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

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9.3

Improvement of Istanbul Earthquake Rapid Response System with new online data and new methodologies

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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

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.

Besides, the improvement on the IERRS, regional Earthquake Early Warning network with the algorithms of Virtual Seismologist and PRESTo has been deployed.

2. INTEGRATION OF KOERI AND IGDAS STRONG MOTION NETWORKS

The KOERI strong motion network has been deployed in 2002 for the rapid response purpose with the distribution of 110 strong motion stations in the densely populated parts of the city (Figure 1).

In 2013, the IGDAS Company has also deployed additional 110 strong motion stations (Figure 2) at its district regulators in order to stop the gas flow independently at the time of an excessive ground motion.

Integration of KOERI and IGDAS strong motion networks is shown in Figure 3. The computed ground motion parameters from these both networks are compiled at the servers of KOERI and IGDAS, and the resulting real-time shake mappings are generated.

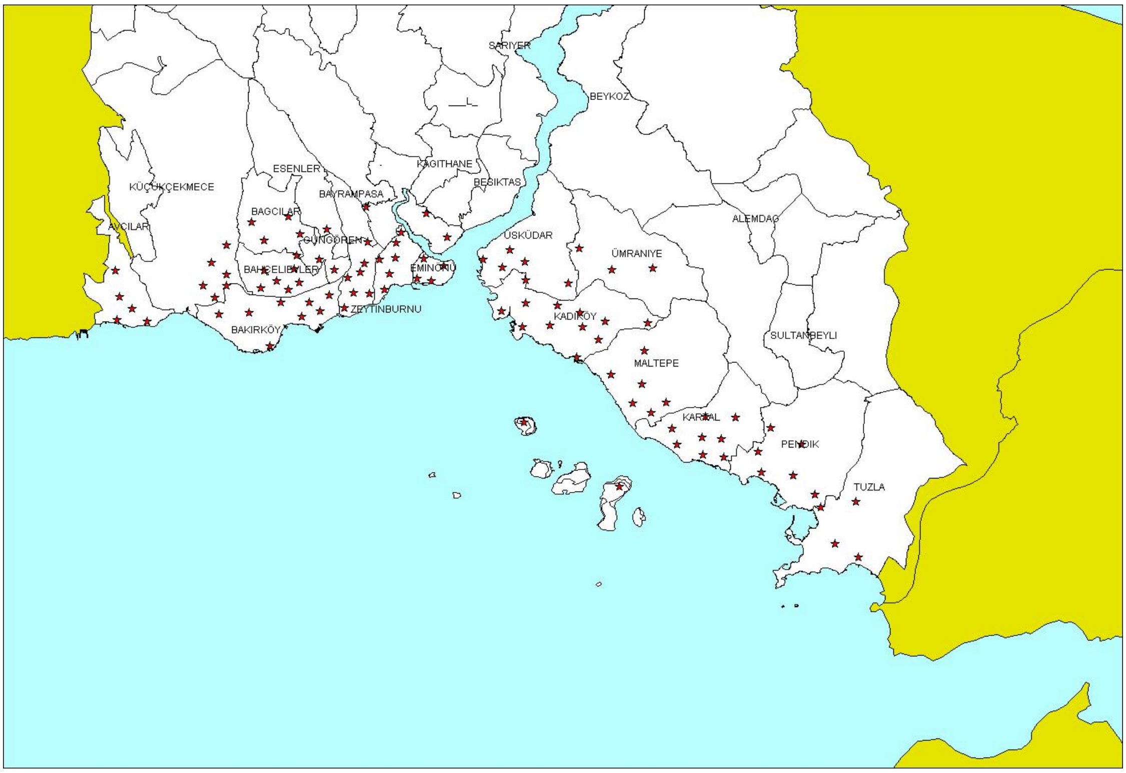


Figure 1: Istanbul Earthquake Rapid Response System (IERRS) deployed by KOERI in 2002

