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Discussions

Interactive comment on "A detailed seismic zonation model for shallow earthquakes in the broader Aegean area" *by* D. A. Vamvakaris et al.

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In the following we provide our reply to the Interactive comment on "A detailed seismic zonation model for shallow earthquakes in the broader Aegean area" by D. A. Vamvakaris et al., sent by Anonymous Referee #1.

We would like to thank the Anonymous Referee #1 for the careful review of the paper and his useful and accurate comments.

Reply to the specific comments (following the order of the comments):

1) In l. 22-23, p. 6730, it is reported "Of course, more recent, instrumentally recorded data are of higher accuracy, hence they participate with a different weighting in the

zonation procedure". This weighting in the zonation procedure is not really a numerical quantity, but it declares a theoretical quality annotation. We considered the instrumental records more accurate than the historical data and based on this concept the zonation has been processed mainly based on instrumental than historical data. Moreover, this zonation procedure is essentially an empirical procedure and not a result of an analysis algorithm where parameters (e.g. weights) could be entered. For this reason this "weighting" is not reported later in the paper as a numerical quantity.

2) In the present manuscript, we initially applied a user "inspection" on the Gutenberg-Richter graphs, as we explain in detail, in order to define the completeness of the catalog for each one of the 113 seismic zones. Following the Anonymous Referees' comment (also a comment of Referee #2, Dr. Slejko), we also applied various numerical methods, readily available in the ZMAP software (Wiemer, 2001), for all zones separately. According to these new calculations, Mc magnitudes were slightly modified for a few zones for the period after 1981. The new Mc magnitudes from this procedure were used in order to re-estimate b-values using exactly the same approach as before, e.g. the use of dM (Mmax-Mmin) cut off was applied in order to exclude the most unstable results. The final more robust results were used for the final b parameter calculations applying a spatial interpolation with an adapted linear variogram and a kriging gridding method. From this spatial interpolation, final values for the seismic parameter, b, were re-calculated for each one of the 113 shallow seismic zones. The geographical distribution of the new b-values using Mc completeness magnitude derived from ZMAP are almost identical to the old estimate using Mc magnitudes from user "inspection" (see attached fig. 1), therefore the results presented in our work were essentially not modified. However, following the reviewer's suggestions we decided to adopt the proposed completeness approach in our manuscript. From this extensive re-analysis, the new results for Mc, a and b parameters were incorporated in Table 1, and new maps for b-values distribution, Mt and Tm were produced. As a result, Table 1 and figures 9, 10, 11, 12, 13 of the manuscript were slightly modified, following the Referees' comment and the method proposed to be applied.

3) Concerning the determination of b parameter, we used the least-squares and the least-absolute values method, mentioning at the same time the possibility to observe instabilities in the final results, especially in the case of insufficient data. For this reason the examination of the employed magnitude range, dM (Mmax-Mmin), was proposed in order to exclude the most unstable results. The derived more robust results were used for the final b parameter, as previously described. The observed spatial variation is in very good agreement with older studies (Hatzidimitriou et al., 1985, 1994, Papazachos, 1999), despite the different methods and data-sets used. This confirms that the least-squares method selected with additional dM constrains, in combination with the spatial interpolation, the compatible linear variogram and the krigging gridding can produce reliable results. Moreover, several authors in the past (Papazachos, 1980; Papadopoulos, 1982; Papadopoulos, 1989 among others) have also employed the least-squares method for the calculation of b-values for the Aegean area. After the Anonymous Referees' comments (also a comment of Referee #2, Dr. Slejko), we additionally applied the Maximum Likelihood Method (Weichert, 1980), in order to calculate independently the b-values for the same datasets. All calculations were repeated as before and the results were compared with the old ones (least-squares method). The comparison of results (fig. 2) shows that b-values derived from the MLM approach show a much wider distribution, not only in the cases with small dM (<1.9), as in cases of large range of dM (theoretically more reliable) b-values still appear to obtain a rather broad value distribution. This graphical comparison suggests that the least-squares method can provide in practice more stable results, with b-values concentrated in a narrower "bandwidth" around the typical value -1.0 when the dM range constrain is also considered, contrary to the MLM results were a much wider spread of values is found. Moreover, the direct comparison of the b-value distribution from the two methods (fig. 3, not included in the revised manuscript) illustrates that the b-MLM and b-LSQ values are really not similar to each other, with large variations that in some cases exceed 50%. In order to evaluate this significant discrepancy, we proceeded to the comparison of the corresponding spatial distributions. The maps presented in fig. 4 suggest that MLM is not able to es-

