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A P-wave based, on-site method for Earthquake Early Warning

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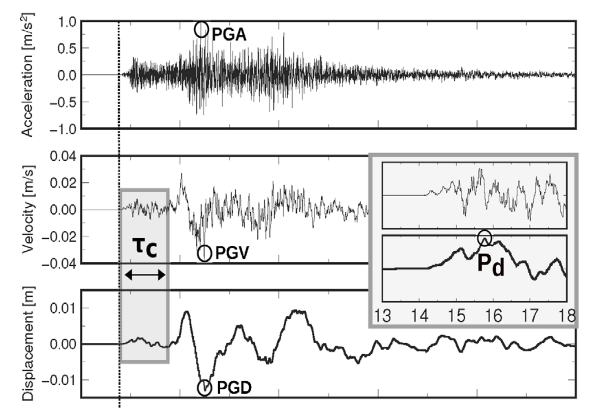
Abstract

A possible approach for the on-site earthquake early warning is to predict the expected peak ground shaking at the site and the earthquake magnitude from the initial P-peak amplitude and characteristic period, respectively. The idea, first developed by Wu and Kanamori (2005), is to combine the two parameters for declaring the alert as soon as the real-time measured quantities exceed the pre-defined thresholds (**Pd-τc Approach**).

Here we generalize this approach and propose a new strategy for a P-wave based, on-site earthquake early warning system (**P-Amplitude Based Approach**). The key elements are the real-time, continuous measurement of three peak amplitude parameters and their empirical combination to predict the ensuing peak ground velocity. The observed parameters are compared to threshold values and converted into a single, dimensionless variable. A local alert level is issued as soon as the empirical combination exceeds a given threshold. The proposed methodology provides a more reliable prediction of the expected ground shaking and improves the robustness of a single-station, threshold-based earthquake early warning system. The methodology has been developed and tested on Japanese data and it is under testing on Italian earthquake data.

Pd-τc Approach



The two parameters are:

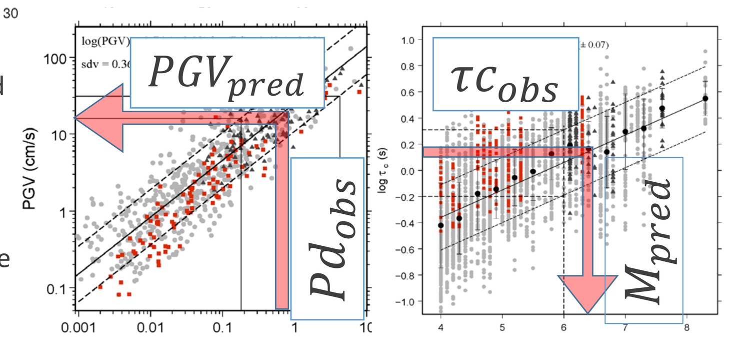
The initial peak displacement (P_d) and the predominant period (τ_c) given by

$$\tau_c = \sqrt{\frac{\int_0^{t_0}[u(t)]^2\,dt}{\int_0^{t_0}[v(t)]^2\,dt}}$$

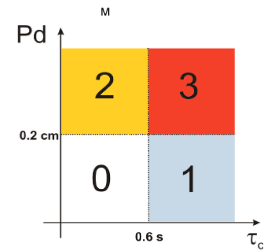
where u is ground displacement, v is velocity on a short time-window of P-waves signal on the vertical component and t_0 is 3 sec.

The initial peak displacement, P_d is used as a proxy for the Peak Ground Velocity

The period parameter, τ_c, is instead used to estimate the earthquake magnitude M



P_d and τ_c are compared to threshold values and a local alert level is assigned at each recording site (0, 1, 2, 3). The threshold values correspond to M=6 (from the τ_c vs. M equation) and to I_{MM}=VII from the P_d vs. PGV equation, assuming the equation of Wald et al [1999].

