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Very rare heat extremes: how anomalous could they get?

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Extreme heat waves as in 2003 and 2010 can have severe consequences for the economy and society. This raises the question how anomalous they could have gotten. Addressing this question is challenging given the lack of long coherent reliably daily data. Multi-millennial GCM simulations and single-model initial condition large ensembles offer a new opportunity to investigate the very upper tail of temperature distribution. Here, we use a nearly 5,000-year long pre-industrial control run and a 84-member large initial condition ensemble performed with CESM1.2. Evaluations show that the simulated climate variability and temperature response to circulation anomalies agree well with the ERA5 reanalysis over large parts of the global land regions.

We show that highest temperature extremes in the long pre-industrial control simulation exceed the temperature records of 2003 by several degrees in the related hotspot region over Western Europe. The anomalies are caused by large anticyclonic circulation anomalies and very dry land surface conditions, leading to amplifying feedbacks in the surface energy budget. Moreover, the simulation results reveal that summer temperature maxima as a function of return period have an asymptotic, suggesting an upper temperature limit.

In a next step, we use a novel method of ensemble boosting to generate even more extreme temperatures. To that end, 100-member ensembles are reinitialized with perturbed atmospheric conditions weeks before the most intense events. Thereby, we gain insight into short-term mechanisms that underly these hot extremes. The result of the ensemble calculation shows that using this method even more extreme event anomalies can be generated, substantially exceeding highest values in the long pre-industrial control simulations. We investigate how the physical mechanisms of these rare and unseen simulated events differ from more moderate events. We further compare the simulated very rare events with maximum anomalies estimated based on statistical methods.