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Revealing hidden tipping in spatially-resolved Earth system analysis

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The assessment of potential tipping elements in the Earth system and their associated tipping thresholds is essential for understanding long-term Earth system change and describing a safe operating space. However, their identification in model outputs and observational data typically requires making assumptions about the spatial extent of individual elements. While the resulting regional to continental aggregates allow for the study of collective time series, they are potentially based on subjective judgement and could mask non-linear behaviour on smaller scales.

In this work, we present a novel method based on a timescale- and variable-independent metric to automatically identify potential tipping elements in the Earth system with a few or no free parameters. Gridded datasets are scanned for abrupt shifts on the grid-cell level, which are subsequently automatically clustered in space and time. This allows for the creation of maps with areas grouped and classified by their dynamical behaviour without an a-priori definition of connected regions.

Applying the presented method to various Earth System model outputs, we detect clusters with different nonlinear responses to future emission scenarios which are otherwise masked. Consequently, our bottom-up approach provides insight into the spatial structures and temporal processes of large-scale tipping elements, and sheds light on ‘hidden’ tipping of their subsystems.