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# Authorizing GRound shaking for Earthquake Early warning Systems, (AGREEs): Application to 2014 South Napa Earthquake

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## Intorduction

1) Preventing false alarms from EEW systems is key.

2) A simple, robust algorithm, Authorizing GRound shaking for Earthquake Early warning Systems, (AGREEs) may reduce falsely issued alarms

3) This is a network-threshold-based algorithm, which differs from existing approaches based on apparent velocity of P- and S-waves. AGREEs is designed to function as an external module to support existing earthquake early warning systems (EEWS) and filters out the false events by evaluating actual shaking near the epicenter.

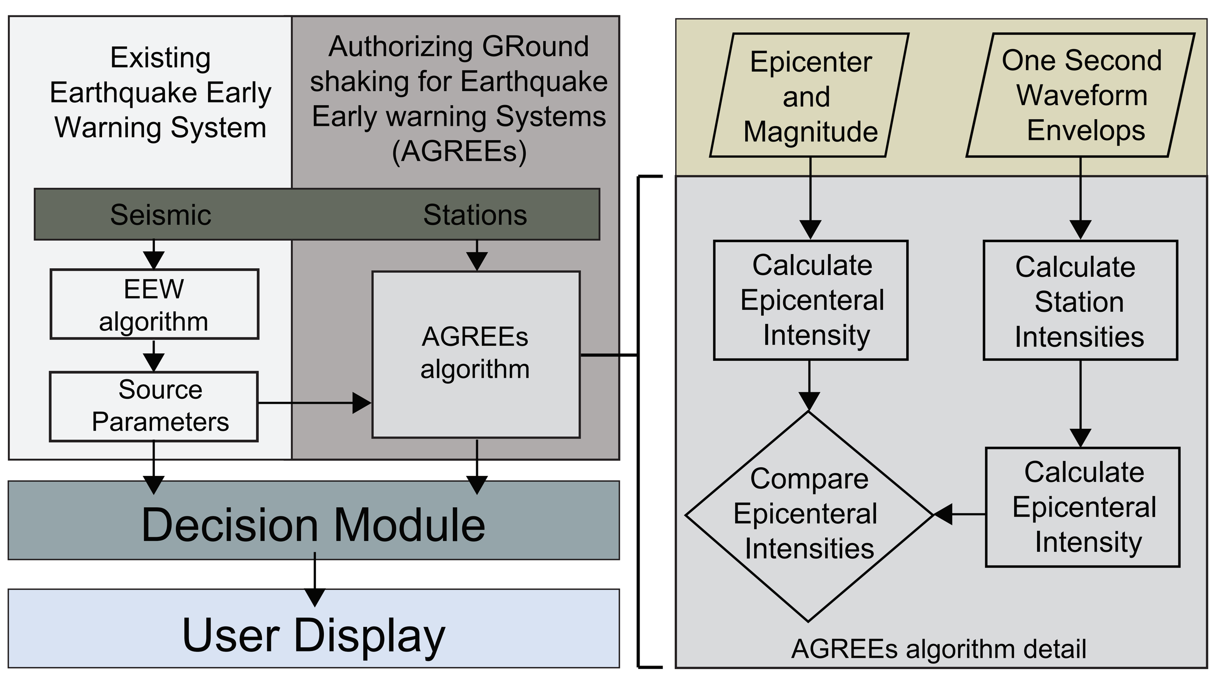


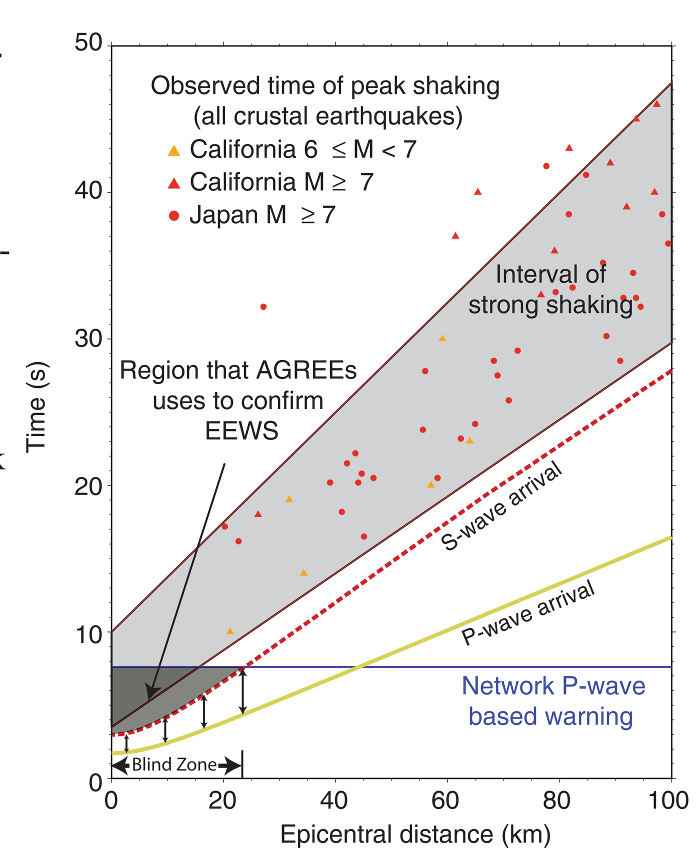