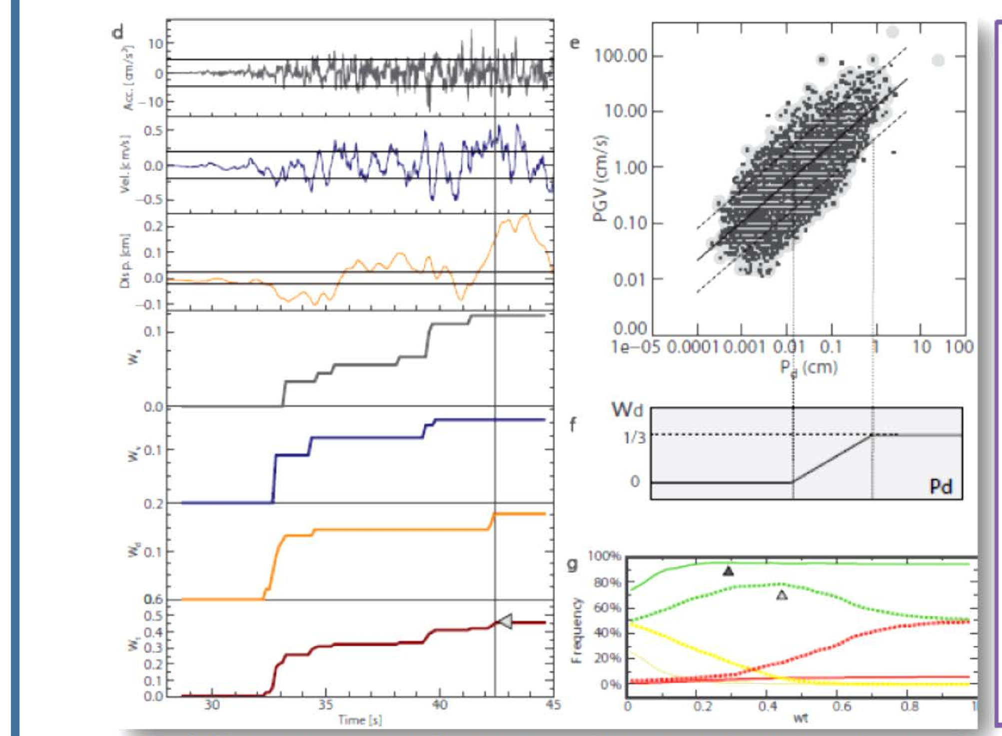


Alert levels			
Damages nearby & far away from the station	Damages only nearby the station	Damages only far away from the station	No damages
3	2	1	0

Finally, an approximate source-to-receiver distance can be estimated by solving the unknown parameter log R, using an empirical relationship of the form:

$$\log R = A + B*M + C*\log P_d$$

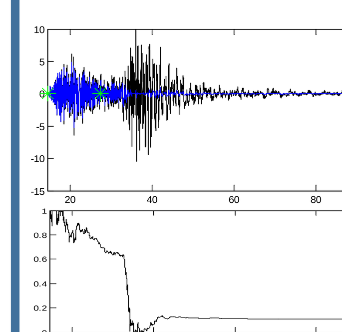
P-Amplitude Based Approach



- PGV vs Pd, Pa, Pv is used to set threshold values
- Fuzzy variables Wd, Wv and Wa are built based on observed Pd, Pv and Pa
- The combined proxy Wt is evaluated at each station and used for warning
- The optimal threshold for Wt is chosen by maximizing the number of successful alarms

