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The M_D Scale in Northern Morocco: A Comparative Study of Two Empirical Approaches

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Abstract—We have derived, evaluated, and compared two empirical methods for computing duration magnitude M_D from 25 short-period vertical component stations of the Northern Morocco Seismic Network (NMSN). M_D has been scaled to IGN (Insituto Geograpfico National, Spain) body-wave magnitude (mb^{IGN}), using a set of 479 shallow (less than 30 km) earthquakes recorded from March 1992 to February 2001, with $2.5 \leq mb^{IGN} \leq 5.4$. In the first approach: Individual Network Calibration, we determined an individual M_D formula for each station. In the second approach: *Global Network Calibration*, we used a single relationship to compute M_{Dij} (from the *j*th observation for the *i*-th earthquake) magnitudes at 25 selected stations as: $M_{Dij} = -0.14 + 1.63 \log_{10}(\tau_{ij}) + 0.031(\Delta ij) + cSta_j$. Residuals ($M_{Dij} - mb^{IGN}$) for both techniques were thereafter deduced. Comparison between the two approaches provided the principal results: (1) The mean correlation between estimated magnitude; M_{Dij} and reference magnitude; mb^{IGN} is about 89.9% for the individual calibration method, and near 95% for global calibration method in which station corrections $cSta_j$ were introduced, (2) Residuals ($M_{Dij} - mb^{IGN}$) are relatively large, and are ranging between − 0.60 and 0.60 magnitude units, for the individual calibration method, whereas they vary in the range − 0.38 to 0.40, for the global calibration method with corrections; $cSta_j$. (3) A random distribution of residuals ($M_{Dij} - mb^{IGN}$) is observed for each station in the case of the individual approach. Thus, the resulting average of these residuals is almost equal to zero. Using a global calibration without corrections results in negative residuals for a group stations and positive residuals for another an group indicating respectively that sites corresponding to these groups have a tendency to underestimate, or overestimate observed magnitude values.

Key words: Duration magnitude, station correction, individual calibration, global calibration, residuals.

Introduction

Since the installation of the last short-period seismic station of the Northern Morocco Seismic Network (NMSNET) in the early nineties, attempts to develop relationships for computing magnitude for regional earthquakes were made to calibrate the seismic network. Duration magnitude M_D was calibrated against body-wave magnitude; mb^{IGN} for events recorded by both the Moroccan Network and the Spanish Digital Seismological Network (Instituto Geografico Nacional: IGN).

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Individual formulas relating M_D to total signal duration; τ, and epicentral distances; Δ were derived for each station as: $M_{Dj} = c_0 + c_1 \log_{10}(\tau_j) + c_2(\Delta_j)$ (FROGNEUX, 1980; MOUAYN, 1994; MOUAYN *et al.*2004). In these relationships the c_i coefficients are different for each station. In what follows, this calibrating procedure is referred to as the *individual network calibration* method; INC.

Another calibration approach is to establish a single M_D formula for all 25 stations of this study. TSUMURA (1967) established a formula for Japan of the shape: $M_D = -2.53 + 2.85 \log(\tau) + 0.0014$. LEE *et al.* (1972) developed an equation for central California as: $M_D = 0.87 + 2.00 \log(\tau) + 0.0035 (\Delta)$. BAKUN (1984), also for central California, established an empirical $M_D - \log^2(\tau)$ relationship of the form; $M_D = 0.92 + 0.607 \log^2(\tau) + 0.00268 \Delta$, $(1.5 < M < 5.3)$. For Northern California the formula given by HIRSHORN *et al.* (1987) is: $MZ = -0.72 + 2.95 \log(\tau) + 0.001\Delta$, from low gain vertical short-period recordings of τ for events in the ML 3.5 to 7 range. The preferred MICHAELSON (1990) formula; $M'_D = -1.03 + 2.1 \log(\tau) + 0.0026(\tau) + \alpha + \delta$, for central California is without term in distance (Δ), but she included two terms of correction; one for the instrument used and the other for the station site, respectively α and δ. EATON (1992), developed for northern California an equation adding a sensitivity and depth correction term as: $M_D = 0.81 + 2.22 \log(\tau) + 0.011.\Delta + \log(CAL15/CAL) + D' + HF(h)$. The duration-dependent magnitude for northern Morocco contains a correction term for each of the 25 studied stations as; $M_{Dij} = -0.14 + 1.63 \log_{10}(\tau_{ij}) + 0.031(\Delta_{ij}) + cSta_j$ (Mouayn *et al.*, 2004). This calibration method is referred to as the *global network calibration* method; GNC.

The objectives of this study are: (1) to develop M_{Dj} individual relationships for 25 stations from the Northern Morocco Seismic Network (the Moroccan Seismological Network still uses individual formulas established in 1994 (MOUAYN, 1994). They give good determination of the M_D magnitude. Now with more and better quality data, updating these individual formulas is in order), (2) to compare the mb^{IGN} reference magnitudes to M_D estimated either by the INC or the GNC approaches, and evaluate the estimated magnitudes, (4) to present results of the comparison between the residuals (M_{Dij}–mb^{IGN}) obtained by using these two different approaches.

Data

The data of this study consist of 479 earthquakes (Fig. 1) taken from MOUAYN *et al.* (2004), selected because they were published in both the Moroccan and Spanish (IGN) seismological bulletins. These events were divided into two subsets: 395 events from January 1993 to December 1998 with a total of 1423 durations measured to the background level. (Fig. 1 and Table 1). These data (395 events: 1423 durations) are used to derive the relationships between (τ), (Δ) and M_D. They are referred to as the

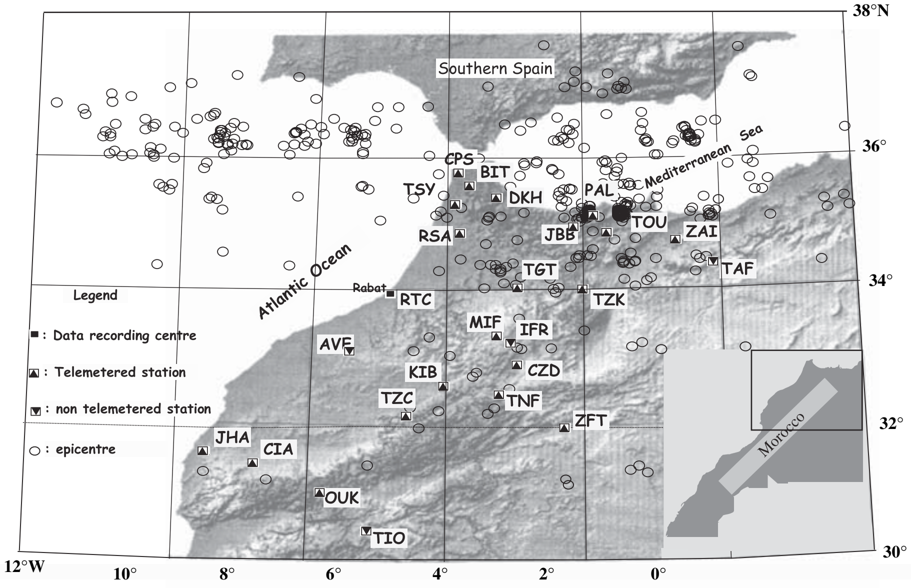

Figure 1
Epicentres and seismic stations used in this study.

independent set. Equations established were then applied to an additional 84 events (511 durations). For this set of data, reference magnitudes are mb^{IGN} taken from the IGN bulletins, to check how well the new M_D predicted mb^{IGN}. This second set is referred to as the test set. Origin times, locations, and mb^{IGN} magnitudes were taken from IGN bulletins.

