EXTRACURRICULAR GEOPHYSICS

When Seismometers and Other Instruments Record What They Were NOT Designed to Pick up

Emile A. OKAL

Department of Earth & Planetary Sciences
Northwestern University
Evanston, IL 60208, USA

emile@earth.northwestern.edu

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The occurrence of exceptional events, such as the 2004 Sumatra earthquake, occasionally gives rise to the recording of physical phenomena by instruments not designed for that purpose.

For example, a seismometer may record an air wave, a hydrophone may record a tsunami...

Such recordings by *"unprepared" or "incompetent"* **instruments often times illustrates a physical coupling between the medium of the phenomenon and that where the instrument is supposed to operate.**

Such coupling being generally weak, requires a very large event (Sumatra, Maule...) to be detectable.

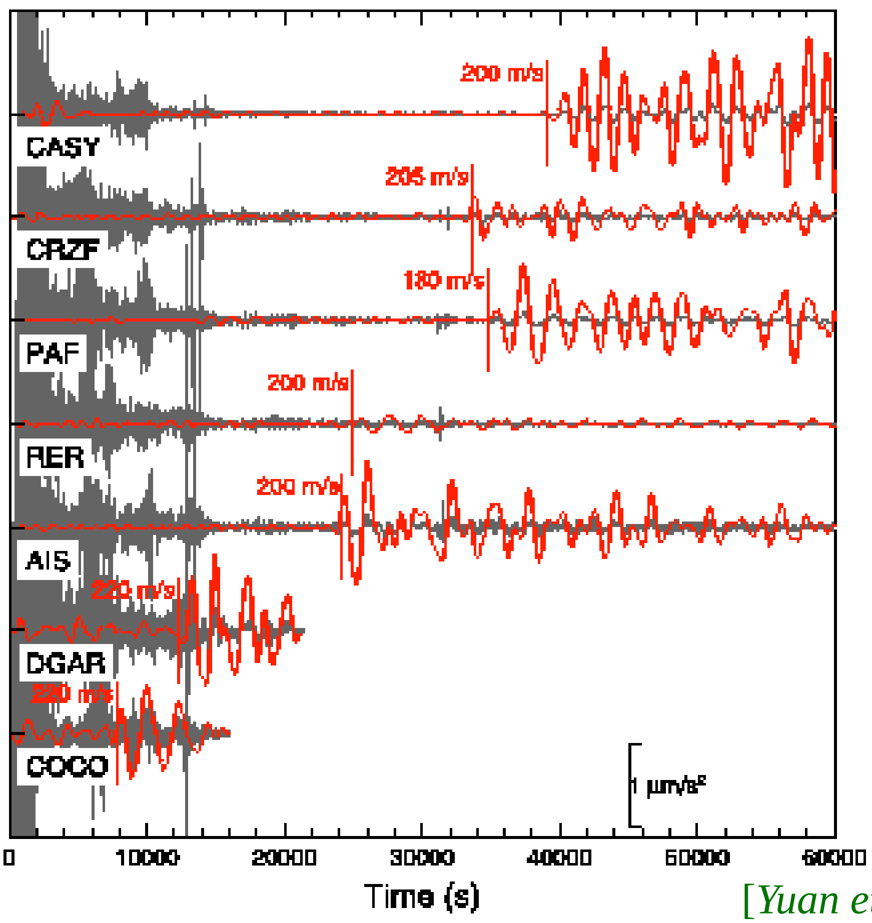
However, such instances of coupling are precious, since they shed light on some unsuspected properties of the physical waves and media involved.

SEISMOMETERS DETECT TSUNAMIS

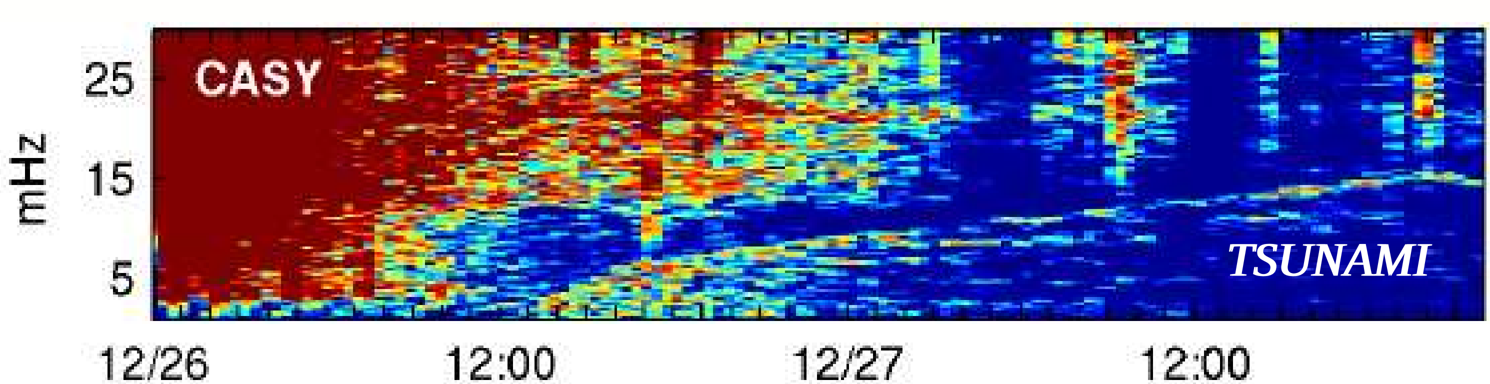
(The Seismic "DART" ?)

TSUNAMI RECORDED ON SEISMOMETERS

- Horizontal long-period seismometers (GEOSCOPE, IRIS...) record ultra-long period oscillations following arrival of 2004 tsunami at nearby shores [*R. Kind*, 2005].
- Energy is mostly between 800 and 3000 seconds
- Amplitude of equivalent displacement is **centimetric**



[*Yuan et al.*, 2005]



[*Hanson and Bowman*, 2005]

TSUNAMI RECORDED ON SEISMOMETERS (ctd.)

Enhanced Study [*E.A. Okal*, 2005−06].

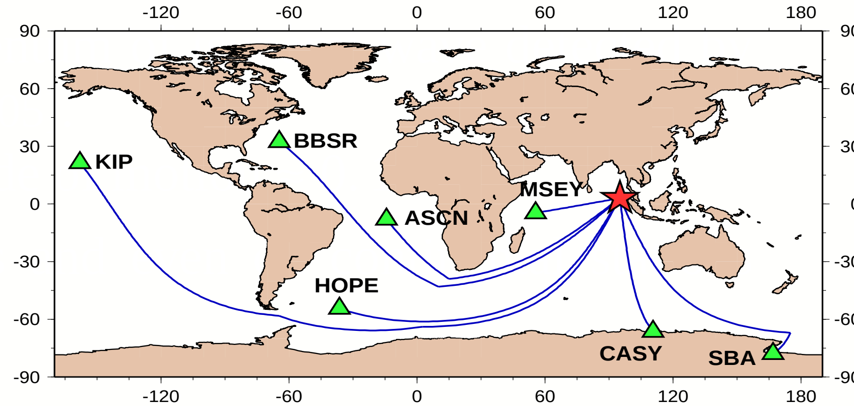
- *RECORDED* **WORLDWIDE** (On Oceanic shores)
- ***HIGHER FREQUENCIES*** (up to 0.01 Hz) *PRESENT* (in regional field)
- Tsunami detectable during **SMALLER EVENTS**
- *CAN BE* **QUANTIFIED** (Variation of M_{TSU})

TSUNAMI RECORDED ON SEISMOMETERS (ctd.)

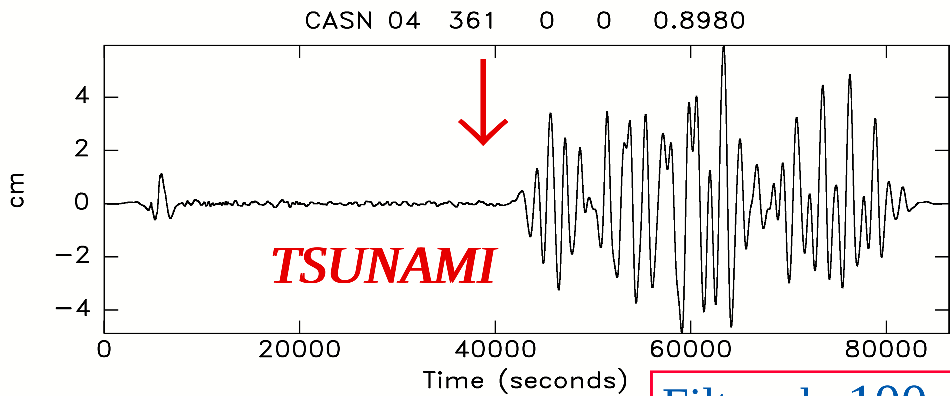
- Recording by shoreline stations is

  WORLDWIDE

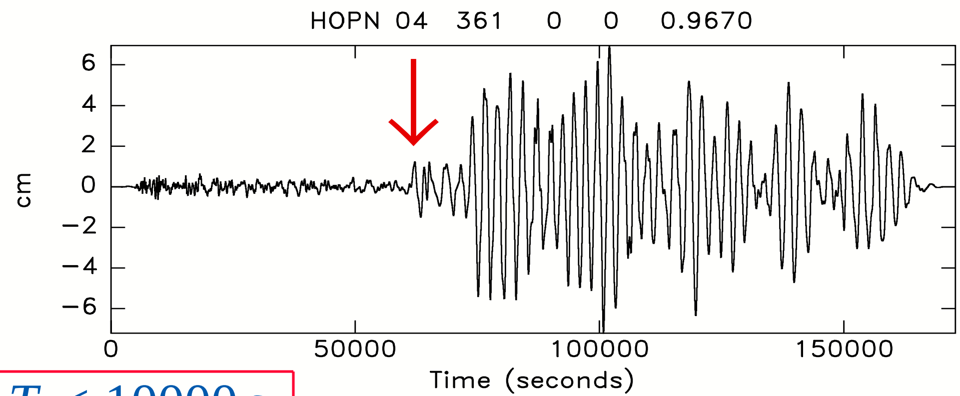
  including in regions requiring strong refraction around conti-nents (Bermuda, Scott Base).



Casey, Antarctica, 8300 km

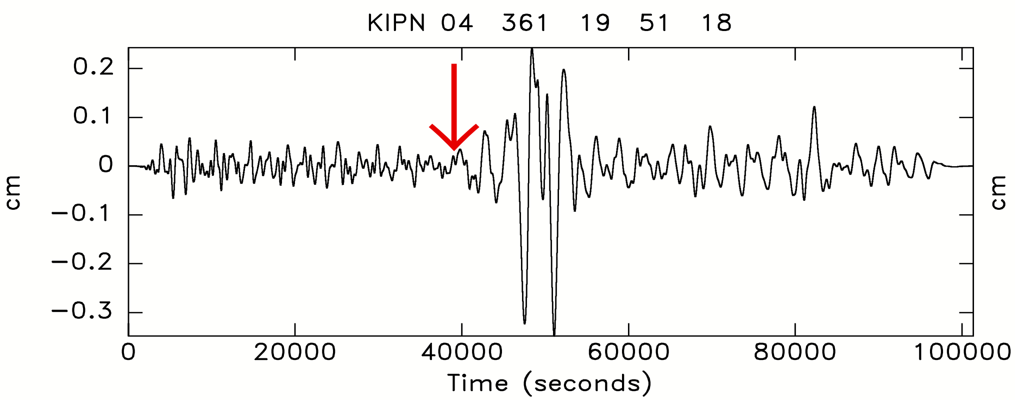


Hope, South Georgia, 13100 km

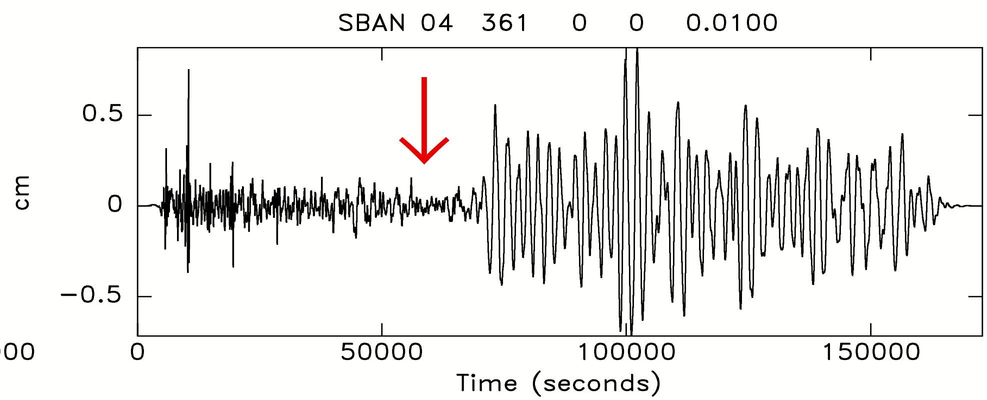


Filtered 100 $< T <$ 10000 s.

Kipapa, Hawaii, 27,000 km

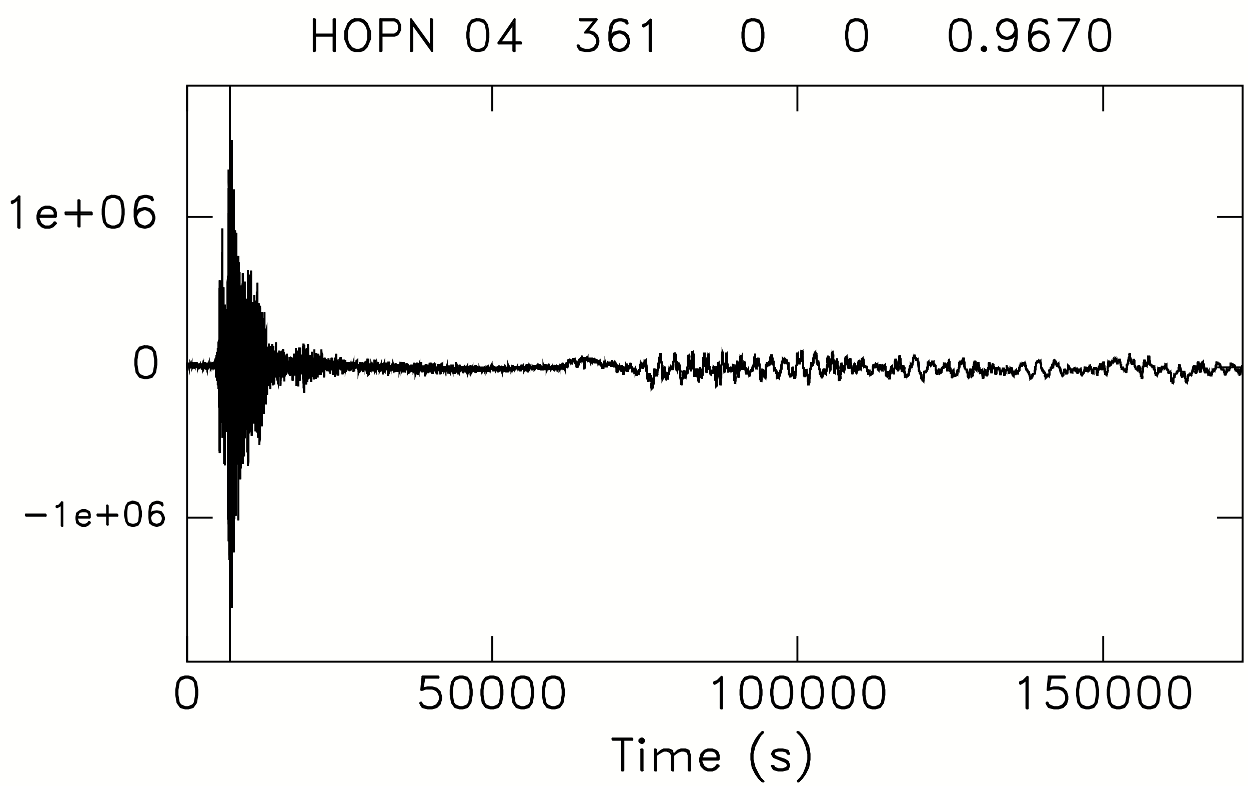


Scott Base, Antarctica, 10400+ km



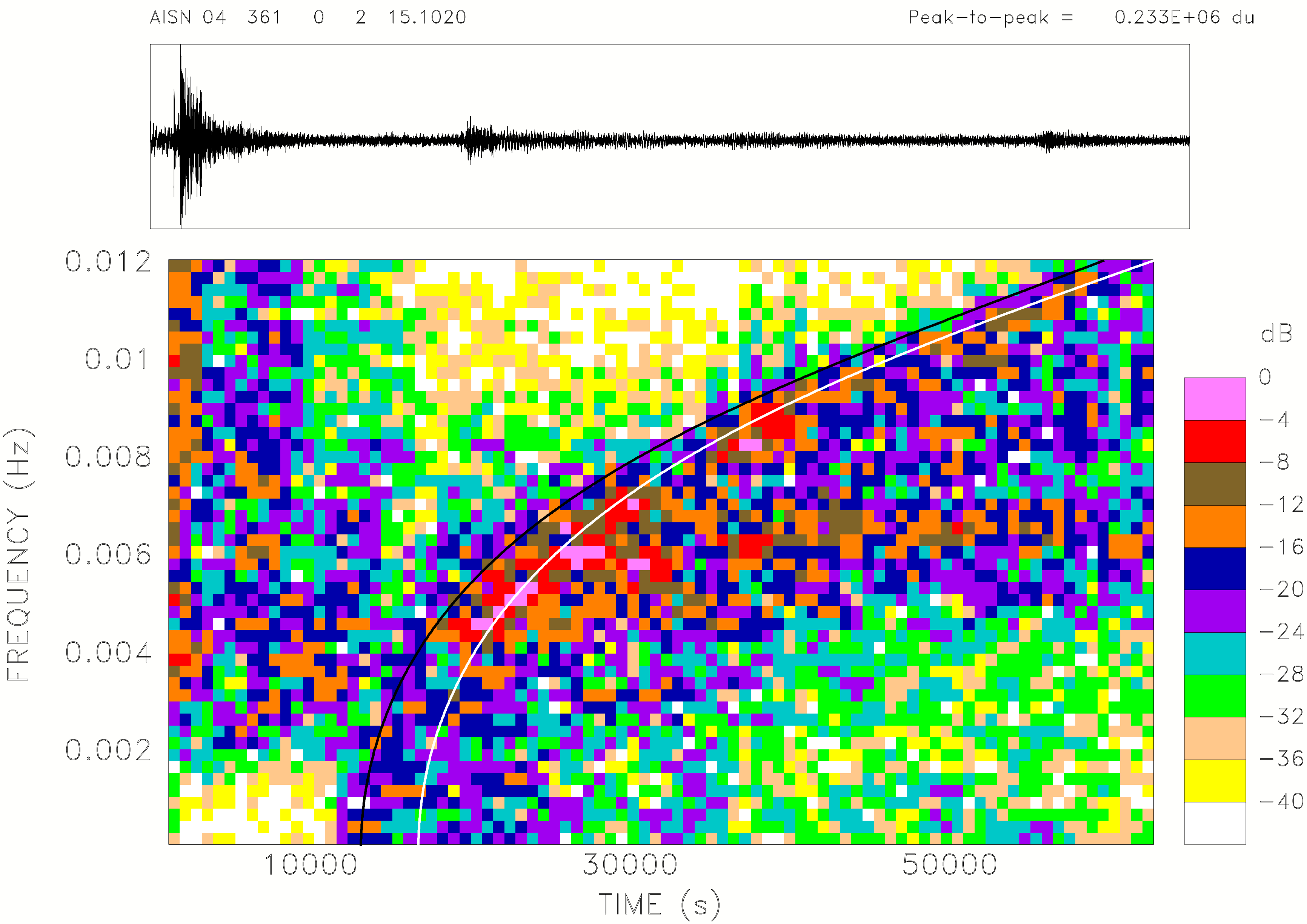
- *On some of the best records, (e.g., HOPE, South Georgia), the tsunami is actually visible* ***on the raw seismogram!!***

[But who "reads" seismograms in this digital age, let alone that of HOPE, South Georgia...]



Dispersed energy resolved down to $T = 80$ s.

Ile Amsterdam, 26 Dec. 2004



NOTE STRONG HIGH-FREQUENCY TSUNAMI COMPONENTS

QUANTIFYING THE SEISMIC RECORD AT CASY

or...

Introducing

THE ON–SHORE O.B.S.

QUANTIFYING the SEISMIC RECORD at CASY

- Assume that seismic record (*e.g.*, at CASY) reflects response of seismometer to the *deformation of the ocean bottom.*

FORGET THE ISLAND (or continent) !

- Use *Gilbert*'s [1980] combination of displacement, tilt and gravity;

Apparent Horizontal Acceleration (*Gilbert*'s [1980] Notation):

$$AV = \omega^2 V - r^{-1} L (g U + \Phi)$$

or (*Saito*'s [1967] notation):

$$y_3^{APP} = y_3 - \frac{1}{r \omega^2} \cdot (g y_1 - y_5)$$

- Use *Ward*'s [1980] normal mode formalism;

Evaluate Gilbert response on solid side of ocean floor, and derive equivalent spectral amplitude of surface displacement $y_1(\omega) = \eta(\omega)$.

- Use *Okal and Titov*'s [2005] Tsunami Magnitude, inspired from *Okal and Talandier*'s [1989] M_m ;

- Apply to CASY record at maximum spectral energy ($S(\omega)$ = 4000 cm*s at T = 800 s).

→ Find $\mathbf{M_0 = 1.7 \times 10^{30}}$ **dyn – cm.**

Acceptable, given the extreme nature of the approximations.

→ Suggests that the signal is just the expression of the horizontal deformation of the ocean floor, and that

CASY functions in a sense like an OBS !!

QUANTIFICATION of SEISMIC TSUNAMI RECORDS

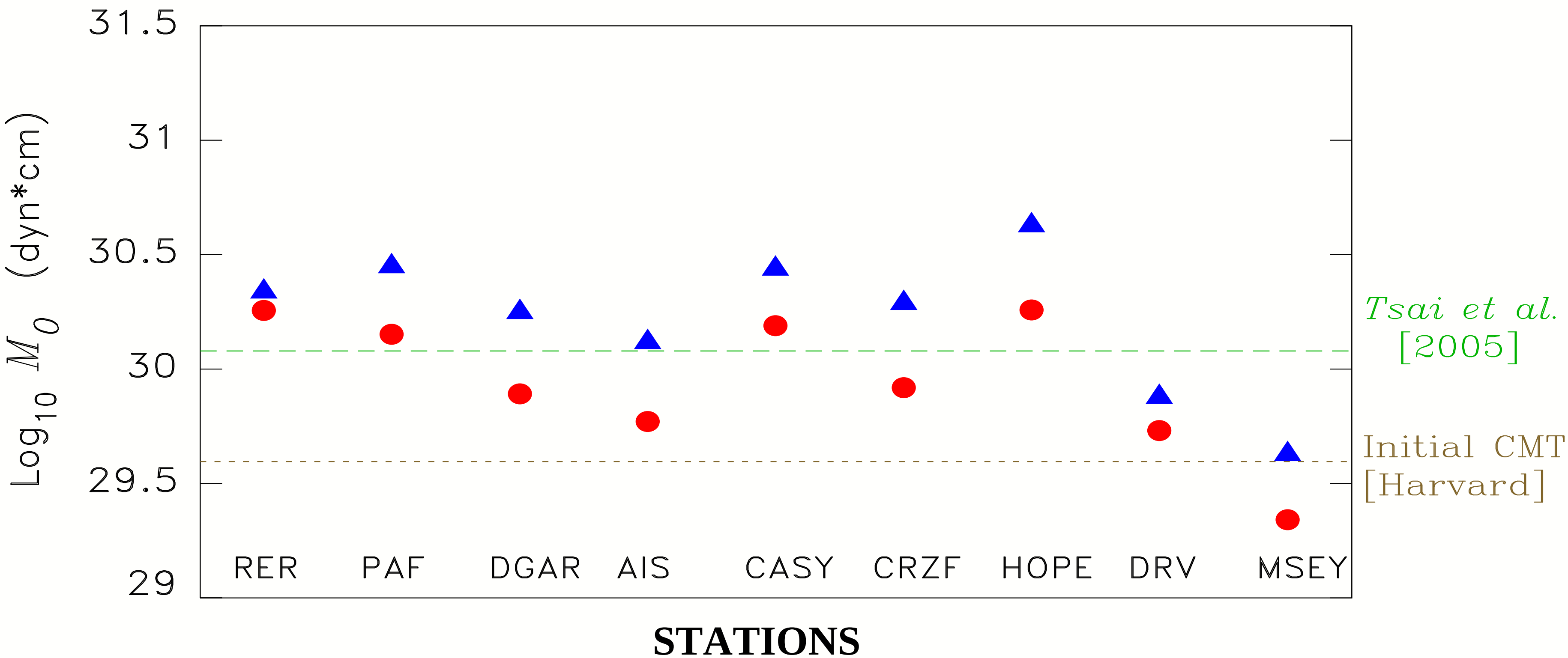
- Apply technique to dataset of 10 stations with direct great circle paths
- Use either Full Source computation (**Red Symbols**)

$$\overline{M_0} = 1.6 \times 10^{30} \text{ dyn} - \text{cm}$$

or M_{TSU} magnitude approach (**Blue Symbols**)

$$\overline{M_0} = 2.1 \times 10^{30} \text{ dyn} - \text{cm}$$

In good agreement with *Nettles et al.* [2005] and *Stein and Okal* [2005] (green dashed line)



NOTE: DRV and MSEY affected by *substantial continental shelves.*

USING AN ISLAND SEISMOMETER AS A "DART" SENSOR?