Figure 1. Flow chart of AGREEs that can be cooperated with existing EEWS. AGREEs requires the earthquake source parameters and station waveforms as input. AGREEs calculates the associated intensity at stations around the epicenter and averages the intensities. The average value of intensity is compared with existing EEWS in order to check whether the forecasted peak ground motion through the magnitude and location of the earthquake is appropriate or not. Based on the deviation between the expected and the observed peak ground acceleration, this information is fed back to the decision module of EEWS in order to confirm or cancel the warning.

adopted from Kuyuk et al. (2015)

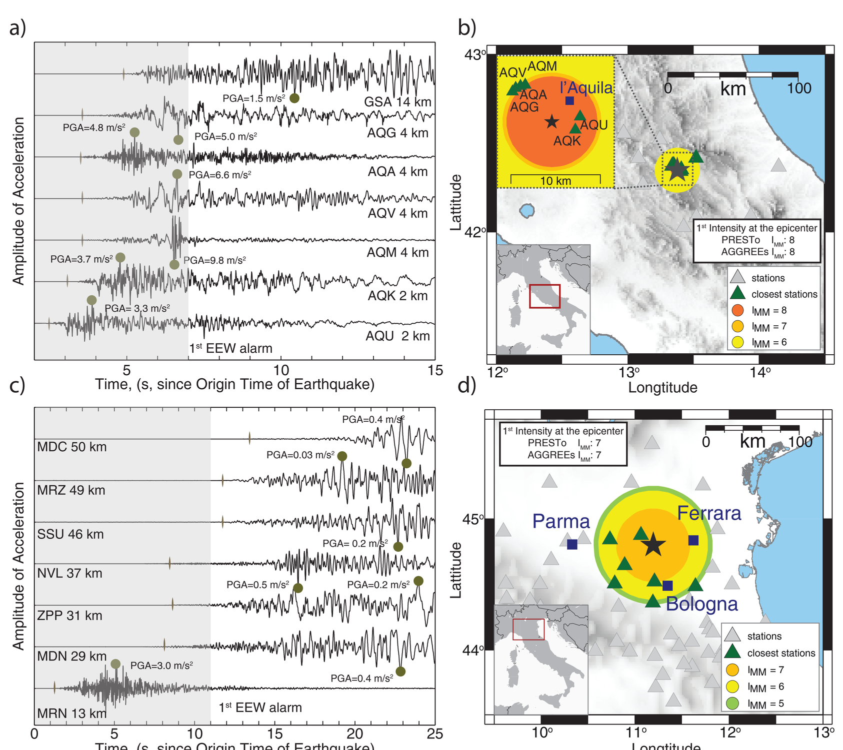
## The Idea behind AGREEs

AGREEs uses the available strong shaking observed within the blind zone (dark gray region) to confirm alerts before they are issued.

