China University of Geosciences

Institute of Geophysics & Geomatics

短臨地震前兆-
地殼振動與多物理參量耦合
Short-term pre-earthquake anomaly - a coupling between crustal vibrations and multiple physical parameters

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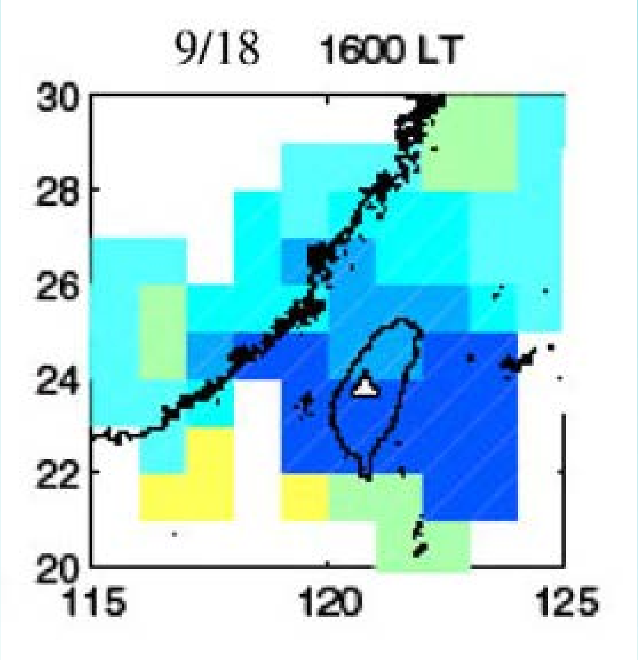
Outline

1. Motivation
2. How to determine seismogeneric areas
3. Analytical results
4. A potential mechanism
5. Comparable results with multiple parameters
6. Conclusions

Characteristics of ionospheric anomalies before earthquakes

Pre-earthquake TEC anomalies often distribute in wide areas with a radius > hundreds kilometers

Sources and/or mechanisms dominate TEC anomaly distributing in large areas are unclear



TEC anomaly associated with the Chi-Chi earthquake

Characteristics of infrasonic waves before earthquakes

Pre-earthquake infrasonic waves mainly ranged at frequency of 0.0001–20 Hz

High-frequency infrasonic waves would be dominated by micro-cracks, tremors and/or small earthquakes

However, mechanisms of low-frequency waves remind unclear

Potential mechanisms of pre-earthquake anomalous phenomena in the ionosphere

1. **Electromagnetic current and/or emission**
2. **Radon decay**
3. **Acoustic-gravity waves**

Electromagnetic current / emission

Electromagnetic waves drive anomaly in the ionosphere and far field.

If tiny anomaly can be found in the ionosphere and far field, strong anomaly should be observed close to hypocenters.

However, no significant anomaly can be observed close to hypocenters.

Unsolved questions/problems

Radon is generally considered to be potential sources driving TEC anomaly, TIR anomaly and so on.

Discrepancy in

Areas

Duration of radioactive decay affecting the atmosphere and ionosphere

Decrease of concentration of Radon

Questions/Problems

Electric currents flow

toward high conductivity materials underground

upward into the ionosphere

~~toward an unknown object with a parallel direction~~

Acoustic-gravity waves

No significant ground motion and/or crustal deformation before earthquakes has been reported by scientists

- **How can we observe**
- **What are causal mechanisms of seismo-anomalies**

Is anything unreasonable in our knowledges?

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Since a long time ago……

Areas where stress accumulates triggering earthquakes are limited around faults

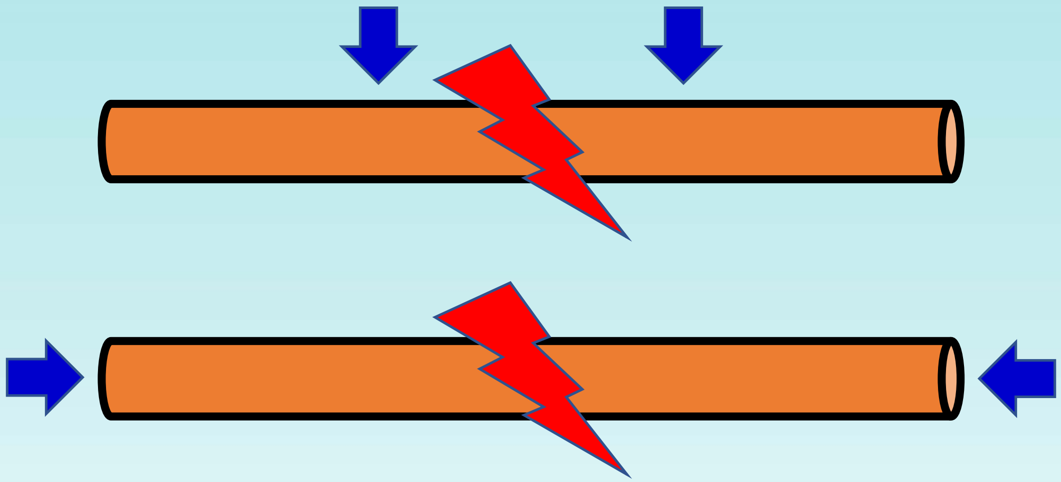
Therefore, most scientists focus on the phenomena along faults

Our cognition limits the areas

or

The areas truly limited around faults

When we break a stick……



What can be the clues before the stick break

Force

Deformation

Micro-cracks

Earthquake catalogs in Taiwan and Japan

more than 10 years

High dense seismic arrays

Even distribution in widely area

Detection of relatively-small earthquake events

Methodology

M >= 3 earthquakes are utilized as mainshocks

M >= 2 earthquakes are considered to be micro-cracks

Compute the distribution using the time and spatial difference between the mainshocks and micro-cracks

Superimpose all the spatiotemporal distribution and normalize the total by using the area

