Università degli Studi di Napoli Federico II

Scuola politecnica e delle scienze di Base

Dipartimento di Strutture per l'Ingegneria e l'Architettura (DiSt)

Consorzio Interuniversitario ReLuis

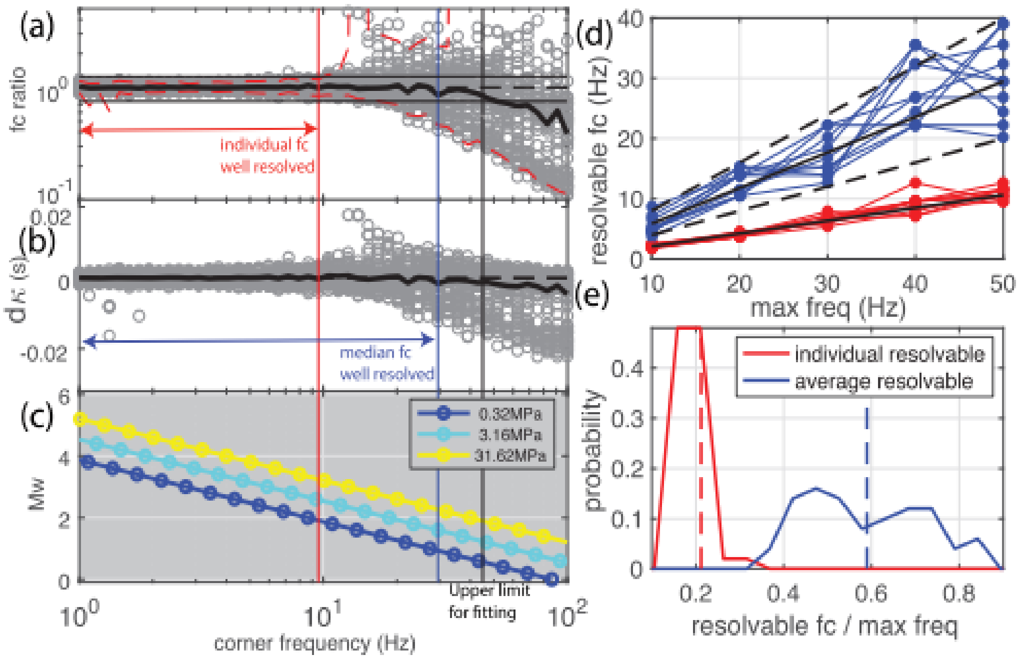
WORKSHOP: Approcci per la valutazione dei modelli di pericolosità sismica in Italia

Villa Orlandi, Anacapri, 7-8 settembre 2023

Stefano Parolai, Università degli Studi di Trieste

Pericolosità sismica e stima di impatto: esempi di applicazioni in diverse regioni

Estimating the uncertainties

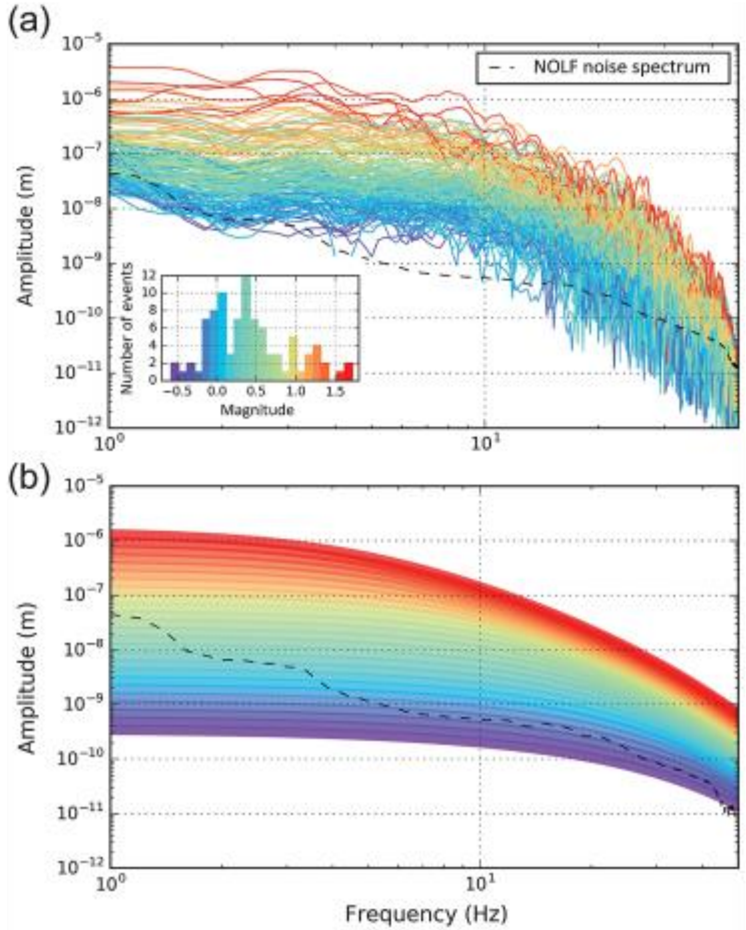


«These results imply that if a corner frequency estimated from spectral fitting to be **higher than 25 per cent of the maximum frequency** in the signal for an individual spectrum, or **80 per cent for an event average, then it is unlikely to be reliable**»