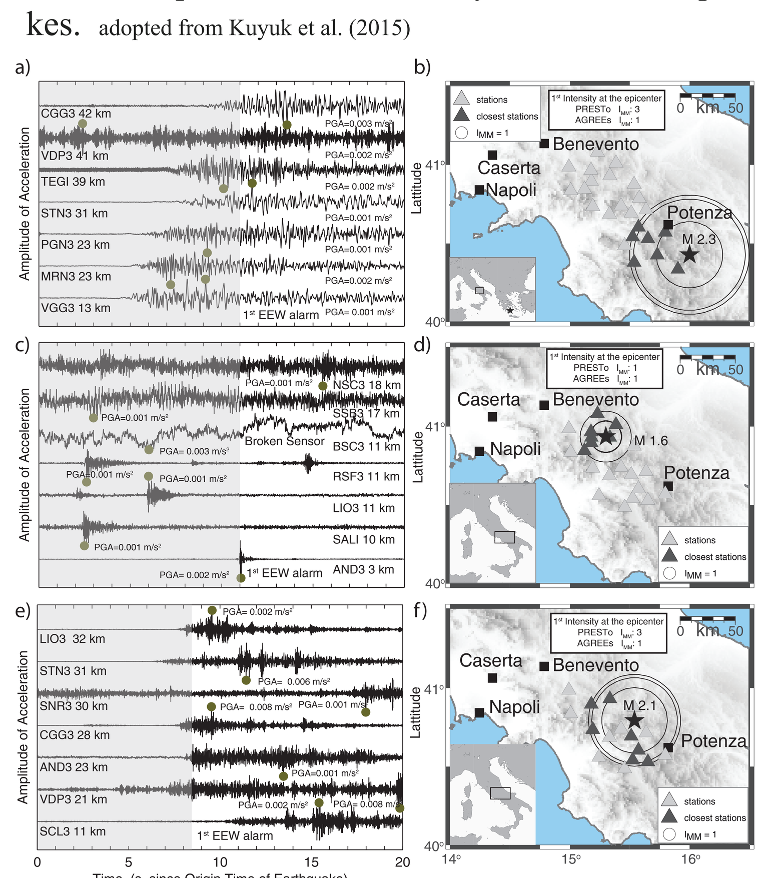
Figure 1. Time-distance plot illustrating the relative timing of seismic arrivals and warnings. The P-wave and S-wave arrival times are plotted as a function of epicentral distance for an earthquake with a hypocenter at 10km depth. The light gray shaded region shows the interval of strong shaking based on observations from crustal earthquakes with depths of 21 km or less. The time of peak ground shaking is calculated for all available stations in nine M > 6 earthquakes from Japan and California. The blue horizontal line at 7.6 s is the warning of regional EEWS (after the origin time). It assumes that P-wave front reaches 32 km (at 5.6 s) and that 2s of P-wave is required to estimate magnitude. This means that the blind zone (an area where S-wave and/or strong shaking has already reached) is ~23 km from the epicenter at this time. (Figure modified from Allen, 2011.) adopted from Kuyuk et al. (2015)




## Previous Results



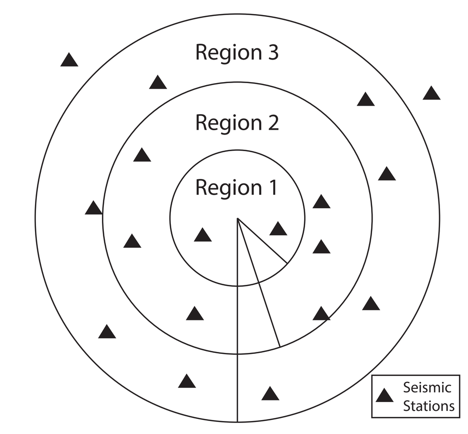
Left figure shows the waveforms of the seven closest stations for the two test events and results from AGREEs at the time of the first alert from P-wave based PRESTo.
(a-b) Mw=6.3, L'Aquila, 2009 and
(c-d) Mw=5.9, Emilia, 2012 earthquakes.
On the waveform plots, the gray region shows the data collected before the PRESTo alert was issued. AGREEs calculates intensities using observed peak accelerations within this shaded region. The waveforms are normalized according to their PGA's and ordered according to their epicentral distances. The maps show AGREEs intensity estimations at the time of the first alarm. Intensities from both algorithms at the epicenter match exactly for both earthquakes. adopted from Kuyuk et al. (2015)



Right figure is a similar plot, but for the three false events. Waveform plots show data for the 7 closest stations to the estimated (false) epicenter for each event and the map figures show the results of AGREEs at the time of first magnitude solution by PRESTo.
(a-b) M=3.7, false event due to a teleseismic earthquake in Greece (Mw=5.8),
(c-d) M=6.1, false event due to one broken sensor and spurious triggers, and
(e-f) M=2.1 false event due to weather noise.
On the waveform plots, the gray region shows the data collected before the PRESTo alert was issued. AGREEs calculates intensities using observed peak acceleration within this shaded region. The waveforms are normalized according to their PGA's and ordered according to their epicenteral distances. The maps show AGREEs intensity estimations at the time of first alarm. Intensities from both algorithms at the epicenter match exactly for both earthquakes. AGREEs's intensity solutions in each instance are zero.

