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On the Development of a Homogenized Earthquake Catalogue for Northern Algeria

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***Abstract*—**Regions with a significant percentage of non-seismically designed buildings and reduced urban planning are particularly vulnerable to natural hazards. In this context, the project 'Improved Tools for Disaster Risk Mitigation in Algeria' (ITERATE) aims at seismic risk mitigation in Algeria. Past earthquakes in North Algeria caused extensive damages, e.g. the El Asnam 1980 moment magnitude (Mw) 7.1 and Boumerdes 2003 Mw 6.8 earthquakes. This paper will address a number of proposed developments and considerations made towards a further improvement of the component of seismic hazard. In specific, an updated earthquake catalog (until year 2018) is compiled, and new conversion equations to moment magnitude are introduced. Furthermore, a network-based method for the estimation of the spatial and temporal distribution of the minimum magnitude of completeness is applied. We found relatively large values for M_c, due to the sparse network, and a nonlinear trend between M_w and body wave (m_b) or local magnitude (M_L), which are the most common scales reported in the region. Lastly, the resulting b-value of the Gutenberg-Richter distribution is sensitive to the declustering method.

***Keywords*—**Conversion equation, magnitude of completeness, seismic events, seismic hazard.

I. Introduction

EARTHQUAKES in North Algeria can have a devastating impact, as has been shown by past events in the northern part of the country, such as the El Asnam 1980 moment magnitude (M_w) 7.1 and Boumerdes 2003 M_w 6.8 earthquakes [1], [2]. To better understand the overall seismic risk, the EC-funded project "Improved Tools for Disaster Risk Mitigation in Algeria" (ITERATE) was initiated. This study addresses the first component of risk, which is the seismic hazard. In particular, it focuses on the earthquake catalog and its completeness.

An earthquake catalog is a parametric list of events with each entry providing an earthquake's epicenter, origin time, magnitude size and perhaps additional metadata such as depth, associated uncertainties and focal mechanism information [3]. Real earthquake catalogs are usually inherently heterogeneous. From the early days of (pre-)instrumental seismology at the beginning of the twentieth century, seismological networks have undergone many changes that are reflected in the databases in use today. These changes can be gradual, such as improvements in location and magnitude estimation over time, as networks gradually increase in size and advances in instrumentation occur. Such changes affect the detectability of the network and hence the completeness of the cataloging. The denser the seismic network the fewer the missed events and the smaller their magnitude. Changes, however, can also be rapid, such as a systematic change in operating, recording and processing procedures [4]. One such change relates to the variety of scales used for recording earthquake magnitude and their evolution throughout the instrumental era.

Heterogeneity among earthquake catalogs leads to significant data contamination and misinterpretations of the results in a plethora of analyses, such as seismicity rate evaluation and hazard assessment. These problems are more evident when the analysis needs to include data from periods with durations on the order of century and in regions where the coverage from the seismic network is sparse. Our case-study region, Northern Algeria, exhibited such lack of local networks for a long time, although it is a seismically active region, close to the subduction zone between the African and the Aegean plate [5].

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II. Scope

The first goal of the present study is to homogenize an instrumental earthquake catalog for Northern Algeria. The latest available catalog includes data till 2008 only [6]. We have developed a fully-automatized data-driven methodology to minimize the need for subjective expert opinion. Specifically, using as sole input the available parametric catalog, we convert the various magnitude scales into a common one.

The second goal is to assess the spatio-temporal variations in the magnitude of completeness, as the monitoring seismic networks in the area expanded and advanced. The magnitude of completeness (M_c) of an earthquake catalog (or subcatalog) is the minimum magnitude above which all earthquakes are exhaustively reported.

The third goal is to derive a magnitude-frequency distribution from the homogenized catalog, given the varying M_c and assess the effects of the declustering on the b-value of the Gutenberg-Richter (G-R) law [7]. An elevated b-value corresponds to a magnitude frequency distribution with relatively high ratio of small-to-large magnitudes. The declustering procedure is meant to isolate the mainshocks (independent events) from the foreshocks/aftershocks (dependent events) [8].