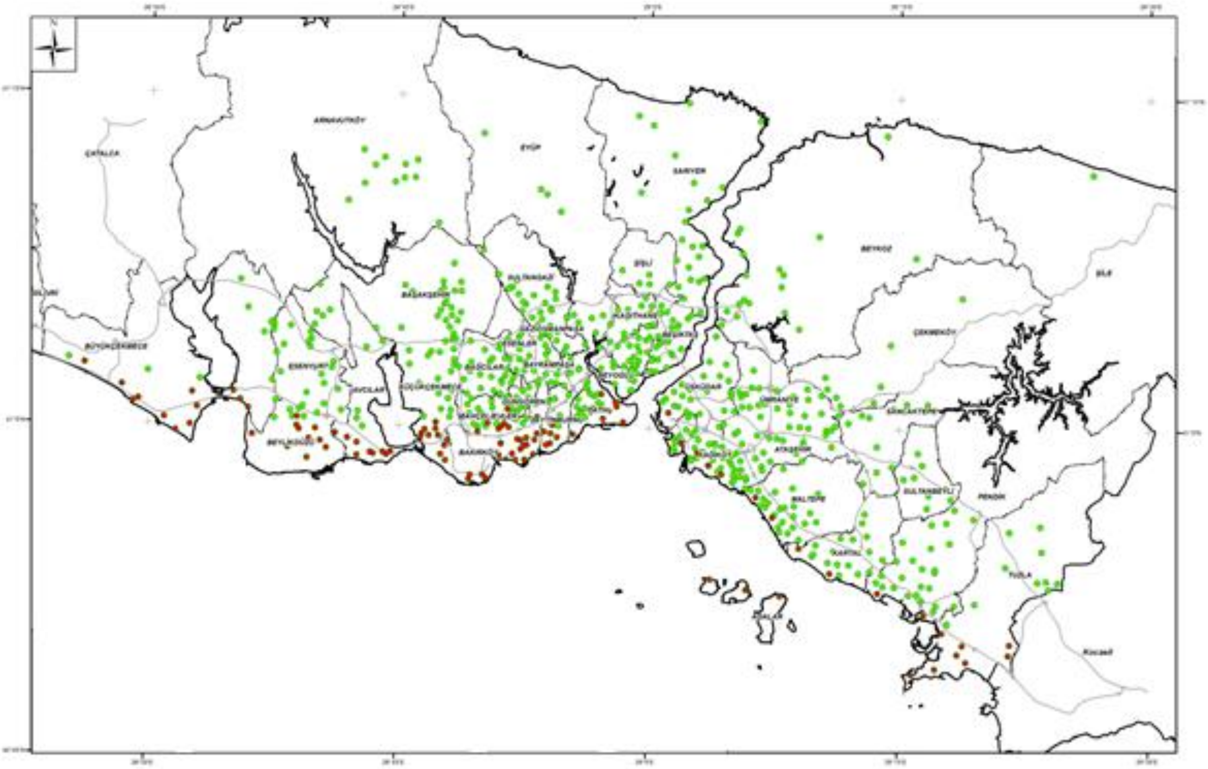


Figure 2: IGDAS Natural Gas Network district regulators (green circle), instrumented by strong motion stations (red circle)

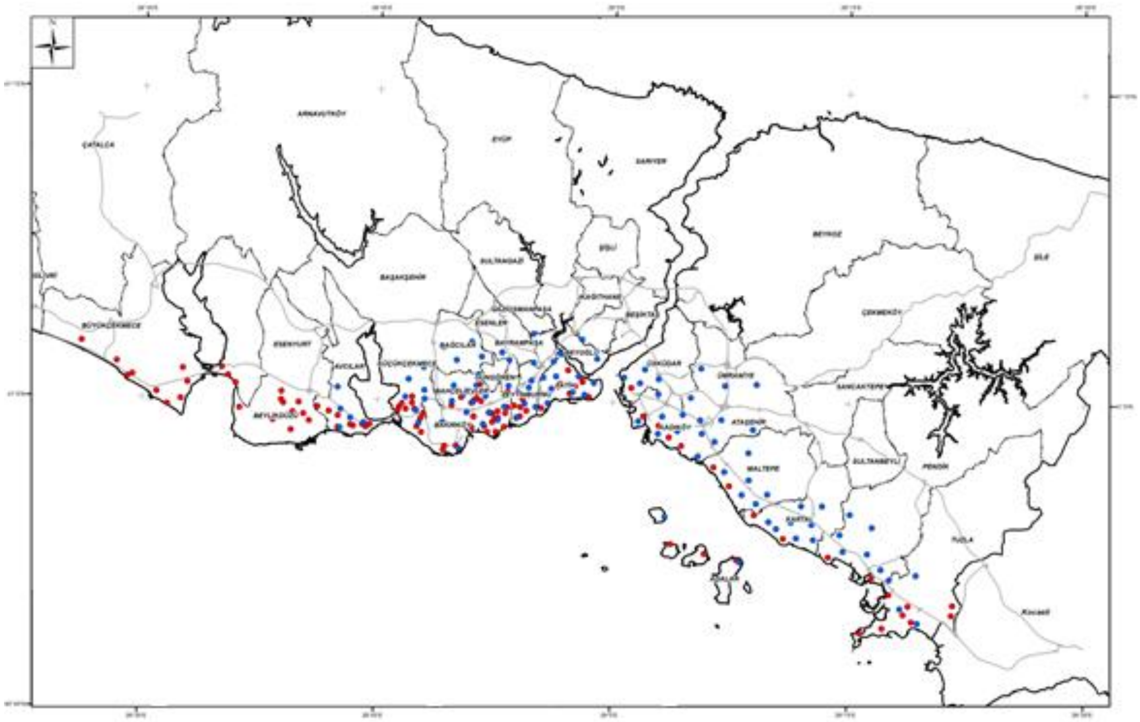


Figure 3: Integration of KOERI (blue circles) and IGDAS (red circles) strong motion networks for real-time shakemapping purpose

2.1 INTERPOLATION OF AVAILABLE DATA THROUGH THE INTEGRATED DENSE NETWORK

Although several ground motion prediction equations are utilized in the IERRS real-time shake mapping algorithm, with the integration of KOERI and IGDAS strong motion networks and increase in the number of real-time strong motion stations, a test study on the several interpolation methodologies have been applied in order to estimate the ground motion distribution without utilizing any ground motion prediction equation. The study results show that although in the southern part of the city with the dense strong motion networks the interpolation methodologies give the reasonable results, in the central and northern part of the city because of the lack of the real-time data there is still a need using the ground motion prediction equations and a combination of interpolation and ground motion prediction equations are proposed as the target methodology.

2.2 KOERI STRONG GROUND MOTION NETWORK IERRS WEBSITE

The real-time data flow at each strong motion station can be monitored through the web site http://www.ew-istanbul.com/. The screenshot of the website is shown in the Figure 4.

