

Reviewer 1:

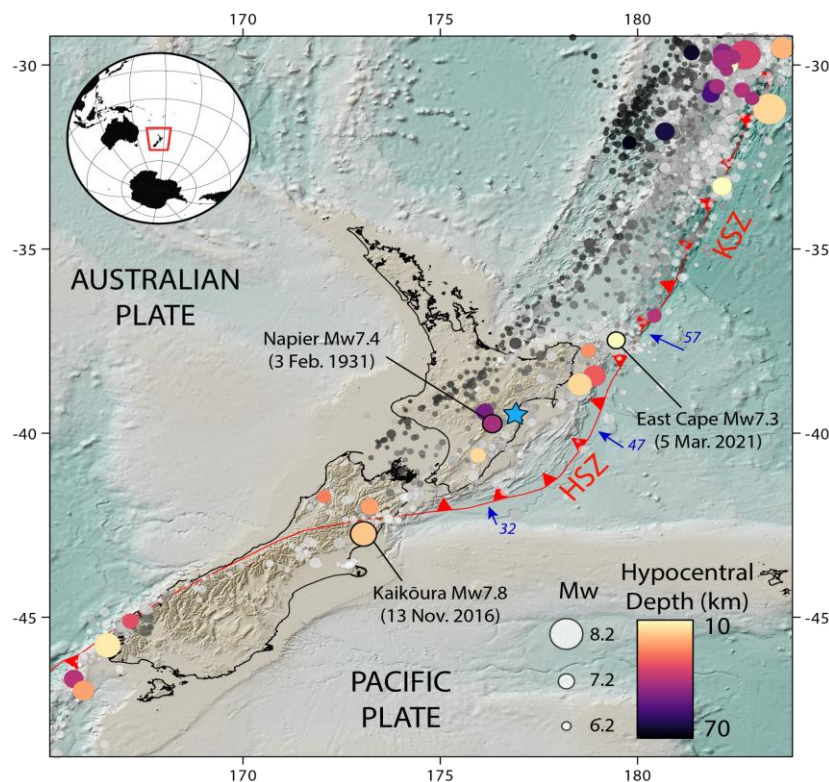
Recommendation: Technical Corrections

The manuscript entitled “An internally consistent framework for calculating cascading probabilistic earthquake risk and its application to a case study in New Zealand” presents a valuable contribution about how to create an internally consistent framework for calculating earthquake risk.

The authors have carefully addressed the reviewers' comments and provided detailed and satisfactory responses to the concerns raised during the previous review process. The manuscript has been substantially improved, and the revisions have enhanced its overall quality. In its current form, the manuscript is well written, the figures are of publishable quality, and the level of originality is appropriate for the journal. I believe that the manuscript has reached a publishable standard and can be accepted for publication in NHESS.

I have only one minor suggestion. In Figure 1, it would be beneficial to include arrows indicating the relative motions of the tectonic plates. In addition, showing the direction of subduction would improve the seismotectonic map and make it easier for readers who are not familiar with the regional tectonic setting to understand the geological framework.

We thank the reviewer for the suggestion. We have updated Figure 1 accordingly. Please find it below:



Reviewer 2:**Suggestions for revision or reasons for rejection**

(visible to the public if the article is accepted and published)

Dear authors,

Thank you for your work. I have included my suggestions below.

Best

We sincerely thank the reviewer for the thorough and thoughtful evaluation of our manuscript. We greatly appreciate the time and effort devoted to providing such detailed and constructive comments, which have helped us improve the clarity, structure, and overall quality of the manuscript. We have carefully considered each comment and revised the manuscript accordingly. Our responses to the individual comments are provided below.

Abstract

It is concise and technically sound. However, several improvements could strengthen it.

1- Novelty should be stated more explicitly. Example, abstract repeatedly mentions "integration" and "correlation," but the specific methodological innovation remains somewhat vague.

We thank the reviewer for this valuable comment. We have revised the abstract to state the methodological novelty more explicitly by including additional details on the proposed modelling framework.

Updated text:

The key methodological innovation is a fully correlated Monte Carlo framework that propagates uncertainty from earthquake rupture through sequential hazard models (ground shaking, tsunami, liquefaction, and landslides) to asset damage, preserving the conditional dependence between primary and secondary hazards at every stage of the simulation. This enables physically consistent realization-by-realization estimates of cascading losses rather than combining independently simulated hazards.

