

Responses to Reviewers Comments

We thank both reviewers for their highly useful comments and feedback. We believe thoroughly addressing all of their feedback within this revision has significantly improved the manuscript.

We respond to each reviewer's individual comment in red text. At the top of the responses to each reviewer we provide a summary comment explaining the most significant changes and anything else of particular note based on their feedback.

In the annotated manuscript we provide comments where appropriate to highlight how we have made changes in accordance with their feedback e.g. "Here we address Point 10 of Reviewer F by rephrasing the terminology used to describe..."

Summary Response to Reviewer F:

We thank Reviewer F for their highly useful comments regarding restructuring, clarification and simplification of the manuscript. We have accommodated nearly all of the suggested changes, which we believe significantly improves the readability and structure of the manuscript, and substantially help to better place the GESE algorithm's novelty and usefulness for application in the seismic source model evaluation and event-response analysis.

Reviewer F (Anonymous Reviewer):

Dear Authors,

I have only minor suggestions, mostly to streamline the text (in this sense I recommend a thorough review of the text, many parts read rushed), hence my recommendation "See Comments" because "Revisions Required" sounds too strong in this case.

We thank Reviewer F for their very useful suggestions for restructuring, clarification and simplification of the manuscript

Here are the detailed points:

Point 1 - The title is somewhat too long, please consider shortening.

Although the title is certainly long, it does a good job of still concisely summarising the algorithm and accompanying database.

Point 2 - Page 3, sentence at lines 73-75: one or two references after "recent scientific literature" would be appropriate.

We have now added references here which refer to existing approaches for evaluating SSCs within the literature.

Point 3 - Page 3, sentence at lines 75-76: Consider rephrasing as "One approach for evaluating the SSC completeness is to check whether an historical earthquake's rupture can be obtained from the SSC" (Note sure what "appropriate" would mean here).

The following text has been rephrased to clarify that we can evaluate an SSC by checking if ruptures which well match the known information for significant historical events (appropriate ruptures) can be retrieved from the SSC's seismic sources when queried.

Point 4- Page 3, just before previous sentence, the reader feels that the purpose of the paper has not been introduced well enough, hence I suggest to strengthen the text to make it clearer what is the scientific gap that this work is focussing on.

We have now significantly improved the explanation of the scientific gap in the literature. Of the few available methods in the literature for SSC evaluation, they exclusively focus on evaluating the temporal, spatial and magnitude distributions of the generated seismicity, rather than evaluating how well the generated ruptures match the known information for significant historical events. GEESE provides a means of performing such checks, and therefore provides a novel methodology for evaluating/verifying SSCs.

Point 5 - Page 3, lines 79-81: possibly the sentence would read better as "... for earthquakes of Mw 7.0 and above in version 10.0 of the ISC-GEM catalogue (Di Giacomo et al. 2018, Storchak et al. 2013) which occurred ..."

The associated sentence has been rephrased as suggested

Point 6 - Page 3, sentence at lines 82-84: the sentence reads a bit vague and it also seems more appropriate in the Conclusion rather than in the Introduction. At this point of the main text it is not fully clear what the scientific gap is and how the authors intend to address that, and with this sentence the authors says that GEESE does "something" but the algorithm is not yet discussed.

We have removed the slightly awkward mentioning here of how the OpenQuake Engine is leveraged by the GEESE algorithm (this is quite obvious in retrospect from the bulk of the manuscript e.g. mentioning the OpenQuake source typologies, as well the title itself). We have also elaborated within the introduction on how the methodologies for testing SSCs are actually quite limited and primarily associated with evaluating the spatial and magnitude distributions of seismicity generated by the SSCs, rather than examining the rupture geometries themselves.

Point 7 - General comment on the Introduction (mostly from page 3 onward): I feel that some restructuring of the text is desirable (I mostly ask to slightly shuffle the text), following this logic:

We respond here to each sub-point individually.

Point 4. Sub-point 1. Better explain what is the scientific gap this work is addressing (i.e., robust SSC matching), in line with a previous comment;

We now elaborate on the current gap in rupture-focussed SSC evaluation (please see our response to Point 2).

Point 4. Sub-point 2. How the authors intend to fill that gap. In this sense Fig.2 and corresponding text should be right here, so that the reader has already an idea of what GEESE does (that means the sentence starting at line 106 need to be moved up in the text).

We have now moved the sentence originally starting at line 106 to the start of the new section (Section 2. The GEESE Algorithm) as suggested in Point 4, sub-point 4 (please see below), which we believe addresses this suggestion.

