Source characteristics of microseisms

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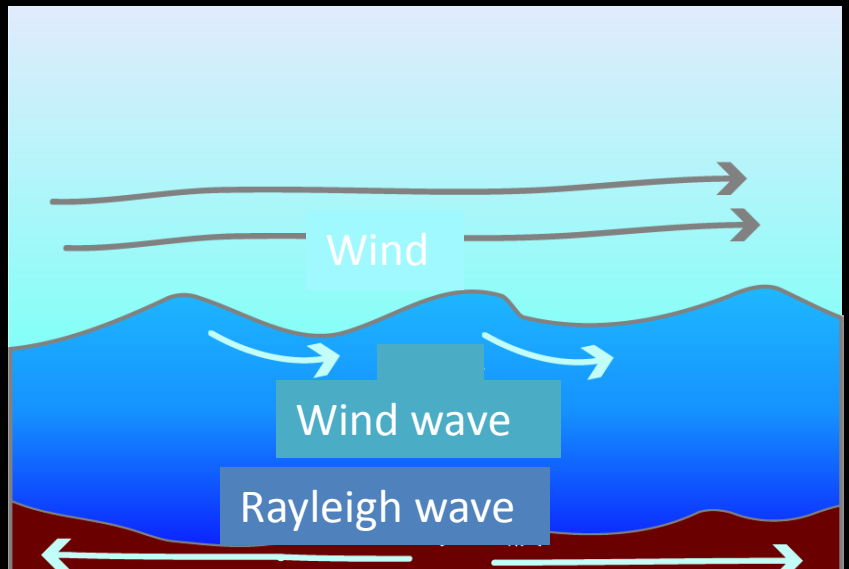
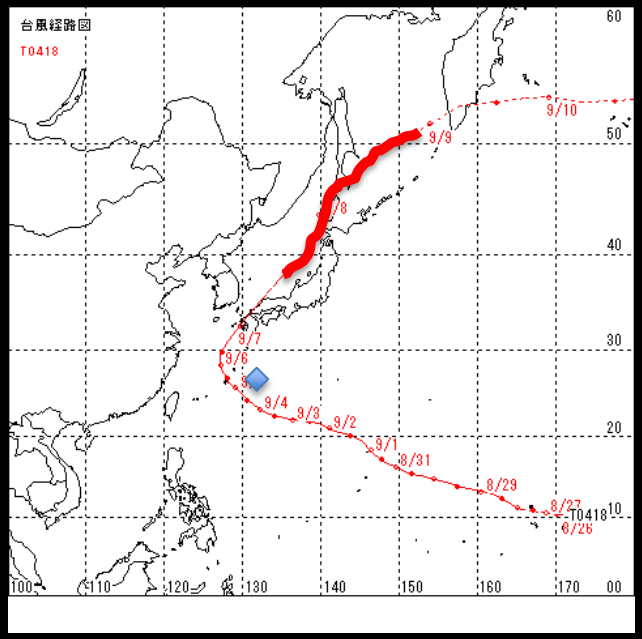
Microseisms excited by ocean swell

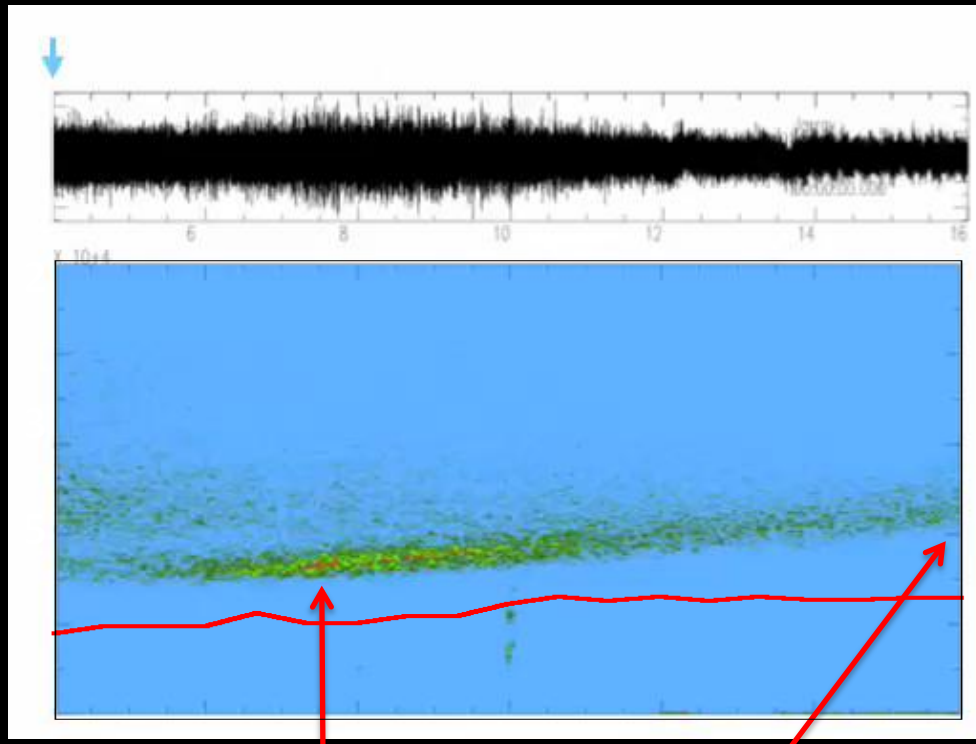
- Primary microseism (PM) 0.05-0.1 Hz: smaller
- Secondary microseisms (SM) 0.1-0.2 Hz: larger
  - Bertelli 1872, Wiechert 1904
- Excitation sources: ocean swell
  - Ocean swell: period 10~15s、phase vel.～20m/s
  - PM: linear process
  - SM: 2nd order effects



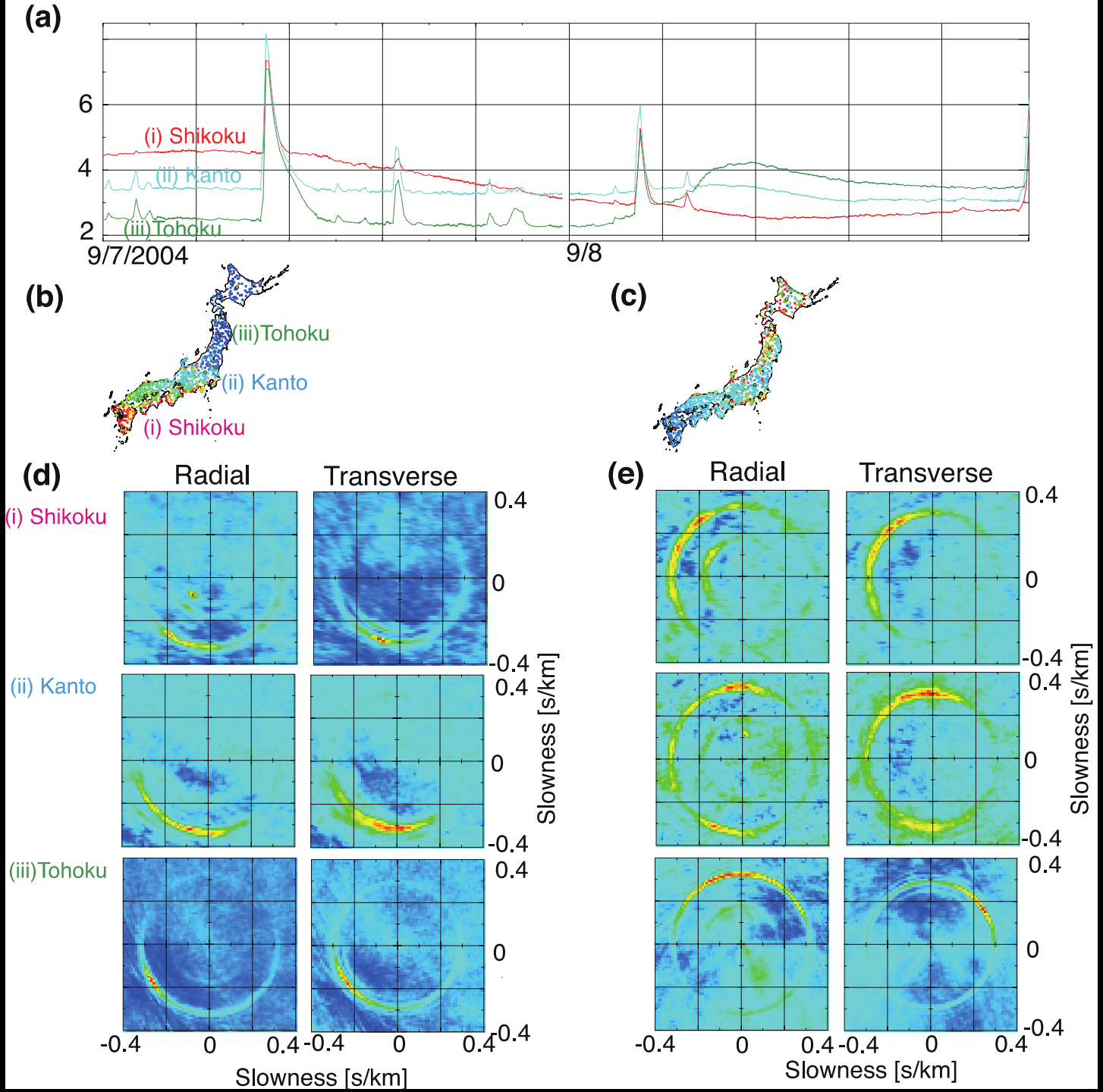
Microseisms when a typhoon hit

(2004 the typhoon 18 9/7-8)

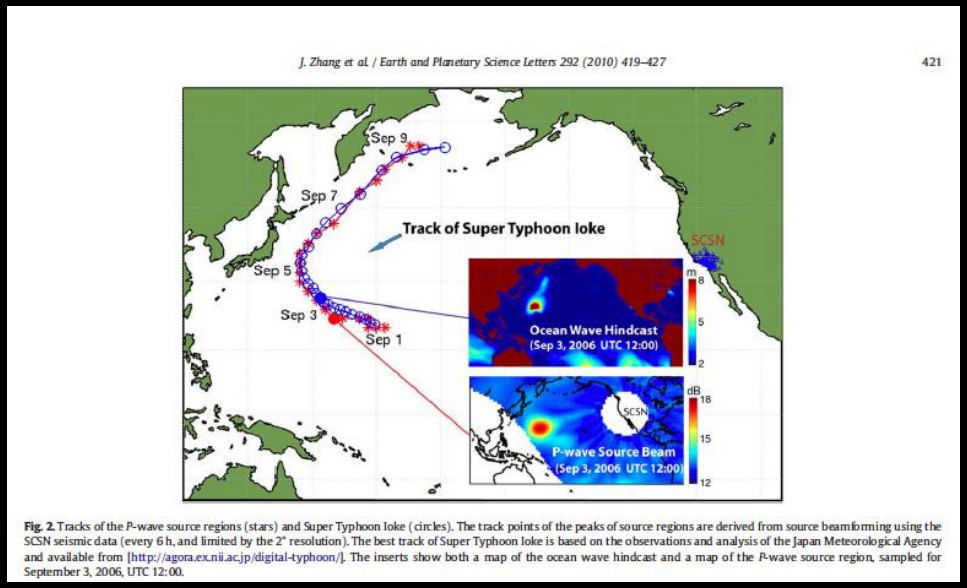




http://www.data.jma.go.jp/obd/stats/data/bosai/report/2004/20040904/20040904.html


(a)
6
4
2
(i) Shikoku
(ii) Kanto
(iii)Tohoku
9/7/2004
9/8
(b)
(iii)Tohoku
(ii) Kanto
(i) Shikoku
(c)
(d)
Radial
Transverse
(i) Shikoku
(ii) Kanto
(iii)Tohoku
0.4
0
-0.4
Slowness [s/km]
Slowness [s/km]
(e)
Radial
Transverse
0.4
0
-0.4
Slowness [s/km]
Slowness [s/km]

