Assessment of the macroseismic field of strong earthquakes using joint information of EMSC testimonies and shakemaps aiming to updated macroseismic intensity attenuation models for the Aegean area

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ABSTRACT

In this work we present a study of macroseismic data extracted from the EMSC database, to examine their spatial variation for recent large earthquakes (M≥6.0) that occurred in the broader Aegean area since 2010. The main target was to perform a combined interpretation of macroseismic data from EMSC and publicly available shakemaps, to evaluate their usefulness, as well as their compatibility with historical macroseismic data for earthquakes of the study area. For this reason, we selected several recent large earthquakes for which a large number of macroseismic testimonies was available from EMSC database. We also collected the corresponding strong-motion (PGA, PGV, etc.) information from the shakemaps produced by ITSAK. As a first step, we compared the collected EMSC macroseismic data with the predicted macroseismic intensities from the empirical relation of Papazachos and Papaioannou (1997). In general, the correlation between observed and modeled macroseismic data was satisfactory; however, at very high and very low values of observed macroseismic intensities (as reported from EMSC) a systematic bias was noticed. A Monte Carlo simulation approach and other statistical analysis were applied to test the validity and the reliability of the EMSC testimonies, and to identify the source of the observed dispersion and bias between two types of macroseismic data. The results suggest that EMSC macroseismic information shows a large variability (~1.5 intensity units) with respect to the modeled (theoretical) macroseismic intensity information. Moreover, a correlation compatible with previous strong motion-macroseismic intensity relations was observed for the EMSC macroseismic information and ITSAK shakemap information. The previous analysis allowed us to demonstrate that the available EMSC information can be efficiently employed to reconstruct the main features of the damage distribution and earthquake properties for strong shallow mainshocks in the broader Aegean area, though with relatively large uncertainties.

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INTRODUCTION

The collection of earthquake testimonies (i.e., qualitative descriptions of felt shaking) is a basic procedure of macroseismology and allows to depict the damage distribution from an earthquake. The European-Mediterranean Seismological Centre (EMSC) collects responses caused by earthquakes via the LastQuake smartphone app, using thumbnail-based questionnaires (Bossu et al., 2017). A ShakeMap is a representation of ground shaking caused from an earthquake and it produces a range of ground shaking levels at sites throughout the region depending on several factors (epicentral distance, faulting type and directivity, site-effects, etc.). Many useful information from a strong ground motion can be extracted from shakemaps (e.g., PGA, PGV etc.) and contribute to the assessment of the expected damage distribution.

The scope of this work was the processing of macroseismic testimonies and strong motion data, as well as a combined interpretation of these two types of data. For this reason, we have selected thirteen (13) recent significant shallow earthquakes that occurred in the Aegean region since 2010. A Monte Carlo simulation approach was adopted to indirectly assess the reliability of the used EMSC macroseismic data, showing interesting results about damage spatial distribution. Moreover, already published strong motion – macroseismic intensity empirical relations from various researchers were checked for the correlation of macroseismic intensities and peak measures of seismic motions (PGA and PGV) for strong shallow mainshocks in the broader Aegean region.

METHODS AND MATERIALS

1. The study area includes of all types of active faults (normal, strike-slip and thrust faults). We only employed shallow earthquakes (focal depth ≤ 60km). Fig. 1 depicts the focal mechanisms of the used earthquakes.
2. A comparison between observed (by the EMSC) and modeled (synthetic) macroseismic intensities (IMM_{syn}) from the empirical relation of Papazachos and Papaioannou (1997) is shown in Fig. 2. The moving average shows a systematic bias at high and low IMM_{syn} values.
3. The histogram (with a fitted) Gaussian curve of the residuals IMM – IMM_{syn} for IMM_{syn} values between 4.5 - 6.5 (since for this range the correlation is satisfactory in Fig.2), shows a rather large error (~1.5).
4. We assume that most of this error is due to the IMM uncertainties and used a Pseudo Monte Carlo simulation, where synthetic IMM values were generated assuming a varying level of error with respect to IMM_{syn}. Fig. 4 (left) depicts the results of this simulation approach for an assumed error of 1.5 intensity units. The distribution, as well as the observed bias at low and high IMM_{syn} levels is very similar with the real data (Fig. 3).
5. We collected all observed EMSC intensity values within a radius of 10km for each station of shakemaps ITSAK and computed their average [IMM (EMSC Average) (Fig. 4 - right).

