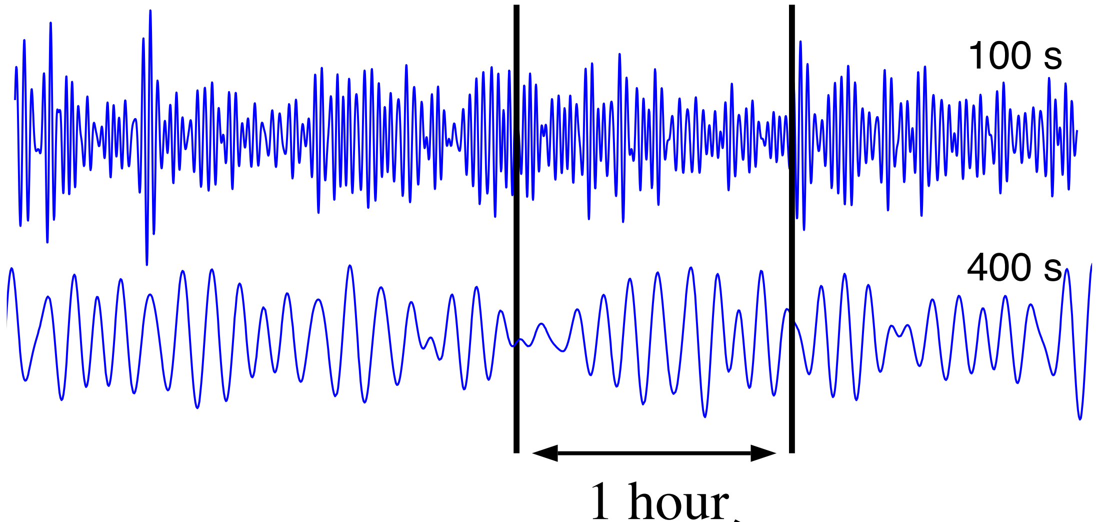
5. Data quality control using noise

6. Finding interesting things in the noise

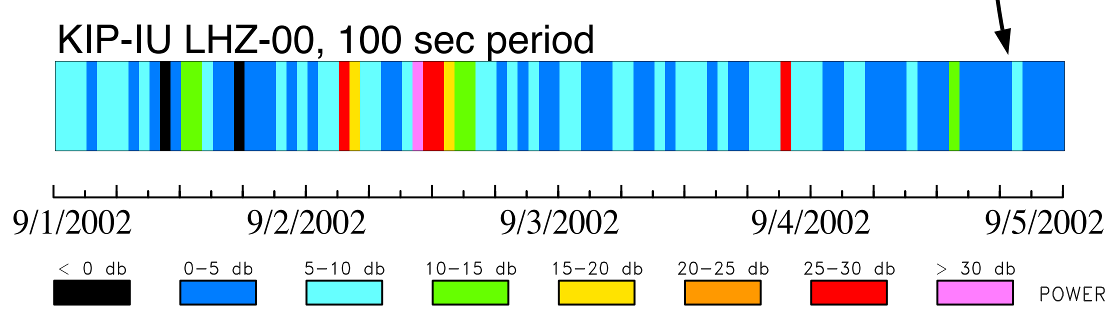
7. Using noise for tomography

Calculation of signal power of long-period GSN data

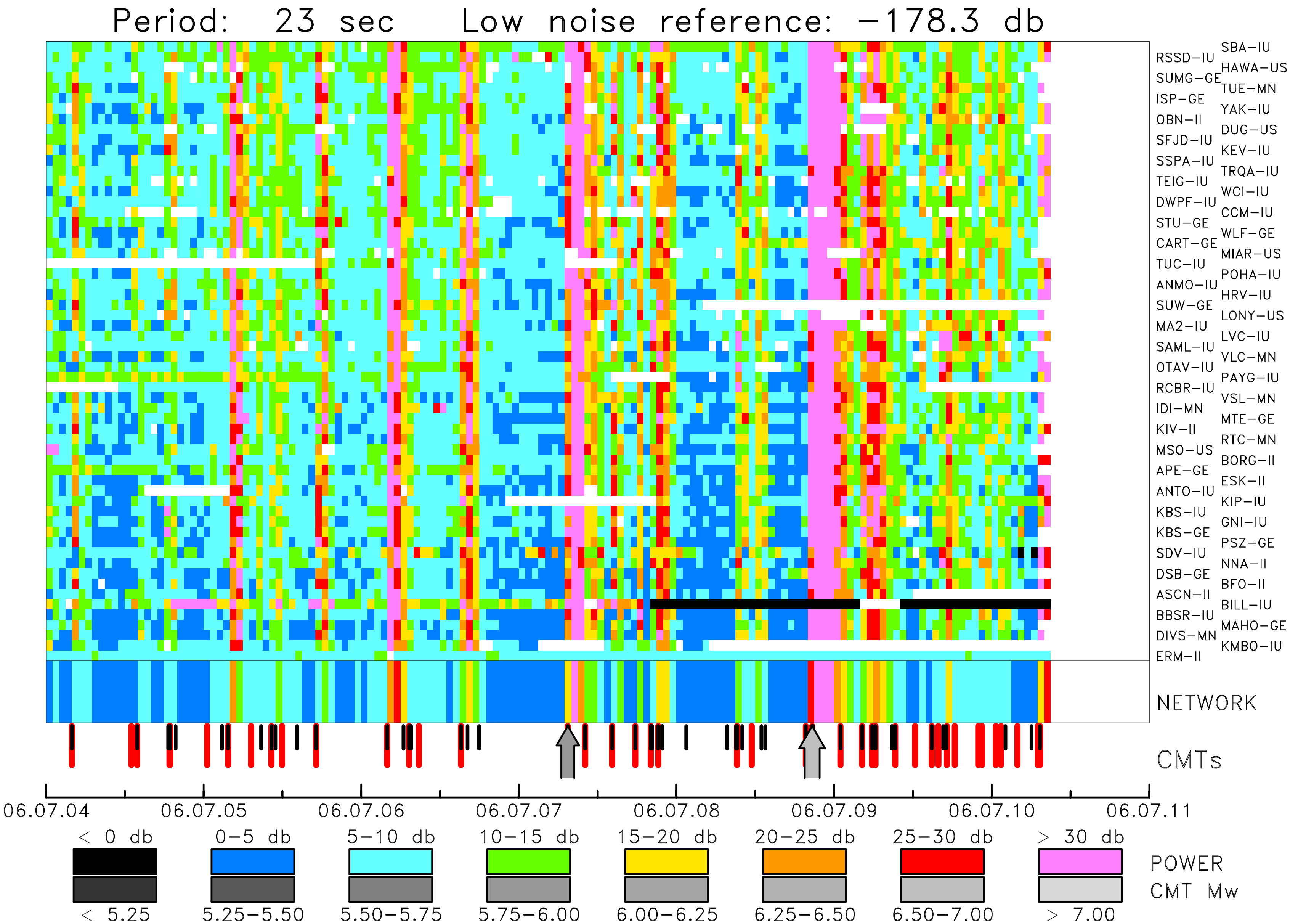
continuous filtered time series:



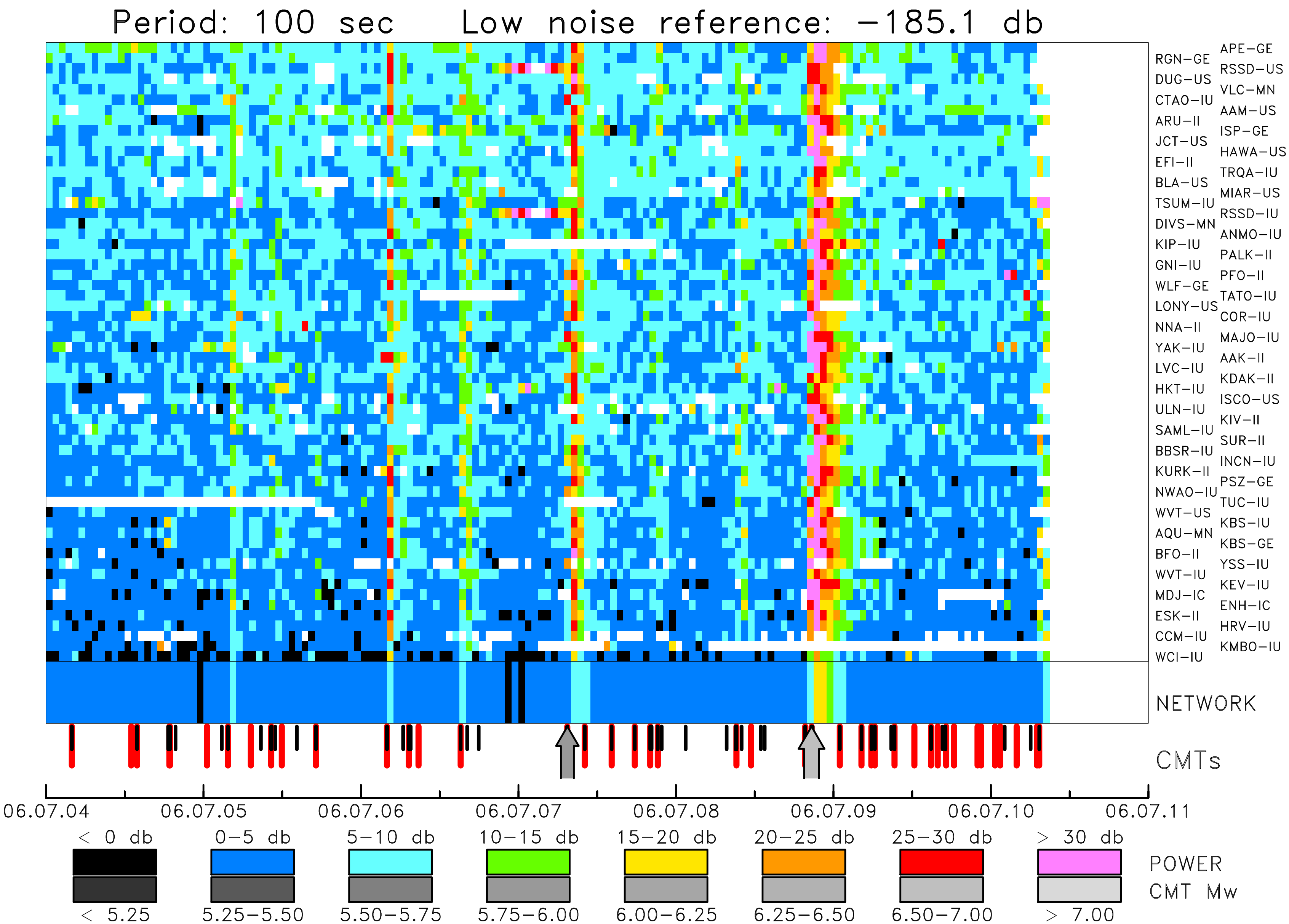
1. calculate rms
2. convert to power spectral density
3. store as hourly samples of signal level



