earthquake source. For the computation of the spatially smoothed seismicity, the declustered earthquake catalogue of magnitude 4.3 and higher events were used. Second step is related to the seismic energy release along well-defined and segmented faults. For this part the fault segmentation model that is developed for this study was used with the assumption that energy along these faults are released by characteristic events identified by magnitude and recurrence time.

For Istanbul, Tekirdağ and Bursa, about 10 to 20% larger hazard values have been found when considering time dependency in the hazard assessment, while for the city of Kocaeli, that experienced a recent major earthquake, time dependent hazard was much reduced. 475 years (10% probability of exceedance in 50 years) PGA values of 0.40 g and 0.48 g were obtained for Istanbul city center from Poisson and renewal models respectively. The results are approximately 8% larger than those obtained by Erdik et al. (2004), as both assessments rely on the same methodology. Considering the Poisson approach, 30% decrease in 475 years PGA obtained from Poisson model (caused by model updates both in terms of source characterization and GMPEs) has been observed while this decrease is only 14% in the time dependent approach (effect of the elapsed time since the last characteristic earthquake). It was also observed that the effect of the rupture directivity is to increase the seismic hazard estimations up to 25% and to predict a reduction up to 15% along the two considered segments (the CMF and the CF) of the North Anatolian faults system at 2 sec. The effectiveness of the correction for directivity depends on the period of the spectral acceleration and its contribution is higher at larger periods.

WORK PACKAGE 6: EARTHQUAKE-INDUCED LANDSLIDE HAZARD IN MARMARA

The Cekmece-Avcilar peninsula located westwards of Istanbul as a highly urbanized concentrated landslide prone area and showing high susceptibility to both rainfalls while affected by very significant seismic site effects, have been investigated. The on-shore area of interest locates at the northern coast of the Sea of Marmara and western part of Istanbul metropolitan city. The active northern branch of the North Anatolian Fault Zone (NAFZ) passes through approximately 10-km from south of the studied site. The majority of landslides in the studied site cluster between Küçükçekmece and Büyükçekmece lakes. Most of these landslides, except two small landslides in the clay levels of the Pliocene at the western side of the Küçükçekmece bay, occurred on the clay and varve bearing levels of the Gürpinar formation. The types of landslides generally occurring in this area are deep-seated translational debris, rockslides, shallow slides and flows. In general, the scarp sections of the landslides are apparent but the toe sections of the landslides are not very apparent. The reason for this is the presence of erosion resistant clay and sand bearing sections of the Çukurçeşme formation at the locations of scarp sections of the landslides. It is thought that the changing slope gradient conditions due to the incision of the rivers, which has increased their erosional activities due to sea level changes in Pleistocene, have been effective on the hillslope instabilities (Arpat, 1999). Nowadays, the landslides are occurring from the reactivation of the old landslides. Residual shear strength of these landslides is quite small (<12°). Besides the deep-seated landslides with very low velocities, there have been also highly damaging earth flows with relatively high velocity in the region. These earth flows are mostly effective in the east coasts of Büyükçekmece. Litho-stratigraphic characteristics of the region are the most important factor controlling the distribution and density of the
landslides in the region. Heavy rains with 10 years of return period and also human activities (i.e. 2004 Veryant landslide near ISKI water pump station in Büyükçekmece) are known to be among the landslides triggering factors. Moreover, although there is no historical record, the earthquakes can also be considered as a potential triggering factor for the landslides on the region (Figure 17).

The offshore entrance of the Izmit Gulf which is close to the termination of the surface rupture of the 1999 earthquake that shows an important slump mass facing the Istanbul coastline has been studied.

As regards the selected offshore area, high-resolution geophysical marine surveys have been conducted to complete its geomorphological description to help in mapping possible incipient mass movements. This is especially expected to provide better-constrained input for both laboratory testing and numerical modeling of tsunami scenarios thank to a unique lab-scale tsunami channel.

The research cruise MARMARA2013 was carried out with the R/V Urania, owned and operated by SO.PRO.MAR. Georeferencing of the data was performed relative WGS84 datum, in UTM33N and 34N projections and time in UTC. Multibeam data were processed using CARIS software and ISMAR’s routines using the SIS production DTMS. Seismic reflection data were analysed and interpreted using SeisPrho.

Finally, the South-Eastern Cinarcik Slump (SECS) was recognized, studied and analyzed in term of tsunami hazards for the coast of the Sea of Marmara (NW Turkey). The SECS is located close to the wester termination of the 1999, Mw=7.4 Izmit earthquake, and for this reason it is most probably close to the epicenter of the earthquake that according to recent studies will struck Istanbul in the next decades.

A plurality of possible scenarios has been indicated, because if the extent of the slumping body is well constrained (25 km2 by 250 m of maximum thickness), the internal geometries suggest multiple gliding planes. These uncertainties heavily affect any possible estimate of the tsunami hazard associated with the possible failure of the SECS due to future earthquakes along the so called Cinarcik segment of the North-Anatolian Fault system in the Sea of Marmara.

Ground motion data and local seismic site effects at Buyukcekmece landslide has been investigated by a prototype observational system, installed by INERIS. The geophysical measurements and the geological field surveys in the landslide area were combined to obtain an engineering-geological model. This model was the starting point to analyze the local seismic response of Buyukcekmece landslide.

The Cekmece-Avcilar peninsula was characterized by landslides, showing high susceptibility to both heavy rainfall and earthquakes. Therefore, an efficient early warning system has to take into account these two triggering factors. Concerning earthquake early warning (EEW), two approaches are possible: regional warning and on-site warning. In this study, the second one which based on individual sensors installed at the Büyükçekmece landslide has been considered. Generally, for on-site warning the beginning of the ground motion (mainly P waves) recorded at a site is used to predict the ensuring ground motion (S waves and surface waves) at the same site.

The exceedance of specific threshold time-domain amplitude of PGA, relationships of both between τc and Mw, and between Pd and PGV for the Marmara Region has been studied. Real-time rainfall data compared with rainfall thresholds can be incorporated into a landslide warning system.

In the case of Büyükçekmece landslide, the numerical modeling that checked the reliability of the simulated local seismic response respect to the actually recorded one both in terms of HVSR and amplification function has been performed. Based on this modeling, the maximum earthquake-induced displacements of the landslide mass has been computed and horizontal displacements up to 10 cm can be expected in case of low period earthquakes having an Arias intensity in the order of 0.1 m/s has been found. This last condition well corresponds to the earthquake scenario for a 475yrs return period and related to the NAFZ.