2- Please explain more clearly what differentiates this study from previous multi-hazard risk models.

Please find below the updated text addressing this question:

Updated text:

Quantifying the combined effects of earthquakes and their cascading hazards is essential for realistic risk assessment, yet most existing multi-hazard frameworks either neglect the correlations between cascading perils or represent them using simplified assumptions.

3- In abstract, you can consider including one or two numerical findings that would strengthen the impact of the abstract.

Thank you for this suggestion, please find below the updated text addressing this question:

Updated text:

Results include damage state and damage ratio metrics for individual and combined perils, allowing attribution of losses across hazards. Ground shaking and liquefaction contribute approximately 60% of the average annual building damage, with lateral spreading accounting for a further ~35%, while tsunami contributes less than 3% on average. However, for very rare events (return periods >10,000 years), tsunami losses become comparable to those from ground shaking and liquefaction, demonstrating the importance of explicitly modelling cascading hazards. The framework provides decision makers, urban planners, and the (re)insurance sector with actionable metrics to guide resilience investments, refine underwriting, and minimize losses from cascading hazard events.

Introduction

4-The introduction section should explain the difference between the proposed knowledge and existing probabilistic multi-hazard approaches more explicitly. It helps being more comprehensive. A clearer comparison with recent frameworks would help readers better understand the methodological novelty and scientific contribution of the study.

We thank the reviewer for this valuable suggestion. We have revised the Introduction to more clearly distinguish the proposed framework from existing probabilistic multi-hazard approaches.

Updated text:

Existing probabilistic earthquake multi-hazard studies have progressively expanded the range of hazards considered; however, they generally involve a trade-off between the number of cascading hazards represented, the treatment of uncertainty, and the ability to quantify long-term probabilistic risk.

Expansion on Goda (2020)

However, the framework was limited to the direct impacts of ground shaking and tsunami, and did not account for earthquake-induced ground failure processes such as liquefaction, lateral spreading, and landslides. Consequently, it did not capture the full cascade of earthquake-induced hazards that can substantially influence losses, particularly in regions such as New Zealand where these secondary hazards are common.

Expansion on Dunant et al (2021)

However, the emphasis of that framework was on representing interactions between different hazard types rather than preserving the realization-by-realization conditional dependence between earthquake source characteristics, cascading hazard intensities, and asset damage.

5-You can also use references of recent multi-risk and cascading hazard studies from the last 3–5 years would strengthen the literature review.

We thank the reviewer for this suggestion. The Introduction has been revised to include additional recent literature on probabilistic multi-risk and cascading hazard assessment, including Goda & De Risi (2023), and to strengthen the comparison between existing probabilistic frameworks and the proposed methodology. We also expanded the discussion of recent studies already cited in the manuscript (e.g., Tocchi et al., 2023 and Iannaccone et

al., 2024) to better highlight the remaining research gaps and the methodological contribution of the present work.

Recent reviews have also highlighted the need for probabilistic frameworks capable of representing cascading hazard interactions and propagating uncertainty consistently across hazard, vulnerability, and loss models (Goda & De Risi, 2023; Behrens et al., 2021). Existing probabilistic earthquake multi-hazard studies have progressively expanded the range of hazards considered; however, they generally involve a trade-off between the number of cascading hazards represented, the treatment of uncertainty, and the ability to quantify long-term probabilistic risk.

Goda and De Risi (2023)

More recently, Goda and De Risi (2023) reviewed the evolution of earthquake–tsunami catastrophe modelling and identified the explicit representation of cascading and compounding hazards as one of the key directions for future probabilistic risk assessment

Behrens et al. (2021)

Existing probabilistic earthquake multi-hazard studies have progressively expanded the range of hazards considered; however, they generally involve a trade-off between the number of cascading hazards represented, the treatment of uncertainty, and the ability to quantify long-term probabilistic risk.

6-Section 1.3 explains much, some of this discussion may fit better in the methodology section, allowing the introduction to remain more concise.

We agree that part of the original Section 1.3 was overly methodological. We have therefore condensed the discussion in the Introduction and retained only a brief description of the framework's key innovation, while referring readers to Section 2 for the full methodological details. The detailed description and novelty of the proposed framework has been moved to Section 2.1 ("A Monte Carlo–based approach for cascading hazards").

