Earthquake Early Warning in Taiwan

Taiwan EEW Group

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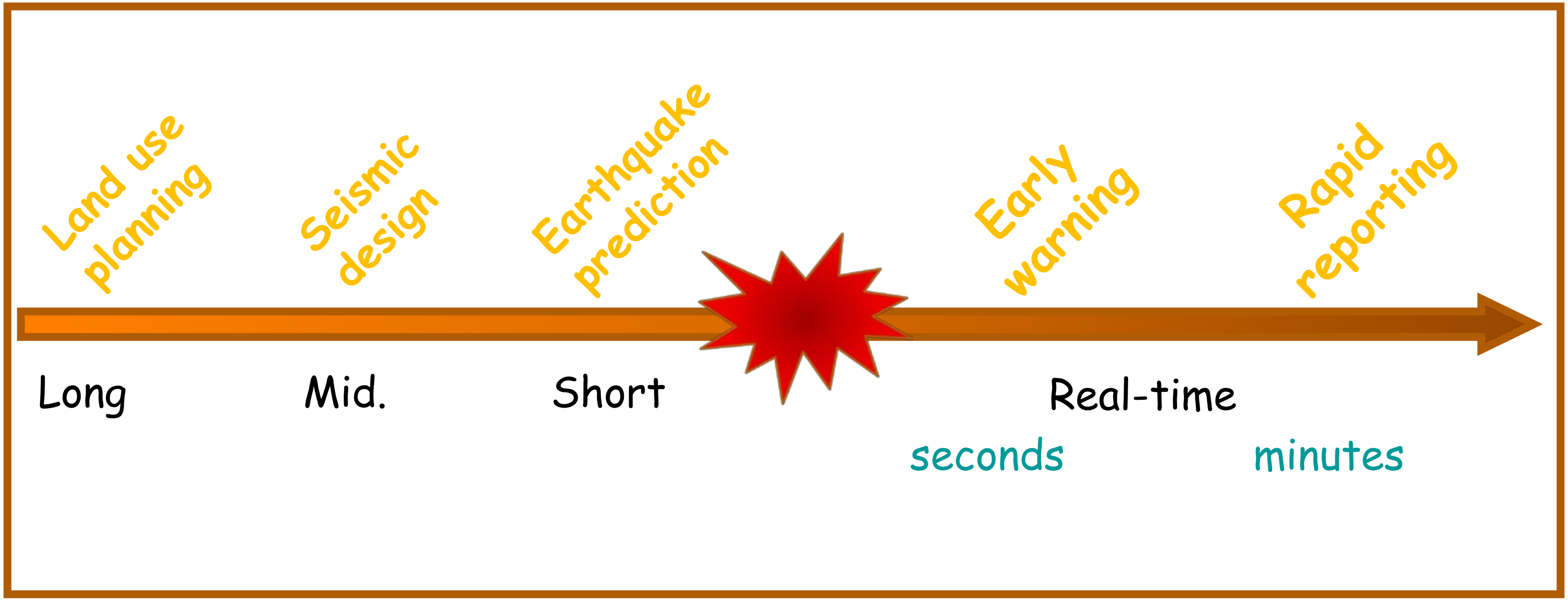
- Sanlien Technology Corp.

- Background of EEW
- Present EEW
- Proposed EEW (time ?)

Earthquake Early Warning and Rapid Reporting

Seismic risk reduction



Background

Physical basis and assumption for EEW

- Strong ground shaking is caused by shear (S) and the following surface waves, which travel at the speed slower than the primary (P) waves.
(Crustal P~ 6.5 km/s S~ 3.5 km/s, 13s per 100 km)

- Seismic waves travel much slower than EM signals transmitted by telephone or radio.
(100 s vs. 400 km / 300,000 km/s = 0.0013 s)

Assumption: The final magnitude of an earthquake is partially controlled by the initiation process within the first seconds of rupturing.

Background

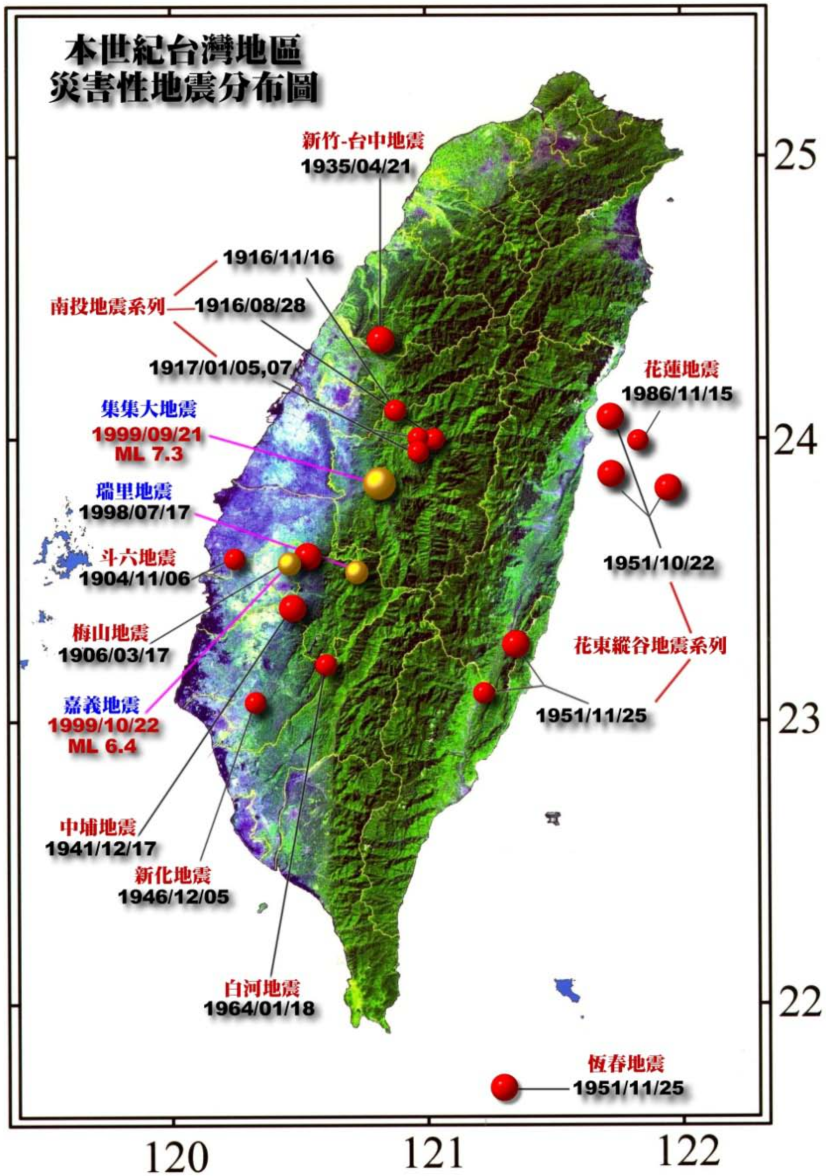
Earthquake early warning (EEW)

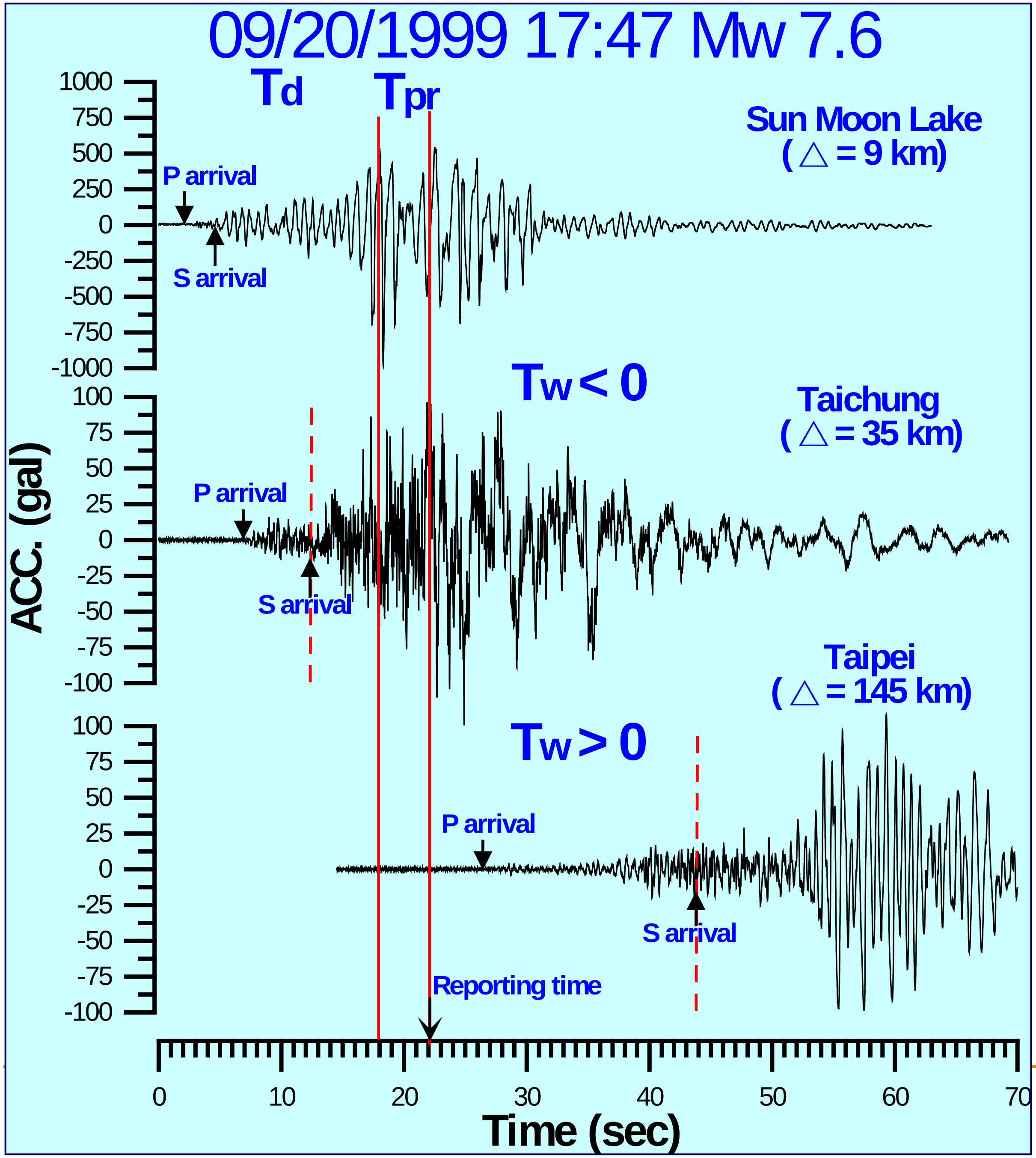
- Warning ahead of the arrival of strong ground shaking
- Rapid estimate of earthquake parameters
- Initiate emergency responses

EEW is a practical, effective approach to seismic risk mitigation.

Present EEWS of Central Weather Bureau (CWB)

Motivation in Taiwan





Td: data recording time
Tpr: data processing time
Tr: event reporting time

$Tr = Td + Tpr$

Ts: S-wave travel time
Tw: early-warning time

$Tw = Ts - Tr$

Earthquake early warning (EEW)

Magnitude estimation

Regional (front-detection)

- M_{L10} method (Wu et al., 1998)
  currently used by CWB

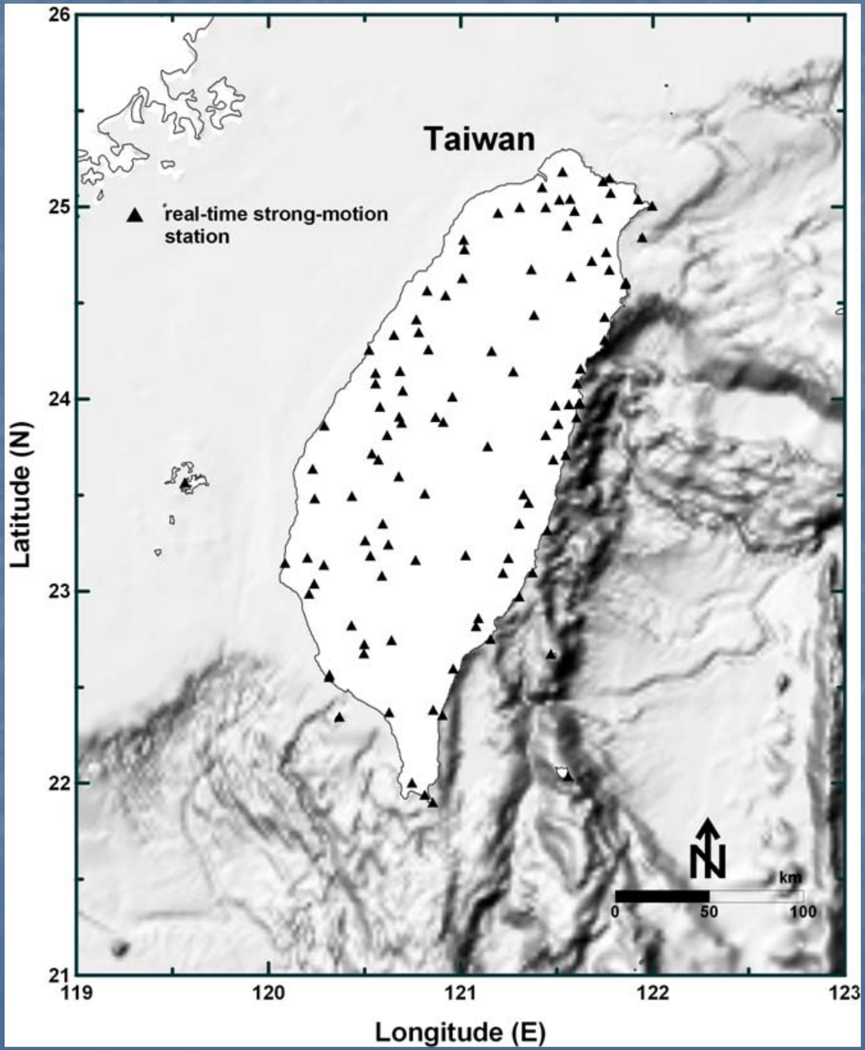
- Mpd: attenuation of *Pd* (Wu and Zhao, 2006)
  proposed by CWB

On-site

- Period terms: τ_C (Kanamori, 2005), τ_p^{max} (Allen and Kanamori, 2003)

  currently used by CWB and southern California

Rapid Earthquake Information Release System (RTD)



