Understanding the tidal response in ambient tremors in Taiwan
(2013 NTNU summer intern project)
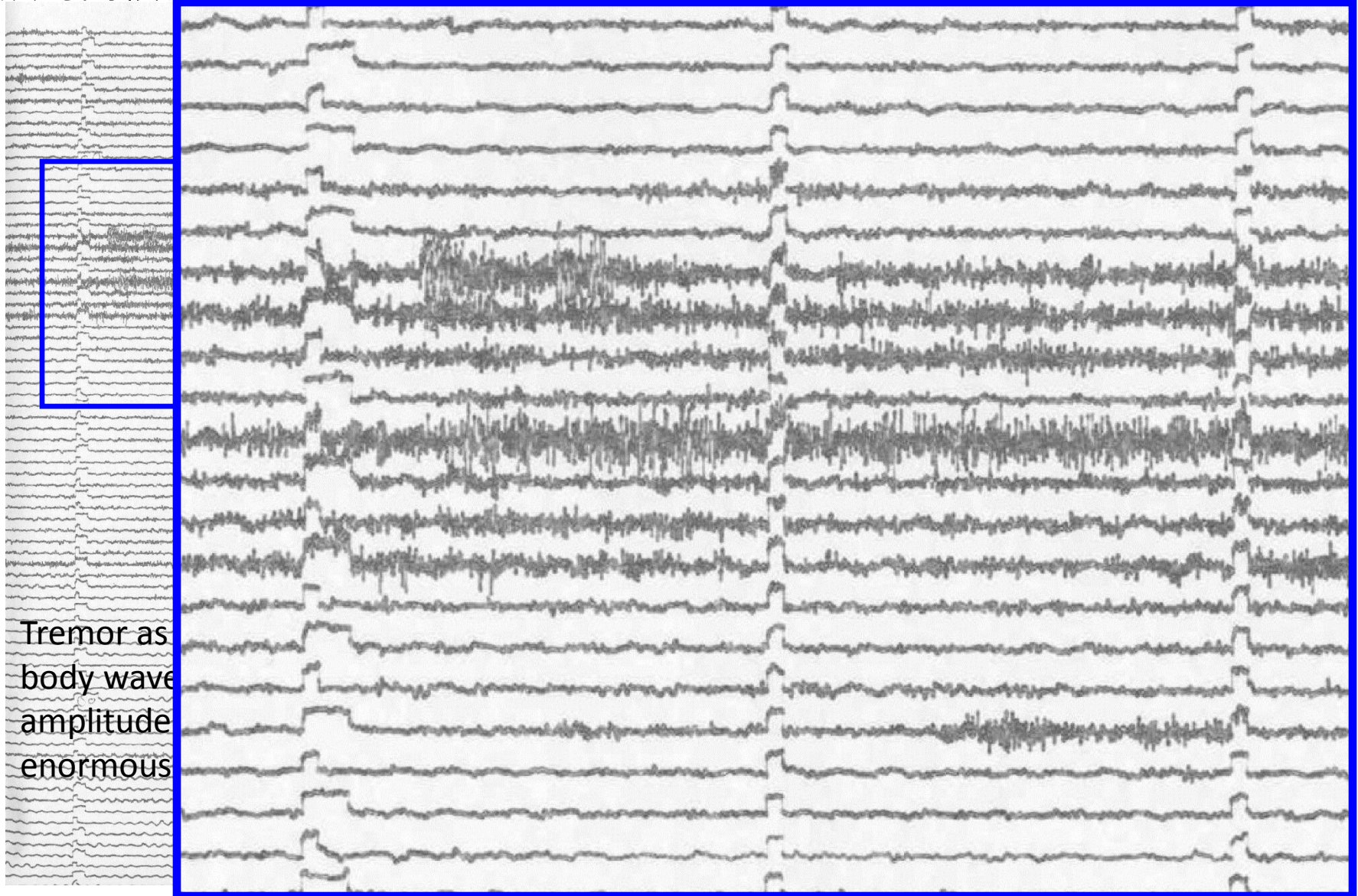
Student: 戴心如 None Tai

Supervisor: 陳卉瑄 Kate Huihsuan Chen

Dep. of Earth Sciences,
National Taiwan Normal Univerisity

在連續紀錄中，事實上埋著特殊的雜訊
(持續時間很長、振幅相對較高)