WORK PACKAGE 7: RE-EVALUATION OF THE SEISMO-TECTONICS OF THE MARMARA

The evolution of the tectonic structure and the behaviour of the faults with time has been investigated by revising the active fault map and by determining slip partitioning and slip rate on individual fault segments, by comparing geodetic vs. geologic rates.
In order to understand better the geometry of Moho, crustal thickness and the amount of extension in the sea of the Marmara, gravity modelling was also performed. The modelling indicated a total of 2100±300 km$^2$ of extension during the formation of the Marmara Sea. Another result is the zone of Moho uplift is wider than the deep basins and extends below the shelf (Figure 19).

To clarify which faults are cutting the seafloor (and thus currently active) and which ones do not was another important point. Several now inactive (or marginally active) fault systems appear to have played a role in the structuring of the basins. Using primarily multichannel data, a GIS fault map was provided and it represented the fault geometry at a few kilometers depth within the syntectonic basins (Sengor et al., 2014). The observation on categorized faults show that some deformation is still accommodated over a broader area, and that subsidiary faults display a complex history of fault activation/deactivation. There is also a tendency toward strain localization in a 7-to-10 km swath along the Main Marmara Fault (Sengor et al. 2014). One of the identified deposit complex yielded a measurable offset across the fault of 7.7±0.3 km, corresponding to a slip velocity range of 15.1–19.7mm/a over the last 405–490 ka (Grall et al., 2013). Geological strike-slip rates obtained on the northern branch of the NAF on land appear compatible with the more recent determinations in the Sea of Marmara. This study gives support to the ideas that intracontinental transform faults begin their lives as broad shear zones and become gradually converted into single- (or at most a few-) strand structures. Moreover the long-term slip-rate of the northern branch of the North Anatolian Fault within the Sea of Marmara was determined to be about 18 mm/yr (Grall et al., 2013).

The studies based on on-land surveys indicated that the fault slip rate on the main fault segments both inland and offshore appear to be only about 2/3 to 3/4 of plate motion. This may suggest that the subsidiary faults could cause damaging earthquakes, although of lower magnitude and with longer recurrence interval (Zabci et al., 2015). Besides, acoustic distance meters also were deployed at the seafloor and sediment cores were taken in Kumburgaz Basin for paleoseismological studies to understand the slip deficit and clarify earthquake recurrence interval on the central segment (Istanbul Segment).

The offshore and inland faults have been compiled and remapped by using various studies or the interpretation of new data. The parameters obtained for these faults such as fault name, fault type, and fault class were integrated into a GIS database.

A seismic hazard scenario has been proposed for the active fault system based on a new morphostructural map using all available high-resolution seismic reflection profiles and multibeam data collected during MARMARA2013 expedition (Gasperini et al., 2013).

In the Sea of the Marmara, three styles of active deformation have been observed. These are; 1) almost pure strike-slip, oriented E-W; 2) trans-tensional, NE-SW oriented, which is the most common pattern; trans-pressive, forming structures oriented NW-SE. At the scale of the entire Sea of Marmara, 3/4 major segments were recognized. From E to W, they were called: the Cinarcik Segment, located to the E of Istanbul; the Istanbul East, and West segments, located parallel to the coast in front of Istanbul; the Tekirdag Segment, from the Central Basin to the western coast of the Sea of Marmara, where the Main Marmara Fault connects with the Ganos Fault.

With regard to the segments of Istanbul East and West, separated by a very small overstep (less than 1 Km), two alternative scenarios, which included a single rupture of each of the segments, or a cumulative break in the course of a single event have been considered. Based on the map of the individual branches of the fault, the deformation along the each segment has been analyzed. According to these analyses, most of the segments are dominated by strike-slip faults such as the Istanbul East and West and the Tekirdag segments. The Cinarcik segment is dominated by faults orientation pointing to N290 ° which characterize a typical trans-extensional deformation pattern.

Taking into account the Istanbul East and West segments as a single element, magnitude is Mw =7.34. As regards the other two segments, Mw = 6.85 is for the segment of Cinarcik and an Mw=7.08 is for the segment of Tekirdag. If these results were compared with historical catalogues, an interesting match has been found, which confirms the validity of structural analysis of this study.

A new segmentation model was also produced using the most detailed fault traces of the NAFZ branches available in the literature and on their geometrical and structural arrangement at the surface. For each fault within the segmentation model, geometrical and behavioural characteristics were integrated by proposing the earthquake magnitude and slip-rates and associated historical and instrumental earthquakes with the individual segments.
In order to re-assess the slip rates and decrease the uncertainty of the slip rates evaluation and collect new data, the area between Geyve and Gemlik were selected. The investigation was based on a new mapping of the main active fault segments between Geyve and Gemlik based on the analysis of satellite imagery followed by field truthing. The maximum measured horizontal offset at the 3 sites is very comparable and varies between 60 and 75 m; thus, suggesting the main surface where the creeks developed is of the same age. A lateral and vertical slip rate of 3.4±0.5 mm/yr and 0.5±0.1 mm/yr, respectively, has been found. The vertical slip-rate is much small than preexisting evaluations.

The sediment cores produce a longer history in Marmara Sea. The only earthquake recorded on the sediment covered Central High segment for the last 15 ka is a faint, a finding possibly related with the 1963 event, suggesting that the Central High segment SW of Istanbul has been creeping, and that the rupture of the 1963 earthquake may have extended from the southern Cinarcik Basin to the Central High. The onland sections of the NAF last ruptured during the 1999 earthquakes in the eastern Marmara Region. The studies based on the Trench on different locations showed 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.

The trenching study offset measurements indicated non-characteristic behaviour for the NAF section that crosses the Hersek Delta. In this area, there was no significant displacement during the 1999 earthquake. In this location, a post-Justinian pipe was measured to have an offset about 10 metres [Kozaci et al, 2012]. Contrary to the northern branch, there is relatively information on the paleoseismology of the southern branch of the NAF. A single submarine study yields a single paleoevent (AD 368 or 447 or 460) from the sediment cores of the Manyas Lake. Trench study on the Yenice-Gönen Segment indicated at least two dated paleoevents (AD 1953 and 1440) for the southern parts of the fault zone.

Although there are quite well distributed earthquakes almost on all segments of the NAF, there is just a single (and questionable) indirect evidence of surface faulting, which is actually correlated with A.D. 1963, within the Kumburgaz Basin. By using both the offshore data and the direct evidences of inland paleoseismological trench results, it is interfered that the westward migrating sequence is not only unique to the 20th century, but there also occurred similar sequences at least for the last 1000 years.

In order to understand better the seismic behaviour of the poorly known southern branch, new paleoseismological trenching was carried out at various locations between the Gemlik Bay and Geyve. The results indicates significantly longer interval of earthquake recurrence for the southern branch of the NAF.