Please find below the updated 1.3 Section:

This study develops a probabilistic framework for quantifying the combined physical damage and loss ratios arising from earthquake-induced cascading hazards, including ground shaking, tsunami inundation, liquefaction, lateral spreading, and landslides. The framework propagates uncertainties consistently through the hazard and damage modelling chain using a fully correlated Monte Carlo simulation, enabling the estimation of physically consistent multi-hazard risk metrics from a stochastic earthquake catalogue.

The framework is demonstrated through a case study of residential buildings in Napier City, New Zealand, exposed to earthquakes generated by the Hikurangi Subduction Zone (Sect. 3). The resulting risk metrics support applications including land-use planning, emergency management, resilience assessment, mitigation prioritization, and insurance decision-making.

Methodology

7-In methods, selected mappings require further justification. A discussion of uncertainty and sensitivity associated with the harmonization procedure would strengthen confidence in the results.

We thank the reviewer for this comment. We interpret the comment as referring to the damage state harmonization procedure, which is described in detail in Supplementary Material S8 (Fragility/Vulnerability Modelling). We have also expanded the Limitations section to discuss the associated assumptions and uncertainties, and to identify this as an area for future research.

Please find below the updated text:

The adopted harmonization procedure also introduces uncertainty into the estimated losses, and a systematic sensitivity analysis of alternative mapping approaches is recommended as future work. Owing to the modular structure of the framework, these components can be updated as improved hazard and fragility models become available.

8-Also, additional validation of the integrated multi-hazard framework would improve confidence in the methodology.

We thank the reviewer for this comment. We agree that additional validation of the integrated framework would further increase confidence in the methodology. However, validation of regional cascading multi-hazard models is inherently challenging due to the scarcity of observational datasets documenting multiple interacting earthquake-induced hazards and their impacts, particularly in New Zealand. The individual hazard and vulnerability models adopted in this framework have been independently developed and validated in the literature. The objective of the proposed framework is therefore to provide a physically consistent and internally coherent representation of the relationships between earthquake shaking and cascading hazards, rather than to reproduce a single historical event. We have clarified this point in the revised manuscript.

9-The study captures conditional hazard dependencies but does not clearly model sequential vulnerability changes caused by preceding damage. The implications of this assumption should be discussed more thoroughly, particularly given the focus on cascading hazards. You acknowledge that path-dependent damage processes are not modelled. This is potentially important because earthquake damage may increase tsunami vulnerability, liquefaction may increase susceptibility to lateral spreading, or cascading impacts may not be adequately represented through simple damage-state aggregation. Because the paper's main contribution is cascading hazard assessment, this limitation deserves greater discussion.

Thank you for this comment. The combination of damage states is handled through the damage state harmonization procedure, which maps damage from individual perils into a unified damage scale based on the fragility model definitions. This approach does not account for sequential weakening effects (e.g., earthquake damage increasing vulnerability to tsunami loads), as described in Section 3.2.7 in the main manuscript. We have clarified

this limitation in the manuscript and added a reference to Petrone et al. (2020), which presents fragility functions for sequential earthquake–tsunami loading.

Lines 364 to 369:

In multi-hazard risk assessment, particularly when evaluating cascading impacts from cascading hazards, a key challenge arises from the need to integrate damage estimates derived from different fragility models, each with their own damage state definitions and granularity. This process, known as damage state harmonization, involves mapping and aligning the distinct damage classifications used for different perils into a unified framework. While this approach enables the combination of damage from multiple hazards, it does not explicitly account for sequential weakening effects, where damage caused by one hazard (e.g., earthquake shaking) may increase vulnerability to subsequent hazards (e.g., tsunami loading). Such path-dependent damage processes are therefore not represented in the current implementation, although they have been explored in previous studies (e.g., Petrone et al., 2020).

Crescenzo Petrone, Tiziana Rossetto, Marco Baiguera, Camilo De la Barra Bustamante, Ioanna Ioannou, Fragility functions for a reinforced concrete structure subjected to earthquake and tsunami in sequence, Engineering Structures, Volume 205, 2020, 110120, ISSN 0141-0296, <https://doi.org/10.1016/j.engstruct.2019.110120>.

10- Liquefaction aggravation factors appear empirical. The authors should explain their derivation, supporting literature, or calibration process.