Tremor as
body wave
amplitude
enormous

這些特殊雜訊，竟然在不同測站具有一致到時！

They arrive at

The coherence between stations indicates it may not be noise but a real signal corresponding to a common source at depth
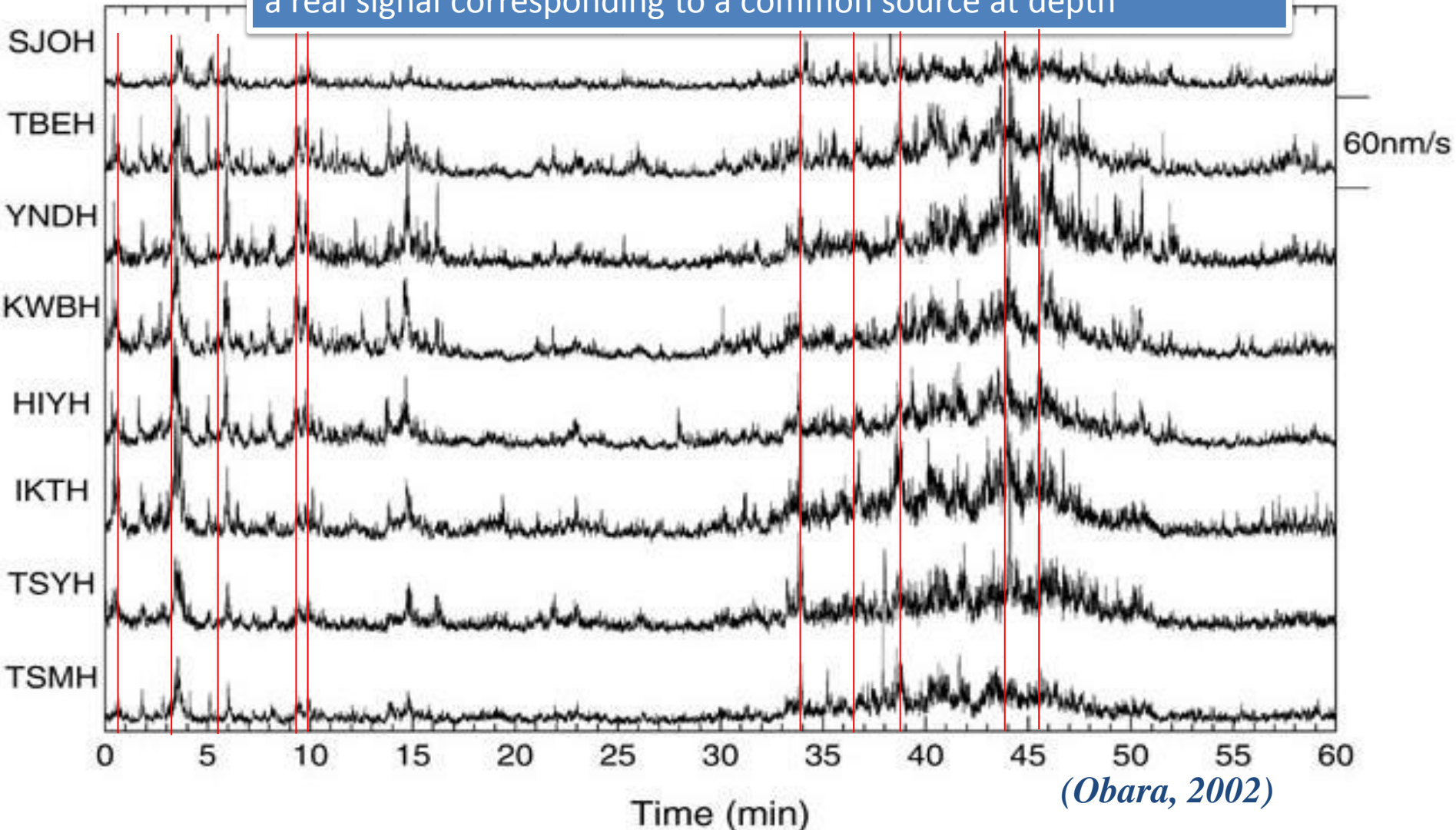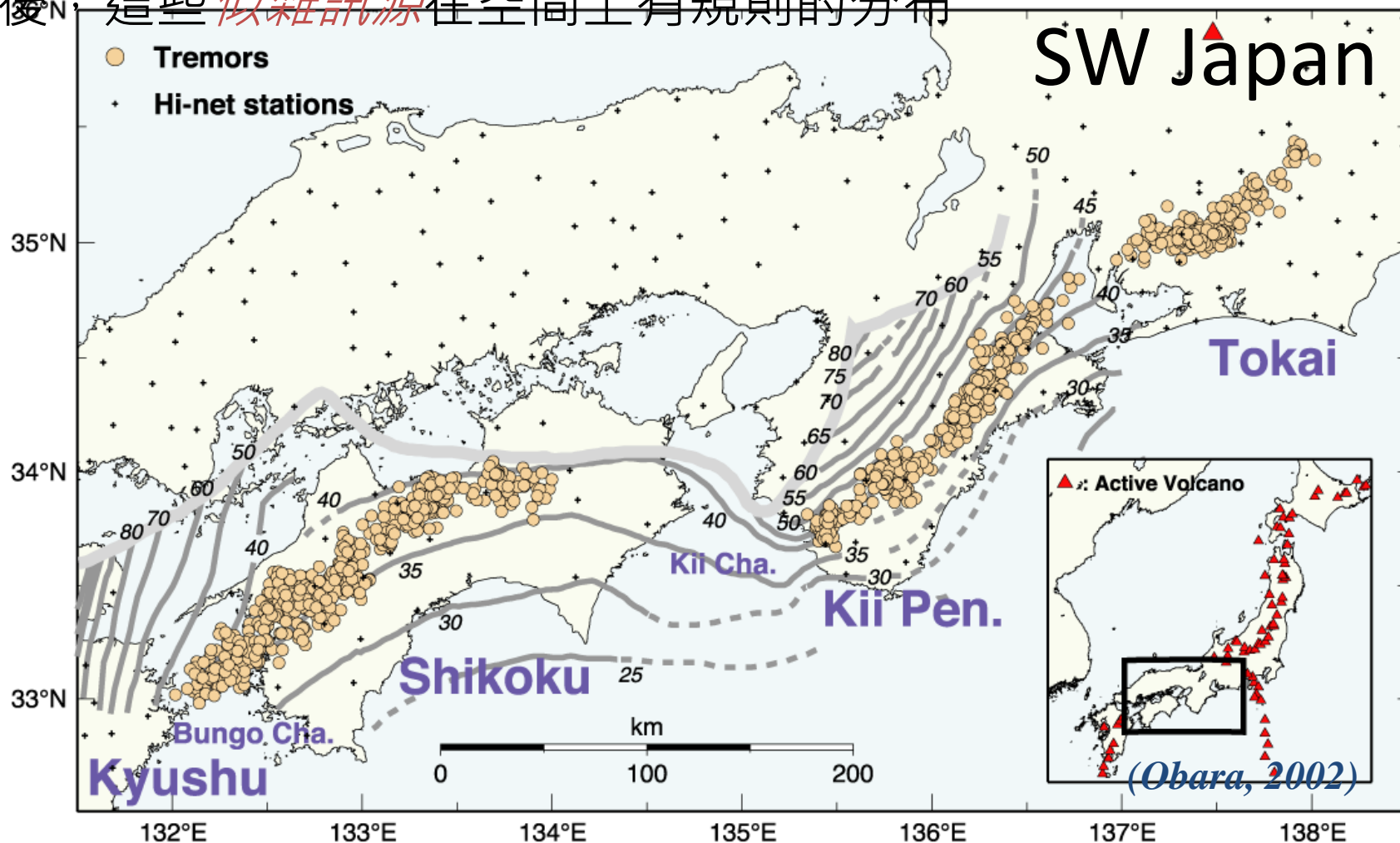

(Obara, 2002)