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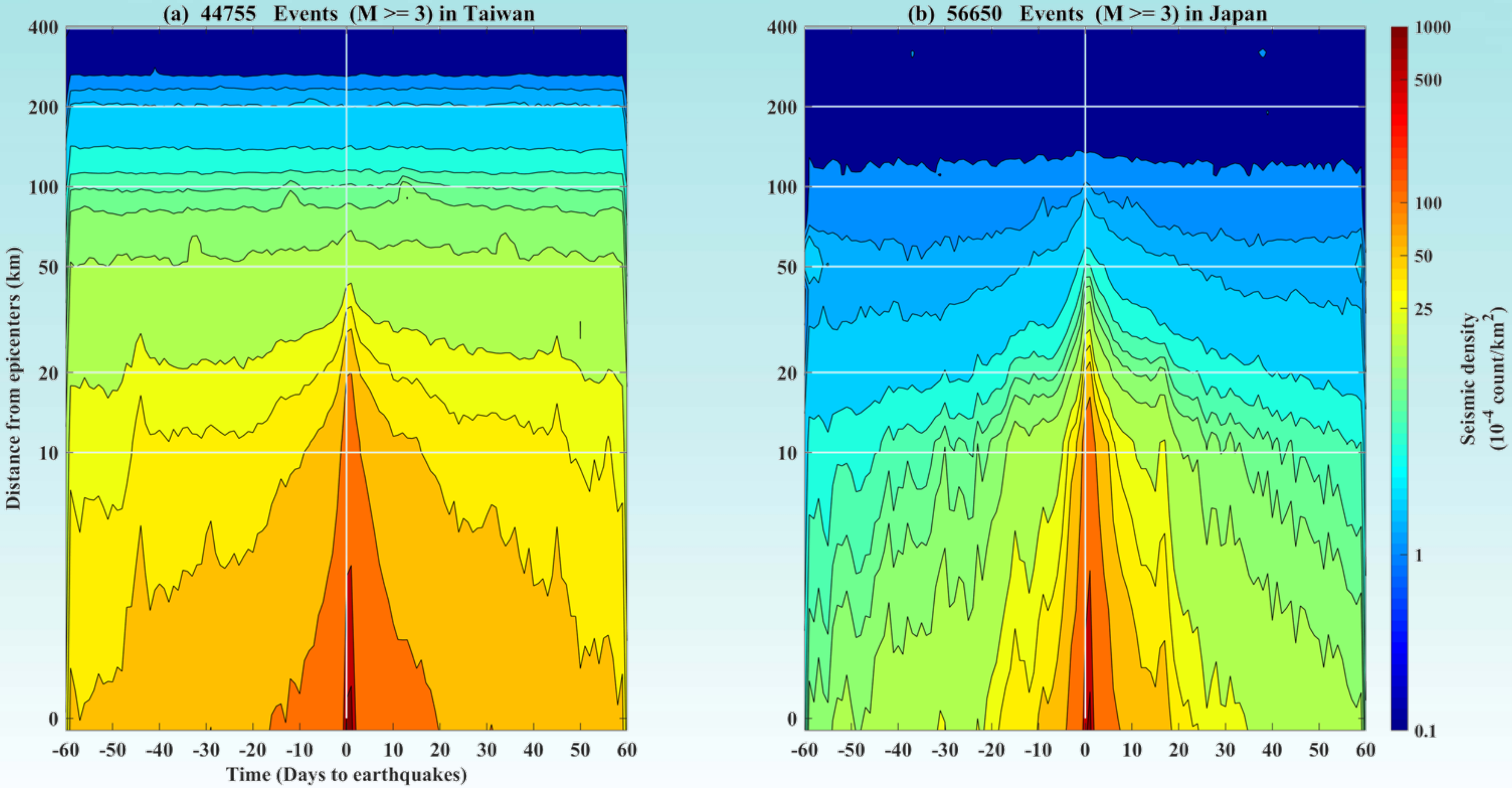
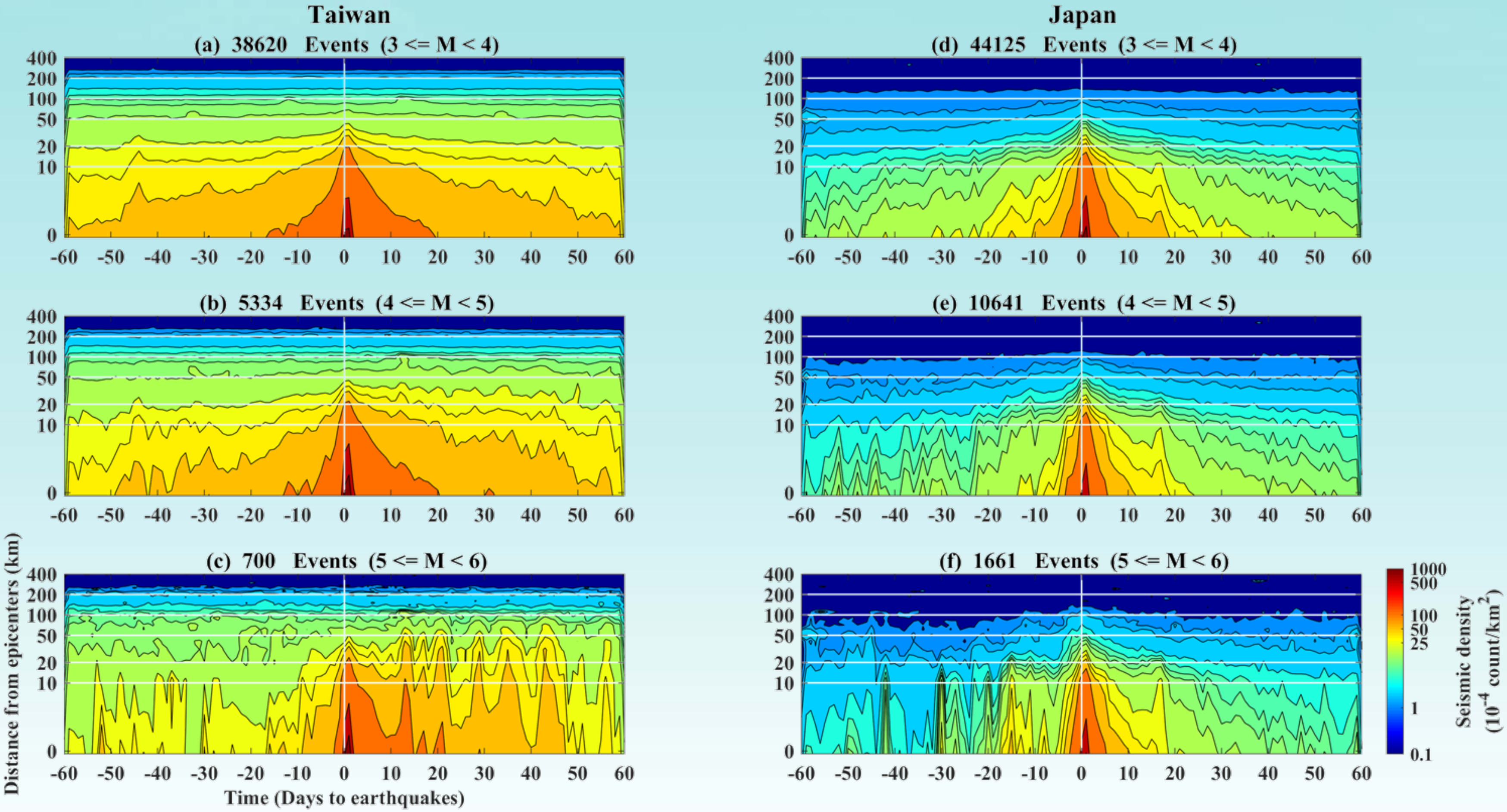
Spatiotemporal relationship between seismicity and earthquakes in Taiwan and Japan



The spatiotemporal relationship associated with distinct earthquake magnitude



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A potential mechanisms of crustal resonance

$$f = \frac{1}{2\pi}\sqrt{\frac{Eh^2}{12(1-v^2)\rho}}\left[\left(\frac{\pi}{a}\right)^2 + \left(\frac{\pi}{b}\right)^2\right]$$

Leissa (1969)

E: Young's modulus 100 GPa

v : Poisson's ratio 0.3

ρ: crustal average density 2700 kg/m^3

h : the thickness of the square sheet

f : resonant frequency

ranged 1.5-3.5 hours in period

a = b : the width of the square sheet

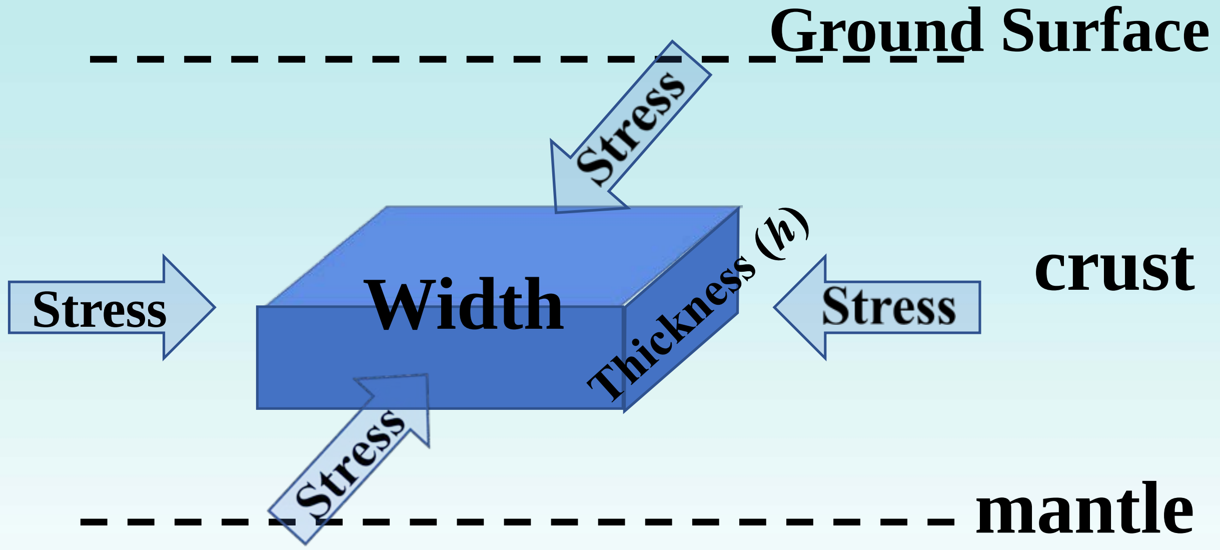
ranged 100-300 km

Crustal resonance

Assumptions

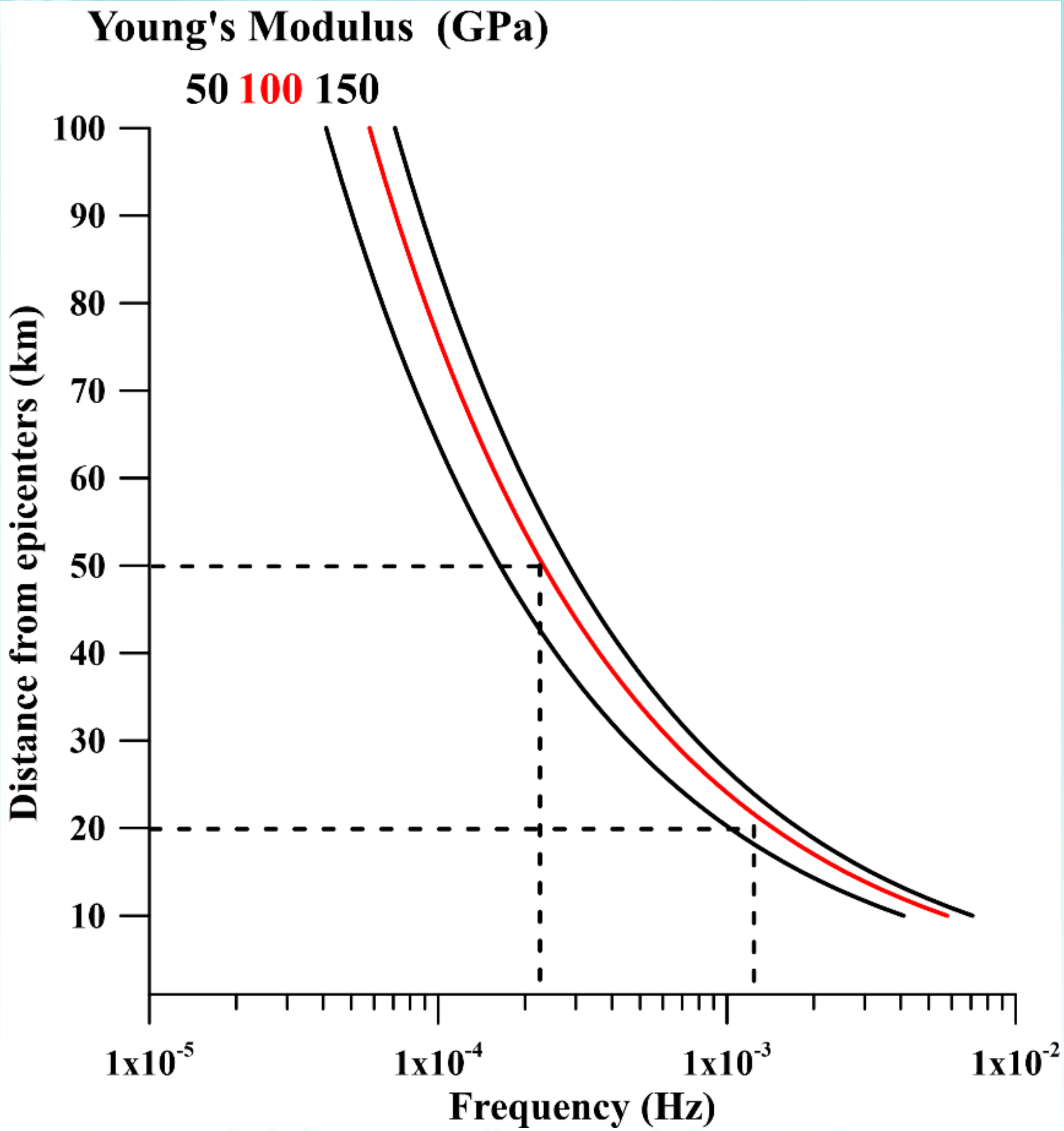
Stress loads in volumes with a square sheet

