

Response to the review of V. De Rubeis

General questions:

- Did you take into account the percentage of not felt to assess an intensity degree, as macroseismic scale recommends?

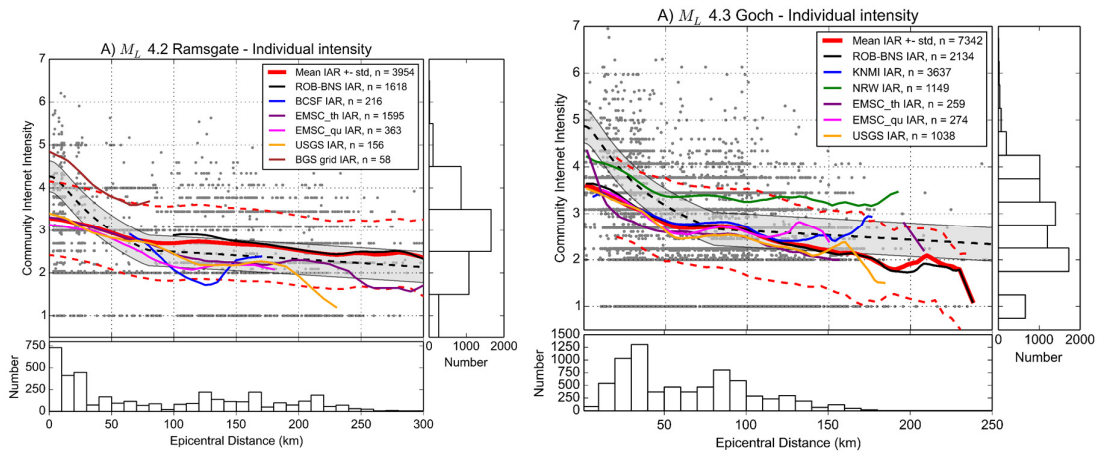
We do take the not-felt reports into account in our analysis, which avoids the intensity in the cells being too high. To clarify the datasets we used, we added the amount and percentage of not-felt reports in tables 1 and 2. The total percentages of not-felt reports in the geocoded dataset are very low (663/8491, 8% for Goch and 260/3953, 7% for Ramsgate). We do agree that working with percentages of not felt responses would lead to a more robust intensity analysis. However, the percentages of not-felt reports within the grid cells are very low (mean=0.03%). As we have no voluntary base such as INGV and don't have an observers network (we do need this in the future) we cannot assess the not-felt percentages reliably and cannot make a more robust interpretation. We added this remark to section 4.3.6

It is clear from the intensity maps that working with cells has benefits above working with ZIP codes as more not-felt grids are shown.

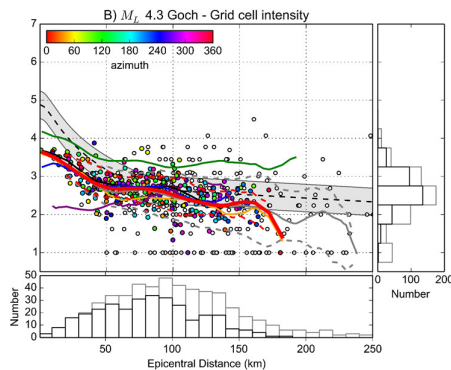
- Can you try to compare attenuation laws for each data sources?

This is a very good idea. Yes we can. We ran our attenuation algorithm again through all individual data sources. Figure 7A & 11A show the results of this analysis. Combined with the questionnaire comparison table (see review Bossu) this plot shows a strong difference for the NRW-DG data (overall higher intensity) and the EMSC_thumbnail data (higher epicentral intensity) for Goch. The shape of the IAR's of all other data sources have a rather similar shape in the first 100 km's, showing that although the individual questionnaires might differ, the intensity results are similar!

For the NRW-GD this analysis confirms that 1) absence of not-felt reports drives their IAR up and 2) their intensity results cannot be used in the overall analysis (see further). For the Ramsgate earthquake we limited the IAR's to those areas in which the data source gathered enough reports. BGS individual data is not available so we plotted the BGD grid data which show higher, but more accurate intensities (see comment review #3).