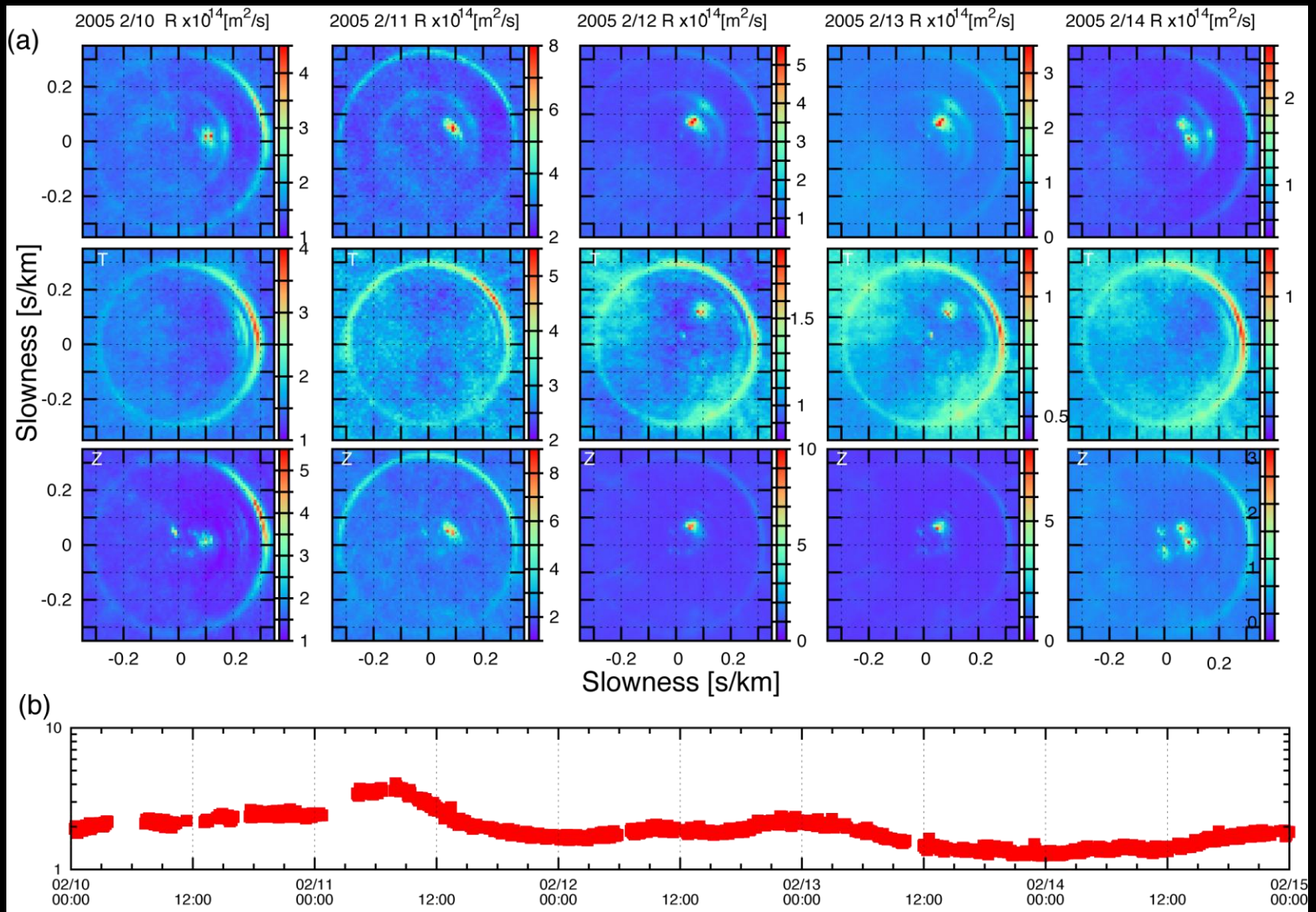
Body-wave microseisms

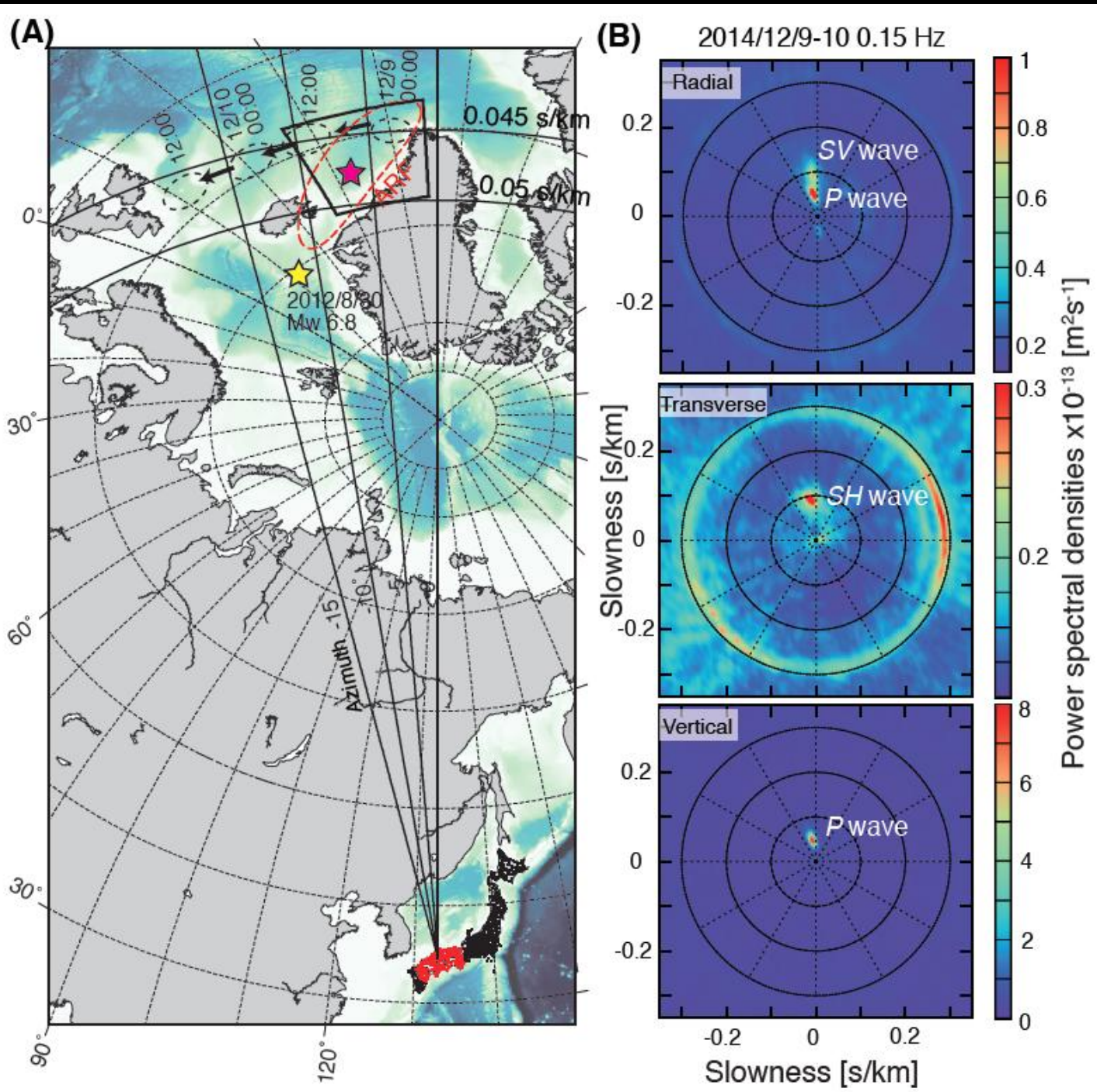


Zhang et al. 2010

- Recently teleseismic body-wave microseisms has been focused
  - e.g. Gerstoft et al. 2008, Gualtieri et al. 2013
- Body wave has rich information of the sources
  - Source locations
- Teleseismic body wave microseisms are crucial for seismic exploration of the deep Earth

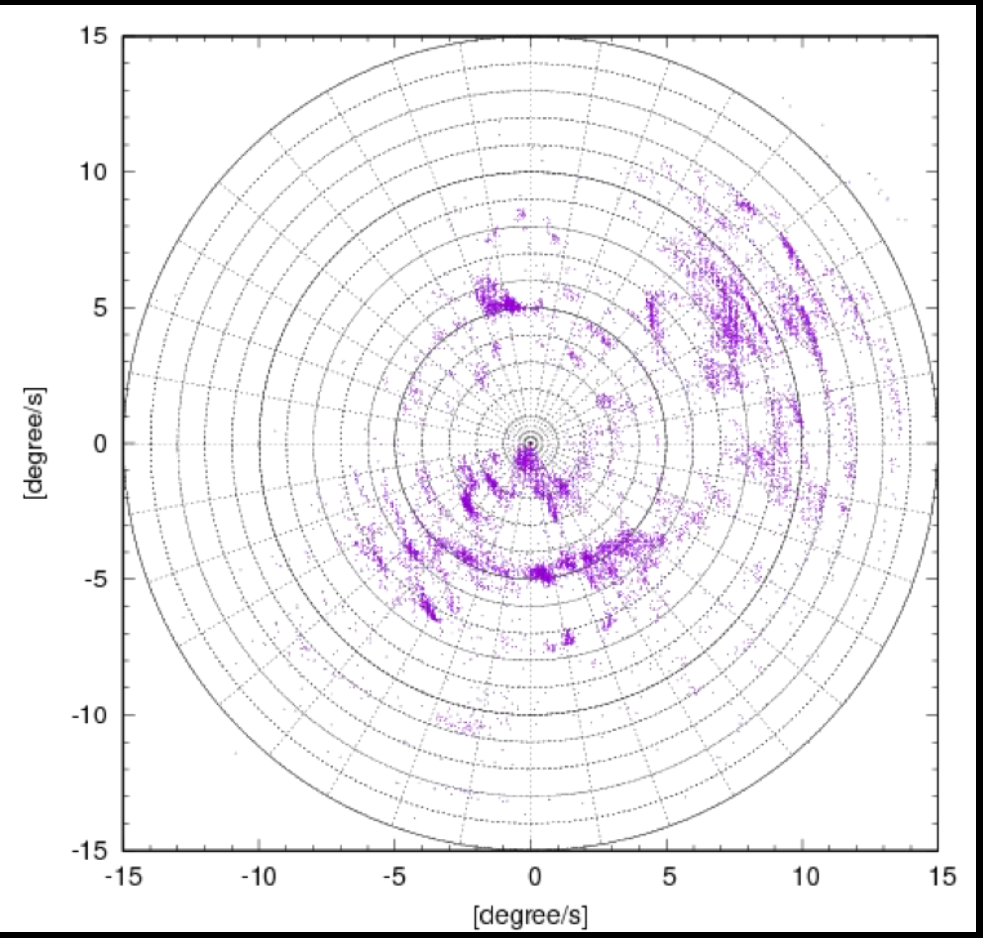
Beamforming analysis





Nishida and Takagi [2016]

