# Tipping cascades between conflict and cooperation in climate change

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## Reply to Review Comment (RC1)

**Summary:** This is an interesting but strange paper. Part of the text is very technical and hard to follow for the average social scientist, and the link to real-world challenges related to conflict and cooperation under climate change is sometimes lost. I appreciate the attempt to bridge perspectives across scales and drawing on a range of methodologies, but due to incomplete integration of these perspectives, I believe the present version of the paper does not fully deliver on its objective "to improve the understanding of the current issues of conflict and cooperation, in particular in climate and environmental and conflict…" (p. 2). It also is too long.

**Response:** Thank you for the constructive comments which are greatly appreciated. To our knowledge this is one of the first papers that brings research on climate and conflict together with research on tipping cascades in conflict and cooperation. While the first field has been addressed mostly by quantitative statistical methods of large-scale data or case-based qualitative research, the second field is rooted in conceptual and modelling approaches of tipping points and cascading events, including system and agent-based models. Aiming for an interdisciplinary approach connecting the communities of social and natural scientists, bridging both perspectives across scales and methodologies is challenging, as the reviewer notes, but the attempt is also promising in a world where multiple crises aggregate into a polycrisis and one discipline or method alone cannot address the complexity of interconnected issues. We will take more effort to bring the different perspectives together and demonstrate the relevance of tipping between conflict and cooperation.
We admit that more could be done to overcome the limits of "incomplete integration". One way is to further develop and expand the framework of pathways of climate-security interaction (Figure 1) to better explain and integrate the different parts and pathways as well as tipping cascades and connect to real-world problems. We provide some ideas and leave more space for inspiring the community to imagine the opportunities in their own way. To follow the comments we aim for a better balance of the different sections and the integrative connections between them, in particular extending the climate-conflict review (Section 2) with providing exemplary cases including cooperation, a shorter review on models of tipping in conflict and cooperation (Section 3) and giving more explanations and details in the result Section 4 and case study Section 5. We are also open to shortening Sections 3 and 4. For example, we can move some of the technical details to an Appendix in response to you concerns, to facilitate the flow of the main text and preserve details for readers who look for approach and evidence.

**Comment 1:** The introductory section 1.2 on concepts was very useful. However, it can be improved further by drawing on concrete examples of tipping elements and cascades in the social sphere as well; presently examples are given predominantly from climate / natural systems. What are good real-world examples of exponential chain reactions through social systems? I also think a brief reflection on the role of climate (incl. weather) versus climate change would be in order, and a cleared and more explicit separation between these distinct phenomena is wanted. To what extent are we able to distinguish between these sources of risk empirically – and what are implications for our ability to offer insights and advice on the nature, probability, and severity of future risks?

**Response:** Thank you for the encouraging note on linking concepts to real-world examples of tipping elements and cascades in the social sphere. To motivate the work earlier in the paper we would like to critically discuss the tipping potential and cascading mechanisms of our main case of Lake Chad (which is studied in more depth in Section 6) and other cases that may be relevant to society and conflict, such as the fall of the Berlin Wall and Arabic Spring, the Syrian civil war and Russia-Ukraine war, pandemic and climate effects on South Asia (for examples

see Lenton et al. 2023). It is also worth discussing and comparing connections between natural and social tipping points (Pruitt et al. 2018; Jin and Guo 2022).
As suggested, we will briefly distinguish between weather, climate and climate change as sources of risk and the implications for addressing future risks and conflicts, at temporal and spatial scales (see Dahm et al. 2023). Where weather is often short-term events (e.g. three consecutive hot days in summer) or an extreme event (e.g. storm or flood of certain intensity), we refer to climate change and systematic change of ambient conditions with long-term forcing effects and thresholds, which are often reflected in the mean or variance of data changing. Examples are the risk of a certain crop dying or a particular road washed away, or behavioural changes when outdoor labour becomes inefficient or conflict emerges more likely beyond a certain average temperature, as reflected in anomalies in a data stream rather than a constant change. In the tipping dynamics we consider climate change as a force on the social system, whereas weather is a short-term shock. Within the limits of this paper, we will discuss the interaction of forces across spatial and temporal scales while a comprehensive theory is beyond the scope of discussion.

**Comment 2:** In several places, displacement and mobility are mentioned as potential pathways to conflict and instability. Here, some consideration of counterfactual outcomes (e.g., staying put) would seem relevant. Mobility is an important risk management strategy – and especially so in dryland regions with large seasonal and annual variations in environmental conditions. While moving may entail exposure to new risks, it also typically reduces some sources of risk, so a holistic approach would need to consider both.

