A Test Bed for Earthquake Early Warning Algorithms in Istanbul: Virtual Seismologist, PRESTo and ElarmS-2

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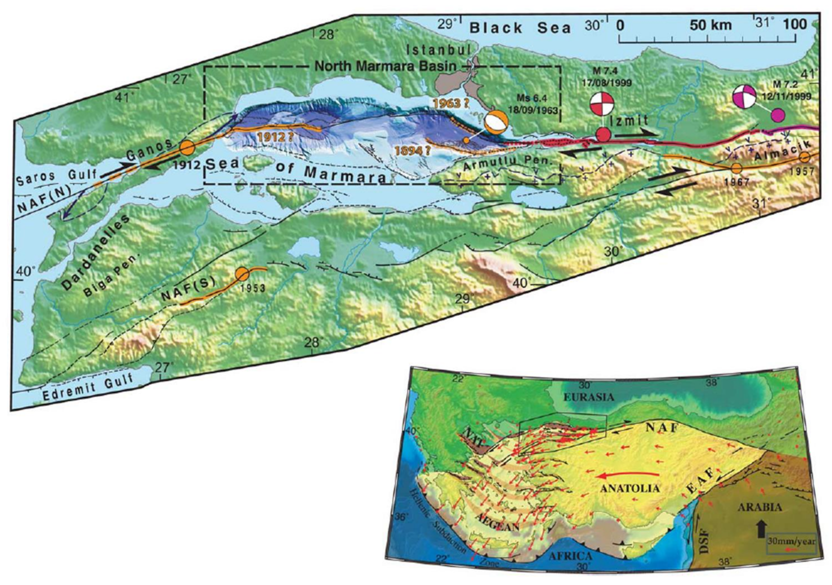
1.Introduction

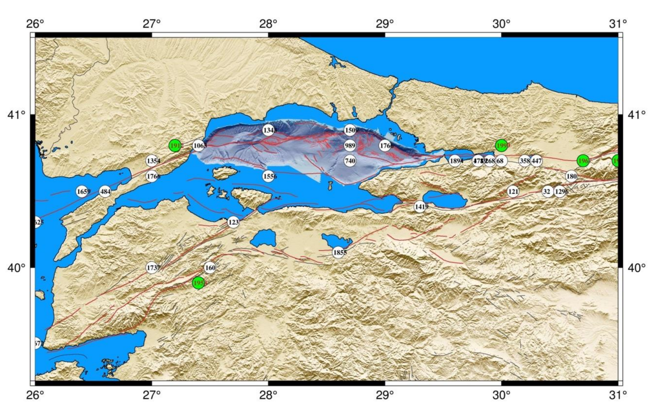
In the frame of REAKT and Marsite EU projects the Virtual Seismologist (VS) and PRESTo EEW algorithms developed in Zurich and Napoli were installed in Kandilli Observatory and Earthquake Research Institute (KOERI). In addition, ElarmS-2 (E2) was the third algorithm that joined KOERI testing site and became operational since the beginning of March 2015. Seedlink data server running as a module of SeisComP3 data acquisition software is used as a waveform provider to the EEW algorithms. The waveform data retrieved from more than 70 broadband and strong motion seismic stations of KOERI seismic network running in Marmara region is utilized. The present installed version of PRESTo operates using only the strong motion stations in eastern Marmara region while VS and E2 process both the broadband and strong motion stations.

After operating three algorithms at the same time for more than six months, we found each algorithm has its own strengths and weaknesses. The main challenge we encountered in issuing alarms was the timeliness of alerts. The key reason of delays on detecting earthquake is packet size of waveform data. We confirmed that Seiscom3 platform requires extra time to locate earthquakes and it needs to be adjusted for EEWS. Even with non-optimized current settings, Istanbul could have up to 20 seconds of warning times for a possible Marmara earthquake if a rupture initiates in western part of Sea of Marmara.

In this study, we gave an example earthquake detected successfully on 04:16, 11-05-2015 by the three algorithms at Gemlik Bay with M_L 3.9. Following table shows source information of earthquake by KOERI. Moreover, real-time performance of three algorithms in estimating origin time, epicenter and magnitude are also presented in the table. We found E2 overestimated magnitude by 0.4 magnitude unit. Although each algorithm used different stations it took less than 16 seconds to release first solutions (Figure 1). Fastest algorithm was PRESTo by one second before E2. Epicenter and origin time errors are very small by three algorithms.

