Review of the manuscript NHESS-2023-213

The aim of the paper NHESS-2023-213 “Probabilistic Seismic Hazard Assessment of Sweden” is to present seismic hazard estimates (hazard maps and hazard curves for selected sites) for Sweden using the probabilistic seismic hazard analysis (PSHA). This country is characterised by low levels of seismicity and therefore the time length of the earthquake observations, which span a few hundreds of years in the best case, is much shorter than the seismic cycle of large earthquakes, which is of the order of thousands of years in low seismicity regions (e.g. Stein et al. 2015). Using sparse and limited sets of data represents a challenge to fully capture the epistemic uncertainties in a national seismic hazard model. In this context, the aim of this paper is of primary importance for seismic hazard analysis. However, there are some inaccuracies in the manuscript (e.g., the description of the steps for PSHA) and more explanations to justify the decisions taken by the authors to develop the seismic hazard model for Sweden are required. Furthermore, the English language seems to be quite poor in some paragraphs. Although I provide below some editorial comments on wording and sentences, I would suggest a significant revision in terms of the language throughout the manuscript.

Here I list the main technical and editorial points.

1- A discussion on the uncertainty in the parameters of the earthquake catalogue is not mentioned at all. What are the uncertainties in the epicentral locations and the magnitude? Are they accounted for in the estimation of the recurrence parameters?
2- The authors do not mention at all the focal mechanisms of the earthquakes in Sweden and Fennoscandia. Are there any focal mechanisms known for earthquakes that occurred in the region? Similarly, what is the hypocentral depth, together with the associated uncertainty, of the earthquakes in the final catalogue built for this work?
3- The discussion on the magnitude homogenisation and assessment of the completeness thresholds (Section 4.1.3) in the catalogue is difficult to follow and lacks crucial information. Is the M_L(HEL) used for all events in the final catalogue, including those from NORSAR, NNSN, and SNSN? If not, the description of how ML(HEL) was estimated is unnecessary. What are the equations used to convert ML into Mw? Are they applied to all the data in the final catalogue? For the assessment of the completeness threshold(s), from which year is the catalogue complete for Mc = 2 Mw? Furthermore, is a single Mc value used for the calculation of the recurrence parameters? Why did the authors not use the completeness thresholds for Fennoscandia estimated in ESHM20 or ESHM13?
4- The authors should explain better how they defined a Mmax distribution between 6.3 and 7.5 (I assume this is Mw, isn’t it?). In analogue regions, there are no examples of 7.5 Mw earthquakes, so the authors should justify better the 7.5 Mw value.
5- If I have understood correctly, the authors have defined new TSZs and ASZs from the ESHM20. If this is the case, why did the authors use the TSZs and ASZs from ESHM20?
6- Is a single source model considered for the PSHA of Sweden? Alternative source models would account for different interpretations of the mapped tectonic structures, large-scale deformation, regional stress field, and observed seismicity in Sweden and Fennoscandia. It would ensure to capture the epistemic variability in the behaviour and location of seismogenic structures and their correlation with seismicity. Did the authors consider to use of the zoneless (zone-free, smoothed) models (see Beauval et al. 2006; Zechar and Jordan 2010 for more details) approach as an alternative sesmic model? This was included in the ESHM20 model and other national seismic hazard models, such as Germany (Grünthal et al. 2018) and France (Drouet et al. 2020).

7- How were the weights in the ground motion logic tree decided? Are there any available ground motion recordings for instrumental earthquakes in Sweden and Fennoscandia? If so, it would be useful to compare them with the predictions from the selected ground motion models. This comparison can be used to assign the weights for the ground motion models in the logic tree, together with expert judgements due to the limited ground motion dataset in the region.
8- Why was a minimum magnitude of 4.5 Mw selected for the hazard calculations? The minimum magnitude (Mmin) in a hazard calculation is defined as the threshold for potentially damaging earthquakes (e.g. Bommer and Crowley 2017). This parameter is usually defined between 4 and 5 Mw for PSHA. In the PSHA for the UK, it was set to 4.0 Mw because it includes the probability that the impulsive nature of small earthquakes and their high-frequency content could be potentially causing damage (Mosca et al., 2022). I would think that due to the low levels of seismicity in Sweden, this may be appropriate also for this country.
9- Section discussion (Section 6 here) should not repeat what was already written previously. It should emphasize the main result, highlight the strengths and limitations of the study, provide the interpretation of the results in the context of regional hazard and eventually give future research directions. For example, Subsection 6.2 “Comparison with previous studies” should be part of Section Results.
10- An acronym should be explained only when it is mentioned the first time in the manuscript. ML and Mw are not explained when they are used for the first time in Section 2.
11- All the geographical names mentioned in the text should be indicated on a map because not all the readers are familiar with the geography, geology and tectonics of Sweden.