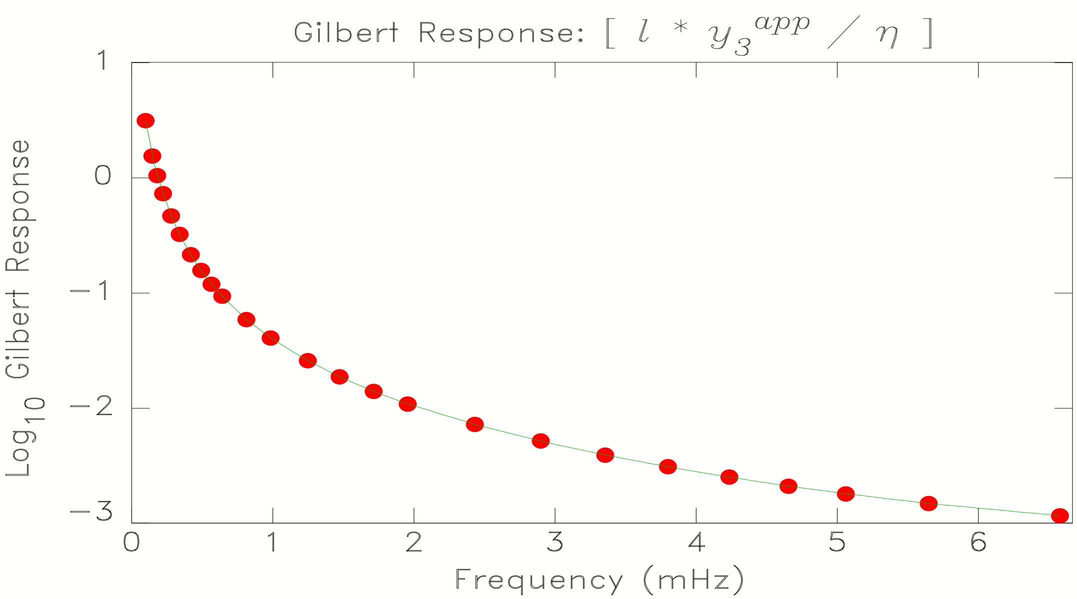
Example: Ile Amsterdam, 26 DEC 2004 (d= 5800 km)

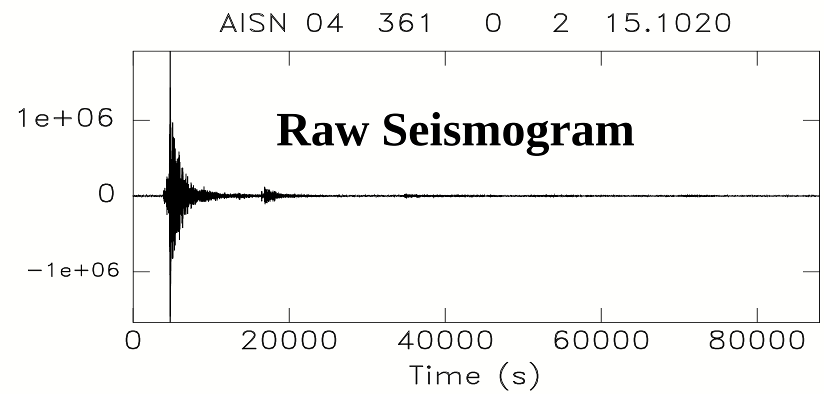
- A horizontal seismometer at a shoreline location can record a tsunami wave.

- Once the instrument is deconvolved, we obtain an apparent horizontal ground motion of the ocean floor

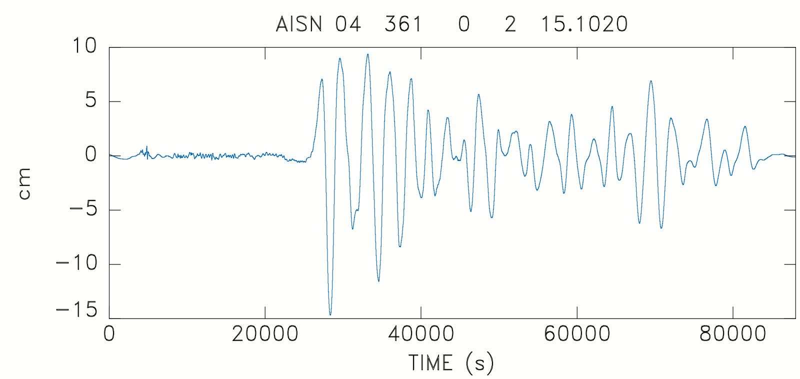
- Further deconvolve the *"**G**ilbert **R**esponse **F**actor"* $[l\, y_3^{app} / \eta]$ and obtain the time series of the surface amplitude of the tsunami.

- The ***G R F*** can be computed from normal modes

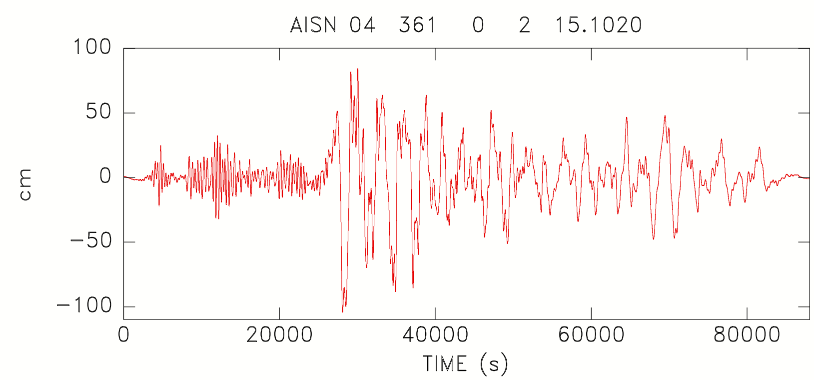




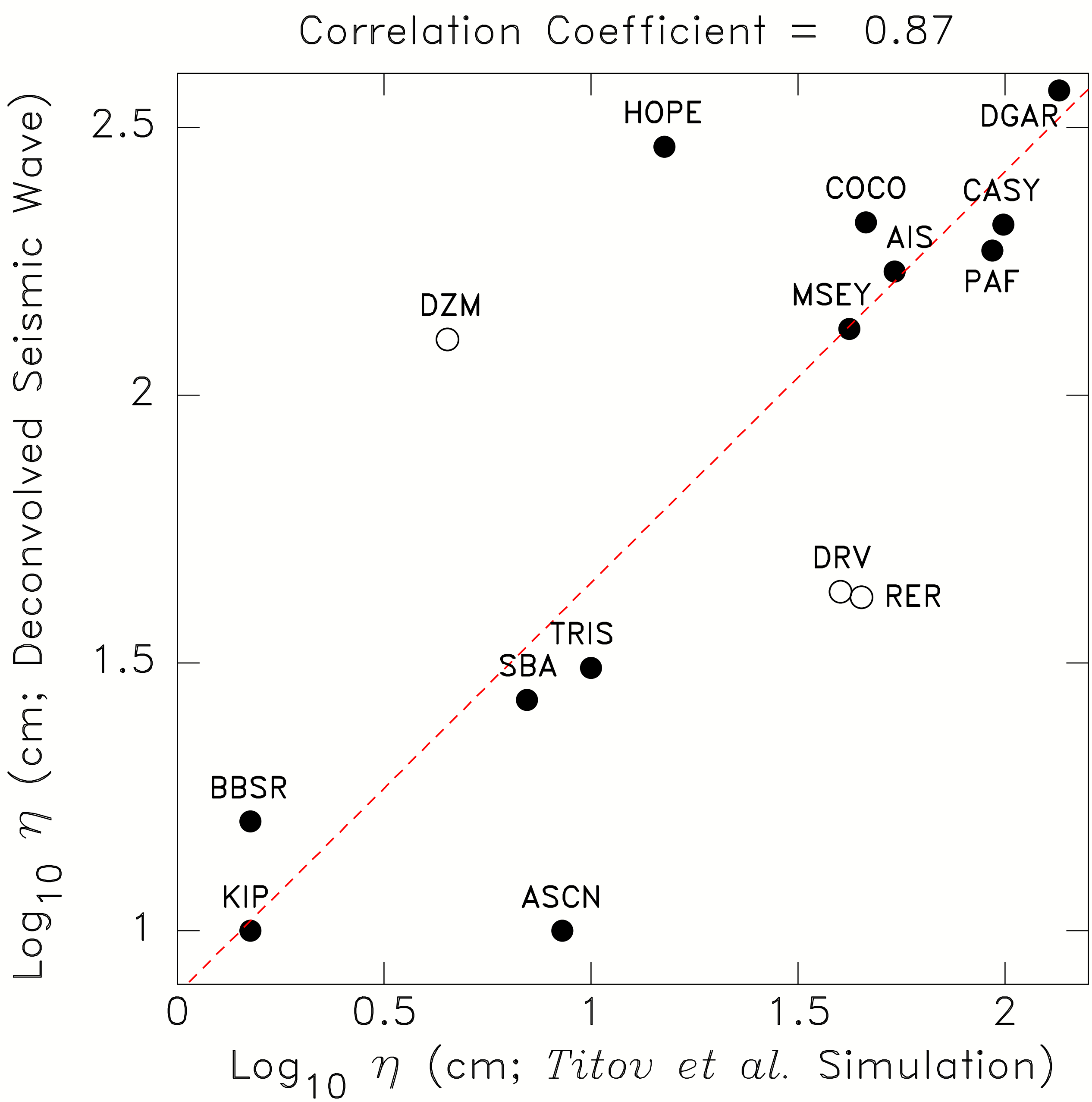
Deconvolve Instrument: **Apparent Ground Motion**



Deconvolve *GRF:* **"Tsunami Record"**



- Indeed, we find a good correlation between tsunami heights deconvolved from seismometers and tsunami amplitudes from the worlwide simulation of *Titov and Arcas* [2005], computed at deep-ocean locations in the neigborhood of the recording seismometers.



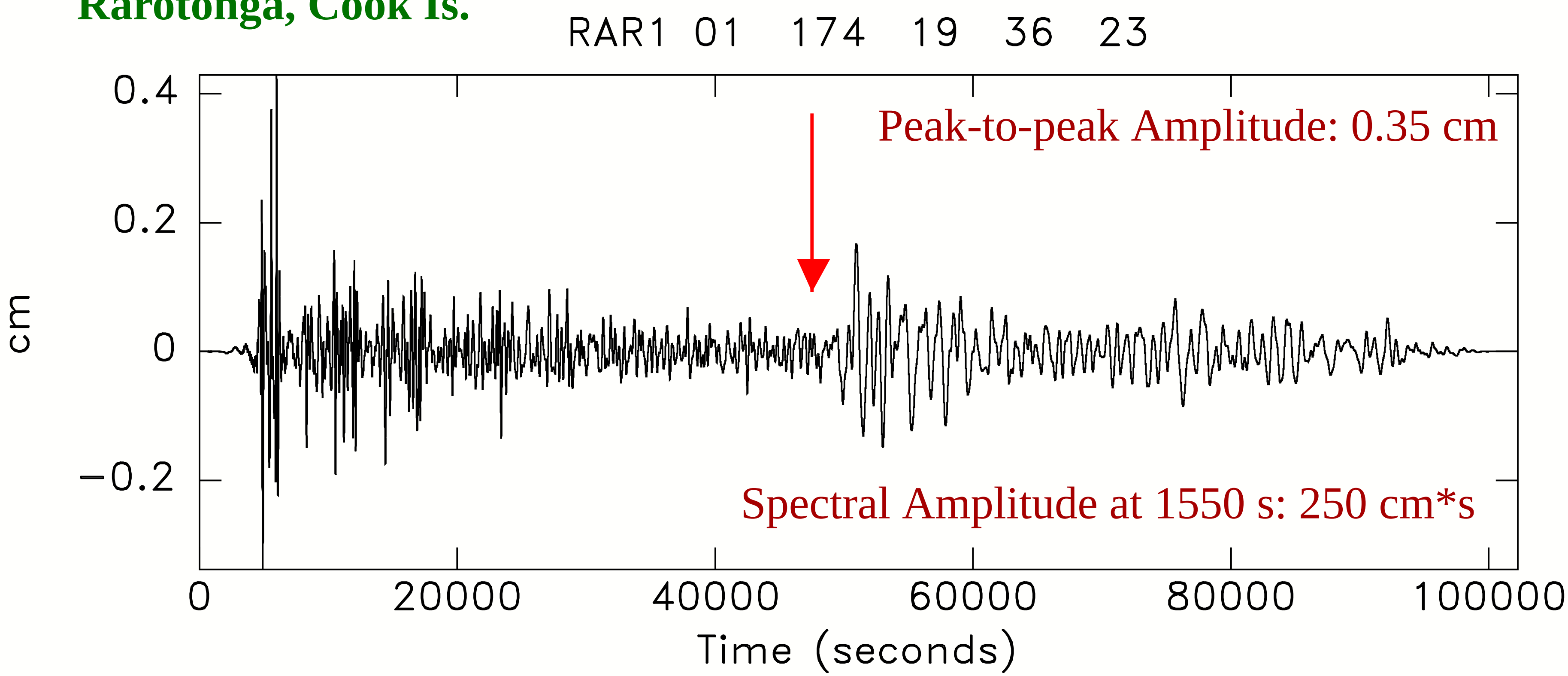
TSUNAMI DETECTED FOLLOWING SMALLER EVENTS

Camaná, Perú, 23 June 2001

Harvard CMT: $M_0 = 4.7 \times 10^{28}$ dyn-cm

FILTERED, Tmax = 10000. s; Tmin = 100. s.

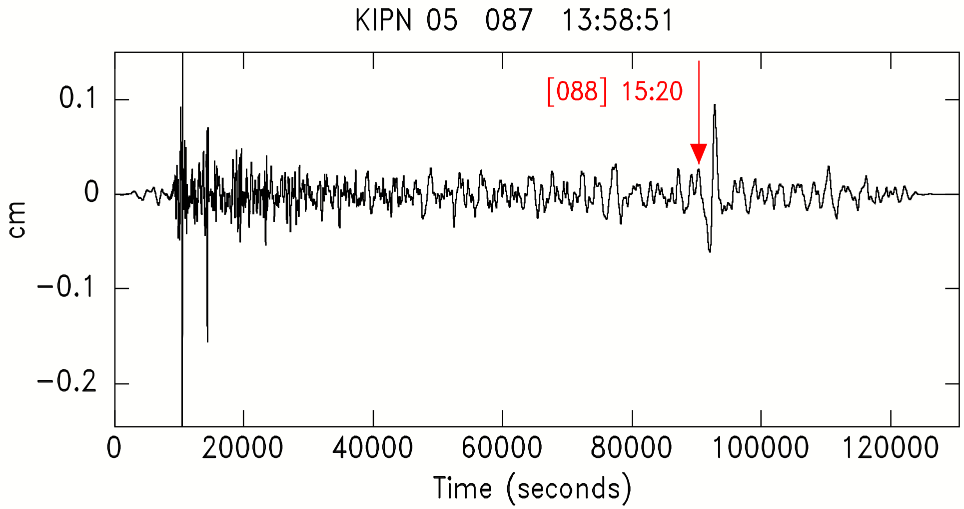
Rarotonga, Cook Is.



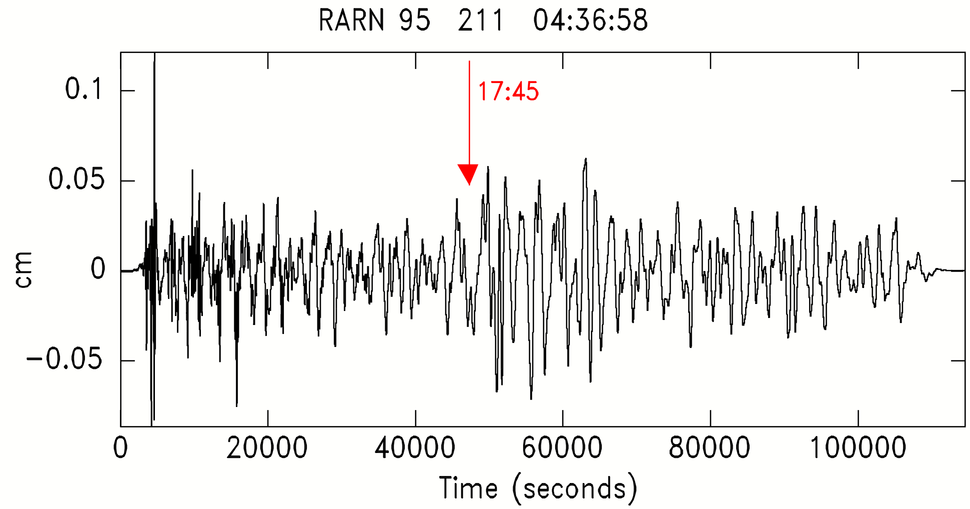
Computed Moment: $M_0 = 4.6 \times 10^{28}$ dyn-cm

Other Examples of Seismic Recording of [smaller] Tsunamis

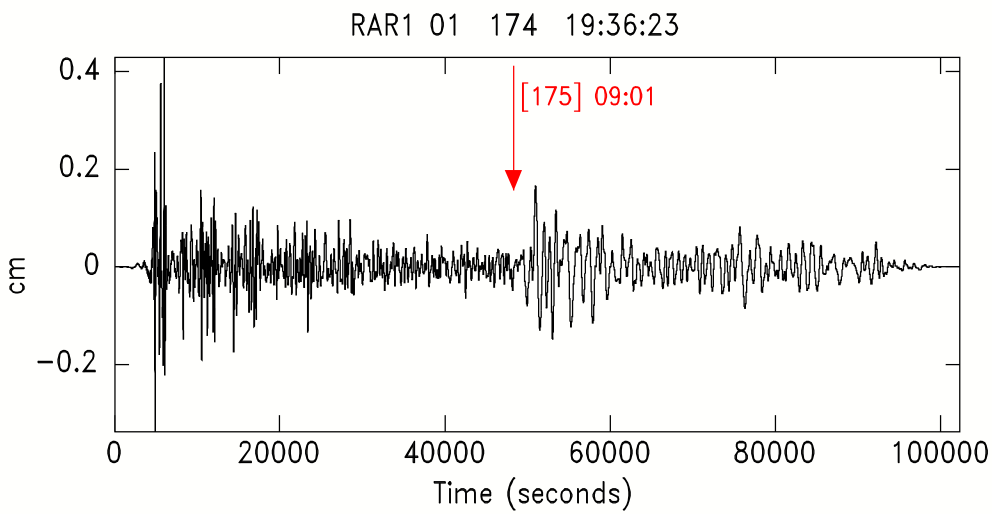
Kipapa, Hawaii, 28 March 2005 [Nias]



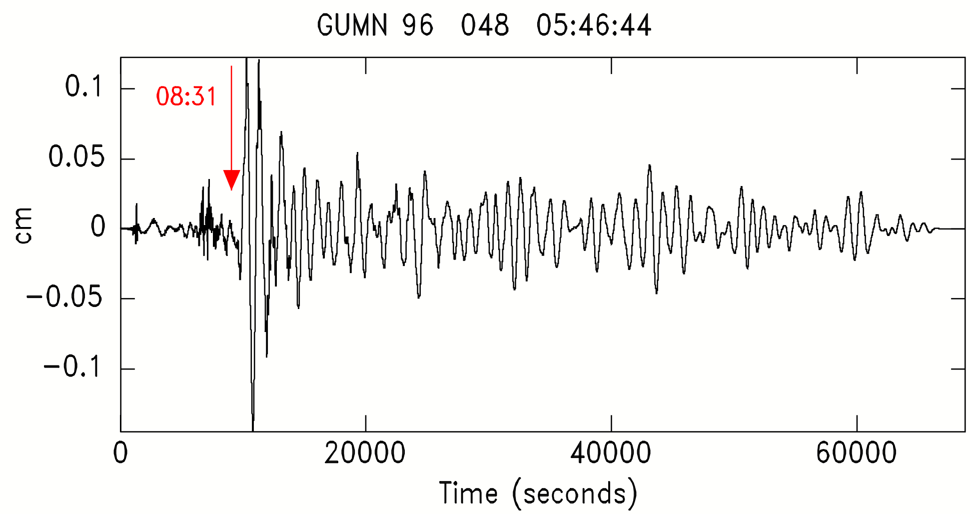
Rarotonga, 30 July 1995 [Chile]



Rarotonga, 23 June 2001 [Peru]



