Determination of Earthquake Early Warning Parameters for the New Madrid Seismic Zone

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ABSTRACT

Increasing vulnerability of metropolitan areas within stable continental regions (SCR), such as Memphis, TN and St. Louis, MO near the New Madrid Seismic Zone (NMSZ), to earthquakes and the very low probability level at which short term earthquake forecasting is possible make an earthquake early warning system (EEWS) a viable alternative for effective real-time risk reduction in these cities. In this study, we explore practical approaches to earthquake early warning (EEWS), and test the adaptability and potential of the real-time monitoring system in the NMSZ. We determine empirical relations based on amplitude and frequency magnitude proxies from the initial four seconds of the P-waveform records available from the Cooperative New Madrid Seismic Network (CNMSN) database for magnitude *M*>2.5. The amplitude-based proxies include low pass filtered peak displacement (P_d), peak velocity (P_v), and integral of the velocity squared (IV2), whereas the frequency-based proxies include predominant period (τ_p), characteristic period (τ_c), and log average period (τ_{log}). Very few studies have considered areas with lower magnitude events. With an active EEW system in the NMSZ, damage resulting from the catastrophic event, as witnessed in 1811-1812, may be mitigated in real-time.

STUDY AREA

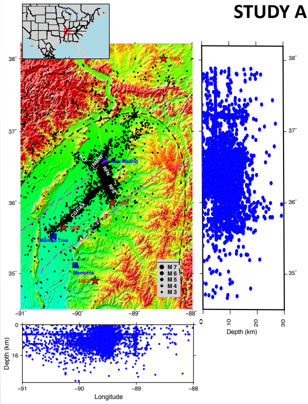


Figure 1: Historical and recent NMSZ seismicity as illustrated by historical earthquakes (1568-1973) and modern seismicity (1974-2017) with moment magnitudes from 2.5 to 6.0 from the CERI catalog and USGS-NSHMP catalogues. The Seismicity delineates several faults i.e., RF (Reelfoot), CGF (Cotton Groove Fault), NMNF (New Madrid North Fault), and Risco Fault. The cross sections show the latitude-longitude-Depth plots. Red stars show the historic earthquakes between M5.0 and M<6.0 since the 1811-1812 earthquake events and on top left corner is an inset of North America showing location of NMSZ marked with box. The squares show some of the cities within NMSZ.

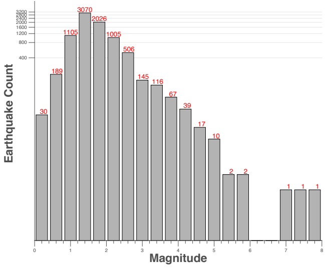


Figure 2: A histogram of number of earthquakes versus magnitude taken from the declustered NMSZ catalog from 1568 - 2017 illustrating the lack of major earthquakes >M 5.0 within NMSZ since the 1811 - 1812 major events. Note that 1843 and 1895 M6s are removed from the catalog because they are considered aftershocks along with the Dec. 1811 dawn aftershock.

GOAL

- ☐ This research focuses on determining different rapid amplitude and frequency magnitude proxies estimation parameters
- ☐ To check the suitability and adaptability of these magnitude proxies to the NMSZ context and
- ☐ Establish empirical relationships useful for this region that can be used in the EEW system.
- ☐ We attempt to answer the following key question; can we estimate accurately the magnitudes from earthquakes in NMSZ from the first arrival P-wave using both amplitude and frequency magnitude proxies?

