Improvements and applications of the earthquake early warning (EEW) system in Taiwan

臺灣地震預警系統的進步與應用

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2022.10.14 @NCU

Outline

1. History and current status of the EEW system
2. CWB Seismic Network and EEW system
3. Machine learning for EEW system
4. Future plan for the EEW system
5. Ongoing projects

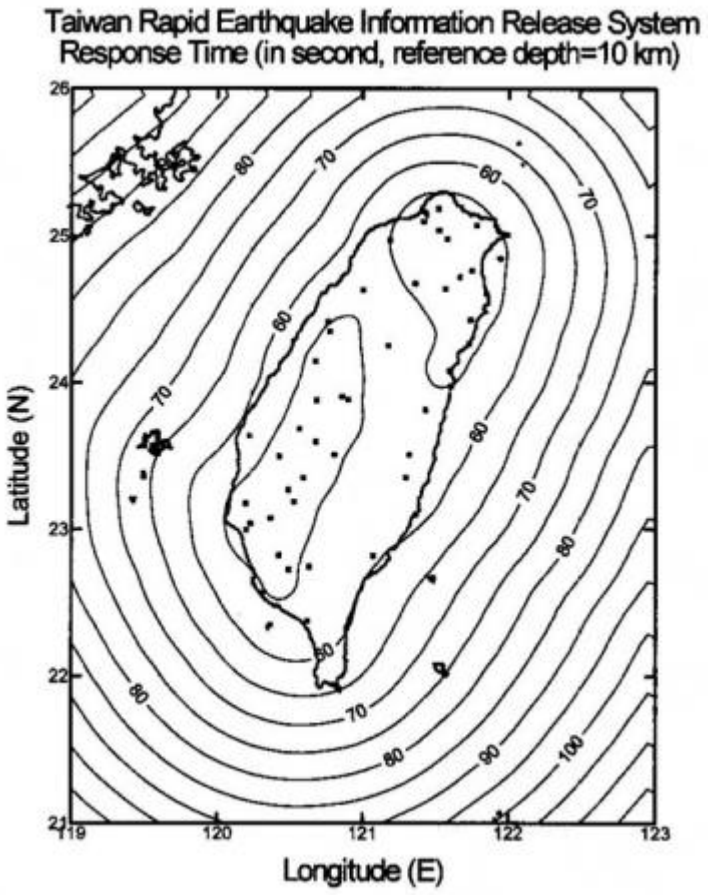
Seismological Center of Central Weather Bureau

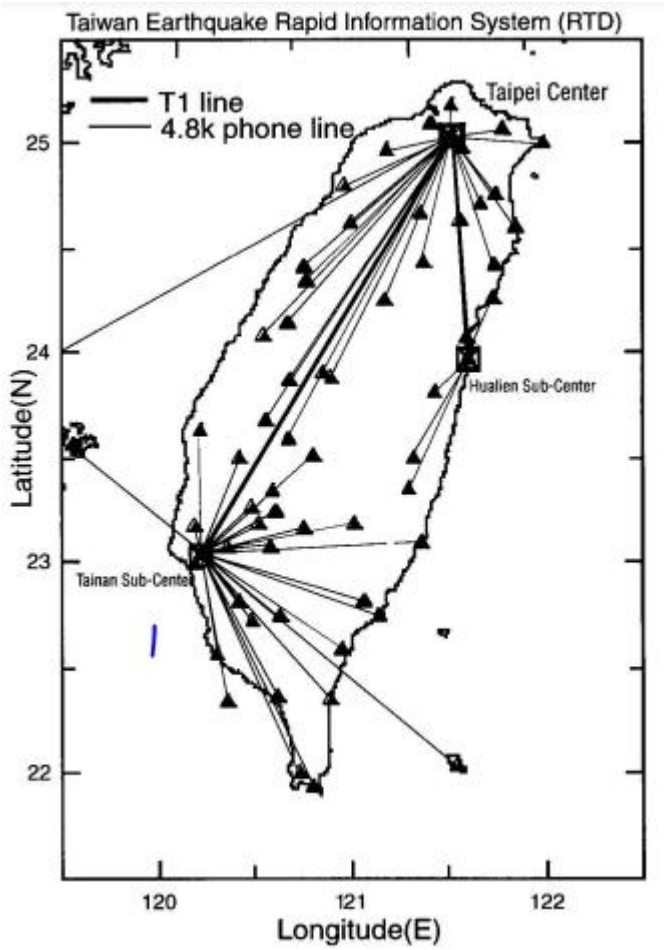
Monitoring System in the Seismological Center

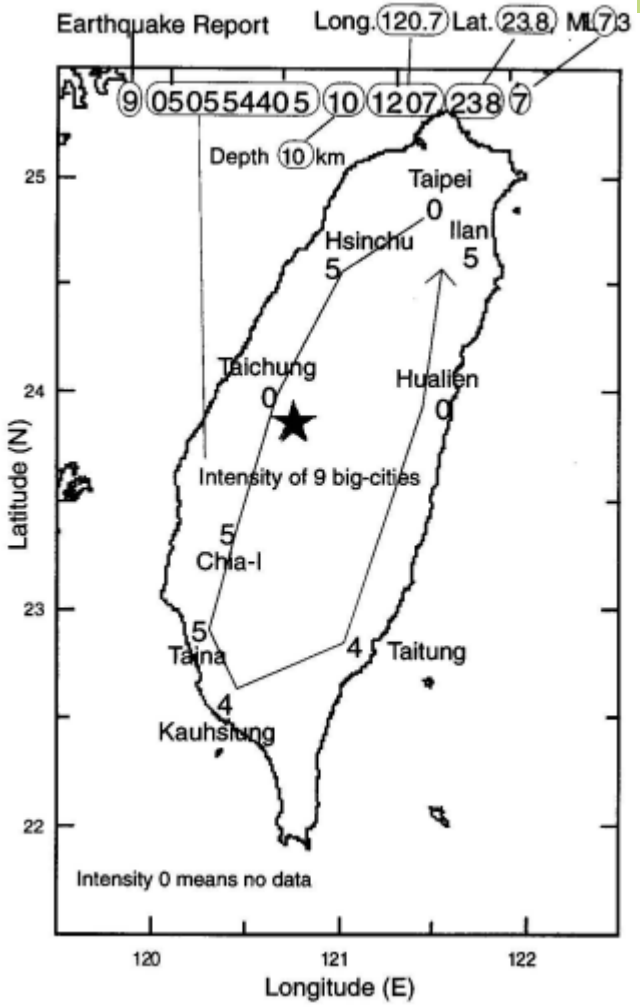
Monitoring System in the Seismological Center

From 1995 to 2002 (processing time 1 – 2 minutes)

Use strong motion sensors

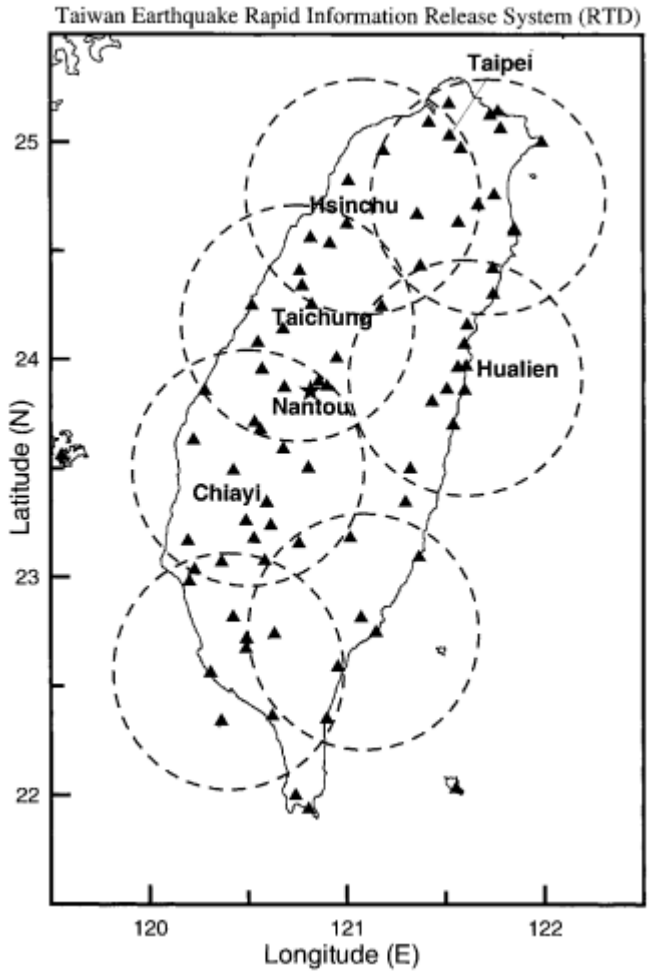


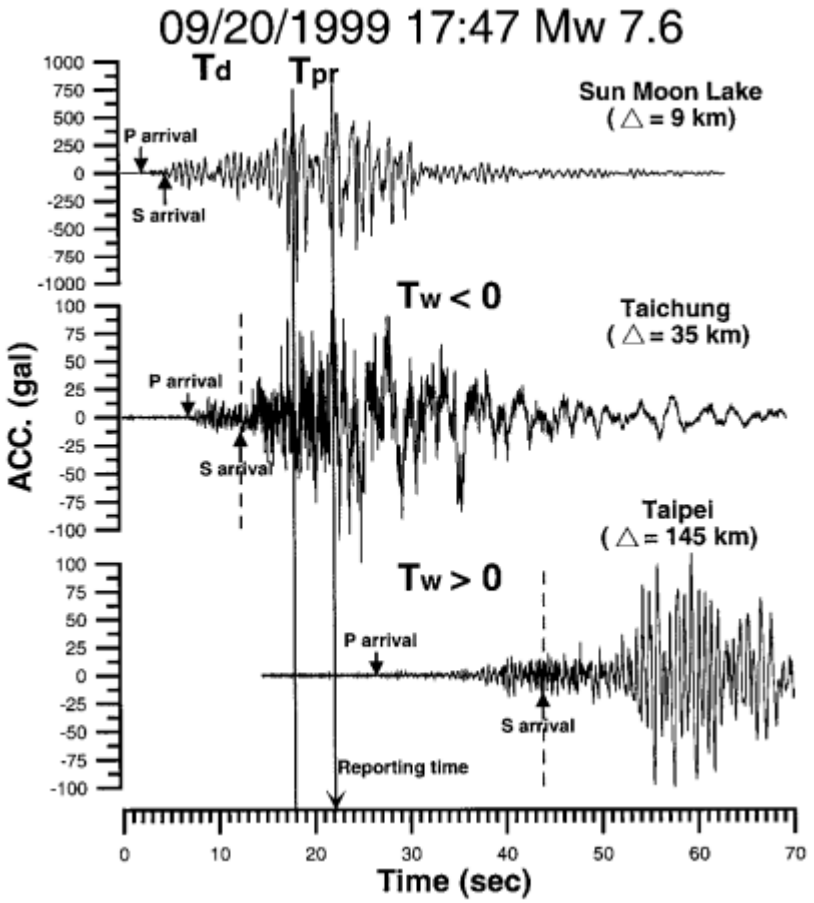


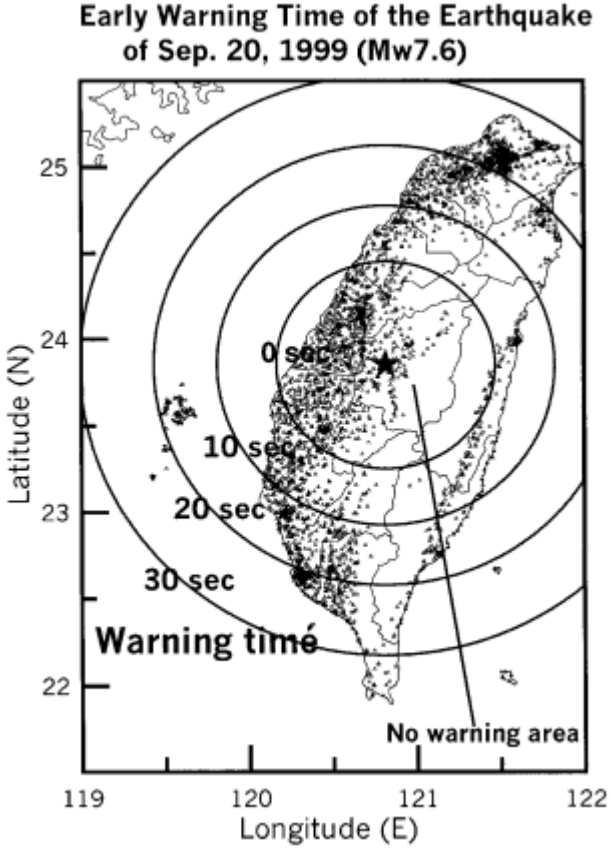


In 2002 (processing time 22s)

Applying Virtual-subnet method and ML-10 method

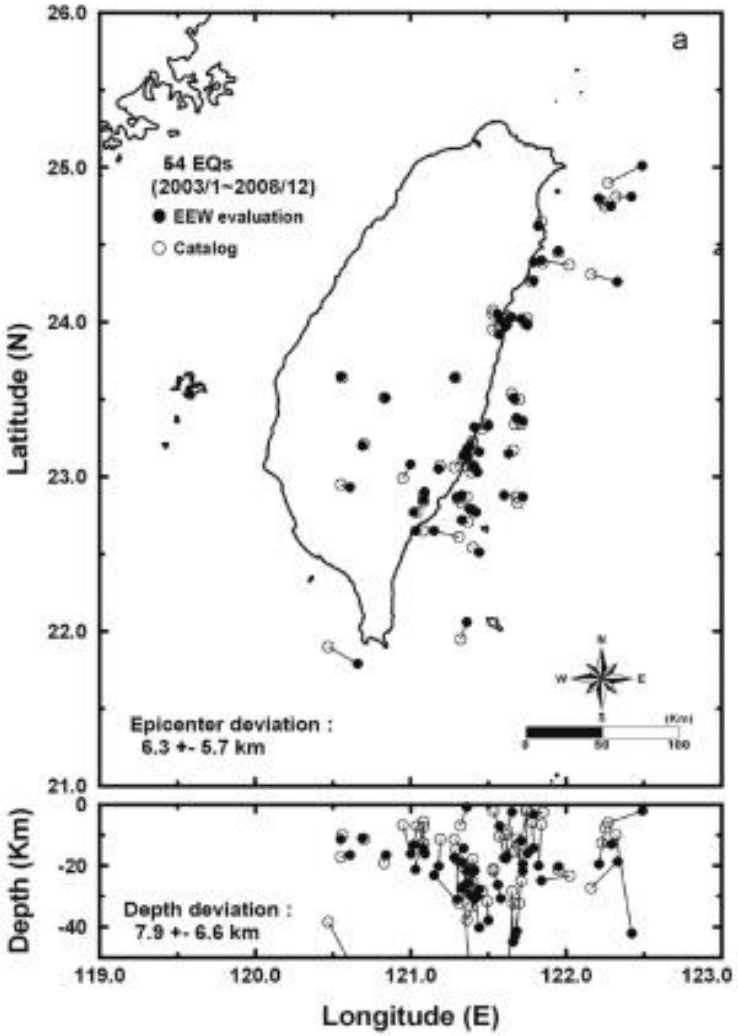


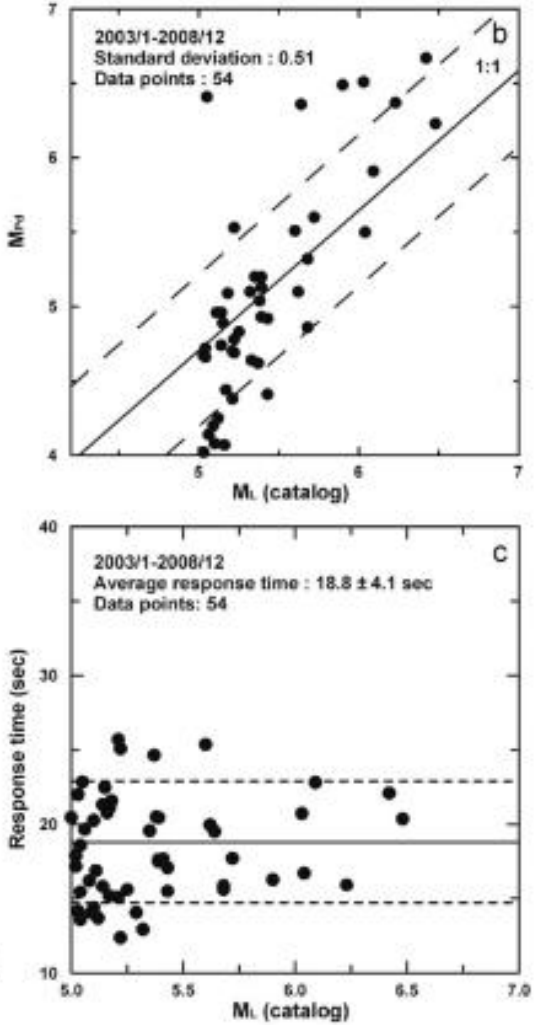


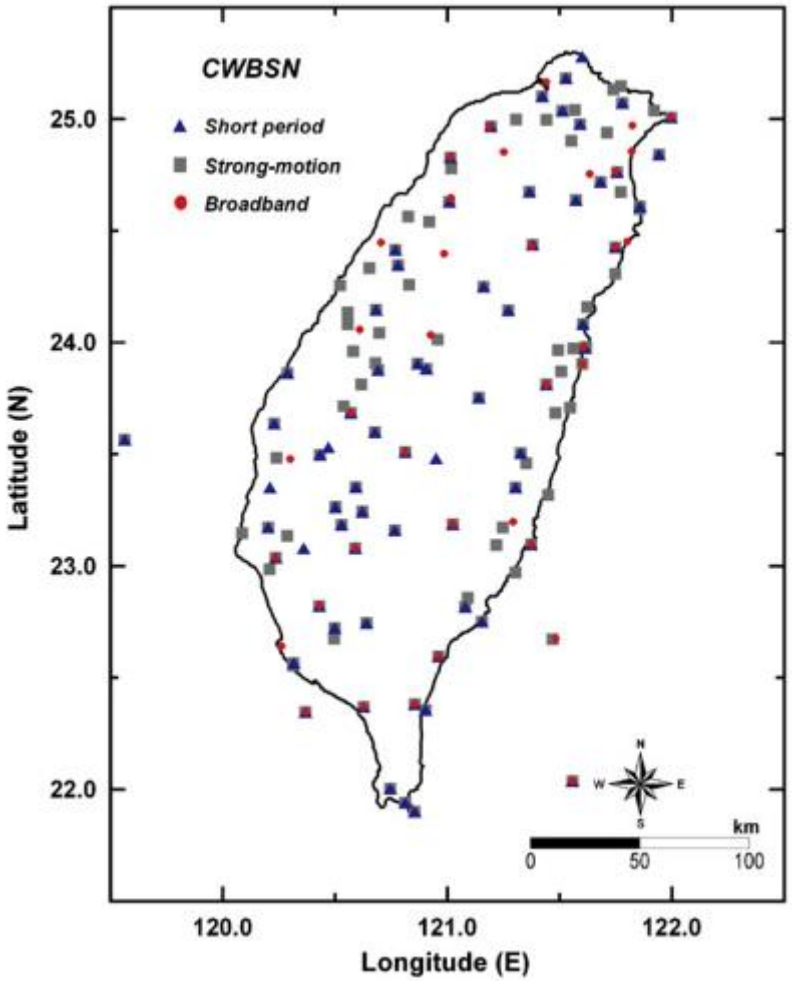


In 2012 (processing time 18s)

Incorporating different kinds of instruments



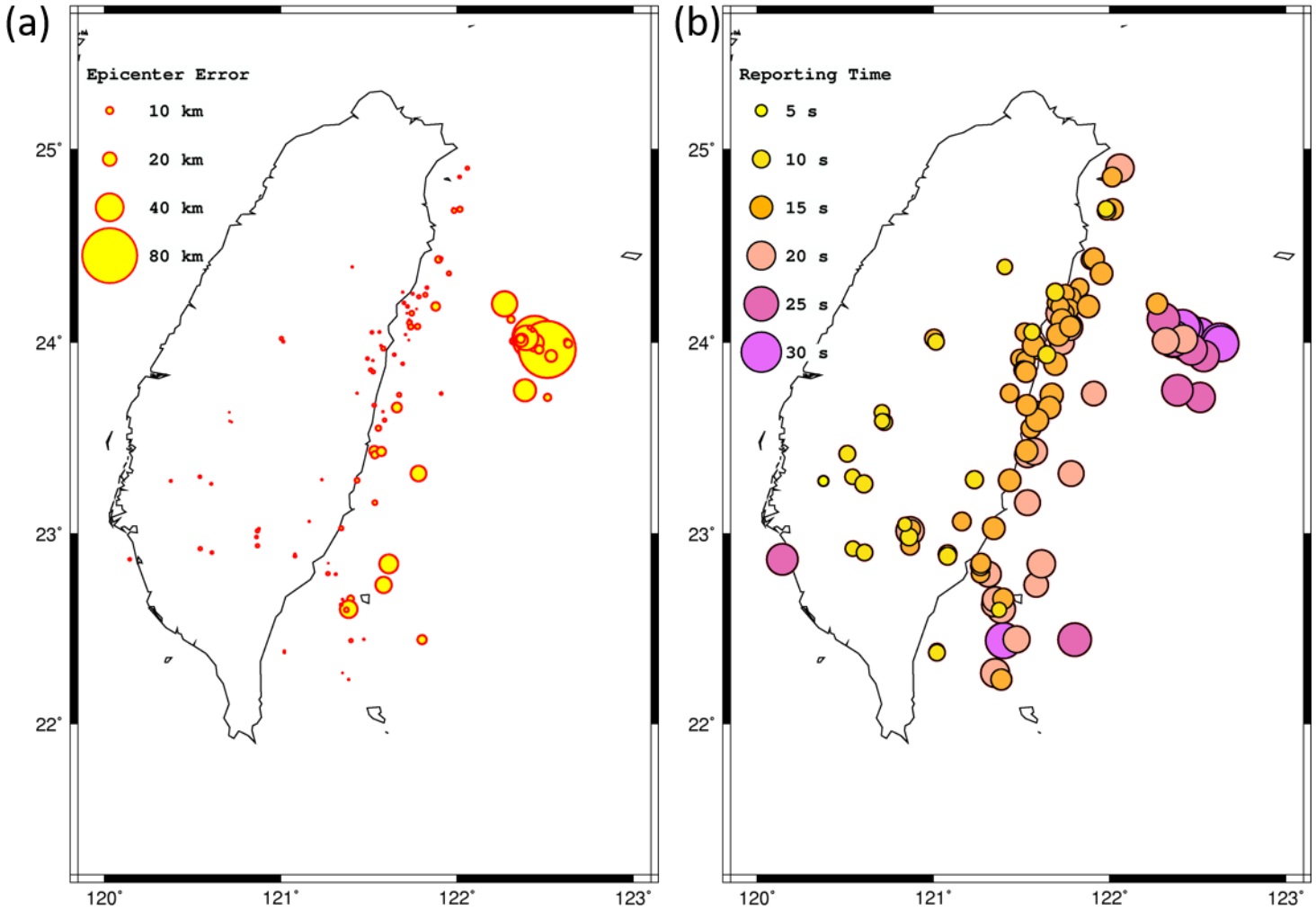




From 2014 to 2019 (processing time 15 s)

Start to issue warnings

Performance of the EEW system in CWB from 2014 to 2020



(a)shows the location error. for inland events are 2.9 km in average. for offshore events are 15.4 kn in average.

