Tides, normal modes, tremors and other seismic and non-seismic signals observed onshore and offshore

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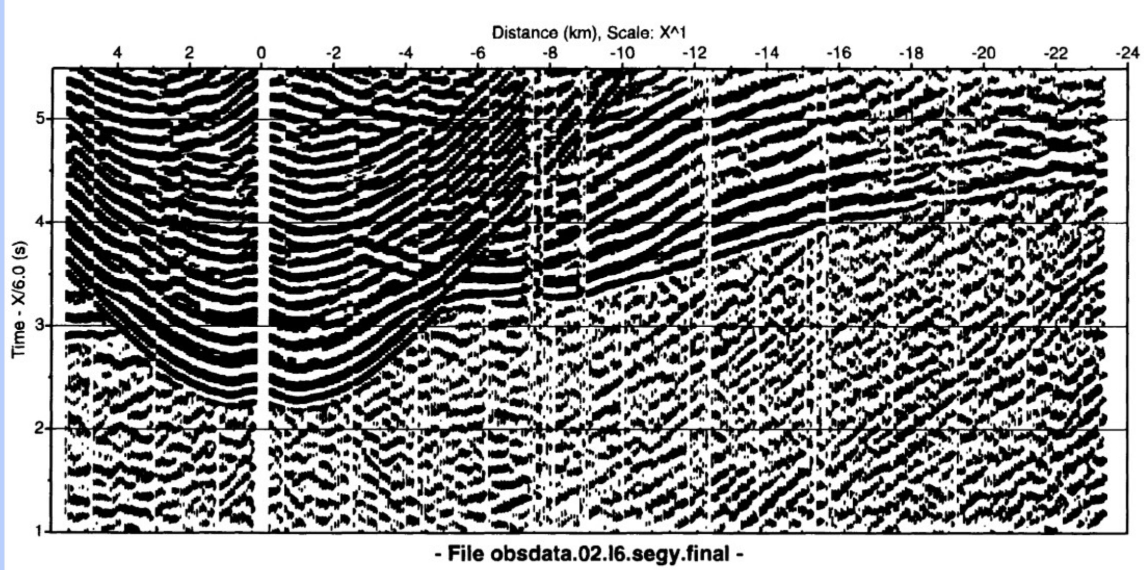

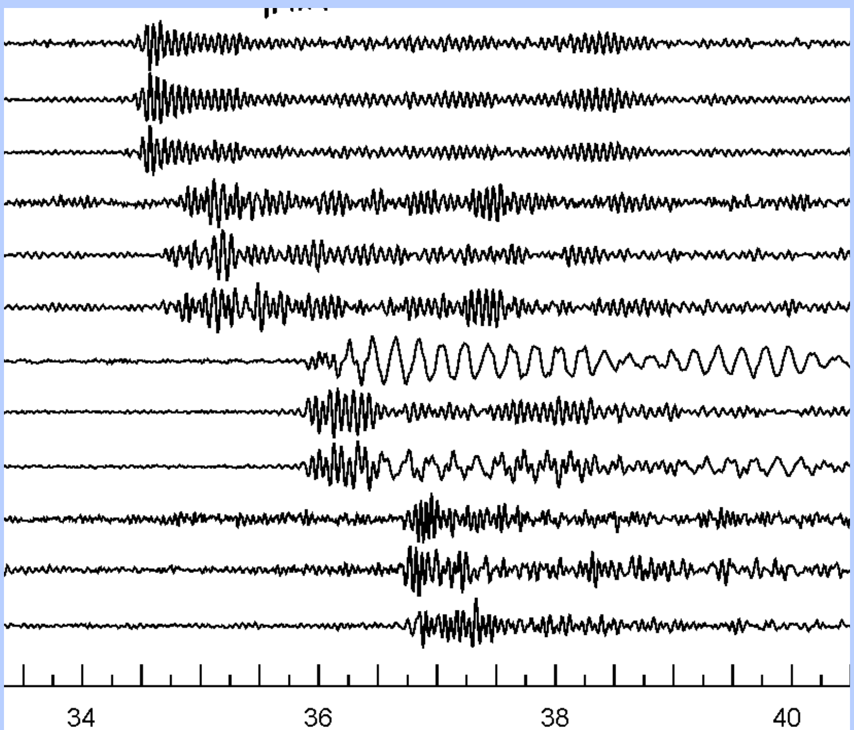

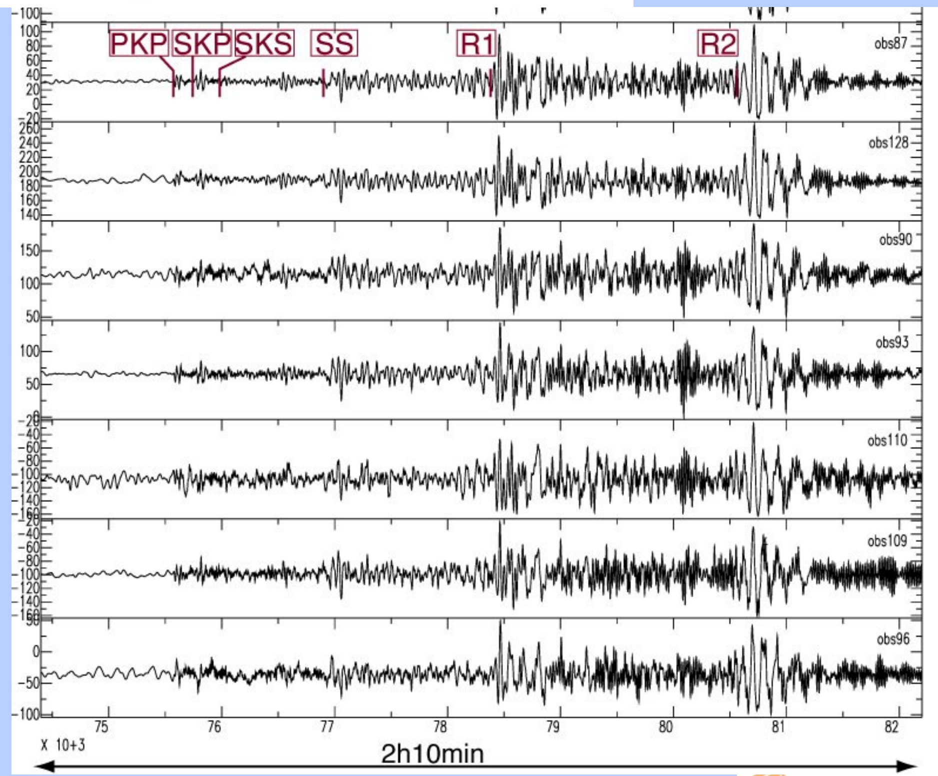

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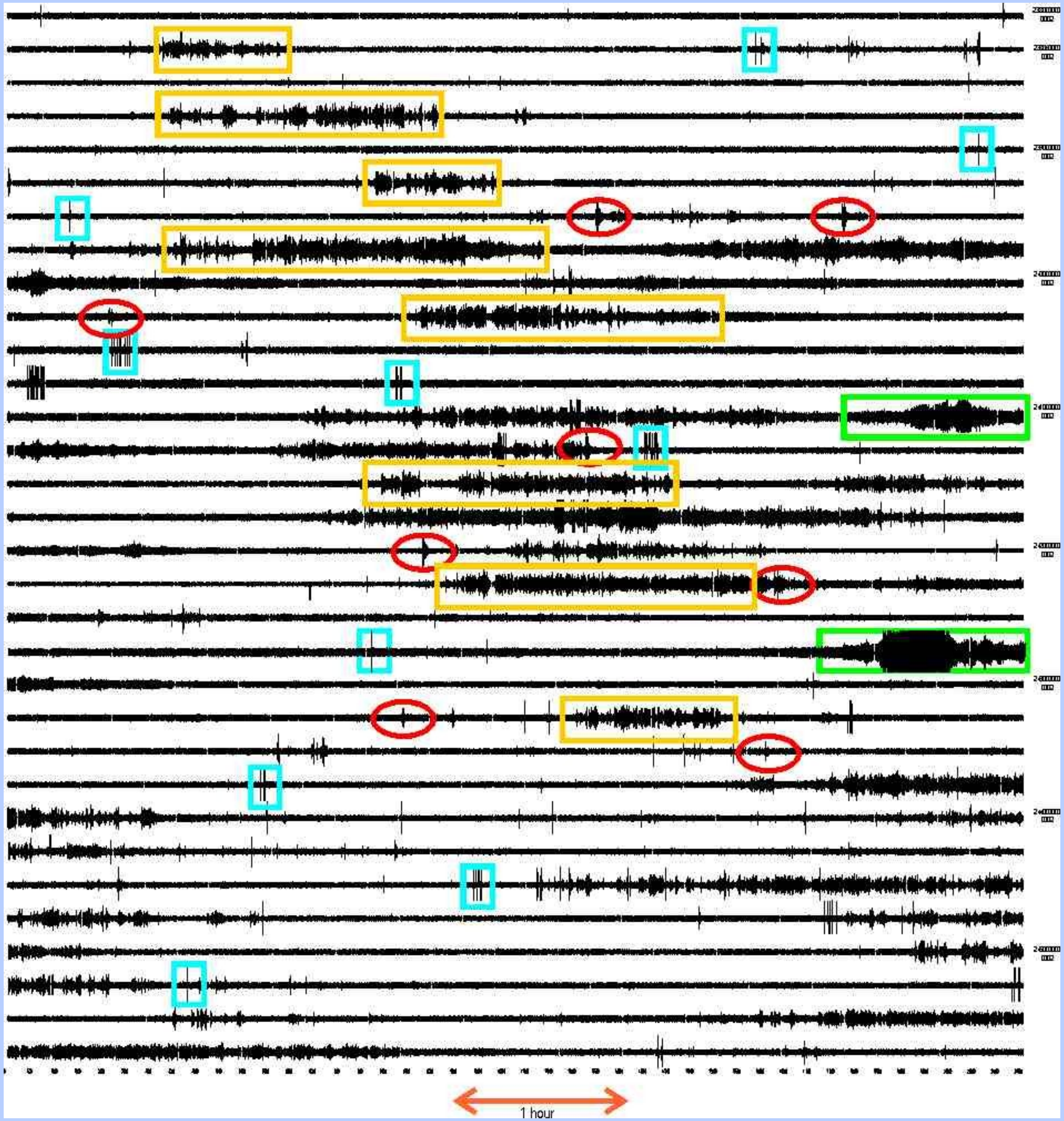

Continuous recording OBS
(6 h each line)

- Red: Seismic events (catalog)
- Blue: transient events
- Yellow: Tremors
- Green: Ship transits.

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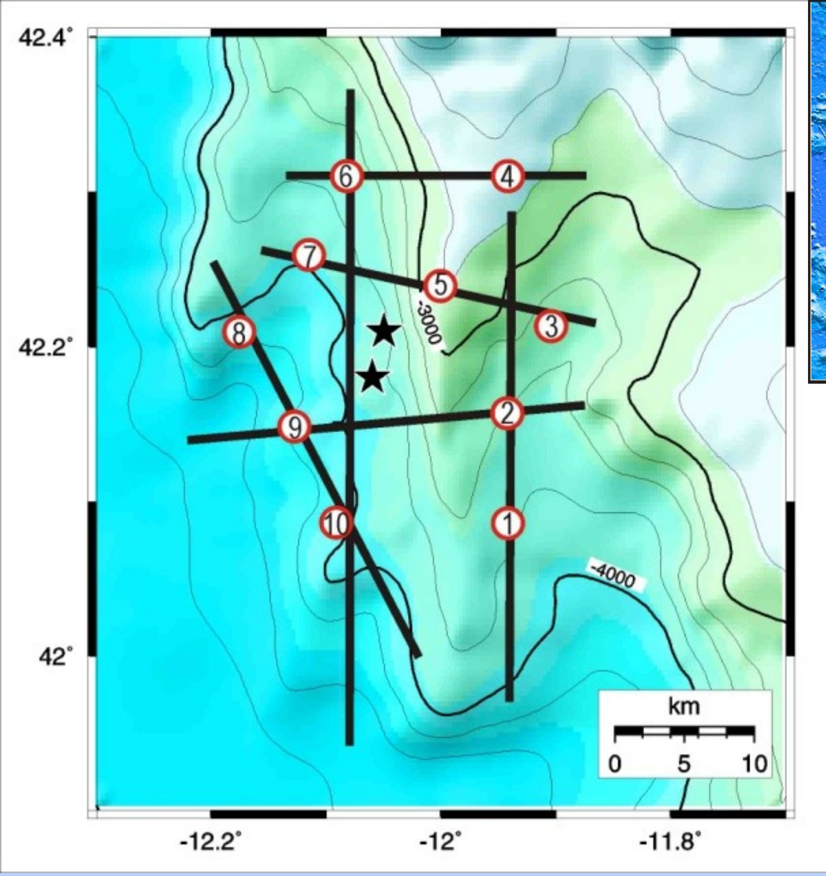
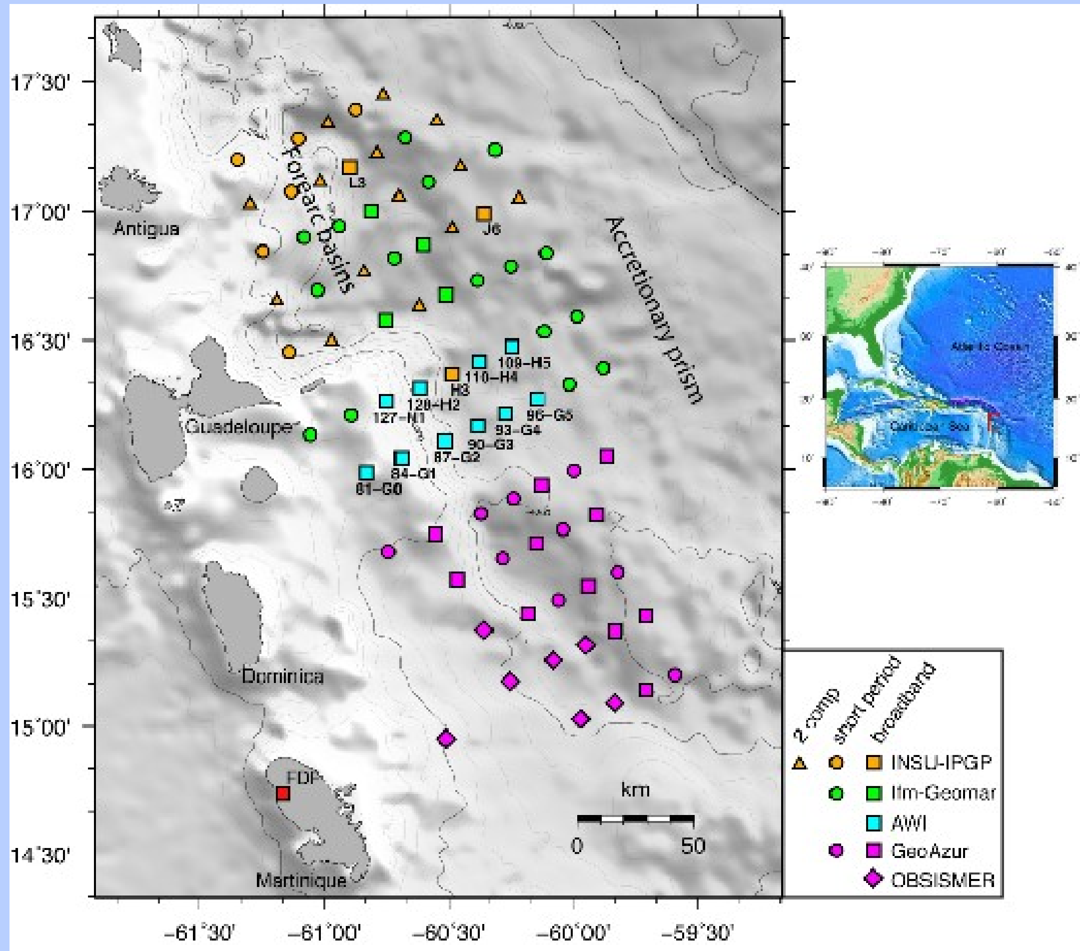


