P 19

2nd EEW Workshop, Kyoto, 21-23/04/09

Early radiation and final magnitude : insights from source kinematics

G. Festa[1] and A. Zollo[1,2]

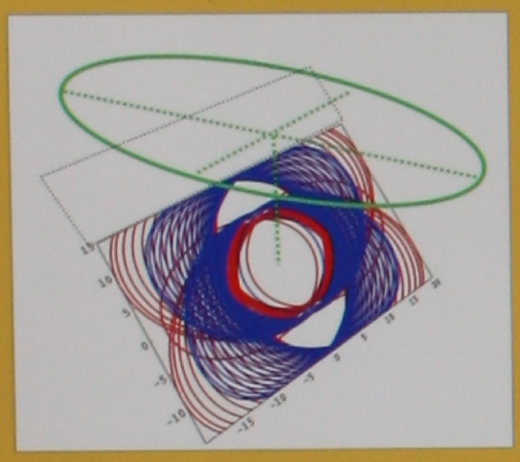
[1]Dipartimento di Scienze Fisiche, Università di Napoli "Federico II"; [2] AMRA Scarl (Analysis and Monitoring of Enviromental Risks)

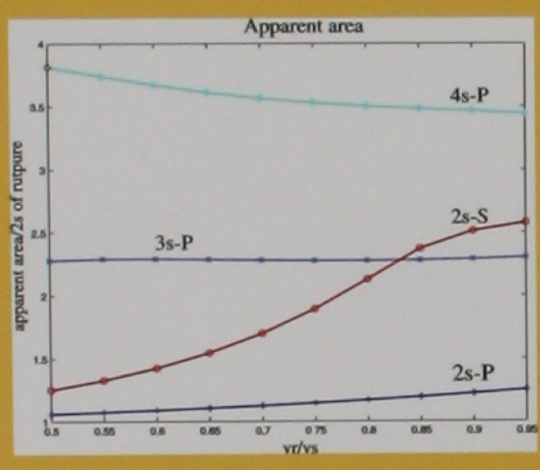
Kinematic problem

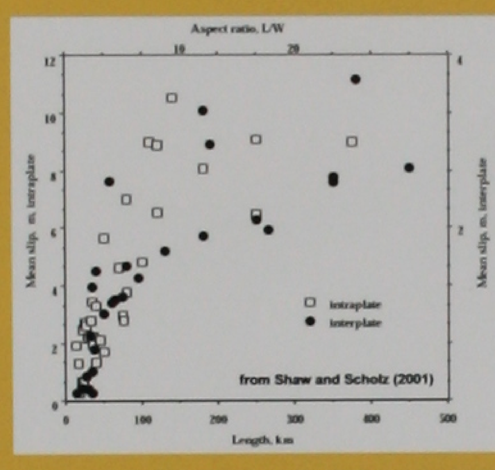
When the far-field dominates the Green function, the representation theorem can be written as a line integral along the isochrone:

$$u_n = \frac{\mu}{2\pi\rho c^3}\int_L \frac{\mathbf{R}_{\theta\phi}}{R} c(v_r,\phi)\delta u(\xi, t-T)dl$$

