Tipping cascades between conflict and cooperation in climate change

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Response to Review Comment (RC2)

Summary: The authors connect research on the dynamics of conflict and cooperation under climate change with research on tipping elements and cascading risks. The scope of the paper fits well with a journal such as ESD, and I agree that there is great potential for modeling and systems dynamics approaches to enrich the study of the climate-conflict nexus. However, after reading it, I cannot recommend this article in its current form for publication since its main intent remained unclear. Is this a literature review (of concepts or model types), a model study, or the application of a model to a case study? Even if the article wants to do everything, the different parts need to be more integrated to justify having them together in a single article.

Response: We appreciate the recognition of the great potential of this paper and the call for better integration of the different parts. First we would like to better explain the structure and positioning of the paper before improving integration. After the introductory part on embedding into complexity challenges, the second section is designed as a critical review of the literature on climate and conflict, followed by a review on tipping cascades and models of conflict and cooperation. While there is literature in each of these fields, there is little research connecting them which limits the scope of the reviews. Section 4 makes an attempt to bring them together and develop forward-looking conceptual and integrative approaches which may appear as technical and "hard to follow". The abstract considerations are supplemented and exemplified with the case study of Lake Chad (Section 5). Finally, Section 6 discusses challenges of governance and management of negative and positive tipping in conflict and cooperation, followed by a summary and conclusions. While this may appear as too much or ambitious for one paper, we thought that a pure review paper would be insufficient given the limited literature on the intersection of both fields, without indicating substance on pursuing potential pathways of integration. While this cannot be done in depth here, we still think that it can be beneficial to bring the complementary parts by the coautors into one paper that indicates main avenues and offer a spirit of research that could be pursued later in greater depth and breadth. Following the suggestion, we revise the paper by better integrating the parts, extending some, shortening others or moving them to an Appendix, and clarifying linkages between them in an integrative framework.

Comment 1: I wonder about the qualitative difference between "Tipping points and thresholds" and "Risk cascades and chain reactions." Could the latter not be regarded as a single tipping process of a larger, higher-level system?

Response: We appreciate this comment, although the difference is not always clear or easy to distinguish because it depends on case-specific circumstances. Each individual system or community can have a tipping point and threshold at which it tips, but as the effects of tipping variables are inducing changes in other variables the question is how far the chain of changes continues and is spreading through the network of connections, leading a single tipping into a tipping cascade affecting the whole system, until a new stable state is reached. Risk cascades and chain reactions induce complex transient behavior that is hard to predict and control. As such we cannot simply say whether the whole system tips or only parts of it. How far this spreading continues, stops at some point, or even recovers, depends on the degrees of heterogeneity in both space-time and context. Regarding the difference of terms we will refer to other publications (e.g. Lenton et al. 2023; Kopp et al. 2016).

Comment 2: It remains unclear what the colour in Fig. 5b represents.

Response: The colours are for nodes and graph links. In Figure 5.b, the node colour represents the state of the city, with red meaning conflict and yellow meaning cooperation. The link colour represents relationships, with blue meaning positive and green meaning the lack of any positive evidence (see data and method details in response to Comment 5). A zoomed in graph visualizing the method can be found in Aquino et al. 2019 (page 12), where we can see it in greater detail for eastern Europe and the Levant. We can either cut this part short and associated Figures 5 and 6 to reduce the complexity to key qualitative messages or provide more in-depth explanations and analysis of the underlying model and the data used, as given in the following response to Comments 3 and 4.

Comment 3: The results in Figure 6 require a more detailed description of how they were obtained.
Comment 4: Figure 6 also lacks label descriptions, which makes it unnecessarily difficult to interpret.

