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# Hearing through the noise: Predictability and tipping points in the climate

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It is taken for granted that the limited predictability in the initial value problem, the weather prediction, and the predictability of the statistics are two distinct problems. Predictability of the first kind in a chaotic dynamical system is limited due to critical dependence on initial conditions. Predictability of the second kind is possible in an ergodic system, where either the dynamics is known and the phase space attractor can be characterized by simulation or the system can be observed for such long times that the statistics can be obtained from temporal averaging, assuming that the attractor does not change in time.

For the climate system the distinction between predictability of the first and the second kind is fuzzy. On the one hand, weather prediction is not related to the inverse of the Lyapunov exponent of the system, determined by the much shorter times in the turbulent boundary layer. These time scales are effectively averaged on the time scales of the flow in the free atmosphere. On the other hand, turning to climate change predictions, the time scales on which the system is considered quasi-stationary, such that the statistics can be predicted as a function of an external parameter, say atmospheric $CO_2$, is still short in comparison to slow oceanic dynamics. On these time scales the state of these slow variables still depends on the initial conditions. This fuzzy distinction between predictability of the first and of the second kind is related to the lack of scale separation between fast and slow components of the climate system.

The non-linear nature of the problem furthermore opens the possibility of multiple attractors, or multiple quasi-steady states. As the paleoclimatic record shows, the climate has been jumping between different quasi-stationary climates. The question is: Can such tipping points be predicted? This is a new kind of predictability (the third kind).

The Dansgaard-Oeschger climate events observed in ice core records are analyzed in order to answer some of these questions. The result of the analysis points to a fundamental limitation in predictability of the third kind.

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