Application of borehole seismometer in earthquake early warning system

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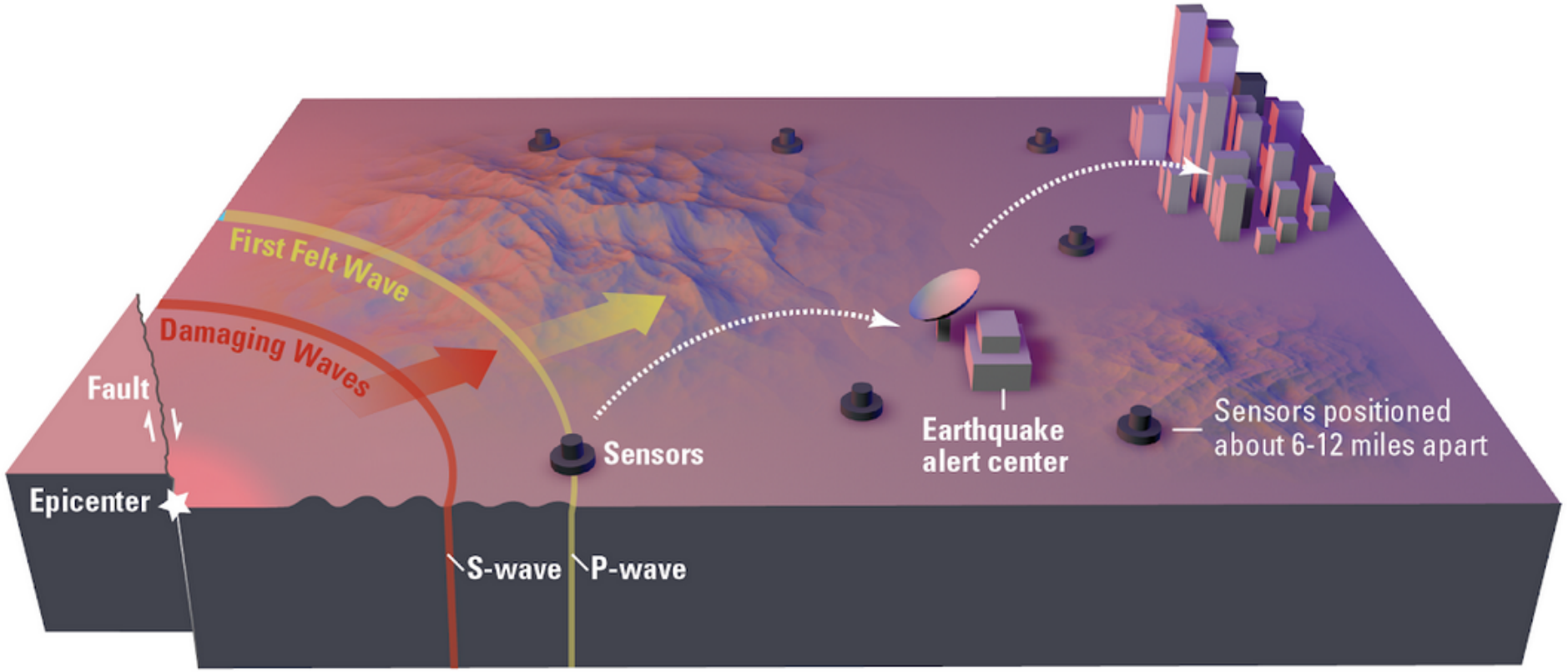
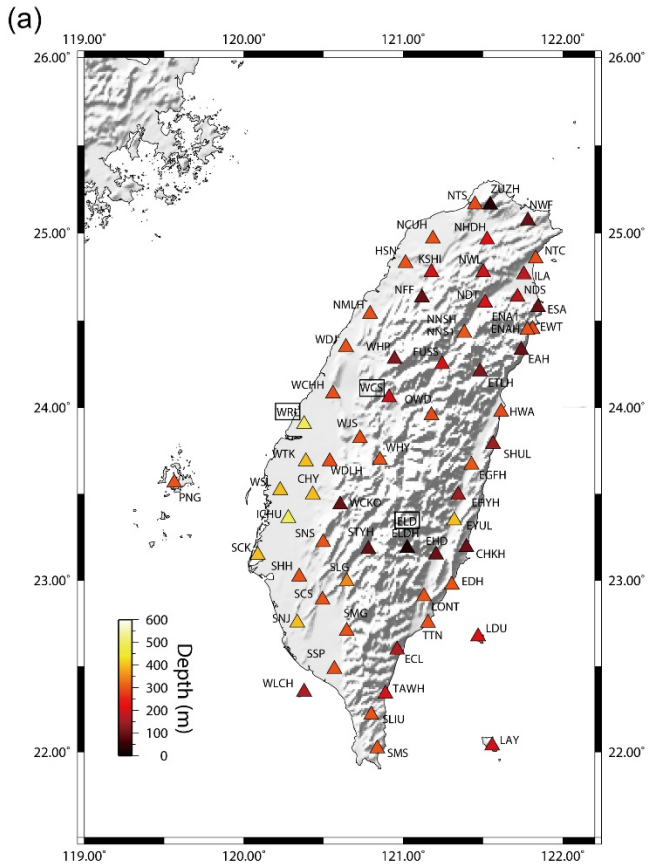
The Earthquake Early Warning (EEW)