Chen and Abercrombie, 2020 GJI

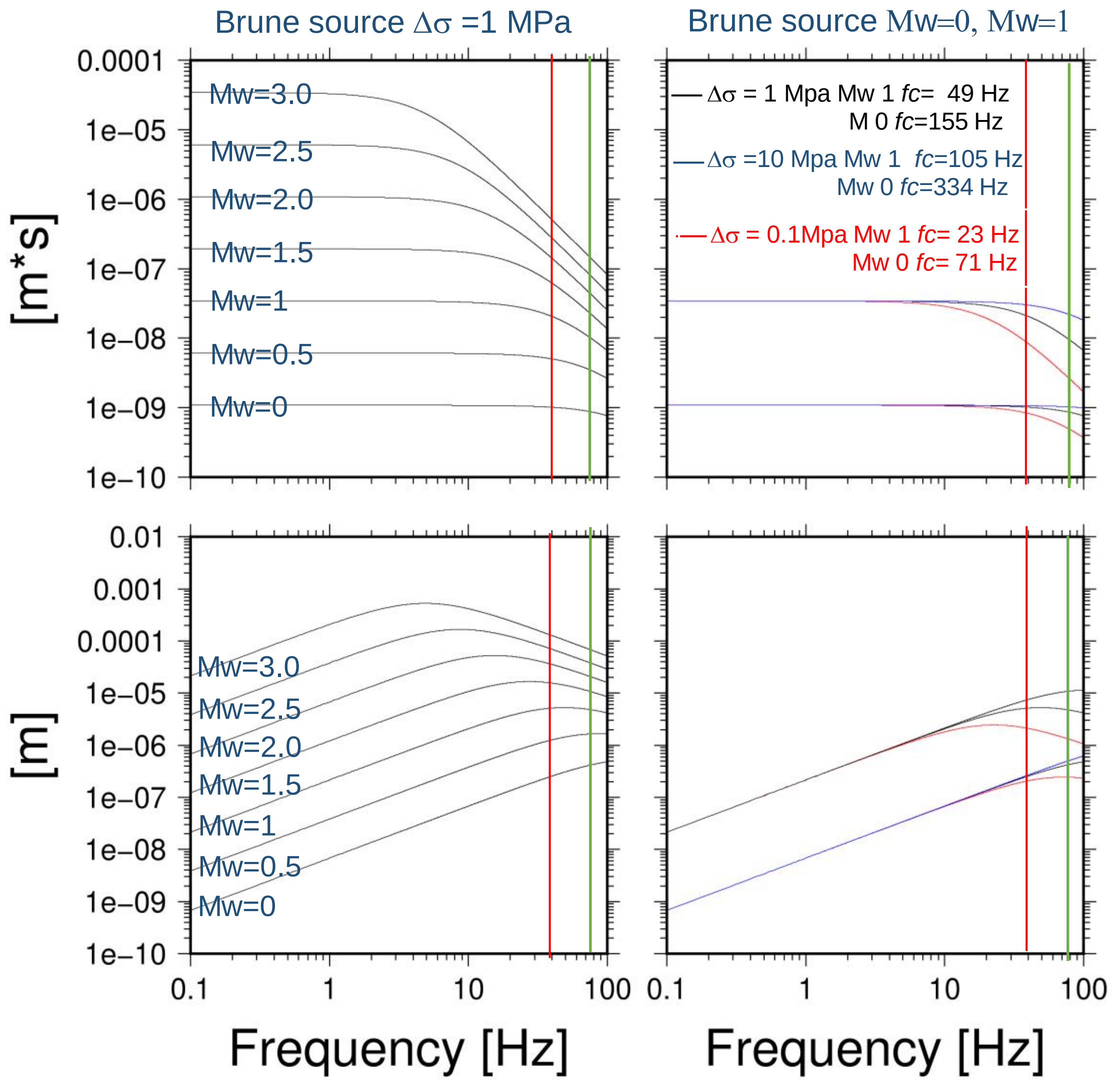
: 2. Synthetic experiment of f_c resolution. (a) Ratio between best-fitting and input f_c (Y-axis) versus input f_c (X-axis). Black circles denote individual ı result. The two horizontal lines denote the 25 per cent variation limit for the f_c ratio. The solid black line denotes the median f_c ratio. Red dashed lines the 95 and 5 per cent limit of f_c ratio for each input f_c. Vertical lines represent: range of 'individual resolvable f_c' (red), range of 'median-resolvable f_c' and upper limit of frequency band for spectral fitting (black). (b) Similar to (a), but shows $d\kappa$. (c) Expected relationship between moment magnitude for different stress drops. (d) Maximum resolvable f_c versus upper limit of frequency band in spectral fitting (f_{max}) from 10 different tests. Maximum dual resolvable f_c' are shown in red, and maximum 'median-resolvable f_c' are shown in blue. The solid black line refers to 25 and 60 per cent of f_{max} sponds to dashed lines in panel e). The dashed black lines correspond to 40 and 80 per cent of f_{max}. (e) Probability density function of the ratio between ıum 'individual resolvable f_c' (red line), maximum 'median-resolvable f_c' (blue line) and maximum frequency for fitting (f_{max}). The median ratio are as vertical dashed lines. It can be noted that maximum 'individual resolvable f_c' is between 20 and 25 per cent of maximum frequency, and maximum ın-resolvable f_c' ranges between 40 and 80 per cent of maximum frequency with an average of about 60 per cent.

The problem becomes bigger for Minor and Micro earthquakes

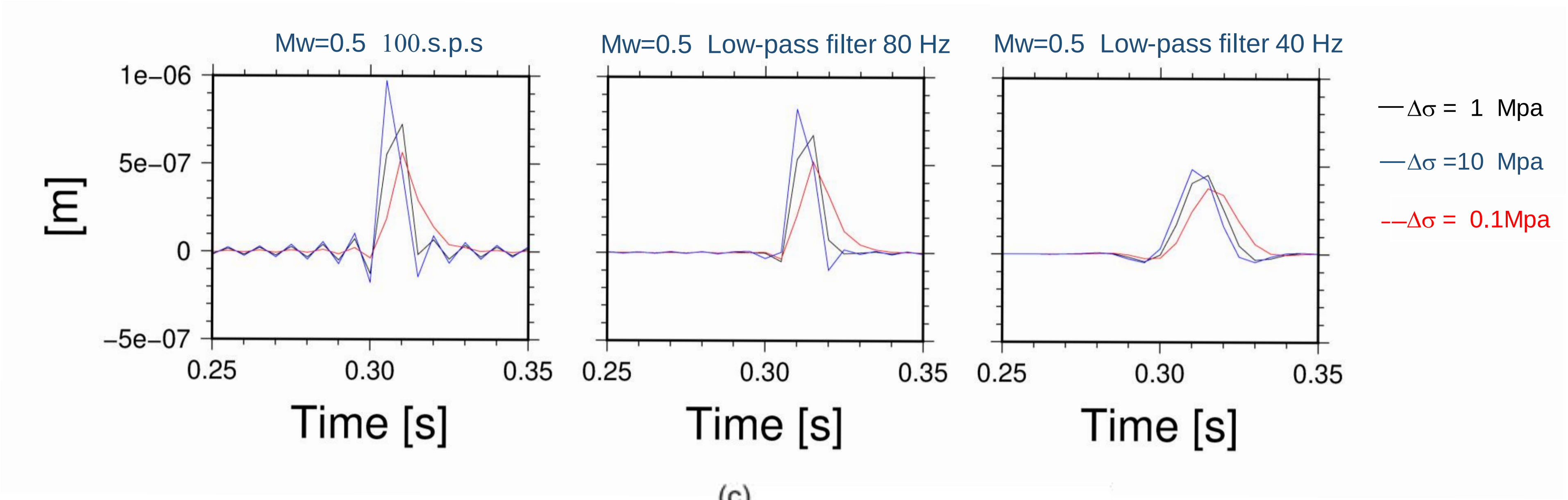


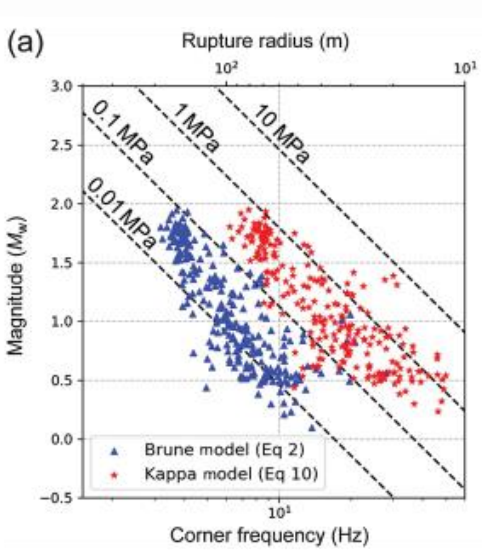
Butcher et al., 2022, BSSA

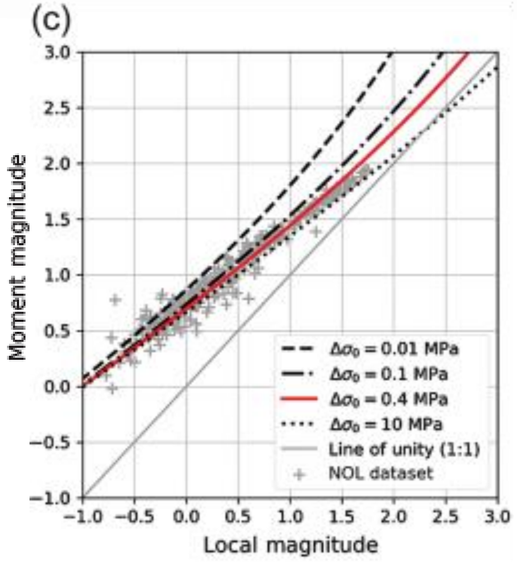
Figure 4. (a) Source frequency spectrum for a cluster of 91 events at New Ollerton recorded on NOLF. Colors indicate the magnitude of the event, as shown by the histogram plot. (b) Brune modeled source spectrum and using a 1:1 scaling relationship between M_L and M_w. While, in general, there is agreement between the modeled and observed data at larger magnitudes, there is a clear difference compared with the observed data at lower magnitudes. The color version of this figure is available only in the electronic edition.