(b) shows the reporting time. for inland events are 15.3 s in average.
for offshore events are 22.6 s in average.

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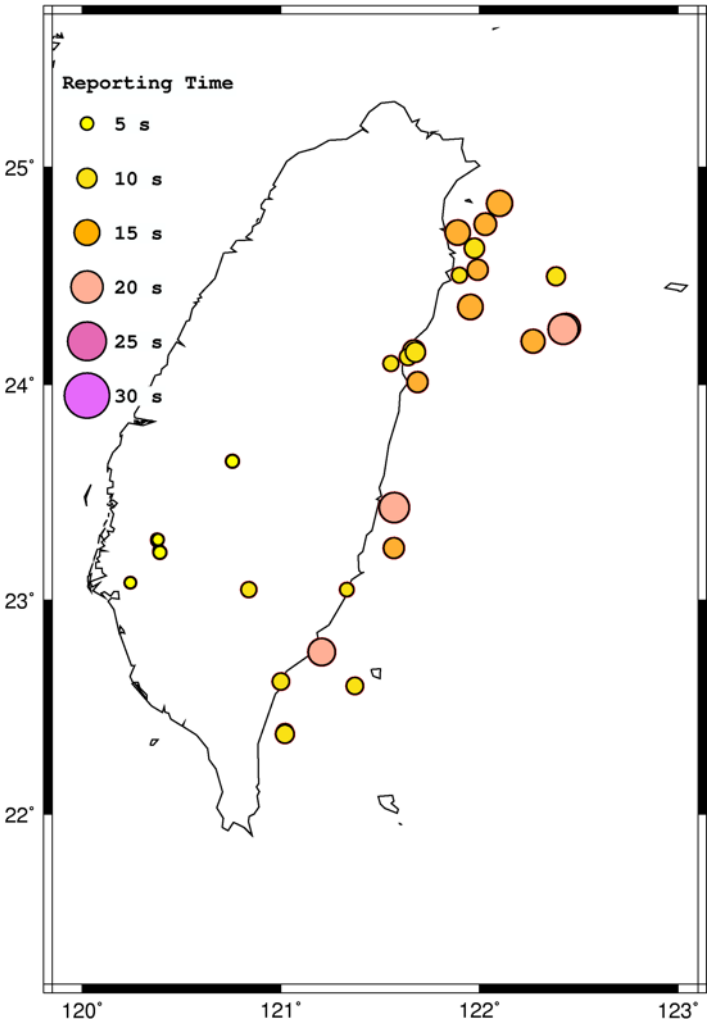
Earthquakes with magnitude larger than 5.0 and depth less than 40 km

In 2020 (processing time 10s)

Increasing number of stations
Changing method for data processing



Toward 10-sec EEW System

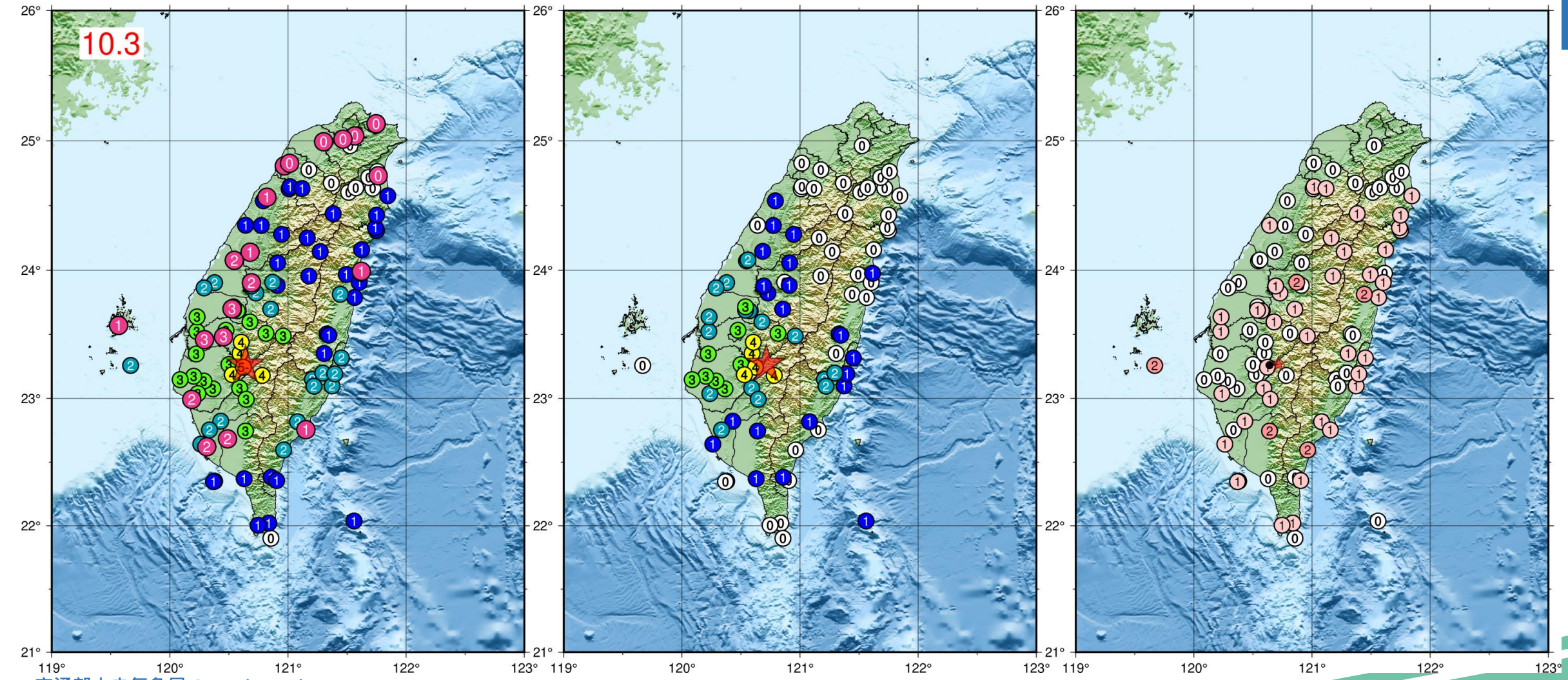
2020. Apr. 6th ~ 2020 December 31st

Reporting time of the EEW system in CWB after upgraded system.

The reporting time of the 12 inland earthquakes issued by the CWB EEW system about 10.5 s is about 10.5 s in average.

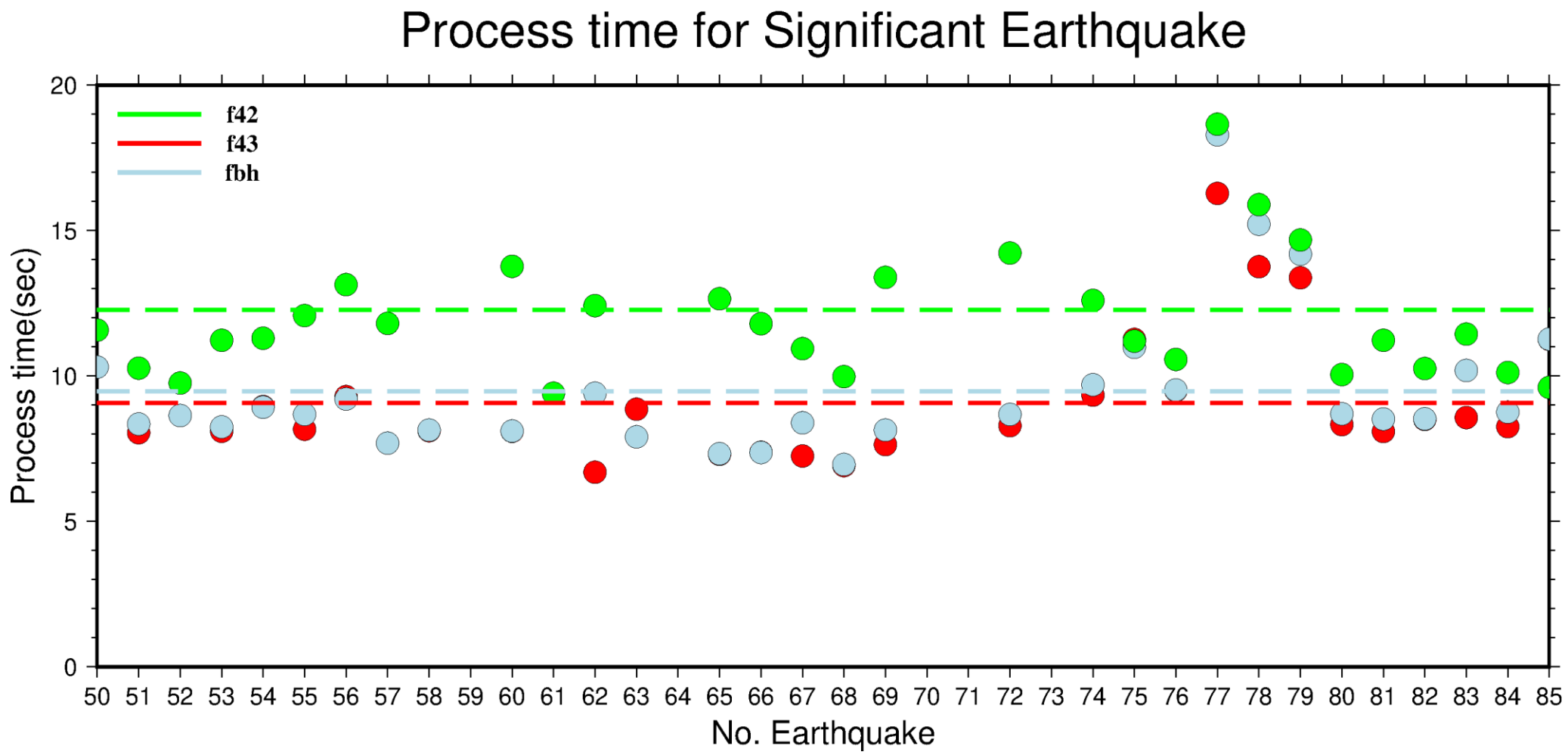
The reporting time of the 12 offshore earthquakes issued by the CWB EEW system about 10.5 s is about 18.0 s in average.

Toward 10-sec EEW System



In 2022 (processing time 7 - 9s)

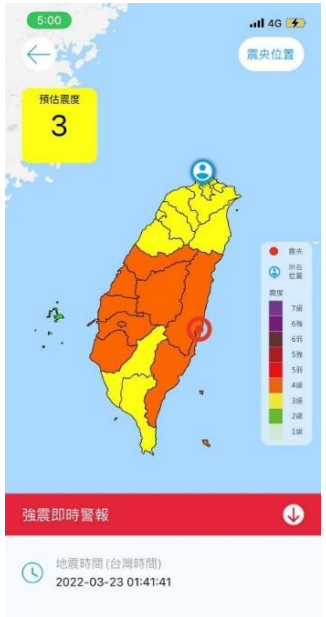
Increasing number of stations



Earthquake warnings Disseminations

▲災防告警細胞廣播訊息系統 (PWS)

▲中央氣象局地震速報訊息軟體(中小學)



▲中央氣象局APP強震即時警報

▲電視台推播地震速報資訊(TV)

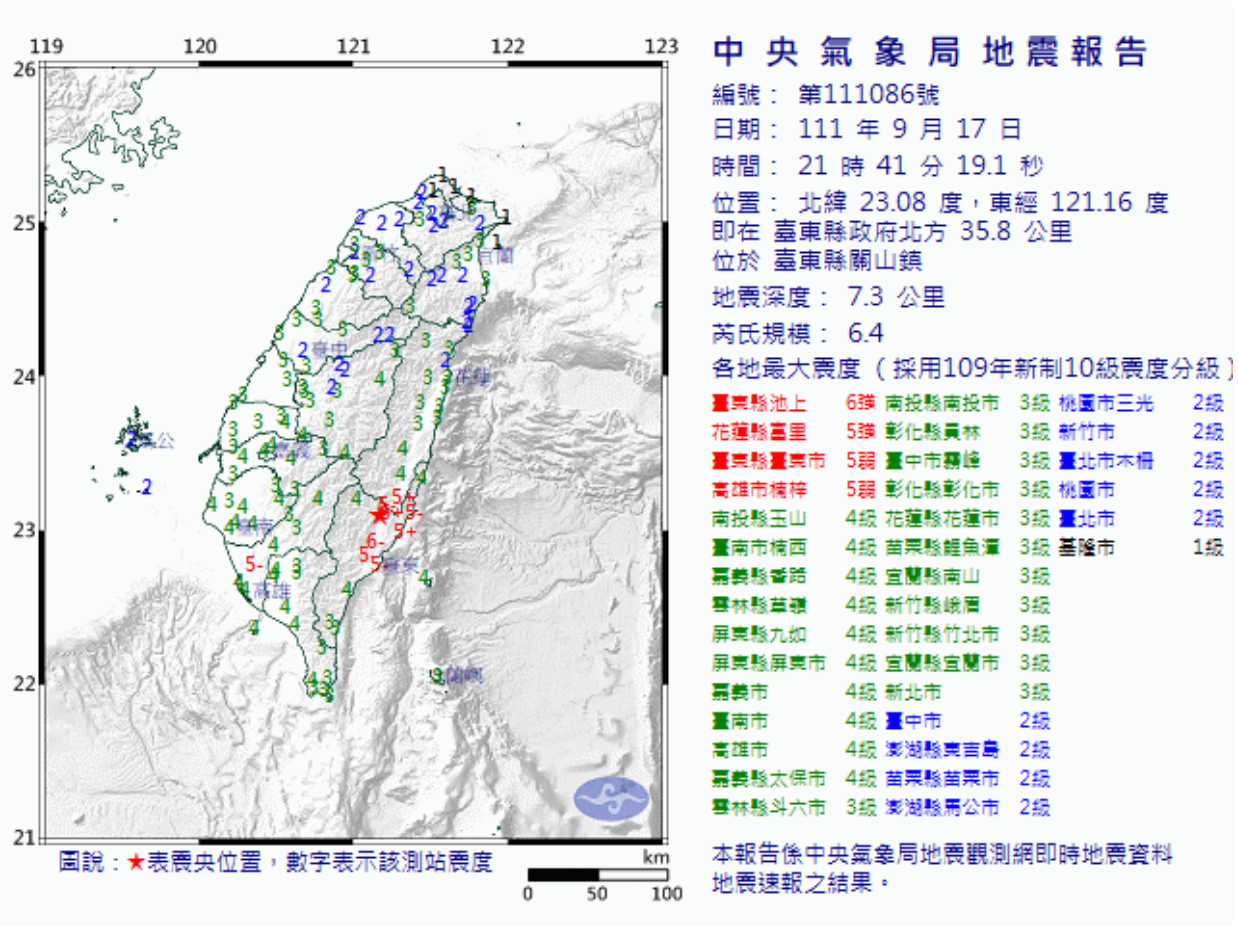
Three approaches to issue warnings for public

PWS — Predicted Magnitude **5.0** and Predicted Intensity **4**

Television — Predicted Magnitude **5.0** and Predicted Intensity **3**

Internet — Predicted Magnitude **4.5** and Predicted Intensity **3**

Public Warning System



中 央 氣 象 局 地 震 報 告

編號： 第111086號
日期： 111 年 9 月 17 日
時間： 21 時 41 分 19.1 秒
位置： 北緯 23.08 度，東經 121.16 度
即在 臺東縣政府北方 35.8 公里
位於 臺東縣關山鎮
地震深度： 7.3 公里
芮氏規模： 6.4
各地最大震度（採用109年新制10級震度分級）

臺東縣池上	6強	南投縣南投市	3級	桃園市三光	2級
花蓮縣富里	5強	彰化縣員林	3級	新竹市	2級
臺東縣臺東市	5弱	臺中市霧峰	3級	臺北市木柵	2級
高雄市楠梓	5弱	彰化縣彰化市	3級	桃園市	2級
南投縣玉山	4級	花蓮縣花蓮市	3級	臺北市	2級
臺南市楠西	4級	苗栗縣鯉魚潭	3級	基隆市	1級
嘉義縣番路	4級	宜蘭縣南山	3級		
雲林縣草嶺	4級	新竹縣峨眉	3級		
屏東縣九如	4級	新竹縣竹北市	3級		
屏東縣屏東市	4級	宜蘭縣宜蘭市	3級		
嘉義市	4級	新北市	3級		
臺南市	4級	臺中市	2級		
高雄市	4級	澎湖縣東吉島	2級		
嘉義縣太保市	4級	苗栗縣苗栗市	2級		
雲林縣斗六市	3級	澎湖縣馬公市	2級		

