Earthquakes scaling laws in Central Apennines

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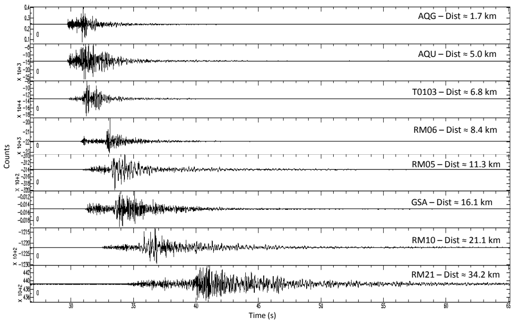
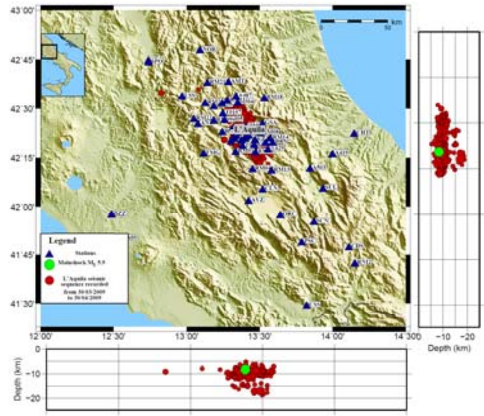
The objective of this work is the estimation of the attenuation and source parameters (seismic moment, source radius, seismic energy and stress release) of the 2009 L'Aquila earthquake sequence.

Dataset

An accelerometric waveform archive of 605 earthquakes recorded between 30 March 2009 and 30 April 2009 by DPC-RAN (National Accelerometric Network) (35 stations) and by INGV (29 stations) permanent and temporary seismic networks has been formatted and compiled. The total number of analysed three-component records is 32275 for events with local magnitude ranging between 2.5 and 5.9. These events are recorded by 3 to 41 stations over a range of distances ranging from near-source (≤ 20 km) to the far-field (100 km).



Waveforms of a small earthquake recorded up to a distance of about 30 km from epicenter
Data: 2009-04-30 T_0 = 16:41:47
Lat (°) = 42.35 Long (°) = 13.342 Depth (km) = 8.6 M_L = 2.5



Map showing the stations of DPC-RAN and INGV networks (triangles). The hypocenters of the earthquakes considered in this study (circle of size proportional to the local magnitude) are also plotted.

Spectral Model

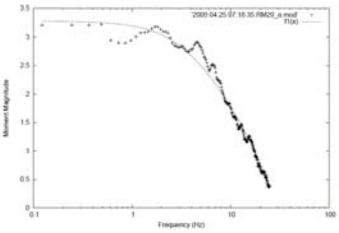
The S-displacement spectra from acceleration sensors have been inverted using the non-linear Levenberg-Marquardt least-square algorithm for curve fitting and assuming the Boatwright (1980)' spectral model:

$$U_{ij}(\omega) = S_{0i}(\omega)\cdot q_{ij}(\omega)\cdot R_j(\omega)$$

where

$$S_{0i}(\omega) = \frac{\Omega_{0i}}{1+\left(\frac{\omega}{\omega_{ci}}\right)^{\gamma}} \qquad q_{ij}(\omega) = \exp\left(-\frac{T_{ij}}{2Q_{ij}}\cdot\omega\right) \qquad R_j(\omega) = C_j SI_j(\omega)$$

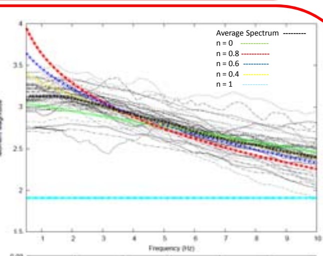
In this analysis we have preliminary assumed $R_j \approx 1$.
The analysis of the displacement spectra was performed on records with a high *signal* to *noise ratio* and events with M_L > 5 are not preliminary considered. The displacement spectra of horizontal components c1(w) and c2(w) are combined to get the modulus cc = sqrt (c1(w)^2 + c2(w)^2) which is used for the inversion in the frequency band 0.05 – 25 Hz.

