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Coda wave attenuation tomography in Northern Morocco

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Abstract
In this study we focused on seismic attenuation (1/ Q_c) tomography in Northern Morocco. For this purpose, two different models are employed: The Single Backscattering model hypothesis of Aki and Chouet (1975) to calculate values of Coda Q (Q_c) and the Back-projection technique of Xie and Mitchell (1990) to estimate lateral variation in Q_c via a tomographic inversion. For this investigation, the Coda Q method is applied to a number of 94 local earthquakes with a magnitude between Ml=0.7 and Ml=4. The digital seismograms of these earthquakes were recorded during the year 2008 by both local temporary and permanent broadband seismic station network deployed in Northern of Morocco. The Q_c quality factor values have been computed at central frequencies 0.75, 1.5, 3, 6 and 12 Hz. The lapse time windows are restricted to 30s in order to sample the earth's crust only. The Q_c results indicate that strong frequency dependence follow a power law for the entire area. The preliminary results of seismic Coda Q_c attenuation tomography shows a dependence at each frequency band, between seismic attenuation and the geology structure units in the study area, especially in the region of Al Hoceima and the eastern part of the Rif which are characterized by high attenuation values due to active faults area, while low attenuation values are seen in the west and the south of the Rif in high frequencies.

Keywords: Single Backscattering model, Back-projection technique, Attenuation, Tomographic inversion, Northern Morocco.

Introduction
The Iberia-Maghreb collision zone, including northern Morocco, is considered one of the seismic active regions in the Mediterranean basin. Numerous seismological studies [1-5] have been carried out beneath the region investigating the seismic wave properties to explore its geometrical structure, heterogeneity and to explain its geodynamical and tectonic evolution. In particular, the north of Morocco is located in north-western tip of Africa where African and European plates collide with different geotectonic environments. It is affected generally by weak to moderate magnitude and shallow depth seismicity. The history records mention several important earthquakes distributed in this region [6]. The last relevant one is 24th February 2004 earthquake (M_w = 6.1) which caused great damage in Al Hoceima city and the surrounding area [7].
Crustal seismic wave attenuation is closely connected with the tectonics and the strength of the crust [7, 8]. The knowledge of regional values of the seismic wave attenuation (inverse of quality factor, Q) and its spatial variation attracts considerable interest in relation to tectonics and seismicity, being an important subject in seismic risk analysis and engineering seismology [1, 2]. It is considered as essential key for the prediction of earthquakes source parameters.
Several studies have been carried out in varied geological terrains worldwide to investigate the seismic wave attenuation property of the medium [9, 10], characterize the seismic activity and discriminate seismically active

regions from stable ones. Boulanouar et al [7] study the spatial variation wave attenuation using the aftershocks of the Al Hoceima earthquake of 24 February 2004. Their work suggests that Al Hoceima area is highly heterogeneous. The seismic tomography using local and teleseismic earthquakes was investigated beneath the region determining the heterogeneity anomalies in the crust and the mantle [11-14].

The attenuation properties of various seismic regions have been determined by a number of investigations [15, 16]. The investigation beneath earth's subsurface structurescan be studied using seismic Coda wave attenuation. The attenuation of seismic waves in Northern Morocco is still poorly known.

The objectives of the present paper were (1) to estimate the attenuation of Coda wave for the northern Morocco and (2) to understand the attenuation mechanism in the crust for the same region using the tomography attenuation.

For that, we selected a good quality dataset signals from moderate magnitude local earthquakes collected at a large broadband array deployed in northern Morocco. The digital seismograms of these earthquakes were recorded during the year 2008 by both local temporary and permanent broadband seismic station network deployed in Northern of Morocco. The Q_c quality factor values have been computed at central frequencies 0.75, 1.5, 3, 6 and 12 Hz. The lapse time windows are restricted to 30s in order to sample the earth's crust only. The quality factor values are used to generate the attenuation map using attenuation tomography in this area.

In this study, two different models are used: The first is the single Back-scattering model of Aki and Chouet [3] and Havskov et al. [16, 18]. It's preferred for Coda Q_c calculation. This model allows to explain the Coda waves as a superposition of secondary waves from randomly distributed heterogeneities [1]. We have chosen the single Backscattering model to be used in the present study because it facilitates the comparison with other regions of the world.