本報告係中央氣象局地震觀測網即時地震資料地震速報之結果。

09 月 17 日 21 時 41 分發佈地震速報，持續時間至 09 月 17 日 21 時 44 分；影響區域如下圖

失效時間 2022-09-17 21:44:26

建議作為

預估接收人數 ≤ 100 (以2022/09/23 12:40資料推估)

https://cbs.tw/alert

False Alarm

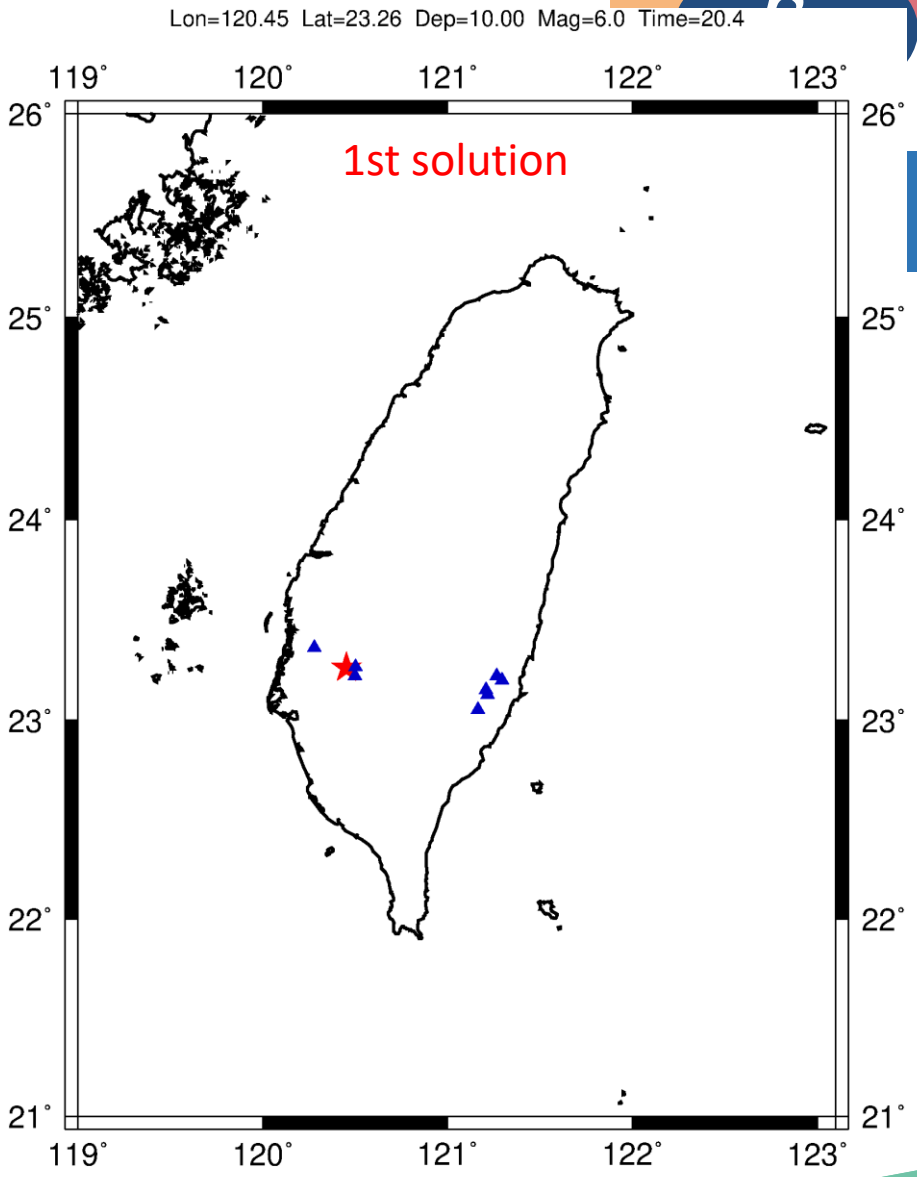
09 月 18 日 20 時 44 分發佈地震速報，持續時間至 09 月 18 日 20 時 47 分；影響區域如下圖

失效時間　2022-09-18 20:47:47

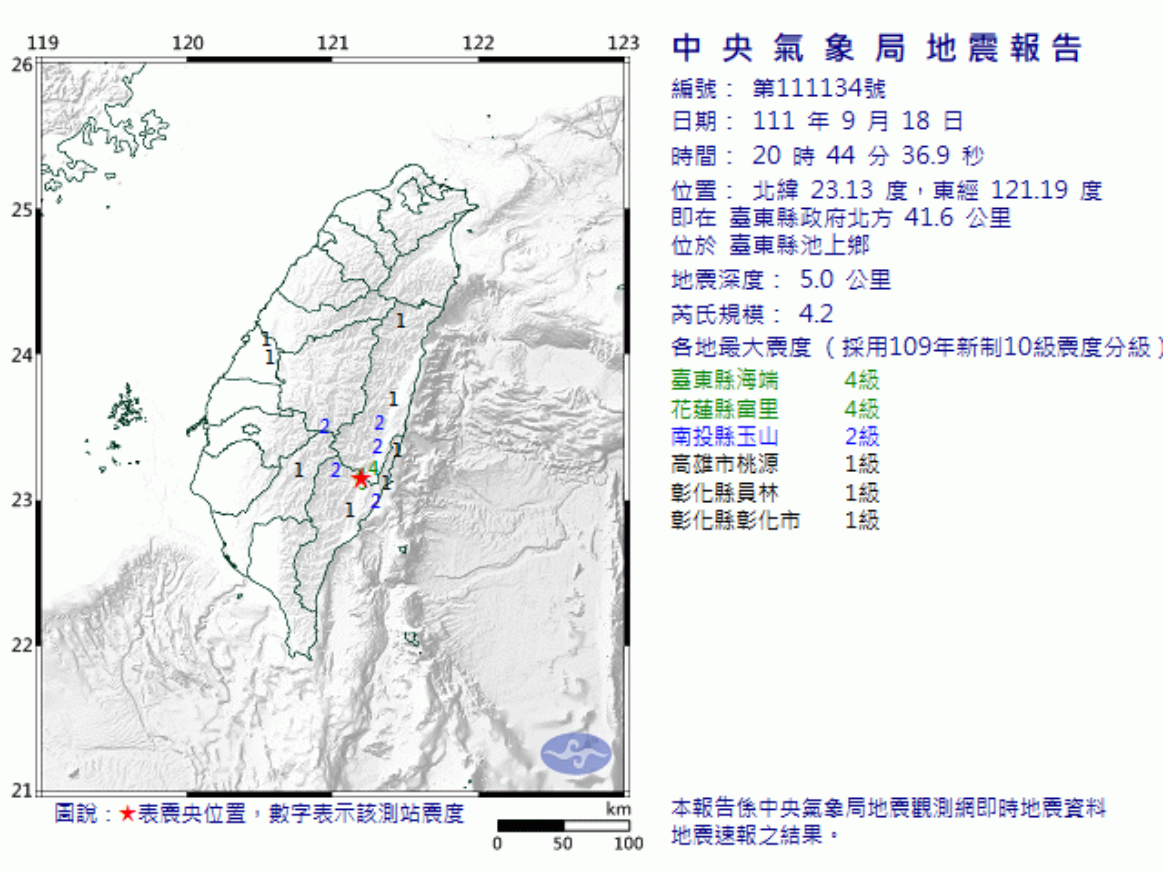
建議作為

預估接收人數 ≤ 100 (以2022/09/23 12:40資料推估)

1. September 18th, at 20:18，two earthquakes occurred simultaneously,，one in Tainan with smaller magnitude (about 2.0), One in Taitung with larger magnitude (about 4.0).
2. All P phases from two events were well recognized。
3. The EEW system associated all phases and considered them from one single event.
4. Unfortunately, the epicenter was located at Tainan, by using the Geiger's method with low RMS value (<0.8s).
5. Therefore in Tainan area the apparent magnitudes are all small. In Taitung area the apparent magnitudes are all large, which were close to 6.0.



False Alarm

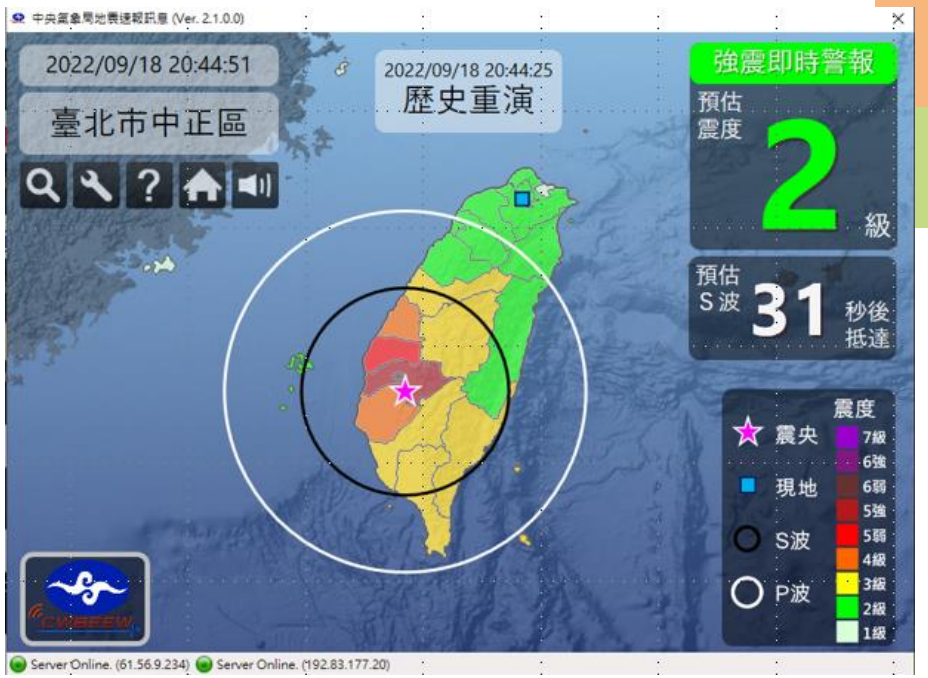


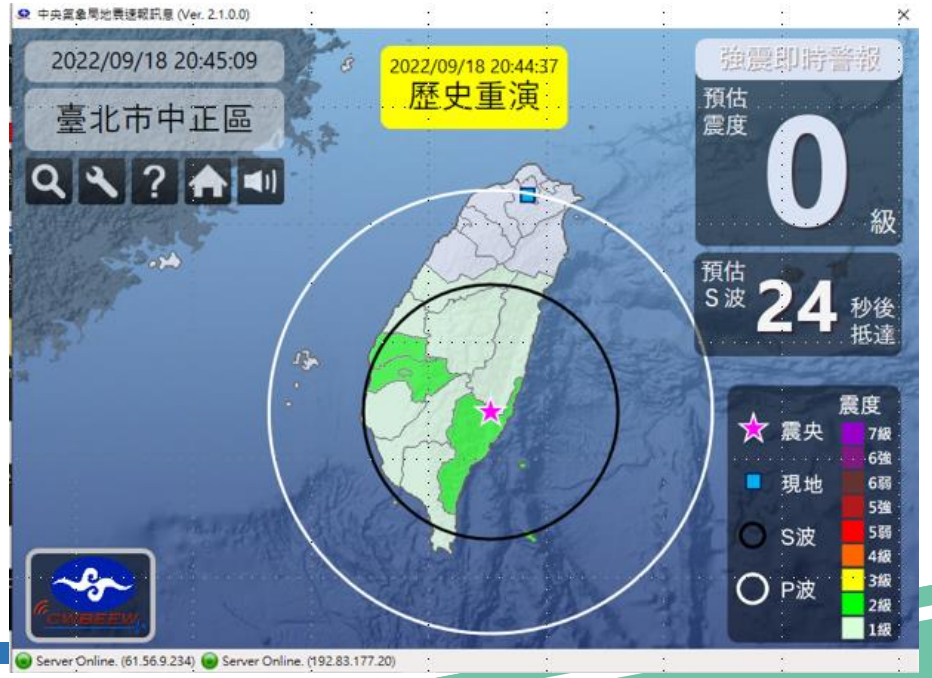
中 央 氣 象 局 地 震 報 告

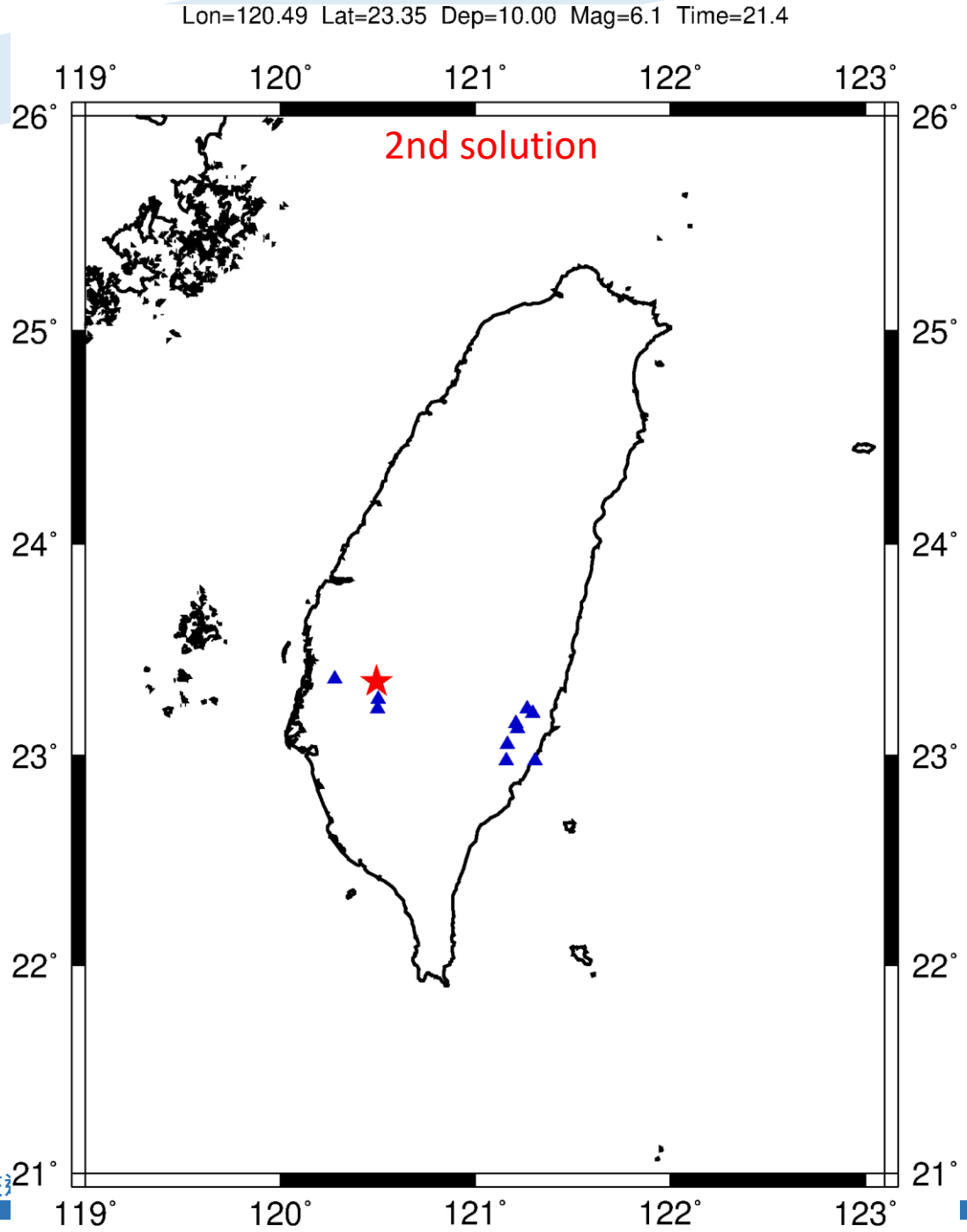
編號： 第111134號
日期： 111 年 9 月 18 日
時間： 20 時 44 分 36.9 秒
位置： 北緯 23.13 度，東經 121.19 度
即在 臺東縣政府北方 41.6 公里
位於 臺東縣池上鄉
地震深度： 5.0 公里
芮氏規模： 4.2
各地最大震度（採用109年新制10級震度分級）

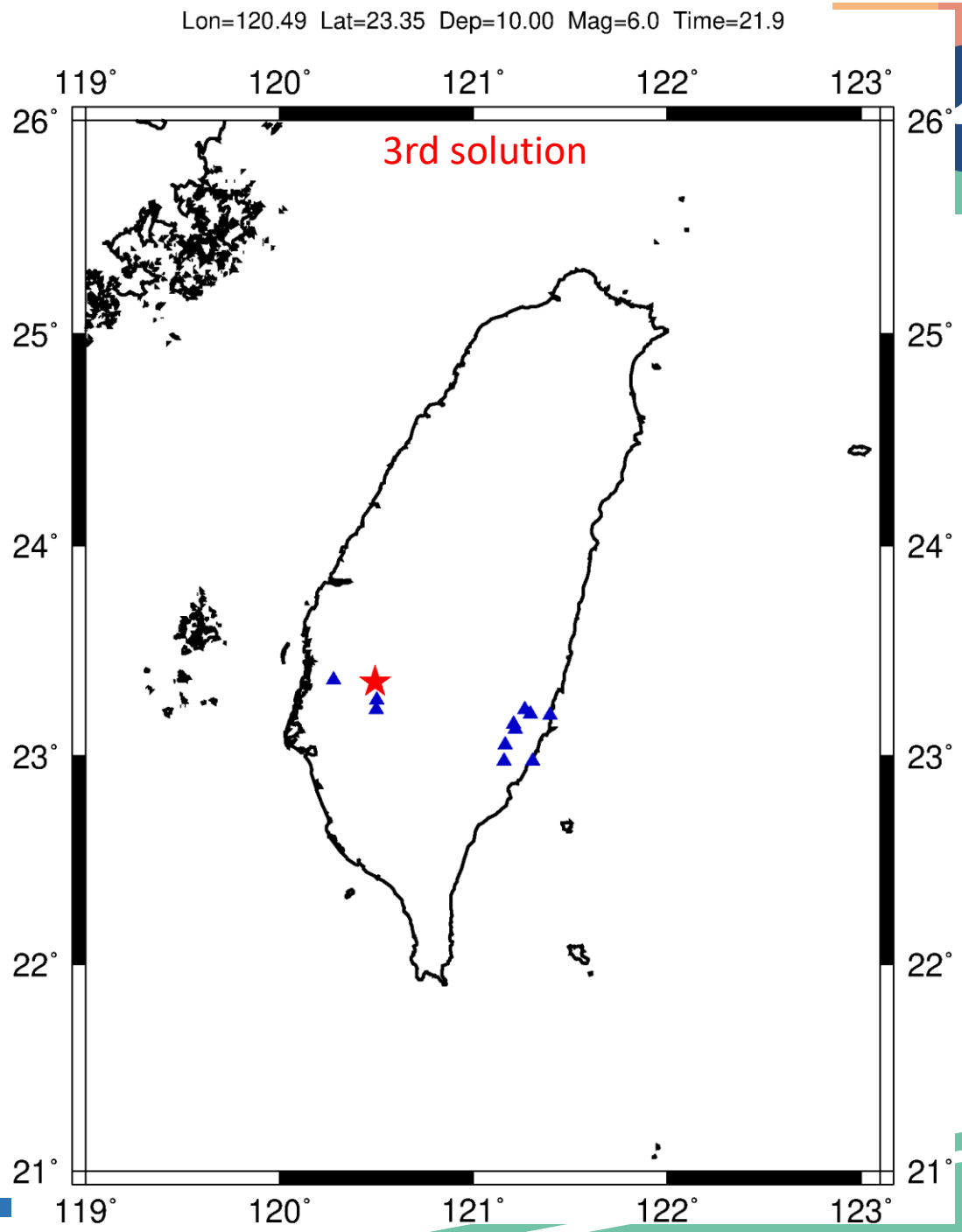
臺東縣海端	4級
花蓮縣富里	4級
南投縣玉山	2級
高雄市桃源	1級
彰化縣員林	1級
彰化縣彰化市	1級