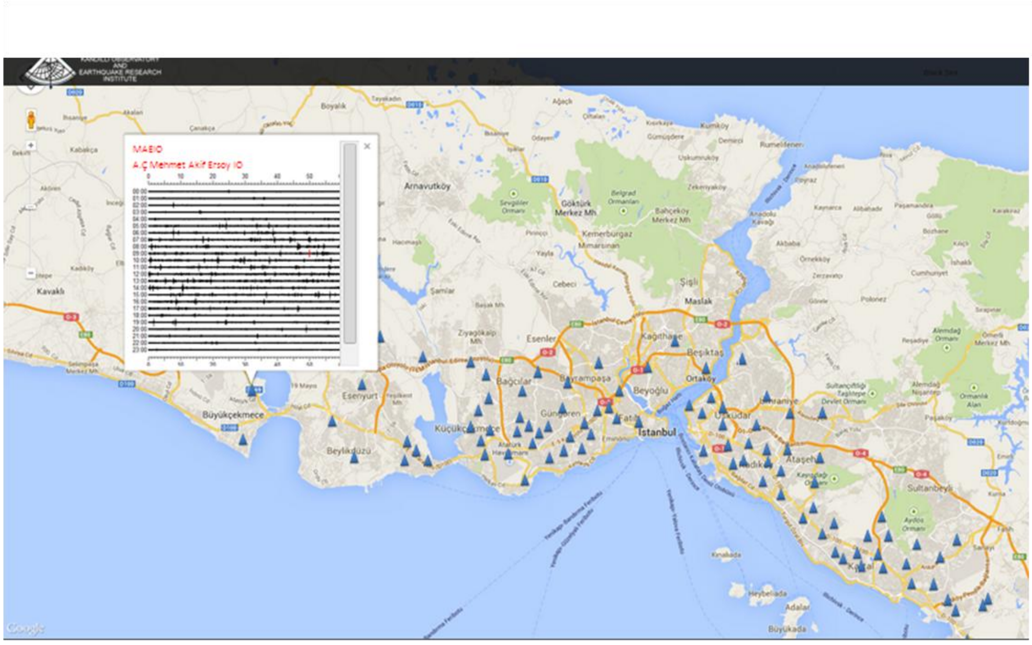


Figure 4: The screenshot of the IERRS website

The website also provides information on the recent earthquake events with the view of intensity and related ground motion parameters maps as shown in the Figure 5.

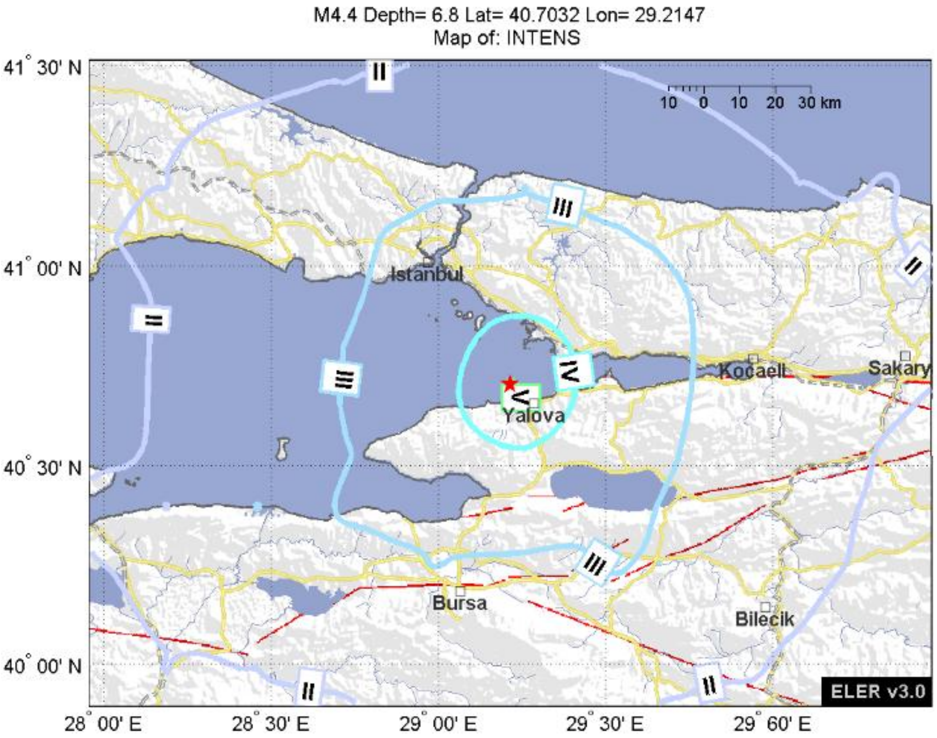


Figure 5: The screenshot of the IERRS automated shakemapping

3. IMPROVEMENT ON THE REGIONAL EARTHQUAKE EARLY WARNING NETWORK FOR MARMARA REGION

The KOERI's regional seismic network as shown in the Figure 6 has been improved for the utilization of regional Earthquake Early Warning (EEW) algorithms.