The width is determined based on the observation ranged 100 ~ 300 km



Crustal resonance

h = 400 meters



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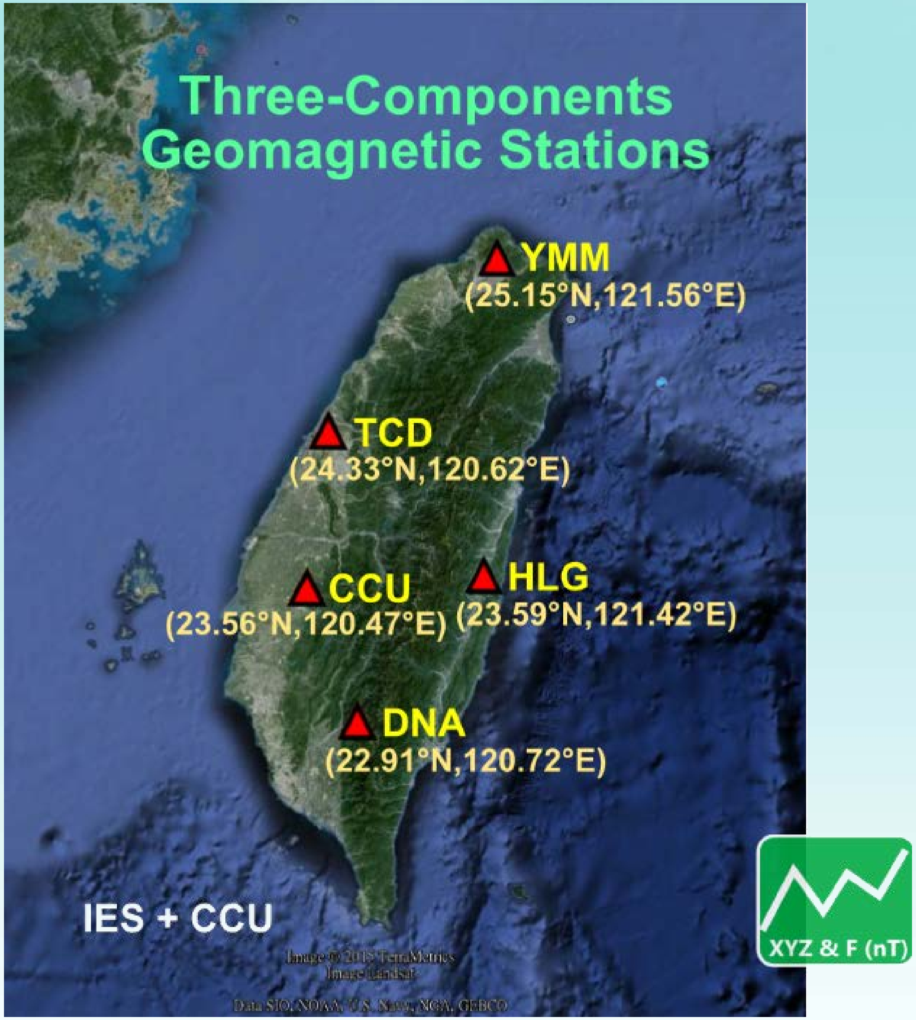
If those are true
What can be observed
in other multiple parameters before earthquakes

Observation from magnetometers at the end of 2016

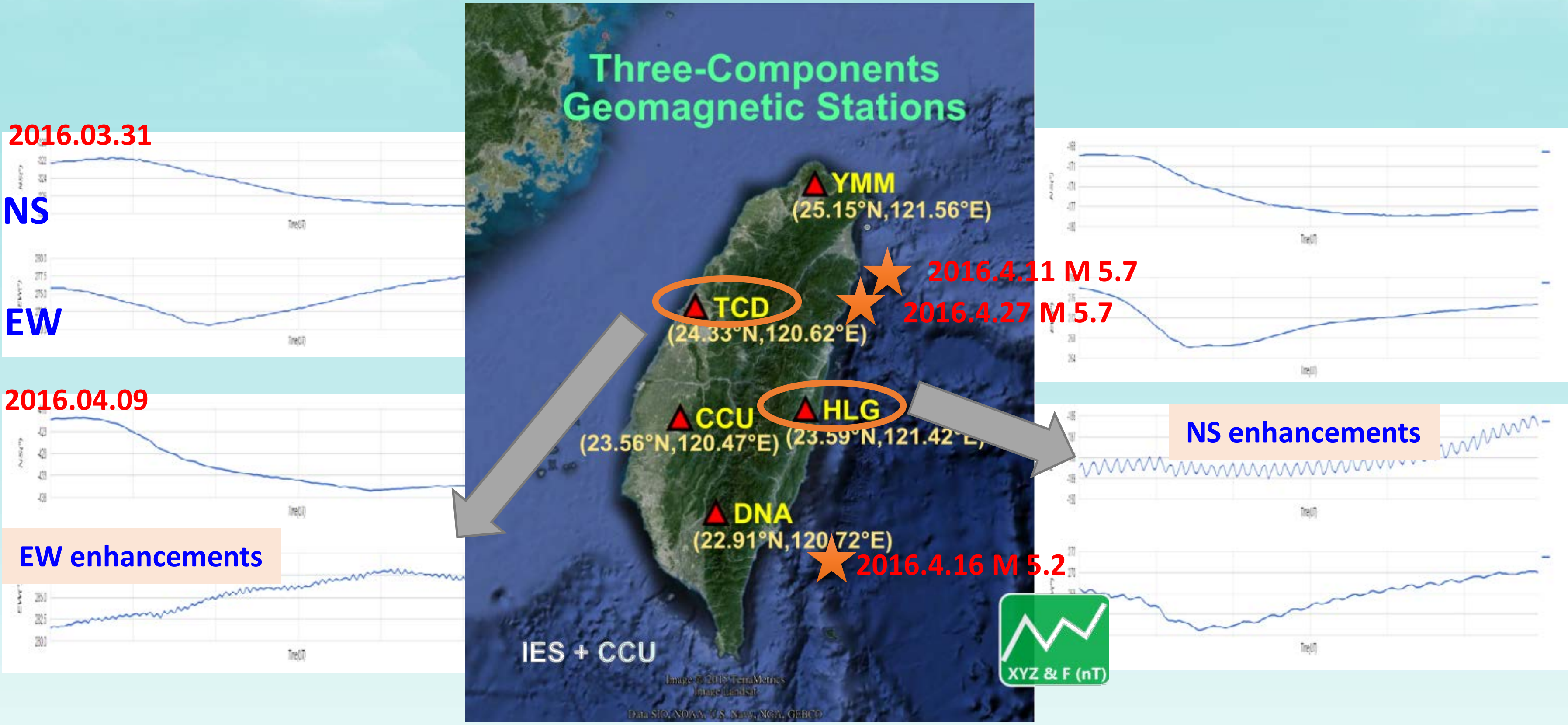


3-component fluxgate magnetometer **FRG-604RC**

Monitoring **absolute** magnetic field with 10 Hz sampling rate and 0.01 nT

Tiltmeters monitor status of sensors of magnetometers

Observation from magnetometers at the end of 2016



Novel observation of long-period ground motion from tiltmeters

Data collection

Solid phenomena can be simultaneously observed by more than two distinct instruments

If the observation is true, long-period ground motion should be observed by using seismometers and/or GNSS

We took about 1.5 years and collected more than 10 TB data to examine associated phenomena