本報告係中央氣象局地震觀測網即時地震資料地震速報之結果。

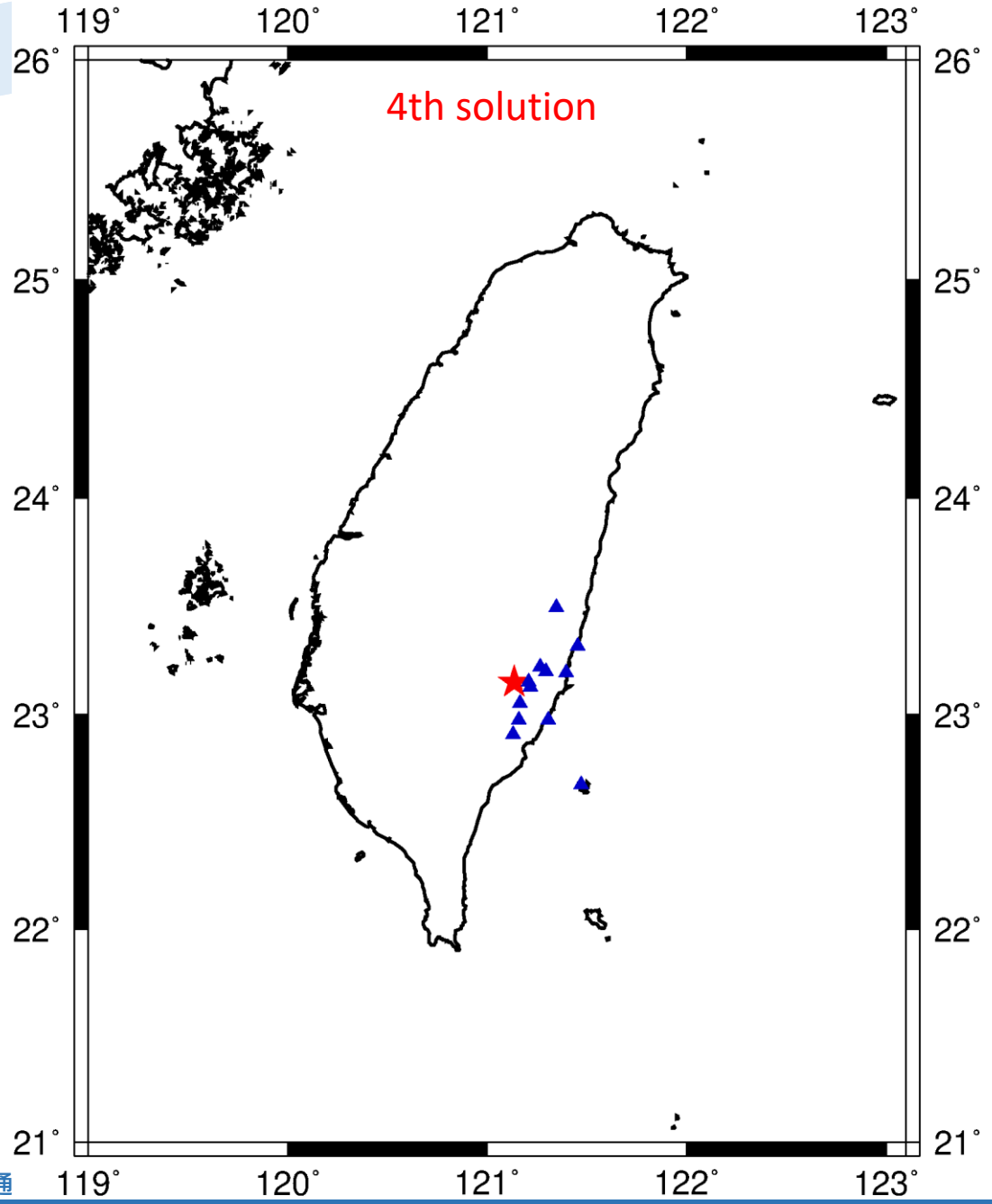




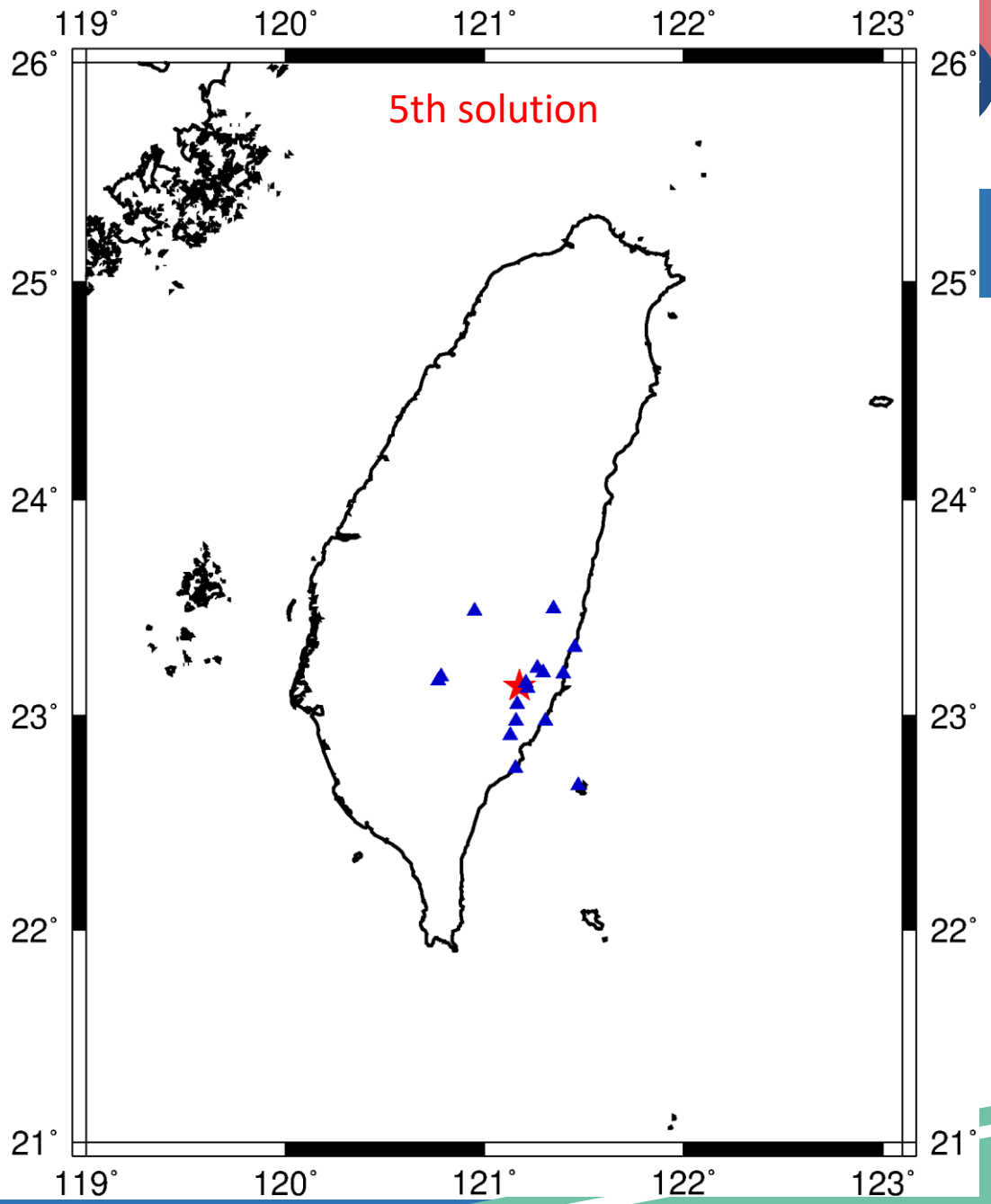

Lon=120.49 Lat=23.35 Dep=10.00 Mag=6.1 Time=21.4
2nd solution
119˚
120˚
121˚
122˚
123˚
26˚
25˚
24˚
23˚
22˚
21˚


Lon=120.49 Lat=23.35 Dep=10.00 Mag=6.0 Time=21.9
3rd solution
119˚
120˚
121˚
122˚
123˚
26˚
25˚
24˚
23˚
22˚
21˚

Lon=121.14 Lat=23.15 Dep=10.00 Mag=4.3 Time=14.7



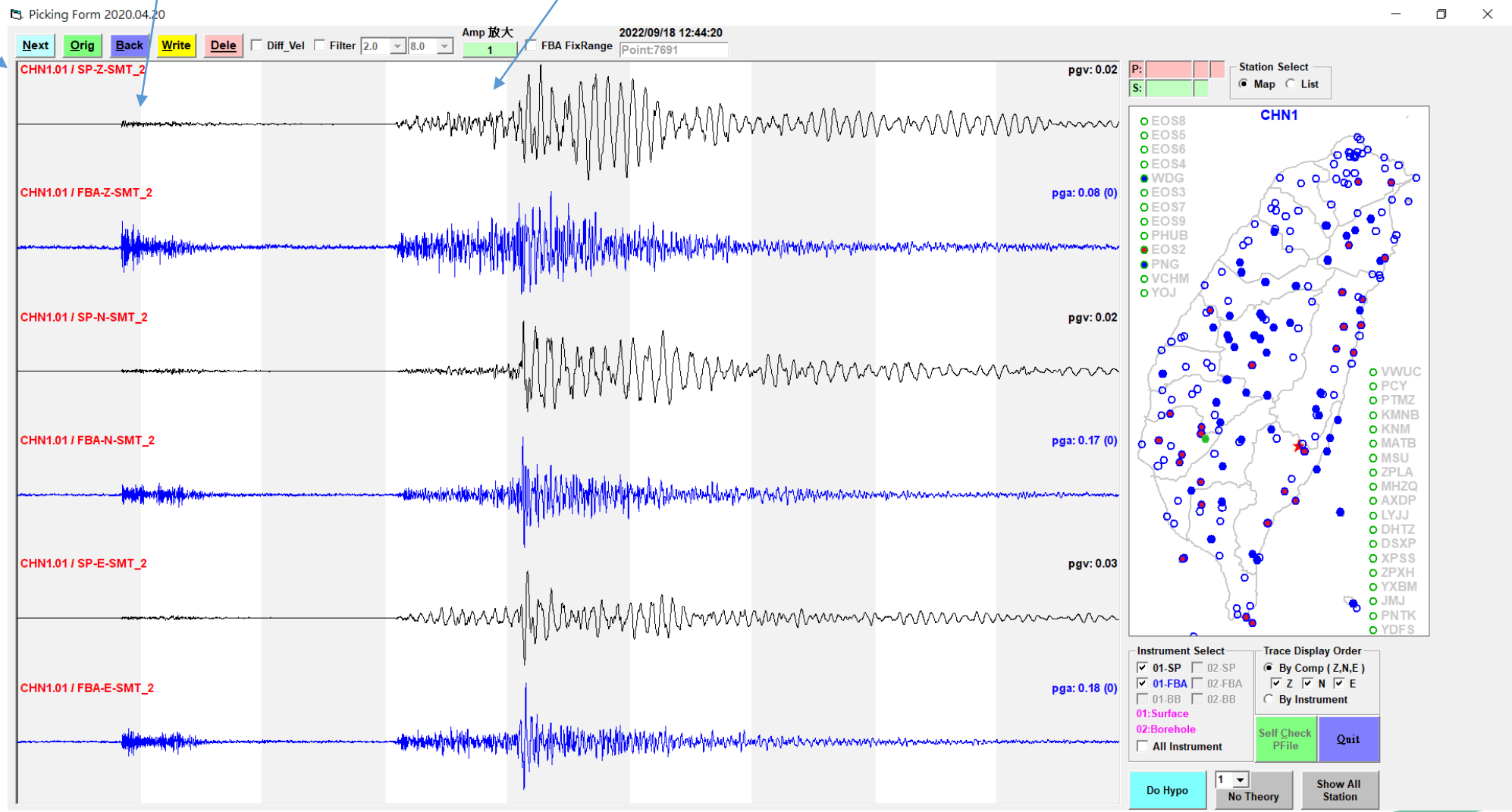
Lon=121.18 Lat=23.13 Dep=10.00 Mag=4.1 Time=15.2



An Earthquake in Tainan

An Earthquake in Taitung

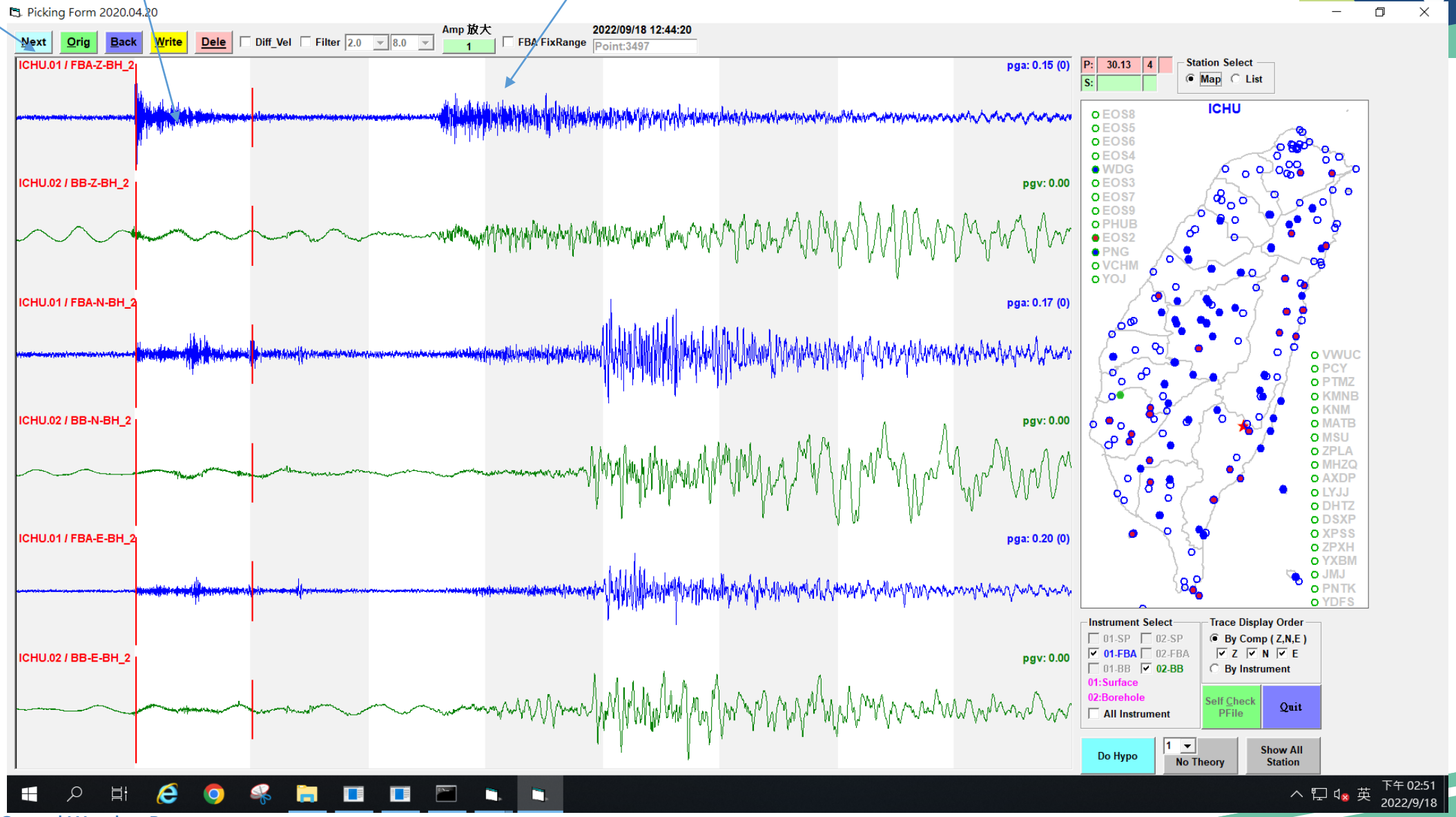
Station in Tainan



Station in Tainan

An Earthquake in Tainan

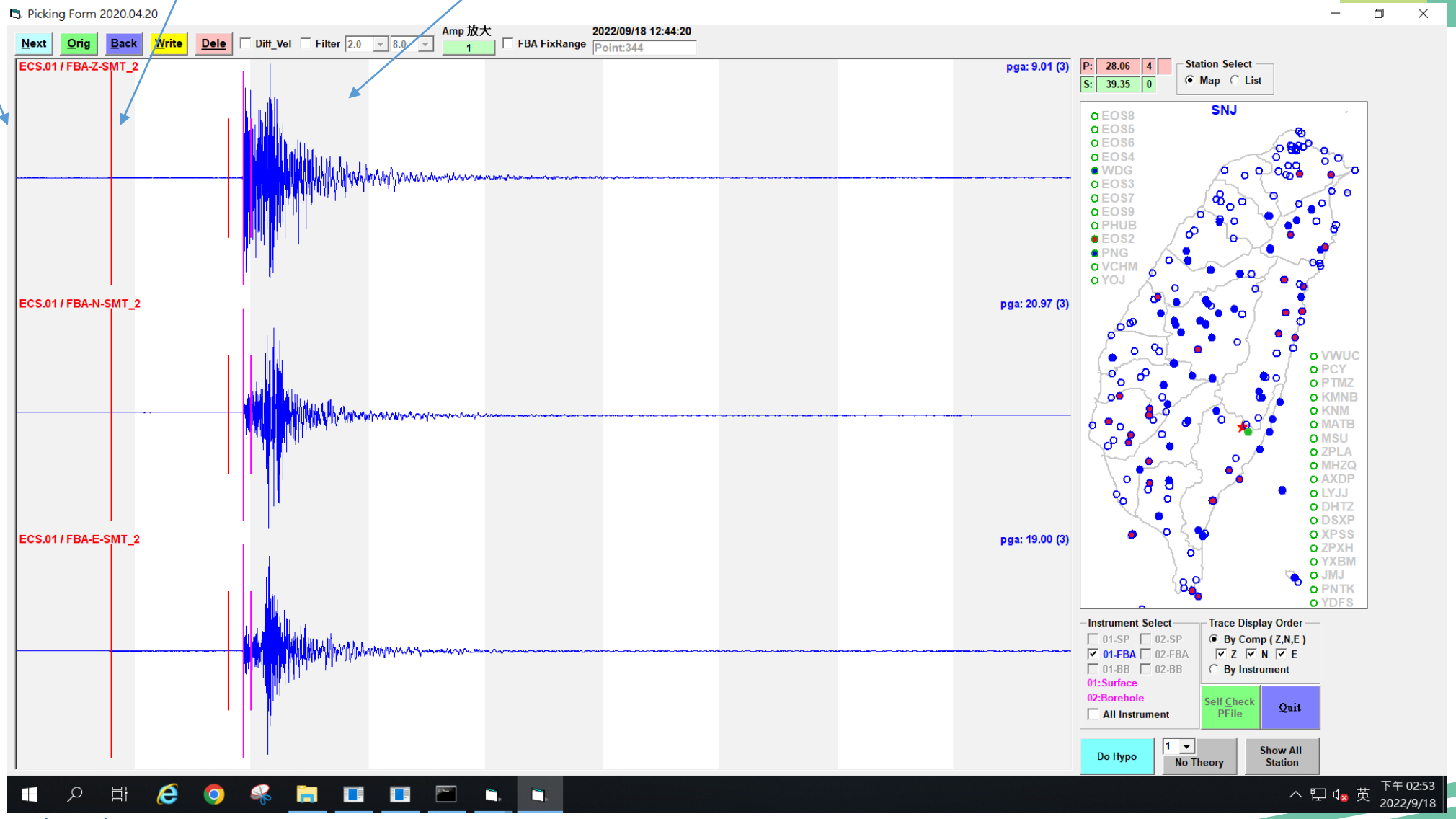
An Earthquake in Taitung



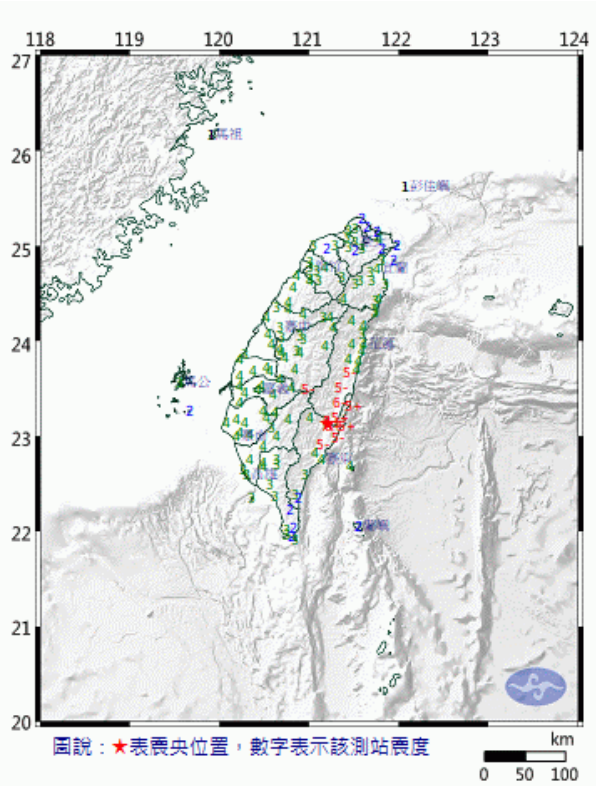
Station in Taitung

Almost cannot see Tainan earthquake

An Earthquake in Taitung



Underestimate Magnitude



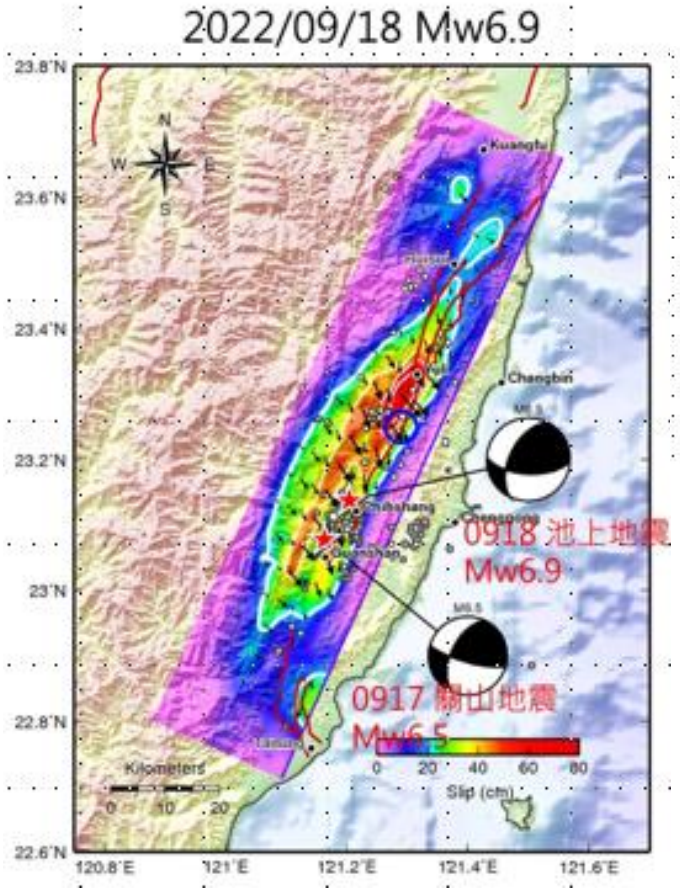
圖說：★表震央位置，數字表示該測站震度

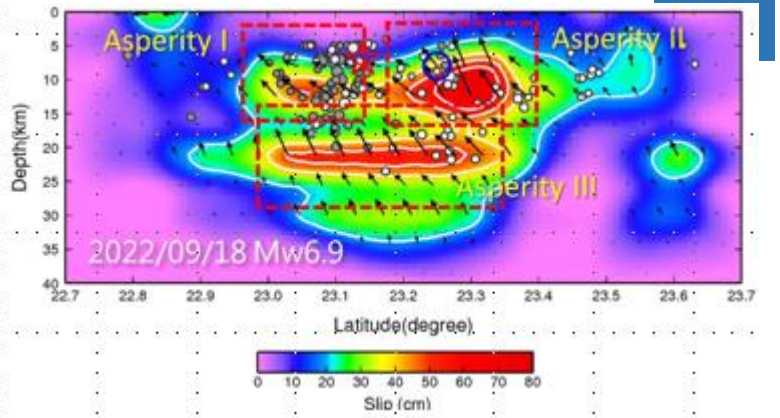
中 央 氣 象 局 地 震 報 告

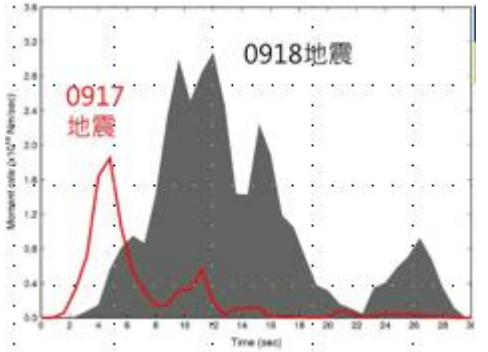
編號： 第111111號
日期： 111 年 9 月 18 日
時間： 14 時 44 分 15.2 秒
位置： 北緯 23.14 度，東經 121.2 度
即在 臺東縣政府北方 42.7 公里
位於 臺東縣池上鄉
地震深度： 7.0 公里
芮氏規模： 6.8
各地最大震度（採用109年新制10級震度分級）