RESULTS

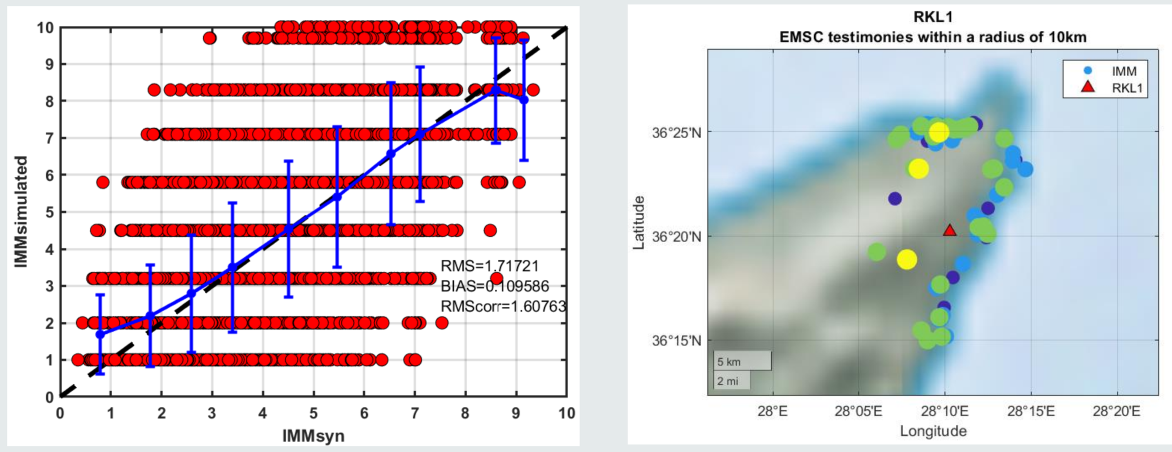

Figure 4. Left: Comparison of the simulated [$IMM_{simulated}$] against modelled macroseismic intensities [IMM_{syn}], for a Monte Carlo simulation with an assumed IMM error of 1.5 intensity units, **Right:** Spatial distribution of EMSC's macroseismic observations within a radius of 10 km from station RKL1 for the recent Kos earthquake (2017/07/20, **M**6.6).

6. We compared these average macroseismic intensities [IMM (EMSC Average)] with the PGA & PGV values from ITSAK shakemaps, as well as against the IMM–PGA/PGV regional empirical relations of Caprio et al. (2015) and Wald et al. (1999) - as modified by Kkallas et al. (2018) (Fig. 5). For all sites, the local site soil class according to NERHP Vs30 categorization is also shown using information provided by Margaris et al. (2021). Both IMM-PGA/PGV relations are in adequate agreement with the moving averages (solid squares) depicted in both figures.

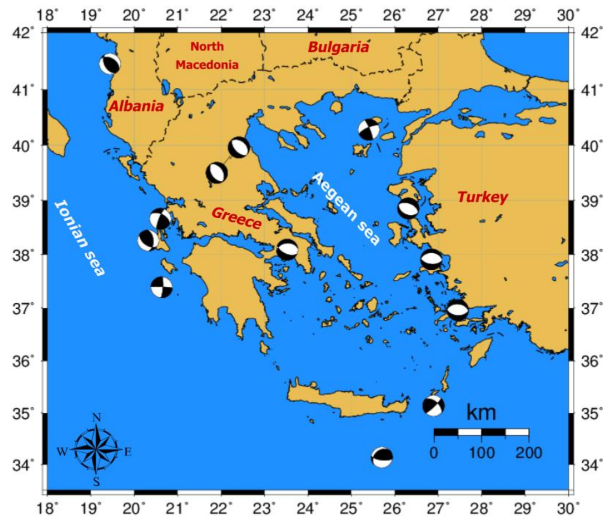

Figure 1. Focal mechanisms of the 13 shallow earthquakes for which data were used in the current study.