We thank the reviewer for this important comment. We acknowledge that the derivation of the liquefaction aggravation factors was not sufficiently explained in the original manuscript. These aggravation factors were adopted from previous work by Lin et al. (2024), where they were derived using Liquefaction Severity Modelling together with observed building damage from the major Christchurch earthquakes. The underlying analyses were undertaken as part of a confidential report prepared for the New Zealand Earthquake Commission (Toka Tū Ake), and therefore the full methodology and calibration data cannot be published. In this study, the aggravation factors are not proposed as universally applicable relationships but are used solely to demonstrate the applicability of the proposed probabilistic multi-hazard framework. To clarify this limitation, we have explicitly stated the confidential nature of the source in the manuscript, included it in the Limitations section, and highlighted the need for future research to develop and validate publicly available liquefaction aggravation factors using additional observational datasets.

Please find below the updated text in Section 3.2.7:

The liquefaction aggravation factors adopted in this study were derived from Liquefaction Severity Modelling and observed building damage from the major Christchurch earthquakes as part of a confidential project undertaken for the New Zealand Earthquake Commission (Toka Tū Ake). The same confidential datasets and analyses were also used by Lin et al. (2023) to develop vulnerability functions for multi-storey residential buildings in New Zealand, although the liquefaction aggravation factors presented here represent a separate output from that project. Owing to the confidential nature of the underlying report and datasets, the detailed derivation and calibration of the aggravation factors cannot be

presented. Accordingly, the factors are used here to demonstrate the proposed framework, and future work should focus on developing and validating publicly available liquefaction aggravation factors.

11- Only 33 tsunami source scenarios and 10 slip realizations per scenario are used. But it remains unclear whether this sample adequately captures tsunami variability. A brief discussion of representativeness would be useful.

We thank the reviewer for this comment. The 330 tsunami simulations (33 source scenarios with 10 stochastic slip realizations each) represent a substantial suite of high-resolution, physics-based hydrodynamic models for a regional-scale study. While a larger number of simulations would further sample the uncertainty, the number of scenarios considered reflects a practical balance between representativeness and the considerable computational cost of solving the non-linear shallow water equations at fine spatial resolution. The selected source and slip realizations were designed to capture the principal aleatory and epistemic uncertainties associated with tsunami generation and inundation. We acknowledge that the uncertainty associated with the most extreme loss estimates cannot be fully quantified without a substantially larger scenario set. However, convergence testing of the Monte Carlo simulations, as described in Section 3.2, indicates that the average and median loss estimates presented in this study are robust. To clarify this point, we have expanded the discussion in Section 3.2.2 of the revised manuscript.

12- The $\pm 2\%$ threshold used in convergence testing, why it was it. The manuscript should explain why $\pm 2\%$ was selected and whether conclusions are sensitive to this choice. You can reduce the repetition. Like “hazard intensities are derived consistently from the same earthquake event” or rephrase.

We thank the reviewer for this comment. We would like to clarify that the $\pm 2\%$ value was not used as a stopping criterion for the Monte Carlo simulations, but rather as a simple indicator to illustrate convergence. In practice, the simulations were continued well beyond the point at which this level of convergence was achieved. We agree that this was not sufficiently clear in the original manuscript and have revised the text to explain that the $\pm 2\%$ value was adopted only as a representative measure of convergence, while the reported results are based on a larger number of simulations.

Please find below the updated text in the Convergence Analysis Section (3.3):

The mean MDR stabilized to within $\pm 2\%$ after approximately 120–180 simulations, indicating convergence (Figure 5 shows an example for a Mw7.5 earthquake). The $\pm 2\%$ value was used only as a representative indicator of convergence and not as a stopping criterion. Accordingly, 200 simulations per event were performed to provide an additional margin beyond the observed convergence point.

13- Figure 2 could be improved by indicating where uncertainty enters, where Monte Carlo sampling occurs, or where correlations are preserved.

We thank the reviewer for this suggestion. Figure 2 was intentionally designed as a simplified overview of the framework to improve readability. To address the reviewer's comment without increasing the complexity of the figure, we have revised the caption to clarify that Monte Carlo sampling occurs between each stage of the workflow and that event-level correlations are preserved throughout the framework. We would be happy to update it if the changes are not considered sufficient.