Point 4. Sub-point 3. At this point one can say how GEESE compares to other algorithms (as already detailed in the text), however this part could be moved down in the text (Discussion / Conclusions) and make the Introduction shorter.

We think that the best place to first mention how GEESE compares to other rupture algorithms is within the introduction, given it more readily highlights the advantage of GEESE not requiring additional data like the other existing algorithms to generate the finite rupture. We continue to (where appropriate) emphasise the advantages of GEESE over other algorithms within both the discussion and conclusion. The additional truncations to the introduction by creating a new section 2 (please see our response to sub-point 4) helps to make the introduction shorter.

Point 4. Sub-point 4. Finish Introduction with the existing paragraph starting at line 111.

We have started a new section (Section 2: The GEESE Algorithm) for the paragraph which was starting at line 111. This section first summarises the workflow, then explains that the rupture matching component is the emphasis of the manuscript and then provides an overview of the example events we use to demonstrate GEESE.

Point 8 - Page 6, sentences between lines 138 and 143: consider moving these sentences down in the main text when discussing the GMFs, here they are a bit confusing.

The sentence has been simplified to avoid confusion - we agree that discussing in-detail the GMF conditioning based on the TRT is a bit confusing here when we are discussing the rupture matching.

Point 9 - Figure 3, text above GEM Mosaic map: review "... of given a 15 km buffer"

We have rephrased this text.

Point 10 - Page 9, line 185: not sure why an incidental sentence starts, should not be part of the sentence? Or a new one?

We have now split into two distinct sentences which are clearer/simpler for the reader.

Point 11 - Page 9, line 191: what "any criteria" means here? Furthermore, after reaching the end of the sentence one has not clear how you addressed the duplicates considered so far, the next sentence jumps to another situation.

We have simplified this part of the manuscript to emphasise that it is only important (assuming duplicate seismic sources have the same magnitude range and set of ruptures) that we retain one "version" of the seismic source. Therefore, the selection of one "version" instead of another is arbitrary, which we now explain better in the text, and remove any mention of "criteria" here.

Point 12 - Page 9, line 196, why MFD and not FMD? I think in the literature it is usually found "frequency-magnitude distribution (FMD)"

We now use FMD to be more consistent with the literature.

Point 13 - Page 10, line 212: Please consider replacing "If the event is located inside no sources" with "If no source is associated to the event"

Updated accordingly within the text.

Point 14 - Page 10, sentence starting at line 214: please consider rephrasing as "For each event, following all filtering steps (i.e., magnitude, depth, deduplication and spatial), the algorithm either proceeds to the rupture generation stage or terminates if no sources are retained."

This sentence has been rephrased as suggested by the reviewer.

Point 15 - Page 14, line 277: please review sentence containing "... here given otherwise..."

This sentence has been rephrased to make it less confusing.

Point 16 - Page 14, lines 281-282: what would be then a score to consider a rupture not matching the event? And the score for a rupture matching well?

If a rupture has a likelihood of less than 0.1 the rupture is not matched to the event. We have now provided a brief explanation in the manuscript of how the 0.1 threshold was determined.

Point 17 - Page 15: lines 291-294: at this point an explanation of why discarding in case of centroid-hypocenters distance > 50 km would be desirable (I mean, we know that for large earthquakes the two locations can be significantly different). In addition, please revise the English ("... regardless of if ...")

We have now explained more explicitly that we treat rupture centroid to event hypocenter distances of greater than 50 km as as non-acceptable matches, but that this parameter can be relaxed in the algorithm's inputs because it is of course a default value only based on our testing of the algorithm/simply what we think seems like a sensible distance for this threshold.

Point 18 - Page 16, line 330: is not just a rounding effect between Mw 6.75 and 6.8?

With consideration of rounding the Mw values of the ruptures are of course identical. We have now slightly modified the text to acknowledge this.

Point 19 - Page 20 line 385: title of Section 7 is the same as Section 6

Sections 6 to 9 are now named as follows:

Section 6: Matching Ruptures to Events

Section 7: Matches Obtained for the Example Events

Section 8: Matches Obtained for the ISC-GEM Catalogue Events

Section 9: Computation of Ground-Motion Fields for the Example Events

Point 20 - Page 21 line 408: title of Section 8 is the same as Section 6 and 7.

Please see response to Point 19.0

Point 21 - Page 24 , line 482: first time use of "OQ" in the text, suggest to use either OpenQuake or the acronym OQ everywhere in the text

The single use of this abbreviation has been removed.

