Comment on "High-Definition Mapping of the Gutenberg–Richter b-Value and Its Relevance: A Case Study in Italy" by M. Taroni, J. Zhuang and W. Marzocchi

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Abstract

Taroni et al. (2021) published a statistical framework to reliably estimate the b-value and its uncertainties, with the goal being the interpretation in a seismotectonic context and

improving earthquake forecasting capabilities. In this comment, we show that the results presented for the Italian region, and the conclusions drawn by the authors, are heavily biased due to quarry blast events in the Italian earthquake catalogue used in the analysis. Without removing this anthropogenic component in the data, a meaningful analysis of the earthquake-size distribution for natural seismicity is, in our opinion, not possible. This comment highlights the need for basic data quality analysis before sophisticated statistical tools are applied to a dataset.

Introduction

Taroni et al. (2021) apply and extend the mapping approach introduced by Tormann et. al. (2014) to analyze the spatial variability of the relative earthquake-size distribution, (the b-value) in Italy. The authors argue that the observed spatial variability has important implications for improving earthquake forecasting capabilities and present also seismotectonic interpretations for the anomalies.

In our own research of the past 20 years, we likewise have often highlighted the surprising spatial variability of b-values, their link to seismotectonics and stress regimes and their use in earthquake forecasting (e.g., Wiemer and Wyss, 1997; Schorlemmer et al., 2005; Gulia and Wiemer, 2010; Tormann et al., 2015; Petrucelli et al., 2019 a,b; Gulia and Wiemer, 2019). Many other groups have also investigated spatial variations in b-value at all scales (e.g., Enescu and Ito, 2002; Katsumata, 2006; Farrel et al., 2009; Goebel et al., 2013; Schurr et al., 2014; Wu et al., 2018). The analysis presented by Taroni et al.

(2021) is in our opinion an important extension of existing mapping techniques; however, we will demonstrate in this comment that sophisticated statistical methods cannot overcome basic limitations and biases posed by the input data. As we show below, the spatial maps of b-values shown in Taroni et al (2021) in their figure 2 do not represent natural earthquakes but map the well-known unusual high b-values of quarry blasts. They hence represent anthropogenic events and cannot be used to infer knowledge on natural seismicity.

The influence of quarry blasts on b-values

Quarry blasts are in terms of their seismic signals often not easy to distinguish from natural events and increasingly sophisticated processing techniques have been proposed to discriminate them based on waveform analysis (e.g., Allmann et al., 2008; Hammer et al., 2013; Dong et al., 2016; Tan et al., 2020). Quarry blasts also cover a similar magnitude range to micro-earthquakes (Kintner et al., 2021; Gulia, 2010). All seismic networks will strive to identify and flag blast events in their seismicity catalogs, but it is common in all seismic networks that a certain - and sometimes very large fraction - of events is not identified correctly, a fraction that varies by network, with time and with location. It also can happen that the flags are either lost or ignored during catalog analysis steps.

Wiemer and Baer (2000) introduced a simple statistical test based on the day-to night-time ratio (from now on D/N) to map and potentially remove quarry blast events from earthquake catalogs. For natural earthquakes, the D/N value is typically slightly below 1, due to the lower magnitude detection threshold in night-time that is resulting from the

reduced level of anthropic seismic noise (e.g., Hermann et al., 2019). In the presence of anthropogenic events, such as quarry blasts, the D/N ratio increases above 1. In regions of moderate to low natural seismicity, D/N sometimes reaches values >50 (Gulia, 2010), because mine blasts are almost exclusively performed during daytime. A value of 1.5 is already indicative of significant quarry blast contamination (Wiemer and Baer, 2000). Blasts often occur at typical hours in a region, coupled to the work schedule of a quarry, for example 10 am and 4 pm, another characteristic signal for blast contamination. The D/N test has been commonly used in statistical seismology since it was introduced in 2000 by Wiemer and Baer (e.g., Godey et al., 2013; Kekovalı and Kalafat, 2014; Gonzales, 2017; Giardini et al., 2004; Gulia and Wiemer, 2010; Gulia et al., 2010, 2016, 2018, 2019). Because quarry blasts are not natural earthquakes, they have obviously the potential to bias research on seismicity analysis, such as studies on seismicity rate changes, b-values, fractal dimensions, seismotectonics and earthquake forecasting. Wiemer et al. (2009) pointed out that they also have the potential to impact seismic hazard assessments. Gulia et al. (2012) provided a tutorial on catalog artifacts and quality control as part of the Community Online Resource for Statistical Seismicity Analysis (www.corssa.org), covering quarry explosions a primary example.