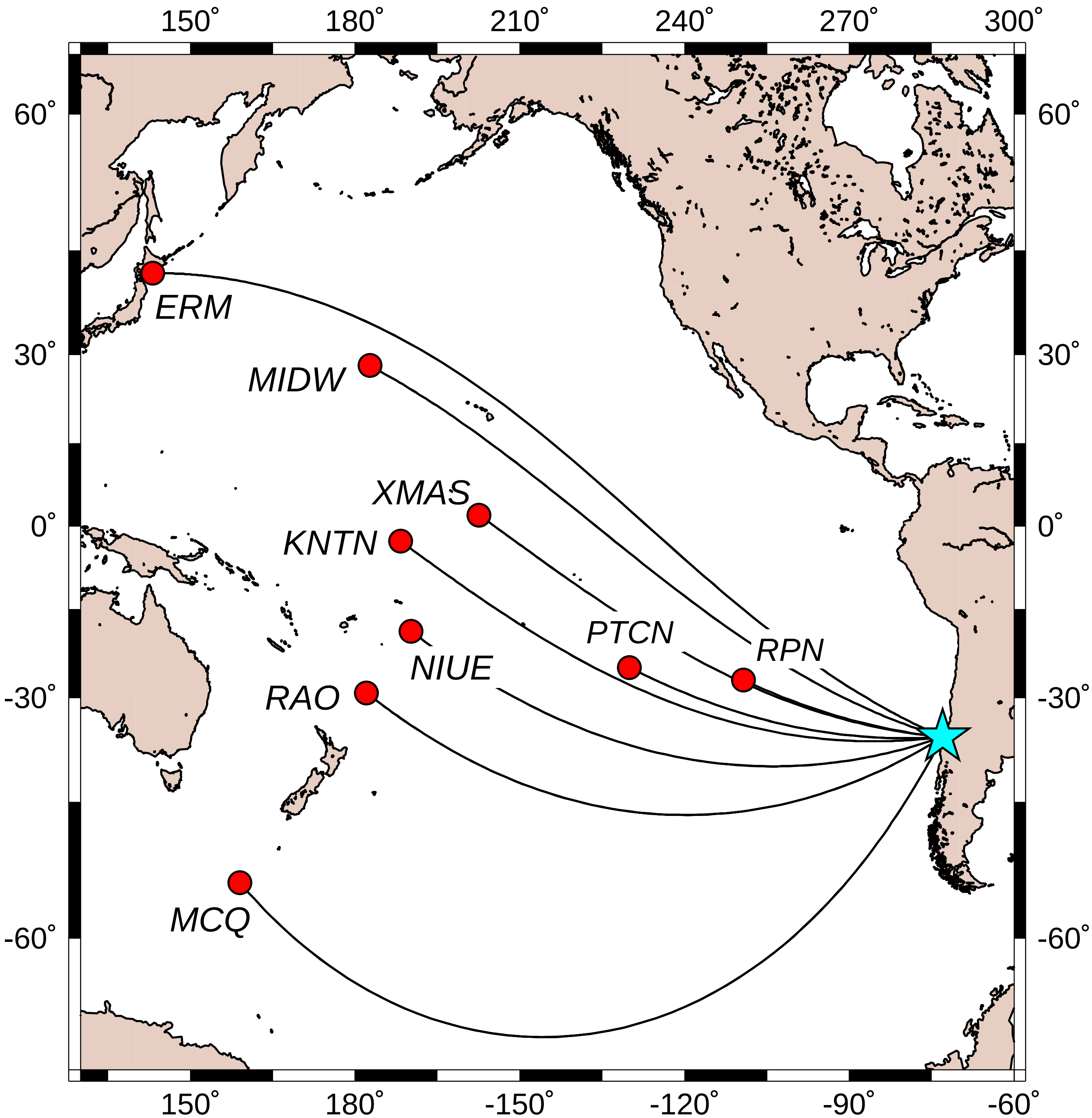
Agaña, Guam, 17 Feb. 1996 [Biak]



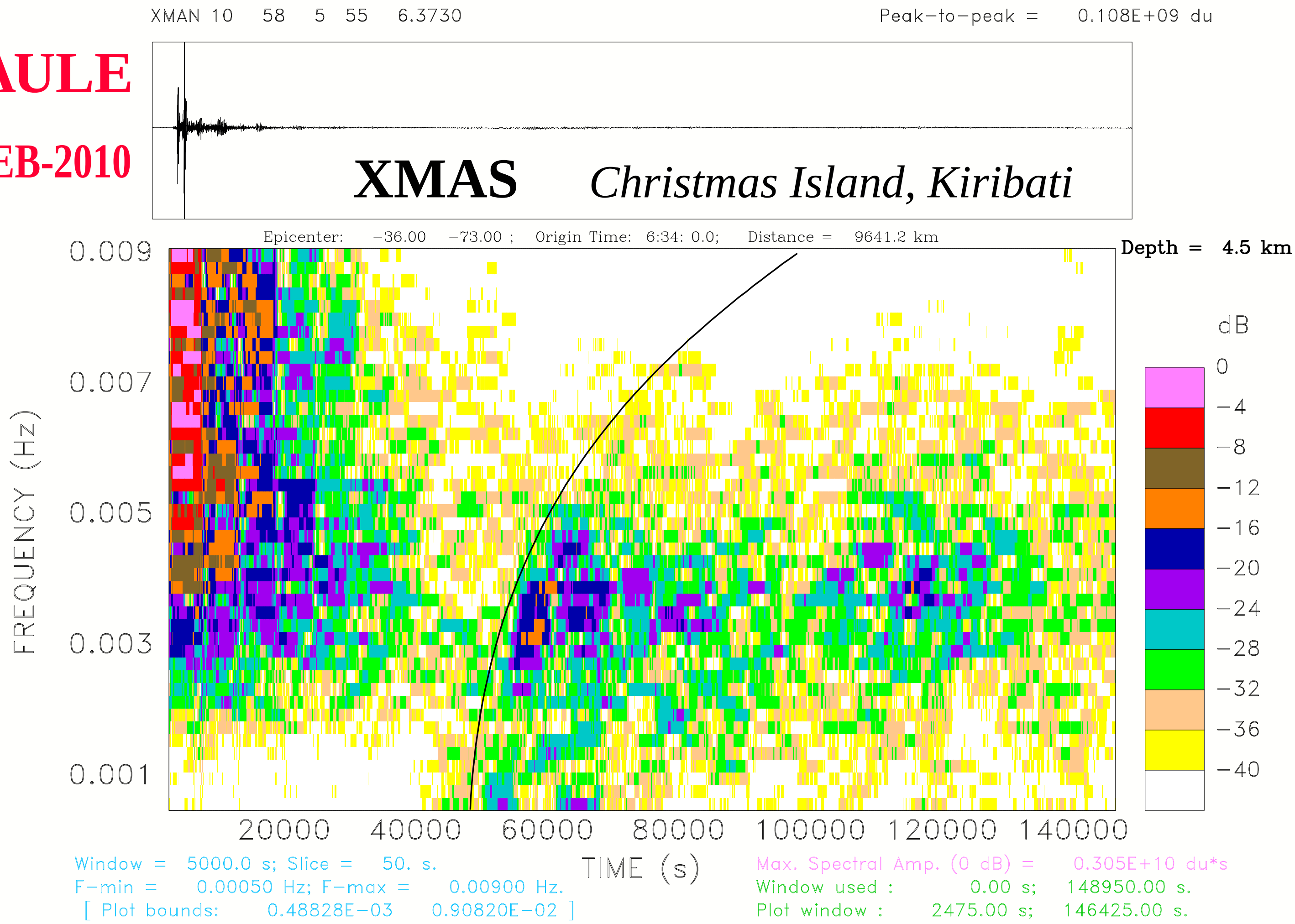
MAULE, CHILE, 27-FEB-2010

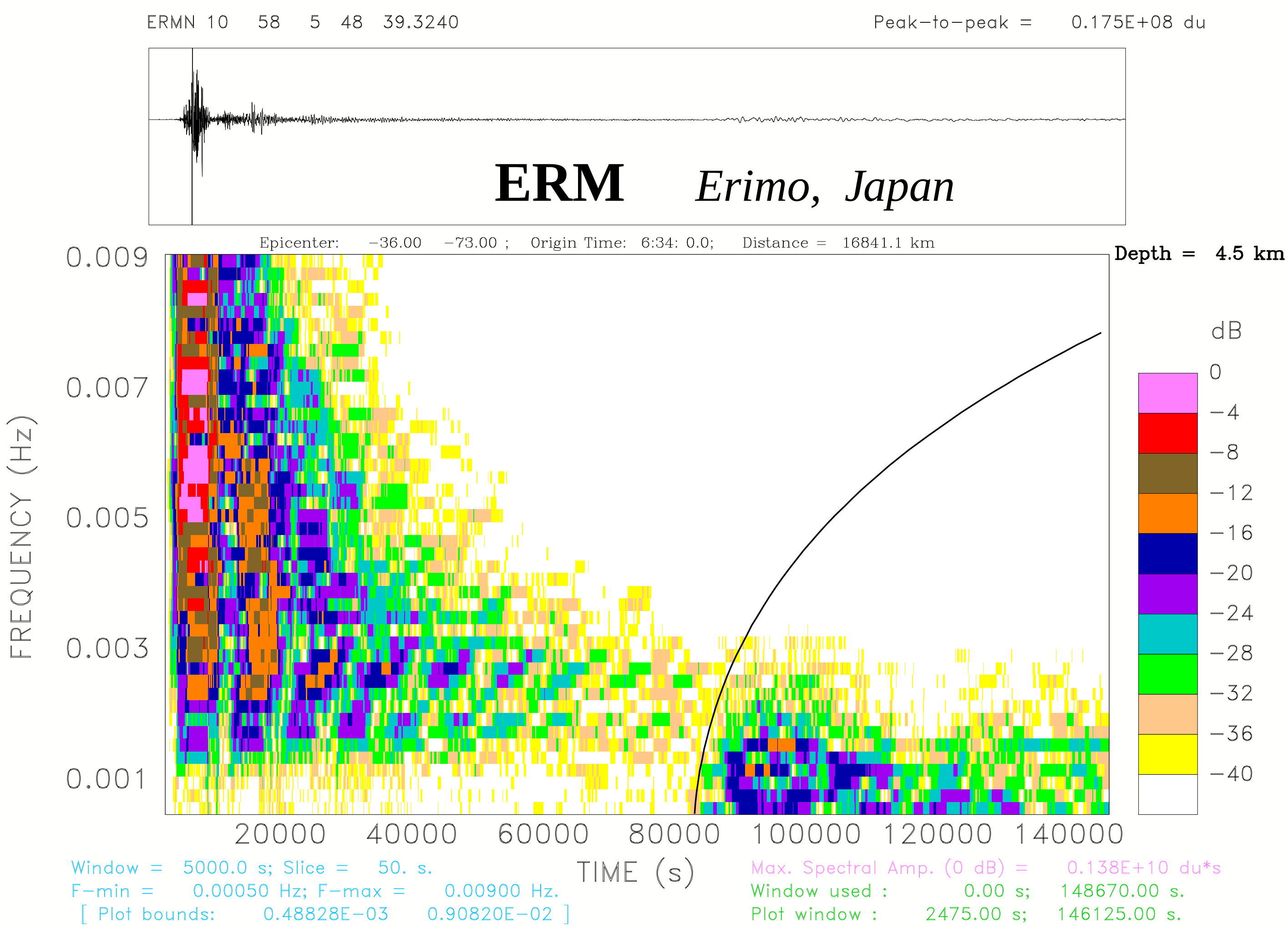
Seismic Recordings of the Tsunami

Following the 2010 Maule, Chile earthquake, we identified its tsunami on horizontal records at nine seismic stations in the Pacific Basin.



MAULE
27-FEB-2010

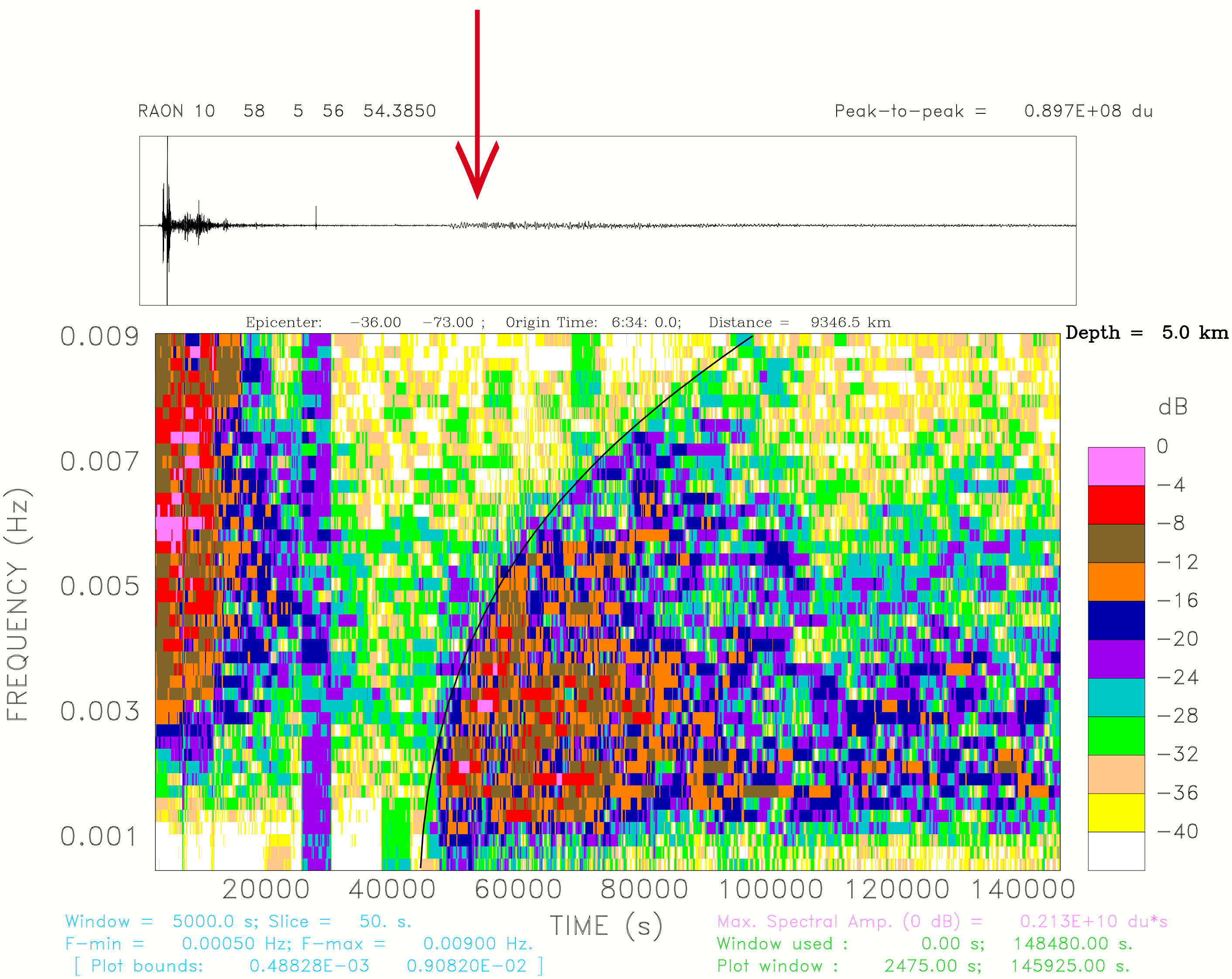




MAULE, CHILE, 27-FEB-2010

The spectacular records at Raoul Island and Pitcairn Island are clearly visible in the raw seismograms, without any processing.

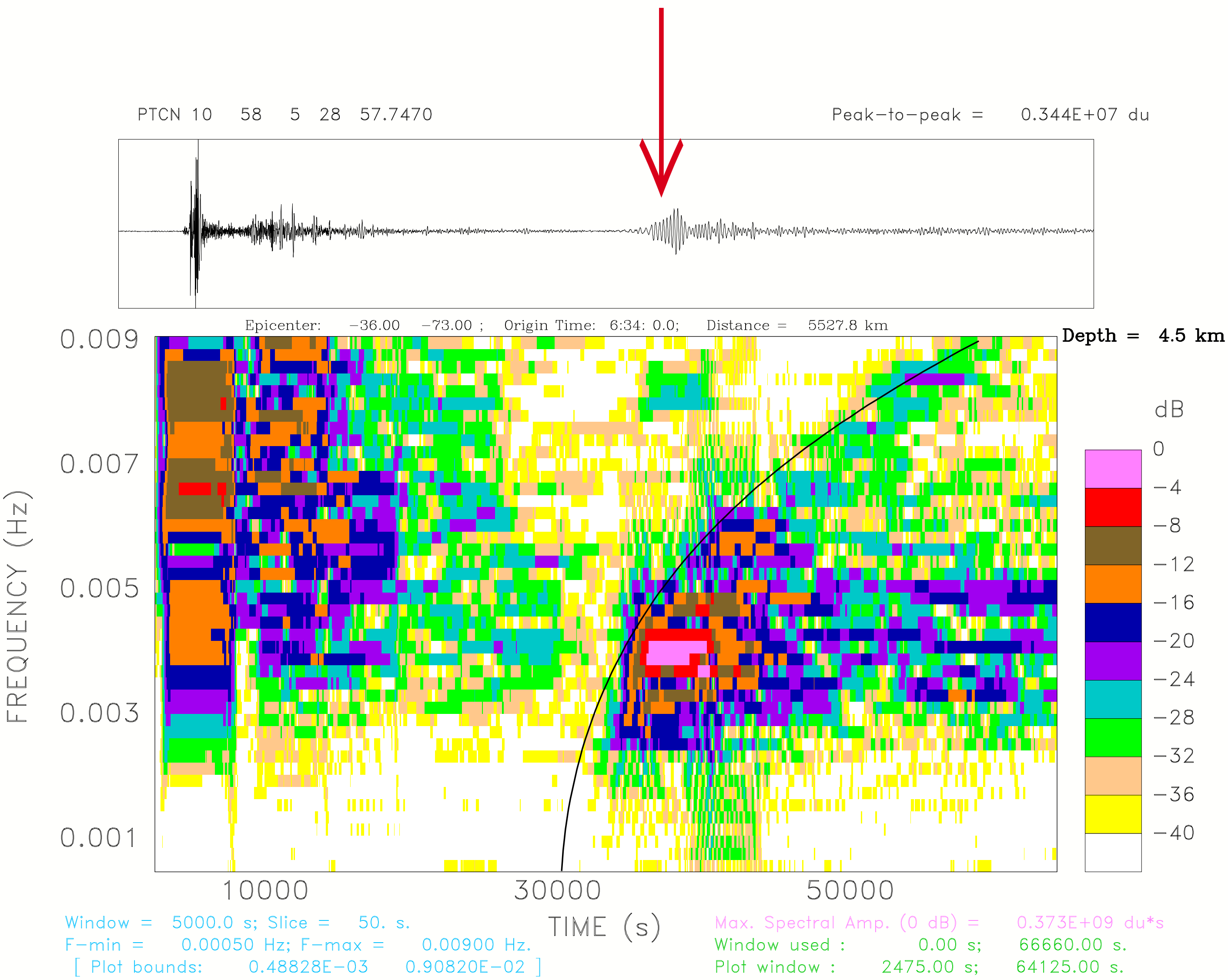
RAO *Raoul Island, Kermadec Islands*



MAULE, CHILE, 27-FEB-2010

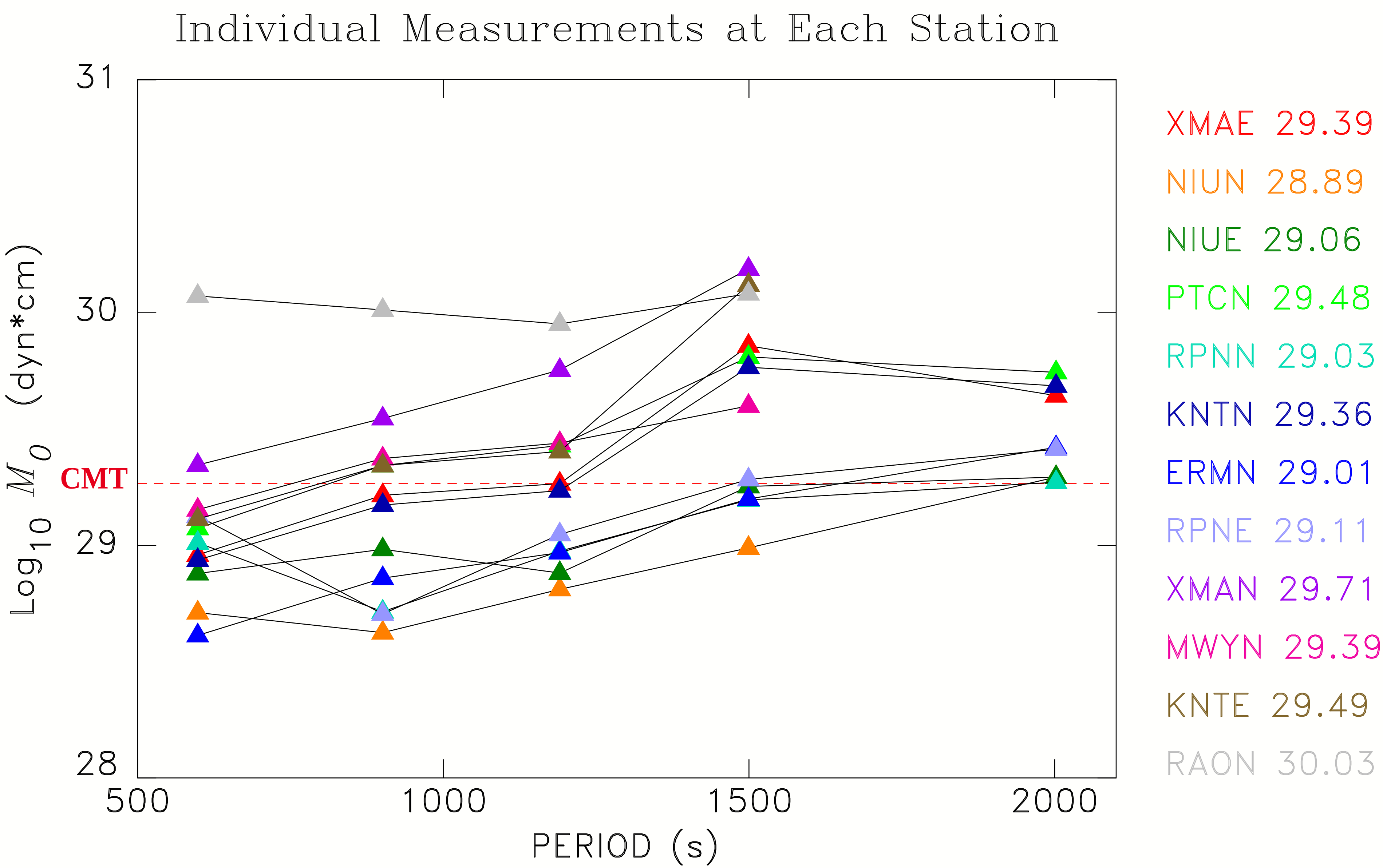
The spectacular records at Raoul Island and Pitcairn Island are clearly visible in the raw seismograms, without any processing.

