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Detecting hotspots of atmosphere-vegetation interaction via Early Warning Signals

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The analysis of so-called Early Warning Signals (EWS) has been proposed as a method to predict sudden transitions that result from a loss in stability of a current climate state. These signals, such as rising variance and autocorrelation, are indicators of an increased relaxation time (slowing down). One particular problem of a prediction based on EWS is the requirement of sufficiently long time series. Spatial EWS may help to ameliorate this problem by combining different observations from the same time. However, the benefit of spatial EWS has only been shown in idealized settings, such as locally coupled grids of a predefined extent. In a more general setup 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.

In our study we analyze the case of a North African and Arabian vegetation collapse during the mid-Holocene with the coupled Planet Simulator - VECODE climate model and a stochastic model of low complexity. We show that EWS at individual grid cells are not detectable if the local feedback is weak. But such grid cells can still be part of a bistable area, if several of them are strongly coupled via the atmosphere. EWS would then only be detectable if the critical mode of the transition were known beforehand. Hence, a prediction will not work in such a general setting.

However, we suggest that EWS can be applied as a diagnostic tool to find the hotspot of a sudden transition and to distinguish the hotspot from regions that rather experience an externally induced tipping as a mere response. For this purpose we have developed a scheme based on a degenerate fingerprinting analysis which can be applied to a set of time slice simulations. The scheme identifies a hotspot as a certain combination of grid cells which maximizes the EWS signal. When we apply this method to Planet Simulator - VECODE time series we find a hotspot of only one to two grid cells near the Red Sea. We then prove that the detected hotspot is indeed a particularly susceptible region in Planet Simulator - VECODE by simulations with a locally perturbed vegetation cover. The method can thus provide information on the causality of sudden transitions and may help to improve the knowledge on the vulnerability of certain subsystems in climate models.