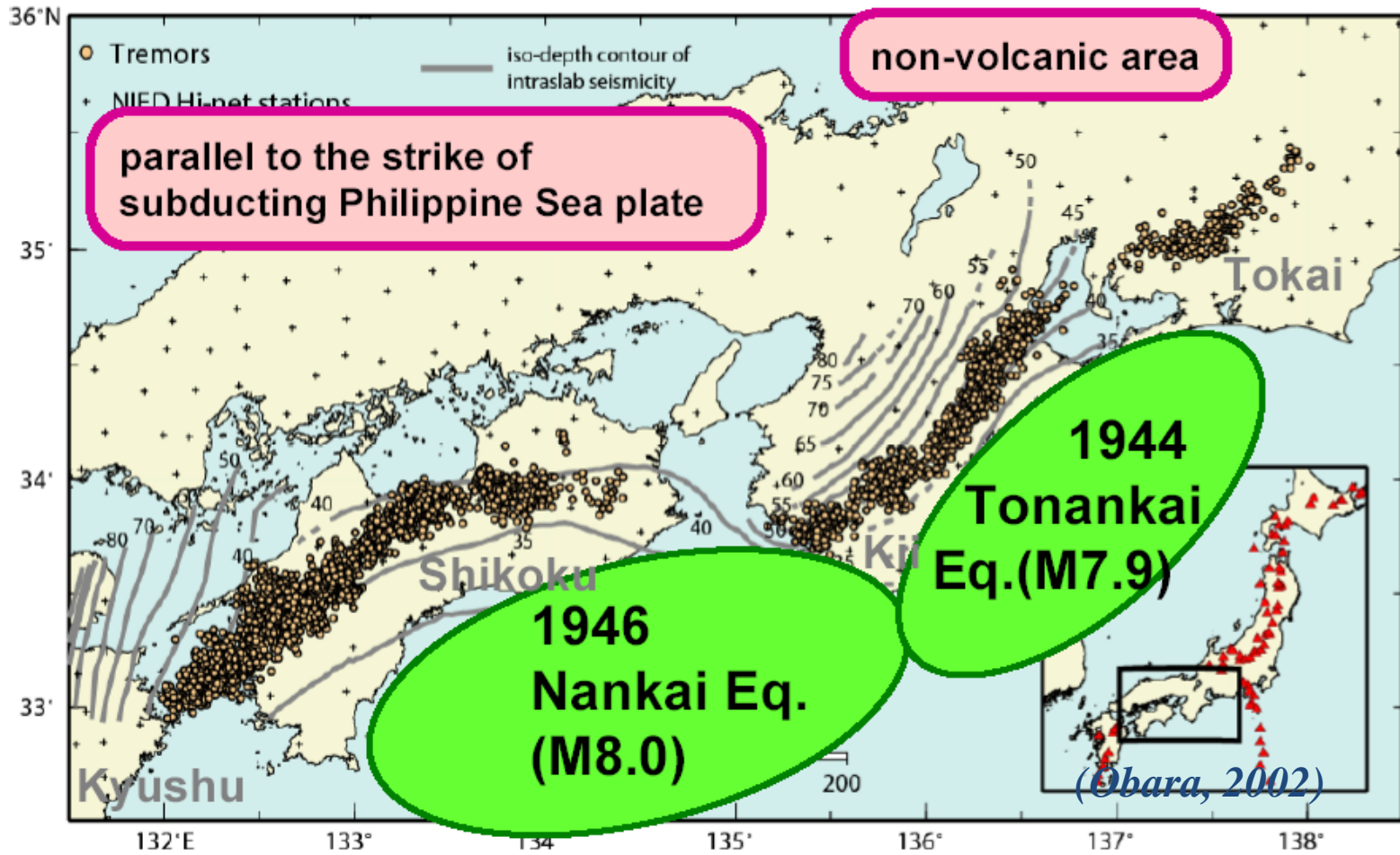IKTH station, vertical component, 2001 Aug. 17 4:00 am

Tremors are widely observed in worldwide subduction zones.
定位後，這些*似雜訊源*在空間上有規則的分布

In Japan, the tremor's shape and position parallel to the strike of the trench, indicating the vibrations may have tectonic origin.

平行於海溝排列，表示這個*似雜訊源*有構造上的起源

長微震發生在孕震帶更深處

(Obara, 2002)

- Tremors are located at the deeper part of the slip distribution of megathrust earthquakes, therefore they might reflect a part of the subduction process.

Under which condition tremors would occur?

In Japan and Cascadia subduction zones, tremors are found to repeat at a regular interval. There exists a clear pulsing of tremor activity with periods of 12.4 and 24 to 25 hours, the same as the principal lunar and lunisolar tides.

- That means the small stresses associated with the solid-earth and ocean tides influence the tremor generation, which is even more effectively than they do the normal earthquakes.

- Tremors therefore, is thought to represent shear failure on a critically stressed fault (near lithostatic pore pressure), so that they can be affected by small tide-induced stress (on the order of 1 kPa).

- Can the tide-tremor correlation be found in different tectonic setting?
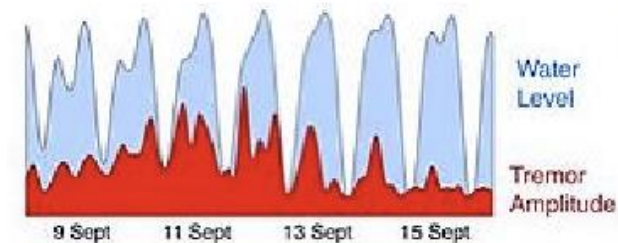
(Rubinstein et al., 2007)