The problem becomes bigger for Minor and Micro earthquakes

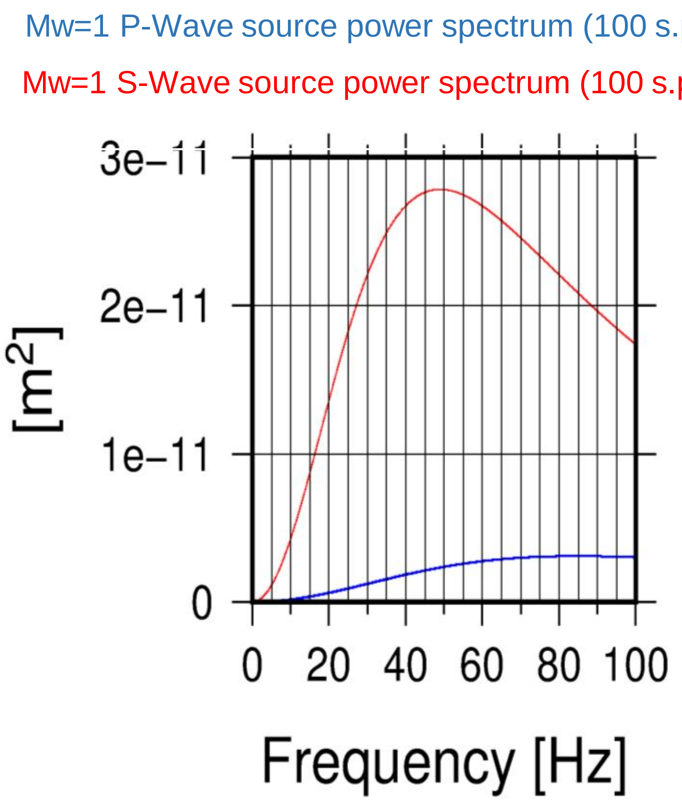


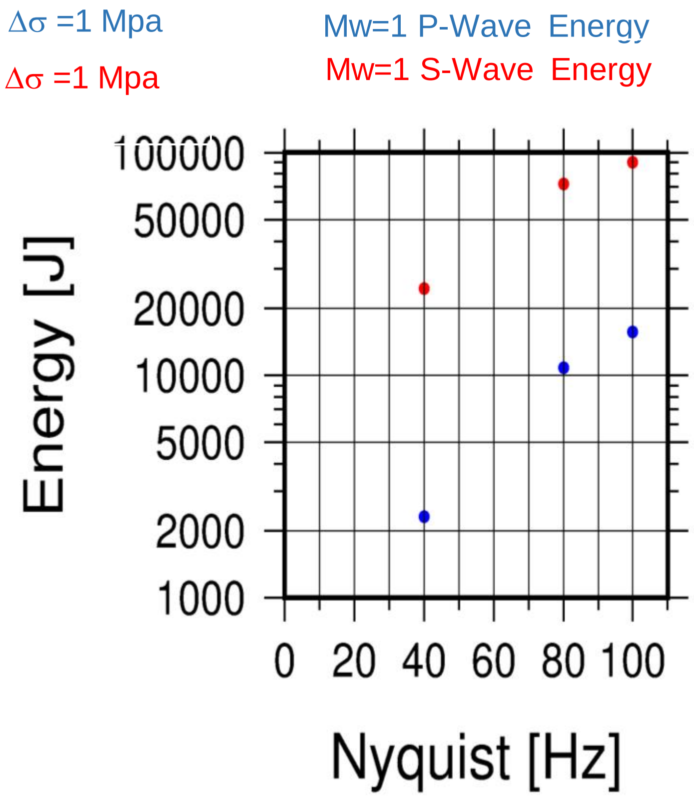


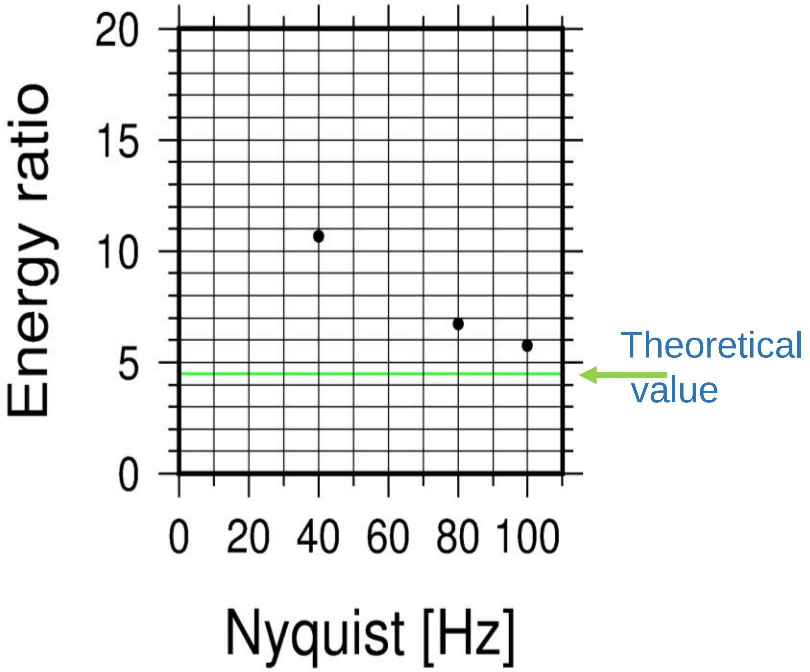


Butcher et al., 2022, BSSA

The problem becomes bigger for Minor and Micro earthquakes

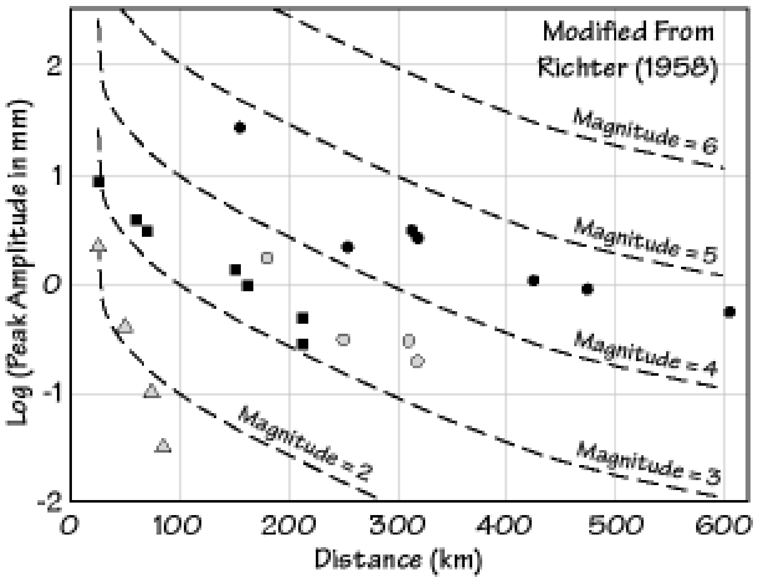






Magnitude Scales - Richter

The concept of magnitude was introduced by Richter (1935) to provide an objective instrumental measure of the size of earthquakes. Contrary to seismic intensity, I, which is based on the assessment and classification of shaking damage and human perceptions of shaking, the magnitude M uses instrumental measurements of earth ground motion adjusted for epicentral distance and source depth.



