2014 Summer Project

台灣重複微地震地震之目錄建置與分析

Study of Repeating Microearthquakes in Taiwan

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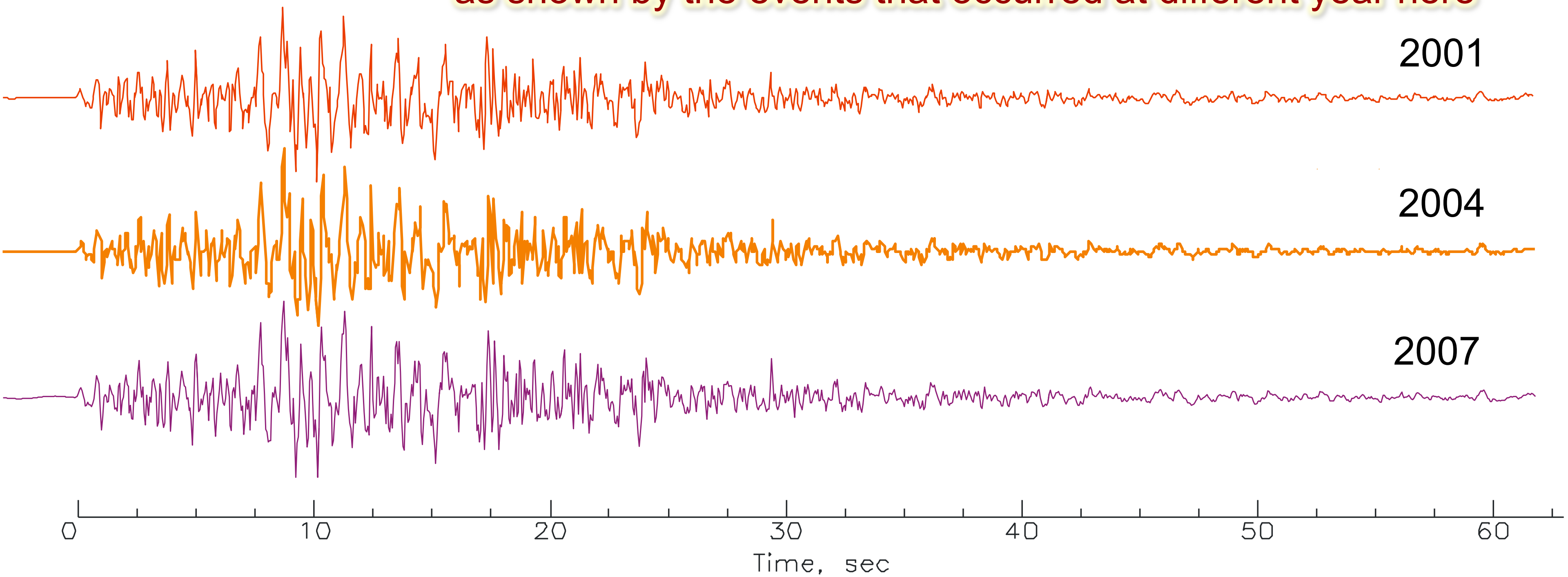
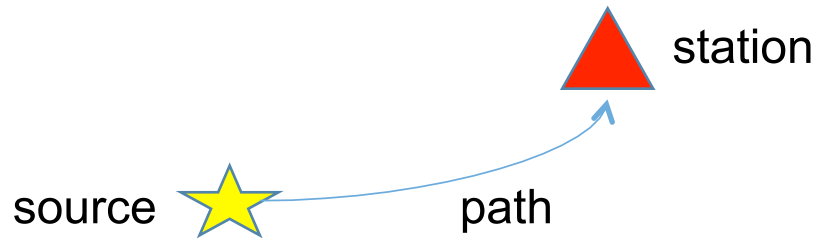
Earthquakes can have nearly identical seismic signature

as shown by the events that occurred at different year here





To have nearly identical waveforms, you need to have the same station, nearly the same source and path effects.

Such earthquakes do exist in natural fault system, they occurred at different time with highly similar seismic signatures are called repeating earthquakes.

Definition of Repeating Earthquakes

1) The same source location

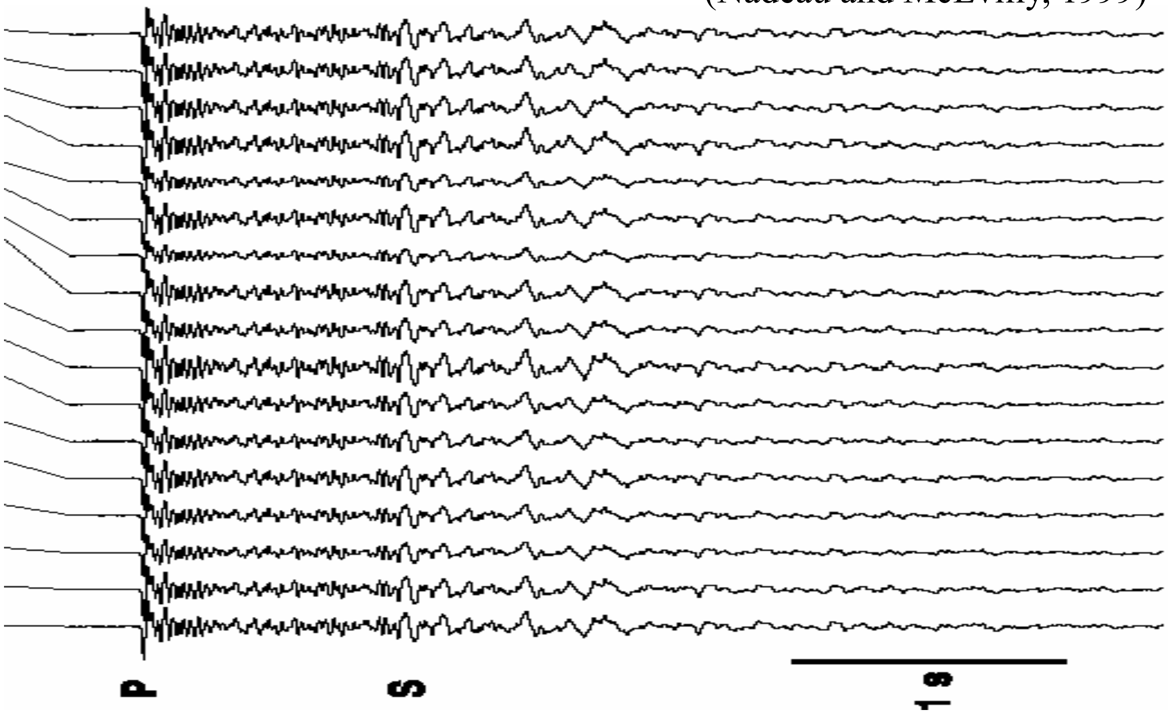
2) Highly similar waveform

3) Identical focal mechanism

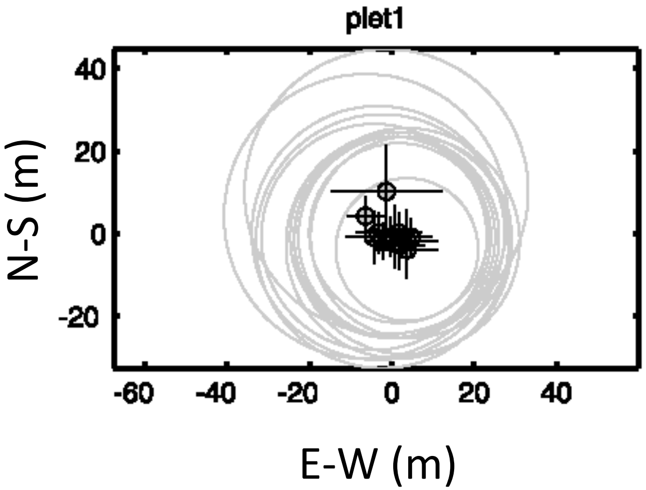
4) Similar size

Nearly Identical Waveforms

(Nadeau and McEvilly, 1999)



The same source location



(Schaff and Beroza, 2004)

Repeating Earthquakes Observation is important

Because they provide the information of recurrence time of earthquakes and slip rate at depth.

