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# AN ALTERNATIVE AMPLITUDE BASED NATIONAL EARTHQUAKE EARLY WARNING SYSTEM

M.Aktas[(1)], H.S.Kuyuk[(2]

[(1)] *Associate Professor, Sakarya University, muharrema@sakarya.edu.tr*
[(2)] *Associate Professor, Sakarya University, serdarkuyuk@gmail.com*
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## *Abstract*
National earthquake early warning systems (EEWS) are one of powerful strategies to mitigate effect of earthquake disaster in the society. However, they are not developed particularly for the engineering applications. Many engineering based companies use hybrid systems that utilize both national EEWS and their own onsite warning. This is mainly because, they are skeptical on the use of P-wave based correlation equations and the false rate along with national EEWS. In this study, I introduce an amplitude and network based earthquake early warning and alarm system (GETAlarm) that is developed for the Disaster and Emergency Management Presidency of Turkey (AFAD). In order to forecast intensity of a location of interest, GETAlarm does not calculate magnitude of the earthquake but rather estimate the intensity in the epicenter and uses direct intensity attenuation relationship. Algorithm uses available direct amplitude measurements at the stations disinterestedly whether amplitudes are from P- or S- waves. This make GETAlarm a robust fail-safe algorithm for engineering applications. GETAlarm is a standalone alternative EEW methodology that also could be integrated into current EEWS to support and confirm alerts. Because it is based on observations of actual shaking, it cannot generate a false event. It is currently being tested in Hatay prefecture, Turkey within a small seismic network. I introduced GETAlarm concept and its application to high-speed rail lines (YHT) of Turkish State Railways. I showed its simulated performance for a few earthquakes in Turkey.

*Keywords: Earthquake Early Warning System, amplitude and network based earthquake early warning, intensity*

## 1. Introduction

Earthquake related casualties and injuries are not just due to collision of structural members but also due to secondary disasters such as furniture dropping, gas leakage, fire etc. Moreover, dangers such as overturning of high speed trains in service, risking patients in surgery, creating economic losses in delicate industry production lines and posing danger to lift off planes can be listed as some other secondary effects of earthquakes [1-4].

Arrival of strong ground vibrations can be reported before 60 seconds in countries like Japan, USA, Italy, Taiwan, Romania and Mexico where intensive research are conducted on EEWS [4-10]. A classical EEWS consists of three components; high-sensitive accelerometers, seismic stations with GPS antenna and data collecting system, center where data are evaluated (Figure 1).

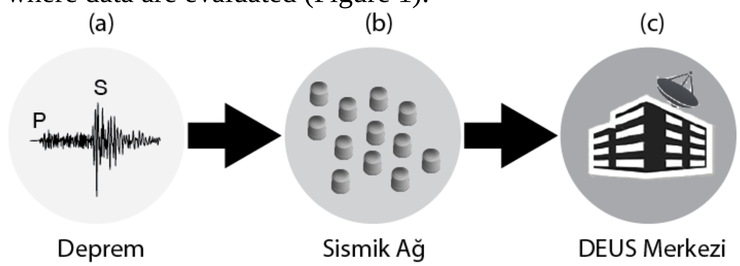



Fig. 1 – Components of classical EEWS, a) Earthquake source, b) network of seismic stations, c) EEWS center

In the existing EEWS like, Earthquake Alarm Systems (ElarmS), Virtual Seismolgist (VS), Onsite, PRobabilistic and Evolutionary early warning SysTem (PRESTo), 2 or 3 seconds of P-wave acceleration data are required to determine the earthquake magnitude and location [9, 11, 12, 13, 14]. Since seismic stations in existing networks are 18 km apart in average earthquake magnitude and location can be calculated after 8 seconds of earthquake [6,15, 16, 17]. This creates a blind zone, an area where S wave and/or strong shaking has already reached, within 20 km diameter around the epicenter. Because the P and S waves will not be separated from each other, clasical algorithms that depends on the velocity difference of P and S waves will not work on networks where seismic stations are located very densely on or around the active fault lines [18]. Vertical accelerations of four different earthquakes are recorded by stations very close to epicenter (~6km) and by stations close to epicenter (~23km) are given in Fig. 2.