Recommendation: See Comments

Summary Response to Reviewer H:

We thank Dr. Thingbaijam for his very useful technical and editorial feedback. We believe we have thoroughly modified the manuscript to address all feedback sufficiently. As suggested by Dr. Thingbaijam, we now also consider the 2023 Türkiye earthquake as an example event within this article. A good match is retrieved for this event, which further demonstrates the capabilities of GEESE for retrieving initial finite ruptures in post-event response.

Reviewer H (Kiran Kumar Thingbaijam):

Review comments on “ Global Earthquake Scenarios (GEESE): An OpenQuake Engine-Based Rupture Matching Algorithm and Scenarios Database for Seismic Source Model Testing and Rapid Post-Event Response Analysis by Brooks et al.”

The authors describe the Global Earthquake Scenarios (GEESE) algorithm. The algorithm matches an event to a rupture defined in a source model (specifically, from the seismic hazard models included in the Global Earthquake Model Mosaic), based on a set of criteria. They

suggested that the algorithm is useful to evaluate the source characterizations and also to rapidly define an initial finite-fault rupture for post-event response analysis.

The authors have provided a very detailed description of the algorithm. This algorithm is a useful tool for source verification and can also be applied in rapid post-event analysis. Furthermore, I find the work to be mostly technically sound. The following lists a few comments that I hope will be useful to the authors in improving their manuscript.

Point 1 - L68: What would be “source geometry”? I believe that is defined by parameters as mentioned by the authors - the faulting mechanism and magnitude-rupture area scaling relation, along with the rupture aspect ratio. Perhaps .. “source location”.

We have rephrased accordingly to use the term “source location” given the geometry of the generated ruptures within each source is constrained by the faulting mechanism, magnitude-scaling relationship and the rupture aspect ratio.

Point 2 - L74: “The recent scientific literature presents various approaches to checking the components of an SSC.” This requires some references.

We now reference some existing methodologies in the literature for evaluating SSCs - which can be used to statistically evaluate the abilities of SSCs to model observed seismicity in the region of interest.

Point 3 - L82: “The GEESE algorithm ...” A new paragraph?

This text has been moved into the new Section 2 (please see responses to Point 7 of Reviewer F) to make the reference to more appropriately mention the leveraging of the OpenQuake Engine.

Point 4 - L99: It might be useful to include this aspect of GEESE (i.e., computing GMF) in the abstract.

The automatic computation of GMFs for each matched rupture by GEESE is now mentioned in the abstract.

Point 5 - 106: “For overview, a schematic diagram of the main stages of the GEESE algorithm is provided in Figure 2.”. Perhaps, “An overview of the GEESE algorithm is depicted in Figure 2.”

Based on Point 7 of Reviewer H we now remove Figure 2 and summarise the main steps of GEESE in the text.

Point 6 - L113-115: These events, in terms of magnitude, are not in agreement with the aforementioned application of the GEESE algorithm. This was also pointed out by the authors themselves. This aspect is a weak point of the manuscript when there are many $M_w \geq 7.0$ events to choose from. Key questions: Does the selection of these two events not contradict the development of the GEESE database ($M_w > 7.0$)? Perhaps, the development of the GEESE database could be based on $M_w > 6.4$. On the other hand, one might also suggest that one of the

reasons would be readily available ground motion (I am not sure about the Morocco event) recordings for these events.

We do not believe the use of $M_w \leq 7.0$ example events contradict the application of the GEESE algorithm. We apply the algorithm when creating the database only to $M_w \geq 7.0$ events to help significantly reduce the number of events which must be stored in this initial version of the GEESE database. We think the use of $M_w \leq 7.0$ events is beneficial to the manuscript because it demonstrates that the algorithm can also be used to retrieve initial finite ruptures for more moderate size events. We have now clarified these points in the associated paragraph of the manuscript.

Point 7 - Figure 2. Is this figure necessary? It might be simpler to list the steps in the text.

We have removed this figure to ensure we stay within the 10 figure limit for Seismica, and also because as the reviewer states it is simpler to list these steps in the text.

Point 8 - Table 1. The web link provided in the caption does not match with one in the text (L122).

The links have been fixed to be consistent now.

Point 9 - L142: "(more information is provided on this component of the algorithm in due course)" where? Perhaps - "(discussed later in Section 8)".

We have now clarified where additional discussion of GMF computation is included in the manuscript (now Section 9).

Point 10 - L145. "...the latitude and longitude of the hypocenter". Perhaps - "epicenter". How about hypocentral depth?

Updated as suggested.