Methodology

Individual Network Calibration (INC)

Derivation of the M_{Dij} equations

Local or near-regional events cause conventional m_b, M_l, and M_s magnitude scales to suffer some limitations, such as saturation (Kanamori, 1977; Hanks and Kanamori, 1979). These scales are based on a signal's amplitude measurement, and above a certain value of magnitude the maximum amplitude of the signal cannot be measured because it can not be identified. In the expectation of an alternating performed and robust scale such as the moment magnitude M_w, which requires sufficient data, not available at this time (Digital VBB stations and large pass-band accelerographs are newly installed in old and new sites of stations. It takes time to record sufficient data to derive the M_w relationship), we adopt for our

Table 1

Station Corrections; $cSta_j$ (according to Mouayn *et al., 2004)*

N.	Code	Name	Sub-network/NT	Location		$cSta_j$	*AMSR*	Number of data
				Lat. (N)	Long. (W)			
1	TIO	Tiouine	Non-Telemetered	30.550	−7.150	***0.29***	***−0.29***	77
2	OUK	Oukaimden	Chichaoua	31.209	−7.868	***0.24***	***−0.24***	24
3	TZK	Tazeka	Ifrane	34.089	−4.184	***0.17***	***−0.17***	151
4	TAF	Tafouralt	Non-Telemetered	34.480	−2.240	***0.16***	***−0.16***	101
5	MIF	Mishlifen	Ifrane	33.409	−5.229	***0.16***	***−0.16***	48
6	ZAI	Zaio	Zaio	34.803	−2.746	***0.15***	***−0.15***	114
7	ZFT	Ezzeft	Midelt	32.034	−4.352	***0.15***	***−0.15***	29
8	KIB	El Ksiba	Beni Mellal	32.576	−6.039	***0.13***	***−0.13***	81
9	IFR	Ifrane	Non-Telemetered	33.310	−5.070	***0.12***	***−0.12***	125
10	CZD	Col de Zad	Midelt	33.033	−5.043	***0.08***	***−0.08***	127
11	TNF	Tounfite	Midelt	32.530	−5.319	***0.07***	***−0.07***	26
12	TZC	Tazercounte	Beni Mellal	32.148	−6.490	***0.06***	***−0.06***	50
13	PAL	Palemas	Zaio	35.225	−3.942	***−0.04***	*0.04*	109
14	JBB	Jbel Babet	Zaio	35.013	−4.198	***−0.06***	*0.06*	49
15	DKH	Dar Kharkour	Tanger	35.490	−5.360	***−0.08***	*0.08*	51
16	TOU	Touzarine	Zaio	34.962	−3.754	***−0.08***	*0.08*	122
17	CPS	Cap Spartel	Tanger	35.791	−5.910	***−0.11***	*0.11*	87
18	TGT	Taghat	Ifrane	34.070	−5.055	***−0.11***	*0.11*	95
19	RSA	Sarsar	Tanger	34.877	−5.828	***−0.12***	*0.12*	74
20	BIT	Ibn batouta	Tanger	35.648	−5.729	***−0.13***	*0.13*	63
21	TSY	Tnine Sidi l'Yamani	Tanger	35.373	−5.970	***−0.14***	*0.14*	97
22	JHA	Jbel Lahdid	Chichaoua	31.736	−9.454	***−0.23***	*0.23*	23
23	CIA	Chichaoua	Chichaoua	31.565	−8.759	***−0.25***	*0.25*	58
24	RTC	Rabat Centre	Data Reception Centre	33.990	−6.858	***−0.32***	*0.32*	44
25	AVE	Averoes	Non-Telemetered	33.170	−7.240	***−0.32***	*0.32*	109

NT: Non−Telemetered Station.
Number of data: Number of duration measurements per station.
Magnitude formula used: $MD_{ij} = -0.14 + 1.63\log_{10}(\tau_{ij}) + 0.031(\Delta_{ij}) + cSta_j$.
AMSR = Average magnitude station residual = $-cSta_j$.

network a duration magnitude scale of the form: $M_{Dj} = c_{0j} + c_{1j}\log_{10}(\tau_j) + c_{2j}(\Delta_j)$, where τ is the total duration recorded by the station, Δ is the epicentral distance in degrees, and c_0, c_1, and c_2 are individual constants to be determined for each of the 25 stations.

In this *INC* approach individual formulas for computing duration magnitude are updated separately for each of the 25 stations selected for this study. These relationships were established in 1994 using less than 20 data per station (Mouayn, 1994), and are still in use. Using more and better quality data recently collected (Mouayn, *et al.*, 2004) will provide more accuracy with well performed formulas.

Using a multivariate regression analysis technique (JOBSON, 1991), duration magnitude formulas were established by calibrating M_{Dj} against the body-wave magnitude mb^{IGN} assumed to be the reference magnitude related to $\log_{10}(\tau)$ and (Δ), with errors ε as:

$$mb^{IGN} = c_{0j} + c_{1j}\log_{10}(\tau) + c_{2j}(\Delta) + \varepsilon.$$

This process is applied to each station individually, and equations derived are presented in Table 2. These formulas were used to calculate estimated magnitudes; $M_{Dij} = c_{0j} + c_{1j}\log_{10}(\tau_{ij}) + c_{2j}(\Delta_{ij})$, and the resulting residuals (M_{Dij}–mb^{IGN}). Subscripts i and j denote respectively, unique event and unique station. Data used to derive the relationships are taken from the *independent set*.