The original Richter scale was based on the observation that the amplitude of seismic waves systematically decreases with epicentral distance.

Data from local earthquakes in California

The relative size of events is calculated by comparison to a reference event, with M_L=0, such that A_0 was 1 µm at an epicentral distance, Δ, of 100 km with a Wood-Anderson instrument:

$M_L=\log(A/A_0)=\log A-2.48+2.76\Delta$.

Magnitude Scales - Richter

“I found a paper by Professor K. Wadati of Japan in which he compared large earthquakes by plotting the maximum ground motion against distance to the epicenter. I tried a similar procedure for our stations, but the range between the largest and smallest magnitudes seemed unmanageably large. Dr. Beno Gutenberg then made the natural suggestion to plot the amplitudes logarithmically. I was lucky because **logarithmic plots are a device of the devil**. I saw that I could now rank the earthquakes one above the other. Also, quite unexpectedly the attenuation curves were roughly parallel on the plot. By moving them vertically, a representative mean curve could be formed, and individual events were then characterized by individual logarithmic differences from the standard curve. This set of logarithmic differences thus became the numbers on a new instrumental scale. Very perceptively, Mr. Wood insisted that this new quantity should be given a distinctive name to contrast it with the intensity scale. My amateur interest in astronomy brought out the term "magnitude," which is used for the brightness of a star.”

Charles F. Richter - An Interview by Henry Spall, Earthquake Information Bulletin. Vol. 12, No. 1, January - February, 1980

[CHAP. 22] MAGNITUDE, STATISTICS, ENERGY 341

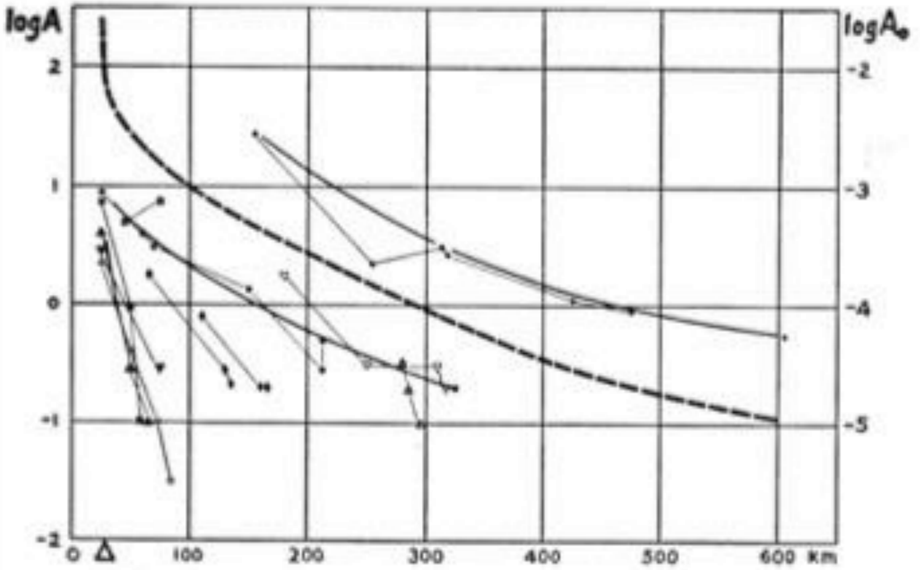
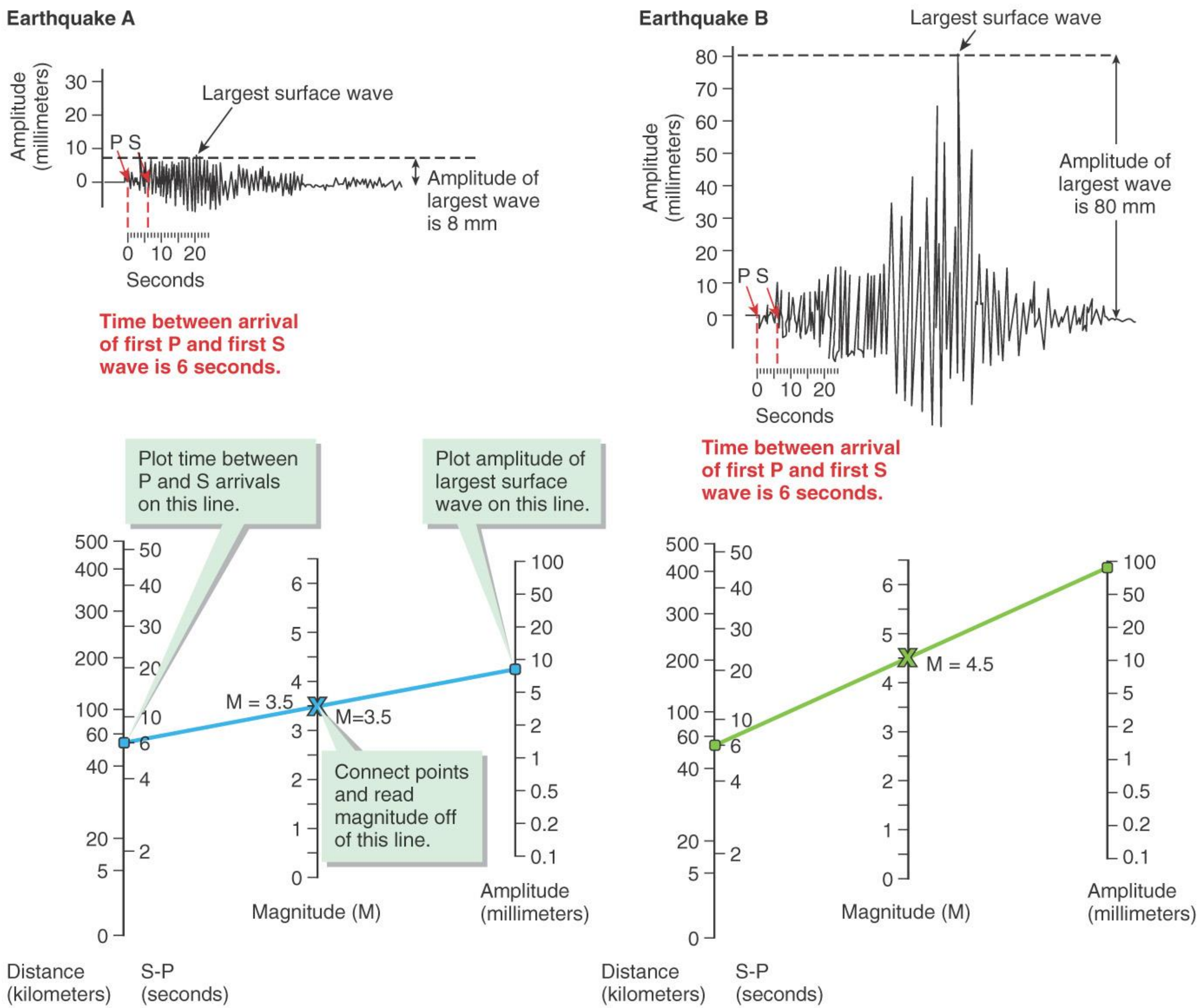


