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A Duration Magnitude Scale for the Irpinia Seismic Network, Southern Italy

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Online Material: Figures showing local magnitude versus duration; table of station correction coefficients.

INTRODUCTION

The earthquake magnitude estimate is a routine task in all seismological observatories. Several magnitude scales are available, based on amplitude measurement of different seismic phases, and/or on total signal duration. Among them, the duration magnitude (M_D) is adopted in many regional networks because it provides a rapid and reliable estimate of the earthquake size through a fairly simple procedure based on the measure of the duration of recorded seismograms. Bisztricany (1958) first demonstrated the existence of a relationship between magnitude and duration, and several authors (e.g., Sole'vev, 1965; Tsumura, 1967; Bakun, 1984; Vidal and Munguía, 2005; Hara, 2007; among many others) later discussed the use of duration of the recorded seismograms as a measure of the event size. Furthermore, in a recent paper, Lomax and Michelini (2009) proposed a duration magnitude procedure for the rapid determination of the moment magnitude, based on the *P*-wave recordings at teleseismic distances, which can be applied for tsunami early warning.

In its more general formulation the duration magnitude depends on the ground-shaking duration, on the hypocentral distance, and accounts for a station correction coefficient. According to Real and Teng (1973) and Hermann (1975), the duration magnitude is defined as

$$M_D = a + b \cdot \log \tau + c \cdot R + Sc, \tag{1}$$

in which τ is the signal duration, R is the hypocentral distance, Sc stands for the station correction, and a, b, and c are coefficients to be determined through a regression analysis.

The present work has a double goal. First, we present an automatic procedure, which has been specifically developed to measure the earthquake duration, based on the estimate of the signal-to-noise ratio (SNR) along the seismic records. We then calibrate a duration magnitude scale for the area monitored by the Irpinia Seismic Network (hereinafter ISNet, http://isnet.na.infn.it, last accessed November 2013; Iannaccone *et al.*, 2010) in southern Italy (Fig. 1a). We derive the duration magnitude relationship, in the form of equation (1), by analyzing a collection of records from ISNet bulletin (http://isnet.na.infn.it/cgi-bin/isnet-events/isnet.cgi, last accessed November 2013) and computed the regression coefficients and the station corrections of equation (1) with respect to the local magnitude (M_L) values provided by the bulletin itself. We apply the proposed M_D relationship to three testing examples and finally we discuss a possible application of duration magnitude, specifically suited for a single station or local network application, aimed at inferring a rough estimate of the source-to-receiver distance.

DATA AND METHOD

Dataset Description

For the present work we started analyzing a collection of 1565 earthquakes, registered at 24 stations of ISNet network from January 2008 to December 2012, with magnitude in the range (0.1–4.5). ISNet is a high-dynamic, dense seismic network of stations mostly deployed in southern Italy, along the Apennines chain in the area where large historical earthquakes occurred in the past (Emolo *et al.*, 2004; Chiauzzi *et al.*, 2012). The network covers an area of about $100 \times 70\ \text{km}^2$ and it is aimed at monitoring the active fault system responsible for the 23 November 1980 M_s 6.9 Campania–Lucania earthquake, which is, the last destructive event occurred in the area (Ameri *et al.*, 2011). The area covered by ISNet network is interested by a continuous background seismic activity, essentially including micro earthquakes but also some moderate events, such as the 1990 (M_w 5.8), the 1991 (M_w 5.2), and the 1996 (M_w 4.9) events. All the stations of ISNet network are equipped with a three-component accelerometer (Guralp CMG-5T) and a three-component velocimeter (Geotech S-13J) with a natural period of 1 s, to ensure a high-dynamic recording range. Moreover, five sites host a broadband velocimeter (Nanometric Trillium, 0.025–50 Hz) to record both regional and teleseismic events. The data loggers used are the Osiris-6 produced by the Agecodagis SARL.

Preliminarily, the SNR has been computed for each available seismogram in order to exclude those records having a dominant noise contamination from the analysis. The SNR has been evaluated by comparing the pre-event noise amplitude with respect to the maximum amplitude along the *S*-wave train, according to the procedure described by Vassallo and Cantore (2010). Following the approach adopted by Bobbio

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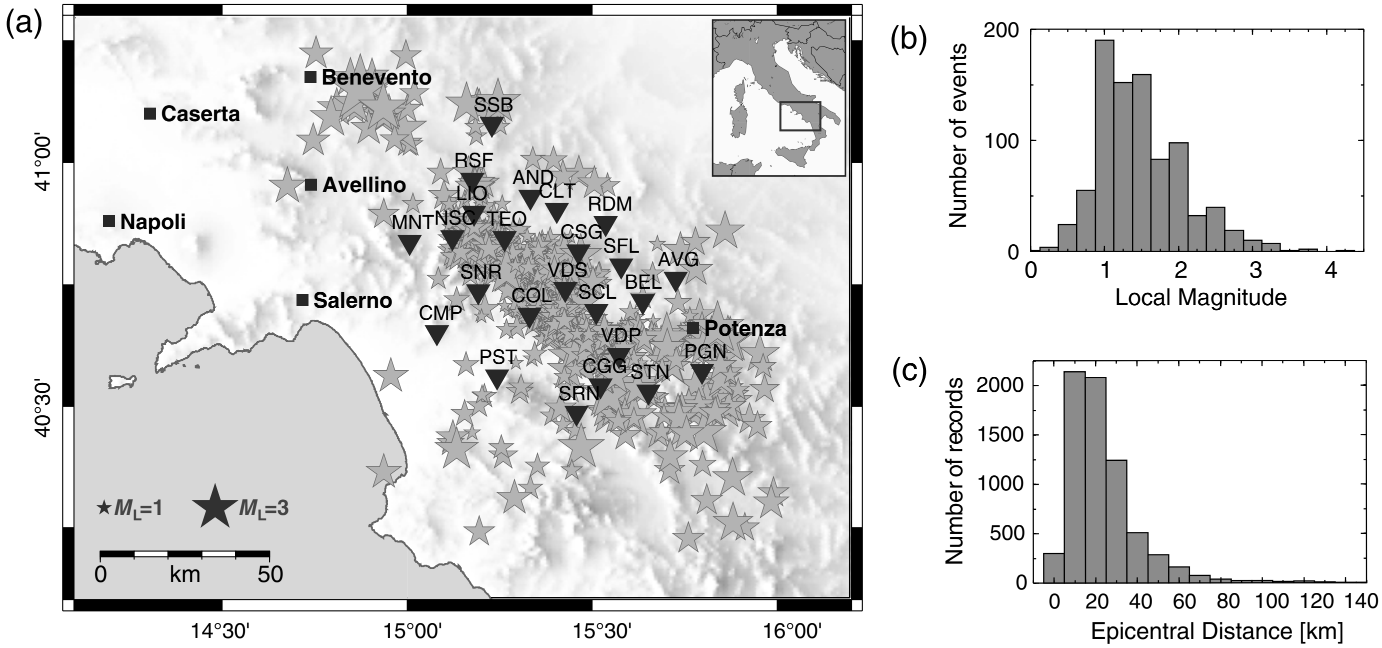