III. Data

Our source for the earthquake catalog was the International Seismological Centre (ISC) [9]. ISC collects raw input data from 130 contributing agencies and, when necessary, reprocess them and computes new estimates. It is the most reliable source of standardized parametric earthquake data worldwide. The national seismic network (agency) of Algeria is operated by the Centre de Recherche en Astronomie, Astrophysique et Geophysique (CRAAG) and shares its data with ISC.

ISC also provides information about the location and operational time of the monitoring stations of its contributing agencies. We used these data when estimating the magnitude of completeness.

IV. Homogenization of Earthquake Catalog

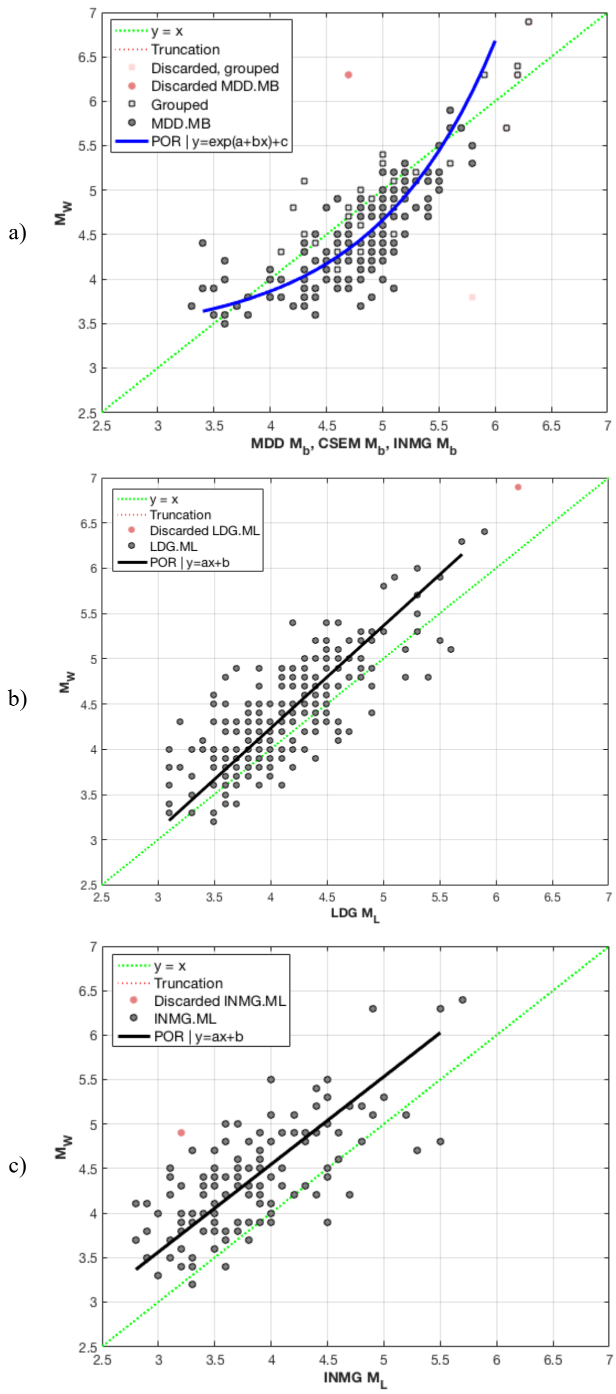
There are numerous different magnitude scales [10], based on different kinds of measurements. The most common ones are the local magnitude M_L, the short-period body wave magnitude M_b and the code duration magnitude M_d. Choices about which magnitude scales to use vary across different seismic networks. Often a single network will use different magnitude scales for different event-sizes or report multiple scales for the same event; the latter case enables empirical correlations. Although attempts were made when defining the different magnitude scales so that they were behaving similarly within certain magnitude ranges, there can be considerable variation between different magnitude estimates for a single event. This heterogeneity may produce artifacts in the statistical distribution of magnitudes in a unified catalog [11].

