Earthquake Magnitude

HISTORY OF MAGNITUDES

> first devised by Charles Richter in 1935 for S California: ``Richter Scale" or ``local" magnitude

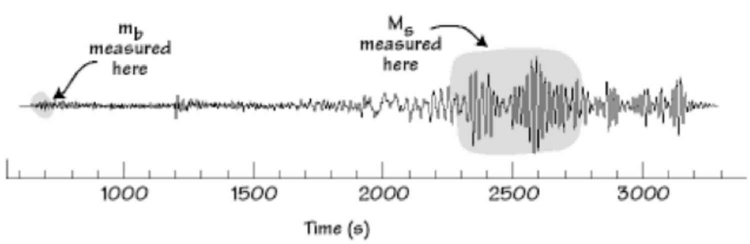
$$M_L = \log A + 2.76 \log \Delta - 2.48$$

> valid for Wood-Anderson seismograph (resonant frequency = 0.8 Hz) and uses S-wave amplitude

> sometimes still reported since good indicator of structural damage

> later modifications include global body wave and surface wave scales:

$$m_b = \log(A/T) + Q(h, \Delta) \qquad M_s = \log(A/T) + 1.6 \log \Delta + 3.3$$



Earthquake magnitude scales: Logarithmic measure of earthquake size

– *amplitude of biggest wave*: Magnitude 6 quake 10 * Magnitude 5

– *energy*: Magnitude 6 quake is about 32 * Magnitude 5

Richter Magnitude is calculated from the maximum amplitude of waves recorded on a seismogram, and distance to the earthquake.

$$10^{M_L} = 10^{(logA + 2.76 log\Delta - 2.48)}$$

$$10^{M_L} = 10^{(logA)} \boxed{10^{(2.76 log\Delta - 2.48)}}$$

this is a constant, we can call it "k".

$$10^{M_L} = A\ k$$

How does the maximum shaking amplitude A of a M6 quake compare to a M4 quake (same hypocenter, same seismograph location?

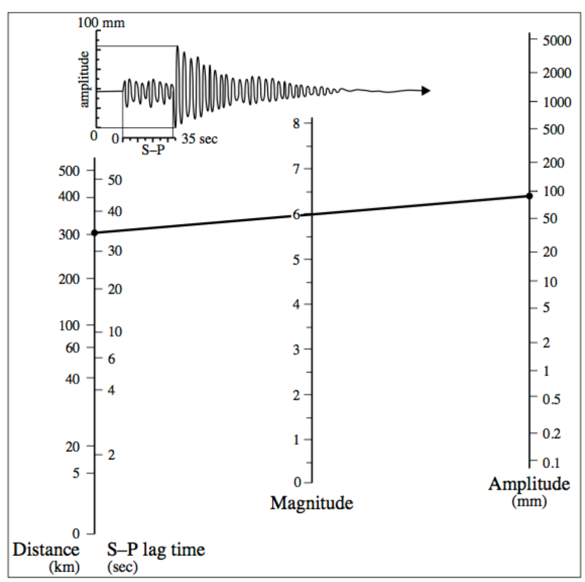
By the same token, you can easily compare the energy release ("seismic moment") of different magnitude earthquakes:

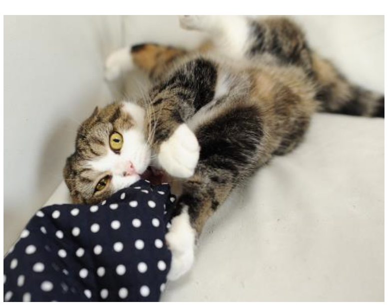
$$32^{M_L} = E\ k$$

How does the energy (moment) of a M6 quake compare to that of a M4 quake?

A quick method (pre electronic calculators), involved using a graphical construct (called a Nomogram) that takes care of the mathematics by constructing the axes in a particular fashion.

