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Comment on " Inferring the depth of preinstrumental earthquakes from macroseismic intensity data: a case-history from Northern Italy". Natureresearch, Scientific Reports, 1-13 (2019).
Sbarra, P., Burrato, P., Tosi, P., Vannoli, P., De Rubeis, V. & Valensise

by

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INTRODUCTION

We have read with interest the article in question[1], because it proposes a technique for inferring the depth of pre-instrumental earthquakes. Our interest was increased by two circumstances: i) the authors announce that they have even developed the Rosetta Stone to obtain the hypocentral depth of earthquakes from their macroseismic intensities and then to re-determine their magnitudes; ii) we hoped that these results could be useful to improve the KF-NGA source inversion procedure[2]-[7]. In fact, unfortunately, the main weakness of KF-NGA is the determination of the hypocentral depth (mostly because KF-NGA does not include a propagation model of the Crust).

TRADITIONAL AND HSIT MACROSEISMIC INTENSITIES

The paper by Sbarra et al.[1] is based on the equivalence between macroseismic intensities obtained from field surveys or from internet (both HSIT and DYFI). This is a long debated matter, perhaps partly conditioned also by the low economic costs of the information collected online from volunteers. To support this equivalence, the authors[1] mention the work of Mak et al. of 2015[8] and then also Sbarra et al.[9] and Tosi et al.[10].
Without going deeper into the matter, our humble opinion would be the following:
i) it seems to us that the goal of the first work[8] is not the direct comparison between the various types of intensity; among other things, it has suffered severe criticism regarding the statistical techniques adopted[11];
ii) the use of HSITs for earthquakes in the Mw 4.0–5.8 range certainly introduces further (albeit small?) uncertainties in a matter where uncertainty is already relevant; the same Sbarra et al.[9] show acceptable results only for a shock with Ml = 5.1 (December 23, 2008) and in conclusion they write: "Our method gives acceptable results for a very low cost" (page 578);
iii) as can be seen from Figure 2 in Tosi et al.[10], the HSIT intensities systematically underestimate the traditional MCS intensities by approx. half a degree (let us quote Tosi et al. [10]; page 990: "The comparison of results estimated with the automatic method with the ones traditionally assigned through onsite survey showed a general agreement in the variability range of ± 1 intensity (Fig. 2), with a tendency of our estimates to be lower than the traditional values");
iv) it seems difficult to apply the proposed procedure[1] to destructive earthquakes, for which the claimed "substantial equivalence" is not yet demonstrated (also because in the most destroyed areas the volunteers - for obvious reasons - are unfortunately less responsive);
v) however, as we have seen, the field survey of the damaged areas is necessary for destructive earthquakes.

ATTENUATION SLOPE FULLY INDEPENDENT OF MAGNITUDE

The central point of the article is this: The authors affirm: "The method we proposed rests on three fundamental pillars: (a) it relies only on the slope of the attenuation curve, not on the absolute intensity levels attained by any given earthquake: as such, it is fully independent of its magnitude [...]"[1] (page 4). In our humble opinion, this point has not been proven (also see paragraph "Attenuation Slopes" that follows).

VARIABLE ATTENUATION IN DIFFERENT GEODYNAMIC FRAMEWORKS
Later, the authors add that "different geodynamic framework may be characterized by highly variable attenuation properties, ultimately resulting in rather different attenuation curves". In this case, we agree with them. So, we think we can say that eqs. (1)[1] and (2)[1] boil down to a local conversion algorythm for the Tuscan-Emilian Apennines and for earthquakes of magnitude included in the Mw 4.0–5.8 range.