▲ **Figure 1.** Seismic events registered at the Irpinia Seismic Network (ISNet) from January 2008 to December 2012 and recording stations used in this study. (a) Gray stars represent the epicenters of the earthquakes with size proportional to the event magnitude. Stations of the ISNet are represented as inverted dark triangles and their codes are also reported in the map. (b) Distribution of selected earthquakes as function of the local magnitude. (c) Distribution of the number of records as a function of the epicentral distance.

et al. (2009) for the local magnitude computation at ISNet network, we then selected those events which were recorded by at least two stations with SNR greater than or equal to 5. This criterion has been found by trial and error and allows excluding very noisy data without restricting the database too much. With this constraint, the original available dataset was reduced to 6935 waveforms corresponding to 880 events. Selected earthquakes have magnitudes and epicentral distances spanning the 0.5–4.5 and 0.5–150 km ranges, respectively. Figure 1a shows the epicenters of the selected earthquakes together with stations used; Figure 1b,c shows the distribution of the events as a function of magnitude (Fig. 1b) and the distribution of records as a function of the epicentral distance (Fig. 1c), respectively.

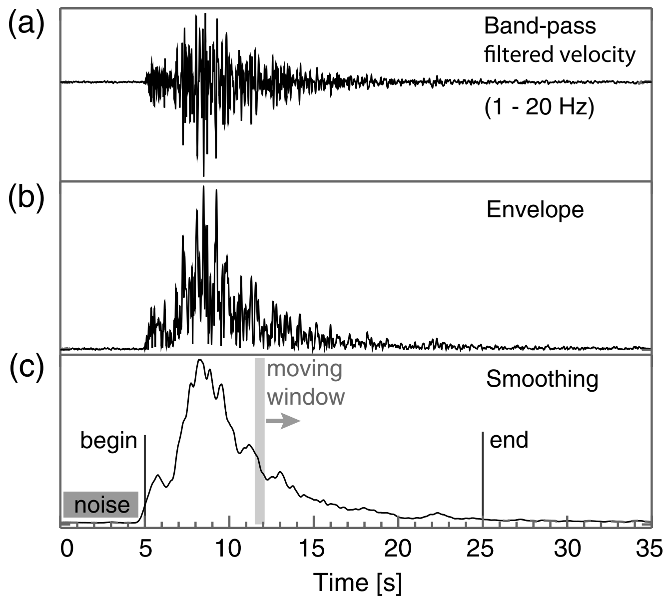
Automatic Duration Estimate

The event duration (hereafter referred to as τ) is evaluated on the vertical component of ground velocity records following the original description of Real and Teng (1973), who defined the duration as the elapsed time from the first *P*-wave arrival to the instant along the trace at which the amplitude of the signal coda has decreased to the noise level. With the aim of implementing an automatic tool for the duration magnitude estimate, we developed an algorithm to measure the signal duration through a simple and fast procedure based on the evaluation of the SNR within a moving window along the record. Figure 2 illustrates each step of the procedure, whose details are described as follows.

Preliminarily, data are processed removing the mean value and the linear trend; a noncausal, eight-pole, band-pass Butterworth filter in the 1–20 Hz frequency range is applied to reduce the high-frequency noise contamination (Fig. 2a). The signal envelope is then computed as the square root of $x(n)^2 + y(n)^2$, in which $x(n)$ is the original signal and $y(n)$ is its Hilbert transform (Fig. 2b). An averaging moving window is finally applied to get a clear and smooth signal, better suited for the following processing (Fig. 2c). The standard automatic picker developed by Allen (1978), which is embedded in SAC code (Goldstein *et al.*, 2003), is used to identify the first *P*-wave arrival time along the smoothed signal. The mean noise amplitude along the envelope is then measured on a five-second window before the *P*-wave picking and its value is assumed as a reference for the pre-event noise amplitude. A 0.5-second moving window is then used to measure the average signal amplitude along the whole envelope signal. The signal ending is declared when the amplitude becomes comparable to the pre-event noise amplitude, that is, when the following condition is satisfied

$$\frac{A_{\text{sign}} - A_{\text{noise}}}{A_{\text{noise}}} < 0.05, \qquad (2)$$

in which A_{sign} and A_{noise} represent the signal average amplitude in the 0.5-second window and the noise amplitude before the *P* picking, respectively. The length of the moving window and the percentage value assumed for the signal ending declaration have been established in a preliminary trial-and-error analysis performed on a limited number of testing earthquakes (which have not been included in the dataset used here) for which we compared the automatic duration estimates for different couples of parameters with respect to manual duration measurements. The optimal couple of parameters for the algorithm has been chosen