Line 4: Include a comma before “which”. Replace “large number of events” with “ high number of events”.

Line 5: Replace “5.9 to -1.4” with “-1.4 to 5.9”. What is the magnitude scale?

Line 6: “less uncertainty” is in contradiction with the first line of the abstract, which states that the seismic hazard assessment in stable continental regions is challenging due to the limited amount of available data ”. Also, “recurrence parameters to be calculated for more source areas than in previous studies” is unclear and I would suggest re-phrasing it.

Line 13: replace “highest PGAs” with “highest PGA values”.

Line 19: What do the authors mean by “disaster development in the event”?

Line 25: Replace the full stop before Occurrence with a comma.

Line 26: Replace “as England and Jackson (2011) show, the risk” with “England and Jackson (2011) show that the risk”.

Line 30: What is the magnitude scale in this case? How were these estimates (one event of magnitude 5 every 100 years and one event of magnitude 6 every 1000 years) computed? Replace “until 2005” with “before 2005”.

Line 34: How large are the “large earthquakes”? Provide an indication.

Line 39: Provide references for “earlier estimates”.

Line 44: Replace “The hazard is calculated using the OpenQuake engine (Pagani et al., 2014) and we produce hazard maps…” with “We use the OpenQuake engine (Pagani et al., 2014) to develop hazard maps …”.

Line 49: The first sentence of Section 2 is more appropriate for the introduction than for this section, which could start with the second sentence. It would be useful to mention which are these damaging earthquakes and which damages were produced.

Line 76: For which year does the completeness magnitude of 0.5 correspond? What is the magnitude scale? In Section 2, both ML and Mw are used. Probably it is better to use only one magnitude scale, preferably Mw.

Line 82: How low is the magnitude? Provide an indication.

Figure 1: Besides reporting the geographical names in the text into Figure 1, it would be useful to show the distribution of the earthquakes in terms of magnitude highlighting those of magnitude 4 and above. Which magnitude scale is used in the figure, ML or Mw? Also, would it be possible to label the earthquakes mentioned in Section 2 into Figure 1, e.g. 1819 earthquake? Last, it is difficult to distinguish the Tornquist and Trans-European Suture zones from the earthquakes (they both are indicated by dots).

Section 3: In general, the main components (i.e. catalogue, source model, ground motion model) of each study, together with the highest hazard computed by the studies, should be explained to facilitate the comparison between models, including the model presented in the manuscript. Probably, a table which summarises the various components of previous studies in Sweden and Fennoscandia may be helpful. I recognise that indication of the resulting hazard in the previous studies is done, but not all the components are briefly described. For example, the ground motion models used in Bath (1979), Wahlström and Grünthal (2001), Mäntyniemi et al. (1993, 2001), etc are not indicated explicitly. The model of GSHAP and ESHM13 are cited but no information about them is provided. It would be useful to see how they differ from ESHM20 in terms of individual components and hazard results. Please indicate the magnitude scale every time (see lines 124-126).

Line 108: It would be useful to indicate how much “highest” is the highest hazard in Bath (1979).

Line 109: Replace “an ML ≥ 5 event” with “an event of 5 ML and above”.

Lines 116: What does “various combinations of seismic source areas” mean? Also, replace “rate information” with “rate estimation”.

Line 120: Move “for a probability of exceedance of 10^{-5} per year and a damping of 5%” at the end of the sentence. Furthermore, the damping is for spectral acceleration, not PGA.

Line 130: Replace “Wahlström and Grünthal (2000) and follow-up Wahlström and Grünthal (2001)” with “Wahlström and Grünthal (2000, 2001)”.

Line 151: Provide the references for “two large PSHA projects for the nuclear industry in Finland”.

Lines 152-153: Replace “The first, the Fennovoima project, assembled seismologists and geologists from Finland and Sweden to perform a full site-specific PSHA” with “In the Fennovoima project, seismologists and geologists from Finland and Sweden perform a full site-specific PSHA…”.

Lines 169-170: Replace “events, from 1497 to 2014, with magnitudes 3.5 ≤ MW ≤ 5.8.” with “events with magnitudes 3.5 ≤ MW ≤ 5.8 from 1497 to 2014.”.

Lines 172-174: It is difficult to follow this sentence. I would suggest rephrasing it.