PTCN *Pitcairn Island, B.C.C.*

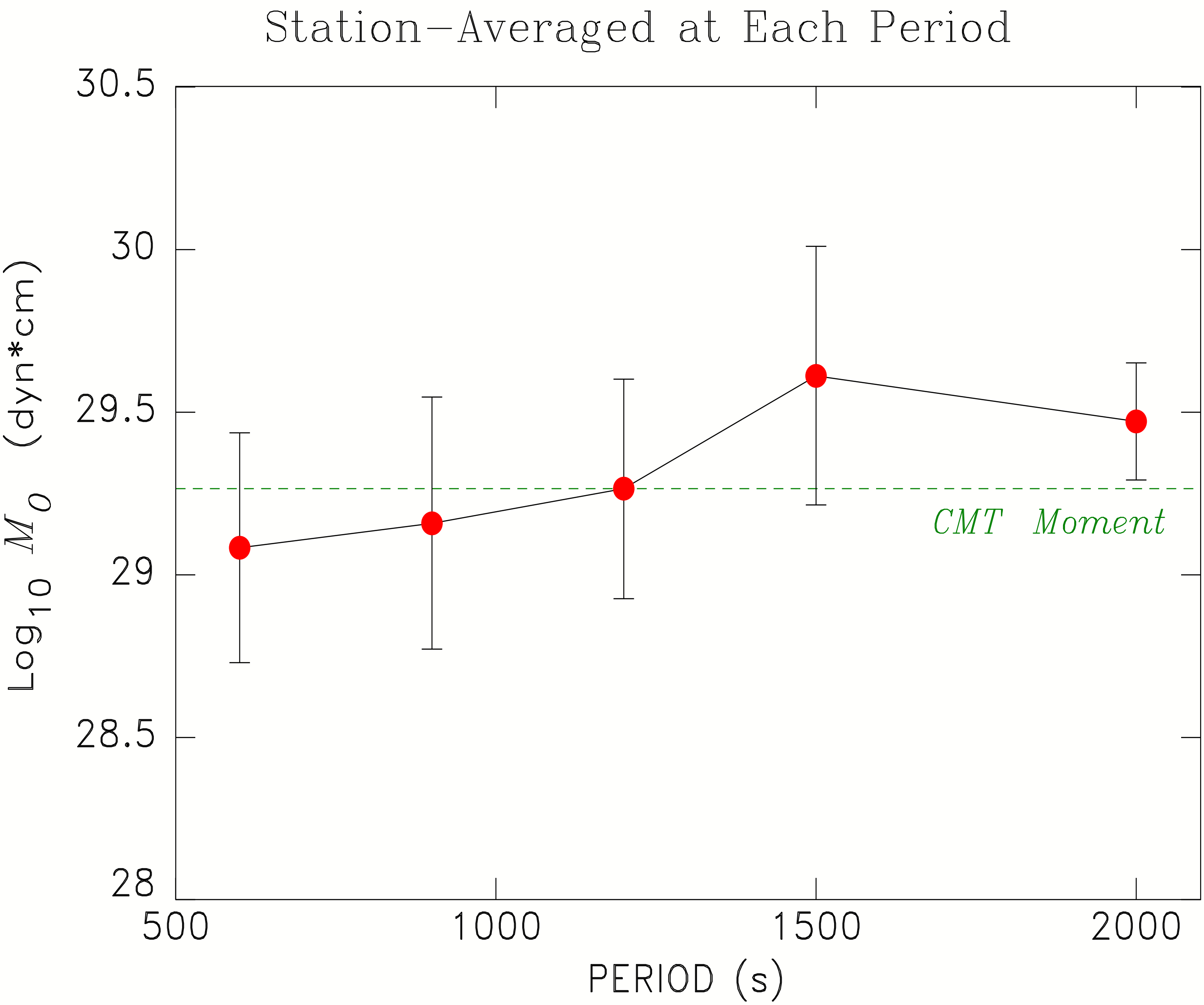


In this case, note the prominent high frequencies, which probably express a non-linear response of the structure of that small island $(4.6\ \text{km}^2)$*.*

→ *Using the previously described algorithm, we derive a seismic moment for the Maule event from the seismic records of its tsunami*



→ *In the 500−2000 s period range, the results are generally in agreement with the CMT scalar moment.*



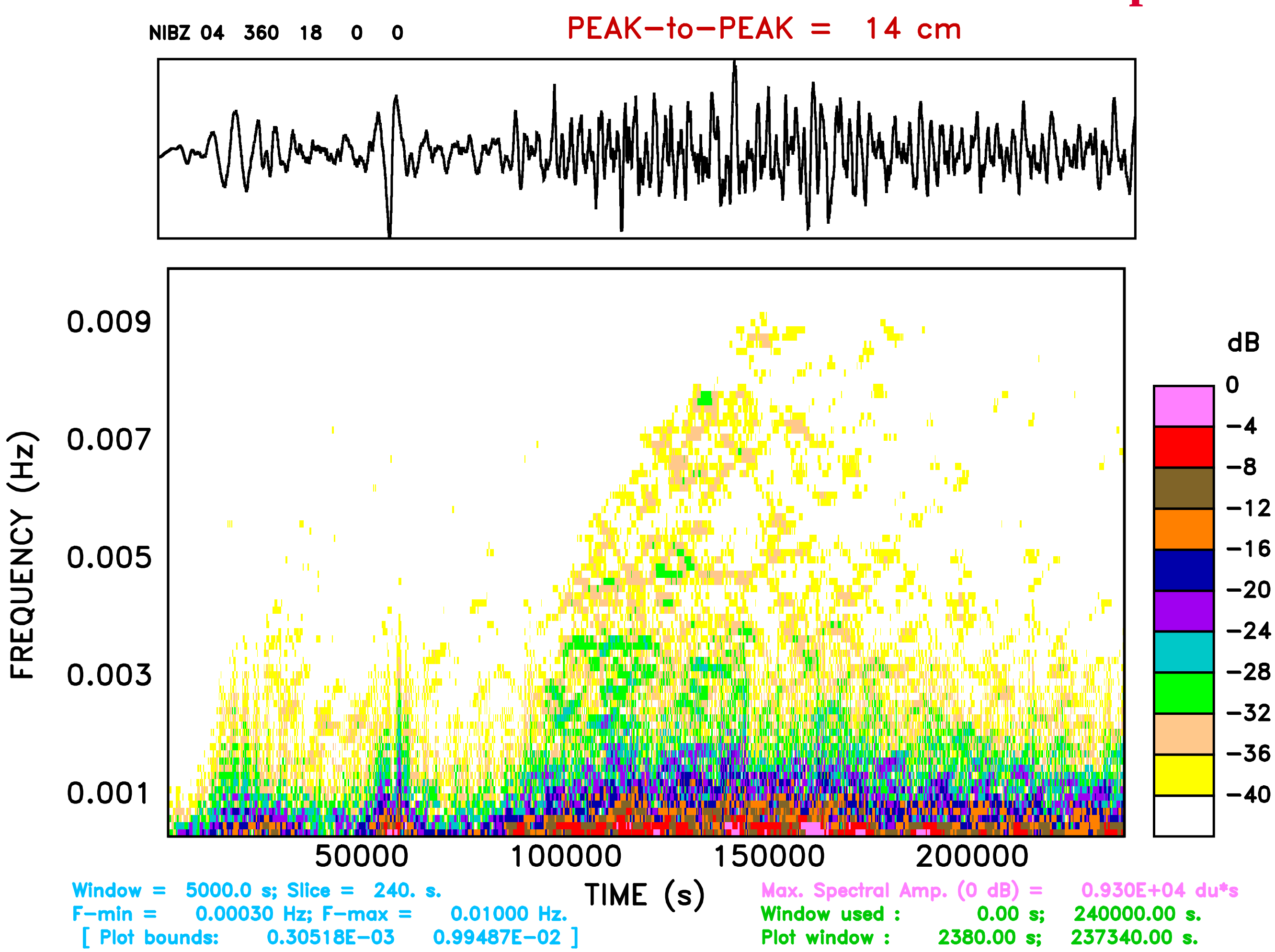
→ At higher frequencies (not shown), the results would depend on the response of the individual island structure.

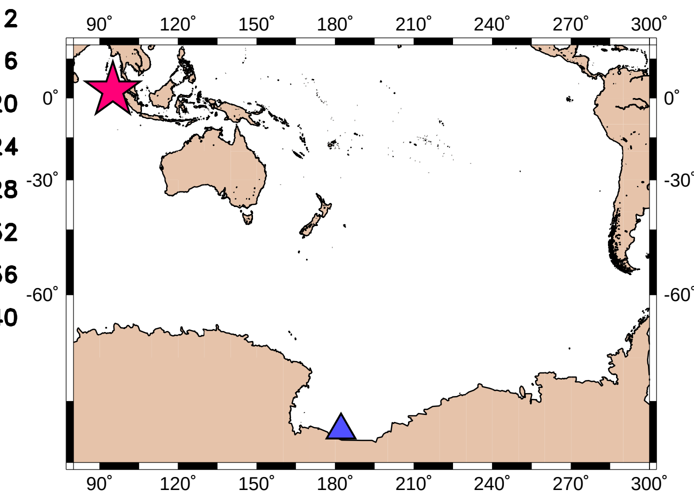
THE FLOATING SEISMOMETER

2004 TSUNAMI RECORDED on ICEBERGS

Since 2003, we had been operating seismic stations on detached and nascent icebergs adjoining the Ross Sea.

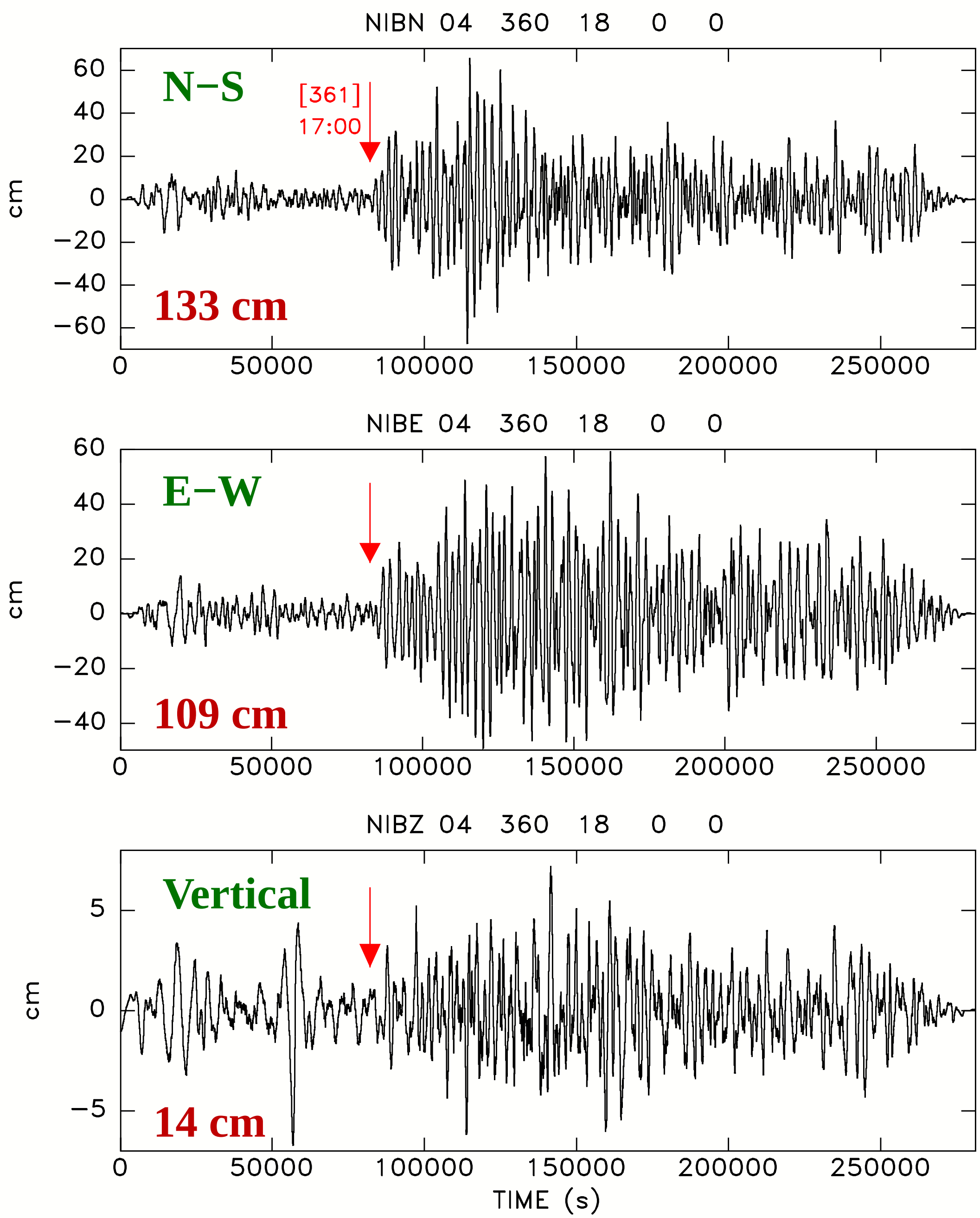
The tsunami was recorded by our 3 seismic stations, on all 3 components, with amplitudes of 10−20 cm.





Seismic recordings of 2004 Sumatra Tsunami on Iceberg

Nascent (NIB); *26 DECEMBER 2004*



This time, the iceberg (and the seismometer) float like a raft on the sea and **record directly the 3-dimensional displacement of the tsunami.**

In the Shallow-Water Approximation,

$$AR = \frac{u_x}{u_z} = \frac{1}{\omega}\sqrt{\frac{g}{h}}$$

Iceberg:

$T = 500$ s; $h = 500$ m $AR \approx 11$

FIRST DIRECT MEASUREMENT OF HORIZONTAL COMPONENT OF TSUNAMI ON THE HIGH SEAS

ELLIPTICITY of TSUNAMI SURFACE MOTION

(Shallow Water Approximation)

$$AR = \frac{u_x}{u_z} = \frac{1}{\omega}\sqrt{\frac{g}{h}}$$

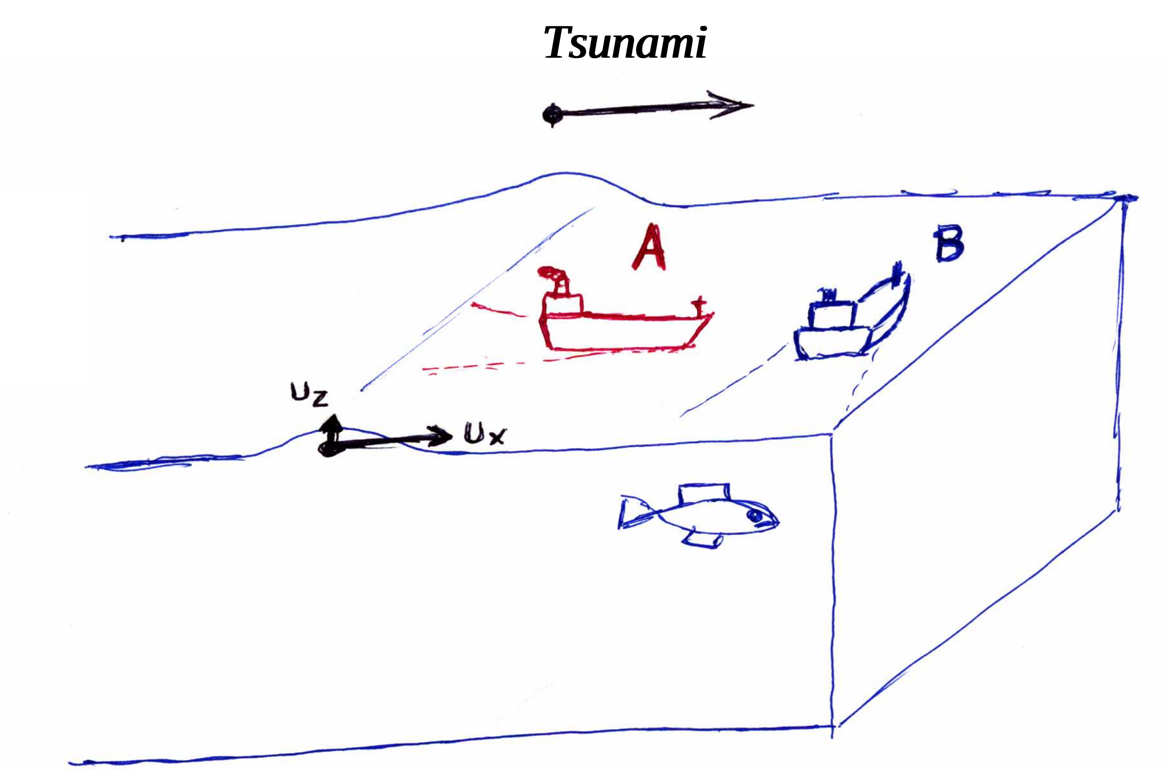
On the high seas ($T = 1000-2000$ s; $h = 2000 - 5000$ m),

AR can be typically between **10 and 25.**

Sumatra 2004: $u_z \approx 1$ m (JASON; seismic stations)

$u_x \approx 15$ meters ?

Conceivable to use GPS-equipped ships to detect tsunami.



Ship A should see a perturbation in speed

Ship B would show a zig-zag in trajectory

CTBT HYDROPHONES

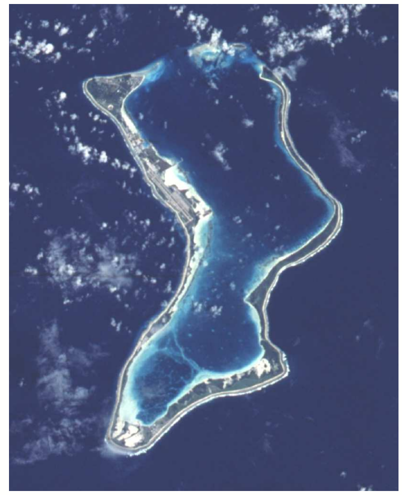
DETECT TSUNAMI

or

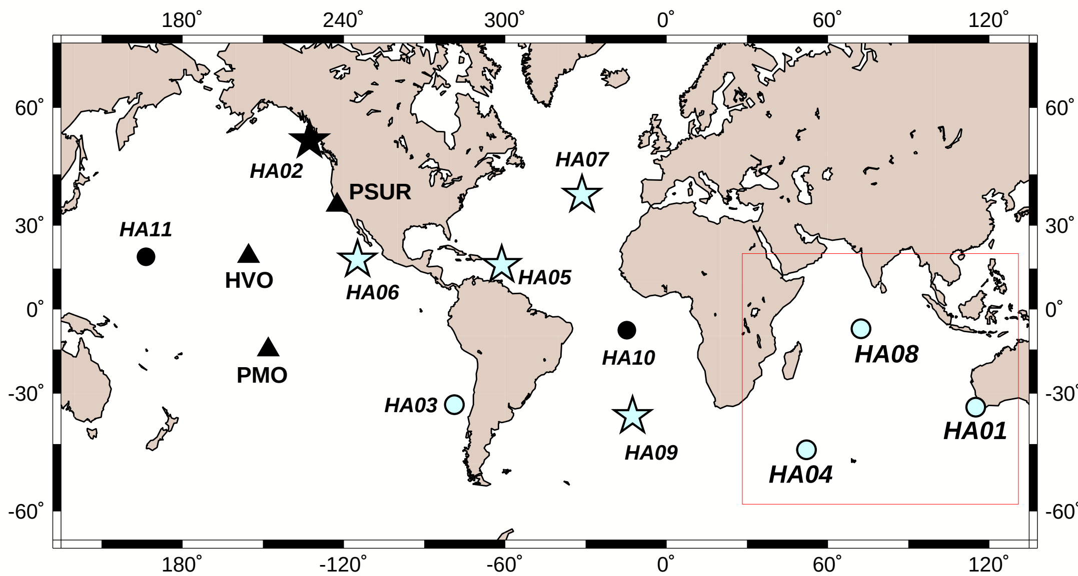
One Filter Too Many !

CTBT HYDROPHONE RECORDS

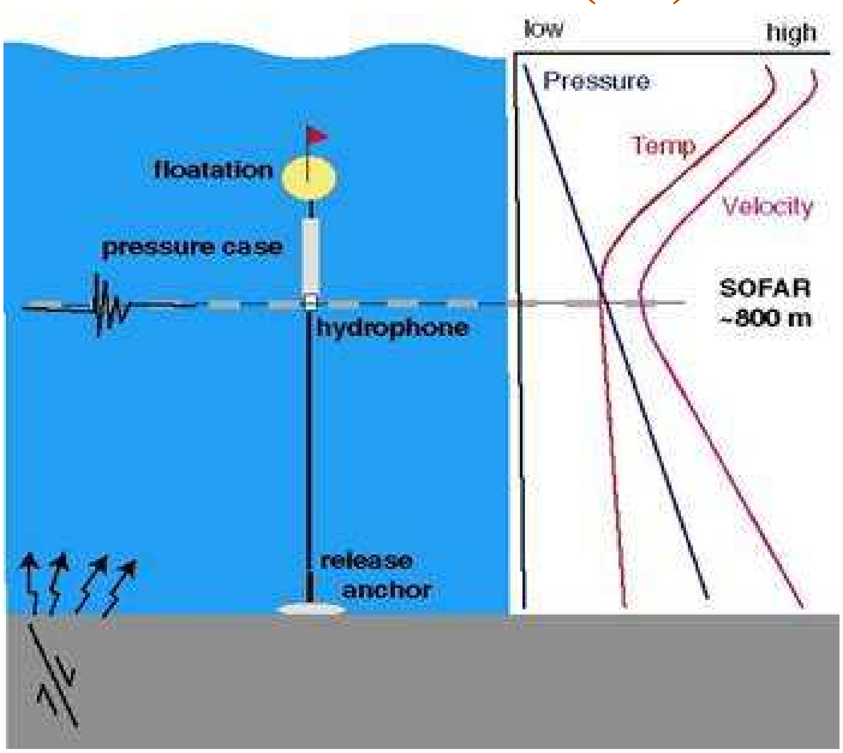
In the context of the CTBTO ("Test-Ban Treaty Organization"), the **I**nternational **M**onitoring **S**ystem comprises six hydrophone stations deployed in the SOFAR channel, including three in the Indian Ocean.



Diego Garcia, BIOT



Each station features several (3−6) sensors, allowing *beaming* of the array



[*M. Tolstoy*, Columbia University]

These instruments recorded not only the hydroacoustic ("***T***") waves generated by the earthquake, but also its conventional seismic waves (Rayleigh), and most remarkably,

the tsunami itself.

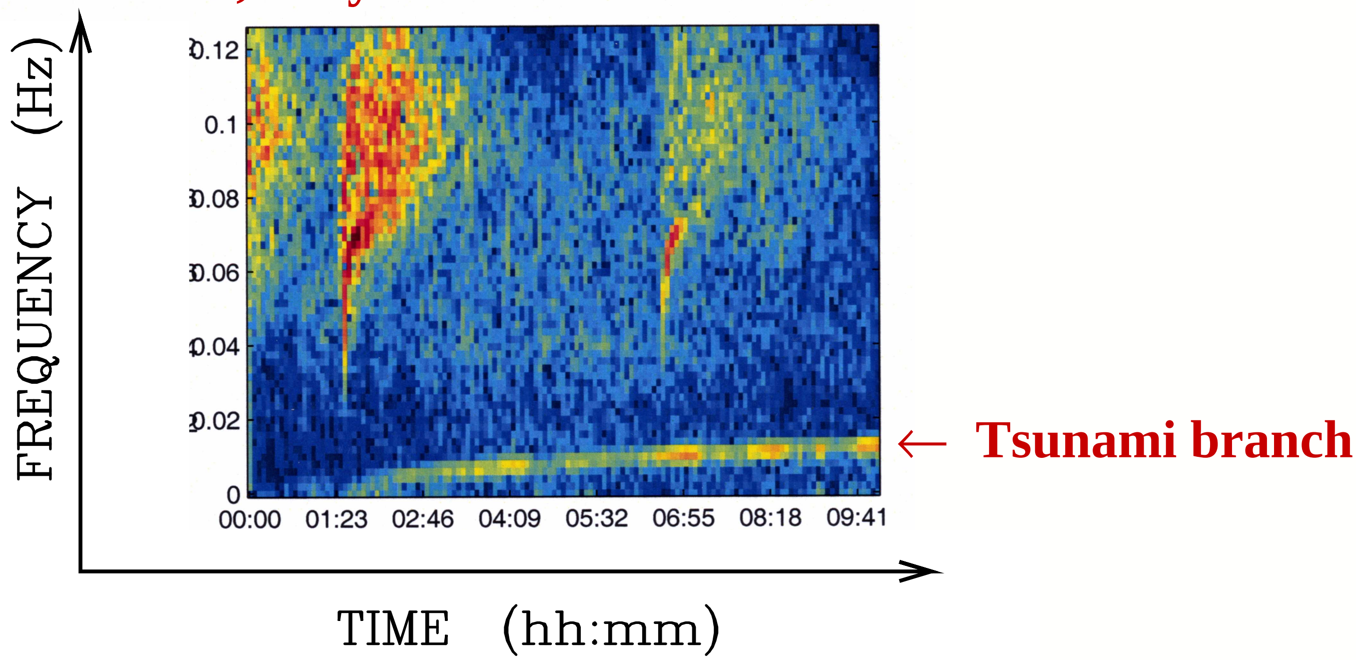
[*Okal et al.*, 2006]

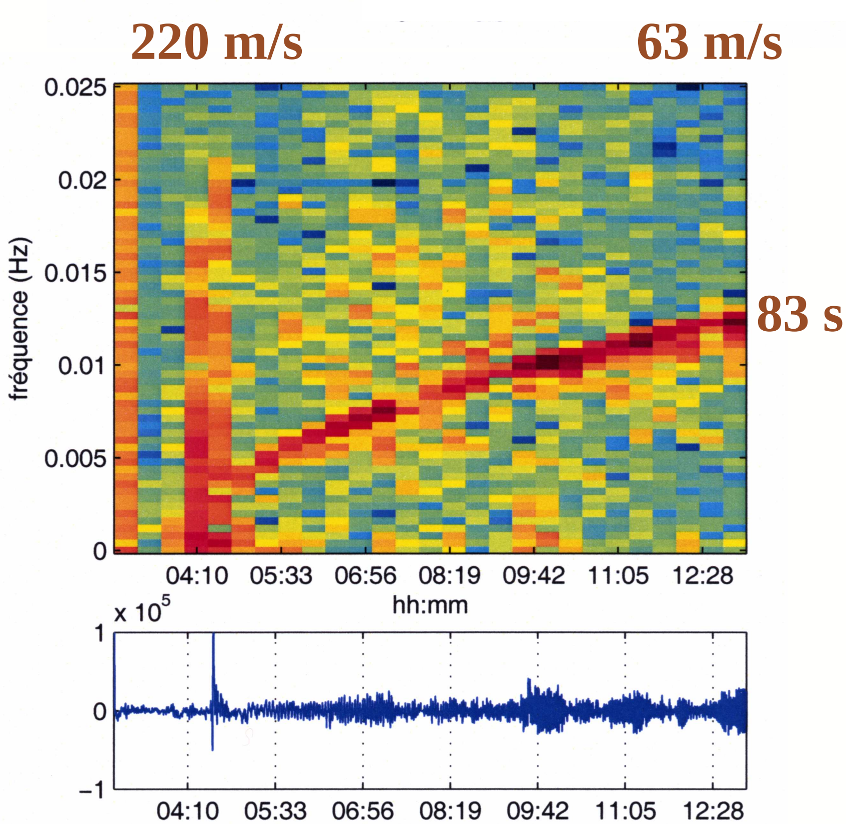
TSUNAMI recorded by HYDROPHONES of the CTBTO

(hanging in ocean at 1300 m depth off Diego Garcia)

→ Instruments are severely filtered at infra-acoustic frequencies.