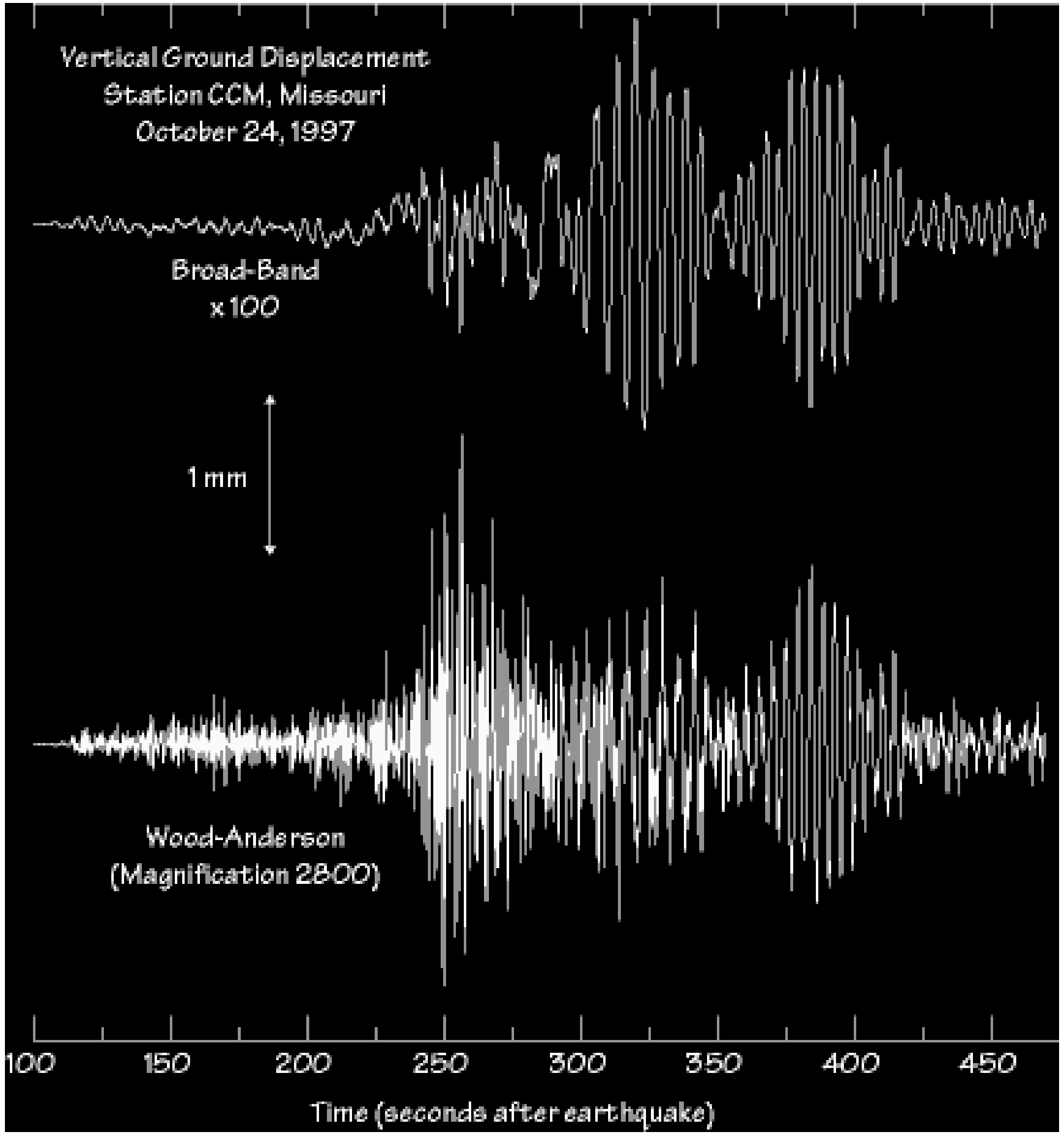
FIGURE 22-2 *Origin of the magnitude scale. Data for Southern California earthquakes of January, 1932. [Redrafted from the original notes.]*



Earthquake A
Largest surface wave
P S
Amplitude (millimeters)
Amplitude of largest wave is 8 mm
Seconds
Time between arrival of first P and first S wave is 6 seconds.
Earthquake B
Largest surface wave
Amplitude of largest wave is 80 mm
Time between arrival of first P and first S wave is 6 seconds.
Plot time between P and S arrivals on this line.
Plot amplitude of largest surface wave on this line.
Connect points and read magnitude off of this line.
M = 3.5
M=3.5
M = 4.5
Distance (kilometers)
S-P (seconds)
Magnitude (M)
Amplitude (millimeters)

Wood-Anderson Seismometer

Richter also tied his formula to a specific seismic instrument.



Magnitude Scales

The original M_L is suitable for the classification of local shocks in Southern California only since it used data from the standardized short-period Wood-Anderson seismometer network. The magnitude concept has then been extended so as to be applicable also to ground motion measurements from medium- and long-period seismographic recordings of both surface waves (M_s) and different types of body waves (m_b) in the teleseismic distance range.

The general form of all magnitude scales based on measurements of ground displacement amplitudes A and periods T is:

$$M = \log\left(\frac{A}{T}\right) + f(\Delta, h) + C_r + C_s$$

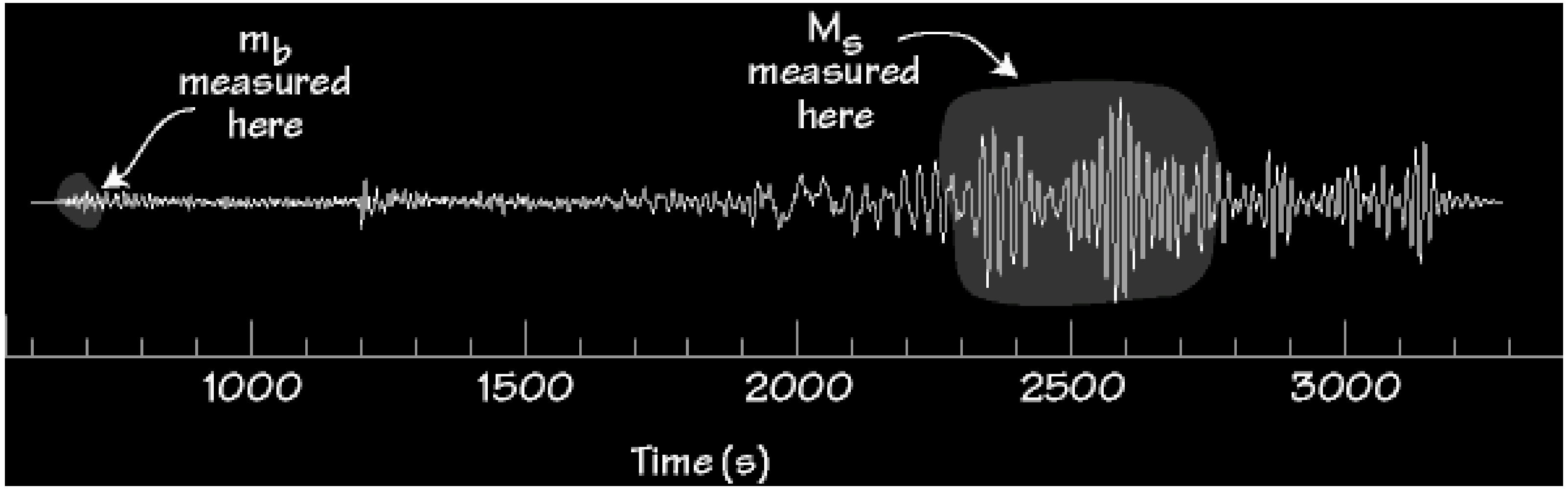
M seismic magnitude
A amplitude
T period
f correction for distance and depth
C_s correction for site
C_r correction for source region

M_L **Local magnitude**
m_b **body-wave magnitude** (1s)
M_s **surface wave magnitude** (20s)

Teleseismic M_S and mb

The two most common modern magnitude scales are:

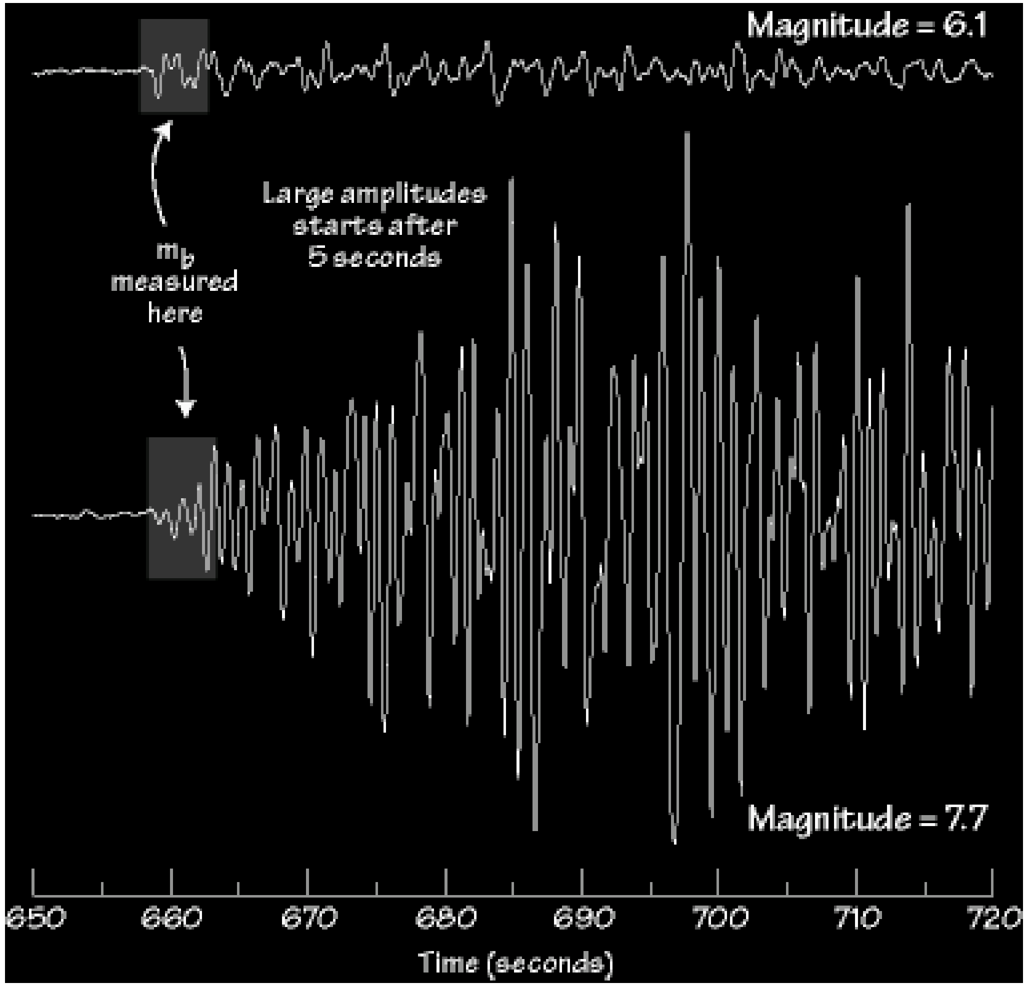
- M_S, Surface-wave magnitude (Rayleigh Wave, 20s)
- m_b, Body-wave magnitude (P-wave)



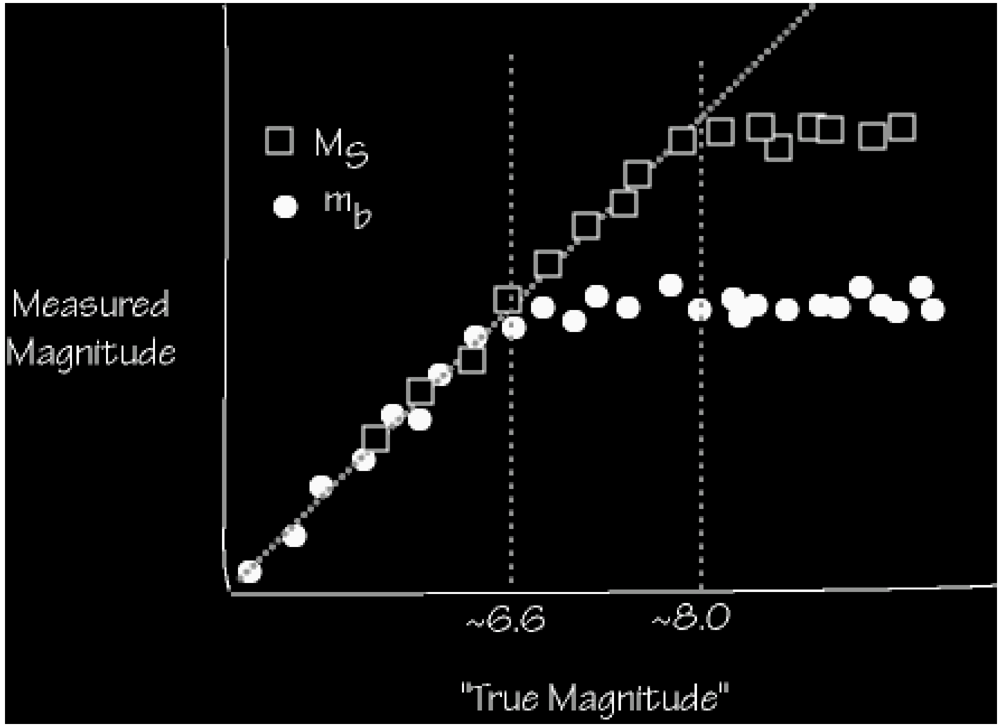
Example: m_b "Saturation"

m_b seldom gives values above 6.7 - it "saturates".

m_b must be measured in the first 5 seconds - that's the rule.