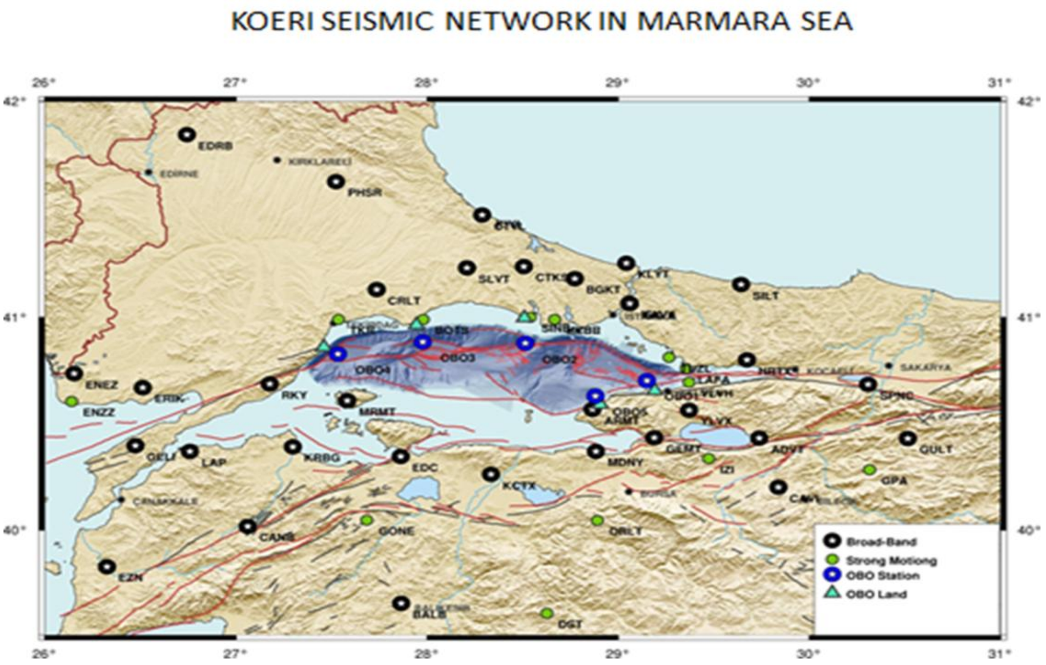


Figure 6: KOERI regional seismic network

The SeisComp3 has been used for the data gathering.

The seismological software SeisComP has evolved within the last approximately 10 years from pure acquisition modules to a fully featured real-time earthquake monitoring software. The now very popular SeedLink protocol for seismic data transmission has been the core of SeisComP from the very beginning. Later additions included simple, purely automatic event detection, location and magnitude determination capabilities.

The Virtual Seismologist and PRESTo algorithms have been utilized for the EEW purpose.

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 (Cua and Heaton). The core of the Vs algorithm is shown in the Figure 7.

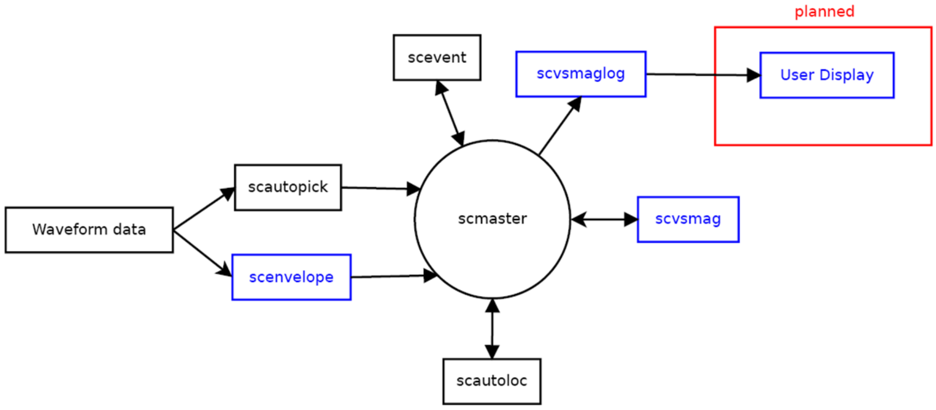


Figure 7: The core of the -VS- EEW algorithm

The eigenvalue analysis results have shown that the first three natural periods of the structure are T=0.75, 0.62 and 0.51 seconds for C16 (Figure 5) and T=0.80, 0.66 and 0.56 seconds for C20, respectively. The natural vibration periods seemed reasonable for high-rise concrete structure with shear walls and without beams.

3.1 DETAILED ANALYSIS ON PAST EVENTS AND IMPROVEMENT ON INSTALLATION OF PRESTo EEW ALGORITHM IN KOERI NETWORK

The North Anatolian Fault accommodates the relative motion between European and Anatolian plates by a right-lateral strike-slip movement. Since the destructive 1939, M 7.9 Erzincan earthquake, this fault experienced several earthquakes with magnitude larger than 7, with a main westward migration pattern toward the Marmara Sea region (e.g. Ambraseys, 2002). The last events of this sequence were the 1999 Izmit-Duzce doublet which developed on the eastern side of the Marmara sea, 70 km away from Istanbul. The present rate of deformation estimated by GPS measurements along the fault portion in the Marmara sea region ranges between 17 and 25 mm/yr (McClusky et al., 2000). As a consequence of both the stress transfer and the strain accumulation, the probability of occurrence of a large earthquake (M>7) beneath the sea of Marmara was estimated to be as high as 50% in the next 30 years (Parsons, 2004). The coupling between such a large seismic hazard and the large vulnerability of the Istanbul megacity, were more than 15 million inhabitants live, raised the interest of the scientific community that supported research and instrument deployment, with more than 400 instruments for recording seismicity and deformation. Although the occurrence of a moderate to large earthquake is very likely in the near future, which fault segment would accommodate the next rupture is almost unpredictable. Geological campaigns have revealed a complex structure beneath the Marmara sea, west of the termination of the Izmit segment. While strike-slip segments cross the sea close to the Istanbul city, with a sharp bend/kink at the Bosporus junction, a different strand borders the Southern coast of the Marmara sea with coupled normal-strike slip mechanisms (Le Pichon *et al.*, 2001; Armijo *et al.*, 2002). Additionally most of the recent seismicity is concentrated west of the Istanbul city, along the Tekirdag segment of the fault (http://www.koeri.boun.edu.tr/). As a consequence, the evaluation of the seismic risk over several time scales requires to account for several earthquake scenarios and a broad magnitude range.