[Wu et al., 1997; Hsiao et al., 2009]

Accelerometer (A900):

- ~ 100 stations
- 20km averaged spacing
- 16 bits resolution
- ± 2g Max. amplitude

Telemetry:

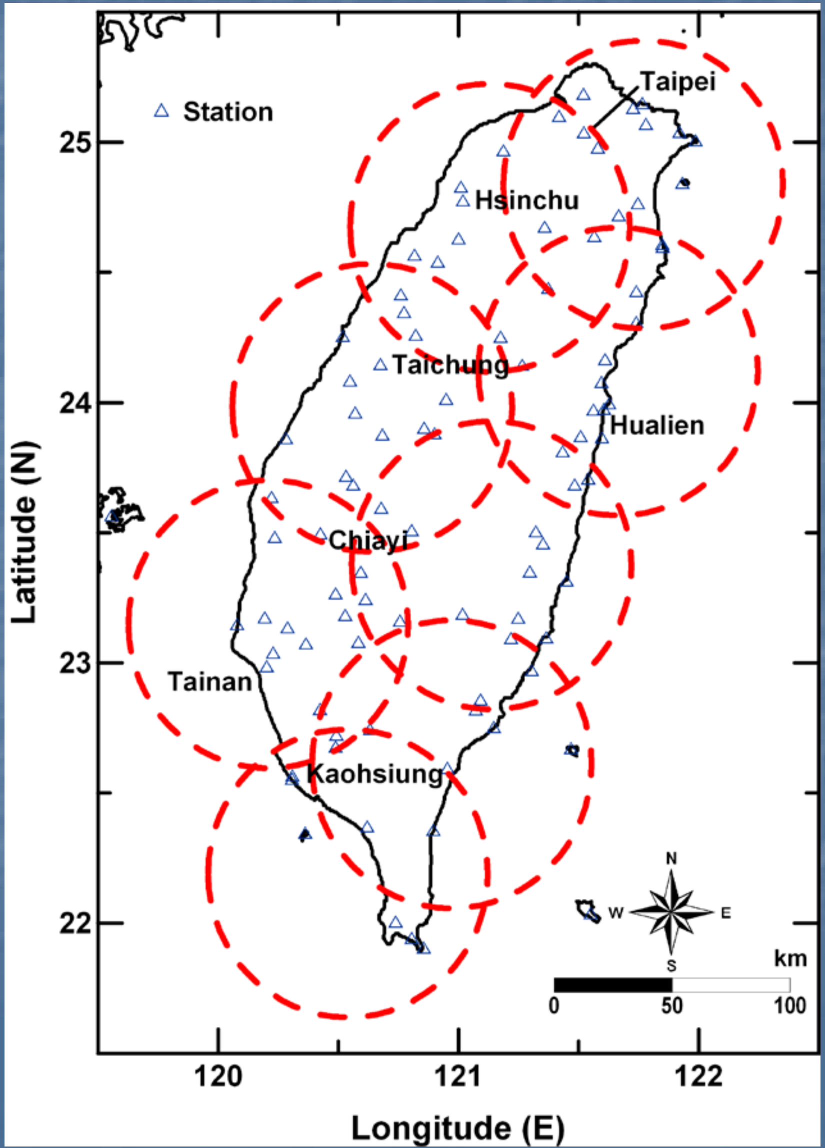
- Real-time data stream (RTD)
- 4.8K dedicated telephone and T1 lines
- Sampling rate 50 sps

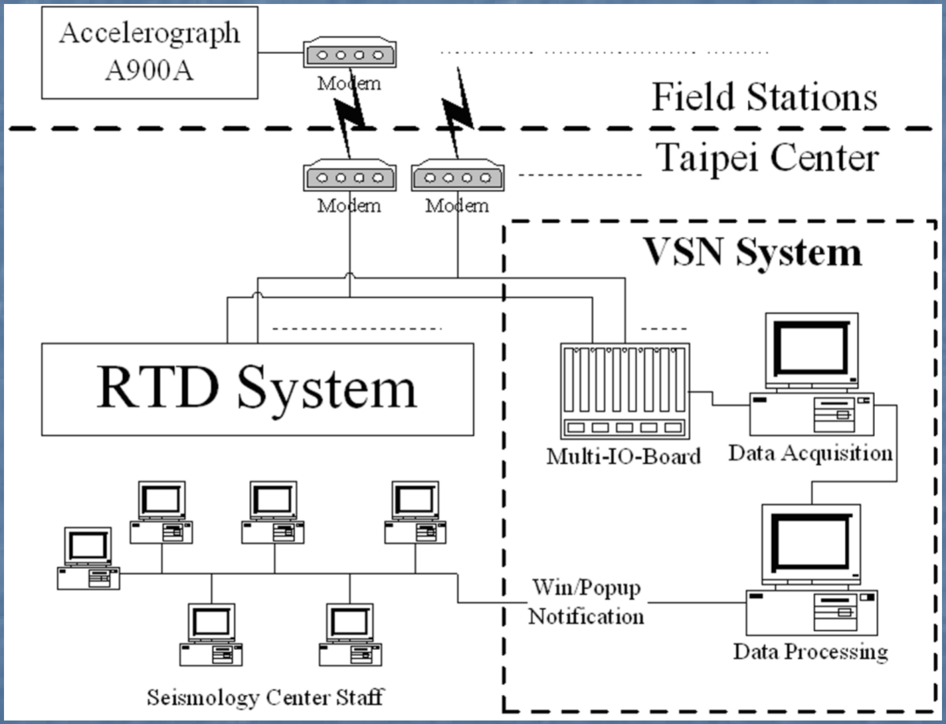
Processing platform:

- Windows-based workstation

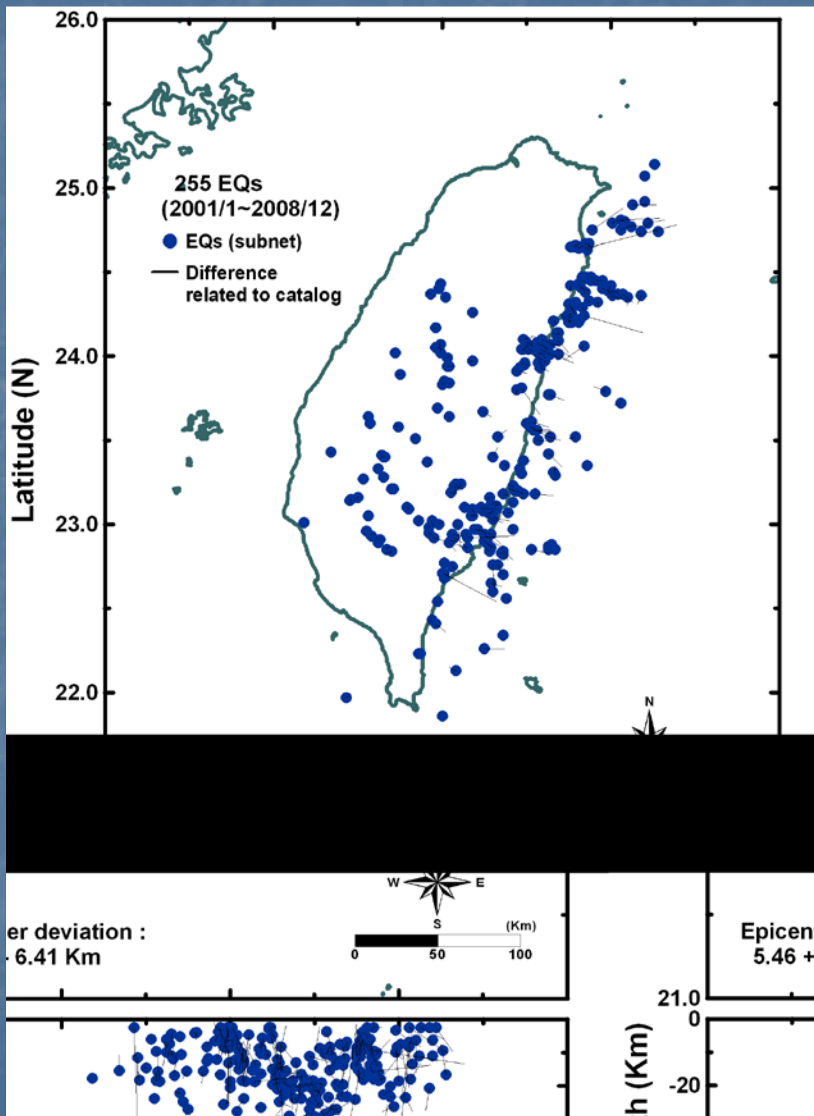
Virtual sub-network approach

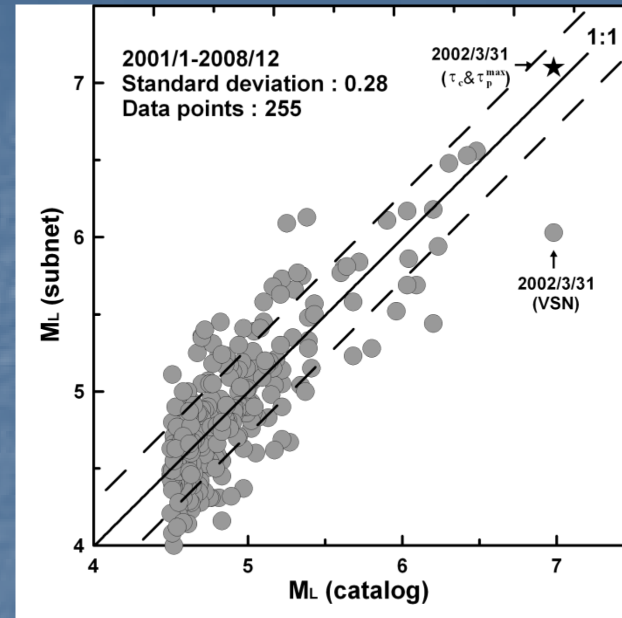
- Rationale: Earthquake location and magnitude are mostly determined by stations close to the earthquake (Wu and Teng, 2002).