2. Seismic Hazard for Istanbul

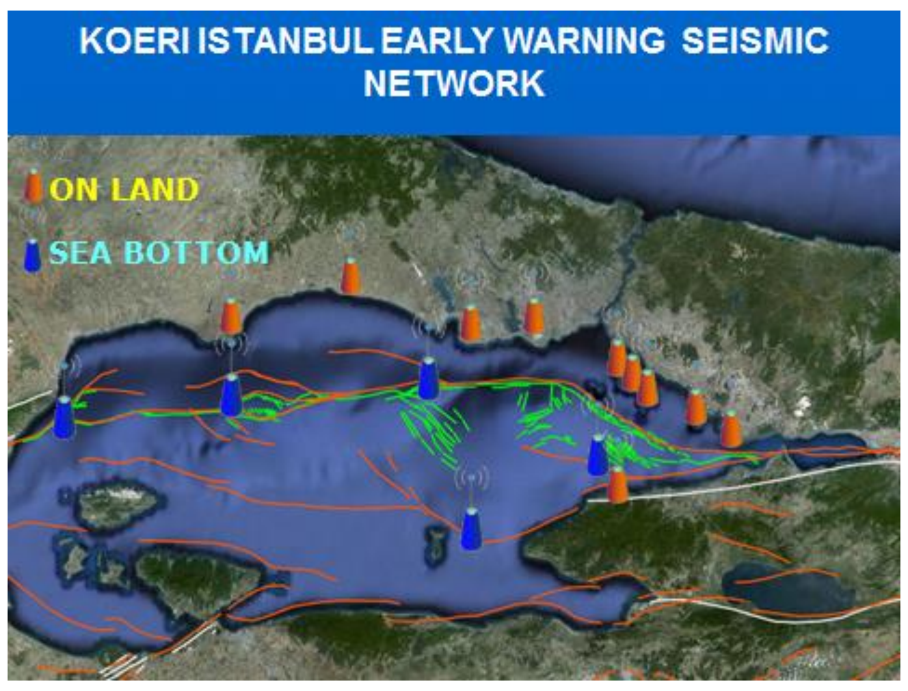




The M>7 earthquakes in Marmara region from 32 AD to 1999. The total number is 34 (Amraseys, 2006).

Marmara region is under the threat of a large earthquake expected to rupture a fault remaining unbroken since 1766. The region is densily populated where solely Istanbul houses about 14 million people.
The long term seismicity of the Marmara region covering a time period of the last 2000 years point out the occurrence of several events with magnitdes M>7 (Armijo et al., 2002).

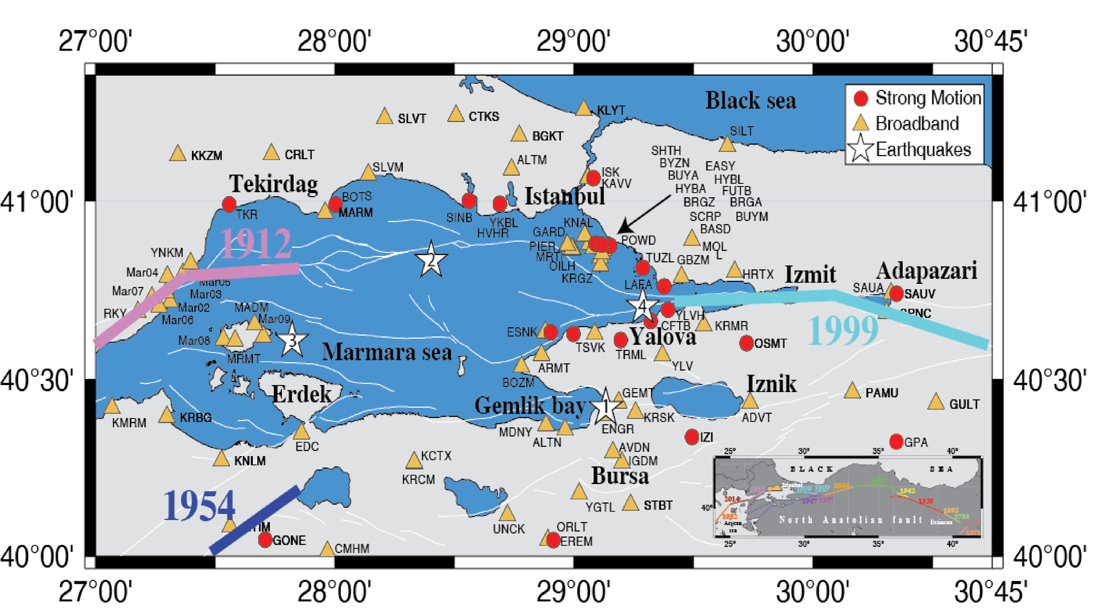
3. Onsite Early Warning Application:



Considering the complexity of fault rupture and the short fault distances, a simple and robust Early Warning algorithm, based on the exceedance of specific threshold time domain amplitude levels (band-pass filtered accelerations and the cumulative absolute velocity) named as CAV is implemented (Erdik et al, 2003).