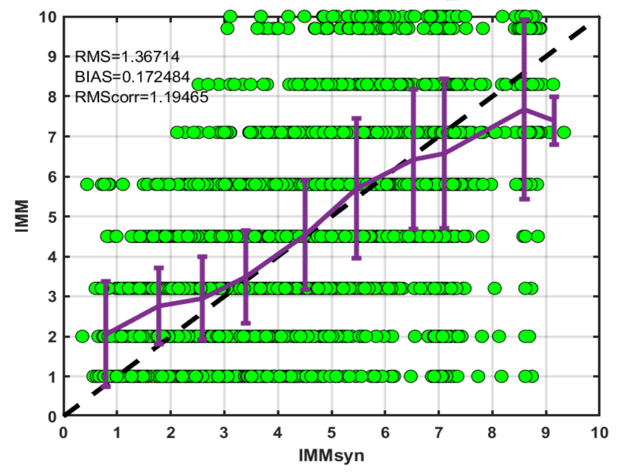

Figure 2. Comparison between observed (EMSC) and modeled macroseismic intensities (IMM_{syn}) using the Papazachos and Papaioannou (1997) empirical relation for all studied earthquakes (green circles). The moving average is depicted with a blue line, showing a bias at low and high IMM_{syn} values

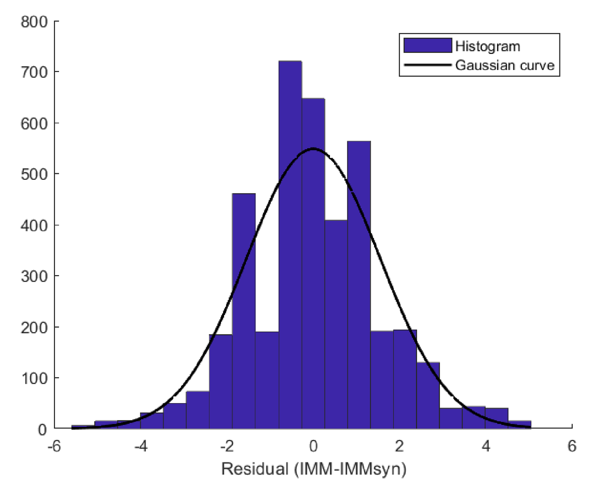

Figure 3. Histogram (with fitted Gaussian) curve of the IMM – IMM_{syn} residuals (between observed and synthetic macroseismic intensities), showing a nearly zero bias and a large standard error (~1.5 intensity units).

DISCUSSION

The main target of the present work was the simultaneous assessment of data provided by two independent automatic damage assessment approaches: the first uses the questionaries produced automatically from the EMSC online database, and the other one uses the shakemaps that are also automatically generated from the ITSAK strong-motion database.

Both types of data employ scientific tools that are operate automatically (after a moderate earthquake) and containing useful information. As shown by the analysis, both EMSC testimonies and PGA & PGV information from shakemaps are well correlated. A smoothing method (e.g. with the use of physical modelling or spatial smoothing) could be applied to reduce the "noise" of the EMSC data (which is shown by the Monte-Carlo simulation to be of the order of ~1.5 intensity units) in order to obtain a better correlation with the PGA & PGV data generated from shakemaps. In summary, this research validates the usefulness of these two different automated types of data, either individually or through their combined interpretation. All the above can be utilized to perform a reliable assessment of the main features of the damage distribution for strong shallow mainshocks in the broader Aegean region.

CONCLUSIONS

The aim of this work was to perform a simultaneous interpretation of two types of data (namely macroseismic and strong motion data) for 13 shallow earthquakes with M≥6.0 [we also included the recent earthquake of Athens, 19/07/2019, **M**5.3], for which both macroseismic data (from EMSC database) and strong motion data (from ITSAK shakemaps network) were available.