▲ **Figure 2.** Sketch of the procedure implemented for the automatic measurement of the signal duration. (a) The vertical component of a velocity record is selected; data processing includes the mean removal, a linear detrending, and band-pass filtering by a noncausal eight-pole Butterworth filter in the frequency range 1–20 Hz. (b) Computation of the signal envelope (see text for further details). (c) The resulting signal is smoothed and the begin and end markers are identified. The begin marker corresponds to the automatic *P*-wave arrival time identification, while the end marker is declared at the instant along the trace when the signal amplitude has decreased to the pre-event noise level, as estimated by the automatic algorithm, that is, when the condition given in equation (2) is satisfied. The amplitude of the pre-event noise is evaluated on a five-second window before the *P*-arrival time (dark-gray window). A 0.5-second moving window is used, instead, to evaluate the average signal amplitude along the record (light-gray window).

as the one providing the best agreement between automatic and manual durations.

Regression Analysis

As discussed above, the general functional relationship adopted for the duration magnitude computation is given by equation (1). Several authors (e.g., Del Pezzo *et al.*, 2003; Bindi *et al.*, 2005; Castello *et al.*, 2007) showed that the term depending on distance provides a poor contribution to the duration magnitude for small hypocentral distances ($R < 100$–150 km). Preliminary analysis performed for events located inside and surrounding the ISNet network (i.e., at a maximum epicentral distance of about 150 km) showed that the coefficient c in equation (1) is indeed negligible, so we assumed $c = 0$ for the following analysis.

To calibrate the duration magnitude scale we used the local magnitude as a reference, that is, we assumed $M_D = M_L$ for each considered earthquake. We also evaluated the possibility of calibrating the duration magnitude with respect to the moment magnitude (M_w). The current data management system of the ISNet network is set to automatically compute both M_L and M_w for each detected earthquake. However, because of the specific data processing required for the spectral analysis, the moment magnitude is assumed reliable for magnitudes larger than 1–1.5. The scaling relationship between the duration and the moment magnitude in the range $1 < M < 4$ is shown in Figure S1 of electronic supplement to this paper Ⓔ.

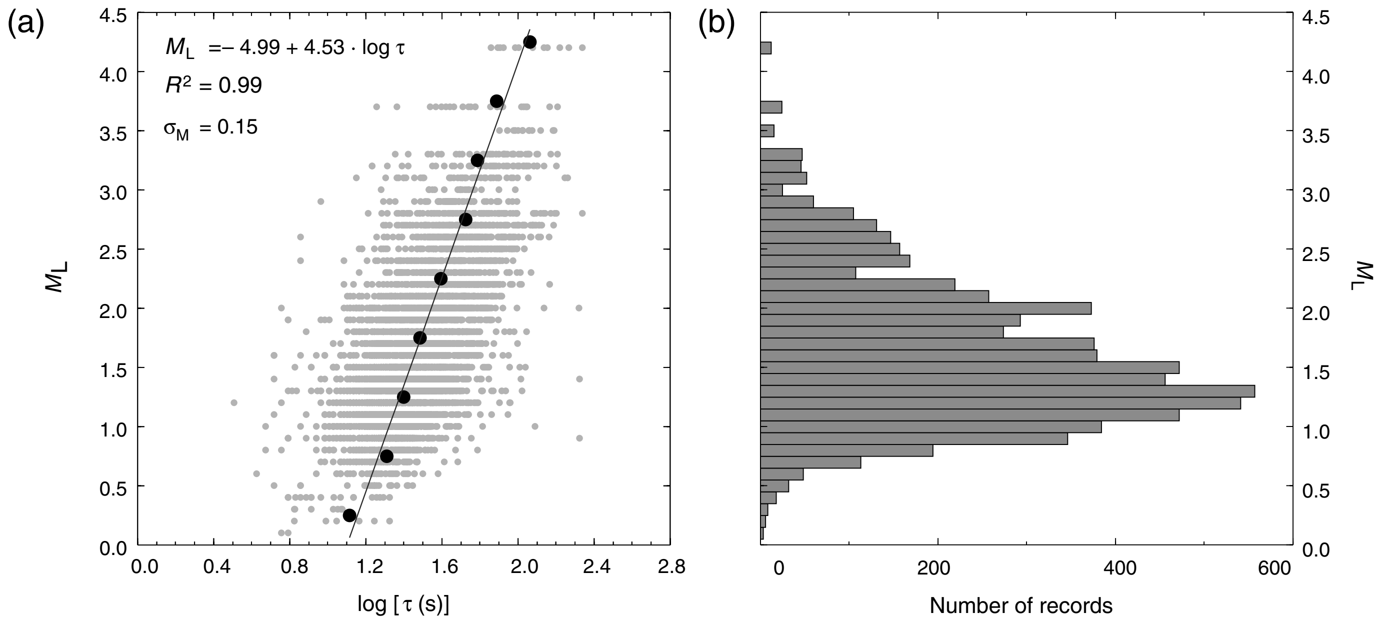
We measured the signal duration on each vertical velocity record (through the automatic procedure detailed above) and looked at its correlation with respect to the local magnitude of the corresponding earthquake. The results for the entire dataset are shown as light gray dots in Figure 3a. Despite an evident correlation between the signal duration and the earthquake magnitude, data show a large spreading which is mainly associated with the natural variability of duration when measured at different stations for the same earthquake. Moreover, the number of data is not uniformly distributed in the considered magnitude range, as it can be inferred from the histogram of Figure 3b. Thus, we figured out that the regression procedure on the whole dataset could be dominated by low-magnitude data, resulting in an underestimate of the slope parameter of the best-fit line and in a poor correlation coefficient. For these reasons, we divided the dataset into magnitude classes of width 0.5, spanning the 0–4.5 magnitude interval. For each magnitude class, we computed the average duration; results are shown as black circles in Figure 3a. A similar procedure has been, for instance, adopted by Wald *et al.* (1999) in the inference of relationships between peak ground-motion parameters and modified Mercalli intensities. Through a least-square linear regression procedure on the average durations, we obtained the following relationship