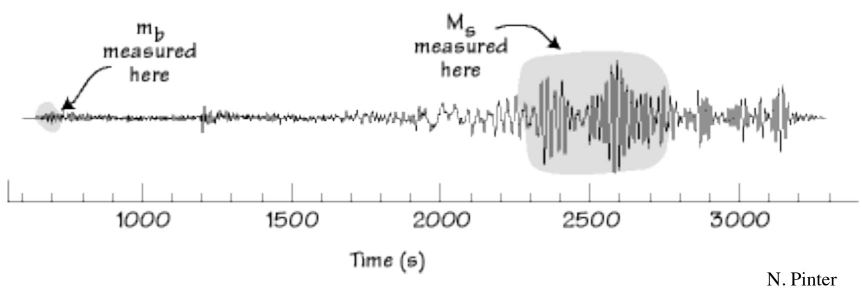
The **Nomogram** allows one to compute the magnitude by plotting the distance between the quake and observatory on the left axis, and the seismometer deflection in millimetres on the right axis. (The amplitude of the deflections are what would have been recorded by a Wood-Anderson seismometer – the actual ground motions have been multiplied by 2000 which is the amplification of the Wood - Anderson seismometer at these frequencies). The points on the left and right axes are connected by a straight line, and the intersection on the middle axis is the earthquake magnitude.





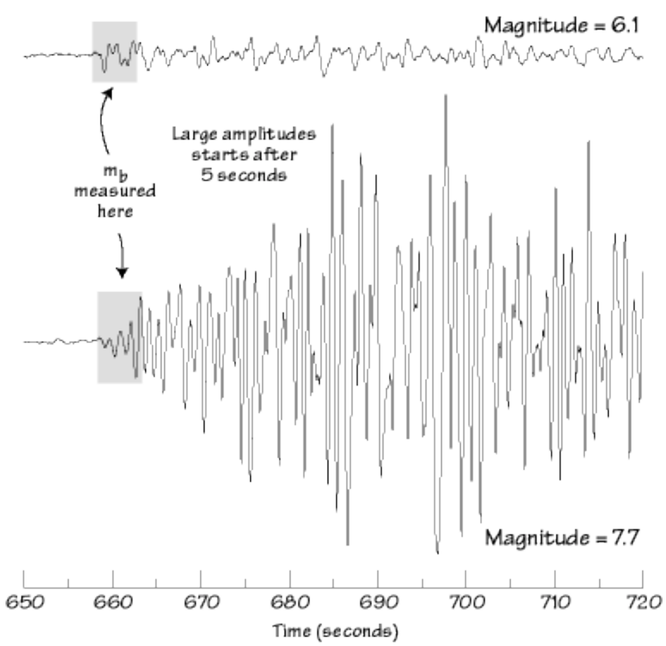
Magnitude	Symbol	Wave	Period
Local (Richter)	M_L	S or Surface Wave*	0.8 s
Body-Wave	m_b	P	1 s
Surface-Wave	M_s	Rayleigh	20 s
Moment	M_w	Rupture Area, Slip	> 100 s

*whichever's biggest at a period of 0.8s (typically the S wave), and ALSO always using a Wood-Anderson seismograph (or converting the amplitude so the seismogram looks just like one from a WA seismograph)



N. Pinter

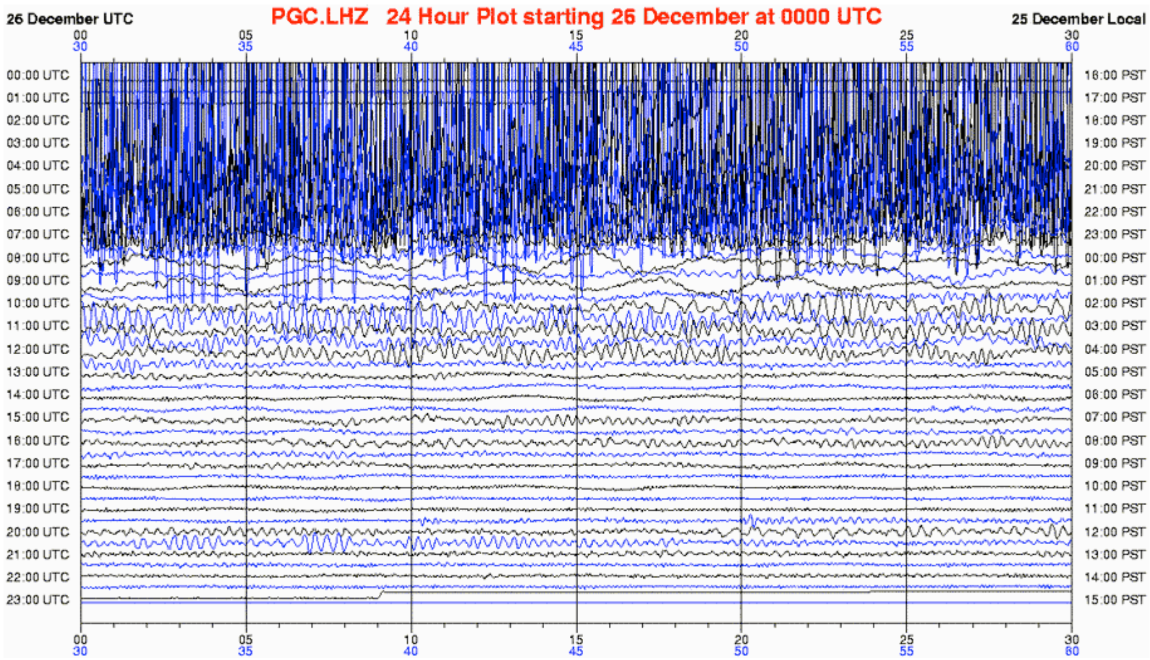
M_b and M_L are inadequate for large earthquakes