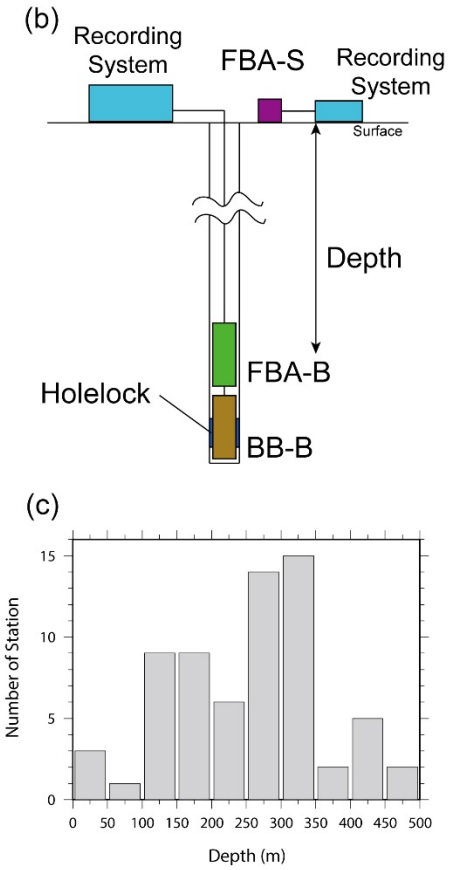
(Caltech ShakeAlert)

Introduction-Borehole Seismometer

- Borehole seismometer is less affected by site effects.
- The seismic data used by the current EEW is come from seismometer on the ground (magnitude estimation).
- Through this study, we can learn that borehole seismometers is helpful to improve the EEW.



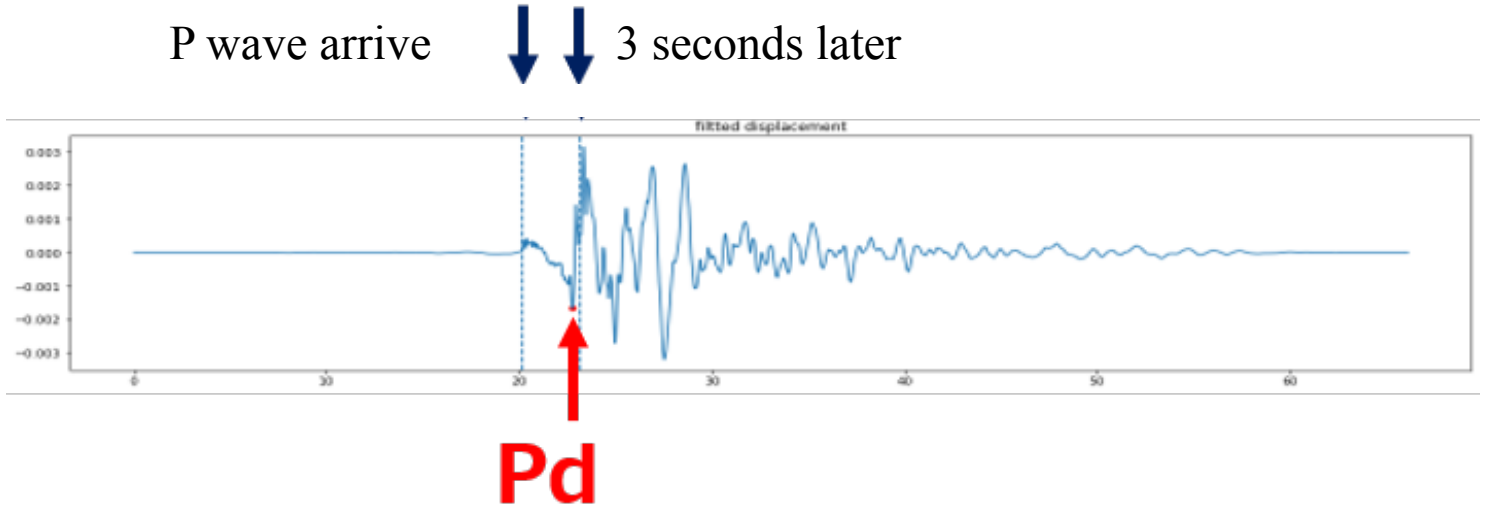
Lin et al. (2021)



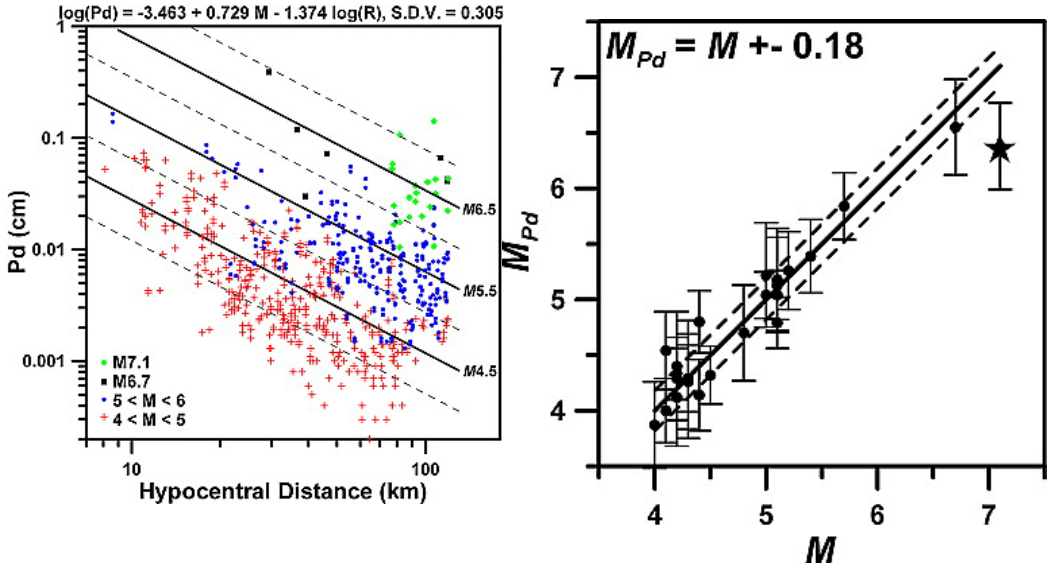
FBA: Force-balance accelerometer
BB: Broadband sensor