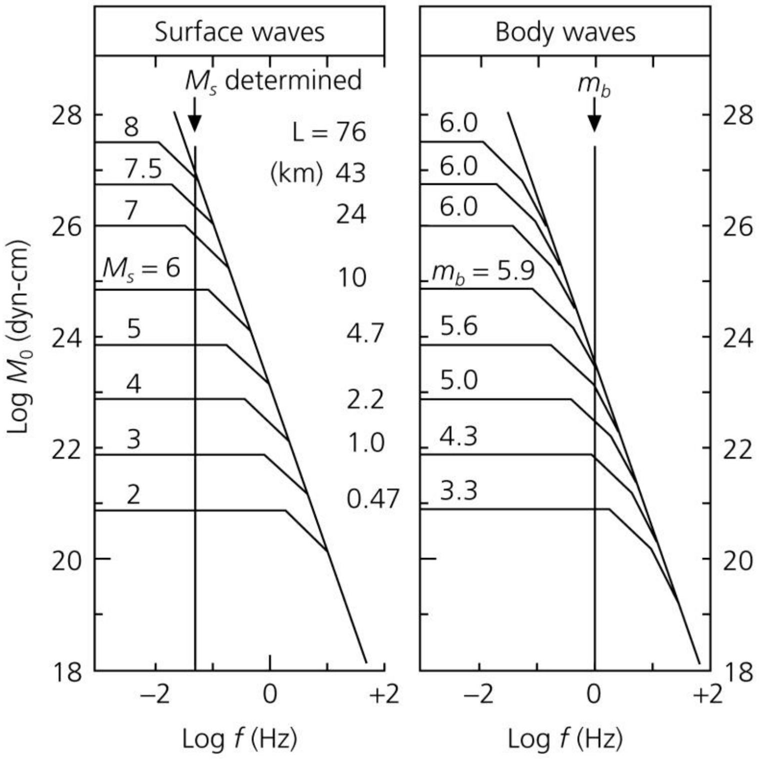


Saturation



Magnitude saturation

Nature limits the maximum size of tectonic earthquakes which is controlled by the maximum size of a brittle fracture in the lithosphere. A simple seismic shear source with linear rupture propagation has a typical "source spectrum”.



Ms is not linearly scaled with M_0 for $M_s > 6$ due to the beginning of the so-called saturation effect for spectral amplitudes with frequencies $f > f_c$. This saturation occurs already much earlier for m_b which are determined from amplitude measurements around 1 Hz.

Moment magnitude

Empirical studies (Gutenberg & Richter, 1956; Kanamori & Anderson, 1975) lead to a formula for the released seismic energy (in Joule), and for moment, with magnitude:

$\log E = 4.8 + 1.5 M_s$ $\log M_0 = 9.1 + 1.5 M_s$

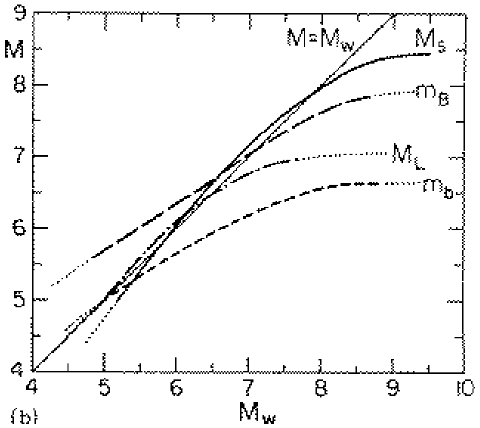
resulting in

$$M_w = 2/3 \log M_0 - 6.07$$

when the Moment is measured in N·m (otherwise the intercept becomes 10.73); it is related to the final static displacement after an earthquake and consequently to the tectonic effects of an earthquake.

$$u(x,t) = A\cos\left(\frac{2\pi t}{T}\right) \Rightarrow v(x,t) \propto \frac{A}{T} u$$

$$\Rightarrow e \propto v^2 \propto \left(\frac{A}{T}\right)^2 \Rightarrow \log E = C + 2\log\left(\frac{A}{T}\right)$$



Earthquake	Body wave magnitude m_b	Surface wave magnitude M_s	Fault area (km^2) length × width	Average dislocation (m)	Moment (dyn-cm) M_0	Moment magnitude M_w
Truckee, 1966	5.4	5.9	10 × 10	0.3	8.3×10^{24}	5.8
San Fernando, 1971	6.2	6.6	20 × 14	1.4	1.2×10^{26}	6.7
Loma Prieta, 1989	6.2	7.1	40 × 15	1.7	3.0×10^{26}	6.9
San Francisco, 1906		8.2	320 × 15	4	6.0×10^{27}	7.8
Alaska, 1964	6.2	8.4	500 × 300	7	5.2×10^{29}	9.1
Chile, 1960		8.3	800 × 200	21	2.4×10^{30}	9.5

Seismic moment (1)

Remember . . . the displacement equation for the P and S wave radiation patterns:

$$u_r = \frac{1}{4\pi\alpha^3 r}\dot{M}\left(t-r/\alpha\right)\sin\left(2\theta\right)\cos(\varphi)$$

e.g. P waves

Amplitude term

Source time function

Describes the pattern

Considering the ***seismic moment rate function*** or ***source time function***

$$\dot{M}\left(t-r/v\right)$$

which is the time derivative of the ***seismic moment function***

$$M(t) = \mu D(t) S(t)$$

where μ is rigidity, and *D(t)* and *S(t)* are the slip and fault area histories, respectively.

(*Lay & Wallace, 1995; Stein & Wysession, 2003*)

Seismic moment (2)

This leads to the best measure of an earthquake's size and energy,

$$M(t) = \mu D_{av} S$$

the ***seismic moment***, where D_{av} is the average slip or dislocation and S is the fault area.

which in turn gives the ***moment magnitude*** M_w

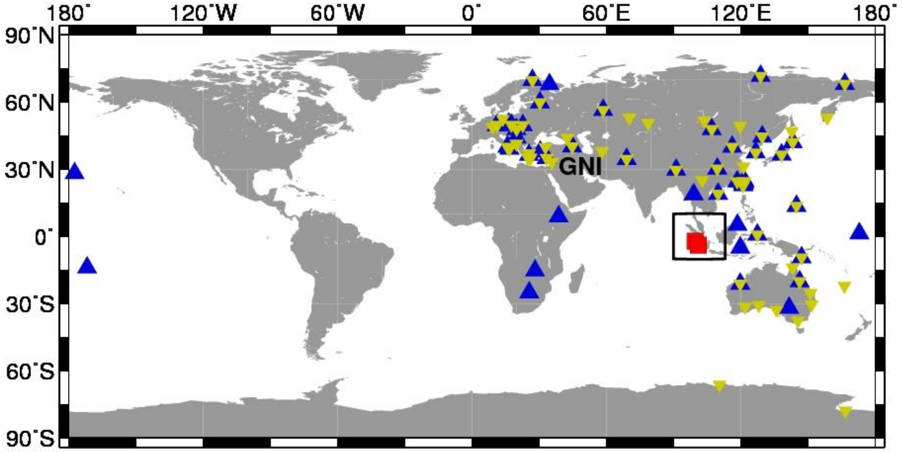
$$M_w = \frac{\log M_o}{1.5} - 10.73$$

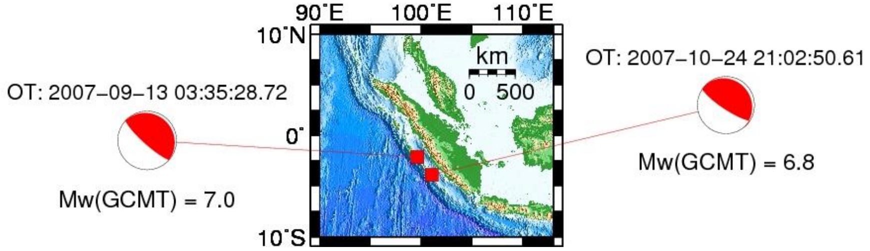
where M_o is in dyn-cm.

