

Dear Editor,

Many thanks for dutifully handling our submission to NHESS (egusphere-2025-4683) “*Invited perspectives: Towards usable compound event research*” and for the positive assessment of *minor revisions*. We were pleased to read the constructive comments of three reviewers, which helped us to make our manuscript more concise.

Please find below a numbered list of the reviewers’ comments (blue, indented) and our respective responses (black, *italic*) for your considerations.

Best regards,
Kai Kornhuber (on behalf of all authors)

Reviewer 1

Kornhuber and many colleagues have submitted an interesting manuscript on the current state of compound event research and align some ways forward. It is well written, and suitable to NHESS I believe. Below my comments on the ideas and text. In general I believe the manuscript will form a welcome addition to the literature, but I do suggest some changes to the text are made before final publication. These should, in my opinion, include rephrasing or extending of some of the ideas presented.

We thank the reviewer for their positive assessment of our work and for their comments that further improved the manuscript. We adjusted the manuscript according to the reviewers comments and provide a list of more detailed responses below.

Major Comments

1. The way to go from climate research to decision making is highly complex. Though highly important, any claim of science being ‘usable’, therefore needs to be at least somewhat build on evidence. The manuscript in its current form I believe addresses many relevant points to advance the science (e.g. improved impact databases) and improve the quality of statements to society (e.g. call for better uncertainty information), but I wonder whether it would truly lead to more usable compound event research. Have any societal users of compound event research, e.g. policy makers, city planners, first responders, insurance companies, etc., been consulted on what they need and/or what they are currently missing? If so, I strongly advise to add this perspective to the manuscript. If not, then I believe the manuscript should be read and presented in a slightly different way, as a statement from the academic community to the same community, on how ‘we’ should aim to do better on these aspects, and maybe also that ‘we’ should reach out to societal partners and have conversations on what is known, available, and unknown, and importantly, what is missing from their point of view.

The reviewer raises an important issue. The authors of this perspective are certainly predominantly academics. While the authors are not the end-users themselves, many of the authors are directly working with stake-holders and decision makers on a regular basis, either through projects or through science communication and outreach efforts. For instance, Kornhuber is leading the acute physical risk assessment efforts in a joint project with partners from international central banks and financial regulators. Experiences from regular consultations and interactions within these projects shape the structure and focus of this manuscript, which primarily targets an academic readership. We nevertheless hope that descriptions of fundamental climate impact science concepts such as ‘bias adjustment’ and ‘downscaling’ could be useful for those working at the industry as well. We acknowledge that the academic authorship could be emphasized more explicitly in the manuscript itself. For we therefore added a sentence to the introduction (l. 126):

“This perspective is written by authors from within the research community, providing reflections on usability principles for major pillars of compound event research, impact data, early warning, modelling and uncertainty based on interactions and consultations with end-users. It thereby serves a dual purpose: to provide usability guidelines for the research community and insights for end-users to better understand challenges and limitations.”

2. Line 753 - “We call for impact data from a variety of sectors, ..., to be made readily.” I of course fully agree with such a call, but can’t see it leading to anything concrete. If the data exists, what are the current barriers and how can they be breached, and if data doesn’t exist, how can we start the systematic collection. For this manuscript to be ‘useful’ the advise should be a bit more concrete.

This specific principle aims at increasing the accessibility of impact data, which may already be available. We noticed that 'available' was missing at the end of this sentence, which may have partly contributed to raising this comments. We adjusted the sentence accordingly. While more work is needed to collect and maintain impact data bases, important impact datasets are often not publicly accessible. In the context of data from official administrative sites this can be linked to valid data protection concerns. However, a lot of valuable impact data is owned by private actors (e.g (re-) insurance companies). Making these datasets available for research would be a very concrete step in the improvement of hazard impact relationships on local scales.