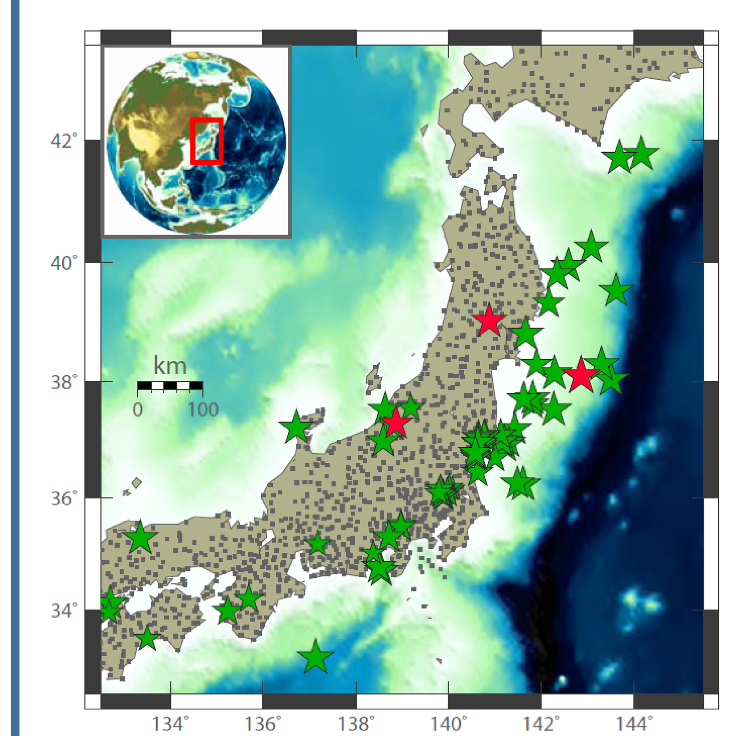
Colombelli, S., A. Caruso, A. Zollo, G. Festa, and H. Kanamori (2015) Geophys. Res. Lett., 42, doi:10.1002/2014GL063002.

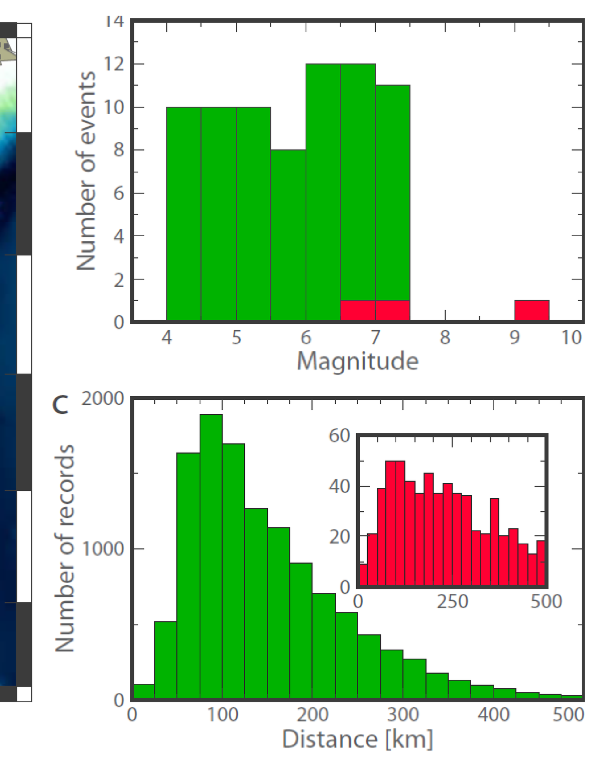
S-detection (SVD method)



- The particle motion of P and S waves is linear, with the S-vector being confined to a plane orthogonal to the P-vector direction.
- Particle motion analysis by recursive singular value decomposition (SVD) is used to distinguish basic seismic phases online from a three-component data with sample-to-sample resolution (Rosenberg, 2010).
- A modulating function (Sn), built upon the incidence angle of particle motion, allows to enhance (or filter-out) the P- and S-wave signal from the original three-component record.
- The "enhanced P-wave" seismogram is used for the onsite early warning analysis.

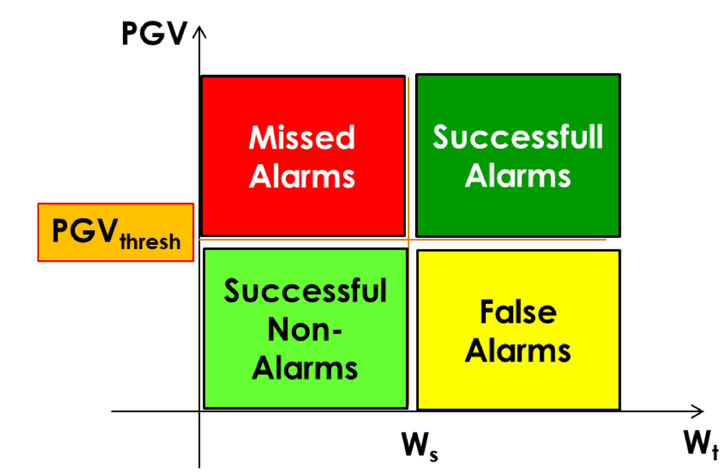
Application to Japan





The data-set used for test is composed of 76 Japanese events in the magnitude range 4.0 ≤ M ≤ 9.0. The distance range R 0-500 km, for a total of 12,792 three-component records. Green stars are the events used for calibration while red stars are the testing events.