2016 M6 Meinong earthquake on Feb. 6

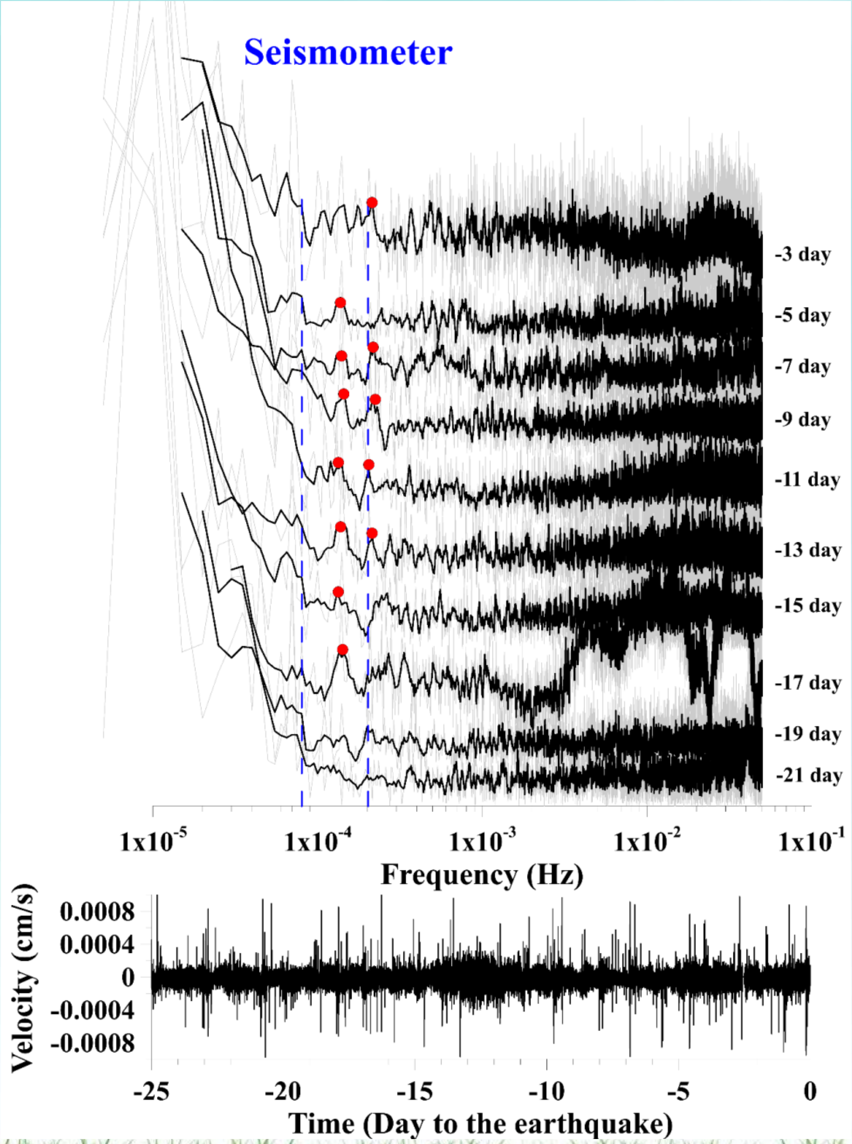
■ **Seismic data from broadband seismometers of NCREE**