As proposed by Nadeau and McEvilly (1995),

Constant recurrence interval (Tr)

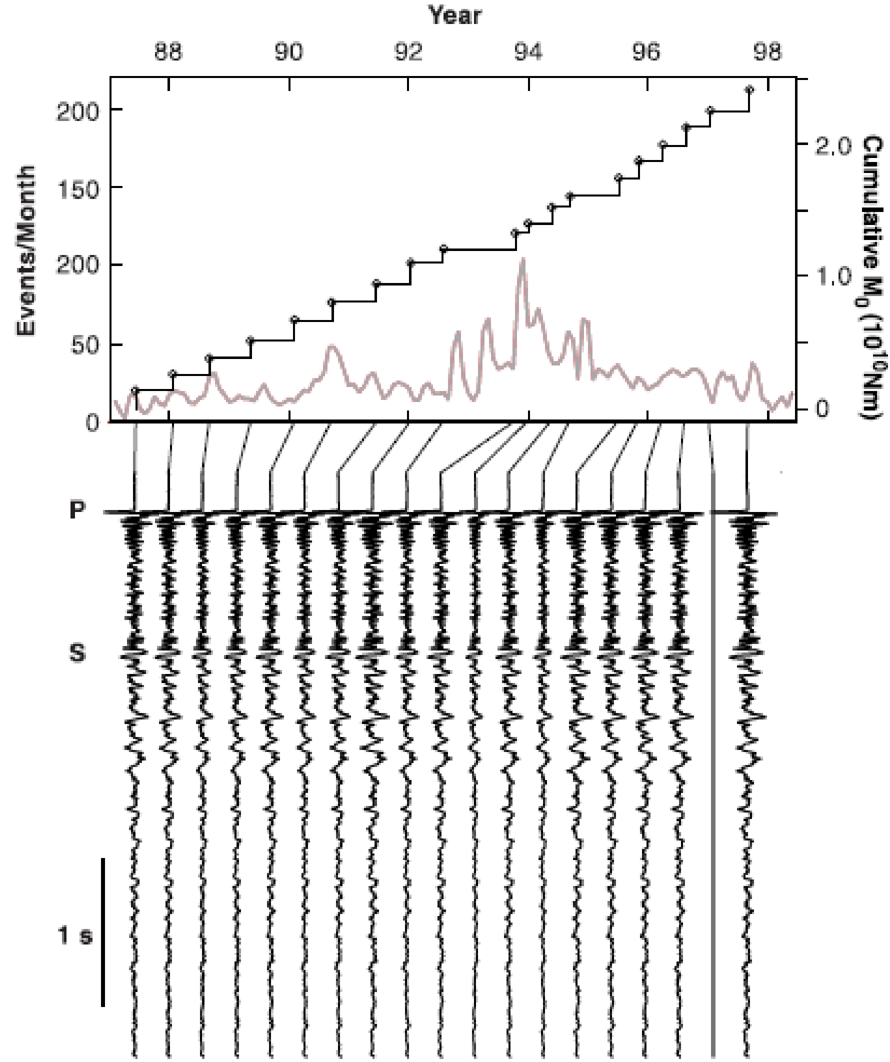
- Uniform moment release rate

- Assumed loading rate on the fault plane (long-term slip rate)

$$\dot{M}_0 = \mu A \dot{d}_{av}$$
$$\dot{\tilde{M}}_0 = \mu A \dot{\tilde{d}}$$

Average seismic moment

$$\dot{d}_{av} = \frac{\dot{M}}{\mu A} = \frac{M_{av}/T_i}{\mu A} = \frac{M_{av}}{\mu A T_i} = \frac{M_{av}}{\mu \dfrac{\dot{\tilde{M}}_0}{\mu \dot{\tilde{d}}} T_i} = \frac{M_{av}\dot{\tilde{d}}}{\dot{\tilde{M}}_0 T_i}$$



can be used to determine the slip rate at each repeating earthquake site.

This method will be introduced shortly.

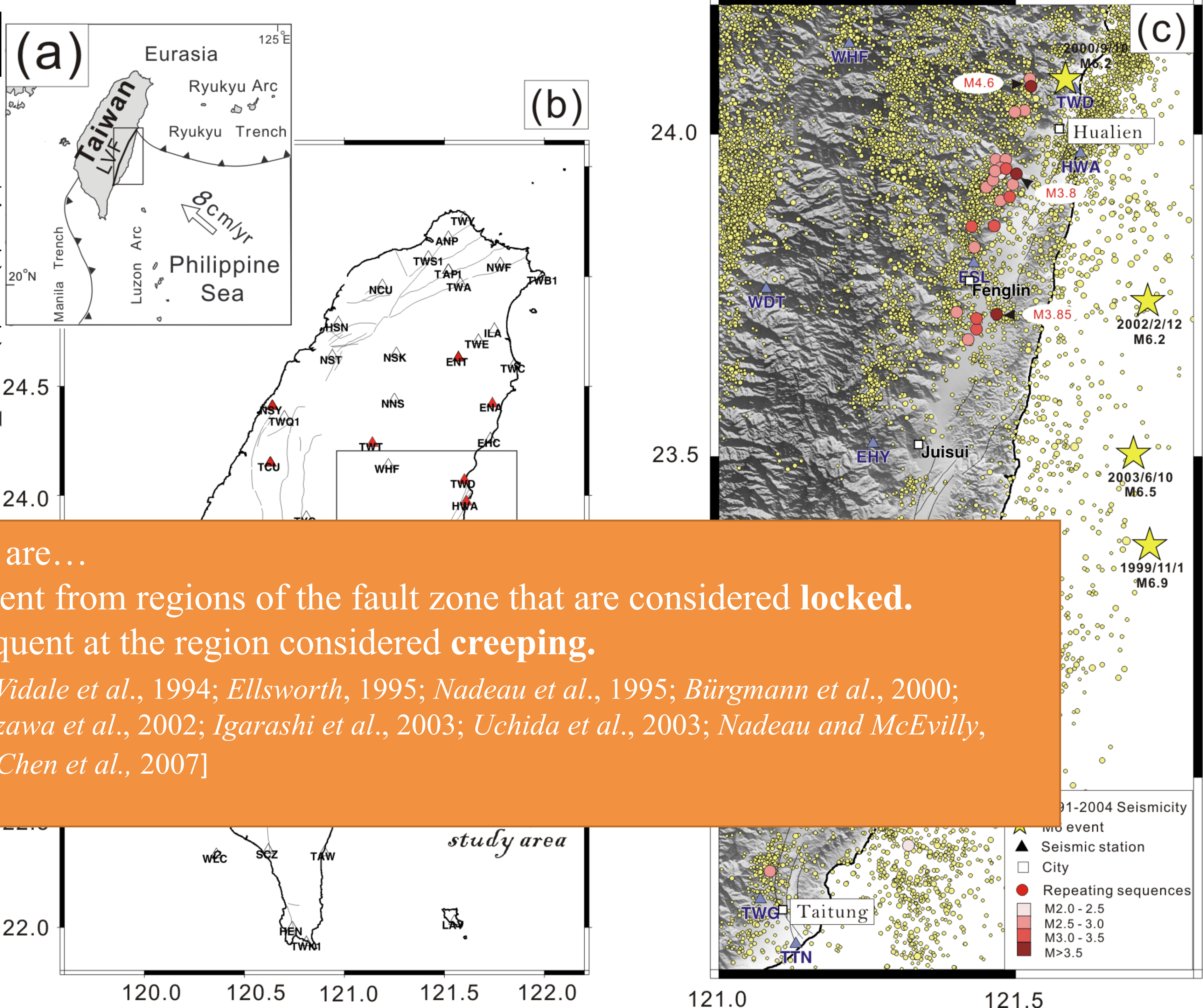
[redacted]

Cent

Nort

Nort

East



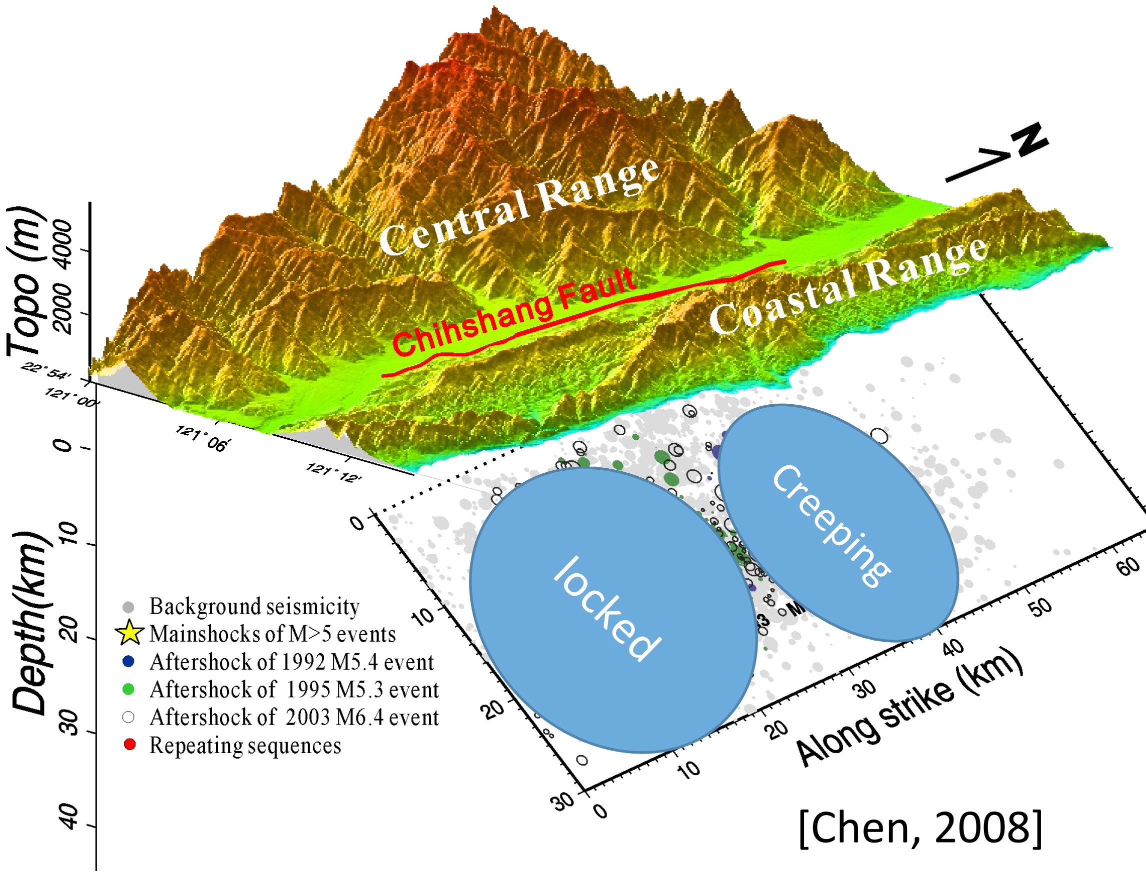
They are…

- Absent from regions of the fault zone that are considered **locked.**
- Frequent at the region considered **creeping.**

