New Directions in Seismic Hazard Assessment through Focused Earth Observation in the Marmara Supersite

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RE	Restricted to a group specified by the consortium (including the Commission)	
CO	Confidential, only for members of the consortium (including the Commission)	

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1.INTRODUCTION

The MARSITE project which started on 1 November 2012 and coordinates 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 urban and country areas. The project coordinates 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 GEO concept of Supersites has generated considerable interest since its first appearance in the GEO Work Programme 2009-2011. The concept of facilitating "Retrieval, integration and systematic access to remote sensing & in-situ data in selected regional areas exposed to geological threats ("Supersites")" was seen as a means to improve efficiency of expensive monitoring and research efforts by geographically focussing them. MARsite will represent a significant European contribution to the Supersite initiative and thus to the Global Earth Observation System of Systems (GEOSS), and it will lead to better scientific understanding of the geophysical processes, contribute in-situ data to a unifying e-infrastructure, broaden our knowledge about geological extreme events and reduce our vulnerability to geologic hazards.

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.
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.

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

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

iv) 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.

MARsite is coordinated by the Bogaziçi University, Kandilli Observatory and Earthquake Research Institute, established in 1868 as the Imperial Observatory with a long tradition of earth observation and science. The MARsite Consortium brings together 18 major European research institutions with a long record of scientific history and success, and 3 SMEs, from 6 nations of the Euro-Mediterranean

area. The consortium is very balanced, both in terms of specialities and in terms of distribution between EU-countries, EU-supported international organizations and Turkish national institutions. The consortium is organized in such a way that it will maximize its efficiency for meeting the objectives of the call and develop a fully integrated conceptual approach based: i) on the collaboration with existing monitoring networks and international initiatives; ii) on the development of new instrumentation such as in-situ sensors; iii) and on the aggregation of space and ground-based observations (including from subsurface), and geophysical monitoring.

2 SUMMARY OF THE ACTIVITIES IN THE LAST YEAR OF MARSite

This section of the Annual Public Report provides a summary of work conducted and achievements accomplished during the period of November 2014 – April 2016. As can be seen in Figure 2.1, 30 deliverables are to be produced within the second year mainly concentrated on the scientific achievements of the project.
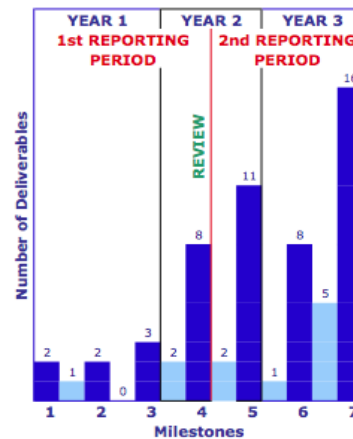
Figure 2.1: Distribution of MARSite Deliverables within Project Life-time

2.1 WORK PACKAGE 1: Management

The second General Assembly of the MARSite project was held in İstanbul, Turkey at KOERI premises on the 17-18, 2014 with the attendance members of the Consortium, Robert Reilinger from MIT and Friedemann Wenzel from Karlsruhe Institute of Technology (KIT) as External Experts Advisory Board Member.

MARSite Milestone Meeting took place on April 13Th 2015 in Vienna with the participation of work package leaders and members of the consortium.

Figure 2.1.1: Participants of the General Assembly 2014

The Final Meeting of the MARSite project was held in Vienna, Austria on the 22nd of April, 2016 with the attendance members of the Consortium and guest speakers Kuvvet Atakan on EPOS IP and Michele Manunta- on the main characteristics and features of GEP and its integration within the TCS-Satellite Data of EPOS.