timate realistic b-values for the study area, in terms of individual calculations over the 113 seismic zones proposed in our model. The geographical distribution of b-values from the MLM shows very poor spatial coherence, extreme local values and is also not in agreement with any of the previously published works (Hatzidimitriou et al., 1985, 1994, Papazachos, 1999). Since both maps were produced with exactly the same techniques and parameters and the only difference is the method of b-values calculation, we adopted the use of the Least-Square method, against the Maximum Likelihood Method and used the corresponding b-values calculations in our manuscript.

- Additional references for this part of our reply:

Papazachos, B.C.; Seismicity rates and long-term earthquake prediction in the Aegean area, Quaterniones Geodaesiae, 3, pp. 171–190, 1980.

Papadopoulos, G.A.; Active Deep Tectonics of the Aegean and Surrounding Area, Ph D. Thesis, Dept. of Geology, Univ. of Thessaloniki , pp. 176, 1982.

Papadopoulos, G.A.; Forecasting large intermediate depth earthquakes in the South Aegean. Physics of the Earth and Planetary Interiors, 57, 192-198, 1989.

Weichert, D.H.; Estimation of the earthquake recurrence parameters for unequal observation periods for different magnitudes: Bulletin of the Seismological Society of America, v. 70, p. 1337-1346, 1980.

Wiemer, S.; A software package to analyse seismicity: ZMAP. Seismol. Res. Lett., 72, 3, 373-382, 2001.

4) Concerning the comment about the size of some seismotectonic zones, the Referee correctly notes that some of them (e.g. S-I2, S-I5 and some others) are perhaps quite small, and it may be more realistic to consider larger zones in order to reduce the uncertainties provided mostly by the historical earthquakes. However, it should be noted that historical earthquakes with their obvious uncertainties were not the only criteria for the zonation. Hence, several important local seismotectonic characteristic such as

stress field, faulting zones or geomorphological settings and their spatial differentiation provided the reason to define smaller seismic zones. For example different faulting settings (e.g. for zones S-C2, S-C3, S-I3, S-I7, N-E16,), stress field variation (e.g. for zones N-L4, N-L5), or local seismicity based on a characteristic major faulting zone (e.g. for zones S-I5, S-E6) has led us to the definition of smaller seismic zones, clearly separated by their neighboring ones. In some other cases, local seismicity and special seismotectonic characteristics (e.g. for zones N-K11, N-J13) has also led to the definition of relatively small seismic zones, that could not be unified with other zones in their immediate vicinity.

5) Anonymous Referee proposes a number of papers to be added. The proposed papers no. 1 (Kondopoulou et al., 1985) and no. 2 (Papadopoulos et al., 1986) contain many fault plane solutions published originally in other sources (e.g. Ritsema, 1974; McKenzie 1972, 1978; Kocaefe and Ataman, 1982; Drakopoulos and Delibasis 1982; Papazachos, 1984; Papadopoulos, 1982). The majority of those fault plane solutions are already used in our work as a part of the dataset of 767 fault plane solutions used from numerous different sources. The original primary source of each data is of course also cited in the paper, as well. Therefore, the proposed papers no. 1 and 2 for fault plane solution information are actually related with the subject of this part of our work, but not with the data contribution. Proposed paper no. 3 (Papadopoulos and Kijko, 1991) is clearly related with our work, as Mmax, a and b parameters (among others) were calculated for the broader area of Aegean Sea, using an alternative method and is now properly cited in the revised manuscript. Paper no. 4 proposed by the Referee (Tsapanos et al., 2003) is not directly related with our work, as it does not calculate either a and b parameters, or Mc and maximum magnitudes for different seismotectonic zones (as the Referee suggests). This paper essentially refers to a seismic hazard assessment in terms of probabilities based on a Bayesian statistics approach, hence we decided to cite it in our revised manuscript as such a reference. For paper no. 5, the Seahellarc working group(2010) proposed a new seismotectonic zonation in a region which is common with a small part of our work. We think that the proposed

