Identifying the dynamics of abrupt climate changes using high resolution ice core records.

P. Ditlevsen
University of Copenhagen

In dynamical systems of high complexity structural and abrupt changes and transitions often characterize the long-term behavior more than does the periods of quiescence. The geologic record witnesses mass extinctions and abrupt changes, caused by external disruptions as massive impacts or catastrophic internal reorganizations, suggesting the dynamics to be characterized as punctuated equilibrium. Ecosystems show sudden collapses and reorganizations, with a suggested possible bifurcation between rain-forest and grassland state describing a collapse of the Amazon forest. The paleoclimatic record, mainly obtained from ice cores shows that the climate system has undergone abrupt changes, both as non-linear response to orbital changes and as internally caused jumps between meta-stable states, the Dansgaard-Oeschger events.

We hypothesize that these abrupt changes are due to nonlinear responses inherent in the climate system, specifically, so-called tipping points. This behavior result from non-linear climate response to either external forcing, internal stochastic fluctuations or a combination of both. At some point the forcing will cause the climate to jump from one stable state to another. This scenario is termed a tipping point. The concept of a tipping point is quite broad, but here we shall refrain from any general definitions and consider the following more restricted framework: We consider the climate or some components of the climate as a dynamical system depending on a set of parameters. Factors, not included in the system interacting with components of the system, can then be considered external forcing or stochastic fluctuations. Two common, and often competing, hypotheses are: The climate systems steady state loses its stability and disappears as an external system (control-)parameter slowly changes, so-called b-tipping, b for bifurcation-induced; or fluctuations spontaneously push the climate system from one stable state to another, so-called n-tipping, n for noise-induced.

The cause of the tipping can be very different in the two cases, and especially the possibility of predicting a tipping will be different. In the case that the underlying dynamics or the control-parameter are not completely known, there could still be early warning signals in the statistics of the observed fluctuations prior to a tipping point.

[l] P.D. Ditlevsen, S. Johnsen, Geophys. Res. Lett. **37**, L19703 (2010).
[2] Z.-G. Shao, P.D. Ditlev, Nat. Comm. **7**, 10951 (2016).
[3] P. Ditlevsen, Monograph **Non-linear and Stoch**, 1-28 (2017).