100 Hz sampling rate

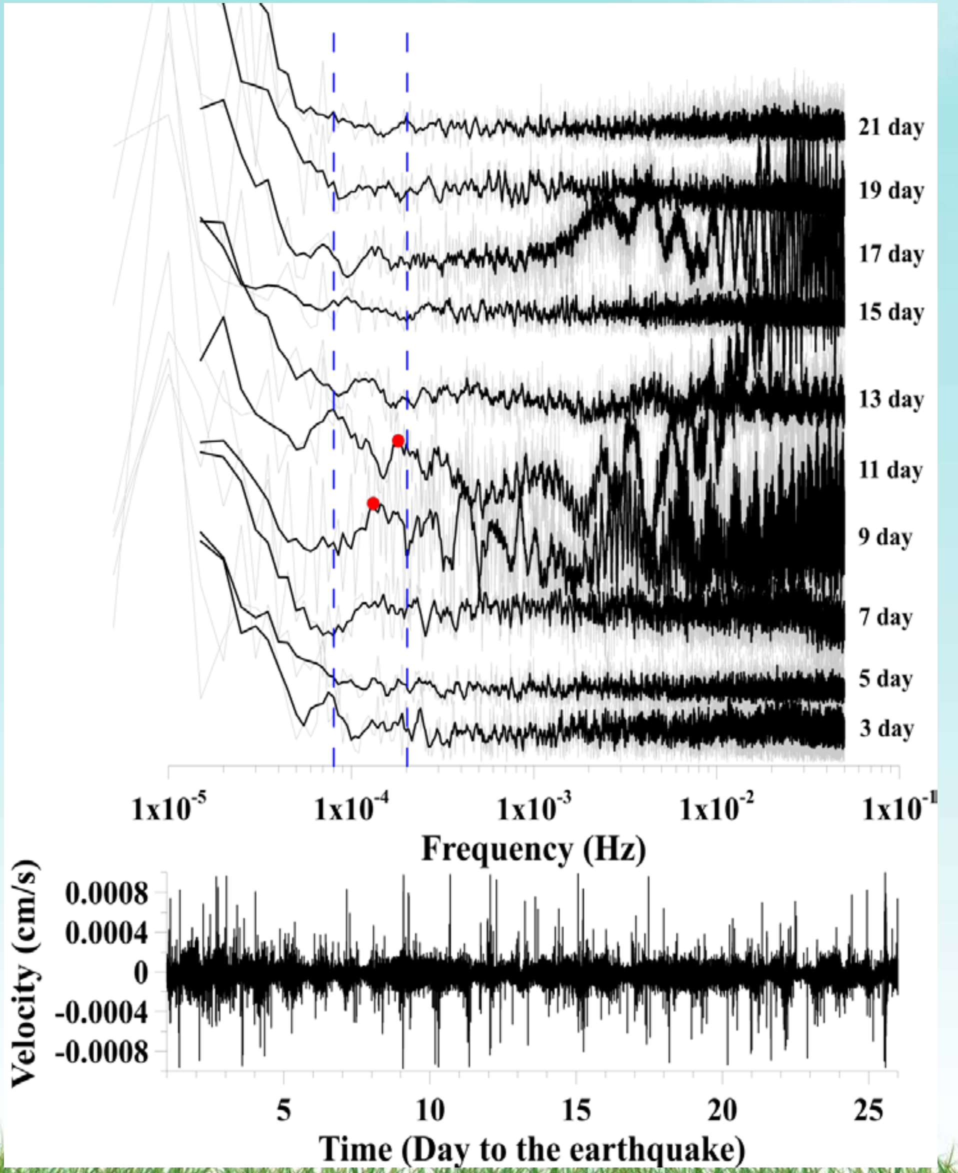
▲ **GNSS data from CWB**

0.033 Hz sampling rate

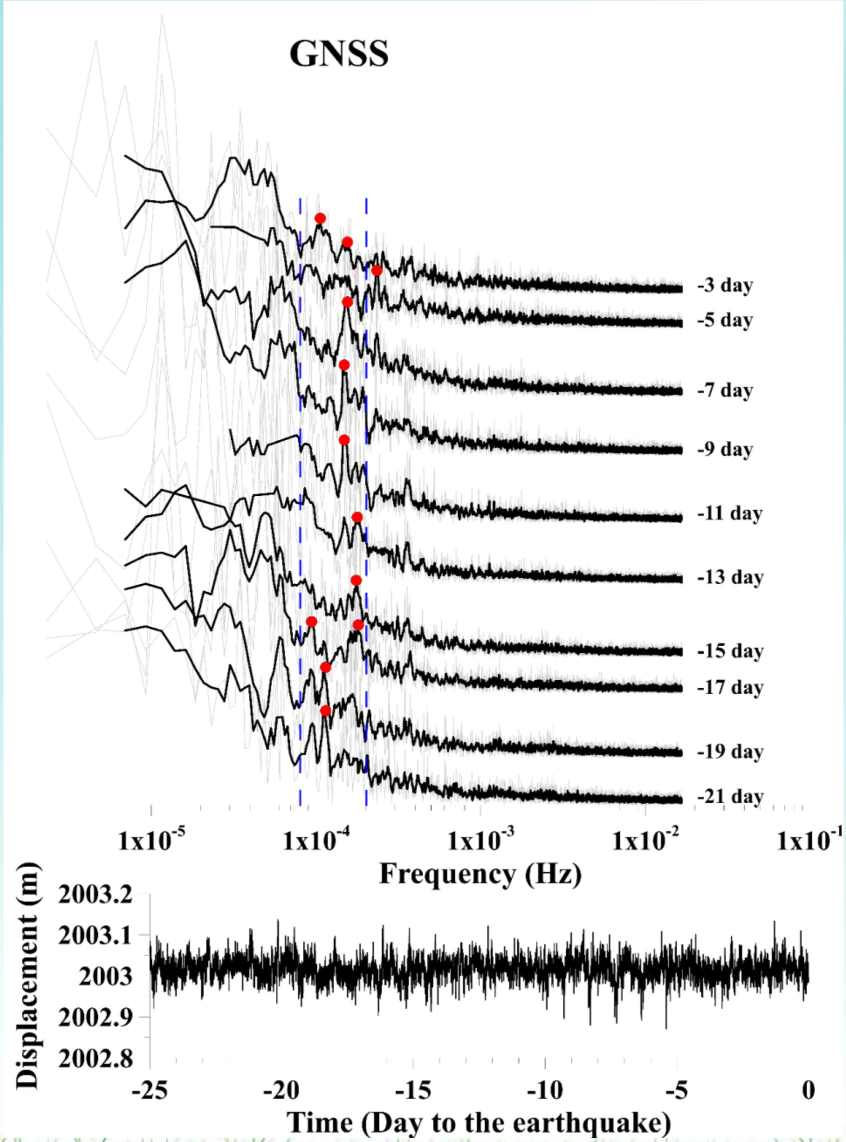
2016 M6 Meinong earthquake on Feb. 6



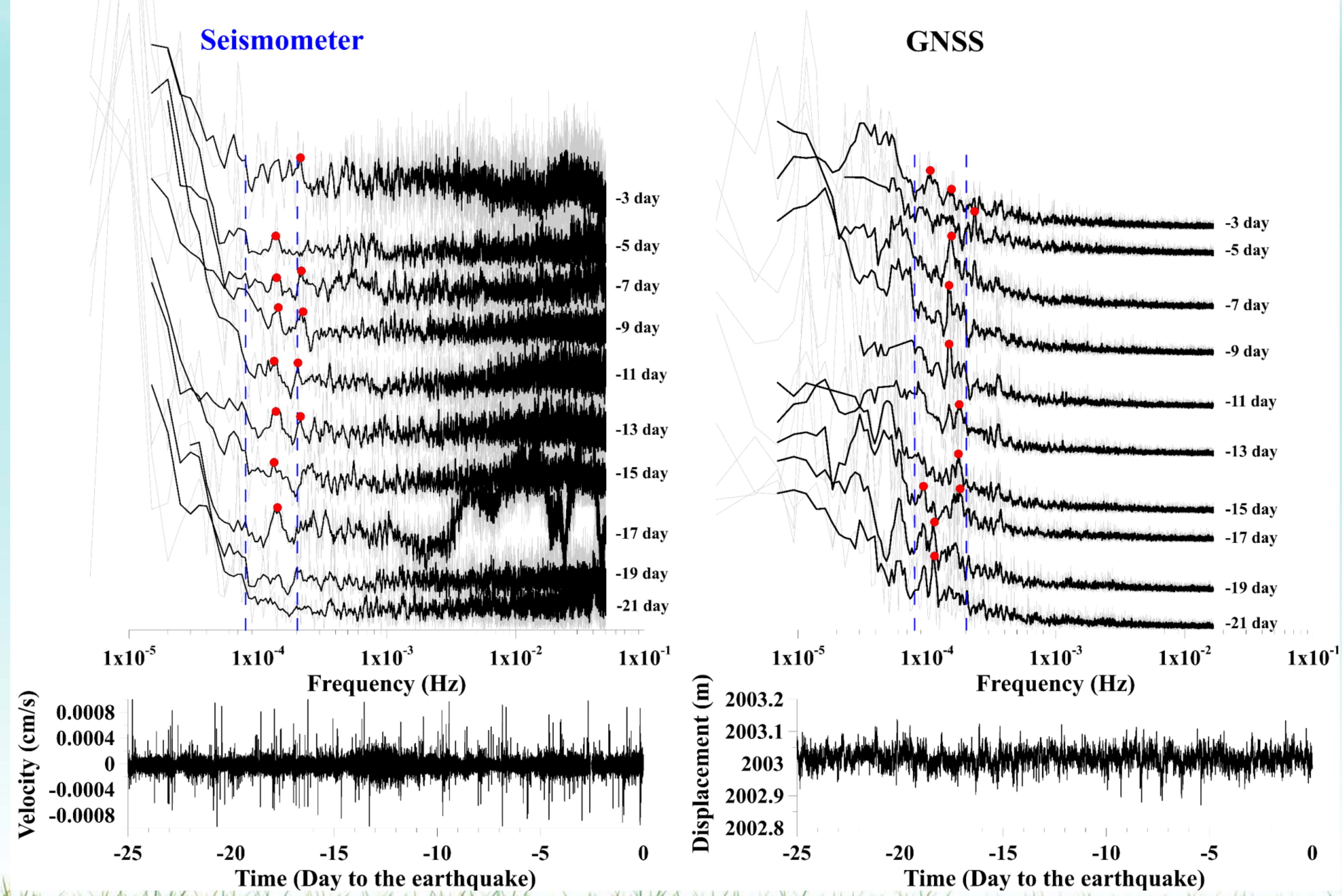
After 2016 M6 Meinong earthquake on Feb. 6



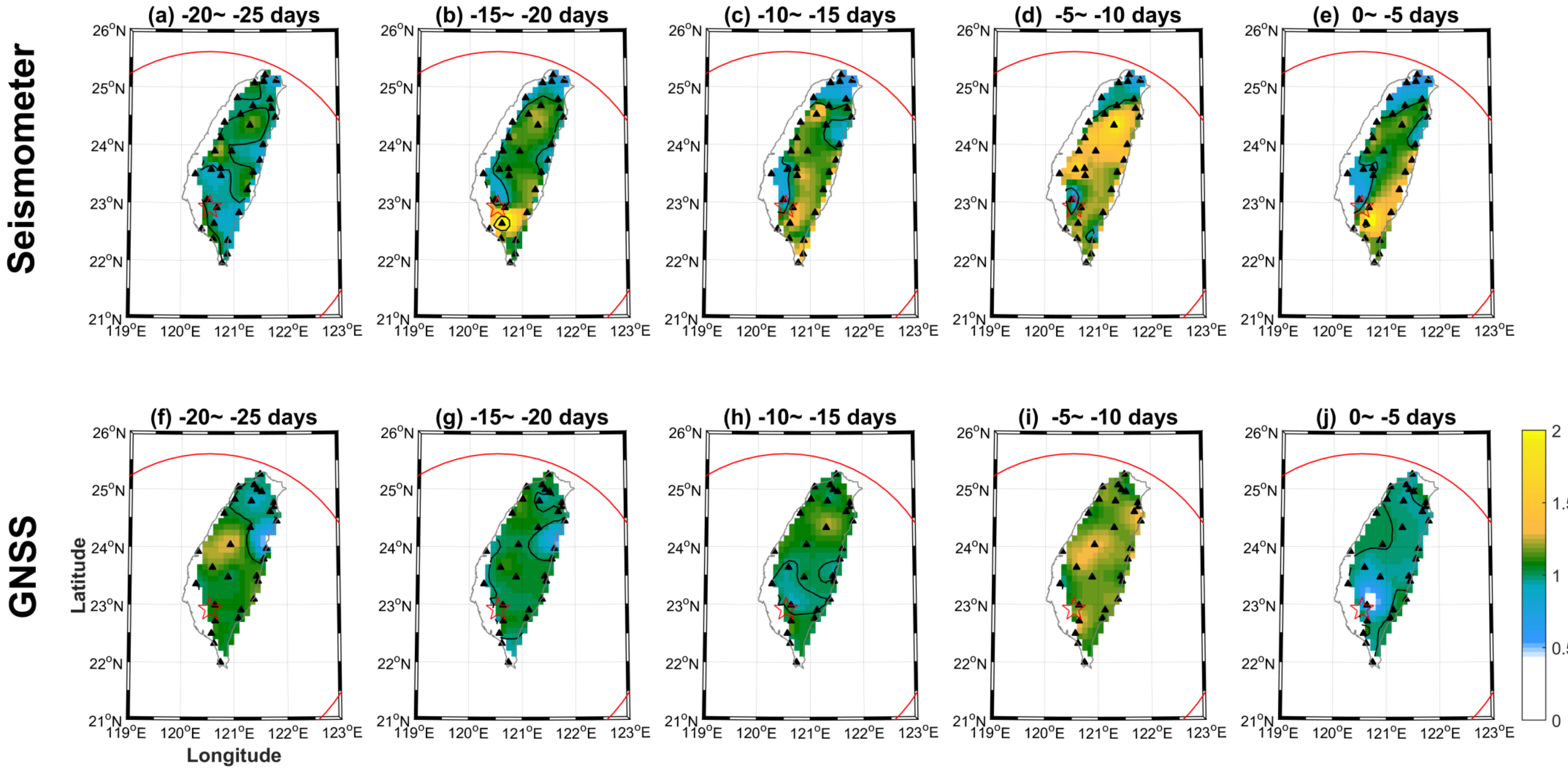
2016 M6 Meinong earthquake on Feb. 6



2016 M6 Meinong earthquake on Feb. 6



Spatial distribution of enhancements



Ratios = amplitude in a 5-day moving window / amplitude of the 60-day background
Amplitude is computed from the period between about 1.5 hours and 3.5 hours

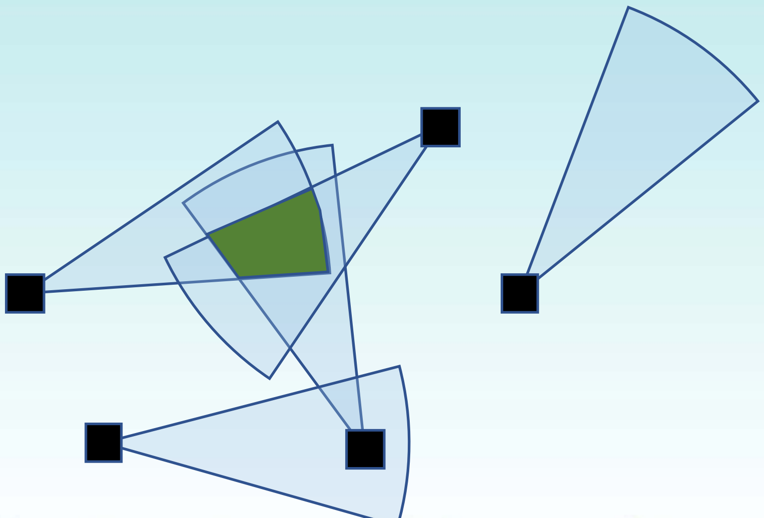
Locating sources of long-period motion

$$I = \sum_{i=1}^{n} |\mathbf{N}(\omega_i)\cos\phi + \mathbf{E}(\omega_i)\sin\phi|^2$$