Prediction of earthquake occurrence is nowadays lacking of a physical ground and solid statistical tools; hence mitigation of the seismic risk can be only performed over long time scales (several years). Nevertheless, over very small time scales early warning systems may allow to perform security actions within few seconds from the rupture nucleation, possibly reducing damage and losses associated with the earthquake. Earthquake early warning systems are operational or under testing in several countries, such as Mexico (Espinoza Aranda *et al.*, 1995), Japan (Nakamura, 1988; Kamigaichi, 2004), Taiwan (Wu *et al.*, 1998), Italy (Iannaccone *et al.*, 2010), California (Brown *et al.*, 2011) and Romania (Ionescu *et al.*, 2007). Although they use different strategies depending on the earthquake/ network distribution and target distances, earthquake early warning systems can be grouped into two main paradigms. Regional systems use P-wave and eventually S-wave information at close sites to perform event location and magnitude estimation and predict the strong motion at target sites by empirical attenuation relationships. For targets located in the distance range 50-150 km from the earthquake hypocenter, maximum lead time, that is the time available at a target site to take security actions before the arrival of destructive waves, ranges between 5 and 30 s. While location is based on standard real-time procedures related to automatic picking, event binding and location algorithms, magnitude estimation is based on regressions between some parameters measured on the early portion of the signal and the final size of the event. Several parameters, such as the peak displacement PD (Wu and Tang, 2002, Zollo *et al.*, 2006), the predominant period t in its different forms (Nakamura, 1988; Allen and Kanamori, 2003) and the radiated energy (Festa *et al.,* 2008) have been proposed as magnitude estimators. Such parameters show good correlation even with large uncertainties with the final size of the earthquake up to magnitude 7.5. Beyond that range, saturation may occur when using few seconds for parameter estimation (Colombelli *et al.*, 2012). As a drawback, predicted ground motion intensity is not verified at the target site, leading to large uncertainties as inherited by the attenuation relationships. From a complementary point of view, an onsite early warning system renounces to a macroscopic description of the earthquake source in terms of magnitude and location, while predict the strong ground motion based on the initial motion recorded at the same site. Prediction is based on the correlation between peak displacement measured in the early P wave portion of the signal and the final peak ground velocity or acceleration. Since both parameters do scale with the distance with almost the same decay owing to geometric and anelastic attenuation terms, scaling relations is expected to be almost independent of the hypocentral distance. While reducing the available lead time in a broad distance range, onsite systems verify the expected ground motion by a local measure of the velocity and/or acceleration and still provide a prediction with a positive lead time even at small distances, although affected by large uncertainties. On the other hand, a single station may trigger even on non-earthquake signals, such as glitches, calibration pulses or ambient vibrations, increasing the number of false alarms. Finally, coupled systems still compute the source parameters as for the regional systems, but also use the local measure and threshold levels to predict the expected damage at the site. Through interpolation algorithms constrained by attenuation laws, expected ground shaking maps are then produced (Wu and Kanamori, 2005; Colombelli *et al*., 2012).

Here we applied the regional methodology PRESTo (PRobabilistic and Evolutionary early warning SysTem) to a set of real 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.

In the first section we described the dataset and the networks used for the analysis. Then we reviewed the PRESTo methodology in the following section and finally we discussed applications to earthquakes with magnitude ranging between 3.7 and 7.4.

3.2 DATA SET AND DATA PREPROCESSING

For this analysis, we used available accelerometric stations located around and East of the Marmara sea, this extension allowing to capture also the large M>7 Izmit and Duzce earthquakes. Stations belong to two different networks: the Istanbul earthquake rapid response (RR) network and the national AFAD strong motion network.

The RR network is located inside the city of Istanbul and counts 100 stations with a dozen of them displaced very close to the Prince Islands segment of the Marmara fault. RR is mainly aimed at characterizing the shaking and the damage, at rapidly providing post-earthquake shaking maps, at recording the motion for post-earthquake performance analysis of structures and at improving microzonation. This justify the installation of the stations within the city, degrading the signal to noise ratio and therefore increasing the detection threshold in magnitude for the network. Additionally, the signal to noise ratio is dramatically subject to daily variations. Accelerometers and dataloggers from GeoSig do not provide continuous seismic data that are collected only after a trigger has been declared. RR data, sampled at 200 sps, are stored in a owner GeoSig binary format and were here converted in SAC (seismic analysis code) format to be used by PRESTo.

The national accelerometric network AFAD has stations displaced all along Turkey and counts about 40 stations in the Marmara region. It is aimed at recording the strong motion at national level and provides earthquake location and magnitude for events with magnitude larger than 4.0. Data from AFAD are available online at http://kyhdata.deprem.gov.tr/2K/kyhdata_v4.php. Acceleration data are provided in ASCII format and are sampled at 100 sps.

3.3 PRESTo SYSTEM AND SETUP

PRESTo is an integrated regional/threshold system, which was initially developed for issuing an earthquake early warning in Southern Italy (Satriano *et al.*, 2011), using continuous data streamed by the ISNet (Irpinia Seismic Network), a seismic network installed along the Apenninic chain surrounding the fault system that generated the 1980 M 6.9 Irpinia earthquake (Iannaccone *et al.*, 2011).

As a regional system, PRESTo provides an evolutionary estimate of the earthquake location and magnitude, to be used for predicting the ground shaking parameters at target sites. Earthquake location is based on the RTLoc (Real Time Location) algorithm (Satriano *et al.*, 2008), which discretizes the region for all the possible earthquake locations in Voronoi cells, each of them centered in a seismic station. When a pick is identified on a vertical component of an accelerogram, the possible location of the earthquake falls within the Voronoi cell associated with the related station. As time goes on and no additionally picks come from neighbor stations, the location region shrinks around the initial station and eventually collapses over it if no more picks are declared. As soon as new picks arrive, isochrone surfaces are identified as the regions having larger probability for hypocenter location while the probability outside the isochrones intersection rapidly decreases as a function of the distance. Within 3-5 seconds, an accurate location with errors of the order of few kilometers or smaller is possible for an earthquake occurring inside ISNet, where the station inter-distance is about 10 km at the center of the network.