The historical earthquakes have been revised in detail using the catalogues and these earthquakes have been assessed in terms of their locations on the fault segments of the Marmara Sea Region. Namely, the earthquakes, which caused damage on a settlement, were grouped according to their influence areas by examining different sources grouped on a historical map without faults. Considering the fault lengths, total slip rates per year and depth of seismogenic zone, it has been possible to carry out the moment magnitude calculation. According to the influence areas, these earthquakes were classified as for the regions, İzmit Bay, Southern Marmara: Yalova-Tekirdağ, Eastern Marmara, Middle Marmara: Western Istanbul-Silivri, Western Marmara: Tekirdağ-Silivri-Bandirma, Gaziköy-Gölçük, Saros-Kavak.

These three models were prepared on a database in ArcGIS software. Firstly, a 1:500000-scale digital geological map of Marmara Region was revised according to the Vs30 data compiled from the literature in the manner of 750x750m grids. Using the calculations on these base and fault maps, Modified Mercalli Intensity (MMI) maps were generated for each segments of each models. Then, 250x250m grids were generated by using 1:25000-scale digital elevation model, geological map and Vs30 values measured by Istanbul Metropolitan Municipality to prepare the other scenario for the historical Istanbul peninsula. The exact locations of the historical constructions in Istanbul have been plotted by using high-resolution satellite images and archaeological maps and then the damages were compared on the basis of these generated maps, fault models and high-resolution MMI maps. The approach about the faults generating the earthquakes was invertedly tested and the historical catalogues and MMI maps were locally compared (Figure 20 and Figure 21).

According to the results after examining the relation between historical earthquakes and fault patterns, each segment has its own periodicity and magnitudes Mw; these are İzmit Bay Segment; 249±30 years, Mw 7.43±0.05 Southern Marmara: Yalova-
Tekirdağ; 476±44 years, Mw 7.65±0.05 Eastern Marmara; 242±40 years Mw 7.20±0.05 Middle Marmara; Western Istanbul-Silivri; 257±40 years Mw 7.31±0.05 Western Marmara: Tekirdağ-Silivri-Bandırma; 244±40 years Mw 7.3±0.05 Gaziköy-Gölcük; 278±41 years Mw 7.28±0.05 Saros-Kavak; 403±42 years, Mw 7.37±0.05.

WORK PACKAGE 8: MONITORING SEISMICITY AND FLUID ACTIVITY NEAR THE FAULT USING EXISTING CABLED AND AUTONOMOUS MULTIPARAMETER SEAFLOOR INSTRUMENTATION

A marine geological cruise, MARM13 was carried out with the 61-meter R/V Urania, owned and operated by SO.PRO.MAR and on long-term lease to CNR in order to collect, share and integrate multidisciplinary data (seismologic, geochemical, surveying, satellite etc.) for the purpose of assessment, mitigation and management of seismic risk in the region of the Sea of Marmara (Figure 22).

Deployment of the SN-4 station in the Izmit Gulf was carried out after high-resolution survey of the site using MBES and chirp-sonar and ROV and MEDUSA dives. The deployment of the station at the previous deployment site was discarded due to the presence of a numerous amount of bricks on the seafloor, raising the doubt of the station to be damaged after future discharges. After deployment, several tests with acoustic transponder guaranteed the communication with the station verifying its functioning and attitude. The MEDUSA system was useful as to spot the suitable location for SN-4 deployment, other than providing CH4 emissions detection and water column analysis. The 4 OBSs were deployed correctly at their proposed stations, as verified by tests carried out soon after deployment. The first piezometer was successfully deployed at the desired location. The second one, after a first problem with an over-consolidated rock layer that bent the iron pole, was successfully deployed after the necessary reparations. After processing geophysical data, results highlighted the high-resolution of the newly installed EM-302 and the Chirp system on board of Urania that perfectly fitted the requirements of accuracy in mapping the seafloor and the active faults in the Marmara Sea. The seabed samples have been collected through the CP20 piston corer with a 10 m pipe by ISMAR and the Turkish sediment/water corer. All piston cores, for a total of 10 of them, recorded a consistent recovery in between 7.40 and 9.40 m, while the sediment/water cores were all satisfactory. Multichannel reflection seismic survey was useful to test the newly acquired streamer, which demonstrated its validity.

An integrated approach based on multiparameter seafloor observatories has been implemented and the micro-seismicity along with the fluid expulsion activity within the submerged fault zone has been continuously monitored. Additionally, low magnitude earthquakes have been detected and the characterization of the near-fault micro-seismicity has been improved, particularly along the central part of the SoM as a particular target of this work. To meet this objective, velocity models were developed by KOERI and by Ifremer to improve earthquake location in the Sea of Marmara, following two different approaches:

1. KOERI has developed a 3D velocity model for the whole Marmara Region, including land and sea bottom stations, with grid spacing of 9 km x 9 km x 3 km.
2. Ifremer has developed an opposite, but complementary approach, strictly based on sea bottom stations, for the Western Sea of Marmara. A high resolution velocity model with a 750 m x 750 m x 400 m grid spacing was built, using multi-beam bathymetry and wide-angle seismic data.

The velocity model developed by KOERI for the whole Marmara region by merging land and sea stations appears to be very useful to improve the quality of earthquake catalogues and the real time monitoring of the regional seismicity. In addition, it has a critical importance to create a high-resolution, 3D velocity model, in order to take into account for the velocity contrast at the water/sediment interface and the slow seismic velocities within the sediment infill in the main Marmara Trough.

Different datasets include data acquired by Ifremer in 2009 and 2011: seismological data from Ocean Bottom Seismometers (OBS), pore pressure data from deep seafloor piezometers, seabottom temperature and acoustic data from a Buble Observatory (BOB) have been used. A specific software (Visumultiparameter) has been developed to visualize, to process and to analyze seismograms, sea-bottom temperature and sediment pore pressure simultaneously. Sea floor pressure records from KOERI observatories and from Marnaut cruise (2007) were also examined. Before data analysis, pre-processing procedures, like data reduction, reformatting, time drift correction, amplitude and gain correction, offset removal, etc, have been applied different data set.
Results of data analysis significantly showed that BOB is a powerful tool to detect gas bubble emissions, within a radius (~a few tens of meters) that directly depends on the acoustic frequency. In active tectonic settings (e.g. in the Cinarçik Basin), gas emission sites tend to follow tectonic lineations. Other factors, related to the sediment cover, also control gas emissions (e.g. in the Central High). Seafloor monitoring using collocated OBS and acoustic gas bubble recorders (BOB) represented a very promising way to directly monitor gas related processes within the uppermost sediment layers. The piezometers have clearly recorded variations in sediment pore pressure triggered by transient, seismic signals. One case of correlation was also observed between the occurrence of SDEs and pore pressure decrease recorded at 5 m below seafloor. The quantitative relation between ground motions and pore pressure variations requires further investigation, through additional data acquisition and numerical modelling.