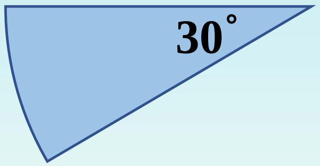
Tanimoto et al. (2006)

We determine direction (ϕ) of wave propagations at particular frequency, *w*, by using maximum horizontal amplitude *I*

Location of areas is determined by using circular sectors via the intersection method

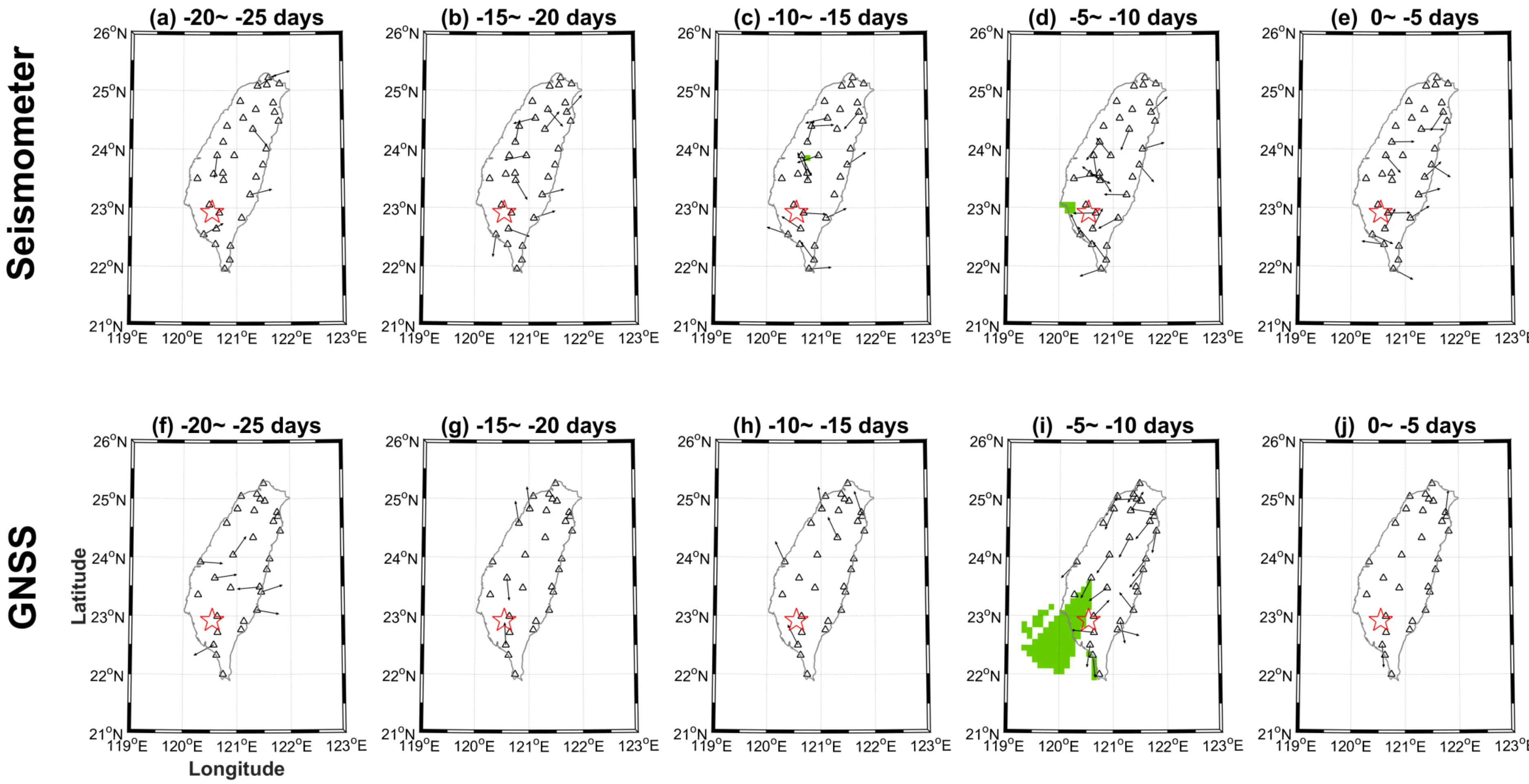


Radius = 300 km



Resolution of the angle is determined as 30°
The radius is given by 300 km through observations