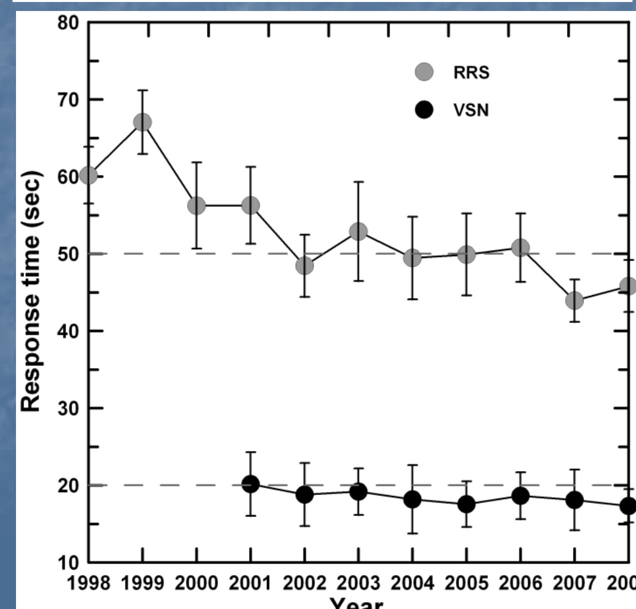


Performances for VSN



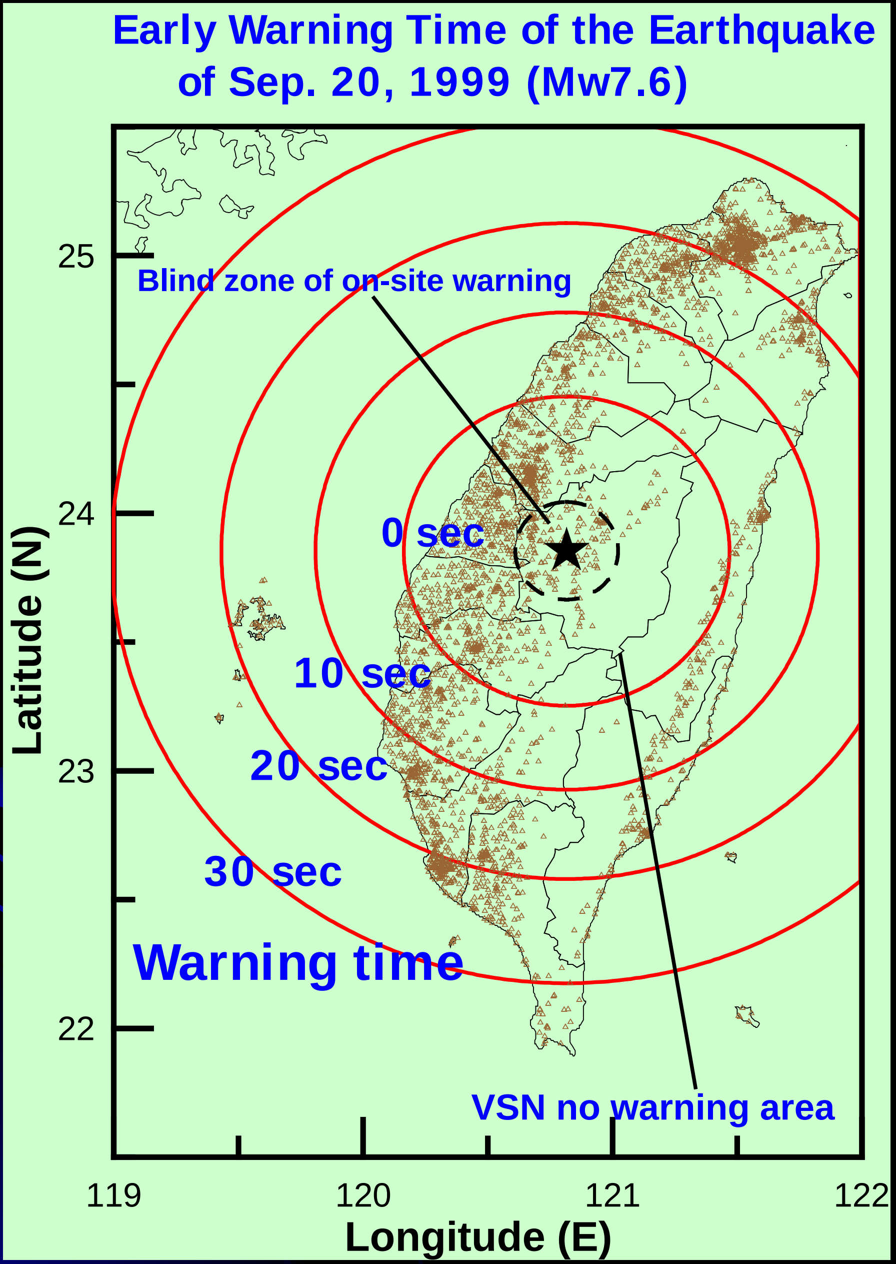


0.28



~17 sec

Regional warning v.s. onsite warning

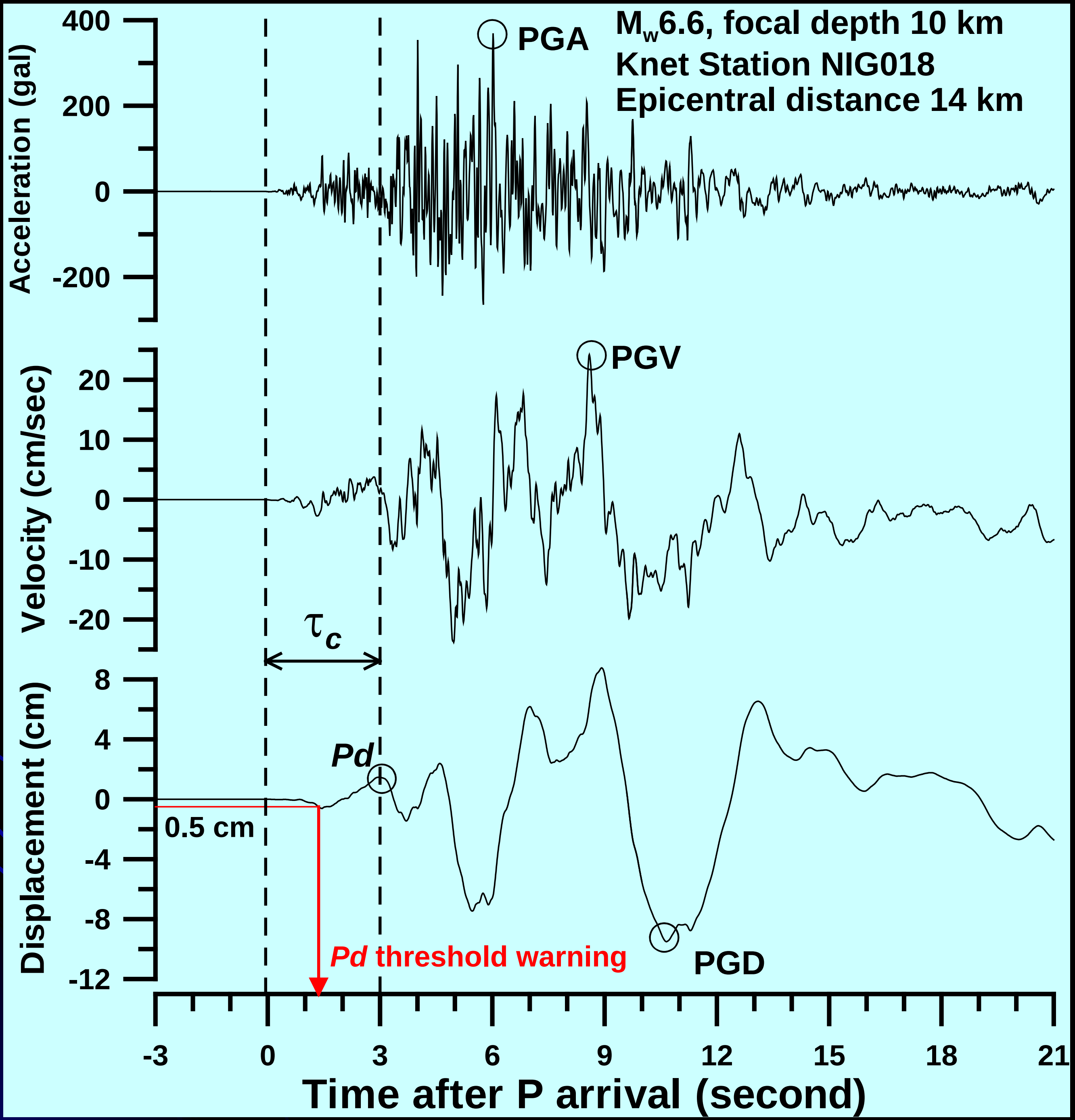


There is no warning time for VSN method within the distance 70 km from epicenter.

τ_c & P_d Methods

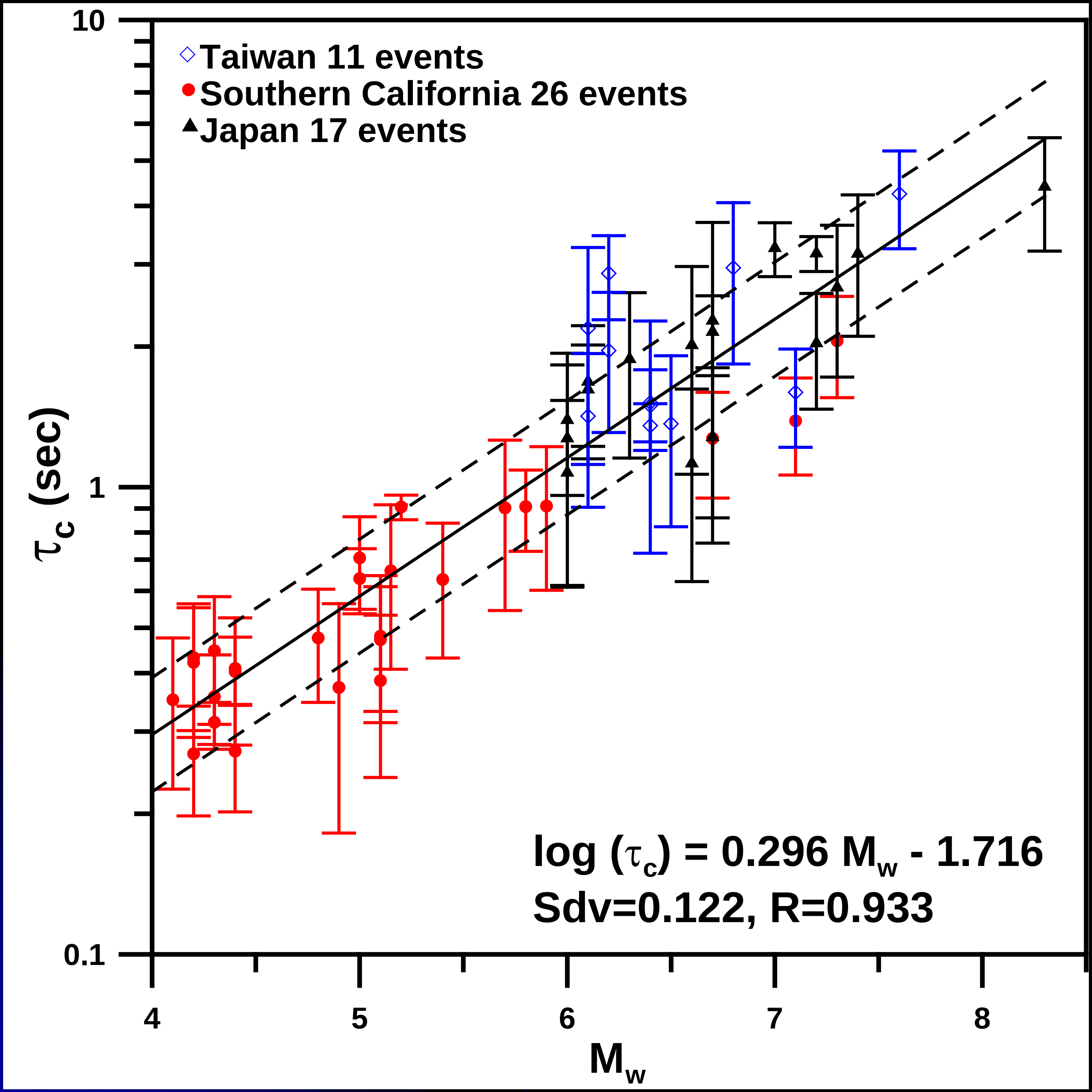
- τ_c average period parameter of the initial three seconds P waves

- P_d 0.075Hz high pass peak displacement amplitude of the initial three seconds P waves



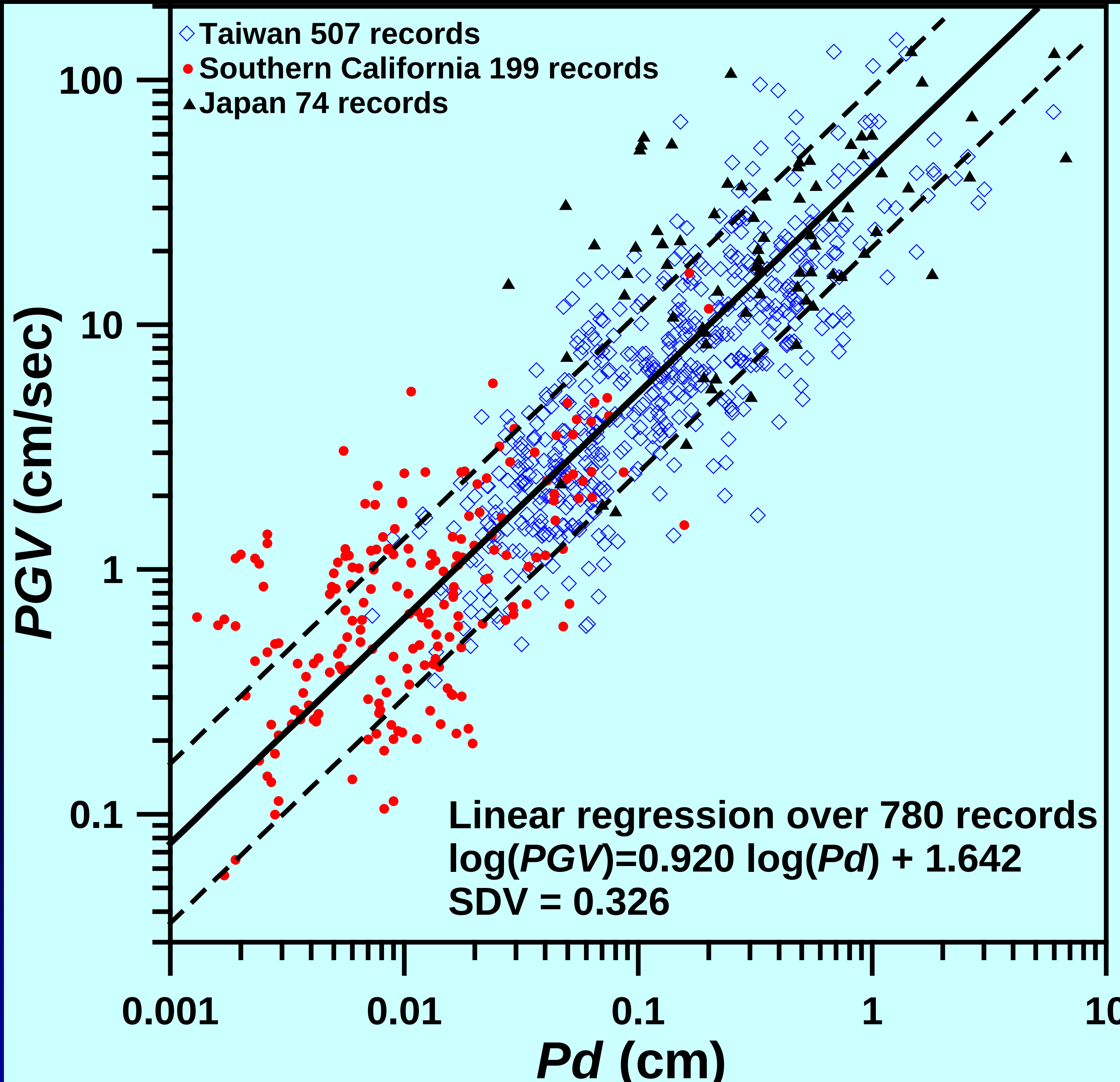
M$_w$6.6, focal depth 10 km
Knet Station NIG018
Epicentral distance 14 km
PGA
PGV
PGD
Pd
τ$_c$
0.5 cm
Pd threshold warning
Acceleration (gal)
Velocity (cm/sec)
Displacement (cm)
400
200
0
-200
20
10
0
-10
-20
8
4
0
-4
-8
-12
-3
0
3
6
9
12
15
18
21
Time after P arrival (second)

Earthquake size could be determined by τ_c!



Wu and Kanamori, 2008

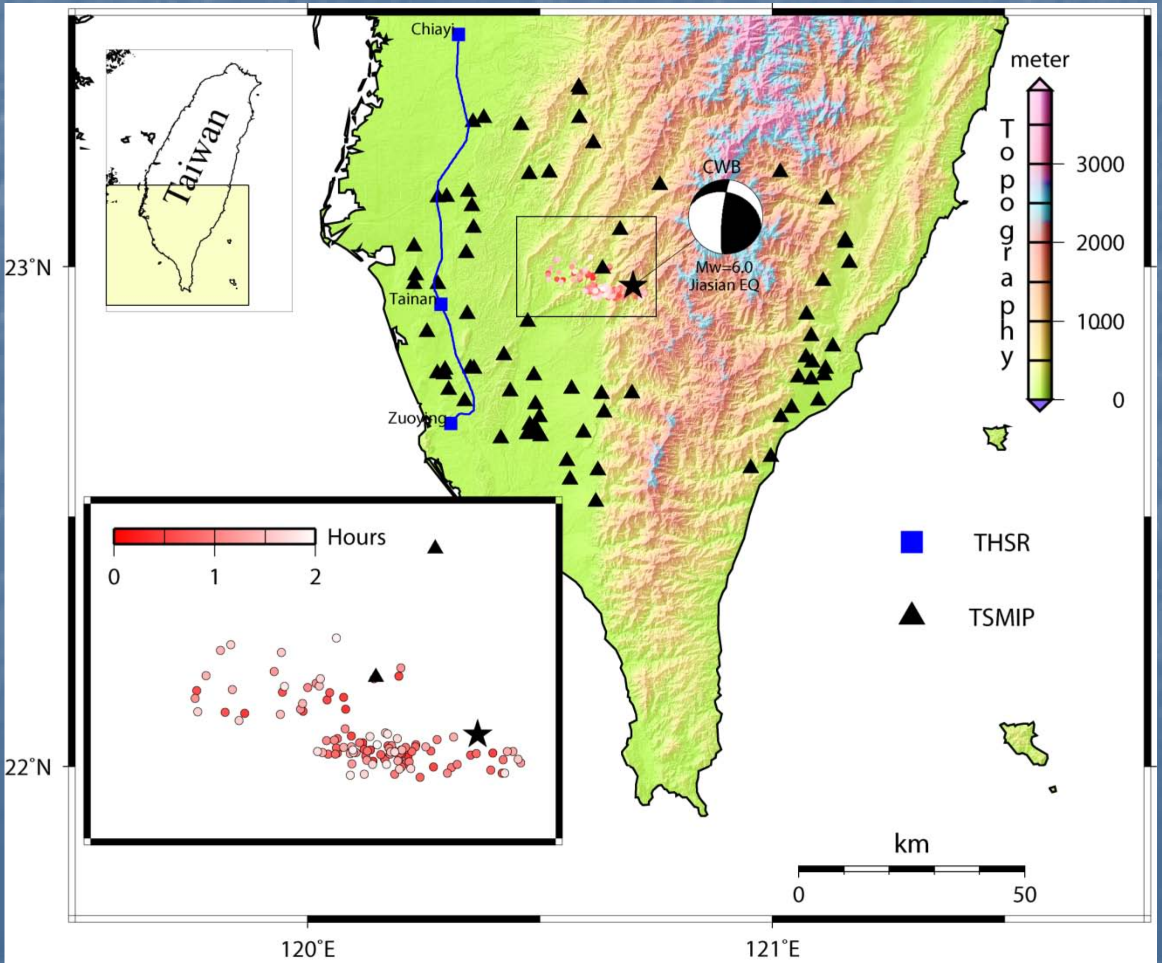
PGV could be predicted by Pd and then Shaking Intensity could be predicted!