Ambient tremor in Taiwan
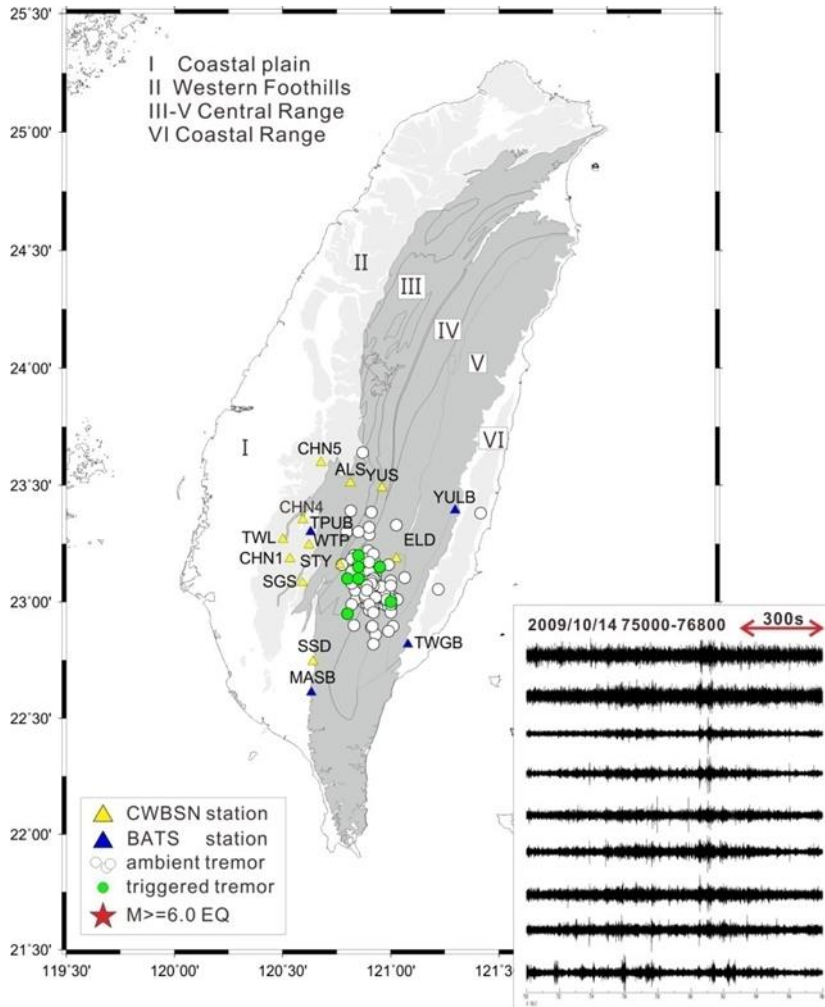
- In Taiwan, 231 ambient tremor events have been found in the southern Central Range from 2008 to 2011 (Chuang et al., 2013).

- Their durations range from 5 to 30 minutes.

- Rather than co-seismic slip induced stress change from nearby major earthquake, increased tremor rate is found to be highly correlated with the active, normal faulting earthquake swarms at the shallower depth.

Temporal distribution of ambient tremors in southern Taiwan

The occurrence time of tremor
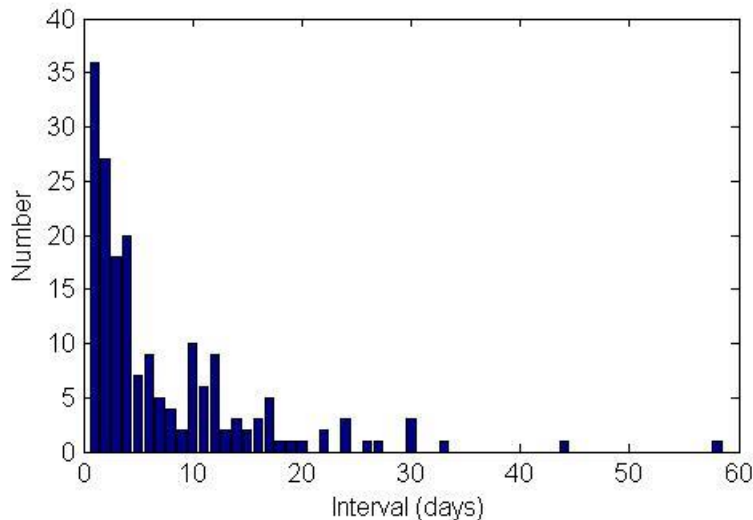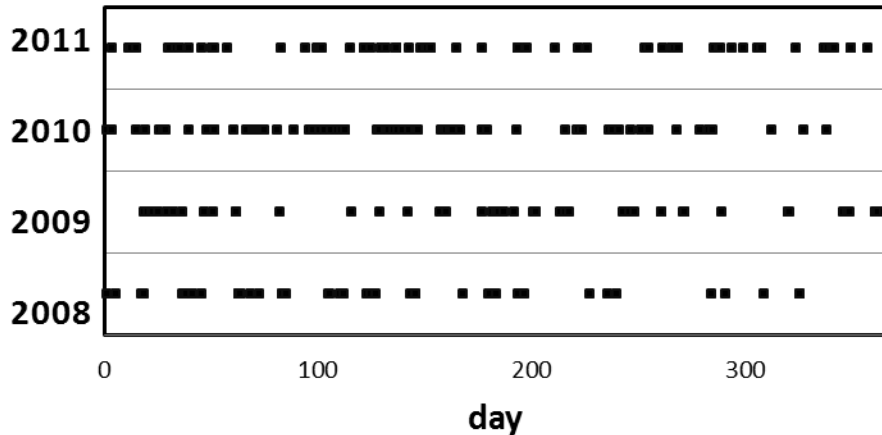
Do they show a particular recurrence interval?

we first analyze the general feature in tremor occurrence time.

64 % of tremor events occur with a interval less than 5 day, whereas 20 % of tremor events occur with a interval less than 1 day, as indicated by the histogram.

However, the number of events in the histogram depends on the selected bin of interval, which cannot represent the preferred cycle very well.

Calculation of tremor recurrence interval

- ## Parameter **s** :