Please find below the updated caption for figure 2:

Damage state (DS) and damage ratio (DR) calculation diagram for each simulation (i) performed for every event in the stochastic catalogue. Monte Carlo sampling is performed between each stage of the workflow, while the hazard realizations remain conditioned on the same earthquake event, thereby preserving the correlations between cascading hazards.

Results

14-Results are largely descriptive. Most findings describe what the figures show. Please explain a little, Why does liquefaction dominate over tsunami?, Why does lateral spreading become relevant at intermediate return periods? What aspects of Napier's exposure drive these results? These would strengthen the section.

We thank the reviewer for this helpful suggestion, we believe this has been addressed in the revised Results section, particularly in the discussion accompanying Figure 8:

The relative contribution of each hazard reflects both the regional hazard characteristics and the spatial distribution of exposed assets in Napier City. Ground shaking contributes to losses across all return periods because the entire building stock is exposed to earthquake shaking, although local amplification varies according to site conditions. Liquefaction also contributes substantially owing to the geological characteristics of Napier, where a large proportion of the urban area is susceptible to liquefaction (Figure S10a). Lateral spreading becomes increasingly important because the city is intersected by numerous rivers, streams, and drainage channels, resulting in many buildings being located within areas susceptible to lateral spreading. Although landslides contribute less to the total city-wide losses, they remain an important hazard because a significant proportion of the building stock is located within the hilly suburbs surrounding Napier. Tsunami represents another key hazard given the city's proximity to the Hikurangi Subduction Zone, whose rupture mechanisms are capable of generating large tsunamis. However, tsunami inundation in Napier is partially constrained by the local topography, as described in Section 3.2.2 and Supplementary Section S3, resulting in significant tsunami losses only for the largest earthquake scenarios.

15-It seems that the proposed framework suggests uncertainty through multiple hazard and damage models, the results should include uncertainty metrics such as confidence intervals, percentile ranges, or exceedance bands.

We totally agree with the reviewer on this point. Please find below:

Following the convergence analysis, the complete stochastic event catalogue was simulated 200 times, with uncertainty sampled and conditionally propagated throughout the ground-

motion, cascading-hazard, and damage-modelling chain during each realization. For each risk metric, the mean, 5th percentile (P5), and 95th percentile (P95) were calculated across the 200 catalogue realizations to quantify the uncertainty associated with the model outputs.

To address the reviewer's comment, we have expanded both the main manuscript and the Supplementary Material to explicitly present these uncertainty metrics. The following additions have been incorporated:

Figure 7- regional damage states:

To account for uncertainty, the complete stochastic event catalogue was simulated 200 times, with uncertainty sampled and propagated through the ground-motion, cascading-hazard, and damage-modelling chain during each realization. The results presented correspond to the median (50th percentile) damage-state distribution across the 200 stochastic catalogue realizations. The relative variability (coefficient of variation) generally decreases with increasing return period, reflecting the more spatially consistent and severe damage associated with larger earthquake events.

Figure 8: Mean damage ratios by peril:

We have calculated the 5th and 95th percentiles for each peril at each return period and included them in the supplementary material.

In addition, this is mentioned in the main manuscript as follows:

Uncertainty differed among hazards, with the smallest variability observed for ground shaking and larger variability for the cascading hazards, reflecting the increasing influence of local site conditions and complex hazard interactions. Detailed percentile estimates are provided in Table S2 and S3 of the Supplementary Material.

Figure 9:

To provide an indication of the uncertainty associated with the Average Annual Mean Damage Ratio (AAMDR) estimates, the coefficient of variation (COV) was calculated for each grid cell across the study region. The resulting COV values are presented as a spatial map in Figure S11, illustrating the relative uncertainty associated with the estimated AAMDR.

16-Several figures present return periods up to 100,000 years. It is technically possible but such return periods are difficult for practitioners to interpret. You may consider emphasizing 100 years, 500 years, 2,500 years, 10,000 years, which are more commonly used in risk management.

We thank the reviewers for the suggestion and agree that return periods up to 10000 years are more commonly used in earthquake risk assessments. We propose the following two paragraphs for emphasising the results at key rps.

Figure 7:

Beyond return periods of approximately 2,500 years, however, the proportion of undamaged buildings (DS0) falls below 20%, while severe damage (DS4) increases rapidly. By return periods of 5,000–10,000 years, DS3–DS4 become the dominant damage states, indicating that widespread heavy damage and collapse are the expected outcomes of these rare megathrust events.