Magnitude estimation is based on the evolutionary Bayesian approach RTMag (Lancieri and Zollo, 2008). When new estimations of magnitude are available from additional stations/seismic phases, they are combined in the Bayes theorem with the previous ones where they are used as *a-priori* information to provide a probability density function for the magnitude. At the first estimate, the *a-priori* information is based on the Gutenberg-Richter earthquake statistics. Single station magnitude estimation is based on a best-fit relationship between the peak displacement (PD) measured on the early portion of the seismogram and the final earthquake size. This estimate is performed on both P waves (2-4 s) and S waves (2s), to reduce the uncertainties in the final estimate (Zollo *et al.*, 2006; Festa *et al.*, 2008). For earthquakes whose magnitude is expected to be smaller than 4.0 from the previous relationships, we use a local magnitude scale, where the P amplitude scaling with magnitude is calibrated assuming that the ratio between P and S waves is , where g is the ratio between P wave and S wave velocity. We used the local magnitude scale obtained for Southern Italy which was shown to be almost consistent with several local magnitude scaling laws in Italy and worldwide in the distance range 50-150 km (Bobbio *et al.*, 2009). Finally peak ground acceleration at the target is predicted using the Akkar and Bommer (2007) empirical relationship, where uncertainties in the magnitude and location are propagated on the final peak estimate. Massive analysis on synthetic data simulated at ISNet showed that uncertainties in the final peak estimates are largely dominated the uncertainties in the attenuation relationships (Zollo *et al.*, 2011).

As a threshold system, PRESTo computes the peak displacement on the vertical component of the integrated accelerogram and the t_c parameter (Wu *et al.*, 2007). These parameters are jointly used to evaluate the severity of the ground motion at the same site and predict the size of the potential damage zone. Estimation is based on the correlations between the initial P-wave peak displacement and the final peak ground velocity and between t_c and the earthquake size.

To use PRESTo algorithm for the analysis of Marmara sea earthquakes we need to define the grid size of possible earthquake hypocenters and a velocity model required by the location algorithm. For the aim the selected grid contains the Marmara sea, the city of Istanbul and a part of the Anatolia region east of the Kocaeli province. Since most of seismicity is concentrated at crustal depths, maximum hypocenter depth was set to

40 km. For computation of travel-times, the grid was discretized in cells with edge size of 1km, such a distance being smaller than or comparable with the uncertainty expected for earthquake location in this area. We use a 1D velocity model (Table 1) obtained by inspection of a 3D tomographic model (Becel *et al.,* 2006), as proposed by Tary et *al.* (2011). Finally, to handle data having a short noise window (<5s) before the P wave first arrival, the length of LTA was set to 3.5s and that of STA to 0.8s.

3.4 EARTHQUAKE ANALYSIS

We applied the PRESTO early warning system to six earthquakes, whose epicenters were located in the Marmara sea region. Earthquake selection was based on the number of available stations in the near source range and the quality of the records. We required to have at least six available stations within 60 km from the epicenter and a signal to noise ratio larger than 3 on the P-wave phase. We evolutionarily estimated location and magnitude and predict ground shaking and lead time at three locations: Istanbul city center (Ayasofya mosque), Silivri, a small city west of Istanbul and Izmit, east of the Marmara sea, where the hypocenter of the M 7.4 Kocaeli earthquake was located. We presented in detail the analysis for four of these earthquakes, while comprehensive results are summarized in the final section.

The 2011 Izmit Korfezi earthquake

The January 20, 2011, M 4.4 Izmit Korfezi earthquake occurred close to the left termination of the 1999 Izmit earthquake, East of the Marmara sea. The earthquake was recorded by both AFAD and RR networks. For the analysis, we selected 23 stations (17 from AFAD and 6 from RR). Some of the AFAD stations were located within 10 km of epicentral distance as computed by AFAD. A snapshot of the PRESTo analysis is shown in the Figure 8.

The first estimation of the magnitude is 5.0; it becomes stable after the second measure (4.5 ± 0.3). The final estimation is indeed 4.5 ± 0.1, which is comparable with the estimation provided by AFAD (4.4). The second estimation is given 7s after the origin time (OT). Earthquake location is stable within errors. While first estimation is comparable with the one provided by AFAD, then location is displaced 5 km southward of AFAD location. Final depth is 14 km, which is shallower as compared to the one provided by AFAD (24 km). However, depth is strongly sensitive to the velocity model and the location of the interfaces. Starting from the second estimation, we still have a positive lead time in Izmit (1s), and 15s in Istanbul, 28s in Silivri. Estimated PGA is 0.2% g in Istanbul and observed PGA ranges between 0.1 and 0.5 % g.