The marine paleoseismological record is established from turbidite-homogeneite deposits in the deep basins, which are presumably shaped by resonant oscillations of the water column (seiche), following earthquakes, landslides and tsunamis (Beck et al., 2015). However, the hydrodynamics of seiche oscillations in the Sea of Marmara, and their triggering by earthquakes were only studied by numerical modelling. Only one record of long period (> 9 minutes) pressure variations at the bottom of a deep basin is available today. Repeat surveys and monitoring in Izmit Gulf have shown a progressive decrease of gas emissions after a maximum immediately following Izmit 1999 earthquake. Establishing temporal relationships between gas emission and fault slip (seismic and aseismic) necessitates the acquisition of long time series within the deeper parts of the Sea of Marmara.

WORK PACKAGE 9: EARLY WARNING AND DEVELOPMENT OF THE REAL-TIME SHAKE AND LOSS INFORMATION CABLED AND AUTONOMOUS MULTIPARAMETER SEAFLOOR INSTRUMENTATION

The improvement on the risk assessment for Istanbul city has been studied through the vulnerability evaluation of typical building structures. For a general building stock, structural (system, height, and building practices) and occupational (residential, commercial, and governmental) parameters are considered in order to evaluate the risk comprising the damage and loss characteristics. A specific building typology has been studied in order to assess the vulnerability of this building structure under a potential earthquake ground motion. It is considered to adopt this developed methodology for the other building typologies in the inventory.

A real-time risk assessment procedure has been developed to be applied to the Istanbul building inventory. The utilization of a set of simple techniques using Ambient Vibration recordings to complement seismic vulnerability assessment to existing buildings has been studied. Decomposing the motion of a building into simple modes (bending and torsion) is the first step in the assessment of its behaviour under an earthquake. The building modal parameters has been extracted by using the Frequency Domain Decomposition (FDD) method, which is easy to perform and reliable even in case of close modes. The analysis of recordings showed that the FDD is able to extract reliable information (frequency, modal shapes and eventually damping) even if the basic assumption of white noise is not fulfilled. The values of the measured frequencies are directly linked to the stiffness of the building so that the average stiffness ratio between the longitudinal and the transverse directions can be assessed.

For vulnerability assessment, only analysis of recordings is not sufficient so the analytical approach with a simple lumped-mass model with an assumption on the stiffness matrix (shear wall) in order to calculate the stiffness at each storey has been applied. The choice of the stiffness model is based on the sequence of the resonance frequencies of the studied building.

The concept of fragility curves in the safety assessment has been first applied for the nuclear power plants and there has been still an ongoing effort towards the generalization of the methodology for the vulnerability and risk assessment of various structures. Furthermore and based on the definition of the seismic fragility of any arbitrary object, the analytical procedures should target the evaluation of the probability of reaching or exceeding a certain damage level under a specific demand state,
here taken to be the ground motion hazard level. It needs to be reminded that all the numerical evaluations have been specifically performed, using the actual recorded data of the reinforced flat slab building at Ataköy so that the derived diagrams and functions could be interpreted as the ‘real-time’ properties of the structure under consideration. It is believed that the developed procedure in this study can be applied to other building typologies.

The existing earthquake early warning (EEW) and Rapid Response (RR) systems in the Marmara Region has been aimed to improve including the installation and test of a pilot seismic landslide monitoring system. In this framework, a first observation prototype system was set up on an active but slow landslide in the Avcilar-Beylikdüzü Peninsula, a large landslide prone area located in westward part of Istanbul and facing the NAF.

The prototype observational system is a multi-parameter type which is composed of GPS devices to measure 3D displacement, seismic probes for seismic shaking, piezometers for pore pressure in the subsurface soils, and a rainfall meter to monitor. This monitoring has been aimed first to collect data on a large and slow landslide on the geological setting of the Avcilar peninsula for a better understanding of the landslide mechanism versus time, underground pore pressure and seismic ground motion. Secondly, it has been aimed to assess the technological integration of the system for both real-time warning towards potential end-users in both situations.

Considering the system used in this frame, a GPS-RTK system based on the state of the art technologies of differential GPS has been used. In addition, two 3D seismic probes (installed at the bottom, -45m, and on the surface of a 70 meters deep borehole close to the farm station) were used to measure seismic ground motion. Finally, a geotechnical system -including two piezometers, a moisture sensor, a rainfall meter and temperature sensor were used.

Potential impact of large earthquakes on urban societies can be reduced by timely and correct action after a disastrous earthquake. Modern technology permits measurements of strong ground shaking in near real-time for urban areas exposed to earthquake risk. The Istanbul Earthquake Rapid Response System (IERRS) has been deployed by Kandilli Observatory and Earthquake Research Institute (KOERI) in 2002 with the 110 strong motion stations distributed in the densely populated parts of the Istanbul city. In 2013, Istanbul Natural Gas Distribution Company (IGDAS) has also deployed 110 strong motion stations at the Natural Gas network district regulators with the purpose of automated shut-off the gas flow. By integrating these two networks KOERI and IGDAS, there have been in total 220 strong motion stations providing real-time data and generating real-time shaking maps during an excessive ground shaking. Virtual Seismologist and PRESTo algorithms have also been deployed to further improve the system. The Virtual Seismologist (VS) method is a Bayesian approach in earthquake early warning to rapidly estimate the source location and magnitude. The VS method shares with other proposed methodologies the use of relative predominant period and attenuation relationships to estimate magnitude and/or location from available ground motion observations. The introduction of prior information into the earthquake source estimation problem distinguishes the VS method from other early warning.

Here we applied the regional methodology PRESTo (PRobabilistic and Evolutionary early warning SysTem) to a set of real earthquakes (2011 İzmit Gulf M4.4 2008 Çınarcık M4.8 6 June 208 İstanbul M<4, 1999 M7.2 Duzce earthquakes) recorded in the Marmara region, representative of different scenarios, with the aim of evaluating the expected ground motion and the lead time for Istanbul and some other cities located in the region.

Evaluation of an earthquake early warning performance for the Istanbul city was also performed by the use of stochastic waveforms at the dense rapid response network displaced in the city along the Asian and European coasts (Oth et al., 2010). Following a threshold based approach, according to which the warning is issued when a threshold in PGA is overcome to a certain number of stations, they found the optimal set of parameters and network distribution to have the longest lead-time and to reduce the number of false alarms. Here we propose a complementary regional approach where the ground motion prediction is based on the real time estimation of the source parameters. We additionally use real data, which also contain complexity in source, propagation and site effects, while ground motion is verified for the Istanbul city by records in the city itself. Because of the limitations in the availability of the accelerometric data at a large number of stations, we were able to
investigate the response of the system on a small number of earthquakes. Anyhow, they are representative of different scenarios, target distances and earthquake size, from which general conclusions may be derived.