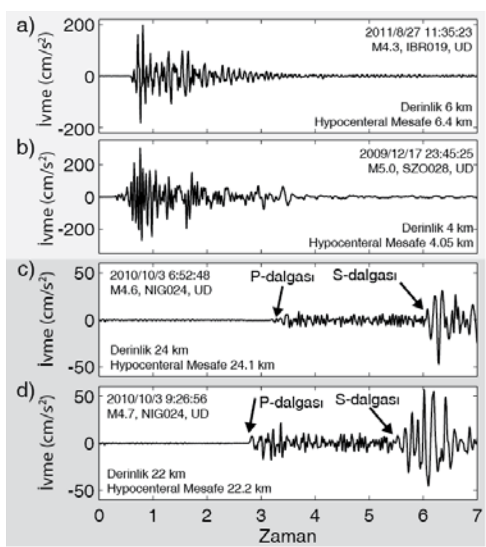



Fig. 2 – Acceleration records from different earthquakes, a) Record from a station which is 6.4 km away from the epicenter of earthquake with M4.3, b) Record from a station which is 4 km away from the epicenter of

earthquake with M5.0, c) Record from a station which is 24.1 km away from the epicenter of earthquake with M4.6, d) Record from a station which is 22.2 km away from the epicenter of earthquake with M4.7

These records prove the existence of blind zone around the epicenter. To overcome this problem amplitude base algorithm in which P wave records are not essential is required [3, 19, 20]. Today there is an amplitude based applications in use. However, they are not network based. EEWS used by Miyagi-Oki electric company in Sendai-Japan and by Bay-Area Rapid Transportation in San Francisco-USA can be given as an example for such approach [21, 22].

In this study EEWS which does not use the approach of P-wave detection is developed. Amplitude and network based algorithm, GETAlarm, which can work on real time is coded in Matlab environment. GETAlarm primarily determines the instrumental earthquake intensity in each location of stations in existing networks considering the level of strong motion amplitude recorded. Magnitude at epicenter is calculated by attenuation relationships.

Table 1 – Treshold levels at stations. Stations are flagged by exceedance of predefined thresholds. Modified from [23].

| 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) | <0.17 | .17-1.4 | 1.4-3.9 | 3.9-9.2 | 9.2-18 | 18-34 | 34-65 | 65-124 | >124 |
| Peak Acc. ($cm/s^2$) | <2 | 2-14 | 14-38 | 38-90 | 90-177 | 177-334 | 334-638 | 638-1216 | 1216 |
| Instrumental Intensity | I | II-III | IV | V | VI | VII | VIII | IX | X+ |
| Attributed Colors | | | | | | | | | |

## 2. Method

GETAlarm is planned to be modular since it will be much more easy to implement any improvement to the algorithm. It is made up from two main modules.

### 2.1 Module 1: Signal processing module

In this module, three axial acceleration records from each station is converted into data package of one second. These data primarily is used to understand whether the station is working or not. Thus, stations which are alive can be observed. The biggest absolute value from 3 component of acceleration record (x,y and z) is selected as one amplitude value from that specific station. Also, ambient noise is filtered at this stage. This module can run independently in different servers from GETAlarm center. Signal records from different networks can be transferred from signal processing module to evaluation module.

### 2.2 Module 2: Evaluation module

The purpose of this module is to calculate instrumental intensity and create the intensity distribution maps using raw data from signal processing module. Direct integration is used to determine the ground velocity. Amplitude value from each station is compared with the predefined thresholds given in Table 1. Stations are then colored in the map by exceedance of these predefined thresholds. Also this module determines the epicenter by using grid search algorithm once it detects P-wave from a station followed by detecting P-wave information from the closest two more station. Ground parameters of earthquake epicenter are addressed with the average peek ground parameters of these three stations. After the first warning location information is updated with the upcoming new P-wave information. This module then forecast the earthquake ground acceleration distribution by using earthquake attenuation relationships. Thus information about earthquake epicenter and arrival time of strong ground motion can be send to the user far from epicenter.

Intensity distribution of earthquake whose epicenter intensity is known can be calculated directly with the relations given in the literature. In this study attenuation relationship of Pasolini [23] is used. Intensity of earthquake within a distance from the epicenter (R) is given as;

$$I = I_e - (0.0086 \pm 0.0005)(D - h) - (1.037 \pm 0.027)[\ln(D) - \ln(h)] \tag{1}$$

Here, $D = \sqrt{R^2 - h^2}$, $h = (3.91 \pm 0.27)$ and $I_e$ is the expected average intensity at the epicenter. It can be calculated by using either moment magnitude (Mw) or epicenter intensity $(I_o)$ as follow;

$$I_e = -(5.862 \pm 0.301) + (2.460 \pm 0.055)M_w \tag{2}$$

$$I_e = -(0.893 \pm 0.254) + (1.118 \pm 0.033)I_o \tag{3}$$

Distrubition relation by using atenuation equations is given in Fig.3 by using different epicenter intensity values.

