First results from an earthquake early warning system in Western Greece with special focus on the city of Patras and the Rion Antirion bridge

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Abstract

Patras with almost 250.000 residents is the third largest city in Greece and it is an ideal candidate for an Earthquake Early Warning (EEW) application due to its high seismic hazard, its existing research infrastructure, and the presence of critical structures such as the Rion Antirion bridge. This bridge, completed in 2004 by the GEFYRA consortium, is the world's longest multi-span cable-stayed bridge, it crosses the Gulf of Corinth near Patras linking the town of Rion on the Peloponnese to Antirion on mainland Greece. It is a very important infrastructure for the road network in central Greece since it is the only connection between Peloponnese and central Greece.

Patras is located a few hundred of kilometers from the Hellenic Arc, where very strong and potentially damaging events occur. This distance is large enough to provide a few tens of seconds of warning time, provided that a dense seismic network exists. Under the REAKT project the Virtual Seismologist (VS) software was installed in Patras Seismological Laboratory (UPAT) as an early warning system and we present here its initial evaluation. The software was installed in UPAT in May 2013 and is using broad band data from the Hellenic Unified Seismic Network and strong motion data from six accelerographs installed during the first year of REAKT project. During this first year of operation VS has processed a few thousand events. In general the software performs quite well in magnitude estimation (regression between officially reported magnitude and VS magnitude gives correlation coefficient equal to 0.84).

The average time that VS needs to evaluate the first magnitude estimate is rather large, of the order of tens of seconds and not yet satisfactory for operational use of early warning. Results of the initial period of early warning operation in western Greece suggest that the network density needs to be enhanced by the addition of extra stations. Nevertheless the application of early warning in the area seems to be interesting and capable of reducing earthquake risk.

VS implementation/ installation in UPAT

The Virtual Seismologist algorithm for the SeisComP system (VS) was installed on the SeisComP server of UPAT in May 2013. After an initial configuration phase it started to produce EEW reports for events in Greece.

The SeisComP server in UPAT acquires data from the Hellenic Unified Seismic Network (HUSN) and from strong motion stations available to UPAT. In Fig.1 we compare the magnitudes published by GI-NOA to those produced by the Virtual Seismologist (VS) running at UPAT. The two datasets are satisfactorily in agreement and show the potential of VS to be used as a reliable EEW system. It can be seen however, even though there are limited data points at magnitudes above M>5, that VS as currently configured slightly overestimates the magnitudes in this magnitude range.

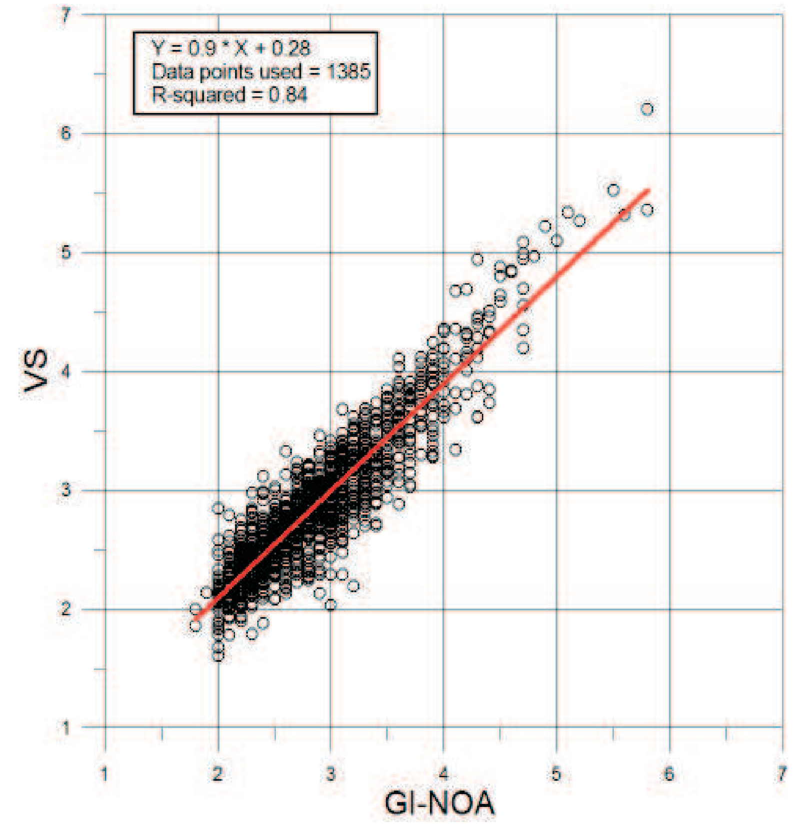

Figure 1: Comparison of GI-NOA and VS magnitudes.