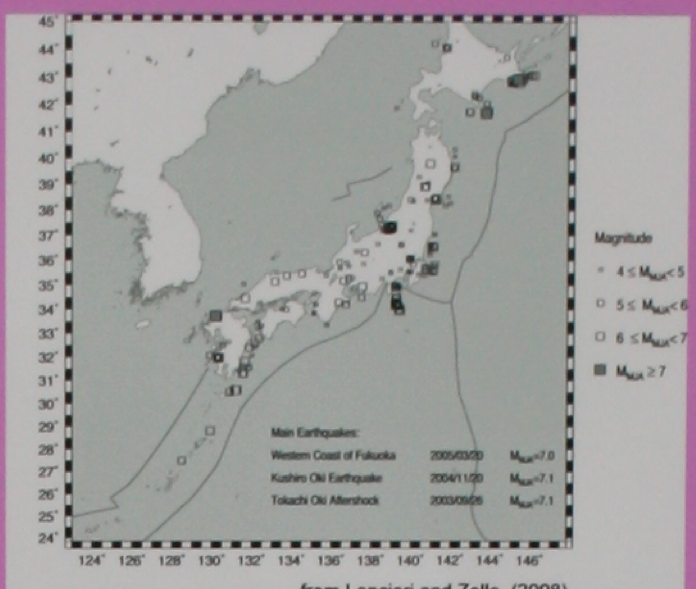
In EEW applications we would detect changes in the early displacement (or its time derivatives) as a function of the magnitude. There are several reasons for that: the absolute value of the slip, the rupture area, the rupture velocity and the rise time are parameters that may depend on the magnitude of the event. However, the rupture velocity is almost constant with the magnitude and changes are likely to be related to smaller space scales, associated with the fault geometry and rheology. The rupture area effectively changes with the magnitude and scales as M for widths smaller than the seismogenic depth W*, as 0.5M beyond such a limit. In addition, few seconds of observation define a space scale on the fault plane, with respect to which we ought to compare the size of the event. Such a characteristic length is associated to a magnitude threshold, beyond that the rupture area does no longer increase. For 4s of P wave/ 2s of S wave such a threshold ranges between 5.8 and 6.3. Finally the slip scales with the magnitude as 0.5 M, with a possible saturation when the rupture length is 10 W* (about at magnitude 8).

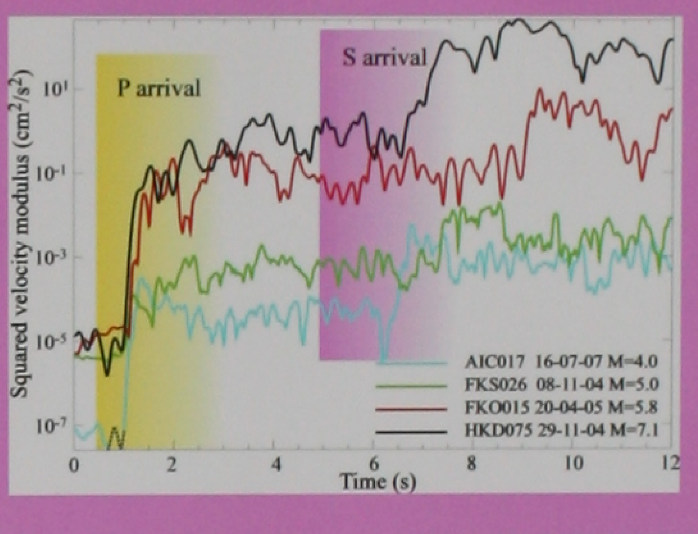






Measurements and Data


from Lancieri and Zollo (2008)



We investigate the behavior of the squared velocity integral (*IV2*)

$$IV2_c = \int_{t_c}^{t_c+T_c} v^2(t)dt$$

and the ratio *PD²/IV2* where *PD* is the peak displacement. *IV2* includes information about the energy radiated by the advancing rupture on the fault plane, while *PD²/IV2* is a proxy for the slip.

The dataset we have processed consists of about 2500 high-quality strong-motion records from the K-Net (http://www.k-net.bosai.go.jp/k-net/index_en.shtml) and Kik-net (http://www.kik.bosai. go.jp/kik/index en.shtml) Japanese databases. The records correspond to events that occurred from 1996 to 2005 and their magnitudes range from *4.0* to *7.0*. We limited the analysis to stations with hypocentral distance smaller than *60 km*. Velocities were obtained by integration and band-pass filtering in the frequency band of *0.075-10 Hz*. For the analysis, we selected Dt_p=*4s* of signal after the first P arrival and Dt_s=*2s* beyond the S arrival.

To compare records from stations located at different distances from the hypocenter, we normalized the measurements to the reference distance R_0 = *10 km*, by analytically removing the geometrical spreading term $\log(R^2/R_0^2)$.