INTRODUCTION

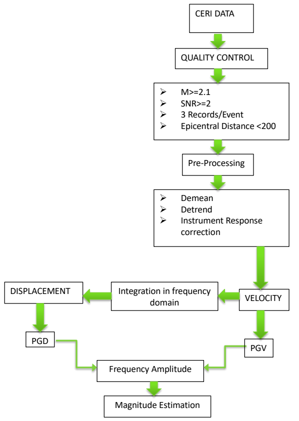
- ☐ Research on EEWSs has undergone a rapid development and is becoming a useful tool that augments risk mitigation efforts both before and after rupture
- ☐ Most EEWSs are designed as either "regional" (network based) or "on-site" (single station) systems. The selection of the configuration of the EEWS essentially depends on the network geometry and on the source-to-site distance.
- ☐ Several studies have established meaningful empirical correlations between earthquake magnitude and different attributes of the early portion of the seismic signal (P-wave) for EEWSs around the world.
- ☐ The NMSZ covers a wide area with several heavily populated cities (Faulkner *et al.*, 2011), vital infrastructure, and facilities located within a radius of less than 70 km from the 1811-1812 earthquakes. A modern-day earthquake has the potential to inflict considerable physical damage and casualties in the eight-state CUSEC region.
- ☐ Preliminary estimates by the Mid-America Earthquake Center (Elnashai, *et al*. 2008; Mid America Earthquake Center MAE, 2009), found that economic losses from a **M**7.7 event in the NMSZ could reach $50-$80 billion dollars in direct losses alone.
- ☐ An **M**7.7 event on the southwest arm of the NMSZ would cause $200 million in damage to Memphis, and $50 to $70 billion in overall damage to the affected region (Elnashai, *et al*. 2008).

Table 1: Some of the Magnitude Proxies found in Literature

#	Attribute	Numerical Formula	Description	Type of information	Reference
1	Peak displacement (P_d)	$P_d = \max[\mathrm{abs}(\int_{t_0}^{t_0+\Delta t} V_R\,dt)]$	Peak Displacement of the first seconds of the P wave	Amplitude	Wu & Zhao, (2006); Zollo *et al.*, (2006); Wu, *et al.*, (2007); Odaka *et al.*, (2003)
2	Peak velocity (P_v)	$P_v = \max[\mathrm{abs}(V_R(t))], t_0 \le t_0 + \Delta t$	Peak Velocity of the first seconds of the P wave	Amplitude	Wurman, *et al.*, (2007)
3	Energy integral of the seismogram	$IV2_c = \int_c^{t_c+\Delta t_c} V_c^2(t)\,dt$	Squared velocity integral	Seismic Energy	Festa, *et al.*,, (2008); Aranda *et al.*, 1995)
4	Signal's frequency content (predominant period (τ_p)	$\tau_{p,i} = \max(2\pi\sqrt{\frac{V_i}{A_i}})$; *Where* $V_i = \alpha V_{i-1} + v_i^2$; $A_i = \alpha VA_{i-1} + (dv_i/dt)^2$	Effective period of the P-wave over a fixed time window	Frequency	Nakamura, (1988); Allen & Kanamori, (2003); Rydelek & Horiuchi, (2006); Yamada & Ide, (2008); Wurman, *et al.*, (2007)
5	Characteristic period (τ_c)	$\tau_c = \frac{1}{\sqrt{\langle f^2\rangle}} = \frac{2\pi}{\sqrt{r}} = \sqrt{\frac{\int_{t_0}^{t_0+\Delta t} u^2 dt}{\int_{t_0}^{t_0+\Delta t} v^2 dt}}$	Predominant period of the first few seconds of the P wave	Frequency	Wu & Kanamori, (2008); Nakamura, (1988); Sokolov, *et al.*, (2009); Wu & Kanamori, (2008), Wu, *et al.*, (2007), Wu & Kanamori, (2005); Zollo, *et al.*, (2010)
6	Probabilistic formulation (Baye's theorem) fM|d (m|d)				Iervolino, *et al.*, (2006); Cua & Heaton, (2007); Lancieri & Zollo, (2008)
7	Seismic Intensity Magnitude (MI)	$M_I = I/2 + \log_{10}(r) + \frac{\pi f T}{2.3Q} + b - \log_{10} C_j$	Magnitude intensity	Intensity/amplitude	(Yamamoto, *et al.*, (2008)
8	Log-transferred P-wave envelop slope (B-delta method) Btexp (−At)	Btexp (−At)		Amplitude	Odaka *et al.*, (2003)
9	Log-average period (τ_{log})	$\log(\tau_{log}) = \frac{\sum_i (P_i^*(w_i)\log(1/w_i))}{\sum_i (P_i^*(w_i))}$		Log-Frequency	Ziv, (2014)
10	Cumulative Average Velocity (CAV)	$CAV = \int_0^{t_{max}} \lvert a(t)\rvert\,dt$		Amplitude	EPRI, 1988
11	Bracketed cumulative velocity BCAV	$BACV = \sum \int_0^{t_i+\Delta t} \lvert a(t)\rvert\,dt$		Amplitude	Alcik, *et al.*, (2009)
12	Windowed Bracketed cumulative velocity (BACV-W)	$BACV - W = \sum_{W=1}^{win\ length} \int_0^{t_i+\Delta t} \lvert a(t)\rvert\,dt$		Amplitude	Alcik, H. *et al.*, 2009
13	RSSCV	$RSSCV = \sqrt{\sum_{i=1}^{n} v_1^2}$	Includes the cumulative effect (amplitude	Amplitude	Bhardwaj *et al.*, 2013

METHODS

We use data from 2000 to 2018 within the NMSZ for this study. The selected events must have at least three records within an epicentral distance of 200 km and focal depths of 4-25km.