The seismic stations in Marmara region: the broadband seismic stations is about 40 and the number of the strong motion stations is about 30. The dense seismic network is used to implement regional early warning algorithm.

4.Regional Early Warning Applications: VS, PRESTo, ELARMS2



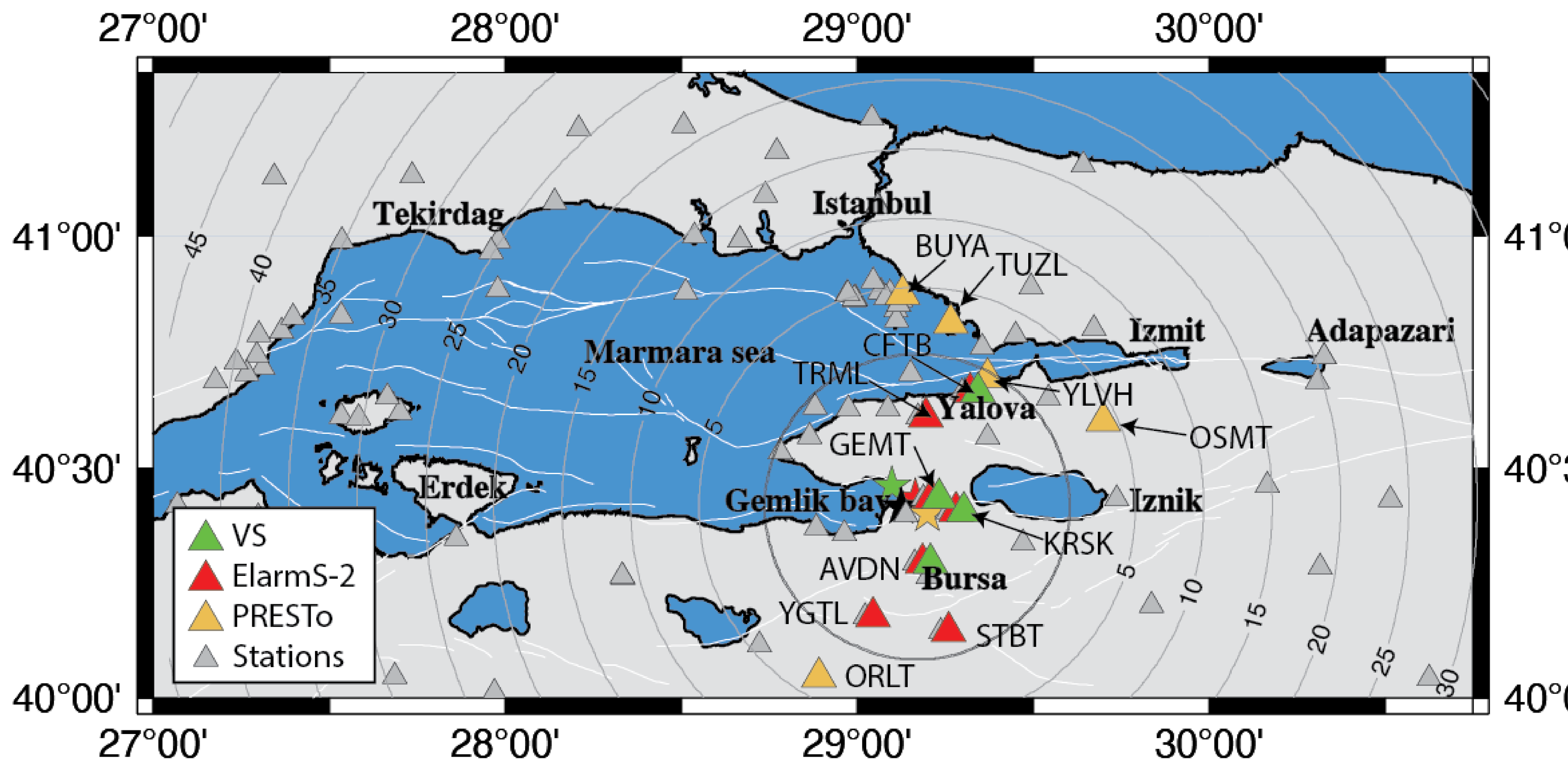
VS is a network based EEW that determines earthquake magnitude and location, using Bayesian approach. It was originally developed at Caltech by Cua and Heaton (2007) however; employment of the VS algorithm into real-time programming is an on-going work of the ETH Zürich Swiss, Seismological Service, and the US Geological Survey. VS was improved by EU projects : I) REAKT , II) NERA and III) Seismic Early Warning for Europe (Bose et al, 2014). VS is running at KOERI as a module of SeisComP3 acquisition software since September, 2013 and recorded more than 17700 events with low to moderate sized magnitudes. Currently VS uses total of 70 both broadband and strong motion stations located around the Marmara Sea. VS process the real-time 3-component streams of data provided by KOERI main Seedlink server.