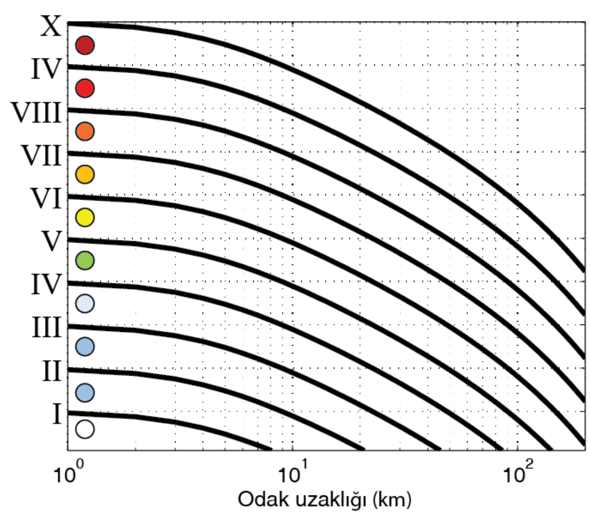



Fig. 3 – Decrease in the intensity value of earthquake can be seen as the distance to the epicenter is increased for each different epicenter intensity value.

## 3. Testing GETAlarm

GETAlarm is tested with Mw 7.1 Kumamoto earthquake. Its origin time was 2016/04/16, 01/25/05 (JST) and its magnitude was recorded as M 6.7 according to High Sensitivity Seismograph Network Japan (Hi-net). Epicenter of the earthquake was determined as 32.75 latitude and 130.76 longtitude with 13.1 km depth. According to Hi-net solution the followings are calculated; Strike 8.5/275.5, Dip 67.3/82.7 Rake-172.1/-22.9. Seismisity of Kumamoto region is given in Fig. 4.