Point 11 - L146: "hypocentral": Is it "epicentral"?

We have changed to "epicentral" to correctly reflect that this 15 km buffer is to consider uncertainty in the event's position in lat and lon, and not considering the hypocentral depth.

Point 12 - L179: "lower seismogenic depth" is suddenly introduced. An explanation of why and how lower seismogenic depth is a key parameter here would be useful.

We have provided an explanation of this parameter within the manuscript. It is now clearer how it is an additional source parameter which has uncertainty associated with its derivation, and therefore is an additional parameter we apply uncertainties to when searching for appropriate sources for a given event in the GEESE algorithm.

Point 13 - L271: What are "nodal plane and rake likelihood scores"? In general, how is a likelihood score calculated? Further, how does assigning 0.5 nodal plane and rake likelihood scores turn off the impact of the focal mechanism on the chosen solutions?

We now provide a table (Table 2) which defines each likelihood score and how each is (in summary) computed. We have also explained how the 0.5 value itself is arbitrary, and that assigning a default value uniformly to all of the potentially appropriate ruptures is negating the impact of the nodal plane and likelihood scores because by considering a uniform value such scores have no influence on the total likelihood score (obtained for each rupture by computing the geometric mean of all the individual likelihood scores).

Point 14 - L295: “OpenQuake ruptures always model the rupture hypocenter as equivalent to the rupture centroid”. Would using a model for distributing hypocenter locations over the rupture plane improve the rupture identification process? If so, it can perhaps be considered in a future version of GEESE.

Indeed the use of a model for distributing hypocenter locations over the rupture planes could improve the rupture identification process given the treatment of the rupture centroid as being equivalent to the rupture hypocenter is a considerable assumption if used as filtering criteria (as currently is done within GEESE). Implementation of such an approach would require some fundamental changes to the OpenQuake Engine, but for regions with sufficient seismicity, the implementation of models for distributing the hypocenters along rupture planes should be possible in future versions of GEESE.

Point 15 - L308: “but should be based on hypocentral location”. Is this not implicit?

Updated accordingly in the text.

Point 16 - L310: “Figure 7 and Figure 8” perhaps “Figures 7 and 8”. It might be better to have these two figures as subplots in one figure.

We agree with the reviewer that having a single figure would be more pragmatic in terms of referencing throughout the text, but we believe that keeping the figures separate is best for clarity after some testing (the subplots created in response to this comment were found to be quite overcrowded). Additionally, we now consider the rupture match obtained for the 2023 Turkiye earthquake, and therefore having a separate plot for each is necessary to maintain detailed and good quality figures.

Point 17 - L314: “...corresponding finite rupture models provided by ShakeMap”. Please check. This may not be factual. ShakeMap does not usually provide rupture models. Rupture models are typically obtained through source inversions.

We have now clarified within the manuscript that the “ShakeMap ruptures” are those downloaded from ShakeMap which have been obtained by source inversions, rather than being automatically generated in the ShakeMap service, which could have been interpreted as the case based on the initial phrasing.

Point 18 - L315-318: Unclear as to what the authors want to say here.

We have rephrased the text to better explain how the basic event information provided by ShakeMap can differ from the equivalent information for the finite rupture model downloaded

from ShakeMap (the compilation of the event information and the source inversion used to produce the finite rupture downloaded from ShakeMap are performed independently).

Point 19 - L323-324: “The surface of the matched rupture is more complex than the surface of the ShakeMap rupture.” One reason could be that the SSC considered complexities in the fault geometry that were not captured by the USGS rupture model.

We have updated the text accordingly to note this as a possible explanation for the increased complexity of the matched rupture.

Point 20 - L326-329: These angles are not close enough to be described as similar. On the other hand, one might argue that differences could have stemmed from the different fault geometry.

We have adjusted this text to acknowledge that the dip angles are not similar (they are only really similar in the sense that they are not extremely shallow dip or near-vertically dipping), and that the differences are potentially a result of differences in fault geometry.

Point 21 - L344: “including the observed jumping between fault sections”. Observed jumps between fault sections could be a modeling artefact due to the considered spatial resolution (for example, in resolving geometrical bends).

We realised there was an error with how the sections were being plotted. We now provide updated figures for the Northridge event which no longer have the jumps present (although such jumps are indeed observed for some ruptures generated by multi-fault sources in the USA model). We also correspondingly remove discussion of the jumps in this rupture from the manuscript.