$$M_D = -4.99(\pm 0.28) + 4.53(\pm 0.17) \cdot \log \tau \quad (3)$$

with a correlation coefficient $R^2 = 0.99$ and a standard error associated with the magnitude equal to $\sigma_M = 0.15$. The best least-square fit is shown in Figure 3a as a solid black line. In calibrating the duration magnitude scale, we assumed that M_D does not depend on the distance, at least in the analyzed distance range. Thus, equation (3) is expected to be suitable for hypocentral distances smaller than about 150 km while a distance contribution should be taken into account for earthquakes occurring outside and far away from the ISNet network.

Station Corrections

In order to improve the accuracy on magnitude estimate, we determined a corrective coefficient *Sc* to be associated with each recording station. Station correction coefficients are introduced to reduce the systematic over- or underestimation of magnitude values obtained at each station. The geological properties of the propagation medium in the vicinity of the registering sites may, in fact, affect the characteristic of the recorded signal and the length of its coda, resulting in a systematic bias on the duration measurement and, consequently, in a systematic error in the magnitude estimate. The station



▲ **Figure 3.** (a) Local magnitude M_L as a function of the logarithm of duration (τ) for all the selected events (light-gray circles). Dark-gray points represent the result of the binning procedure: each point is the average duration value computed for different magnitude classes, with a 0.5 magnitude unit step. The solid line is the best-fit curve and the best-fit equation, together with correlation coefficient and the standard error values are reported in the panel. (b) Distribution of records used in this study as a function of the local magnitude. Most of data are in the range of $0.5 < M_L < 2$.

correction coefficients are obtained by comparing predicted and observed magnitude values and, for the ith event and the jth recording site, are defined as

$$Sc_j = \frac{1}{N_j}\sum_{i=1}^{N_j}(M_{L,i} - M_{D,ij}), \tag{4}$$

in which N_j is the number of seismic events recorded at the jth station, $M_{L,i}$ is the local magnitude for the ith earthquake provided by the ISNet bulletin, and $M_{D,ij}$ is the duration magnitude estimated for the ith event at the jth receiver. Equation (3) is then generalized as

$$M^*_{D,ij} = -4.99(\pm 0.28) + 4.53(\pm 0.17) \cdot \log \tau_{ij} + Sc_j \tag{5}$$

including the station correction coefficients. Thus, when an earthquake is recorded at a set of stations, each seismogram provides an independent estimate of duration magnitude obtained through equation (5). Finally, for each event, the duration magnitude is computed as the average value among all the $M^*_{D,ij}$s obtained.

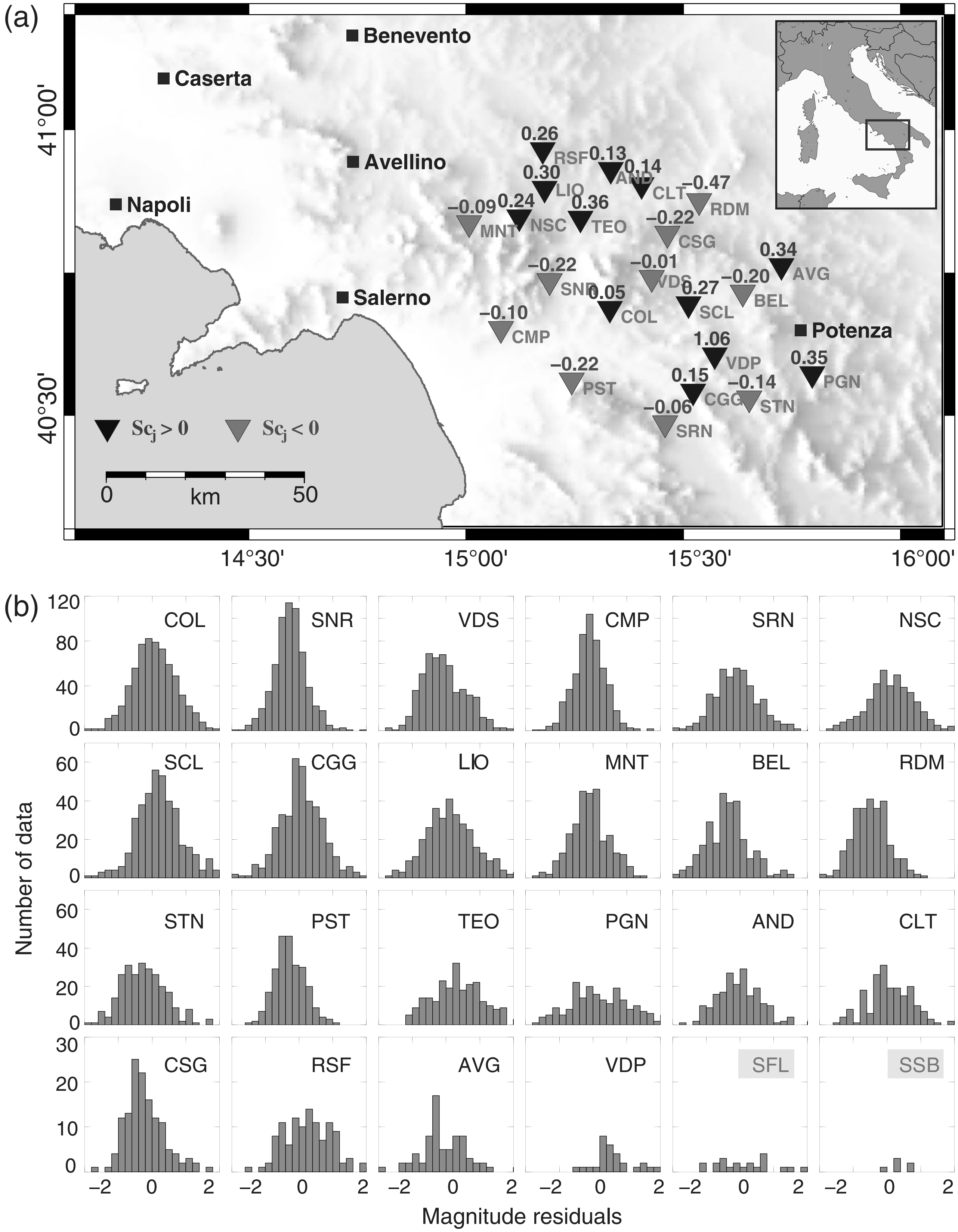
Station coefficients range from −0.48 to 1.07 with a standard deviation varying from 0.29 to 2.11 (Table S1 of the electronic supplement to this paper Ⓔ). We exclude from the analysis of two stations (SFL and SSB) for which only records for few earthquakes were available ($N_j < 30$). The correction coefficients and the residual distributions for each station of the ISNet network are shown in Figure 4a and b, respectively.