The second model is the Back-projection inversion technique [17] to create a tomographic map of the distribution of attenuation at various frequencies over the Northern Morocco. Moreover, this work may be useful for other research mainly in earthquake hazard assessment. To the best of our knowledge, this is the first study of attenuation tomography in this region and will be a new contribution for scientific research.

2. Data

Data obtained are from the seismic network of the Scientific Institute of Rabat. A map of the events and stations is given in Figure 1. Measurements of Coda wave [18] are made at the following center frequencies (and bandwidths) given in Hz: 0.75 (0.5), 1.5 (1.0), 3 (2), 6 (4), 12 (8). The seismograms used in this research were recorded by 29 seismological stations during 2008. All of the stations are 3-component broadband sensors were used for the network. For the analysis we used only 94 local earthquake recorded by a station network operating with an epicentral distance less than 250 Km. The magnitudes of the analysed events range from Ml=0.7 to Ml=4. Data were recorded digitally at 100 samples/s. Only good quality seismograms were processed, with signal to noise (S/N) greater than 3 for a given data set.

3. Methodology

The attenuation of Coda wave is measured by the quality factor (Q_c) and calculated via the method of Havskov et al. [16]. These model assume that the Coda wave amplitude at frequency, f, and lapse time (time since event), t, is given by:

$$A(f,t) = S(f)t^{-\nu} \exp(-\pi ft / Q_c) \quad (1)$$

Where S(f) is the source factor and ν is the geometrical spreading parameter.

The Coda waves are generated by scattering processes inside the Earth [15].

The logarithmic transform of eq. (1) allows it to be written:

$$\ln(A(f,t)) + \nu \ln(t) = \ln(S(f)) - \pi ft / Q_c \quad (2)$$

If we assume that the geometrical spreading is dominated by body-wave type spreading then ν is unity and Q_c can be estimated from a regression of narrow band-passed amplitude on time. An example of this measurement is given in Figure 2.

Multiple measurements of Q_c made at several different stations for several events are used to estimate lateral variations in Q_c via a tomographic inversion. We follow the approach of Xie and Mithcell [17], which assumes single scattering so that each measurement is sensitive to a crustal volume. Pulli [4] suggests the volume is mapped out by an ellipse given by:

$$\frac{x^2}{(\beta t/2)^2}+\frac{y^2}{(\beta t/2)^2-(R/2)^2}=1 \qquad (3)$$

Where β is the shear-wave speed, R is the epicentral distance, and the foci of the ellipse are the station and event locations. An example of such an ellipse is given in Figure 1. The measurements are made beginning with a lapse time that is two times the S-wave arrival time, $t_S = R/\beta$, so that the major and minor axes of the ellipse are given by R and $\sqrt{3}R/2$, respectively.