ElarmS-2 is one of the network based EEW systems within in CISN/ShakeAlert project which is a demonstration system for the state of California (Bose et al, 2014). ElarmS-2 is the new production-grade version of previous ElarmS (Kuyuk et al. 2014). It is not an open source software and designed to maximize California seismic network's configuration, hardware and software performance capabilities. It is known for speediness of the early warning processing and the accuracy of the warnings (Kuyuk et al, 2014, Henson et al, 2014). ElarmS-2 is running at KOERI since February, 2015. For about 9 months, it reported more about 475 events in Turkey. ElarmS-2 is not optimized for KOERI network. We use the default settings designed for California. Likewise VS, the data for ElarmS-2 is provided by KOERI main Seedlink servers. ElarmS-2 process the real-time streams of vertical components from 70 broadband and strong motion stations.

PRESTo is an open source EEWS algorithm (http://www.prestoews.org) written at the University of Naples in 2009 (Satriano et al. 2011). It is a free easily portable and highly configurable software platform and uses both an on-site and a regional methodologies. For regional EEW applications a seismic network is utilized; however, for on-site algorithms single station measurements are sufficient. PRESTo originally built upon the Irpinia Seismic Network (ISNet) with single execution program that can work in Windows or Linux servers. PRESTo is successively producing more than a hundred low to moderate earthquakes with a small number of missed events since implemented in the ISNET (Zollo et al., 2013, 2014). Currently, it processes the real-time of 3-component acceleration data from the stations of the KOERI network in Marmara region, Turkey. PRESTo is working at KOERI since 2013 and recorded more than 50 low to moderate size events. Currently PRESTo uses total of 18 stations including 10 early warning strong motion accelerometer stations located around the Marmara Sea.