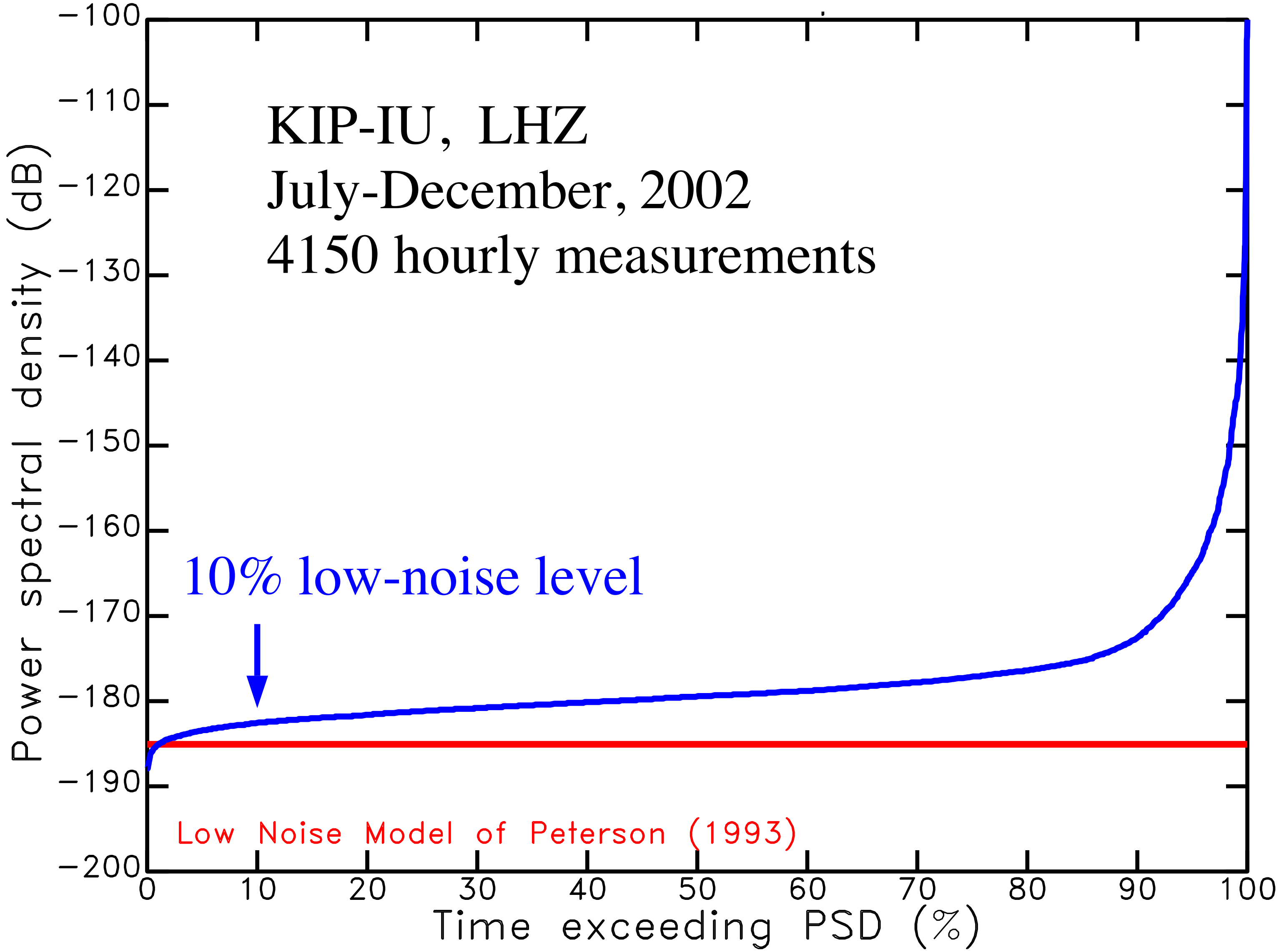
One week of noise at 23 seconds period



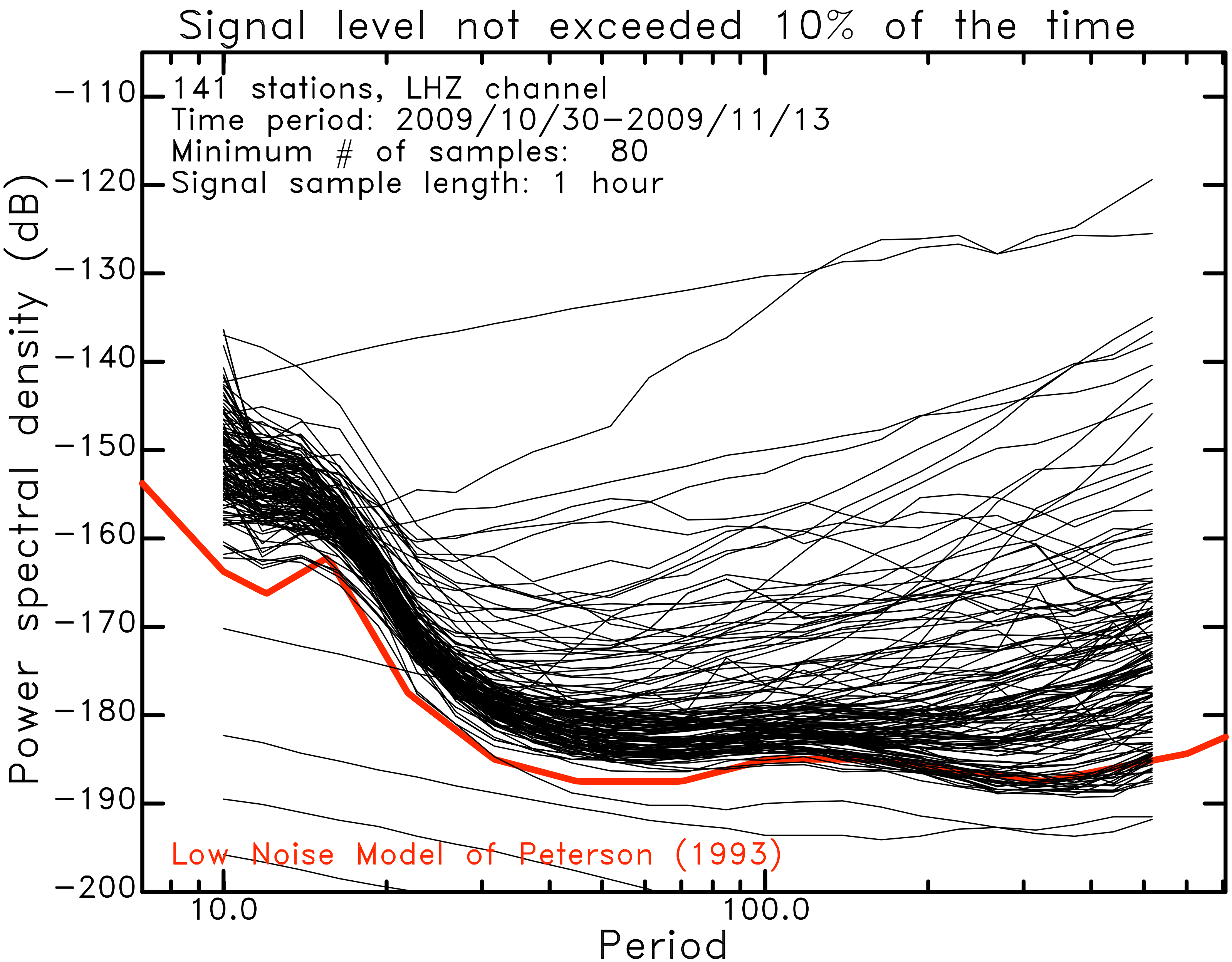
One week of noise at 100 seconds period



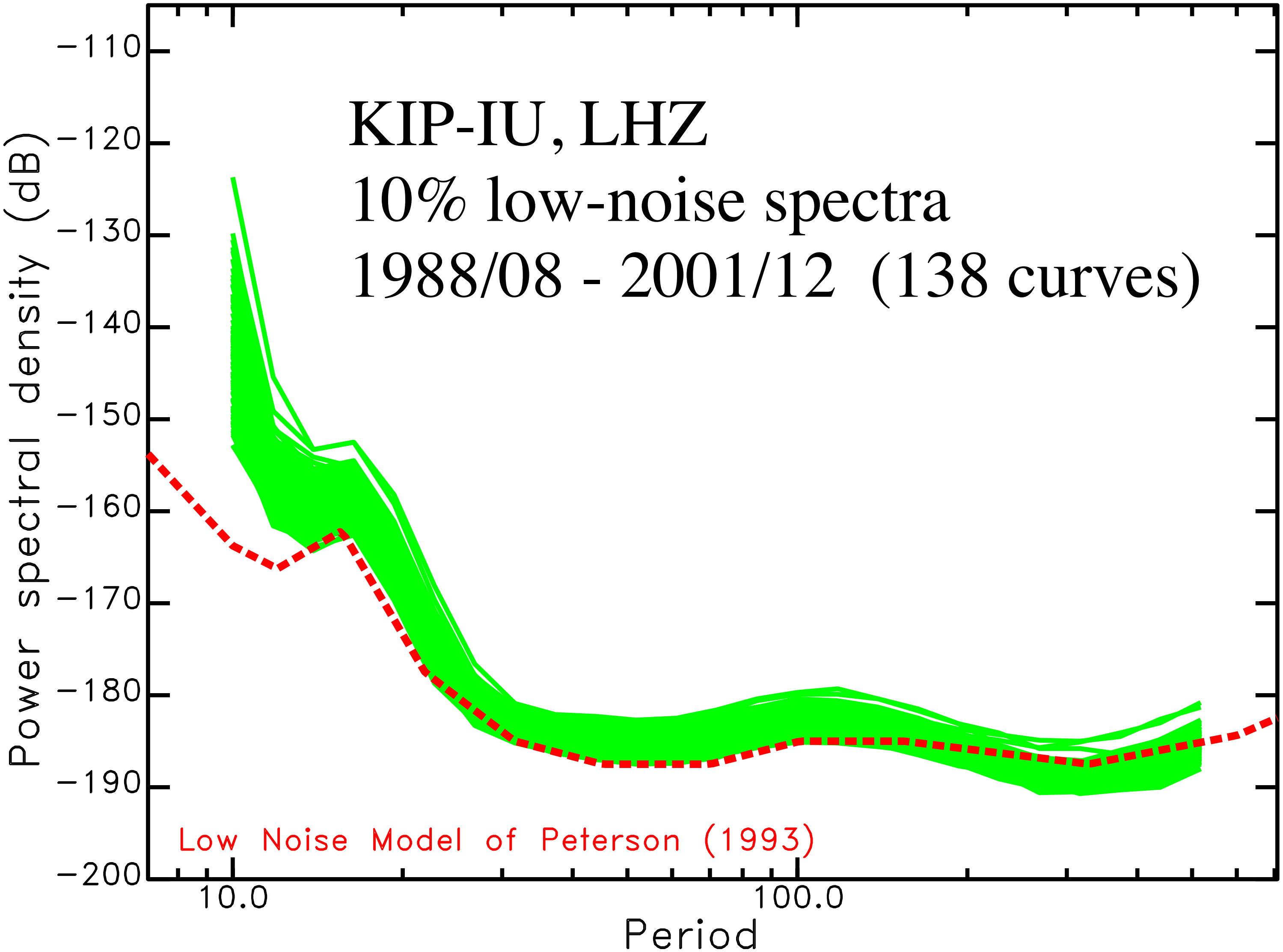
100 sec period - distribution of PSD



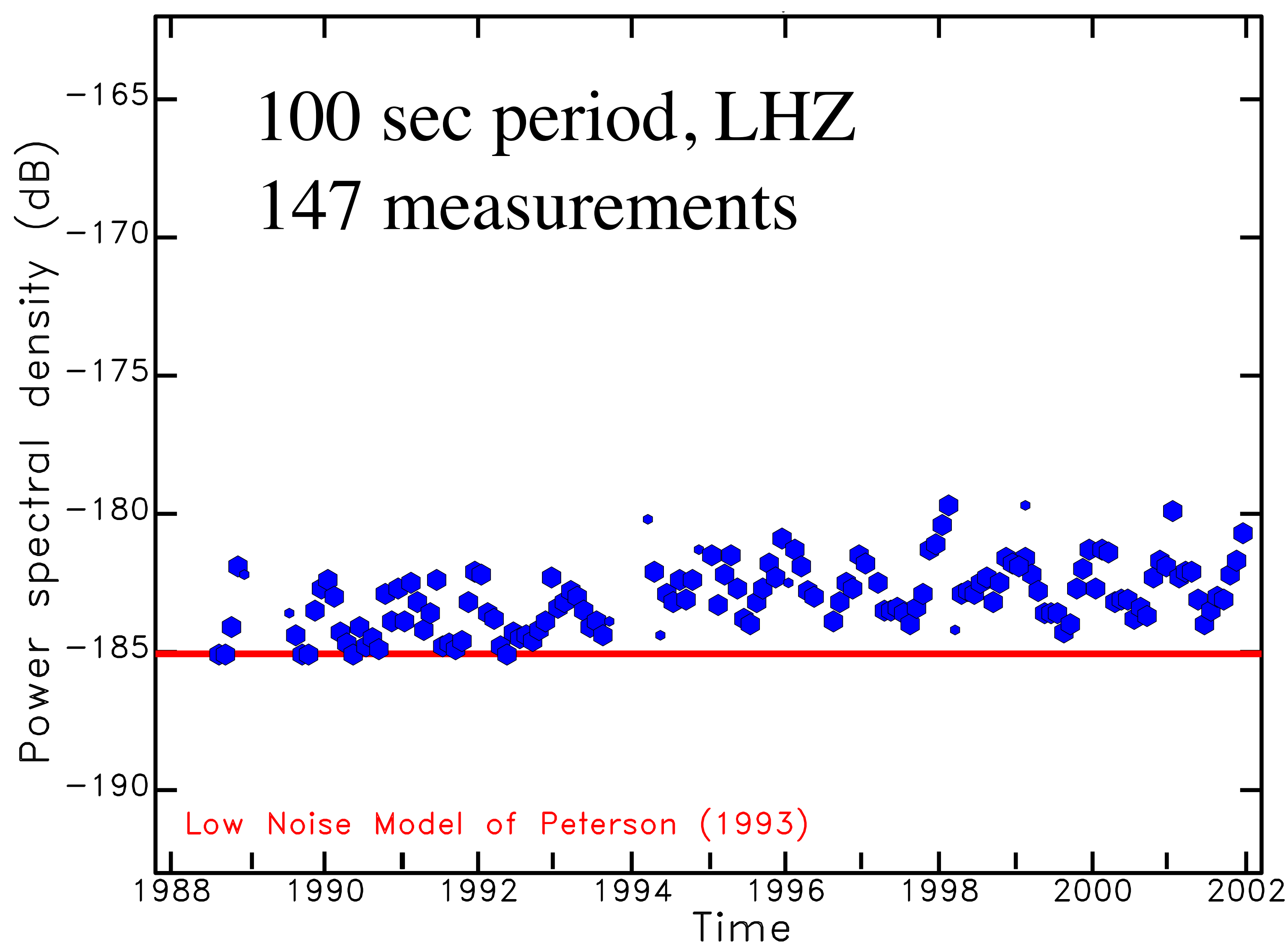
Noise spectra from the Global Seismic Network

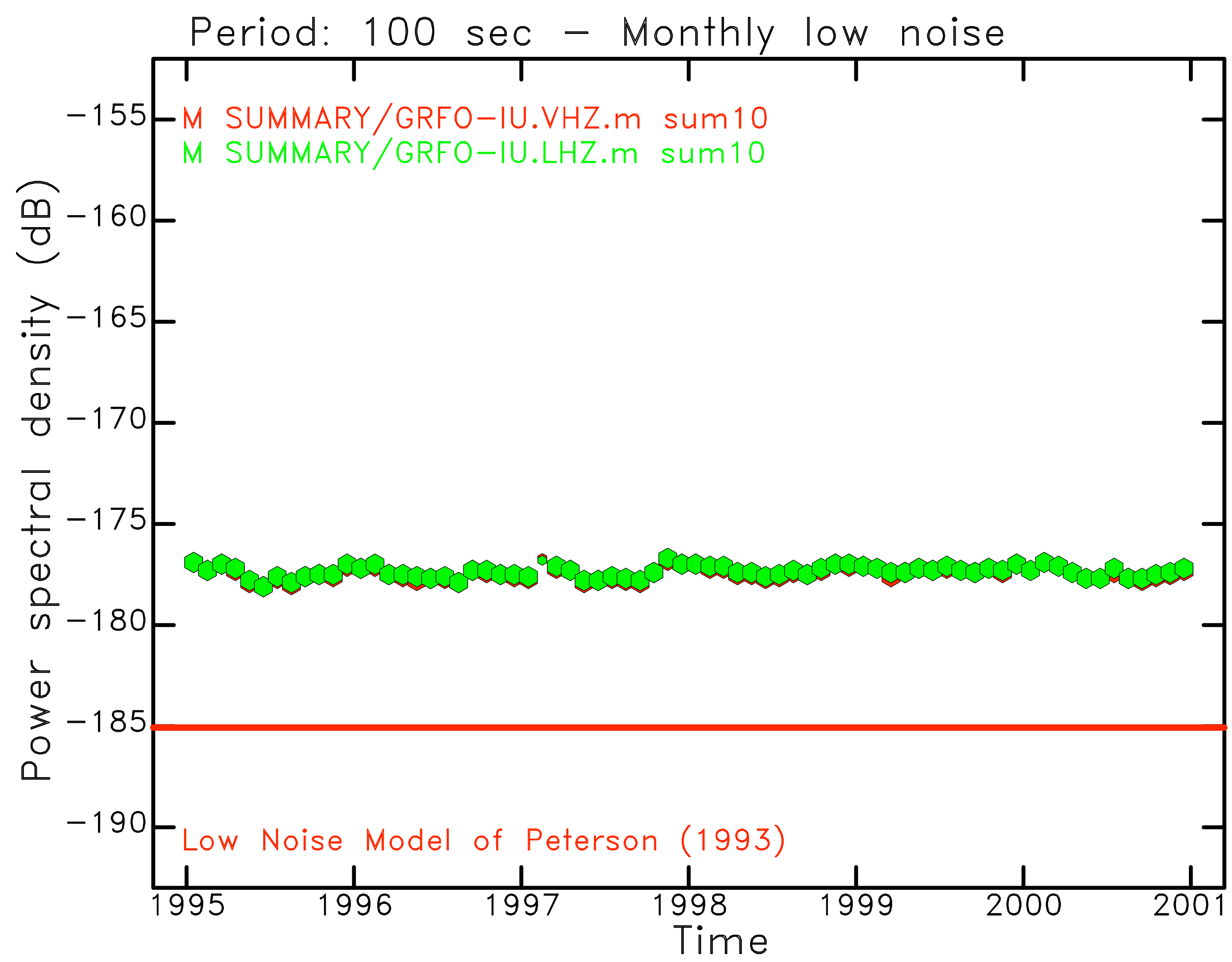


Stability of low-noise spectra

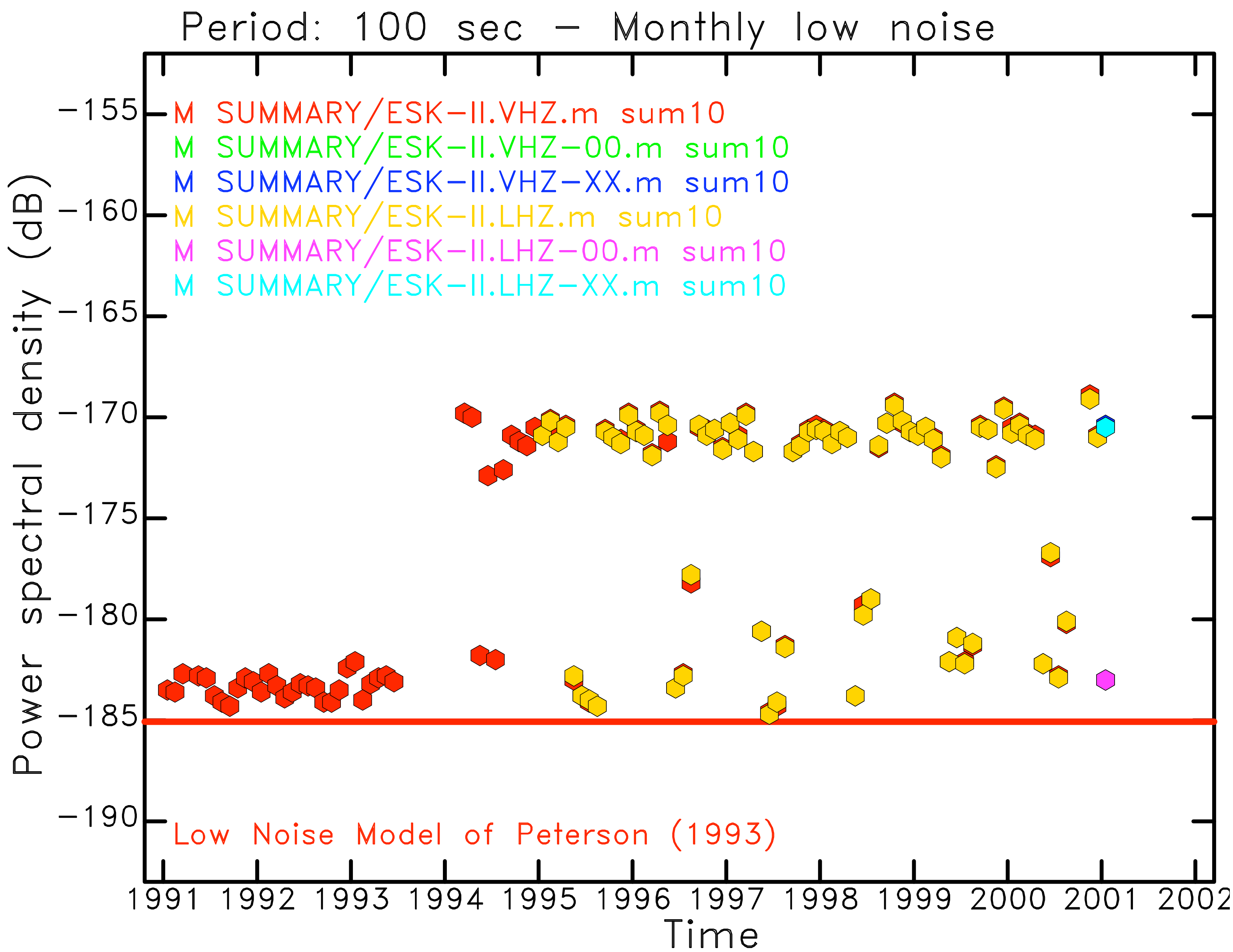


10% low-noise level at KIP since 1988





Period: 100 sec – Monthly low noise
M SUMMARY/GRFO-IU.VHZ.m sum10
M SUMMARY/GRFO-IU.LHZ.m sum10
Low Noise Model of Peterson (1993)
Power spectral density (dB)
−155
−160
−165
−170
−175
−180
−185
−190
1995
1996
1997
1998
1999
2000
2001
Time



Period: 100 sec - Monthly low noise
M SUMMARY/ESK-II.VHZ.m sum10
M SUMMARY/ESK-II.VHZ-00.m sum10
M SUMMARY/ESK-II.VHZ-XX.m sum10
M SUMMARY/ESK-II.LHZ.m sum10
M SUMMARY/ESK-II.LHZ-00.m sum10
M SUMMARY/ESK-II.LHZ-XX.m sum10
Low Noise Model of Peterson (1993)
Power spectral density (dB)
-155
-160
-165
-170
-175
-180
-185
-190
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
Time

6. Finding interesting things in the noise

7. Using noise for tomography

Seismographs record signals with frequencies between ~10 Hz to 1000 seconds.