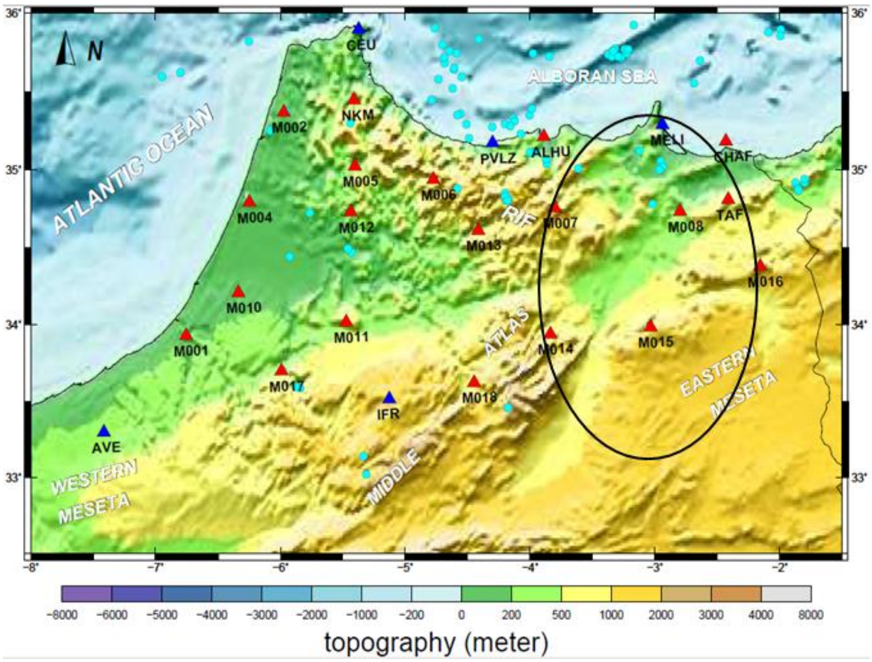

Figure 1: Regional map of Morocco. Triangles are stations (blue ones belongs to WM seismic network and the red ones are the IberArray network), cyan circles are the events [19, 20]. The ellipse with black color as shown in the figure, is the assumed Q_c sensitivity region for a given station and event

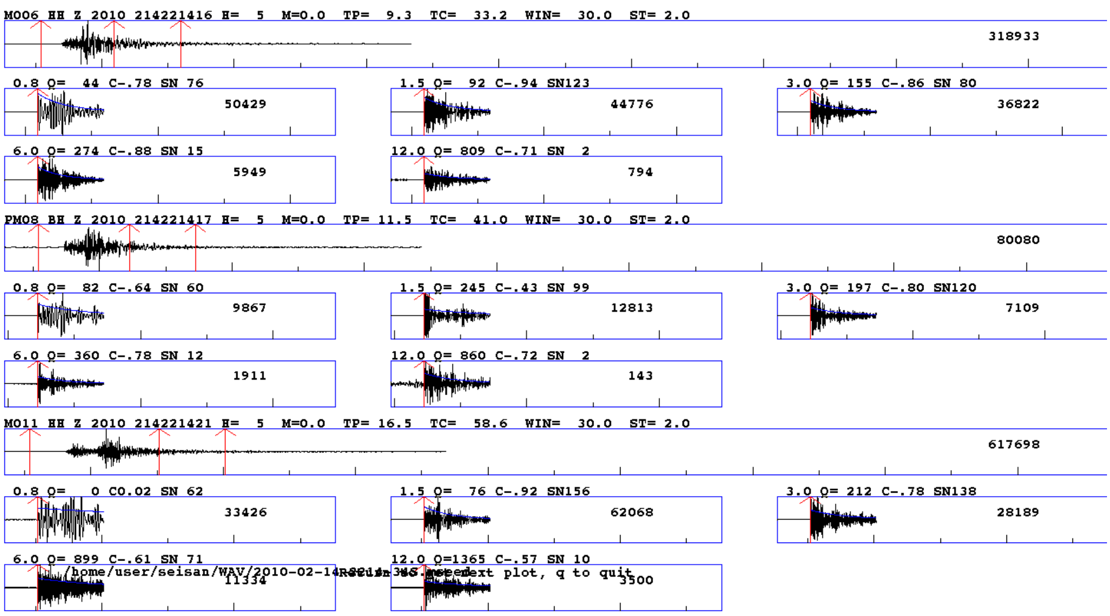

Figure 2: The figure shows the vertical component seismogram from the three stations: M006, M011 and PM08. The first arrow on the left side of the top panel shows origin time and the other two arrows indicate the Coda duration. The lower panels of each station in each set of figures show filtered Coda windows for 5 central frequencies at t_{start}=2ts. Abbreviations: SN-Signal to noise and C-correlation coefficient. The x axis represents the lapse time windows are restricted at an interval of 30s and the y axis represents amplitude.

The forward problem is discretized by finding the portion of the n-th ellipse that is contained in the m-th block (m=1, 2, 3,..,N) of a gridded region that contains the stations and events,

$$\frac{1}{Q_n} = \frac{1}{S_n}\sum_{m=1}^{N}\frac{S_{mn}}{Q_m} \qquad (4)$$

where S_n is the total area of the ellipse, S_{mn} is the area of the ellipse in the m-th of N blocks. A damped least-squares inversion (0-th order Tikhonov regularization [21]) using eq. (4) is performed to calculate Q_c in the gridded region. A roughening matrix (e.g., finite-difference approximation to a Laplacian) is not used since the areal extent of each measurement imparts smoothness to the solution.