CERI DATA

QUALITY CONTROL

- M>=2.1
- SNR>=2
- 3 Records/Event
- Epicentral Distance <200

Pre-Processing

- Demean
- Detrend
- Instrument Response correction

VELOCITY

Integration in frequency domain

DISPLACEMENT

PGD

PGV

Frequency Amplitude

Magnitude Estimation

Figure 3: Flowchart of Methodology

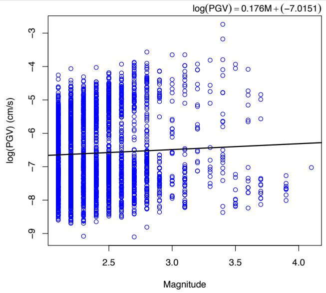


Figure 4: Plots of regression equation (solid line). Circles represents log base 10 **PGV** values at each station.

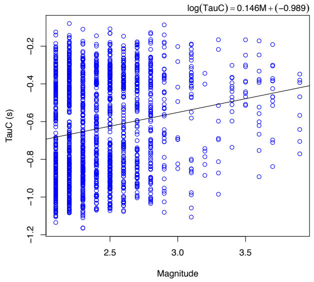


Figure 5: Plots of regression equation (solid line). Circles represents τ_c values at each station.

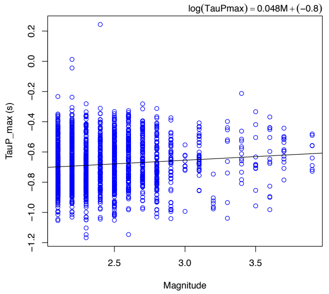


Figure 6: Plots of regression equation (solid line). Circles represents τ_p values at each station

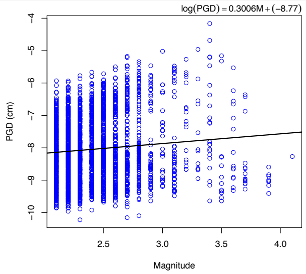


Figure 7: Plots of regression equation (solid line). Circles represents **PGD** values at each station

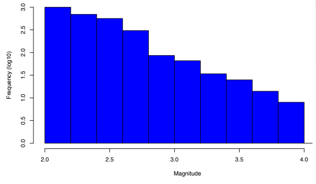


Figure 9: Histogram of Magnitudes used in this study

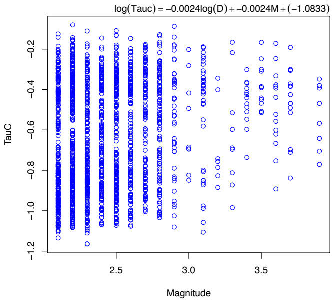


Figure 8: Plots of regression equation (solid line). Circles represents τ_C values at each station

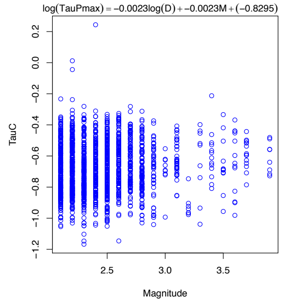


Figure 10: Plots of regression equation (solid line). Circles represents τ_C values at each station

CONCLUSIONS

We have evaluated several magnitude proxies for EEW system in NMSZ. The Multiple regressions are promising compared to single variable regression. Also the amplitude based proxies are far better than the amplitude based proxies. This research is still on-going and the results are not yet definitive.

DATA AND RESOURCES

We used GMT (https://www.soest.hawaii.edu/gmt/), r(http://www.R-project.org/.) and Adobe Illustrator (http://www.adobe.com/products/illustrator.html) to prepare figures. CERI data were used. All data were accessed lastly on May 2018.

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