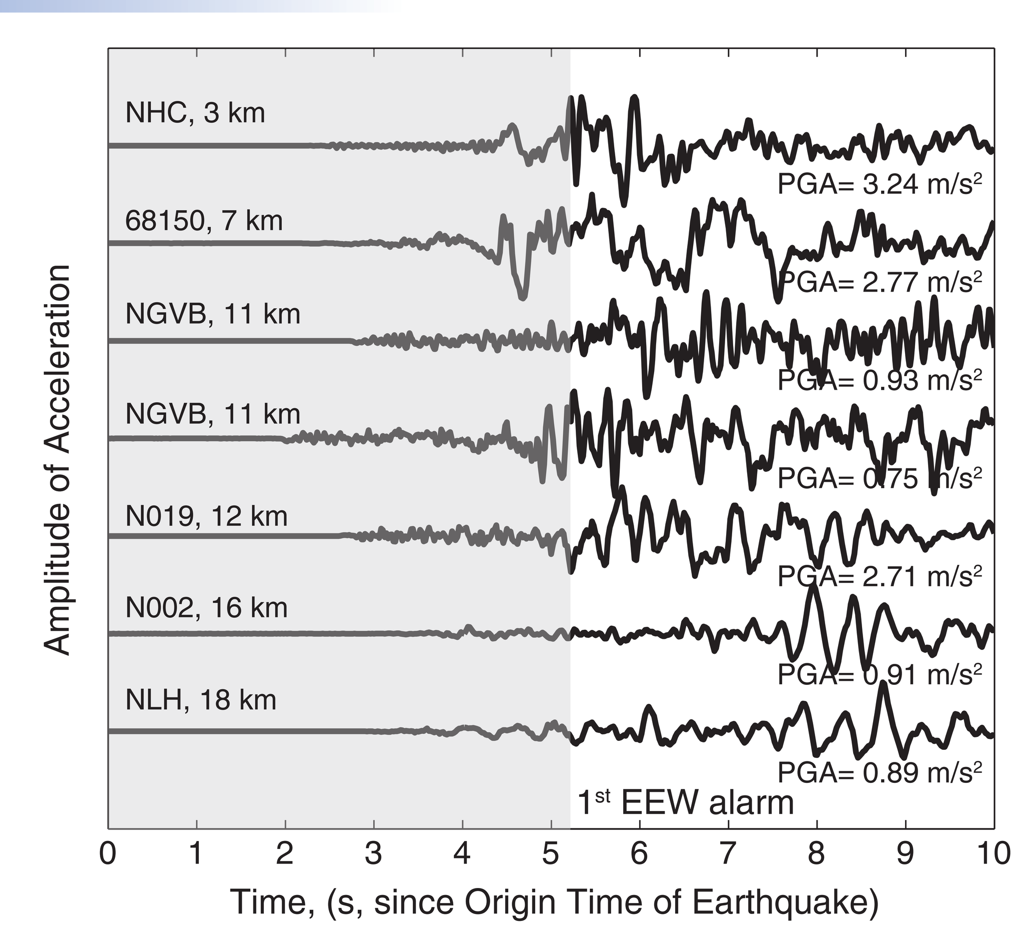
## Method

1) AGREEs requires the earthquake location as input which we assume that this is correctly provided by the existing EEW platform, through the first P-wave arrival times
2) Once the earthquake location is released, AGREEs measures the instantaneous peak acceleration value of ground motion and calculates the associated intensity at stations around the epicenter, according to the conversion table of Wald et al., 1999. T
3) The acceleration is computed along the ground motion vector and is updated every second, so that continuously refined intensity estimates are delivered.
4) AGREEs then averages the intensities at the closest three, five, and seven stations and creates three concentric circles whose radii correspond to distance of the third, fifth and seventh closest station, respectively.
5) The user interface of AGREEs create three circles and variable numbers of stations act as filters on top of the regular EEWS and work separately in case of failure of any of them.
6) The average value of intensity is updated at each second and is fed back to EEWS in order to check whether the forecasted peak ground motion through the magnitude and location of the earthquake is appropriate or not.
7) AGREEs compares the expected and the observed peak ground acceleration and feeds this information back to the EEWS in order to confirm or cancel the warning.