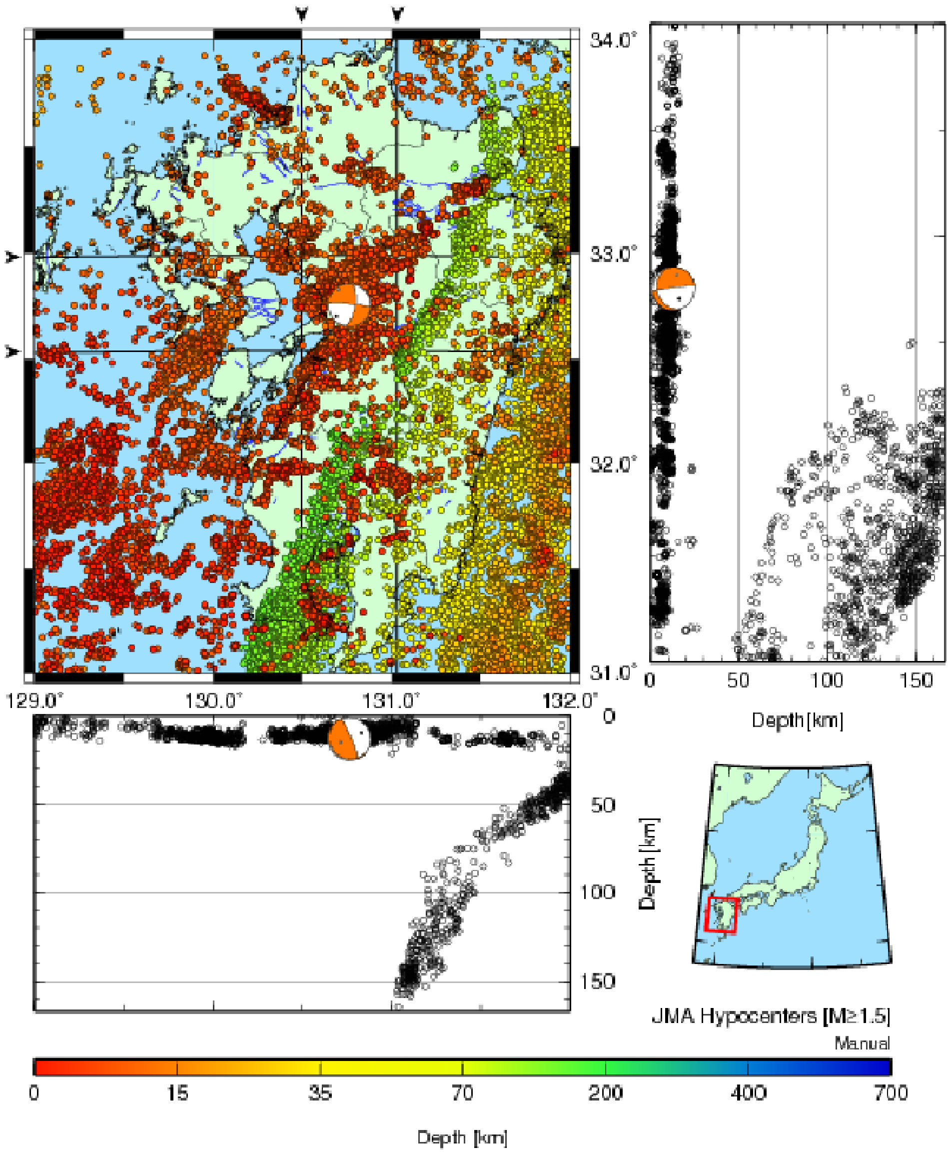
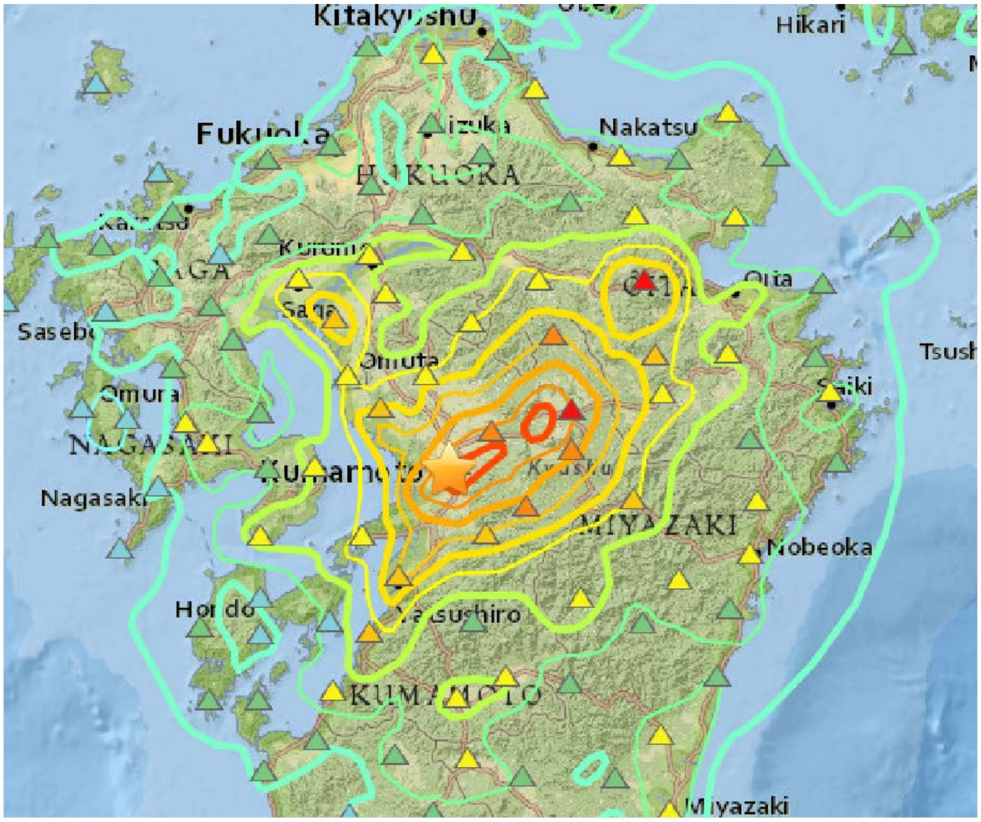



Fig. 4 –Seismicity of Kumamoto Region and hypocenter solution of 7.1 Kumamoto earthquake, (adopted from Hi-net) [25]