VS alert time analysis

In the ideal case only the time for P wave data to arrive at the first six stations would be included in the VS-alert time (t_{diff}). In practice this time span consists of four parts a) the time of P wave propagation from the earthquake hypocenter to the (at least) six stations required by SeisComP3, b) the telemetry delay, and the processing time that can be divided in c) the SeisComP3 processing time and d) the VS module processing time

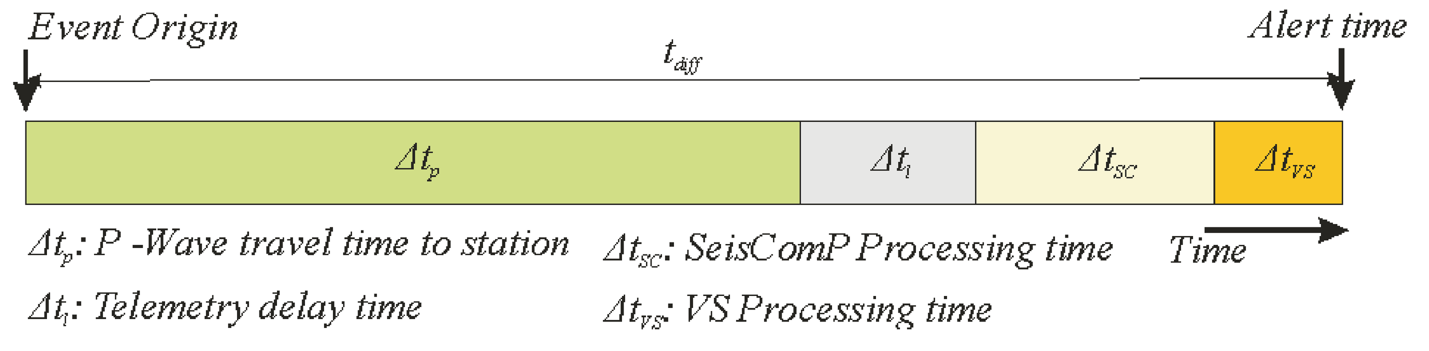

Figure 2: Analysis of delays affecting EEW.

Simulation of EEW performance

Initially a simulation of the EEW system under ideal conditions was made. The assumptions made for these optimal conditions were that the seismic network stations would be fully operational, and there would be no delay due to delays in data transmission or processing. The earthquake's depth was assumed to be at 10Km while the medium's velocities were fixed, that is P wave velocity 6km/s and S wave velocity 3.5km/s respectively.

Based on this the optimal times for issuing a warning for an earthquake occurring in the network's area were calculated for two scenarios a) a minimum of P-wave arrival at four stations are needed before issuing a warning and b) the corresponding times when a minimum of P-wave arrival at six stations are needed. The first case is the minimum number of arrivals needed by the VS algorithm to work, while the second case is the standard minimum number of stations required by SeisComP3 system in order to produce a location that will be used by the VS implementation for this system.

Fig. 3a,b created by the above calculations show that an average value of 10-15sec for the initial possible alert time can be estimated for events in the Western Greece area show (using six stations). While for Central Greece were the station density is higher the alert time has an average value of 5sec. It is also clear that in the case of the four stations minimum requirement, the possible alert time is reduced by an average value of ~4-6sec.