The moment magnitude, M_w, scale is based on the log of the moment of the earthquake, rather than on the amplitude of a particular phase at a particular frequency, and therefore, it is the most accurate scale for the whole range of magnitudes. We converted all available magnitude estimates to M_w.

To derive an appropriate relation to convert a magnitude type (e.g. an M_L estimate by CRAAG) to M_w, one should first identify which events are available in both types, plot the reported values (in pairs), and derive a best-fit curve using regression analysis [12]. With the functional form of the curve known, one can then use this relation (conversion equation) to transform any M_L estimate of CRAAG to M_w.

For each magnitude type (pair of network and scale), we checked how it correlates with any other magnitude type that shares compatible magnitude scale; if the minimum root of the mean squared orthogonal errors with respect to the one-to-one line (green dashed line in Fig. 1) was smaller than 0.20, then the two magnitude types were grouped together (e.g., Fig. 1 (a)). The selected equation for each magnitude type, was the one which presented the minimum root of the mean squared orthogonal errors, corrected for sample size ($RMSOE_{adj}$), among the available ones.

The simplest functional form to fit and apply is the linear case. However, the old magnitude scales saturate at larger magnitudes due to their limited frequency bandwidth [10]. They also sometimes suffer from inverse-saturation at very low magnitudes due to amplitude scaling and signal-noise-ratio related issues. The functional form of the fitted curve should be able to capture both tendencies. We experimented several functional forms and concluded that the most reasonable fits for our dataset were (i) linear $y=c_1x+c_2$; (ii) exponential $y=e^{(c1+c2x)}+c_3$ and (iii) power law $y=c_1x^{c2}+c_3$. The three free parameters c_1, c_2, c_3 were fitted using Particular Orthogonal Regression [12]. Again, the selected equation was the one which presented the minimum $RMSOE_{adj}$.



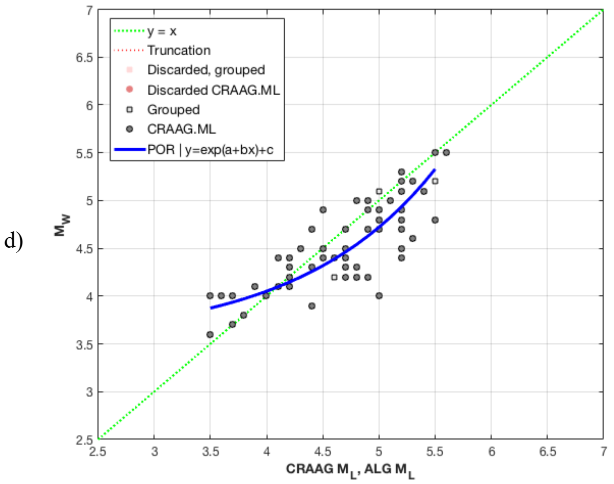


Fig. 1 Derived relation to convert various magnitude types found in the catalog to moment magnitude M_w

V. Magnitude of Completeness

M_c is usually estimated with catalog-based methods. Such methods determine M_c as the magnitude where the magnitude-frequency distribution starts deviating from the log-linear G-R law. This deviation however can be very smooth and hard to identify [13]. On top of that, all catalog-based methods make at least five crude assumptions, most of which are violated [14]. The most important one is that they require (both spatially and temporally) uniform levels of seismicity and uniform station spacing.

To overcome this problem, we employ a network-based approach, which uses the density of the active stations as proxy for M_c instead of the magnitude-frequency distribution. Since seismic waves attenuate fast with distance, the denser the seismic network the less likely it is that an event will not be cataloged. The Algerian national network (operated by CRAAG) started in 1988 and by 1990 they had installed 32 stations. Shortly after, the political situation in Algeria deteriorated. From 1992 to 1998, most of the stations were not functional. In 1998, only four regional stations remained active. In 1998 the Algerian seismic network was progressively reinstalled. Following the Boumerdes earthquake of 21 May 2003, the system was updated with a new broadband digital seismological network. In 2013, the network had 69 seismic stations of several types [15].