ATTENUATION SLOPES
We obviously agree that - by keeping the geodynamic framework fixed, and assuming that attenuation is isotropic and independent of magnitude - for purely geometric reasons the distance between the decreasing isoseismals would depend solely on the depth of the hypocenter (point source). Unfortunately, the practical experience suggests that the situation is more complex than these authors[1] describe it; it suggests that the distances between the isoseismals generally grow with the increasing magnitudes, but other source characteristics and the geological contest seem to be also important.
At this point, it may be useful to bring some examples that we believe falsify the authors' assumption of "the slope of the attenuation curve [...] fully independent of its magnitude" (page 4[1]). To do this, we are forced to refer to at least two types of isoseismals: i) traditional, traced according to different conventions and algorithms, which do not honor the point intensities because they introduce various types of filtering (almost never explained); ii) Natural-neighbor isoseismals, that strictly honor the point intensities and are traced with the N-n algorithm[13].
As for traditional isoseismals, we can for example consult those of the Greek earthquakes up to 1995[17]. The following examples all have focal depths of about 10-14 km, one excepted. For example, the distance between the isoseismals of degree VIII and VI ($D_{[VIII-VI]}$) of the Cephalonia earthquake (1953; M 7,2[17]) is about 70 km and seems conditioned by the high magnitude; the same applies to the earthquake of the Marmara Sea (1964; M 6,9[17]) with $D_{[VIII-VI]}$ = 80 km (the event of 1964 seems to have a slightly higher focal depth, however: 27 km). The Kalamata earthquake (1986), with a lower magnitude than the previous ones (M 6.0[17]), has $D_{[VIII-VI]}$ = 22 km, and the Kozani earthquake (1995; M 6.6[17]) has $D_{[VIII-VI]}$ = 35 km. On the other hand, the 1963 Skopje earthquake with M 6,1[17] (6 km focal depth) has a high $D_{[VIII-VI]}$ distance (about 60 km), while the Stivos earthquake (1978; M 6,5[17]) has $D_{[VIII-VI]}$ = 25 km. In short, the situation appears rather complicated, probably also dependent on rupture mechanisms and local geology.
Then, regarding the Natural-neighbor isoseismals, we mention the earthquakes of Loma Prieta (1989; M_S 7.1; Figure 6A[14]), Irpinia (1980; M_S 6.9; Figure 4a[15]), Northridge (1994; Mw 6.7; Figure 7A[14]) and L'Aquila (2009; Mw 6.3; Figure 2[16]). These events have similar depths, but $D_{[VIII-VI]}$ is at least 60-70km in the first two cases, about 25-35 km in the third and about 20 in the fourth.
Coming back to the learning set of the paper that we are commenting here[1], our opinion is that it has three flaws, which prevent to draw general conclusions (the claimed "Rosetta Stone"): 1) the learning set has a range of magnitude (Mw 4.0–5.8) too small; 2) some events have intensity decrease with distance that is far from a regular isotropic attenuation; rather, they exhibit a wavy trend also for epicentral distances <50 km (see Figures 2[1] and 3[1]); 3) in

several cases, in Figure 3[1] the intensity decreases do not follow the assumption of the authors.
Furthermore, as the magnitudes increase, obviously the size of the sources increase. Therefore, when the 50 km epicentral distance is chosen as a reference, it soon ends up being of the same length of the source.
Let's now examine the slopes of the attenuations in Figures 2[1] and 3[1] in more detail. Three more things come to mind:
1) as a first approximation, the attenuations have - as expected - a bilinear aspect; but the corner points are not always close to 50 km; instead, they often are between 30 and 50 km approximately. Over 30-50 km, in Figures 2[1] and 3[1] the attenuations often assume oscillating tendencies. This could be a partly spurious effect, due to the moving average technique with 5 km of overlap adopted by the authors[1]. This wavy pattern could come out when the search interval intercepts points of anomalous intensities (too high or too low compared to their epicentral distances). This means that the choice[1], to always calculate the attenuation within 50 km from the epicenter, could introduce random elements, consisting of the intensity points in the approximate 30-50 km distance range. We can observe this phenomenon in the red points and curve (# 12) of Figure 2[1]. The points at distances <30 km suggest a fast attenuation. Beyond 30 km the points begin their undulating course, so that between 30 and 60 km they tend to go up again. The slope = 0.003 is obtained only because the authors include 4 or perhaps 5 anomalous points in their regression. The value of 0.003 meets the expectations of the authors, but is clearly unreliable.
Points and attenuations of the 20 earthquakes used in Figure 3[1] are not visible with the same clarity as in Figure 2[1] and yet it seems that this problem of attenuations obtained using spurious points can also affect the points relevant to earthquakes # 18, # 20, # 8, # 19, # 6.
The authors explain that 3 out of the 20 events selected for their Table 3 do not meet the MDP>100 criterion. An event even has MDP = 18, which is really a very low number in terms of macroseismic information.
We now come to Figure 4[1]. The authors mention the slopes obtained by Gasperini[12] (values between 0.05 and 0.062). Can we ask whether and how these values are compatible with the others shown in the figure? Still on Figure 4[12]: there are only 4 earthquakes beyond 35 km and the slopes of #6, #12, and #19 seem not well determined (the points of #9 are not well visible in Figure 3[1]). It seems to us that, in these conditions, the regression shown in the figure is not sufficiently constrained.

RELIABILITY OF MAGNITUDES OBTAINED FROM INSTRUMENTAL MEASURES OR FROM MACROSISMIC INFORMATION

In our humble opinion, when trying to extract information on seismic sources using macroseismic data, the hypocentral and magnitude determinations obtained from good instrumental seismology must always be taken as reference values, if available. This is especially true when dealing with earthquakes that occurred in recent times. We therefore do not understand the attitude of the authors[1] when they celebrate as "quite striking" the magnitudes they recalculate from macroseismic data ("Some of the results we obtained are quite striking"; page 8); it appears that they claim this success when the M values they obtain are more than eight tenths of a degree different from the instrumental magnitudes (#18 and #20 in Table2[1]; #29, #31 and #35 in Table 3[1]).
Still in our opinion, rather these discordances should suggest that the technique[1] does not work.