5. An axample

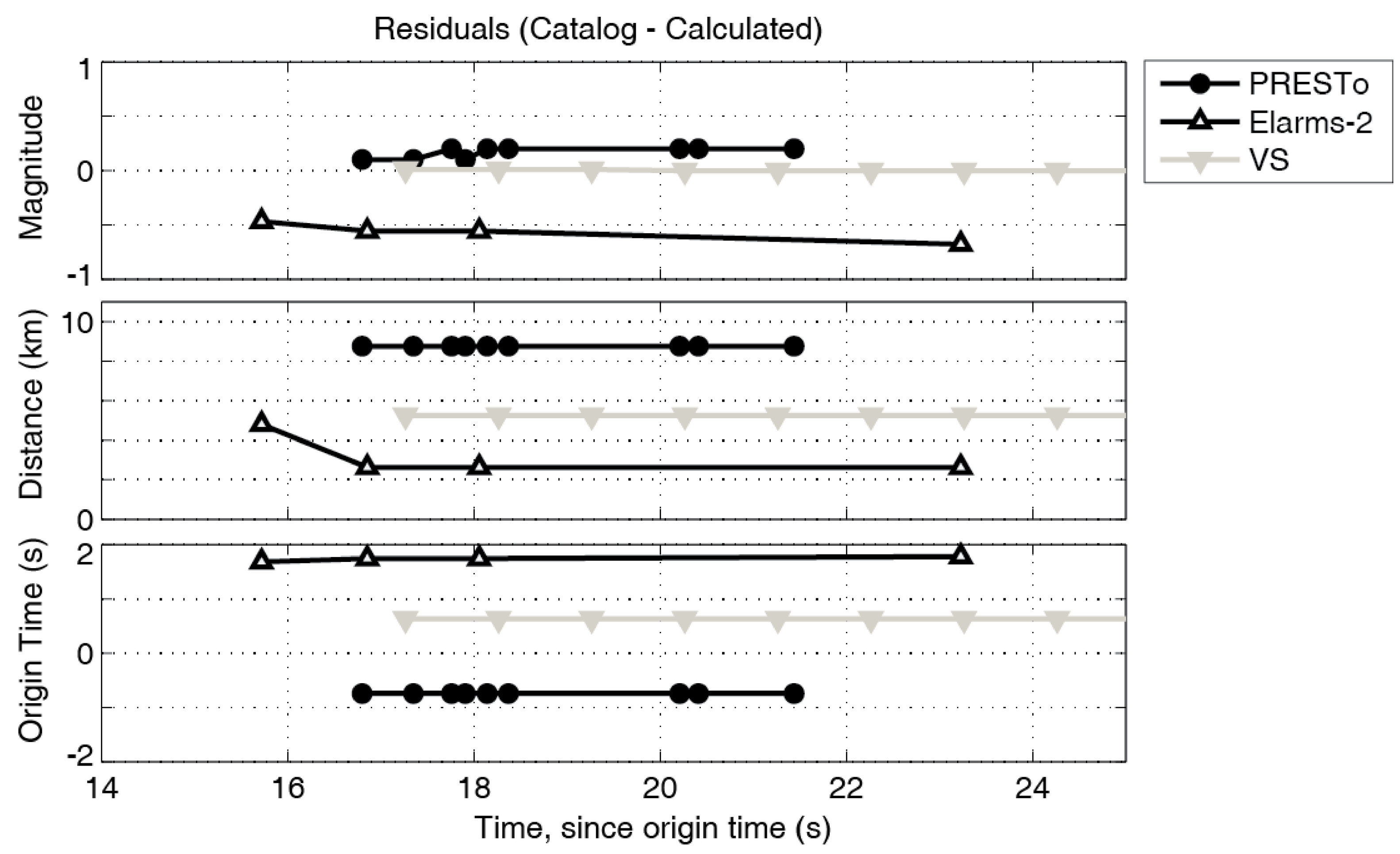
The epicenter locations determined by the three algorithms are close to each other; but, the EEWS utilized completely different stations despite the fact that they use the same data server. The three algorithms reacted to this event in quite different manner. VS utilized three broadband seismic stations (GEMT, KRSK, and AVDN) and one strong motion station (CFTB). The locations of the three stations are the nearest to the epicenter while CFTB is a bit away skipping a station used by ElarmS-2. The VS stations are indicated in green color. The first magnitude estimates of VS and PRESTo matches perfectly with catalog magnitude of KOERI. However, ElarmS-2 calculated the magnitude as M4.4, by using five broadband seismic station (AVDN, GEMT, KRSK, STBT, YGTL) and two strong motion stations (TRML, CFTB). The ElarmS-2 stations are shown in red color. VS and ElarmS-2 used four common stations in their first solution. PRESTo, however utilized five stations none of which were used by the other two algorithms (YLVH, TUZL, ORLT, BUYA, OSMT). They are all indicated with solid yellow triangles.



Each algorithm updates initial source information as new waveforms arrive at the servers. First source information is calculated 15.7 seconds after origin time by ElarmS-2. VS and PRESTo provide their first solution within two seconds after ElarmS-2. Residuals are estimated by subtracting calculations from KOERI catalog values. ElarmS-2 overestimate magnitude by 0.5 unit. However, it has the closest epicenter solution by 2 km. VS estimates of the location and origin time of the event is within 5 km and less than 1 second of the origin time of KOERI.

The difference between the origin time of an earthquake and the first estimation time of the earthquake parameters is called diff time. The product of the diff time with the S-wave velocity estimates the blind zone. The blind zone is an area where the destructive waves emanating from the source pass through before an earthquake alert is issued. The difference between the S-wave travel times and the diff time with the positivity constraint is called warning time (S-wave travel velocity is assumed to be 3.5 km/s).

The circles above show contours of warning time with 5 second intervals. Bursa and Yalova cities are within the blind zone of a circular area with 55 km radius from the epicenter. Istanbul has 8 to 15 seconds warning time where Izmit and Adapazari have more than 10 and 20 seconds warning time respectively. Because the epicenter of earthquake was located at the southeast of the Sea of Marmara, Tekirdag laying to the northwest of the Sea of Marmara has more than 30 seconds warning time.



6. Summary

In this study, we measured the performance of VS, PRESTo, ElarmS-2 algorithms in terms of calculating origin time, location, and magnitude of an earthquake in Marmara region. Although investigated algorithms neither developed in Turkey, nor optimized for Marmara seismic network infrastructure, their results are quite promising to explore more for their full capacities. Each system has its own dynamics to detect P-wave, associate stations and to calculate magnitude and location of events.

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