DO PLANTS KNOW ABOUT DYNAMICAL SYSTEMS THEORY?

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Climate change poses a significant threat to the resilience of terrestrial ecosystems. Resilience, commonly defined as the ability to recover after perturbations, and quantifiable as the recovery rate, is a key indicator of ecosystem stability. There is growing concern that ecosystems are losing resilience, making them increasingly vulnerable to extreme events and long-term climate change. The Amazon rainforest, in particular, is projected to become drier, with worst-case scenarios suggesting a tipping point where forest dieback could lead to a transition into a savanna-like state. Dynamical systems theory suggests that resilience changes over time can be diagnosed from observed natural fluctuations; more specifically, that autocorrelation can be used as an estimator of engineering resilience (the rate of recovery from perturbations). Recent studies show that at least some observational data agrees with this theoretical expectation, but the generalisability of this result has not been investigated. It is also unclear which physiological or ecological processes are responsible for the observed trends.

We approach this question with a hierarchy of models, from the state-of-the-art dynamic global vegetation model LPJmL, to simplified versions of LPJmL, simple box models of the terrestrial carbon cycle, and versions of the most idealised and iconic Ornstein-Uhlenbeck process. We find that even the full LPJmL model does not reproduce the observed relationship between resilience and its autocorrelation-based proxy. Obviously, the model is not able to represent the large variety of vegetation types with its few, parameterically rigid plant types. We also demonstrate that the reliability of resilience estimators depends on a large number of processes and conditions in the model, most importantly on (i) the nature, sign and magnitude of perturbations, (ii) the model description of essential processes like carbon allocation and population dynamics, (iii) the spectrum and amplitude of environmental fluctuations, and (iv) the vegetation property under consideration.
Interestingly, the most important deviation from the theoretical, desired 1:1 relationship occurs already at very low complexity, namely in very simple box models of the terrestrial carbon cycle. A process of particular importance is the fractionation of carbon into pools with different lifetimes (e.g. leaves and stems), which affects autocorrelation but not necessarily recovery rates. The results hence indicate that a correlation between ecosystem resilience and its observable proxies (e.g. autocorrelation) neither rules out false alarms, nor does it guarantee that a resilience loss would be picked up by state-of-the-art methods. Moreover, the results have implications for other components of the Earth system, like the Atlantic Overturning circulation (AMOC).