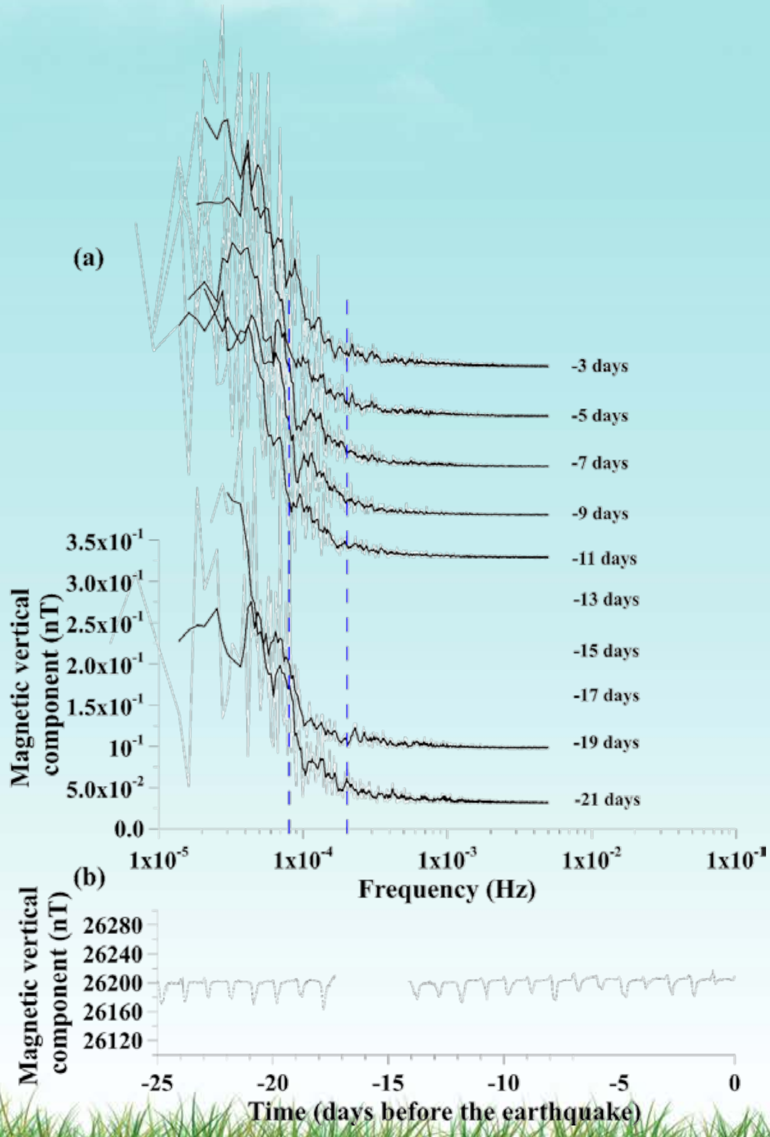
Locations of potential sources

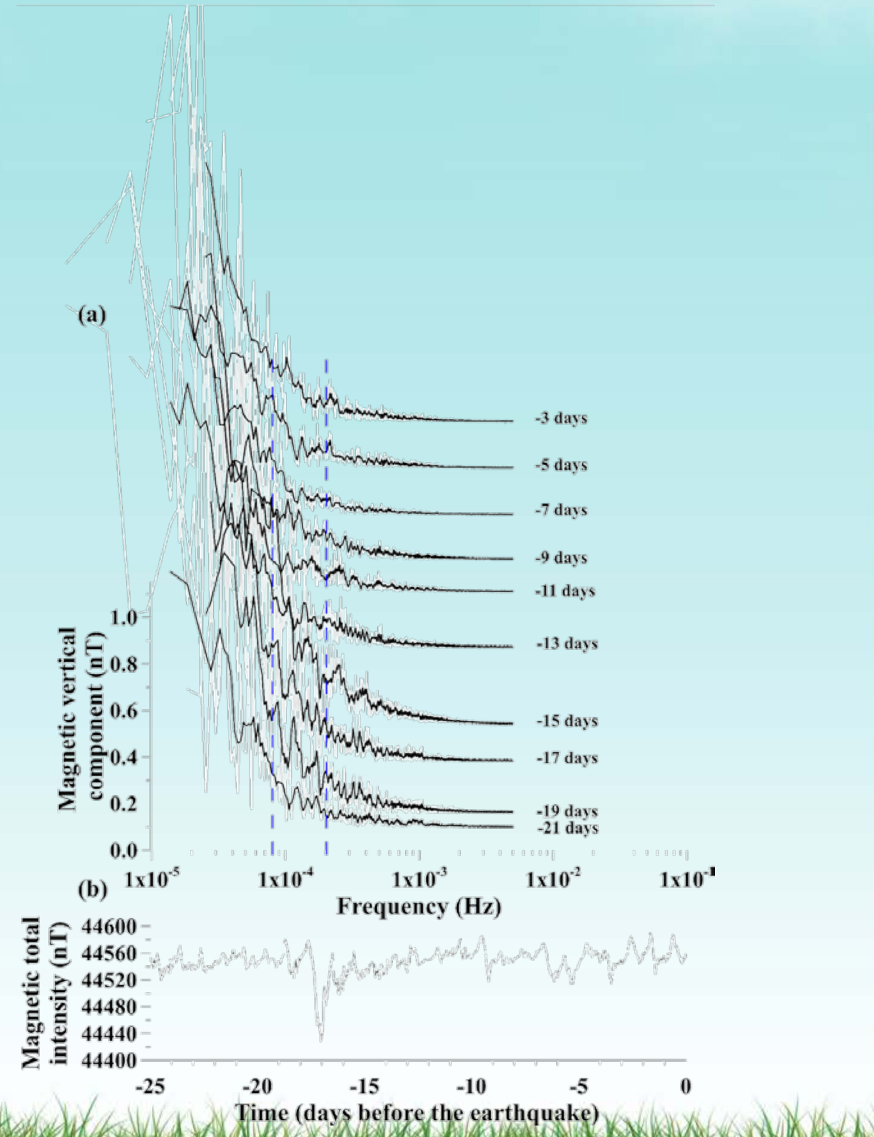


Locations of potential sources

seismometers **GNSS**

Geomagnetic anomaly before the Meinong earthquake





Is long-period ground motion a common behavior of earthquakes?

We further examined the other six events

1999 M7.6 Chi-Chi earthquake
2004 M6 Parkfield earthquake
2010 M7.2 Baja earthquake
2014 M6.6 Jinggu earthquake
2014 M6.5 Ludian earthquake
2018 M6.0 Hualien earthquake

Desires of long-period ground motion before earthquakes

- **AGWs are generally considered to be potential sources of**

VLF anomalies proposed by Dr. Hayakawa

TEC anomalies proposed by Dr. Oyama

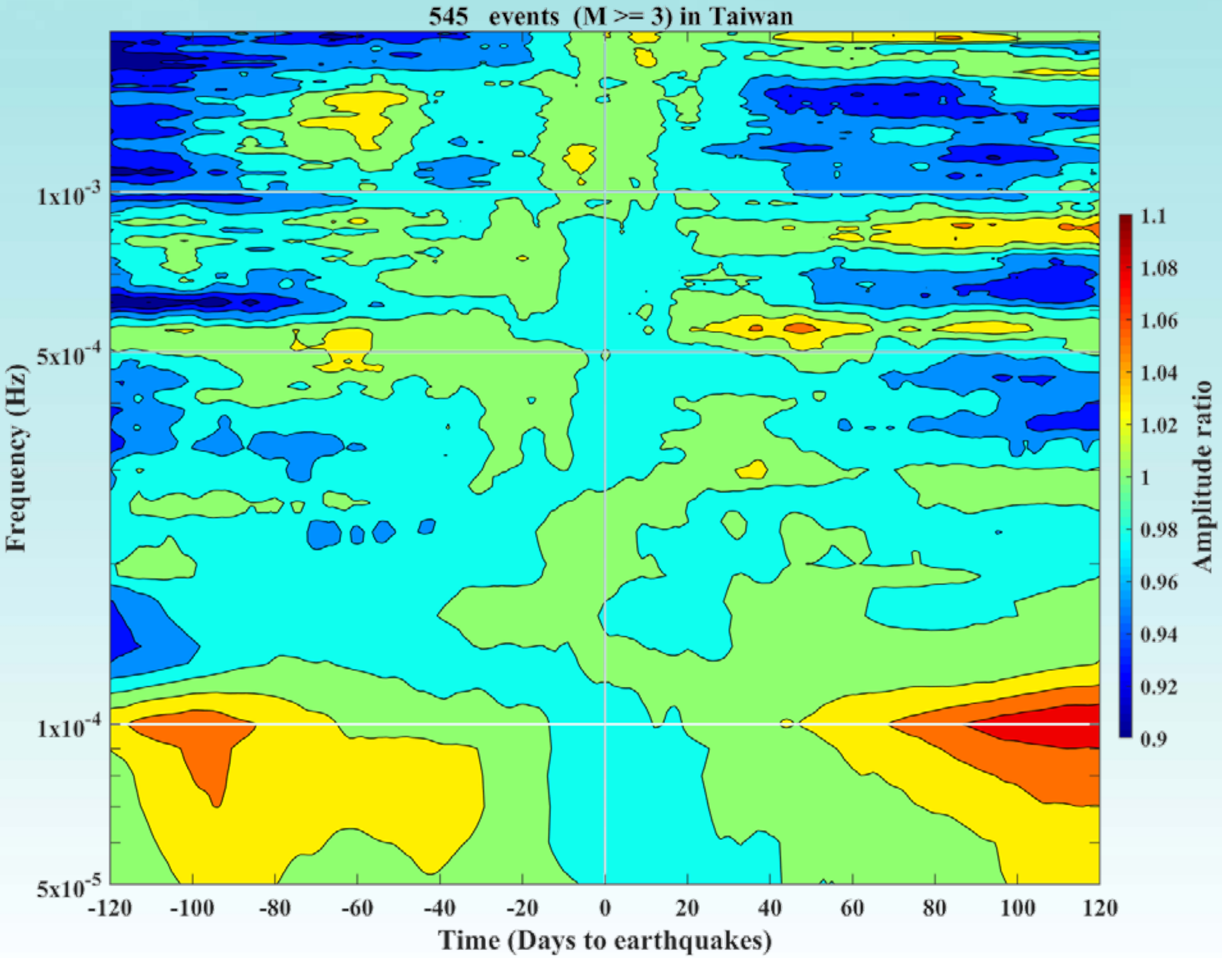
large-scale and long-period ground motion before earthquakes