A z-test has been finally performed to evaluate the statistical significance of the station coefficients. We tested the null hypothesis of a Gaussian distribution with zero mean and 0.15 standard deviation (which corresponds to the standard error we found on duration magnitude). For each jth station, we computed the variable z_j as

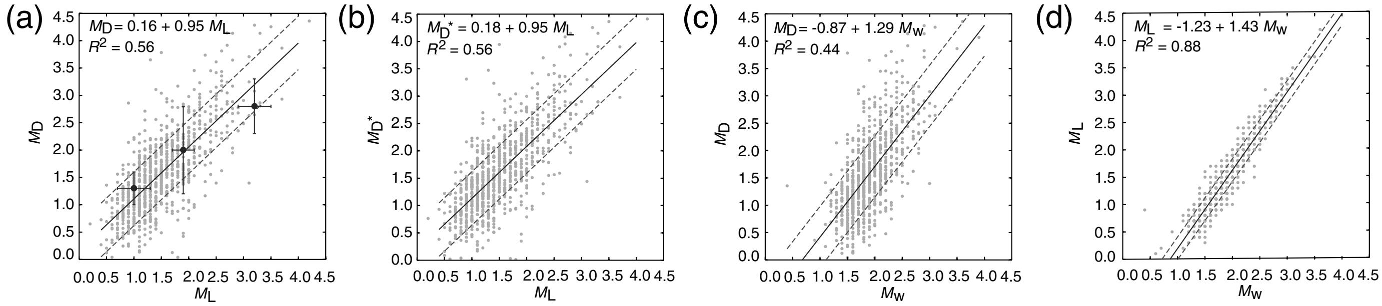
$$z_j = \frac{Sc_j}{\sqrt{\frac{\sigma_j^2 - \sigma_T^2}{N_j}}}, \tag{6}$$

in which $\sigma_T = 0.15$ and N_j is the number of available data for the jth station. Assuming a significance level of 5%, the null hypothesis has to be rejected for stations for which $|z_j| > 1.96$, while it cannot be rejected for the remaining stations. The z_j variable for each station is listed in Table S1 of the electronic supplement Ⓔ.

A positive/negative coefficient reflects the general characteristics of the area where the station is located. The more Sc_j differs from zero, the more local site properties may influence the recorded signals. Generally, in compact old rocks characterized by high acoustic impedance factor, the seismic energy is almost entirely transmitted, with a poor dissipation. For these media, wave scattering is not relevant and consequently the ground motion corresponds to a short signal, resulting in a negative correction coefficient. On the contrary, young and unconsolidated sediments, possibly fractured and with low acoustic impedance produce reverberation and amplification of signals which extend their duration, so determining positive correction coefficients. The distribution of station coefficients



▲ **Figure 4.** Station correction coefficients. (a) Distribution of station correction coefficients over the area interested by the ISNet network. The coefficient value for each station is reported on the map. Black-inverted triangles correspond to positive station coefficients whereas gray-inverted triangles refer to the negative corrections. (b) Distribution of magnitude residuals for each station. For stations SFL and SSB the correction coefficient has not been computed, due to the small number of samples.



▲ **Figure 5.** Comparison between magnitude scales. (a) Comparison between local magnitude and duration magnitude computed through equation (3), that is, without using the station coefficients. The solid line represents the best-fit curve, whereas the dashed line represents the ± one standard deviation bounds. The best-fit equation and the correlation coefficient values are also reported in the panel. Black dots represent the three testing earthquakes, for which we found that duration magnitude and local magnitude are consistent each other within the error bars. (b) Same as (a) but with the duration magnitude computed through equation (5), that is, accounting for the station correction coefficients. (c) Same as (a) but with the duration magnitude computed through equation (3) and moment magnitude taken from the ISNet bulletin. (d) Comparison between the moment magnitude and the local magnitude as reported in the ISNet bulletin.

(Fig. 4a) does not show any clear correlation with the geological structure of the considered area. Because of the extreme structural complexity of the southern Apennines (Improta *et al.*, 2002), a very detailed analysis, which is beyond the scope of this paper, is required to understand if a correlation between station correction coefficients and local geology does exist.