[e.g., *Vidale et al.*, 1994; *Ellsworth*, 1995; *Nadeau et al.*, 1995; *Bürgmann et al.*, 2000; *Matsuzawa et al.*, 2002; *Igarashi et al.*, 2003; *Uchida et al.*, 2003; *Nadeau and McEvilly*, 2004; *Chen et al.*, 2007]

Creeping vs. locked segments

Taking Chihshang fault as example, where you have repeaters (red circles) is away from where you have aftershocks of M5 mainshock in 2003 (opencircles). Using spatial distribution of repeating earthquakes Chen [2008] characterize the 30-km-long Chihshang fault to be creeping segment in the north and locked in the south.



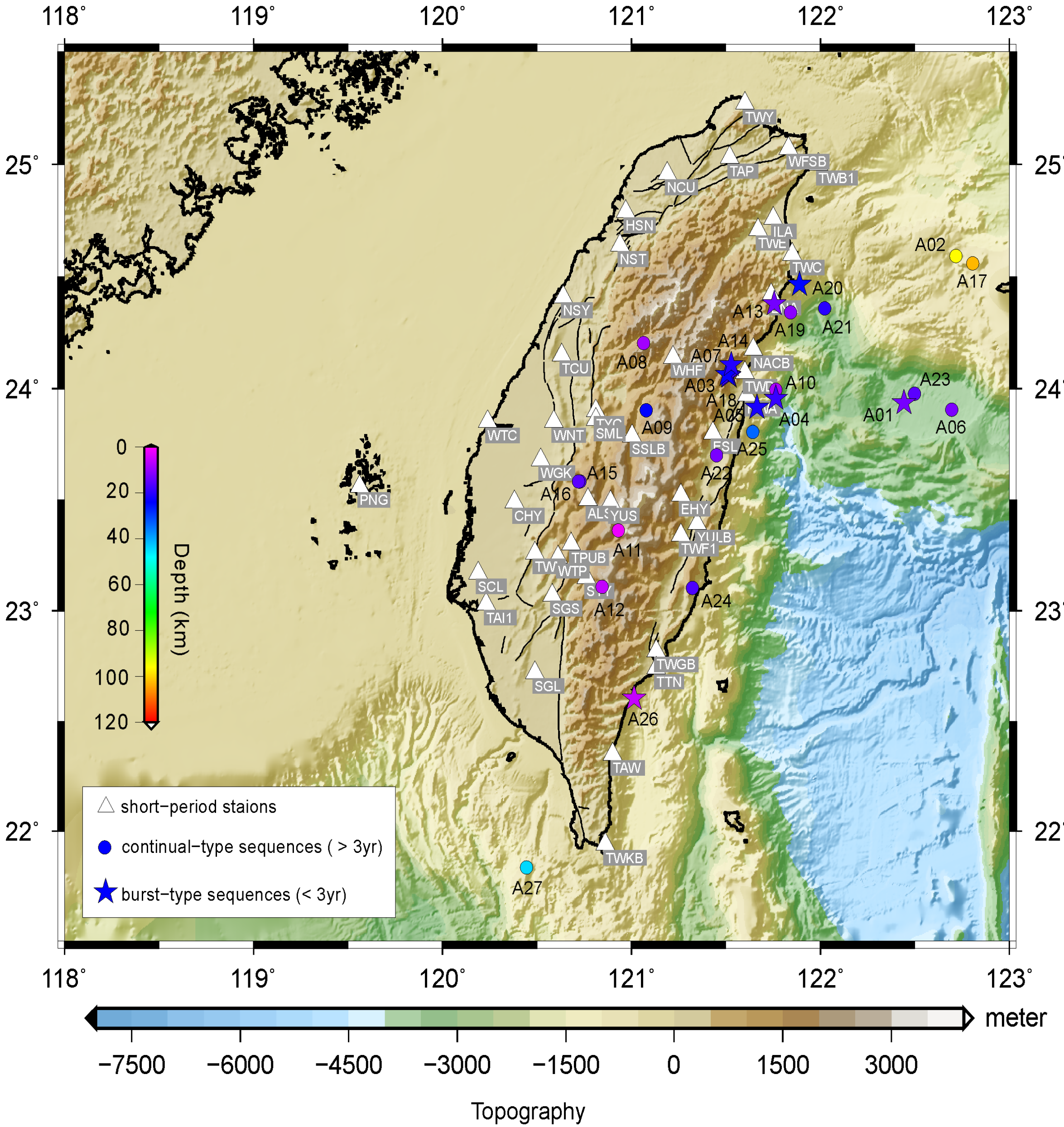
[Chen, 2008]

Purposes of this study

- **To understand the deep slip rate in different fault zones of Taiwan**

- **To discriminate creeping segments from locked segments if possible**

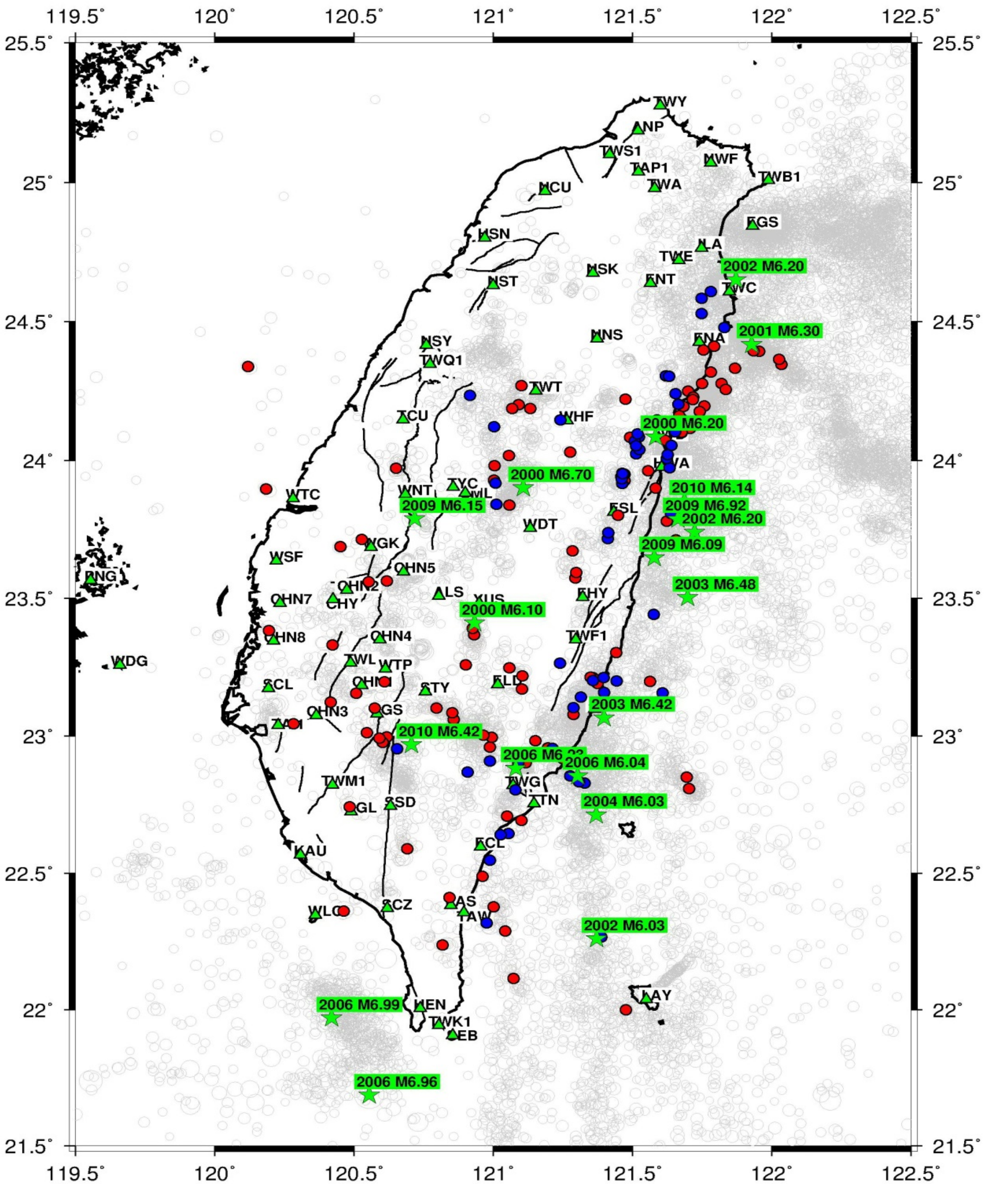
Previous study have done...