Quarry blasts magnitudes are usually not power law distributed but have similar, 'characteristic' sizes, a normal distribution is a better approximation. Consequently, quarry blasts when mixed with a fraction of natural events will exhibit a highly unusual b-value, typically very high ($b > 1.5$), a fact pointed out already by Wiemer and Baer (2000), Wiemer et al. (2009) and Gulia (2010). In a review paper on b-value mapping, Wiemer and Wyss (2000) suggested that contamination by explosion need to be considered and rules out as potential biases.

The contamination by quarry blasts in the Italian catalogs provided by INGV (as well as other European catalogs) has been investigated by Gulia (2010) and was considered in the CSEP experiment for Italy (Schorlemmer et al, 2010). The maximum magnitude of European quarry blasts is around 2.5 (see Gulia, 2010, and references therein), a value well above the magnitude of completeness adopted by Taroni et al. (2021) for the time interval from 2005 to present (Table 1 in their paper), contamination is thus a possibility to be considered.

Quarry blast influence on the Taroni et al. (2021)

In their Figure 2, Taroni et al. (2021) show a b-value map for the Italian territory, a second map containing the standard deviation and a third map which combines both b-value and its standard deviation to show only the zones with a b-value significantly different from 1.04, the value of the overall catalog. The authors find significantly higher b-values (up to b = 1.4) and low standard deviation in three regions: central Apennines, the western part of Tuscany and the northern part of Apulia (yellow areas in their Figure 2c, the map combining b-value with standard deviation) and explain these anomalous high values by referring to the prevalent normal faulting (as suggested by Gulia and Wiemer, 2010) or to the higher heat flux (in particular for Tuscany, Della Vedova et al., 2001).

To compute these maps, the authors use the HOmogeneous catalog of Italian instRrUmental Seismicity, HORUS (Lolli et al., 2020; available at https://horus.bo.ingv.it). It is a composite catalog obtained by merging data from different online resources

126 available for the Italian area; in particular, from 16 April 2005, an automatic procedure
127 periodically downloads the data of the on-line bulletin of the Istituto Nazionale di
128 Geofisica e Vulcanologia (INGV). The events are then automatically homogenized in terms
129 of moment magnitude, while all the other parameters, like location and time, remain
130 unchanged: the potential biases affecting the original data remain in the homogenized
131 catalog.
132
133 We analyzed the effect of blasts on the b-value analysis by Taroni et al. (2021) and show
134 in our Figure 1 the histogram of the daily distribution of events for the highest b-value
135 areas (marked 2, 3, 4). The histograms and the corresponding D/N are computed for
136 circular volumes of 20-km radius (centered in 43.35-13.2, 43.35-13.1 , 40.7-16.7), and
137 shown for two different time periods:
138
139 • the entire HORUS catalog (1960-Sept2020) with magnitudes above the value
140 provided in Taroni et al (2021), in order to refer to the same dataset.
141 • the time period 16 April 2005 to the end of the catalog, cut at Mc 1.8: this is the
142 part of the catalog with the lowest Mc, thus the more affected by quarry blasts and
143 the richest of small-magnitude events.
144
145 All the three sampled regions exhibit a typical quarry event dominated pattern and a high
146 D/N, ranging from 1.7 to 26, which indicative of very high quarry blast contamination.
147 The dominance of quarry blasts is evident in both periods analyzed. Note that all events
148 used in our analysis and shown in the histograms are above the Mc assumed by Taroni et
149 al. (2021) and thus used in their b-value calculation. Our analysis shown in Figure 1