Figure 2.1.2: Participants of the Marsite Final Meeting 2016

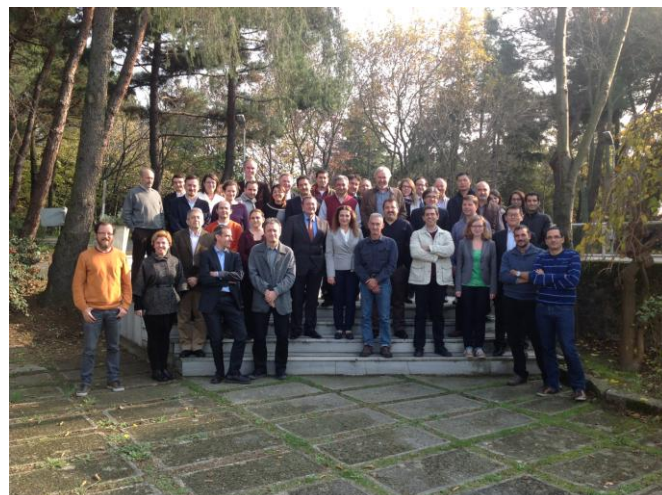The project results were shared with end user and members of the press in a meeting that took place in Istanbul. A wide range of end users from municipalities, gas distribution companies, the military, transportation systems etc were present at the meeting.

Figure 2.1.3: MARsite End-users Meeting 2016

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. 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.

2.2 WORK PACKAGE 2: Land Based Long-term Multi-disciplinary Continuous Monitoring

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 2.2.1). Samples of free bubbling gases were taken whenever feasible; additionally, water samples with dissolved gases were collected. 52 CO_2 and CH_4 soil degassing measurements were also carried out at 9 locations in the vicinity of thermal/mineral springs. A comparison between both CO_2 and CH_4 concentration and flux distribution maps highlights an overlapping of the highest values in the Adapazari area.
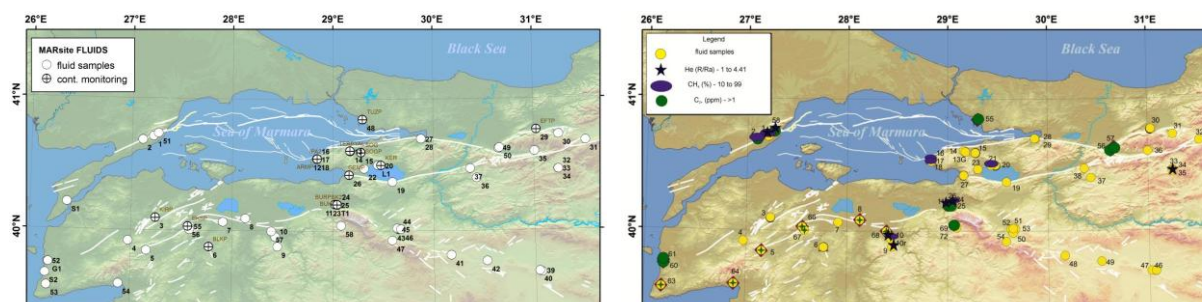

Figure 2.2.1: Fluid samples taken from 61 thermal and mineral water springs/wells during two MARsite fluid monitoring campaigns (2013 and 2014) around the Sea of Marmara (left) and distribution of sample sites around the Sea of Marmara with the main geochemical features of the gas phase (right).

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 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 sited 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 N_2 and the other dominated by CO_2. 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 CO_2 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 behaviour 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.

2.3 WORK PACKAGE 3: Long-term Continuous Geodetic Monitoring of Crustal Deformation

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 2.3.1).
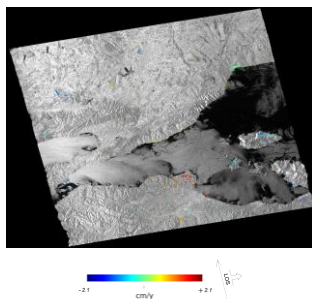
Figure 2.3.1. Results (cm / year) of the stacking procedure applied on 45 unwrapped interferograms.