interval of tremor events

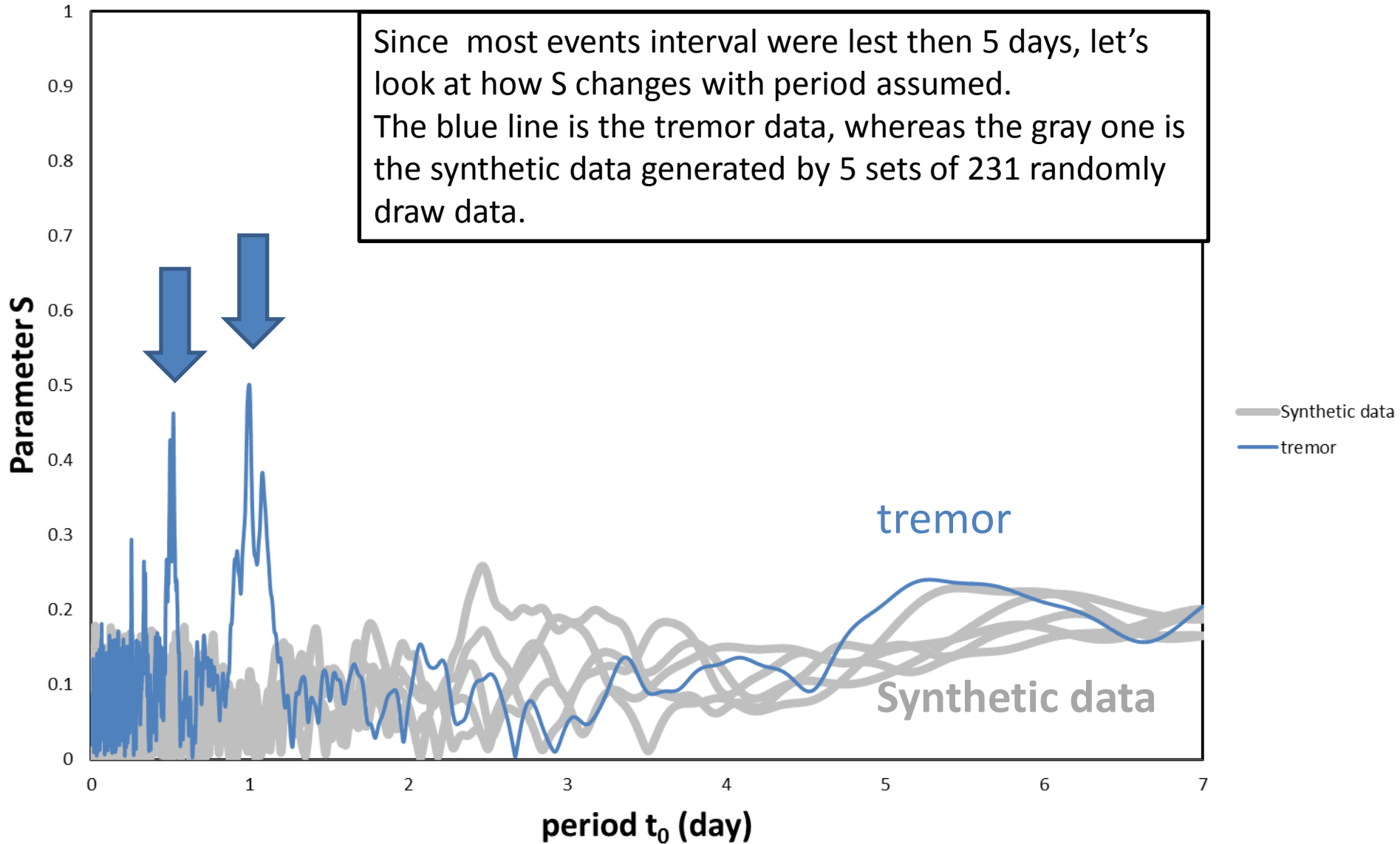$$s = \left| \sum_{i=1,..N} \exp(2\pi i \frac{t_i}{t_0}) \right| / N$$

the number of t_i

the period assumed

(Ide, 2012)

If the tremor events (sequence) is perfectly periodic, then S = 1

Parameter S change during period(t_0) 301s to 7days

Since most events interval were lest then 5 days, let's look at how S changes with period assumed.
The blue line is the tremor data, whereas the gray one is the synthetic data generated by 5 sets of 231 randomly draw data.

Synthetic data

tremor

tremor

Synthetic data

Parameter S

period t_0 (day)

Approximate period for tremor using "s"

Parameter S change during different period(t_0) between 301 second to 2days

11.93 is half of 23.86, so we only need to discuss three peaks: 12.42, 23.86, and 25.85 hours.
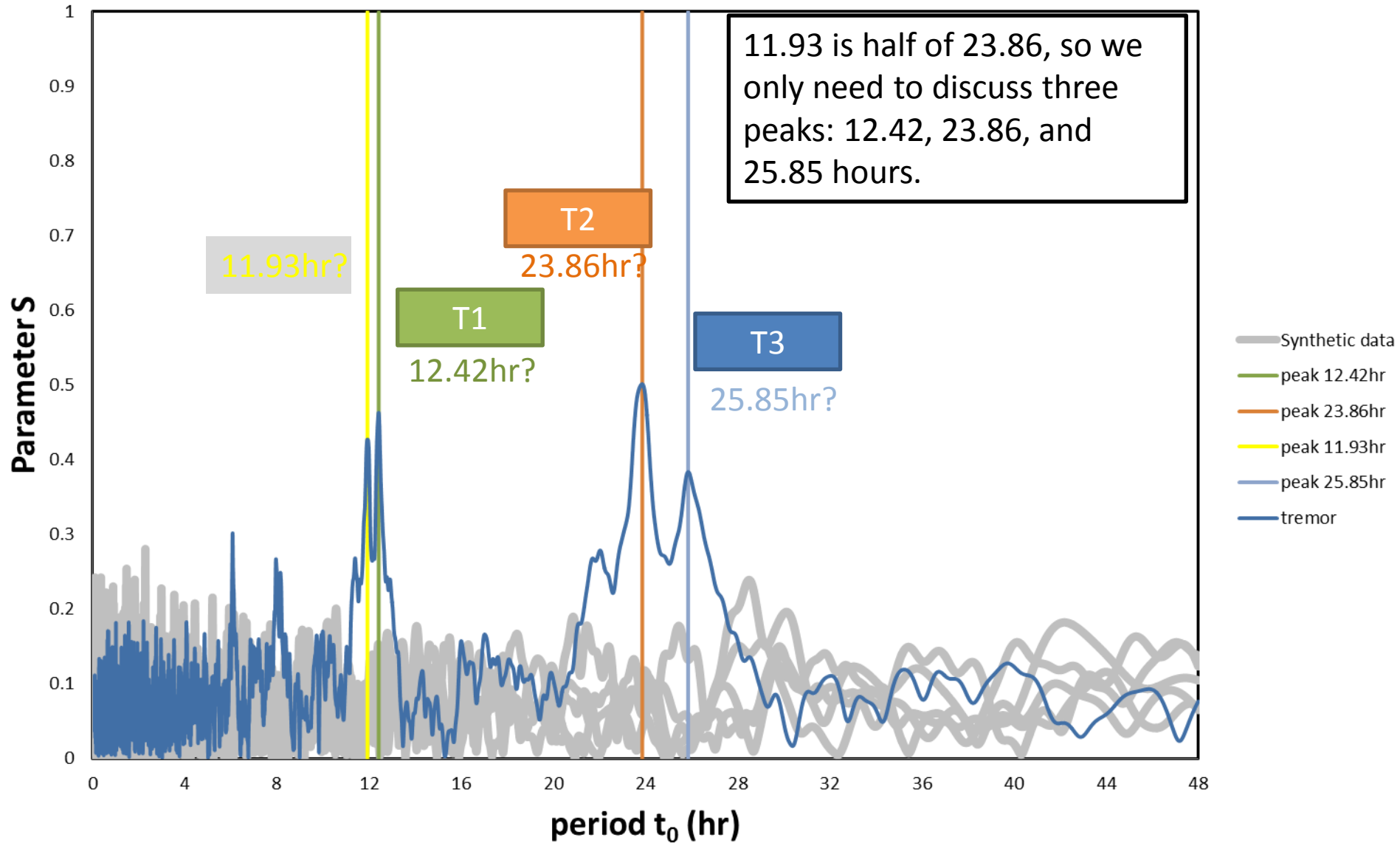
Measure a more precise period for tremor