- Lin [2013]
- 林承恩，2013台灣大學碩士論文
- 陳卉瑄老師指導

M> 4 repeating earthquake sequences in Taiwan

Previous study have done...



- Chang [2013]
- 張育群，2013台灣師範大學碩士論文
- 陳卉瑄老師指導

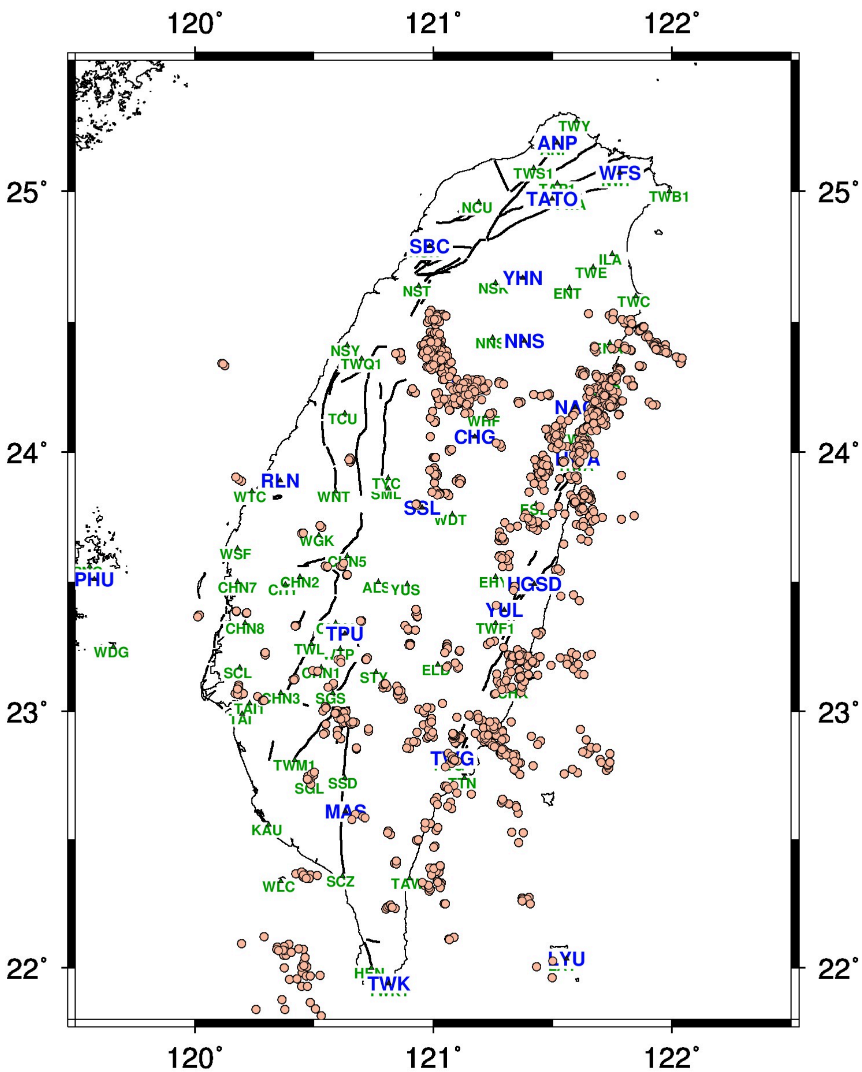
M> 3 repeating earthquake sequences in Taiwan

● Continual type

● Burst type

But not microearthquakes

The reason is, for smaller earthquakes, there are a lot more data to process and analyze →this work is time consuming but important!



This study	Chang [2013]

分區	緯度	經度	M>2事件數	M>3事件數
cb	120.0 ～ 120.5	25.0 ～ 25.5	0	0
cc	120.0 ～ 120.5	24.5 ～ 25.0	4	1
cd	120.0 ～ 120.5	24.0 ～ 24.5	19	10
ce	120.0 ～ 120.5	23.5 ～ 24.0	443	37
cf	120.0 ～ 120.5	23.0 ～ 23.5	1842	244
cg	120.0 ～ 120.5	22.5 ～ 23.0	171	37
ch	120.0 ～ 120.5	22.0 ～ 22.5	457	92
ci	120.0 ～ 120.5	21.5 ～ 22.0	336	70
db	120.5 ～ 121.0	25.0 ～ 25.5	0	0
dc	120.5 ～ 121.0	24.5 ～ 25.0	190	22
dd	120.5 ～ 121.0	24.0 ～ 24.5	4062	259
de	120.5 ～ 121.0	23.5 ～ 24.0	3558	373
df	120.5 ～ 121.0	23.0 ～ 23.5	4670	616
dg	120.5 ～ 121.0	22.5 ～ 23.0	4356	497
dh	120.5 ～ 121.0	22.0 ～ 22.5	1330	133
di	120.5 ～ 121.0	21.5 ～ 22.0	445	89
eb	121.0 ～ 121.5	25.0 ～ 25.5	4	0
ec	121.0 ～ 121.5	24.5 ～ 25.0	1422	77
ed	121.0 ～ 121.5	24.0 ～ 24.5	6573	469
ee	121.0 ～ 121.5	23.5 ～ 24.0	4603	623
ef	121.0 ～ 121.5	23.0 ～ 23.5	5376	803
eg	121.0 ～ 121.5	22.5 ～ 23.0	4440	817
eh	121.0 ～ 121.5	22.0 ～ 22.5	1790	360
ei	121.0 ～ 121.5	21.5 ～ 22.0	359	124
fb	121.5 ～ 122.0	25.0 ～ 25.5	275	86
fc	121.5 ～ 122.0	24.5 ～ 25.0	6108	1167
fd	121.5 ～ 122.0	24.0 ～ 24.5	10246	1970
fe	121.5 ～ 122.0	23.5 ～ 24.0	2683	719
ff	121.5 ～ 122.0	23.0 ～ 23.5	774	230
fg	121.5 ～ 122.0	22.5 ～ 23.0	774	177
fh	121.5 ～ 122.0	22.0 ～ 22.5	144	51
fi	121.5 ～ 122.0	21.5 ～ 22.0	156	83