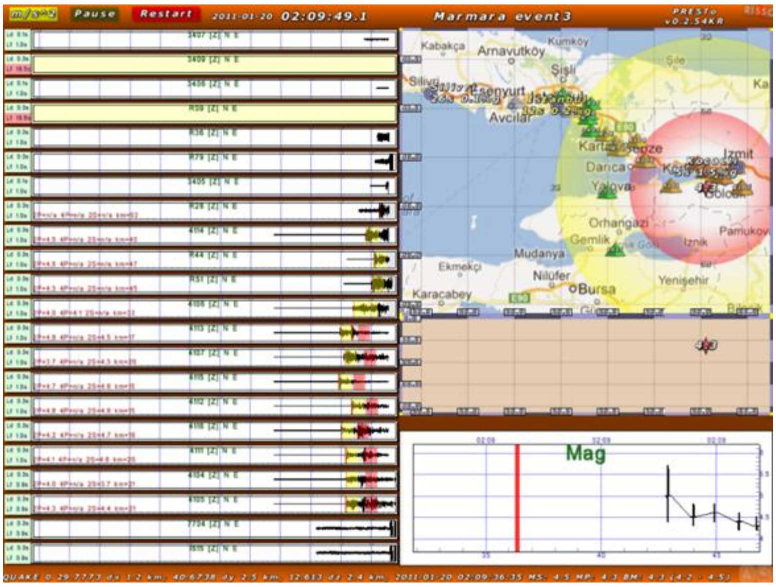
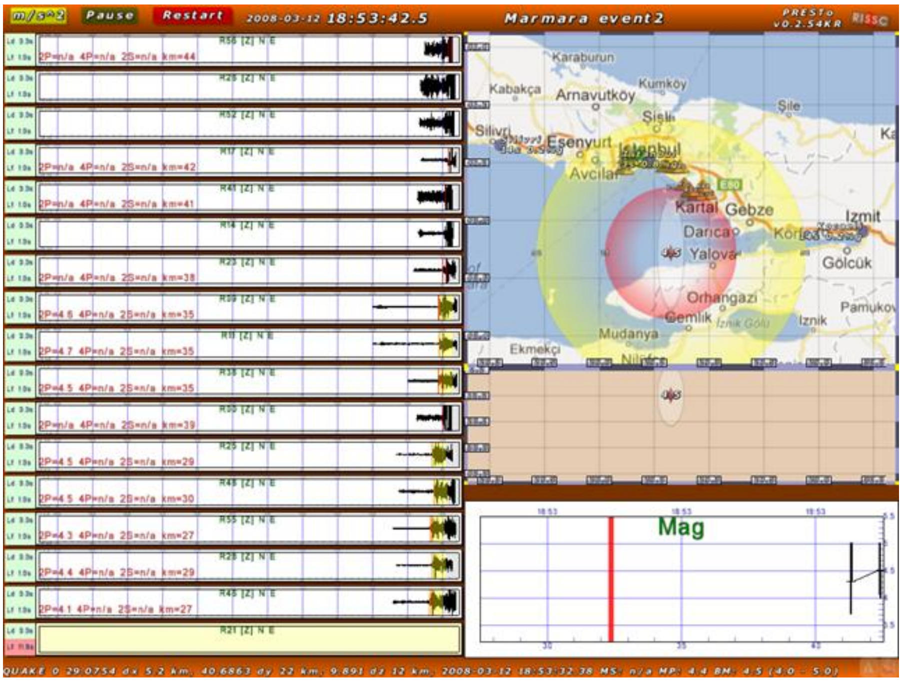


Figure 8 : Snapshot of the PRESTo simulation for the Izmit Korfezi event. Location is very close to the one given by AFAD (epicentral difference is about 5km), lead time in Istanbul from the first stable estimation is 15s. PGA prediction in Istanbul Ayasofya is comparable with observations provided by the RR network.

The 2008 Cinarcik earthquake

The March 12, 2008, M 4.8 Cinarcik earthquake occurred on the Cinarcik peninsula, south of the Marmara Sea, close to the Yalova city. For the analysis, we used 26 stations from the RR network. A snapshot of the PRESTo analysis is shown in the Figure 9. This earthquake represents a challenging test for a regional earthquake early warning system since the event is outside the network itself. Hence the location is resolved by the detection of the wave front and by an accurate picking of the P-wave phase. Because of the network density and staggered geometry, epicenter back-azimuth is expected to be correctly retrieved while distance may be not well resolved without any S-wave picking (Satriano *et al.*,2008).

The first estimation for the magnitude is 4.3 ± 0.7, 12s after OT; then the magnitude slightly increases, while the uncertainty is reduced to 0.3 after 2s from the first measure. The final estimation is 4.6±0.2, which is comparable with the estimation of 4.8 provided by KOERI (Kandilli Observatory and Earthquake Research Institute). Earthquake location is stable within errors. While the longitudinal direction is well resolved by the network, latitudinal direction shows a large uncertainty (20km) which is not reduced even when adding more picks. Final epicenter estimation falls inside the Marmara sea, 12km north of the estimation from KOERI and closer to the network. The difference in distance also justifies the underestimation of the magnitude. From the first alert, 5s of lead time are available for the Istanbul city center, while this number is reduced to 3s when waiting for a more accurate estimate of the magnitude. At the same time the lead time is 16s for both Izmit and Silivri. It is worth to note that since the estimation for the location is closer to the network of about 12km, the effective lead time is 3s larger for the Istanbul city center, as compared to the time provided by PRESTo. Finally, predicted PGA at the target site is 0.8%g, while observed one ranges between 0.2-1%g.



QUAKE 0 29.0754 dx 5.2 km, 40.6863 dy 22 km, 9.891 dz 12 km, 2008-03-12 18:53:32.38 MS: n/a MP: 4.4 BM: 4.5 (4.0 - 5.0)

Figure 9: Snapshot of PRESTo simulation for the Cinarcik earthquake. Location is closer to the Istanbul city as compared to the KOERI estimation, because of P waves apparently arriving before at some of the RR stations.