Magnitude Comparison

For each earthquake in our database, we computed the average duration magnitude using both equations (3) and (5). In both cases, we compared the duration magnitude with respect to the local magnitude (M_L) assigned to each event in the ISNet bulletin. Figure 5a and 5b show the comparison between the duration magnitude and the local magnitude without (Fig. 5a) and with (Fig. 5b) the application of the station correction coefficient. The best result would obviously be represented by the quadrant bisector. A linear regression analysis of local magnitude data and corresponding duration magnitude estimates provided us the relationship

$$M_D = 0.16(\pm 0.05) + 0.95(\pm 0.03) \cdot M_L, \tag{7}$$

obtained assuming equation (3) for M_D, and

$$M_D^* = 0.18(\pm 0.05) + 0.95(\pm 0.03) \cdot M_L, \tag{8}$$

obtained using equation (5), instead. Because of the generally small values of the Sc_j coefficients, no significant change in the best-fit regression relationship is evident when the station correction is included. We therefore believe that the simpler functional form of equation (3) could be adopted.

The comparison between M_D and M_L confirms that an independent and reliable estimate of the earthquake magnitude can be obtained using the event duration. Because the duration magnitude scale has been calibrated by assuming $M_D = M_L$ for each earthquake, this result is not so much surprising. A useful test is the comparison among duration magnitude and moment magnitude (M_w), which is shown in Figure 5c. A linear regression analysis of duration magnitude estimates versus moment magnitude provided us the relationship

$$M_D = -0.87(\pm 0.09) + 1.29(\pm 0.05) \cdot M_w. \tag{9}$$

Although a linear correlation among M_D and M_w is evident from the plot, the best-fit regression line is rather different from the expected quadrant bisector. This can be explained in terms of the relationship between M_L and M_w (Fig. 5d) for which we found

$$M_L = -1.23(\pm 0.03) + 1.43(\pm 0.02) \cdot M_w. \tag{10}$$

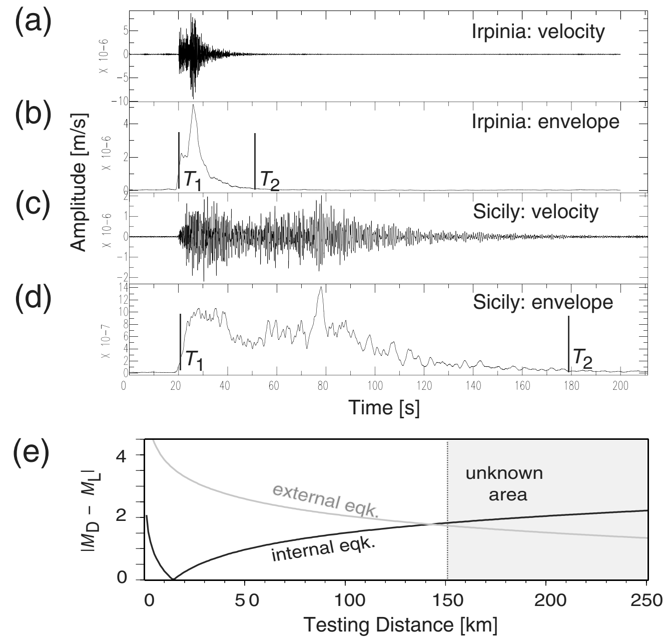
From equation (10) it is clear that the local magnitude is different from the moment magnitude estimate. In particular, for the same earthquake, the local magnitude is lower than the moment magnitude up to M_w about 3. For M_w larger than this threshold value, the local magnitude estimates are systematically higher. The automatic procedures that are currently used at the ISNet network for the computation of both local and moment magnitude require restrictive criteria for the records to be considered in the average magnitude computation (e.g., a restrictive selection criterion on data quality and the exclusion of minimum/maximum magnitude values from the average computation). We strongly believe that the scatter of data (Fig. 5a–c) can be significantly reduced if similar strategies were adopted during the computation of the duration magnitude (see Discussion and Conclusions).

Finally we compare our duration magnitude relationship (equation 3) with the one proposed by Castello *et al.* (2007), that has been calibrated for the entire Italian territory and that is assumed to be the national reference scale. The regression relationship we found for ISNet network turned out to be different from the national scaling law and both coefficients (slope and intercept) are not consistent even once accounting for data uncertainties. We identified two reasons that could be responsible for the observed discrepancy. A first factor could be the use of a regional database which may be strongly influenced by local geophysical/geological properties of the area, whereas these effects are mediated when the national catalog is used. A similar discrepancy with respect to a more general behavior at national Italian scale has been also observed by Emolo *et al.* (2011) who calibrated ground-motion prediction equations for low-magnitude earthquakes, specific for ISNet network using a similar database as in this study. Emolo *et al.* (2011) pointed out that the regionalization of prediction equations is particularly needed for low-magnitude earthquakes for which attenuation effects, related to the tectonic area of interest, can be predominant with respect to the source effects. A second, probably more relevant, reason for discrepancy could be associated with the different approaches adopted in data analysis. In fact, although we used a binned dataset to derive our regression relationship, Castello *et al.* (2007) calibrated the scale on the entire available catalog. The parameters of the best-fit regression line, that is, the slope and the intercept, are largely influenced by the nonuniform data distribution in the analyzed magnitude range and this may produce the discrepancies observed between the two duration magnitude scales. In Ⓔ Figure S2 of the electronic supplement to this paper, we show the best-fit regression line obtained on the entire dataset, without any binning procedure. If all the data were used, the estimated slope of the best-fit line would be evidently smaller. In the case of our catalog, however, it would not be suitable to fit the highest magnitude data, as well as the lowest magnitudes.