The system PRESTo was installed at KOERI to run in real-time and analyze earthquakes occurring in the Marmara sea region. In its early version PRESTo worked only on accelerometer stations, whose availability at the control center of the network was limited. This is due to the fact that most of Rapid Response stations do not directly flow into the datacenter and additional stations belong to AFAD. The use of a limited number of available data was shown to significantly reduce the performances of the system as compared to other worldwide areas. Hence, recently an updated version of PRESTo was installed that also processes the velocity stations, to improve the performances of the system.

The exposure term of risk and consequently stresses on the importance of remote sensing in locating the exposed elements have been monitored. The concept of risk has been evolving during the last five decades. It extends from being only hazard-dependent to more complicated approaches considering the mutual interaction of the added components: exposure, vulnerability and capacity. Vulnerability is defined as the conditions determined by physical, social, economic and environmental factors or processes, which increase the susceptibility of a community to the impact of hazards (Birkmann, 2004). Building-related physical vulnerability can be expressed in the form of indices or curves. Indices, vulnerability is estimated with indicators that are not directly related to the hazard intensity. Curves, based on the interaction between hazard intensities and damage; in particular, they reflect the monotonic increasing relationship between the damage state and the hazard intensity level.

Built-up areas and their evolution in time are of key importance for exposure monitoring. Satellite remote sensing demonstrates its usefulness thanks to the regular revisit time and the coverage of long time spans that are being increasingly made available on open policies. The availability of Landsat imagery with its open policy enables public access to one of the longest archives of Earth observation that extends over 40 years. Moreover, the similar spatial resolution for the multispectral bands of the Landsat 5, 7 and 8 enabled a consistent derivation of information from the acquisitions.

In conclusion, it is noted how the urbanization on the northern edge of the European side of Istanbul reported in the last decade has been made well visible by mapping the urban area extent at different dates. These algorithms were included as part of the “SENSUM Earth Observation Tools QGIS plugin”. The same procedure can be applied to any relevant site in the Marmara area, thus helping to map the exposure of people and property in the concerned region.

WORK PACKAGE 10: INTEGRATION OF DATA MANAGEMENT PRACTICES AND COORDINATION WITH ONGOING RESEARCH INFRASTRUCTURES

MARSite has planned to participate in the coordination of major European initiatives focused on the collection of multidisciplinary data, their dissemination, interpretation and fusion to produce consistent theoretical and practical models, the implementation of good practices so as to provide the necessary information to end users, and the updating of seismic hazard and risk evaluations in the Marmara region. In order to achieve this objective, all the European and international initiatives and projects that could have links with MARSite were identified. As an example of the potential links, MARSite is one of three Supersite projects recently funded by the European Commission (EC), the other two being the Mediterranean Supersite Volcanoes (MEDSUV) and the Icelandic volcanoes (FUTUREVOLC) projects. Also the project’s fields of interest (e.g. seismic risk and data dissemination) and the geographical region studied (the Marmara Sea and the megacity of Istanbul) overlaps with many on-going projects, for instance the EC-funded Project REAKT and large-scale initiatives such as the European environmental infrastructures of the ESFRI roadmap EPOS and EMSO, of which the Marmara Sea is a node.

Concrete collaborations and the exchange of information have been pursued by the MARSite. An update on collaborations between MARSite and related projects and initiatives have been provided. Members of the MARSite consortium participated in the final meeting of the EPOS Preparatory Phase in Rome in 22nd to 24th October 2014.
Close cooperation with EPOS has been maintained in the field of data policy. Similarly MARSite partners have participated in GEOSS meetings. Collaboration with the European project REAKT on earthquake early warning has been maintained during the second year of MARSite. Also collaboration with the Research Infrastructures EMSO, EPOS and FIXO3 have been performed in the final year of MARSite. Finally, results and data from MARSite could be shared with projects funded by H2020. The MARSite portal (http://marsite.brgm-rec.fr/marsite/) is a vehicle for such data sharing.

The aspects of proposed architecture of the interoperable web portal for the diffusion of data of relevance to MARSite, potential data models and relevant services were illustrated by a pilot implementation available at: http://marsite.brgm-rec.fr/marsite/.

The design of the architecture of the proposed MARSite system, based on the principles of interoperability and distributed systems were discussed and several similar or overarching existing architectures, such as OneGeologyEurope, ESA Thematic Exploitation platform, GEOSS and GEO Supersite Initiative, INSPIRE, EPOS, EMSO, GEOWOW, GENESI-DEC, ENVRI, iCORDI, NERA and RESIF have been considered.

A distributed system was based on the use of several components, connected over a network, that follow standard specifications to exchange information. The interoperability between all components is possible when they observe the specifications both in the exchange and in the structure of the information. The architecture of a distributed system should implement the “Publish-Find-Bind” pattern. The data and services providers must be able to describe and publish their resources, the users should have the tools to find these resources, and if they meet their requirements, to use them. To publish the resources (datasets and web services) they must be first described by metadata. Datasets are served according to standard data models and discovered, viewed, downloaded, and processed by web services.

ESA has provided to the MARSite partners a range of innovative processing services, tailored for the generation of Earth observation (EO)-based products. The processing services are usable by the MARSite partners, and more generally the geohazards research community, on a geospatial data platform, the Geohazards Exploitation Platform (GEP). Processing results are made available via interoperability standards, so they can be readily integrated in the MARSite portal. With this approach, ESA contributes to the MARSite project with data provision and integration of satellite data and new products elaborated on GEP, tailored to the needs of the geohazards researchers community working on the Marmara sea region.

Providing a validated approach and services for sound integration of EO data, products and toolboxes, GEP contributes to connecting the MARSite system to overarching systems like GEOSS and EPOS. From February to October 2015, ESA is running a GEP validation phase with early adopters, in order to prepare for the pre-operations phase, which starts at the end of 2015. The geohazards community is welcome to apply as early adopters, by committing to run one or several of three scenarios: EO data exploitation, new EO Service development, or new EO Product development. It is an opportunity for the MARSite partners to engage with this process and contribute requirements, use cases and community feedback. ESA edited an Early Adopter Registration Document or explosion scenario during the Platform’s Validation Phase to support partner’s application. This process has already been adopted by the MED-SUV project.

One key activity to engage with the MARSite partners and community is the coordination with BRGM in charge of the MARSite Portal and Map Viewer, in order to leverage the interoperability protocols that will allow BRGM to integrate the GEP services and products within the MARSite Portal.