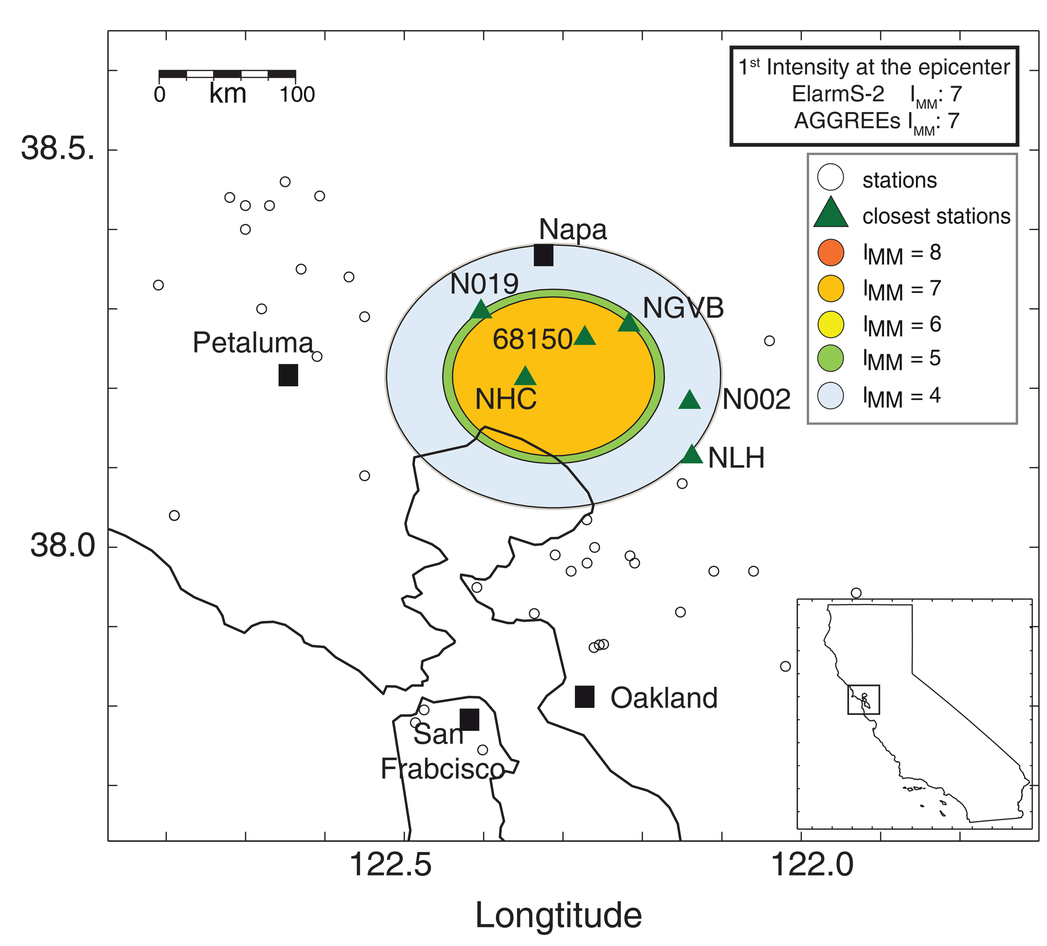



## Application to South Napa Earthquake

We applied AGREEs algorithm to 2014 south Napa earthquake. Mw 6.0 earthquake occurred on August 24 at 3:20 am local time occurred in the city of Napa, California.
This was the largest earthquake since the 1989 Loma Prieta earthquake in greater San Francisco Bay Area. This event was also one the most important evidences in California that EEWS operated as expected.
The first ShakeAlert, the demonstration earthquake early warning system was generated by the ElarmS-2 algorithm 5.1 sec after the origin time of the earthquake based on P-wave triggers from four stations.




We simulated the earthquake offline using 117 stations from available networks in California. This event had dense station coverage around the epicenter. Two stations are within 7 km from the epicenter and another four stations are within 18 km. The earthquake data were processed by simulating real-time data streaming of records through AGREEs.




Above figure shows normalized waveforms for the closest seven stations. Gray shaded areas indicate the ground motion before the P-wave based ElamsS-2 alarm, which is given 5.1 sec after the origin time. At the time of the first alert, AGREEs creates three circles and calculates the intensities in each disk. An epicentral intensity of 7 is computed by AGREEs; intensities of 6 and 5 are determined for the outer circles. In this case both ElarmS-2 and AGREEs produced exactly the same intensity information at the epicenter at the time of the alert. Thus, AGREEs confirmed the (accurate) ElarmS-2 alert.

**Acknowledgements**

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