If the real period of tremors = t_o, then the x/t_o would concentrate at a particular number.

t_o

$3t_o + x$

$T = nt_0 + x$
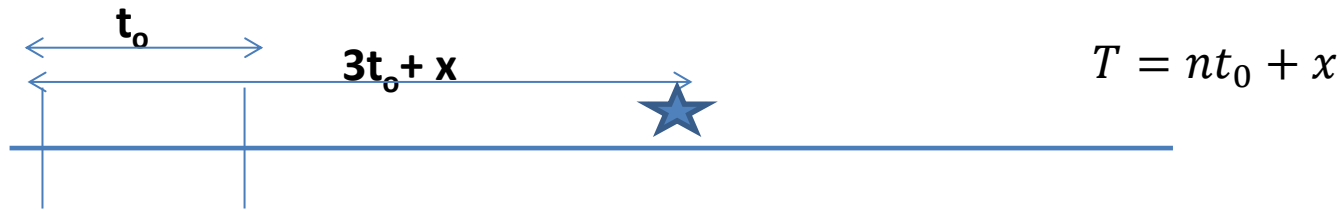
Occurrence time of event (T)

For example, if the real period t_o = 1000 s , then you will see the vertical blue line corresponding to x=500, therefore x/t_0=500/1000=0.5. If we assume a wrong period (even very minor difference, e.g., t_o =999 s or 1001 s), the n vs. x/t_o plot will not show a vertical line.

$$T = 1000n + 500 \; , n = 1, \dots 50$$
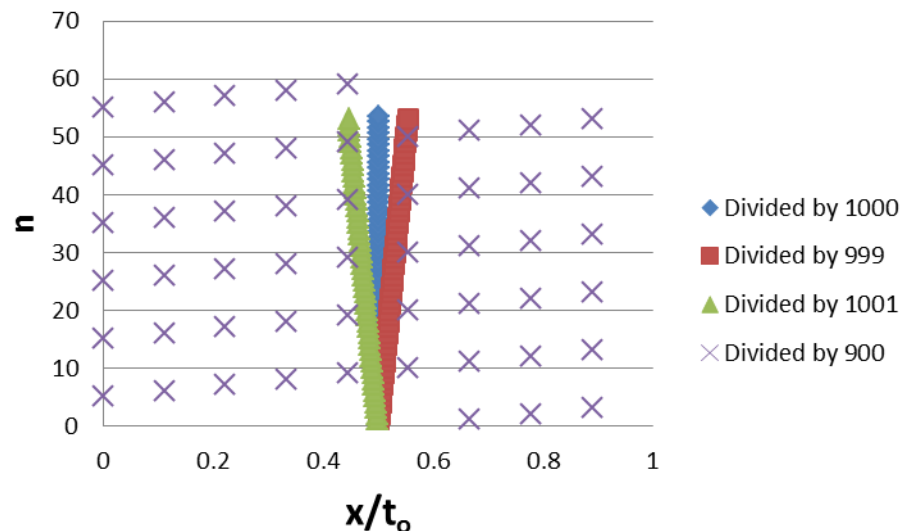
♦ Divided by 1000
■ Divided by 999
▲ Divided by 1001
✕ Divided by 900