APPLICABILITY TO DESTRUCTIVE EARTHQUAKES

Finally, it seems unlikely that the proposed technique could also be extended to earthquakes with M >> 5.8. In fact, as already touched, the sizes of the sources obviously increase with magnitudes, and therefore the reference epicentral distance of 50 km[1] soon ends up being of the same order of the fault size. Not to mention the asymmetries of the macroseismic fields due to the complexity of the rupture, propagation and radiation of strong earthquakes.

REFERENCES

1. Sbarra, P., Burrato, P., Tosi, P., Vannoli, P., De Rubeis, V. & Valensise, G. Inferring the depth of preinstrumental earthquakes from macroseismic intensity data: a case-history from Northern Italy. Natureresearch, Scientific Reports, 1-13 (2019) 9:15583 | https://doi.org/10.1038/s41598-019-51966-4.

2. Gentile F., F. Pettenati and L. Sirovich, 2004. Validation of the Automatic Nonlinear Source Inversion of the U. S. Geological Survey Intensities of the Whittier Narrows, 1987 Earthquake, Bull. Seism. Soc. Am., Vol. 94, 5, 1737-1747.

3. Sirovich L. and F. Pettenati, 2004. Source inversion of intensity patterns of earthquakes: a destructive shock in 1936 in northeast Italy. J. Geophys. Res., 109, B10309, doi:10.1029/2003JB002919, pp. 16.

4. Pettenati F. and Sirovich L. 2007. Validation of the Intensity-Based Source Inversions of Three Destructive California Earthquakes, Bull. Seism. Soc. Am., BSSA Volume 97-5, 1587-1606, doi: 10.1785/0120060169.

5. Sirovich L., F. Pettenati, and F. Cavallini (2013). Intensity-Based Source Inversion of the Destructive Earthquake of 1694 in the Southern Apennines, Italy. J.G.R. Solid Earth, Vol. 118, 1–17, doi:10.1002/2013JB010245.

6. Sirovich L. and F. Pettenati (2015). Source inversion of the 1570 Ferrara earthquake and definitive diversion of the Po River (Italy). J.G.R. Solid Earth, 120, 5747–5763, doi:10.1002/2015JB012340.

7. Pettenati F., L. Sirovich, and L. Bjerrum (2017). Fault sources and kinematics of the 1897 Assam (MW8.1) and the 1934 Nepal (MS8.2) earthquakes retrieved by KF-NGA inversion and their seismotectonic implications. Bull. Seism. Soc. Am., 107, 5, 2480-2489. DOI: https://doi.org/10.1785/0120160391.

8. Mak, S., Clements, R. A. & Schorlemmer, D. Validating Intensity Prediction Equations for Italy by Observations. Bull. Seism. Soc. Am. 105, 2942–2954 (2015).

9. Sbarra, P., Tosi, P. & De Rubeis, V. Web-based macroseismic survey in Italy: method validation and results. Nat. Hazards 54, 563–581, https://doi.org/10.1007/s11069-009-9488-7 (2010).

10. Tosi, P., Sbarra, P., De Rubeis, V. & Ferrari, C. Macroseismic intensity assessment method for web questionnaires. Seismol. Res. Lett. 86, 985–990, https://doi.org/10.1785/0220140229 (2015).

11. Raschke, M. Comment on “Validating intensity prediction equations for Italy by observations" by Sum Mak, Robert Alan Clements and Danijel Schorlemmer, Bull. Seismol. Soc. Am. 106, no. 5, doi: 10.1785/0120160007 (2016).

12. Gasperini, P. The attenuation of seismic intensity in Italy: a bilinear shape indicates the dominance of deep phases at epicentral distances longer than 45 km. Bull. Seismol. Soc. Am. 91(4), 826–841 (2001).

13. Sirovich L., Pettenati F., Cavallini F., Bobbio M., 2002. Natural-Neighbor Isoseismals. Bull. Seism. Soc. Am., Vol. 92, 5, 1933-1940.

14. Pettenati F. and Sirovich L. 2007. Validation of the Intensity-Based Source Inversions of Three Destructive California Earthquakes, Bull. Seism. Soc. Am., BSSA Volume 97-5, 1587-1606, doi: 10.1785/0120060169.

15. Sirovich L., F. Pettenati, and F. Cavallini (2013). Intensity-Based Source Inversion of the Destructive Earthquake of 1694 in the Southern Apennines, Italy. J.G.R. Solid Earth, Vol. 118, 1–17, doi:10.1002/2013JB010245.

16. Pettenati F., Sirovich L. and D. Sandron (2011). Rapid simulation of seismic intensity for civil protection purposes; two recent cases in Italy. Seism. Res. Lett., 82, 3, 420-430. Doi: 10.1785/gssrl.82.3.420.

17. Papazachos, B., C., Papaioannou, Ch., A., Papazachos, C., B., and Savvaidis, A., S. (1997). Atlas of isoseismals maps for strong shallow earthquakes in Greece and surrounding area (426BC-1995). University of Thessaloniki, Geophysical Laboratory. Publication No4.

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