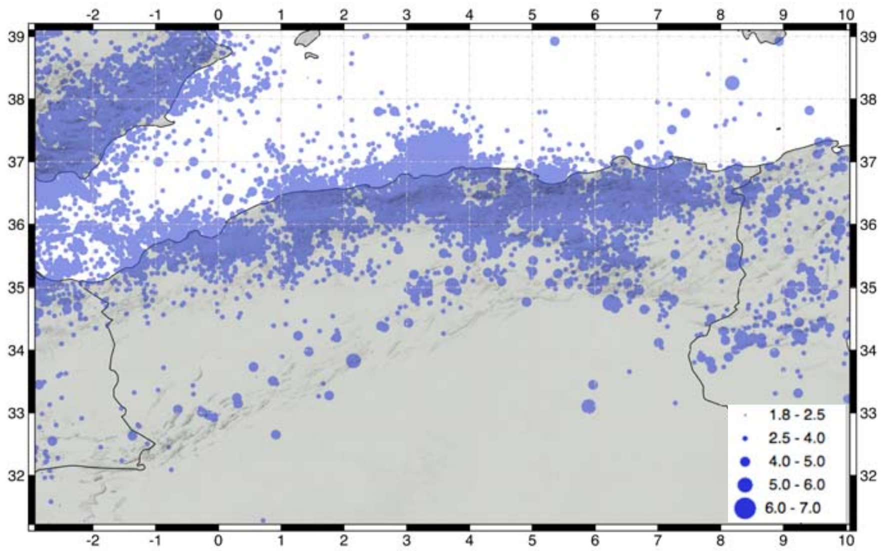


Fig. 2 Homogenized earthquake catalog for North Algeria between 1910-2018. The size of the circle is correlated with M_w

To quantify the effect of station density in the actual M_c, we employ the empirical relation of Mignan et al. [16] to translate the distance to the 4th nearest station to M_c. Most networks require at least four phases to detect an event to avoid false positives. We used only stations that were in operation. We got this information from ISC, together with the location of each station. Sometimes, even though stations are out in the field, technical issues (e.g. battery issues, part failure) prevent them from transferring/collecting data. ISC does not report such short-term changes. The results in terms of M_c are shown in Fig. 3. The spatio-temporal variation of M_c is evident. The coverage is much better in the north close to the urban areas. The southern part is mostly a desert. The installation of the national network improved the coverage significantly.

Even though the empirical relation [16] was calibrated for the instruments, attenuation, magnitude scale and triggering mechanism of the Taiwan network, we still believe our approach has advantages, at least for N. Algeria, where there are few data to properly constrain a G-R slope outside the main cities. Mignan et al. [16] discretized Taiwan in non-overlapping cells of ~5 km and calculated the M_c in each one, as the magnitude bin with the highest (non-cumulative) number of events. Having mapped the M_c, they then correlated the spatial distribution of M_c with the density of the seismic network and derived empirical relations between M_c and the distance to the 4th nearest station.