N. Pinter

M 9.2 2004 Sumatra Earthquake

measured in Victoria BC



MAGNITUDE DISCREPANCIES

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

> note discrepant body-wave and surface wave magnitudes (due to empirical nature, no account for radiation pattern, local ground effects, etc.

> body-wave magnitudes saturate at ~6.2, surface wave magnitudes at ~8.4

Earthquake magnitude scales

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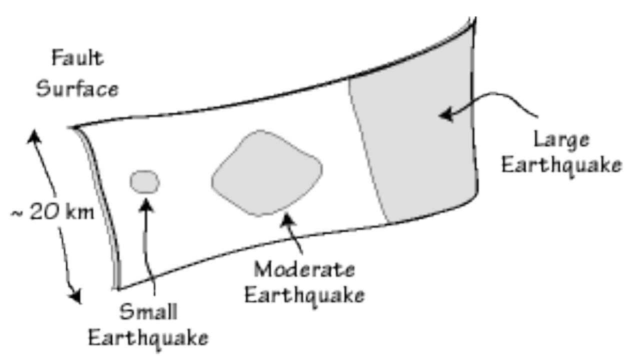
M_w is calculated from the **earthquake energy release**, which can be done with **many** different kinds of data, such as very long-period surface wave recordings from broadband seismometers and even GPS measurements of permanent ground displacement

M_w is best for large earthquakes

Energy released by an earthquake (seismic moment)



C. Ammon

$$M_o = A \, \mu \, s$$

Seismic moment (Newton m)

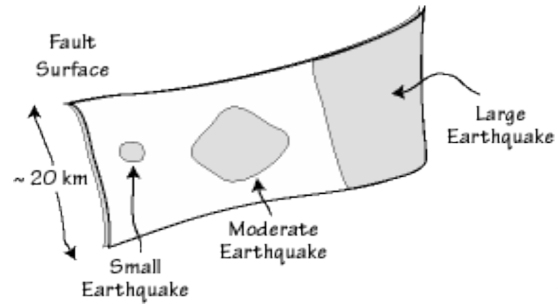
A is the area of the fault that slipped in the earthquake (m^2)

μ is that SAME constant ("shear modulus" or "rigidity") that appeared in the seismic wave speed equations on Monday. Pascals, i.e., Newtons / m^2)

s is the slip (m)

Moment magnitude M_w comes from seismic moment M_o

$$M_o = A\ \mu\ s$$



C. Ammon

= unwieldy large number, for example, “10^{21} Newton meters”