150 strongly suggests that the observed high b-value anomalies are resulting from
151 anthropogenic events rather than natural earthquakes.
152
153 Taroni et al. (2021) also found high b-values in the western part of Tuscany (labeled 1 in
154 Figure 1). We could not perform a D/N analysis in this volume, because there are actually
155 no events in the catalog here (see Figure 1, inset). We speculate that the analysis by
156 Taroni et al. (2021) samples the fringes of the seismicity in the region. Because small
157 events are often having larger uncertainties in epicenter locations, it is possible that these
158 are scattered beyond the actual extent of the seismicity and fringes will have a size
159 distribution biased towards higher ratios of small earthquakes (Jolly et al., 2007). Such
160 edge-effects are a well-known artifact, the grid sampled thus should be focused closely
161 on active regions (Wiemer and Wyss, 2000), or exclude areas which a large 'gap'. The
162 edge effect is especially clear in the maps shown in the Supplemental Material (Taroni et
163 al., 2021, Figure S1), where a smaller radius (20 km instead of 30) is adopted.
164
165 To further strengthen the argument that the high b-value shown by Taroni et al. (2021)
166 are artifacts, we refer to an independently conducted and recently published study of
167 quarry blast contamination in the Italian earthquake catalog and their impact on b-values
168 by Gulia and Gasperini (2021, in press). Gulia and Gasperini (2021) repeated the same
169 D/N mapping analysis for Italy performed originally by Gulia (2010), showing an overall
170 better performance of quarry-blast discrimination by the Italian network operators.
171 Gulia and Gasperini (2021) then extended the 2010 analysis by also investigating the
172 impact of the quarry blasts, misclassified as natural events, on the b-values in Italy. Areas
173 2, 3, and 4 in our Figure 1 correspond to the areas labeled as F, G and I in Gulia and
174 Gasperini (2021), where the D/N reaches 82 and at the same location very high b-values

(b>1.5) are observed. Note that Gulia and Gasperini (2021) performed their analysis on the Italian Seismological Instrumental and Parametric Database, ISIDe (ISIDe Working Group, 2007): it is the source catalog of HORUS for the investigated time interval, so in terms of location, date and time the two datasets are equivalent.

Conclusion

Taroni et al. (2021) presented a b-value map for Italy refining the approach by Tormann et al. (2014). However, the application of the methods to map b-values in Italy is in our opinion strongly dominated by quarry blasts and the interpretation presented by the authors that relate high b-values with high heat flux, as well as the implication for the use in earthquake forecasting, are flawed. Quarry blast contamination is a well-known and well-understood phenomenon from more than 20 years (Wiemer and Baer, 2000) that must be considered in all seismicity analyses using events below magnitude 3. Its impact has been documented several times specifically for Italy (Gulia, 2010; Gulia et al., 2012) and it is unfortunate that Taroni et al. (2021) did not consider the available literature or conduct an analysis of the day-to-night-time ratio as a simple quality check. We suspect that other seismicity studies also are biased by quarry explosions, and we welcome efforts by seismic networks to flag these events.

Because the ability of seismic networks to locate smaller events today is steadily improving, the challenge posed by unrecognized quarry blast contamination may actually increase in some regions. We therefore would like to urge all groups interested in statistical, seismotectonics and seismic hazard related studies to carefully consider anthropogenic events as a potential bias before moving on to ever more sophisticate

200 statistical analysis. We also urge reviewers to request checks of quarry blast
201 contamination for relevant manuscripts. This comment highlights the need for basic data
202 quality analysis before sophisticated statistical tools are applied to a dataset, otherwise
203 the garbage in, garbage out (GIGO) principle applies, meaning that flawed, or nonsense
204 (garbage) input data produces nonsense output.
205
206 ***Response to the reply to our comment*:**
207 In their response Taroni et al. compute night-time b-value maps, and we agree that these
208 are a useful additional quality check, in addition to maps of the day to nigh-time ratio.
209 These maps confirm our assessment that in selected areas, the b-values are
210 overestimated due to quarry blasts.
211
212 In Taroni et al. (2021), the authors perform 3 different maps (Figure 2 a-c in their paper):
213 the b-value map, the standard deviation map and a third map showing only *the b-values*
214 *in the spatial cells in which the b-value computed for the whole catalog falls outside the 95%*
215 *CI of the b-value computed for the spatial cell.* The authors themselves argue that "…*the*
216 *most important one is the third one*". We would thus have expected in the response to our
217 comment to see the filtered maps, but this was not the case as they only provided (in their
218 Fig. 1) the first kind of maps. As we agree with Taroni et al. (2021) that the most
219 important maps are the filtered ones, we recomputed these maps for the total and night-
220 time catalogs by using the code and data released by the authors with the original paper
221 and provided them here in Figure 2a-f.
222
223 While we agree with Taroni et al. (2021) that in many areas the differences are small,
224 there are in our opinion selected and important places that are very different. In the