Figs. 11A & 7A



Figs. 7B

Specific questions of V. De Rubeis

- P2, 13: *change real time to quasi real time.*

ok

- P2,111: *not complete. Pattern depends on source also, change the sentence like: Concentric pattern of intensity decay is only a theoretical very first approximation, which may serve only to indicate seismic epicentral best location.*

Thank you for this suggestion. Sentence changed.

- P2,125 and 134: *explain the meaning of real time or quasi real time.*

As there might be a confusion with these sentences, the paragraph has changes as follows:

“Despite this high number of inquiries only a minority of these national institutes, i.e. BGS, INGV, BCSF, SED, IGN, ROB-BNS (see appendix A), calculate and map intensities from the people’s submissions online and update a macroseismic map in quasi real-time (a small amount of time is still needed to process the data).”

- P5,111-12: *too generic: unrealistic? Manual check? What is the algorithm (objective method) behind it?*

We did not explain this in the paper. First we analysed all data and constructed an IAR through the data. Afterwards if individual intensities are higher than +III intensity units above the IAR at larger distances (e.g. for Goch > 150 km), we delete these high intensities as they are not very reliable. This procedure should be similar to the procedure used at the INGV. Afterwards we re-computed the IAR, now without these high intensities.

- P5,120: *“IDP are statistically too high or too low”, this sentence is generic.*

We deleted this sentence.

- P5,121: *“too high” - “slightly overestimate intensity” the two sentences appears in contradiction.*

We changed this sentence to avoid this contradiction.

- P5,129: *Mean is not very appropriate for int. estimation, if you follows intensity degrees definition you will find, for example, an evaluation of percentage of people observing such effect which it is associated an int. Value.*

We agree with this comment, but we cannot do better than taking the mean. Apart from the USGS, the data provided by the institutes were only individual intensity data. We do not have the detailed answers to each individual question, which complicates to assess a proper EMS98 intensity value. See our reply to R#3 for a detailed answer.

- P5,130: *statistical errors: unhappy terms in this contest, what does it mean? Probably an error component too high.*

Indeed, we rewrote this sentence.

- P6,119-20: *check language.*

Ok, this sentence has been rewritten: The Goch epicentre is located 6 km ± 2.7 km NE of the surface trajectory of the SW-dipping Viersen fault. Given the 10 km source depth, it is thus not possible to attribute the Goch earthquake to the Viersen fault.

- P6,122: *which is the time length of the catalogue? Otherwise the sentence has a poor meaning.*

The ROB and BNS instrumental catalogues start from 1985 and 1975, respectively.

- P7,121: *Agencies are national but some collect also international data: whole set of data is international.*

OK, we rewrote this sentence following your suggestion.

- P7,122-28: *was a statistical test conducted to assess spatial variability and localization precision of data? I think it should be worth to quantify it instead to give a qualitative evaluation based on personal opinion.*

No statistical test was performed. The high precision of the geocoded data (ROB-BNS, KNMI) is provided by the quality factor after the Google geocoding. Given the small error on the location precision (1.11 km for USGS; 0.11 km for NRW) we don't see the need of performing a statistical test. In 100 km² cells the worst case scenario that can happen is that a few points might fall in the next cell, shifting the intensity.

- P7, 135-36: *“The impact of differences between the institutional questions on the intensity scale remains very low “ How can you state it? Statistical analysis? Referenced results? Please specify.*

Please see our detailed reply to Bossu who asked a similar question.

- P7, 137: *Same as above: what do you mean with “spatial variability” ? Do you have a quantification of it to assert the differences among different data sources? P8,11-2: I do not understand why merging data removes spatial variability. Merging different data sources increases variability.*

This is true, due to the different datasets, different precisions of location and the different intensity procedures, merging data will increase the variability of the total dataset. We changed this as follows:

“Merging different macroseismic data sources allows having more data and provides a denser spatial coverage of the area over which the earthquake was felt. It however also increases the variability of the dataset due to increased uncertainty in the respondents’ locations as different location procedures are used by the agencies. “

- *P10,116-20: Here the hypothesis of normal distribution is not correct because intensity data are strongly conditioned by radial geometry and log distance attenuation laws. Explanation does not seem reasonable and well argued. Intensity data for a whole macroseismic field are not supposed to be normally distributed being influenced by the aforementioned factors plus undersampling and dependence of estimation error to intensity.*

This is a true comment. We deleted this argument.