YET, they recorded the TSUNAMI!





Note first ever observation of ***DISPERSION*** of tsunami branch at *VERY HIGH* [tsunami] frequencies in the far field

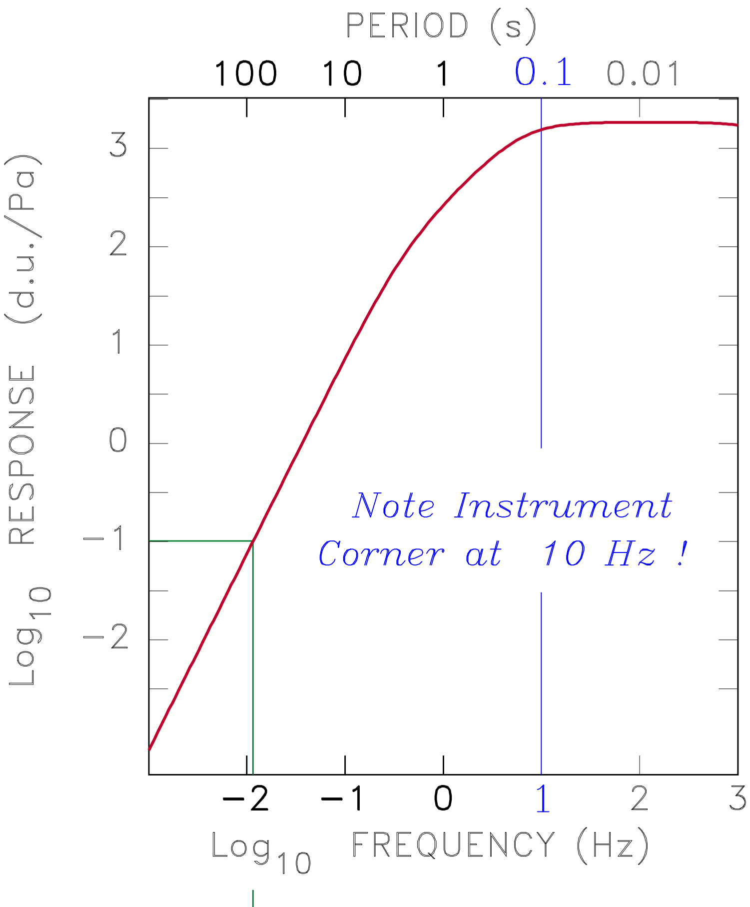
$$\omega^2 = g\,k \cdot \tanh(k\,h)$$

All of this on the high seas, unaffected by coastal response.

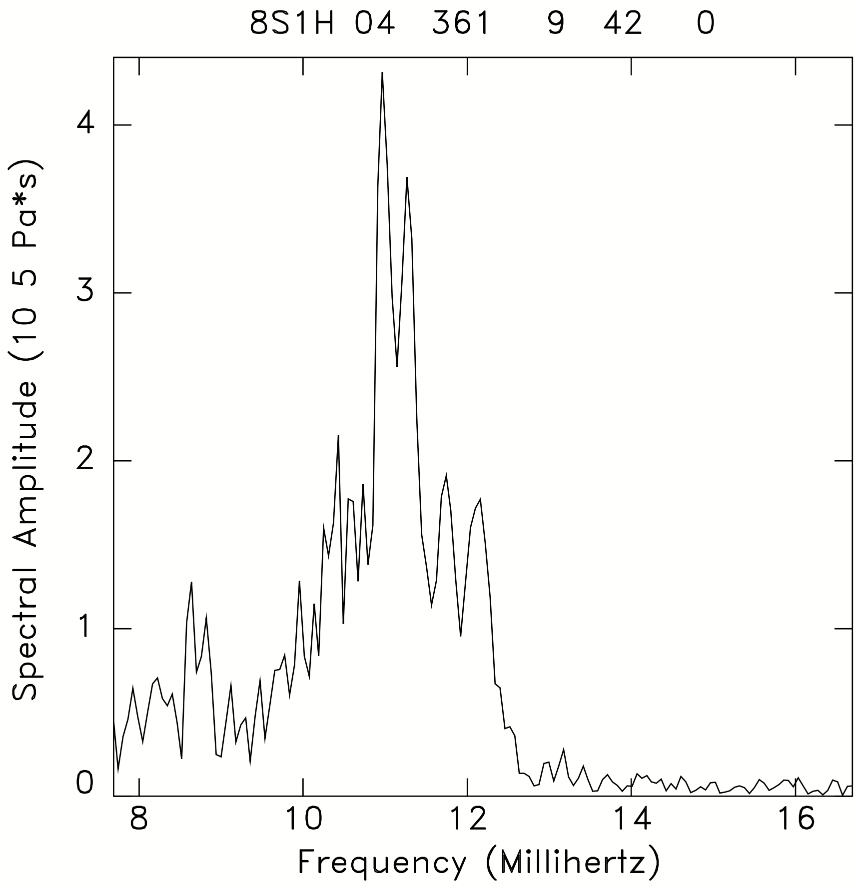
NOTE STRONG HIGH-FREQUENCY TSUNAMI COMPONENTS

Retrieving Seismic Moment from High-Frequency Tsunami Branch

- Use Hydrophone H08S1 from IMS at Diego-Garcia (BIOT)
- Deconvolve instrument and retrieve pressure spectrum



Note Instrument Response Down
by Factor 17,800 at 87 s.

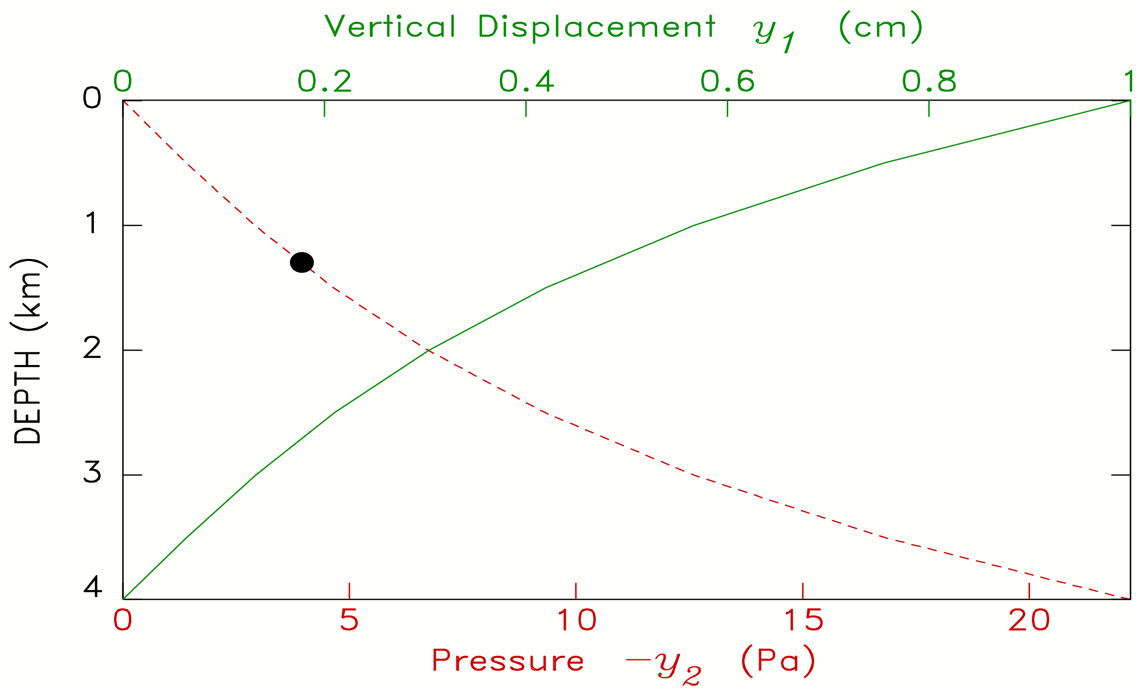


$$P(\omega) = 0.35 \text{ MPa} * \text{s at } 87 \text{ s}$$

Retrieving Seismic Moment from High-Frequency Tsunami Branch (ctd.)

- Use *Okal* [1982; 2003; 2006] to convert overpressure at 1300 m depth (0.35 MPa*s) to surface amplitude η ,

outside classical Shallow-Water Approximation.



Structure of tsunami eigenfunction through water column outside S.W.A.

Find $\eta(\omega) = 78000$ cm*s at $T = 87$ s.

- Use *Haskell* [1952], *Kanamori and Cipar* [1974], *Ward* [1980], *Okal* [1988; 2003] in normal mode formalism to compute excitation coefficients.

Find $\mathbf{M_0 = 8 \times 10^{29}}$ **dyn – cm**

ACCEPTABLE !

(Moment from Earth's free oscillations: $\mathbf{1 \text{ to } 1.2 \times 10^{30}}$ **dyn-cm**)

[*Stein and Okal*, 2005; *Nettles et al.*, 2005]

CONCLUSION: We understand ***QUANTITATIVELY*** the **excitation of the high-frequency components of the tsunami...**

TOAMASINA, Madagascar

(a)

(b)

(c)

Figure 5. *(a):* The 50−m freighter *Soavina III* photographed on 2 August 2005 in the port of Toamasina. *(b):* Sketch of the port of Toamasina showing its complex geometry. *(c):* Captain Injona uses a wall map of the port (ESE at top) to describe the path of *Soavina III* from her berth in Channel 3B (pointed on map), where she broke her moorings around 7 p.m., wandering in the channels up to the location of the red dot (also shown on Frame *b*), before eventually grounding in front of the Water-Sports Club Beach (white dot; Site 17).

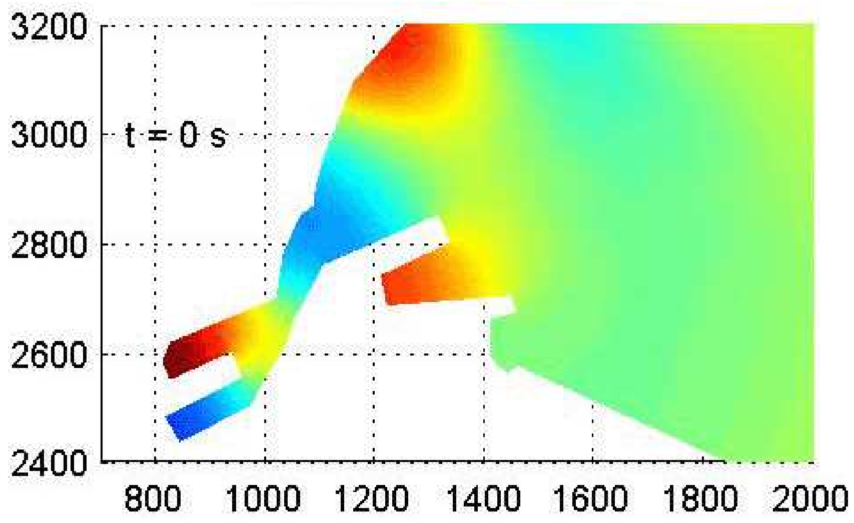
50−m SHIP BROKE MOORINGS around 19:00 (GMT+3), FOUR HOURS AFTER MAXIMUM WAVES

Preliminary modeling for Toamasina [Tamatave], Madagascar

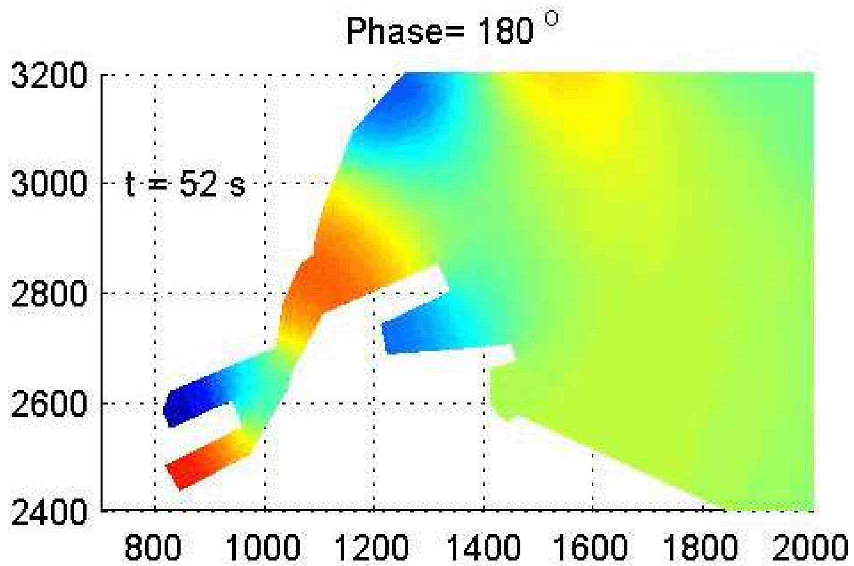
[*D.R. MacAyeal*, pers. comm., 2006]

- Finite element modeling of the oscillations of the port of Toamasina reveals a fundamental mode of oscillation at T = 105 s, characterized by sloshing back and forth of water into the interior of the harbor, thus creating strong *currents* at the berth of *Soavina III*.
- At this period, the group velocity of the tsunami wave is found to be **97 m/s** for an average ocean depth of 4 km.
- This would correspond to an arrival at **16:55 GMT, or 19:55 Local Time**.
- This is in good agreement with the Port Captain's testimony

"After 7 p.m. and lasting several hours"

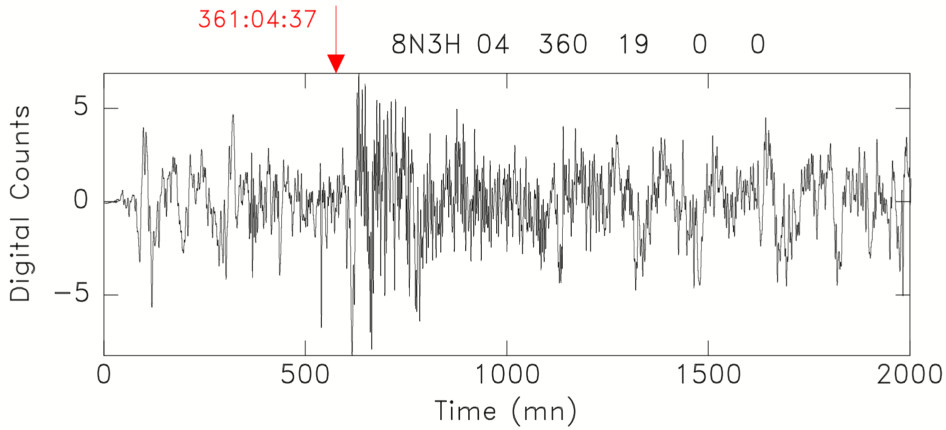


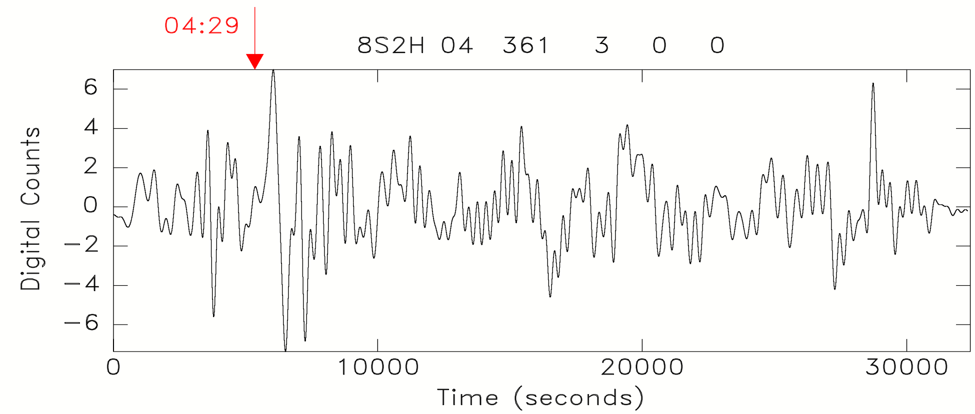
T = 105 seconds



CLASSICAL TSUNAMI WAVES (S.W.A.) RECORDED BY HYDROPHONES

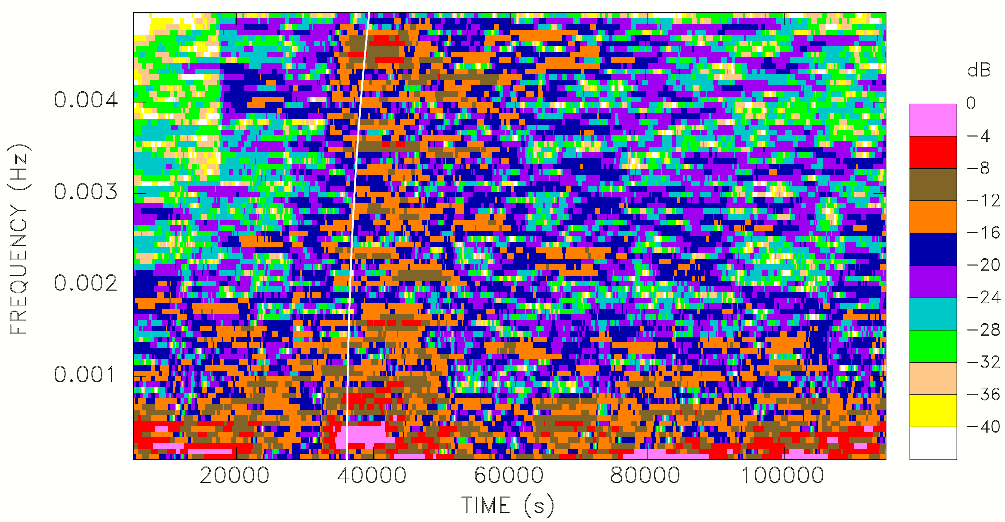
Diego Garcia, 26 December 2004

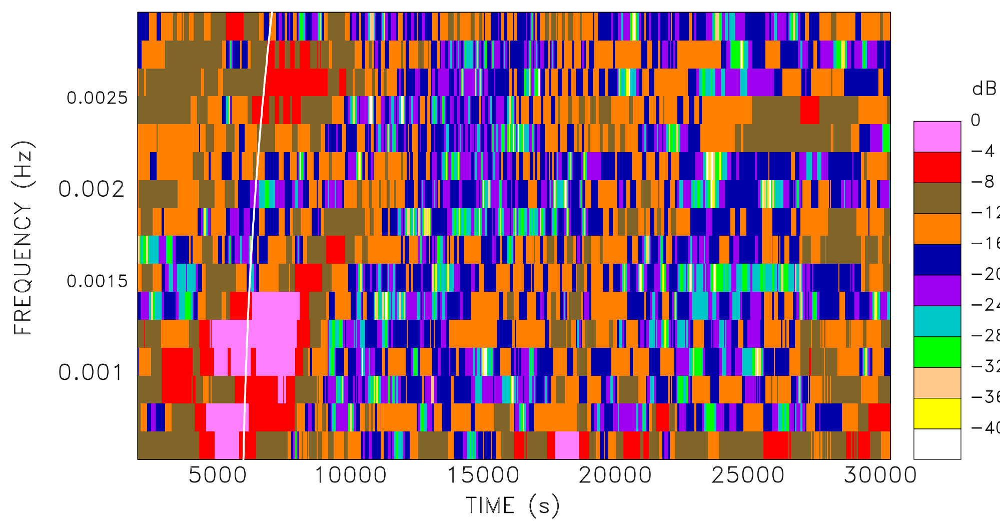




Northern Triad

Southern Triad

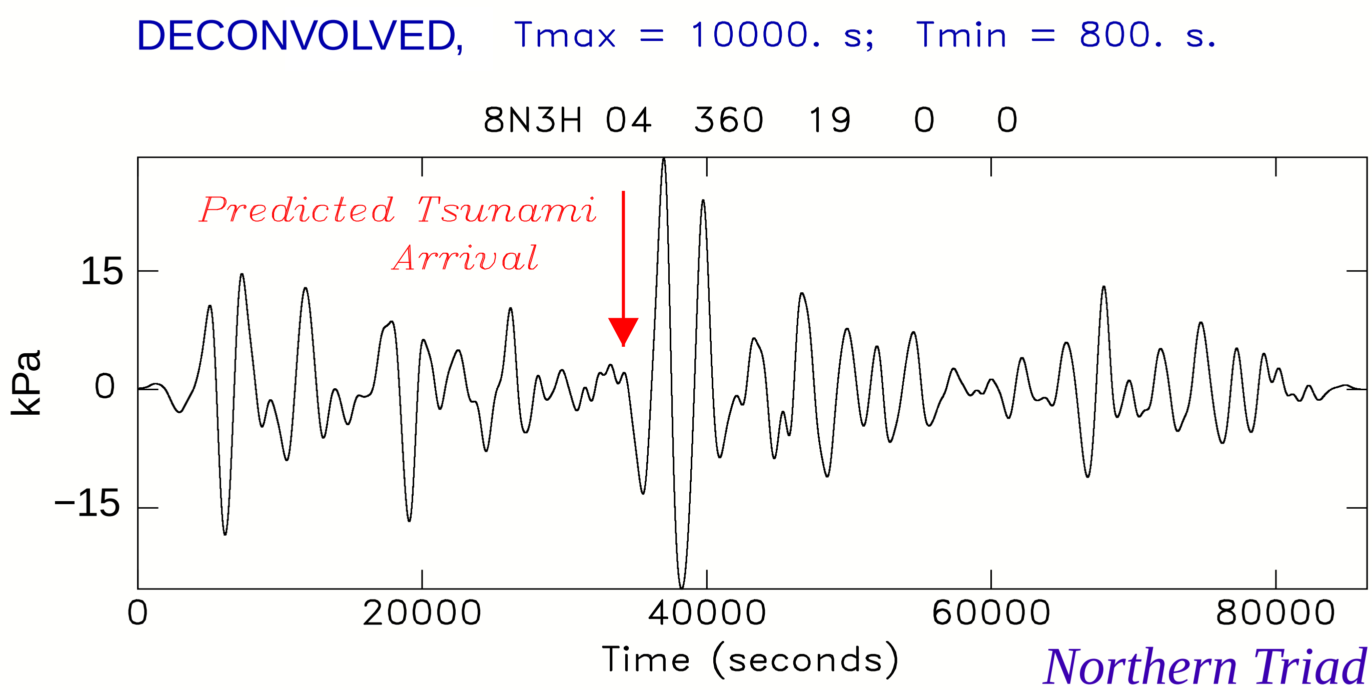


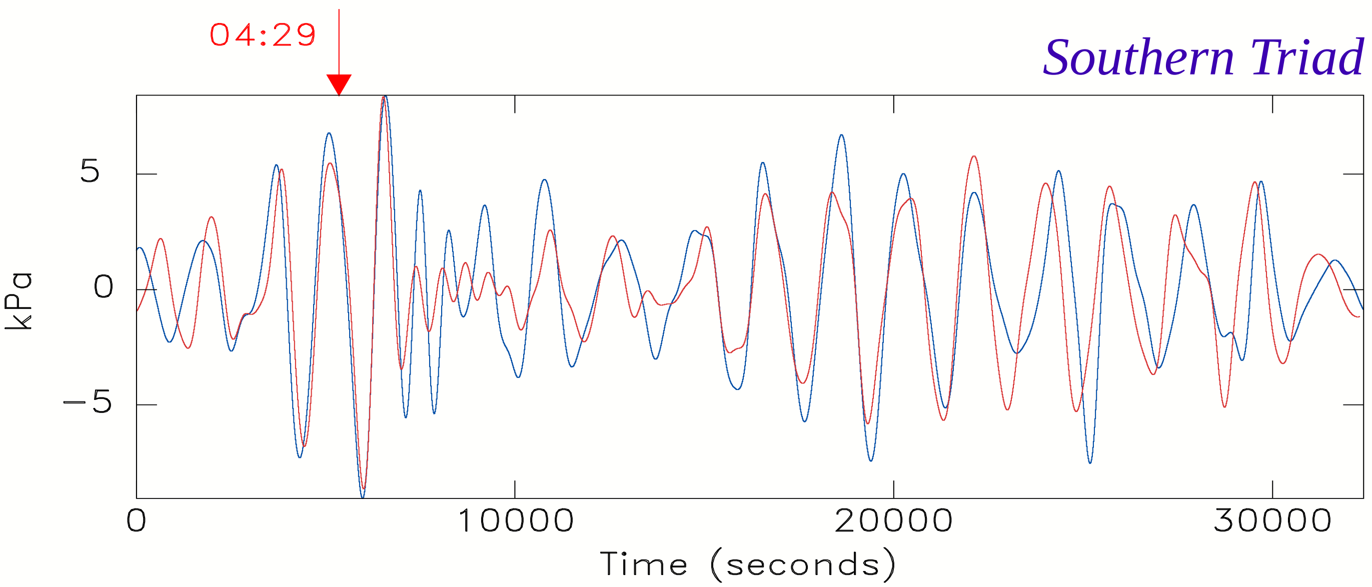


→ These long-period components (≥ 1000 s) are well recorded by the hydrophones.