night-time b-value map with the cells outside the 95% CI (Figure 2f), the quarry blast contaminated area labelled in our comment as 4 disappears entirely and area 3 is substantially reduced, confirming that these high b-value anomalies are pure artifacts. The spatial extent of the area 1 is substantially reduced. Another difference between maps 2c and 2f is the coastal area located just on north of area 1, corresponding in part to the mining district of Apuane, Northern Tuscany: This area disappears in the night-time maps, suggesting that these b-value were computed mainly based on explosion (day-time) events.

We also note that the maps shown in Figure 2 are computed using large radii (30km) and for long time series (60 years, with decreasing magnitudes of completeness): the effect of blast contamination, often local in space and limited in time, is thus smoothed; for smaller radii (e.g., 20 km, Appendix to Taroni et al, 2021) we would expect to see an even larger difference in b-values between overall and night-time only maps. For area 2 for example, Gulia and Gasperini (2021) show that the b-value changes from 1.4 in the period April 2005-April 2012 to 1.2 for the period May 2012-October 2020, due to the better identification of blasts in the last 8 years of the dataset.

In conclusion, the night-time b-value mapping, especially when focussing on the cells outside the 95% CI, confirms in our opinion that a bias in the analysis by Taroni et al. (2021) was introduced in selected places by quarry blasts. The seismotectonic interpretation and implications for hazard assessment presented in Taroni et al. (2021) must therefore be read with caution for these places.

Declaration of Competing Interests

The authors declare no competing interests

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Data and Resources

The HOmogeneous catalog of Italian instRrUmental Seismicity, HORUS (Lolli et al., 2020) is available at https://horus.bo.ingv.it.

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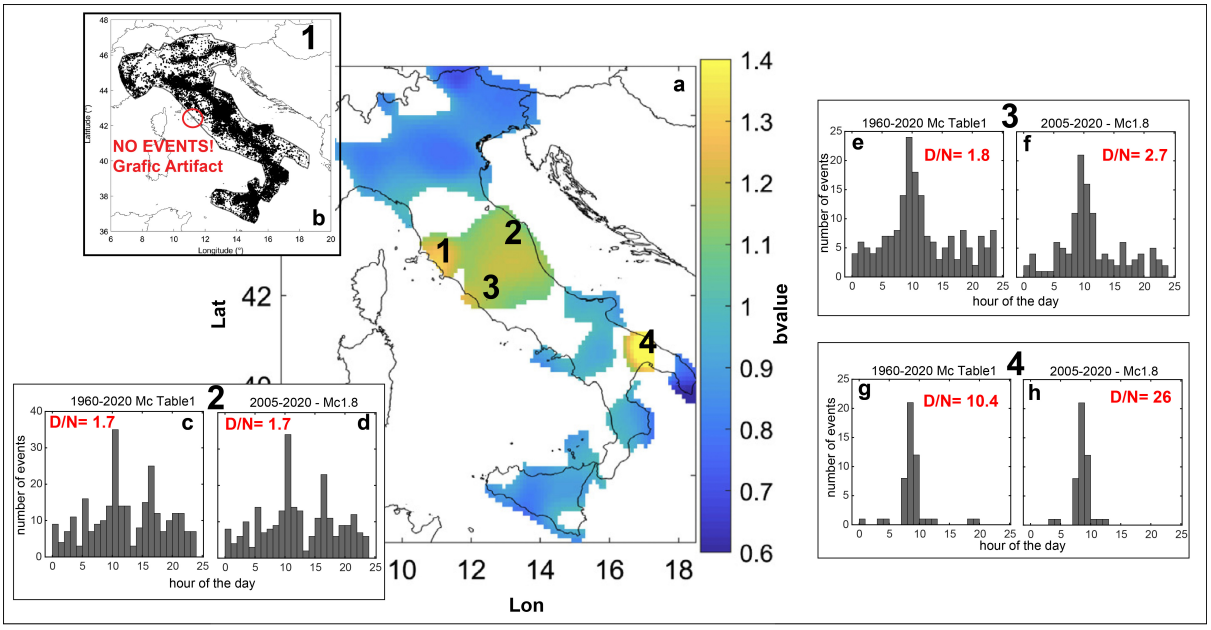
Figure caption