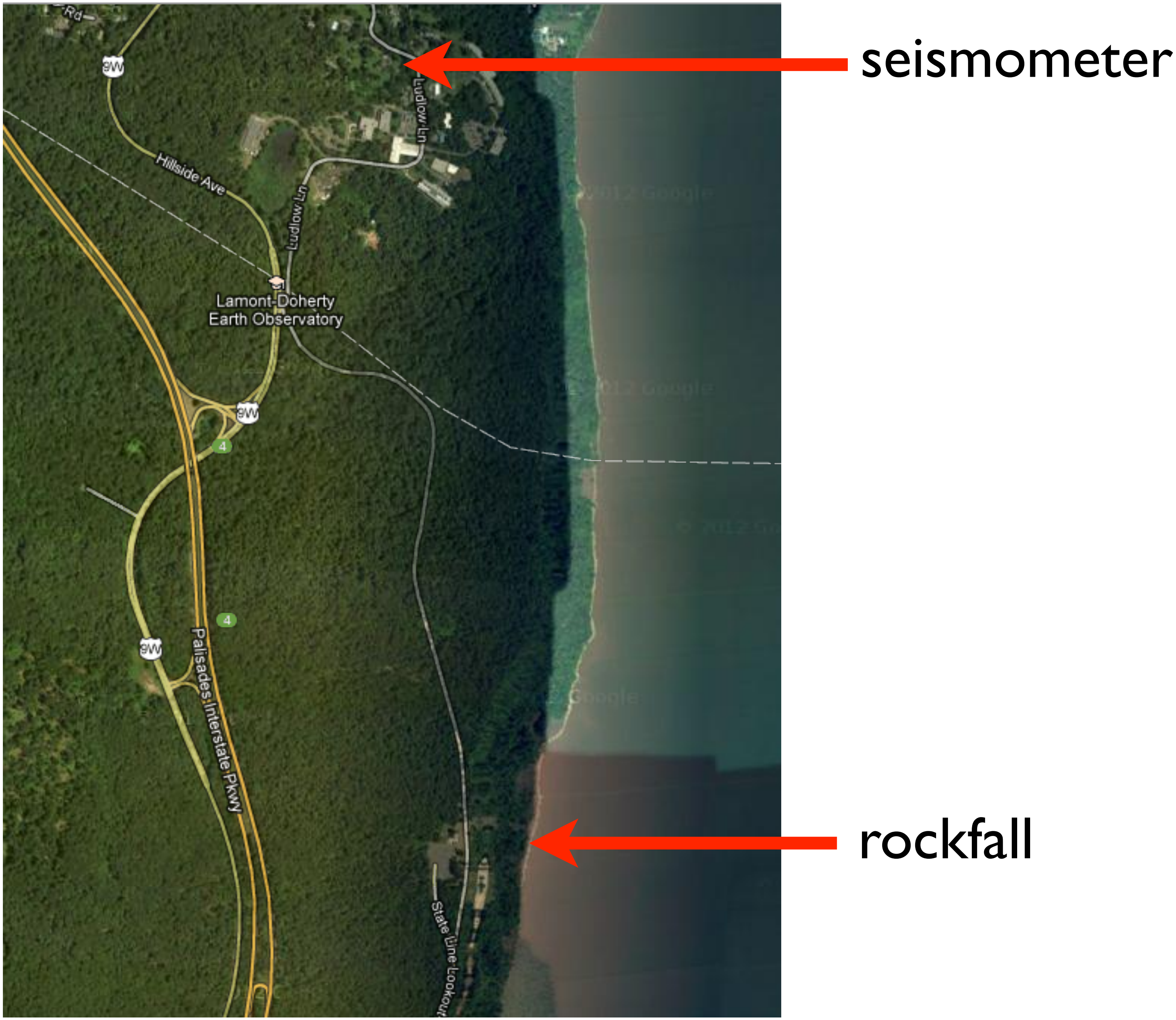
Earthquakes are detected and located using high-frequency signals (around 1 Hz).

Are there short-lived geophysical phenomena that generate seismic waves at long periods but that are not detected at short periods?

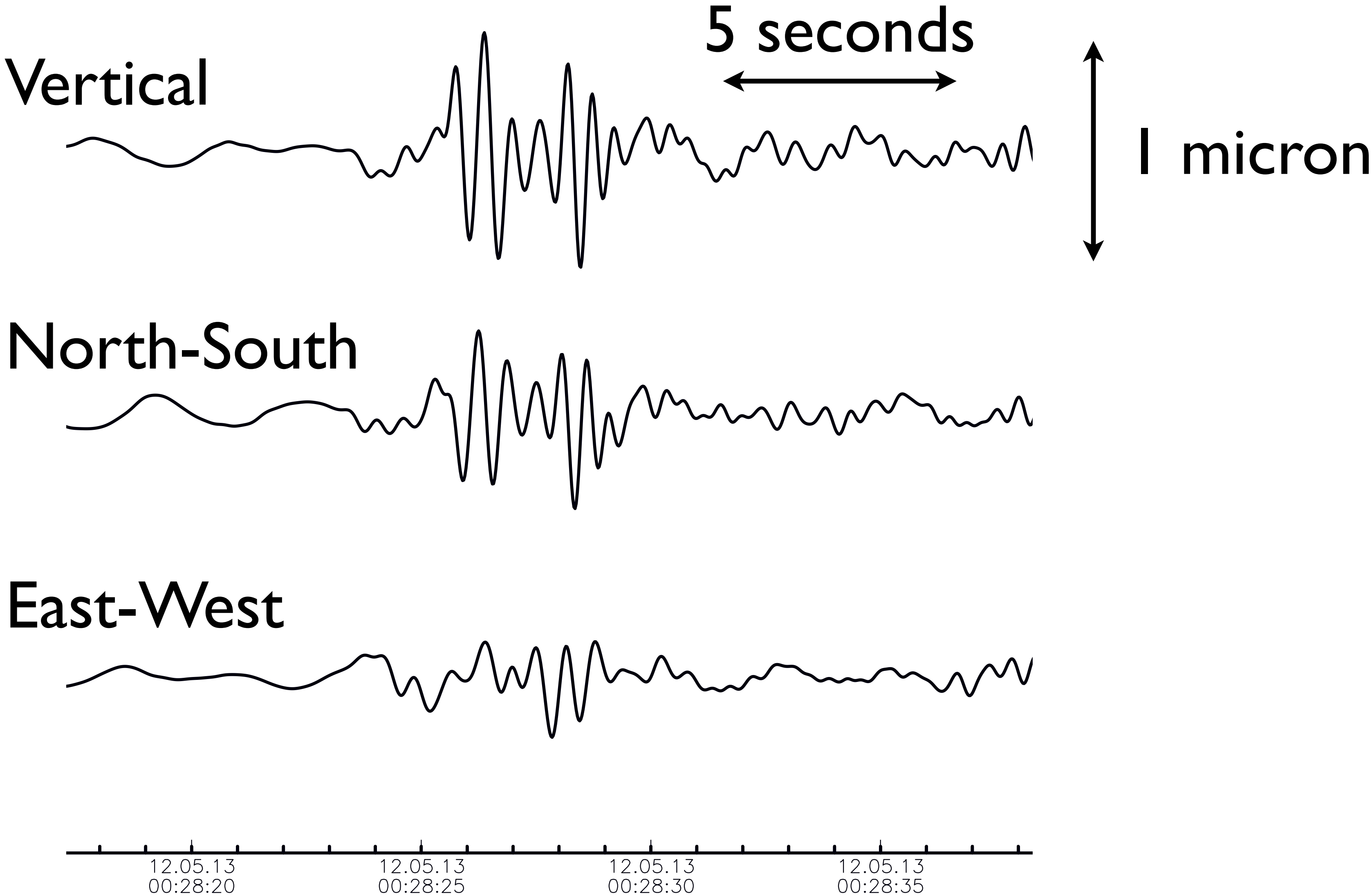
Palisades Rockfall, May 12, 2012

10,000 tons?

Photo: W. Menke


seismometer
rockfall
Hillside Ave
Ludlow Ln
Lamont-Doherty
Earth Observatory
9W
4
Palisades Interstate Pkwy
State Line Lookout

Ground vibration at Lamont, 1 km away



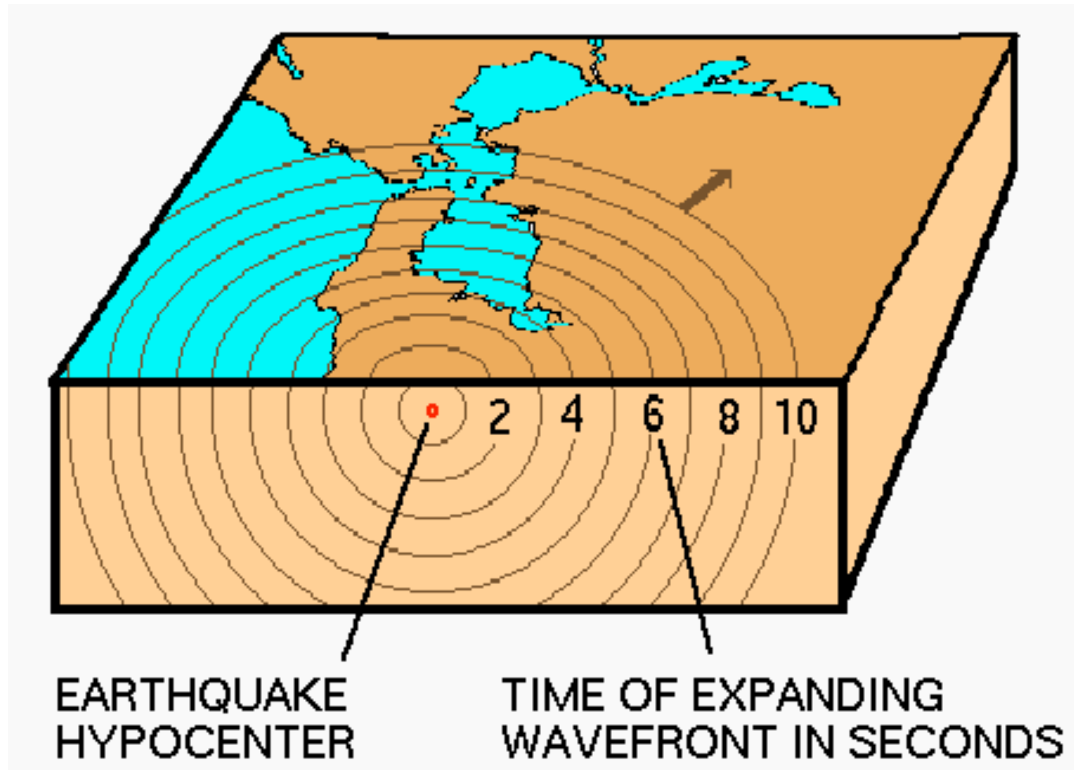
Seismographs record signals with frequencies between ~10 Hz to 1000 seconds.

Earthquakes are detected and located using high-frequency signals (around 1 Hz).

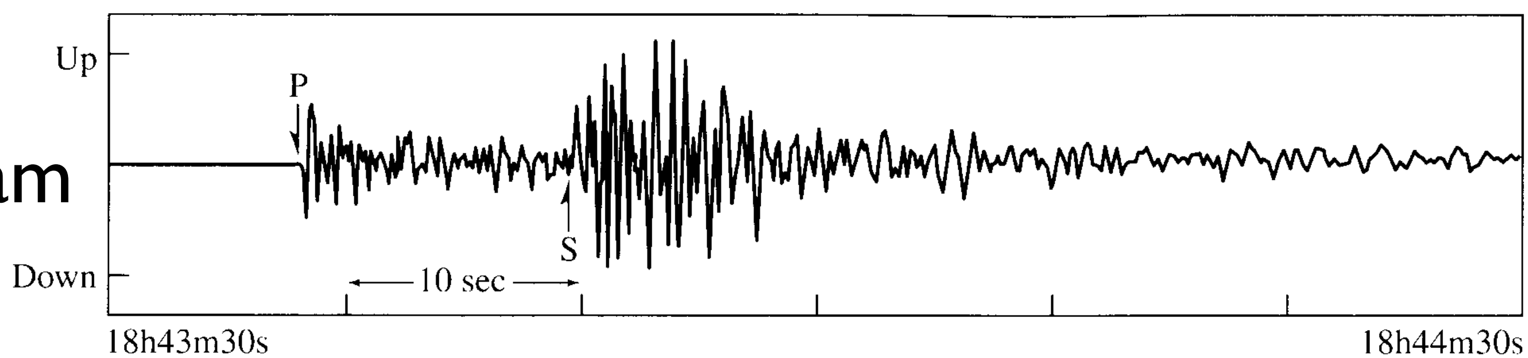
Are there short-lived geophysical phenomena that generate seismic waves at long periods but that are not detected at short periods?

How do we locate earthquakes? (1)

earthquakes send out vibrational waves

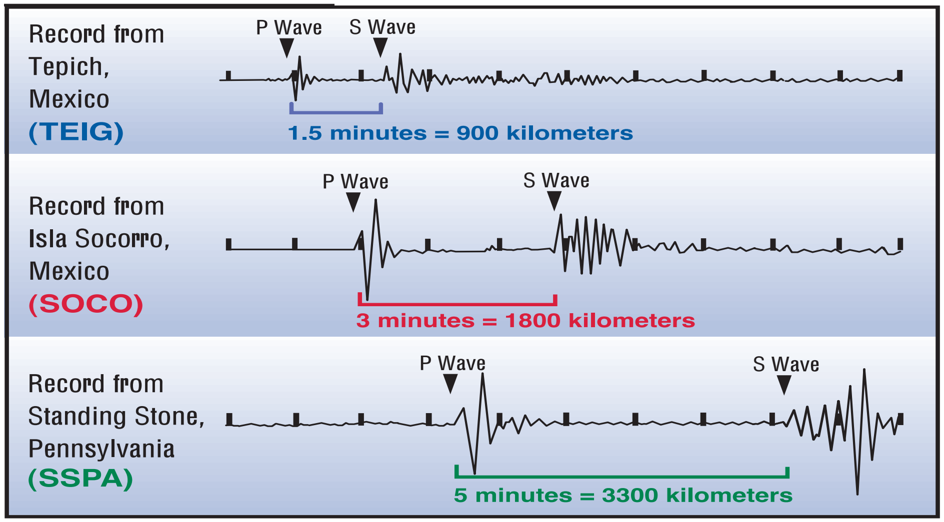


seismogram

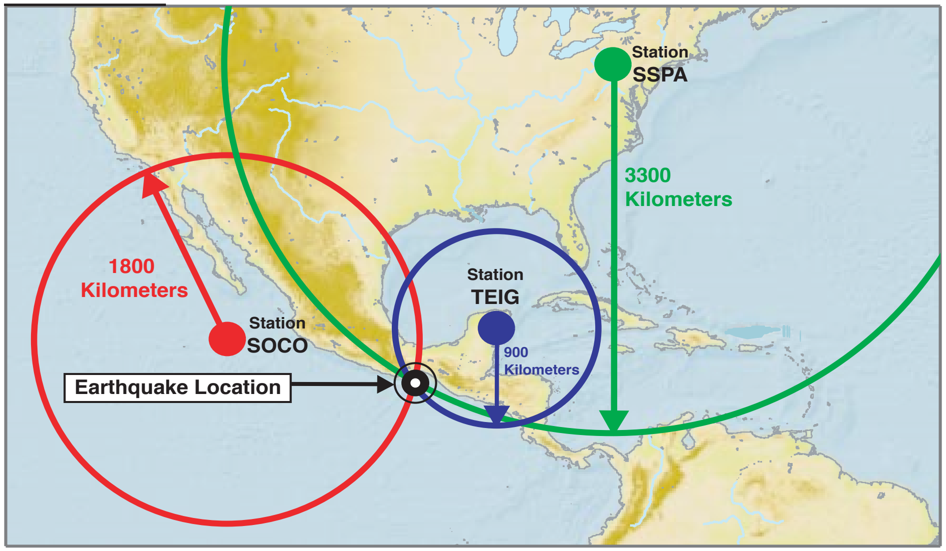


How do we locate earthquakes? (II)

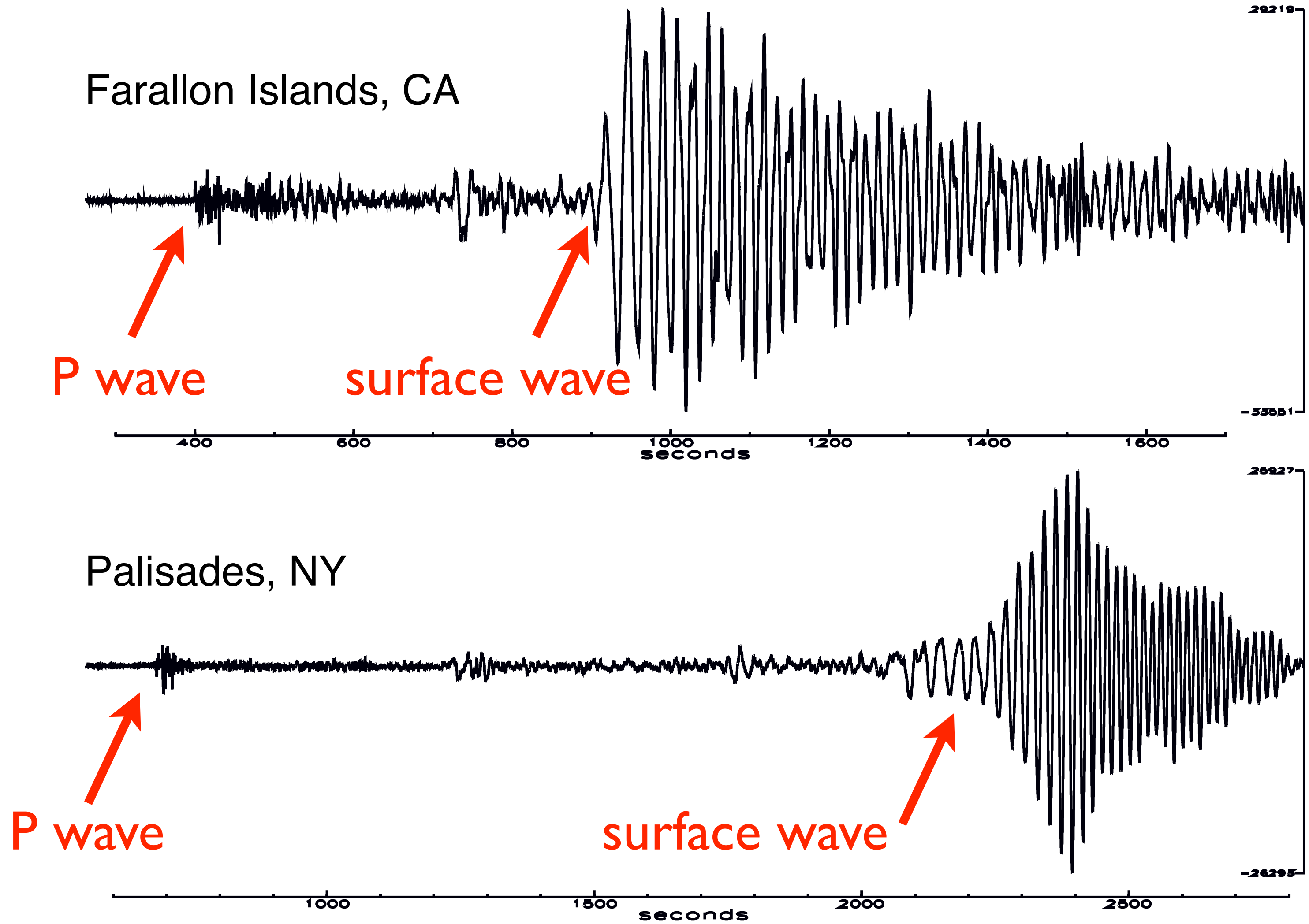
vibrations arrive
at different stations
at different times