4. Results and discussions

In this study, we have selected 94 local earthquakes recorded with the best signal to noise ratios in 29 seismological stations during the year 2008. All of the stations are equipped with three component broadband sensors. The seismograms used are filtered in five centre frequencies: 0.75, 1.5, 3, 6, 12 Hz. The study is restricted to 30 s. Two different models are used: The Back-projection Tomography method of Xie and Mitchell [17] and the Single Backscattering Aki and Chouet [3]. The results of the attenuation tomography of Coda wave at different center frequencies are given in Figure 3, where only blocks with resolution > 0.95 are shown. The model resolution matrix is obtained from the generalized singular values.

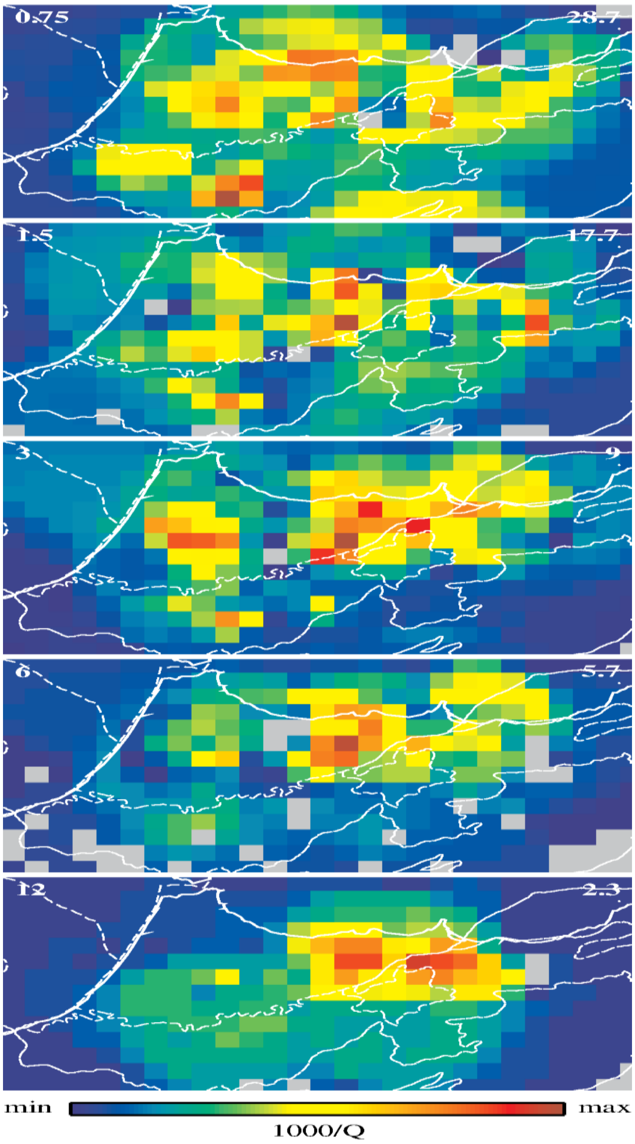

Figure 3: Q_c tomograms of Morocco at different center frequencies (given by number in top-left of each panel). The color scale is linear from a minimum q (1000/Q) of 1 to a maximum q given by the number in the top-right of each panel.

L-curves for each inversion are given in Figure 4. A damping parameter of 0.1 gives a good balance between model roughness and fit to the data at all center frequencies. The quality factor, Q, as a function of center frequency in each cell is plotted in Figure 5. A best fit to the median at each frequency is $Q_c = 500f^{0.9}$. Our results indicate that the attenuation decreases with increasing of frequency. These results are consistent with the findings of the previous study [1, 2, 5].