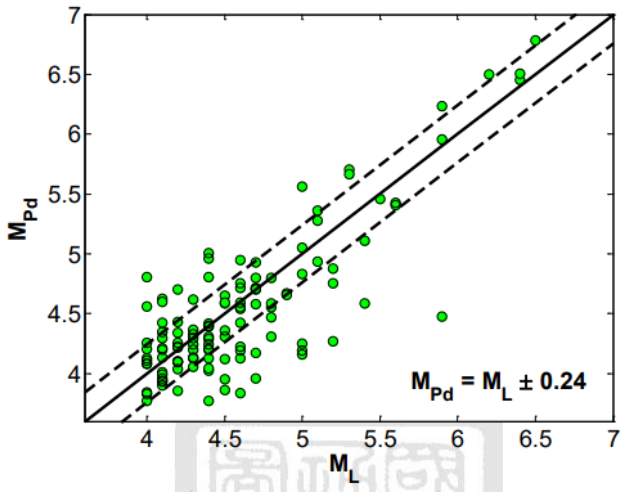
Introduction-Pd

- Pd is the peak amplitude of displacement in the first three seconds after the arrival of the P wave. (Wu and Zhao, 2006)



Introduction-previous study





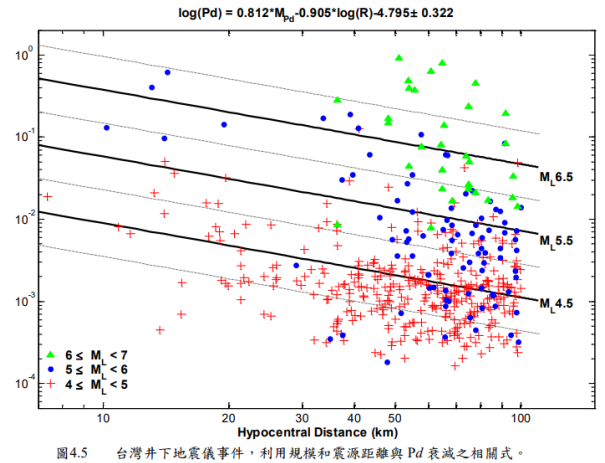
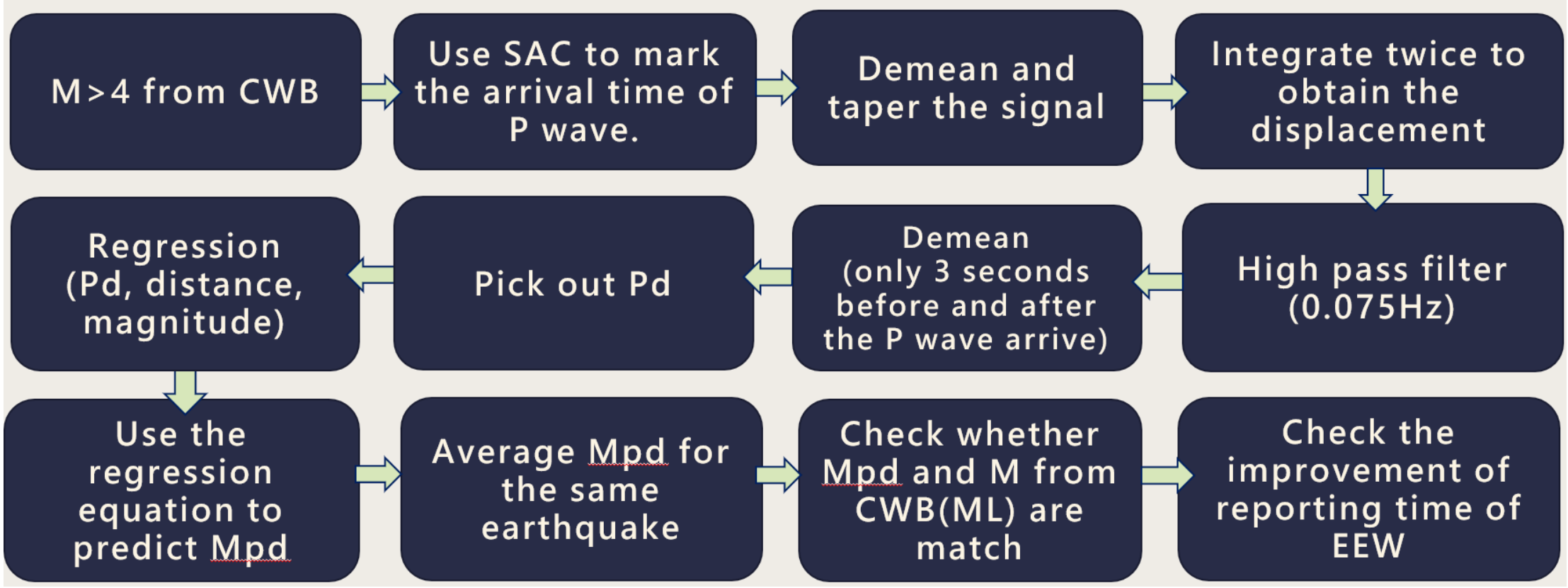