**Response:** Thank you for this important point which needs an extended perspective on mobility and migration. In the paper, we already highlight climate-conflict pathways through migration, mobility and other context-specific factors, with an example of the Lake Chad. While mobility is sometimes portrayed as a path to social harm under climate change and conflict, sparking divergent viewpoints and controversies, we agree that mobility can influence multiple outcomes. Alternative perspectives are important to integrate migration into adaptation and risk management strategies, as suggested by the reviewer and some of us on other occasions (e.g. Scheffran et al. 2012; Gioli et al. 2016), as well as in a recent PNAS Special Feature on "Migration and Sustainability" (Adger et al. 2024). We can refer to some of this work from a more holistic approach.

**Comment 3:** I found the language on pp. 5-6 on risk dynamics too deterministic and insensitive to context. At the same time, all given examples are from Sub-Saharan African countries / regions so presumably these pathways are not equally likely to play out everywhere, at any given time. (I'm sure the authors would agree to that.) It also reminded me of Adams et al.'s critique of sampling bias in this field, which is cited elsewhere in the paper I think but not reflected on here. Is there a general problem that we lack case studies of communities / locations / periods where a climate shock (tipping point) is observed but no resulting change in human behavior (tipping point) is documented? Lastly under this point, the discussion of pathways focuses almost exclusively on conflict, while cooperation also is supposed to be covered by the study. So perhaps add some examples of cooperative responses to various risk dynamics as well?

**Response:** Following your comment, to avoid making the "risk dynamics too deterministic and insensitive to context" we agree that risk pathways depend on regional conditions. We can expand on our statement on page 5 "The relationship between cooperation, climate change and security risks therefore varies depending on context, is often indirect and not linear." In particular, we emphasize here more contextual conditions and the role of agency which was already considered in Sections 2.4 and in Section 6.1. Regarding sampling bias we also refer here to Adams et al (2018) and consider cases beyond Sub-Saharan Africa and more examples of cooperative responses to risk dynamics, which we have already addressed in response to Comment 2. We consider potential connections between climate shocks and

economic losses with or without resulting tipping in human behaviour. This can clarify the distinction between tipping points, critical thresholds and economic shocks associated with tipping elements, gradual climate change, or non-climatic triggers (Kopp et al. 2016).
Our argument, which is emphasized across the paper, but perhaps not clear enough, is not that there is universality but dependency on specific circumstances. Just because we couple climate shocks with social tipping, it does not mean a certain shock will universally tip over society, because the parameters of resilience, cohesion and mutual support between societal communities are vastly different. Of course, there are cases where nothing happens (in terms of conflict), and in Figure 7a we show that certain societies may have a low barrier to transition, whereas others have high barriers from societal organisation or mutual support.

**Comment 4:** There is very little consideration of risk resulting from human / social responses to climate change. This is an opportunity missed. While doomsday scenarios of uncontrollable impacts of draconian geoengineering may be speculative and fanciful, what about protests to climate policies (think yellow vests) as well as protests to insufficient climate policies (Greta Thunberg…). With increasing warming, both these dynamics might be expected to become more prevalent and perhaps increasingly violent.

**Response:** This comment rightly points out that some of the many interactions between climate conflict and cooperation are considered in the paper but there are more. We can revise the manuscript and refer to the mentioned and other connecting pathways, including joint work by one of the coauthors (J.S.) on cooperation in conflict (Bukari et al. 2018), climate impact of violent conflict (Vogler et al. 2023), or conflict and protest over climate policies (mitigation, adaptation, disaster management, climate engineering) (Scheffran and Cannaday (2013) which need to consider conflict sensitivity (Nadiruzzaman et al. 2022).

**Comment 5:** Section 3 of the paper is too long, too detailed on historical evolution of models, and does not stick to the thread of the paper throughout. It would be good if the presentation of these models could engage more explicitly and concretely with the topic at hand: tipping points in climate-driven conflict and cooperation.

**Response:** We agree to condense the review on models of tipping in conflict and cooperation (Section 3) and focus more specifically on the essential aspects suggested (possibly in the form of a table), to classify the model types and their relevance to tipping cascades in conflict and cooperation. In response, we can also move some of the details into an Appendix.

**Comment 6:** Likewise, Section 4 remains too detached from the substance. It would help if the model could use specific (if arbitrary) values for the parameters to estimate conflict / cooperation outcomes under various assumptions, as opposed to leaving it as a hypothetical mathematical equation and illustrations that contain no information about climate stressors, social actors, specific risk metric (probability or magnitude of some outcome), etc.

