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# Drivers and predictability of extreme summer Arctic sea ice reduction with rare event simulation methods

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Various studies have identified possible drivers of extreme Arctic sea ice reduction, as observed in the summers of 2007 and 2012, including preconditioning, the oceanic heat transport and the synoptic-scale to large-scale atmospheric circulation. However, a quantitative statistical assessment of these drivers and a better understanding of the seasonal predictability of these events are hindered by the poor statistics of extremes in observations and in numerical simulations with computationally expensive climate models. Recent studies have addressed the problem of sampling extreme events in climate models by using rare event algorithms, computational techniques developed in statistical physics to increase the sampling efficiency of rare events in numerical models. In this work, we study the statistics of summer seasons with extremely low pan-Arctic sea ice area under pre-industrial greenhouse gas conditions, applying a rare event algorithm to the intermediate complexity coupled climate model PlaSim. Using the rare event algorithm, we oversample dynamical trajectories leading to events with extremely low summer and September mean pan-Arctic sea ice area. Compared to standard simulations of the same computational cost, we increase the sample size of the extremes by several orders of magnitude, which allows to perform statistically robust composite analyses of dynamical quantities conditional on these events. In addition, we have access to ultra-rare events with return times of up to $10^5$ years. We exploit the improved statistics of summers with extremely low pan-Arctic sea ice area to study precursors of these events, including a surface energy budget analysis to disentangle the oceanic and atmospheric forcing on the sea ice. Particularly, we investigate the linkage between the extremes in summer Arctic sea ice area and the preceding states of the Arctic Oscillation and of the Arctic Dipole Anomaly pattern, as well as between the extremes and the preconditioning in the sea ice-ocean system during the onset of the melt season.