PRESTIGE (2003)

10 OBS (IRD-Geosciences Azur)

1 month

Active and passive experiment

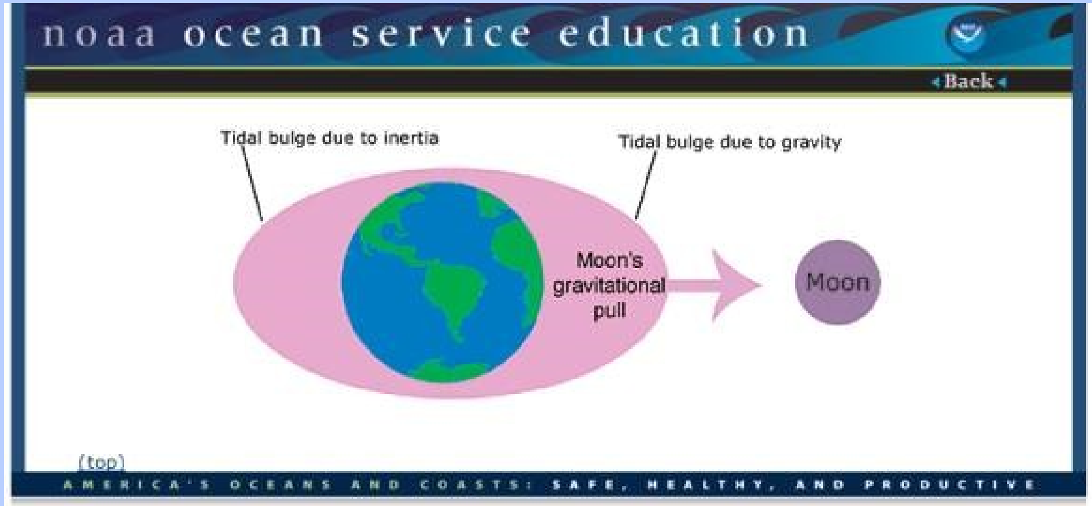


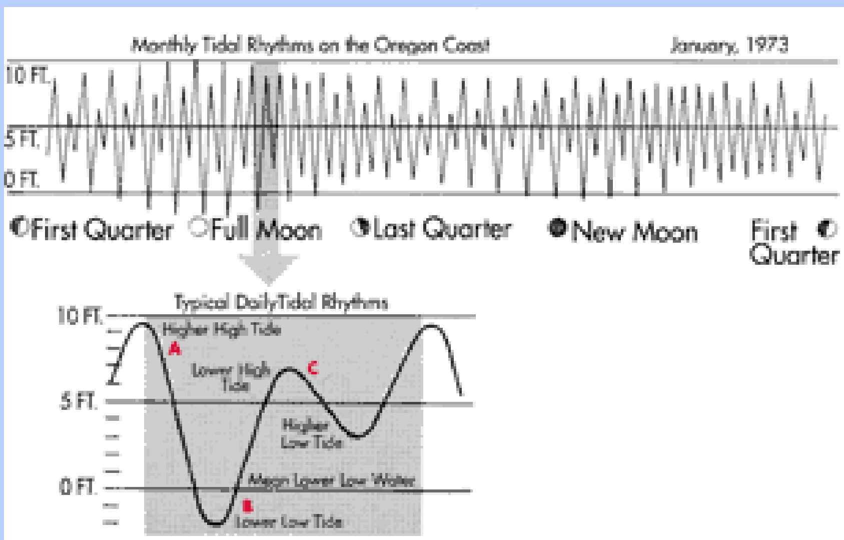
THALES – Antilles (2007)

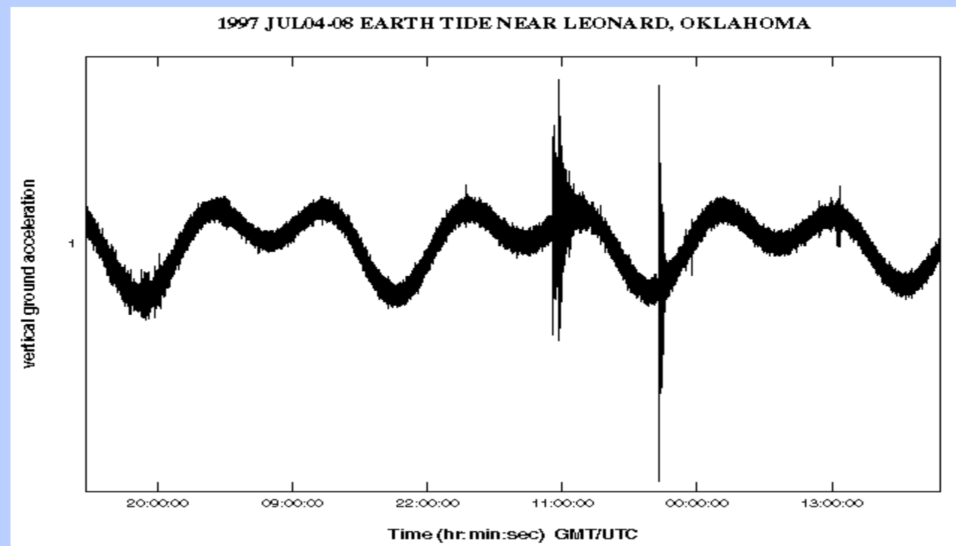
- Deployment of a dense array of 84 OBS
- 16 OBS with BB geophones and DPG or broan band hydrophone in the Northern sector (3 to 6 months)
  - 3 BB IFM-Geomar (Guralp CMG40)
  - 10 BB AWI (Guralp CMG40)
  - 3 BB INSU_IPGP (Trillium 240s)

Tides

0.00002 Hz
(0.02 mHz)







1997 JUL04-08 Solid Earth Tide
tide with Mw=6.8 Chile and Mw=5.8
Caribbean earthquake

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Ultra-long period response: recording of Earth tides

Geoscope land station = OBS

→ It is not due to the tidal current (water layer above The OBS)

Day 75

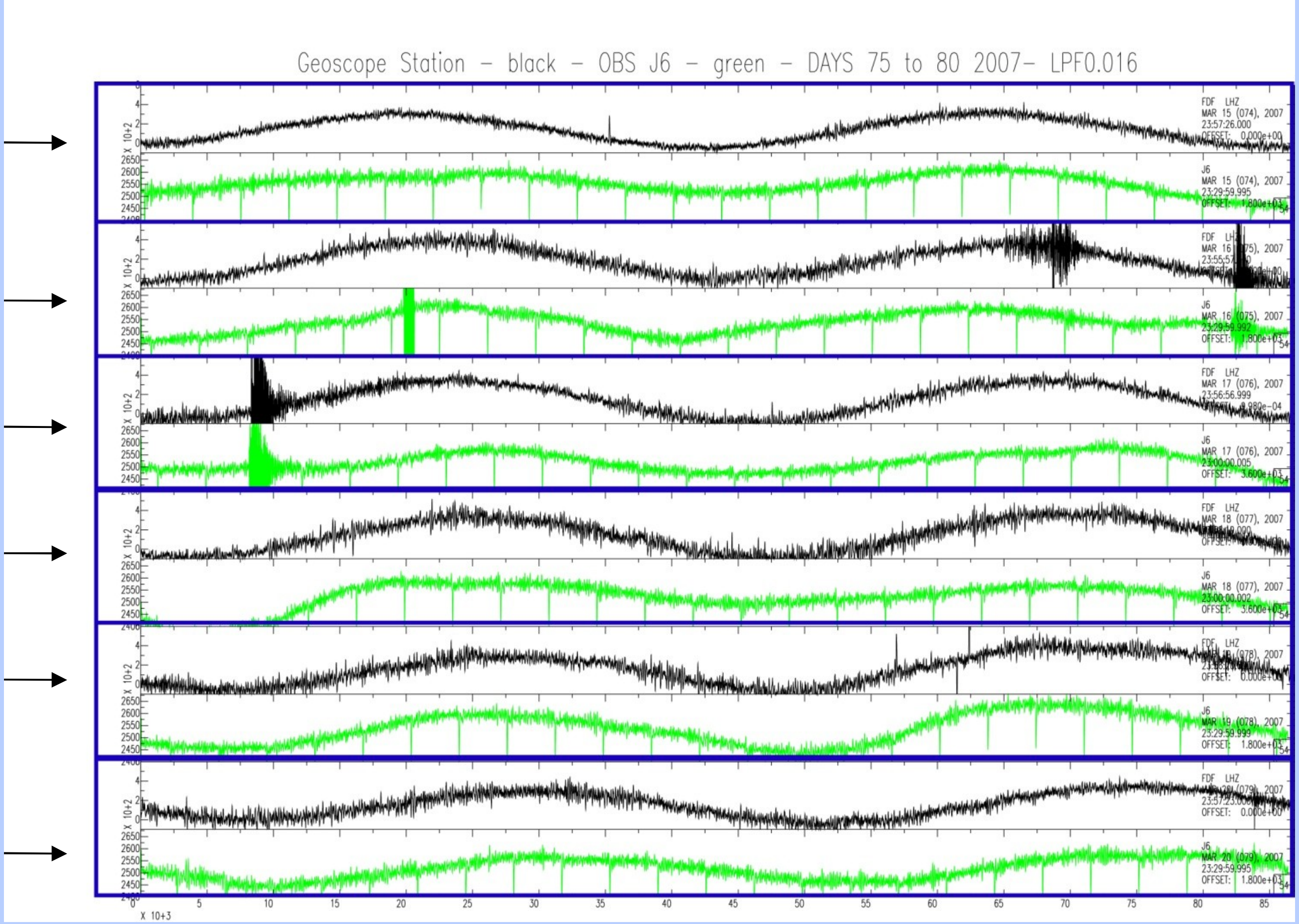
Day 76

Day 77

Day 78

Day 79

Day 80



Green - BB station geoscope / Black - BB OBS sismantilles II

Low pass filtering 60s

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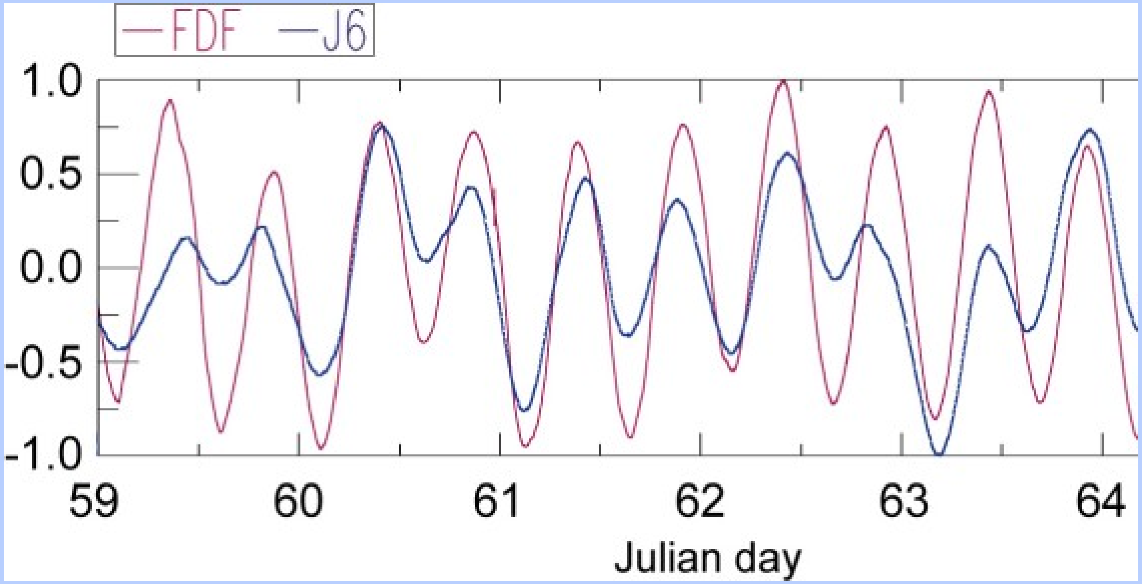
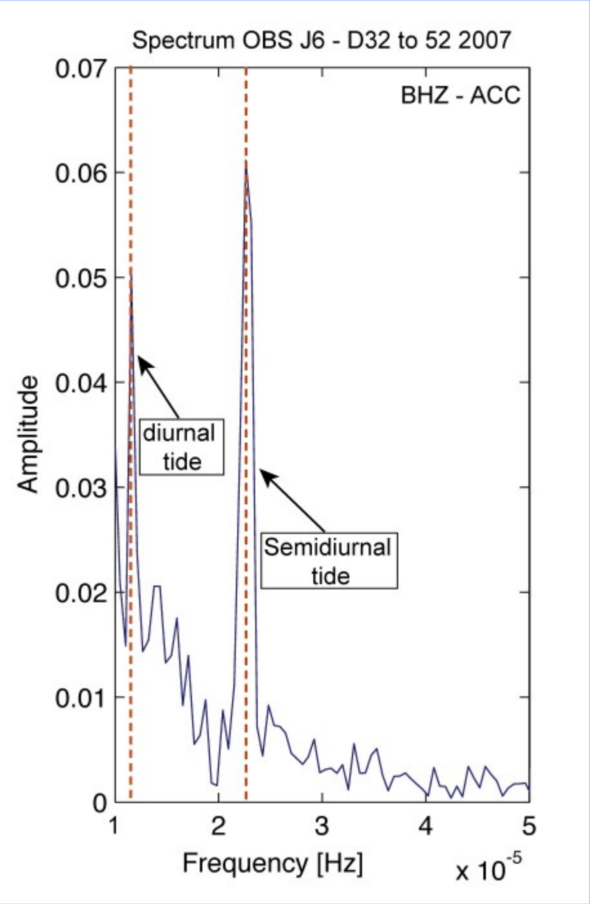
Ultra-long period response: recording of Earth tides



Becel et al, 2011



Normal Modes

0.0005 – 0.008 Hz

Few minutes after the earthquake
Constructive interferences ➔ free oscillations
(or stationary waves)

Few hours after the earthquake ($_0S_{20}$)

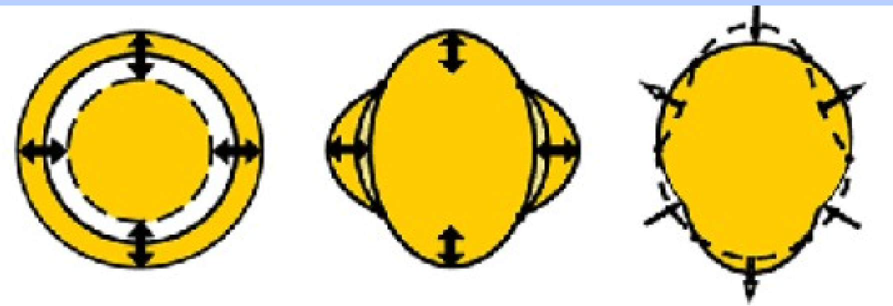
From Michel van Camp, Royal Obs. of Belgium

Standing Waves with Periods < 54 min, amplitudes < 1 mm

Observable months after great earthquakes

Useful for studies of

- Interior of the Earth
- Largest earthquakes



Spheroidal modes $_0S_0$ (20.5 min), $_0S_2$ (53.9 min) and $_0S_3$ (25.7 min)