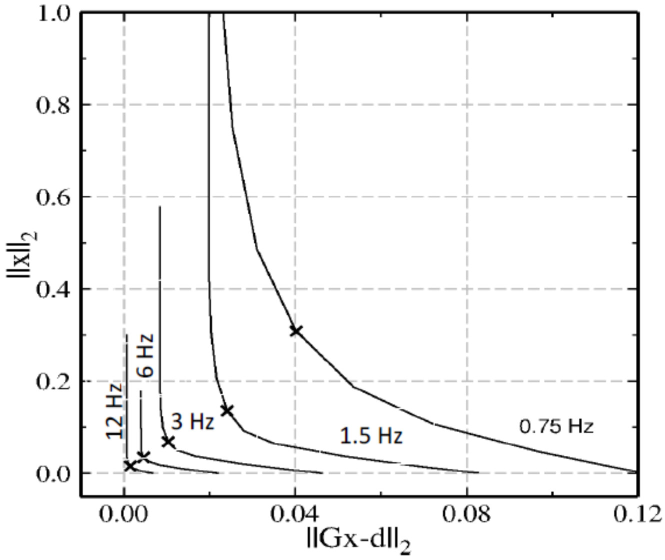

Figure 4: L-curve for Q_C tomography where the cross is for a damping parameter of 0.1. Each curve is for an inversion at a specific center frequency where the one for 0.75 Hz is noted and the curves decrease for increasing center frequency 0.75, 1.5, 3, 6, and 12 Hz.

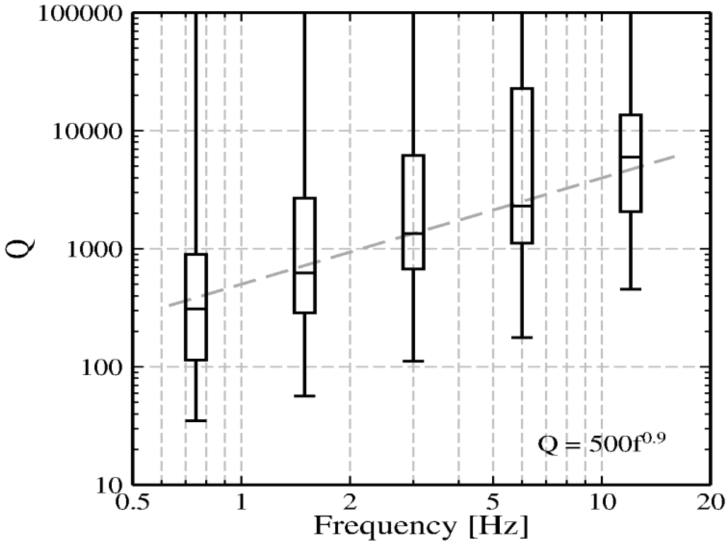

Figure 5: Boxplot of Q_c as a function of frequency at each point in the grid. The best fit to the median Q at each frequency is given by the dashed line, $Q_c = 500f^{0.9}$.

The results using tomography are very interesting especially in the region of Al Hoceima (35.5N, –4W), because this region is seismically active and contains many active faults. In this region, it has occurred two destructive earthquakes. The first one in 1994 with a magnitude Ml=6 and the second in 2004 with magnitude Ml=6.1. Their seismicity is mainly shallower in this region.

These preliminary results of seismic Coda Q_c attenuation tomography show a dependence at each frequency band, between seismic attenuation and the geology structure units in the study area, especially in the region of Al Hoceima and the eastern part of the Rif which are characterized by high attenuation values due to seismic active faults area and the soft materials, while low attenuation values are seen in the west and the south of the Rif in high frequencies.

Conclusions

The quality factor of Coda wave was estimated for the first time in northern Morocco. It was possible due to the record of 94 local earthquakes with a magnitude between 0.7 and 4 during the year 2008 by both local temporary and permanent broadband seismic station network deployed in Northern Morocco. The quality factor values, Q_c, have been computed at central frequencies 0.75, 1.5, 3, 6 and 12 Hz. The lapse time windows are restricted to 30s in order to sample the earth's crust only. Two different models are employed in this study: The Single Backscattering model hypothesis of Aki and Chouet [3] to calculate values of Coda Q (Q_c) and the Back-projection technique of Xie and Mitchell [17] to estimate lateral variation in quality factor of Coda wave, Q_c, via a tomographic inversion. We concluded that for the entire Northern Morocco area the attenuation values are varied. This can be interpreted as a difference in the inhomogeneity structure of this complex tectonic region. The obtained results showed that the correlation between large crustal thickness and low attenuation is true when the large thickness is maintained. Strong variations in the crustal thickness are associated with low quality factor, Q, values. High and maintained values of crustal average of P-wave velocity correlate well with low attenuation. This fact may be used for the detailed Q_c map obtained in this study as an important input for seismic risk analysis andengineering seismology.

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