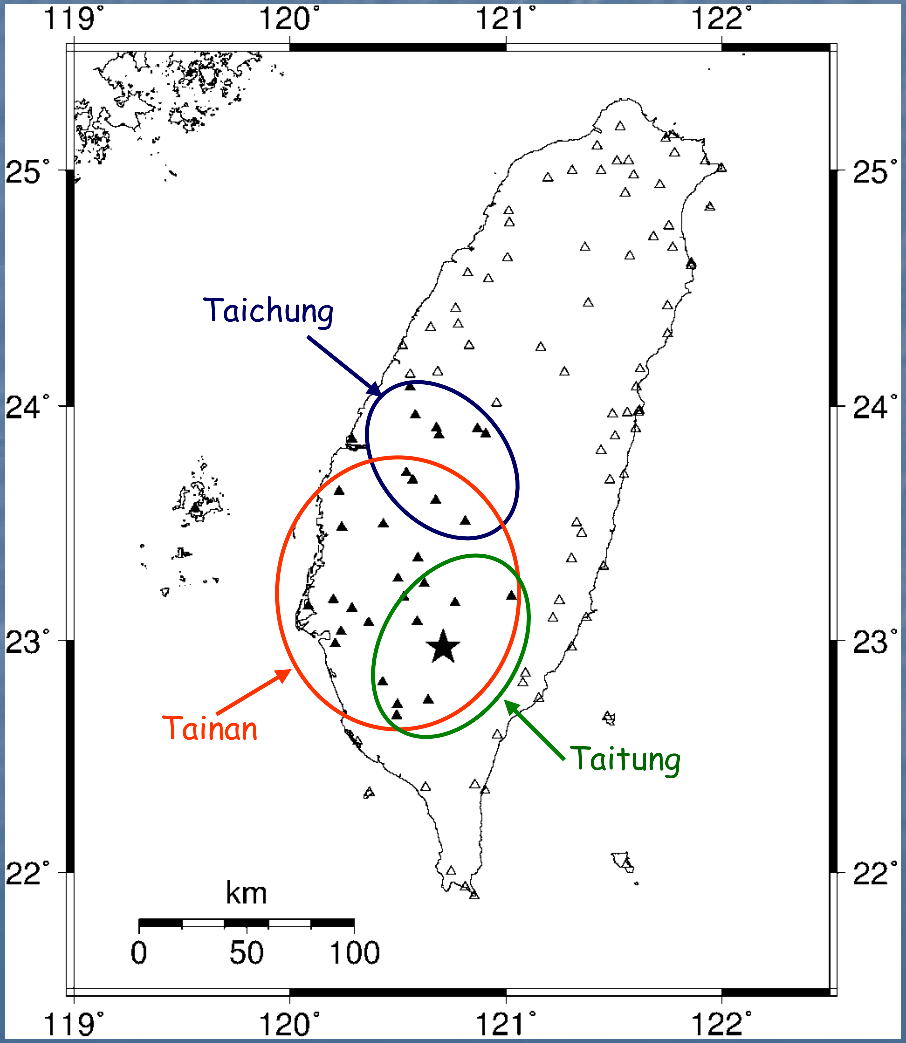
Wu and Kanamori, 2008

Example: The 2010 Jiasian earthquake

- Inland earthquake of $M_w = 6.0$ and $M_L = 6.4$
- ~20 km in focal depth ~40 km to the cities
- Rupture direction mainly pointed to the urban areas



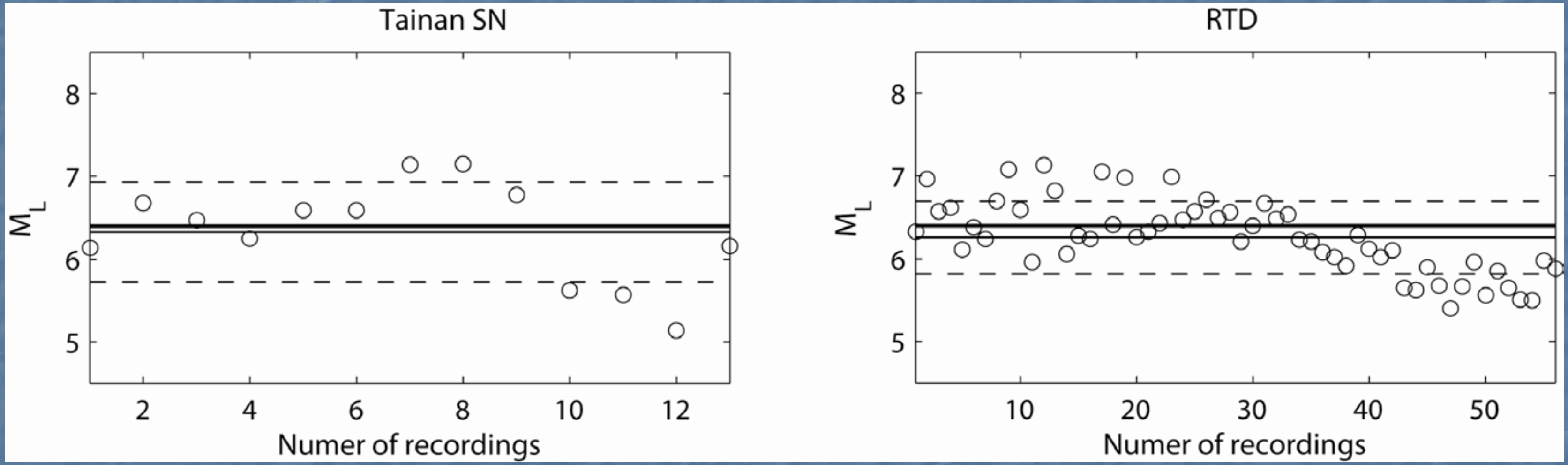
Virtual Sub-Network, VSN method



Virtual Sub-Network, VSN method

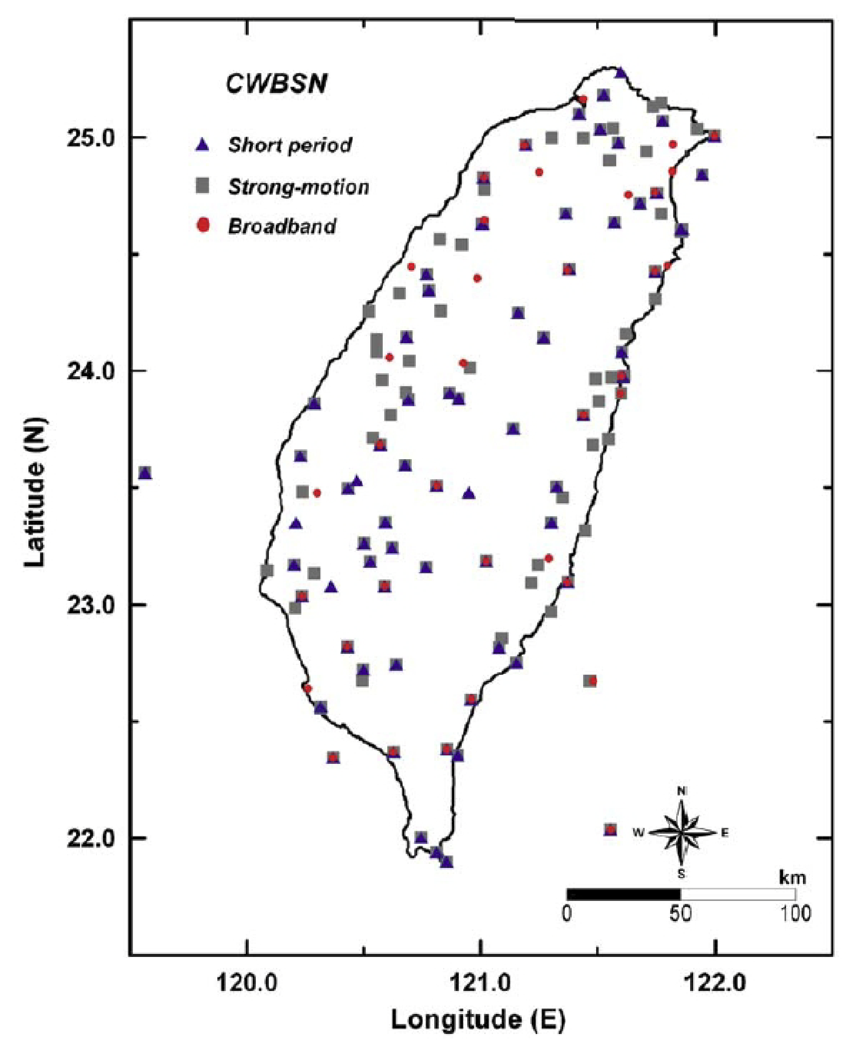
- Process times
  VSN: 27 s
  RTD: 48 s

- Magnitudes
  VSN: 6.33 ±0.60
  RTD: 6.26 ±0.44



Prototype EEWS in CWB by Hsiao et al., 2011

❑ Central Weather Bureau Seismographic Network (CWBSN)