only one location
explains all
arrival times

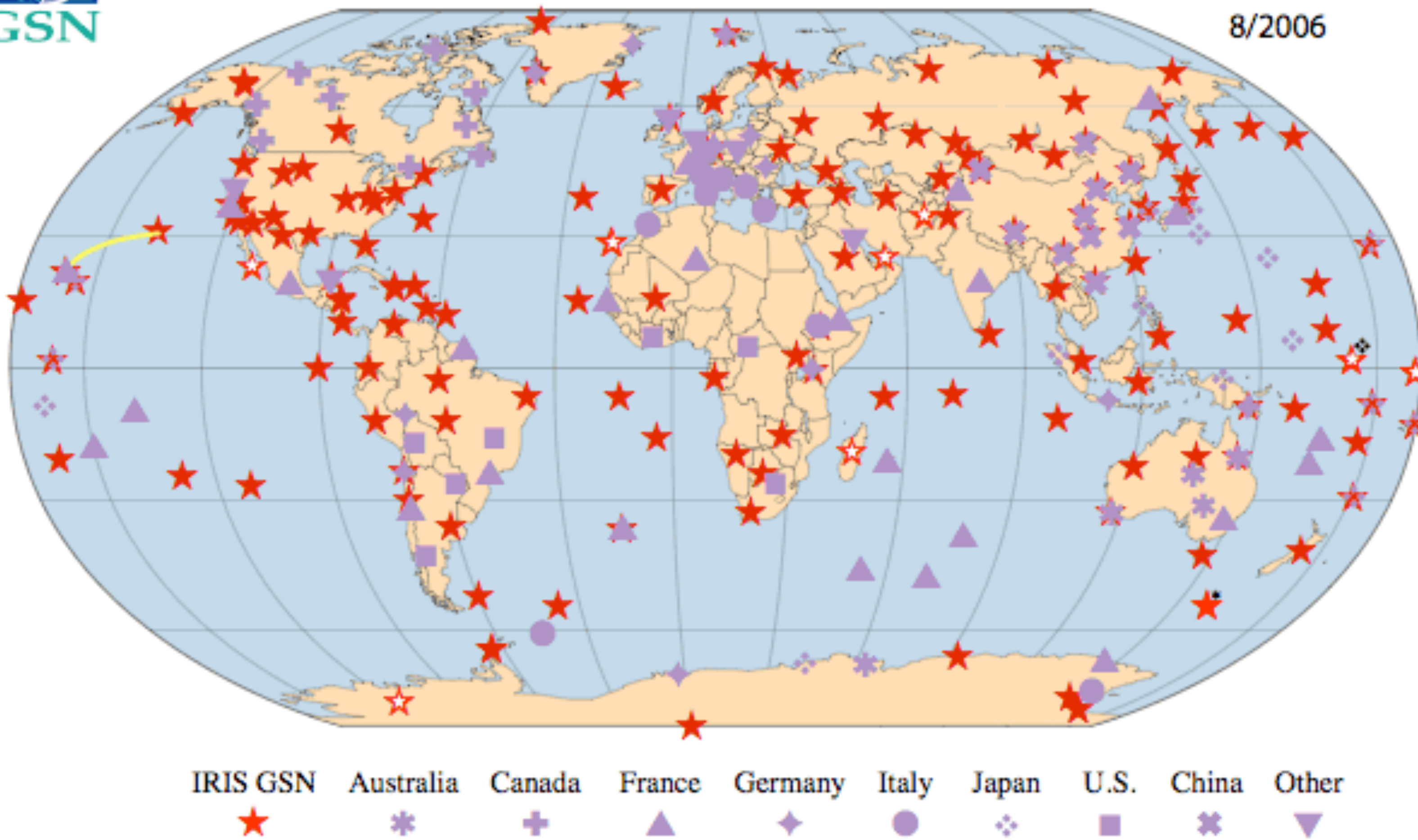


October 15, 2006, Hawaii earthquake, M=6.7

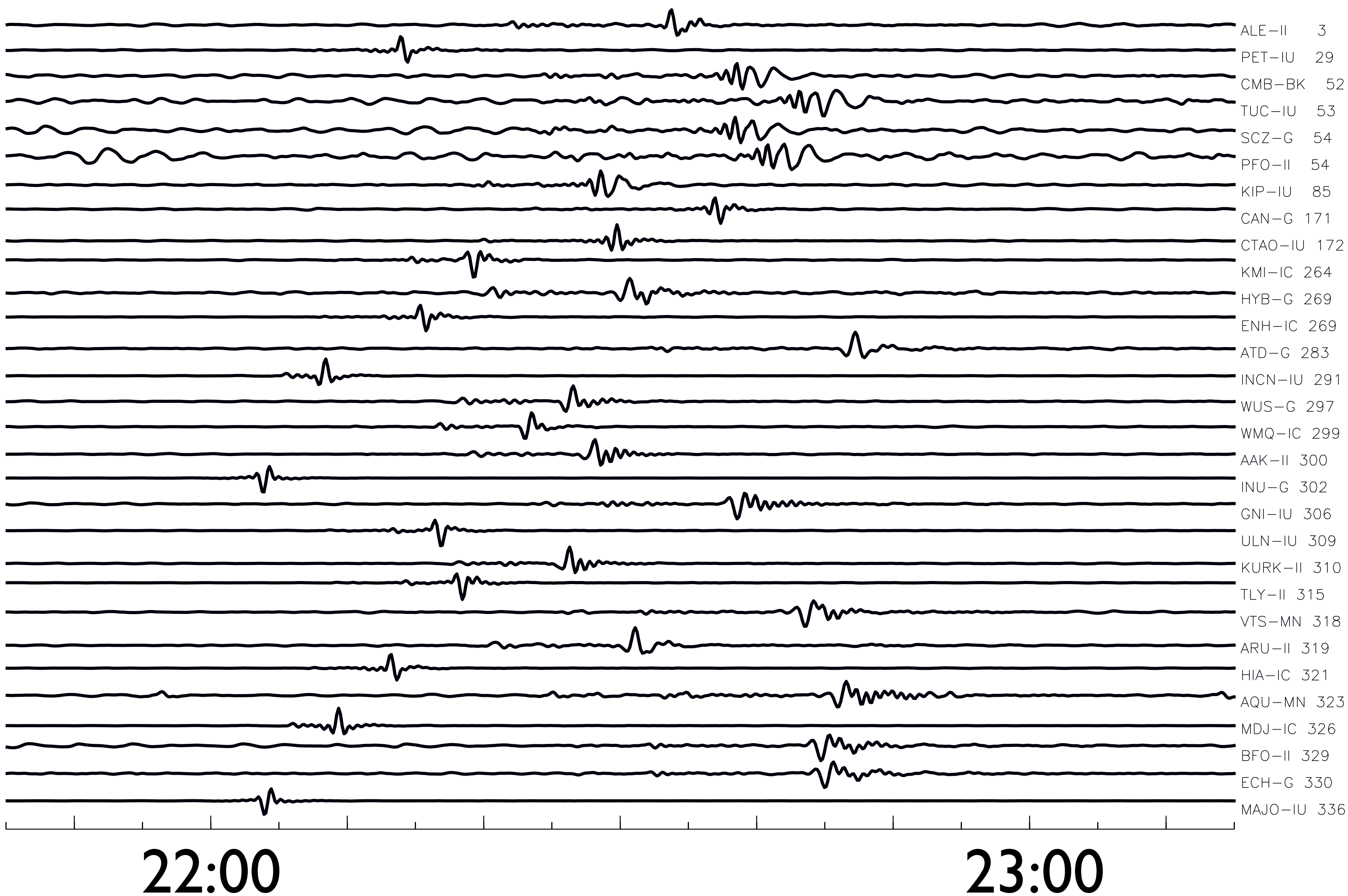


GLOBAL SEISMOGRAPHIC NETWORK

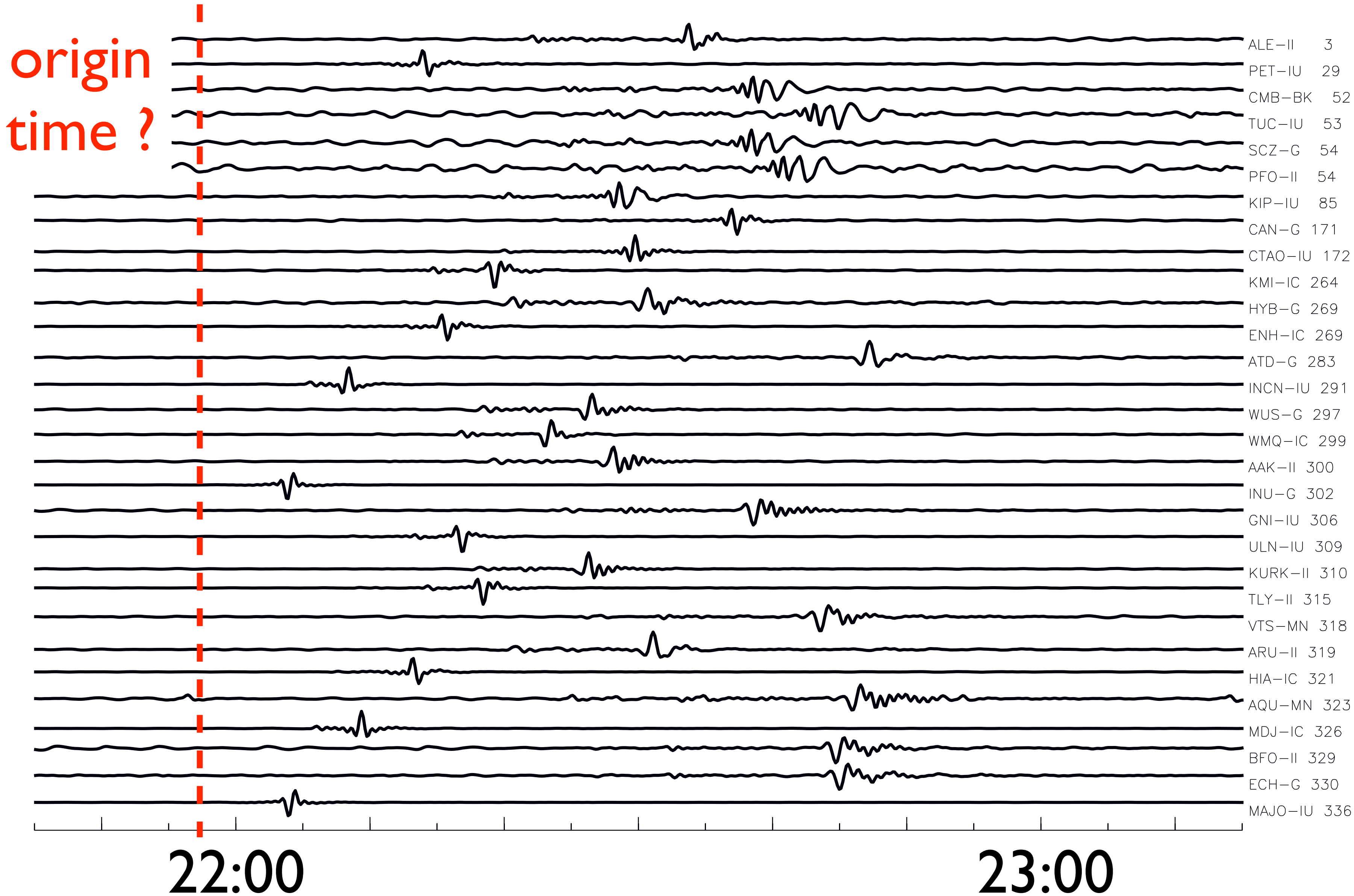
& INTERNATIONAL FEDERATION OF DIGITAL SEISMIC NETWORKS



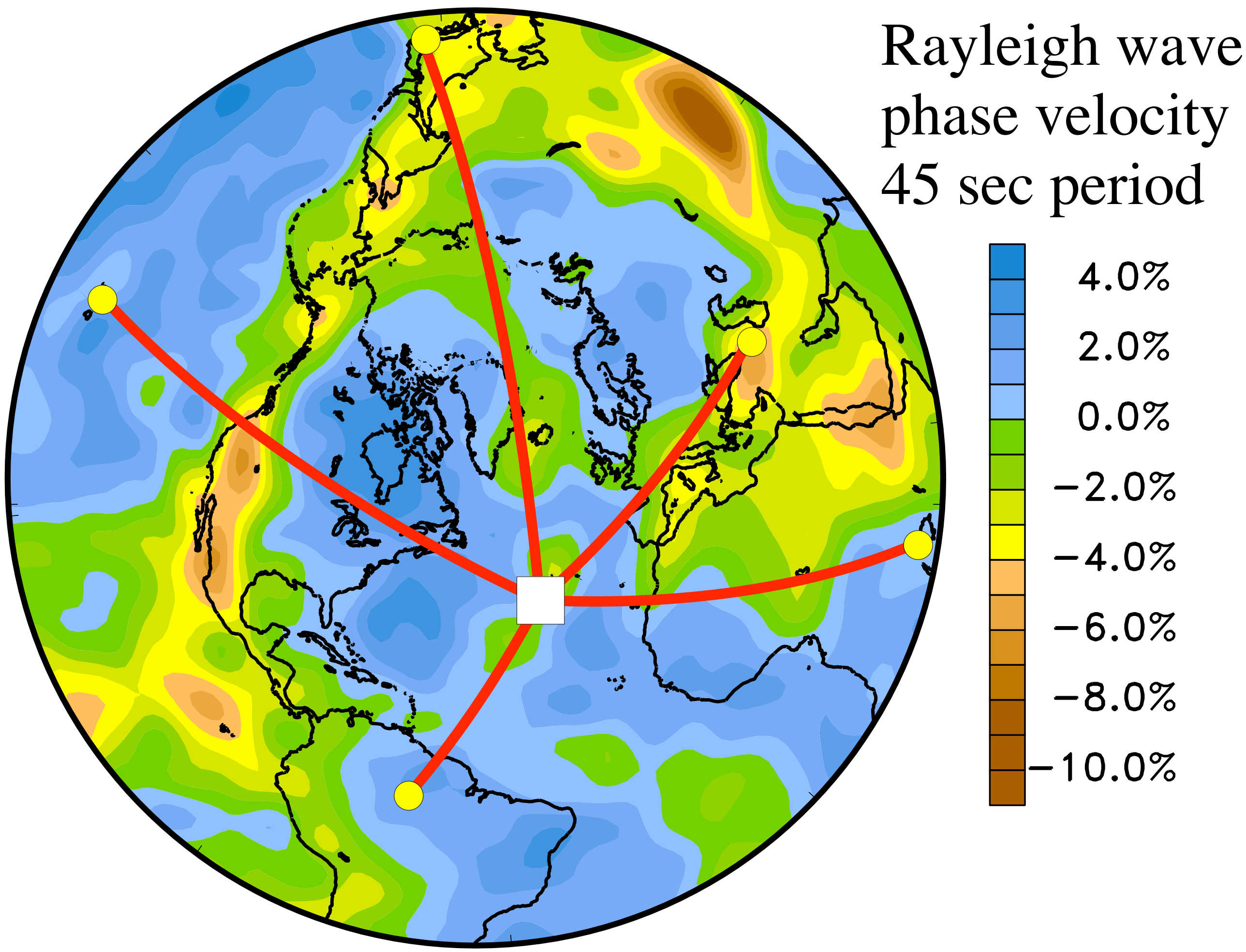
1. Collect data from the GSN
2. Filter in period range 35- 250 seconds