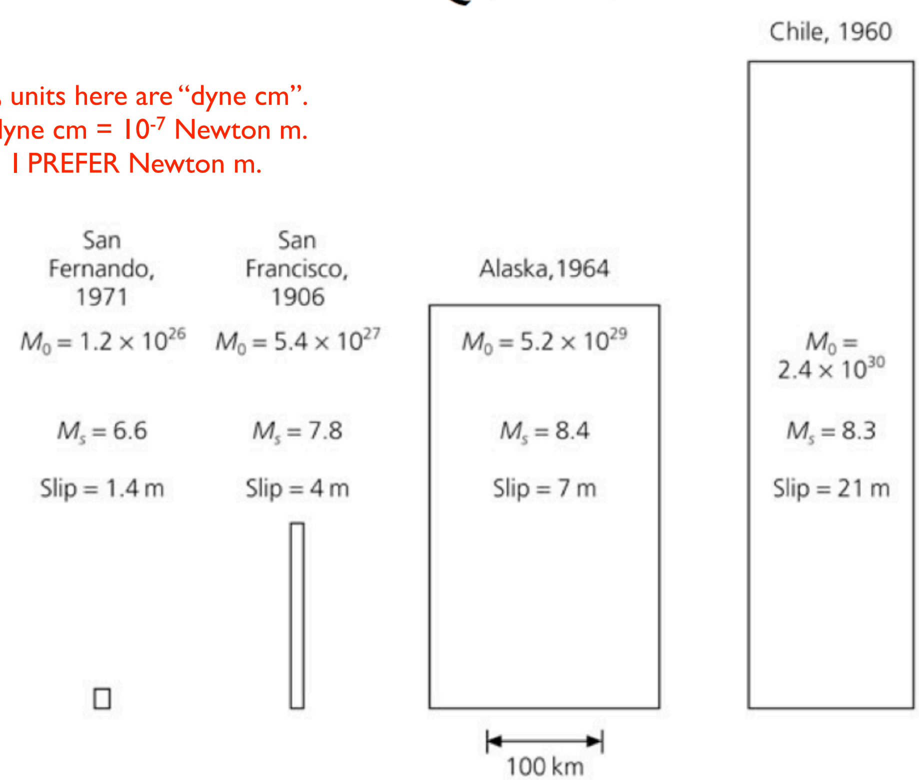
To get a number that looks like a Richter magnitude, we use this equation:

$$M_w = \frac{2}{3}(7 + log M_o) - 10.73$$

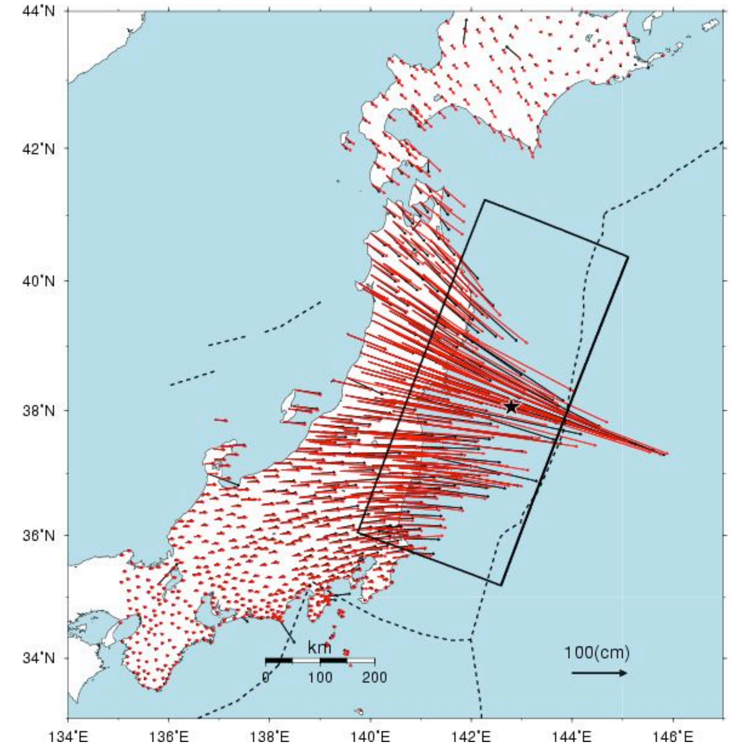
$$M_w = \frac{2}{3} log M_o - 6.07$$

RELATIVE AREAS, SLIP MOMENTS OF SOME EARTHQUAKES

M_o units here are “dyne cm”.
1 dyne cm = 10^{-7} Newton m.
I PREFER Newton m.