Seismograph:
- Short period (picking)
- Strong-motion
- Broadband

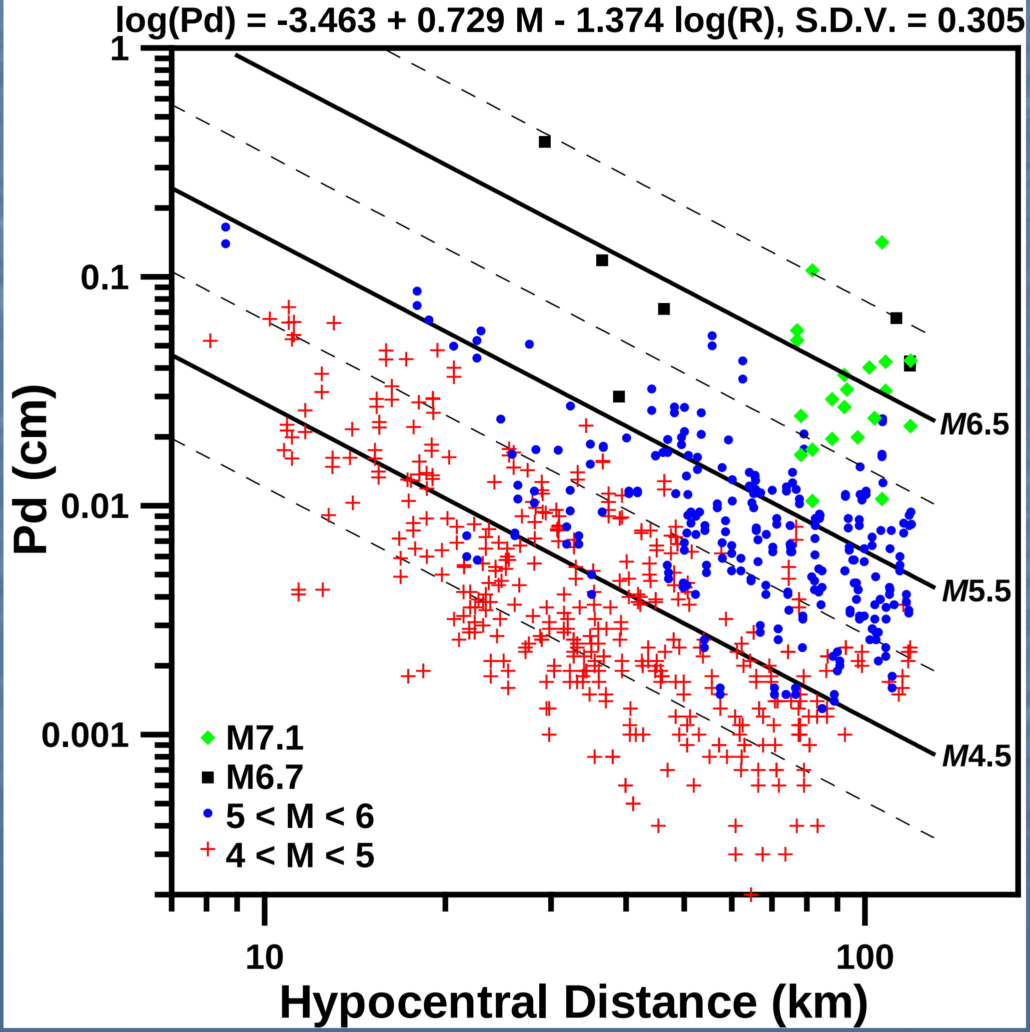
Communication:
- IP-based network

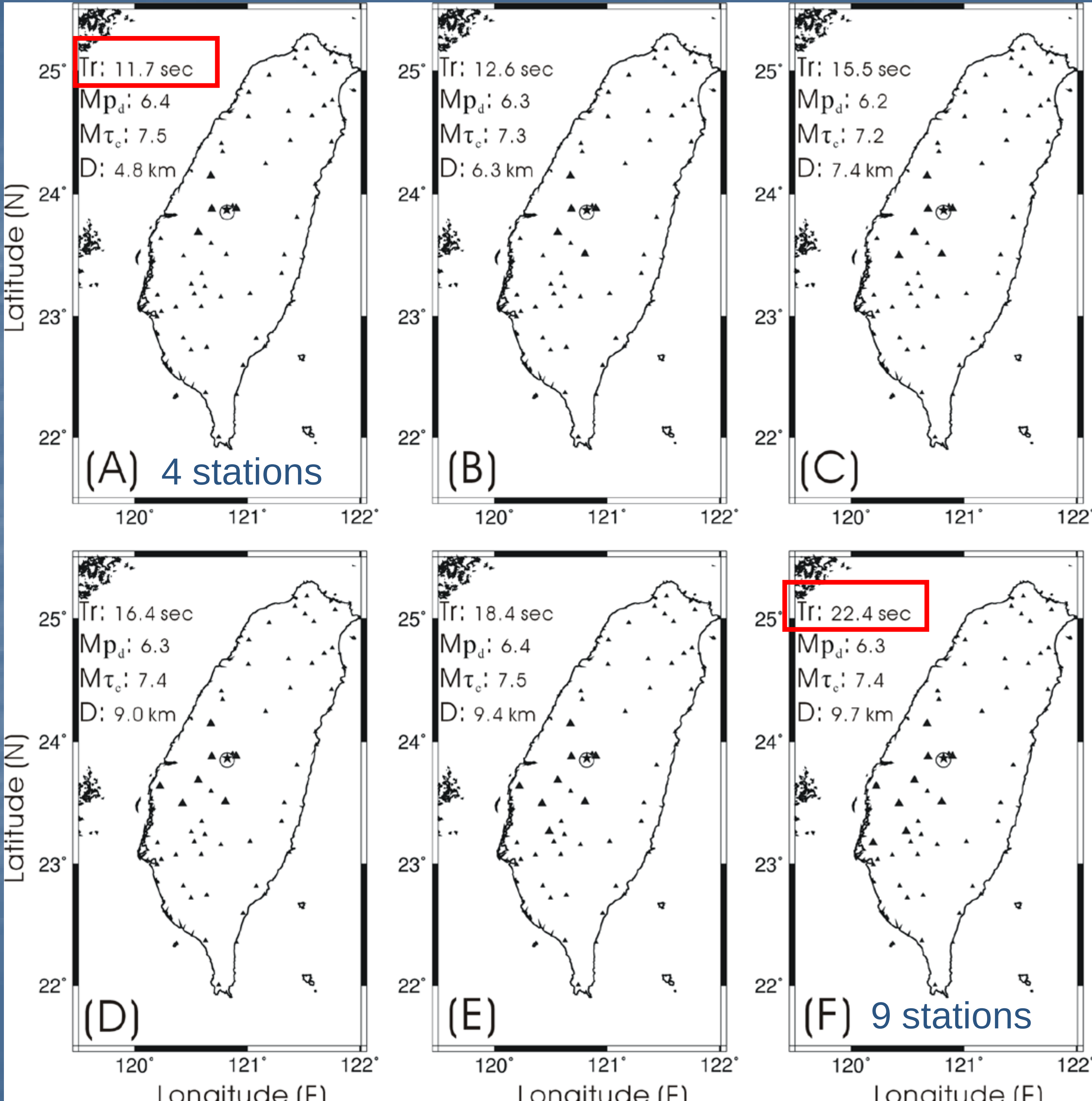
Processing platform:
- Earthworm system (USGS)

Prototype EEWS in CWB by Hsiao et al., 2010

CWBSN + Mpd

- M_{Pd}: (Wu and Zhao, 2006)





the 1999 Mw7.6 Chi-Chi earthquake

Chen et al., 2011

Proposed EEW and RR methods

Regional

- Magnitude estimation (I): Strong ground-motion attenuation relationship (Lin and Wu, 2010a)

- Magnitude estimation (II): PGA-contour enclosed area (Lin and Wu, 2010b)

- Magnitude estimation (III): Pd-contour enclosed area (Lin and Wu, 2011c)

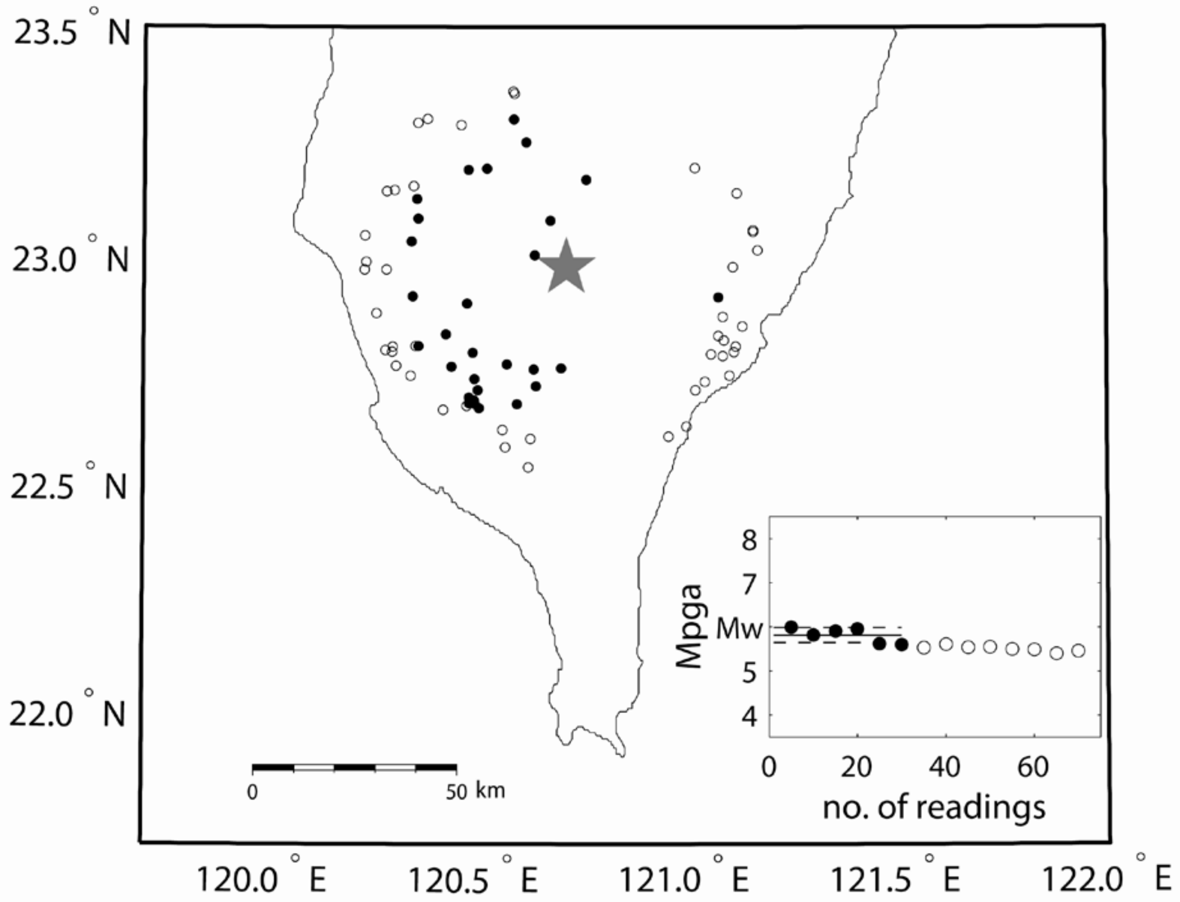
- Magnitude estimation (IV): Total effective energy magnitude (Lin and Wu, 2012)

On-site

- Faster short-distance EEW (Wu et al., 2011a)

Magnitude estimation (I): Strong ground-motion attenuation relationship

$$\log_{10} PGA = -0.395\log_{10}(r) + 0.125M + 1.979 \pm 0.161$$



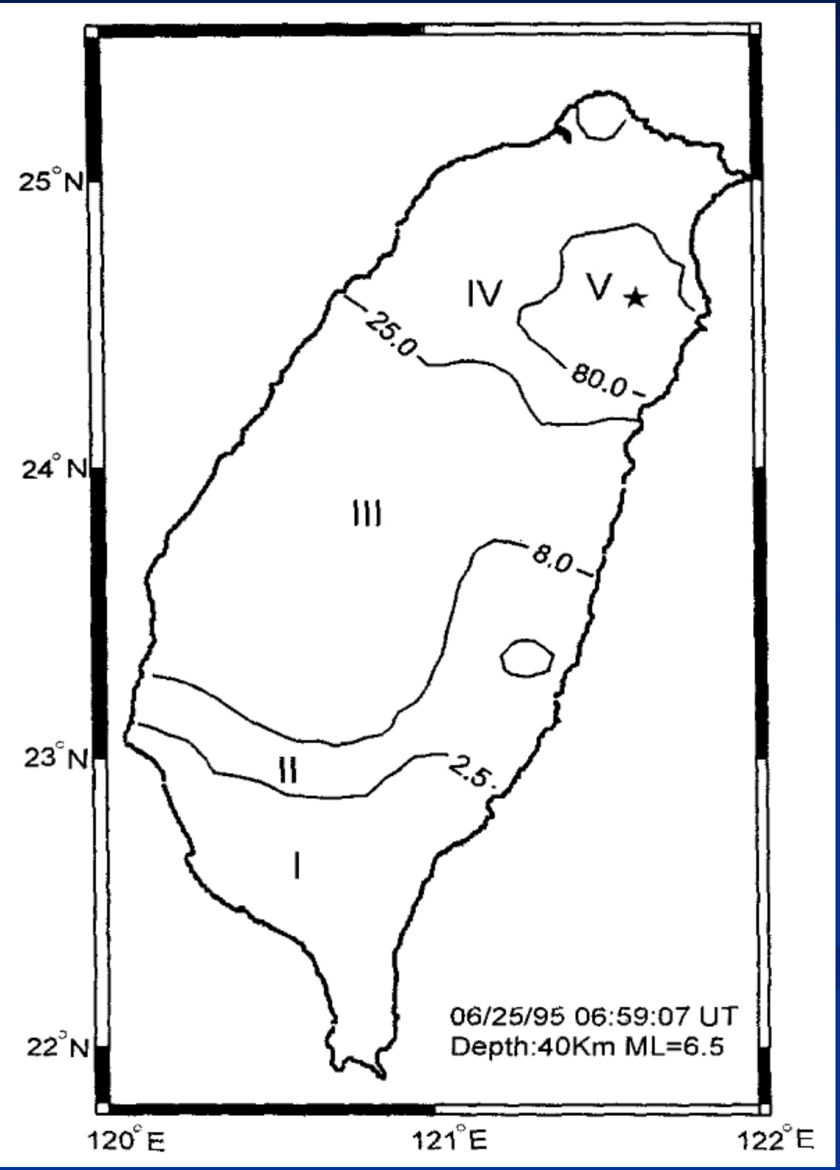
- Mpga = 5.8± 0.17
- 30 stations < 40 km

Magnitude estimation (II): PGA-contour encircled area

$$M_W = a \log A + b$$

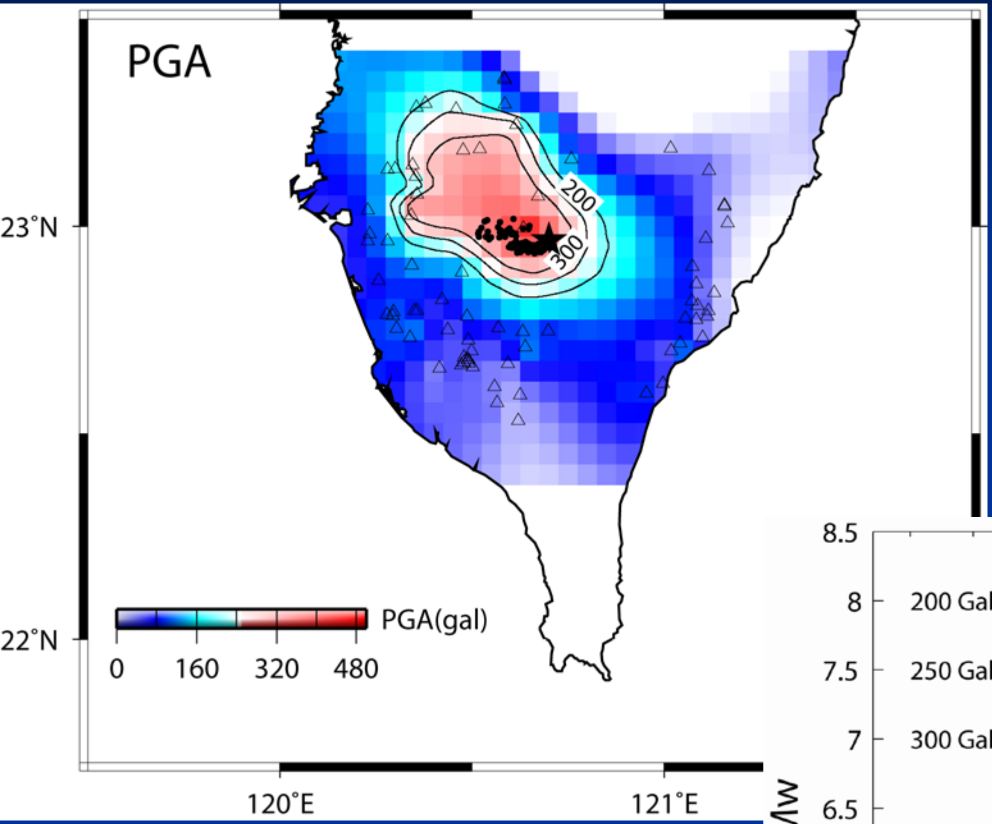
area

- For a particular value of PGA contour, larger earthquake (M) will have a larger contour-enclosed area (A).