Localized source extent

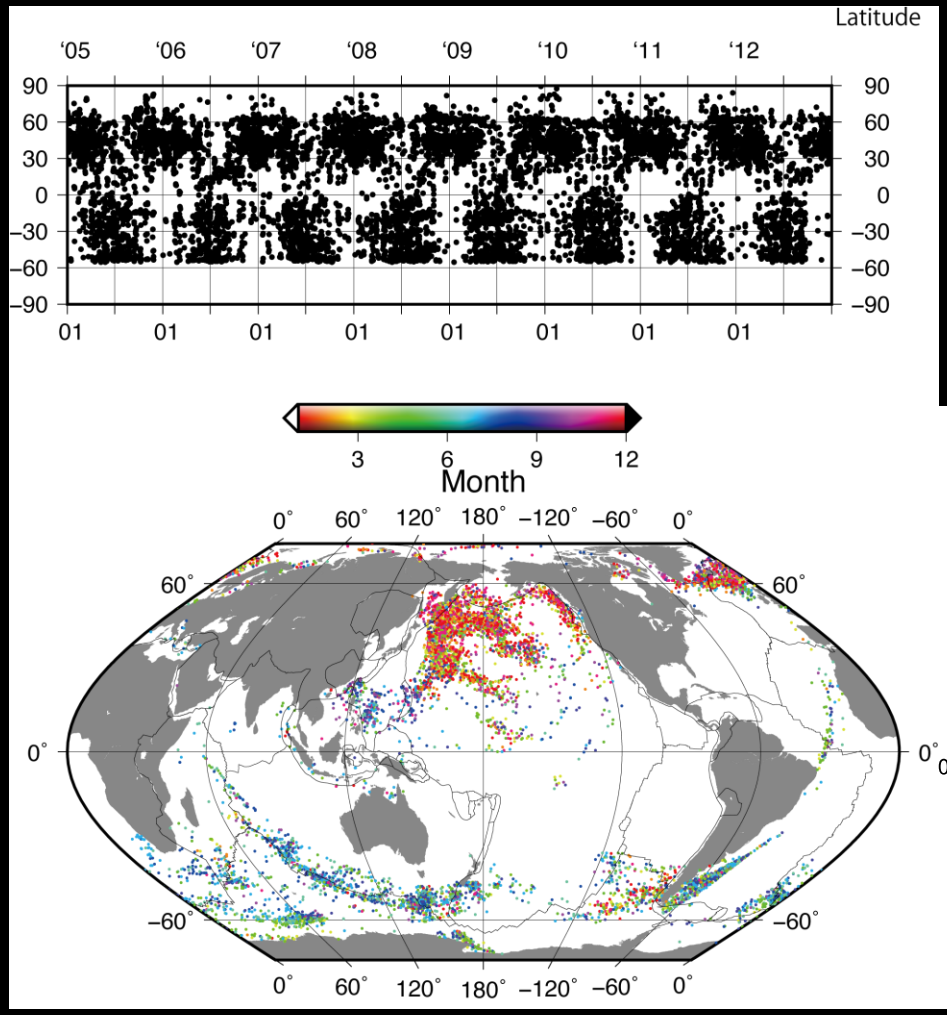


- Bright spots
  - Exist in 80% days
  - P, PKP, PKIKP, PKiKP
  - SM tends to be localized
- Characterizations by
  - Centroid locations
  - Vertical single force

Catalogue of Centroid Single force (CSF)

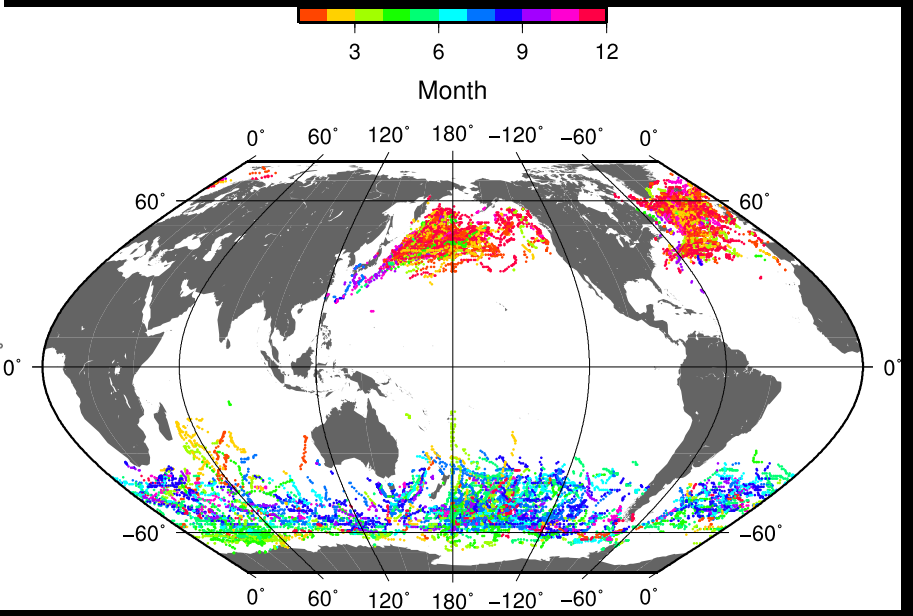
1. Data: 1024-s segments, Z cmp, 0.1-0.2 Hz
2. Beamforming analysis
3. Grid search of local maxima in slowness domain
4. Source locations from the slowness (P or PP)
5. RMS of CSF are estimated
    1. Ray theoretical Green's function using IASPEI91 [Gualtieri et al., 2014]

Centroid locations

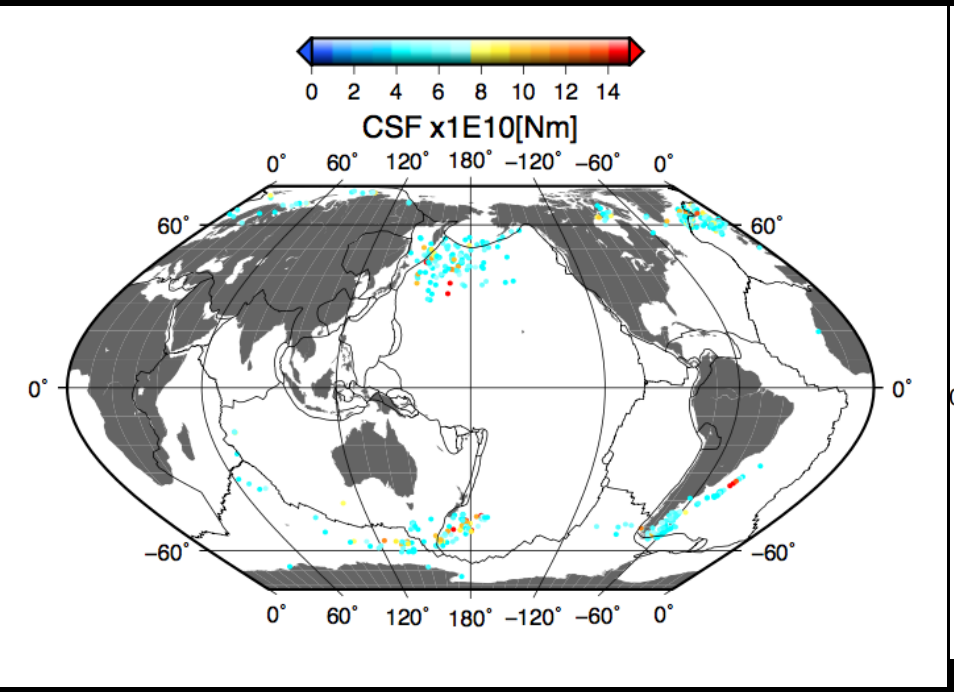


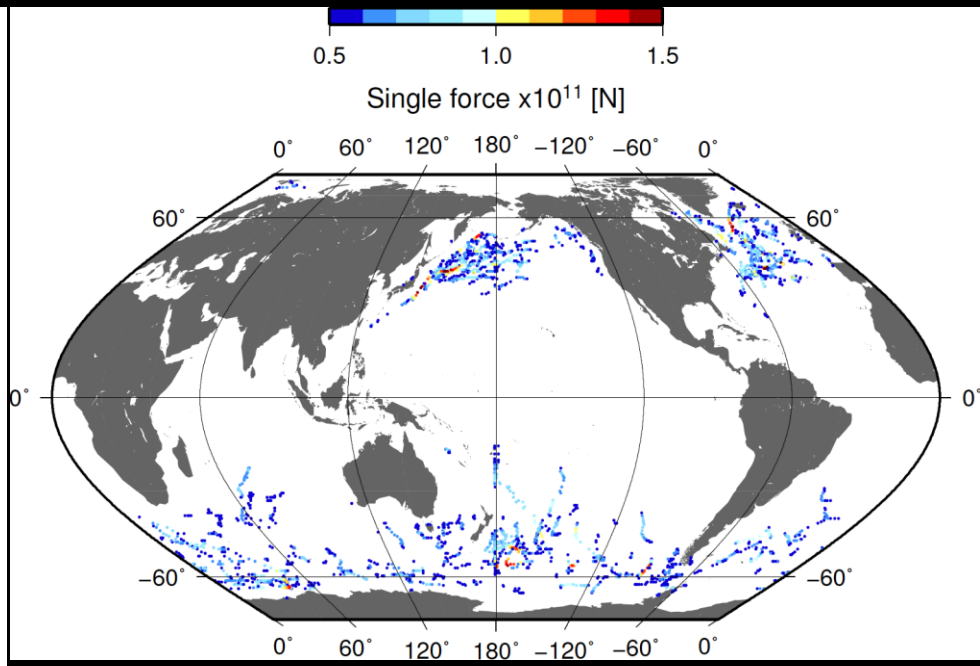
- Winter: Northern hemisphere
- Summer: Arctic ocean

WaveWatchIII (Ardhuin et al. 2011)



CSF: Comparison with a model



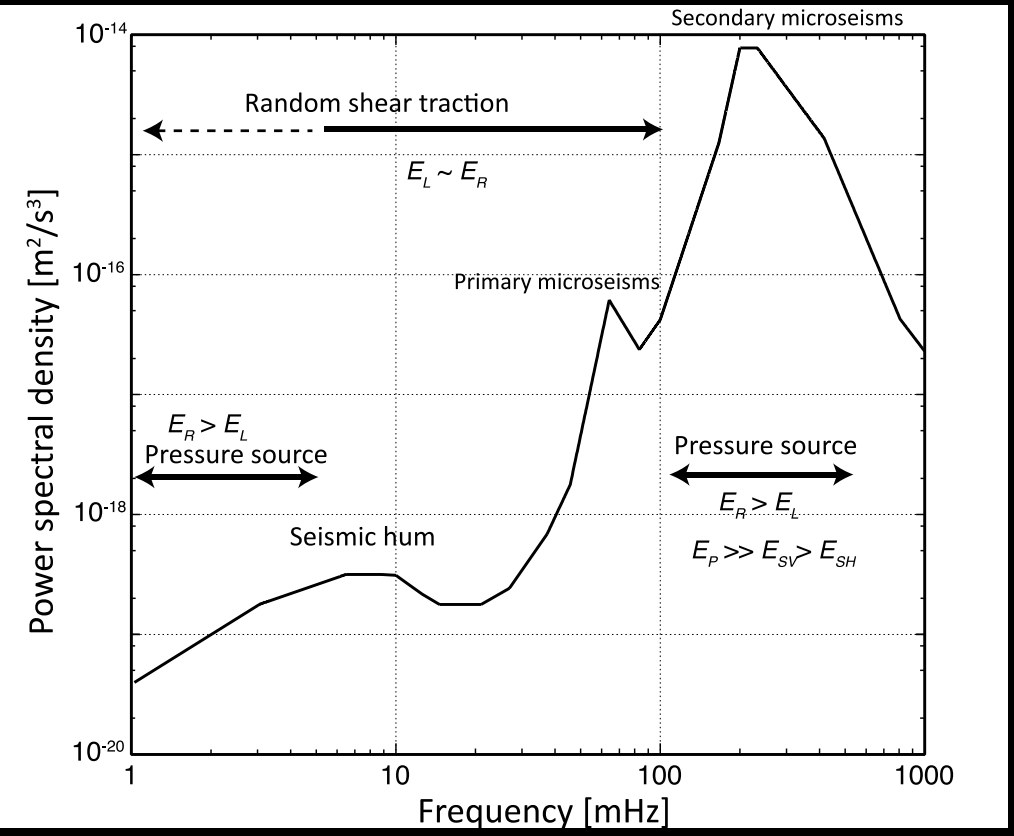


WaveWatchIII (Ardhuin et al. 2011)

Summary of body wave microseisms above 0.1 Hz

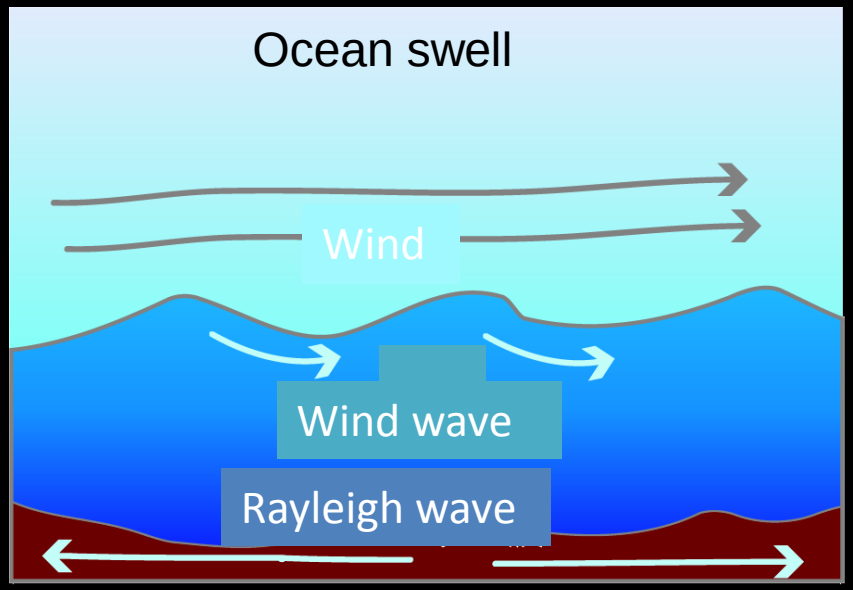
- Teleseismic P-wave microseisms: 80% of data
- Centroids were located based on beamforming
  - Seasonality
  - CSF ~ 10^{10} [N]: consistent with wave height model
- SV-wave: P to SV conversion on the seafloor