Table 2

Individual Network Calibration M_D formulas

Station		Model	Correlation
No.	Code	$M_{Dij} = c_{0j} + c_{1j}(\pm\Delta_{c_{1j}})\log_{10}(\tau) + c_{2j}(\pm\Delta_{c_{2j}})\Delta$	R^2
1	TIO	$M_D = 0.53 + 1.52(\pm0.13)\log_{10}(\tau) - 0.007(\pm0.044)\Delta$	0.90
2	OUK	$M_D = 0.45 + 1.44(\pm0.22)\log_{10}(\tau) + 0.002(\pm0.057)\Delta$	0.89
3	TZK	$M_D = 0.12 + 1.51(\pm0.08)\log_{10}(\tau) + 0.051(\pm0.017)\Delta$	0.90
4	TAF	$M_D = 0.16 + 1.61(\pm0.12)\log_{10}(\tau) + 0.012(\pm0.024)\Delta$	0.87
5	MIF	$M_D = 0.25 + 1.56(\pm0.17)\log_{10}(\tau) + 0.020(\pm0.040)\Delta$	0.88
6	ZAI	$M_D = 0.10 + 1.47(\pm0.11)\log_{10}(\tau) + 0.098(\pm0.035)\Delta$	0.88
7	ZFT	$M_D = 0.03 + 1.57(\pm0.26)\log_{10}(\tau) + 0.014(\pm0.041)\Delta$	0.87
8	KIB	$M_D = 0.43 + 1.54(\pm0.12)\log_{10}(\tau) + 0.033(\pm0.022)\Delta$	0.90
9	IFR	$M_D = -0.08 + 1.68(\pm0.04)\log_{10}(\tau) + 0.019(\pm0.006)\Delta$	0.98
10	CZD	$M_D = -0.19 + 1.64(\pm0.09)\log_{10}(\tau) + 0.028(\pm0.017)\Delta$	0.91
11	TNF	$M_D = -0.19 + 1.65(\pm0.20)\log_{10}(\tau) + 0.009(\pm0.034)\Delta$	0.88
12	TZC	$M_D = -0.29 + 1.64(\pm0.09)\log_{10}(\tau) + 0.057(\pm0.023)\Delta$	0.96
13	PAL	$M_D = -0.07 + 1.64(\pm0.12)\log_{10}(\tau) + 0.023(\pm0.039)\Delta$	0.90
14	JBB	$M_D = -0.14 + 1.62(\pm0.13)\log_{10}(\tau) + 0.006(\pm0.13)\Delta$	0.88
15	DKH	$M_D = -0.29 + 1.67(\pm0.16)\log_{10}(\tau) + 0.017(\pm0.038)\Delta$	0.89
16	TOU	$M_D = -0.30 + 1.66(\pm0.11)\log_{10}(\tau) + 0.024(\pm0.031)\Delta$	0.89
17	CPS	$M_D = -0.12 + 1.68(\pm0.13)\log_{10}(\tau) + 0.005(\pm0.041)\Delta$	0.89
18	TGT	$M_D = 0.27 + 1.67(\pm0.12)\log_{10}(\tau) + 0.018(\pm0.028)\Delta$	0.90
19	RSA	$M_D = -0.21 + 1.64(\pm0.14)\log_{10}(\tau) + 0.002(\pm0.041)\Delta$	0.88
20	BIT	$M_D = -0.56 + 1.72(\pm0.16)\log_{10}(\tau) + 0.024(\pm0.039)\Delta$	0.88
21	TSY	$M_D = -0.22 + 1.63(\pm0.11)\log_{10}(\tau) + 0.024(\pm0.022)\Delta$	0.89
22	JHA	$M_D = -0.60 + 1.67(\pm0.25)\log_{10}(\tau) + 0.033(\pm0.050)\Delta$	0.89
23	CIA	$M_D = -0.55 + 1.72(\pm0.08)\log_{10}(\tau) + 0.020(\pm0.011)\Delta$	0.97
24	RTC	$M_D = -0.44 + 1.71(\pm0.23)\log_{10}(\tau) + 0.032(\pm0.070)\Delta$	0.88
25	AVE	$M_D = -1.14 + 1.81(\pm0.12)\log_{10}(\tau) + 0.048(\pm0.044)\Delta$	0.89

Magnitudes M_{Dij} estimated and corresponding residuals (M_{Dij}–mb^{IGN}) are plotted versus the reference magnitudes mb^{IGN} for the 25 stations (for the derivation set), but only 6 of them (randomly chosen) are represented in Figures 2.1 to 2.6.

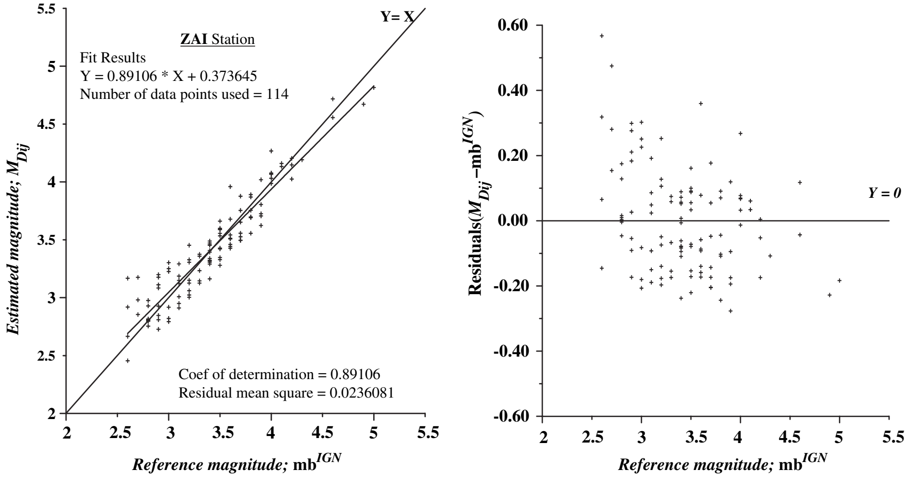

Figure 2.1
M_{Dij} magnitudes and (M_{Dij}–mb^{IGN}) residuals plotted versus the reference magnitude; mb^{IGN} for ZAI station.