Scaling laws

The IV2 points evaluated for the whole signal S (diamonds in the case of large events) are aligned along a straight line, with a slope compatible with the expected scaling factor of *1.5*. Straight lines with this slope fit both the P and S data up to a magnitude *M = 5.8*. Beyond this, the early energy increases less, or does not increase at all, with respect to the final magnitude. A rupture size having a magnitude *M=5.8* is comparable with the area imaged by the back-propagation of the selected P- and S-windows. By interpreting the velocity integral representations in the light of the scaling laws, we can conclude that below *M=5.8* the apparent duration is smaller than the investigation time window and the increase in the emitted radiation is associated with both the increasing fracture area and the increasing average slip. Beyond *M=5.8*, the data provide a partial image of the advancing rupture, coming from a fault portion which has almost the same area, despite the magnitude. IV2 is here not predictive and any increase in the velocity integral has to be ascribed to the slip.

For this, we transform the velocity integral into the radiated energy *E* :

$$E_c = 4\pi\frac{R^2}{F^2\Re_c^2}\rho c IV2_c \qquad E_s/E_p = 16.7$$

The radiated energy is related to the slip as:

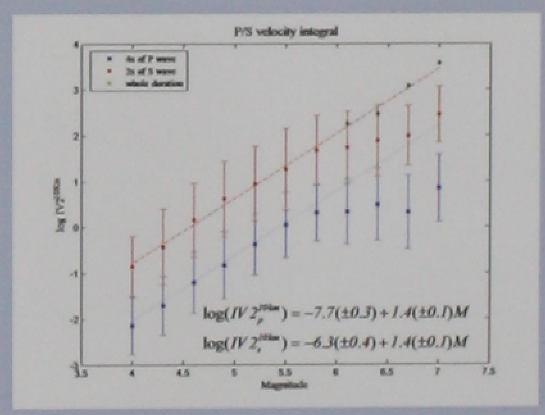
$$E = \tfrac{1}{2}\Delta\sigma\langle D\rangle A \qquad \Delta\sigma = 6.7\,MPa$$

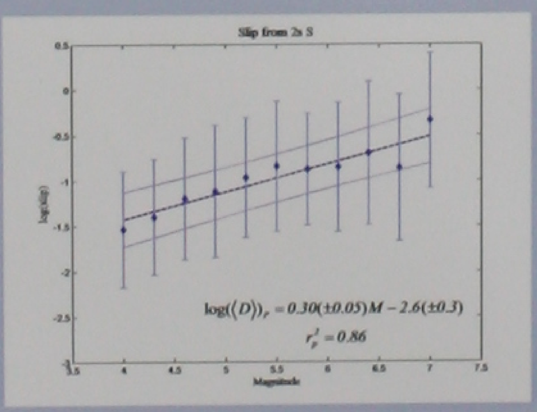
Finally, to obtain the slip, we normalized the radiated energy for the rupture area: for *M<5.8*, we use the moment versus area scaling for a circular crack:

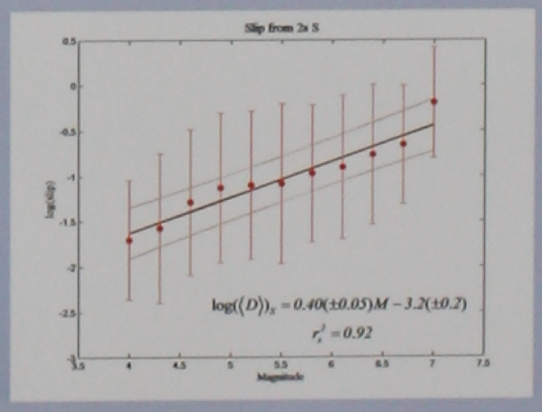
$$M_0 = \frac{16}{7\pi^{3/2}}\Delta\sigma A^{3/2}$$