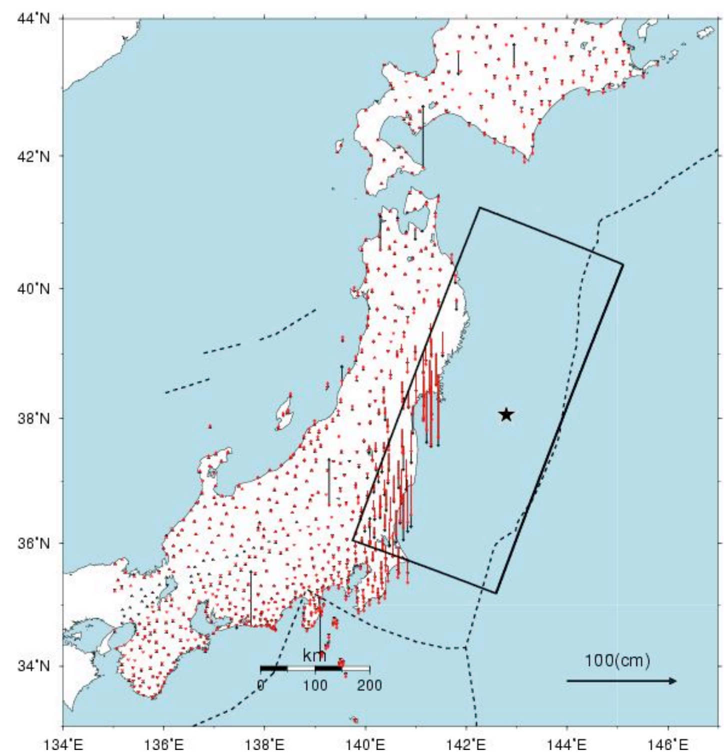


Moment magnitude M_W of the 2011 Tohoku earthquake from GPS



Horizontal displacements

http://www.tectonics.caltech.edu/slip_history/2011_taiheiyo-oki/



Vertical displacements

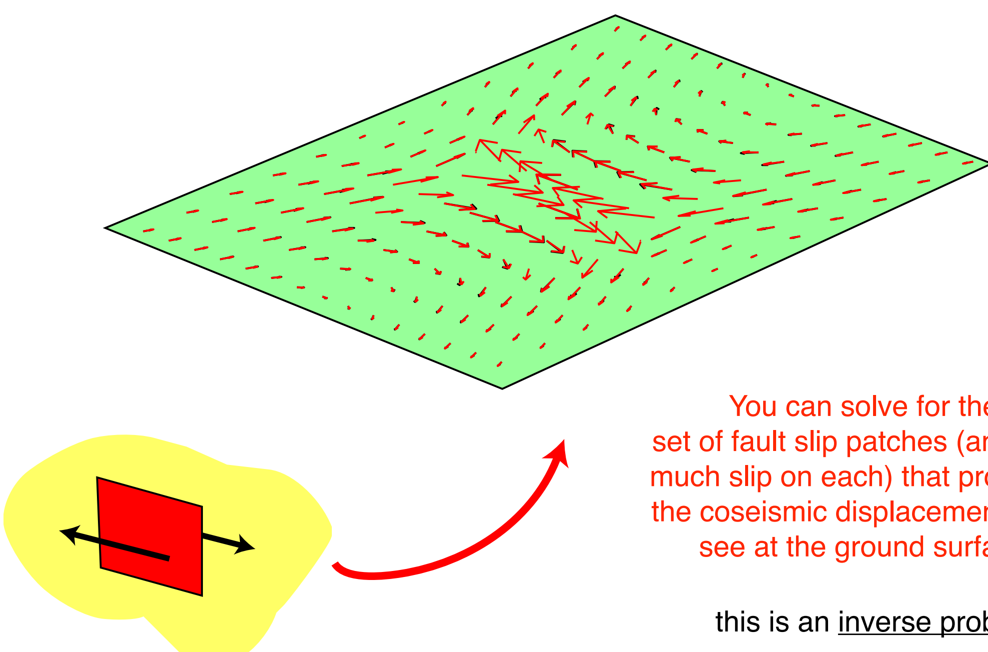
http://www.tectonics.caltech.edu/slip_history/2011_taiheiyo-oki/

• we know how to calculate surface displacements resulting from slip on a fault.

• here, we are given surface displacements and we want to know slip on the fault (and sometimes, where the fault is and its orientation)

• this is <u>another</u> example of an "inverse problem", like the earthquake location problem. (we have lots of these in geophysics)

Let's say you know how to calculate how much the ground deforms if there is 1 m of slip on any 1 km patch of a fault (you do: Okada, 1985)



You can solve for the set of fault slip patches (and how much slip on each) that produces the coseismic displacements you see at the ground surface

