Equivalent Hazard Magnitude Scale
Yi Victor Wang, Antonia Sebastian

Referee - John Hillier

I like the idea of this paper, but it needs to be much more clearly written - I am afraid I had to re-read many times to understand the driving purpose, method proposed, and assumptions. It would benefit greatly from being focussed and simplified. A major revision is needed in terms of the text, whilst the underlying work seems mainly robust.

12 hazards are considered. The innovation is a creating a new standardized measure of impact (*IM*) by combining 3 loss/impact measures from EM-DAT after log transforming and standardizing data each. *IM* is then related (linear regression) to measures of hazard severity (e.g. Richter scale) for each hazard, such that for each hazard event (e.g. M_w = 6.7) a *IM* can be estimated, which is then linearly scaled to fit a range [0,10], called 'equivalent magnitude' *EM*. Finally, on the premise that hazard characteristics of events that appear in EM-DAT are a representative sample of all similar events, and that averaging (via regression) allows all local risk related aspects (e.g. exposed assets, vulnerability) to cancel out, the authors argue that measures of hazard severity (e.g. Richter scale, area flooded) can be compared via their *EM* values. This permits events (e.g. a cat 5 hurricane and a M_w 6.7 earthquake) to be compared in terms of potential to cause damage (i.e. hazard) in a way that is as decoupled as possible from local human exposure (i.e. assets at risk), albeit entirely based upon the relative typical size of impact of each event type.

Please find below some more major comments, and a non-exhaustive selection of minor comments. I have only considered the text in any detail to the end of Section 4.1 as I assume a second round of review will be necessary.

Major comments

1. I have substantial difficulty with the authors' desire to name a scale they '*propose*' (L10) in this paper after a person (i.e. Gardoni). This is primarily for two reasons.
   - The first reason is the appropriateness of doing this, something not related to the scientific content of the article, so I explicitly ask the journal's editorial team to take a view. For instance, has Gardoni been asked? Is it in the editor's view acceptable scientific practice?
   - The second reason follows from this, and in my view needs the manuscript (e.g. Abstract, Introduction to be rephrased). If the authors use 'the Gardoni scale', a citation to the work it was developed in is sufficient, without further elaboration. If the scale is developed in this paper, I question the justification for the naming. '*Equivalent hazard*' scale should be sufficient if it's novel ..... and others may call it the Wang Scale later if they so choose.

2. Clarity of writing: Throughout, the paper would benefit from simplification and focussing on key points. Illustratively, L11-21 of the abstract provide details, but make little sense before a detailed reading of the paper. Please seek to provide an overview of purpose and a sense of some of the assumptions involved. To simplify, please consider what is truly

necessary for the paper; e.g. (i) reduce Section 2 to Fig. 1 and a short paragraph (ii) Section 3 could be written considerably more succinctly. And, is Table 3 really need to understand the paper's main point? (iii) Section 3.3 might be best in an Appendix to preserve the flow of the paper.

3. Introduction and framing: This work does something new I think, but the way it is presented does not help this argument.

Selected minor comments

L17 - 'we argue' instead of 'we show', you are suggesting something, not providing a definitive and unique answer.

L25 - Use 'hazardous events' rather than 'hazard event'.

L25 - Suggest delete 'with a strong natural force' - example of words that are vague and as such add little meaning and detract from the focus of the text. I illustrate in the next comment.

L27 - "..... these events. The impact of events, whatever their type, can be quantified directly (e.g. by financial loss)(Hillier *et al*, 2015). Various impact scales have also been proposed including the Bradford ....." - I would just name 1 or 2 scales and put the references at the end of the sentence.

L30-38 - Consider using examples to communicate more clearly e.g. the Christchruch quake in New Zealand is an example of a small quake causing lots of damage.

L53-61 - This paragraph finishing the framing of the work needs re-writing. My first point is observation, and my second is a suggestion.

- I didn't use the Gardoni scale in Hillier *et al* (2015, 2020a). Indeed, how could I have as it is proposed here. In 2015 & 2020a I used financial impact as a metric to allow comparison of multiple hazards and their severity (4 and 7 hazard respectively). In Hillier *et al* (2020b), I use what I refer to as 'impact-based proxies' for hazard to map and understand the estimated combined severity of two hazards (extreme wind and flooding).
- The work proposed here certainly builds on the limited (i.e. two hazard) work in Hillier (2020b), which itself builds on a substantial history of what I dubbed '*impact-based proxies*' (i.e. hazard measures designed to - hopefully - closely relate to impacts) e.g. v^3 over a threshold is very established for wind (e.g. refs [33-38] in Hillier 2020b - Southern (1979), Klawa (2003)). So, I suggest starting the paragraph with this context (and likely references for other hazards) building to the necessity of a generalized Equivalent Hazard Scale - perhaps with a structure similar to the bullets below.
    - Impacts (e.g. financial losses) have directly used to compare and understand dependencies between multiple (up to 4 or 7) hazards (e.g. Hillier *et al* 2015, 2020b), but strictly this limits understanding to a particular stakeholder (e.g.

