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Comment on "Test of Seismic Hazard Map from 500 Years of Recorded Intensity Data in Japan" by Masatoshi Miyazawa and Jim Mori

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Miyazawa and Mori (2009) propose testing probabilistic seismic hazard assessments (PSHAs) for Japan in terms of predicted macroseismic intensities against those observed over the past 500 yrs. While the comparison presents a real interest to the seismological and engineering communities, their reasoning is based on an incorrect hypothesis and leads to several problems. Comparing probabilistic estimates and observations is an important topic; any available observations should be used to infer constraints on the probabilistic estimates. Testing long-term earthquake hazard predictions is currently one of the biggest challenges in the area of engineering seismology. Several current large-scale seismic hazard projects have work packages dedicated to developing so-called validation techniques (e.g., the European Commission-funded Seismic Hazard Harmonization in Europe [SHARE] project and the Global Earthquake Model). Obviously, this task should be performed with great caution, as such validation studies have a direct impact on, for example, estimates of seismic risk and building regulations.

Miyazawa and Mori propose to compare "the maximum recorded intensity map for the past 500 yrs" and "the maximum predicted intensity map for the ~500-yr return period from the PSHM [probabilistic seismic hazard map]" (see their abstract). They state that "the purpose of [their] article is to compare the records of historical maximum intensities for the past 500 yrs with the predicted maximum intensities from the HERP hazard map" (Miyazawa and Mori, 2009, p. 3141, see next paragraph for the misuse of "maximum"; Headquarters for Earthquake Research Promotion [HERP], 2005). Later in the paper, they indeed directly compare the maximum "recorded" intensities for 1498–2007 and the seismic intensity maps for a 10% probability of exceedance in 50 yrs (p. 3145, fig. 4, and fig. 5). Therefore, their article apparently relies on the hypothesis that at a site, the maximum observed intensity value during 475 yrs is equivalent to the intensity at a 475-yr return period (intensity with 10% exceedance probability over 50 yrs). This assumption is not correct. The error in making this hypothesis is rather well known within the PSHA community, and it has recently been clearly demonstrated by Beauval *et al.* (2008). In brief, within PSHA, the occurrences of intensities at a site are generally assumed to follow a Poisson process. A Poisson process with a 475-yr return period has an average occurrence of 1 every 475 yrs; hence, there is a probability of 37% that this Poisson phenomenon (exceedance of a considered intensity level) does not occur at all in a time window of 475 yrs. Furthermore, Beauval *et al.* (2008) show that, for a meaningful comparison with a 20% uncertainty level, a minimum observed time window of 12,000 yrs is required for estimating site accelerations corresponding to a 475-yr return period at a single given site. Therefore, if the intensity catalog covers 475 yrs, the maximum intensity observed at a site cannot be so easily linked with the intensity for a 475-yr return period. It can be higher or it can be lower. Both can be compared only in probabilistic terms. The maximum acceleration over 500 yrs is a random variable characterized by a probability distribution (e.g., Beauval *et al.*, 2006, in which synthetic seismic catalogs were used to establish the distribution for the maximum "observed" acceleration over time periods of 50 yrs).

Furthermore, in the probabilistic seismic hazard community, terms used are of utmost importance. There has been much misunderstanding since the beginning of PSHA, and efforts have been made to clarify terms and definitions (e.g., Abrahamson, 2000; Bommer, 2002). In many places in their article, Miyazawa and Mori (2009) refer to the "maximum intensity for a 475-yr return period" (see the abstract, p. 3141, and their conclusion that "the PSHMs show the maximum intensity for a 475-yr return period"). What is calculated in a probabilistic seismic hazard study is the intensity for a 475-yr return period, which is not a "maximum" intensity. This misuse is persistent through the paper, and it brings even more confusion because this intensity is compared to a true maximum "observed/recorded" intensity. Note that the intensity with a given probability of at least one exceedance during 50 yrs can be calculated from the distribution of maximum intensities over time windows of 50 yrs (using many time windows; see Musson, 1999 and Beauval *et al.*, 2006). The intensity with 10% probability of exceedance can be extracted from this distribution; it is no longer a maximum intensity but rather a threshold.