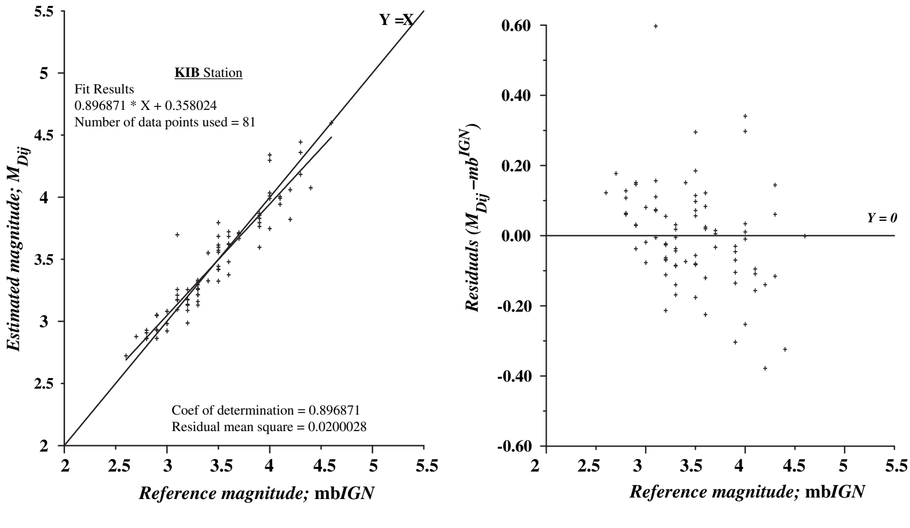

Figure 2.2
M_{Dij} magnitudes and (M_{Dij}–mb^{IGN}) residuals plotted versus the reference magnitudes; mb^{IGN} for KIB station.

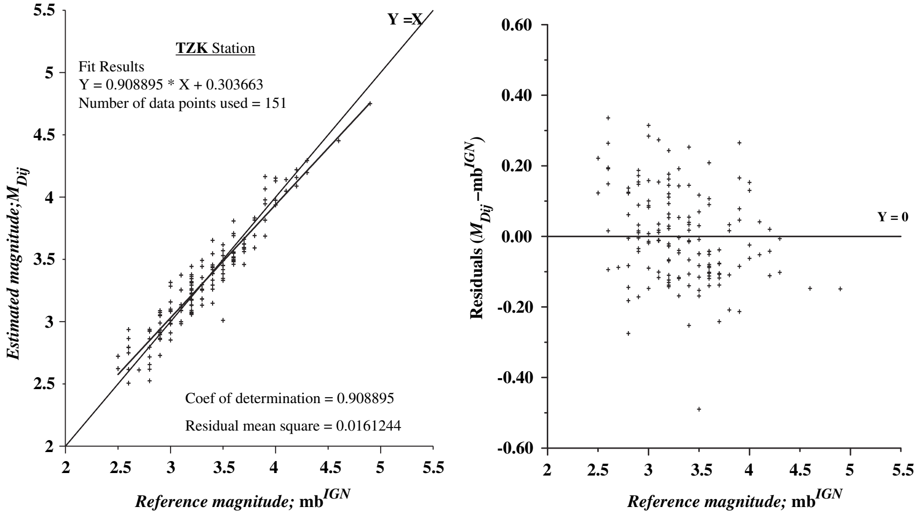

Figure 2.3
M_{Dij} magnitudes and (M_{Dij}–mb^{IGN}) residuals plotted versus the reference magnitudes; mb^{IGN} for TZK station.

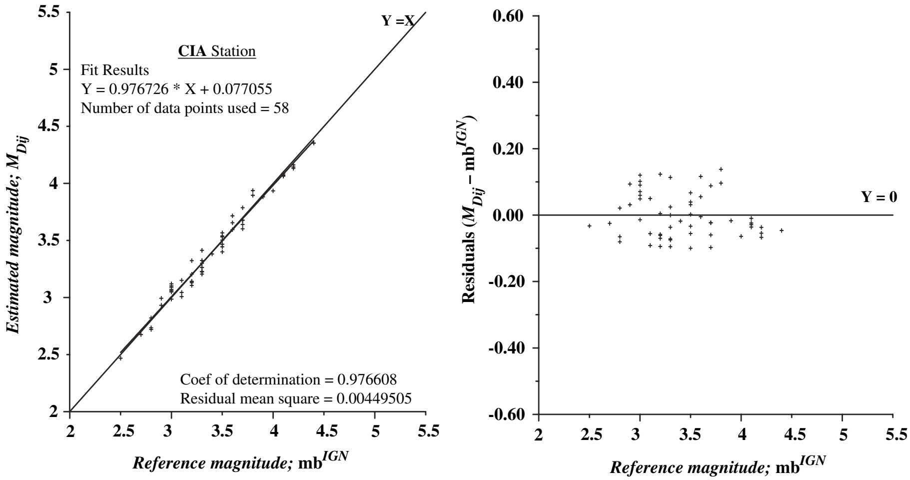

Figure 2.4
M_{Dij} magnitudes and (M_{Dij}–mb^{IGN}) residuals plotted versus the reference magnitudes; mb^{IGN} for CIA station.

These graphs show the good agreement of M_{Dij} estimate for the mb^{IGN} values. Therefore, considering the overall character of the data used in this study (MOUAYN *et al.*, 2004), the established formulas seem adequate. The correlation between M_{Dij} and mb^{IGN} values is very significant, and it ranges between 87% and 98% for the 25 stations with an acceptable mean value of 89.9%. The diffuse distribution of the

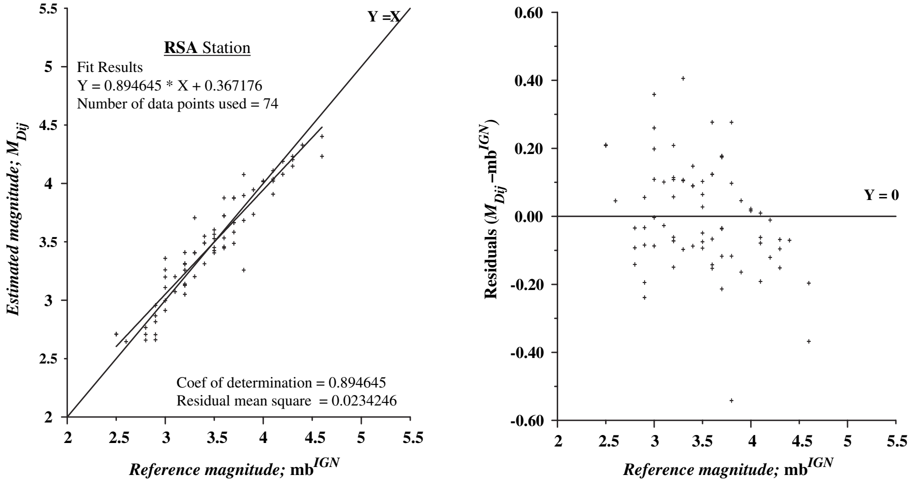

Figure 2.5
M_{Dij} magnitudes and (M_{Dij}–mb^{IGN}) residuals plotted versus the reference magnitudes; mb^{IGN} for RSA station.