1. Collect data from the GSN
2. Filter in period range 35- 250 seconds

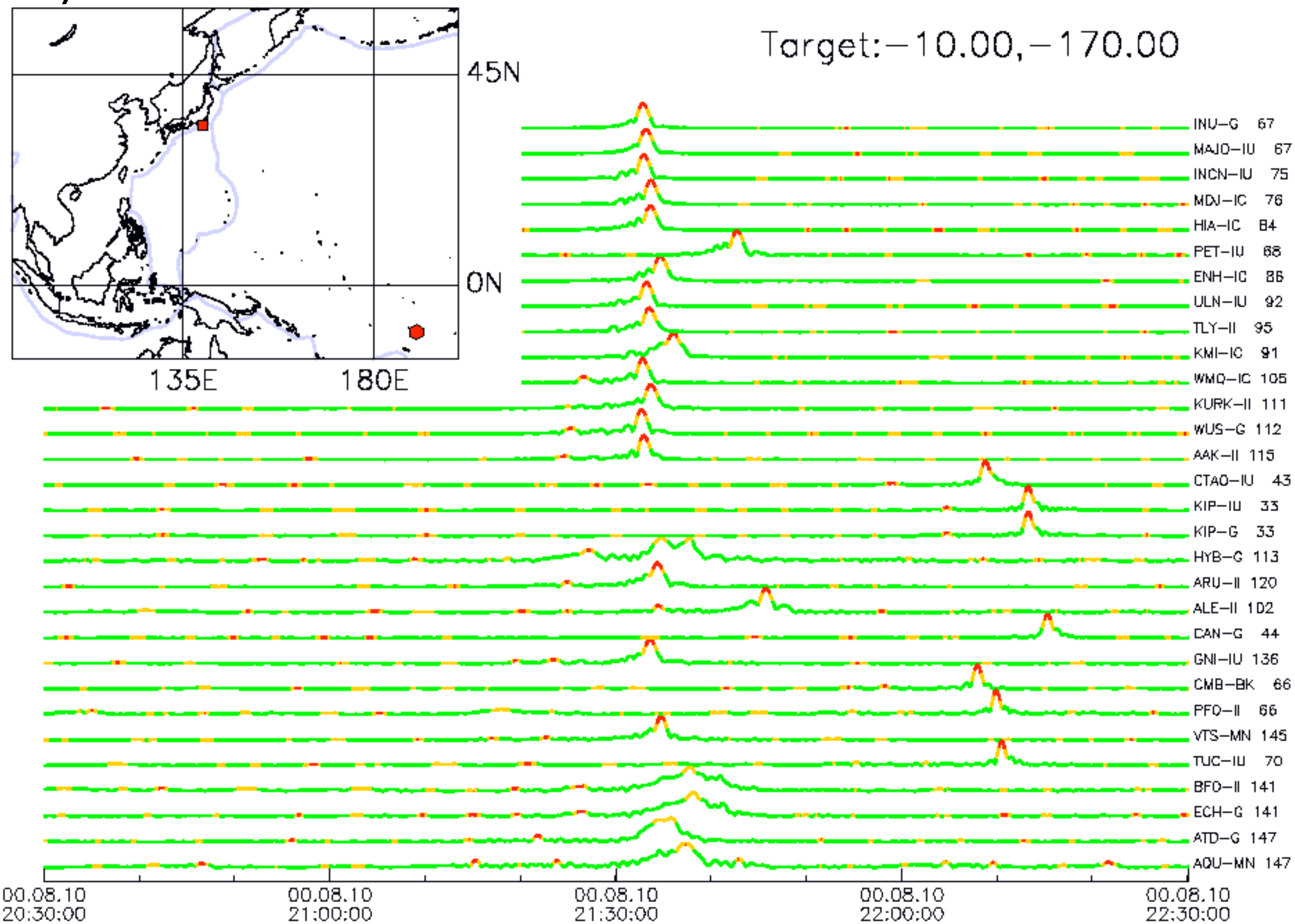


3. Select a target location

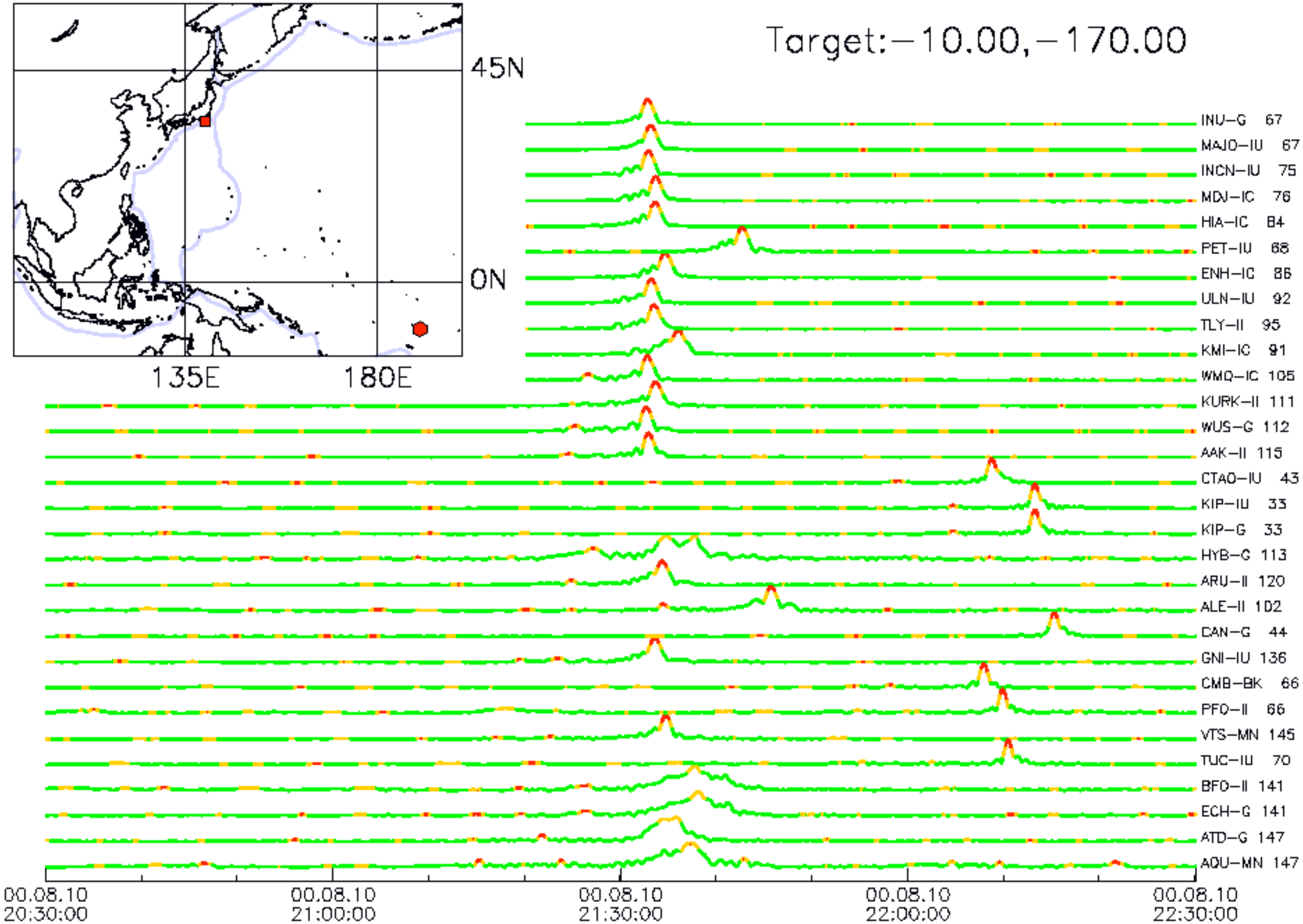


4. Calculate and remove dispersion from each station to the target

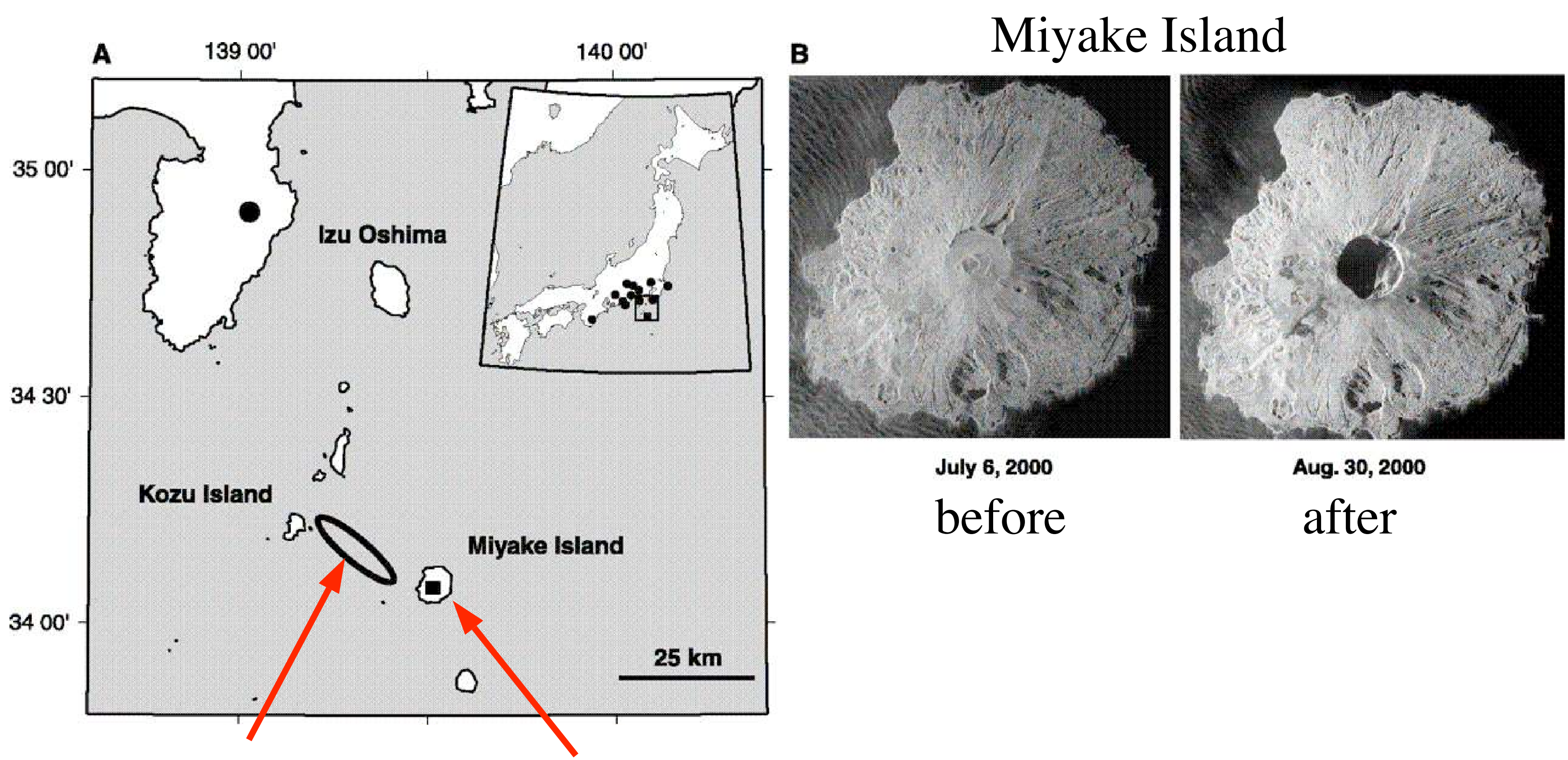
Miyake Island, 2000/08/10



Miyake Island, 2000/08/10



Caldera formation on Miyake Island associated with magma migration in the Izu Islands, June-September, 2000



dike injection, earthquakes

caldera formation

(Figure adapted from Kumagai et al., Science, 2001)

Systematic global search:

4050 points on the Earth's surface
100-200 stations
15 years
365 days/year
6 4-hour seismograms/day

20,000,000,000 4-hour event stacks

check for event every 4 seconds:

80,000,000,000,000 detection tests

5. Perform grid search to detect events and determine epicenters and M_{SW}

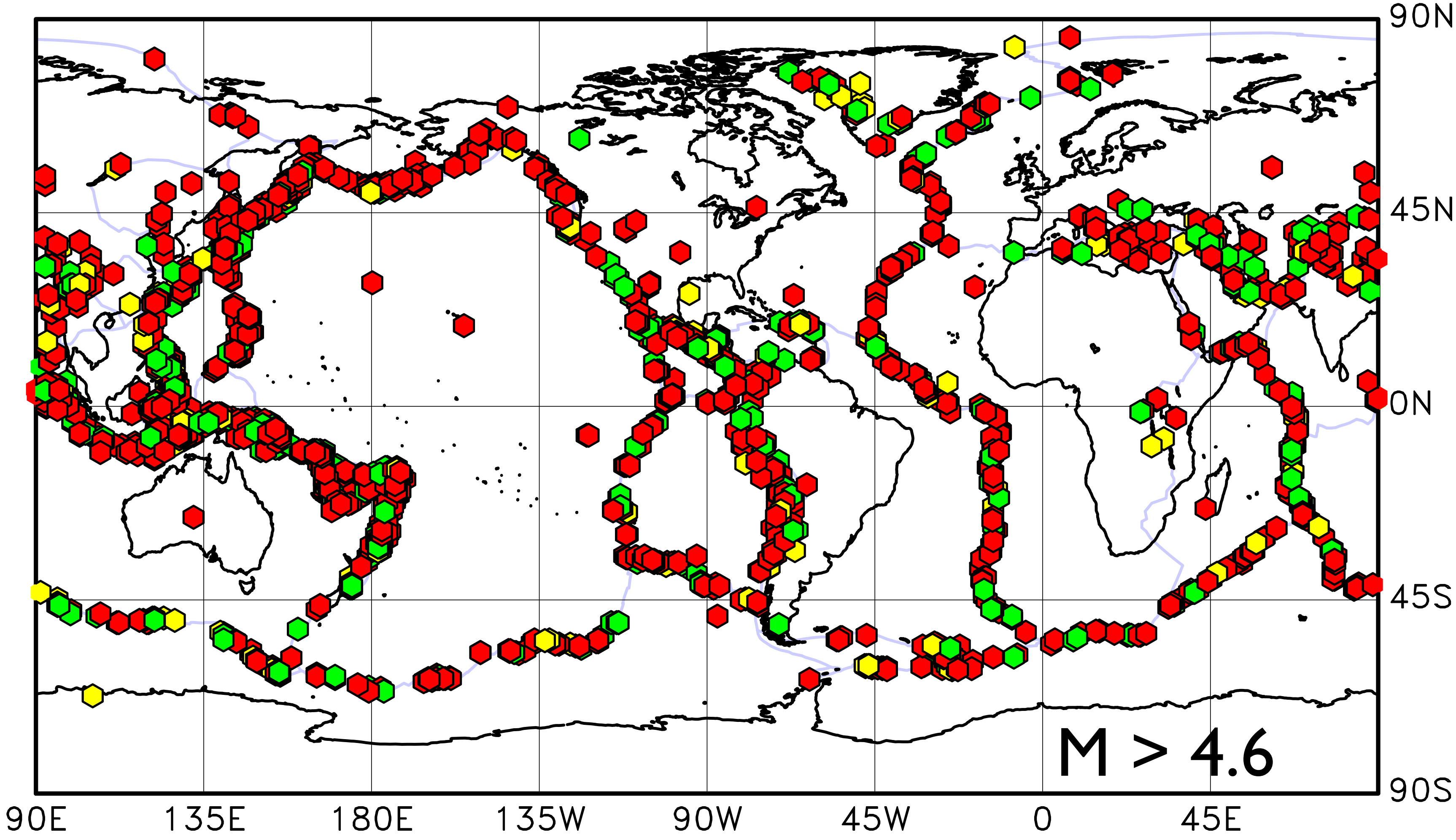
2014	4	11	8	16	48.0	-6.50	155.50	33.0	6.3	SOLOMON ISLANDS
2014	4	11	7	7	44.0	-6.50	155.50	33.0	6.8	SOLOMON ISLANDS
2014	4	11	2	41	44.0	38.25	-25.75	33.0	5.1	AZORES ISLANDS, PORTUGAL
2014	4	11	0	1	52.0	-21.00	-71.00	33.0	6.0	OFF COAST OF NORTHERN CHILE
2014	4	10	23	27	44.0	12.50	-86.50	33.0	6.2	NICARAGUA
2014	4	10	22	27	12.0	-19.75	-172.75	33.0	5.7	TONGA ISLANDS REGION
2014	4	10	17	49	12.0	-20.25	-71.25	33.0	5.0	OFF COAST OF NORTHERN CHILE
2014	4	10	4	3	28.0	-26.25	71.75	33.0	5.0	MID-INDIAN RIDGE
2014	4	9	20	30	32.0	-54.50	-133.50	33.0	5.2	PACIFIC-ANTARCTIC RIDGE
2014	4	9	19	33	44.0	10.25	56.75	33.0	4.8	CARLSBERG RIDGE
2014	4	9	11	14	48.0	-20.50	-71.50	33.0	5.1	OFF COAST OF NORTHERN CHILE
2014	4	9	8	32	40.0	-9.75	154.75	33.0	5.3	D'ENTRECASTEAUX ISLANDS REGION
2014	4	9	8	29	28.0	-50.25	-114.75	33.0	5.8	SOUTHERN EAST PACIFIC RISE
2014	4	9	4	33	4.0	-19.75	-71.75	33.0	4.8	OFF COAST OF NORTHERN CHILE
2014	4	9	4	25	4.0	19.25	146.25	33.0	5.1	MARIANA ISLANDS REGION
2014	4	8	22	22	40.0	-6.25	152.25	33.0	4.8	NEW BRITAIN REGION, P.N.G.
2014	4	8	20	15	4.0	3.00	-31.00	33.0	4.8	CENTRAL MID-ATLANTIC RIDGE
2014	4	8	15	49	52.0	-34.25	179.75	33.0	4.9	SOUTH OF KERMADEC ISLANDS
2014	4	8	15	2	8.0	36.50	141.50	33.0	4.8	NEAR EAST COAST OF HONSHU, JAPAN
2014	4	8	10	14	40.0	-21.25	-71.25	33.0	5.5	OFF COAST OF NORTHERN CHILE
2014	4	8	5	44	0.0	-20.50	-71.50	33.0	4.9	OFF COAST OF NORTHERN CHILE
2014	4	8	5	20	24.0	-19.75	-71.25	33.0	4.8	OFF COAST OF NORTHERN CHILE
2014	4	7	19	26	56.0	44.25	6.75	33.0	5.1	FRANCE
2014	4	7	17	18	48.0	13.25	120.75	33.0	4.8	MINDORO, PHILIPPINES
2014	4	7	13	43	28.0	-20.50	-71.50	33.0	5.7	OFF COAST OF NORTHERN CHILE
2014	4	7	9	34	48.0	50.25	157.25	33.0	5.3	KURIL ISLANDS
2014	4	7	8	12	24.0	28.75	130.25	33.0	4.7	RYUKYU ISLANDS, JAPAN
2014	4	7	7	48	32.0	53.25	171.25	33.0	5.1	NEAR ISLANDS, ALEUTIAN ISLANDS
2014	4	7	6	24	32.0	-20.75	-71.25	33.0	4.8	OFF COAST OF NORTHERN CHILE
2014	4	7	1	9	52.0	8.75	58.25	33.0	4.9	CARLSBERG RIDGE