3. Line 828 - "New accountability standards for hazard and climate risk estimates from the private sector could help in securing reliability and trust in such products." Who is to set and check such standards? What does the private sector think of such standards? From an academic point of view I understand this idea and wish, but I wonder if it is workable. Do users currently not trust the risk estimates from the private sector? I fear they might actually have too much trust, and would not be able to check adequately whether the supplier of climate information adheres to (any) standards. If you are not an expert, how would you know to question the uncertainty information or assumptions?

That is exactly the point we want to make here. There is a risk that users might trust unreliable data too much. Standardisation and certificates would avoid further harm, by assuring a transparent communication of assumptions and limitations. Governments have been successful in setting industry standards in the past for other sectors, which have overall increased the trust, reliability and have reduced harm from misuse and poor quality.

Minor Comments

4. I fully realise there is a massive amount of literature on the topic of compound events, as such it is impossible to refer to all relevant studies. However, I find the literature cited to be too focussed on the papers by the authors of the submitted manuscript. For example, the below sentence holds 11 references, of which (upon quick inspection) it seems 10 are effectively self-citations. The next example scores 3/3, where better examples exist that already use impact indicators for renewable energy system risks, even for compound and co-occurrence problems. Please cite a wider range of the available relevant literature.
 - Line 78 - "Sectors at risk include infrastructure and urban resilience (Hemmati et al. 2022), agriculture (Kornhuber et al. 2023; Lesk et al. 2022), water and ecosystem management (Lian et al. 2025), and biodiversity conservation, public health (Raymond, Matthews, et al. 2020; Rogers et al. 2021), energy systems (Lesk and Kornhuber 2022), and particularly globally interconnected networks such as food systems (Kornhuber et al. 2020; Lesk et al. 2021), transport, trade and supply chains, and the insurance and financial sectors (Dolk et al. 2023; Singh et al. 2023)."
 - Line 688 - "For example, for the renewable energy sector, an impact indicator could use climate model simulations to identify future extreme, widespread heatwaves and wintertime cold spells (Singh et al. 2024; Mattu et al. 2025), (which increase electricity demand), that co-occur with very low wind conditions (which decrease energy production) (Meng et al. 2025)."

We agree with the reviewer that a wider range of experts needs to be cited here. The author team was selected based on their topical expertise which also shaped the content of the perspective itself, thus self

citations will not be preventable entirely. We added following references to the paragraphs in question (topics in brackets):

Mahecha et al. 2024 (biodiversity), Bastos et al. 2023 (ecosystems), Wang 2025 (public health), Haqiqi et al. 2021 (food), Dunz et al. 2021 (finance risk), Levermann 2014 (supply chains), Mofstakhari et al. 2019 (energy), Van Duinen et al. 2025, Wang et al. 2025, Zheng et al. 2025 (renewable energy).

5. This is probably my own lack of knowledge, perspective or misunderstanding, but I assumed ‘impact data’ would hold information on (societal) impacts. Reading your list of challenges, I am then surprised (line 148) that a problem is that events are not described in their full complexity, particularly the interactions between drivers. Are we talking about ‘impact data’ in that case, or are we talking about ‘hazard/vulnerability/exposure interactions leading to risk and then events data’. I suggest you define what you mean by ‘impact data’ early in section 1, maybe in the paragraph starting at line 141?

Many thanks for this comment. We adjusted the sentence to provide more clarity. This sentence refers to impacts in existing databases that are often assigned to a single hazard (e.g., drought), at times not paying tribute to the fact that several hazards have contributed to the impact magnitude. Further, we added a sentence in the impact data section, which provides a short definition of what we consider impact data in this context (l. 150: “We consider Impact data as structured datasets that provide quantitative societal or ecological information, allowing for the investigation of impacts associated with specific hazard types.”)

6. Line 463 - Another source of those datasets are simulations done with numerical weather prediction (NWP) models, especially those for seasonal forecasts. Many applications of UNSEEN rely on smartly mining the hindcast archive of seasonal forecasts.

Many thanks for this comment, we adjusted the section, now explicitly mentioning NWP model ensembles.