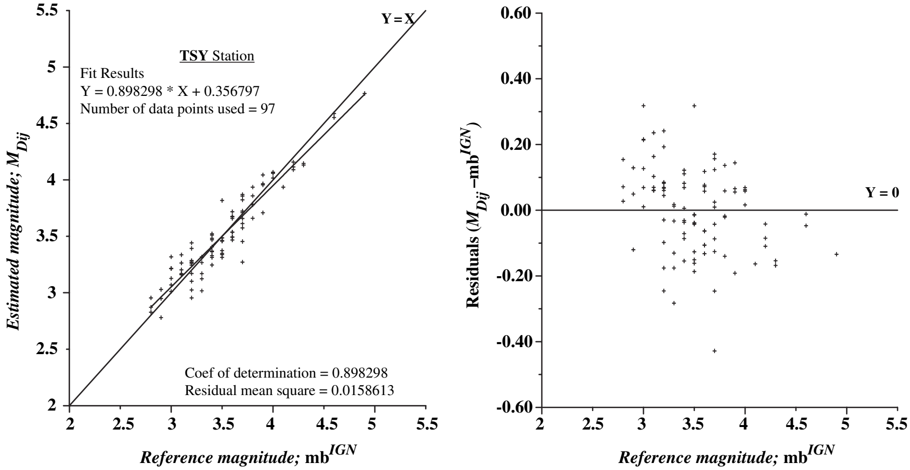

Figure 2.6
M_{Dij} magnitudes and (M_{Dij}–mb^{IGN}) residuals plotted versus the reference magnitudes; mb^{IGN} for TSY station.

residuals (M_{Dij}–mb^{IGN}) versus the mb^{IGN} magnitudes indicates clearly that the estimated M_{Dij} values are not biased over the magnitude interval; 2.5–5.5. This random distribution obtained for the residuals is well appreciated in the graph presented in Figure 3. This figure also shows that deviations (M_{Dij}–mb^{IGN}) range between −0.59 and 0.60 magnitude units.

Test of the M_{Dij} equations (INC)

To check for quality and precision provided by the newly established formulas we apply them to the *test set* data for each of the 25 stations. Graphs of 6 randomly chosen stations are presented in Figures 4.1 to 4.6.

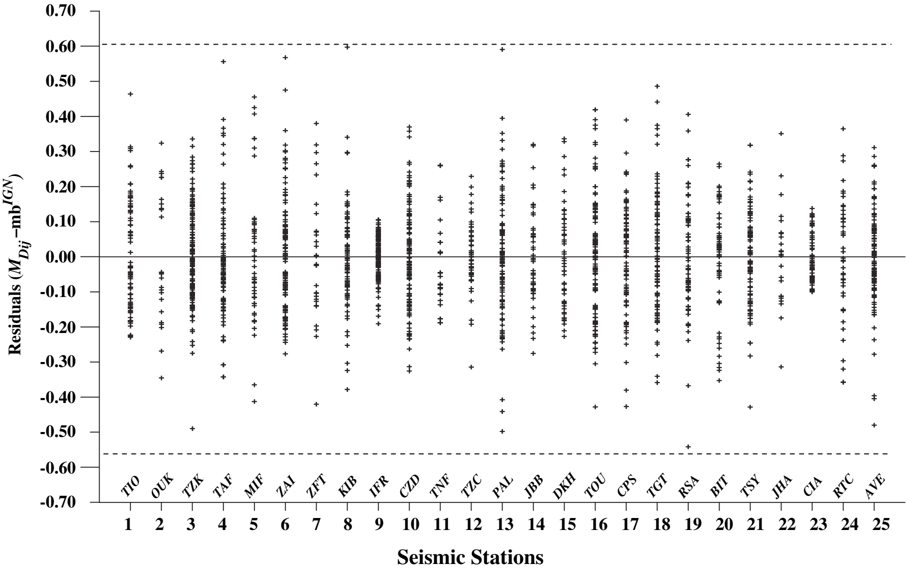

Figure 3
Seismic stations with correspondent residuals (M_{Dij}–mb^{IGN}) for the INC approach.

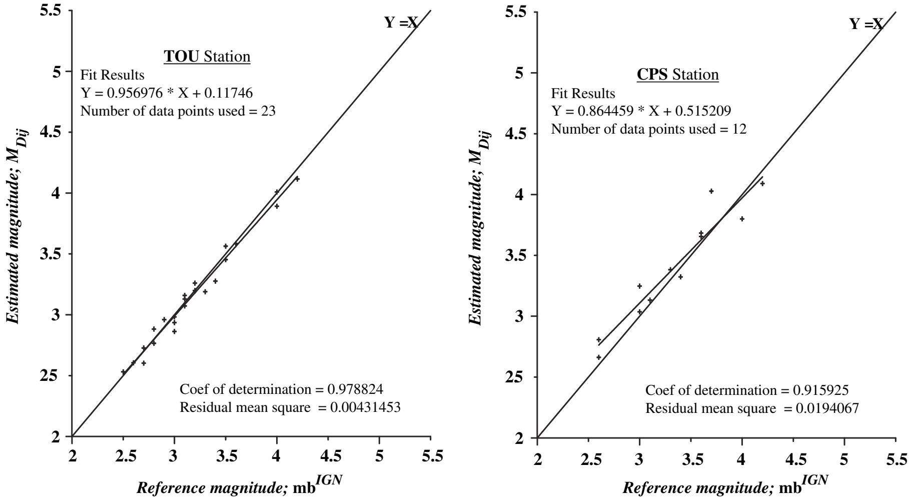

Figure 4.1–4.2
(4.1) M_{Dij} *versus* mb^{IGN} for TOU station. Test of the INC method; (4.2) M_{Dij} *versus* mb^{IGN} for CPS station. Test of the INC method.

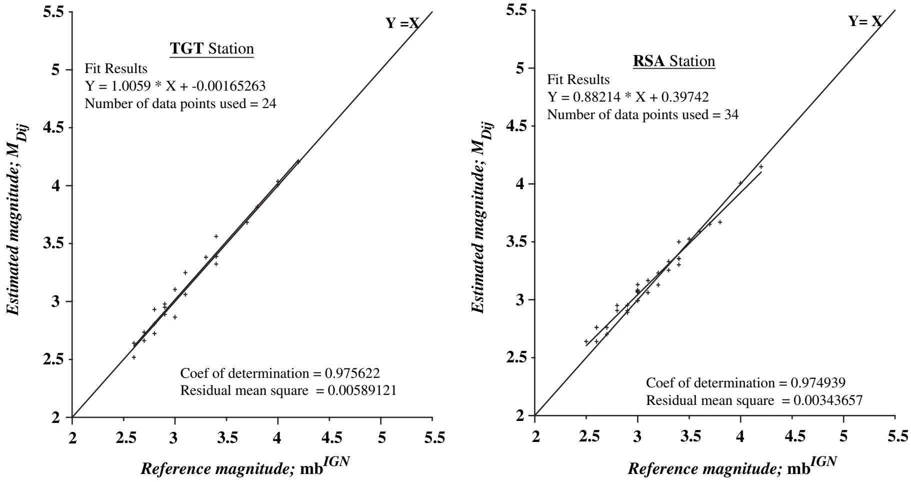

Figure 4.3–4.4
(4.3) M_{Dij} *versus* mb^{IGN} for TGT station. Test of the INC method; (4.4) M_{Dij} *versus* mb^{IGN} for RSA station. Test of the INC method.