臺東縣池上	6強	嘉義縣太保市	4級	新竹縣竹北市	3級
花蓮縣玉里	6弱	臺中市梨山	4級	桃園市	3級
南投縣玉山	5弱	花蓮縣花蓮市	4級	新北市	3級
臺東縣臺東市	4級	彰化縣彰化市	4級	臺北市	3級
嘉義縣阿里山	4級	苗栗縣鯉魚潭	4級	基隆市	2級
高雄市六龜	4級	宜蘭縣南山	4級	連江縣馬祖	1級
臺南市楠西	4級	苗栗縣苗栗市	4級		
雲林縣草嶺	4級	新竹縣關西	4級		
屏東縣九如	4級	宜蘭縣宜蘭市	4級		
嘉義市	4級	新北市五分山	4級		
屏東縣屏東市	4級	高雄市	3級		
雲林縣斗六市	4級	臺中市	3級		
南投縣南投市	4級	桃園市三光	3級		
臺南市	4級	澎湖縣馬公市	3級		
彰化縣員林	4級	新竹市	3級		

本報告係中央氣象局地震觀測網即時地震資料地震速報之結果。

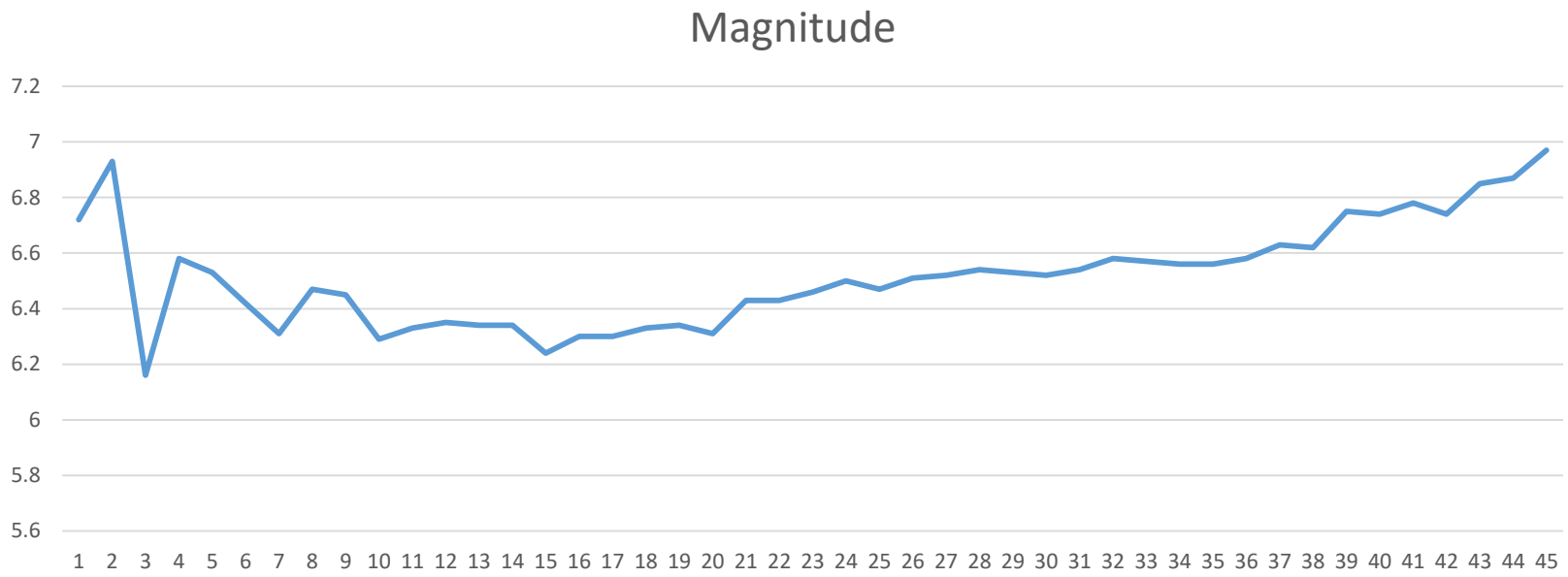






(李憲忠，2022)

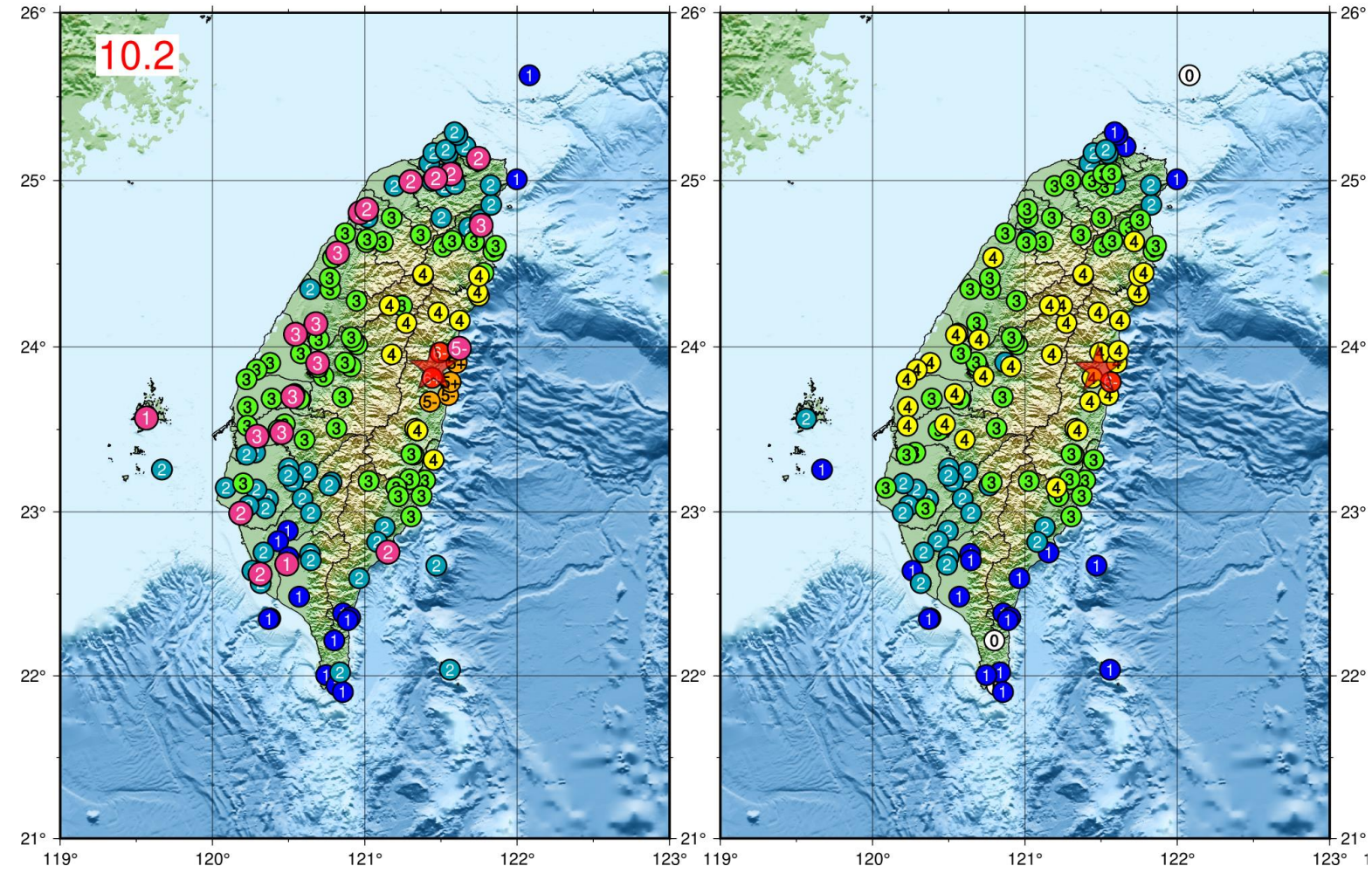
Underestimate Magnitude



The rupture time is about 25 s and rupture is about 60 km
The EEW system only used few seconds of P wave from few nearby stations.

If we took enough length of P-wave time window and used far enough stations, the magnitude could be estimated around 6.8.

Problems We Met



Problem List

Feel shaking but no warning
Feel shaking but get delayed warning
No shaking but get warning

Earthquakes occurred simultaneously

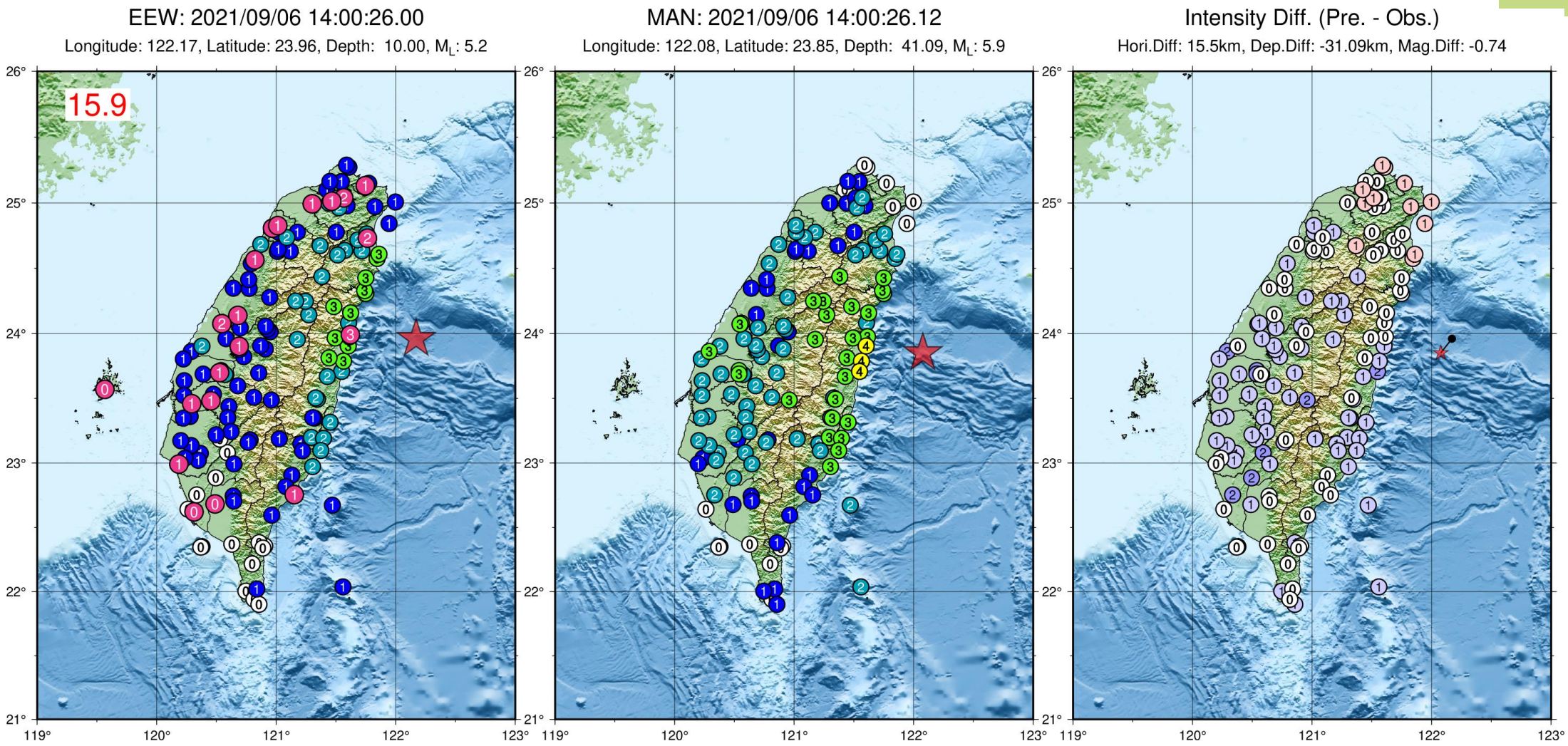
Communication delay

Offshore or deep earthquake location

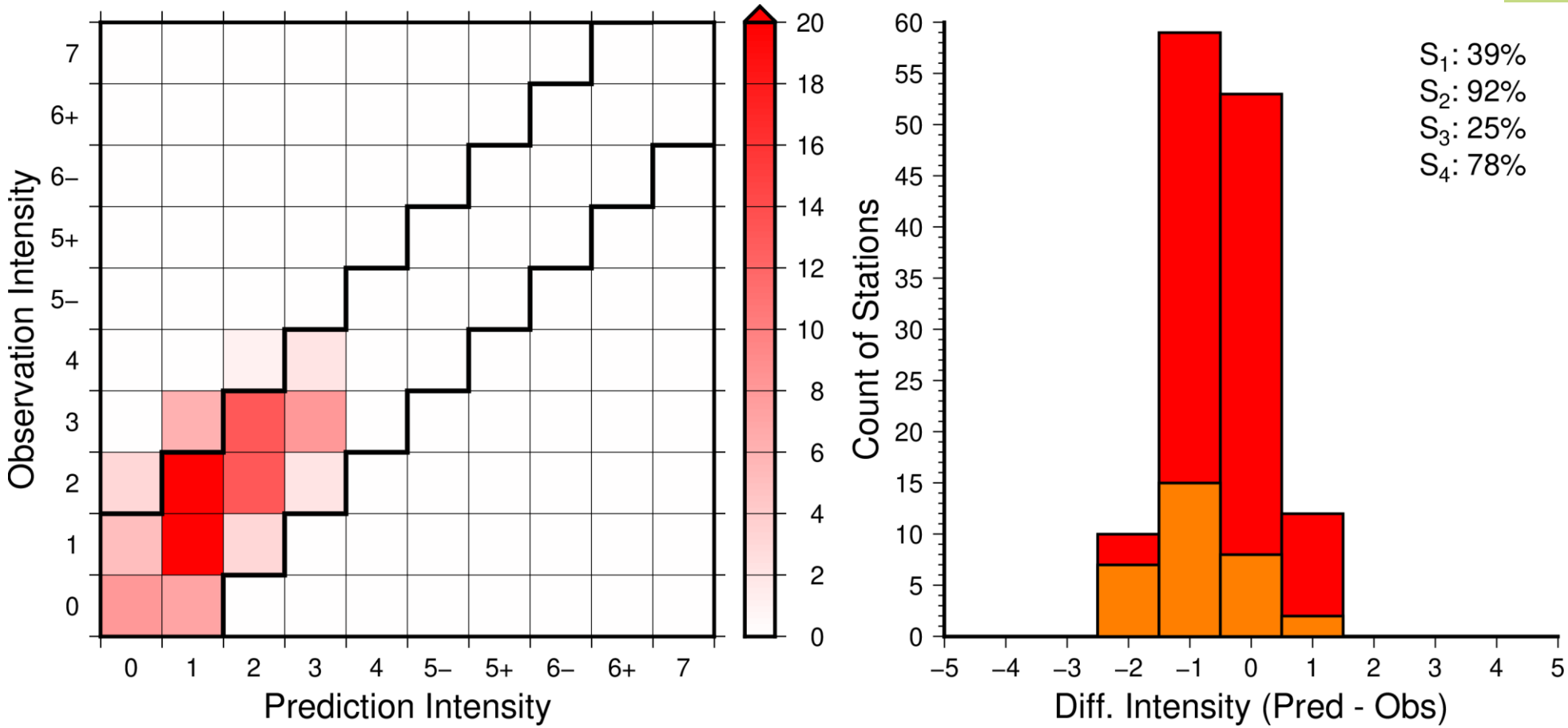
Threshold of the warning ?

Accuracy predicted intensity and magnitude ?