This progression reflects not only the increasing intensity of ground shaking but also the growing contribution of cascading hazards. As earthquake magnitude and rupture extent increase, stronger and more spatially extensive shaking leads to higher probabilities of liquefaction, lateral spreading, landslides, and tsunami inundation, which compound the direct effects of seismic loading. Consequently, the damage progression with return period is driven by the combined effects of multiple hazards rather than by ground shaking alone.

Figure 8:

Disaggregated MDR results (Figure 8) show that ground shaking and liquefaction dominate building damage across most return periods. The difference between the ground-shaking and shaking-plus-liquefaction curves increases with return period, demonstrating the increasing contribution of liquefaction under stronger shaking. This behaviour reflects Napier's highly susceptible geological conditions and is consistent with observations from the 1931 Mw 7.3 Hawke's Bay earthquake.

Tsunami damage contributes little at short and intermediate return periods but increases rapidly for return periods exceeding approximately 10,000 years, where its TMDR becomes comparable to that from ground shaking. This behaviour is consistent with the tsunami hazard curves (Supplementary Section S3), which show threshold behaviour associated with inundation of the Ahuriri Estuary and overtopping of the 4–6 m coastal gravel ridge.

Lateral spreading is the most important secondary ground-failure hazard after liquefaction, particularly at intermediate return periods. Although its contribution to TMDR remains relatively small because of the limited exposed area, the RMDR results show that it can produce substantial damage to buildings located within susceptible zones.

Landslides contribute the least to TMDR because relatively few buildings are located in susceptible terrain. However, the RMDR results and Figure 9 show that, for exposed buildings, landslides become one of the dominant damage mechanisms, indicating that their low city-wide contribution reflects limited exposure rather than low hazard severity.

Figure 9: we have included a more detailed text (described in comment 19)

17-Figure 7 presents building proportions across damage states. However, it would be useful for readers/ adding these, expected number of damaged buildings, percentage increase between return periods, cumulative exceedance probabilities (if possible). Because available presentation seems somewhat difficult to practical implications.

We agree that expressing the results solely as proportions may limit their practical interpretation. To address this comment, we have added Table S2 to the Supplementary Material, which reports the estimated number of buildings in each damage state for every return period.

18-AAMDR is one of the most valuable outputs of the study. But interpretation remains brief. You can address, why do certain zones emerge as hotspots? Which hazards dominate these hotspots? Are they driven by exposure density or hazard intensity? Would be much better.

We suggest enhancing the AAMDR results section including the following text:

The highest AAMDR values are concentrated in the central-eastern part of Napier, where relatively high exposure coincides with areas susceptible to liquefaction and lateral spreading. These hotspots are therefore controlled by the combination of high hazard intensity and high exposure, rather than by either factor alone. Additionally, zones identified as landslide-prone display elevated AAMDR values, indicating the significant influence of local topographic effects on the spatial pattern of cascading hazard impacts. This spatial pattern is consistent with the hazard disaggregation results (Figure 8), which show that ground shaking and liquefaction dominate the average annual damage, while landslides and lateral spreading produce localized increases in damage where buildings are exposed to these hazards.

Discussion

19- This section largely repeats the results. In particular, it restates findings already presented in Figures 7–9. For example ,shaking is dominant, liquefaction amplifies losses, tsunami becomes important at long return periods, landslides contribute less overall. These are okay, but there is limited effort to place these findings within the broader earthquake risk literature.

In the revised manuscript, we have revised the structure of the paper to provide a clearer distinction between the Results and Discussion sections. The Results section now focuses on presenting and describing the findings, while the Discussion emphasizes the proposed methodology, the broader implications of the results, and the contribution and value of the framework in the context of existing earthquake risk assessment literature. We have also expanded the Discussion by comparing our findings with previous studies and highlighting the advantages of the proposed probabilistic multi-hazard framework for regional earthquake risk assessment.

20- The discussion section needs stronger engagement with existing multi-hazard risk literature and critically discussing their implications.