Figure 1 - *a) b-value map, modified from Taroni et al. (2021) with, superimposed, the map of the epicenters of events adopted in their paper (b) and, for the sample areas of 20-km radius, in the regions labeled from 2 to 4, the histograms of the hour of events for the whole catalog (c, e and g) and for the time interval 16 April 2005 to the end of the catalog (d, f and h).*

Figure 2 - *a) b-Value map for the whole catalog; (b) standard deviation map for the b-values in figure 2a; (c) map for the b-values that are significantly different from the one of the whole catalog; d) b-Value map for the night-time events; e) standard deviation map for the b-values in figure 2d; f) map for the night-time b-values that are significantly different from the one of the whole catalog.*

Figure



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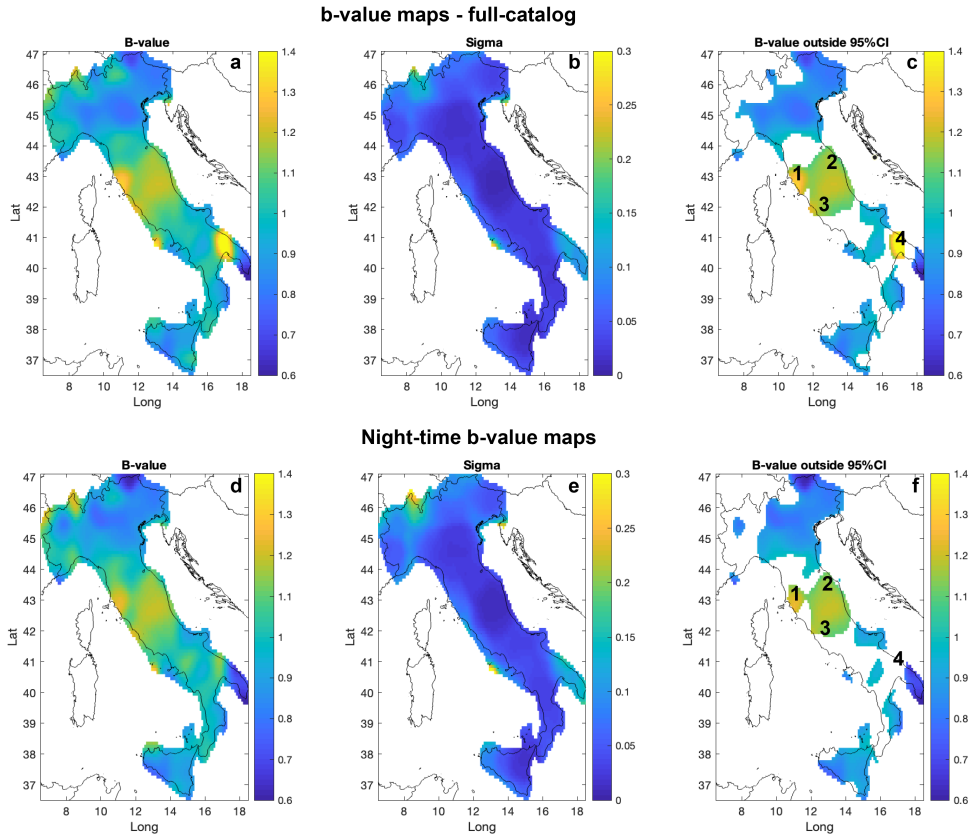

462

463 ***Figure 2 -*** *a) b-Value map for the whole catalog; (b) standard deviation map for the b-values in*

464 *figure 2a; (c) map for the b-values that are significantly different from the one of the whole catalog;*

465 *d) b-Value map for the night-time events; e) standard deviation map for the b-values in figure 2d; f)*

466 *map for the night-time b-values that are significantly different from the one of the whole catalog.*

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