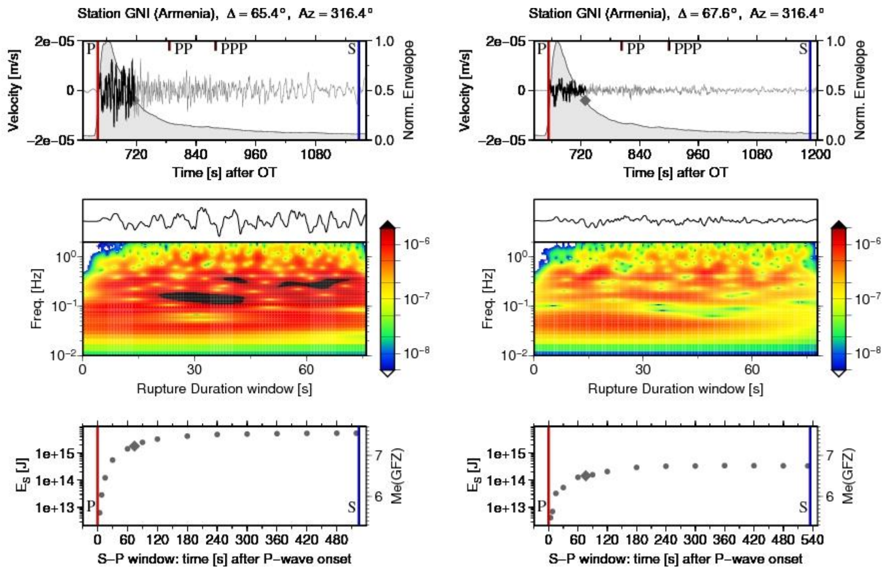
and which we will discuss again with respect to other magnitude scales.

(*Lay & Wallace, 1995; Stein & Wysession, 2003*)

Importance of comparing Mw and Me







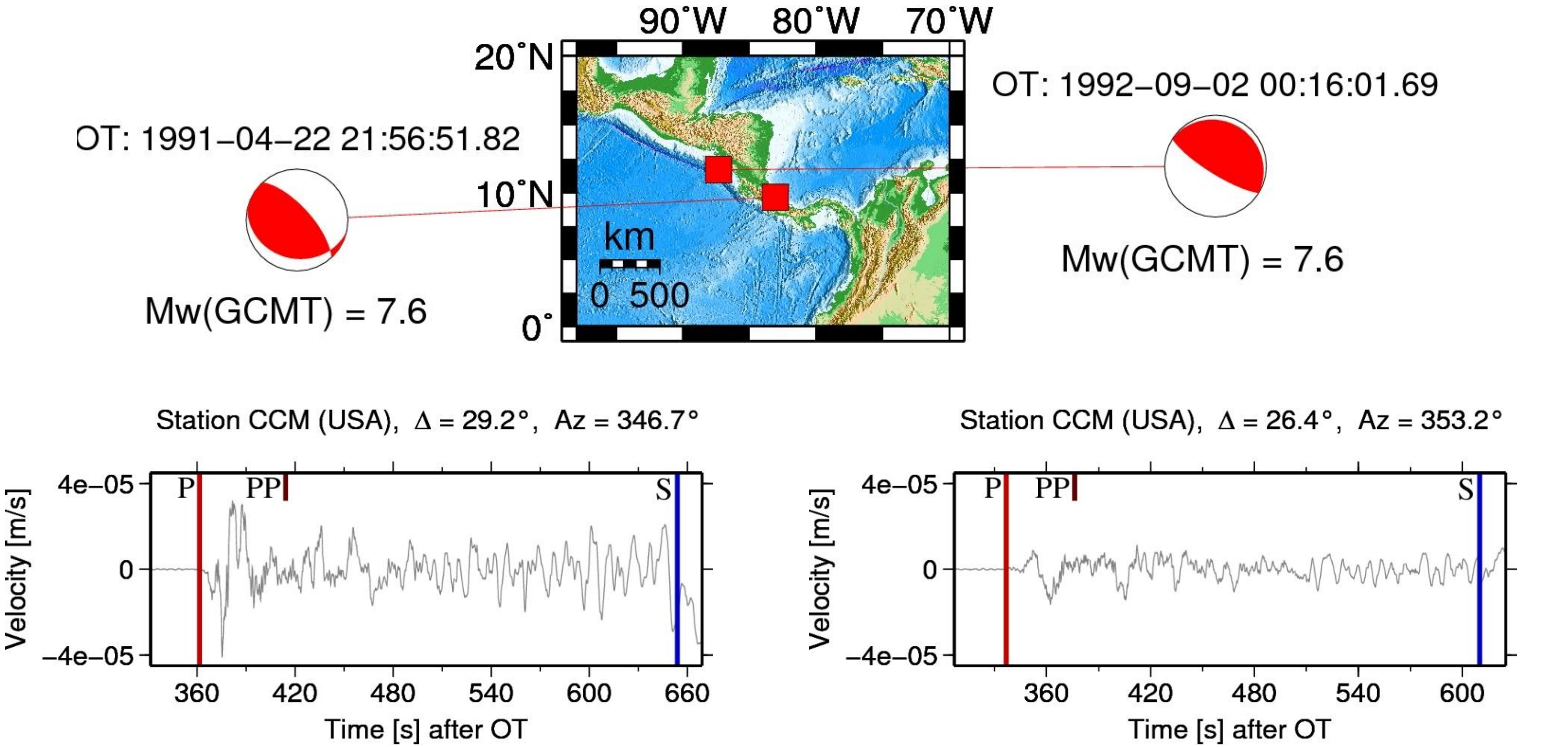
Mw(GCMT) = 7.0
Me(GFZ) = 7.1

Mw(GCMT) = 6.8
Me(GFZ) = 6.4

However, the high frequency content observed in the seismograms is significantly different and cannot be explained by Mw only.

The locations differ by about 250 km and the moment magnitudes Mw and the fault plane solutions are very similar.

Importance of comparing Mw and Me



Mw(GCMT) = 7.6, Me(GFZ) = 7.19

Mw(GCMT) = 7.6, Me(GFZ) = 6.75

The locations differ by about 500 km and the moment magnitudes Mw are nearly identical, therefore the differences in the high frequency content observed in the seismograms can be attributed to different source characteristics.

Di Giacomo and Bindi (2009)