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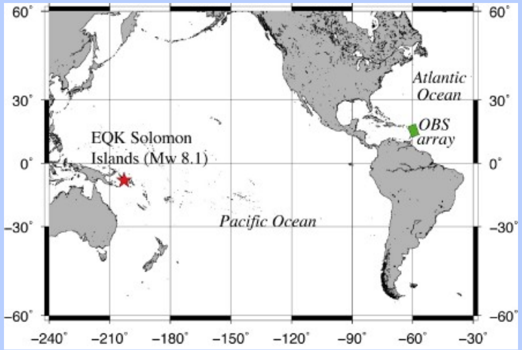
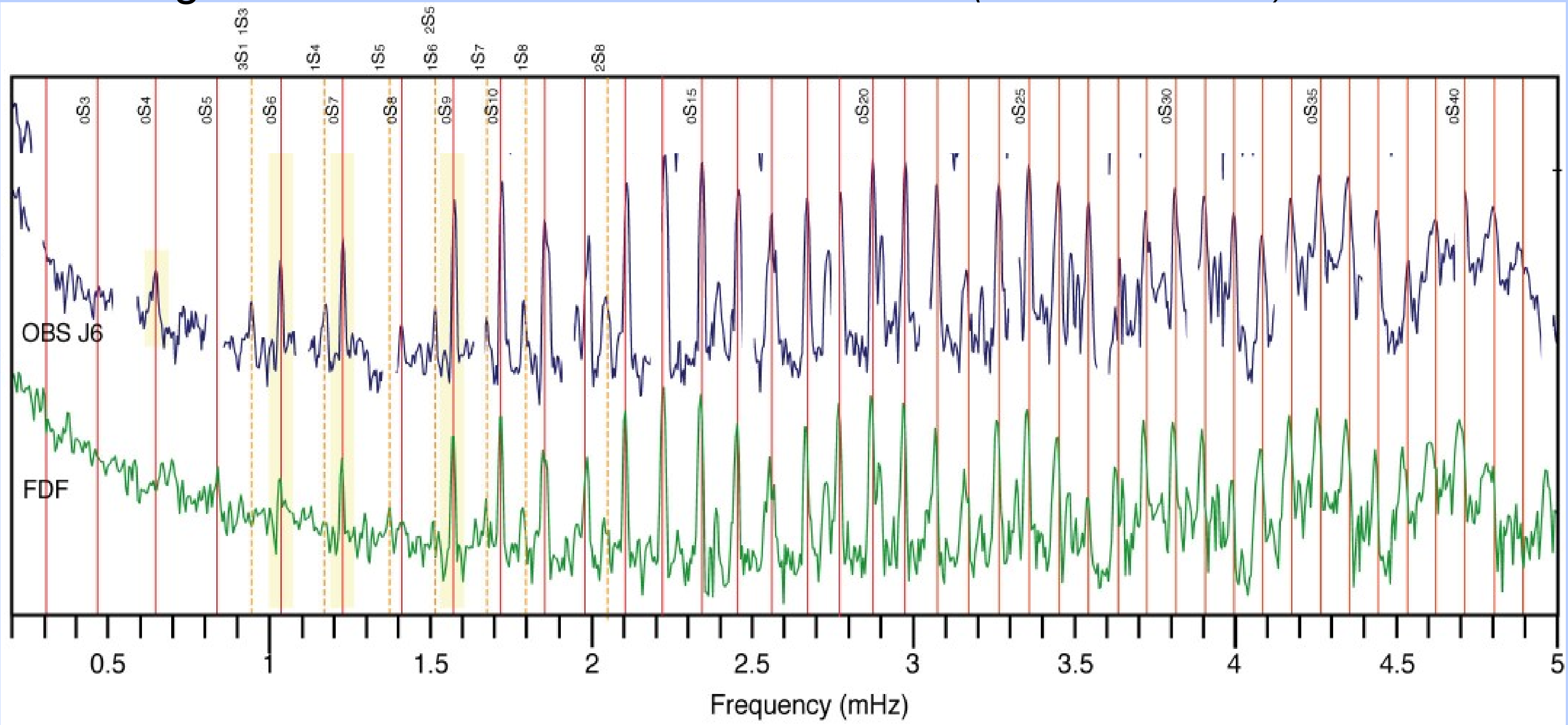
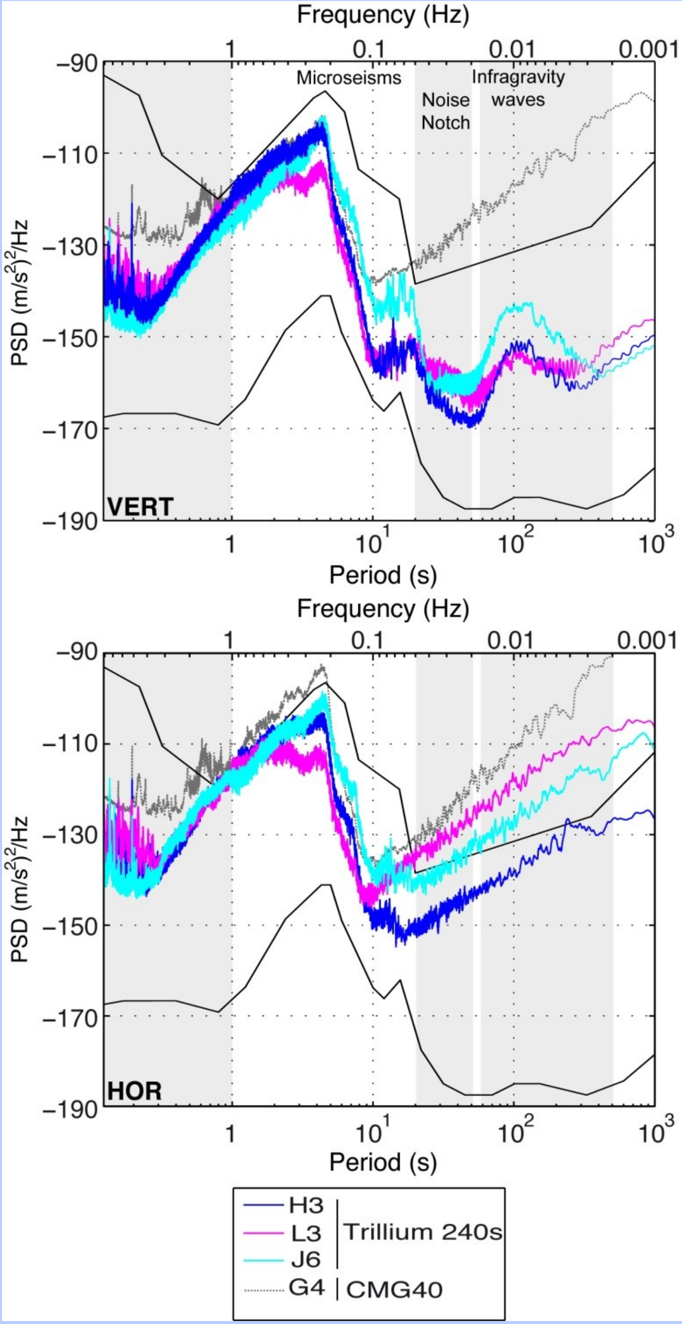


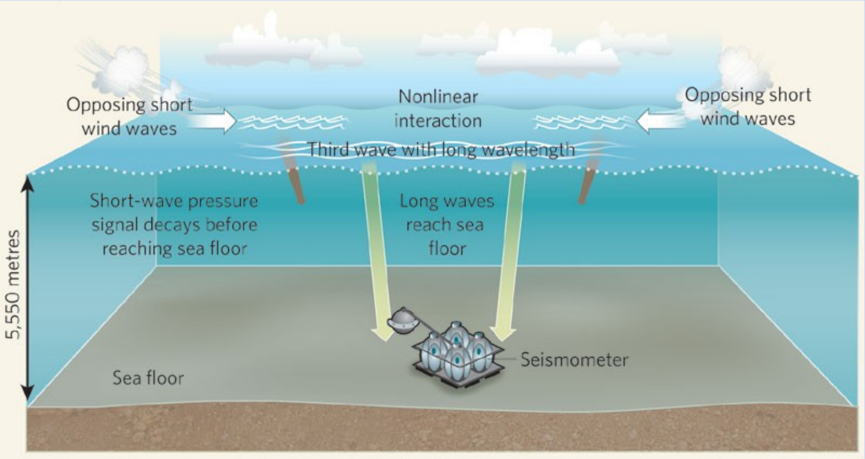
Normal modes observed at OBS J6 and land station FDF following a Mw 8.1 event at Solomon Islands. *(Becel et al., 2011)*



Infragravity waves

0.004 – 0.02 Hz





Elgar, Nature (2009)

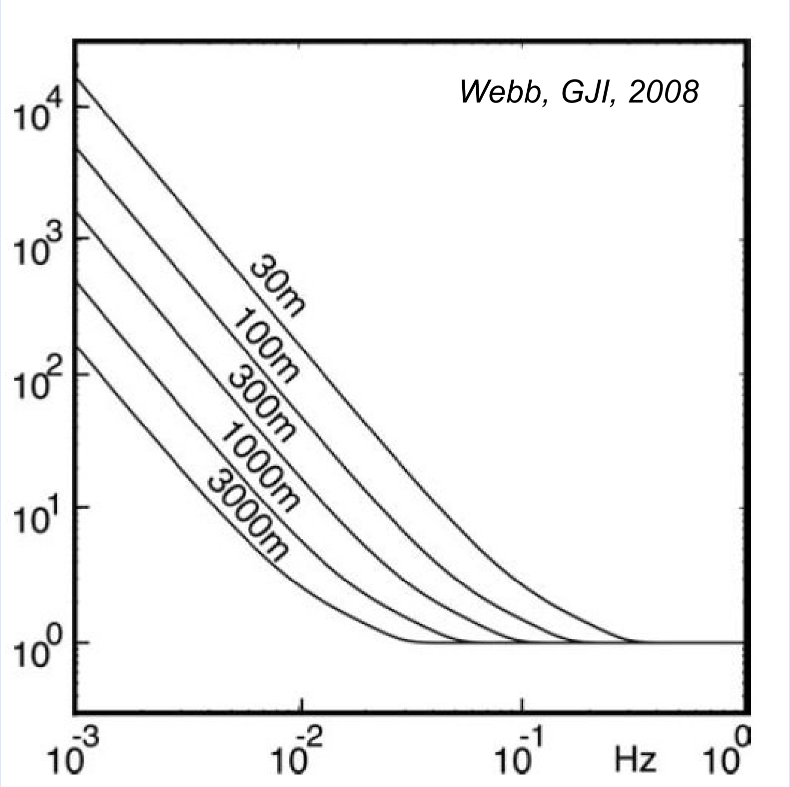
The infragravity waves are generated into the ocean by the non linear interaction of short wavelength ocean surfaces waves/swell which create a long period ocean surface gravity waves.

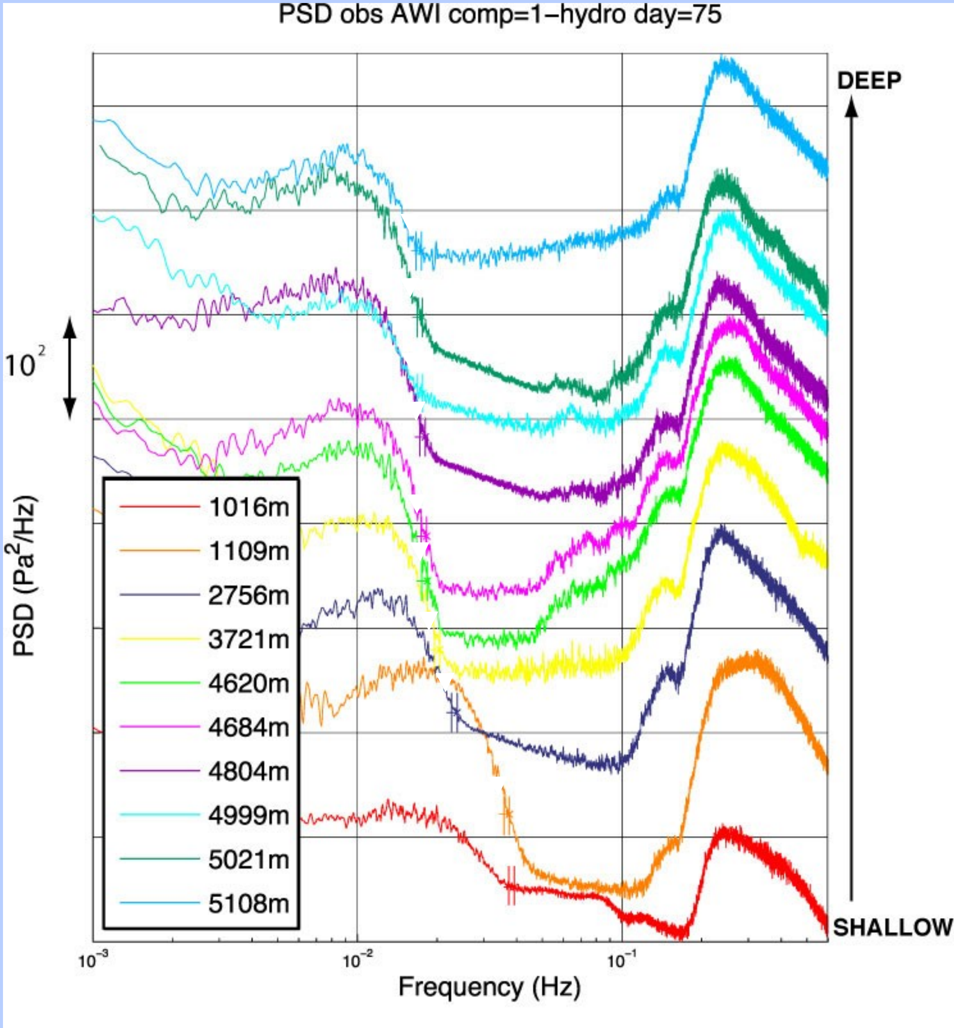
Use of BB-OBS allows to identify IGW at the 0.004 – 0.02 Hz (50-250s)

IGW: Interaction of short-wavelength surface waves to create a long wave

→ Upper Frequency cut-off of the infragravity waves depends of water depth

Becel et al., 2011





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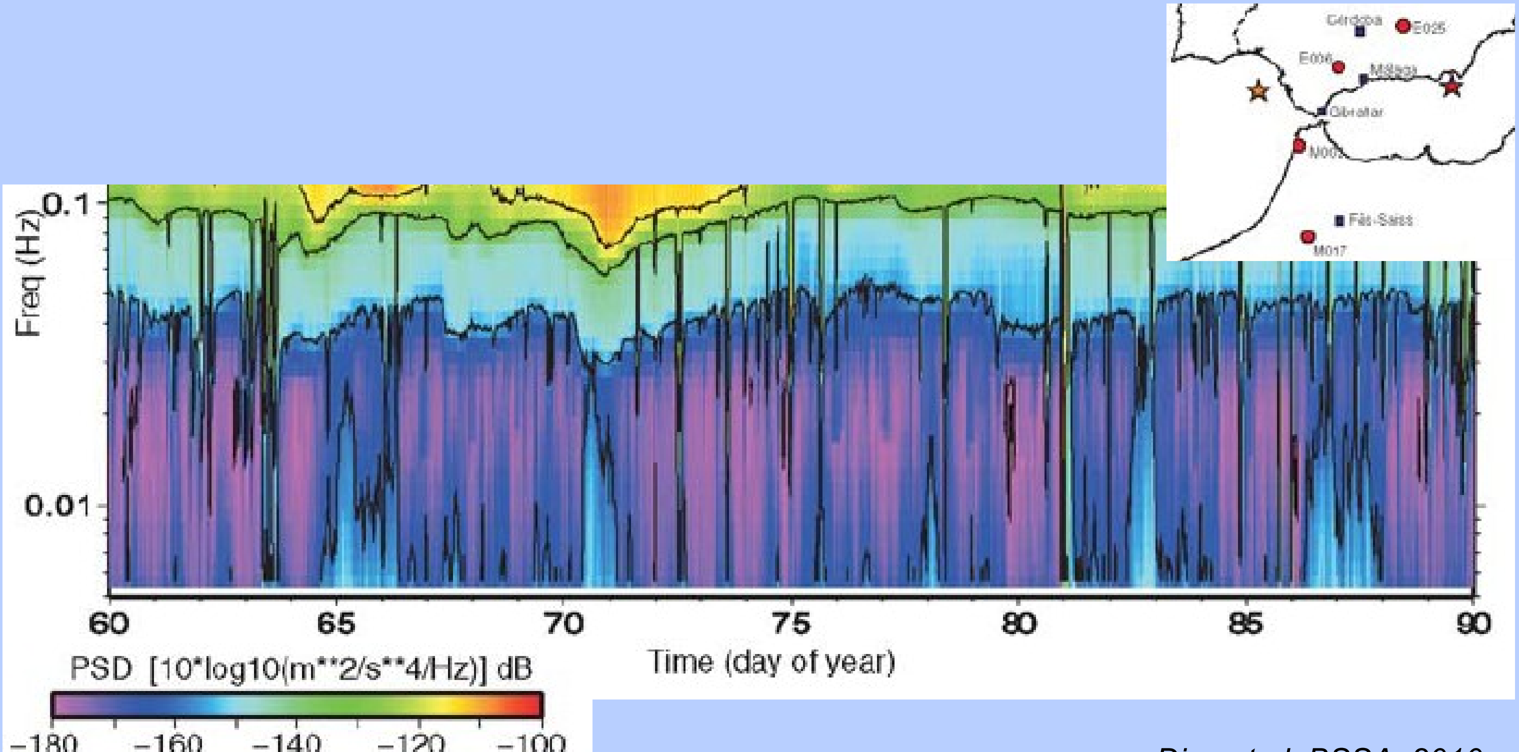