An Istanbul small earthquake

The June 6, 2008, earthquake was recorded with a S/N>5 by 9 RR stations in Istanbul. It was not reported by the AFAD bulletin, hence its magnitude is expected to be smaller than 4. In this magnitude range it is interesting to check the performances of the PRESTo system, because predictive magnitude relationships are no longer valid (Zollo *et al.*, 2006) and the system is expected to switch on a local magnitude scaling law. A snapshot of the analysis is shown in Figure 10. For this event the estimation of the magnitude was around 3.0 since the first measurement. Only the uncertainty was reduced from 1.5 to 0.5, at the end of the computation. The earthquake was located in the North-East part of Istanbul, outside the small array that detected it. By manual picking of both P and S-waves, estimated location is pretty accurate. For an earthquake occurring in the Istanbul municipality, no warning is available for the city center, with a predicted PGA of 0.1%g. Lead time for Silivri was 9s, for Izmit 22s.

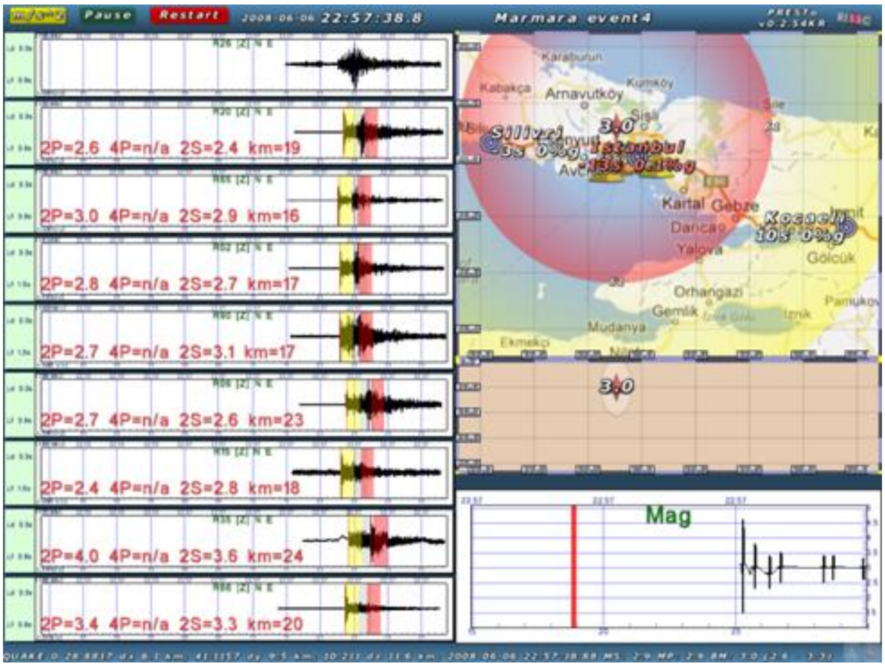


Figure 10: Snapshot of PRESTo simulation for the M 3.0 Istanbul earthquake. Location is declared in the North-West part of the Istanbul city.

Duzce earthquake

The November, 12, 1999, M 7.2 Duzce earthquake occurred East of the Marmara sea region, with the hypocenter located nearby the city of Duzce, 150 km from Istanbul. This earthquake followed the destructive M 7.4 Kocaeli earthquake, which stroke the same region three months before. The Duzce earthquake killed more than 500 people and damaged many structures and infrastructures that were severely shaken during the previous earthquake. This earthquake was recorded by several stations, many of them installed after the Kocaeli earthquake for aftershock monitoring. We used 27 accelerometric data collected by ERD (now AFAD), KOERI, ITU (Istanbul Technical University) and LDEO (Lamont Doherty Earth Observatory-Columbia University). Most of the stations lie west of the epicenter, while only one station is located on the other side, limiting the azimuthal coverage. Since absolute time was manifestly not correct for most of the stations, except for the LDEO sub-network, we modified absolute time on the uncorrected traces using origin time as estimated by AFAD and theoretical traveltimes from the earthquake hypocenter to the stations. Correction was performed by attributing the computed traveltime to the manually picked P wave first arrivals. With this correction, if we located the event in the same velocity model as used for the computation of the traveltimes, we would only check the effect of automatic picking as compared to the manual one. To introduce some variability in the measure, we computed the theoretical traveltimes in a different velocity model, the one used for earthquake location at national level (Table 2). An image of the PRESTo analysis is shown in Figure 11.

We get the first location estimate 7s after OT, 11 km away from the epicenter location, with a shallow focus (5 km). Initially uncertainties in locations are very large (ellipse errors are of the order of 30 km). At the end of the process, uncertainties decrease to few kilometers while the epicentral distance from the earthquake decreases to 5 km. Final depth estimate is still shallow (4 km), which may depend on the differences in the velocity model and on the limited station coverage.

First estimation of the magnitude is 6.5, which is due to the saturation of the 2s P-wave versus magnitude regression law. However, from the second estimate, 11s after the OT, the magnitude increases to 7.3, with an error of 0.3, this value being comparable with standard uncertainties on earthquake magnitude. Final estimate increases to 7.5±0.2. It is worth to note that threshold based early warning systems have an alert level for magnitude around 6/6.5. Despite the inaccuracy in the location and uncertainties in the magnitude, the probability for the occurrence of a destructive earthquake is enough large to issue an alarm from the second magnitude estimate. Lead times are 32s in Istanbul, 45s in Silivri and 12s in Izmit. Estimated PGA in Istanbul city center is 3% g, while measured one ranges between 1.4-6 % g.

Figure 11: Snapshot of the PRESTo simulation for the M 7.2 Duzce earthquake. Earthquake location is very close to the one estimated by the ERD center. Expected PGA in Istanbul is 3%g with a lead time of 32s.

Real time installation

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 accelerometric stations, whose availability at the control center of the network was limited. This is due to the fact that most of RR 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 velocimetric stations, to improve the performances of the system.

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