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 therefore 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 2.3.2). 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.
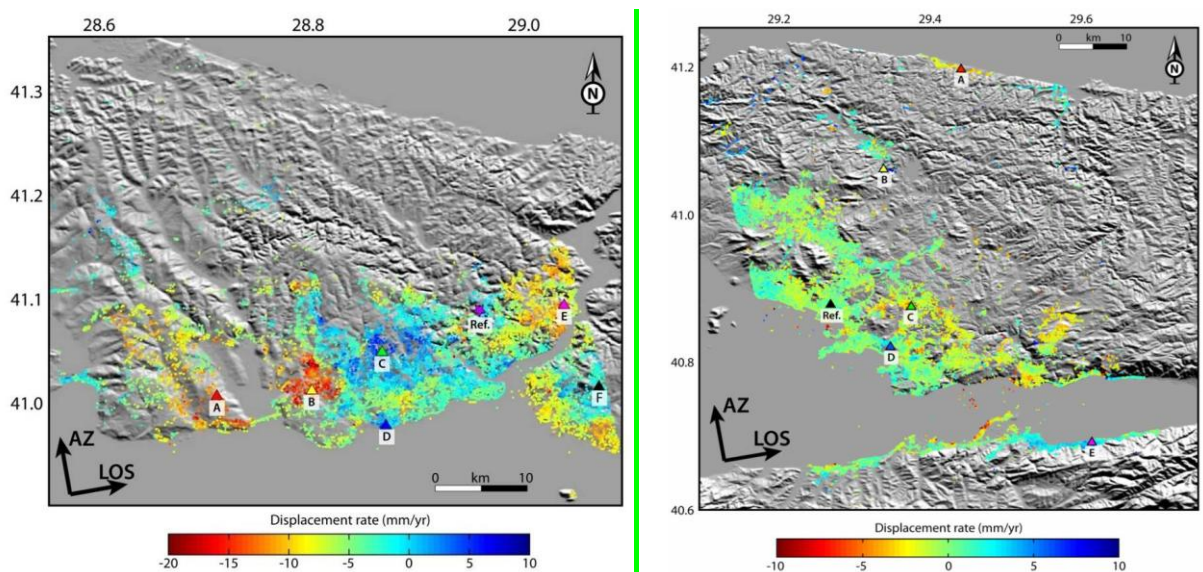

Figure 2.3.2: Mean velocity map for the CSK Western Track (preliminary results) retrieved by applying the StaMPS method and mean velocity map for the CSK Eastern Track (right).

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 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.

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 coverage is highly necessary for further assessing the earthquake potential of this fault segment.

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. As a consequence, a kind of tutorial for the software usage with Sentinel Data and some demonstrative result were provided.

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.

2.4 WORK PACKAGE 4: Establishment of Borehole Observation System and High Resolution Seismic Studies in the Marmara Sea

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 30°-90° 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 (40°-70°) and Java-Sunda subduction (100°) 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 2.4.1). 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.
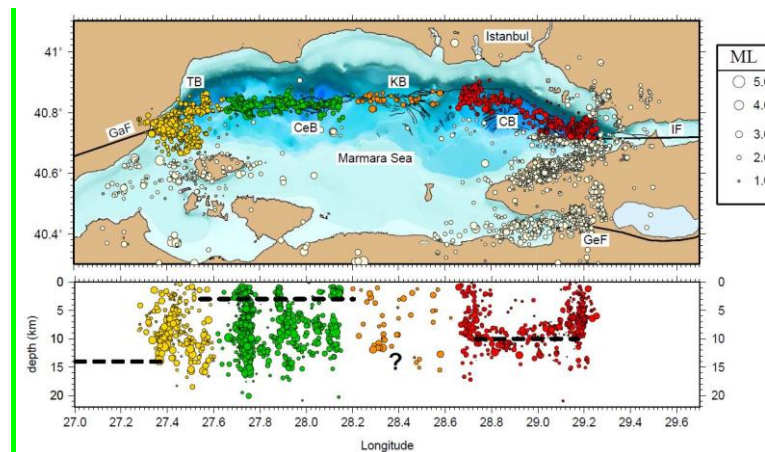

Figure 2.4.1: Map (top) and cross section (below) of the seismicity along the Main Marmara Fault during the period 2007-2012. Four domains are introduced: The Tekirdag basin (TB) in yellow, the Central basin (CeB) in green, the Kumburgaz basin (KB) in orange, and the Cinarcik basin (CB) in red. All the regional seismicity away from the MMF is plotted in white. Fault network:GaF for Ganos fault, IF for Izmit fault, GeF for Gemlik fault. Dotted lines in the depth section show the geodetically estimated locking depth of each domain.

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.

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.