圖4.5 台灣井下地震儀事件，利用規模和震源距離與 Pd 衰減之相關式。

- 25 earthquakes from the SCSN catalog with $M \geq 4.0$, including one $M > 7$ earthquake. (Wu and Zhao, 2006)

2012 to 2014 in Taiwan, $M \geq 4.0$, use borehole seismometer. (Huang, 2015)

Data process flow



Picking P arrival & calculate Pd

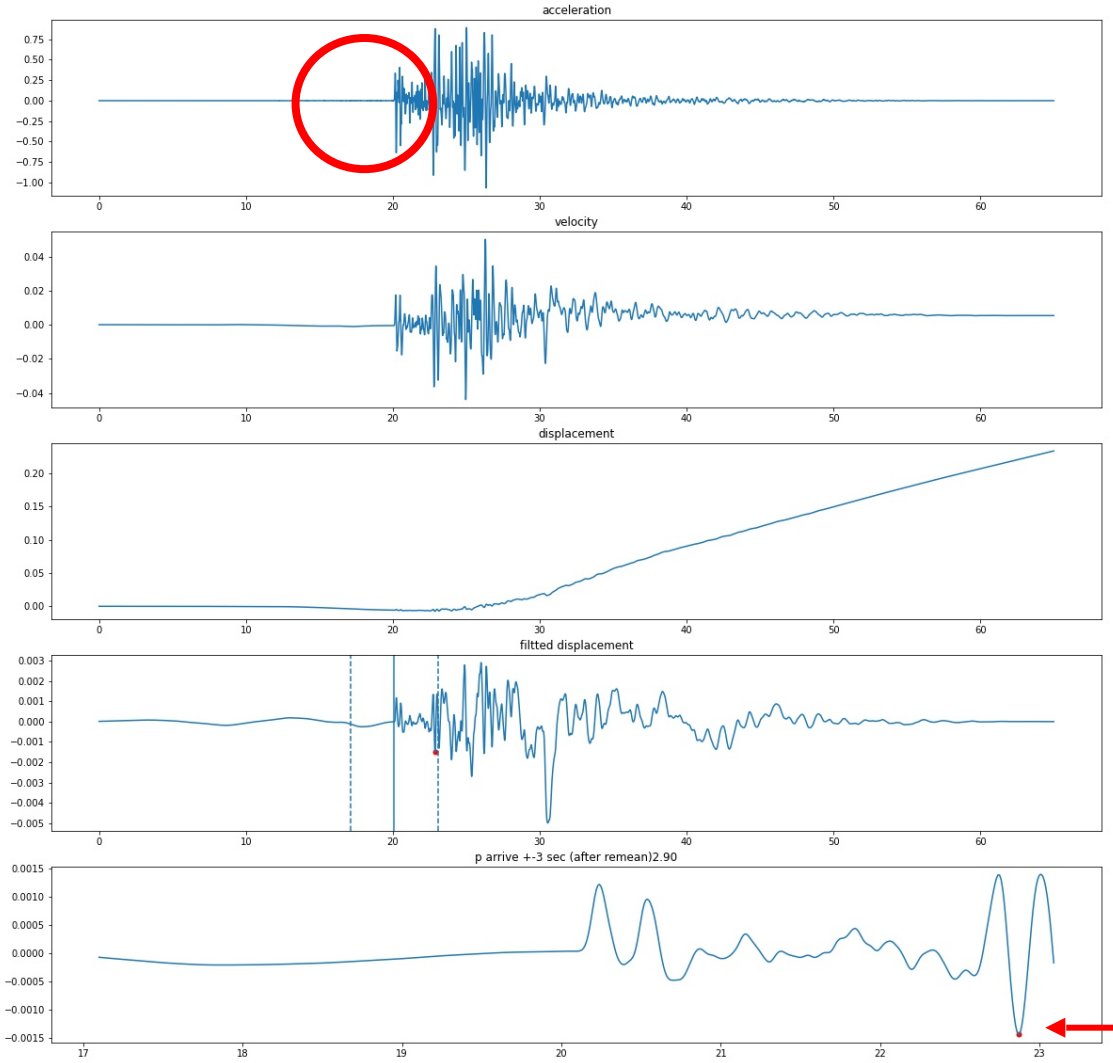
Acceleration wave after demean and taper