- *P10,121-22: This sentence is obvious: it is as to say that the whole is more than a part.*

The original sentence was badly phrased, sorry. What we want to state is that for the Goch earthquake, the sum of responses submitted to the national institutes is far larger than the sum of those which arrived at international agencies. This shows the importance of the national institutes in collecting macroseismic data, particularly for moderate earthquakes!

- *P10,131-34: Why not trying to statistically correct this discrepancy? For example making a correlation among different data set, looking for corrective coefficients.*

We actually tried this by comparing the intensity values for those cells in which NRW-GD and ROB-BNS have common data. It is clear that the NRW-GD overestimates intensities. There are several ways to correct for this error but they all would depend on the chosen fit through the correlated data. As we have no idea in which way the error is consistent (linear, powerlaw, exponential,...) we decided to not correct the data and only use the NRW-GD data as “felt”. Correcting the data would increase the uncertainty. In almost the entire region where NRW has data, we have overlapping responses from other institutes.

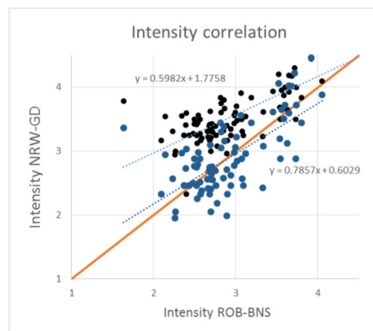


Fig: black points = NRW-ROB correlation for common cells. Blue cells = “correcting” the data to the 1:1 line by inverting the linear interpolation between the black points.

- *P10,138: It is known that data deriving from non-permanent effects are strongly based on compilers’ memory: it could be useful to search for a dependence of answers errors with compilation times.*

See response to next question.

- *P11,11-2: This sentence is not clear, entries are generally not random in time. In fact they follow a time decay law (resembling a sort of Omori law) modulated by day-night cycle. In space the distribution could be compared with spatial citizen density distribution.*

This was indeed wrongly formulated in the text. We added a figure in the Supplement explaining the response submission rate of the Goch and Ramsgate earthquakes to the seismology.be website (ROB-BNS). Both curves show that submissions were indeed not random in time. See explanation in the Supplement.

Also in space this is not random but both controlled by the population density. As we discuss the distribution and population density in the discussion, we removed this sentence here.

- *P11,14-10: Intensity spatial distribution is based on qualitative evaluation and results are expressed with vague, colloquial terms, as example “far from circular radiation”. A quantitative approach could be based on analytic comparison with experimental data and isotropic fitting.*

The expected circular behaviour of the Goch intensity pattern is altered by the local geology. We highlight this in the discussion. In section 4.4.6 we only want to describe the shape of the intensity distribution. We understand your concern so reformulated this sentence to have a more precise description: “The Goch grid cell intensity pattern distribution deviates from an expected circular pattern as intensity cells are absent in the SW quadrant (Fig. 6).”

- *P11,113-14: But it is biased on radial areal increment due to polar distribution. Moreover IAR derived from an equal area is not sufficient to assess unbiased results. There is a need of further analysis, for example comparing attenuation relations from each agency separately.*

The areal increment is best visible in the datasets of KNMI and NRW. We calculated the institutional IARs (Fig. 7A) of the institutes from both the individual and grid cell data. We added these IARs to Fig. 7A but left them out of Fig. 7B to not complicate this figure. But the trends are the same. The IARs show that the KNMI, ROB-BNS, USGS and EMSC (qu) all result in a similar distance decay. This confirms that although the questionnaires might differ, the gathered intensity data are rather similar and the radial areal increment due to polar distribution does not affect the IAR. We added this aspect to the paper.

- *P11,136: I find a contradiction: on one side the authors find that their data are at the epicentral zone characterized by lower intensity comparing with suitable attenuation law (Atkinson and Wald), on the other side they state that first 50 km attenuation is due to fast energy decay of seismic energy from the source. It could be explained why fast decay did not affected attenuation laws.*

In fact this is a local versus regional effect. In the epicentral area, the local site effect (deep bedrock) attenuates the intensity and lowers the IAR with respect the A&W (2007) attenuation law. With increasing distance, a larger area is considered and intensity data above different geological units is gathered. This smooths the IAR into a 'normal' situation where it approaches the A&W07 CEUS law. We deleted the suggestion that this is related to fast energy decay of seismic energy from the source and added the explanation above to the discussion.

