Project title

Dynamical-systems informed stability analysis of Amazon climate

Principle Investigators

Sebastian Bathiany, Niklas Boers

Abstract

The Amazon rainforest is among the elements in the climate system that have been labeled as “tipping elements”. There is concern that as global warming and Amazonian deforestation progress, nonlinear thresholds and positive feedbacks will amplify the projected drying of the rainforest, leading to large-scale loss of forest cover, carbon pools, and biodiversity. There are also nonlinear thresholds within ecosystems when environmental conditions change, for instance when individual trees die from hydraulic failure, and are replaced by other plant types that are more competitive under dry conditions. Furthermore, two important positive feedbacks between vegetation and atmosphere have been identified which could lead to self-amplified Amazon dieback. First, on large spatial scales, the strong atmospheric water recycling over the Amazon could amplify the reduction in precipitation as trees transpire less water in a world with lower soil moisture, higher air temperature and higher CO2. Second, on small spatial scales, increased fire frequency can sustain an alternative savannah state where forest trees cannot compete anymore with more fire-prone grasses.

So far, studies have investigated the potential drivers and feedbacks of such self-amplified loss in a variety of models. A particular line of research is the diagnosis of resilience with indicators informed by dynamical systems theory that may serve as “early warning signals” of large-scale forest loss. There are indications for such warning signs in satellite records; however, these records are often short, hard to interpret, and prone to missing data and artifacts of the measurement process. Current simulations with coupled complex climate models like in CMIP6 project a tendency of Amazon drying and enhanced respiration, but no large-scale forest loss. The existence and robustness of “early warning signals” in such simulations are inconclusive.

In this project, we perform numerical simulations with an offline vegetation model as well as a coupled vegetation-atmosphere model to establish the plausibility of tipping points and associated early warning signals in the Amazon. We will do this by systematically studying the variability and resilience of vegetation properties under idealised conditions and idealised forcing in long simulations. We can hence improve our understanding about the natural variability of vegetation variables (carbon pools, leaf-area index and tree cover fractions) under different environmental conditions, and the associated mechanisms. By comparing offline to coupled simulations, we can also infer how large the purported positive feedbacks actually are in a complex Earth System model, and how these feedbacks affect the diagnosed resilience indicators. Moreover, we diagnose moisture recycling (an essential positive feedback involved in potential Amazon dieback) and assess the potential of this diagnosis for make inferences about the impact of deforestation.

Our experiments can help bridge the gap between the highly complex real world and conceptual models, and improve our understanding of whether human activities are moving the Amazon forest closer to a tipping point.