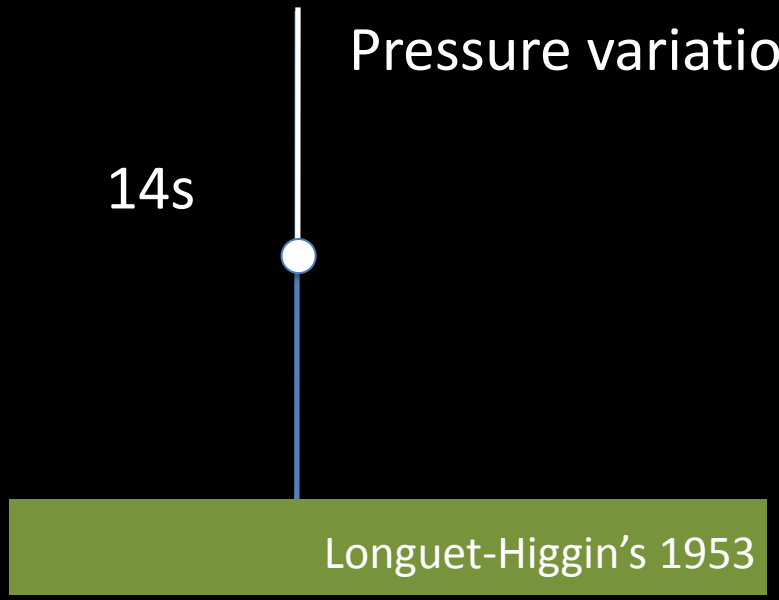
Energy partition: Rayleigh/Love wave



- Dominance of surface waves
  - R/L >1, f > 0.1Hz
  - R/L ~1, f< 0.1 Hz.
- Vertical single force on sea surface, f > 0.1 Hz
- Dominance of random shear traction, f < 0.1Hz
  - Linear topographic coupling between surface waves and ocean waves on the ocean floor [*Hasselmann* 1963, *Fukao et al.*, 2010; *Saito*, 2010]

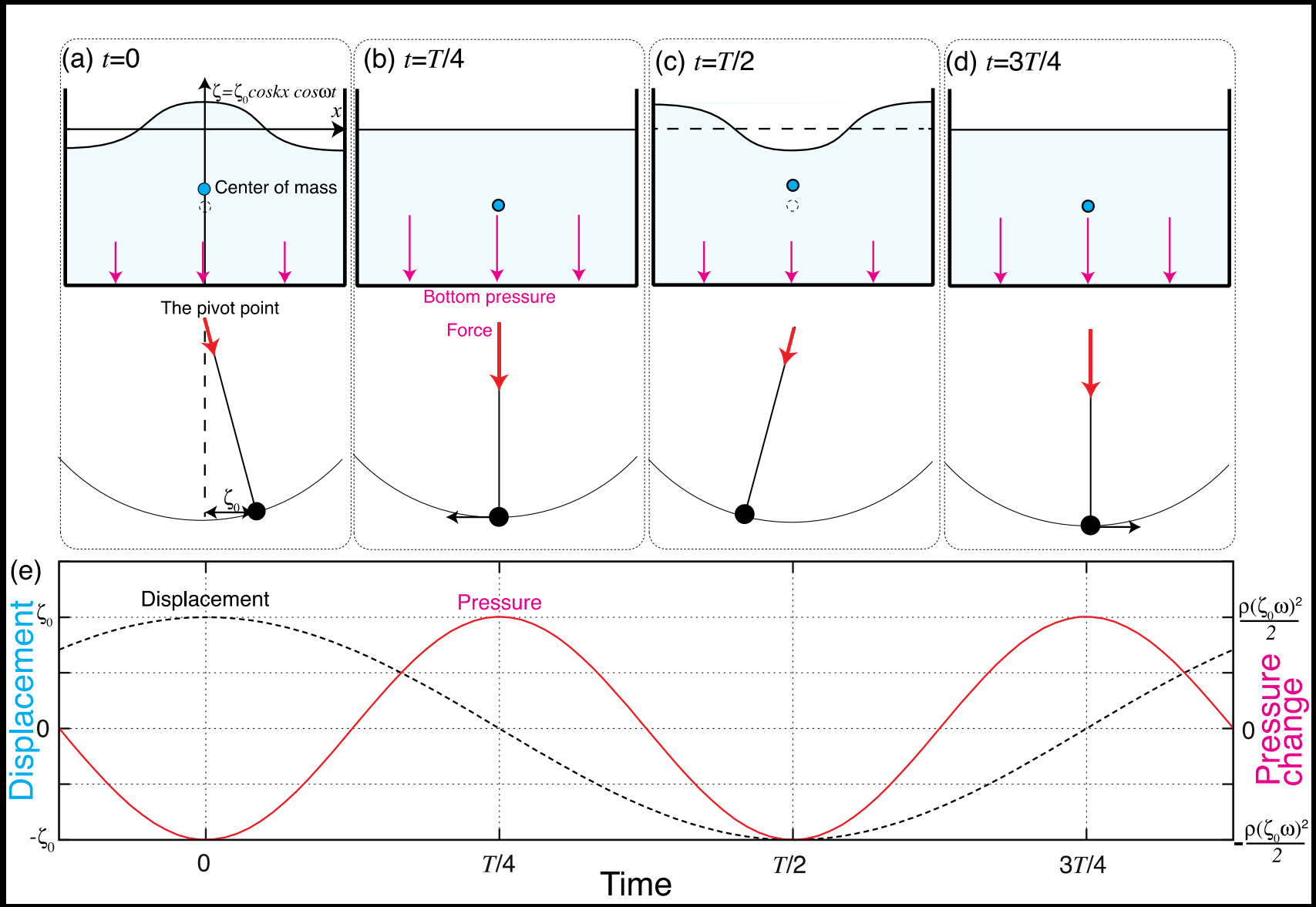
Longuet-Higgins's mechanism





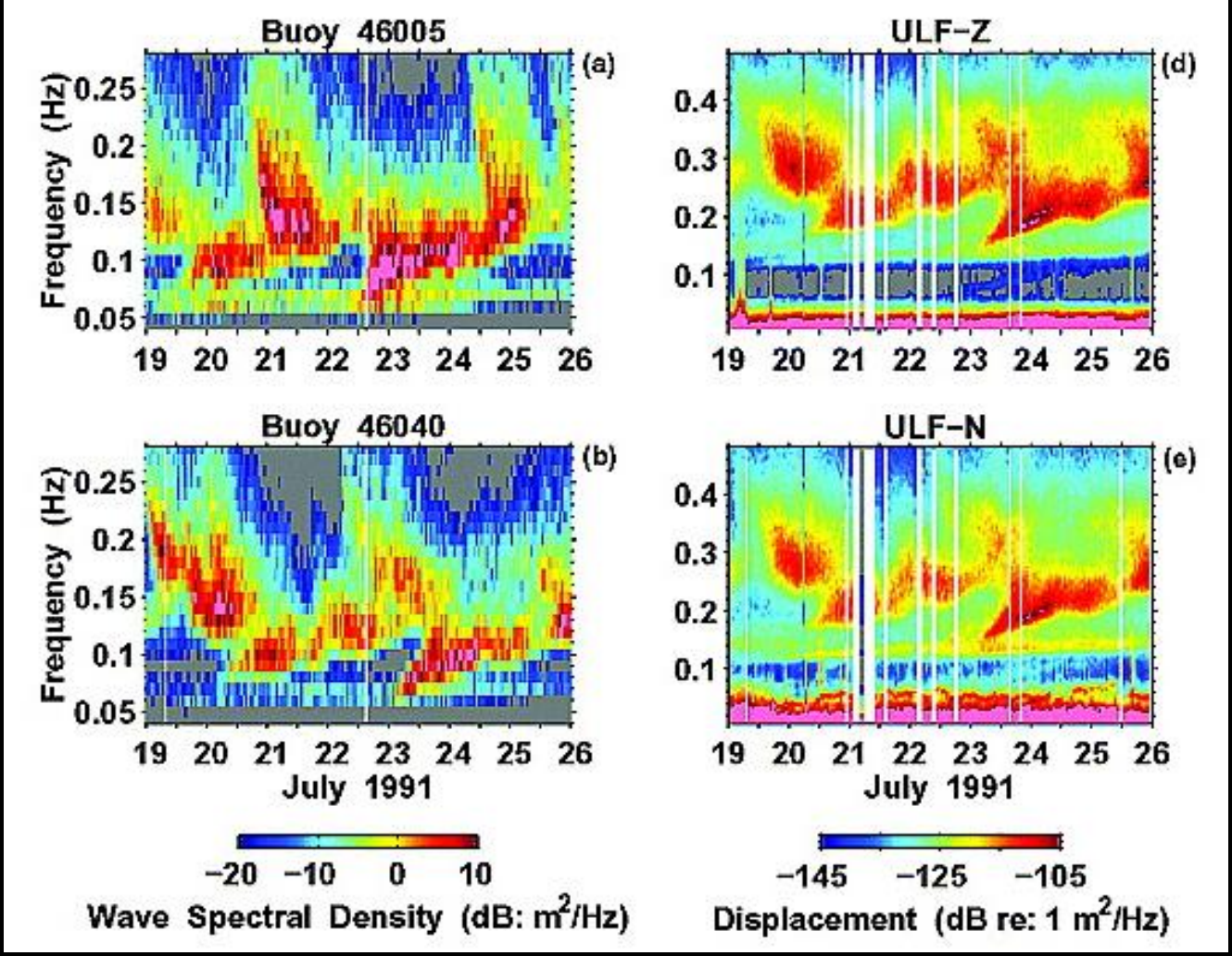
- Wind wave (period ~14s)
- Pressure perturbation (2nd order) excites seismic surface waves : microseisms
  - Typical period of microsisms ~7s
  - When a typhoon, larger amplitude and longer period.