Integrated twice

Displacement wave

After 0.075Hz high pass filter

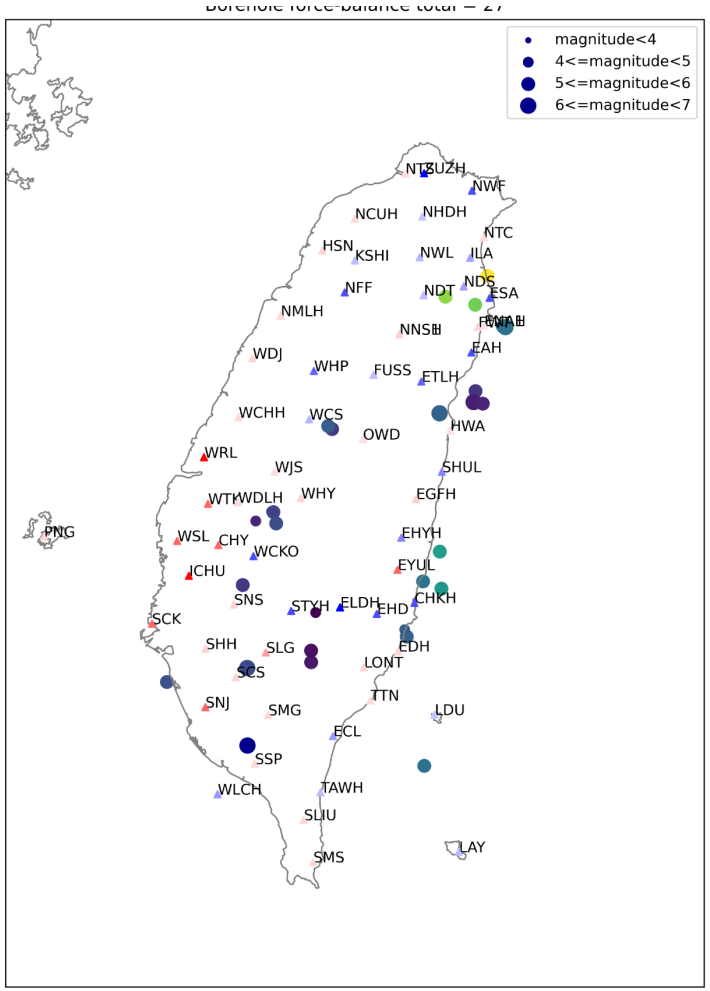
Pick out Pd

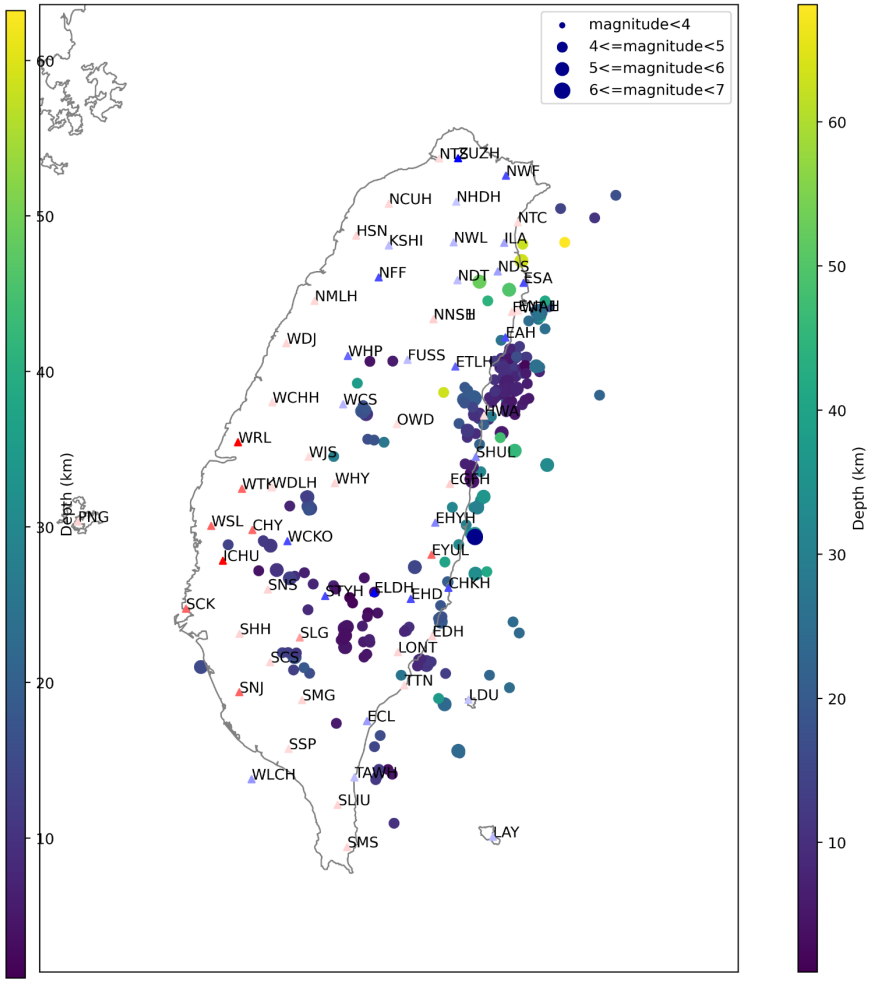


Data pass the threshold

- Earthquake that occurred in 2016 to 2019
- FBA: 27 earthquakes
- FBA: 189 waveforms
- BB: 242 earthquakes
- BB: 1891 waveforms
- Sampling rate: 100 points/s

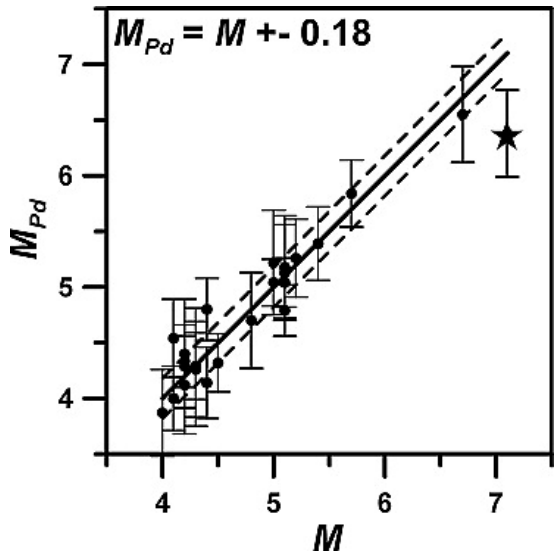
FBA: Force-balance accelerometer
BB: Broadband sensor





