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Downscaling criticality in tipping elements in the Earth system: the Indian summer monsoon case

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Tipping elements are large-scale components of the Earth System. A rapid and often irreversible qualitative change its state might have dramatic consequences on the system as a whole. Despite recent advances in developing early warning indicators for the time series evaluation and in the analysis of pattern formation, predicting the future abrupt transitions in tipping elements remains an outstanding scientific challenge.

In our study, we make a step forward in this direction by proposing a new method of downscaling criticality. In particular, it allows identifying local-scale tipping elements in the large-scale tipping element. We define a tipping element as a region of an origin of critical conditions in spatially - distributed systems. We use the phenomenon of critical growth of fluctuations to detect such regions. We show that monitoring the temporal evolution of a system in tipping element opens a possibility for prediction of the timing of the upcoming critical transition or tipping events.

To illustrate the proposed approach, we use the case of the Indian Summer Monsoon (ISM) as one of the large-scale tipping elements. We consider the onset of ISM as an example of an abrupt spatial-temporal transition which mechanism is not fully understood. Hence, an accurate model to predict the exact timing of the transition to monsoon is not developed yet. For the analysis of the timing of the transition to the ISM we use observational data only: near-surface air temperature and relative humidity.

We show that the identification of local-scale tipping elements in large-scale tipping elements might lead to improving predictability of impending tipping events. The proposed approach is applicable for systems of different nature, thereby offers a general framework for predicting critical transitions in spatial-temporal systems from observational data only when the model cannot accurately anticipate the transition or does not exist yet.