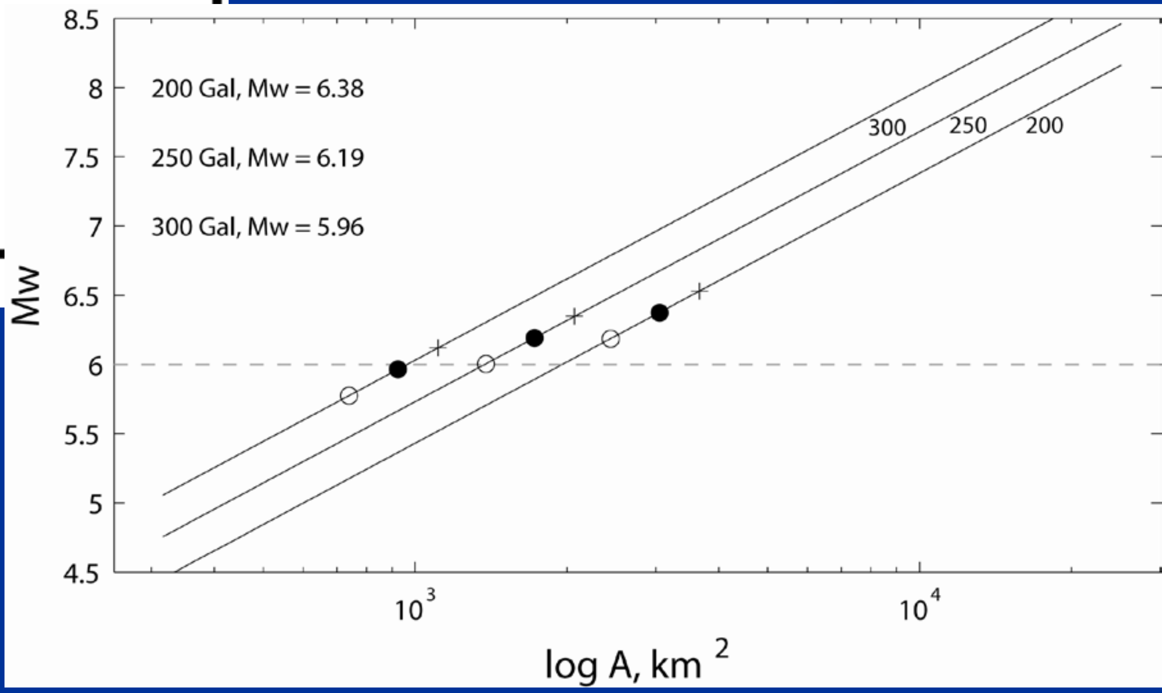


(Teng et al., 1997)

Magnitude estimation (II): PGA-contour encircled area



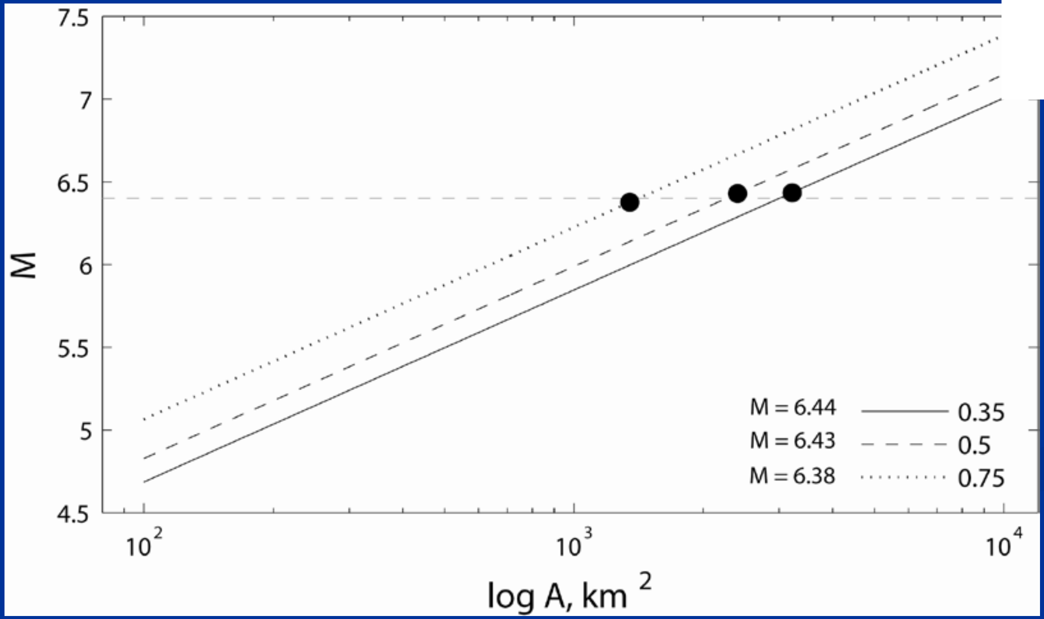
$$M_W = 1.95 \log A + 0.006P - 1.619$$

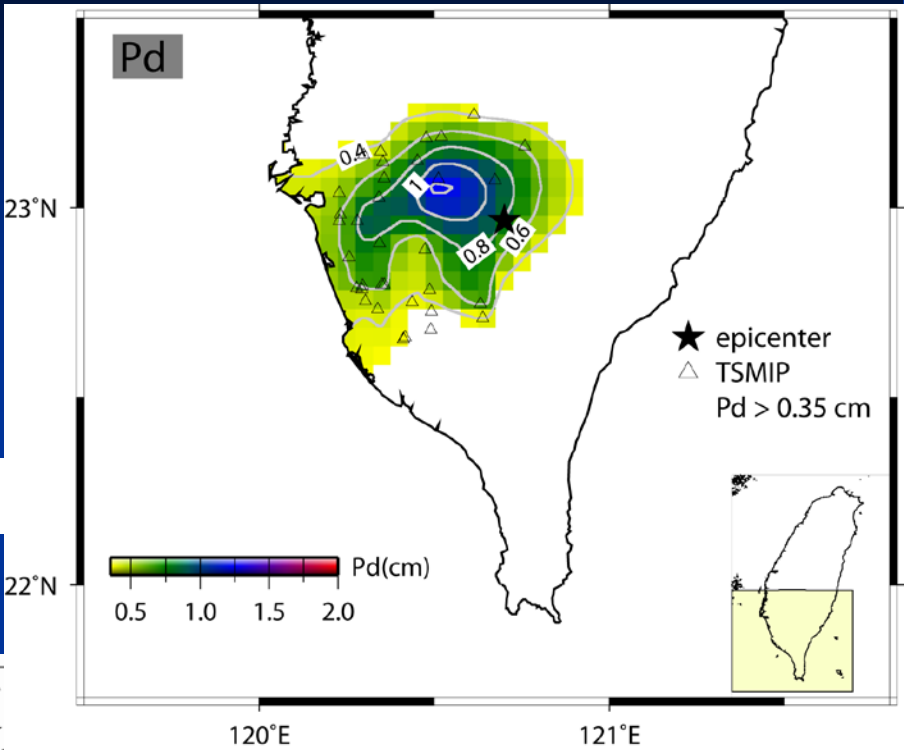


Magnitude estimation (III): Pd-contour encircled area

- Early portion of P wave
- Faster process time
- Might be less accurate

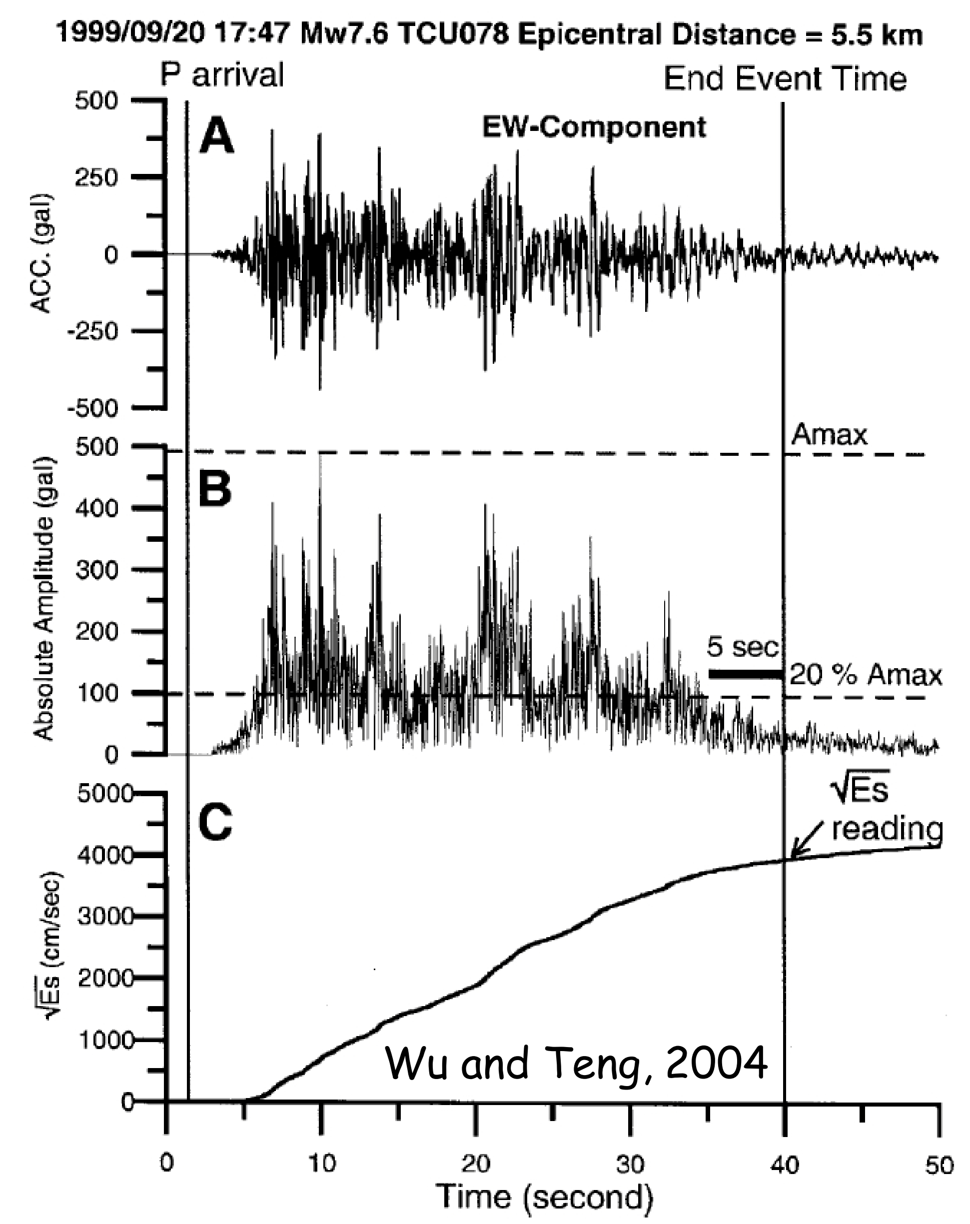
$$M_{Pd-A} = 1.207\log_{10}(A) + 0.651Pd + 1.566 \pm 0.18$$





- 2010 Jiasian earthquake

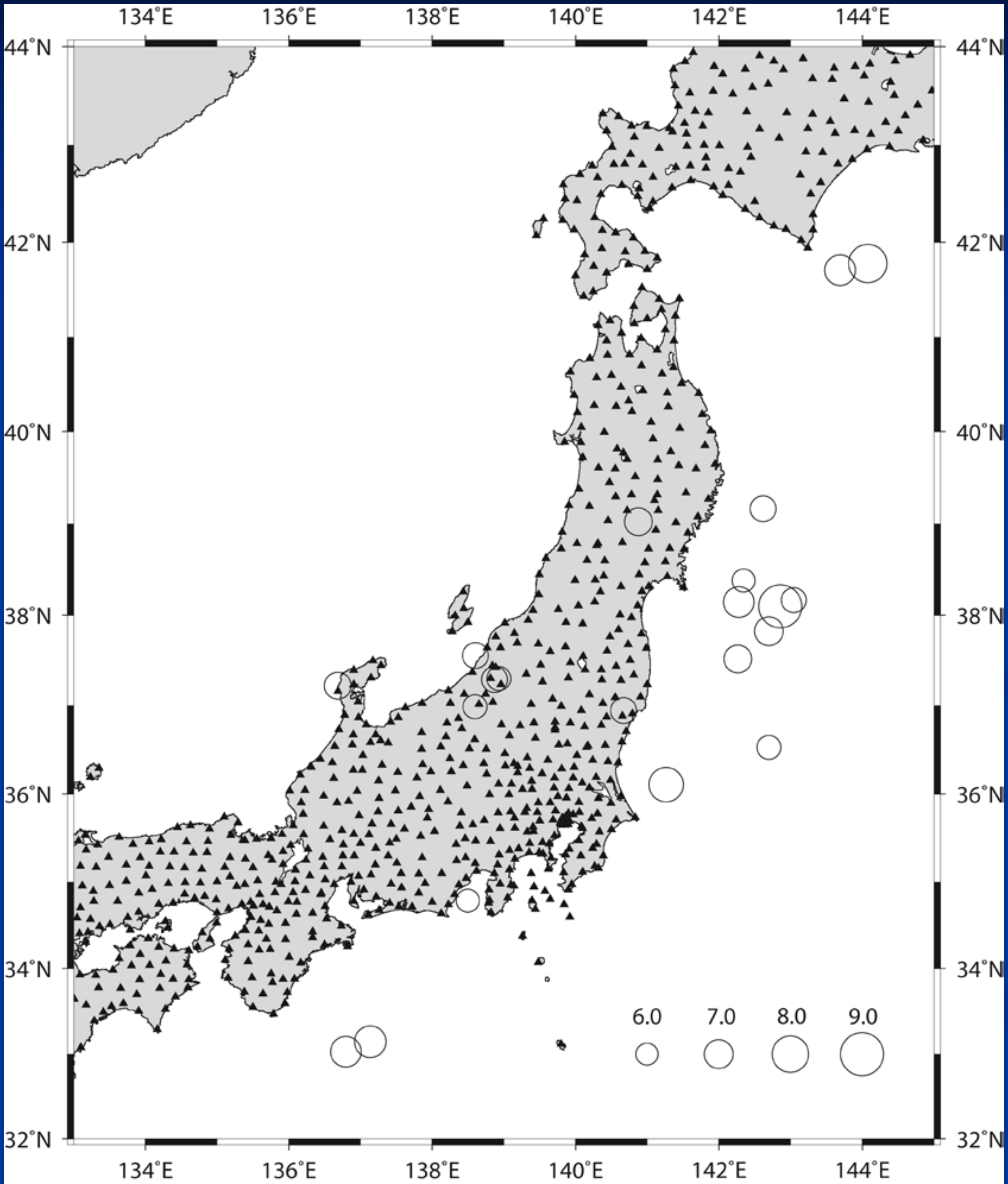
Magnitude estimation (IV): Total effective energy magnitude