Analogy of a pendulum



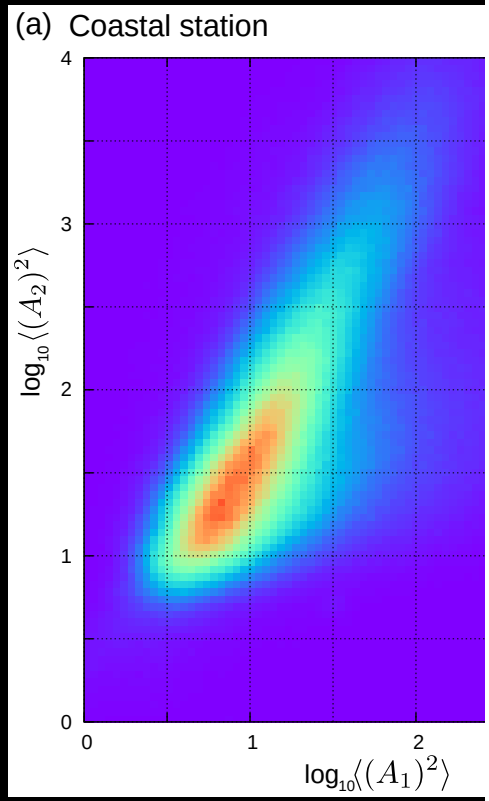
Nishida 2017

(1) Frequency relation to ocean swell

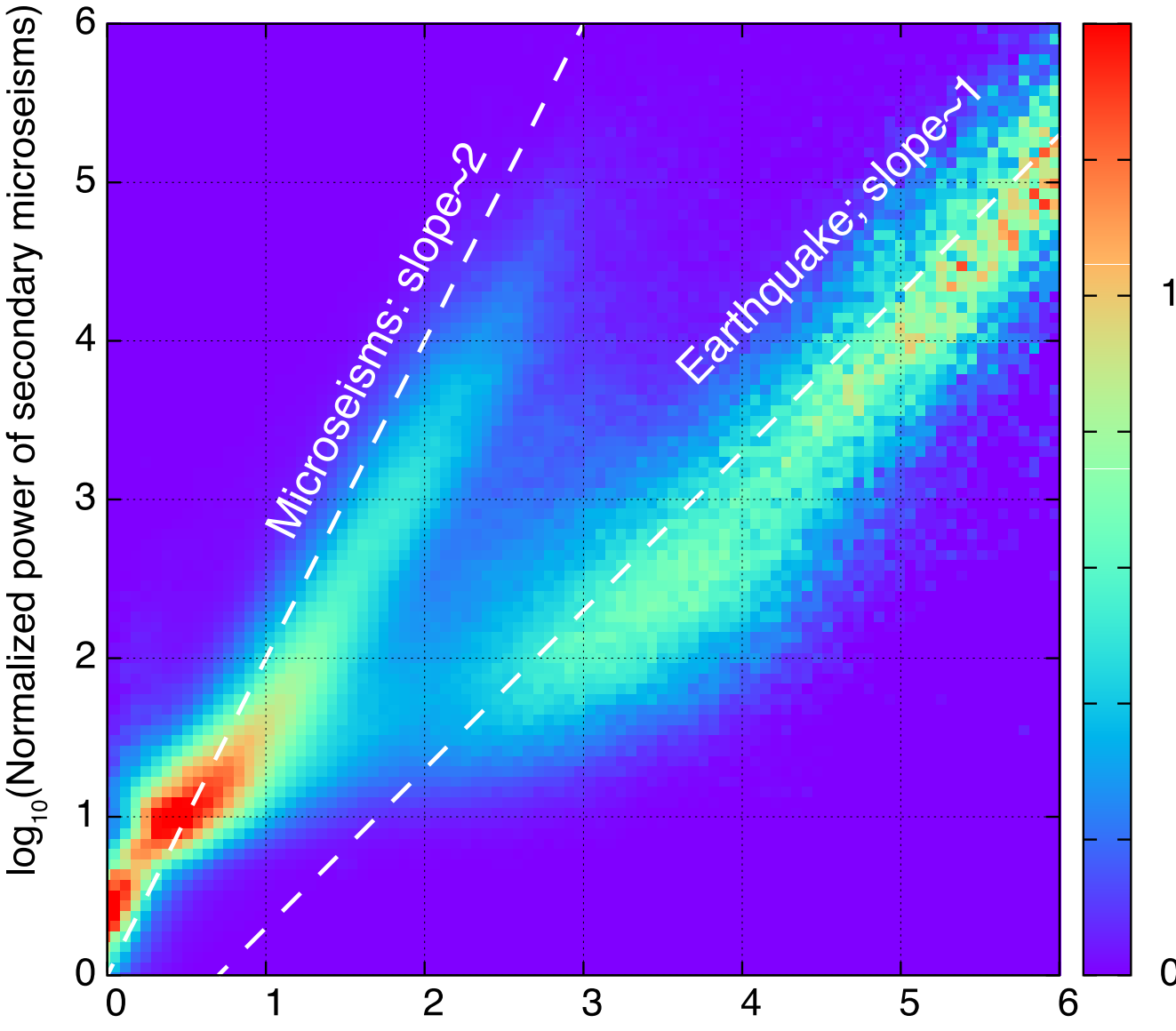


Bromirski 2002

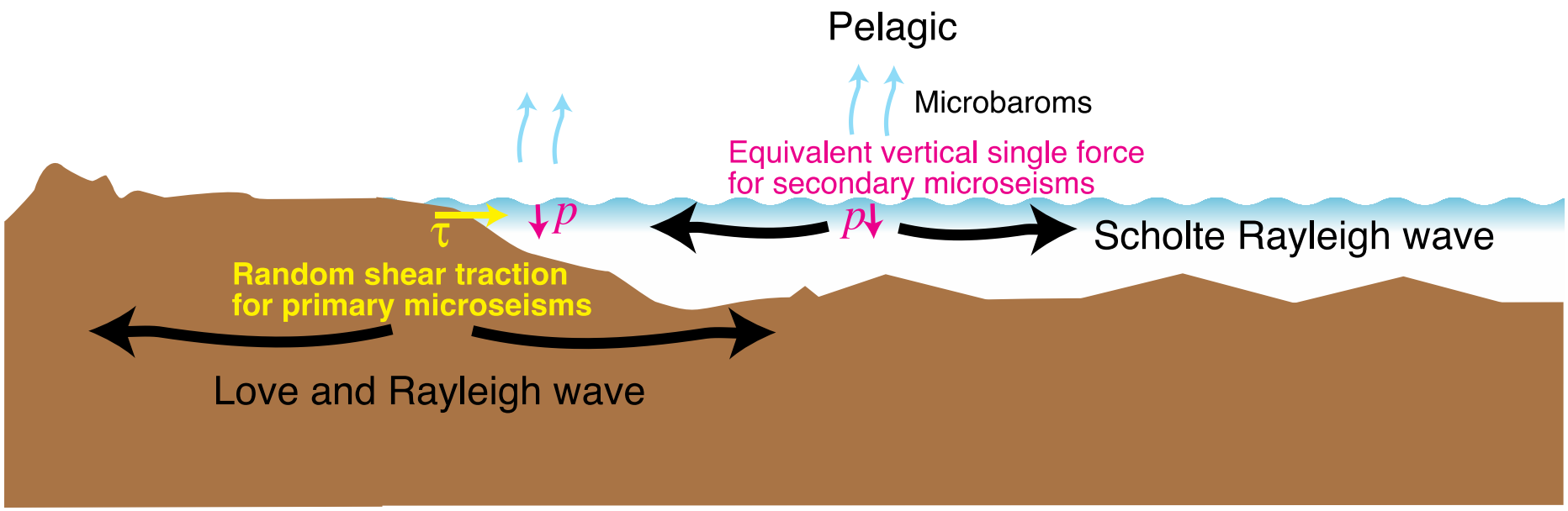
(2) Amplitude relation



Nishida 2017

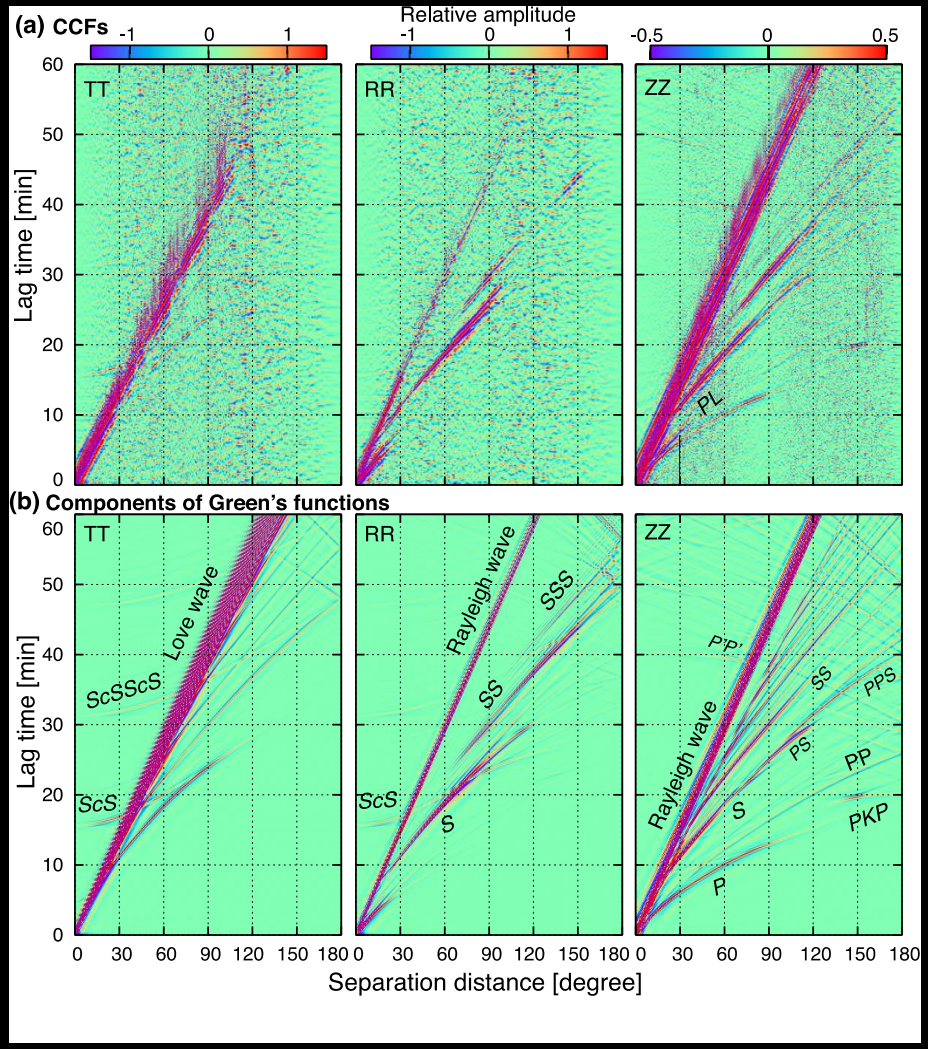


Excitation mechanism



Nishida 2017

Body wave retrieval below 0.1 Hz

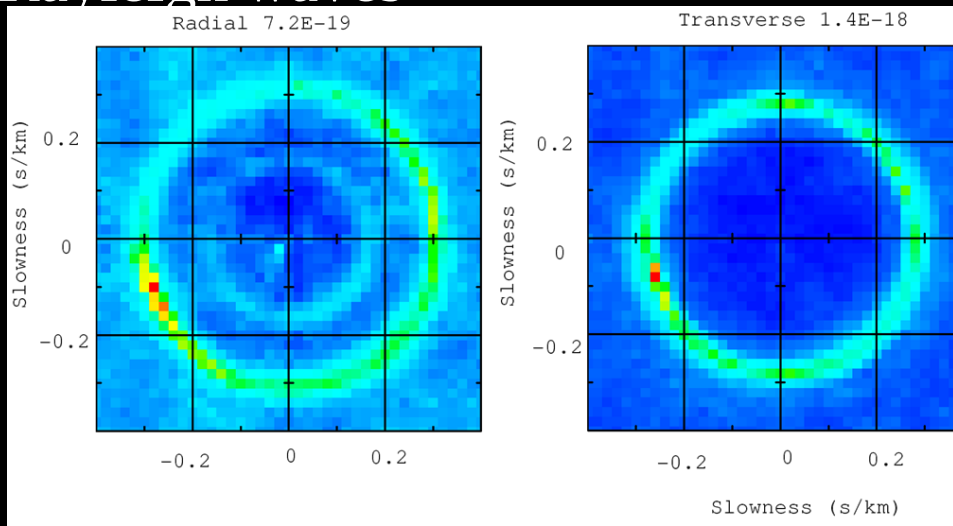


Nishida 2013

- Direct waves (P, S, PKP) are detectable but small
- Lack of reflection phases in observation
- Dominance of Shear-coupled PL (SPL) wave