Diaz et al, BSSA, 2010

Microseismic peak

0.1 – 1 Hz

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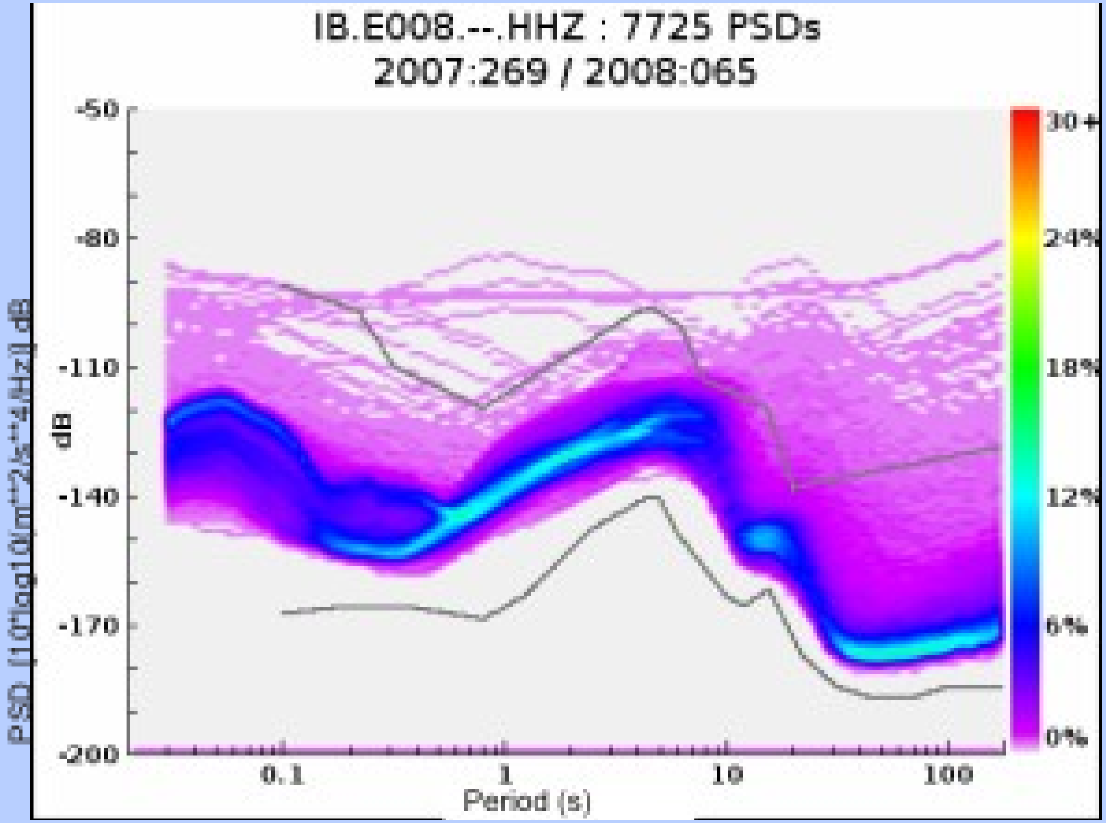

-Single Frequency peak: (0.05 to 0.08Hz)
-Related to ocean waves reaching the shoreline

-Double Frequency peak: (0.1 to 0.3Hz)
-Generated by non linear interaction between ocean waves

(Longuet-Higgins, 1950)

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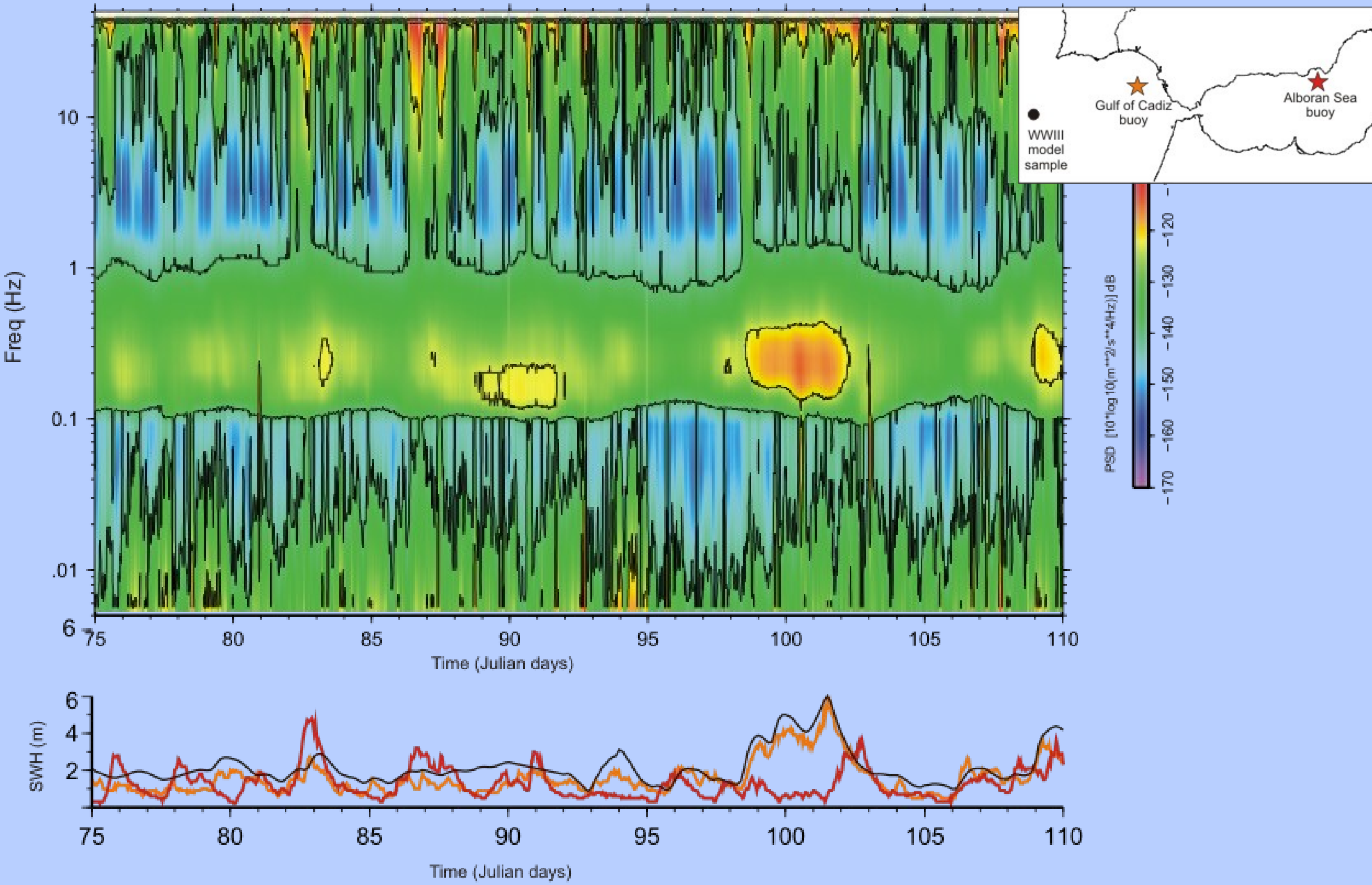
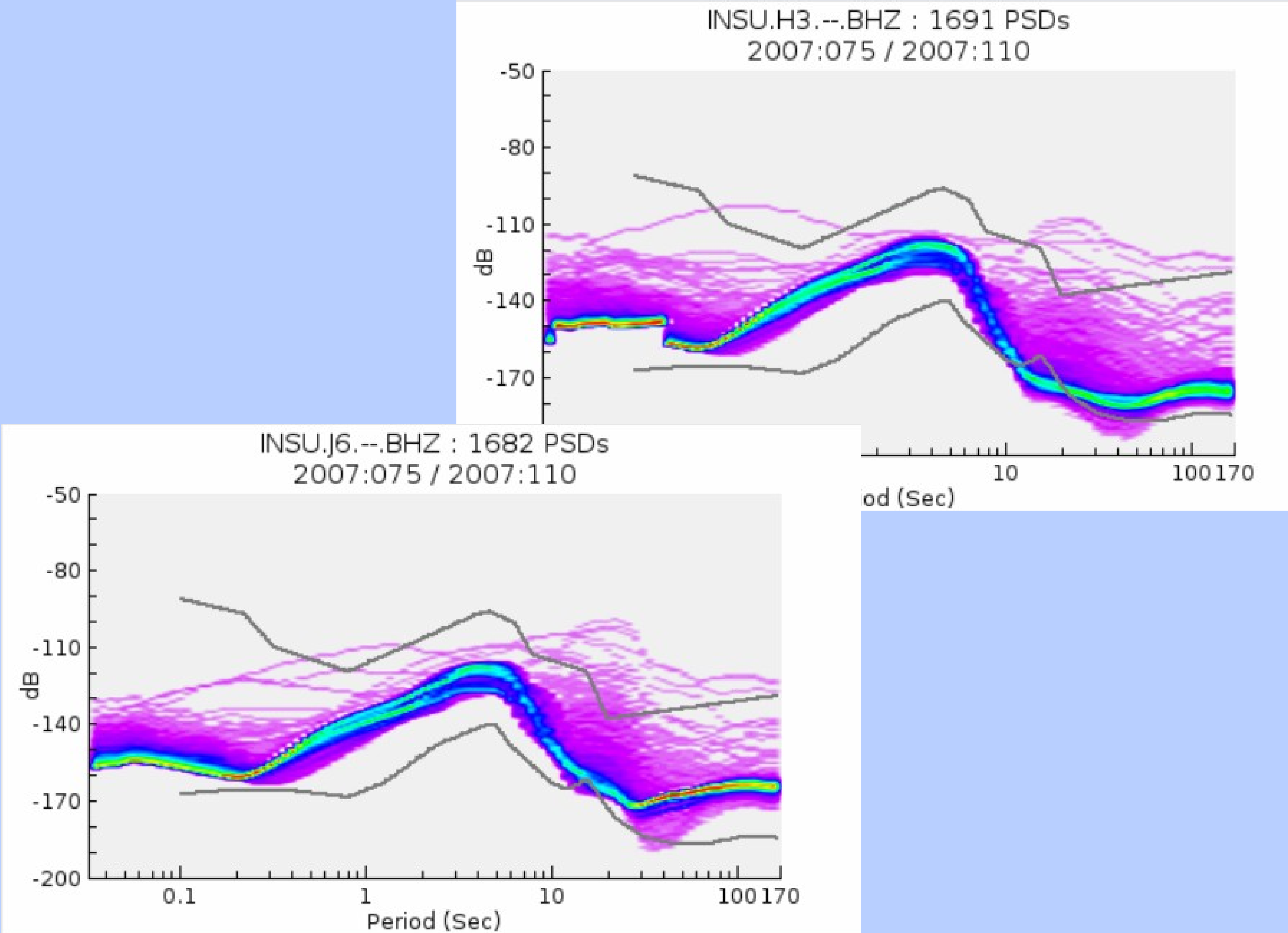


Diaz et al, BSSA, 2010


INSU.H3.--.BHZ : 1691 PSDs
2007:075 / 2007:110
-50
-80
-110
-140
-170
dB
10
100
170
Period (Sec)
INSU.J6.--.BHZ : 1682 PSDs
2007:075 / 2007:110
-50
-80
-110
-140
-170
-200
dB
0.1
1
10
100
170
Period (Sec)