$$\sqrt{Es} = \int_{T_p}^{T_e} \sqrt{V^2 + N^2 + E^2}\, dt$$

$$\log(\sqrt{Es}) = A + B \cdot M_W + C \cdot R + D \cdot \log(R)$$

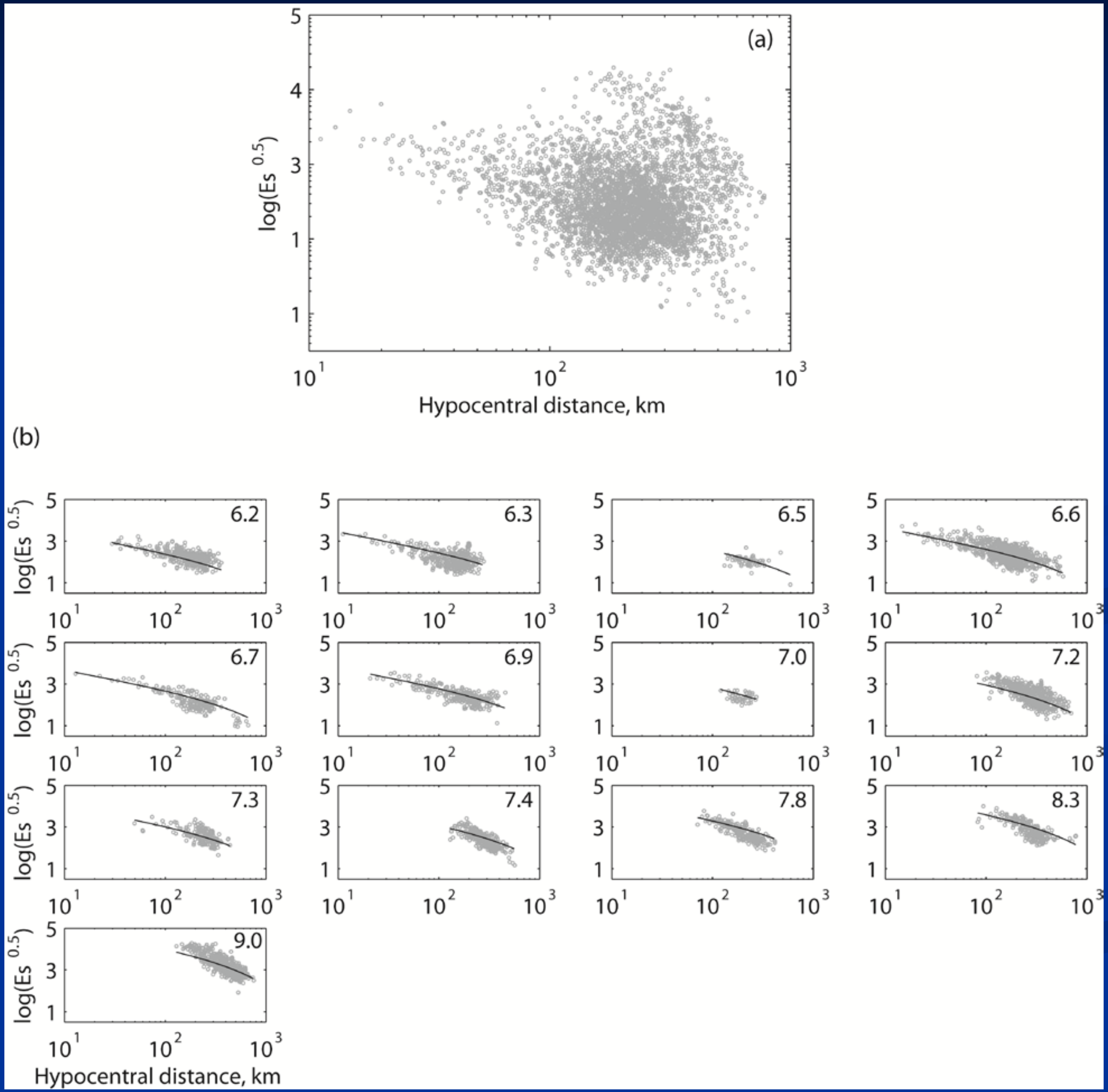
Magnitude estimation (IV): Total effective energy magnitude



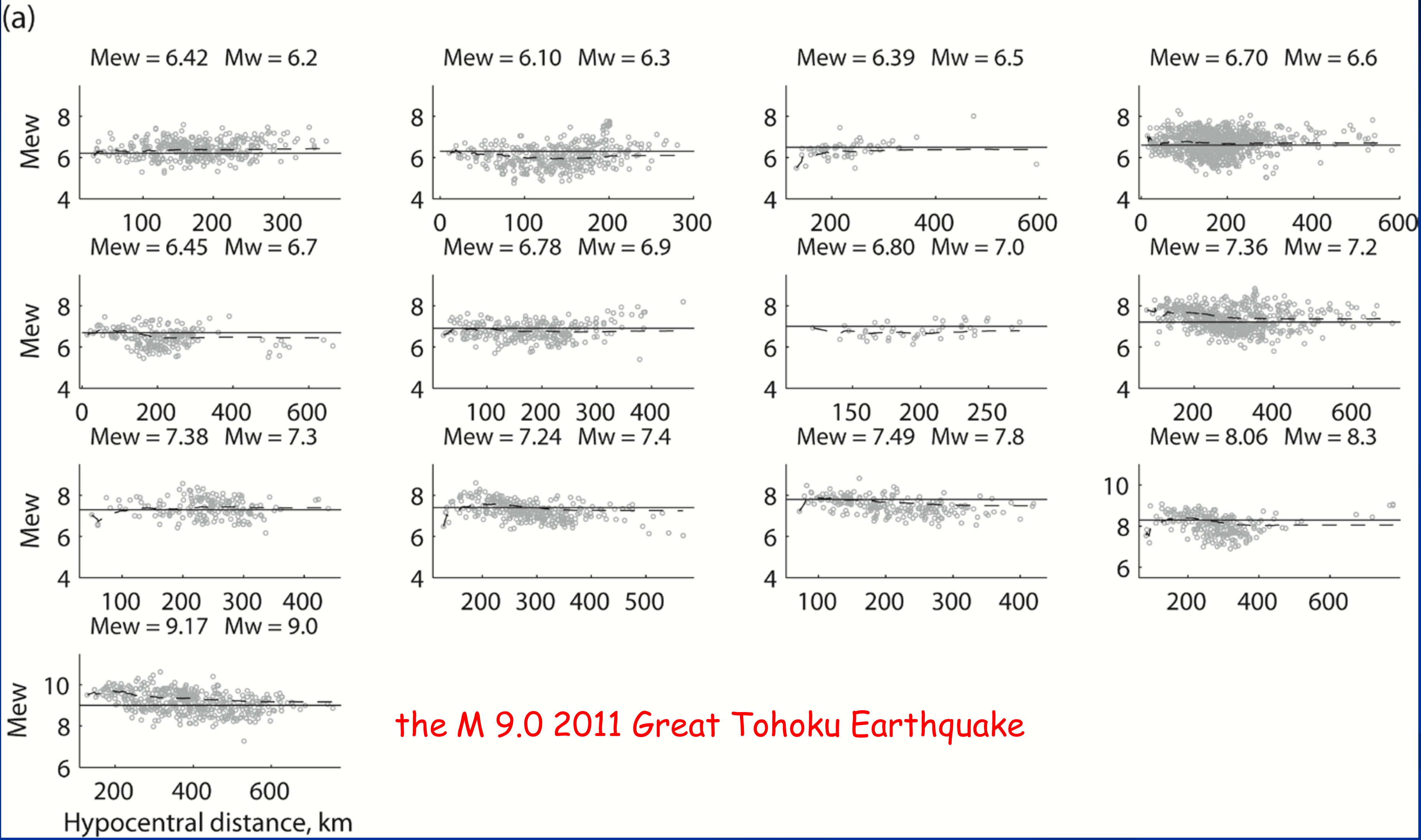
▲ : NIED K-NET seismic network.

○ : Epicenters of the 17 crustal earthquake events

Magnitude estimation (IV): Total effective energy magnitude

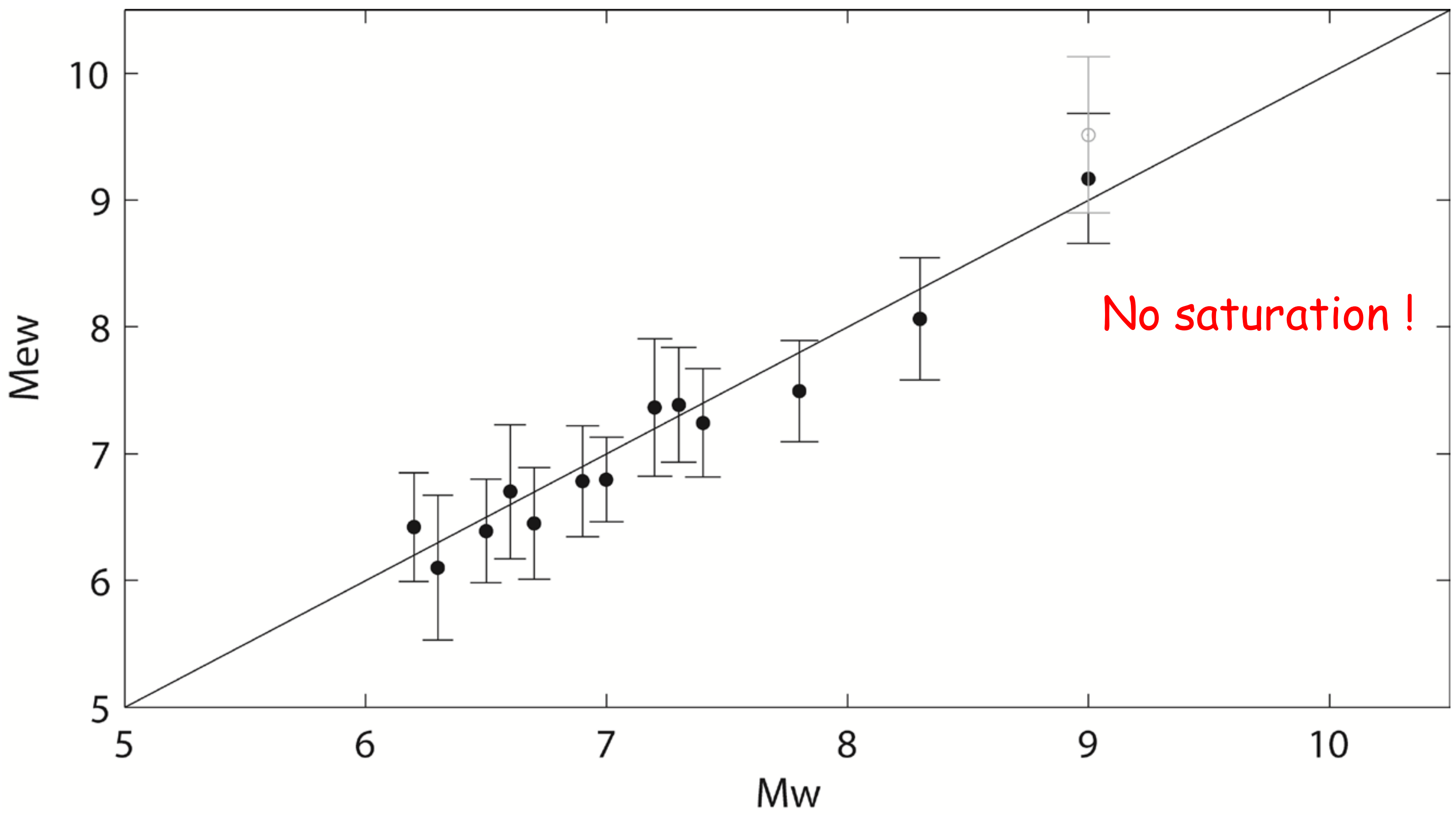


Magnitude estimation (IV): Total effective energy magnitude



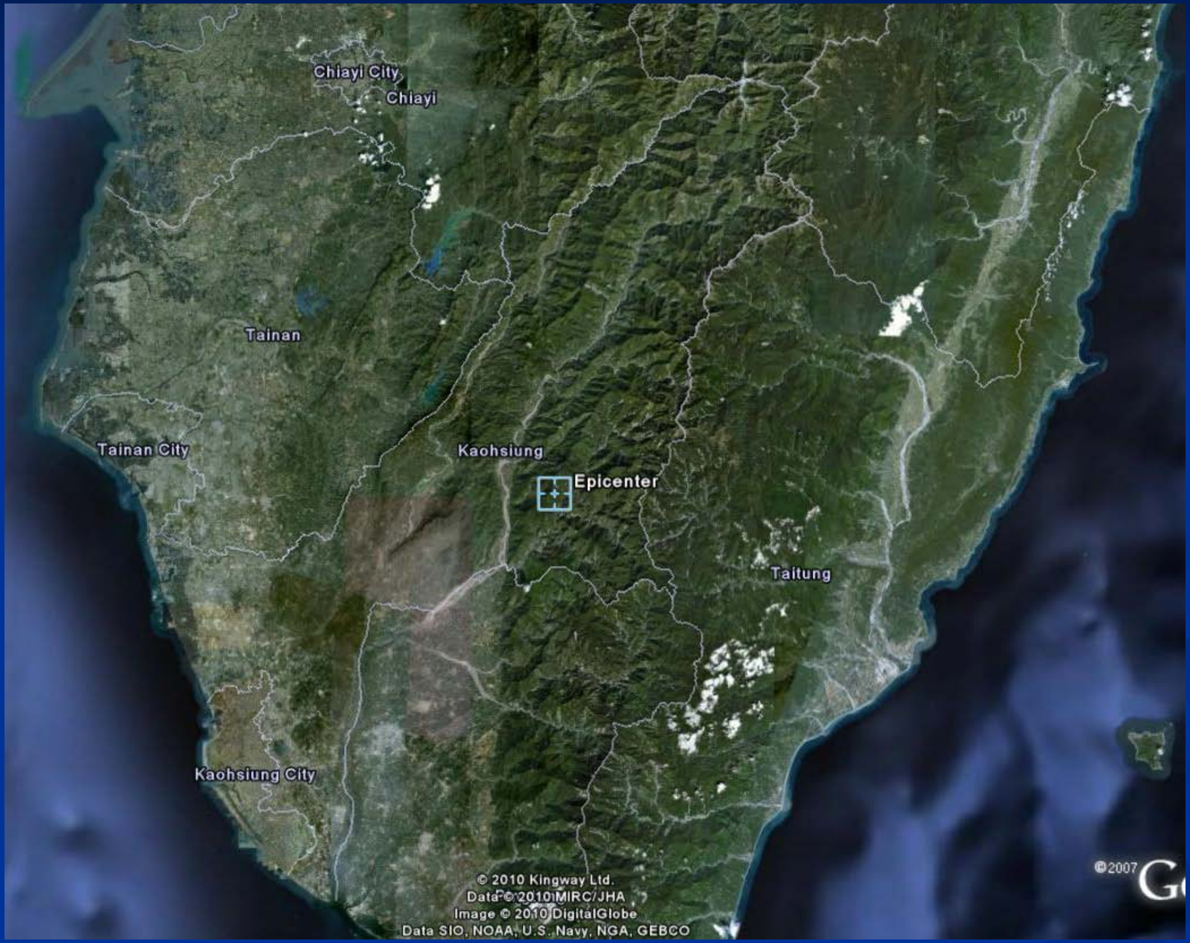
the M 9.0 2011 Great Tohoku Earthquake

Magnitude estimation (IV): Total effective energy magnitude



Black error bar: using data of the M_w = 9.0 2011 Tohoku earthquake
Gray error bar: without using data of the M_w = 9.0 2011 Tohoku earthquake