The performance of the proposed EEWS is evaluated by counting the percentage of Successful Alarms or Non-Alarm (SA and SNA), False Alarm and Missed Alarm.



Local intensity parameter

MODERATE POTENTIAL DAMAGE (PGV = 16 cm/s)

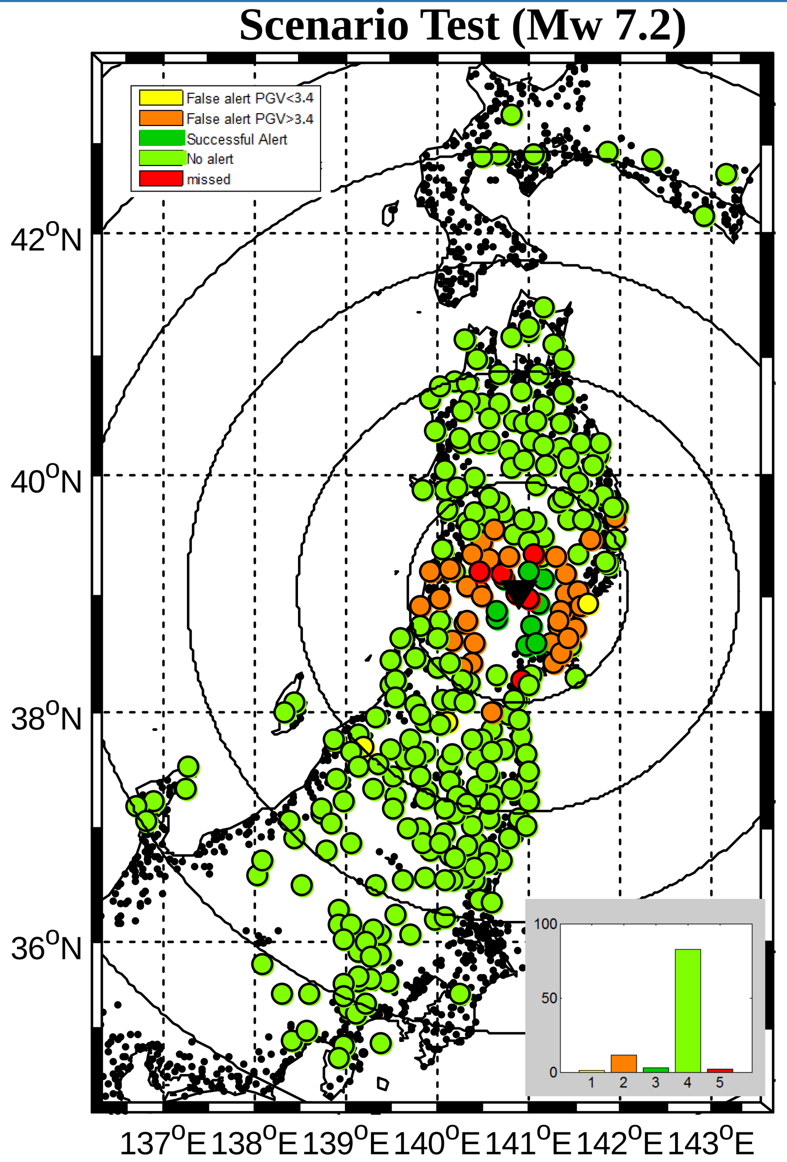
VERY LIGHT POTENTIAL DAMAGE (PGV = 3.4 cm/s)

Conversion table (Wald, 1999)

PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<.17	.17-1.4	1.4-3.9	3.9-9.2	9.2-18	18-34	34-65	65-124	>124
PEAK VEL.(cm/s)	<0.1	0.1-1.1	1.1-3.4	3.4-8.1	8.1-16	16-31	31-60	60-116	>116
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

