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# Early Warning Signals – conceptual limitations and opportunities

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Due to potentially large positive feedbacks in the climate system, the existence of tipping points is under debate. At these points, small changes in forcing can lead to abrupt climate change due to the destabilising feedbacks. In order to predict such abrupt changes or to distinguish changes in stability from random state transitions, it has been proposed to exploit statistical precursors of instabilities, also called early warning signals (EWS).
However, we argue that the limitations of the underlying concept generally do not allow conclusions on the mechanism of abrupt changes without substantial physical knowledge - the burden of proof lies with the applier of EWS. We demonstrate these limitations with examples from vegetation dynamics and sea ice cover change in models of very different complexity. Apart from the practical problem of short and non-stationary time-series, statistical properties such as variance and autocorrelation usually change for reasons unrelated to the system's stability. In particular, it has to be known, how the natural variability (noise) in a system is caused and how it propagates through the system.
A further fundamental limitation is imposed by the large number of spatial degrees of freedom. The benefit of EWS has only been shown in idealised systems of predefined spatial extent. In a more general context like a complex climate system model, the critical subsystem that exhibits a loss in stability (hotspot) and the critical mode of the transition may be unknown. An abrupt change can therefore come as a surprise. However, we suggest that EWS can be applied as a diagnostic tool to find the hotspot of a sudden transition and to distinguish this hotspot from regions experiencing an induced tipping. For this purpose we present a scheme which identifies a hotspot as a certain combination of grid cells which maximise an EWS. The method can provide information on the causality of sudden transitions and may help to improve the knowledge on the susceptibility of climate models and other systems.