The shakemap of Kumamoto Earthquake is reported by USGS as Fig 5. Maximum intensity was recorded IX at the epicenter. The minimum intensity value of IV is felt through the Kyushu island. 698 stations of Kik-net and K-NET in Japan recorded the earthquake. According to Japanese intensity of 6.5 is recorded at Mashiki station which is 7 km from epicenter. Peak acceleration was 1362.1 cm/s2. Foreshock and mainshock killed more than 49 people and injured about 3000. Severe damage occurred in Kumamoto and Ōita Prefectures, with many structures collapsing and catching fire.




| PERCEIVED SHAKING | Not felt | Weak | Light | Moderate | Strong | Very strong | Severe | Violent | Extreme |
|---|---|---|---|---|---|---|---|---|---|
| POTENTIAL DAMAGE | none | none | none | Very light | Light | Moderate | Mod./Heavy | Heavy | Very Heavy |
| PEAK ACC.(%g) | <0.05 | 0.3 | 2.8 | 6.2 | 12 | 22 | 40 | 75 | >139 |
| PEAK VEL.(cm/s) | <0.02 | 0.1 | 1.4 | 4.7 | 9.6 | 20 | 41 | 86 | >178 |
| INSTRUMENTAL INTENSITY | I | II III | IV | V | VI | VII | VIII | IX | X+ |

Scale based upon Worden et al. (2012)

Fig. 5 –Shakemap of Kumamoto earthquake (adopted from USGS) [26]

GETAlarm is tested with 104 stations records obtained from Kik-net and K-NET network. Seven closest stations are plotted in Fig. 6. These stations are at different distance from epicenter ranging from 5 km to 22 km. Hi-net solutions indicated that origin time of the earthquake was on 1:25:05 JST. However, JMA EEWS reported the origin time as 1:25:10.1 seconds with almost error of 5 seconds. And it gave its first warning after 9 seconds of origin time as M5.9. After 6$^{th}$ warning (15 seconds of origin time) it updated its warning as M6.8. On the other hand, GETAlarm gave its first warning just four seconds after origin time with intensity level of IV. After one second it updated intensity as V and followed by 6 after one more second. 9 seconds after origin time GETAlarm sent its warning with an intensity value of VIII. GETAlarm gave its final warning when the JMA EEWS gave its first warning.

The verification of GETAlarm is also discussed with the results obtained from 104 observations. Two tables are created for such effort. In Table 2 GETAlarm results are compared with instrumental intensities. In Table 3 instrumental intensities are compared with those obtained by magnitude of JMA EEWS. First, peak ground accelerations are calculated using JMA EEWS's magnitude and epicenteral distance with attenuation relationship [27]. Then, PGA's are converted to intensities by using thresholds table.