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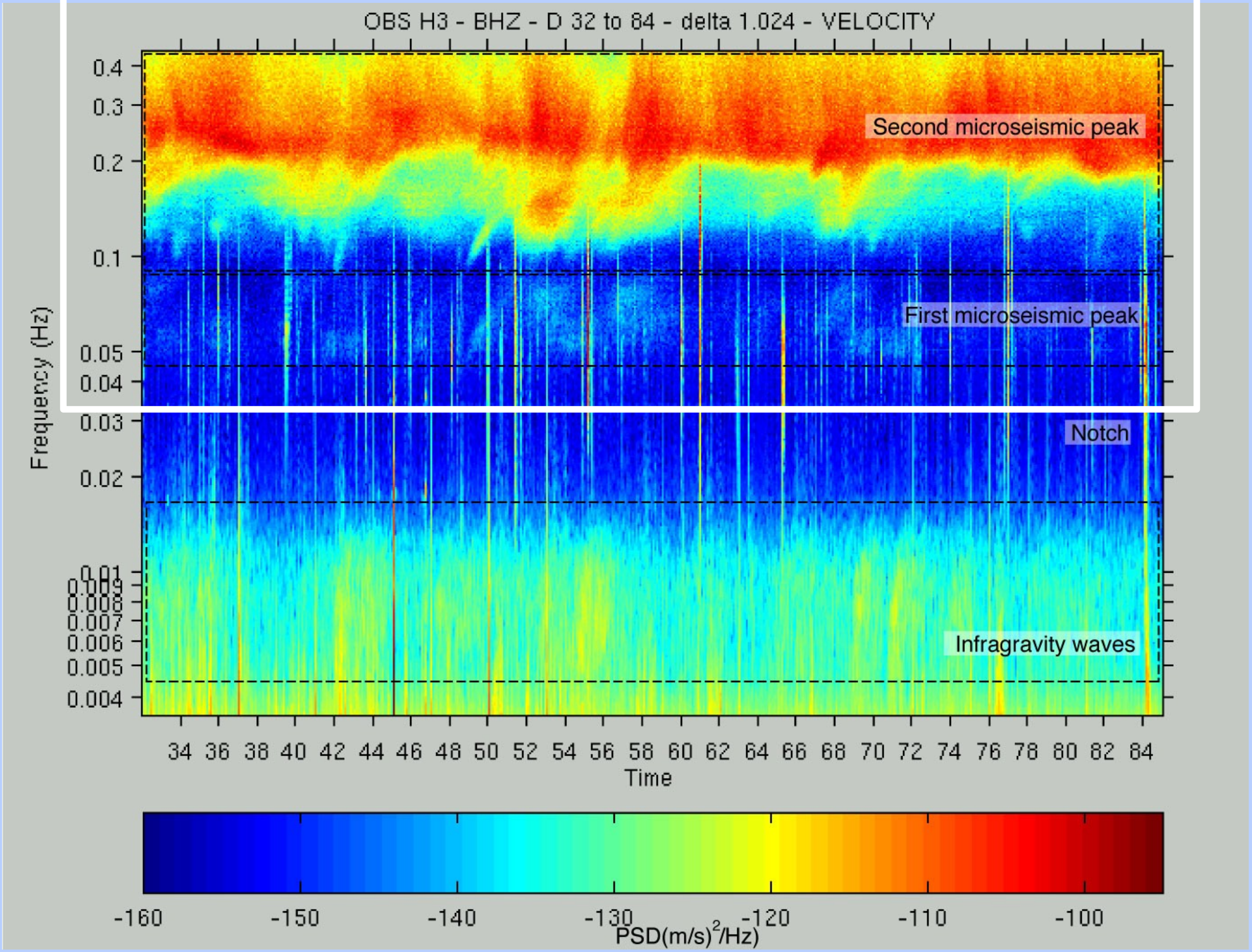
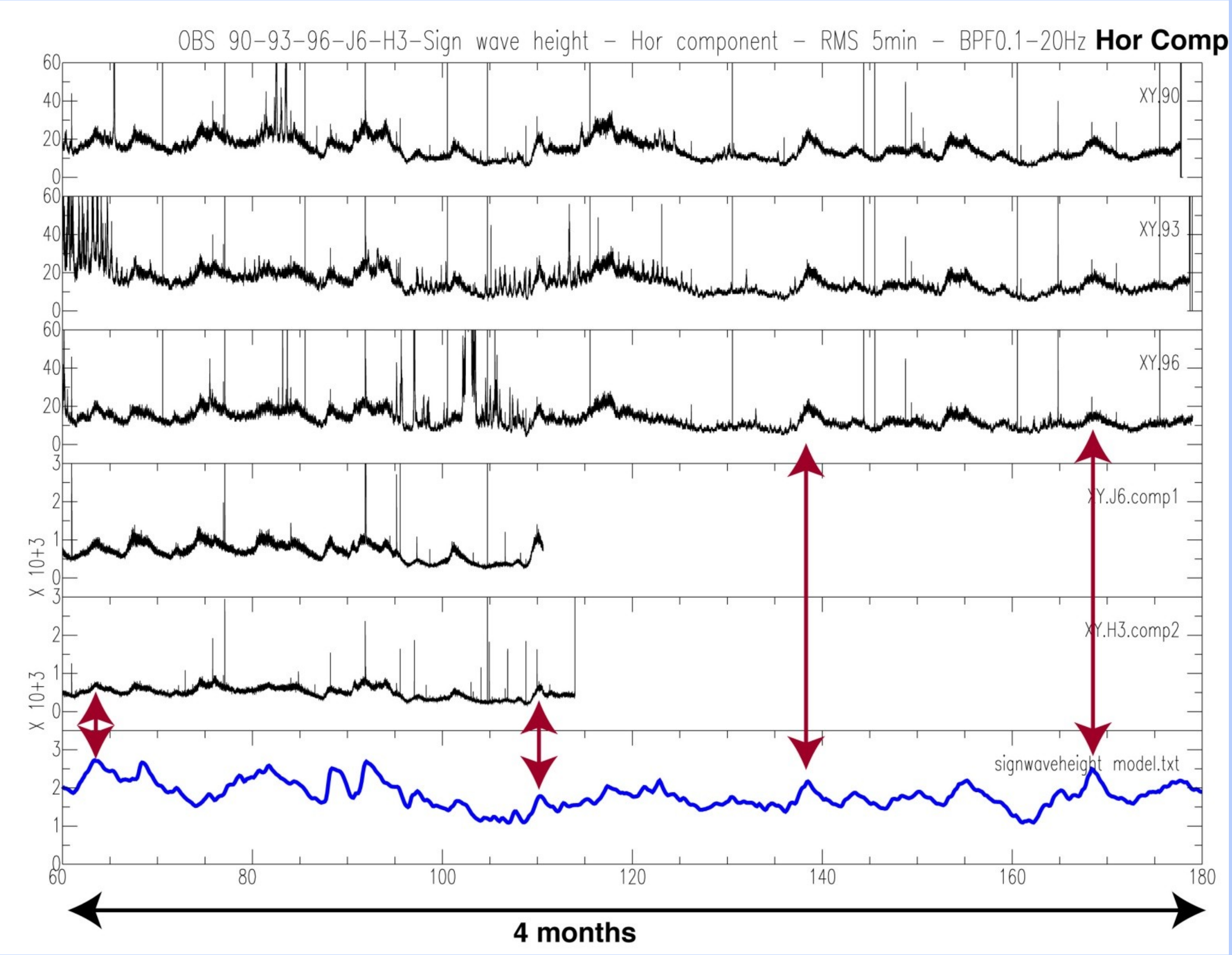

OBS H3 - BHZ - D 32 to 84 - delta 1.024 - VELOCITY
Second microseismic peak
First microseismic peak
Notch
Infragravity waves
Frequency (Hz)
0.4
0.3
0.2
0.1
0.05
0.04
0.03
0.02
0.01
0.009
0.008
0.007
0.006
0.005
0.004
34 36 38 40 42 44 46 48 50 52 54 56 58 60 62 64 66 68 70 72 74 76 78 80 82 84
Time
-160 -150 -140 -130 -120 -110 -100
PSD(m/s)^2/Hz)

Correction with the significant wave height
→ Meteo

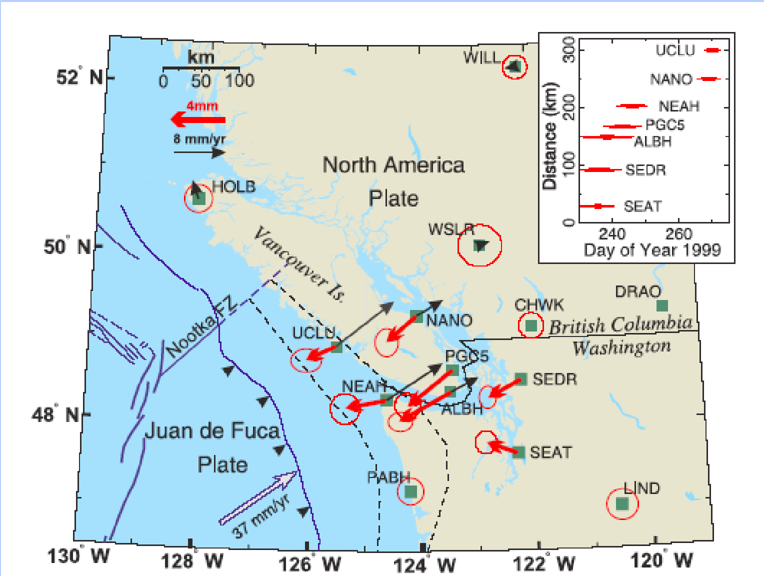


Raw seismograms are transformed to root mean square amplitude (0.1-20Hz ; time window 5 min.)

Harmonic (non-volcanic) tremors

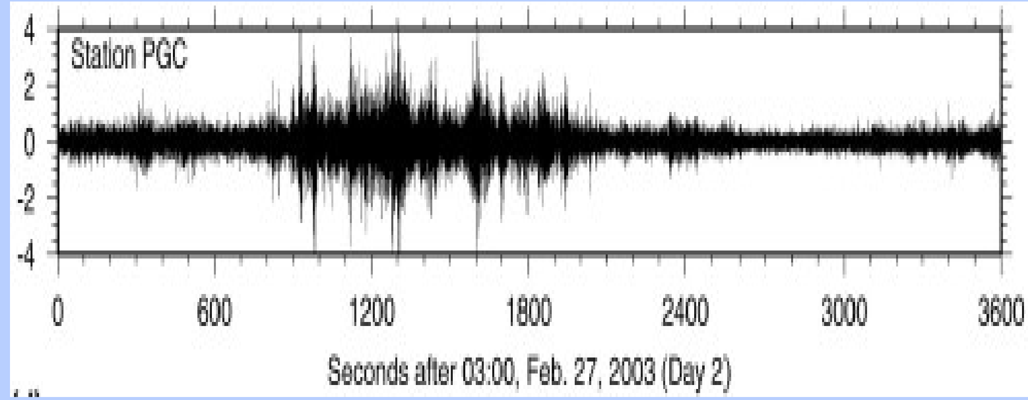
1 – 10 Hz

Slow-Slip events (SSE):
Geodetically detected

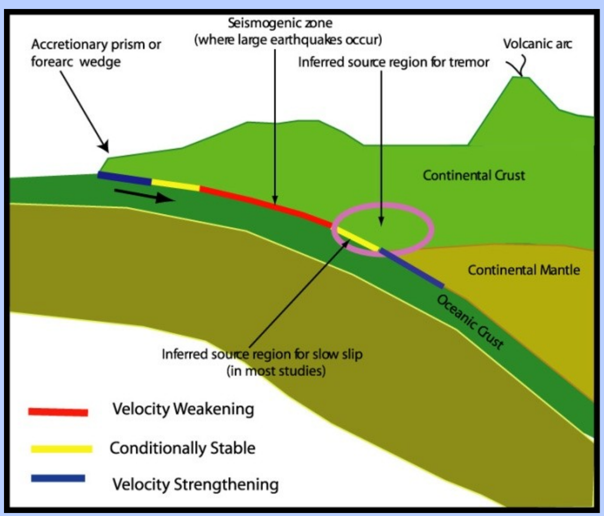


Thatcher et al., Science, 2001

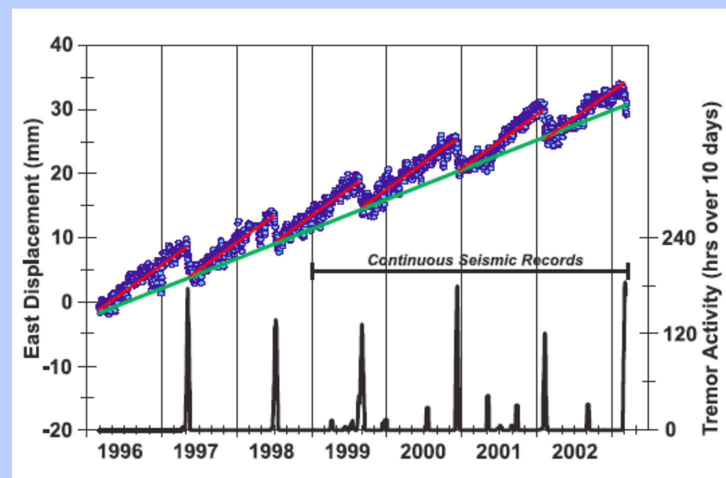
Non-volcanic tremors (NVT):
Seismically detected



Kao et al., 2006



Schwartz and Rokosky, 2007



Rogers et Dragert, Science, 2003

Locked to aseismic transition

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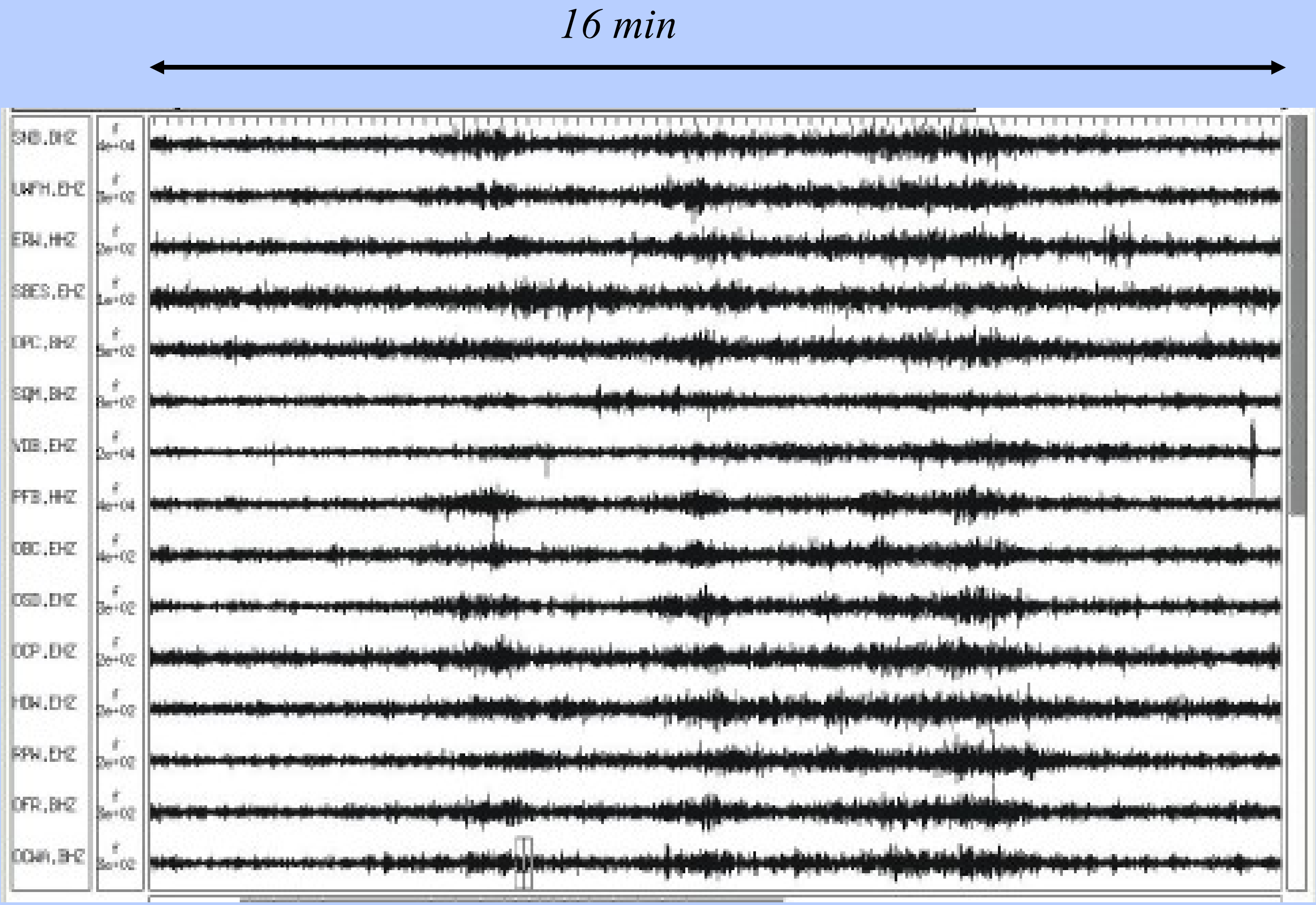

www.pnsn.org

Cascadian NVT recorded onland

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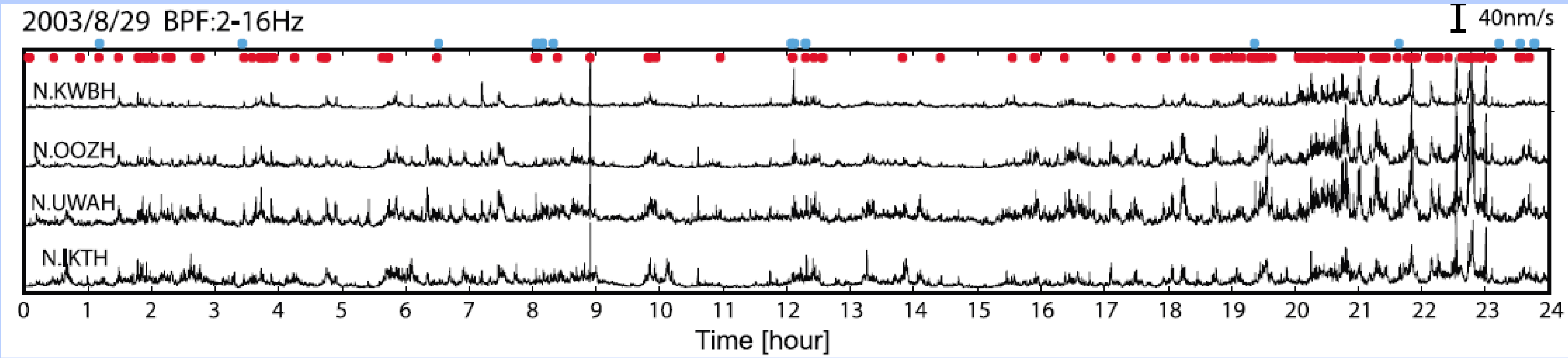
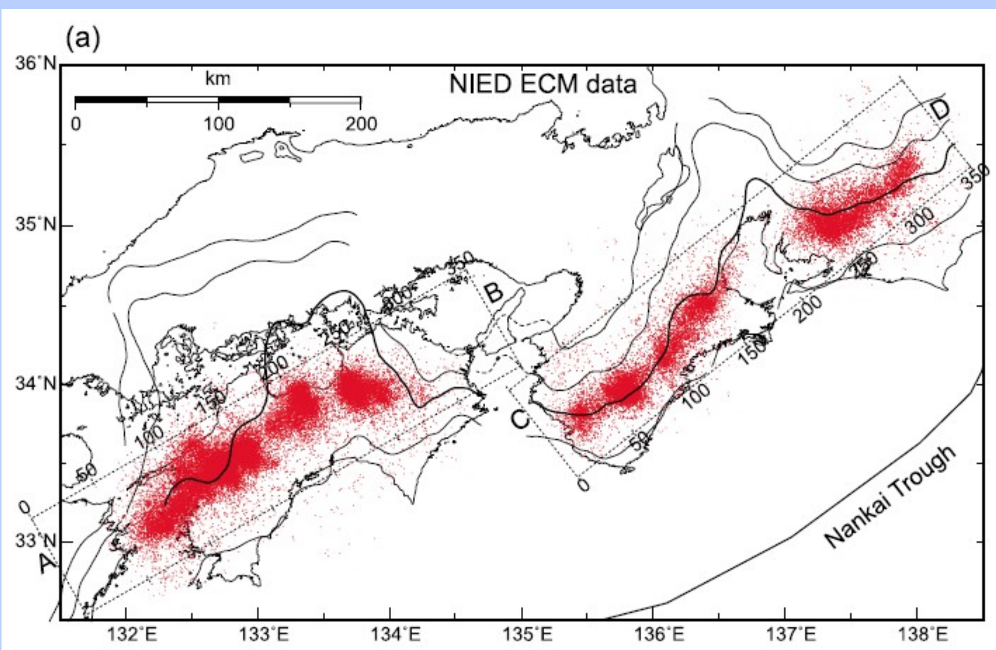
Such kind tremors have been interpreted as non-volcanic tremors.