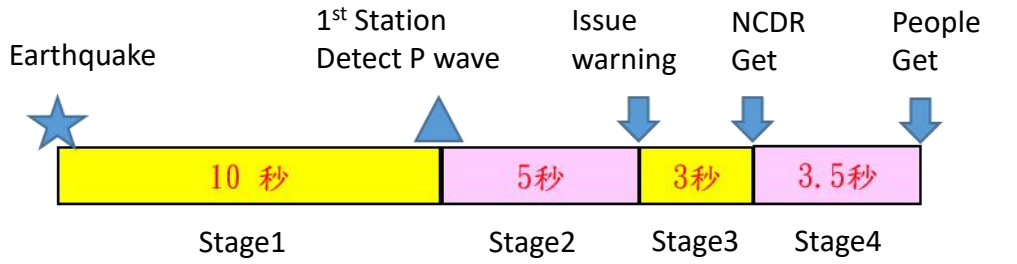
Difficult to predict Intensities 100% correctly

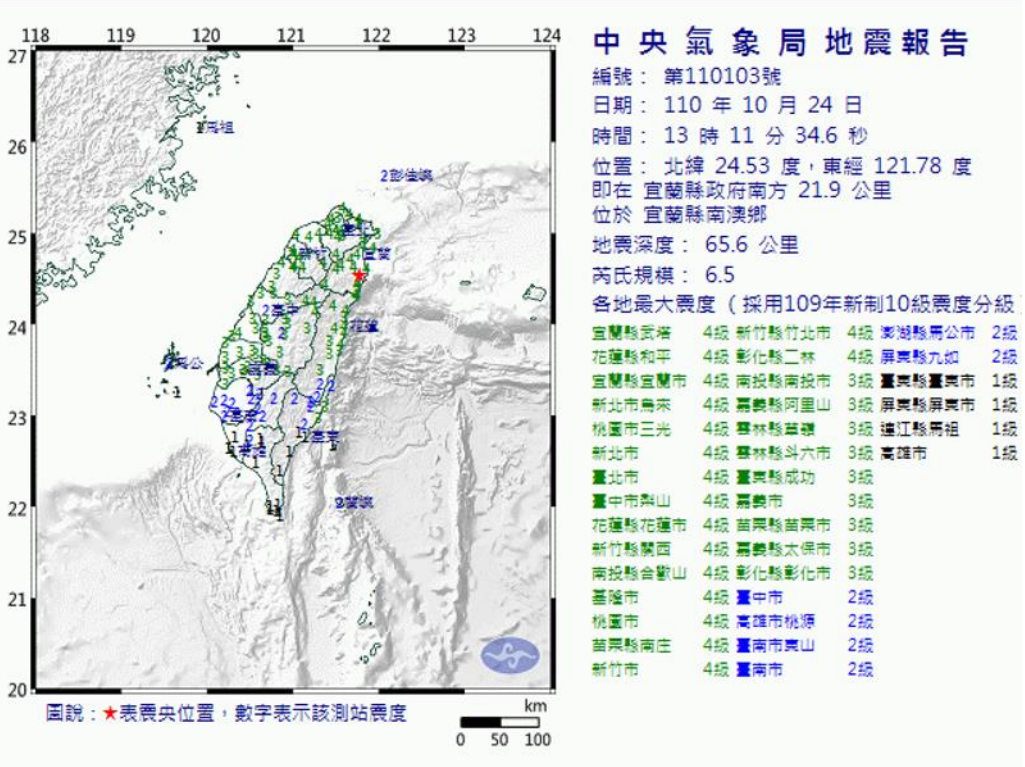


Difficult to predict Intensities 100% correctly

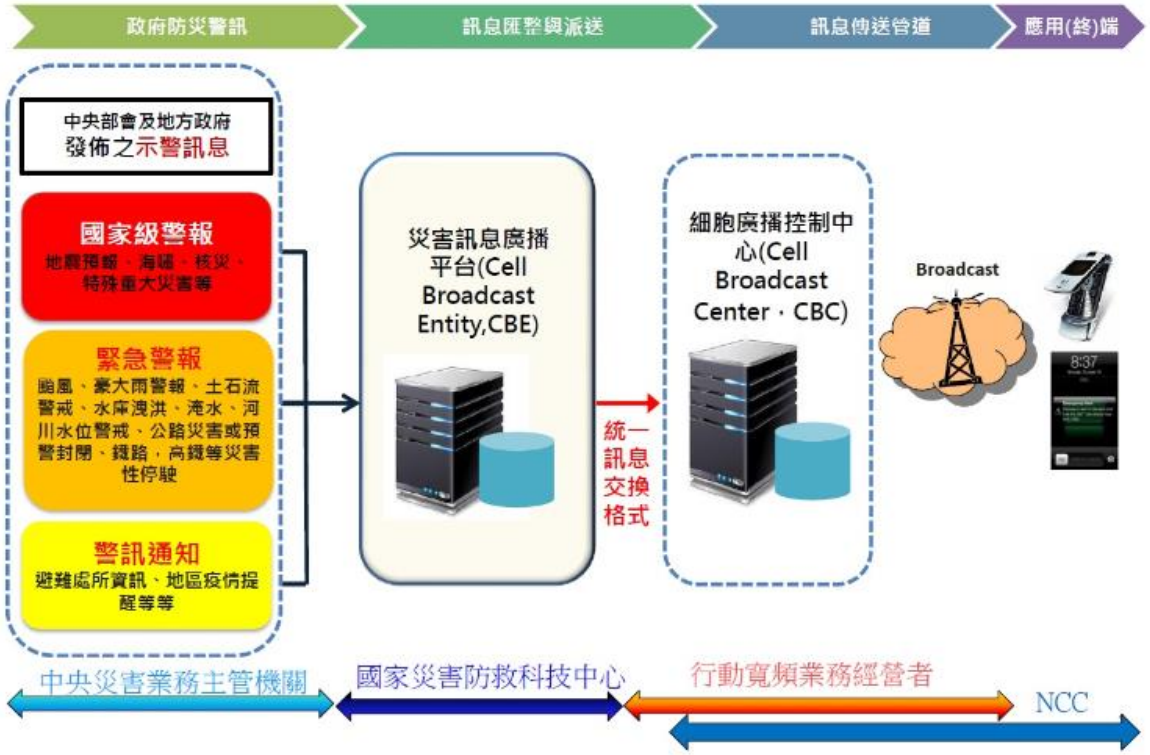


Four steps to issue warnings for the public





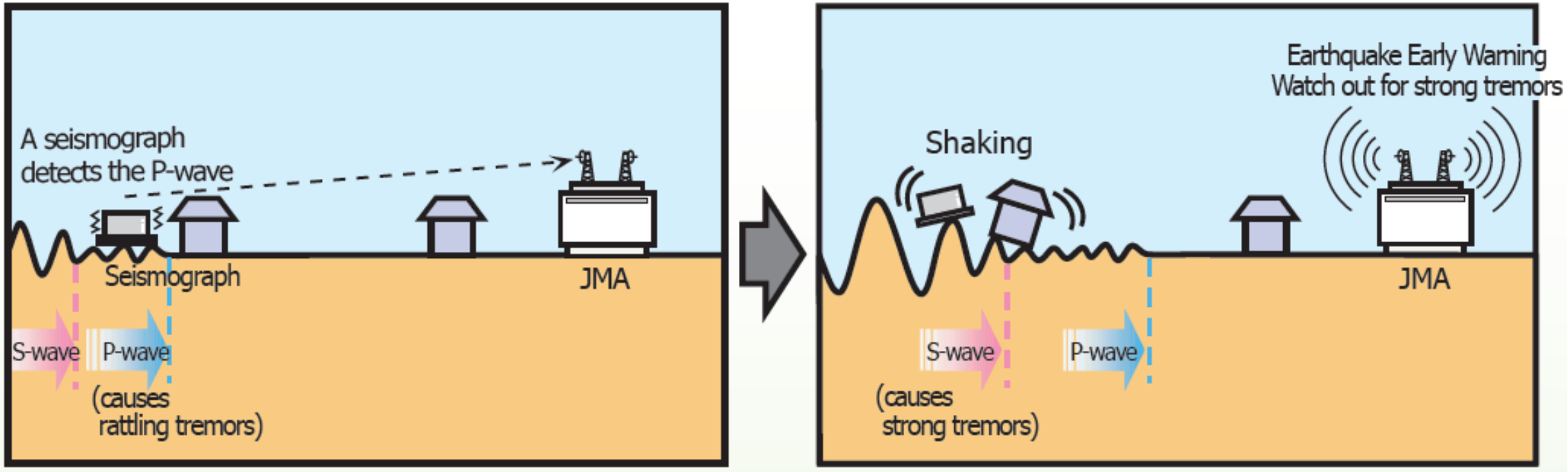
Public Warning System (PWS)



Concept of the Earthquake Early Warning (EEW)

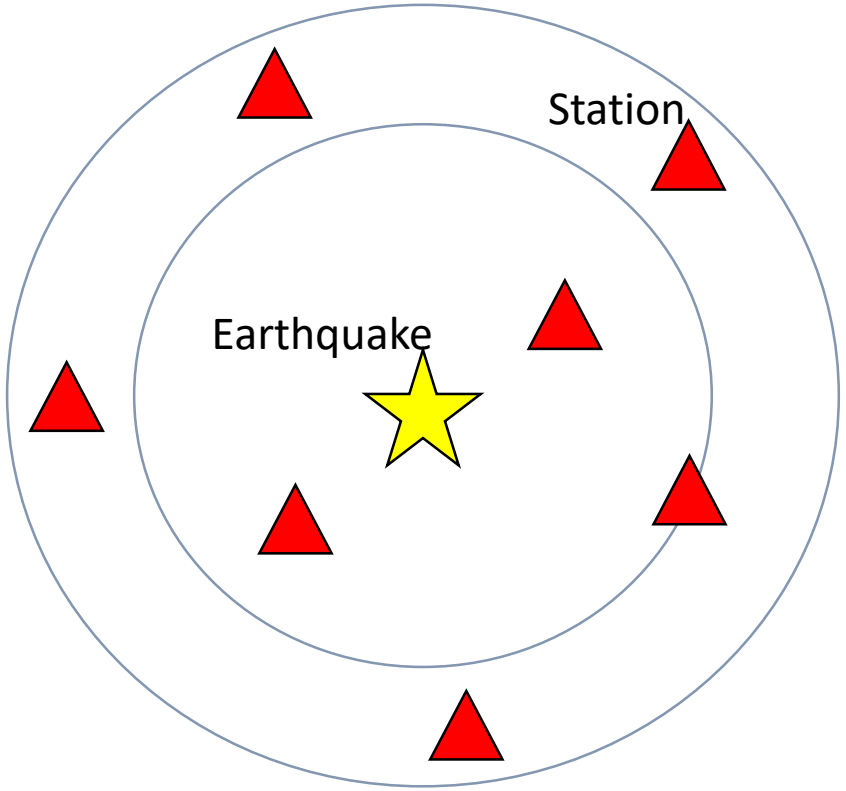
On-site EEW

Regional EEW



(JMA web site)

Data Processing in the EEW System



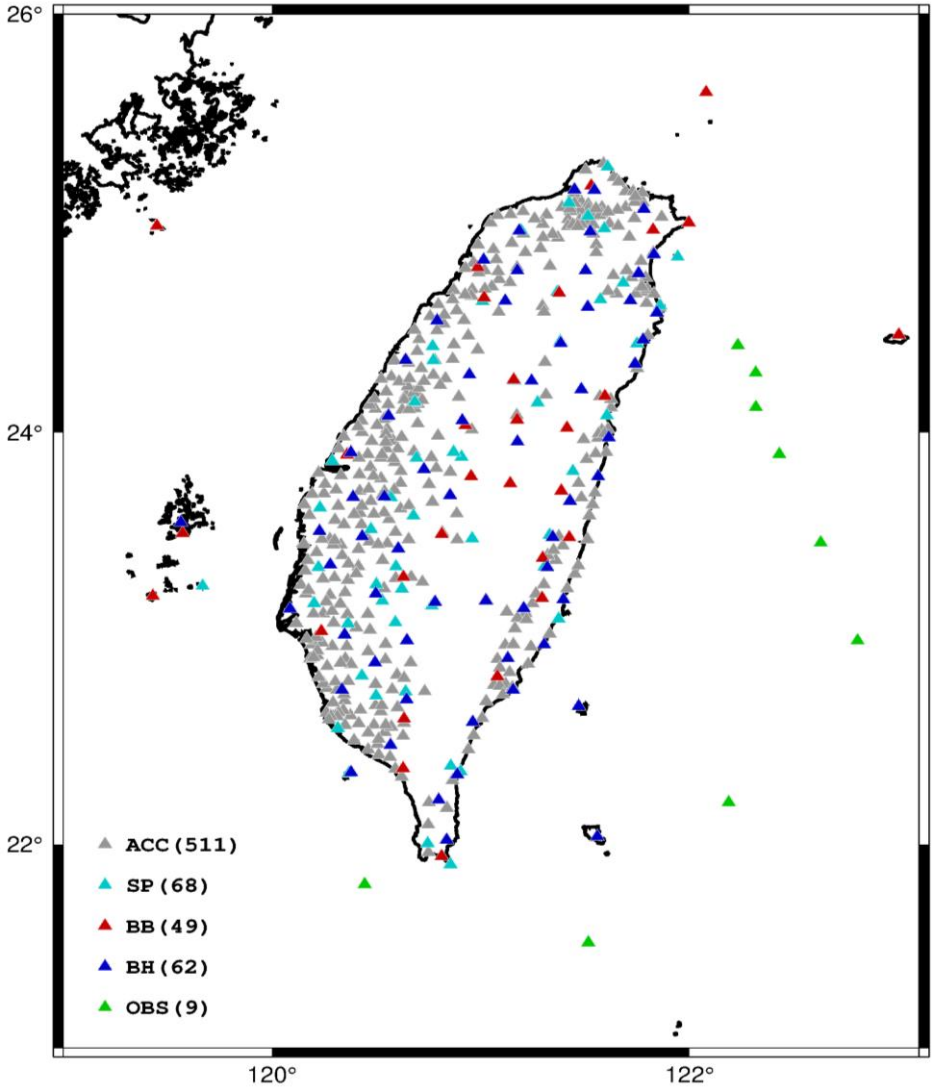
Real-time Seismic Network

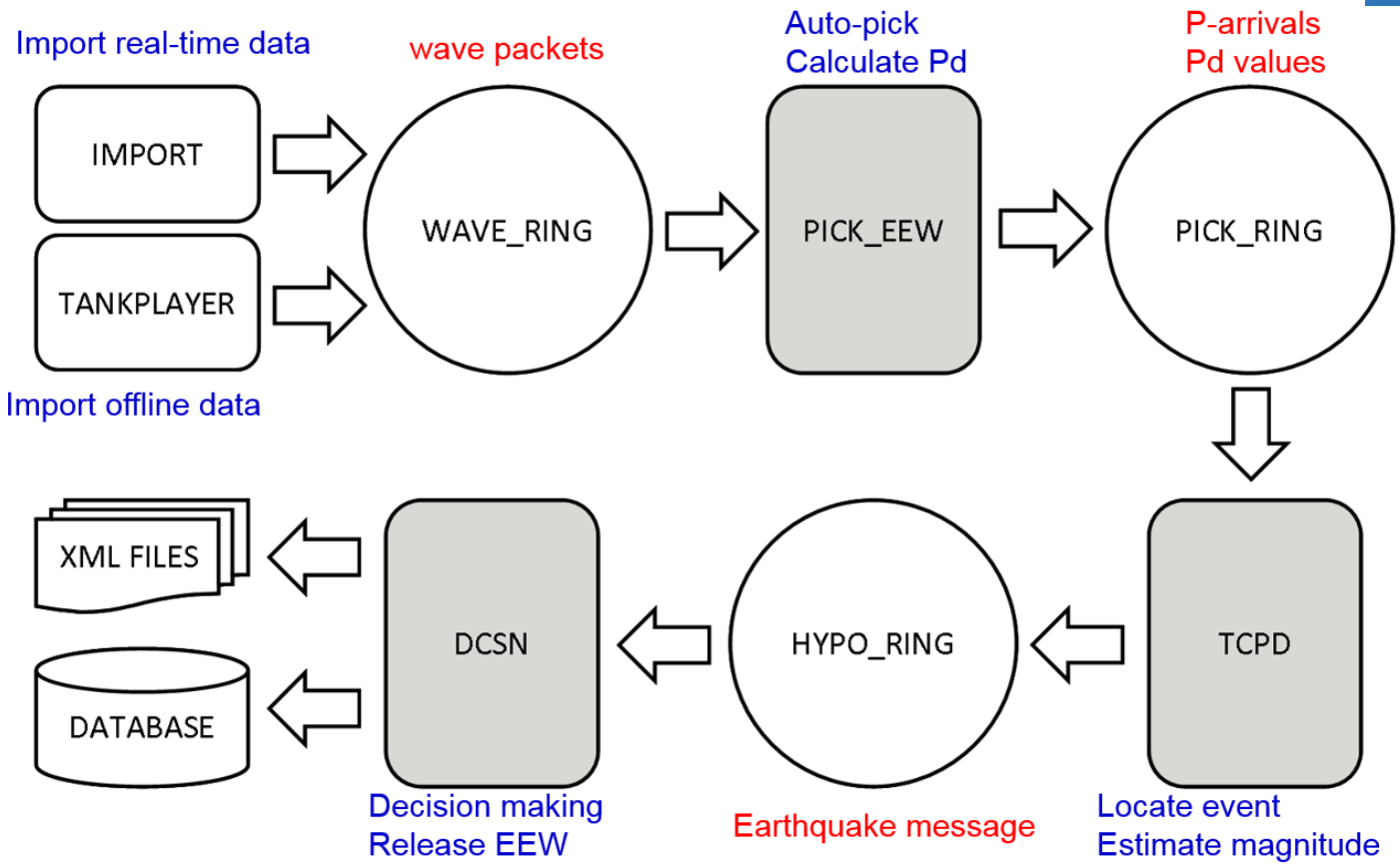
Regional	Onsite	AI Onsite
Detect P wave	Detect P wave	Detect P wave
Associate	P wave amplitude	P wave Features
Location		Intensity
Magnitude		
Intensity		

Decision Making

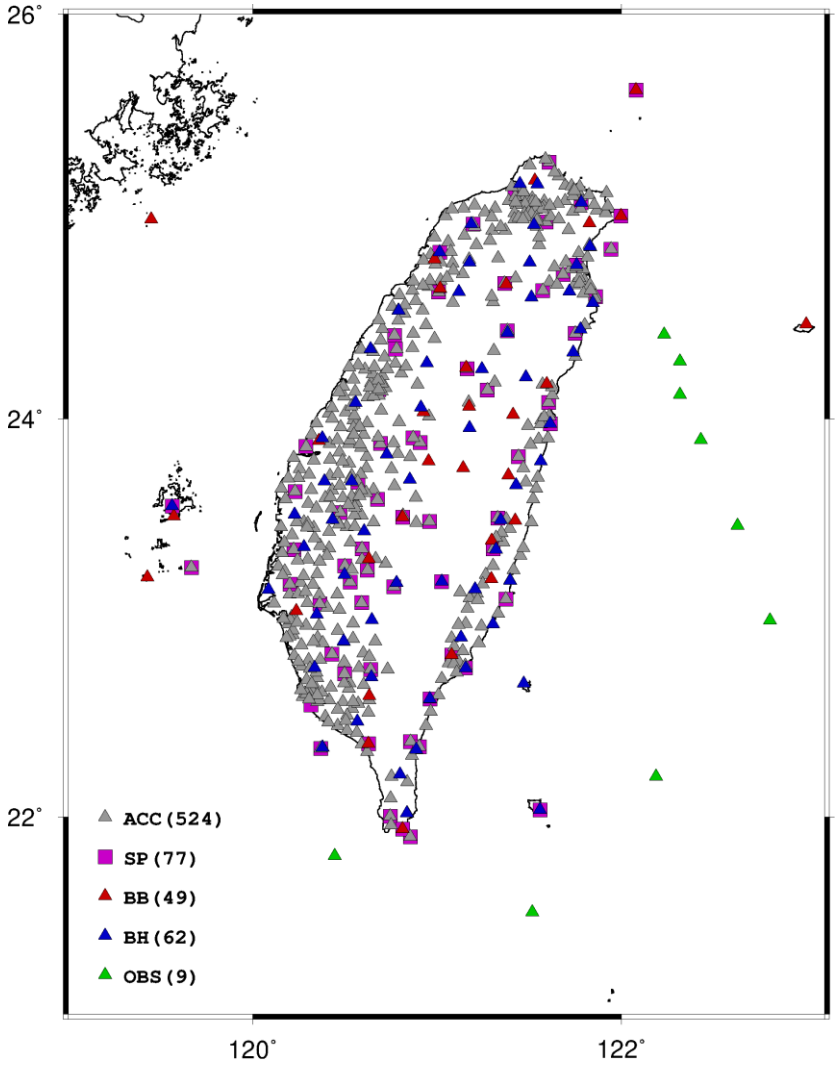
Issue warnings

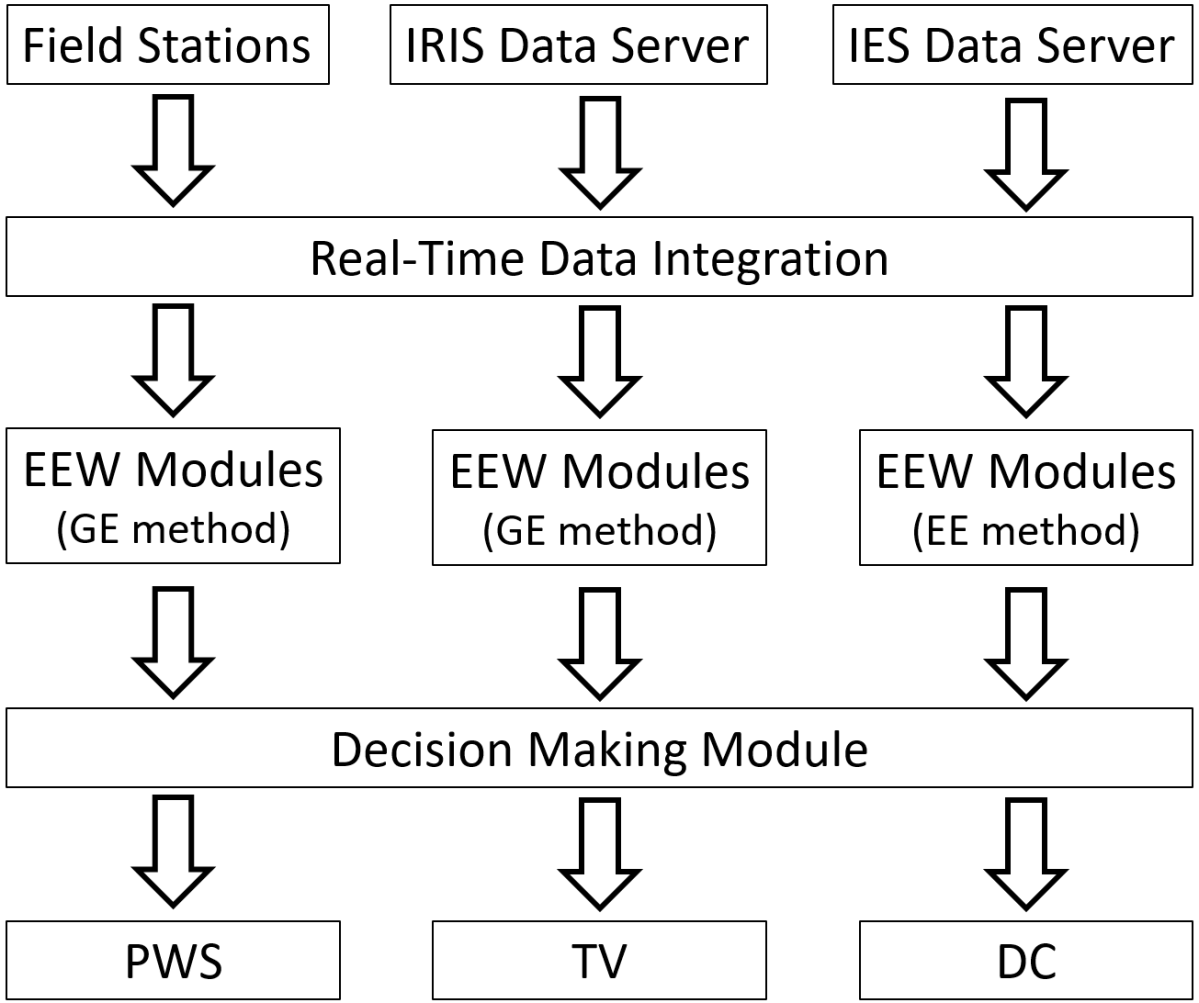
Seismic Network and the Regional EEW System