vertical ground motion in large areas

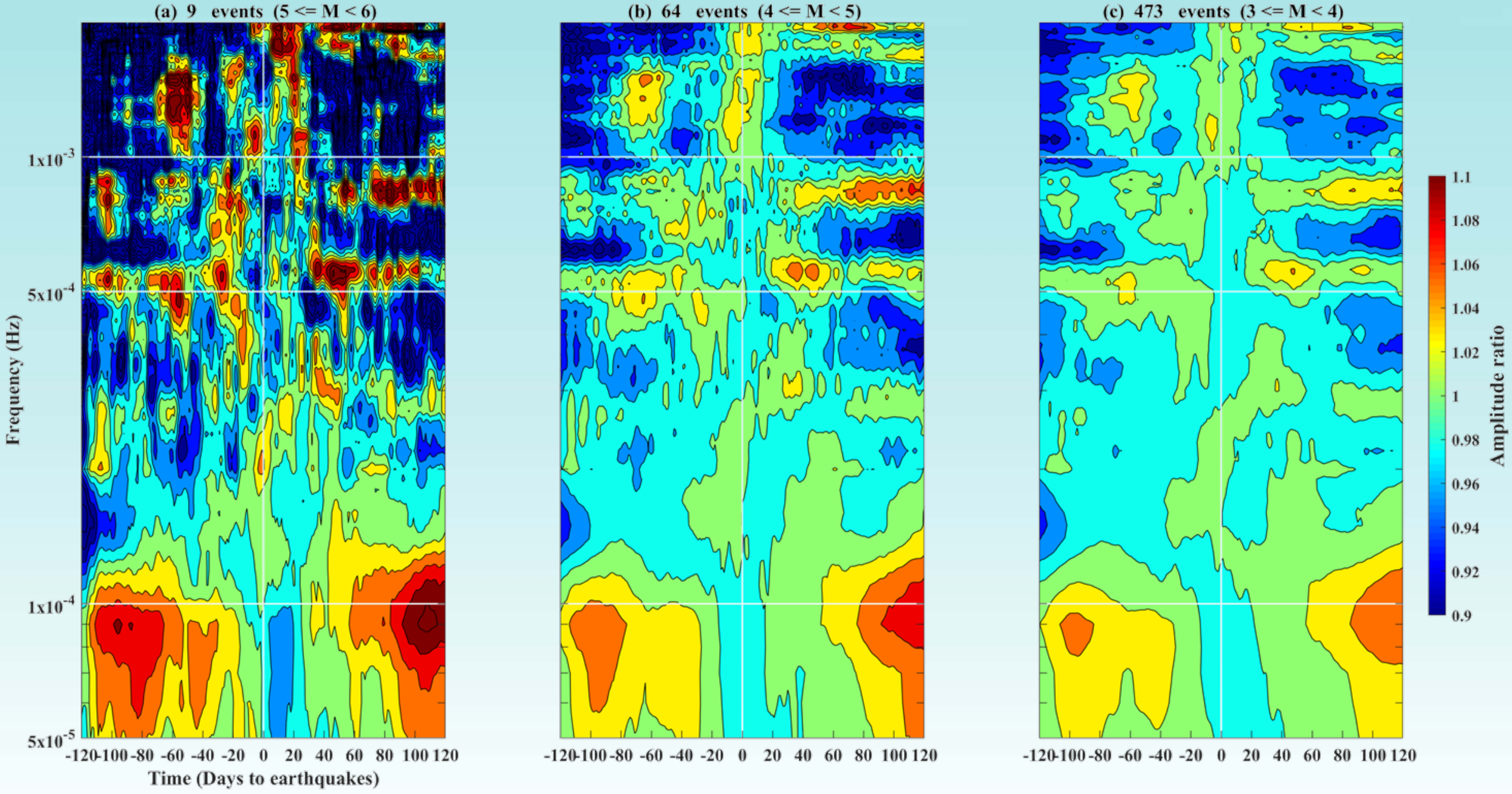
Generate AGWs

Drive VLF and TEC anomalies in large areas

Amplitude of ground motion during earthquakes



Amplitude of ground motion associated with distinct earthquake magnitude

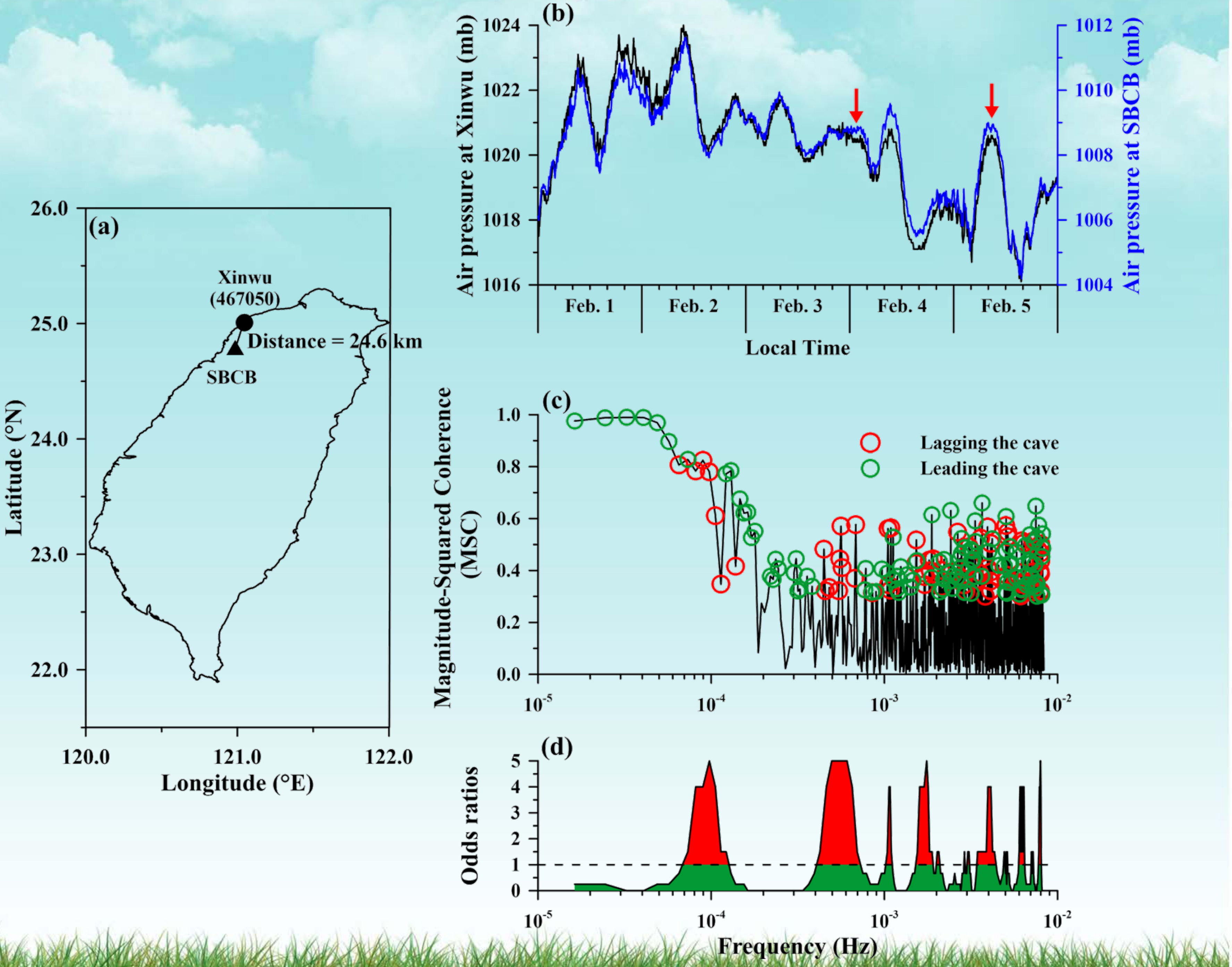


large-scale and long-period ground motion before earthquakes

vertical ground motion in large areas

Generate AGWs

Drive VLF and TEC anomalies in large areas



(a)
26.0
25.0
24.0
23.0
22.0
Latitude (°N)
120.0
121.0
122.0
Longitude (°E)
Xinwu
(467050)
Distance = 24.6 km
SBCB
(b)
Air pressure at Xinwu (mb)
Air pressure at SBCB (mb)
1016
1018
1020
1022
1024
1004
1006
1008
1010
1012
Feb. 1
Feb. 2
Feb. 3
Feb. 4
Feb. 5
Local Time
(c)
Magnitude-Squared Coherence (MSC)
Lagging the cave
Leading the cave
0.0
0.2
0.4
0.6
0.8
1.0
(d)
Odds ratios
0
1
2
3
4
5
10^{-5}
10^{-4}
10^{-3}
10^{-2}
Frequency (Hz)

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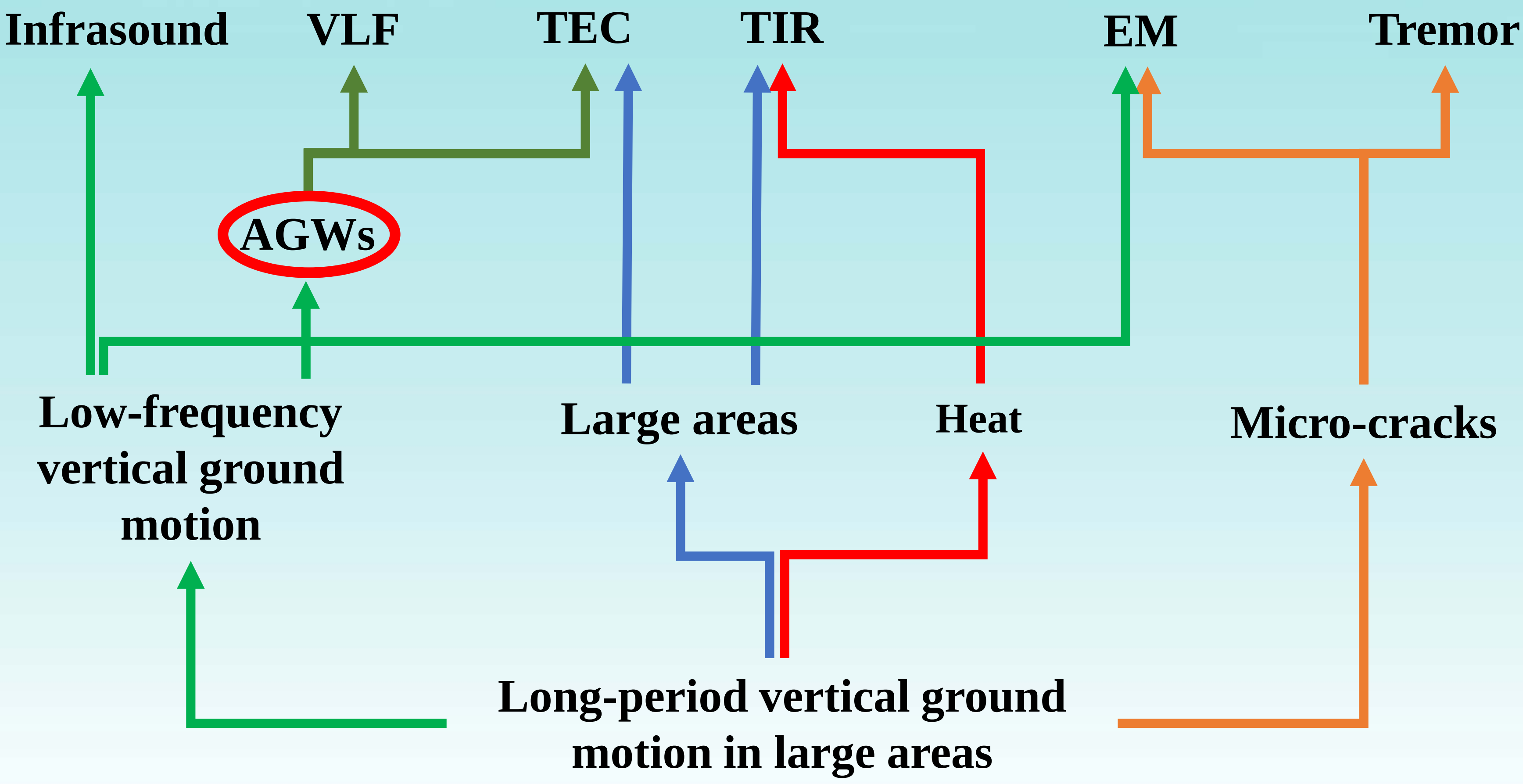
Discussions



Conclusions

1 year — Ground water; Crustal deformation

2 months — Crustal resonance

Electro-magnetic anomaly

Air pressure anomaly

Pre-earthquake acoustic-gravity waves

2 days — TEC anomaly

Co-seismic phenomena

After shocks

Acoustic-gravity waves