**Response:** The core of Section 4 is to introduce and demonstrate the concept of bi-stability of two states such as conflict and cooperation between which tipping occurs beyond thresholds. This is based in complex systems science and an essential contribution of our paper to connecting conflict and cooperation with tipping point research. While not everyone may be familiar with related methods, the aim is to translate qualitative features of reality into the modelling world and its equations to build bridges across the communities. We use mathematical equation (1) as a basic representation of a bi-stable dynamic system that contains its main qualitative features and can be visualized in the graphs to show the intuitive meaning. Adapting the general model to real applications in climate and conflict-cooperation tipping cases is subject to future research based on case-specific. We can either cut this part short to reduce the complexity to key qualitative messages and minimum figures or provide more in-depth explanations and analysis of the underlying model and the data used.

*[We explained our approach in the response to Reviewer 2 and we copy that response here.]*
To indicate the possible direction, we refer to the work by one of the coauthors (W.G.), building on a nonlinear dynamic model of conflict via interaction networks (see Aquino et al. 2019 and other sources, cited in Section 4). Here, conflict data *x(t)* per city/town are used as the node level dependent variables at time *t*, to fit with independent variables that are: historical state of *x(t-1)* and the weight of graph connections to the node as independent parameters. Equation (2) describes the nonlinear relationship between *x(t)* and *x(t-1),* as well as the graph connections with other nodes via the connection matrix *A*. The independent parameters are weighted by the g(.) function: (i) land transport connection (*A* matrix: 1 or 0), (ii) friendly ties based on existence of economic or political treaties (1 or 0), and (iii) cultural similarity based on religious belief vector of major religions (distance between vectors). We use a multi-variate regression to find the weight of the independent parameters. The data ranges are from 2001 to 2017, and the conflict data (x) is from the Global Terrorism Database (GTD), whereas the trade and transport data is from different UN, CIA and National Geographic databases.

**Comment 7:** The discussion of Lake Chad is easier to follow, but I am not sure it helps us understand the relevance of tipping elements very well. Any observed change in behavior that is hard to reverse – e.g., the outbreak of violent clashes – constitutes a tipping point of some kind. But what is the challenge here is to assess the contribution of climate (variability or change) stressors (tipping point?) to that outcome, and I did not see much specific evidence of that. The presented causal narrative sounds reasonable, but how could it be evaluated? What would it take to conclude that the storyline doesn't reflect realities? One potential challenge to the narrative is the fact that the lake has not continued to shrink but rather show evidence of gradual increase in volume in recent decades, when violence has become more widespread. At least, the presentation of the hydrology of the lake should take account of this, although one might argue that it is inconsistent with assumptions about increasing climate-induced livelihood challenges. https://doi.org/10.1038/s41598-020-62417-w.

**Response:** Thank you for raising these questions about the justification of tipping points in the Lake Chad case which we can better explain, including Figure 7. According to a definition in the 2023 Global Tipping Point Report, a tipping point occurs "when change in part of a system becomes self-perpetuating beyond some threshold, leading to substantial, widespread, often abrupt and irreversible, impacts." Which of these mechanisms are actually met can be subject to discussion. Most important is the self-perpetuation of change which is often but not necessarily abrupt or irreversible. In the revised paper we can further discuss a few tipping elements associated with conflict, violence and terrorism in Lake Chad: (i) tipping in terms of abrupt breakdown in small-scale farming, fisheries, and local food systems triggered by multi-year oscillations of the Lake Chad water (potentially climate-induced); (ii) self-perpetuating chains of violence and displacement triggered by a rebel-controlled conflict economy.
As an example of change in behaviour that is hard to reverse, abrupt breakdown in chains of livelihood services motivates young people to embrace extremism. Creating income from conflict economies, they build capacity to defend rebel groups and seek opportunities to perpetuate chains of violence (observed change in behaviour). This is made worse by the climate crisis and has become more widespread despite recent rebound in the Lake waters (Pham-Duc et al 2020). Gradual variations of water level have added a new twist: communities that moved and built homes towards the dry and small Lake Chad during the droughts of 1980s and 1990s are now having to confront massive flooding (during rainy seasons and times the Lake overstretched it banks); many have lost their natural and physical assets (land, farms and houses) as the Lake expands, rebounds and recovers (the Lake is somehow reclaiming the land areas it initially lost). To strengthen evidence we could present hydrological changes next to conflict data and also discuss counterfactuals, as far as the length of the paper permits.

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