Potential Impact:
The main aim of the MARSite project was assessing and managing using state-of-the-art methods seismic risk at the European level. MARSite represented a key case study and qualifies as a Global Earthquake Model (GEM) Regional Initiative, thus augmenting efforts in addressing geo-risk at both global and regional levels. Effective coordination between the MARSite consortium, GEO and GEM were ensured by the participation of many of the main national and European institutes and research groups within these initiatives.

The importance of the selected site, Marmara, was evident for the MARSite Project, as this is one of highest seismic risk region in Europe. The Marmara region, as well as the impact on the near-by mega-city, Istanbul, is in a unique situation where a large
earthquake along a plate boundary is anticipated in the near future. Since 1900, around 90,000 people have lost their lives in 76 earthquakes in Turkey, with a total affected population of around 7 million and direct losses of around 25 billion USD. Based on a time-dependent model that includes coseismic and post-seismic effects of the 1999 Kocaeli earthquake with moment magnitude (Mw) = 7.4 Parsons (2004) concluded that the probability of an earthquake with Mw > 7 in the Sea of Marmara near Istanbul is 35 to 70 % in the next 30 years (Erdik 2013). A recent study also confirmed that the probability of occurrence of an earthquake of magnitude greater than 7 is high in the Marmara region. While most of the large events are characterized by epicenters located in the central or eastern parts of the Sea of Marmara, the possibility of a western-initiated rupture propagating eastwards cannot be ruled out (Aochi and Ulrich 2015). Bohnhoff et al. (2013) indicated that the remarkable sequence of large earthquakes over the last century in the North Anatolian Fault Zone (NAFZ) has left an earthquake gap south of Istanbul and beneath the Marmara Sea, which has not been filled for 250 years. They argue, furthermore, that the Prince Islands segment is locked and is therefore a potential nucleation point for another Marmara segment earthquake. This hypothesis has been further supported by Ergintav et al. (2014), where they reported direct observations of strain accumulation on the Prince Islands segment, constraining the slip deficit rate to 10–15 mm/year, concluding that the Prince Islands segment is most likely to generate the next M > 7 earthquake along the Sea of Marmara segment of the NAFZ. According to a 2011 study, an earthquake with Mw = 7.25 on the Main Marmara Fault is expected to heavily damage or destroy 2 to 4 % of around 1,000,000 buildings in Istanbul with a population around 13 million, with 9 to 15 % of the buildings receiving medium damage and 20 to 34 % of the buildings damaged lightly (Erdik 2013).

The development of the MARsite project in the Marmara sea region ensured the integration of data from land, sea and space. The processing of this composed data based on sound earth-science research has been shown as an effective tool for mitigating damage from future earthquakes. This is achieved by monitoring the earthquake hazard through the ground-shaking and forecast maps, short- and long-term earthquake rate forecasting and time-dependent seismic hazard maps to make important risk-mitigation decisions regarding building design, insurance rates, land-use planning, and public-policy issues that need to balance safety and economic and social interests. Time-dependent probabilistic forecasting and seismic hazard maps have been developed for applications of real and quasi real-time mitigation of earthquake risk.

The scientific achievement of the MARsite that directly contributed to its societal impact could be summarized as below:

With the contribution of all WP3 partners, KOERI submitted a proposal to GEO in order to make available SAR data sets through Supersites Initiatives. As a result of this, Marmara region is now monitored by space agencies where the collected data is open to scientific community. Partners demonstrated the power of the use of different sensors in the assessment of the earthquake hazard. The attributes of fault zones are estimated in Marmara region, which will provide new insight to the scientific community. The critical results were published and shared with decision-makers in order to contribute the long-term hazard plans.

The InSAR ground displacement time series provide one of the best methods to monitor the evolution of slow-moving landslides, and of other phenomena as land subsidence and sinkhole collapse. The results will be useful for the identification of spatial and temporal patterns of such phenomena in the Istanbul area.

All the required instrumentation set out in the proposal for the WP4 has been completed, designed and successfully installed and is operational. A multidisciplinary innovative borehole seismic observatory equipped with “VBB” broad band “CMG-3TB” sensor incorporating strong motion instrument “CMG-5TB” consistently provides higher quality data with an amplitude dynamic range exceeding 200 dB which can detect signals from Earth Tides to 250 Hz and its data can be used for a range of seismic studies. Irrespective of the environmental conditions the quality of data from a borehole VBB Broad band sensor is superior compared to a very well designed surface seismic vault. This improvement is particularly evident and extensive in the horizontal components. The signal to noise ratio improvements achievable with a borehole installation at the short period and long periods of seismic spectrum has been identified as significant. During the installation, a new method of setting up stable borehole seismic stations has been tried where a new method for creating a watertight borehole and cementing the
borehole casing was successfully applied. A dilatometer attached to a borehole casing has been installed and successfully cemented. A set up that facilities comparison of surface Broad band sensor to that of a VBB borehole close to a fault line has been achieved. The station data provides information on coupling of sensor to formation and advantages of reduced background noise on the detection of seismic signals. The marsite multi-parameter instrumentation also provide the high quality data to study some of the more recent ideas on monitoring seismic events such as, tremors. Tremors are extremely faint and periodic rumblings originating in complex fault lines. There are strong indicators that tremor activity may precede earthquakes.

Social implications of multidisciplinary seismic station are substantial; especially considering the fact that the observatory uses less space and is not intrusive to the community. The cost of setting up the prototype Marsite station has been proved to be economically viable for setting up large scale arrays without effecting the environment especially populated areas. The stations can be spatially organised without compromising the scientific objectives of the array due to the fact that the space required to set up such stations is virtually one-meter square of land space Therefore the Marsite borehole multi-parameter station allows the setting up of very high performance seismic stations in densely populated earthquake prone areas. This was not possible until proving the performance of such Marsite stations being viable and possible. The data obtained from the multi-disciplinary seismic station brings together many different instrumentation disciplines as a single installation reducing cost. Furthermore Marsite project also brings together the study of crustal deformation and semiology to be conducted at a single observation point with reduces cost and effect to the environment. Due to the encouraging results obtained from this experiment, it is likely that smaller number of stations will be required reducing the cost of national seismic networks.

The technical infrastructure of the continuous GPS stations of MAGNET network has been updated since the beginning of the project within WP5. Progress has been made in the ground motion simulations around the Marmara Sea and simulations were compared at several selected stations for the 1D and 3D models. Two different finite-fault techniques have been proposed and tested where the obtained results show 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. 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. A methodology of ground motion simulation was demonstrated and adjusted for the Sea of Marmara. In particular, the available data about the structure models for constructing heterogeneous medium was assembled and the earthquake scenarios were adopted dynamically and stochastically simulated with weighing functions. This provides the regional PGV map for each simulation and then allows analysing statistically the ground motion estimations. Improvement of Seismic Hazard Assessment for Marmara Region has been accomplished through improving the fault source model geometry and parameterization based on recent literature as well as outputs of different work packages of MARSite.