not yet reported by NEIC/USGS

http://www.ldeo.columbia.edu/~ekstrom/Research/SWD/current/RADB_SWD_grd.html

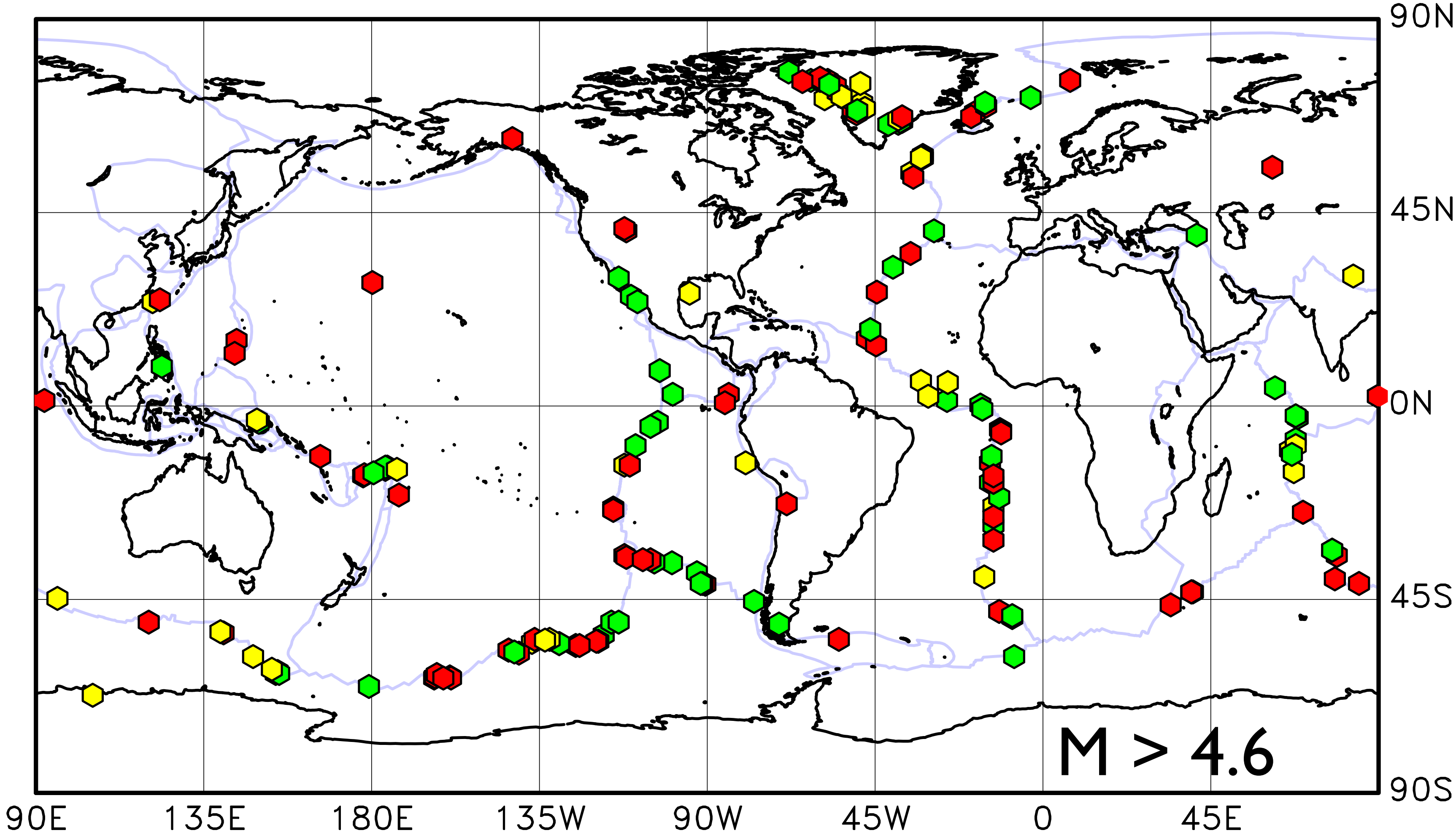
Detected earthquakes, 2013

Best
Very good
Good

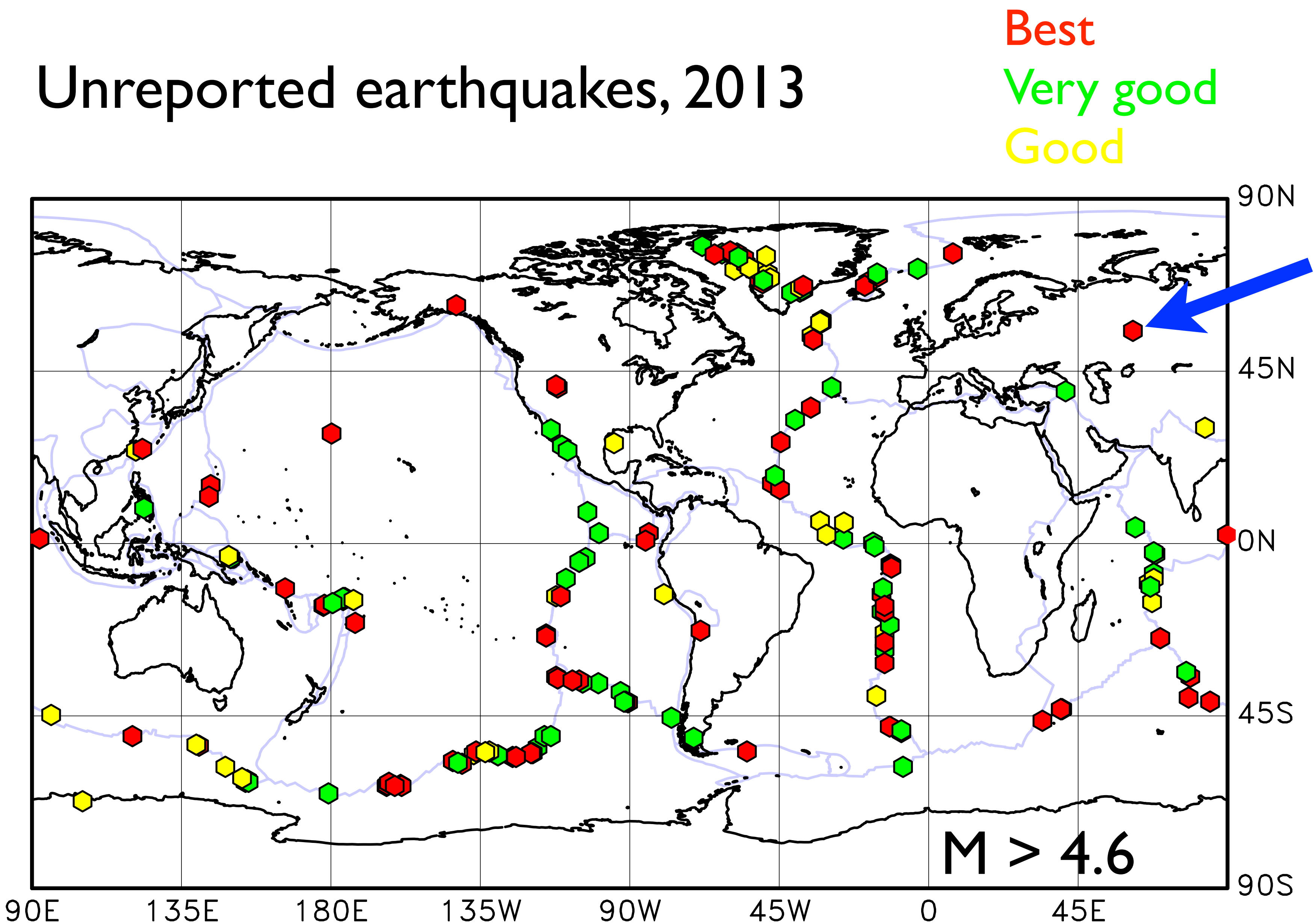


Unreported earthquakes, 2013

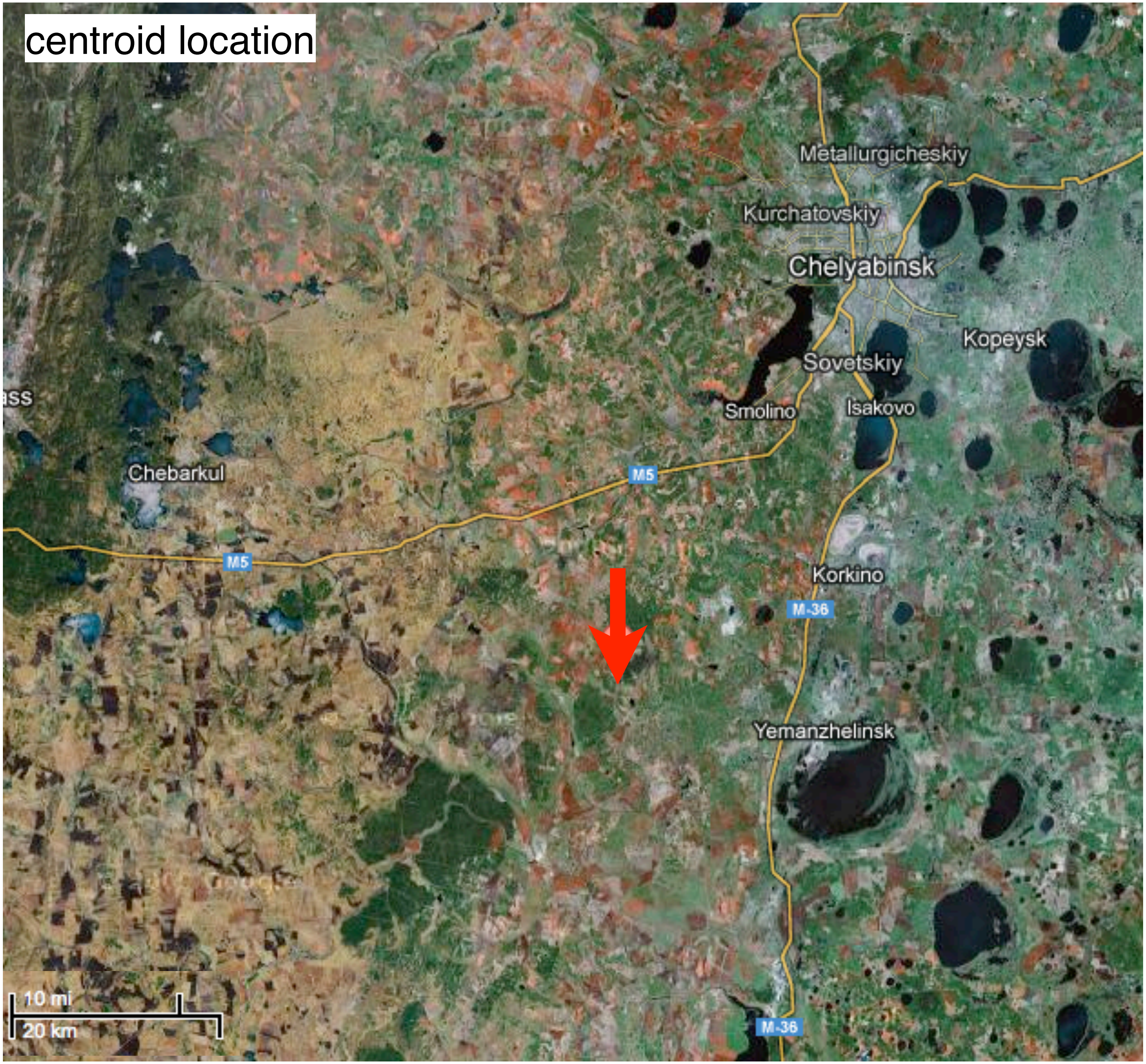
Best
Very good
Good



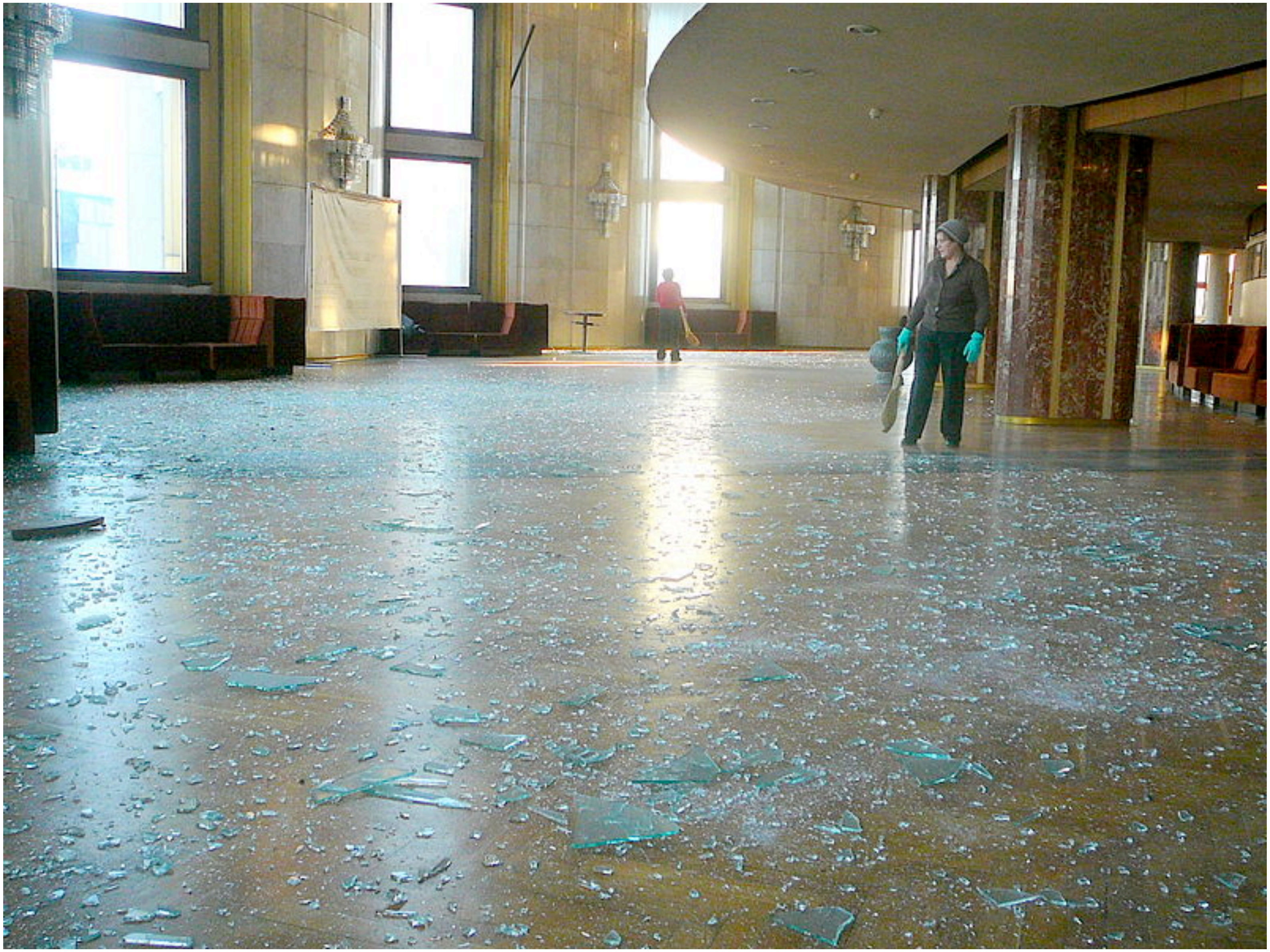
Unreported earthquakes, 2013



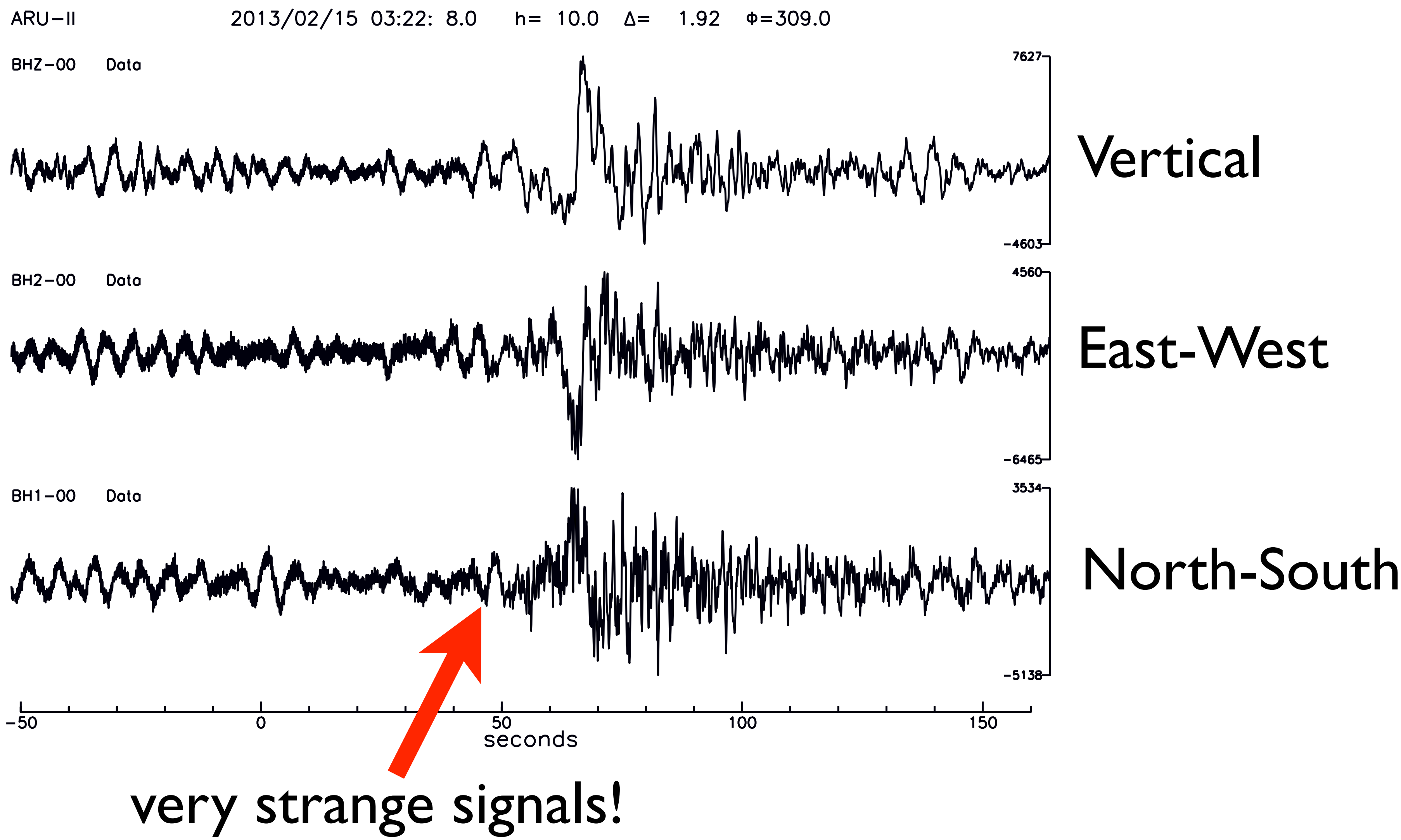
Chelyabinsk meteor, 2013-02-15


centroid location
Metallurgicheskiy
Kurchatovskiy
Chelyabinsk
Kopeysk
Sovetskiy
Smolino
Isakovo
Chebarkul
M5
M5
Korkino
M-36
Yemanzhelinsk
M-36
10 mi
20 km

Chelyabinsk Drama Theatre, 2013-02-15



seismic data from the closest Federation station Арти at ~200 km distance



What is the source?