this is an <u>inverse problem</u>

Slip inversions from surface displacement data

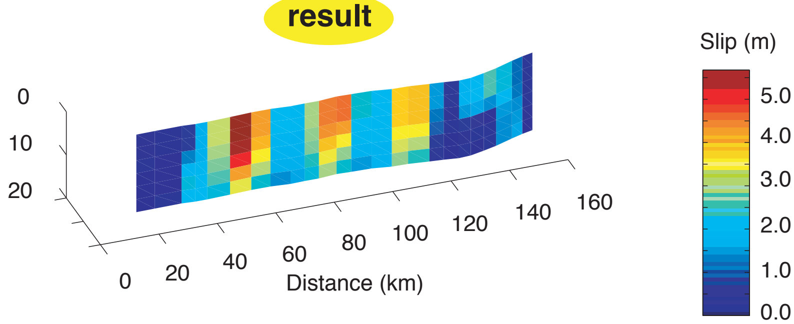
- minimize L2 norm of [*misfit between modeled and measured surface displacements weighted by meas. errors*]
  ("weighted residual sum of squares")
- smooth slip distribution (also minimize Σ curvature of slip distribution)
- no backward slip

$$d_i = \sum_j \Gamma_{ij} s_j \quad \text{j patches, i displ. dof}$$

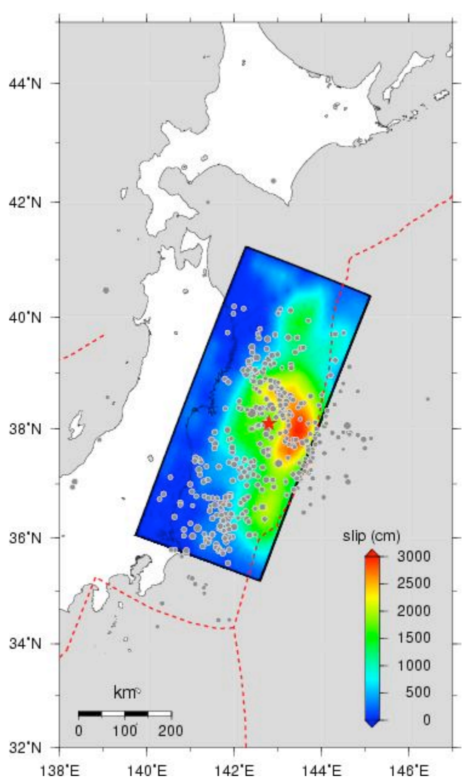
$$s = (\Gamma^T\Gamma + \beta^2 H^T H)^{-1}(\Gamma^T d)$$