As a further test of our results, we applied the proposed methodology to three recent events occurred within the area covered by ISNet network and which have not been included in the database used for retrieving the duration magnitude relationship. The testing earthquakes occurred on 2 January 2013 (M_L 3.2 ± 0.3), 13 January 2013 (M_L 1.0 ± 0.3), and on 23 January 2013 (M_L 1.9 ± 0.2) (see the ISNet bulletin for further information). For each of them, we simulated the automatic duration measurement procedure. Duration magnitudes were computed as the mean value among the estimates obtained at all the recording stations, without accounting for the station correction coefficients, that is, using equation (3). The duration magnitude estimates are 2.8 ± 0.5, 1.3 ± 0.3, and 2.0 ± 0.8 for the three events, respectively, and are shown as black circles in Figure 5a. For the three testing cases, duration magnitude and local magnitude turned out to be in good agreement and consistent each other within the error bars.

SINGLE STATION AND LOCAL NETWORK APPLICATION OF DURATION MAGNITUDE

In this section we describe a simple and intuitive application of the duration magnitude derived so far, based on the simultaneous measurement of the amplitude and duration on the same signal. The example described here has to be intended as a case study for testing limitations and conditions of applicability of the adopted (M_L) and proposed (M_D) magnitude scales. This example lacks of any generality and we do not mean to propose it as a rigorous approach. Further testing over a variety of earthquake magnitudes and distances would be required to propose a general methodology.



▲ **Figure 6.** Comparison of durations for an Irpinia earthquake and a Sicilian earthquake as recorded by SRN station from the ISNet. (a) and (b) The velocity seismogram and its envelope for the Irpinia earthquake; (c) and (d) The corresponding traces for the Sicilian event. T1 and T2 markers on the envelopes represent the signal beginning and end, respectively, as declared by the automatic procedure. (e) Difference between M_D and M_L as a function of the testing distance. The duration magnitude is fixed, while the local magnitude value depends on the distance. The more the testing distance tends to the real one, the better is the agreement between the two magnitudes. The gray area (denoted as "unknown area") is the region in which we cannot rely on neither the duration nor the local magnitude estimates.

The basic idea is the well-known dependence of amplitude and duration of ground-motion records on the source-to-receiver distance. Generally, given an earthquake with a certain magnitude, the closer the earthquake is to the recording station, the smaller the travel-time difference between P and S waves and thus the shorter the signal duration at the station. On the contrary, in case of a distant source, the increased S–P delay time and the arrival of later, indirect phases, imply a longer duration of the corresponding signal. As an example, let us consider the two earthquakes shown in Figure 6a,c. The first one (Fig. 6a) is an earthquake occurred in the Irpinia region (i.e., inside the network) on 23 January 2013 (M_L 1.9 ± 0.2); the second one (Fig. 6c) is an earthquake (M_L 4.3), occurred in Sicily (about 300 km away from the network center) on 4 January 2013. Both earthquakes have been recorded at ISNet network and Figure 6a,c shows how they appear at the station SRN, on the vertical component of the velocimeter sensor. Let us now measure the automatic duration with the methodology described in the previous sections. Figure 6b,d shows the signal envelope for both records; T1 and T2 marker along the waveforms represent the earthquake beginning and end, respectively, as declared by the automatic procedure. The distant and local quakes exhibit different durations, amounting to ~160 and ~30 s, respectively. We could suppose the use of the signal duration as a discriminating factor between a close and a far-away event. A large duration value, however, could also be associated to a nearby but large event, for which the ground-motion amplitude may require longer times to be completely attenuated. Keeping this in mind, once the duration is measured, the amplitude can then be used to distinguish the two cases. Given a large duration value, if the amplitude is also large, the earthquake will likely be close to the recording site, while a small amplitude value is presumably synonymous of a distant event. The coupling of long durations and small amplitudes would therefore identify, in a unique manner, a far-away earthquake.

Using equation (3) we would get $M_D = 1.7(\pm 0.15)$ for the Irpinia event and $M_D = 4.9(\pm 0.15)$ for the Sicilian event. For the internal earthquake the valid M_D estimate (M_L 1.9 ± 0.2) is not surprising, being the M_D relationship calibrated for events occurred inside the network. Similarly, for the Sicilian event the overestimated M_D value is not alarming, because the general formulation (in the form of equation 1) should be used to account for the dependency of duration on distance. Let us now estimate the local magnitude for the two same events. According to the Richter definition, the local magnitude of an earthquake is the logarithm of the half peak-to-peak amplitude measured in microns, recorded by a Wood–Anderson seismograph at a distance of 100 km from the epicenter of the earthquake. The local magnitude at ISNet network is computed by the relationship of Bobbio *et al.* (2009):

$$M_L = \log A + 1.79 \log R - 0.58, \quad (11)$$

in which A is the peak-to-peak amplitude of a Wood–Anderson seismometer in millimeters and R is the hypocentral distance in kilometers. Because the earthquake location is unknown with a single recording station, let us then assume different testing distances ranging from 10 to 500 km, and compute the corresponding M_L values for each of them. Table 1 summarizes the results for the two events. The comparison between M_D and M_L shows that, for both cases, the difference between the magnitudes is rather large when unreasonable distances are assumed for the considered event. On the contrary, as the testing distance tends to the real one, the discrepancy between M_D and M_L is reduced. Figure 6e shows the magnitude residuals (absolute value of $M_D - M_L$) as a function of the testing distance for the two earthquakes. For the internal earthquake the magnitude residual curve shows a clear minimum point (around 15 km, to be compared with the true epicentral distance of 28 km) followed by a slow, but continuous, increase for larger distances. Small distances would therefore justify the observed duration and amplitude, whereas the same duration–amplitude couple could not be jointly observed if larger distances were assumed. In case of the external event, instead, the residuals decrease with distance and the curve never reaches the minimum before 150 km, suggesting that large distances would better reproduce the observed amplitude and duration values. Both M_D and M_L scales have been calibrated for earthquakes occurred in the Irpinia region at a maximum distance of about 150 km from the ISNet stations. We therefore consider 150 km to be the maximum confidence distance: outside this region, we could rely on neither the duration nor the local magnitude estimates.