Standard deviation definition

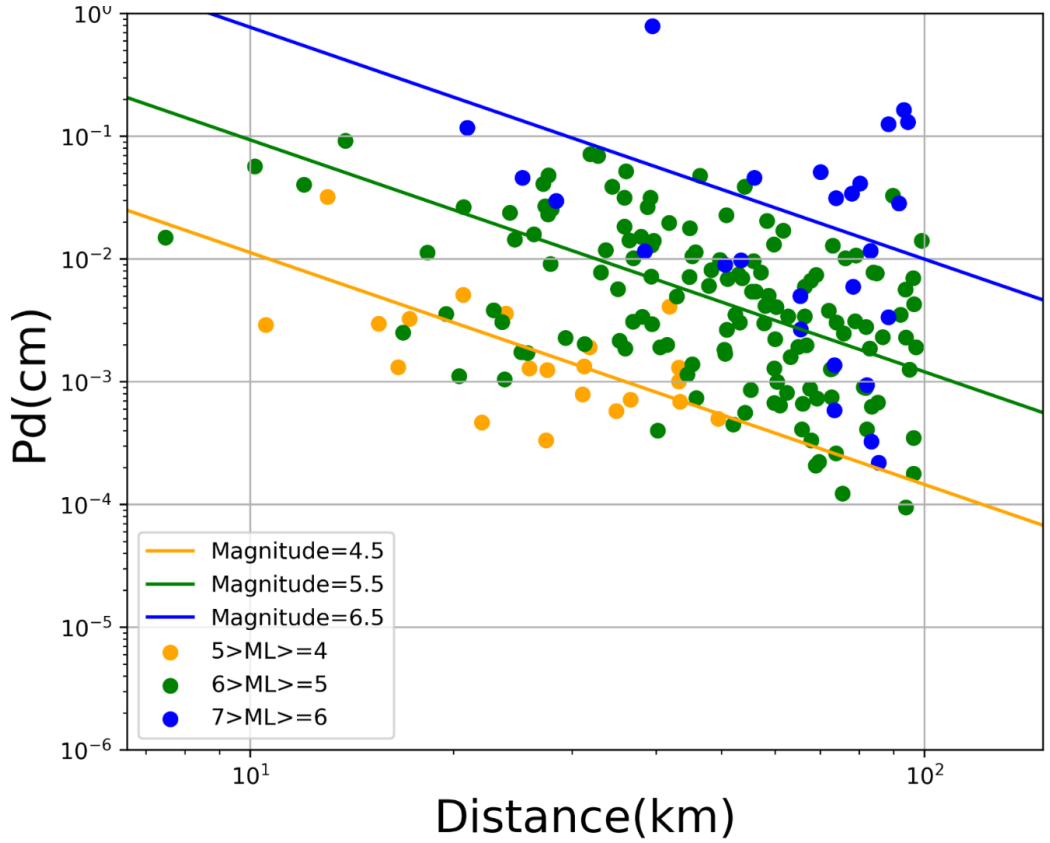
- $$standard\ deviation\ \sigma = \sqrt{\frac{1}{N}\sum_{i=1}^{N} |M_{Pd} - M_L|^2}$$

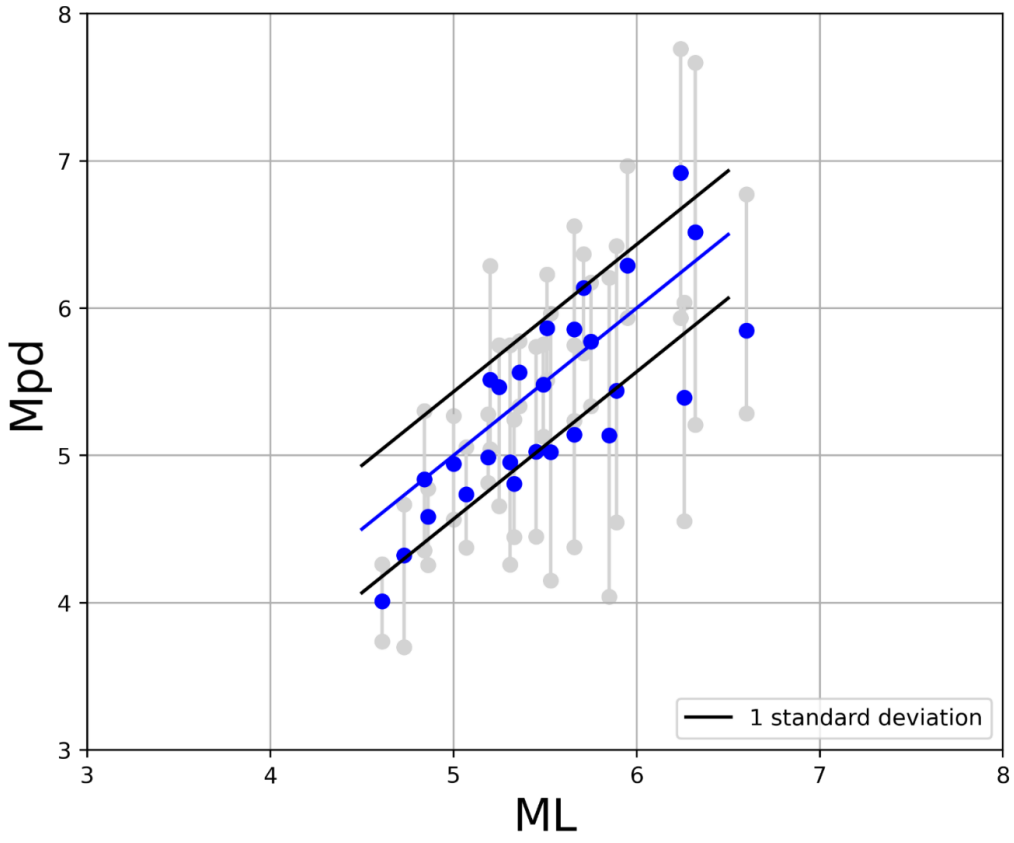


The relations of Pd and M determination (FBA)