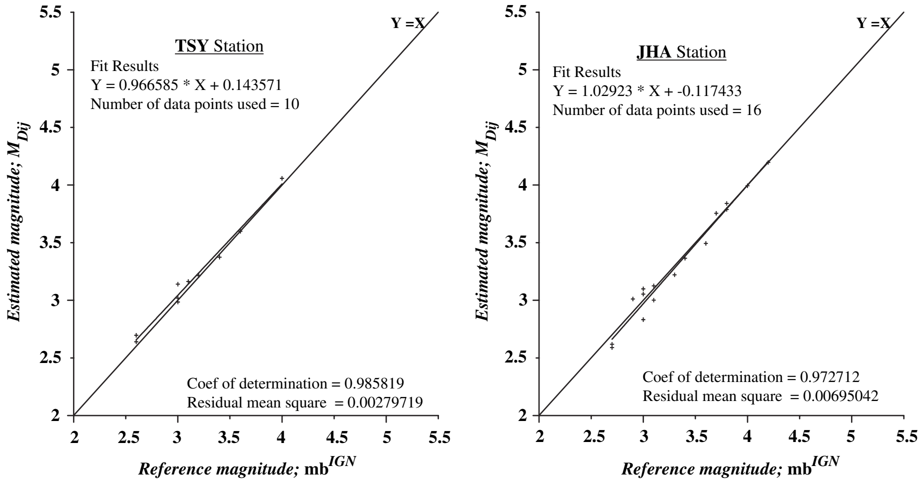

Figure 4.5–4.6
(4.5) M_{Dij} *versus* mb^{IGN} for TSY station. Test of the INC method; (4.6) M_{Dij} *versus* mb^{IGN} for JHA station. Test of the INC method.

1. The estimated magnitude; M_{Dij} are in good agreement with mb^{IGN} reference magnitudes. M_{Dij} estimated account for 91 percent of the variance about the regression (R-Squared = 0.91), predicting mb^{IGN} reasonably well.

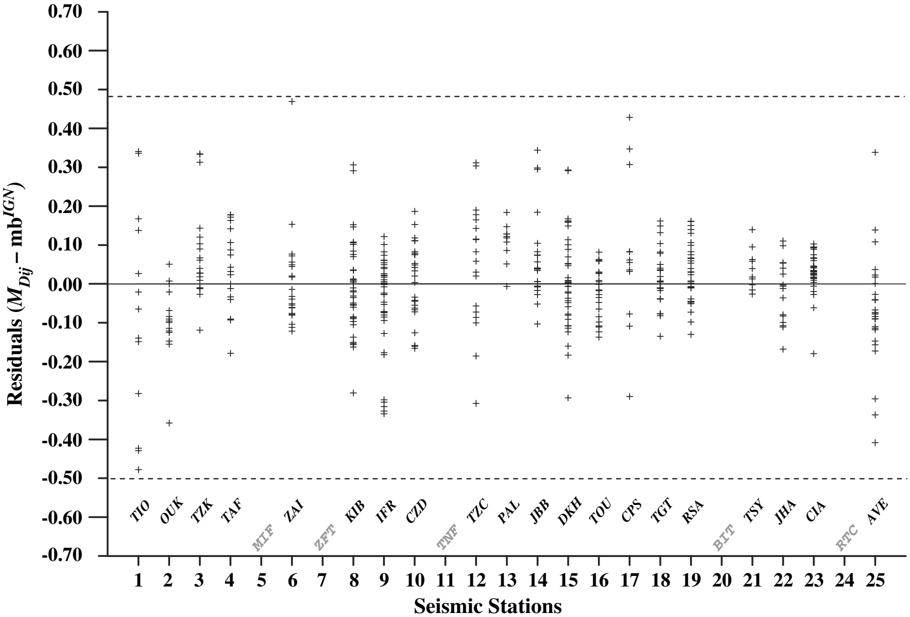

Figure 5
Seismic stations with correspondent residuals (M_{Dij}–mb^{IGN}) for the *INC* approach's *test*. Stations in grey; with less than 10 data are not represented.

2. By comparing the graph of Figure 3 to the graph relative to the tested equations (Fig. 5), we observe a clear decline in the residuals (M_{Dij}–mb^{IGN}), which in this case, range between −0.47 and + 0.46.

Principal Results and Discussion

In general, results obtained using the individual calibration network approach are satisfactory, in spite of the fact that residuals are in some way important (large). However, considering an averaged value of the magnitudes M_{Dij} calculated separately by each station for a seismic event, we may obtain a good estimation of the magnitude.

Interesting result arising from this approach is that the calibration coefficients c_i (Table 2) do not present any similarity (despite the proximity of some stations) which can allow us to regroup stations with the same c_0 or c_1 for example. Discrepancies in these coefficients may be an inevitable consequence of having calibrated each station separately. Thus, the c_0 coefficient which simply reflects the distribution interval of the magnitude values recorded by each station, compensates systematically the duration-attached coefficient c_1. We may assume that it is only when we consider a system (the network) globally, then we may isolate some of particularities of its components (stations). This is the objective of the following section.

Global Network Calibration (GNC)

Recent studies yielded relative differences in signal durations recorded at identical stations placed at different sites (Bakun, 1984; Michaelson, 1990; Eaton, 1992; Kang and McMechan, 1993; Mouayn *et al.*, 2004). This influence may reflect the geophysical near-station predominant conditions and thus, stations seem to produce signals where durations and amplitudes depend upon these conditions. Consequently, to reduce this influence, corrections for the instrument and the site effect are usually attributed to the stations (Bakun, 1984; Michaelson, 1990; Eaton, 1992) for their tendency to underestimate or overestimate earthquake magnitudes.

In this approach (*GNC*), a single duration–dependent magnitude relationship was established (from the independent data set) and tested (against the test set) for the 25 studied stations (Mouayn *et al.*, 2004) as:

$$M_{Dij} = -0.14 + 1.63\log_{10}(\tau_{ij}) + 0.031(\Delta_{ij}) + cSta_j. \quad (2)$$

$cSta_j$ are the corrections attributed to each station j, and are listed in Table 1. The magnitude of the i^{th} event is the mean of individual station estimates M_{Dij}, and the estimated uncertainty is the standard deviation of the mean.