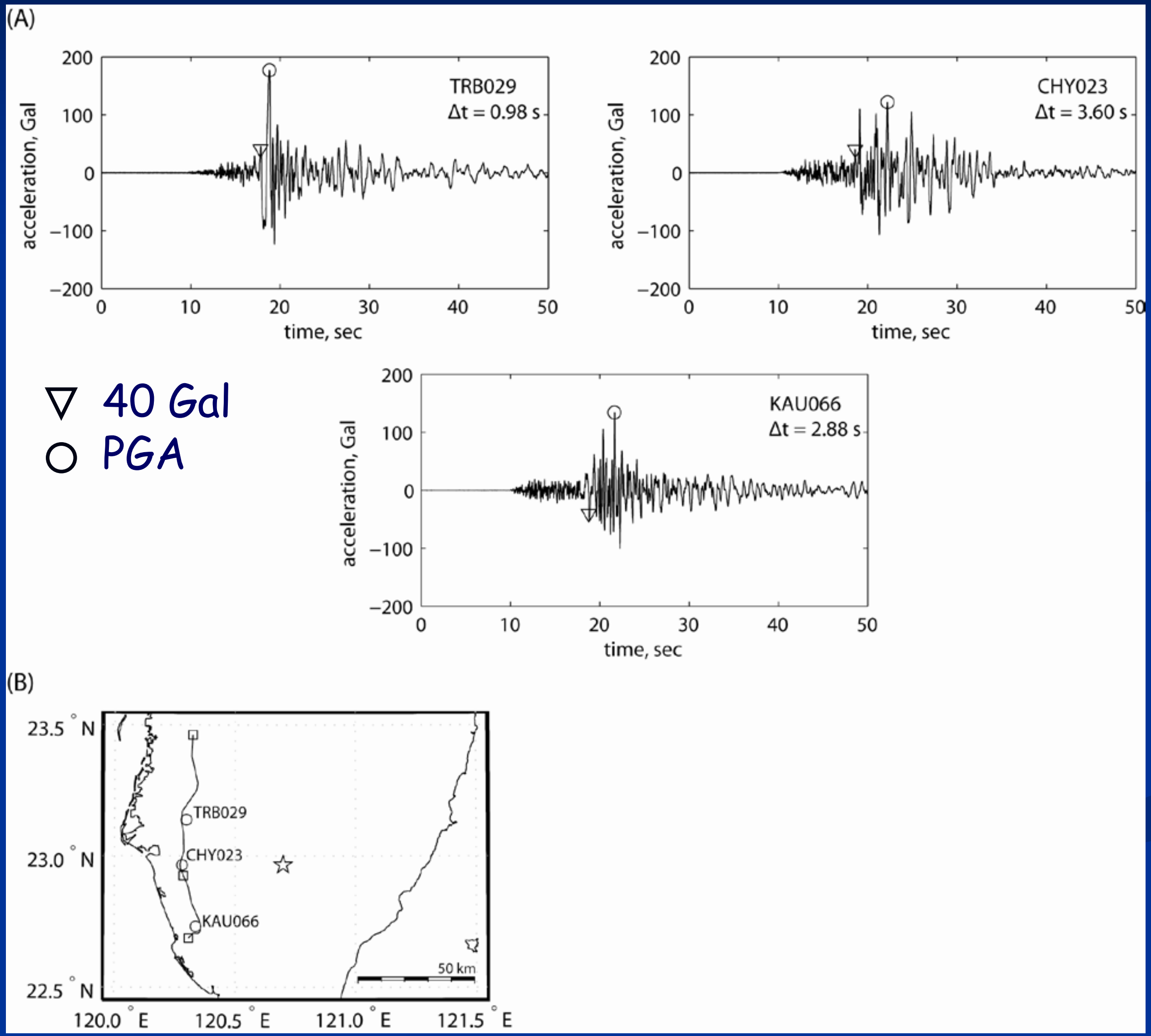
On site: Faster short-distance EEW



The 2010 Jiasian earthquake demonstrates the vital need for the short-distance EEW.

Faster short-distance EEW

Derailment of the Taiwan High Speed Rail, THSR

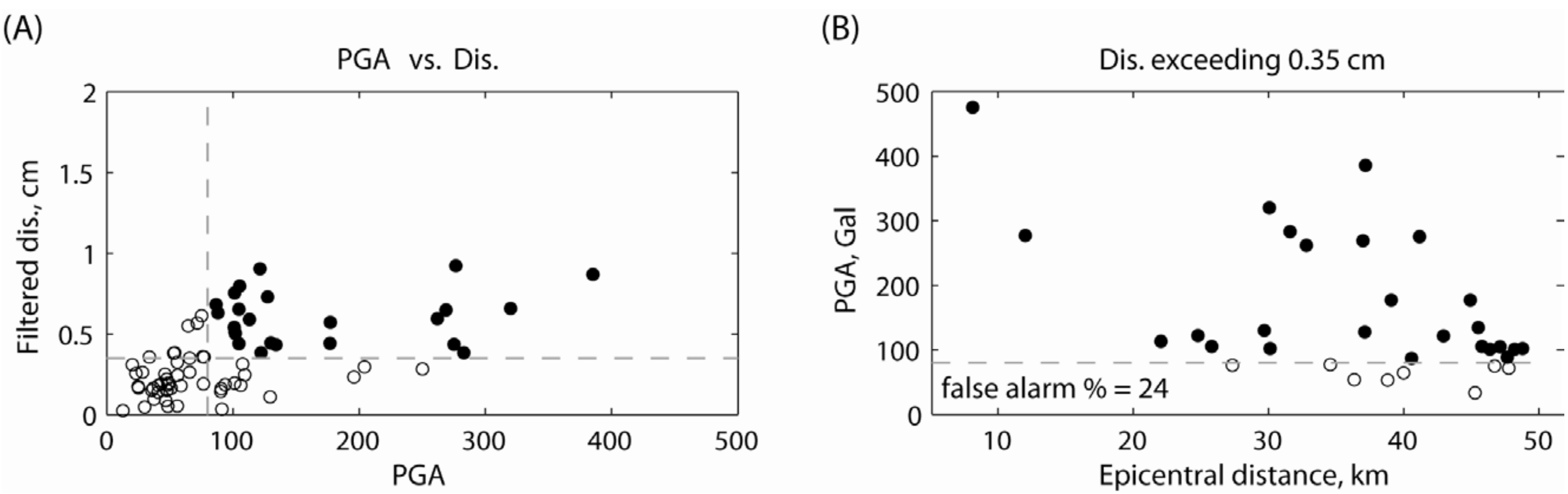


Faster short-distance EEW

Relate early portion of the filtered vertical displacement to PGA

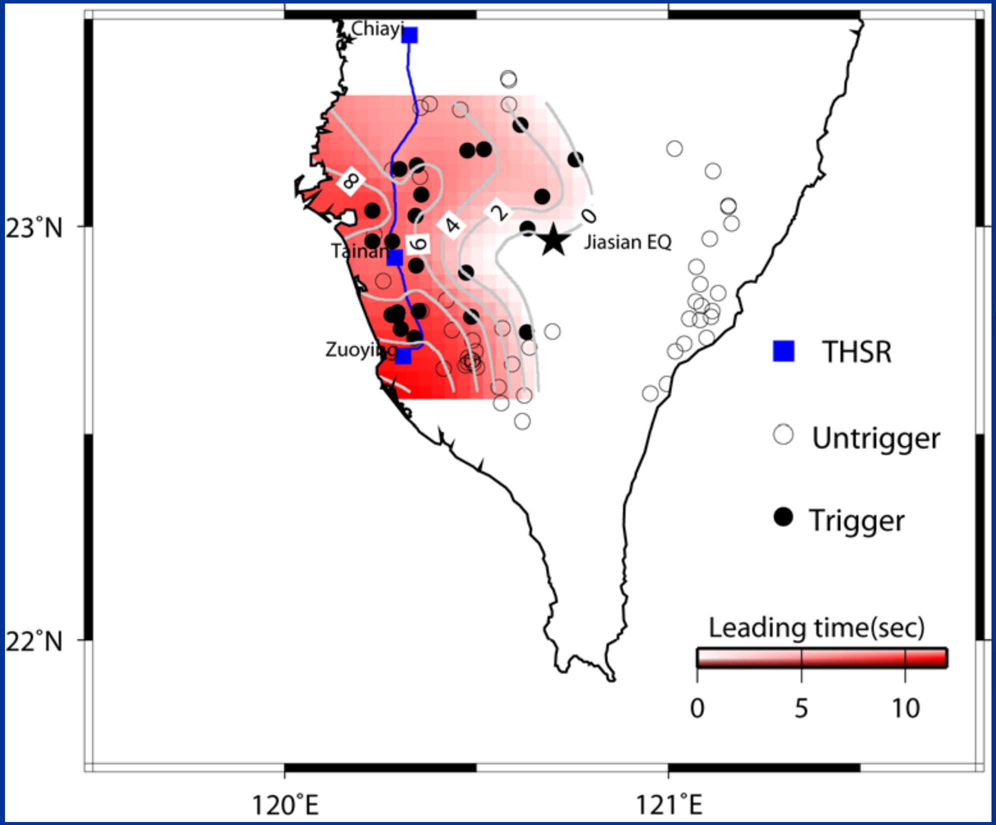
$$\log(PGV) = 0.920\log(Pd) + 1.642$$

$$\log(PGA) = 0.595 + 1.069\log(PGV)$$



Faster short-distance EEW

- A threshold value of 0.35 cm for the filtered vertical displacement.
- If exceeds, ~ 80% of the warning sites will have PGA larger than 80 gal.
- Warning time = time (PGA > 80 gal) — time (Displacement > 0.35 cm)



Next step in next years

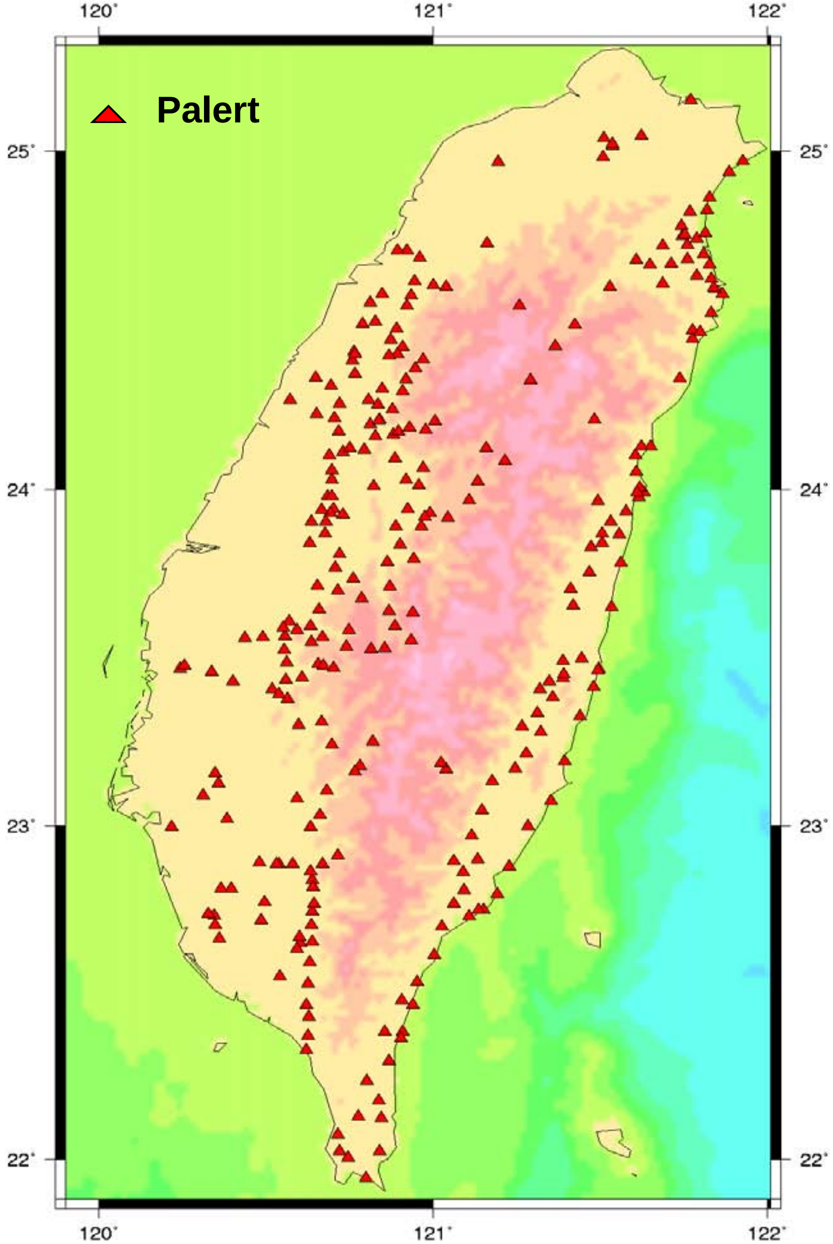
- In next two years, over 400 sets *P*alert will be installed throughout the whole Taiwan region (three times denser).

- Real-time shaking map for rapid reporting purpose by using *P*alert network.

- Quick and Potable aftershock EEW monitoring

- Local EEW Array (Hybrid onsite and regional types)

Palert Seismic Network



- A total of 280 as of 2012/12