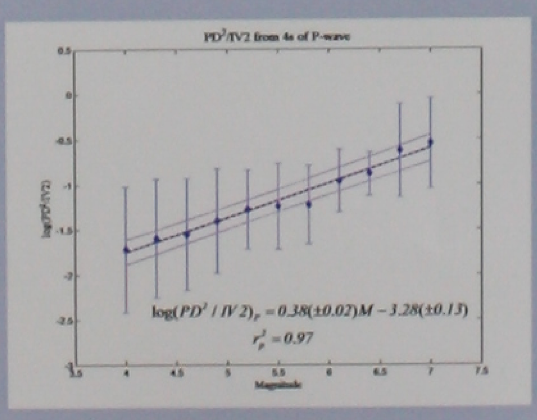
Then, beyond magnitude *M = 5.8*, a constant value for the rupture area is used, corresponding to the one estimated for an earthquake of *M = 5.8*.

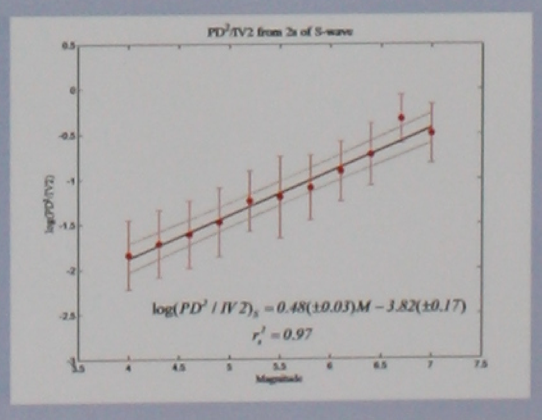
We note that, assuming a constant stress drop, the radiated energy scales as the product *<D>A*, while the peak displacement *PD* scales as *<D>A^1/2*. Hence, if the scaling law holds also in the early portion of the signal, the ratio *PD²/IV2* should scale as the slip. The scaling between *PD²/IV2* and the magnitude implies that the average slip in the early stage of the rupture looks similar to its final distribution, according to the hypothesis that large slip zones are likely to be located within or close to the hypocenter. Additionally, the slip in the initial part of the rupture has reached or is closed to its final value, indicating that the rise time should be associated with a time scale smaller than *4s* of the P-wave and *2s* of the S-wave.











A similar parameter: τ_c

The predominant period is:

$$\tau_c(T) = 2\pi\sqrt{\frac{\int_0^T u^2(t)dt}{\int_0^T v^2(t)dt}}$$

The low-frequency displacement is representative of the seismic source moment rate the displacement can be described by a time function as simple as a triangle. With this hypothesis, the displacement integral scales as:

$$ID2 = \int_0^T u^2(t)dt \propto \begin{cases} PD^2 t^* \propto <D>^2 A^{3/2} & \text{small eqks} \\ PD^2 T \propto <D>^2 & \text{large eqks} \end{cases}$$

where t* is the source time function duration, which scales as $A^{1/2}$.

Analogously , the velocity integral scales as

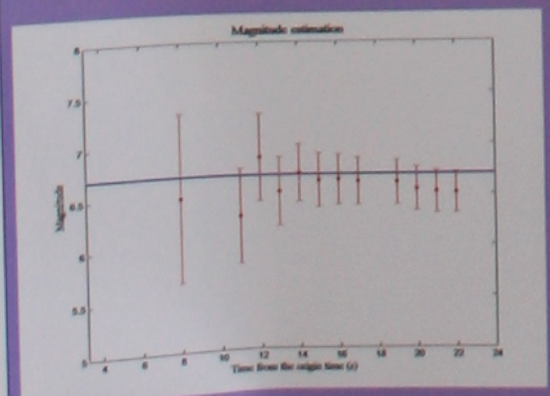
$$IV2 = \int_0^T v^2(t)dt \propto E_R \propto \begin{cases} <D> A & \text{small eqks} \\ <D> & \text{large eqks} \end{cases}$$

τ_c therefore scales as:

$$\tau \propto \begin{cases} <D>^{1/2} A^{1/4} & \text{small eqks} \\ <D>^{1/2} & \text{large eqks} \end{cases}$$

That is a scaling with *0.5M* for small earthquakes and *0.25M* for large earthquakes, as commonly observed in the data.