M_{Dij} estimated by equation (2) accounts for 95 percent of the variance pertaining to the regression (coefficient of determination R-squared = 0.95), predicting mb^{IGN} reasonably well (Fig. 6, Table 3), while introducing station corrections which are assumed to be the site corrections, and the opposite of the average station magnitude residuals. Thus, only instruments with similar response curves were selected (1Hz natural frequency, vertical component SS-1 Kinemetrics Ranger seismometers). Sensitivity (36 ± 6 dB) and category component (vertical) had consequently, no significant errors introduced in $cSta_j$ corrections. Amplification/attenuation is practically constant for stations of this study. We attribute $cSta_j$ corrections entirely to compensate the effect of site of station.

As for the first approach, we shall proceed to analyze obtained residuals in the case when no corrections are attributed. The formula used for all stations is:

$$M_{Dij} = -0.14 + 1.63\log_{10}(\tau_{ij}) + 0.031(\Delta_{ij}).$$

We noted that without the $cSta_j$ corrections, the estimated magnitudes; M_{Dij} account only for 84 percent of the variance of the regression with respect to the

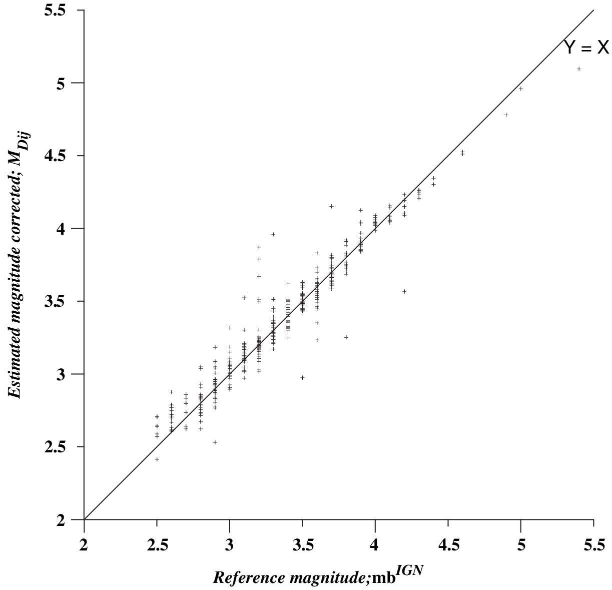

Figure 6
M_{Dij} Corrected derived by the GNC method versus mb^{IGN} for the independent data set.

Table 3
Analysis of the Variance

	Variables log10		Standard Error	R^2	*F* Test	Number of degrees of freedom
Independent Set						
Without $cSta_j$	(+)	(+)	1.08	0.84	5248	1931
With $cSta_j$	(+)	(+)	0.87	0.95	17190	1931
Test Set						
With $cSta_j$	(+)	(+)	0.97	0.91	2346	508

(+) : variables include in this model.
R^2: Correlation coefficient.
F Test: F test compared to the F of the model.

reference mb^{IGN} (see Table 3). Residuals (M_{Dij}–mb^{IGN}) obtained are presented in Figure 7. Their distribution is not random. Some stations can be regrouped according to their corresponding averaged residuals.

Global network calibration technique offers one way to classify the calibrated stations according to algebraic value of their resulting averaged residual. Stations with high negative (positive) residuals tend to reduce (increase) the recorded

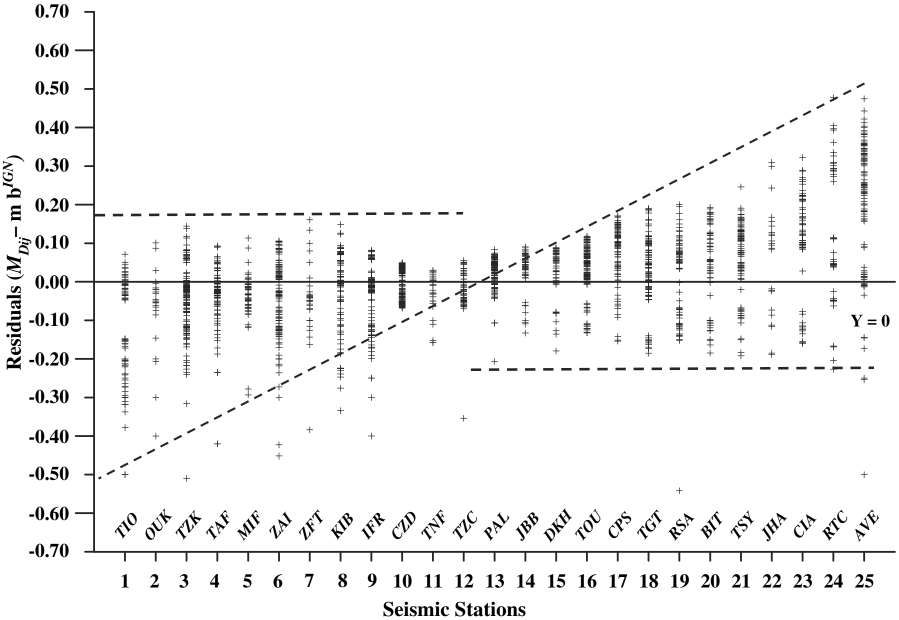

Figure 7
Seismic stations with correspondent residuals (M_{Dij}–mb^{IGN}) for the G*NC* approach. No corrections are attributed to the stations.

durations and then underestimate (overestimate) magnitudes. The corrections attributed to the stations are here to compensate the effect described above. They have the same absolute value but the opposite sign of the average magnitude station residuals. As a correction term; $cSta_j$ is integrated in the estimated magnitudes; $M_{Dij} = -0.14 + 1.63\log_{10}(\tau_{ij}) + 0.031(\Delta_{ij}) + cSta_j$. These magnitudes will be called corrected estimated magnitudes. The representation of the residuals issued from corrected magnitudes (Fig. 8), shows an evident diminution in the mean absolute value of these deviations (−0.38 to 0.40). This graph also shows the disappearance of any tendency to influence corrected magnitudes values.