Combined Response: Indeed, Figure 6 needs axis labels. In Figure 6a, the 3 axes would be the states or dependent variables of interest (for example: conflict event count, protest count), and what the region of attraction (RoA) analysis shows is that there exists an attractor attracting these states to a single value range. Here, this would correspond to a potential well or a stable equilibrium in Figure 4 (e.g., point x=C according to equation 1).
In Figure 6b, the x-axis is the average loss of supporting graph connections (N) that reduces aid to all graph nodes. As a result, the graph nodes slowly lose performance, sliding from the optimal equilibrium point (C) towards the unstable brink (K), We see each node's x value represented by the lines that are bounded by a theoretical framework. Here, the work by Moutsinas and Guo (2020) uses a random link removal perturbation analysis. As N reduces, a cascade effect occurs, the whole graph reaches a criticality that causes ecosystem collapse.

Comment 5: How is the parameter fitting performed when the authors write, "We use historical data to learn the parameters of the model above by fitting independent variables to the dependent variable x."

Response: 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 are from different UN, CIA and National Geographic databases.

Comment 6: It remains unclear whether Figure 7 is purely conceptual or if some model-fitting with empirical data has occurred.

Response: Figure 7 is entirely a pictorial narrative on how tipping models can give different tipping dynamics based on how they reinforce or compete with each other through a network. We can make this more clear in the text and better explain.

Comment 7: It remains unclear how the model is applied to the case study of Lake Chad. What specific elements of the model go beyond the possibility of having two stable states of cooperation and conflict influence the discussion of the case study? In other words, why is this specific model useful for the case study?

Response: Thank you for pointing to this lack of clarity which we hope to remove with more explanations in this response and the manuscript. Within the framing of this paper we largely focus on the duality of conflict and cooperation, as indicated by the paper title. Therefore, we found it useful to demonstrate the applicability of the bi-stable tipping model introduced in Section 4 to the case study of Lake Chad in Section 5, which seems in accordance with RC1. This allows to translate qualitative results from the literature and own research into the modelling frame of tipping points. While we limited ourselves to the two states of conflict and cooperation separated by a tipping point, there can indeed be more than two stable states. Although we wanted to avoid making this problem too complex within the limits of this first paper, we take the comment to make these limits more clear and point to the need for multi-stable approaches in future research.

Comment 8: The authors use the passive voice often. As a consequence, I cannot distinguish whether the scientific community is doing something or whether it is the authors who did something. The frequent use of the passive voice makes it difficult for the reader to distinguish the authors' contribution from standard community practices. For example: "Due to the high-dimensional nature of the problem (e.g., number of tipping equation parameters exacerbated by the size of the graph), a range of standard assumptions are often used."

Response: We regret if it was difficult to distinguish our work from others. In much of the results sections 4 and 5, in particular in the example case, the work has been carried out by the authors for this paper and our previous work. We will make our contributions more clear in the revision by more active voice, less confusing tense and cited references.

Comment 9: Figure 4 could show the parameters C and K.

Response: Here, C is the capacity point (highest stable point), and K is the critical tipping point (middle unstable brink) which will be included in Figure 4.

Comment 10: In my view, the butterfly effect from chaos theory symbolizes the sensitivity to initial conditions, not necessarily a bifurcation point.

Response: Here we rather mean that near a bifurcation or tipping point, small effects can have large consequences. We can adjust wording to make the difference of terms clear.

Comment 11: What is the difference between a phase transition and a tipping point or threshold?

Response: Phase transition is a broader term of transitions between different states of a system (such as solid and liquid phases of matter) which does not have to be self-enforcing and irreversible tipping from one state without necessarily indicating a new state or reversibility from it, possibly requiring distortional effort.

Comment 12: In l. 547, the authors most likely want to refer to Fig. 4, not Fig. 3.

Response: Indeed, correct is Fig.4, thank you.

References

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Kopp, R.E., Shwom, R.L., Wagner, G., Yuan, J Tipping elements and climate–economic shocks: Pathways toward integrated assessment. 4(8): 346-372. https://doi.org/10.1002/2016EF000362, 2016.

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