Line 173: Replace “In these zones,” with “In ASZs with more than 30 earthquakes,” and remove “for zones with more than 30 earthquakes” at the end of this sentence.

Line 177: It is double (not doubly) truncated Gutenberg-Richter. Correct it throughout the manuscript. Also, replace “using an automatic maximum” with “and an automatic maximum”.

Line 179: Replace “is re-used” with “is assumed as a prior value”.

Line 194: It should be mentioned that the GMM in Kotha et al. (2020) are for active shallow crustal regions in the ESHM20.

Section 4: The description of PSHA is inaccurate. It consists of four steps (e.g., Reiter, 1990; Baker et al., 2021): 1- Definition of seismic sources based on knowledge of the tectonics, geology and seismicity of the study area. 2- Quantification of the rate of earthquake occurrence for each seismic source zone using the Gutenberg-Richter frequency-magnitude law. 3- Characterise the ‘earthquake effect’ expressed in terms of some instrumental ground motion measure, such as PGA, or seismic intensity. 4- Estimation of the hazard at the site(s) by analytically integrating over the source models for the location and size of potential future earthquakes (Steps 1 and 2) with expected values of the potential shaking intensity caused by these future earthquakes (Step 3), including the associated variability in each. The development of the earthquake catalogue is part of step 1.

Subsections 4.1 and 4.2: They can be merged. Why few events from the ESHM20 catalogue are not included in the FENCAT catalogue? When did these events occur? and what was their magnitude? How small were the events in the SNSN catalogue that were included in the final catalogue? How were quarry, industrial or military blasts, rock bursts, mine collapses etc identified as nontectonic earthquakes? Did the authors remove also non-tectonic events offshore?

Line 231: Indicate the magnitude range for the 24,215 events in the final catalogue.

Section 4.1.2: How do the results of the declustering method (modified Gardner and Knopoff, 1974) compare with that from the method of Burkhard and Grünthal (2009) that was calibrated for the earthquake catalogue in Central Europe and was used in ESHM13 and ESHM20?

Line 223: Replace “at our disposal spans the year 1375 until the end of” with “that we used spans between 1375 and the end of”.

Line 234: Provide a reference for the first sentence.

Lines 249-251: It is difficult to follow this sentence, so I would suggest rephrasing it.

Line 257: Replace “a smaller fraction of dependent events of only 11%, a difference to our result which is likely due to the fact that” with “less dependent events than those in our study. The difference (11%) is probably because”.

Line 249: How do the earthquakes in the FENCAT compare with those in the ESHM20 catalogue in terms of epicentral location and magnitude? In Figure 4 the earthquakes should be plotted in terms of magnitude to facilitate this comparison.

Figure 2: I would suggest adding an extra figure to show the distribution of the seismic source model. Figure 2 should show only the final catalogue for this work where the distribution of earthquakes in terms of magnitude should be highlighted.

Line 312: Replace “is complicated by” with “is difficult due to”.

Line 315: Delete “purposes”.

Lines 320 and the following lines: Indicate the magnitude scale.

Table 2: Why aren’t the recurrence parameters of all ASZs reported in this table? The *a* and b-values for zones 1,4-8,10-12, etc are missing. For transparency, they all should be reported. Is the activity rate computed for 0 Mw? It would be also useful to indicate how many earthquakes within the completeness thresholds were used to estimate the recurrence parameters. As mentioned before, it is unclear which completeness thresholds were used for the estimation of the recurrence parameters. For many zones, the b-value seems to be quite low (< 0.9), what is the reason for this? How do the b-values compare with previous studies, in particular the ESHM20 for similar zones?

Line 383: replace “construct” with “develop”.

Line 415: What is Model 5?

Line 433: Replace “yearly” with “annual”.

Lines 441-444: The hypocentral depths of the earthquakes in the catalogue have not been discussed at all in the manuscript to justify the depth distribution indicated here for the hazard calculations.

Section 4.7: Openquake requires also the definition of the faulting style for potential, future earthquakes, defined by rake, dip and strike. This set of parameters has not been discussed at all in the manuscript.

Line 456: In the revision of the Eurocode 8, the seismic hazard is described in terms of the 5% damped maximum spectral acceleration at a short period and 1.0 s period, and PGA is not mentioned anymore. Would it be useful to estimate national maps also for spectral acceleration for a representative short period (e.g. 0.2 s) and 1.0 s?

Figure 10: What is plotted in Figure 10 exactly? Is this the relative or absolute difference between the new map for Sweden and the ESHM20 maps? It would be helpful to produce such a map also for ESHM20 and the other previous maps discussed in Section 6.2.

References

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