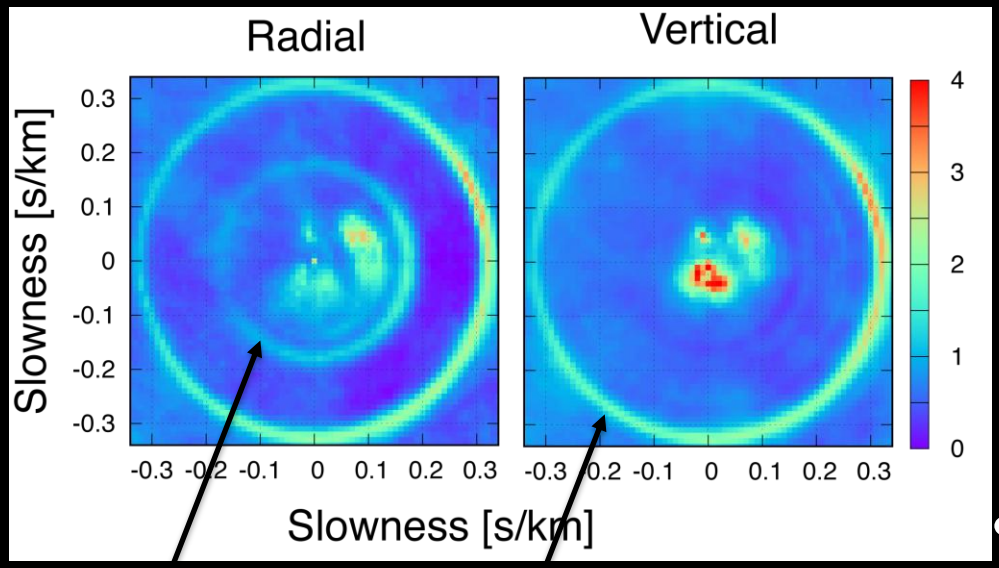
Rayleigh waves

Love waves



Body wave 0.1-0.5 Hz

0.1 – 0.2 Hz Hi-net



Crustal P wave

Rayleigh wave

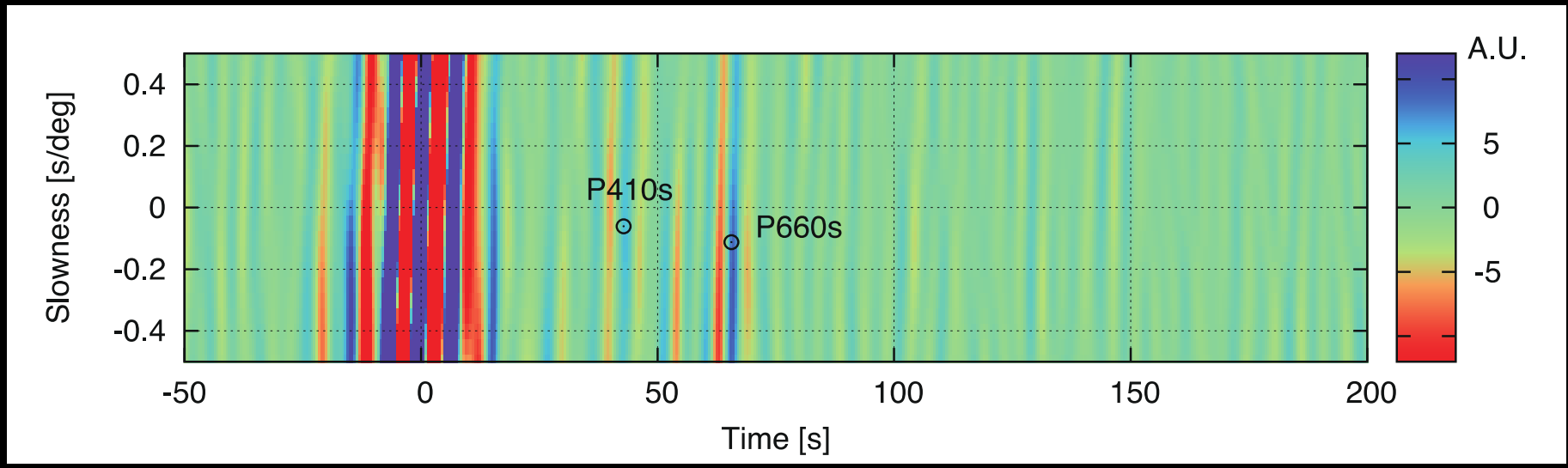
- Teleseismic body wave
  - P, PKP, PKIKP, PKiKP
    - Bright spots
    - localized sources
  - Weaker S wave
  - Deterministic
- Crustal P waves
  - Homogeneous azimuthal distribution

Two types of body waves

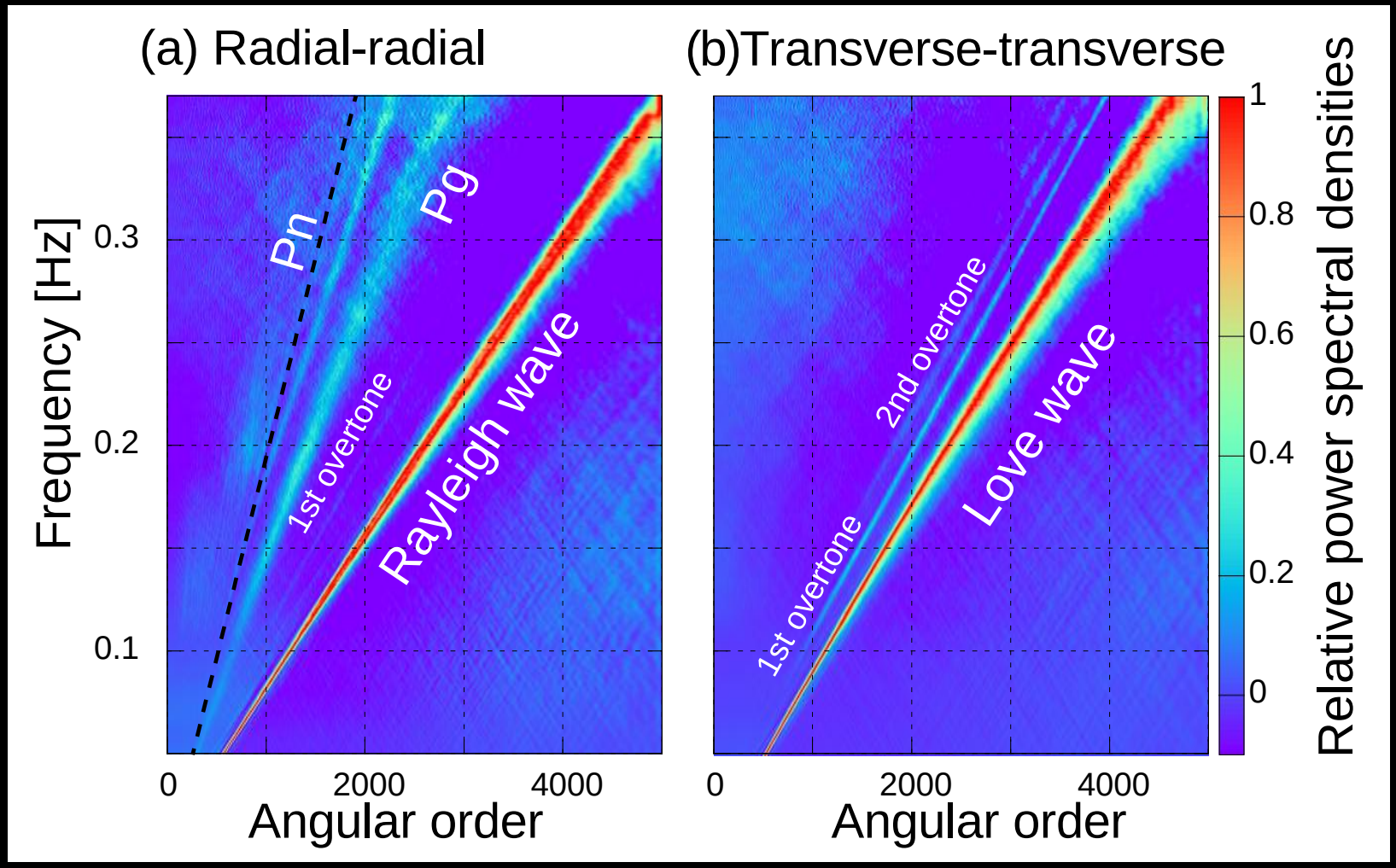
- Crustal trapped modes:
  - Crustal P waves, SPL waves
  - Homogeneous distribution
    - Multiple reflection and scattering
    - Better body wave retrievals by SI
- Teleseismic body waves is dominant on SM
  - Mantle is more transparent
  - Localized events
    - detected as bright spots in FK domain
    - Biases of body wave retrievals by SI due to the source heterogeneity