COULD THEY BE QUANTIFIED ?

ATTEMPTING TO QUANTIFY LONG-PERIOD ($T \approx 3000$ s) TSUNAMI RECORDED BY DIEGO GARCIA HYDROPHONES





HOWEVER, **the resulting overpressures (15 to 50 kPa peak-to-peak) are much too large as they would require tsunami amplitudes of 3 to 10 meters on the high seas.**

This is probably due to digital noise introduced by the extremely low response of the instrument at such long periods (10,000 times the filter's corner).

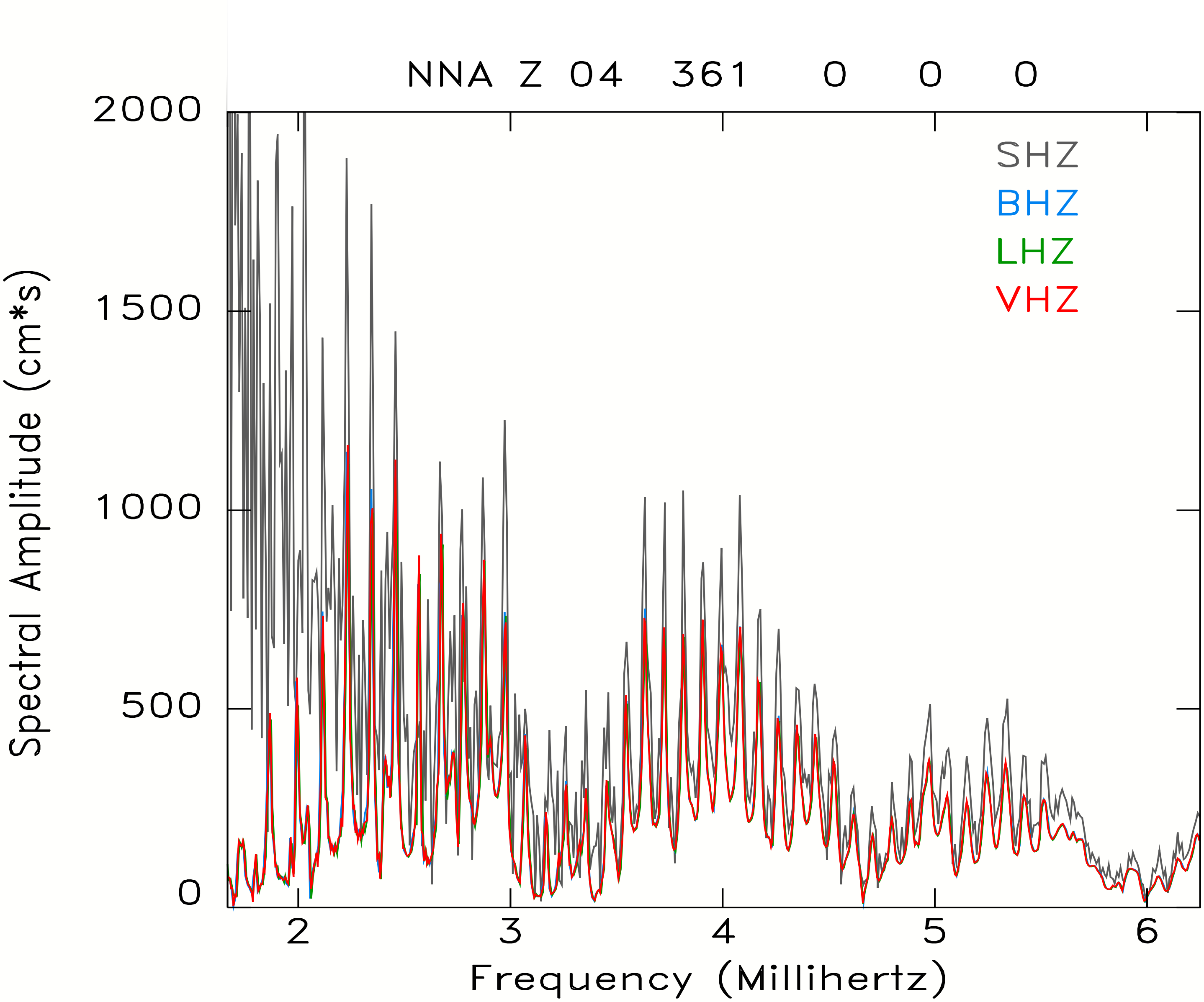
AFTER FILTERING, THE TSUNAMI SIGNAL SHOULD BE LESS THAN **1** *DIGITAL UNIT...*

THIS SUGGESTS AN INTERESTING TEST

What happens if we try to recover the Earth's normal modes from a Short-Period Seismometer ?

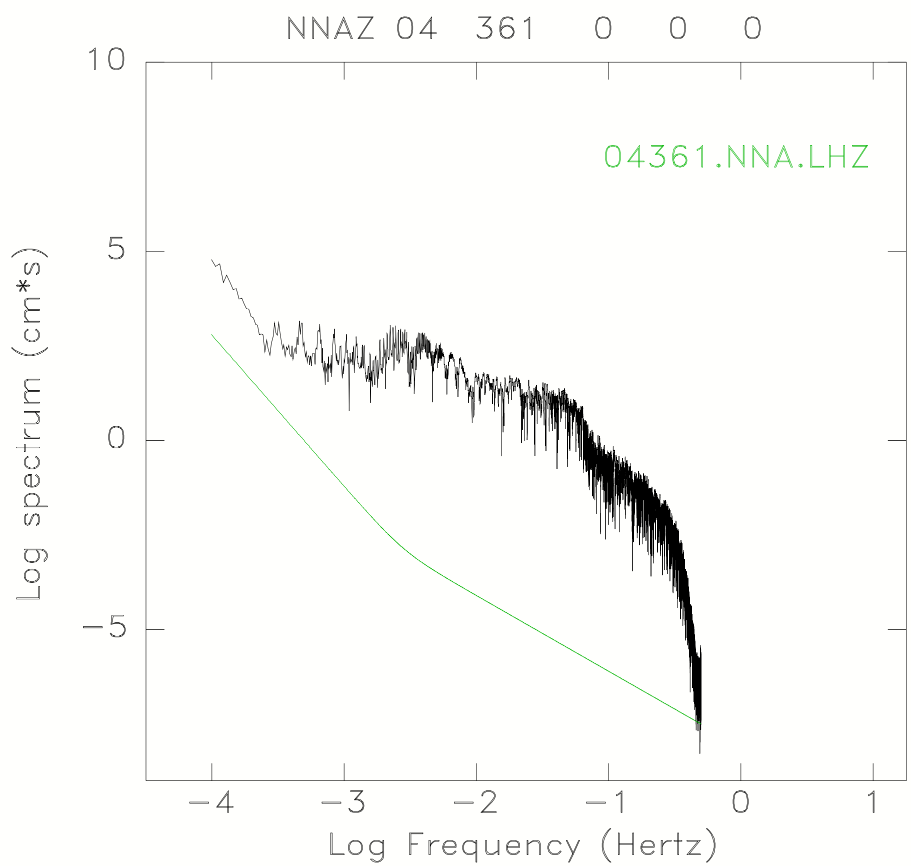
- We examine the spectra of the Sumatra earthquake (and the background noise) on VHZ, LHZ, BHZ and SHZ channels at the same station (NNA; Ñaña, Perù).

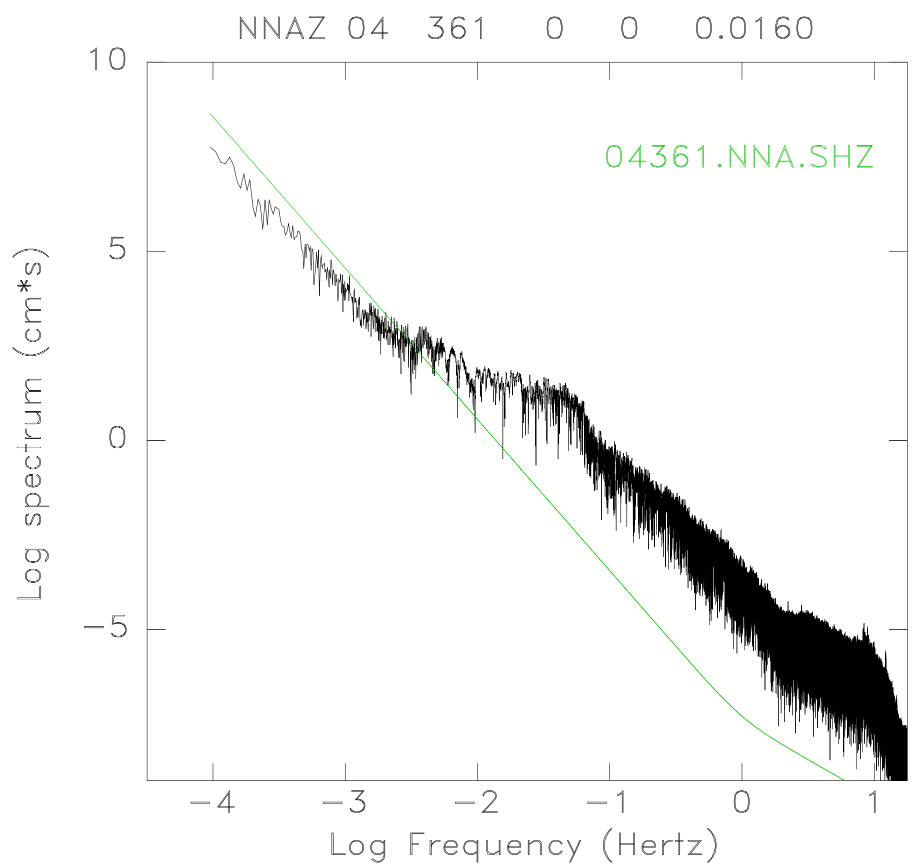
- We find that **VHZ**, **LHZ**, **BHZ**, *which share the same corner frequencies*, give exactly the same results (which allows the quantification of the modes), **while SHZ gives a beautiful spectrum (down to 2.5 mHz), but with spectral amplitudes too large by a factor ~ 1.5 .**



- We trace this effect to the fact that, at frequencies $f \leq 10$ mHz, the response of the SHZ instrument is so low, that an Earth's mode would be recorded with a time-domain amplitude of less than one digital unit.
- The spectral amplitude of a harmonic oscillation recorded with an amplitude of one digital unit is shown as the green line on the figures below.
- The resulting non-linearity introduced by this digital noise gives rise to a systematic bias overestimating the true spectral amplitude of the signal.

This is probably the origin of the excessive amplitude of the low-frequency components of the 2004 tsunami as recorded on the CTBT hydrophones.





FROM GROUND UP ...

or

Could Ionospheric Seismology

Help Tsunami Warning ?

IONOSPHERIC RADAR DETECTS SEISMIC RAYLEIGH WAVE 150 km UP !

Tokachi Oki — 16 May 1968

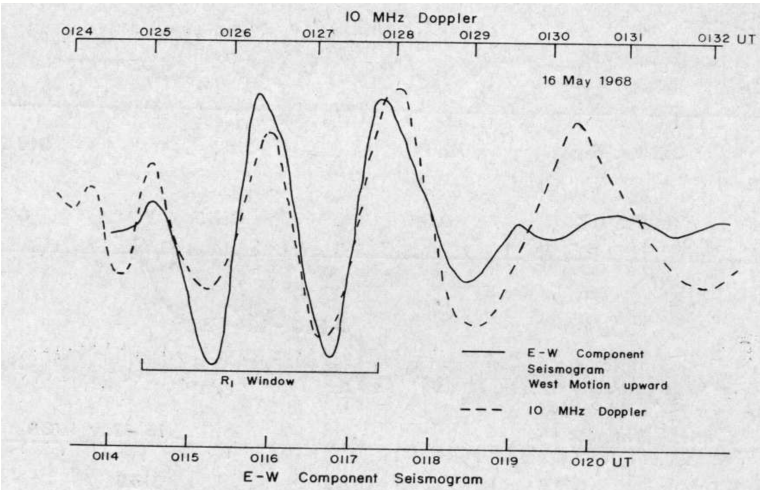


Fig. 5. Comparison of Doppler and longer-period seismogram data.

JOURNAL OF GEOPHYSICAL RESEARCH, SPACE PHYSICS VOL. 74, NO. 9, MAY 1, 1969

Continuous, Traveling Coupling between Seismic Waves and the Ionosphere Evident in May 1968 Japan Earthquake Data

P. C. YUEN, P. F. WEAVER, AND R. K. SUZUKI

Department of Electrical Engineering
University of Hawaii, Honolulu, Hawaii 96822

A. S. FURUMOTO

Hawaii Institute of Geophysics
University of Hawaii, Honolulu, Hawaii 96822

Detected in Hawaii

Kuriles, 11 August 1969

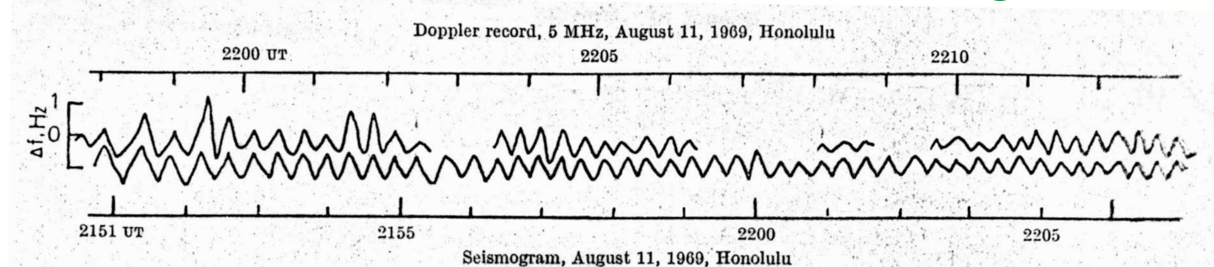


Fig. 2. Comparison of 5 MHz Doppler record and seismogram with expanded time scale.

WHY and HOW ?

- Atmosphere is not vacuum... and so, Rayleigh waves do not stop at a free boundary, but rather are continued upwards in the form of an pseudo-gravity wave, whose phase velocity is forced to that of the main Rayleigh wave.

- Energy density decays exponentially upwards, but since *material density decays faster,* wave amplitude can actually **increase with height !** Radar detects variation in TEC due to perturbation of ionosphere.

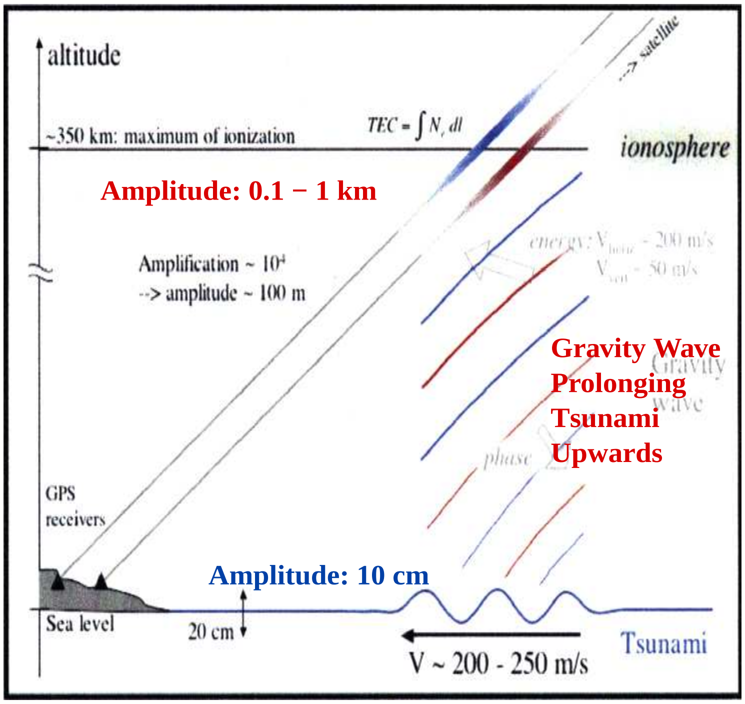
- *Peltier* [1976] suggested a similar coupling for tsunamis. It took close to 30 years to observe...

TOWARDS DIRECT DETECTION of a TSUNAMI on the HIGH SEAS

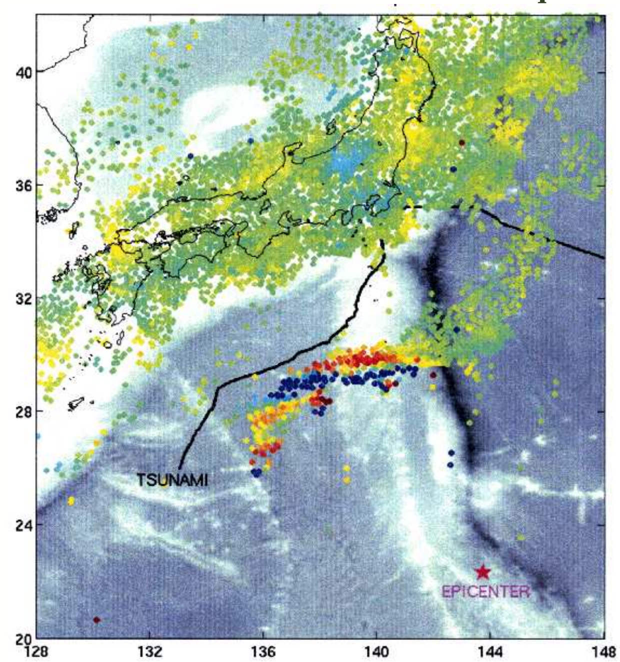
3. TSUNAMI DETECTION by GPS IONOSPHERIC MONITORING

J. Artru, H. Kanamori (Caltech); M. Murakami (Tsukuba); P. Lognonné, V. Dučić (IPG Paris) -- (2002)

- Ocean surface is not free boundary — Atmosphere has finite density
- Tsunami wave *prolonged* into atmosphere; *amplitude increases* with height.
- Perturbation in ionosphere (h = 150−350 km) detectable by GPS.



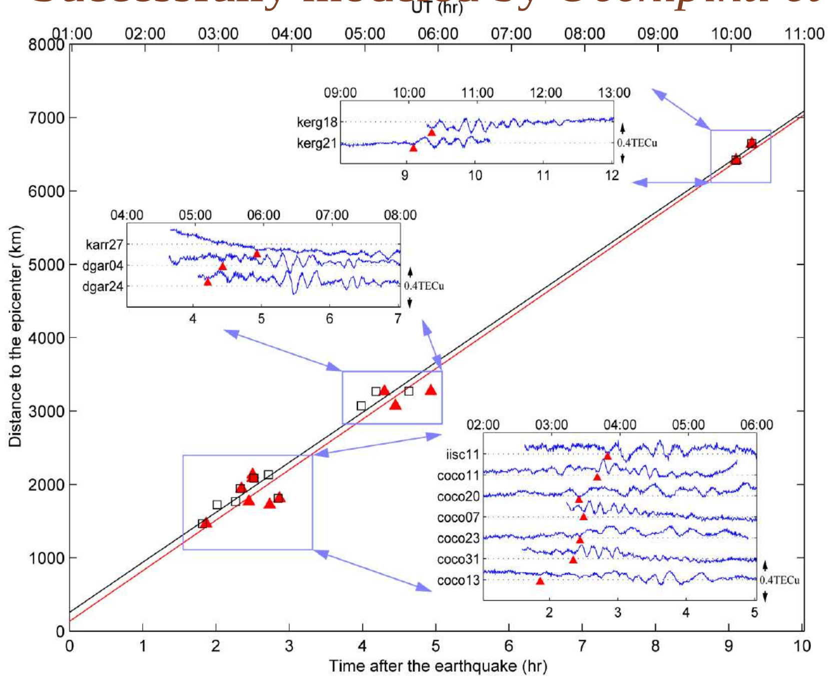
28 MAR 2000 -- 90 mn after earthquake

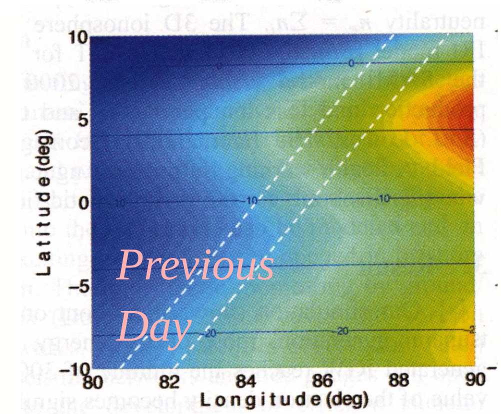


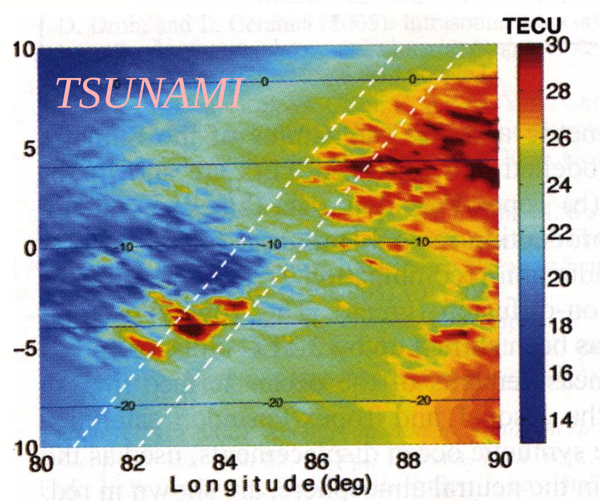
SUMATRA 2004

Perturbations detected in ionospheric
Total **E**lectron **C**ontent [*Liu et al.*, 2006]

Successfully modeled by *Occhipinti et al.* [2006].