Search for repeating microearthquakes in Taiwan

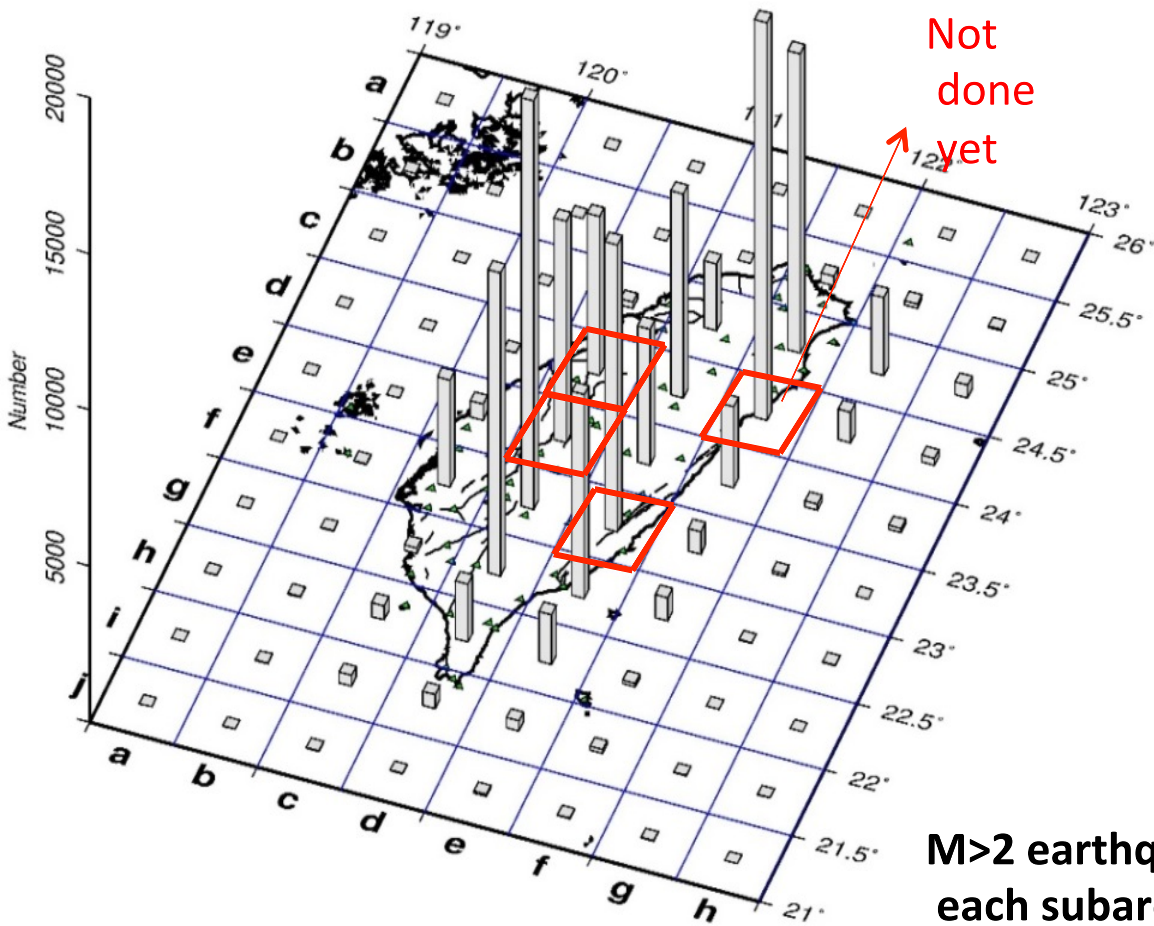
Study period: 2000-2010

Magnitude range: M_L 2~3

Number of similar earthquakes (ccc >0.7): 33197

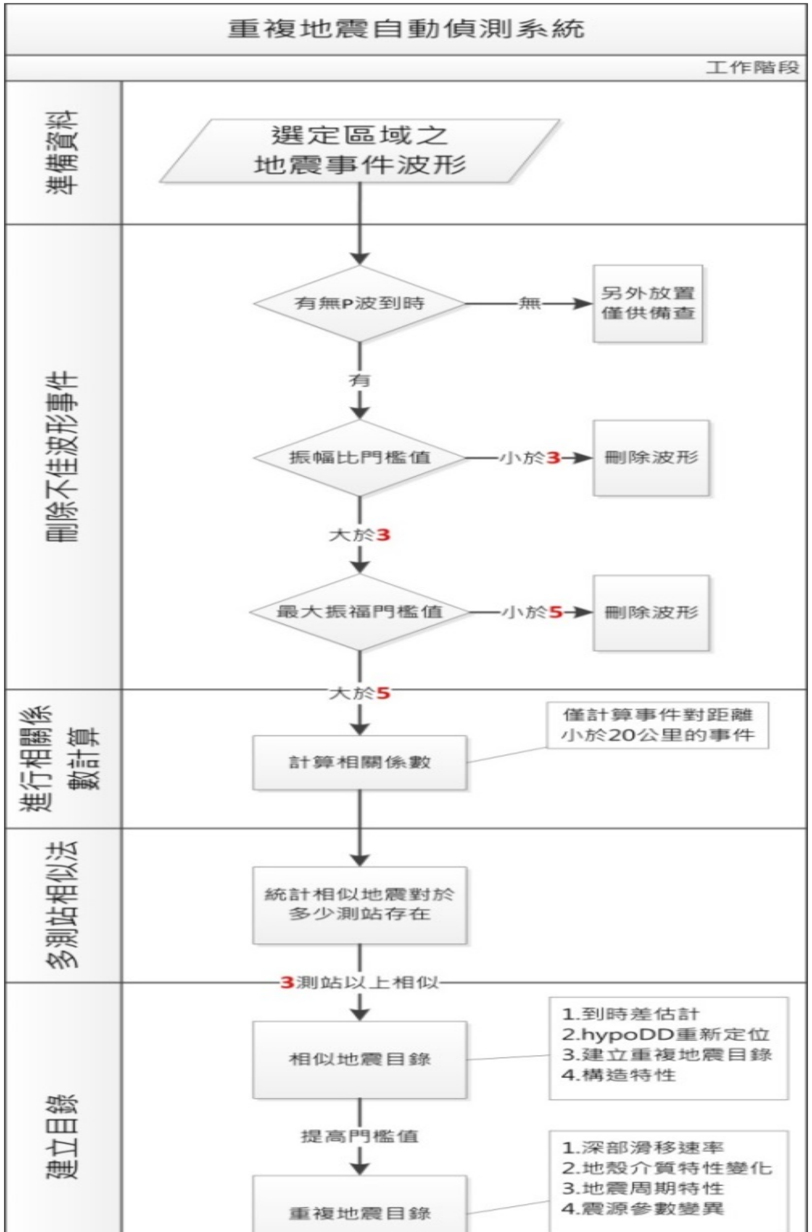
(areas dd,dg,ef,eg,fd are not included – need more time to process)

Unfiltered,
30 sec – long,
vertical seismograms



M>2 earthquakes in each subarea

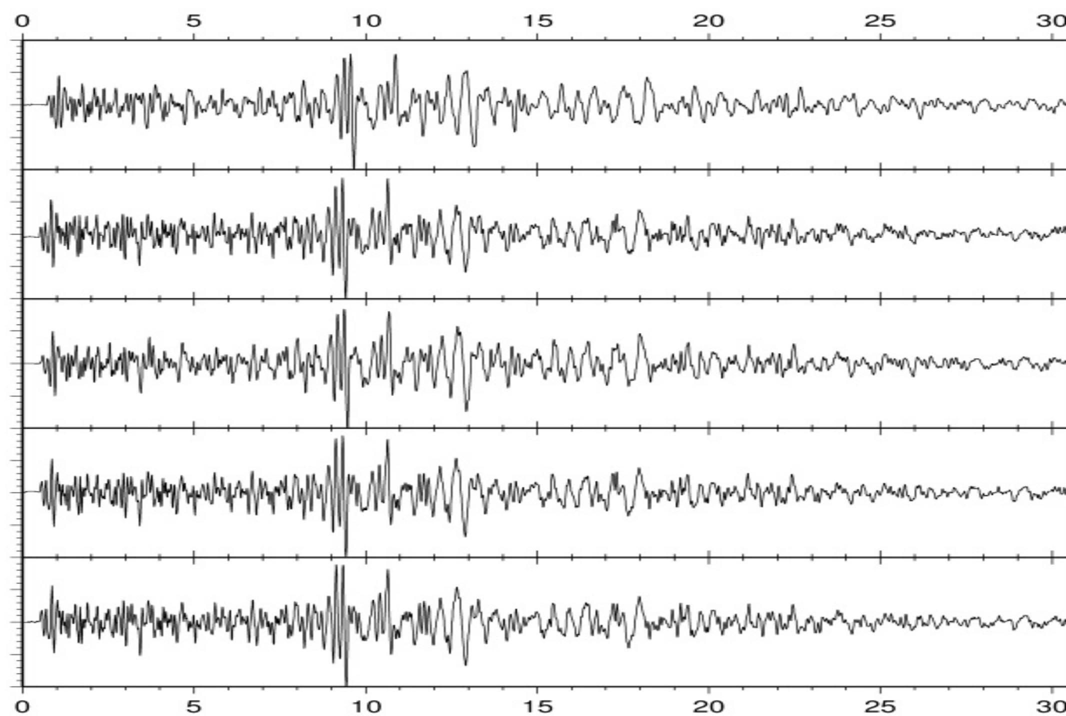
Method: Identify repeating earthquakes



Chang [2013]

1. More than 3 stations have ccc> 0.7 for similar earthquake catalog
2. Visual inspection to select the repeating earthquakes (ccc> 0.85)