Seahellarc zonation does not fit the historical seismicity distribution but it is mostly related with the identified (within Seahellarc) fault zones. Nevertheless, it has been added as a reference in the revised manuscript, concerning a new proposal for local seismic zonation.

Reply to the technical comments:

We adopted the technical correction marked by the Referee, in L. 25, p. 6738, where the correct year should be 1950.

Interactive comment on Nat. Hazards Earth Syst. Sci. Discuss., 1, 6719, 2013.

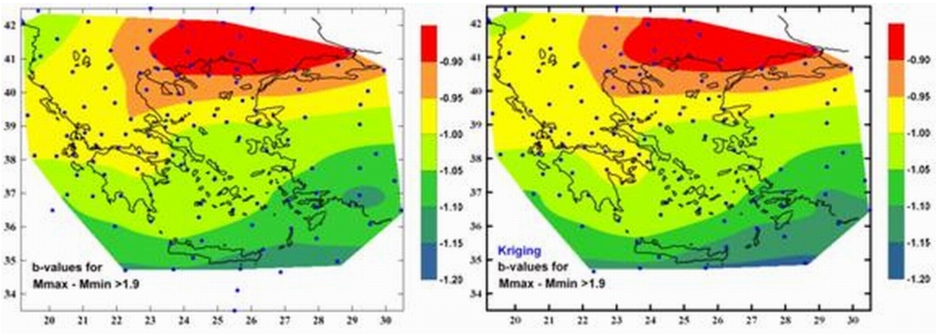

Fig. 1. Comparison of b-values using ZMAP for new Mc calculation (top) and original completeness estimates from G-R graph user inspection (bottom). Results from the first method were finally adopted in the ma

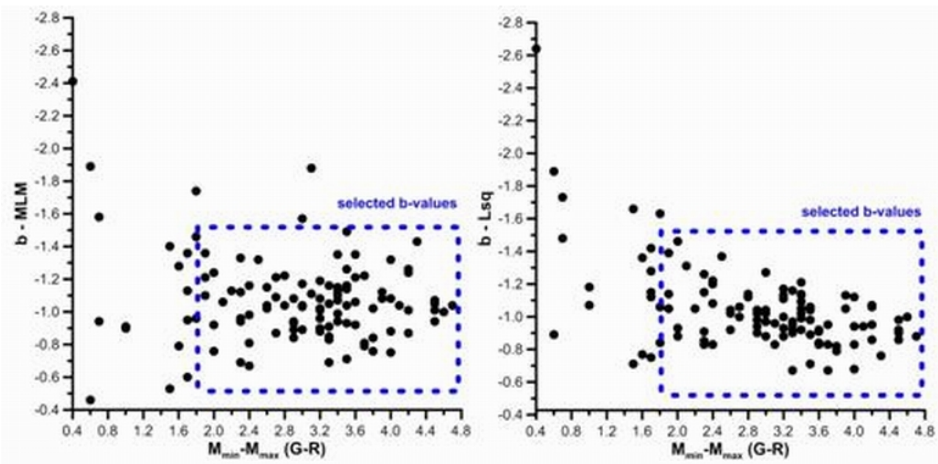

Fig. 2. Comparison of b-values using the Maximum Likelihood Method (left) and the Least-Square Method (right), for the 113 zones. The figure on the right was also included in our revised manuscript.