In some cases is possible to locate their origin





Obara et al , JGR, 2010

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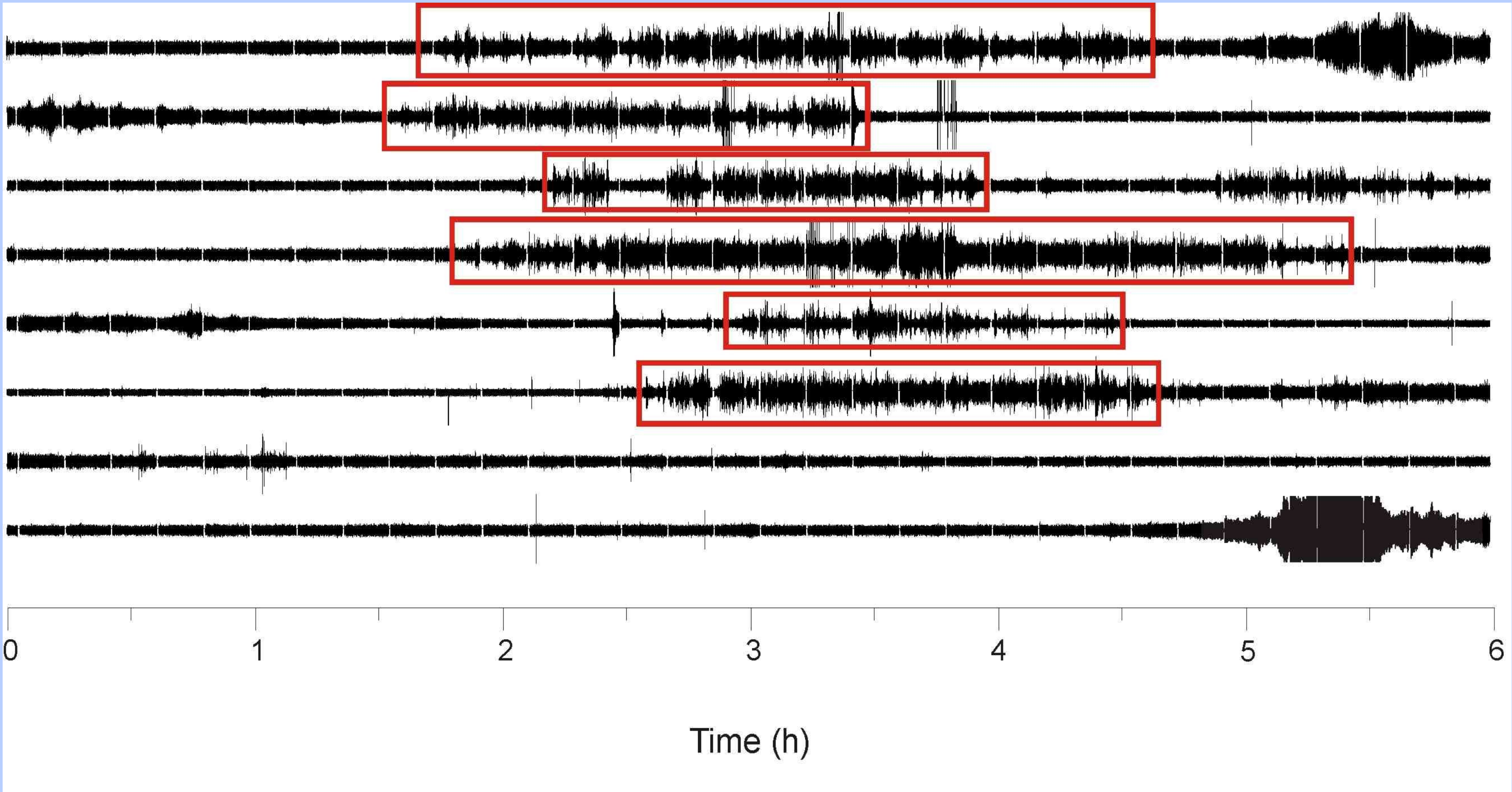
Similar tremors are also recorded offshore,
but other origins are possible...……



Galicia Bank

- Not always correlated within OBS
- Not possible to infer a consistent source position
- Not recorded at hydrophones

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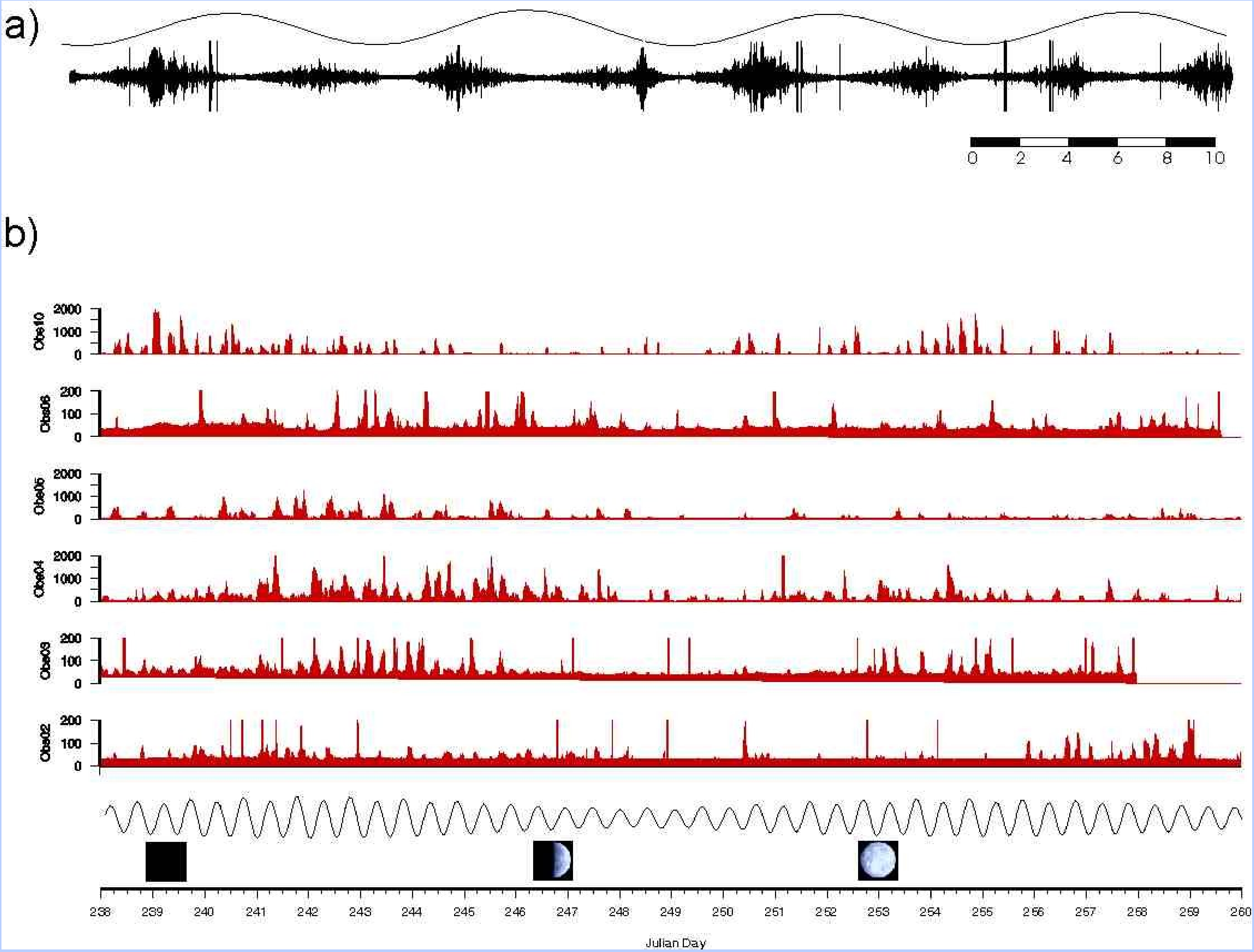


a)
0 2 4 6 8 10
b)
Obs10
Obs06
Obs05
Obs04
Obs03
Obs02
2000 1000 0
200 100 0
238 239 240 241 242 243 244 245 246 247 248 249 250 251 252 253 254 255 256 257 258 259 260
Julian Day

Synthetic seismograms (3 comp) generated by crack excitation at different stations along profiles 1, 2, and 3 for a crack buried at 0.5 km (Chouet, JGR, 1988)

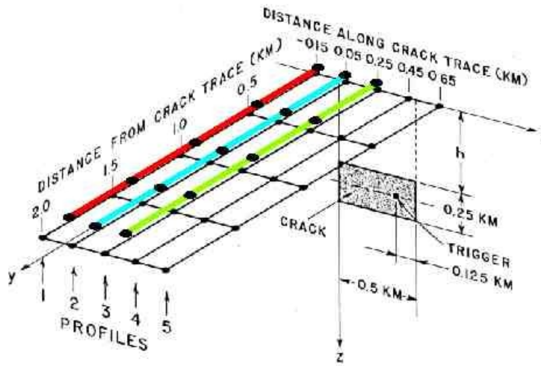
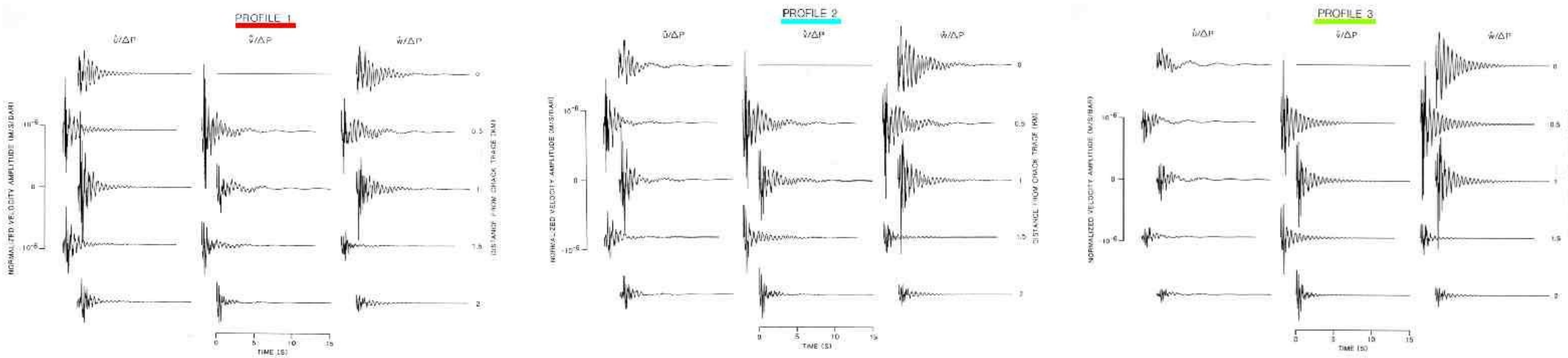
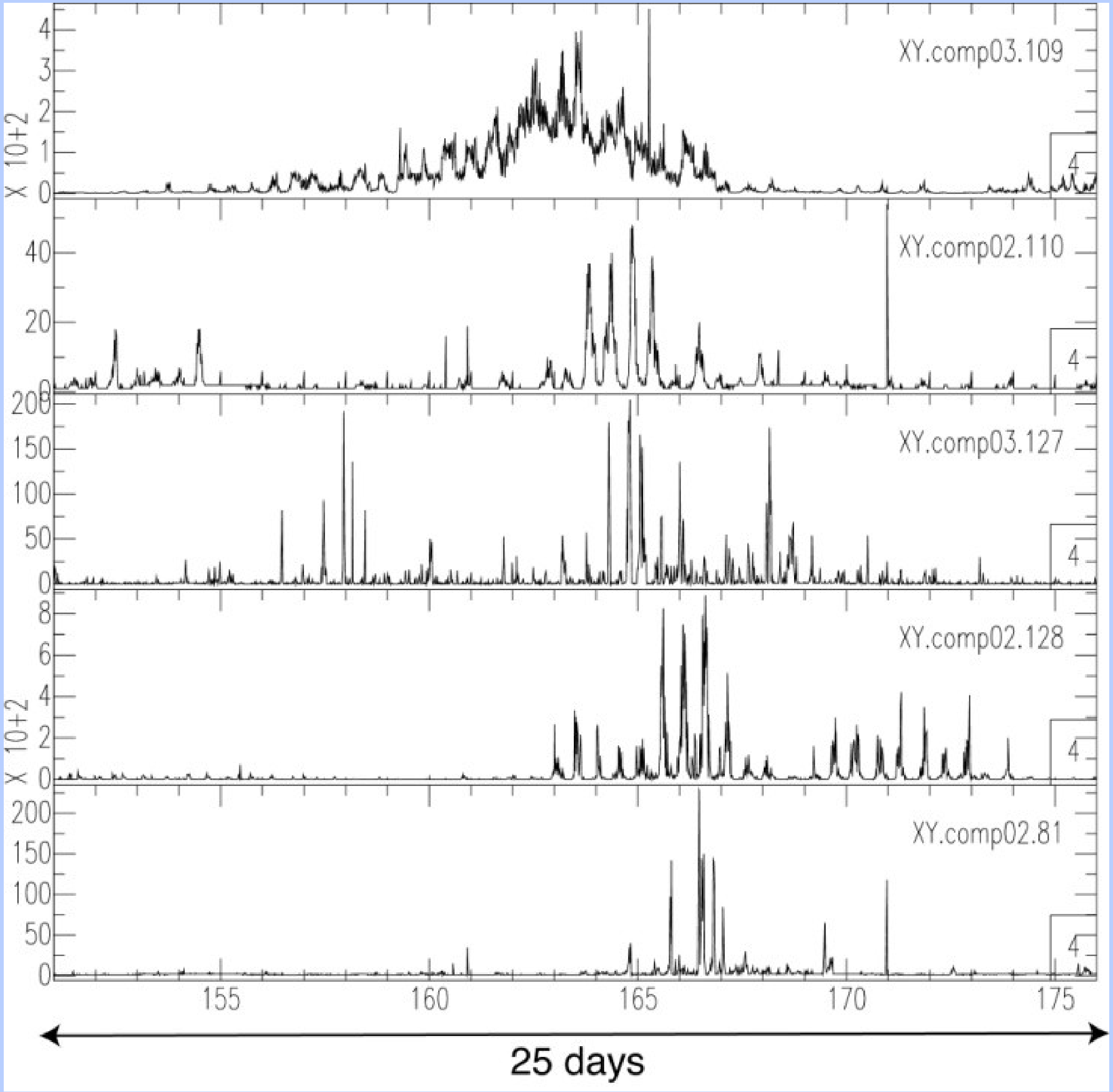


Fig. 18. Configuration of the source, medium, and receivers used in the computation of the ground motion generated by the crack excitation. The source is represented by the stippled rectangle set in the vertical plane $y = 0$ at a depth h. The source dimensions are 0.25 by 0.5 km, and the pressure transient triggering the crack excitation is applied over an area $\Delta S = 312.5$ m^2 ($\Delta W = 25$ m, $\Delta L = 12.5$ m) located on the main axis of the crack at a distance $l = 0.125$ km from the crack edge. The fluid is inviscid and the crack has the stiffness $C = 100$.