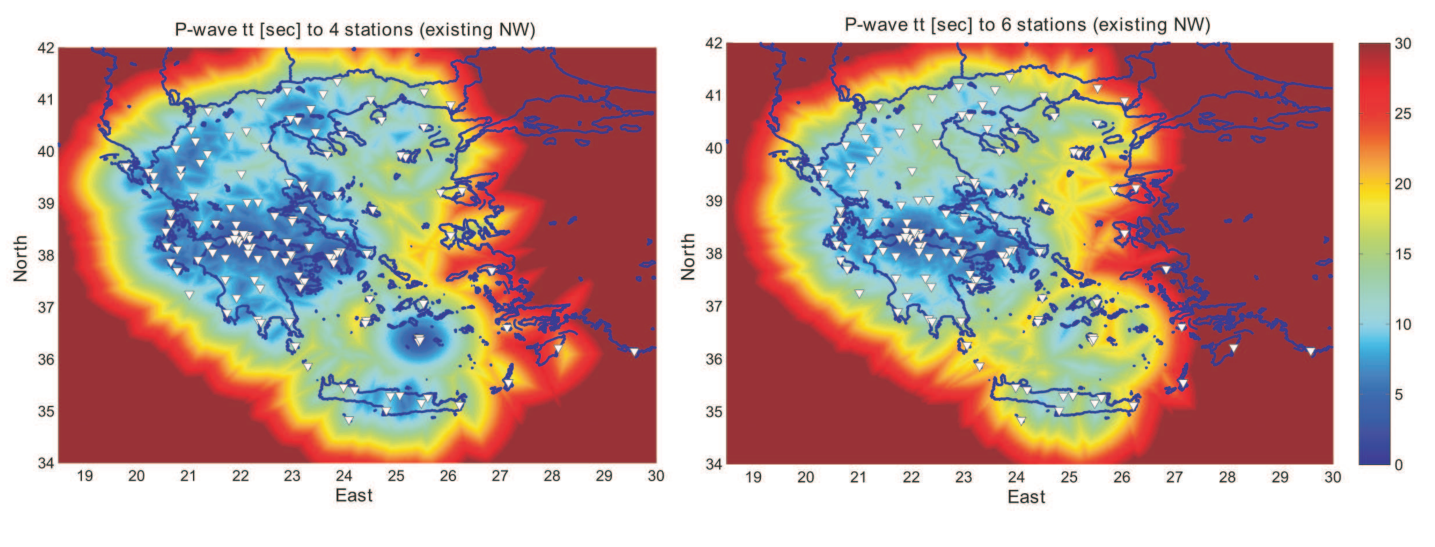

Figure 3: Simulation of possible event alert time a) using four stations b) using six stations, as the minimum number of stations needed for initial location.

VS total alert time analysis

Analyzing the VS reports, for 2014 up to April the 8th, the average t_{diff} time, that VS needs to evaluate the first magnitude estimate, is ~55s (Fig.4a).

Fig.4b shows that in the late January early February in a period when the aftershock sequence of the Cephalonia earthquake occured there is a slight increase in the t_{diff} time probably because of increase in processing time due to increased number of picks.

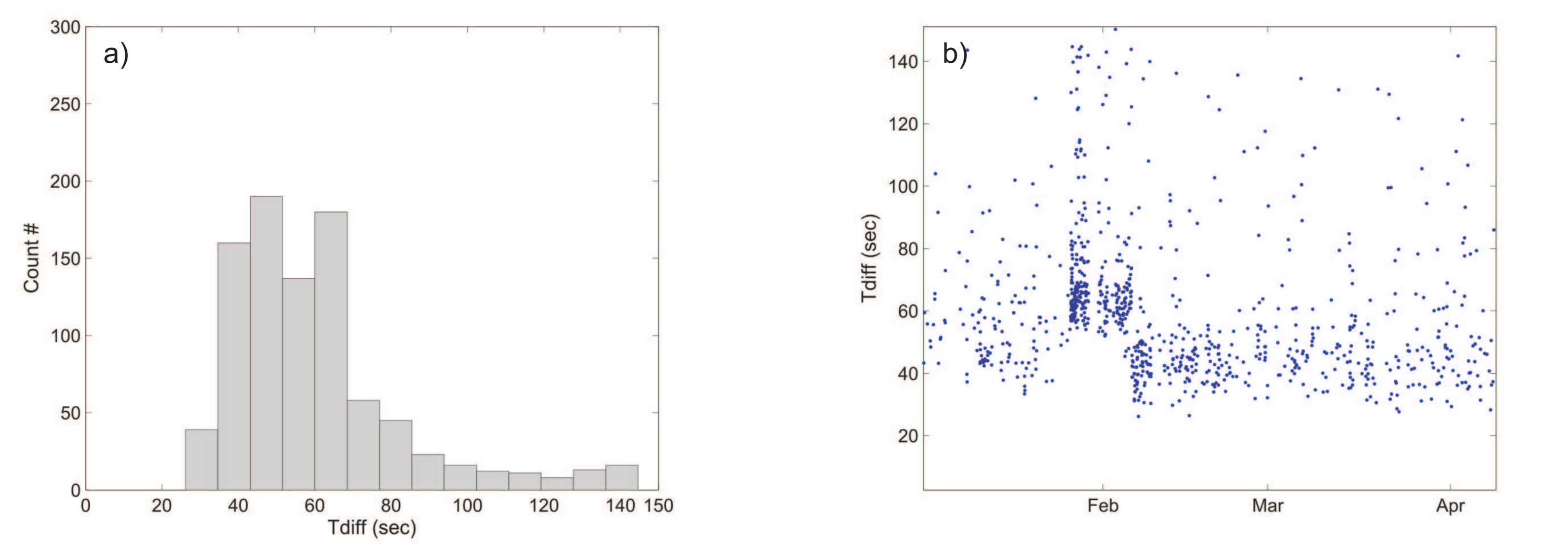

Figure 4: (a) Histogram of the t_{diff} for 2014 up to April 8th, (b) mapping the time evolution of the t_{diff} for the same period.