insurers, the UK rail network). Indeed, insurers are very experienced at using loss as a metric to understand the relative significance of various hazards [see detail below].
    - Similar about nuclear sector, perhaps mentioning scenarios [I know this exists, but don't have details to hand].
    - There are also indices that integrate multiple weather extremes, but ..... [again see below].
    - A calibration of hazard to impact has been used to create 'impact-based proxies' for hazard, linking two extremes and allowing them to be studied in a way that is relevant to risk and yet decoupled from the detail of local human exposure (Hillier, 2020a).
    - But, there is not as yet a general multi-hazard measure that permits events (e.g. a cat 5 hurricane and a M_w 6.7 earthquake) to be compared in terms of potential to cause damage (i.e. hazard) in a way that is as decoupled as possible from local human exposure (i.e. assets at risk). And, Hillier (2020a) do not create a scale for ease of comparison. We propose .....

- Indices of Climate Change for the United States - Karl (1996) Bull Am Met Soc.
- "*The Extreme Climate Index (ECI) is an objective, multi-hazard index ..... of extreme weather events*" Malherbe, J. et al. 2018. The Extreme Climate Index (ECI), a tool for monitoring regional extreme events. In: Climate Change and Adaptive Land Management in southern Africa: Assessments, Changes, Challenges, and Solutions, pp. 144-145

- The need to combine risks (between geographic regions and types of risk) has a greater history than currently acknowledged. '*Accumulation*', '*roll-up*' or '*aggregation*' e.g. see Ch 2.7 of Mitchell-Wallace 'Natural Catastrophe Risk Management and Modelling' for an introduction to this subject (p97-105), and how it has been handled for decades (if not centuries) in the provision of insurance. Very well established commercial products have existed for at least 13 years (e.g. Remetrica/Igloo) i.e. this is my personal memory only from when I first saw then embedded within insurers.

L56 - Gardoni (2014) is very explicitly a *risk* scale, not a hazard scale as proposed here. Please use only references that are directly relevant.

L58 - This manuscript should not depend upon Wang & Sebastian (2021b), so please remove as this is still under review.

L124 - (i) consider splitting section 3.1 into 'Data' and 'Magnitude Indicator', (ii) A few sentences before section 3.1 explaining the overall structure of the Methods would help, similar to my second paragraph in this review.

L127 - Are you sure there are no biases (e.g. omissions) in EM-DAT?

L132 - Which did you keep for each hazard, and why? Please justify choices, providing appropriate references.

L135 & L138 - What duration of gust? (e.g. 3 sec or 10 sec, and at what height). These are important distinctions e.g. for tropical cyclones the recording method and therefore apparent severity differ between the USA and Japan.

L140-L144 - Please justify the thresholds used (e.g. Richter magnitude >= 6).

L146 - Sentence does not make sense. No transformation is needed to fit losses in the range ±infinity. Is the purpose to centre the impact metric on zero?

L145-150 - Please add rationale (i.e. systematic logic for when transformation was needed and when it wasn't).

L198 - by 'by applying' I assume you mean a simulation of individual values, rather than using an expectation from the trend line. Using an expectation would not replicate the variability of the data. Please clarify.

L212 - Section 3.4 & Table 4. Whilst significance of individual parameters is interesting, please compute and provide *p* values for the models as a whole, and consider omiting any hazards where the statistical model is not significant.

L270 - Fig. 3 - Are these relationships (i.e. R^2 values) all statistically significant? If not, please consider the validity of including them in the paper. Those omitted can simply be removed, helping brevity.

L435 - A fundamental limitation (but also benefit) of any impact-based measure of hazard is that it is specific to a user (i.e. the subject of the potential loss). The authors have endeavoured to define a widely relevant measure, but a brief discussion of the benefits and limitations of this specific is necessary.

References

1. **Hillier, J. K.** and Dixon, R. S. (2020b) Seasonal impact-based mapping of compound hazards *Env. Res. Lett.*, **15,** 114013 doi:10.1088/1748-9326/abbc3d

2. **Hillier, J. K.** , Matthews, T., Wilby, R., Murphy, C. (2020a) Multi-hazard dependencies can increase or decrease risk *Nature Climate Change*, **10**, 595–598 doi:10.1038/s41558-020-0832-y [https://rdcu.be/b5kuz]

3. **Hillier, J. K.,** Macdonald, N., Leckebusch, G., Stavrinides (2015) Interactions between apparently primary weather-driven hazards and their cost. *Env. Res. Lett.* **10**(10), 104003, doi:10.1088/1748-9326/10/10/104003