Γ = Green's function
H = curvature operator

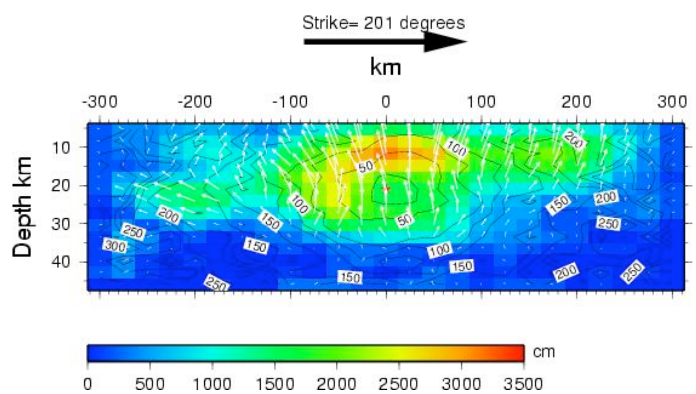
result



bvls method, Stark and Parker, 1995



Caltech's estimate of slip and moment for the March 2011 Tohoku Earthquake



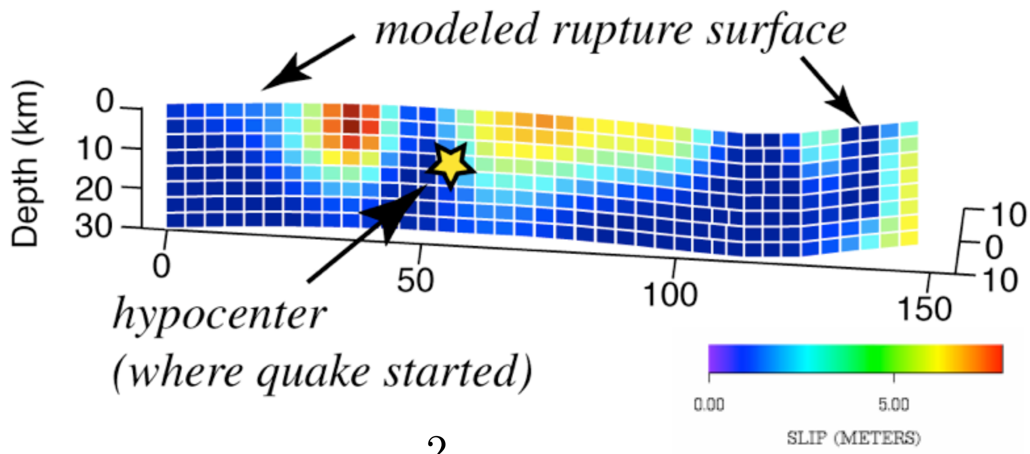
$$M_o = A\ \mu\ s$$

$$M_w = \frac{2}{3} log M_o - 6.07$$

$$M_w = 9.0$$

http://www.tectonics.caltech.edu/slip_history/2011_taiheiyo-oki/

My estimate of slip and moment for the 1999 Izmit, Turkey Earthquake

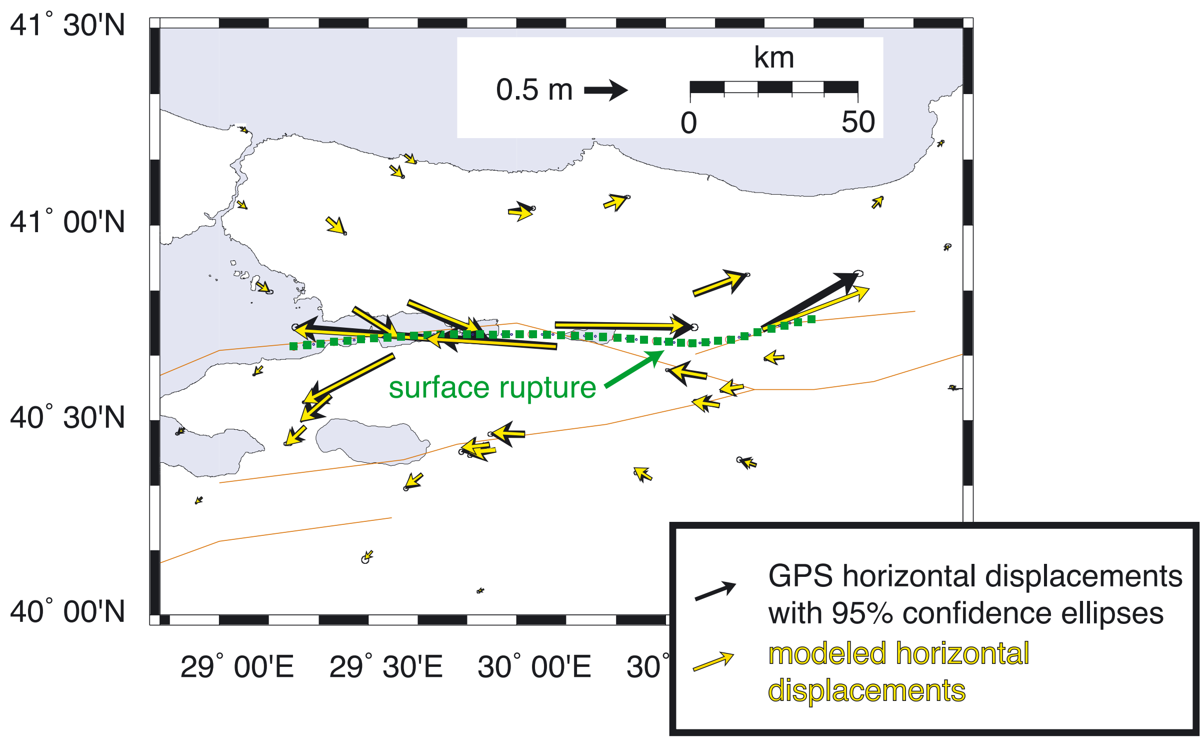


$$M_o = A\ \mu\ s \qquad M_w = \frac{2}{3} log M_o - 6.07$$

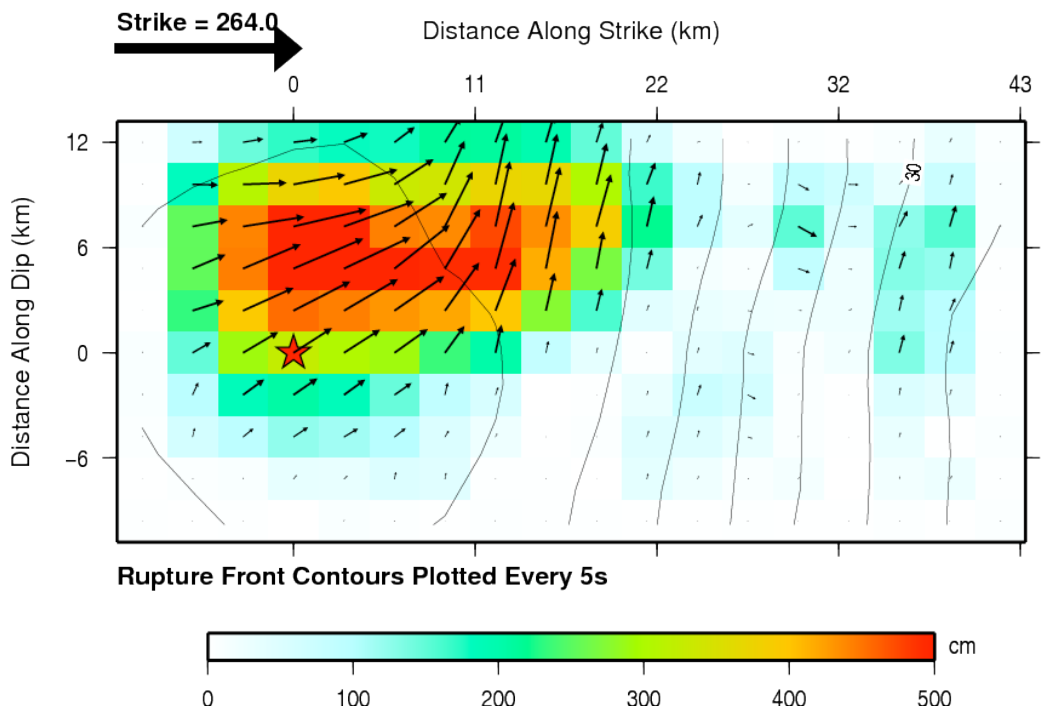
