

Interactive comment on “Earthquake-induced landslides in Norway” by Mathilde B. Sørensen et al.

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“General comments”

The submitted paper presents the systematic work conducted and the criteria followed with the aim of producing a new dataset of earthquake-induced landslides occurred over the last two centuries in Norway (Norwegian EQIL), while contributing to the understanding of some characteristics of earthquake-induced landslides in intraplate tectonic settings/conditions.

Large databases concerning earthquakes and landslides (e.g. NNSN, UiB, SEA, NLD) are cross-checked to this end, and the criteria for attributing a trigger-response connection between earthquake and landslides are well detailed (e.g. locations in time and space allowing to establish temporal and spatial coincidences between an earthquake and associated landslides).

The paper presents a clear in-depth analysis of the listed events, discriminating between earthquake-induced landslides with a lower degree of uncertainty, and those associated to a higher degree of uncertainty caused by the inability to locate the landslide or the earthquake or by an insufficient documentation of the failures' link to a seismic trigger. Hence, it is appreciated that the inclusion of records into the final dataset is presented in a clear and transparent manner.

Although the output slope failure dataset is reduced in number (containing merely 22 events), which is recognized by the authors as a shortcoming of their study, its value, and hence that of the study, resides in the pioneering effort put into designing and following a systematic approach for producing a first dataset of seismically induced landslides for an intraplate region. Such an initial database could form the base for a future much developed one, which could be updated through remote sensing, as the authors mention. The study also contributes to supporting the idea of potentially much larger maximum landslide distance limits and landslide-affected areas than previously estimated by global studies, but in accordance with findings from other intraplate regions.

The manuscript is well structured and written and illustrations and tables are all necessary. The conclusions are concise and comprise the most important findings related to the significance of the constructed EQIL catalogue. Overall, it was a pleasure reading this submission, and, for the reasons listed above, the paper is valuable and worth publishing with only some minor revisions which are suggested below.

“Specific comments”

1. On the Figure displaying earthquake of $M \geq 2$ in the region (Section 1.2 Seismicity of Norway, Fig. 1), I would recommend the inclusion of some tectonic features which would enable a better understanding of the general seismic and tectonic settings of Norway, defining the region as an intraplate one.

2. For Section 1.3 Landslides in Norway and their trigger mechanisms, a figure with photos of representative landslide types in Norway would be very helpful. In such a figure, of interest would be to also find at least one photo of a known seismically triggered landslide. If not here, then at least later on

in the paper, (a) photo(s) of recent recorded EQIL would help the reader understand the types of movement triggered by earthquakes.

3. From what I understand, Table 1 (section 3 Results) lists the EQIL dataset constructed in this study. For more clarity, maybe you could add “Norwegian EQIL” in brackets in the table caption. Also, for more clarity, a column listing the “No” would help seeing that this table refers to the 22 EQIL. Further, in this context, I find the explanation “* indicates an uncertain event” a bit confusing. As far as I understand, this table doesn’t contain the uncertain events, which were eliminated from the dataset, as was explained in Section 2 Methods (page 5, lines 129-134). Then, what is indicated with “*”? Does the uncertainty refer to the existence of the landslide? Or does it refer to the movement type attributed to it? This is not very clear and should be explained, in a table footnote or/and in the text.

4. Section 2 Methods, page 5, line 122: The search for seismically induced landslides is restricted to earthquakes of magnitudes $M \geq 4.5$. An explanation would be needed at this point as to why this magnitude threshold was selected when constructing the EQIL catalogue.

5. In Section 4 Discussion, when discussing the landslide distance limits and landslide-affected areas, I would suggest the following:

- page 17, line 348: please specify “limit curve” in: “the empirically derived limit curve of maximum landslide area...”;

- I would recommend using a softer wording for formulating some conclusions, like at page 18, line 349: since the number of observations is small, indeed, I would suggest rewording with the vaguer “seem to confirm the systematically larger distance...” instead of just “confirm the systematically larger distance...”; this would be more truthful to the degree of uncertainty inherent in the data;

- page 18, lines 352-353, caption of Fig. 6: for clarity, I would find it necessary to list the areas’ names and corresponding citations for the grey dots in the caption as well (not only in the text); I also would write the extended explanation for the black curve: “maximum landslide distance limit for disrupted slides and falls from Keefer (1984)”;

- page 18, lines 355-356, caption of Fig. 7: I would suggest adding the reference for the maximum landslide distance corresponding to the 2011 Virginia earthquake; I also would write the extended explanation for the black curve: “maximum landslide area limit from Rodriguez et al (1999)”;

- page 20, line 375: I would suggest putting more emphasis by replacing with: “...lead to differences in the identified/estimated landslide distance limits”, since the differences do not concern the limit itself but rather its identification or estimation based on the available data;

6. The discussion of the relation between EQIL and ground motion intensity for the 1904 earthquake is very important; at this point it would be interesting to also include in the discussion a map displaying EQIL distributed in relation to the Peak Ground Acceleration, if available.