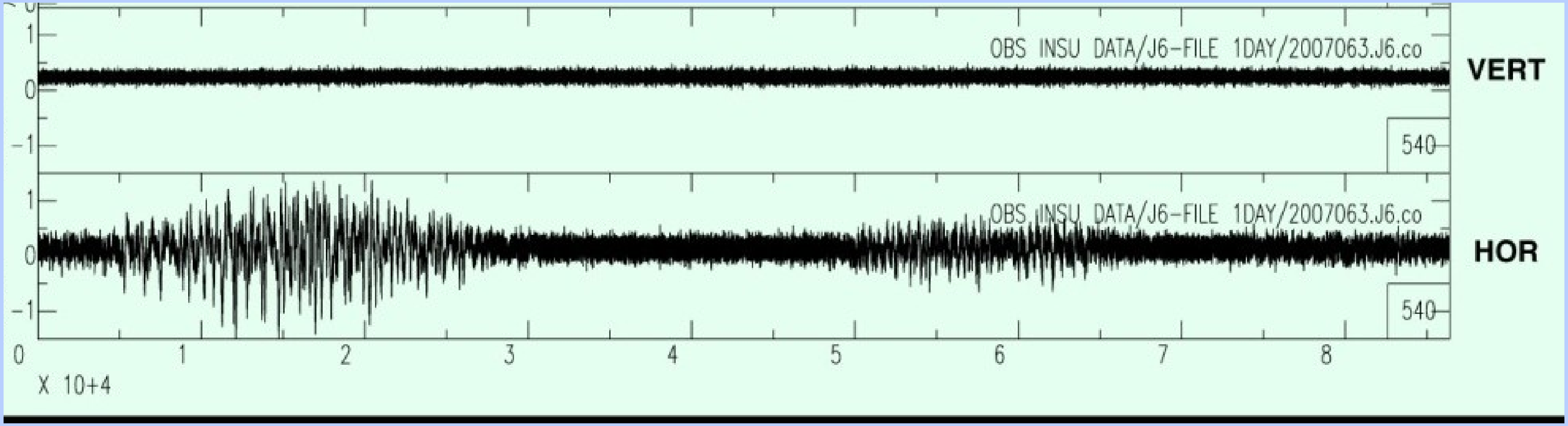
•Resonance of fluid-filled cracks

The model of Chouet (1988), that imply the presence of fluid-filled cracks at the vicinity of the receivers, can explain our observations. According to this model, **harmonic tremor is viewed as the oscillations in response to a sustained excitation (Kumagai and Chouet, 1999).**



Lesser Antilles

:



Trillium 240s (120º, Galperin component mounting), only show tide-modulated tremors on horizontal comp.

record of laminar fluid flow, related to ocean loading or tidal currents → **Near-bottom currents**

Transient Events

6 – 25 Hz

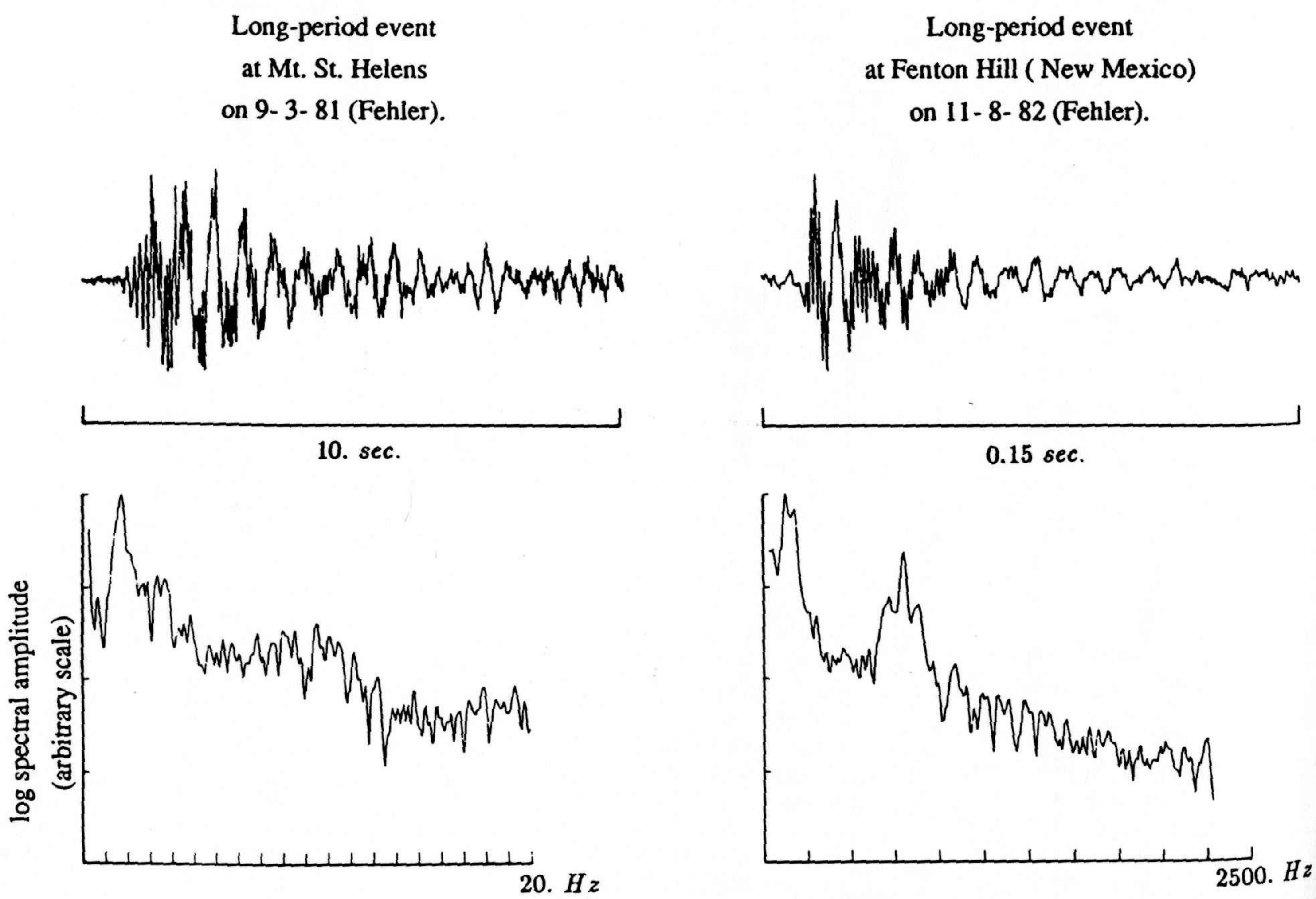
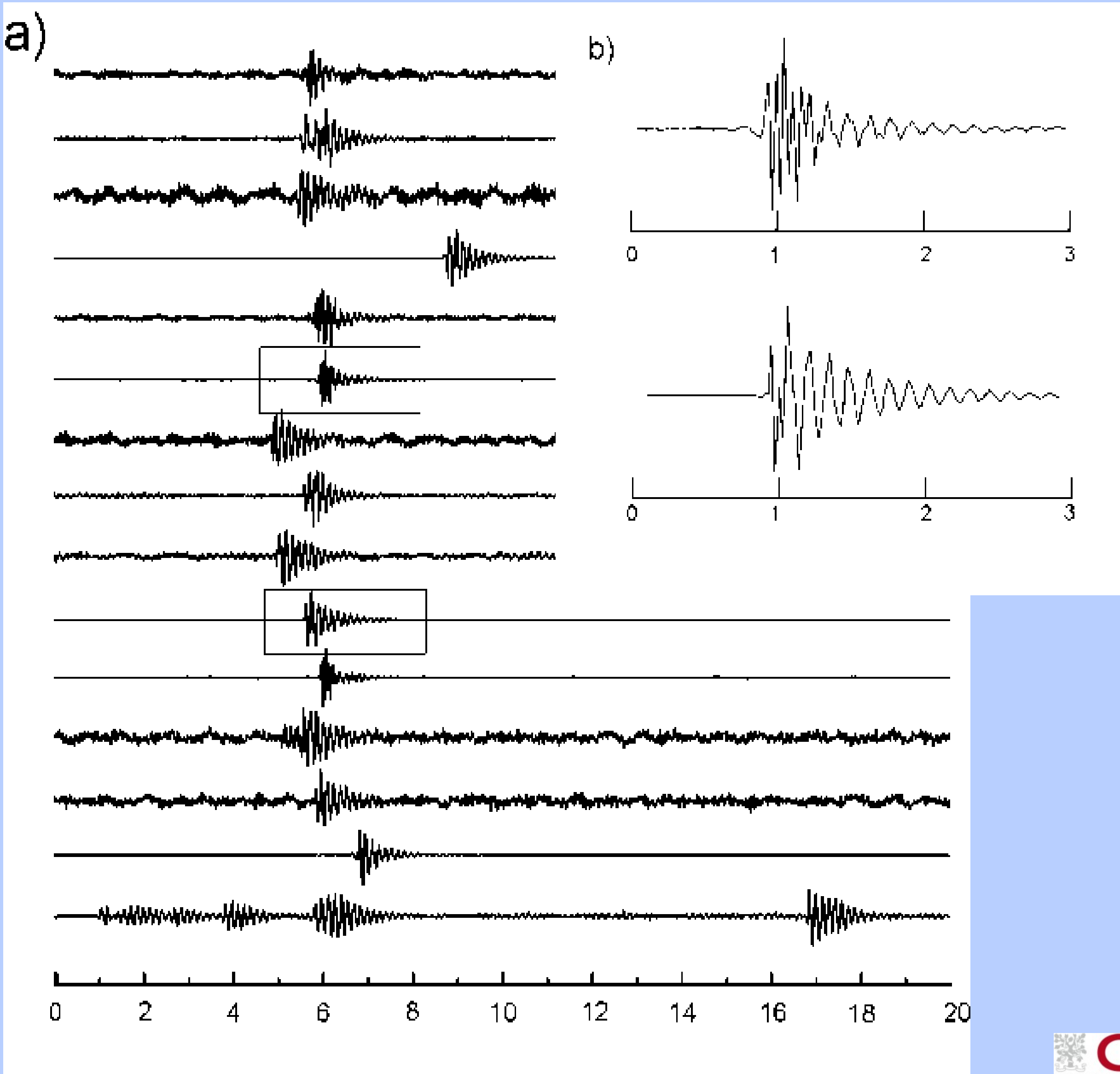


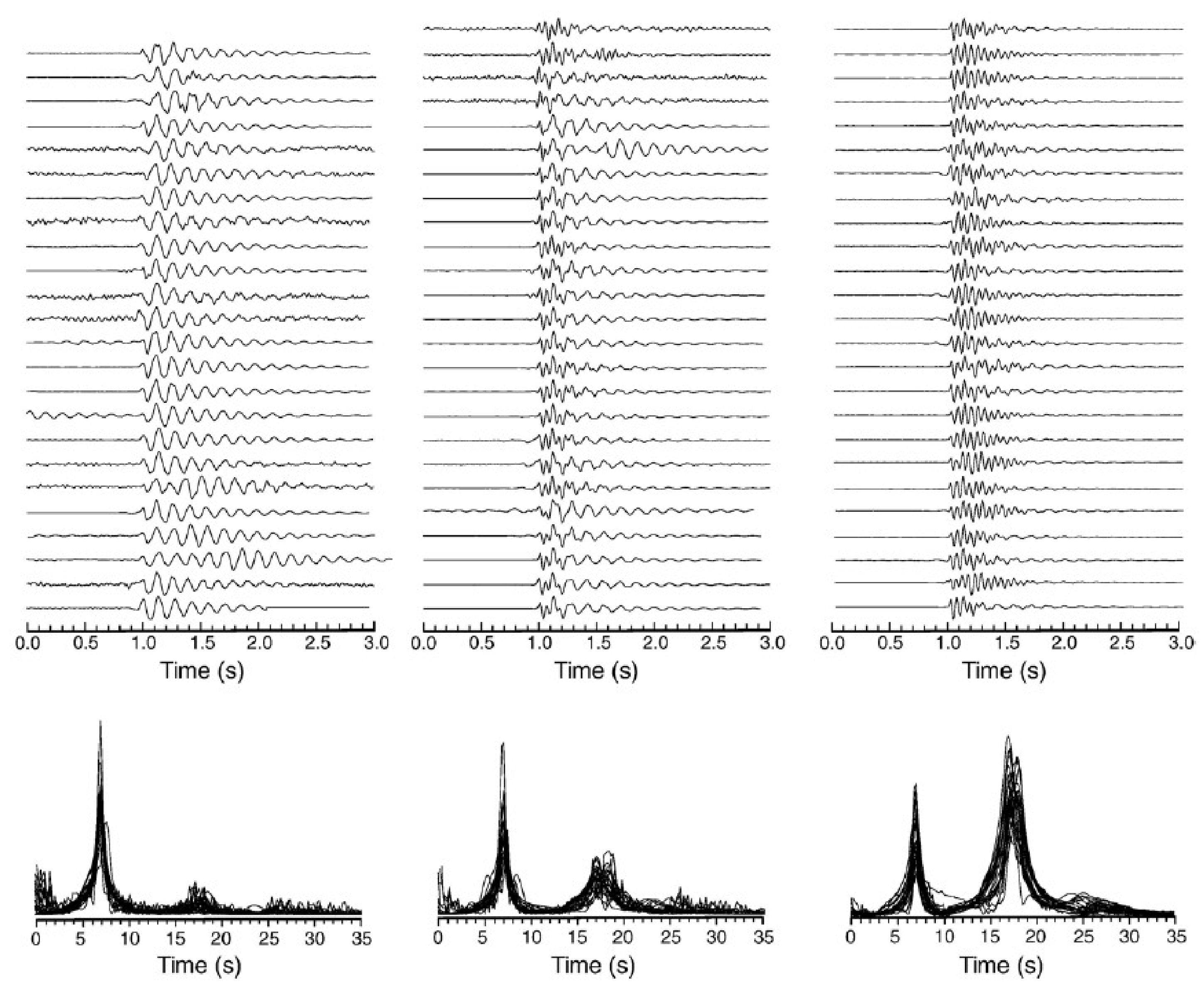
Fig. 1. Examples of long-period events observed at Mount St. Helens, Washington, and at Fenton Hill, New Mexico. Seismograms represent ground velocity as recorded by the geophone. The time scales differ by a factor of almost 100.