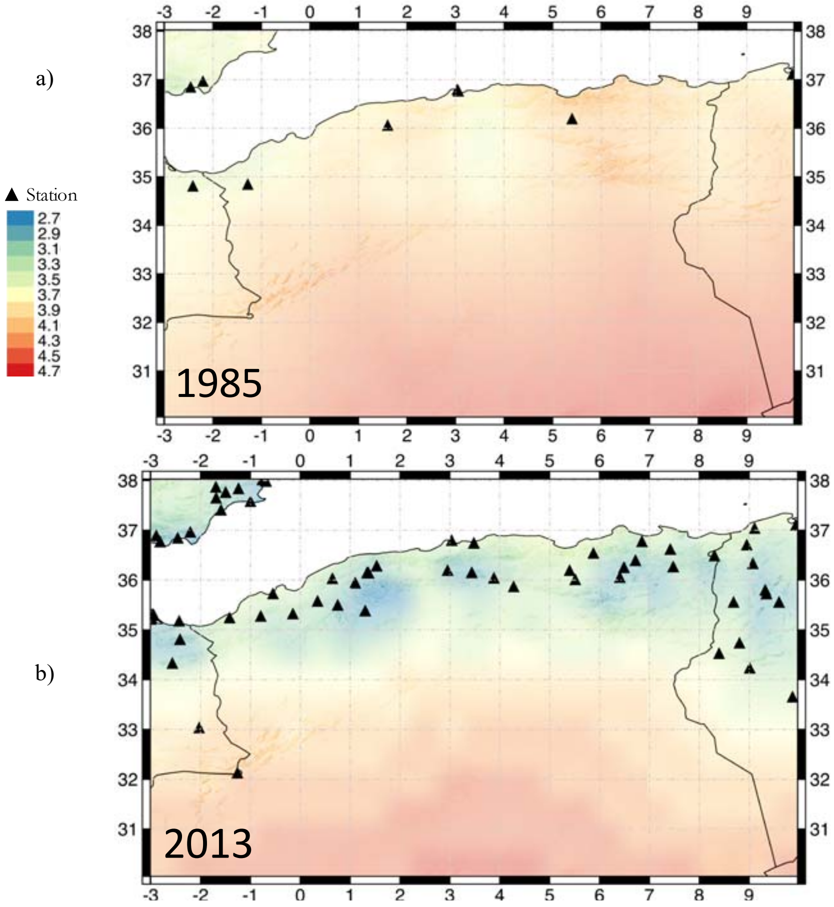


Fig. 3 Spatial distribution of M_c (colorbar) in 1985 (a) and in 2013 (b). The black triangles represent the active stations [9]

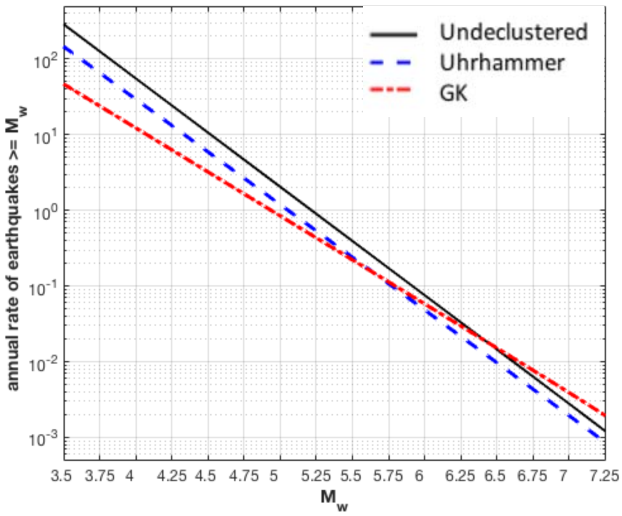


Fig. 4 G-R curve derived from the ISC catalog [7] (1910-2018) within the geographical boundaries -2E to 8.5W and 34.6S to 37.6N

VI. Seismicity Rates

Having a homogenized earthquake and the spatio-temporal variation of M_c, we can now estimate the seismicity rates, i.e. the frequency and size of the observed earthquakes. If we combine these rates of the instrumental era with the historical ones (pre-1900), we could forecast future seismicity.

Using only the post 1910 data that we analyzed, we derived a G-R curve from the catalog. To fit a G-R curve, it is common practice to first remove the fore/aftershocks from the catalog. We did that using two different techniques. Gardner and Knopoff (GK) [8] is the most aggressive one removing 81% of the events, while Urhrhammer [17] removes 53%. The effect that this has on the b-value is shown in Fig. 4. Fore/aftershocks are, by definition of smaller magnitude than the mainshocks, and therefore their removal increases the ratio of large to small events and hence decreases the b-value.

Acknowledgment

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