Examples of repeating earthquakes



Method: determine deep slip rates

Time deviation of cumulative moment release on a RES site is shown by:

$$\dot{M}_0 = \mu A \dot{d}_{av}$$

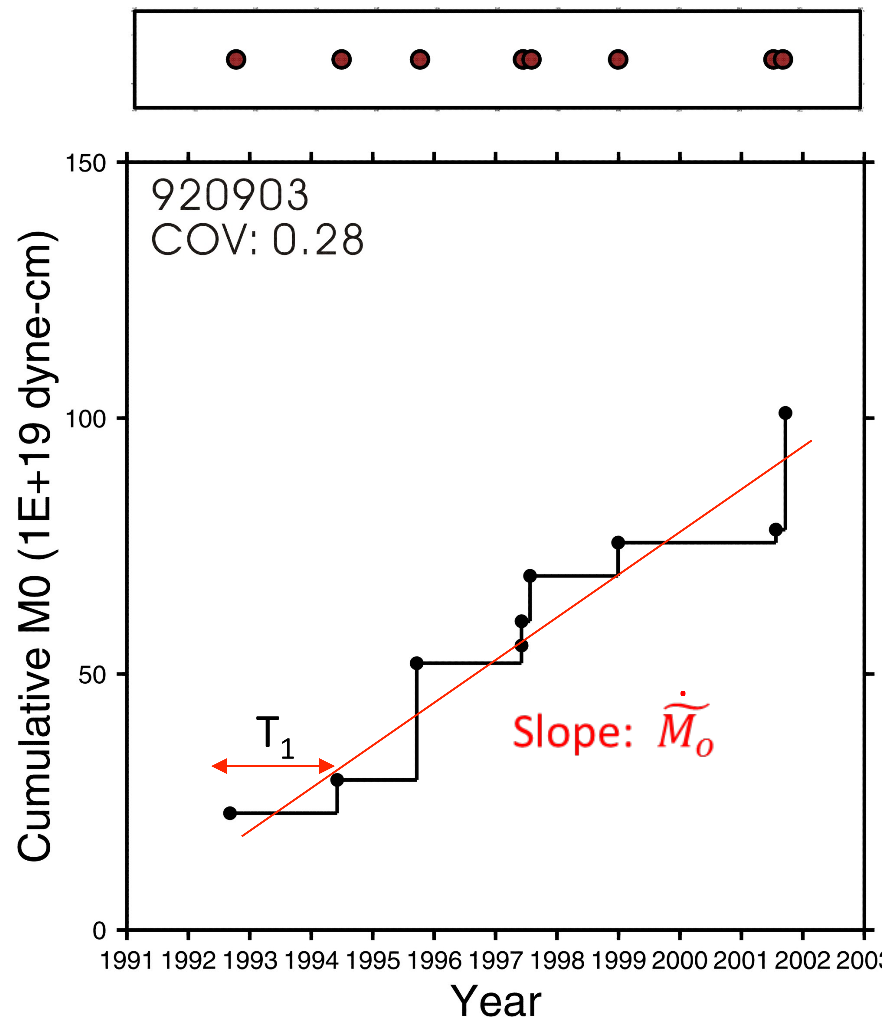
While average rate of moment release on a patch of the fault is

$$\tilde{\dot{M}}_0 = \mu A \tilde{\dot{d}}$$

Average rate of seismic slip on the fault

The average slip rate at the sequence site:

$$\dot{d}_{av} = \frac{\dot{M}_0}{\mu A} = \frac{M_{av}/T_i}{\mu A} = \frac{M_{av}}{\mu \frac{M_0}{\mu d_0} T_i} = \frac{d_0 M_{av}}{T_i M_0}$$



Using this methodology, the worldwide repeating earthquake are later found to follow an empirical relationship between slip and seismic moment, which is used in this study for slip estimate.

$$d_i = 10^{\alpha} M_0^{\beta}$$

α=-2.36±0.16 and β=0.17±0.01

[*Nadeau and Johnson*, 1998]

Method: determine deep slip rates

For each repeating earthquakes you can calculate "slip" based on the event magnitude

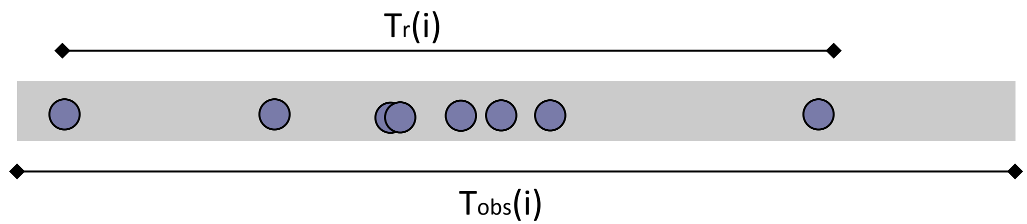
$$d_i = 10^{\alpha} M_0^{\beta}$$

α=-2.36±0.16 and β=0.17±0.01

Slip divide by time = slip rate

If the time period is considered to be the time span between the first and last repeating events, it is so called short-term slip rate; While the time period considered as the overall data period, it is so called long-term slip rate.

1. short-term: $V_d(i) = d_i / T_r(i)$
2. Long-term: $V_d = \Sigma_{i=1}^{N} d_i / T_{obs}$



Event chronology

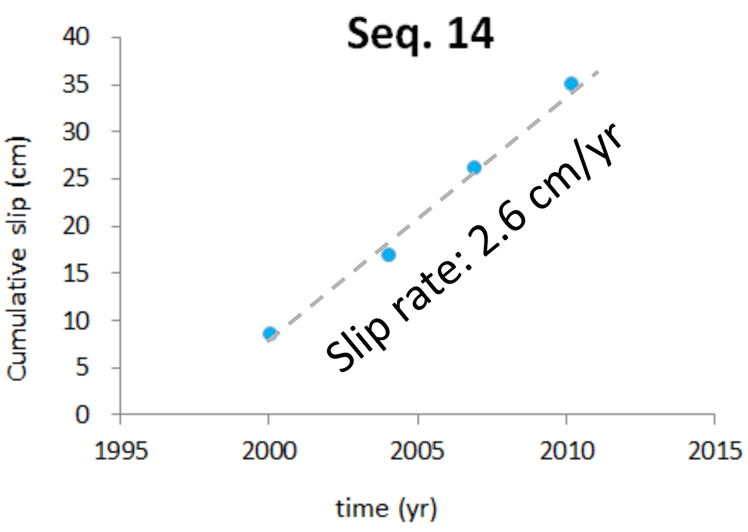
Result: Characterization of repeating sequences

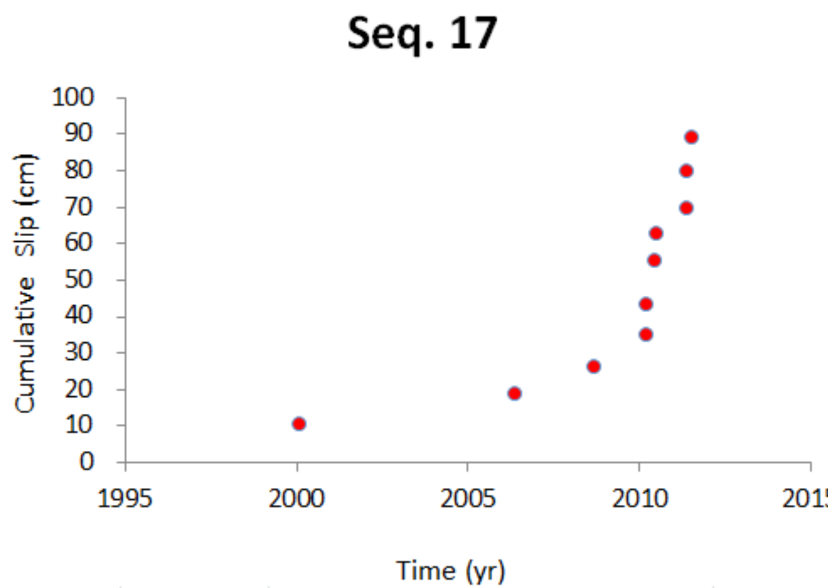
Different types of repeating earthquake sequences

Burst type:
Lifetime shorter than 3-yr

Continual-type:
Lifetime longer than 3-yr
Regular repeat time
(Quasi-periodic)

Continual-type:
Lifetime longer than 3-yr
Not regular repeat time
(Aperiodic)