7. Line 562 - Are the inconsistencies between bias-corrected-output and drivers really larger (i.e. amplified) after multi-variate bias correction than after univariate bias correction?

There might be a misunderstanding as this is not what this sentence aimed at communicating. Rather, we state that evidence exists that for some variables the mismatch is not as severe as one might think (see cited reference Wilcke et al. 2013, for further details).

8. Line 572 - Even the most data rich regions, e.g. North America or Western Europe, have blind spots for some variables. Soil moisture is a very unconstrained model variable, and highly relevant for compound drought-heat events.

This is absolutely correct, and the sentence has been extended accordingly.

9. Line 635 - you note high-impact and low-impact storylines here, which essentially capture model uncertainty. I think it might be better to reserve the word ‘impact’ for (societal) consequences in your manuscript, and use a different term here. Using the actual terms for the source of uncertainty, here model uncertainty, in my opinion helps stakeholders/users to better understand why the uncertainty exists and hence design policy in a way that deals with the

uncertainty in the correct way. As such, maybe high-sensitivity and low-sensitivity storylines might be a better term? Consider aligning the terms in Figure 3.

In this case the storylines are explicitly designed with a societal impact in mind (see red section in upper right corner of Fig. 3a) and a low or high societal risk (see panels Fig. 3 b, c). High and low sensitivity might not always translate into high and low impacts in every case (e.g. risks of cold spells, which decrease regionally in a high sensitivity storyline). We would therefore prefer to remain with the chosen terminology.

10. Line 655 - PGW and also spectral nudging simulations (Feser et al), both take an observed event and transpose it to a different climatic condition. Besides the downside you mention in the next paragraph (no unprecedented event types), I would like to somewhere see added that you also can't investigate event-specific changes in dynamics, e.g. longer lasting blocked patterns.

True, thanks for this comment. We added a sentence on this to the manuscript.

11. Line 93 - Is it Sobel & Cohen or Coen & Sobel? Are Coen and Cohen two people, if not, why was the order of names reversed relative to the authorship of the paper?

This has been corrected.

12. Line 173 - Consider adding a reference to "Drought is a continuum" to this line at your example of drought, I believe the paper matches quite well with your example.

Thanks, this reference has been added!

13. Figure 2 - good figure. However, the colouring choices make that the most important/novel aspects are least prominent. Is there a way to slightly tone down the colours in the middle row, whilst making more prominent your identified challenges and potential solutions (e.g. black font)?

Thanks for this suggestion, the colors have been adjusted slightly.

14. Line 433 - "Climate models are essential tools for exploring compound events under different climatic conditions on timescales of decades to centuries." I find the last part of this sentence slightly confusing, 'under different climatic conditions' seems strong enough, 'on timescales of decades to centuries' is then confusing. I wonder whether the here and now, or the past are not relevant, I believe they are.

Absolutely, this sentence does not make an explicit statement about past, present or future climates as all of them are important, we adjusted the sentence accordingly.

15. Section 3 - maybe consider adding a subcaption when you start discussing bias adjustments?

Many thanks for this suggestion, instead of adding a subsection we highlighted this paragraph by setting 'bias adjustment' as italic.

Reviewer 2 (David Bresch)

The perspective is very well written. It provides a comprehensive overview, followed by a structured account of the way forward.

I do not see a need for revision, only two truly minor suggestions:

1. line 196ff, you might consider to cite also: Themessl, M., Enigl, K., Reisenhofer, S., Köberl, J., Kortschak, D., Reichel, S., Ostermann, M., Kienberger, S., Tiede, D., Bresch, D. N., Röösl, T., Lehner, D., Schubert, C., Pichler, A., Leitner M., and Balas, M., 2022: Collection, Standardization and Attribution of Robust Disaster Event Information – A Demonstrator of a National Event-Based Loss and Damage Database in Austria. *Geosciences*, 12/8, 283. <https://www.mdpi.com/2076-3263/12/8/283>

Thanks added !