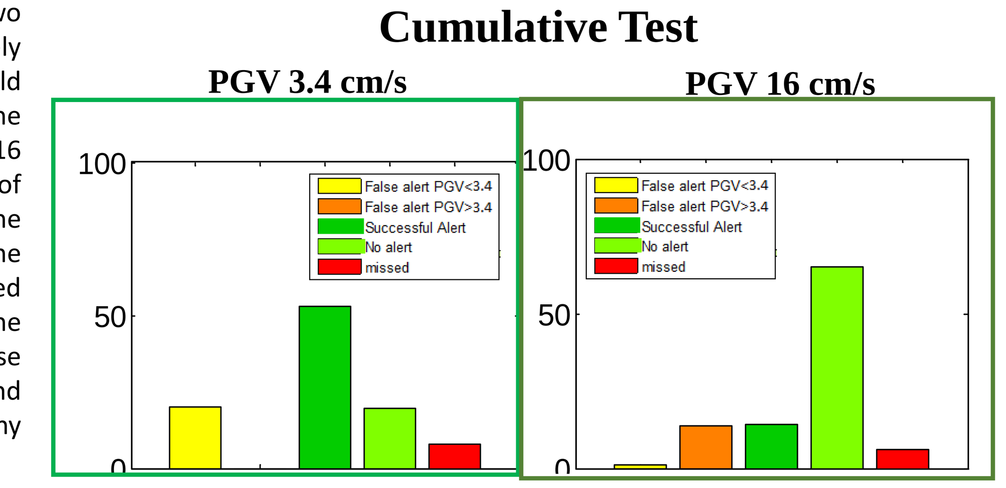
The histograms show the cumulative statistics on the whole database. We chose two reference thresholds, respectively related to the felt threshold (PGV=3.4 cm/s) and to the damage threshold (PGV=16 cm/s), according to the table of Wald et al (1999). Among the false alerts we distinguish the cases in which the observed ground shaking overcomes the "felt" level (orange) from those cases where the observed ground motion is not associated to any perceived shaking (yellow).

Scenario Test (Mw 7.2)



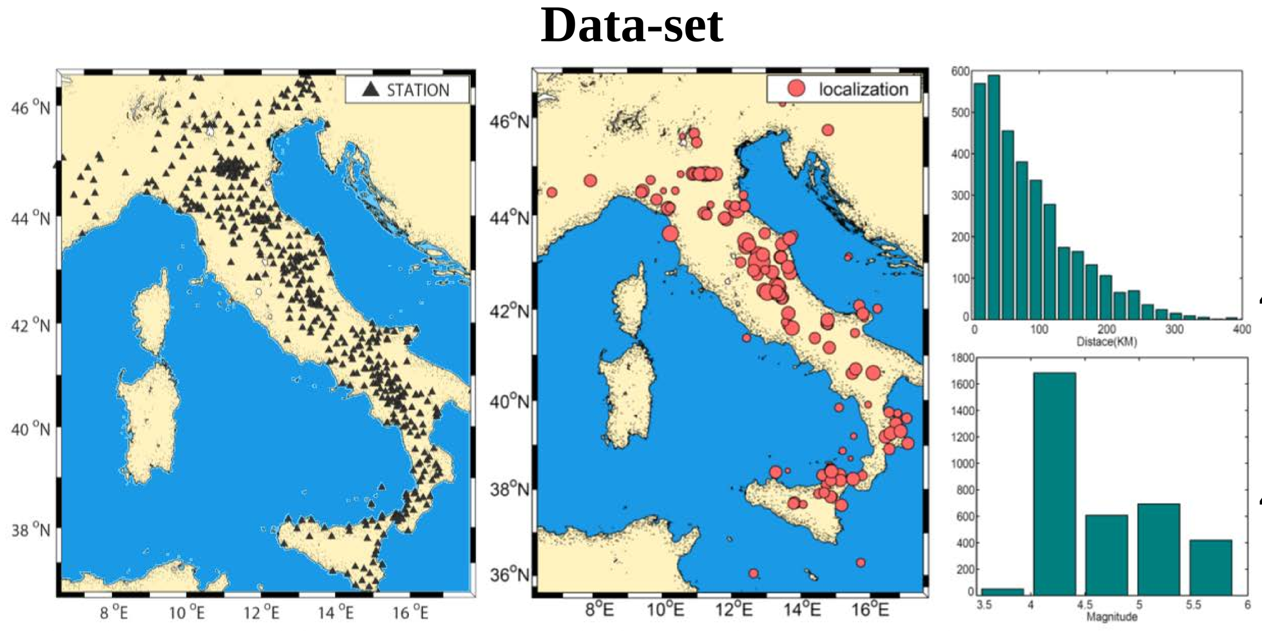
An example of scenario test of a Japanese event. The threshold selected is set on the damage level (PGV=16 cm/s). The results show that the success rate is 80 - 90 percent of the case and the area of the damage overestimation is well confined, and in false alert case are registered of shaking at or above the threshold of felt.

