Simulation of Extreme Events in Climate Models with Rare Event Algorithms

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The study of extreme events is one of the main areas of application of numerical climate models. Events like heat waves, floods or wind storms, as well as state transitions related to tipping elements of the climate system, can have huge impacts on human societies. Studying rare events and transitions on a robust statistical basis with complex climate models is however computationally challenging, as very long simulations and/or very large ensembles are needed to sample a sufficient number of events. This problem can be tackled using rare event algorithms, numerical tools designed to reduce the computational effort required to sample rare events in numerical models. These methods typically take the form of genetic algorithms, where a set of suppression and cloning rules is applied to members of an ensemble simulation, in order to oversample trajectories leading to the events of interest. Here we show recent applications of one of these algorithms to three different classes of events: 1) heat waves and warm summers in the Northern hemisphere, 2) extremes of Arctic sea ice reduction and 3) the weakening and collapse of the Atlantic Meridional Overturning Circulation. We show how the rare event algorithm allows to efficiently sample events where the persistency of a specificic quantity is a key element of the dynamics of the extreme or transition, and we analyse the physical properties of the trajectories leading to the events. Finally we discuss how these results open the way to further applications to a wide range of problems.