2.5 WORK PACKAGE 5: Real and quasi-real-time Earthquake &Tsunami Hazard Monitoring Seismic Studies in the Marmara Sea

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. 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 2.5.1).
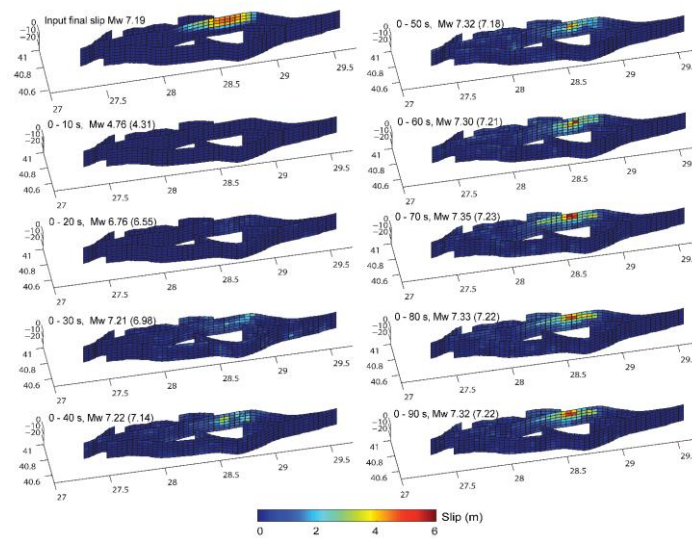

Figure 2.5.1. Comparison between the input (top left) and real-time reconstructed slip models. The moment magnitudes outside the brackets are inferred from the seismic moment distributed on the whole fault system, while that in the brackets corresponds to seismic moment located on the main rupture fault.

The 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. 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 Buyukada 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 2.5.2).

Figure 2.5.2: The distribution of calculated maximum wave amplitudes at each gauge points for all earthquake scenarios.

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 occurred (Figure 16).

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.

2.6 Work Package 6: Earthquake-Induced Landslide Hazard in Marmara

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 western 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.

2.7 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 2.7.1).

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).

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 pre-existing 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 [Kozacı et al, 2012]. Contrary to the northern branch, there is relatively information on the paleoseismology of the southern branch of the NAF. A single 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 palaeoseismological 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, Izmit Bay, Southern Marmara: Yalova-Tekirdağ, Eastern Marmara, Middle Marmara: Western Istanbul-Silivri, Western Marmara: Tekirdağ-Silivri-Bandırma, Gaziköy-Gölcük, 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 İstanbul Metropolitan Municipality to prepare the other scenario for the historical İstanbul 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 Izmit 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.

2.8 WORK PACKAGE 8: Monitoring seismicity and fluid activity near the fault using existing cabled and autonomous multiparameter seafloor instrumentation

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.

2.9 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 Izmit Gulf M4.4, 2008 Çınarcık M4.8 6 June 208 Istanbul 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.

2.10 WORK PACKAGE 10: Integration of data management practices and coordination with ongoing research infrastructures

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 Plathorm'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.

2.11 WORK PACKAGE 11: Dissemination

In the second period (from May 2014 to April 2016), the focus was on the communication of the project results to a larger public worldwide. To encourage dissemination of all the data and achievements realised within the MARsite project, we summarized them in a brochure in English and Turkish presenting the whole project, its results and legacy. The results and achievements of each Work Package are shown and described in dedicated chapters that included didactical illustrations. This brochure has been designed and formatted to be read by everyone, and especially for non-experts. The brochures were also posted on the project web site.

Fig. 2.11.1: MARsite Brochure cover and WP9 presentation page

A dedicated video was prepared in Turkish for the Turkish public.

Social media was used to update the scientific community (and beyond) about these events, and about new publications available on the website (results by WP, videos, etc.) MARsite used the social media accounts of the partners to disseminate key messages. We decided to use the partner's accounts to be efficient quickly. Indeed, new users face slow growth, so we benefitted from the already well-known accounts to spread MARsite news. Indeed, through the EMSC social media accounts each post or tweet potentially reached at least 36,400 networks' nodes worldwide.
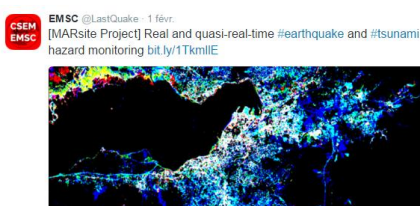
Sample of a tweet

Sample of a facebook post

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.

Participated in key meetings, workshops and conferences, including EGU & AGU, to inform the scientific community.

Part of the strategy has been reliant on visual communication. 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.