There is limited comparison with previous studies. In the paper, there are references like Goda, Dunant et al., Moratalla and Uma, Iannaccone et al. but the discussion does not revisit these studies to explain similarities or differences in findings. Such comparisons would help contextualize the contribution and generalizability of the proposed framework. The manuscript's main contribution is methodological rather than the Napier case study itself. However, the discussion focuses mostly on Napier-specific results. This is arguably the most important scientific discussion missing from the paper. More attention should be given to the methodological implications of preserving inter-hazard dependencies and the advantages of this approach over independent hazard modelling.

We thank the reviewer for this valuable comment. We have substantially revised the Discussion to focus on the methodological contribution of the proposed framework rather than the Napier case study alone. In particular, we now discuss the advantages of preserving the dependencies between ground shaking and cascading hazards within a single probabilistic framework, compared with conventional hazard-independent approaches.

21-A dedicated "Limitations" subsection would improve transparency. Because there are limitations like no path-dependent damage, no tides/storm surge, no sea-level rise, limited tsunami scenarios.

Thank you for this suggestion, a new Limitations subsection has been added to the manuscript. Please find below:

The proposed framework has limitations that should be acknowledged. Path-dependent damage is not represented, such that structural damage caused by earthquake shaking does not modify the vulnerability of buildings to subsequent hazards (e.g., tsunami), owing to the limited availability of fragility models describing sequential hazard interactions. The tsunami modelling does not account for debris impact, tidal stage, storm surge, or long-term sea-level rise. The earthquake-induced landslide model considers only coseismic triggering and therefore does not account for antecedent rainfall, seasonal groundwater conditions, or other hydrological controls on slope stability. The liquefaction and lateral spreading assessments rely on empirical relationships, while the harmonization of damage states across hazards represents a necessary simplification to enable the integration of different fragility models within a unified probabilistic framework. Owing to the modular structure of the framework, these components can be updated as improved hazard and fragility models become available.

22-Discussion and conclusions could be separated. Future research directions are brief, it could be improved.

In the revised manuscript, we have included a separate Conclusions section, which now incorporates a dedicated paragraph outlining future research directions. We have also revised the structure of the manuscript to provide a clearer distinction between the Results and Discussion sections. The Results section now focuses on presenting and describing the findings, while the Discussion is centered on the proposed methodology, the broader implications of the results, and the contribution and value of the framework in comparison with existing earthquake risk assessment literature.

In conclusion (separated)

23- The conclusion should sufficiently emphasize the scientific contribution. Now, manuscript's main contribution is the development of an internally consistent probabilistic multi-hazard earthquake risk framework. However, the concluding statements focus largely on general observations. In conclusion, you should use this structure, main findings, scientific contribution, practical implications and future work.

We agree with the reviewer and appreciate the suggestion. new Conclusions section has been added to the manuscript. It summarizes the main findings, emphasizes the scientific contribution of the proposed internally consistent probabilistic multi-hazard earthquake risk framework, discusses its practical implications, and outlines future research directions. Please find the new section below:

This study presents an internally consistent probabilistic framework for assessing earthquake risk from cascading hazards by integrating ground shaking, tsunami inundation, liquefaction, landslides, and lateral spreading within a unified modelling approach. The framework preserves the conditional dependence between primary and secondary hazards through a fully correlated Monte Carlo simulation, enabling physically consistent estimates of damage and loss across multiple interacting perils.

By preserving the conditional dependence between cascading hazards throughout the modelling chain, the proposed framework provides a physically consistent basis for regional multi-hazard earthquake risk assessment. Its modular structure enables both empirical and physics-based hazard models to be integrated within a common probabilistic framework and facilitates the incorporation of improved hazard and vulnerability models as they become available. The resulting risk metrics can support resilience planning, emergency management, infrastructure prioritization, and (re)insurance applications by quantifying the relative contributions of individual hazards to overall earthquake risk.

Application of the framework to Napier, New Zealand, demonstrates the importance of explicitly modelling cascading hazards in regional earthquake risk assessments. While ground shaking and liquefaction dominate average annual losses, tsunami becomes increasingly significant for very rare events. Landslides have a more localized influence but can produce substantial impacts in affected areas, making their relative contribution important at the local scale. Together, these findings highlight the value of considering multiple interacting hazards when assessing earthquake risk.

Future work will focus on incorporating additional earthquake-induced hazards, improving fragility modelling to better represent sequential hazard interactions and path-dependent damage, and further validating the integrated framework as observational data from cascading hazard events become available.

Thank you again for your work.
Best