Measure a more precise period for tremor

As described earlier, to measure a more precise period, we use the occurrence time of tremors divided by t0 of the peaks (or near the peaks) to make sure most of their normalized inter-event time is similar and won't change during the number of cycles.
We measure the more precise period for tremor:
12.42, 24.00, 25.74 hrs.
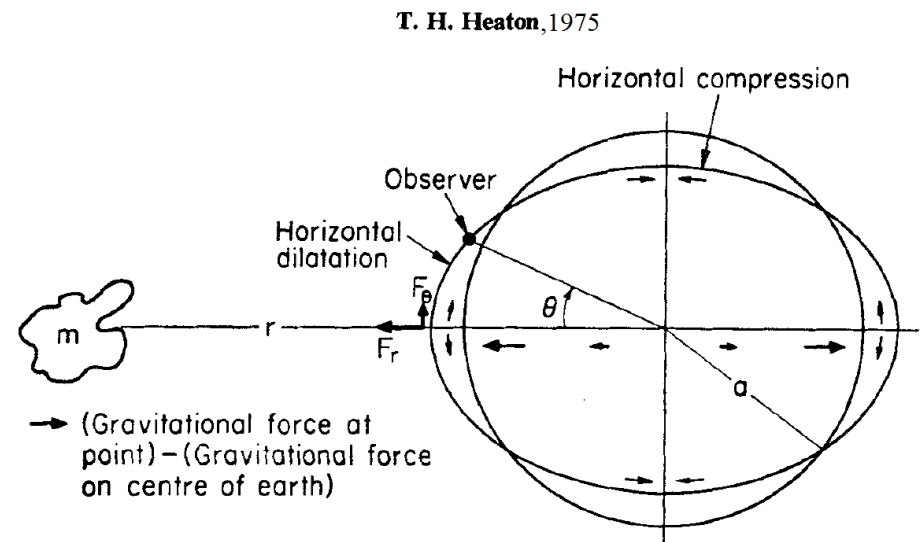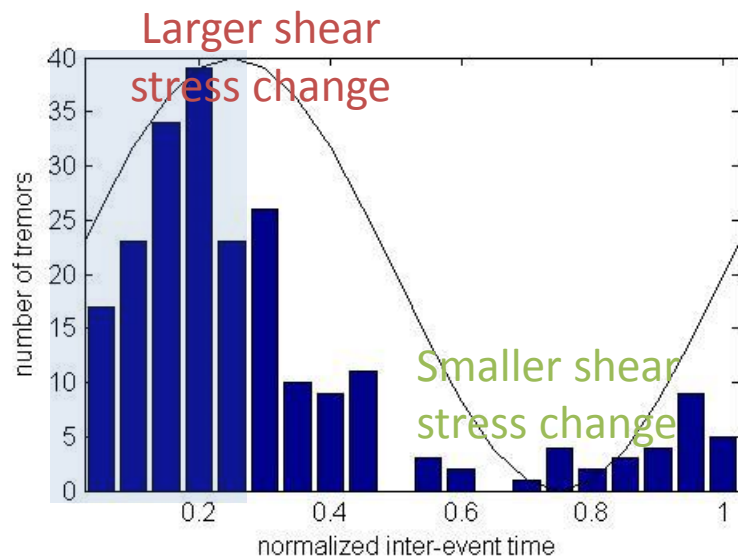(which we will discuss in the following slides)
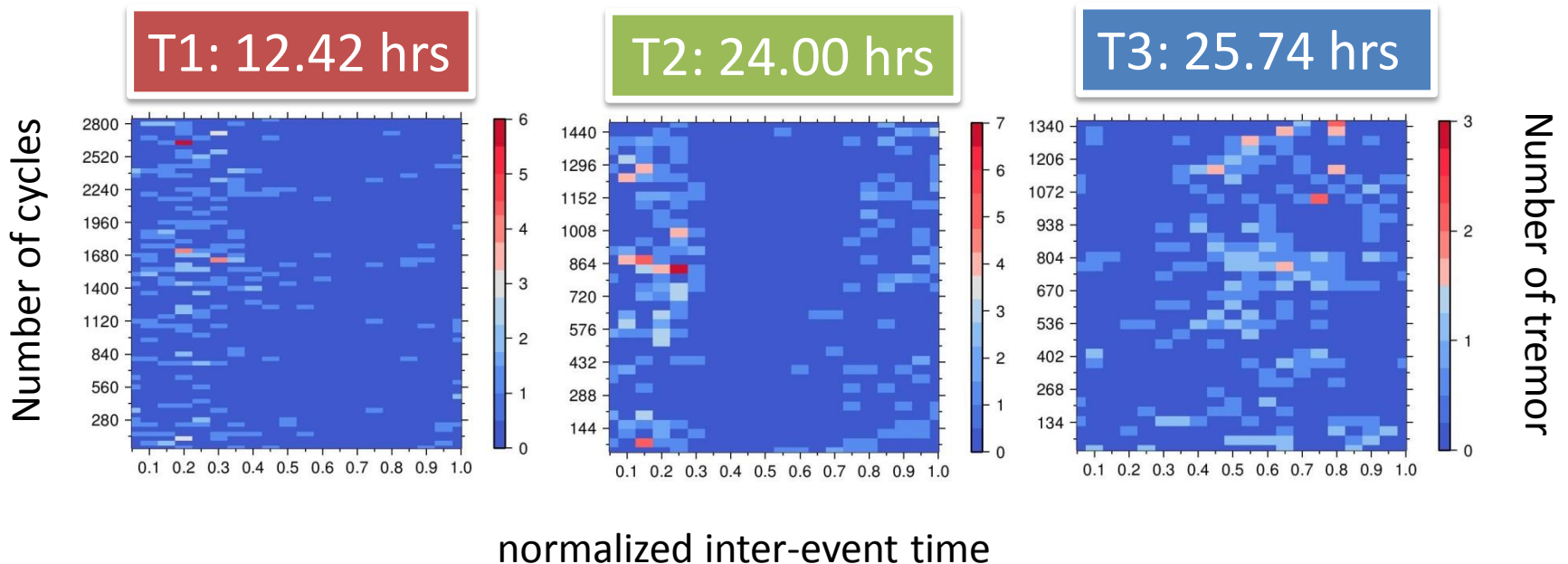
(T1) 12.42 h

This period is consistent with the semidiurnal principal lunar period of 12.42 h.

We use location of the Moon to measure the shear stress change at where tremors occurred.

→ 58% tremor events occurred in the early 1/4 cycle, corresponding to relatively greater shear stress change.

Possible explanation:
**12.42 h tremor period is likely a result of gravitation of the Moon**

Larger shear stress change

Smaller shear stress change

number of tremors

normalized inter-event time

T. H. **Heaton**,1975

Horizontal compression

Observer

Horizontal dilatation

F_θ

F_r

m

r

θ

a

→ (Gravitational force at point) − (Gravitational force on centre of earth)

(T2) 24.00 h

When tremor event is adjusted to local time, we find that:

(1) In Time: There exists a quiescence between 6-16.
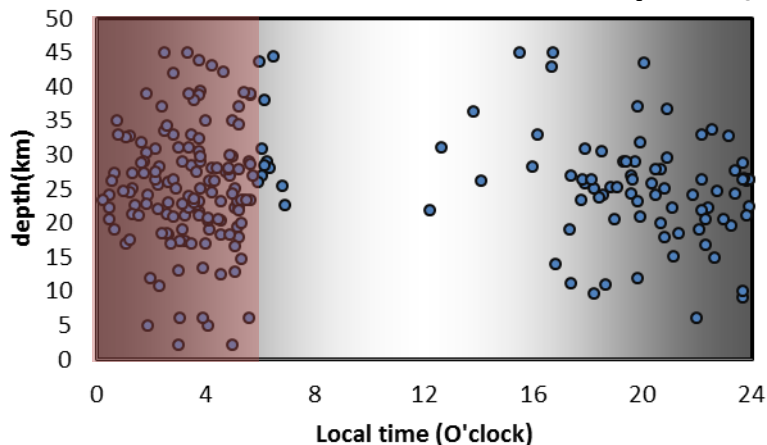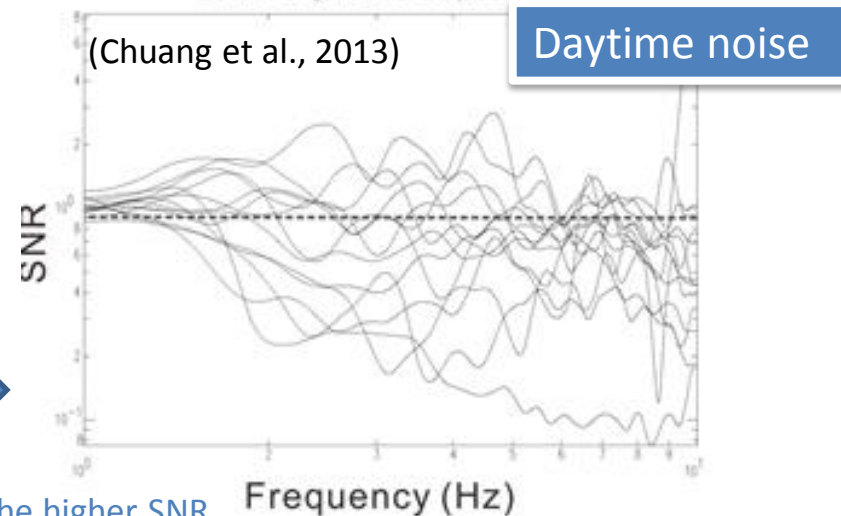**And most of the tremor events occurred at 0-5 AM.**

55% tremor events occur in the early ¼ cycle.