Cumulative Test

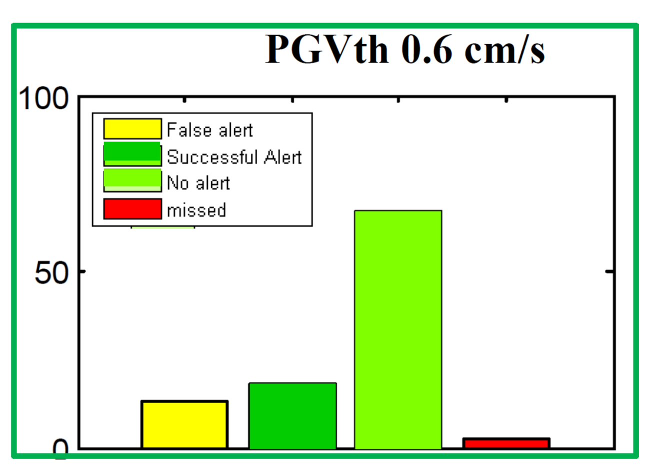


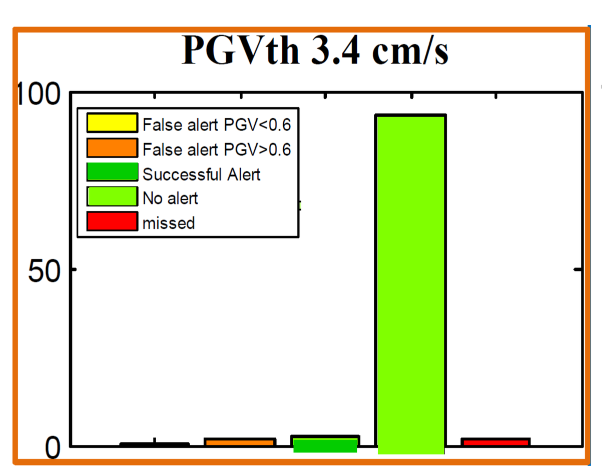
Application to Italy

Data-set



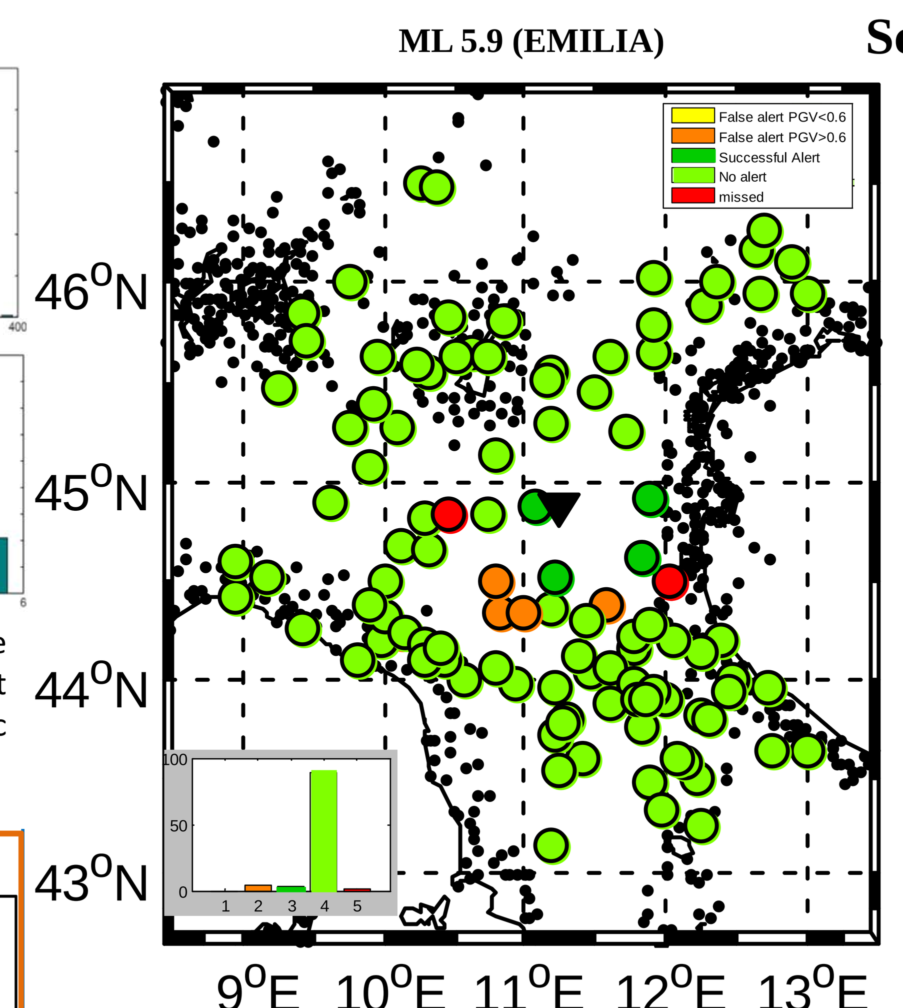
The data-set used for test is composed of 195 Italian events in the magnitude range 3.5 ≤ M ≤ 6. The distance range R 0-400 km, for a total of 3451 three-component records. Blacks triangles are the stations belonging to the National Accelerometric Network (RAN) , Red circles are the locations of earthquakes.

