Stage de Master 2 - Sujet de thèse - Master and/or PhD project.

SIMULATION OF CLIMATE EXTREME EVENTS WITH RARE EVENTS ALGORITHMS

1 Rare event algorithms: a new paradigm for studying climate extremes

One of the goals of climate sciences is to determine the statistics of extreme events in the present and future climates, for instance extreme heat waves, cold spells, wind storms, droughts, floods, and hurricanes. Extreme events might indeed be one of the main drivers of the impact of climate change in the future [4, 3].

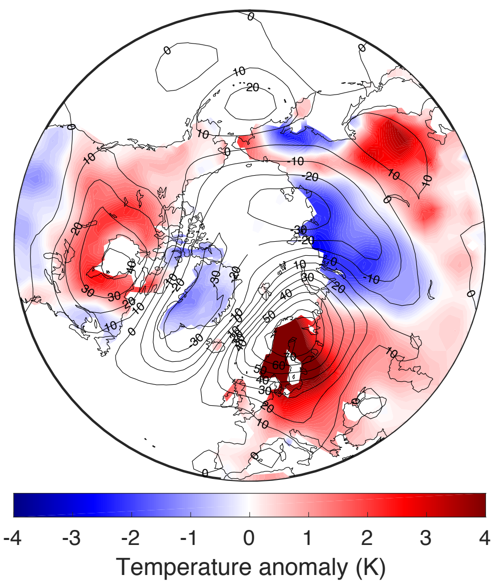

Figure 1.1: (a) Using a new rare event algorithm, we have been able to compute the return time and the dynamics of extreme heat wave that could not have been studied previously [6]. With this approach, we have computed a composite map of surface temperature anomalies (colors) and 500 hPa geopotential height (contours) (see figure), conditional on the occurrence of an extreme European heat wave with return time larger than 1000 years. Here we can see how strong warming over Europe is linked to strong cooling over central Asia and Greenland, and strong warming over East Asia and North America. These are features that cannot be studied at a reasonable computational cost with usual simulation techniques. This new tool might be the new paradigm for studying rare events using climate models in the future.

While the impact of future climate extremes has been clearly assessed at a qualitative level, precise quantification is much harder and is still beyond the reach of climate sciences. One of the reasons is that studying extremes on a robust statistical basis is challenging, since the most extreme events are also the rarest. Historical records are too short to give reliable estimates for events with return periods longer than a few decades, and cannot be used to study future climates. Climate scientists thus often rely on numerical general circulation models of the atmosphere and the climate system, that can be run in a controlled environment, and used to perform long simulations and projections of future climates. Using realistic models is however computationally very expensive. Studying events with return periods of hundreds of years requires running the models for tens of thousands of years, which involves many millions of hours of computing time on the most powerful supercomputers. State of the art models are typically run for a few centuries at most, making it impossible to study even approximately very rare events, on a good statistical basis.

Rare event algorithms are a possible solution to this problem. Those algorithms, developed in statistical physics, are dedicated to the computation of rare events in a numerical model at a much smaller computational effort than direct sampling [6, 5, 2, 1]. The goal of these methods is to make rare events effectively less rare in a simulation, while being able to compute exactly their model probability. This makes possible to compute faithfully the probability of rare events using simulations that are several orders of magnitude shorter than the ones required by direct numerical sampling. This approach often uses genealogical algorithms. In a typical implementation, a simulation of an ensemble of trajectories of the model is interrupted after an interval of free evolution, to select the trajectories that are moving towards the desired rare events. Trajectories that are performing well are copied, whereas badly performing ones are killed, thereby focusing the computational effort on the more promising ones. The specific way the trajectories are selected and cloned determines the class of rare events under target and the rule to compute their probability.

We have for the first time applied such an algorithm to a climate model [6], and studied extreme heat waves. We have been able to estimate the return times of extreme events which are hundreds of years longer that the duration of the simulation. We have observed extremely rare events which were impossible to observe before because of the lack of statistics. We have obtained hundreds more extreme events than with a direct numerical simulation of the model. This tool, with such an improvement, gives the opportunity to make unprecedented studies in the future, and to advance the science of climate extremes in a decisive way.

2 Master and PhD project: Studying midlatitude extreme heat waves with an unprecedented statistics

The aim of the master project will be to apply the rare event algorithm that we have developed, in order to study the dynamics and the probability of extreme heat waves. This new tool opens the study of a range of problems that can not be studied through conventional ways. The master project will focus mainly on climate issues and problems. The first aim is to better quantify the increase of the probability of extreme heat waves for midlatitude climates, as an effect of climate change. Applying this algorithm to several areas of the globe, and with several different definitions of heat waves, we will be able to assess the differences between different regions as far as heat waves are concerned.

The outcome will be a better classification of the type of potential heat waves, of their probability, and of their evolution with a changing climate. This question is a crucial one for understanding the future impact of climate change.

A second aim will be to discuss precisely the dynamical mechanisms that lead to extreme heat waves. Are they always related to blocking events? Which kind of blocking events? What are the precursors of blocking events? This type of questions can not be addressed properly using conventional tools for very rare events, because of the lack of statistics related to the huge cost of the numerical simulations. These new dynamical studies will be a way to address the comparison of the ability of different models to actually reproduce faithfully the dynamics leading to extreme heat waves. In order to consider these questions, we will use both Plasim model and an IPCC class model. We will compare extreme heat waves, their dynamics and precursors in both models. This second aim will probably not be achievable during the Master project and would be part of the PhD project.

Depending on the taste and interest of the student, the PhD project could be focussed either on climate applications or could also be pushed towards more challenging work requiring theoretical work and insights. We could for instance develop new algorithms in order to study other types of extremes events that can not be studied using the approach we have developed so far.

Practical informations

Scope: This is intended as a few month research internship at the Master's level, and could potentially be continued as a PhD project. Start date is flexible.

Profile: We are looking for candidates with a background either in climate sciences, in physics, or in mathematics. The candidate should be ready to run numerical simulations. We are already running routinely the climate models to be used, hence no numerical skills is required, beyond some motivation to learn.

Location: Laboratoire de Physique de l'ENS de Lyon, Lyon, France.

Supervisors: Freddy Bouchet (CNRS, ENS de Lyon) and Francesco Ragone.

Potential candidates should contact Freddy Bouchet: Freddy.Bouchet@ens-lyon.fr

References

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