Effect of data transmission

HUSN is composed of several different types of instruments and data is transmitted using a variety of methods (e.g. satellite, GPRS, ADSL), and protocols (e.g NAQS, SCREAM, SEEDLINK). This can cause varying delays in the arrival of data packets (Fig.5).

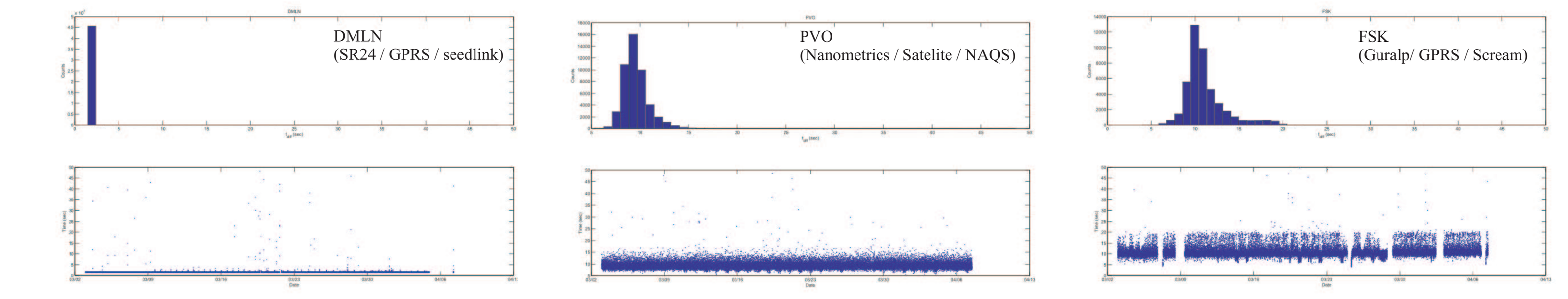

Figure 5: Delay of data packets due to telemetry for 2014 up to April 8th for three selected stations presented as histograms of delay time, (top) and delays vs time for the same period.

Analyzing the telemetry delays, for the HUSN network shows that these depend highly on digitizer configuration and used telemetry method and can on average exceed 10 sec. This is a major drawback for an EEW system implementation.

Data transmission is currently not tailored to EEW purposes, that needs a high quality low delay system with fine tuned parameters such as packet length, probably at the expense of bandwidth usage.

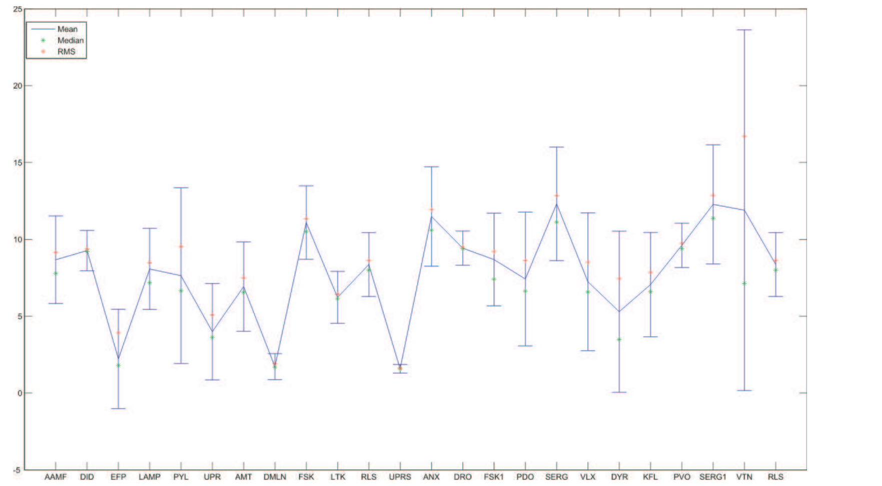

Figure 6: Mean delay of data packets ± 1σ for selected stations .