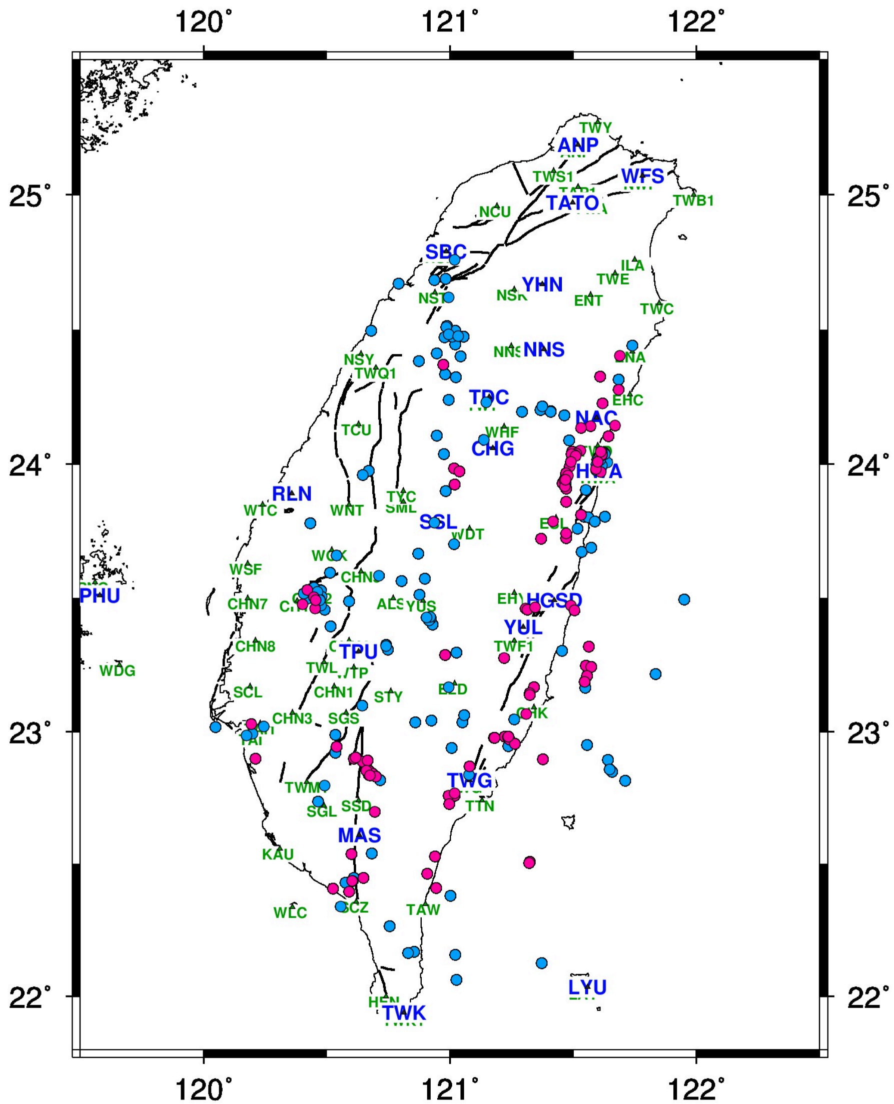




Allow us to determine slip rate

Triggering of very close-by earthquakes

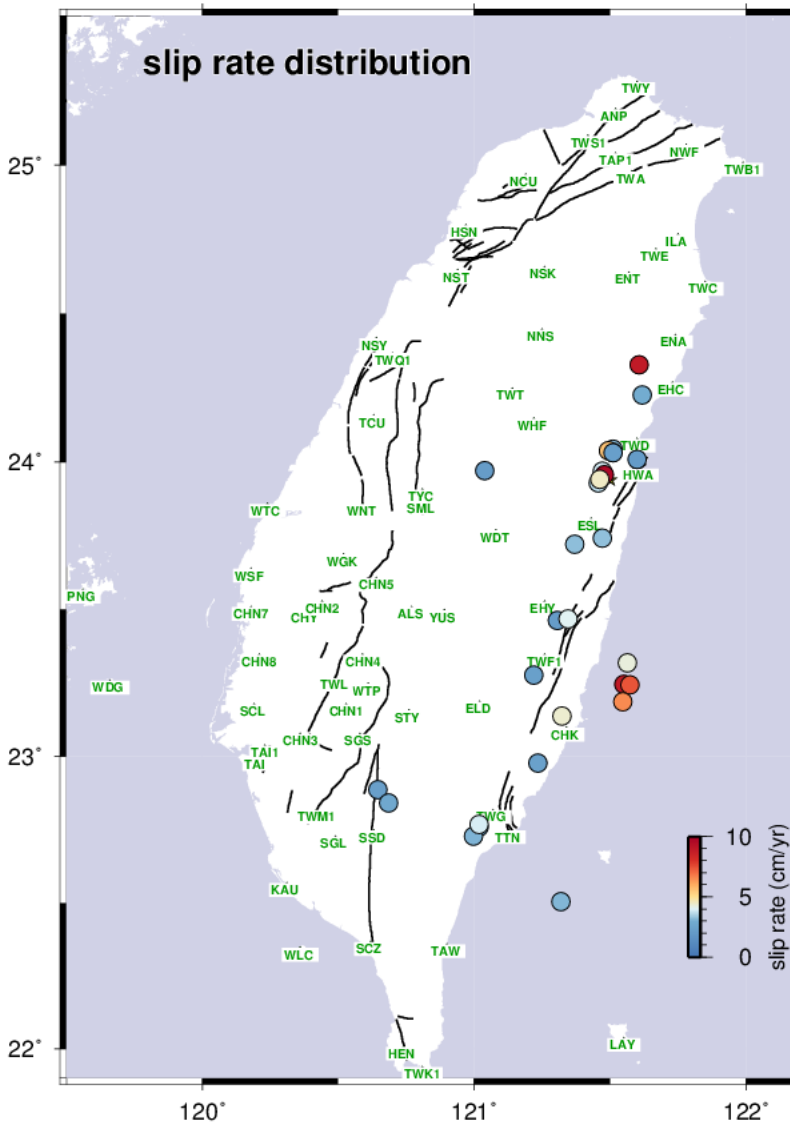
Result: Spatial distribution



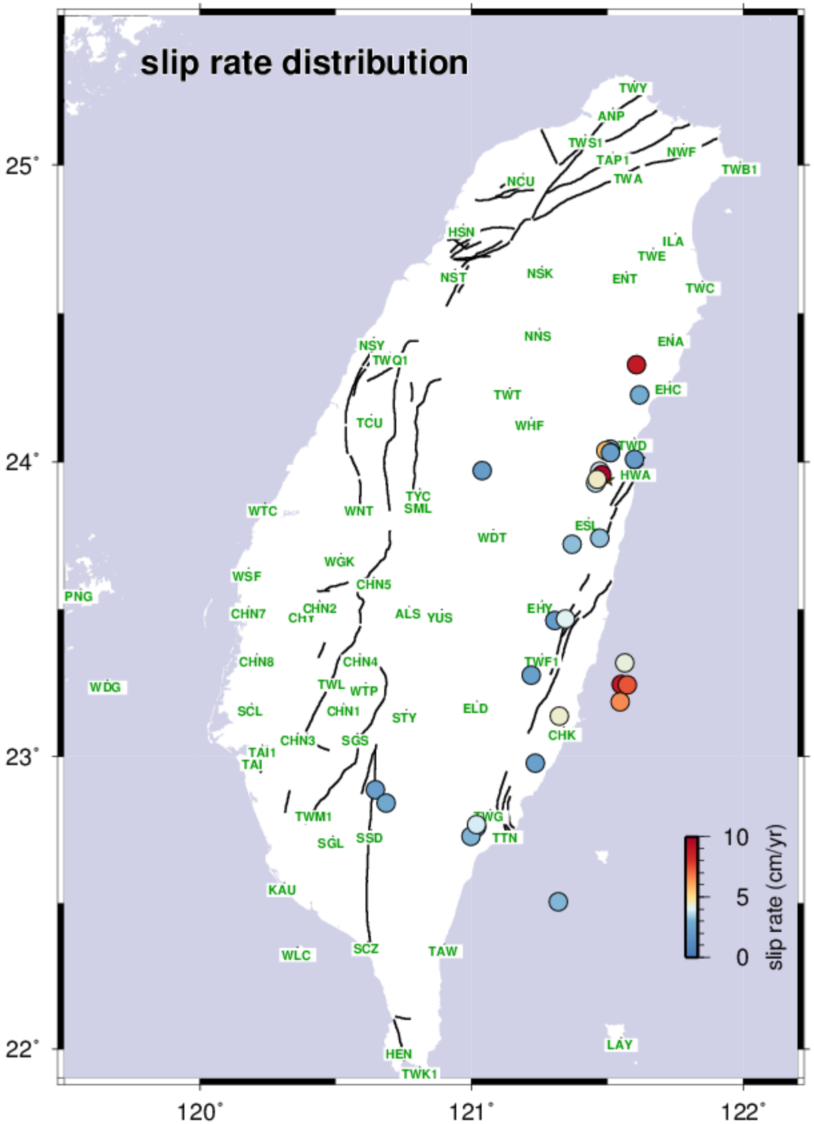
- B-type: 150 sequences
- C-type: 109 sequences
  - 30 quasi-perioidic sequences
  - 79 aperiodic sequences

Result: Spatial distribution of deep slip rate

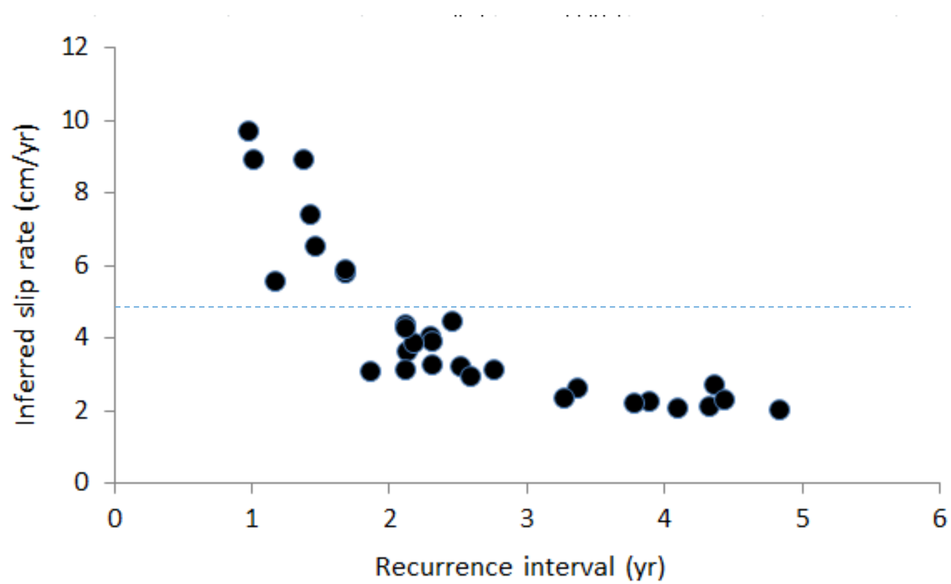
1. 30 quasi-periodic sequences inferred deep slip rate
2. Slip rate ranges from 2.0~9.7



Large slip rate occurred in Hualien and offshore Taitung



- These greater than 5 cm/yr slip rate are likely due to the short recurrence interval in that sequence.