- Thank you

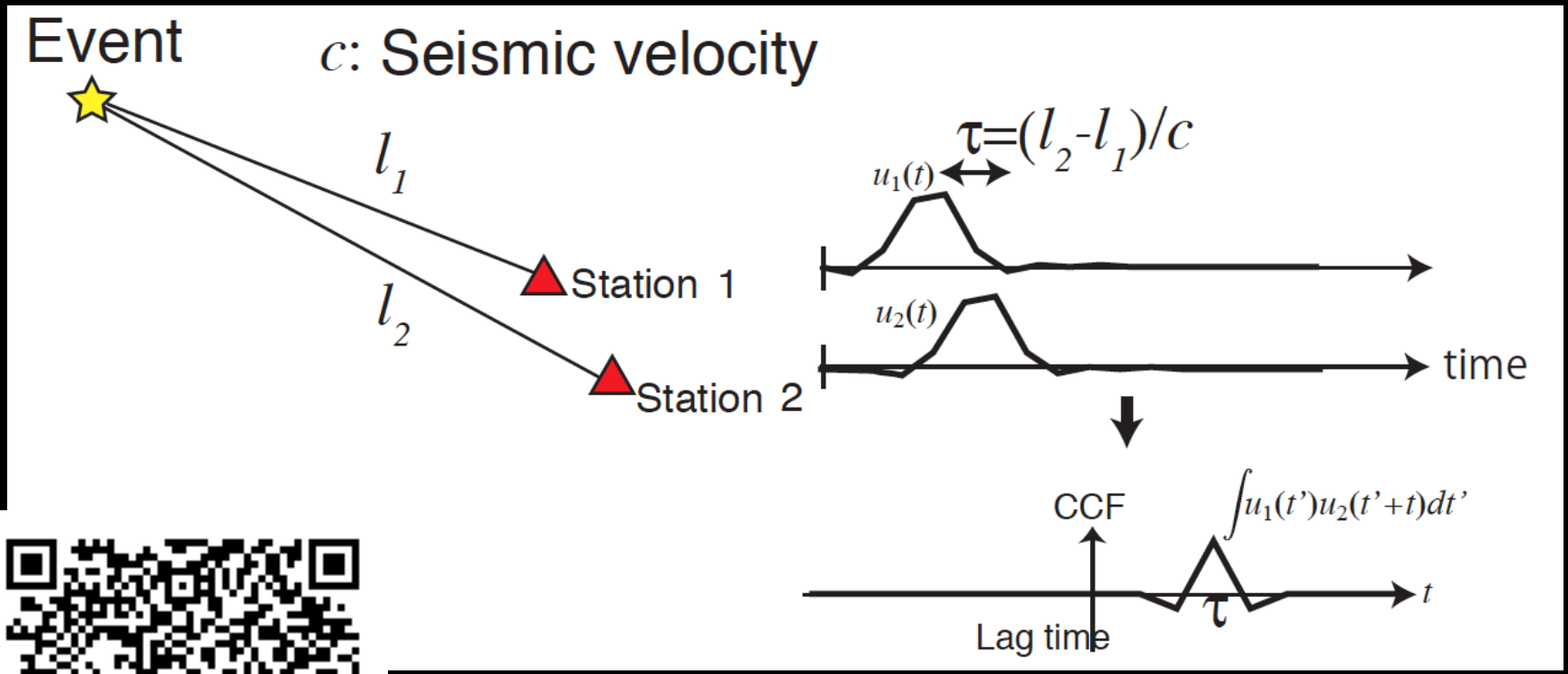
Vespagram of receiver functions



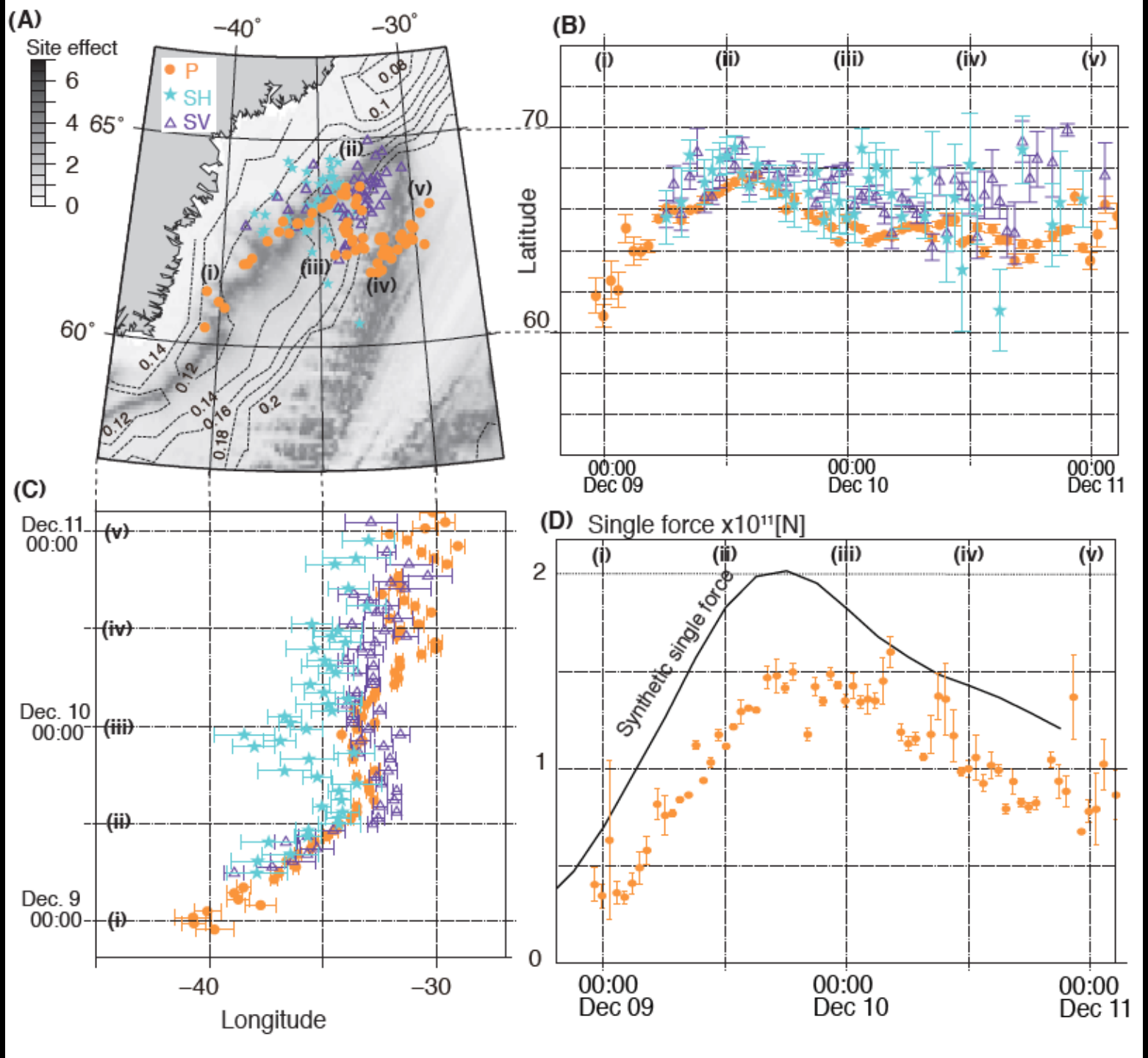
Weather bomb on Dec. 9th -10th in 2014


(a) Radial-radial
(b)Transverse-transverse
Frequency [Hz]
0.3
0.2
0.1
Pn
Pg
1st overtone
Rayleigh wave
2nd overtone
Love wave
1st overtone
0
2000
4000
Angular order
0
2000
4000
Angular order
1
0.8
0.6
0.4
0.2
0
Relative power spectral densities

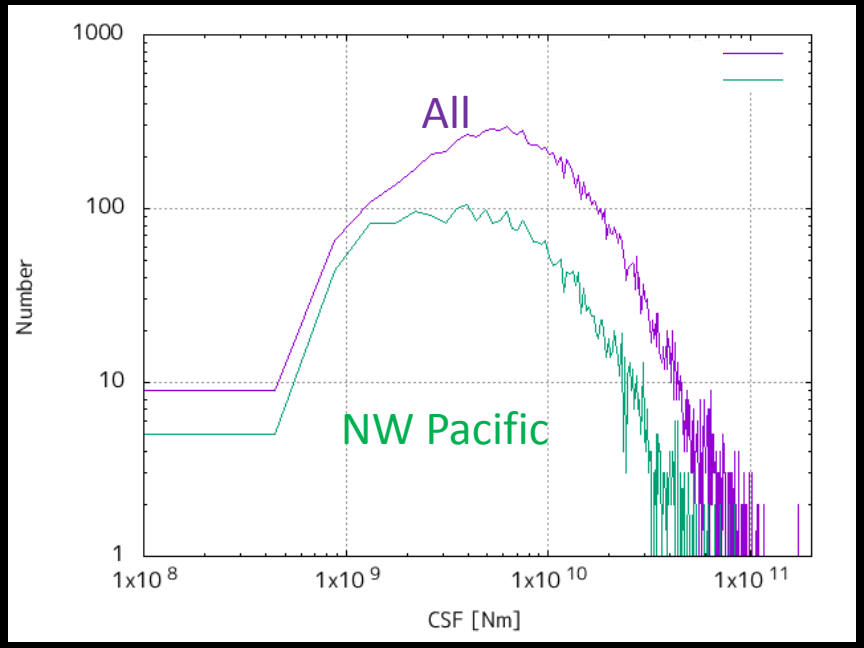
Revisit of cross-correlation analysis: seismograms by an impulsive force



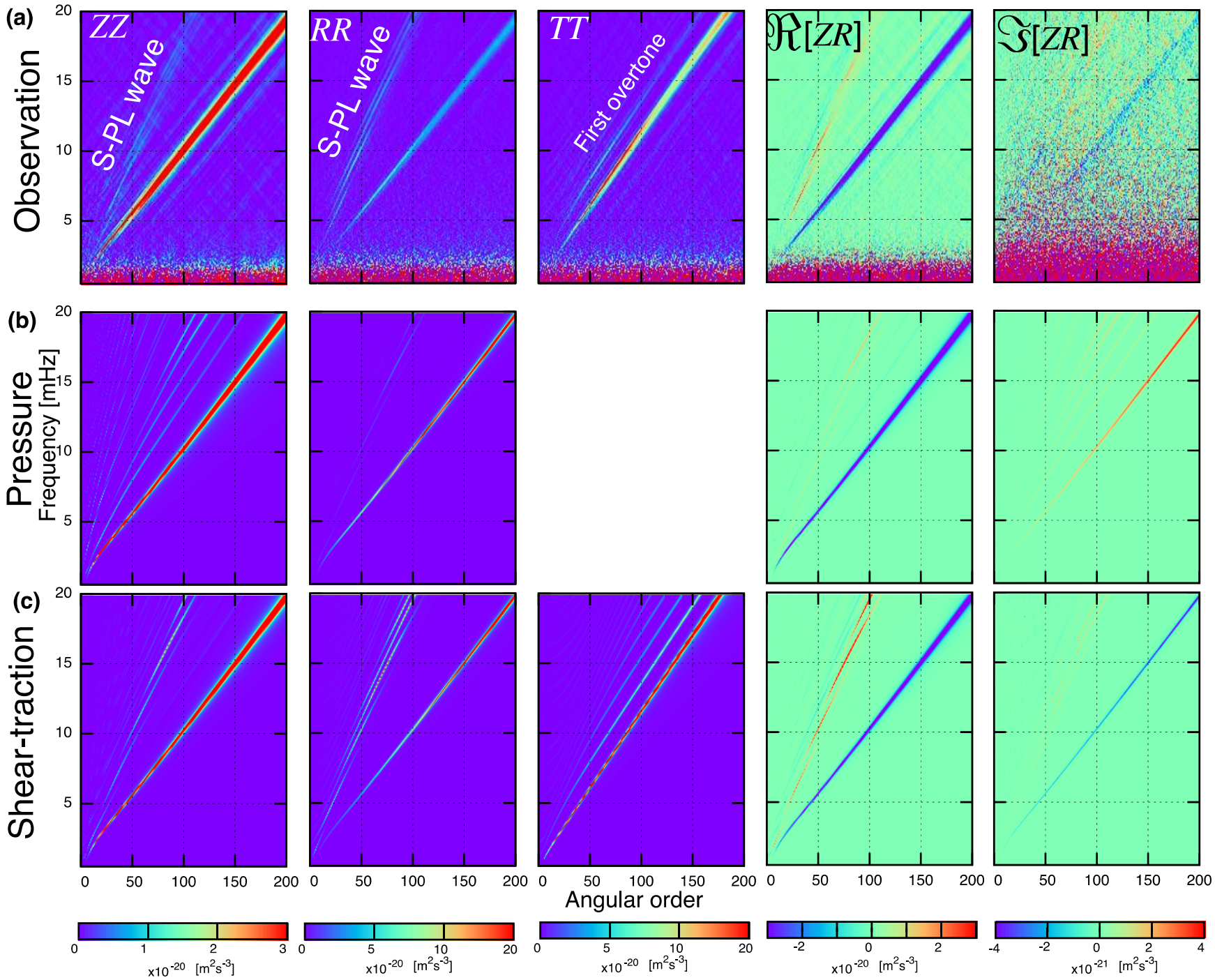
http://www.eri.u-tokyo.ac.jp/people/knishida/eng/Seismology/wave2Drandom2.html

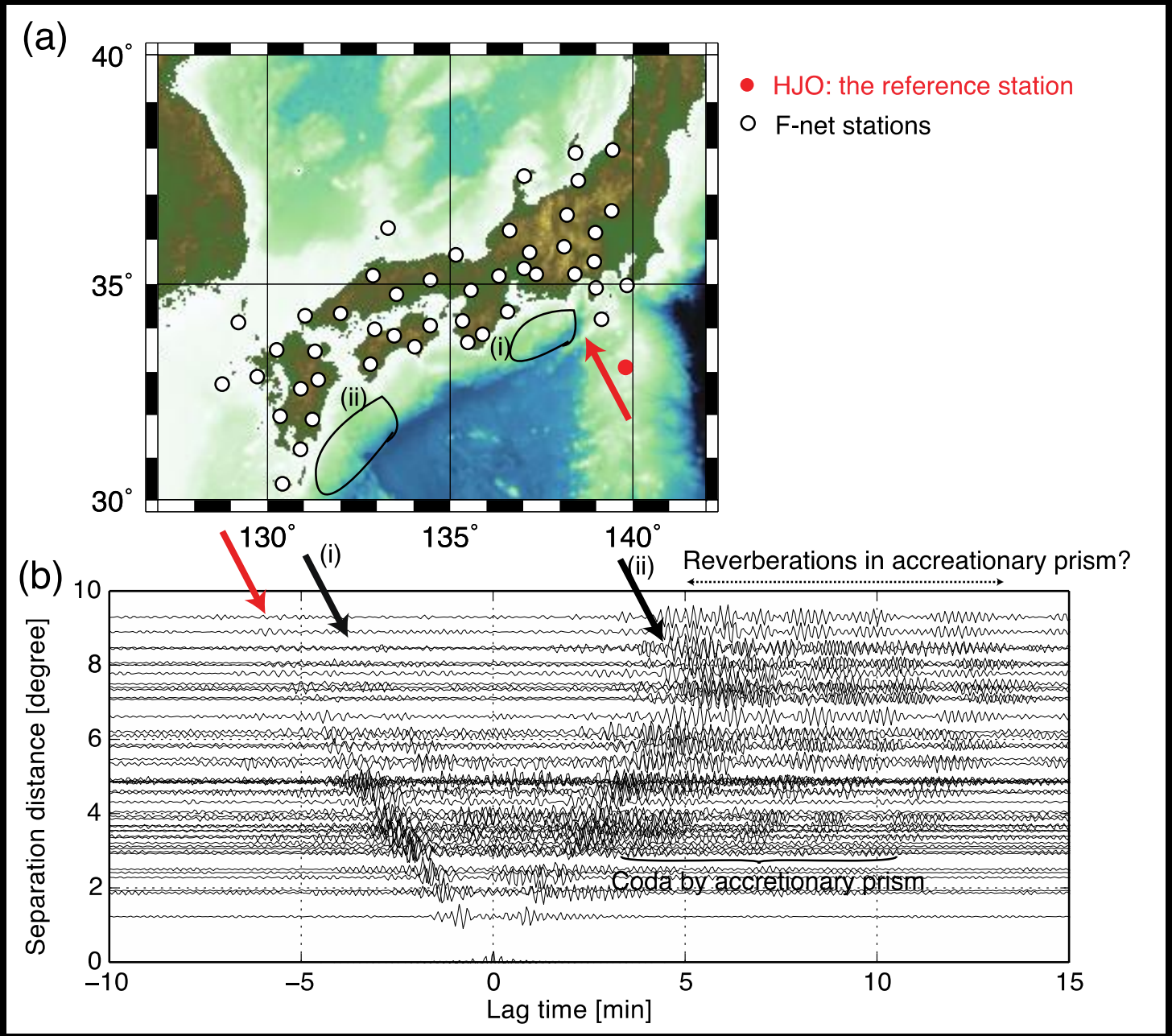

(A)
Site effect
6
4
2
0
P
SH
SV
−40°
−30°
65°
60°
0.08
0.1
0.14
0.12
0.14
0.16
0.2
0.12
0.18
(i)
(ii)
(iii)
(iv)
(v)
(B)
(i)
(ii)
(iii)
(iv)
(v)
70
60
Latitude
00:00
Dec 09
00:00
Dec 10
00:00
Dec 11
(C)
Dec.11
00:00
(v)
(iv)
Dec. 10
00:00
(iii)
(ii)
Dec. 9
00:00
(i)
−40
−30
Longitude
(D)
Single force x10¹¹[N]
(i)
(ii)
(iii)
(iv)
(v)
2
1
0
Synthetic single force
00:00
Dec 09
00:00
Dec 10
00:00
Dec 11