$$\log(Pd) = -4.189 + 0.918 \times M - 1.889 \times log(R) \pm 0.613$$

S.D.V = 0.43

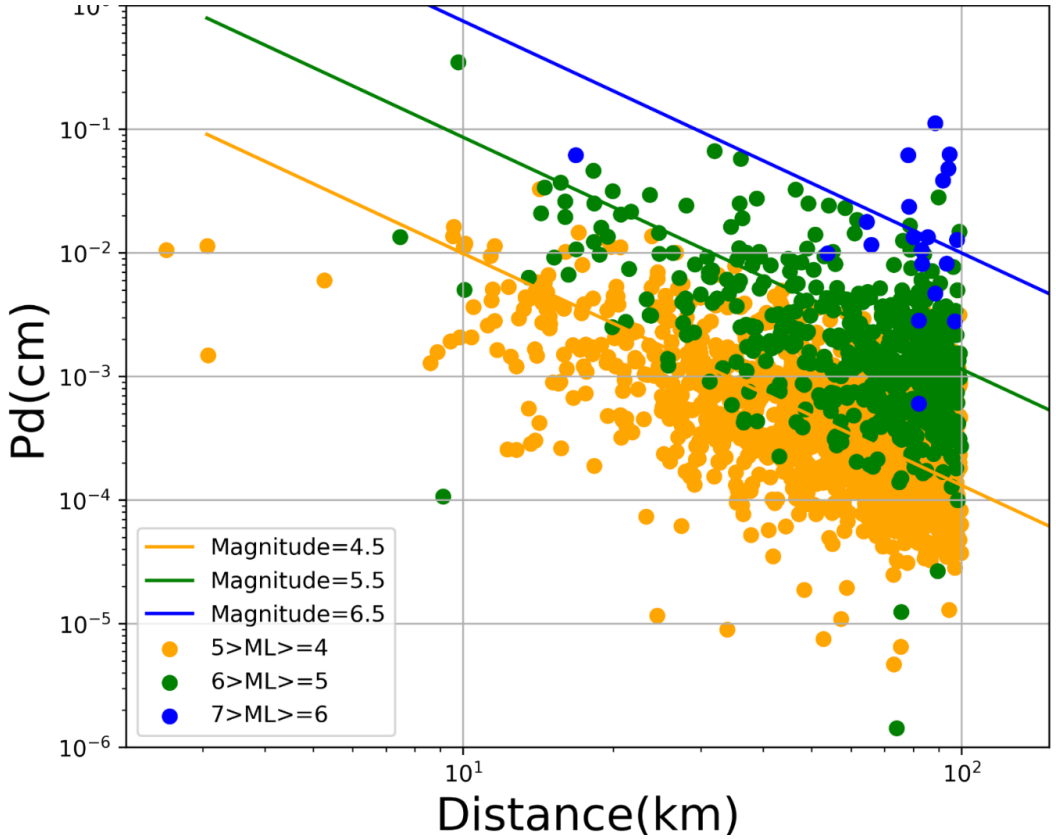


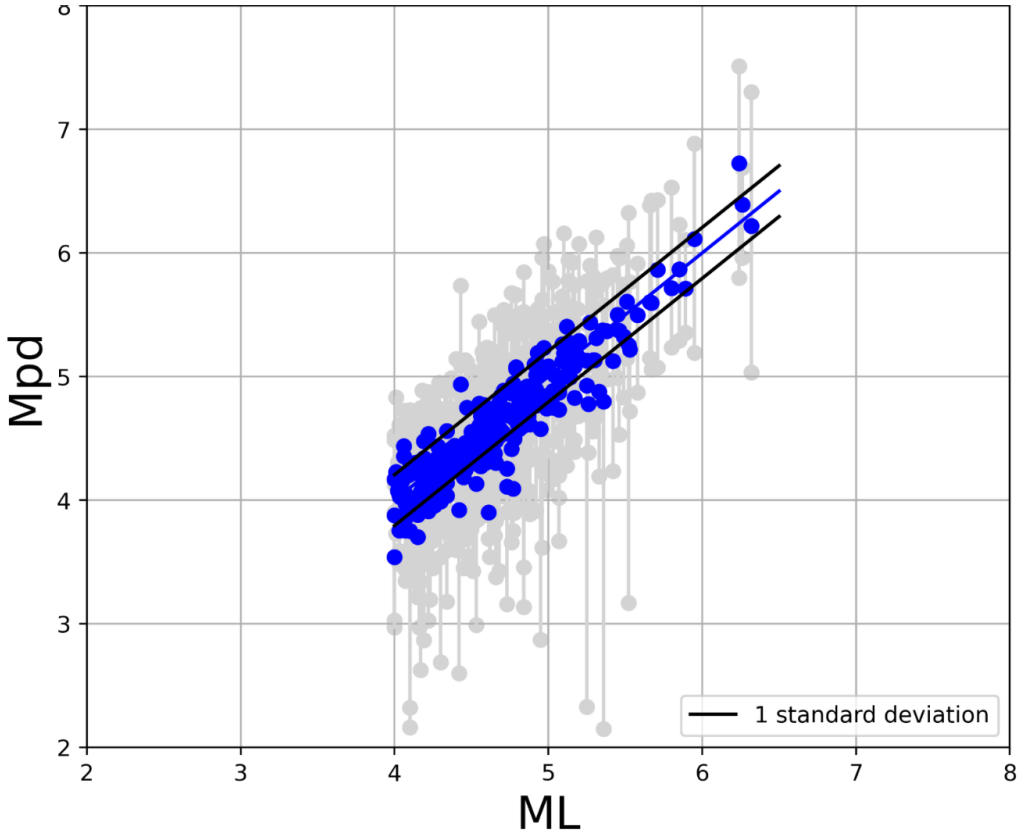


The relations of Pd and M (BB)