Within WP5, a tsunami scenario database has been compiled in Marmara Sea referring to 30 different earthquake scenarios obtained with the combinations of 32 fault segments. The results show that the maximum wave amplitudes from earthquake-only generated tsunamis is around 2m, which provides evidence that historically observed tsunamis in the Marmara region with wave heights exceeding in this study are mainly due to submarine landslides. The fact that a submarine landslide triggered by an earthquake could be the primary cause of a tsunami in the Marmara Sea, as indicated by the historical catalogues and previous studies, shows the importance of an earthquake early warning-coupled tsunami warning system without waiting for any focal mechanism parameter determination that may lead to an underestimation of the tsunami risk in the case of a strike-slip fault earthquake, which sets the dominant seismo-tectonic characteristic of the Marmara Sea. Through the proposed tsunami warning system directly coupled with the Istanbul earthquake early warning system and based on system-to-system communications, an effective tsunami warning could be made within 3 min to ensure that citizens of the coastal areas would stay away from the direct coastline for at least 2 h after the earthquake has occurred.

The methodology developed in WP6 to analyse hyper spectral data may be useful both to analyse hyper spectral data and obtain abundances of different end members in a number of applications, from vegetation mapping to urban area
characterization to mineral exploration and pollutant characterization in water and soil. In addition, the web monitoring can permit the data and information sharing with each end-user. Furthermore, the observational multi-parameter monitoring system can evolve in a local early warning system to reduce landslide risk.

The evolution of the tectonic structure and the behaviour of the faults with time have been investigated and slip partitioning and slip rate on individual fault segments have been determined in WP7 by comparing geodetic vs. geologic rates. A GIS database of the fault parameters has been created. In addition, fault parameters from paleoseismic and historical data for hazard assessment have been integrated. The historical earthquakes have been revised in detail using the catalogues and these earthquakes have been assessed in terms of their locations on the fault segments of the Marmara Sea Region. As a result of this, the faults generating the earthquakes were tested and the historical catalogues and Modified Mercalli Intensity maps were locally compared to better understand the impact of the historical earthquakes in the Marmara Region.

An integrated approach based on multi-parameter seafloor observatories has been implemented in WP8 to continuously monitor the micro-seismicity along with the fluid expulsion activity within the submerged fault zone. This allows a better assessment of seismic hazards. The observation of shallow, likely gas-related, seismicity implies a re-interpretation of micro-seismicity maps, hence a new vision of earthquake hazard assessment.

Velocity models were developed to improve earthquake location in the Sea of Marmara to detect low magnitude earthquakes and improve the characterization of the near-fault micro-seismicity, particularly along the central part of the Marmara. A synthesis of spectral and statistical analysis of marine multi-parameter time series has been made. All these accomplishments have contributed in the better understanding of the seismo-tectonic characteristics of the Marmara Region. Another important outcome of WP8 is a demonstration that seafloor acoustic systems display sufficient precision and stability for strain monitoring along submarine faults. An instrumental deployment performed within the MARSITE framework has the potential, in the next 3 to 5 years, to resolve questions posed by estimations of slip deficit based on land GPS data [Ergintav et al., 2014]. Although the geodetic experiment was not part of the initial WP8 plan, it could not have been done without MARSITE support.

Also it can be positively concluded that the Central segment across the Kumburgas Basin, which is characterized by a low level of shallow seismicity and of gas emissions, is not subject to active deformation. Hence our conclusion, that the Kumburgaz segment (~ Istanbul – Siliviri segment) is likely to be locked.

As a result of the work carried out recommendations for the next future, permanent monitoring systems were presented. A concept of nodes based on junction boxes deployed on the seafloor and cabled to shore was developed. Also innovative solutions with sea-surface platforms have been proposed. The new multi-parameter data acquisition system which was designed. This newly-designed generation of seafloor observatories is able to support the observation of parameters marked by both slow and quick temporal variations over long time intervals. The system can be used on standalone observatories. It also allows data collection in real-time or, at least, in near-real-time mode.

The existing earthquake early warning (EW) and Rapid Response (RR) systems in the Marmara Region have been improved in WP9. The Istanbul EEW System signal was extended to the Marmaray Public Transportation system - benefiting the enduser in earthquake safety. Marmaray is a major public transportation system that connects two continents which is used by more than 150,000 people per day. The installation and test of a pilot seismic landslide monitoring system has taken place in the Avcilar-Beylikdüzü Peninsula, a large landslide prone area located in westward part of Istanbul and facing the North Anatolian Fault. Seismic vulnerability interpretation of risk assessment has also been made.

An integrated set of open-source tools was designed to process medium- and high- resolution Earth Observation (EO) optical satellite imagery with the aim to monitor evolution in time of the exposure component in the framework of risk assessment against natural disasters. These tools were developed and tested, and finally released in two different forms: source code [1]
and QGIS plugin [2]. The former solution is targeted to developers, offering a chance to instantaneously modify the workflows; the latter version is oriented to GIS users with less programming skills and used to interact with a graphic interface.

The system PRESTo was previously installed at Koeri to run in real-time and analyze earthquakes occurring in the Marmara sea region. An updated version of PRESTo was installed that also processes the velocimetric stations, to improve the performances of the system.

Strong integration and links have been established in WP10 with major European initiatives focused on the collection of multidisciplinary data, their dissemination, interpretation and fusion to produce consistent theoretical and practical models, the implementation of good practices so as to provide the necessary information to end users, and the updating of seismic hazard and risk evaluations in the Marmara region.

By spreading its results to a wide audience through the activities in WP11, the MARsite project has contributed to improving public awareness. It has also led to the improvement of existing policies and programs on preparedness, risk mitigation and emergency management, meeting one of the key goals of the project: to reduce the seismic risk of this future Marmara earthquake.

MARsite project has proactively linked together existing and planned observing systems on- and off-shore and it supported the development of new systems where gaps currently exist. These developments significantly improved our technical know-how as well as our scientific understanding for monitoring potential geological disasters and contributed to the development of relevant European industrial sectors, such as in scientific instrument design and manufacture and remote-sensing. It has furthermore promote common technical standards so that data from different instruments can be combined into coherent data sets and addressed toward a unified understanding of the Marmara region. Such combined use of the observations will help further the policies, decisions and actions associated with disaster prevention, preparedness and mitigation in this region. MARsite developed a portal that offers access for users seeking data and results relevant to the Marmara region. It connected users to existing databases and portals and provides reliable, up-to-date and user-friendly information – vital for the work of decision makers, planners and emergency managers to facilitate warning, response and recovery.

Following the GEO concept of Supersites, the idea of facilitating "Retrieval, integration and systematic access to remote sensing & in-situ data in selected regional areas exposed to geological threats ("Supersites")", MARsite has the most remarkable impact from the point of view of seismic hazard/risk and is now a reference site.