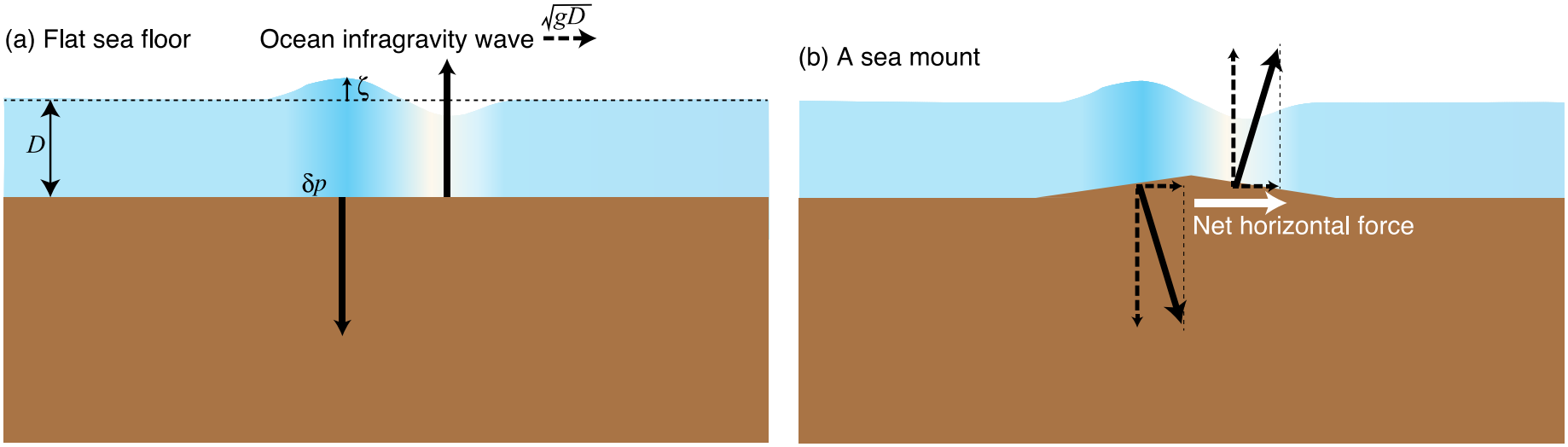
Amplitude-Frequency relation



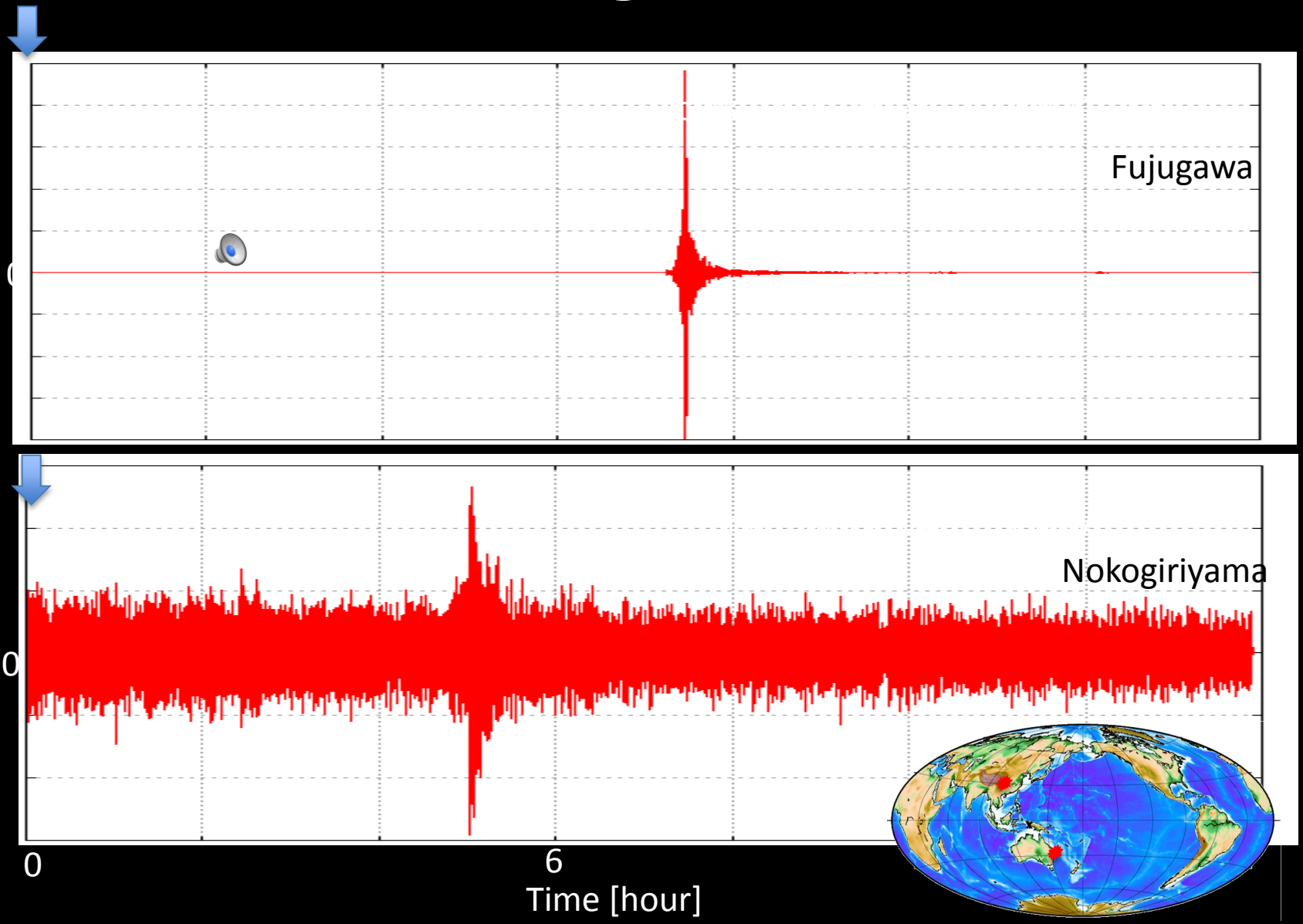
- Detection limit:
  - Regional 10^9 [Nm]
  - Global 10^{10} [Nm]
- 10^{11} [Nm]: ~10 /years


(a)
Observation
ZZ
S-PL wave
RR
S-PL wave
TT
First overtone
ℜ[ZR]
ℑ[ZR]
(b)
Pressure
Frequency [mHz]
(c)
Shear-traction
20
15
10
5
0
50
100
150
200
Angular order
x10-20 [m2s-3]
x10-20 [m2s-3]
x10-20 [m2s-3]
x10-20 [m2s-3]
x10-21 [m2s-3]

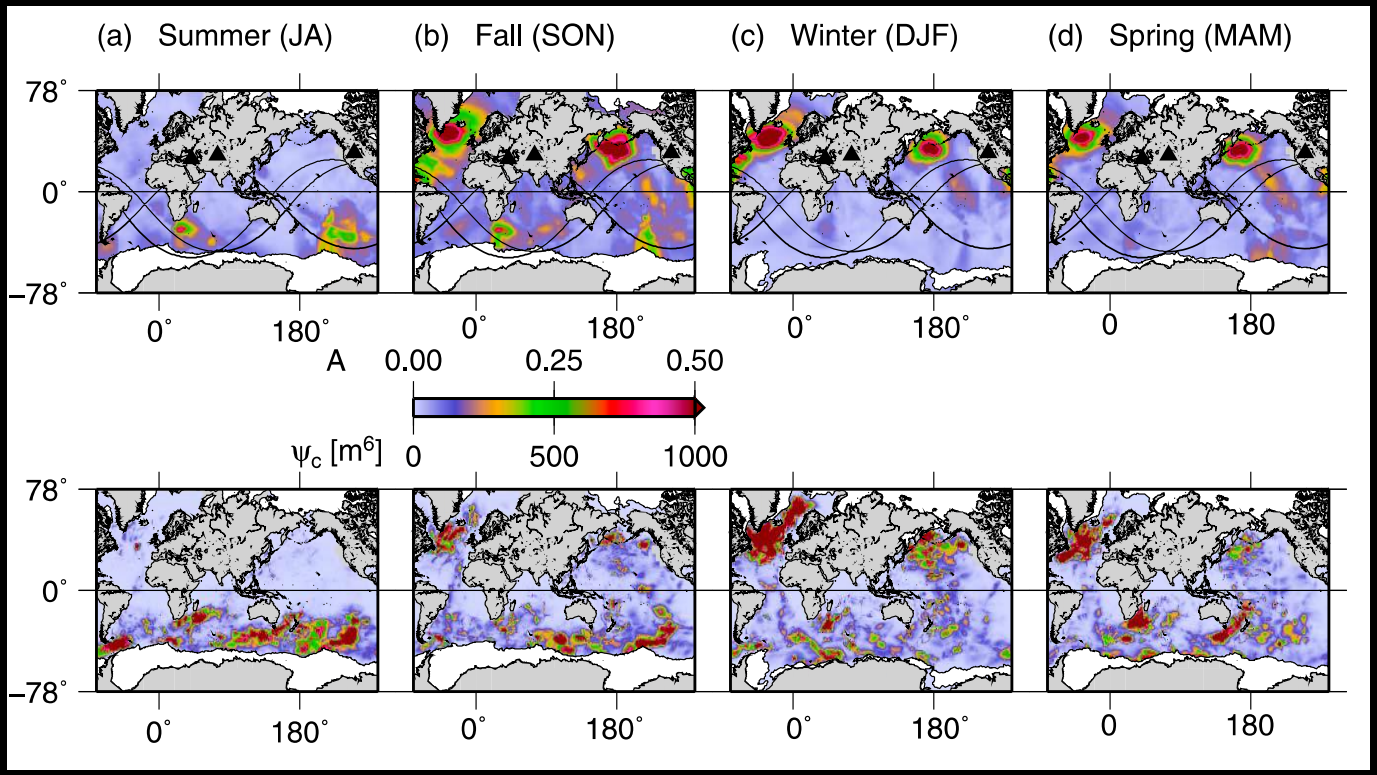

(a)
40°
35°
30°
130°
135°
140°
HJO: the reference station
F-net stations
(i)
(ii)
(b)
Reverberations in accreationary prism?
Coda by accretionary prism
Separation distance [degree]
Lag time [min]
0
2
4
6
8
10
−10
−5
0
5
10
15


(a) Flat sea floor
Ocean infragravity wave
$\sqrt{gD}$
ζ
D
δp
(b) A sea mount
Net horizontal force

Sounds of seismograms (x10000)



Global observations of P-wave microseisms



Hillers et al. 2012