VS alert for S wave arrivals

The time difference between the issuing of an alert and the arrival of the S wave arrival at the Rion Antirion bridge site has also been estimated for two time periods. S wave arrival is used since it is more important for a large construction as the Rion Antirion bridge and of course it reduces the blind zone for EEW. Fig.7a is for VS operation in 2013 and Fig.7b for 2014, up to April the 8th. Adding several strong motion stations and fine tuning SC3 location parameters shows an improvement by narrowing the area where the warning arrives after the S wave arrival. We can roughly estimate an alert time of ~10s for a distance of ~150 - 200 km.

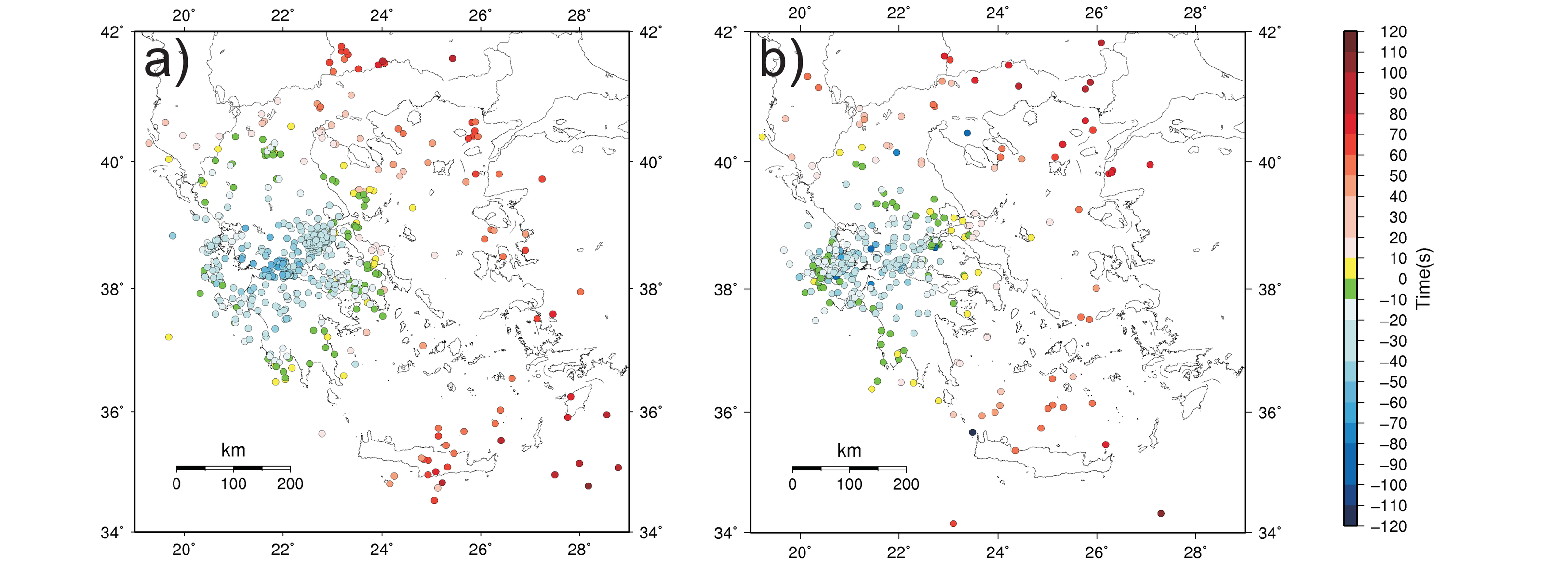

Figure 7: Time difference of warning arrival minus the S wave phase arrival at the Rio Antirio Bridge site. (a) shows the performance of VS during its operation in 2013 , (b) shows the same for 2014 up to April the 8th.

Discussion

Virtual Seismologist (VS) was installed in the SeisComP server of UPAT in May 2013. The software has been running without problems for a long period and produces EW reports for events located by SeisComP3. The overall evaluation of the process is positive, i.e. magnitudes are very close to reported ones and warning time for S-waves is of the order of ten seconds for events at a distance of ~200km.

According to evaluation of EEW performance by the Rion-Antirrion bridge personel, the main advantages of the system are a) Good correlation between the VS output and the data provided by the Geodynamic Institute of Athens regarding the earthquake magnitude and b) there is a fare amount of warning time for S arrival from events located in the Greek subduction zone.

The main problem identified up to now is the uninterrupted operation of the network and the increase of the available strong motion data. Our efforts for the next year will be focussed in providing faster information to the end user (User Display), in the addition of strong motion stations and changes in SC acquisition process.

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