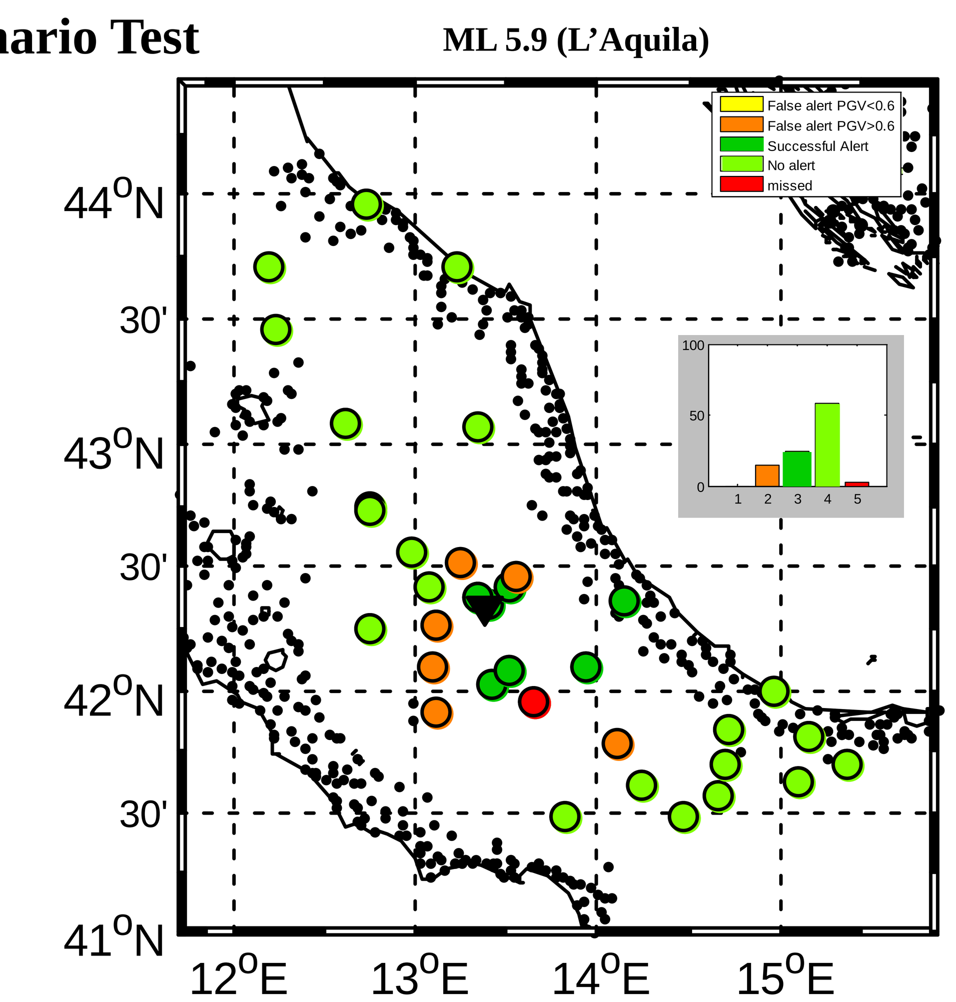




The histograms show the cumulative statistics on the whole database. We chose two reference thresholds, respectively to the felt threshold (PGV=0.6 cm/s) and to the damage threshold (PGV=3.4 cm/s), according to the intensity table of Faenza and Michelini (2010).

Scenario Test





The methodology was applied to the 2012 Emilia earthquake and the 2009, L'Aquila event. The threshold is set on the damage level (PGV=3.4 cm/s). In both cases, the success rate is very high and the false alerts are confined in the epicentral region. However, for the Emilia event the low density of stations in the epicentral region does not allow to have a significant number of correct alerts.

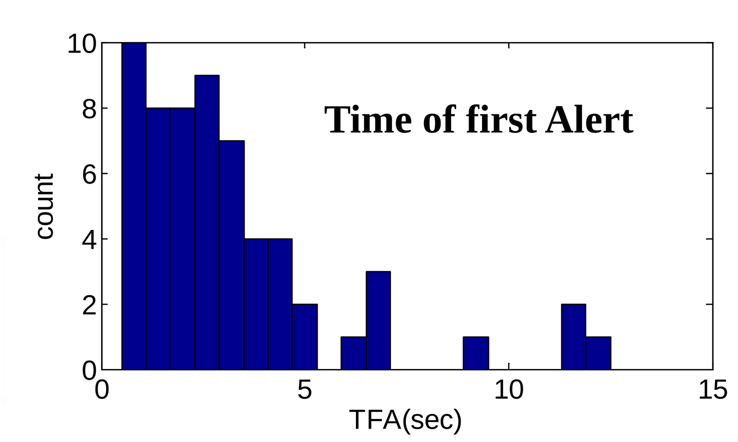
Local intensity parameter

VERY LIGHT POTENTIAL DAMAGE (PGV = 0.6 cm/s)

MODERATE POTENTIAL DAMAGE (PGV = 3.4 cm/s)

Conversion table (Faenza and Michelini, 2010)

PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<.21	.21-0.52	0.52-1.3	1.3-3.1	3.1-7.5	7.5-18	18-45	45-109	>109
PEAK VEL.(cm/s)	<0.08	0.08-0.2	0.2-0.6	0.6-1.5	1.5-3.4	3.4-10	10-28	28-74	>74
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+



The figure draws the histogram of the Times of First Alert (TFA). The threshold selected is set on the damage level (PGV=3.4 cm/s) In most of the cases the TFA of the EEWS is 1-4 sec.

Conclusions

- The proposed EEW methodology is likely to provide reliable warnings and more robust prediction of potential earthquake damaging effects.
- The use of the vertical component of ground motion recordings, in principle, minimizes the S wave contamination on the P wave amplitude measurement.
- With the application of the proposed methodology, the S-wave contamination on the vertical component is significantly reduced and the amplitude pick of the vertical component is only associated to the P waves. The robustness and reliability of the system are therefore improved. The statistical and scenario tests confirm the robustness of the on-site methodology.

References

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5. Kanamori, H. (2005). Real-time seismology and earthquake damage mitigation, Ann. Rev. Earth Planet. Sci., 33, 195–214.