500 kT TNT

30 km

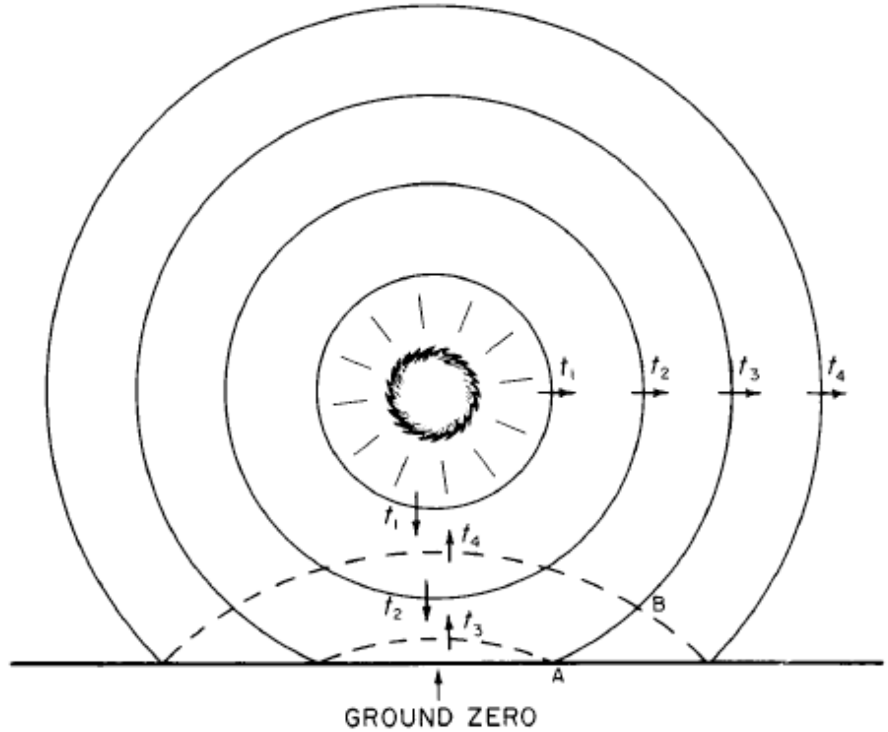


Figure 3.21. Reflection of blast wave at the earth's surface in an air burst; t_1 to t_4 represent successive times.

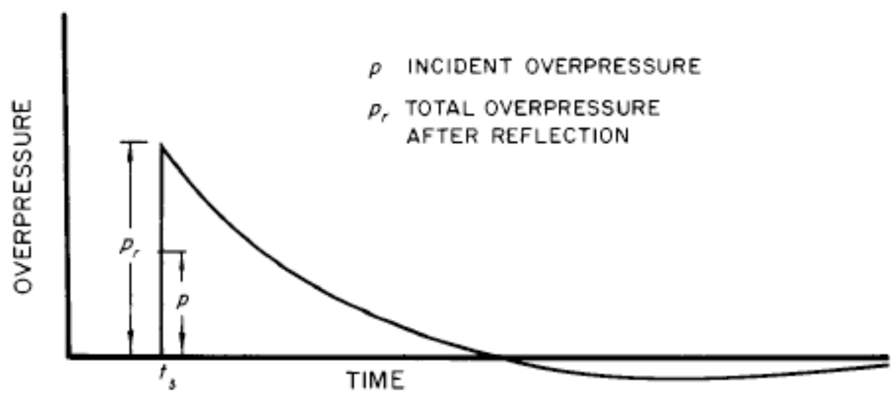


Figure 3.22. Variation of overpressure with time at a point on the surface in the region of regular reflection.

What is the source?

A vertical impulse

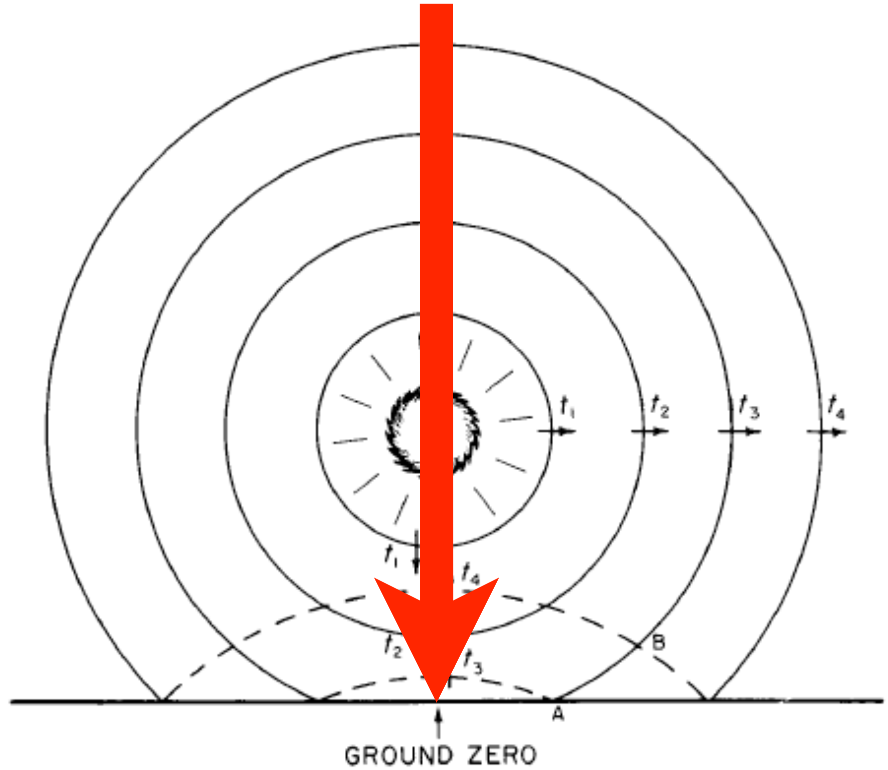


Figure 3.21. Reflection of blast wave at the earth's surface in an air burst; t_1 to t_4 represent successive times.

500 kT TNT

30 km

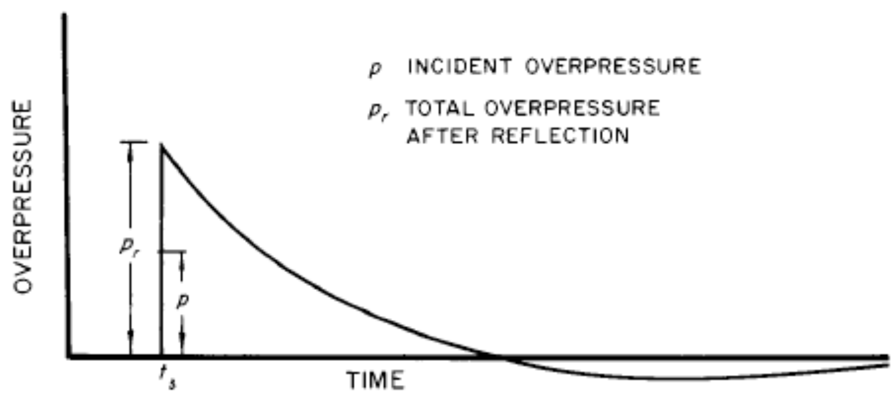
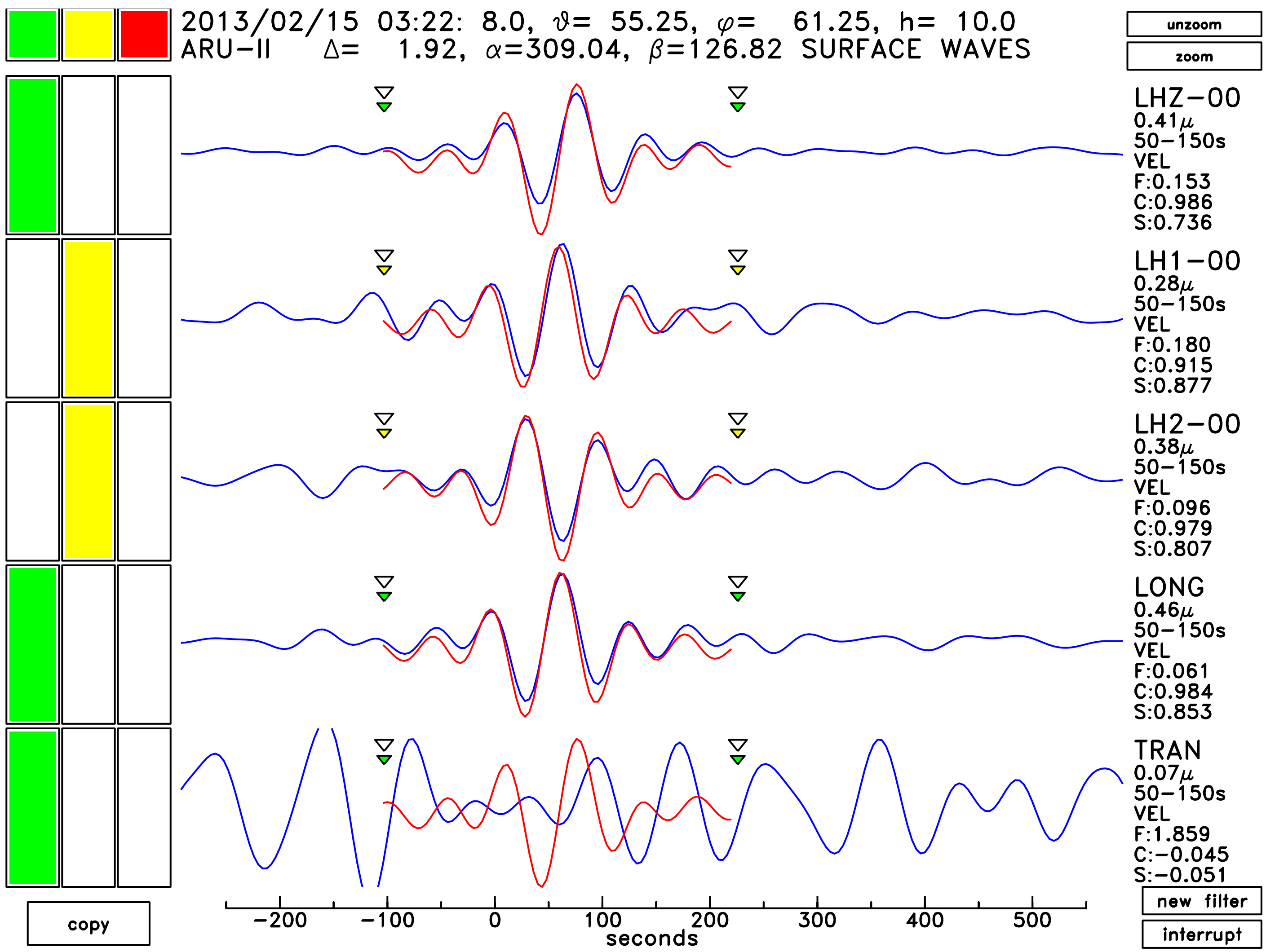


Figure 3.22. Variation of overpressure with time at a point on the surface in the region of regular reflection.

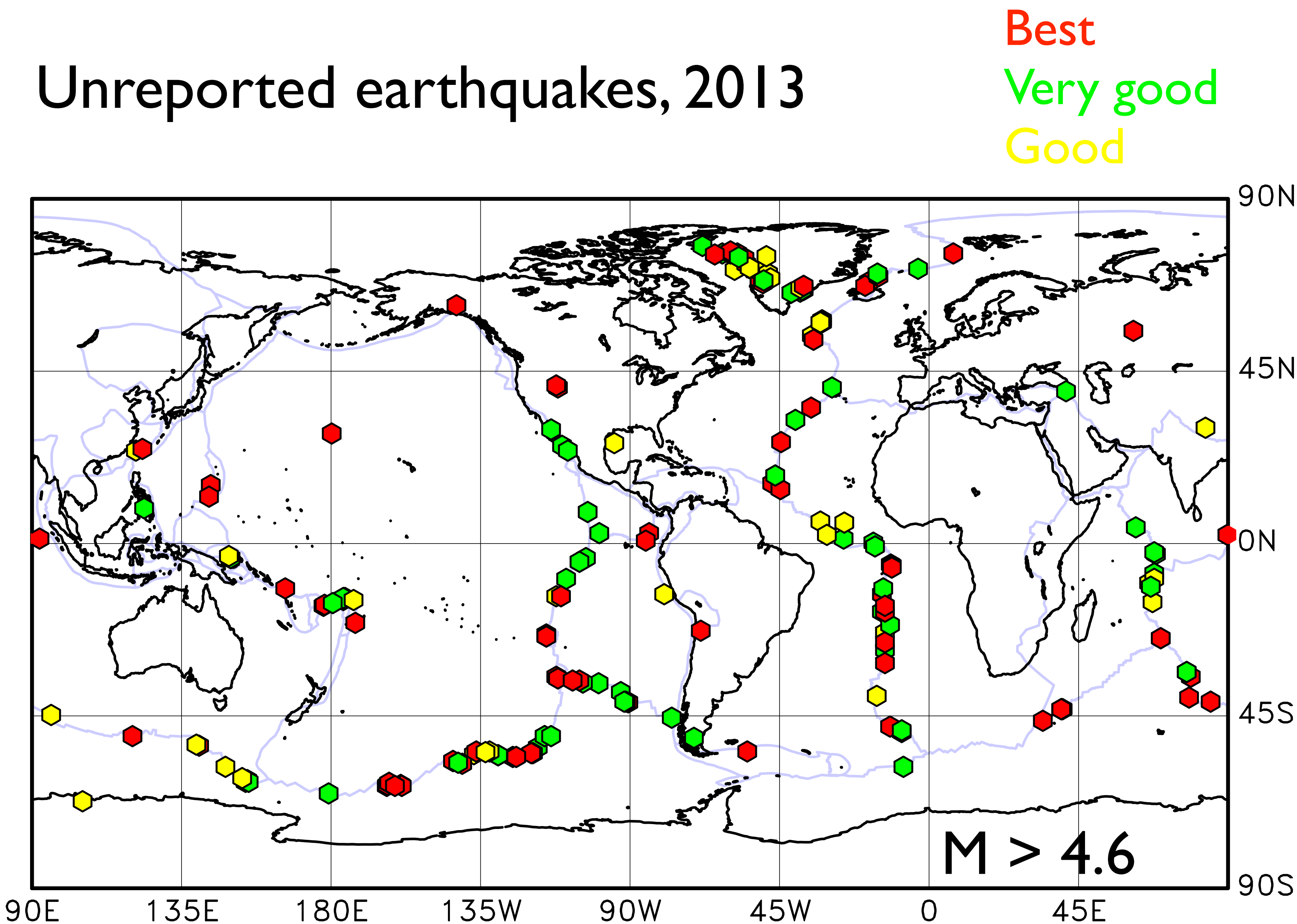
Inverting the seismic data for an impulse source:



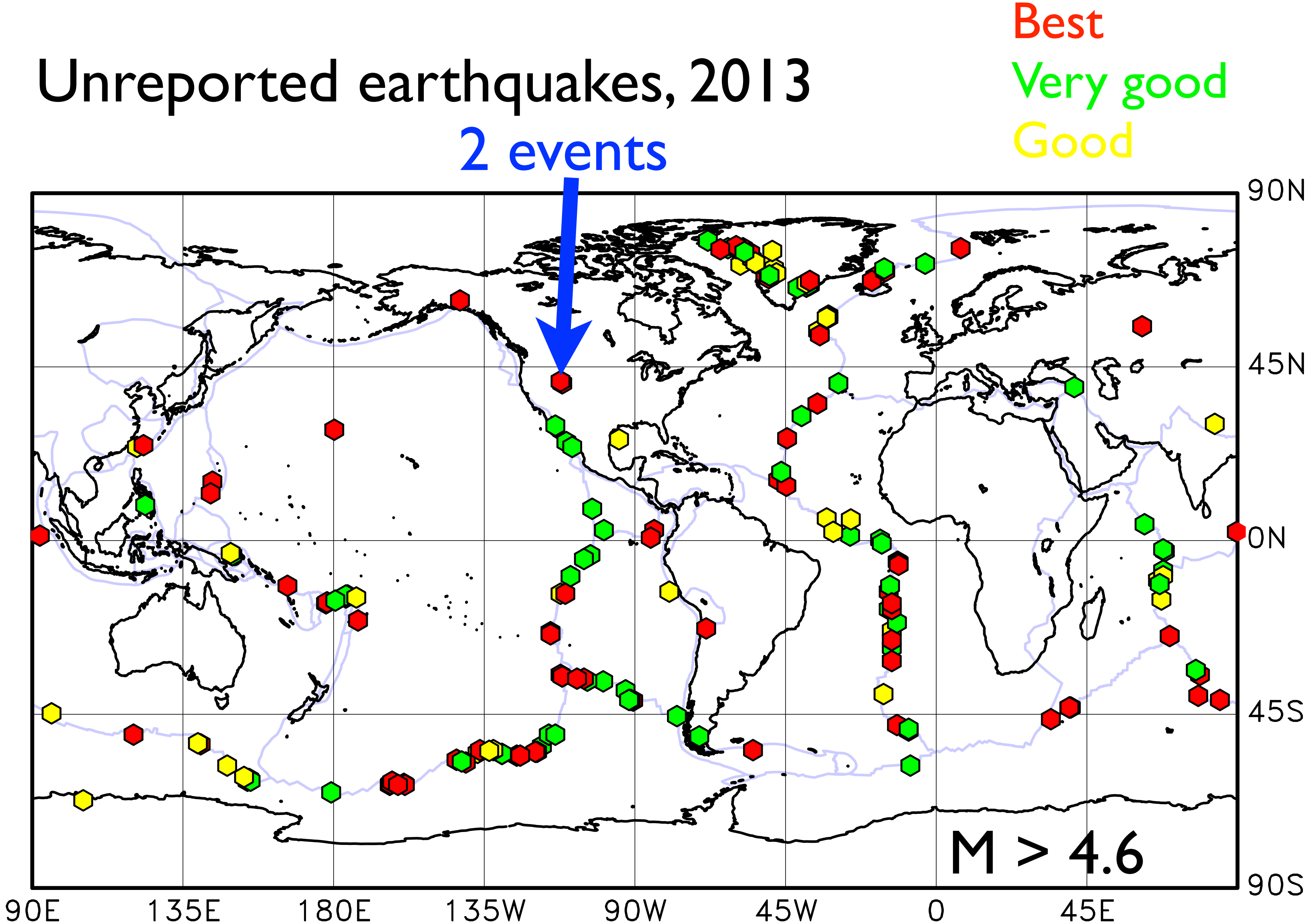
plunge 76 deg;
2.8×10^{17} dyne-s

blue = data ; red = model

Unreported earthquakes, 2013



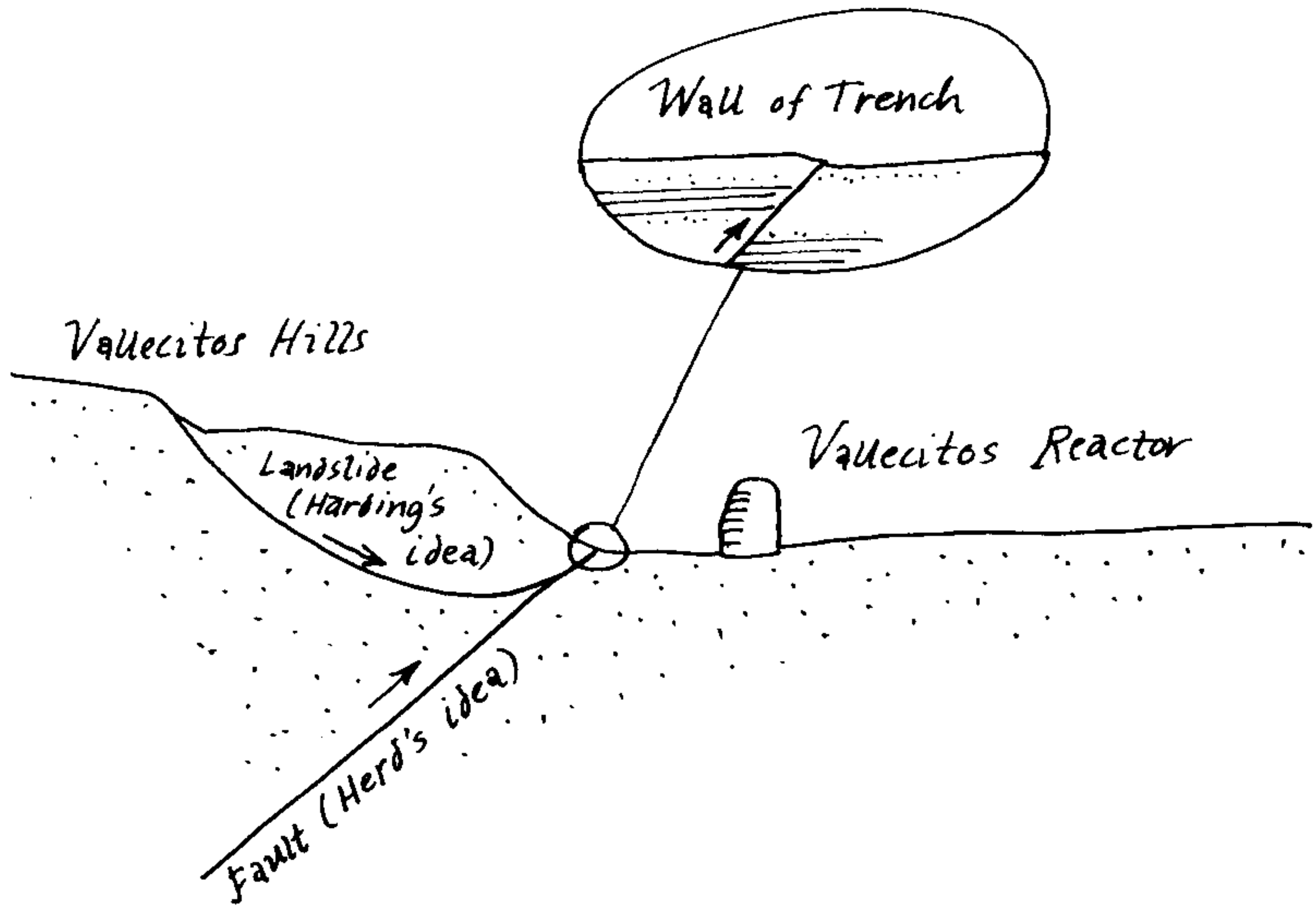
Unreported earthquakes, 2013




Bingham Canyon Mine, Utah

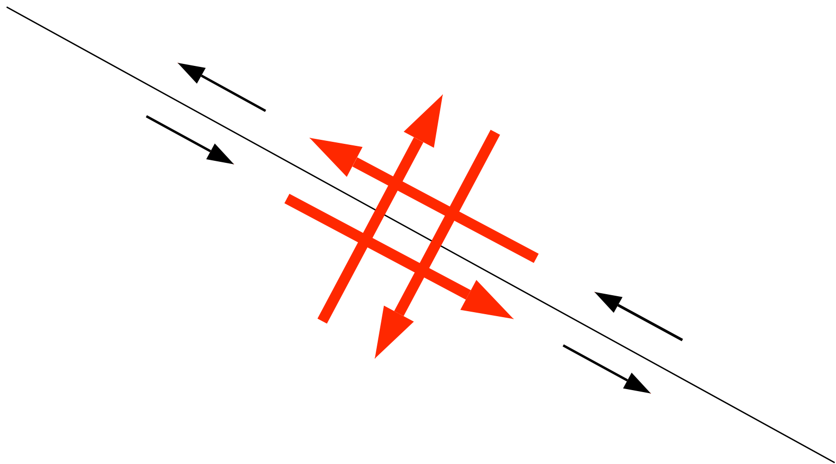

April 11, 2013

The difference between a fault and a landslide



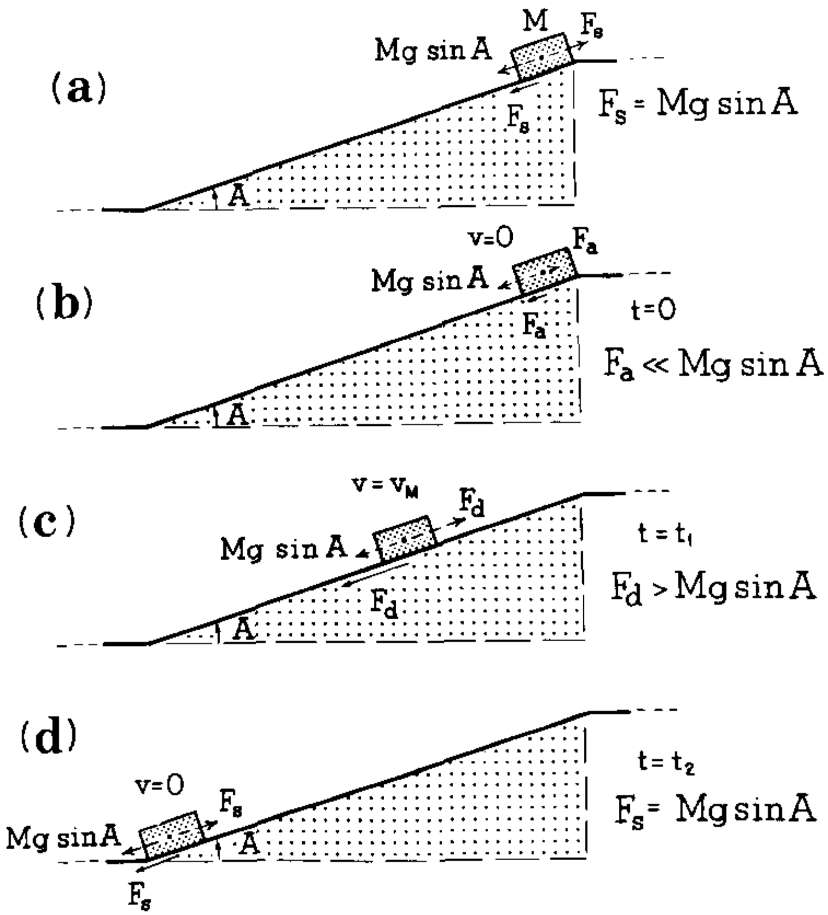
Meehan, The Atom and the Fault

Faulting force model



The elastic stress release in an earthquake is described by a double couple of forces

What are the forces acting on the Earth in a slide?



Hasegawa and Kanamori, 1987

$$\mathbf{F} = \frac{d(m\mathbf{v})}{dt}$$

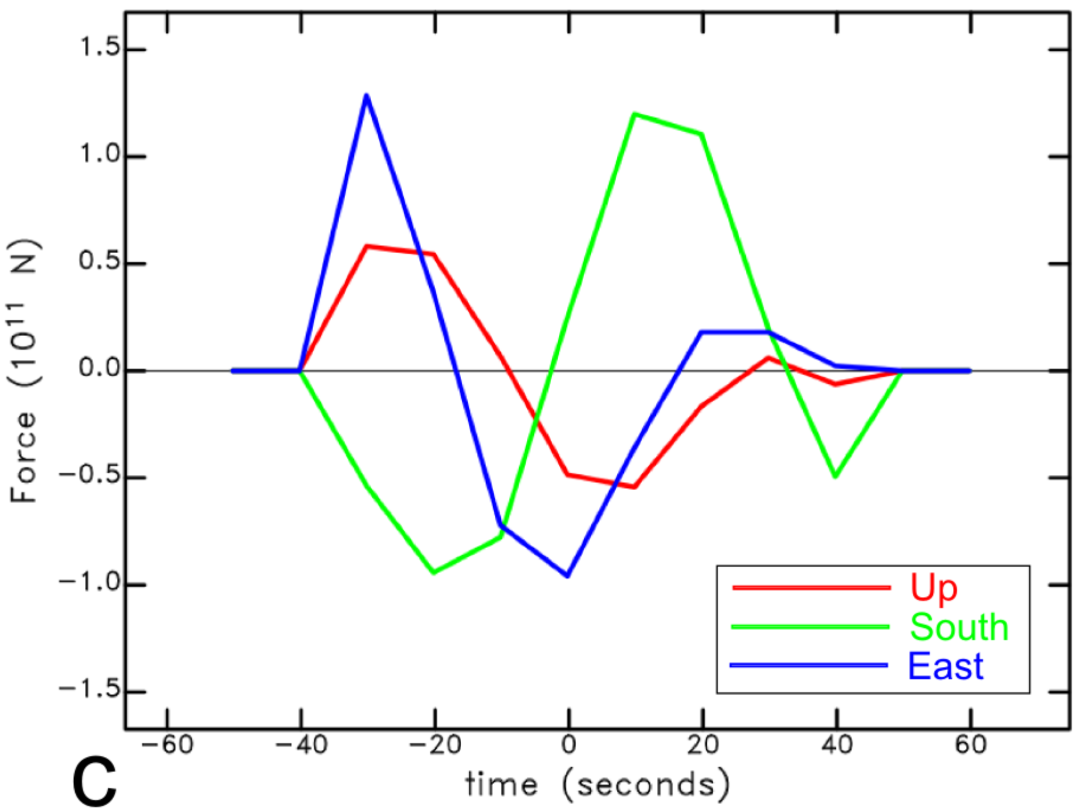
$$\mathbf{F}_{\text{action}} = -\mathbf{F}_{\text{reaction}}$$

$$\boxed{\mathbf{F}_{\text{on Earth}} = -\frac{d(m\mathbf{v})_{\text{slide}}}{dt}}$$

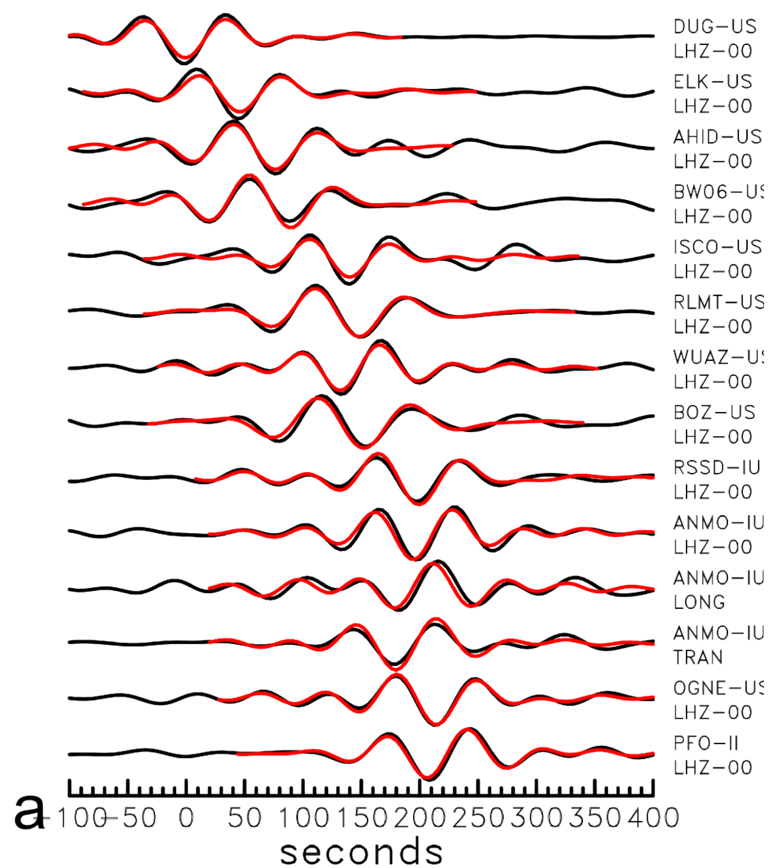

ASTROLAND
CLONE
ASTROLAND
Cyclone

Bingham Canyon Mine - first event

Landslide Force History



Waveform Fits



Hibert et al., 2014

Integrating the forces to get mass displacement

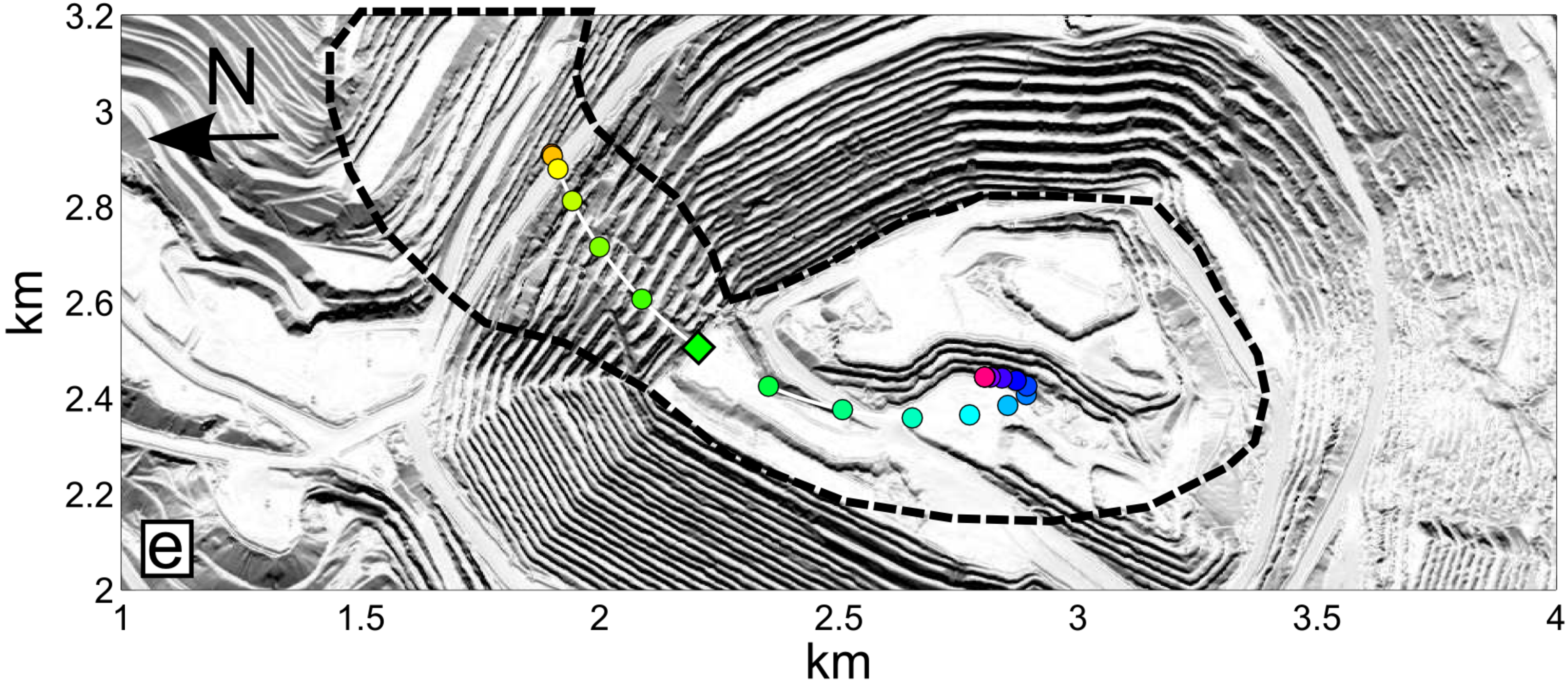
$$\mathbf{F}(\mathbf{t}) = -\frac{d(m\mathbf{v}(t))}{dt} = -\frac{d\mathbf{p}(t)}{dt}$$

$$\mathbf{I}(t) = \int \mathbf{F}(t)dt = -\mathbf{p}(t)$$

$$\int \mathbf{I}(t)dt = -\int \mathbf{p}(t)dt = -m\mathbf{D}(t)$$

where the mass is constant and D is the center-of-mass displacement

Inverted geometry agrees with ground truth



First slide: 70 million tons

Hibert et al., 2014

Main points

1. Noise can be very interesting

2. There are many geophysical phenomena that produce seismic signals (other than earthquakes):
   volcanos, landslides, cavity collapses,
   glaciers, asteroids, storms, waves, ...

3. Seismology can be used to investigate and monitor events other than earthquakes