FROM AIR DOWN …

or

Seismometers Listening

to Loud Sound !

SEISMOMETERS RECORD ATMOSPHERIC WAVES

Project "Царь Бомба"

23 October 1961

Journal of Geophysical Research Volume 67, No. 10 September 1962

Propagation of Acoustic-Gravity Waves in the Atmosphere[1]

Frank Press and David Harkrider

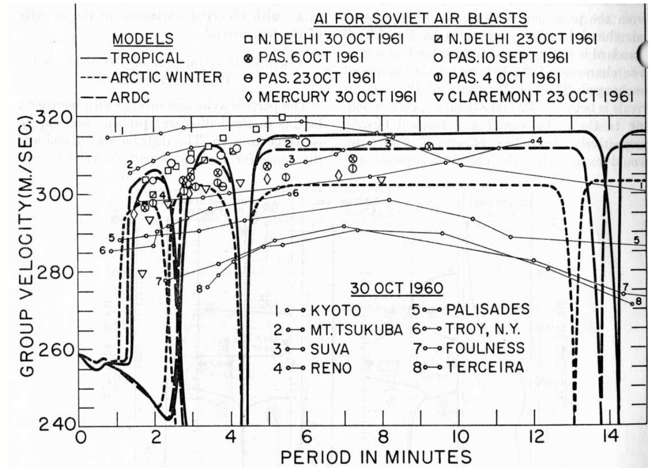


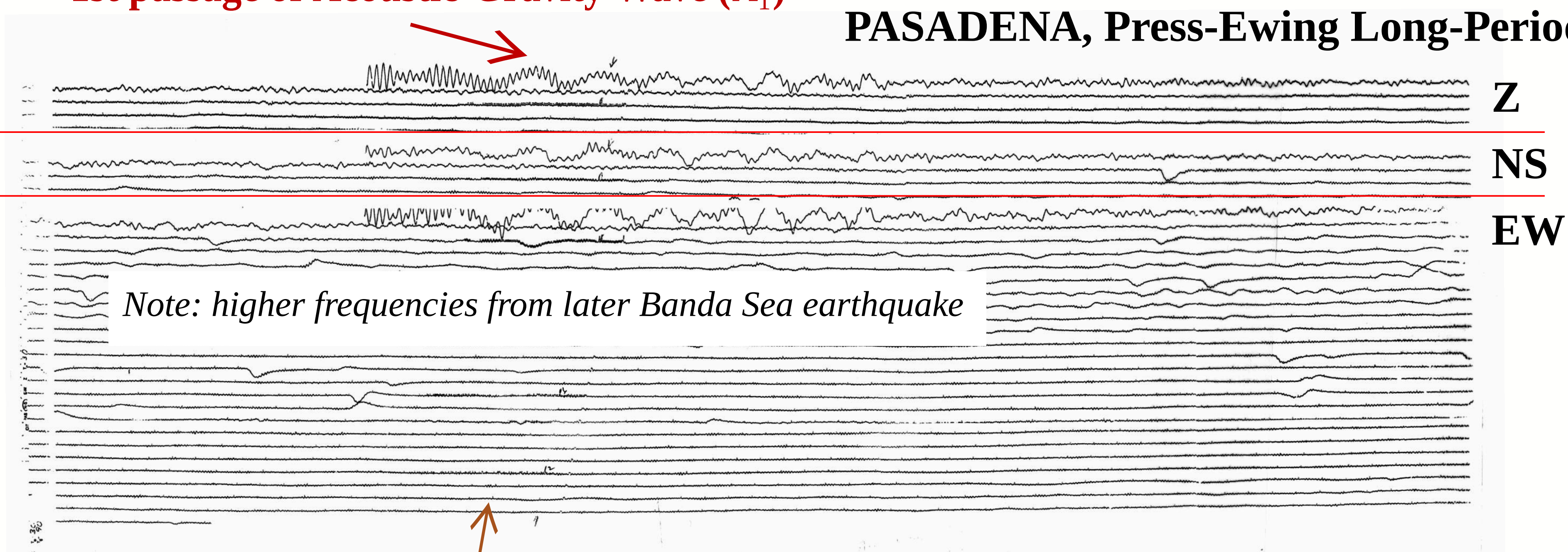
Fig. 18. Comparison of experimental group velocities for A_1 waves from Novaya Zemlya explosions with standard and extreme ARDC models. Data curves 1 to 8 from *Donn and Ewing* [1962].

Novaya Zemlya

25 Megatons

1st passage of Acoustic-Gravity Wave (A_1)

PASADENA, Press-Ewing Long-Period



Note: higher frequencies from later Banda Sea earthquake

2nd passage (A_2)

[Courtesy *D.G. Harkrider*]

SEISMOMETERS RECORD BOLIDE EXPLOSION

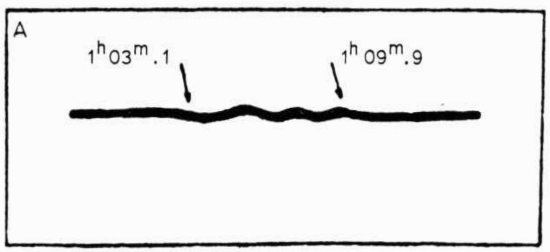
Tungunska (Siberia)

SOURCE PARAMETERS OF THE SIBERIAN EXPLOSION OF JUNE 30, 1908, FROM ANALYSIS AND SYNTHESIS OF SEISMIC SIGNALS AT FOUR STATIONS

ARI BEN-MENAHEM

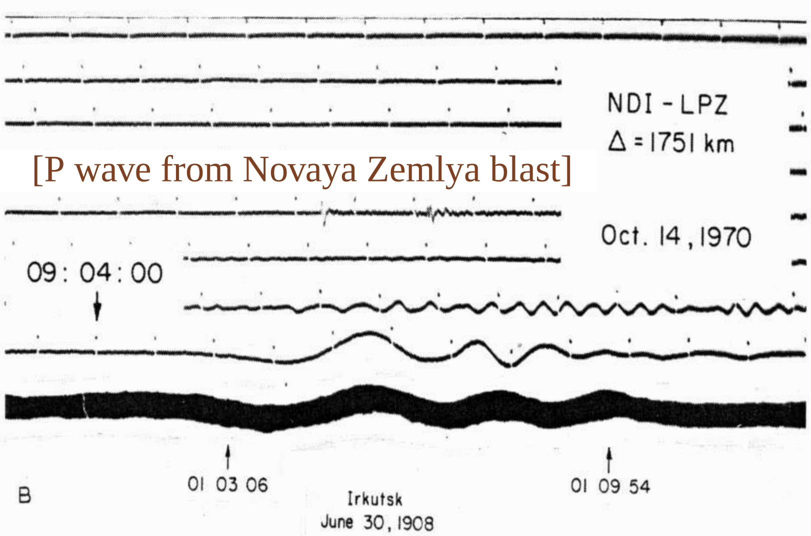
Phys. Earth Planet. Int., **11,** 1−35, 1975

30 June 1908 (n.s.)



Irkustsk, 1908

Air Wave



[P wave from Novaya Zemlya blast]

NDI (Lop Nor), 1970

Rayleigh Air Wave

Irkustsk, 1908

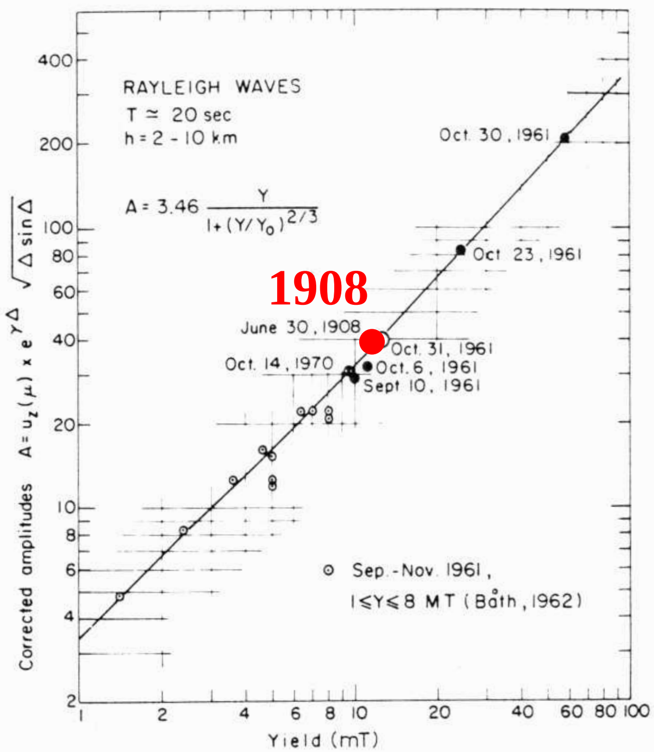
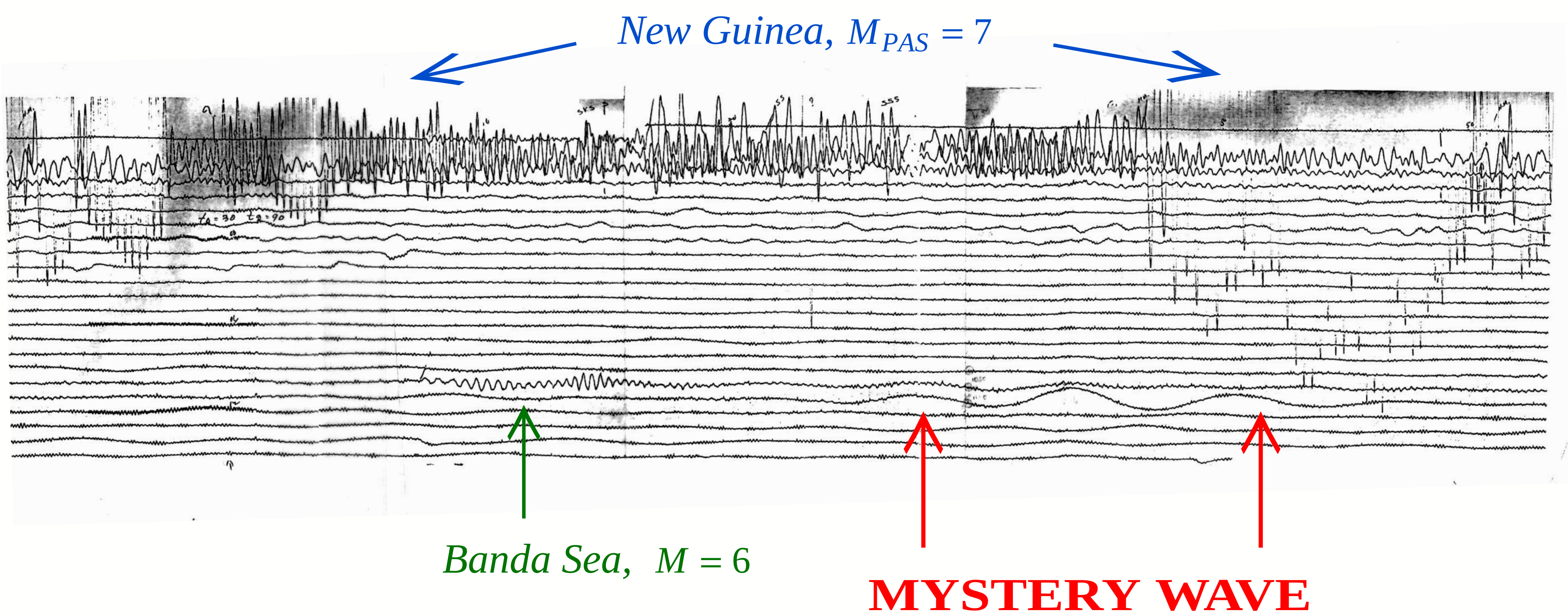


Fig. 12. Dependence of the Rayleigh-wave amplitude at 20 sec on the yield of the air explosion.

Yield from Body- and Rayleigh-wave modeling: **12.5 Megatons**

MYSTERY WAVES RECORDED ON L.P. SEISMOMETERS

PASADENA 02 MAR 1959 — *Press Ewing East-West*

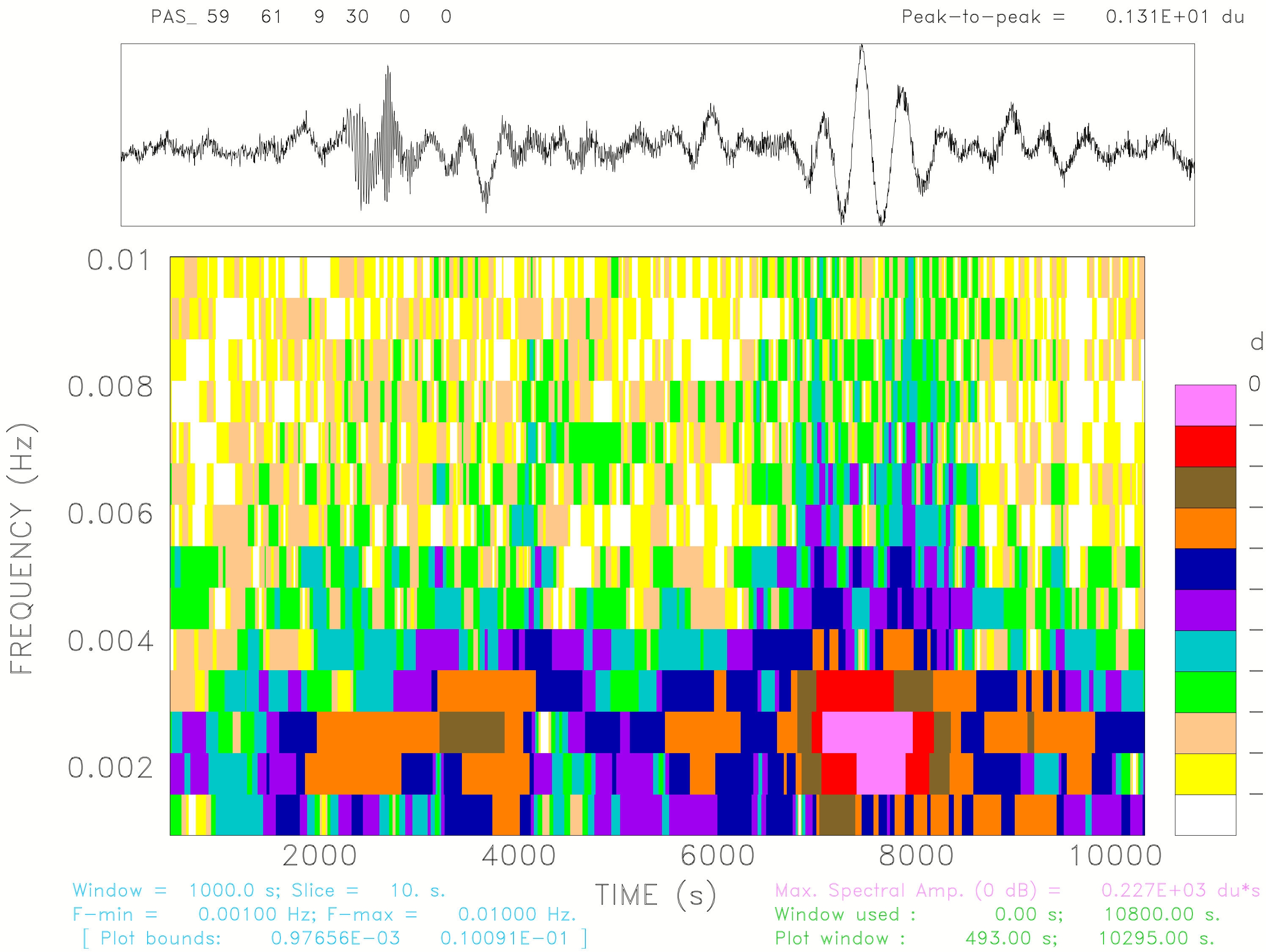


The "Mystery Wave" is an extremely long-period oscillation ($T \approx 500$ s) recorded on all L.P. instruments at Pasadena, but absent at other stations.

THE MYSTERY WAVE (ctd.)

PASADENA — *02 MARCH 1959*

The "Mystery Wave" is reminiscent of atmospheric waves generated by large explosions (volcanic or man-made), nut none is known at the time.



IT IS NOT RECORDED ANYWHERE ELSE

THE MYSTERY WAVE : MORNING GLORY

- **2004:** *Tsai, Kanamori and Artru* crack the case of the mystery waves, showing that they are non-linear internal gravity waves, trapped by a temperature inversion inside the Los Angeles Basin, where they propagate at very slow speeds (5 to 25 m/s).

The morning glory wave of southern California

Victor C. Tsai, Hiroo Kanamori, and Juliette Artru
Seismological Laboratory, California Institute of Technology, Pasadena, California, USA

Received 21 May 2003; revised 26 September 2003; accepted 14 November 2003; published 13 February 2004.

J. Geophys. Res. **109,** *(B2)*, B02307, 11 pp., 2004.

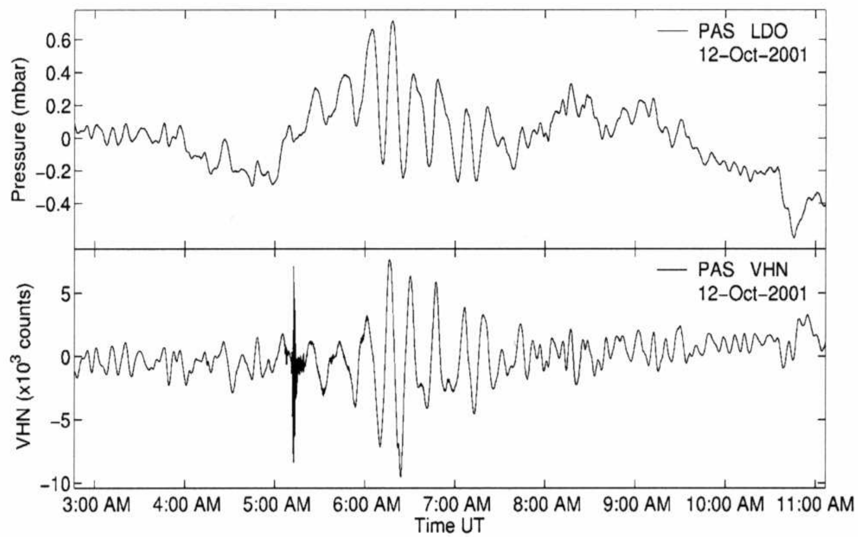
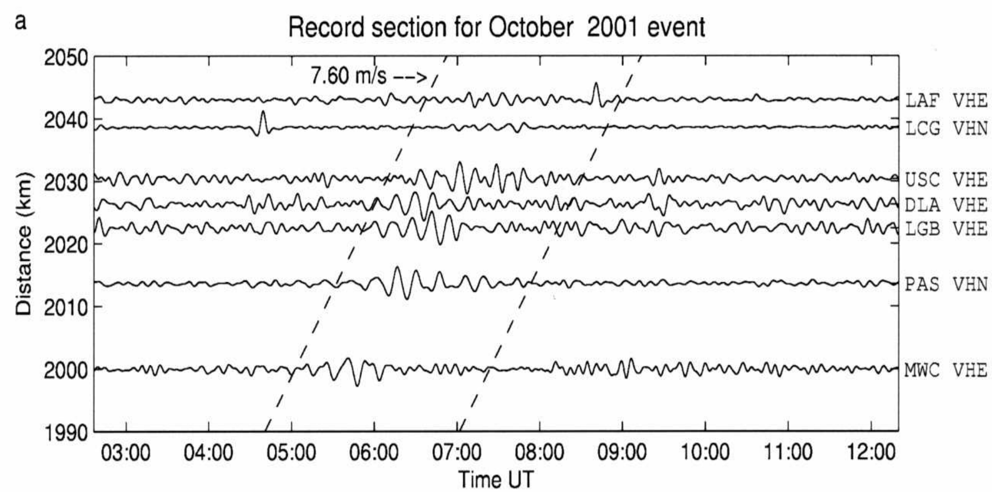


Figure 1. (top) Barograph record and (bottom) seismogram (very broadband channel) from station Pasadena for the 12 October 2001 event. The signals are correlated well in the ~1000 s period range. As a further note, there is an earthquake in Figure 1 (bottom) at around 0510 LT. For further information, refer to section 4.2.



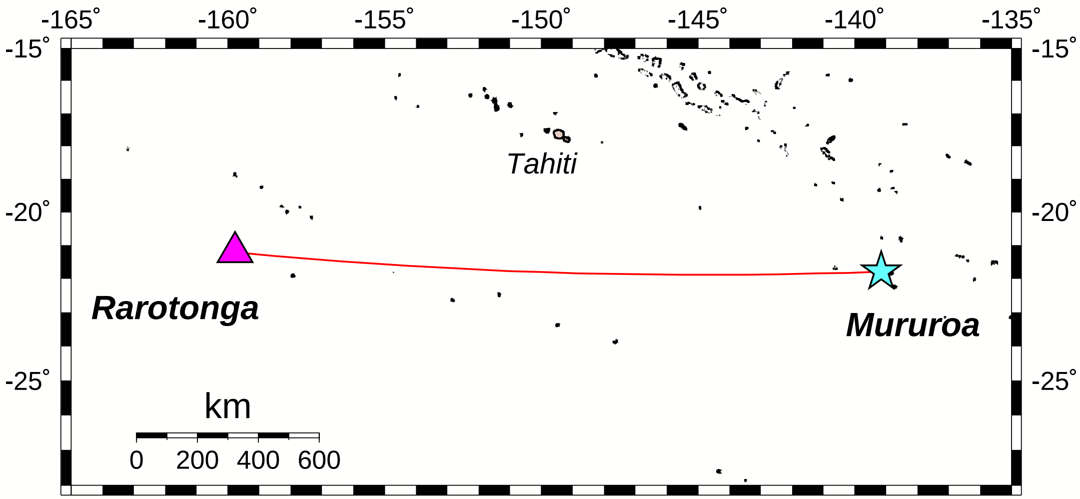
- This phenomenon was observed in Northern Australia, where it was called the "Morning Glory", and studied by *Christie et al.* [1978] and *Clarke et al.* [1981].