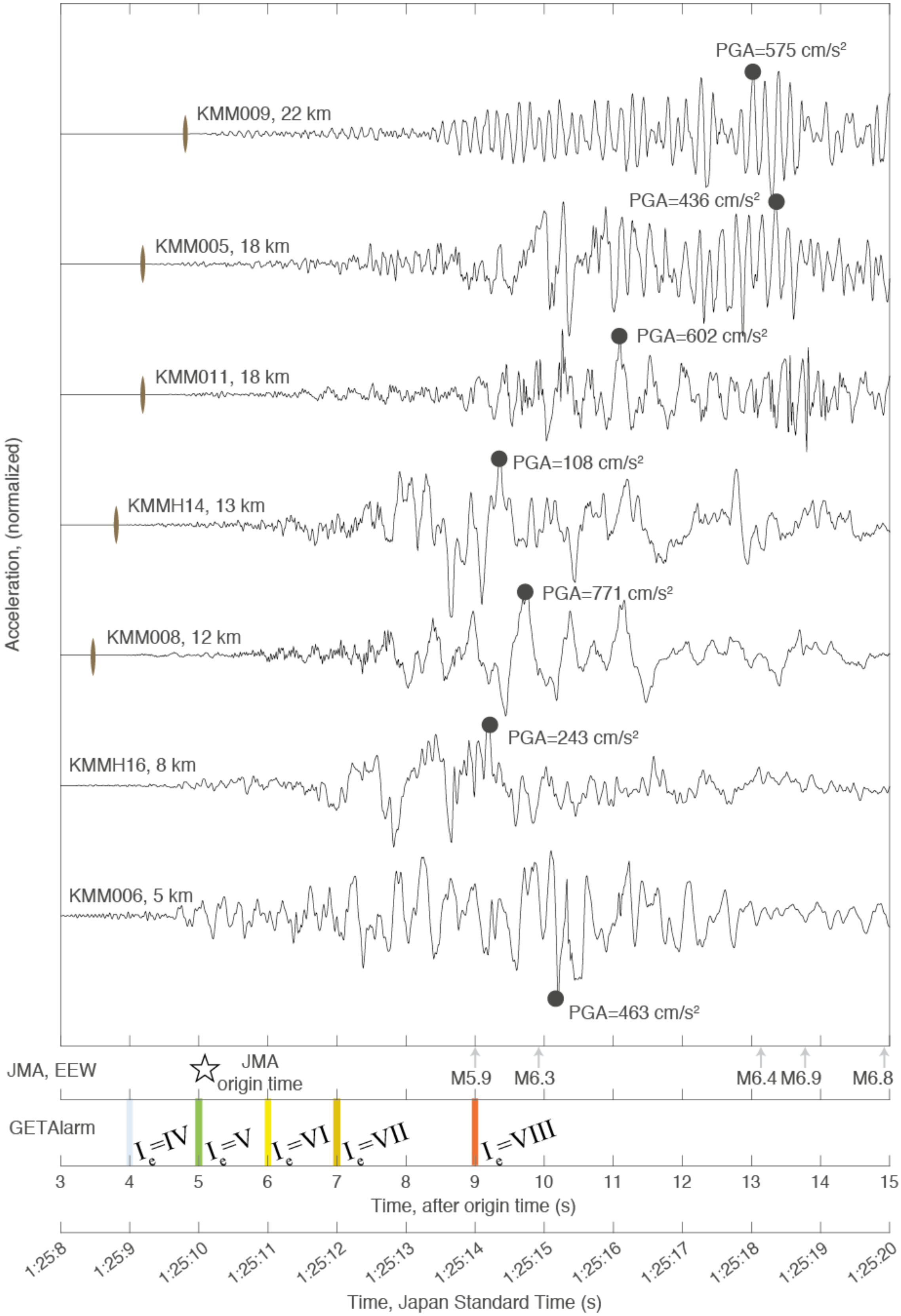



Fig. 6 –Test of GETAlarm

On both Table 2 and 3, the diagonal of the matrix shows the perfect match with instrumental intensity. Most of the time, ± one intensity difference between instrumental intensities and forecasted intensities are acceptable in EEWS. This is shown with gray shaded band in a matrix. Number of stations out of this band are assumed to be reporting either over- or under estimates. GETAlarm over-estimated the intensity at 10 stations and under-estimated 5 stations. JMA EEWS did not over estimate at any stations but it under-estimated at 18 stations.

Table 2 – Comparison of instrumental intensity and GETAlarm results

| | | Instrumental Intensity | | | | | |
|---|---|---|---|---|---|---|---|
| | | 3 | 4 | 5 | 6 | 7 | 8 |
| GETAlarm | 2 | - | - | - | - | - | - |
| | 3 | - | - | - | - | - | - |
| | 4 | 19 | 21 | 15 | 1 | - | 1 |
| | 5 | 6 | 11 | 9 | 5 | 2 | - |
| | 6 | - | 3 | 2 | 2 | 2 | 1 |
| | 7 | - | - | 1 | 1 | 0 | 1 |
| | 8 | - | - | - | - | 1 | - |

Table 3 – Comparison of instrumental intensity and magnitude based intensity

| | | Instrumental Intensity | | | | | |
|---|---|---|---|---|---|---|---|
| | | 3 | 4 | 5 | 6 | 7 | 8 |
| Magnitude Based | 2 | - | - | - | - | - | - |
| | 3 | 7 | 7 | 7 | - | - | - |
| | 4 | 18 | 25 | 17 | 6 | 1 | 1 |
| | 5 | - | 3 | 2 | 2 | 1 | 1 |
| | 6 | - | | 1 | - | 2 | 1 |
| | 7 | - | - | | 1 | 1 | - |
| | 8 | - | - | - | - | - | - |

## 4. Conclusion

A new algorithm, GETAlarm, which uses amplitude and network based earthquake early warning and alarm system rather than using information about P-wave like in classical EEWS is discussed in this study. Results revealed that the proposed algorithm is robust to forecast the earthquakes like existing classical EEWS. Even its mistakes are in the safe side since in those mistakes the algorithm overestimates the intensity of the real earthquake. This approach is useful for engineering application. Industrial buildings, public services can use their own onsite warning for their individual need.

## 5. Acknowledgements

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