- *P13,129-30: this part is an example of uncertainties stemming from not considering of not felt individual reports, in fact the authors decided to reduce intensity from III to II based on reasonable consideration. Not considering not felt percentage is a weak point of the investigation.*

See main answer above.

- *P13,136: Another example of qualitative analysis: the Ramsgate intensity distribution shows a WNW-ESE orientation (Fig. 10), can you quantify/justify this sentence?*

Yes we can. We performed azimuthal analysis through all cells for which we have intensity data. Figure S1 in below and provided in the Supplement shows the results of this analysis.

The polar plot shows the mean azimuth calculated through all response cells on the continent and in the United Kingdom. **On the continent**, the mean orientation (red line, brown area = $\pm 1\sigma$) of the felt distribution is 111.5° , corresponding to an ESE orientation with respect to the epicentre. The ESE-oriented felt distribution clearly deviates from the mean azimuth (132.7° , grey area = $\pm 1\sigma$) derived through all available cells, i.e. the response potential on the continent. This orientation shows that the distribution is not a population, nor an "emerged land vs sea (blue dots)" effect.

In the UK, the response distribution is more widespread (1σ between 260° to 350°) but the azimuthal mean is 305.6° ~WNW. This larger spread is likely related to the dispersing occurrence of the Anglo-Brabant Massif in the subsurface (see Fig. 12 in the paper).

This polar plot proves a WNW-ESE orientation of the felt distribution of the 2015 Ramsgate earthquake, an orientation clearly following the tectonic structure of the Anglo-Brabant Massif.

We added to the text "Numerical azimuthal analysis of the grid cell centroids relative to the epicentre (see Fig. S1 in the Supplement) quantitatively proves that the Ramsgate intensity distribution is clearly WNW-ESE oriented with a mean circular azimuth of 112° on the continent and 306° in the UK, respectively."

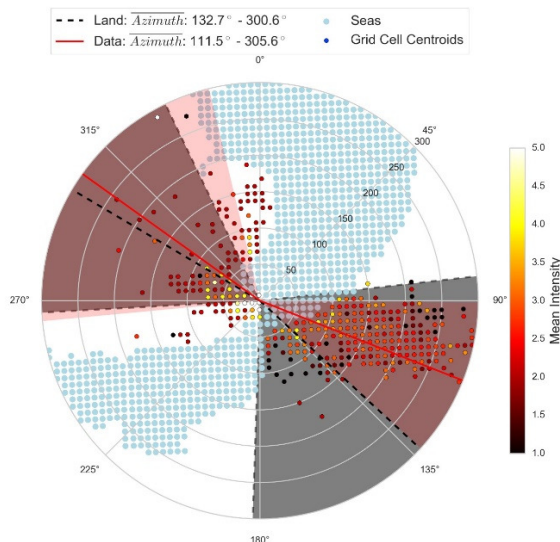


Figure S1 added to the Supplement.:

Blue plots = cells within the North Sea and English Channel

Coloured cells = intensity data.

Shaded areas = $\pm 1\sigma$ around the circular mean.

P16,120-30: the comparison between intensity and depth of geological structures could be done in more qualitative way, for example performing a correlation between intensity residuals and structures.

In order to apply intensity residuals, we need to have an established attenuation model; however, such an IAR constructed from internet data is currently lacking in our regions. We are not convinced that constructing intensity residuals from the Goch IAR would confirm the geological structures. Whatever existing IAR we would take (either from historical analysis or internet data) it would always be a rough approximation, especially because of the different geology over the whole area. You are right that this needs to be done in the near future to perform a more qualitative analysis, but only after evaluating all felt earthquakes in our database and not only with the IAR of the Goch or the Ramsgate earthquakes.

P17,11-3: depth differences of the two earthquakes is small taking into account depth estimation uncertainty.

After revision of the seismic data we could reduce the depth uncertainty to 1.2 km for Goch and 3 km for Ramsgate. Goch was thus still shallower than Ramsgate indicating that a depth effect is still present in the macroseismic data. This depth difference is clearly reflected in the difference in epicentral distances over which the Goch and Ramsgate events were felt. Ramsgate (max ~ 360 km) > Goch (max ~ 250 km). This is clear in the discussion and we did not change anything.