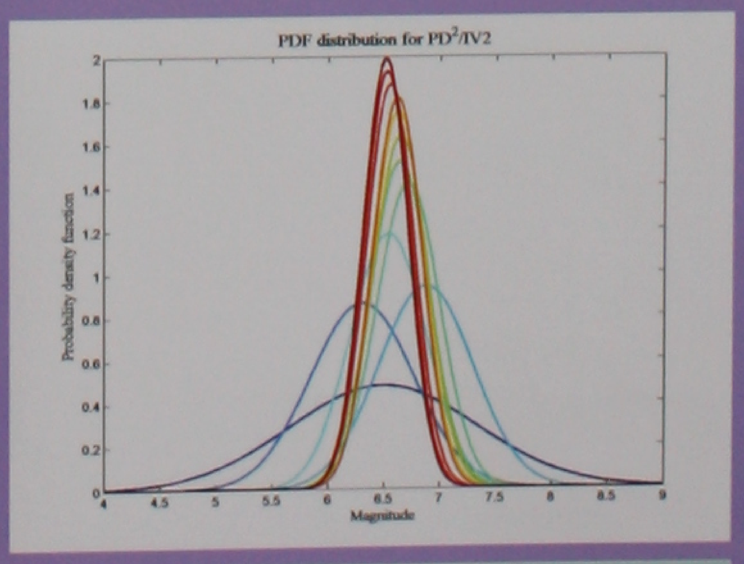
The 2007, Noto-Hanto earthquake



The Noto Hanto earthquake (Mw = 6.7), occurred on March 25, 2007, at 37.22N, 136.69E and 11km depth. The focal mechanism indicates a reverse, low-angle fault. 12 accelerometric stations recorded the earthquake at epicentral distances smaller than *60 km*. The slip map, obtained by inversion of strong motion data, show a large slip patch located in the shallower part of the fault, NE of the hypocenter (Yagi, http://www.geo.tsukuba.ac.jp/press_HP/yagi/EQ/20070325), with a maximum slip of 1.6 m.

We compute the ratio *PD²/IV2* for 4s of P wave and 2s of S wave. The first station which triggers the event is ISK006, at about 3.5s after the origin time. However the S-P time is smaller than 4s, therefore the first information available comes from the S wave train recorded at the same station. We use a Bayesian approach to combine the information coming at a given time from one or more stations with the information acquired at the previous time steps, which is used as an priori probability. The pdf associated with a single measure of log(*PD²/IV2*) is a Gaussian distribution centered in the magnitude value expected from the regression law.

As more and more stations process their records, the shape of the Gaussian function becomes peaked around the final value which has been estimated to be 6.5, with an error of 0.2. When looking at the evolution of the magnitude with time we see that the value is mostly stabilized after 14s (6s after the first information). We also superimpose on the slip map the isochrones corresponding to the stations ISK006, located above the fault, ISK003, a directive station, ISK009, almost anti-directive, and ISK007, a lateral station. For this geometry, we note that the area spanned by 4s of P wave is larger than the area spanned by 2s of S wave. For the P wave, the investigated area covers most of the fault: only the station ISK009 averages out the slip in low-slip regions. The isochrone distribution for S wave significantly differ from station to station. On the contrary the average slip is almost the same for all of the stations, except for ISK009. At this station the corresponding PD²/IV2 is lower than the one measured at the other stations.



Station	$(PD^2/IV2)^P$	$(PD^2/IV2)^S$	Slip P(m)	Slip S(m)
ISK006	-	-0.70	0.84	1.03
ISK003	-1.02	-0.77	0.78	0.92
ISK009	-1.09	-0.89	0.51	0.57
ISK007	-0.87	-0.67	0.70	0.92