(2) In space:
No clear concentration in space (depth).
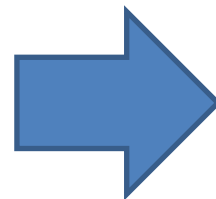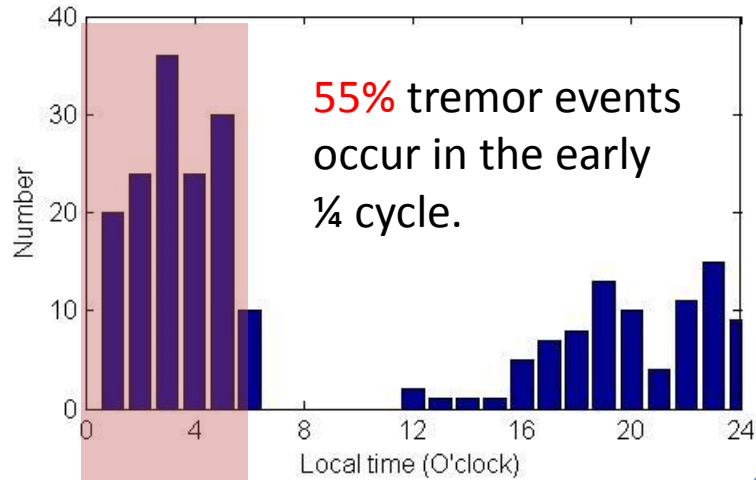
Consistent with the higher SNR in nighttime (6PM-6AM)

(Chuang et al., 2013)

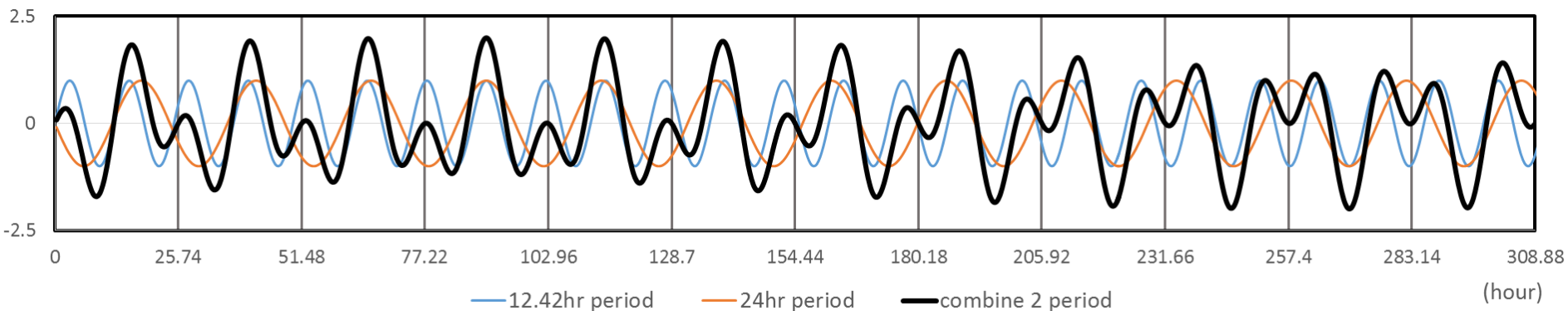SNR- signal to daytime noise

Daytime noise

SNR- signal to nighttime noise

Night time noise
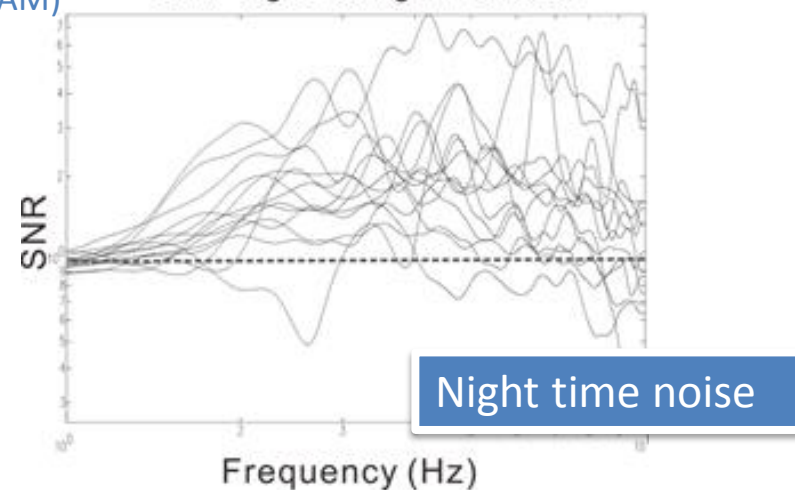
(T3) 25.74 h

The combined effect of 12.42hr and 24hr periods gives the 25.74 h, suggesting the 25.74 h is a result of the previous two major tremor periods.

Summary

- The ambient tremor events in this study are characterized by repeat time of **12.42 (T1), 24.00 (T2),** and **25.74(T3)** hours.

- **T1:**
  We found that most tremors occurred when moon gravitation induced shear stress change is high. This indicates the correlation between tremor generation and tidal stress. And such correlation explains the 12.42-hr tremors period.

- **T2** and **T3**:
  The 24.00-hr recurrence interval is likely a result of different tremor detectability in daytime and night time, whereas the 25.74-hr period is a combined effect of 12.42 and 24.00 hr periods.

- **The tide-tremor correlation follows a universal feature, which is applicable in Japan, Cascadia subduction zones, San Andreas fault, and southern Central Range of Taiwan.**