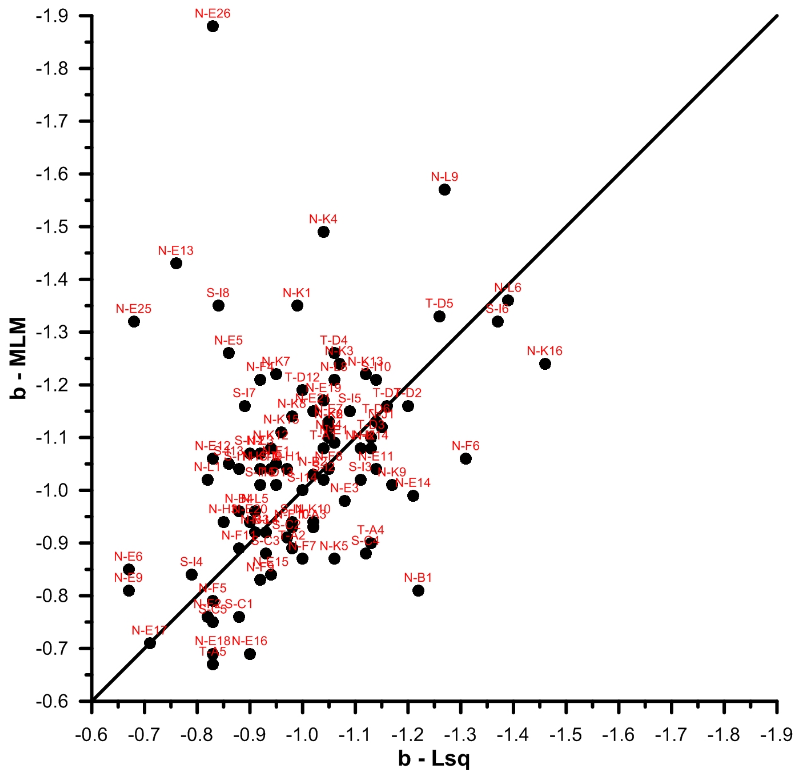

Fig. 3. Variation of b-values derived from the Maximum Likelihood Method versus the b-values from the Least-Square method, for each one of the 113 seismic zones with dM>1.9.

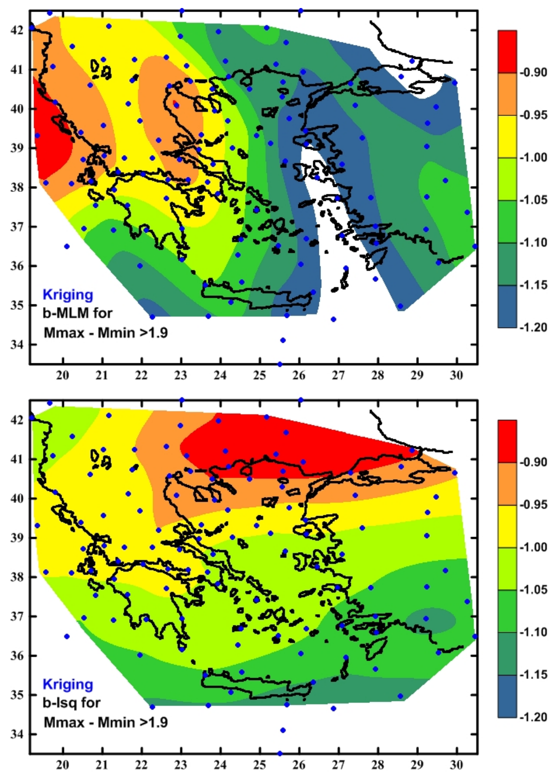

Fig. 4. Geographical distribution of b-values calculated with the two different methods, Maximum Likelihood Method (top) and Least-Square method (bottom). The bottom figure was the one finally adopted in the