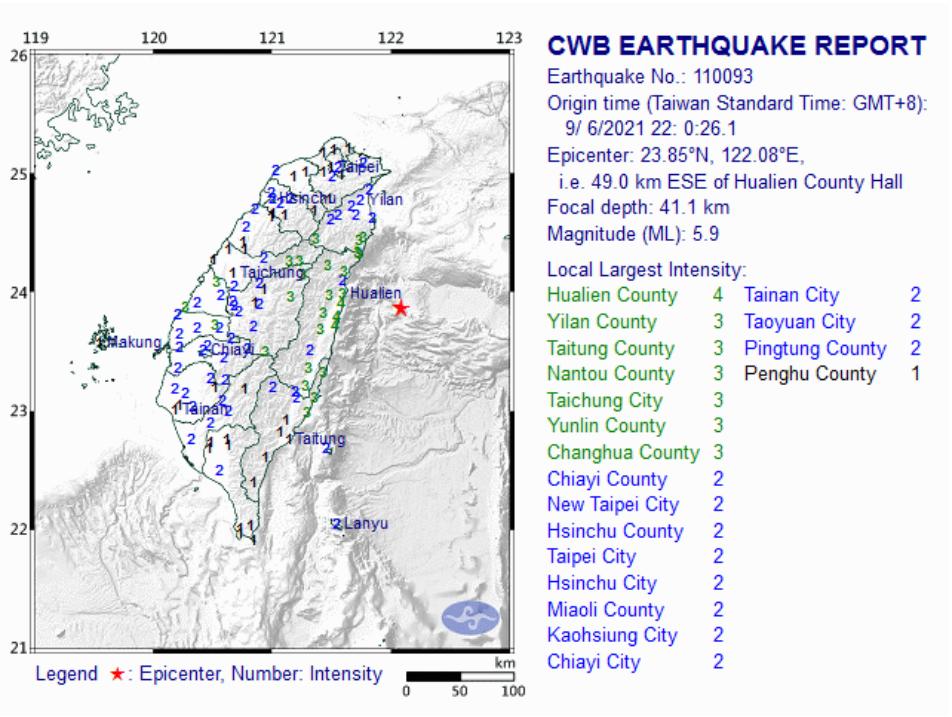


Seismic Network and the Hybrid EEW System





OBS Network Improve the EEW System

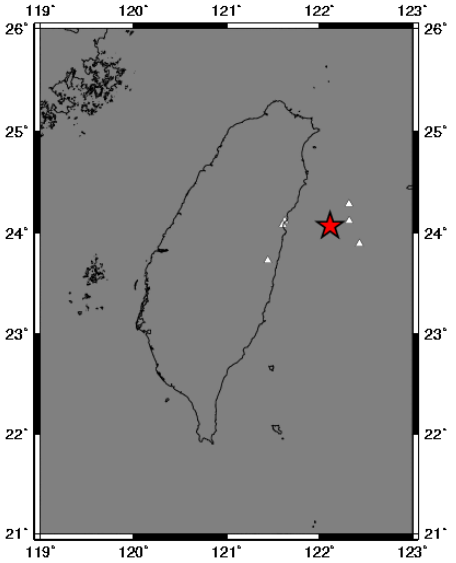


CWB EARTHQUAKE REPORT

Earthquake No.: 110093
Origin time (Taiwan Standard Time: GMT+8):
9/ 6/2021 22: 0:26.1
Epicenter: 23.85°N, 122.08°E,
i.e. 49.0 km ESE of Hualien County Hall
Focal depth: 41.1 km
Magnitude (ML): 5.9

Local Largest Intensity:

Hualien County	4	Tainan City	2
Yilan County	3	Taoyuan City	2
Taitung County	3	Pingtung County	2
Nantou County	3	Penghu County	1
Taichung City	3		
Yunlin County	3		
Changhua County	3		
Chiayi County	2		
New Taipei City	2		
Hsinchu County	2		
Taipei City	2		
Hsinchu City	2		
Miaoli County	2		
Kaohsiung City	2		
Chiayi City	2		



Report: n1

Event time: 2021 / 09 / 06 14:00:33.41

Latitude: 122.1134

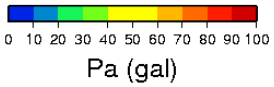
Longitude: 24.0704

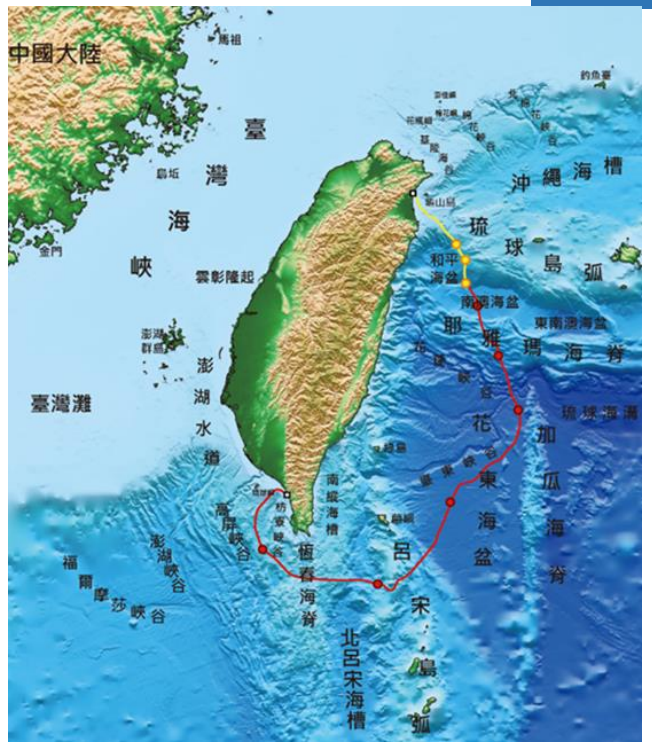
Depth: 10.00 km

Magnitude: 5.29

Report Time: 2021/09/06 14:00:41.42

OT(RTD):

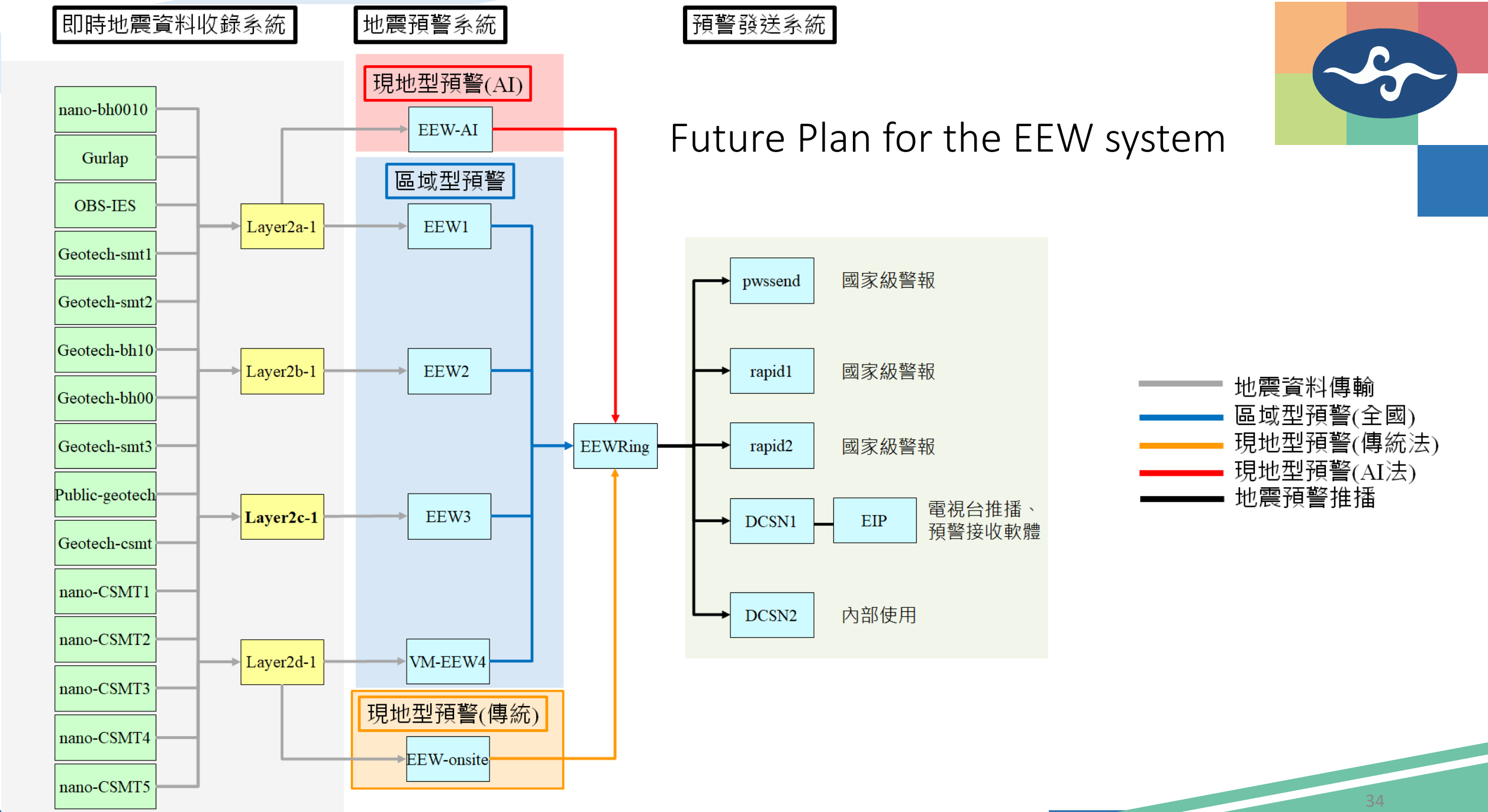




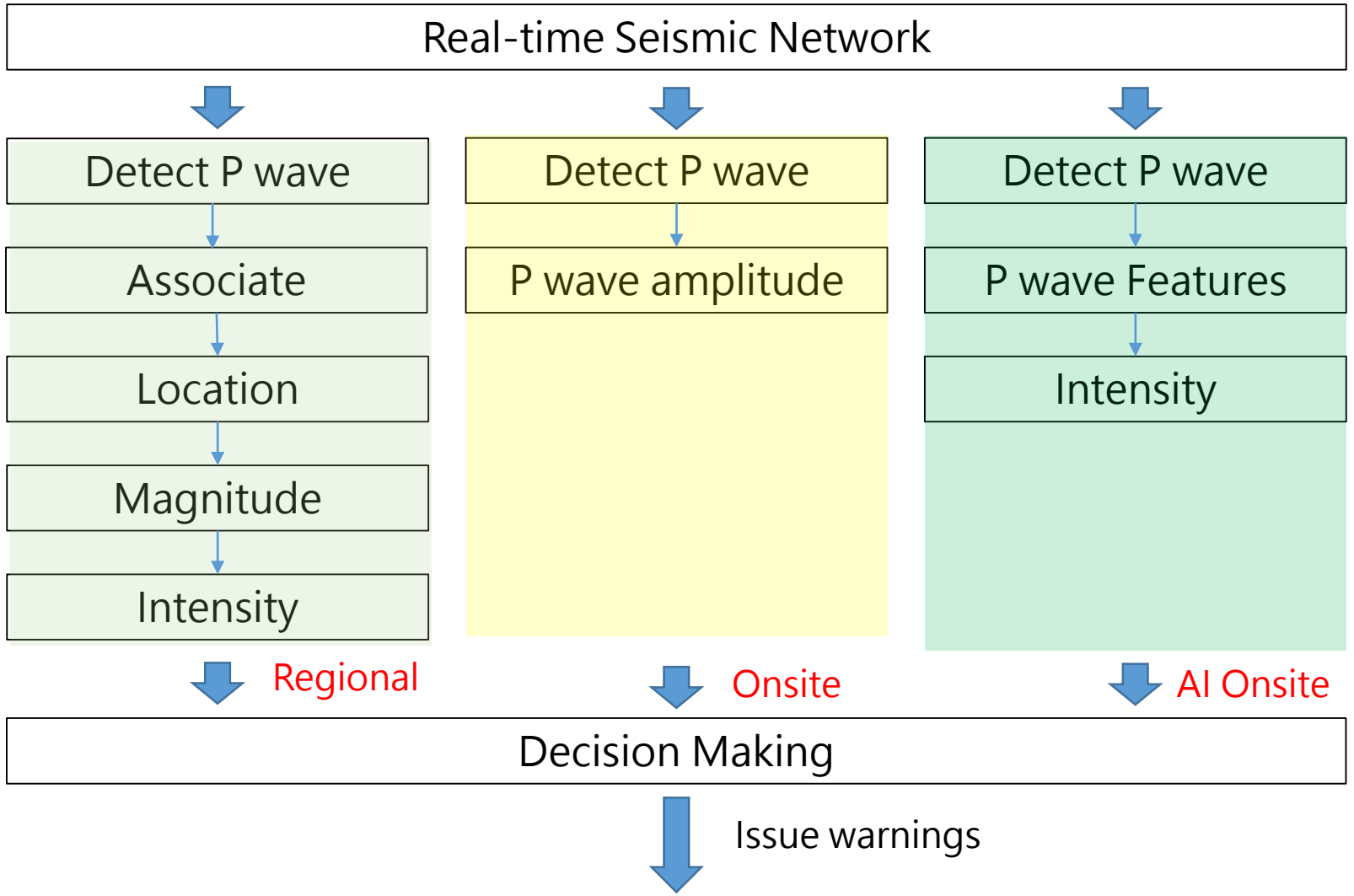
With OBS network the warning was issued at 15 sec after the event occurred