FROM AIR TO WATER TO GROUND

More Bombs at Sea

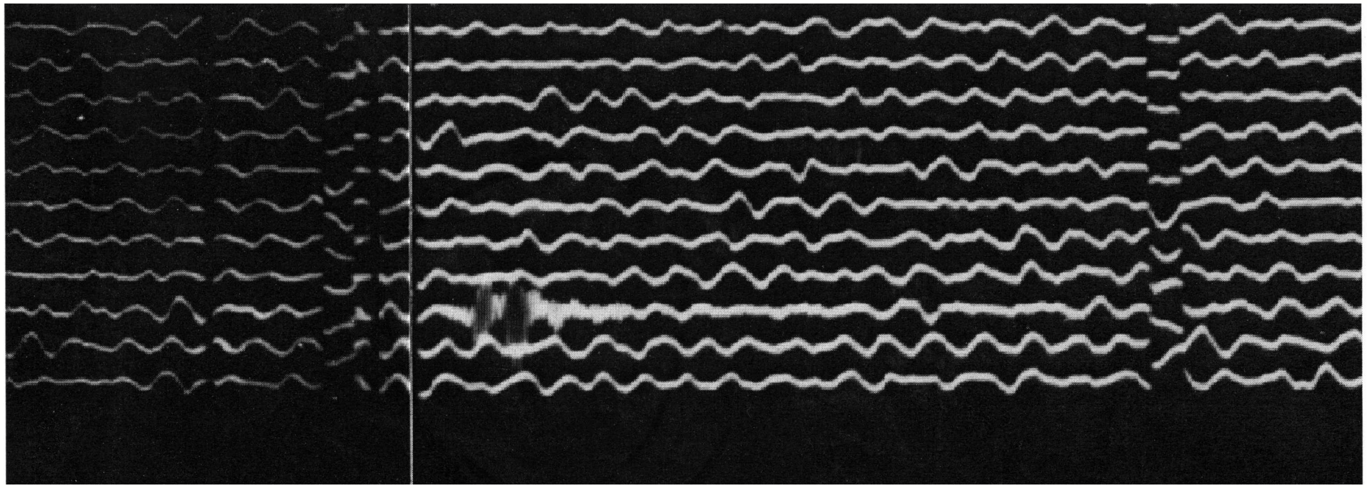
SEISMOMETERS DETECT *T* PHASES FROM ATMOSPHERIC NUCLEAR EXPLOSIONS

"PROCYON", *Mururoa Atoll, 08 SEPTEMBER 1968*



1.28 Megatons

Rarotonga, Cook Islands, WWSSN SPZ, Original magnification × 6250



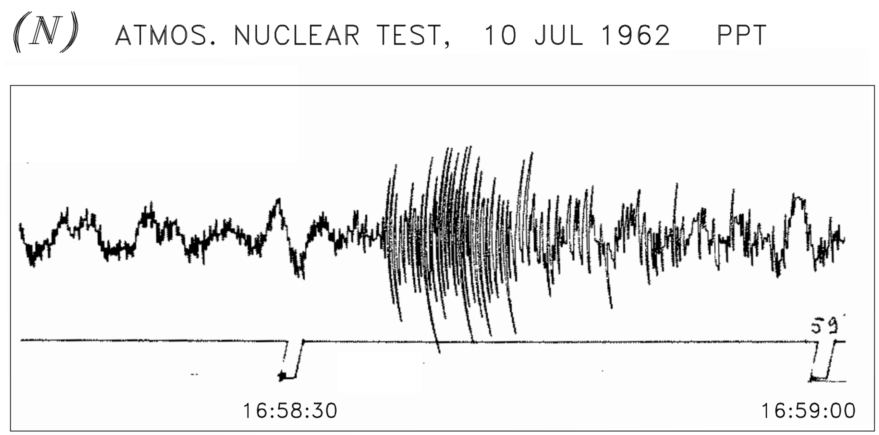
Note large amplitude (26 μm/s) but very short duration (2.7 s).

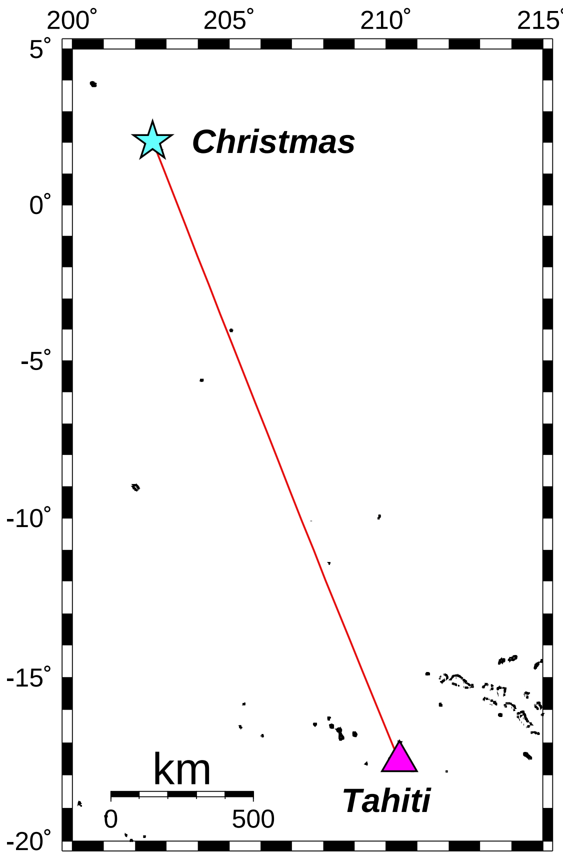
SEISMOMETERS DETECT *T* PHASES FROM ATMOSPHERIC NUCLEAR EXPLOSIONS (ctd.)

"SUNSET" *(Operation DOMINIC)*

10 JULY 1962

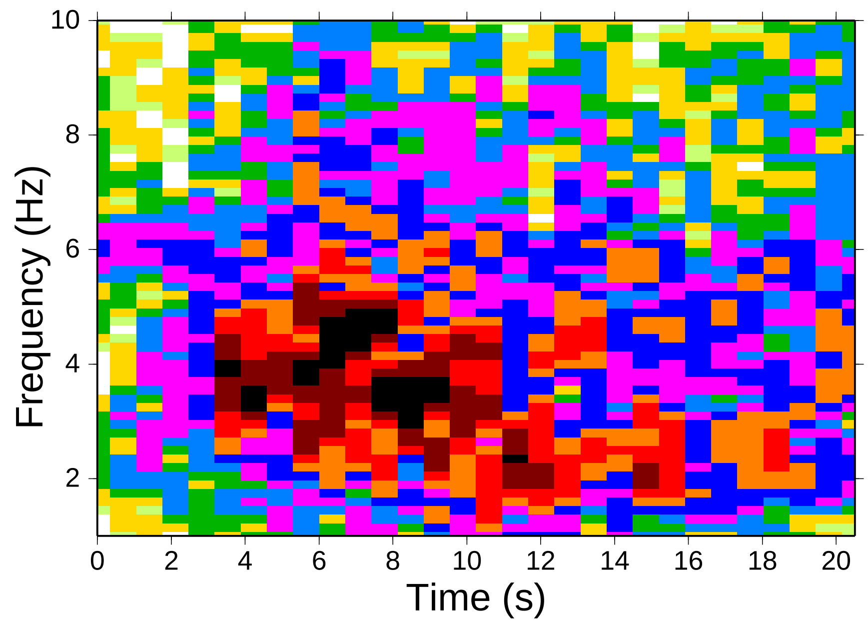
Christmas Island





1 Megaton

Recorded at PPT, Tahiti

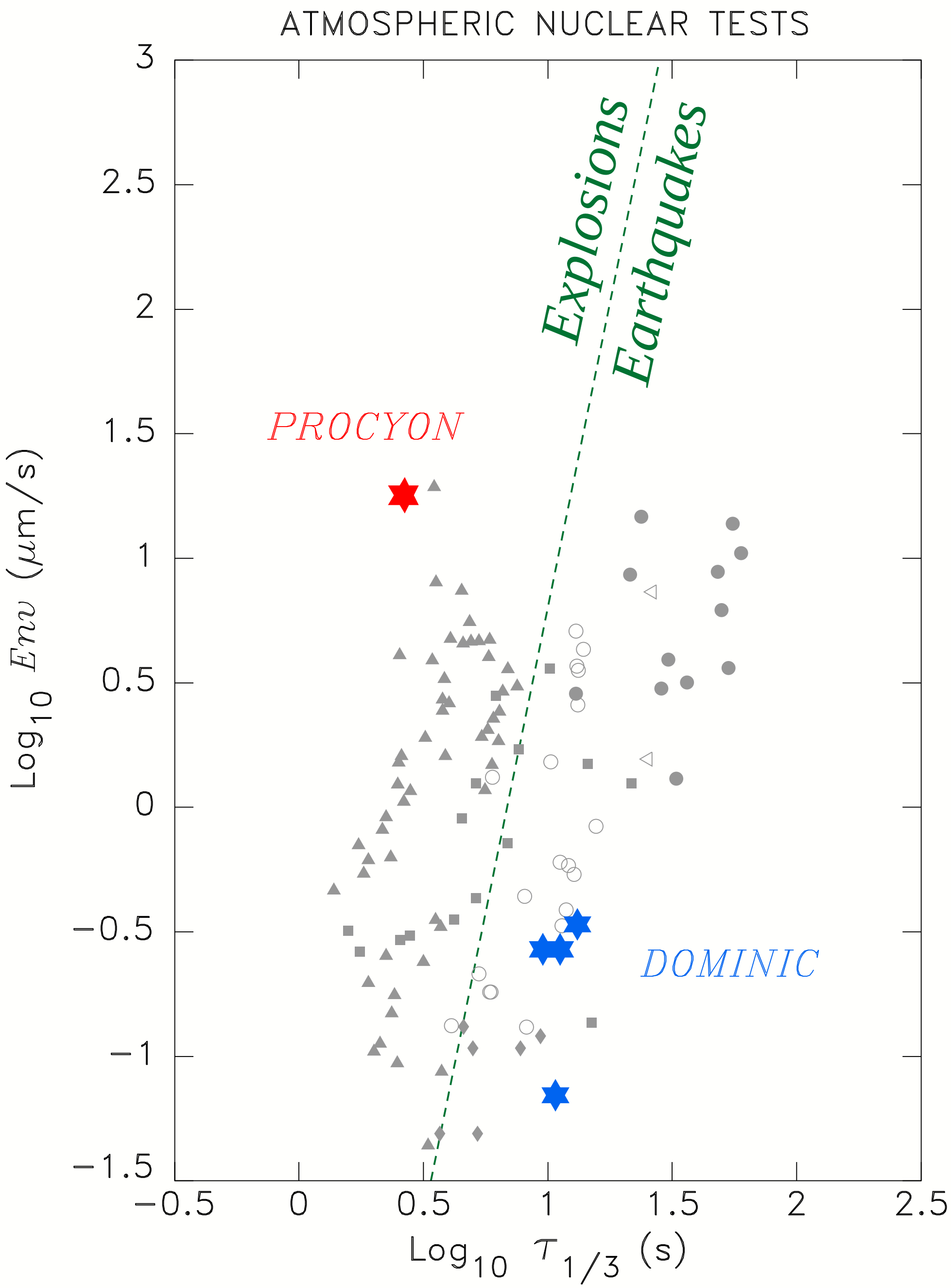


Note much smaller amplitude (0.27 μm/s) and longer duration (11.2 s).

- This difference in behavior would result in a *mis−identification* of the DOMINIC blasts as "earthquakes" using the amplitude-duration discriminant for T waves introduced by *Talandier and Okal* [2001].

→ As the T phase is probably generated by the shaking of the island structure inside the water column, itself due to the coupling of the air blast with the solid structure, the characterisitcs of the T wave are expected to be controled by the geometry of the atoll, in relation to the source.

- In this respect, we note differences in the [available] characteristics of the **PRO-CYON** and **DOMINIC** tests: altitude (**700 m** *vs.* **1.7 km**), location (**over the atoll** *vs.* **off shore**), and to a lesser extent in the size of the atolls themselves (**154** *vs.* **322** km^2).



THE OBS – OBH RELATIONSHIP

The Mourning of H 2 O

Ocean-Bottom Hydrophone operated as OBS

A simple generalization of body- and surface-wave theory in the presence of an oceanic layer shows that an ocean-bottom hydrophone can function as a seismometer, which will record

- Body-waves proportionally to ground velocity, *e.g.*, for P waves

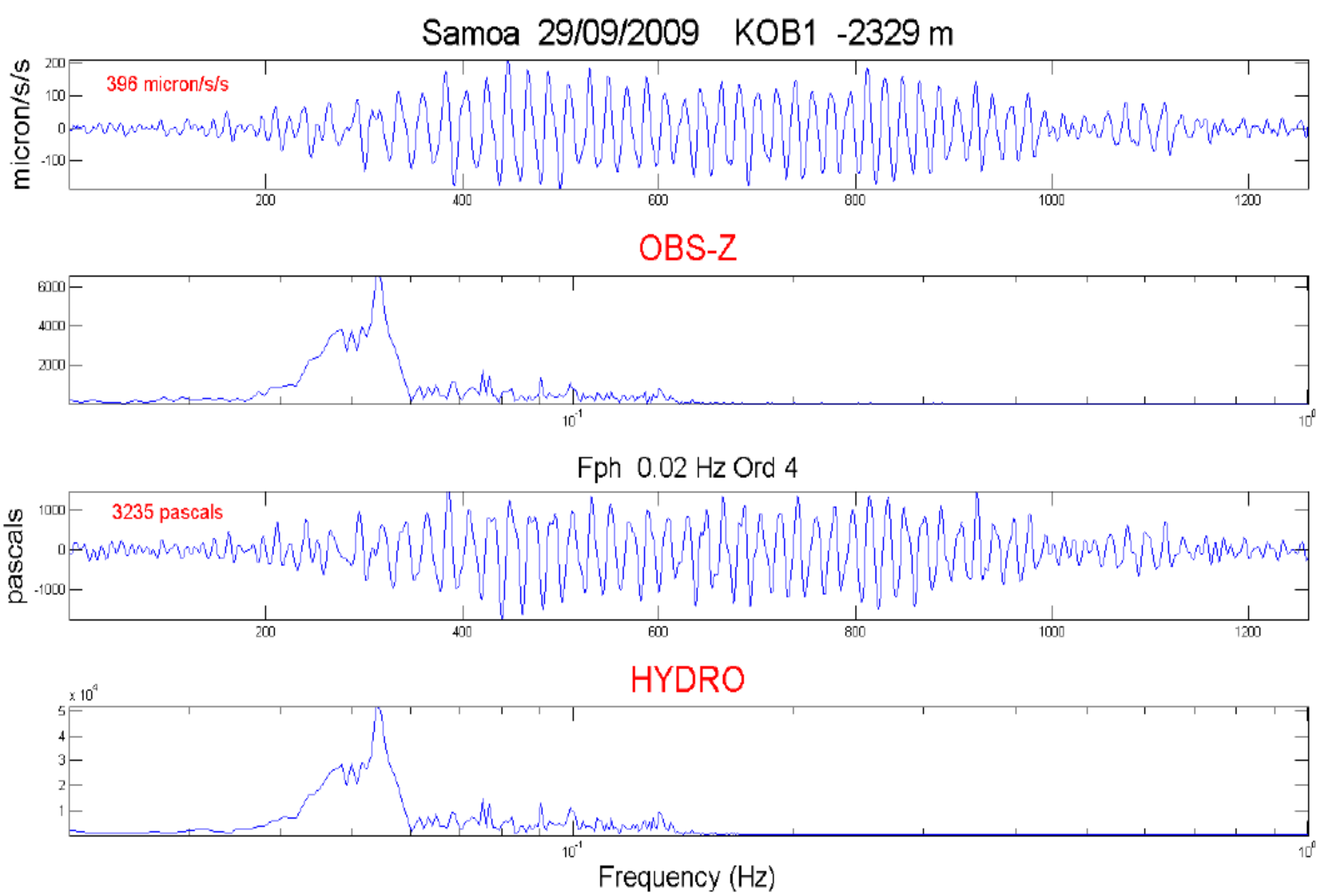
$$Z = \frac{P_s}{u_z} = \rho_l \, \alpha_l \, \omega$$

- Rayleigh waves, proportionally to *acceleration*, the response being itself proportional to the *thickness of the water column* (at long periods)

$$Z = \frac{P_s}{u_z} = \rho_l \, \omega^2 \, h$$

The latter is well verified using OBS and OBH records off the coast of Hokkaido

Samoa, 29 September 2009

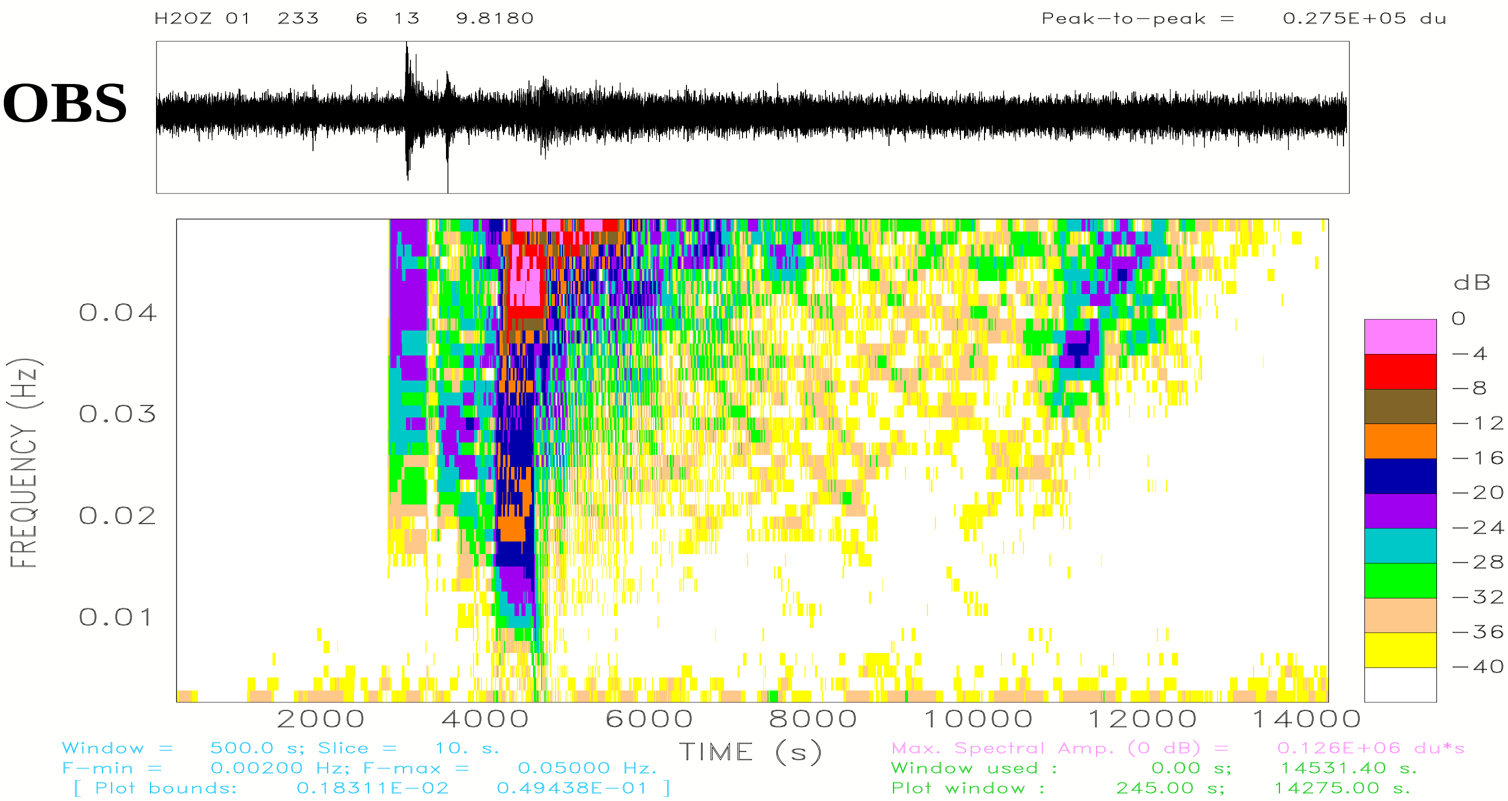


H2O: The LIMITATIONS of O.B.H.s

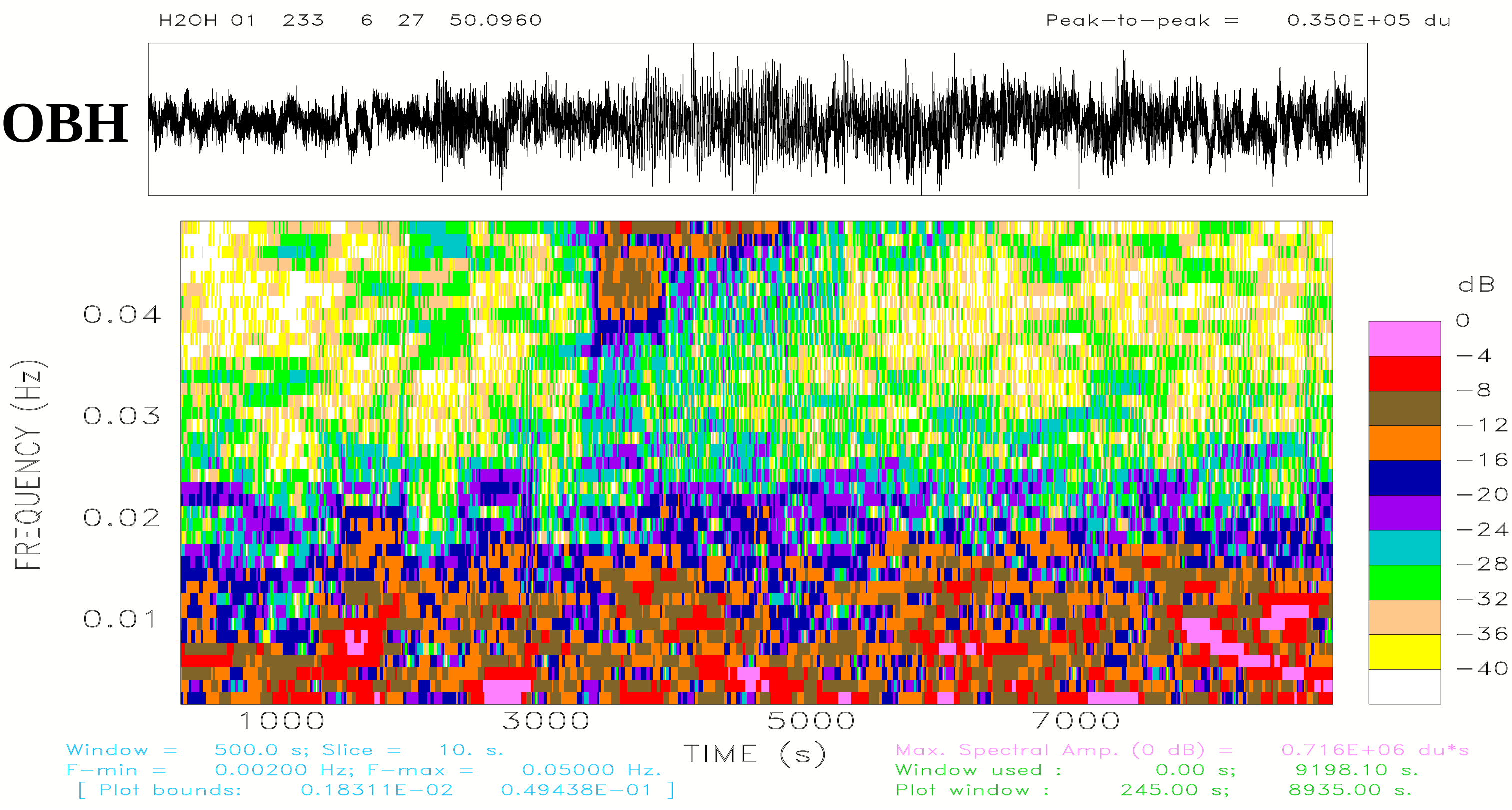
We compare here spectrograms of the same event recorded at H2O by an OBS and an OBH. Note *(i)* the low-frequency noise of the hydrophone; *(ii)* the lack of sensitivity at low-frequency (instrument working as an accelerometer)

21 AUG 2001 NEW ZEALAND

OBS



OBH



H2O: THE LONE TSUNAMI

During its short opertaion, H2O recorded one significant tsunami: the Peruvian event of 23 June 2001.

While the event is clearly detected, both by the horizontal OBS and by the hydrophone, the recording characteristics are strongly non-linear, possibly raising doubt about the coupling of the instrument to the ocean bottom. At any rate, such signals cannot be quantified.