Sum moment for all 312 4-km "patches"

The seismic moment from this is 2.3 x 10^{20} Newton m, which is a moment magnitude of 7.4

Moment magnitude from GPS data: M_w = 7.5 Izmit, Turkey earthquake

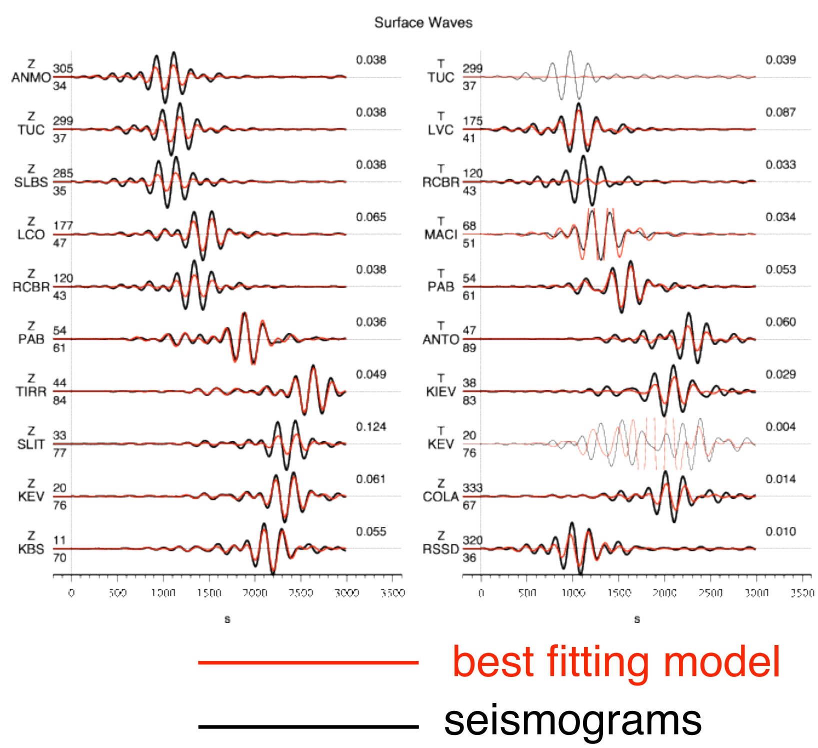


Slip for the 2009 Haiti earthquake



$$M_o = 4.95 \times 10^{19} N\ m$$

Slip and moment for the 2009 Haiti earthquake are from an inversion of surface wave data



Slip versus time from an inversion of seismic records (strong motion data, frequencies between 0.01 and 0.2 Hz)

http://www.youtube.com/watch?v=A_dWf9Lr9qE

S.-J. Lee et al., 2011.