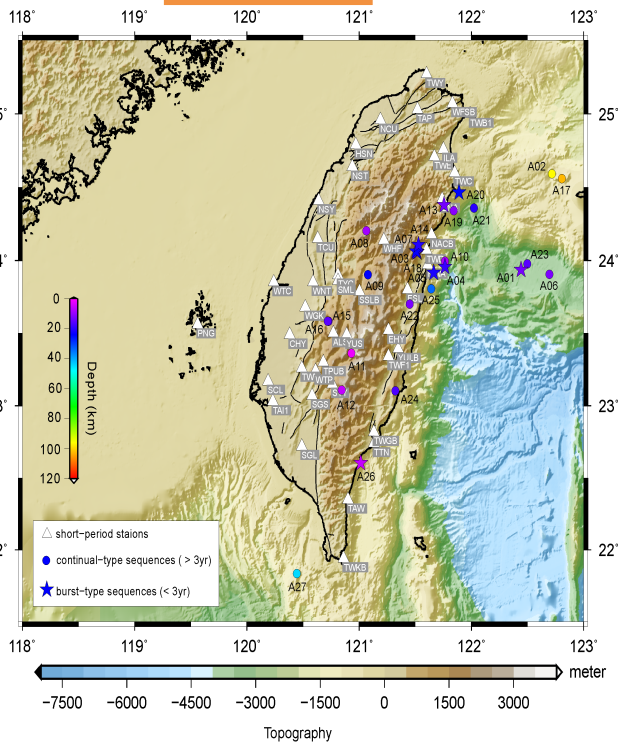
Summary

- Due to the large number of M2 earthquakes in Taiwan, identification of repeating microearthquakes has been a challenge.
- In this summer I've processed 33197 similar earthquakes carefully, to identify repeating earthquake sequences and understand their characteristics.
- The result shows that among the processed data, there are 259 M2 repeating earthquake sequences in Taiwan. 58% of them have short lifetime, while 42 % have lasted longer than 3 years.
- The slip rate inferred from the 30 quasi-periodic sequences ranges from 2.0~9.7 cm/yr. Greater than 5 cm/yr is a result of short recurrence interval, which is taking place in Hualien and offshore Taitung.
- The control of deep slip rate, its relationship with surface deformation needs further exploration.

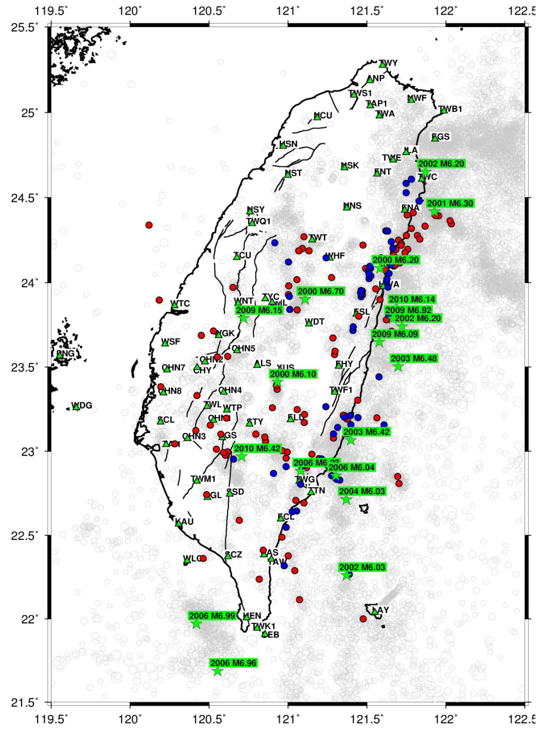
Future Works

- This is just a beginning.
- Complete the repeating earthquake identification for areas dd,dg,ef,eg,fd.
- Combine with the previous studies on M4, M>3 repeating earthquakes, to make an integrated repeating earthquake catalog in Taiwan.

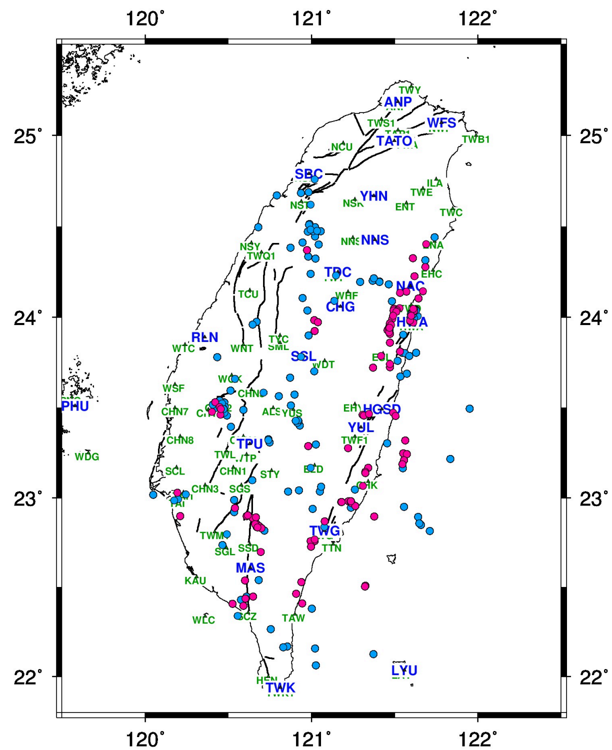
M4



M3



M2



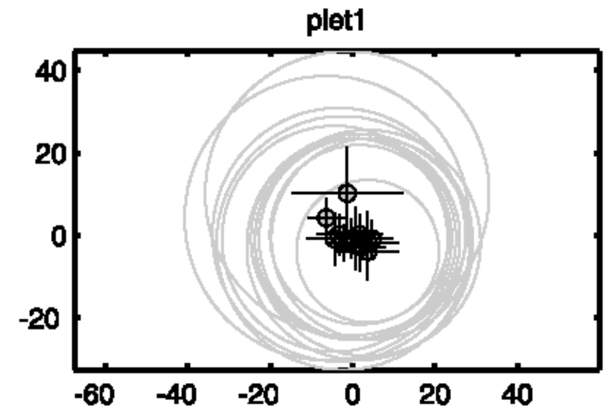
Thank you for listening~

Identification of repeating earthquakes

Criterion based on closeness in location:

[e.g., Vidale et al., 1994; Ellsworth, 1995; Rubin et al., 1999; Schaff and Beroza, 2004]

Remarkably successful in regions with well distributed station coverage and accurately timed data

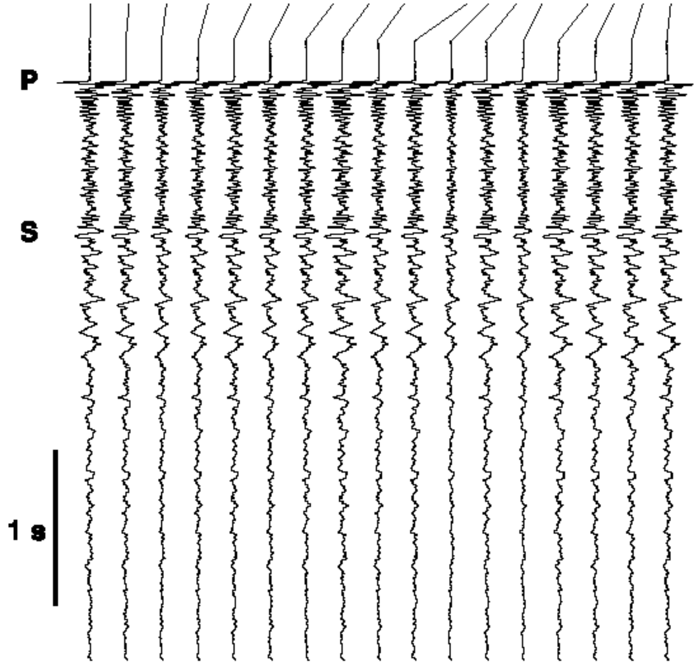


[*Schaff and Beroza*, 2004]

Criterion based on waveform similarity:

[Nadeau et al., 1995; Nadeau and McEvilly, 2004; Matsuzawa et al., 2002; Igarashi et al., 2003; Matsubara et al., 2005]

Criterion selection is arbitrary without location constraint.
In this study we start from the similar earthquake catalog (waveform cross-correlation coefficient greater than 0.7).



[*Nadeau and McEvilly*, 1999]