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Interactive comment on "Earthquakes on the surface: earthquake location and area based on more than 14500 ShakeMaps" *by* Stephanie Lackner

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Reply to RC2

I would like to thank the reviewer for the comments and suggestions made to improve the present work. Please find below the reviewer's comments and author's replies to these comments.

RC2: *This paper aims to provide a discussion of earthquake shaking for an interdis-*

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ciplinary audience and with applications in earthquake impact research, particularly in the social sciences in mind. The author is not a seismologist but has a strong background in mathematics, natural disasters, their socio-economic impacts, and sustainable development. In other words, the main purpose of this paper seems to be an earthquake communication about global seismic hazard based on past events (of limited duration) in the social science literature.

A dataset of relevant global earthquake ground shaking from 1960 to 2016 based on USGS ShakeMap data has been constructed and applied in this paper, where it is claimed to be the first global quantitative analysis on the size of the area that is on average exposed to strong ground motion (PGA), while introducing two new definitions of earthquake location (the shaking center and the shaking centroid) based on ground motion parameters.

The idea is great. However, the paper appears to be lacking in-depth knowledge of complexities in the earthquake rupture, seismic hazard and risk. References to local/site/geologic conditions and/or quality/seismic performance of buildings/structures have been kept to a minimum if none, and there are no discussions on the rupture heterogeneity and directivity and their relations to seismic hazard. Statements on earthquake rupture physics are generally very simplistic, such as "waves radiate out from every point of the rupture area", where there is no single reference to asperities and frequency content of the waves radiated and how these are connected to seismic hazard studies. The discussion on any relevant uncertainties seems to be kept to a minimum. ...

[...]

It may be very well that the author might have intentionally kept the technical/scientific details to a minimum, especially with relevance to the uncertainties in the physics of the phenomena and in the methodology, since the target audience is particularly in the social sciences. However, the communication of such uncertainties specifically to *these audiences is crucial in terms of global earthquake preparedness.*

Reply: Yes, the discussion of the complexities of earthquake rupture processes and other scientific details on earthquakes that are relevant for seismic hazard and risk have intentionally been kept to a minimum. I do agree that acknowledging these factors is important. However, a detailed discussion of all the factors that play a role for what levels of strong ground motion manifests on the surface does not fit in the context of this paper. The primary concern is that social scientist need to be aware of the general limitations of the data due to the connected uncertainties. Earlier versions of this work actually included more technical details, which have been reduced in an attempt to make it easier readable for a social science audience. This reduction might have reached beyond the intended objective and I have now added again some more technical details throughout the paper.

RC2: *The argument of "the literature commonly uses magnitude or other suboptimal measures to quantify the natural hazard of earthquakes for impact research" could be true for social sciences, but definitely not acceptable for a seismologist, and this paper does not appear to be improving this deficiency. It is not the "parameter" that is misleading in earthquake hazard communication, it is "how we communicate or not communicate" the parameters to the outside community. In that respect, the paper, despite its good intentions, does not necessarily serve the purpose set by the author.*

Reply: I absolutely agree that "how we communicate or not communicate" scientific parameters is of great importance. Nevertheless, despite many efforts from the scientific community, misunderstandings of what magnitude refers to do prevail among the general public. It is very common for people (without any seismological training) to assume that magnitude is either a measure for surface shaking or at least a good proxy for it (some evidence for this is demonstrated by ()). While seismologists (and earthquake engineers) do very well understand that this is not necessarily the case it is still normal to compare magnitude with impacts (e.g a scatter plot of magnitude vs.

fatalities in ()).

While it is important how a parameter is communicated, it also matters how often a parameter is communicated. Magnitude is a term that is well known (if not necessarily understood) by the general public. It is used in some form in essentially any public discussion and communication on earthquakes, even when it is not actually of direct relevance for the particular topic being discussed. Earthquake shaking on the other hand is often not included in discussions in which it would actually be a more meaningful parameter to consider than magnitude. In the social sciences (or public discourse, newspapers, etc.) magnitude is often used as “the parameter” for earthquake size, when actually a quantification of earthquake shaking is desired (e.g. ()). The mere ease of availability (in terms of being used to the parameter as well as the data for the parameter) of magnitude compared to quantifications of shaking, is an important contributing reason for why this happens.