Conclusion

This study is a comparison of two empirical techniques for calibrating 25 short-period analog stations from the Northern Morocco Seismic Network (MNSNET) using data from MOUAYN *et al.* (2004). In the first approach (*Individual Network Calibration: INC*) we established and tested an individual duration-dependent relationship; M_D for each of the 25 stations (MOUAYN, 1994; MOUAYN *et al.*, 2004) by calibrating M_D against the body-wave magnitude; mb^{IGN} (mb from the Instituto

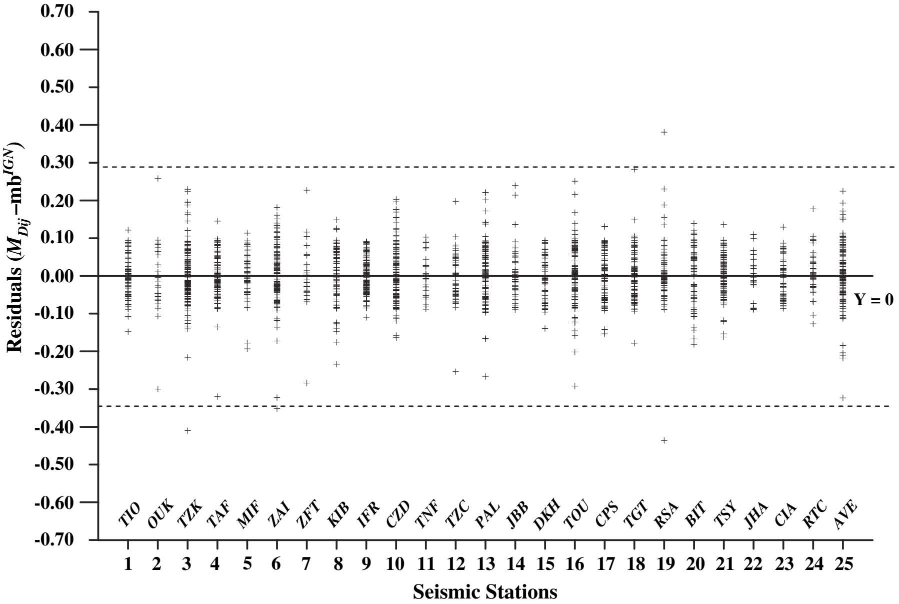

Figure 8
Seismic stations with correspondent residuals (M_{Dij}–mb^{IGN}) for the G*NC* approach. Here, station corrections are introduced.

Geografico Nacional bulletins, Spain). The equations are derived by regressing mb^{IGN} against the duration and the epicentral distance Δ. These 25 equations are of the form: $M_{Dij} = c_{0j} + c_{1j}\log_{10}(\tau_i) + c_{2j}(\Delta_i)$, and are listed in Table 2. The magnitude; M_D of an event is the main value of individual M_{Dij}, and uncertainty; ΔM_D is the standard deviation of the data of the mean. In the second approach (*Global Network Calibration: GNC*), we used a single relationship established and tested for the stations of this study: $M_{Dij} = -0.14 + 1.63\log_{10}(\tau_{ij}) + 0.031(\Delta_{ij}) + cSta_j$. This equation is established using a two-stage iterative procedure in which, first we solve for the constants, then we calculate the correction; $cSta_j$ for each station *j*. This technique is detailed in MOUAYN *et al.* (2004).

Comparison between the two techniques yields the following principal results:

— M_{Dij} estimated by the *INC* approach accounts for 89.9 percent of the variance pertaining to the regression, predicting mb^{IGN} reasonably well. The *GNC* method gives more precise M_{Dij} magnitudes with a strong correlation of about 95% (with the site correction).
— Residuals (M_{Dij}–mb^{IGN}) are significant, and range between −0.60 to 0.60 magnitude units for the *INC*, whereas a decrease in these deviations (−0.38 to 0.40) is observed while using the *GNC* approach (with the site correction).

— A random distribution of residuals ($M_{Dij} - \mathrm{mb}^{IGN}$) is observed for each station by applying the *INC* approach. The average of these residuals is near zero. By adopting the global network calibration, residuals seem to take particular mean algebraic values for distinct groups of stations, indicating an apparent systematic tendency for these groups to either over-estimate or underestimate magnitude values.

Discussion

Empirical relationships presented in this work are certainly of great interest for magnitudes and residuals computation, since they are newly established and carried out using original, numerous, and better quality data. An effort to examine advantages and disadvantages of the two techniques indicates that these approaches may be considered as complementary. The *INC* technique gives M_{Dij} values adjusted to the mb^{IGN} with a good agreement, although no correction is attributed to the stations since the corresponding residuals (M_{Dij}–mb^{IGN}) are randomly distributed and no central tendency parameter such as the median or the mean can represent this correction. The average (M_{Dij}–mb^{IGN}) and the median (M_{Dij}–mb^{IGN}) are near zero. Regardless, the precision of M_{Dij} equations is acceptable when considering the main value of individual M_{Dij} to estimate earthquake magnitudes. The formulas ($M_{Dij} = c_{0j} + c_{1j} \log_{10}(\tau_i) + c_{2j}(\Delta_i)$) obtained are specific for each station, and reflect this interaction of all geometrical, geological and geophysical parameters characterizing a given station. Thus, the c_2 coefficient is related to epicentral distances which depend on the geographical distribution of events with respect to the station. Duration-dependent coefficient c_1 represents the theoretical geometrical spreading coefficient (HERMANN, 1975; FRANKEL and WENNERBERG, 1987), which also describes the coda decay resulting from attenuation in a medium with intrinsic absorption and scattering (AKI and CHOUET, 1975; FRANKEL and WENNERBERG, 1987), whereas the c_0 coefficient may result as an additive corrections c_0' and c_0'' ($c_0 = c_0' + c_0''$), one for the instrument and the other for the site of the station. To separate these corrections requires the installation of all the used seismographs in the same emplacement (site), to record sufficient events to calibrate the station, and thus the instrument correction is directly estimated. When instrument correction is subtracted from initial c_0, we then can evaluate the site correction. This last one is of great importance since it indicates the site effect on the seismic wave propagation in the vicinity of the stations. Moreover its good precision in computing magnitudes, *GNC* technique allows regrouping stations with respect to their relative corresponding residuals. Some of these stations appear to underestimate magnitudes; others are favorable to overestimating magnitudes, whereas no influence (with respect to references magnitudes) on estimated magnitudes is noted for the remaining group of stations.

This is an interesting result, because it is known that, when calibrating similar instruments (in this study: Kinemetrics SS-1 Ranger Seismometers, 1-Hz, vertical component, 36 ± 6 dB attenuator setting) for duration-magnitude scales, there is no obvious change in the residuals (durations) when amplification gain changes slightly (±6 dB) at station (LEE *et al.*, 1972; BAKUN, 1984), and therefore discrepancies between residuals which nearly result in the site effect may be correlated to geological and geophysical conditions of the site in the immediate vicinity of the stations (BORCHERDT and GIBBS, 1976; ROGERS *et al.*, 1979; BAKUN, 1984; MICHAELSON, 1990; SU *et al.*, 1992; EATON, 1992; MOUAYN *et al.*, 2004). This last reflection has been developed in a recent work soon to be published (MOUAYN *et al.*, 2006).

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