The following data and outcomes of the MARsite project are its primary strength:

- Geodetic monitoring of 4D deformations in order to understand earthquake cycle processes, to develop probabilistic earthquake forecasting models and to constrain the seismic hazard models in the Marmara region;
- High resolution data acquired by a new generation deep multidisciplinary complete digital borehole seismic station;
- Rapid and quantitative ShakeMap scheme by implementing finite-source descriptions and calibrating with multiple geodetic/seismic data;
- Characterization of activated and reactivated Deep-seated Gravitational Slope Deformations (DGSD) determined through the integration of geological and geomorphological analyses with high-resolution DInSAR;
- Knowledge on the distribution of active structures in the Marmara Region and the amount of motion they localize;
- Geophysical, seismological, physical and geochemical data from automatic sea-floor devices (e.g. OBS, Piezometers, acoustic station and multidisciplinary SN4-type observatory) including data from periodical cruises for water column sampling and laboratory analyses, for seafloor degassing measurements; and
- Results on earthquake early-warning (EW) and rapid-response systems in the Marmara Region (Istanbul) with the addition of a pilot landslide monitoring and EW system and introduction of new space technologies for monitoring and assessment of vulnerabilities.
Based on all of these, MARsite has an important impact on the regional response for seismic risk prevention, but also plays a scientific/technical significant role as a European supersite.

There is a clear need for public-private partnerships in this field, as the observation material and analysis techniques become more and more sophisticated (and thus expensive), and also the socio-economic impact of seismic risk (especially the impact that will be caused by a large earthquake) become a worldwide concern. Without excluding other possibilities of public-private collaborations, we will be able to enhance this aspect. The direct outcome of this project (hazard assessment and risk prevention) has demonstrated itself as useful for industrial domains and public policy makers in this region, where the impact of a European collaborative project is evident.

Moreover, MARsite has adopted Advancing GEOSS Data Sharing Principles and incorporated related GEOSS strategic targets defined as “Provide a shared, easily accessible, timely, sustained stream of comprehensive data of documented quality, as well as metadata and information products, for informed decision making….“ in GEOSS Strategic Targets. These high level Data Sharing Principles represents one of the foundations for GEOSS, and their effective yet flexible implementation remains a major challenge and MARsite provided a good opportunity to experiment their application. These principles applied to MARsite products contributed to the development of disaster mitigation policy and strategies based on multidisciplinary research activities in MARsite. The process and the results of MARsite provided decision makers with newly found timely knowledge for its implementation to the current regulations and contribute to the development of new regulations.

MARsite has an impact that is much greater than the sum of its parts. This is because the coherent collection, analysis and dissemination of the wide range of data types on all aspects of the geohazards (earthquakes, landslides and tsunamis) cycles from many different instruments that is envisioned in MARsite has enable a step change in understanding in hazard and risk in the Marmara region. This dramatic improvement in understanding would have not been possible without concentrating efforts on a single supersite and without bringing together all of these different data sources to create a synergy, where each overlapping piece of information reinforces another. The vast majority of previous studies on earthquake processes in the Marmara region have looked at simply a handful (or often fewer) of different aspects and, thereby, have had, at best, a partial, and in some cases a false, view of the tectonic cycle. MARsite has provided an opportunity to gain a fuller view of this cycle. Although, obviously, MARsite concentrated its efforts on a relatively small part of north-western Turkey, its scientific and technical impacts go far beyond this region since the scientific findings are likely to be applicable to other seismically-active areas in Europe and beyond and its technical developments (e.g. new instrumentation and processing techniques) will be able to be used globally. In addition, the MARsite’s impact has gone far beyond the project’s consortium through, e.g. scientific papers, newspaper articles for the wider public, guidance and information for end-users (e.g. risk mangers), but also thanks to the dissemination of the collected raw and processed data through easy-to-use and interoperable web portals. The impact of this project is expected to last far beyond the three and a half years of its duration.

The MARsite project was presented and discussed in over 100 participation/presentations in events such as key meetings workshops and conferences, including EGU & AGU. Special attention was given to offering efficient visual communication with media such as the leaflets, the newsletters, the poster or the brochure. For each communication tool, a coherent visual code was respected to stay consistent with the defined colour chart. Paper material, including a leaflet, a poster and a brochure, to publicize the MARsite project goals and achievements were created. A brochure was created and published in order to promote the MARsite project goals and achievements in English and in Turkish. (Figure 23)

MARsite website was fully optimized for search engines (Google, Bing...). MARsite used the social media accounts of the partners to disseminate key messages. The partner’s accounts were used to be efficient quickly, thus benefitting from the already well-known accounts to spread MARsite news. To reach the general public (non-specialists, governments, national public services, policy-makers and industry actors), we mainly used social media to inform them about new publications that
could be found on the website (results, videos, etc.). For example from the social media accounts of EMSC, each post or tweet potentially reached at least 36,400 networks’ nodes worldwide. The MARsite website was the repository to which users were directed in order to increase its web traffic and to give the opportunity to the users to discover every aspect of the MARsite Project. In addition to the MARsite’s website, some partners display information about the project or links on their own website in order to share part of their web traffic with MARsite website, and to increase its page rank in search engines (Google, Bing, etc.). The EMSC website counts 1.5 million unique visitors a month.

Four videos describing the project are available on the MARsite project website. They are based on interviews with the project coordinator (Prof. Nurcan Meral Özel, KOERI) and 3 WP Leaders (John Douglas, BRGM; Louis Geli, IFREMER; Paolo Favali, INGV). These videos describe: the main goals and improvements of the project; the way data collection contributes to seismic hazard assessment; the gas related seismicity within the Marmara seismic gap; and the ground motion simulations for a M7 earthquake in the region of Marmara. During the second period, these videos were uploaded on the EMSC YouTube channel and announced again on the EMSC’s social media accounts. A dedicated video was prepared in Turkish regarding the outcomes of the project.

The project results were shared with end user and members of the press in a meeting that took place in Istanbul. A wide range of end users from municipalities, gas distribution companies, the military, transportation systems etc were present at the meeting. (Figure 24) The meeting received a strong media coverage. 12 national newspapers and 3 local newspapers reported the results of the project. In 8 of the newspapers the MARsite Project made the first page. This has enables the project results to reach 4,419,180 people. (Figure 25) There were 166 articles published on the internet regarding the results that were shared in the meeting. Furthermore 19 television programs in major national channels were broadcasted some with live interviews with the project coordinator. (figure 26)

List of Websites:
www.marsite.eu
Coordinator: Prof. Dr. Nurcan Meral Özel e-mail: ozeln@boun.edu.tr

**Related information**

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