RC2: *The dataset is clearly biased, as also acknowledged by the author. While a magnitude threshold has been introduced by the author to remove the effect of geographical bias as much as possible, at least in Northern America, several geographical regions hosting seismotectonic settings resulting in catastrophic earthquakes with long recurrence intervals, such as Dead Sea Fault or Hellenic Arc, for example, are simply shown with low percentages of average annual maximum PGA (%g) exceeded as a result of no- big-earthquake record for the time interval considered in this paper. In addition to the issues related to the temporal analysis, the resolution of 2.5 x 2.5 degree grid cell is most likely introducing spatial problems due to its large size, which may explain the geographical bias introduced in various regions as a result of large earthquakes during the study interval. The discussion on such uncertainties in the data set need to be clearly improved, since the figures of this paper, if communicated to non-seismology experts, may lead to convey misleading messages on the global seismic hazard and risk.*

Reply: This paper is not trying to make a claim on presenting a full picture of the seismic hazard potential in general, but merely document the data for what did happen (or partially what has been estimated to have happened) in the specific time range of 1973-2015. Any dataset restricted to a couple of decades will obviously suffer from the "temporal bias" of only actually representing that time range and missing events that didn't occur because of longer recurrence intervals. It would obviously be desired to solve this by including more data, which is unfortunately not possible at this point in time. Nevertheless, this is not the same as the data itself being biased in terms of misrepresenting what happened in the specified time range.

Turning to the representation of the data in Figure 5 and C2. The issue of the coarse resolution of 2.5 x 2.5 has also been raised by the first reviewer and they have now been updated at a resolution of 1.25 x 1.25. However, the choice of the resolution makes a decision on how to balance spatial granularity vs. sample size. The finer resolution reduces the sample size in each gridcell (see Figure C1 for reference) and therefore gives more weight to each individual event when calculating the averages. Thus making the Figures more sensitive to the "temporal bias" of only having data on a couple of decades. I have added more information on the uncertainties and limitations of the data in the captions of these figures as well as in the text.

RC2: *The author states that other factors (e.g. geology and water bodies) introduce significant noise in the relationship of magnitude and the area exposed to a particular shaking threshold as a result of this magnitude. This "noise", in reality, is the "data" for seismic hazard and risk studies, and impact assessment. The case of 7.4 1999 Izmit earthquake, for example, is a good example where extensive damage has occurred to high residential buildings in AvcAÌĹślar-Istanbul, 120 km away from the epicenter, which is attributed to both the long distance effects of the high period waves of the earthquake and soil amplification.*

Reply: I think this might be an instance where the term "noise" is used in different ways in different disciplines. I do not mean to say that these factors introduce “random noise”, the “noise” is obviously meaningful data. The point is that these factors make the relationship between magnitude and the size of the shaking area less straightforward. I have reformulated this paragraph to make this clearer, but I have kept the term noise, since I believe that it makes this point easier to understand for social scientists. I have also added some more information on the characteristics about an earthquake that matter for the manifestation of shaking on the surface in section 3 ("Past Earthquake Shaking").

RC2: *It is questionable whether introducing two new definitions of earthquake location, namely the shaking center and the shaking centroid, respectively, will provide any additional benefit, both in terms of seismic hazard studies and earthquake communication. Earthquakes, even on the same fault with same/similar size, do not behave identically, and the well-established term “intensity” in seismology, as a measure of the strength of shaking produced by the earthquake at a certain location, is still not “digested” by many communities around the globe. In that respect, for example USGS’ Pager is a considerable approach to link Modified Mercalli Scale with strong ground motion parameters, such as PGA and PGV, population exposed and potential damage.*

Reply: For certain applications in the social sciences as well as in earthquake communication being able to assign a singular location to an earthquake can be very crucial. In these cases the shaking locations would often be preferred compared to using the epicenter. A particular example that I provide in the conclusion is the use of the shaking centroid for spatial regression models or other statistical tools that require coordinates for each event. Using the epicenter for such applications can introduce significant noise into what the location is intended to represent.

Shaking intensity, while having its own problems, is an important concept that (just as instrumental quantifications of shaking) still often does not receive enough attention yet from some communities. The here introduced shaking locations can actually be com-

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plimentary to the concept of intensity in terms of bringing focus to earthquake shaking. The shaking location could even be calculated based on MMI data for locations with well established and consistent methods to generate MMI maps.

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