Without OBS network the warning was issued at 22 sec after the event occurred

Future Plan for the EEW system

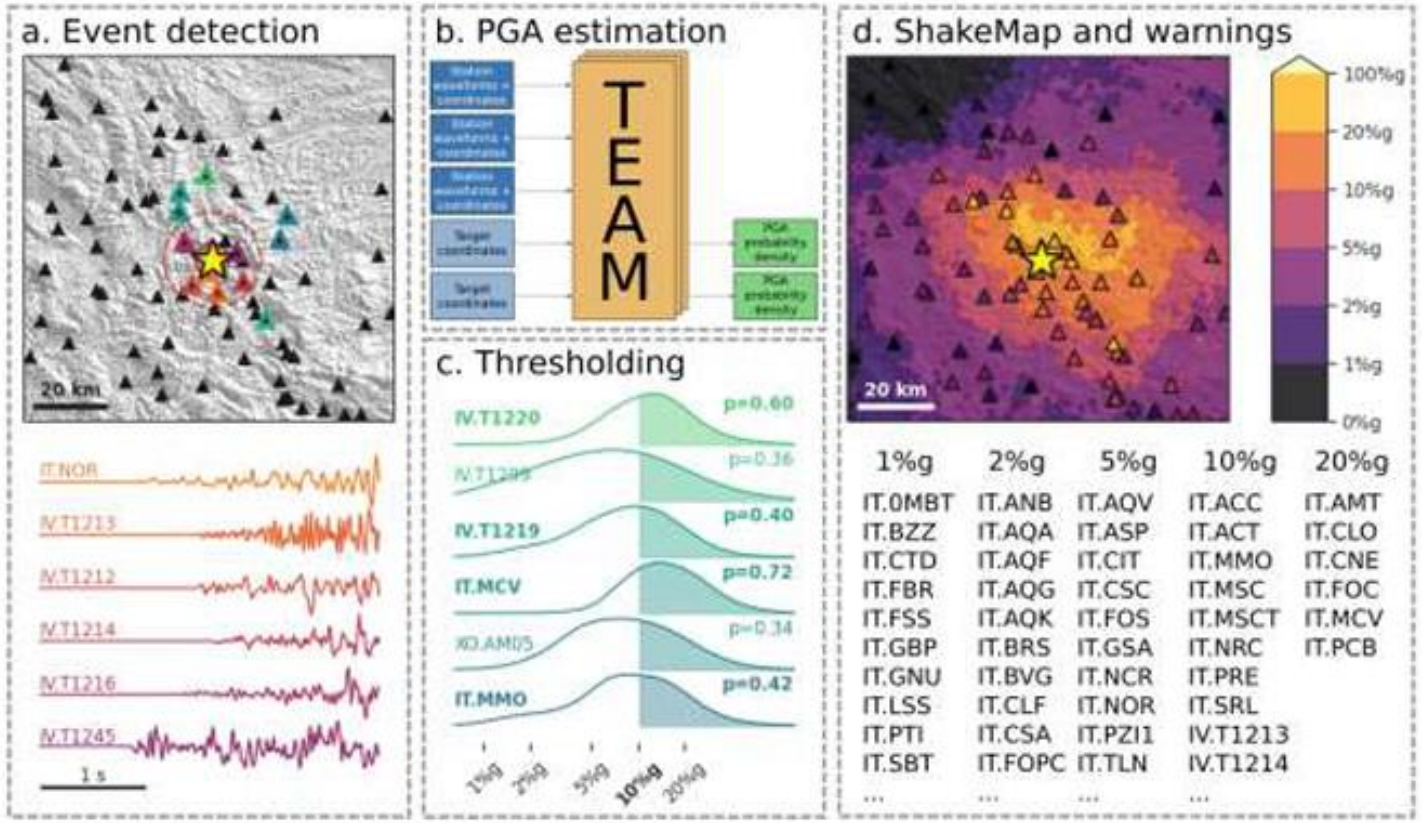


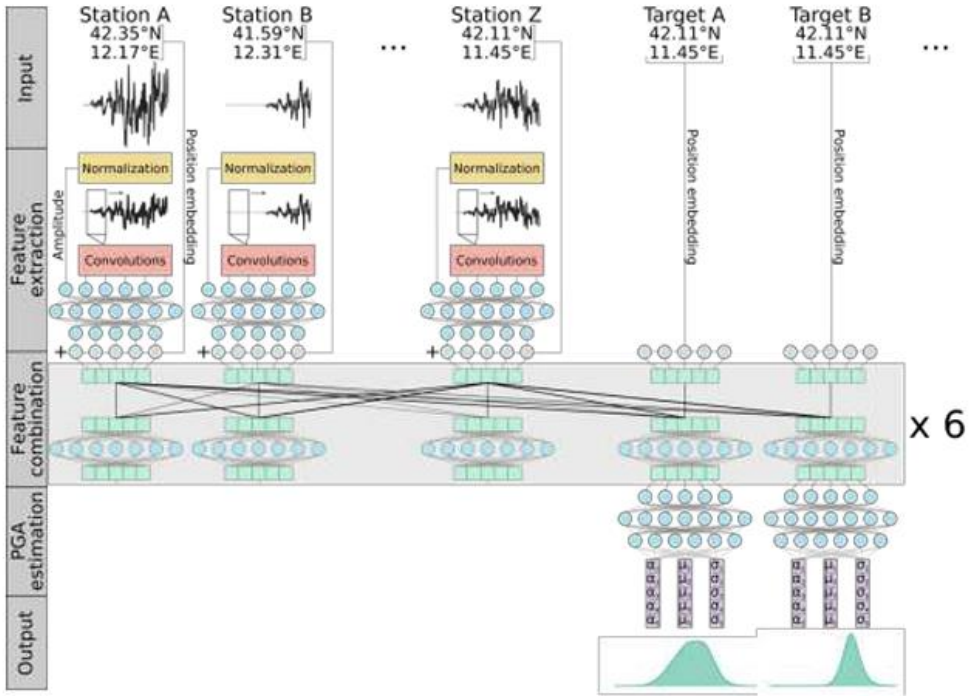
AI technology for the EEW



AI technology for the EEW

Predict Intensity

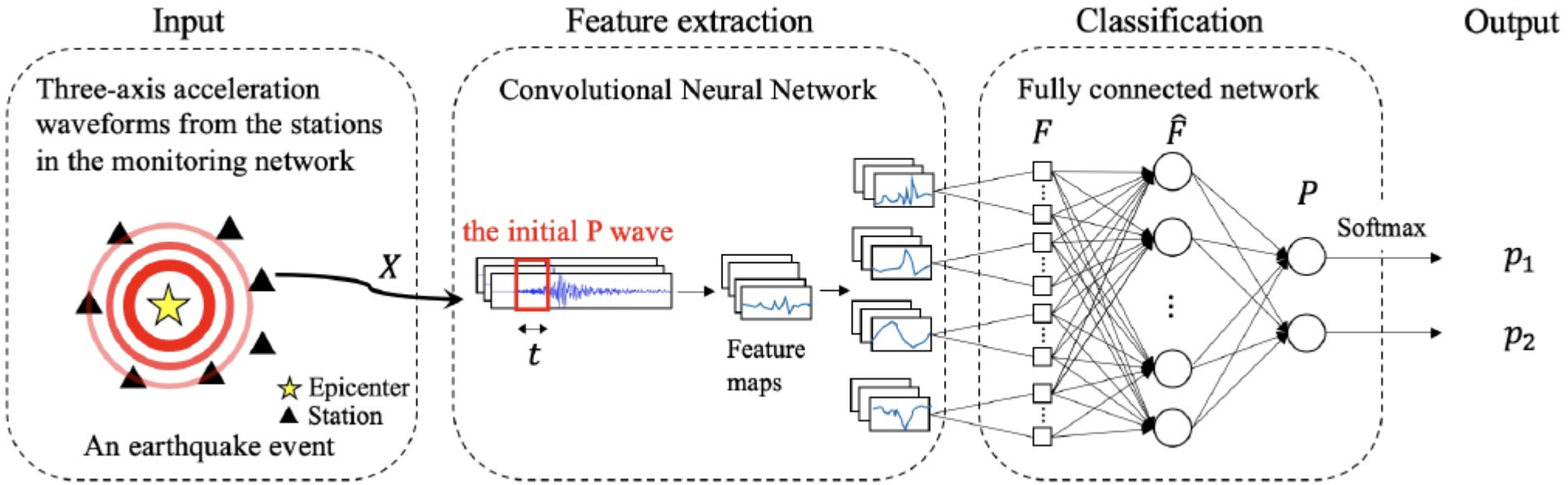




(Munchmeyer et al., 2021)

AI technology for the EEW

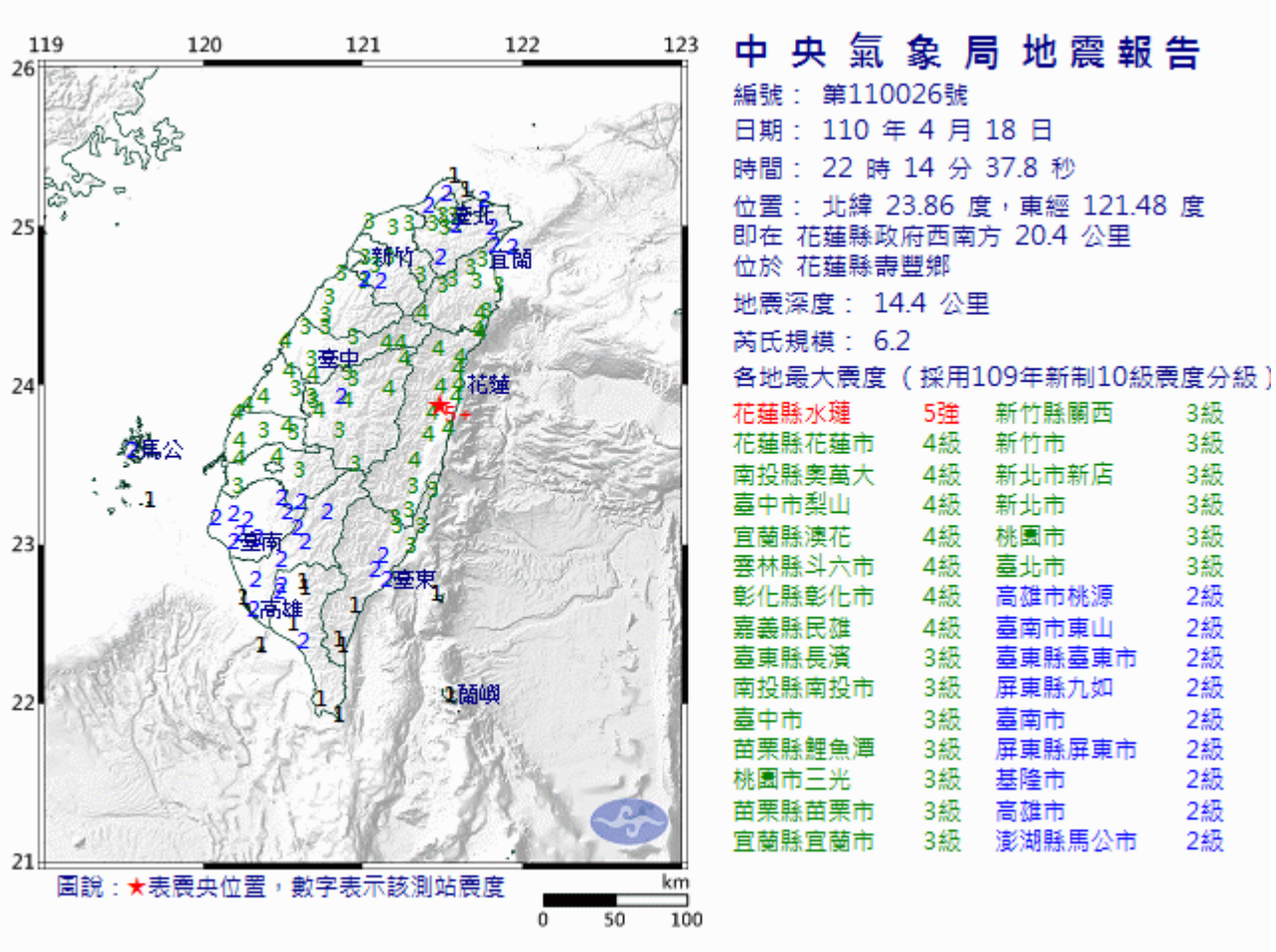
Predict Intensity

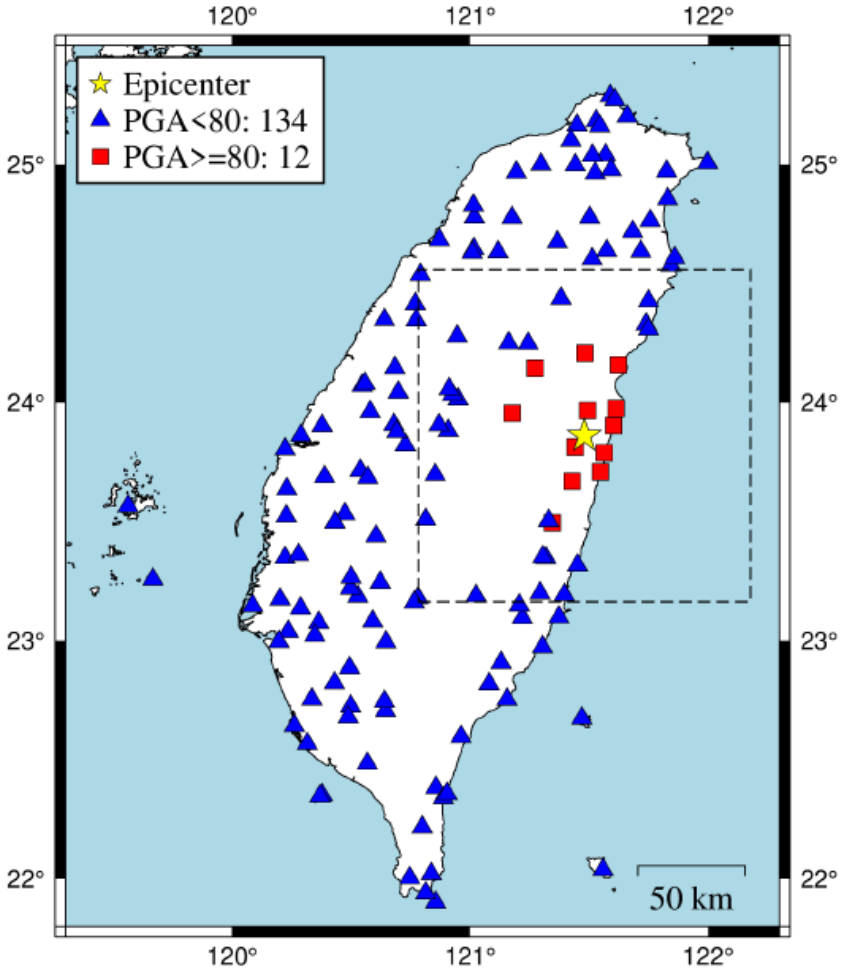


(Chiang et al., 2022)

AI technology for the EEW

Predict Intensity

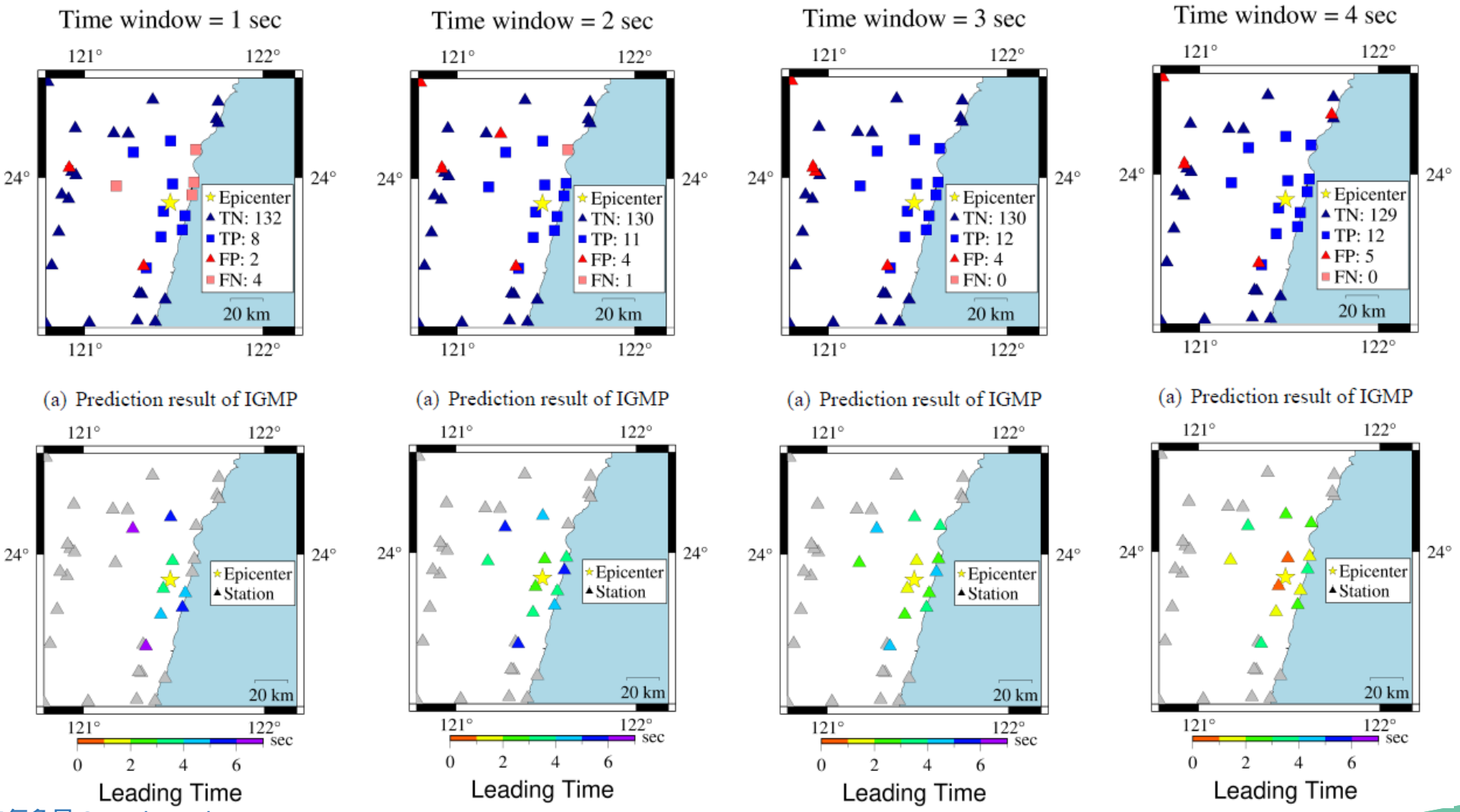




(Chiang et al., 2022)

AI technology for the EEW

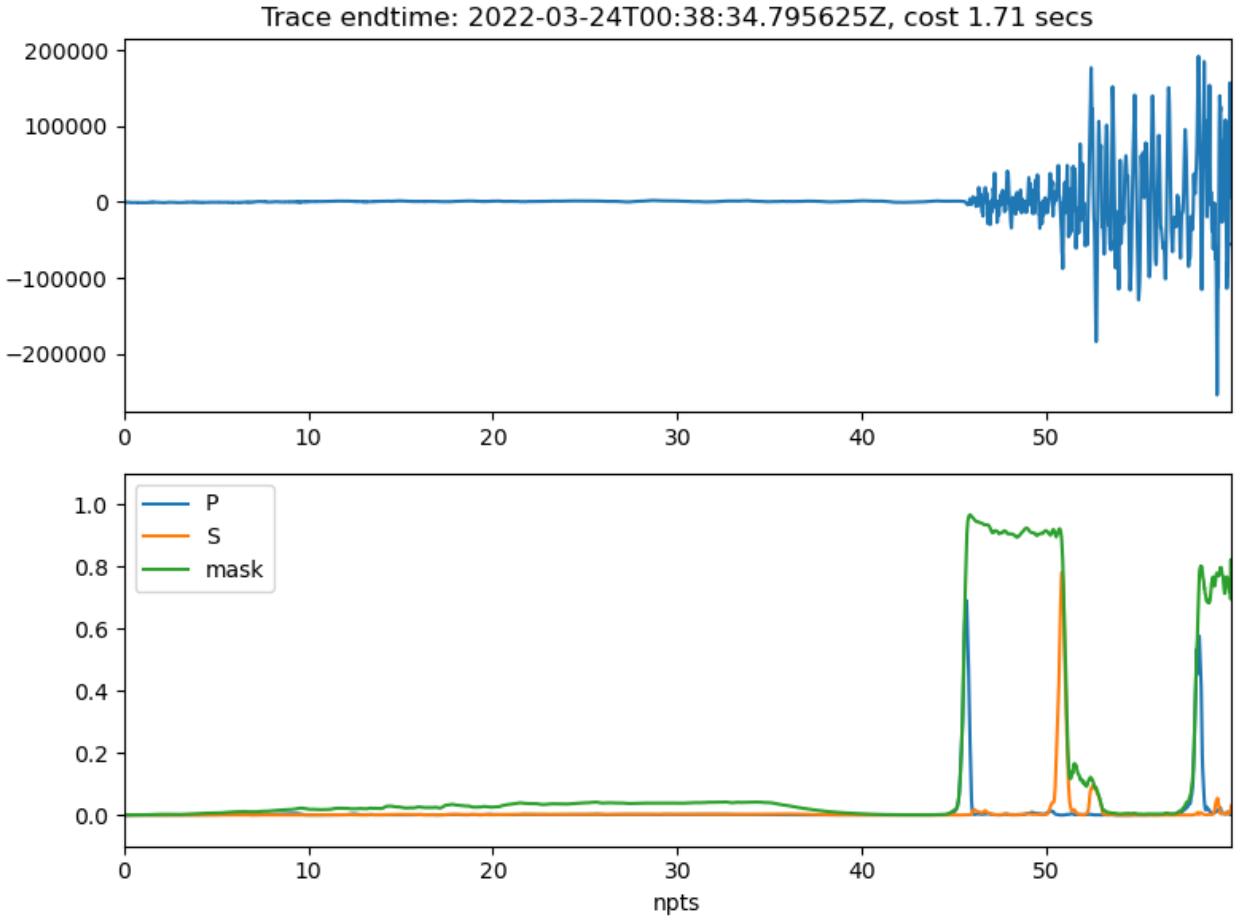
Predict Intensity

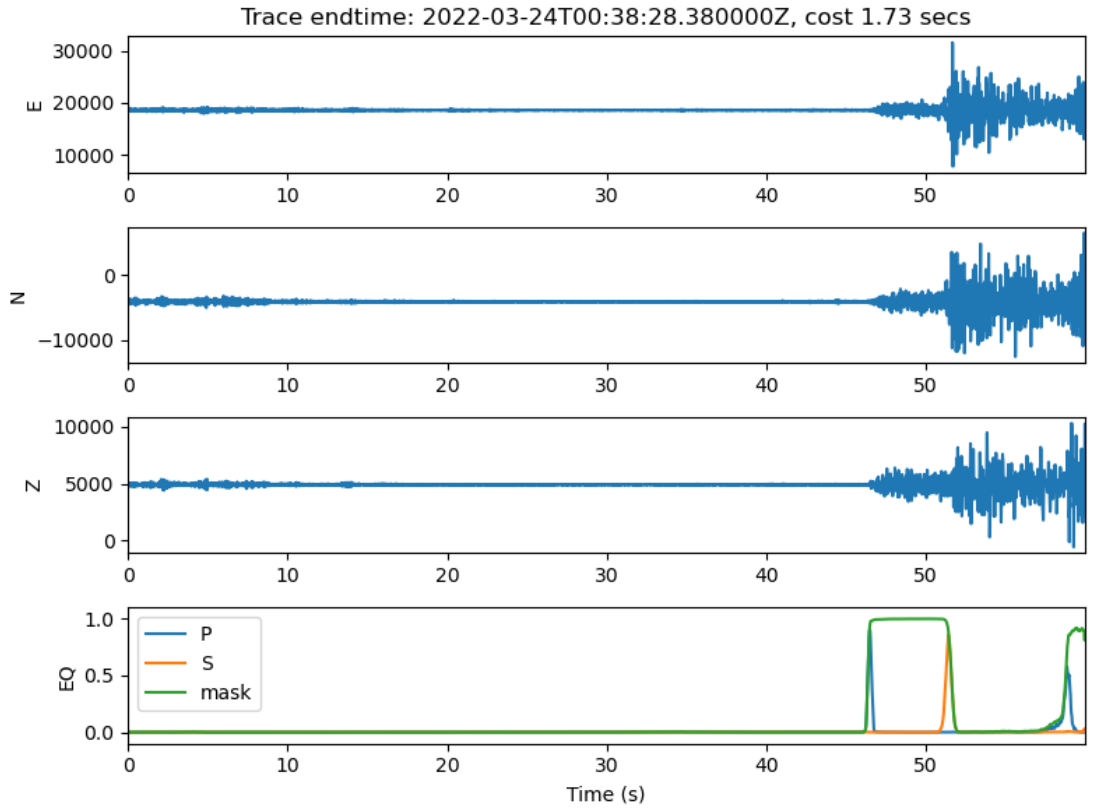


(Chiang et al., 2022)

AI technology for the EEW

Detect P Wave





(Liao et al., 2022)

Ongoing projects

1. Work with NCU : attenuation equations for magnitude estimations
2. Work with NTU : machine learning method for intensity prediction
3. Work with NCKU : machine learning method for phase picking
4. Work with NTUST : machine learning method for phase picking and intensity prediction.
5. Work with IES : Equal Differential Equation method for locating events
6. Work with Kyoto University : IPFx method for earthquake locations
7. Work with PanSci : Education for public people
8. Increasing seismic stations: borehole stations (32) and Accelerations (96) in 4 years.
9. Accelerating the communication.

Thanks for your listening