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Risk analysis approach for tipping cascades and domino effects in the Earth system under global warming

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Tipping elements in the Earth's climate system are continental-scale subsystems that are characterized by a threshold behavior with potentially large short- to long-term impacts on human societies. It has been suggested that these include biosphere components (e.g. the Amazon rainforest and coral reefs), cryosphere components (e.g. the Greenland and Antarctic ice sheets) and large-scale atmospheric and oceanic circulations (e.g. the AMOC, ENSO and Indian summer monsoon). Interactions and feedbacks of climate tipping elements via various processes could increase the likelihood of crossing tipping points under a given level of global warming and interaction strength. However, studying these potential domino effects and tipping cascades with process-detailed state-of-the-art Earth system models is difficult so far, because relevant tipping elements are often not represented and uncertainties in their properties and interactions are large.

To bridge this current gap in the model hierarchy, we present a risk analysis approach based on a paradigmatic model of interacting tipping elements that propagates uncertainties in interaction structure, sign and strength as well as critical thresholds and other parameters via large Monte Carlo ensembles. Our approach allows to study the likelihood of domino effects and tipping cascades to emerge due to pairwise interactions and feedbacks to global mean temperature. We apply our approach to a subset of five potential tipping elements (Greenland and West Antarctic ice sheets, AMOC, Amazon rainforest and ENSO) with known parameter uncertainty estimates and find that their interactions overall tend to be destabilizing. The presented framework is flexible and can be adapted to study the interaction effects of other or additional tipping elements and more detailed submodels for describing their individual dynamics.