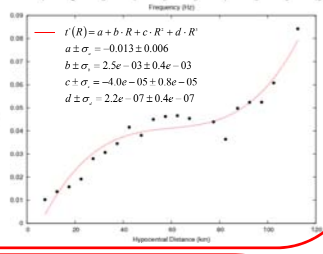


Examples of fit between the observed and theoretical spectrum

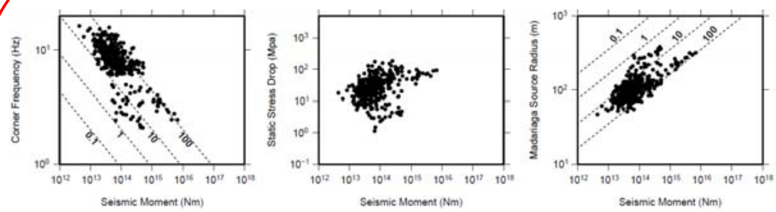
Anelastic Attenuation

The anelastic attenuation effect is accounted by a constant-Q, attenuation operator in the frequency range 0.05-25 Hz, since preliminary analyses have shown that the frequency dependent Q-models (having the form $Q(\omega)=Q_o\cdot\omega^n$) do not provide a significant misfit improvement. The optimal Q-model is chosen according to the minimum of the Akaike Information Criterion.
To get more robust estimations of the attenuation parameter, a two step inversion procedure is applied to the S-wave displacement spectra in the frequency range 0.05-25 Hz. In the first step the spectra are inverted for estimating the t* parameter (t*=S-wave travel-time/S-wave quality factor) for each source-receiver couple, as well as the event-average estimations of the low-frequency spectral level Ω_o and corner frequency ω_c. In the second step the spectral inversion is performed fixing Ω_o and ω_c at the previous found average values providing with estimation of parameter t* only.





Source Parameter



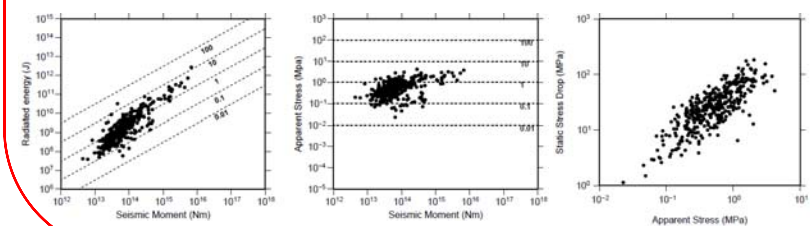
More robust estimations of Ω_o and ω_c are obtained by inverting the displacement spectra fixing for each record the attenuation parameter t* as computed from the retrieved relationship t*(R). The seismic moment (N·m) is computed through the relationship (Aki & Richards,1980) assuming an homogeneous velocity model:

$$M_o = \frac{4\pi\rho c^3 R}{F\langle R_{\theta\phi}\rangle}\Omega_o$$

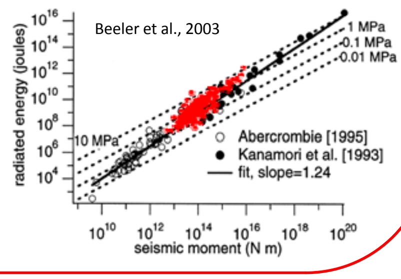
with F = 2, $\langle R_{\theta\phi}\rangle$ = 0.70, ρ = 2700 kg/m^3. c is the S-wave velocity equal to 3374 m/s (Bagh et al., 2007). Radiation pattern coefficient is inferred from Boore & Boatwright (1984) assuming a dominant normal fault mechanism.
Using the retrieved corner frequencies and the Madariaga (1976)' crack model to get the source radius, we computed the variation of the source radius and static stress release with seismic moment. The results show a nearly constant stress drop scaling of source parameters (earthquake self-similarity) within about four orders of magnitude for the seismic moment. The average Madariaga static stress drop is about 35 MPa, which corresponds to a Brune's stress drop of about 6.4 MPa.

The dependence of apparent stress AS = μ·E_S / M_o (where μ=3.3e10 Nm is the crustal shear modulus and E_S is the radiated energy) has been interpreted as an effect of source or an artifact of measurement, e.g. band-width effect on the seismic energy measurement. We have corrected the radiated energy for the band-width effect using relationships given by Ide and Beroza, 2001:

$$E_s^{true} = \frac{E_s^{observed}}{F(f_m,f_c)}\cdot\frac{2}{\pi}, \qquad F(f_m,f_c) = \frac{(-f_m/f_c)}{1+(f_m/f_c)^2} + arctg(f_m/f_c)$$



The data from Abercrombie (1995) are shown combined with data of Kanamori et al. (1993) that extend to higher seismic moment. The solid line is a fit to both data sets and has slope equal to 1.24 (Beeler et al., 2003). The results of this study are plotted as red dots.



Conclusions

- The frequency – independent Q-model is preferred to any frequency dependent model.

- We observe a constant stress-drop scaling of source parameters (earthquake self-similarity) within about four orders of magnitude for the seismic moment. The average Madariaga static stress drop is about 35 MPa, which corresponds to a Brune's stress drop of about 6.4 MPa. The latter is given for comparison with previous stress drop estimations in this and other similar tectonic regions of Italy. Although preliminary (no correction of spectra for site response is applied), this result confirms the evidence for a relatively high value of the average static stress release in this region of Central Apennines relative to the world average (Brune stress-drop around 3-5 MPa) and similar estimations in Southern Apennines (Brune stress drop of 2-3 MPa).

Future Prospective

The site response function (R_j) and refined source parameter estimations will be obtained by an iterative procedure based on the computation of displacement spectra residuals and stack at each receiver site.