It is worth noting that several authors have worked on this validation issue using strong-motion records or instrumental intensities and have proposed robust methods that could be applied to historical intensities; none of these studies are cited in Miyazawa and Mori (2009). The main idea is to combine multiple sites in space, to compensate for the fact that available observation time windows within earthquake catalogs are too short, and to compare observed probabilities of exceedance of given intensity/acceleration levels with calculated probabilities (PSHA). Such techniques were first

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proposed by Ward (1995), who used area-based tests of seismic hazard maps, and new developments were recently introduced by Albarello and D'Amico (2008). Ward (1995) assumed "that the observed likelihood of exceeding a threshold acceleration averaged over an area A should follow in proportion to the predicted likelihood of exceedance" (p. 1288) and "the areas A covered […] are arbitrary, but they should be large enough to insure stable estimates of [the probability of exceedance of a given acceleration level]" (p. 1288). Albarello and D'Amico (2008) compare observed and occurrence rates calculated from a 30-yr time window at 68 strong-motion stations distributed over the Italian territory. They insist on the fact that results must be considered with caution, as the underlying hypothesis is that the occurrences are assumed to be realizations of the same stochastic variable (and, therefore, independent). With similar hypotheses and using the recordings at the K-NET strong-motion stations, Fujiwara *et al.* (2009) compare exceedances of instrumental intensities with PSHA results in Japan, using short time windows (10 yrs) and compensating by multiple sampling in space. They compare the average (calculated) probability of exceeding, for example, intensity VI over 10 yrs (averaged over all Japan) with the ratio of the number of K-NET stations that recorded an intensity ≥ VI during the period 1997–2006 to the total number of stations (table 3, Fujiwara *et al.*, 2009). Applying the same idea to an observation time window of 500 yrs would imply selecting sites with such a long history and calculating the ratio of the number of sites where an intensity higher than VI (in this example) has been observed to the total number of sites. This ratio would then be compared to the average calculated probability of exceeding intensity VI over 500 yrs (averaged over all considered sites).

Moreover, throughout the paper, Miyazawa and Mori (2009) compare the observation time window (500 yrs) of intensities with time recurrences of earthquakes. This has a meaning in the case of maximum observed intensities because the earthquake that produced the maximum observed intensity at a site is known. However, in the case of the intensity calculated for a 475-yr return period, the link between this return period and the recurrence times of earthquakes that contributed to the exceedance rate is not straightforward. Based on recurrence time deaggregation, Beauval *et al.* (2008) demonstrate that the common belief that earthquakes having a recurrence time of *X* that contributes to the ground motion at *X* return period is not correct. Earthquakes with different recurrence times are contributing to the acceleration/intensity at 475 yrs (between a few hundred years up to a few thousand years; see fig. 3 of Beauval *et al.*, 2008).

Furthermore, as stressed by Albarello and D'Amico (2008), results of comparison tests should be regarded with great caution and only considered as warnings because of the strong hypotheses required. Miyazawa and Mori (2009) take much less care and conclude, for example, that "the good correlation with the two maps for subduction zone earthquakes probably supports the conclusion that the ground-motion estimates used in the PSHMs are appropriate" (their discussion section, p. 3148). As the underlying assumptions do not seem correct, there might be other explanations for this apparent agreement. Moreover, when Miyazawa and Mori evoke the possibility for the recorded intensity "to represent the levels of future intensity distribution better than the PSHM" (p. 3141), they completely ignore the great developments of the last decades in conducting PSHAs. Their conclusion that "a map of the distribution of maximum intensities, based on data recorded for a period longer than or comparable to the earthquake recurrence interval, is capable of showing the probabilistic ground shaking in the future and can be [...] used for testing probabilistic hazard maps" (p. 3141) appears to us not only incorrect but also quite dangerous, as many countries have observation time windows of 500 yrs available and could make this false assumption.

Lastly, a widely applied, sound method that makes use of intensity catalogs establishes a recurrence model for intensities observed at a site (taking into account the completeness of time windows with respect to intensity) and compares these recurrence rates to the rates obtained from a probabilistic hazard curve (e.g., Stirling and Petersen, 2006; Bozkurt *et al.*, 2007; Mucciarelli *et al.*, 2008). This method and its variants should be favored over the technique of Miyazawa and Mori (2009). We would like to stress that all hypotheses underlying comparisons should be clearly and transparently explained; otherwise, these studies will bring even more confusion instead of providing a means to discriminate between different hazard maps.

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