The correlation between observed and modeled macroseismic data from Papazachos and Papaioannou empirical relation (1997) was satisfactory, despite the systematic bias introduced at low and high intensities. A Monte Carlo simulation approach demonstrated the error level but also the validity of the EMSC testimonies from thumbnail – based questionnaires. A good correlation between averaged macroseismic intensity values from EMSC with strong ground motion data was observed, in adequate agreement with the Caprio et al. (2015) empirical relation. The obtained results suggest that we can possibly reconstruct the main features of the damage pattern for strong earthquakes in the Aegean area by the joint evaluation of automatically generated EMSC macroseismic data and automatic shakemap information (e.g., from ITSAK).

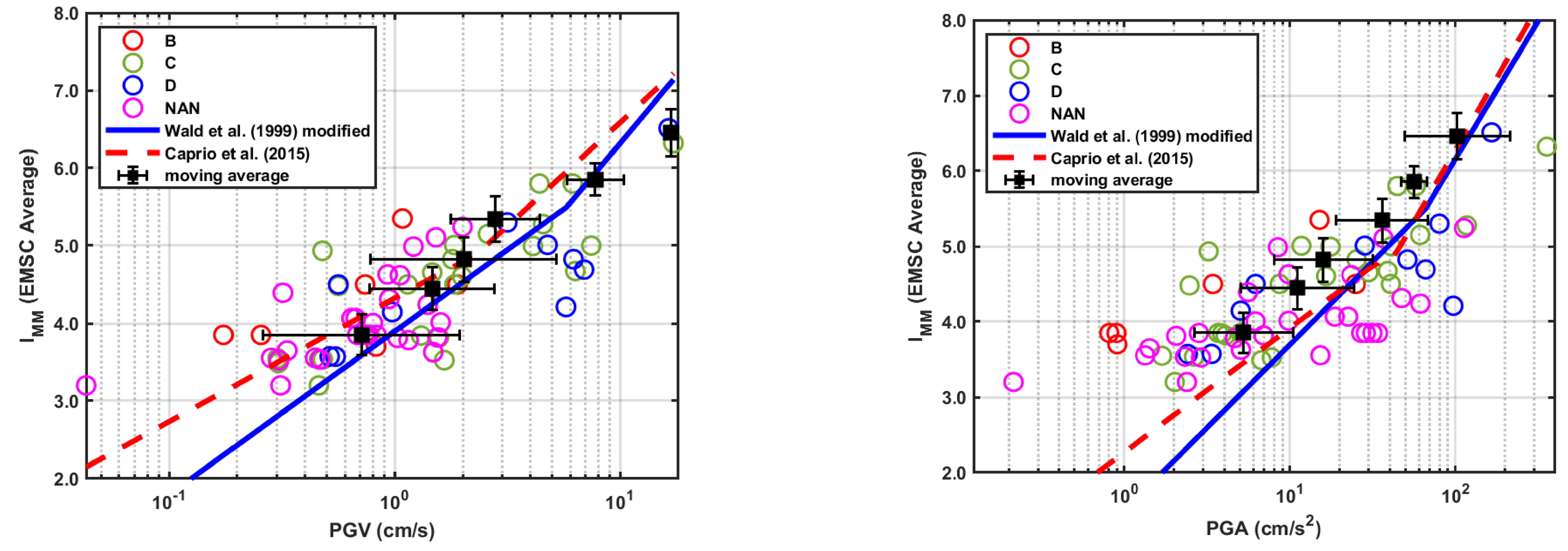

Figure 5. Comparison of the average macroseismic intensity values [IMM (EMSC Average)] with the PGA & PGV information from ITSAK. The IMM – PGA/PGV regional relations for the area of Greece [modified Wald et al. (1999) and Caprio et al. (2015) relations] are also shown. The moving average for different PGA & PGV classes, as well as its standard error (based on the original data variability) are also depicted (red circles for rock – B class, green circles for stiff soil – C class, blue circles for soft soil– D class, and pink circles for sites with no Vs30 information using the NEHRP classification).

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