2. And on a more general level, the following two papers outlines a conceptual approach that could easily be extended to multiple hazard and compound perspectives: Kam, P. M., Ciccone, F., Kropf, C. M., Riedel, L., Fairless, C., and Bresch D. N., 2024: Impact-based forecasting of tropical cyclone-related human displacement to support anticipatory action. *Nature Communications*, 15:8795. <https://doi.org/10.1038/s41467-024-53200-w>; and Stalhandske, Z., Steinmann, C.B., Meiler, S., Sauer, I., Vogt, T., Bresch, D. N., and Kropf, C. M., 2024: Global multi-hazard risk assessment in a changing climate. *Sci. Rep.* 14, 5875. <https://doi.org/10.1038/s41598-024-55775-2>

Thanks, both added!

Reviewer 3

This perspective aims to advance the visibility of research on compound (extreme) events, and assess its usability along four dimensions: impact data, prediction and early warning, modelling and projection, and addressing uncertainty. The paper has a very long author list, and possibly suffers from that as it certainly has the feeling of being written by a committee. On the other hand, it is a state-of-the-art summary and there is not much in there to disagree with. Perhaps ironically, the ways forward (the italic text in section 5) are all quite idealistic so I'm not convinced they are themselves "usable". So I think the paper is perhaps skirting the really hard questions. Nevertheless, for someone new to the field, this will be a useful reference.

We thank the reviewer for their comments. According to the description of the submission NHESS submission types "Invited perspectives articles present new ideas, views, or perceptions on a topical aspect of natural hazards. They intend to stimulate an open debate among peers via the discussion phase. [...]". We hope that the reviewer and editorial board considers the level of exhibited idealism to be the margins of what a perspective submission type foresees and while we realise that not all the suggestions some suggestions can be adopted in their present form, our hope is to provide talking points that may be interesting for some. Please find a list of more detailed responses below.

Minor comments:

3. Line 93: I am confused by "Sobel & Cohen (Coen and Sobel 2022)". It should just be "Coen and Sobel (2022)".

Absolutely, apologies for this error which was adjusted in the manuscript accordingly.

4. Line 96: I don't think that Sobel (2021) argues against blue-sky fundamental research, only that we have long had enough knowledge to justify mitigation, so if one is interested in usability, it is better to focus on adaptation than on the drivers of climate change.

Thanks for this comment, we adapted that sentence, now reading: "Coen & Sobel (Coen and Sobel 2022) argue that a lack of scientific evidence is often not a limiting factor in ongoing efforts to mitigate global warming and proposed that those interested in the usability of their research should strengthen their focus on adaptation science. In essence, 'usable climate science is adaptation science' (Sobel 2021). "

5. Lines 99-101: That seems over-stated. You seem to be suggesting that we cannot act without perfect information. There is so much uncertainty in the human dimension that even rather uncertain climate information can be useful. It all depends on the decision context.

Agreed, we softened that statement by swapping 'only' with 'mostly'.

6. Lines 462-468: This text concerning CMIP-class models seems extremely glib when it comes to compound extremes, especially for anything involving heavy precipitation (many papers by Kendon, Fowler, Prein, etc.). And don't most CMIP-class models still struggle to simulate persistent flow anomalies?

Many thanks for this comment, we adjusted this section and added further references: "While models perform well for averages over large spatial and temporal scales some inaccuracies remain for extreme weather events, in particular for hydroclimatic extremes (Shepherd 2014) and those involving processes at scales below the model resolution such as tropical cyclones (Camargo and Wing 2016). "

7. Lines 602-603: Why do you say "non-deterministic"? After all, the title of Lorenz (1963) is "Deterministic nonperiodic flow". Chaos can be deterministic, and the Navier-Stokes equations are deterministic. (Not that it matters: I would suggest simply deleting "non-deterministic" since it is beside the point.)

Agreed, 'non-deterministic' was deleted.

8. Line 615: Why deterministic? Wouldn't a probabilistic prediction be acceptable, if it was available?

Right, we adjusted this section and swapped 'deterministic' for 'reliably' which is more true to the point.