Point 22 - L346-354: The match in focal mechanism is adequate. However, the conclusion about “successfully retrieved very large and complex fault sources” is not entirely accurate (see the previous comment). Also, one needs to investigate known complex ruptures (like the 2016 Mw 7.8 Kaikoura earthquake) to substantiate that conclusion adequately.

We have clarified in this sentence that we are referring to the multi-fault sources themselves being “complex”, rather than the rupture matched here itself. As summarised in Section 5.0 of the updated manuscript, the multi-fault sources behave differently to more conventional seismic source typologies within the OpenQuake Engine, and therefore we consider the ability to well matching rupture for the 1994 Northridge event from a multi-fault source a good example of the GEESE algorithm’s ability to manage and retrieve the most appropriate multi-planar ruptures contained within a multi-fault source.

As suggested by Point 24 we also now consider the 2023 Turkiye earthquake, which does provide an example of GEESE’s ability to provide an appropriate finite rupture for a relatively complex and large rupture.

Point 23 - L364: What would be “additional rupture characteristics”?

We have rephrased this part of the text to explain that we can manually check if the matched ruptures also are consistent with additional information provided in the literature which is not considered in the total likelihood score (for example in the Northridge rupture evaluation we check that the matched rupture is also blind).

Point 24 - L377-381: The cases of other events need references. Are the authors referring to these events as a study of post-event response? In any case, would it be possible for the authors to at least include the analysis for the 2023 Turkiye earthquakes in this manuscript?

We now include the Turkiye 2023 Mw 7.8 event in addition to the existing 2023 Morocco and 1994 Northridge events, and updated where appropriate throughout the manuscript. We obtain a good match in terms of it being an initial rupture. We obtain similar GMFs (expressed as a ratio plot - Figure 9 in the updated manuscript), which well demonstrates the use of GEESE to obtain an initial finite rupture prior to data being available to perform a source inversion within a post-event analysis context for a large event.

Point 25 - L394: “theoretically” Is it “manually”?

We retain the phrase “theoretically” because if an event is assigned to a Mosaic model, then a matching rupture should be retrievable if the associated SSC is well-modelling the rupture surfaces of observed seismicity in the region covered by the model.

Point 26 - L399: Would the authors consider the application of the GEESE algorithm a testing or verification of SSC?

We believe GEESE is applicable for both testing and verification. We can either use the algorithm during development (testing) to make sure we have seismic sources which can generate ruptures representative of significant historical events (or any events) in our catalogue, or we can use it on an already existing model to verify the model can generate finite ruptures for these historical events. This verification process also extends to post-event response - we can check that new significant events not considered in the development of an SSC are still represented by the ruptures within a given Mosaic model's SSC.

We have updated the manuscript's conclusions section to make this clearer, and expanded upon the testing/verification capabilities where appropriate throughout the manuscript.

Point 27 - L427: Perhaps, it would be useful to mention that “a spatial correlation model is used” in L102.

The manuscript has been updated accordingly.

Point 28 - Figure 9. Would it be useful to include a subplot where the GEESE gmf is compared one-to-one (cross plot) with the corresponding intensities given by the ShakeMap?

The new figure 9 provides a similar crossplot to that requested in this Point, but for the Turkiye event (albeit with the same GMMs) to demonstrate how the initial finite rupture provided by GEESE (with no additional data used to inform the rupture model) provides similar GMF values for SA(0.3) as those using the ShakeMap finite rupture resulting from a detailed source

inversion. We prefer to keep figure 10 as a single, regular GMF plot to ensure we provide a clear visual example of the output of the post-rupture matching stage of GEESE and the conditioning process (maximum station distance, retained and discarded stations etc).

This ratio plot now provided in Figure 9 is (in our opinion) more appropriate because using the same GMMs better demonstrates the impact of using different rupture models (the site models are already likely very similar given we used the USGS vs30 mosaic for our own Mosaic site models), whereas comparing the Northridge GMF computed in GEESE with that directly from ShakeMap (where different GMMs are used) makes the impact of the most important component of GEESE (the rupture matching) on the scenario hazard less clear to the user.

We also acknowledge that placing Figure 9 (a GMF cross plot) in the rupture matching results section for the example events (Section 7) is preceding the in-depth discussion of the GMFs in Section 9, but it is both an important and interesting way to demonstrate how the less complex GEESE rupture provides similar GMFs to the ShakeMap rupture.s

Point 29 - Line 543 "... permits additional interrogation". What would be the additional interrogation?

We have now made clear in the text that by "additional interrogation" we are performing further checks on the parameterisations of the seismic sources which are not capable of generating matching ruptures despite being selected by the GEESE algorithm

Recommendation: Revisions Required