The discriminating criterion could then be the trend of magnitude residuals with the testing distance: if residuals increase while moving the earthquake far away, the event will likely be close to recording site and the minimum point of the curve would provide an approximate estimate of the source-to-receiver distance. In case of decreasing residuals with distance, on the contrary, a far-away earthquake would be more

Table 1
Comparison between Duration and Local Magnitude for Different Testing Distances

	Irpinia Event 23 January 2013 (M_L 1.9, Distance=28 km)		Sicilian Earthquake 4 January 2013 (M_L 4.3, Distance=296 km)	
Testing Distance	M_D	Estimated M_L	M_D	Estimated M_L
$R = 10$ km	1.7	1.4	4.9	1.1
$R = 20$ km	1.7	2.0	4.9	1.6
$R = 50$ km	1.7	2.7	4.9	2.3
$R = 100$ km	1.7	3.2	4.9	2.8
$R = 500$ km	1.7	4.5	4.9	4.1

Single station application: comparison between duration and local magnitude for different testing distances for an Irpinia earthquake (close to the recording site) and a Sicilian earthquake (far away from it). For both cases the duration magnitude is fixed, because it is assumed to be independent on the distance, while the local magnitude changes as a function of the testing distance. Assuming M_D as a reference magnitude, for both the Irpinia and the Sicilian event the scatter between M_D and M_L reduces when the testing distance tends to the real one and diverges as the earthquake is moved, as it were, toward unreasonable positions.

probable, although in this case a reliable estimate of the distance would not be possible. This qualitative observation can be used to have a rough, but rapid, estimate of the relative distance between the earthquake and the recording station allowing, at least, to discriminate between seismic events occurring inside or outside the recording network. Assuming that similar estimates can be performed at several stations of a local network, an automatic decision scheme could be implemented to automatically discriminate whether the event occurred within or outside the network, which is very useful information to be included in automatic earthquake bulletins.

DISCUSSION AND CONCLUSIONS

In this paper, we proposed a tool for the automatic duration measurement along the seismic records and calibrated a duration magnitude scale for the Irpinia Seismic network, in southern Italy. The algorithm used to estimate the signal duration is based on the evaluation of the SNR within a 0.5-second moving window along the records and on the comparison between the event amplitude and the pre-event noise level. The duration magnitude relationship is derived through a linear regression analysis, after binning data into different magnitude classes. For each recording site in our database, we computed a station correction coefficient and performed a z-test to evaluate its statistical significance. After calibrating the duration magnitude scale, we compared the M_D value to the local and the moment magnitude estimates (provided by the ISNet bulletin) for each analyzed event. The comparisons showed an excellent agreement between M_D and M_L and an evident linear correlation between M_D and M_w. This result confirms that an independent estimate of the earthquake size can be obtained using the event duration.

This approach represents the first step for the implementation of the automatic duration magnitude computation at ISNet network. In terms of practical implementation of the proposed methodology, the routine for the duration–magnitude computation can be easily included in the automatic procedures that are currently running at the ISNet network for the magnitude computation. Furthermore, several factors can be improved in order to get more stable and reliable magnitude estimates. Among them, for example, more restrictive criteria may be adopted for the selection of records or a weighted average duration could be computed by weighting each available record according to the SNR. Finally, the standard average magnitude computation can be substituted by more robust statistical methods (such as the Huber mean computation) as is usually done at the ISNet network for the local magnitude computation.

For the duration measurement, we used only vertical components of velocity records. For a given source-to-receiver distance and earthquake magnitude, the amplitude (and hence the duration) of individual components of ground motion can vary significantly as a function of the source radiation pattern. Measuring the signal duration on the vertical component may thus introduce an important source of error. However, the duration here is computed by averaging all the available estimates at a set of stations. If an adequate number of stations are used, the average is expected to reduce the source effects related to the focal mechanism. A more robust approach would be to account for all the components of ground motion. This could be done, for example, by simply averaging the durations measured over the three components, or through more refined techniques, such as those adopted in the polarization analysis. Once the azimuth and incidence angle of the direction of maximum polarization of the signal are determined, the ground motion can be rotated into its vertical, radial, and transverse components; a detailed analysis of the influence of the source mechanism on the signal duration of each component could thus be performed.

The automatic procedure that we developed is fairly simple and gives stable and robust estimates of the event duration. The main advantage of using the duration magnitude rather than the local magnitude is that in the former case any knowledge of the earthquake location is required. For the earthquakes occurring inside or at small distances from the network, the duration magnitude is assumed independent of the distance. A rapid and reliable estimate of the event size can thus be obtained by measuring the signal duration.

In the final part of this paper, we propose a demo exercise to discuss a possible use of duration magnitude in combination with the local magnitude computation. The coupling of duration and amplitude can be used to distinguish the case of an earthquake in the vicinity of the recording station from a far-away event. To this purpose, the simple time difference between the P-wave onset and the peak value of signal could be used for a rapid assessment of the earthquake distance. Although for local events (i.e., distances < 150 km) such an approach is expected to provide a reasonable estimate of the distance, it may provide biased results in the case of regional and teleseismic distances ($R > 250$–300 km) for which the peak amplitude is likely associated to later arrivals (i.e., surface waves). Moreover, the simple use of the time difference between the P-wave onset and the peak value of signal envelope would not provide any information about the size of the event, whereas the proposed approach (which is actually a combined measure of amplitude and duration) could potentially also distinguish the case of a small/large event. The implementation of the proposed methodology could provide a rapid and independent estimate of the event size and could be a valid tool for other massive/statistical analysis of earthquakes registered at the ISNet network. Further testing is of course required, and will be performed to validate the proposed strategy and develop a more general methodology.

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