Ferrazzini et al., JGR, 1990

- Examples of detected short-duration events

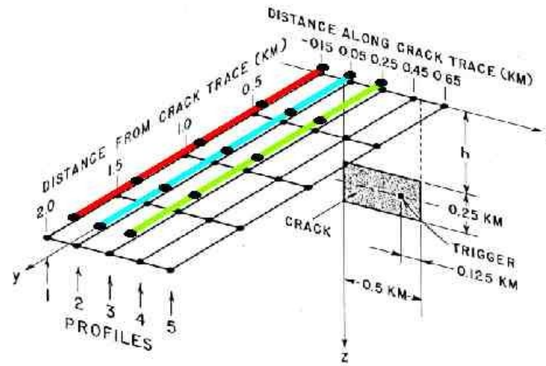


- Example of families association of the short-duration events



Diaz et al, Tectonophys, 1997

Synthetic seismograms (3 comp) generated by crack excitation at different stations along profiles 1, 2, and 3 for a crack buried at 0.5 km (Chouet, JGR, 1988)



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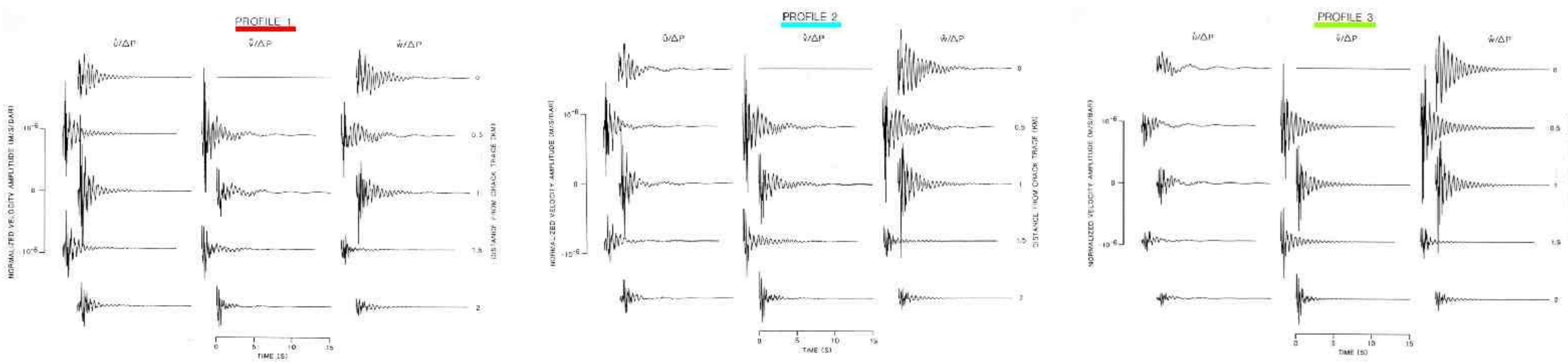

- Resonance of fluid-filled cracks

  The model of Chouet (1988), that imply the presence of fluid-filled cracks at the vicinity of the receivers, can explain our observations. According to this model, the SDE are interpreted as oscillations of a fluid-filled resonator triggered by a time-localized excitation.

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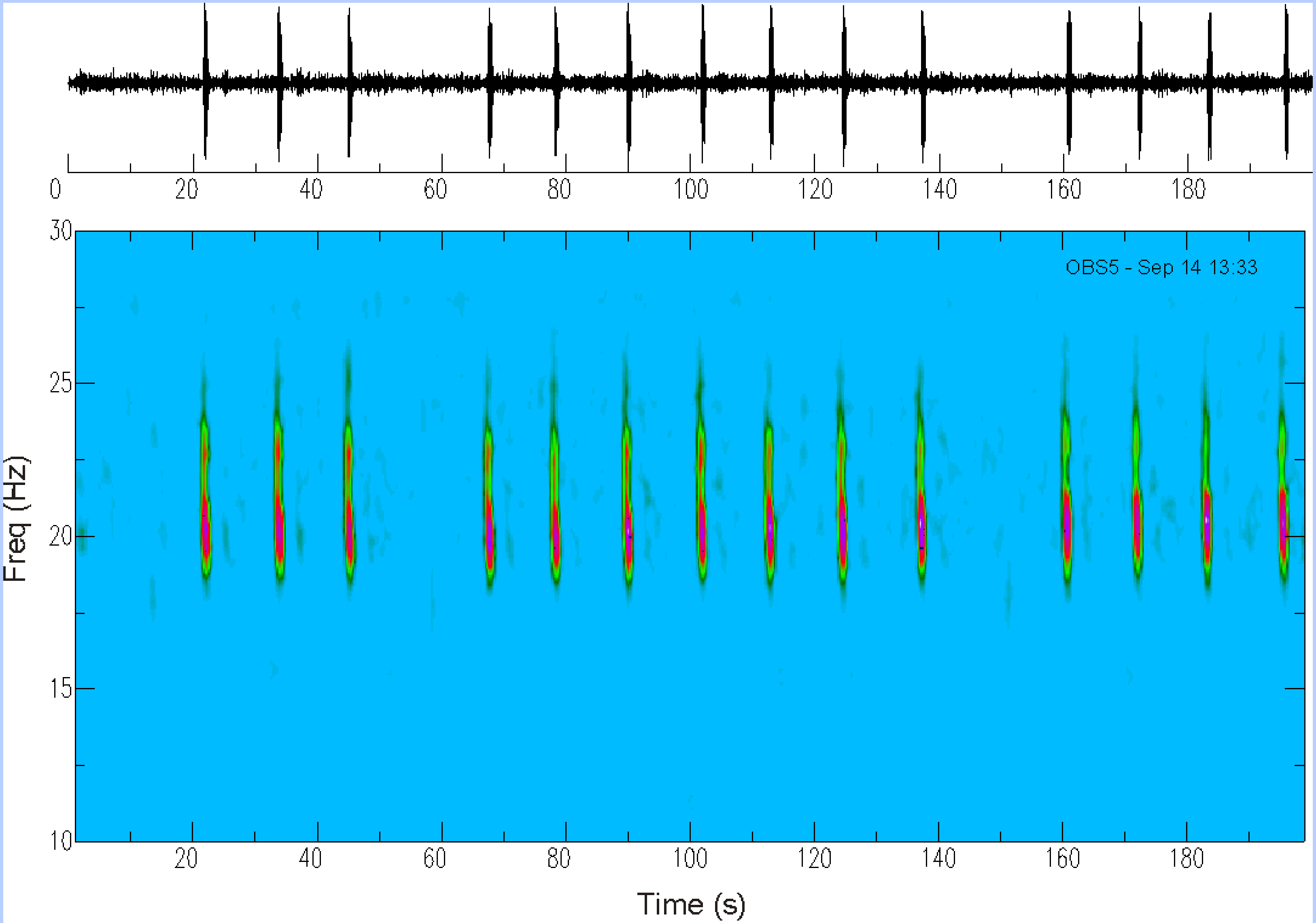
Finback whales vocalizations

15 – 25 Hz



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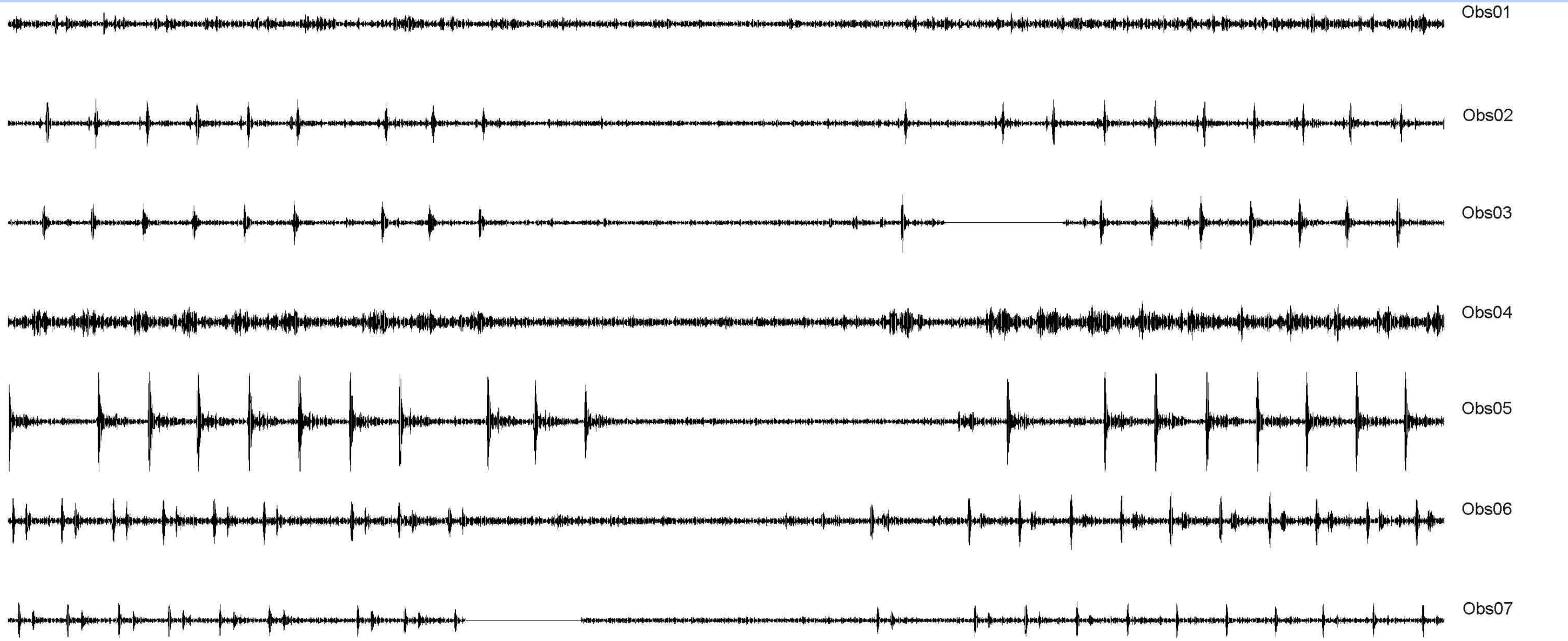

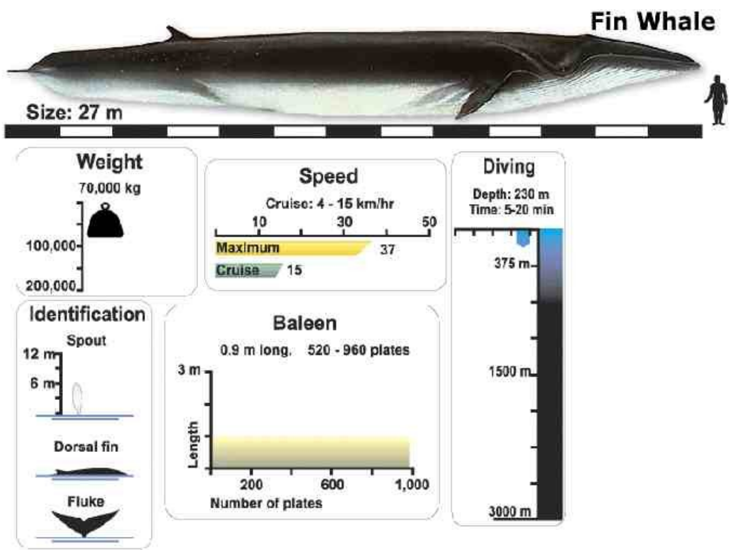

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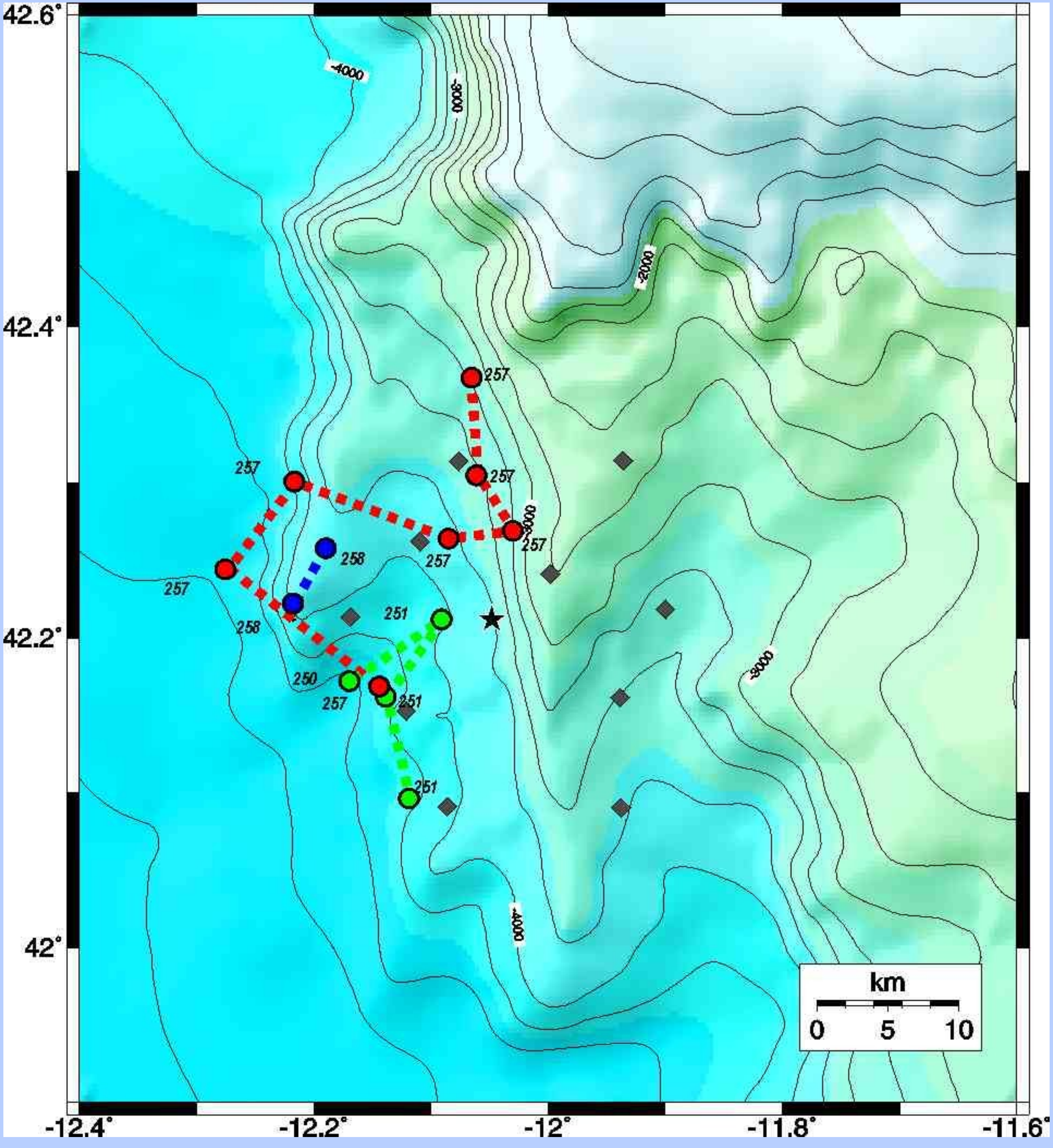

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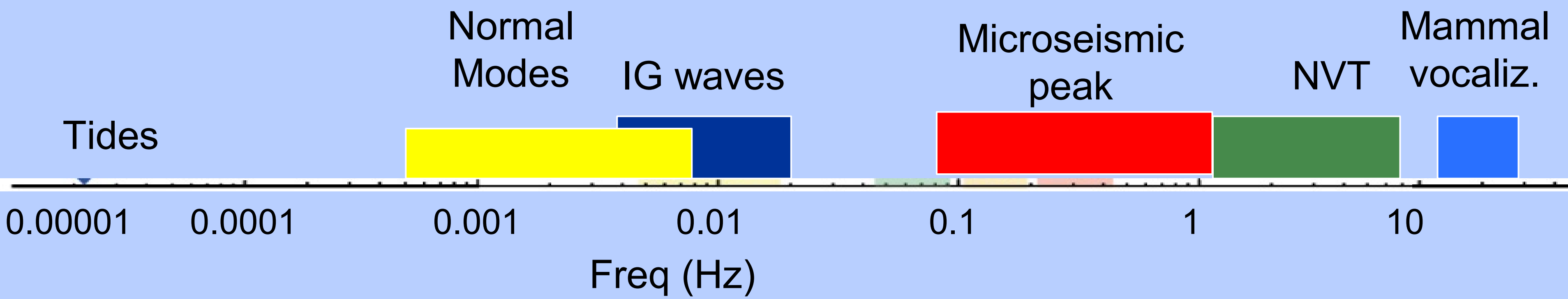

Use of long-term, continuously recording broad-band OBS allows to investigate seismic signals extending up to 6 orders of magnitude in the frequency range