7. With regard to the role of precipitation (presented in Sections 3.3-3.8., pages 13-16, in Section 4 Discussion, page 20, lines 378-385, in Section 5 Conclusions, page 21, lines 412-414, and in the Abstract, lines 15-16), in my opinion, the triggering and the preparatory roles of precipitation are presented a bit confusingly. While in the Results section, precipitation is being analyzed in order to rule out a possible precipitation trigger for the events included in the EQIL dataset (i.e. from a trigger perspective), in the Discussion and Conclusions sections, precipitation is discussed more in the context of its possible contribution to increasing terrain proneness to landsliding (i.e. from a preparatory perspective, of antecedent precipitation leading to soil moisture conditions). While from a trigger perspective, it is common to analyze precipitation amounts up to 5 days before an event, for drawing conclusions regarding the antecedent precipitation conditions, it would be recommended that the period prior to the earthquake and, thus, to the earthquake-induced landslides be a little extended, e.g. commonly at least up to 30 days (e.g. Rosi et al, 2019). Therefore, I would suggest either extending the period prior to the events in order to be able to draw conclusions related to the antecedent role of precipitation potentially increasing terrain susceptibility to landslides, or being more precise in the Discussion and

Conclusions sections about what could be found so far, namely that antecedent moisture conditions may have played a role in preparing the slopes to respond to seismic shaking but that the preparatory role of precipitation and its combination with the earthquake trigger was not investigated in this study. E.g. line 412-414: instead of writing “and for three of the earthquakes triggering EQIL, precipitation is expected to have increased the susceptibility of the affected slopes before the earthquake”, you could write only what has been found/is suspected until now: “and for at least three of the earthquakes triggering EQIL, precipitation is expected to have increased the susceptibility of the affected slopes before the earthquake’.

8. When discussing that all landslide-triggering earthquakes in the constructed dataset are contained in the period April-October (in Section 4 Discussion, page 20, lines 379-381), for more clarity, it should be put into the context of the larger earthquake database which also includes earthquakes occurring in winter but for which no corresponding records of induced landslides were found (Appendix A); this would make the reasoning much clearer.

“Technical corrections”

- Section 3, page 9, caption of Table 1: all the abbreviations in the table (M_L , M_s , M_w) should be explained (either in the caption or as a table footnote);

- Section 3.1, page 10 line 183: please replace “from” with “of”;

- Section 3.1, page 10 line 193: please replace “from” with “of”;

- Section 3.1, page 10 line 196: please insert a comma after “In this study”;

- Section 3.1, page 10 line 200: please move the word “almost” after the word “being”;

- Section 3.1, page 11 line 201: please replace “identified for this earthquake” with “identified in connection to this earthquake”;

- Section 3.1, page 12, Table 2: although it is clear in the text, NLD should also be explained for the table (either in the caption or in a table footnote – depending on the journal’s guidelines). Please also replace the comma with a point in: “Referred to as Storstrand in NLD. NLD...”;

- Section 3.3., page 13, line 240: Please replace the singular with the plural form in: “The precipitation data (Fig. 5) show ...” (since „data” is a plural noun);

- Section 3.3., page 13, line 248: I think you mean “300-400 m” and not “3-400 m”, right?;

- Section 3.3., page 13, line 249: You mean “70 m² of forest” and not “70 m”, correct?;

- Please pay attention when writing the dates. If you choose the British style for dates, I think there shouldn’t be any “.” sign after the date (see lines 247, 254, etc.): e.g. “7 October”- not “7. October”;

- Section 3.4, page 14, Figure 5: please export this illustration with a better resolution, as the graphs appear a little blurry; please standardize the notation on the y-axis: either 24-hour or 24-h”; also, the word “precipitation” on the vertical axes of the graphs appears underlined/underlined - for esthetic reasons this should be removed;

- Section 3.5, page 15, line 262-263: please change the sentence to: “had a magnitude $M_L=4.6$ and a maximum intensity of V ”;

- Section 3.5, page 15, line 281: please replace “the” with “a”: “We expect that this rockfall was triggered by a combination of ...”;

- Section 3.7, page 15, lines 284-285: Please change the phrase as follows: “...with a magnitude of $M_w=4.9$. The event was felt throughout the Nordland region with a maximum intensity of V ”;

- Section 3.7, page 16, lines 292-293: the sentence needs reworded as follows: “This supports the interpretation/hypothesis/conclusion of the earthquake being the main trigger...”;

- Section 3.8, page 16, lines 295: please delete “it”: “...and was strongly felt in...”

- Section 3.8, page 16, line 296: please change to: “with a maximum intensity of V ”;

- Section 3.8, page 16, line 298: I think “the” would need to be changed to “a”, as follows: “where a respondent describes”, right?;
- Section 4, page 19, line 359: please replace with the plural form: “...at similar or higher latitudes”;
- Section 4, page 19, line 360: I would recommend replacing “may” with “would”, as follows: “the landslide area would have been larger if...”;
- Section 4, page 19, line 367 (caption of Fig. 8): I think you mean “Blue squares”, not “Grey squares”;
- Section 4, page 20, line 374: please insert “the” in: “...also suggest that differences in the levels of investigation...”;
- Section 4, page 20, line 377: please remove “it”, as follows: “...and is thus directly comparable to the global studies”;
- Section 4, page 20, line 378: I am not sure future is the correct tense to be used after “It is expected”, maybe it should be: “It is expected that slope susceptibility is important for the extent...”; please check the tense;
- Section 4, page 20, line 389: Please check the English regarding the beginning of the phrase “This is as expected for earthquakes...”, it’s not very clear; maybe it could be replaced with something like: “This is in agreement with the effects of earthquakes of moderate magnitudes....”;
- Section 4, page 20, line 390: please introduce a comma after “From a hazard perspective”;
- Section 4, page 20, line 396: I would recommend replacing “Most of the most landslide-prone areas...” with “Most of the high landslide-prone areas...”;
- Section 5, page 21, line 410: please use the full word instead of “1/2”, as follows: “ ...and half to one order of magnitude larger than....”;
- Section Appendices, page 21, lines 422-424: In the caption of Table A1, also the abbreviations M_L and M_w should be explained as are the others;
- Please be consistent with the use of tenses throughout the paper: e.g. in section 3 Results you use, for similar statements, both present tense (line 242: “and the event is not included in our list”) and perfect (line 289: “ the debris slide has not been included as a separate event”).