$$log(Pd) = -4.359 + 0.940 \times M - 1.876 \times log(R) \pm 0.486$$

S.D.V = 0.21



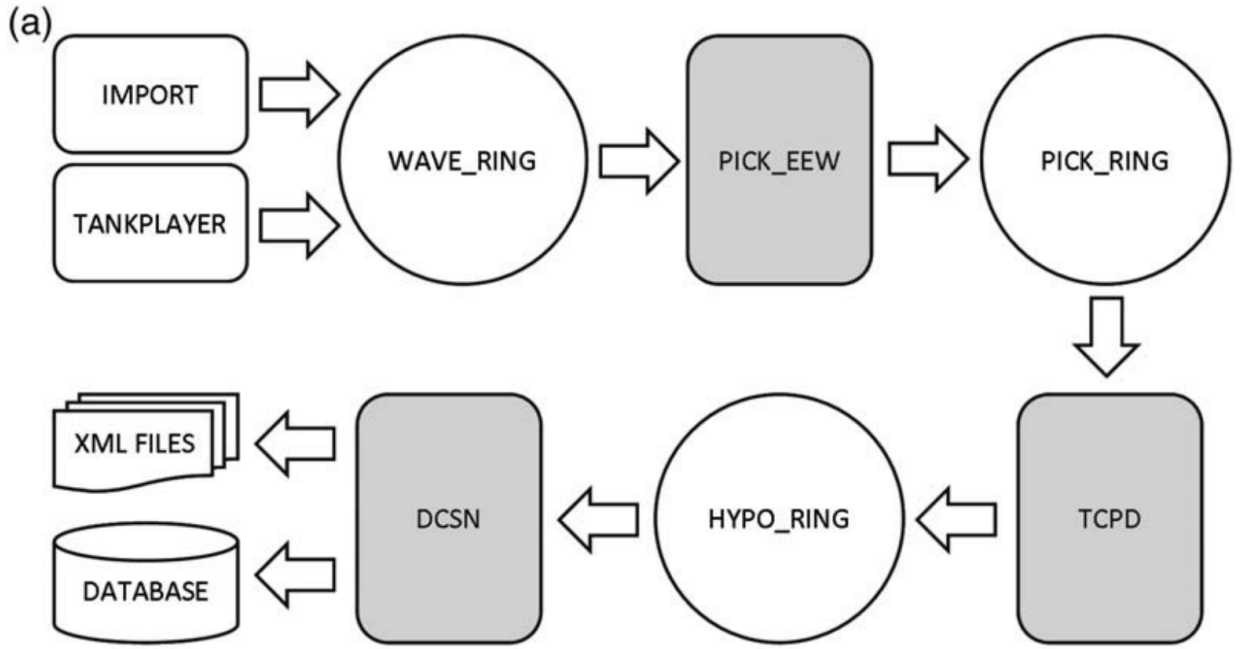


Introduction of CWB's EEW

- Use geometric center method to locate the hypocenter while assume the depth is 10 km.
- Estimate the magnitude based on the empirical formula of Hsiao et al. (2011)

$$log(Pd) = -1.777 + 0.455 \times M - 1.230 \times log(R) \pm 0.362$$

Chen et al., 2015



Application into the CWB EEW system

- August ~ October, 2021
- 13 earthquakes
- The threshold of alert is magnitude > 4.5 and intensity > 3
- We figure out that the magnitude estimation error of new EEW is smaller than the older one (new: 0.66, old: 0.80).
- Moreover, the average reporting time is reduced by 0.2 seconds.
- However, 3 earthquakes can report about 1 second faster than the old system.

date	time	time	m	fbhm	f43m
2021/8/5	05:50	0	6	1.32	1.45
2021/8/5	05:56	1.1	5.3	0.41	1.83
2021/8/6	16:10	0	5.6	0.79	1.38
2021/8/6	19:12	0	5.4	0.52	0.58
2021/9/6	22:00	0	5.9	0.5	0.59
2021/9/13	18:41	0	5.6	0.47	0.61
2021/9/26	06:21	0.91	5.7	0.4	0.56
2021/10/18	13:49	0.03	5.2	0.95	0.13
2021/10/23	11:16	0.01	5.3	1.78	1.78
2021/10/24	13:11	0.93	6.5	0.11	0.16
2021/10/24	13:11	0.02	6.5	0.37	0.6
2021/10/23	18:32	0	4.5	0.46	0.57
2021/10/24	12:38	0	4.5	0.47	0.17
		0.2		0.65	0.80

Conclusions

- Two formulas established in this study can improve on EEW.

$$log(Pd) = -4.189 + 0.918 \times M - 1.889 \times log(R) \pm 0.613 \quad (FBA)$$

$$log(Pd) = -4.359 + 0.940 \times M - 1.876 \times log(R) \pm 0.486 \quad \text{(BB)}$$

- Magnitude estimation is more accurate. (new: 0.66, old: 0.80)
- Reporting time is reduced 0.2 seconds, 3 of them reduced 1 second.

Future work

- Using more earthquakes had been alarmed in the past to test the new EEW system and analyzing the improvement in different regions.

Thanks for listening