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Changes in land-atmosphere coupling may amplify increases in very rare temperature extremes

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Extreme heat events are becoming more severe. Attribution studies have demonstrated the effect of anthropogenic climate change on recent devastating events, including the heat waves in Canada in 2021, Northern India in 2022 and the Western Mediterranean in 2023. Such impactful events are very rare with return periods of 100 years and more even in present climate. Their rareness is in stark contrast to the typically considered return periods ranging from less than a year to maybe 20 years. This choice might often be inevitable because of practical limitations, mainly the length of observational and climate model records. But generalising from such analyses to extreme events in general tacitly assumes that very rare events respond to climate change in a similar way as the analysed moderate extreme events. Several studies investigating land-atmosphere feedbacks and atmospheric circulation changes indicate, however, that this assumtion may not be justified.

Here we use three single model initial condition large ensembles (SMILES) to assess differences between projected changes in moderate heat extremes (represented by 2-year return values of the hottest day in a year) and very rare extreme events (represented by corresponding 200-year return values). We analyse changes from 1990-2014 to 2075-2099 according to the SSP5-8.5 scenario.

We find large regions where projected changes in very extreme events are markedly different - both stronger or weaker - to those in moderate extreme events. Model uncertainty about these differences is very high though: all considered SMILES suggest that such regions exist, but they do not agree on the locations. The underlying mechanisms, however, are robust across models: in regions of increasing soil moisture temperature coupling strength, changes in very rare events can be almost twice as high as those in moderate extremes. Vice versa, in regions of decreasing coupling strength, changes may be much weaker. These changes can to a large extent be traced back to changes in precipitation patterns, highlighting the role of atmospheric circulation changes.

The corresponding patterns emerge already over shorter time horizons and are thus relevant for mid-century projections, low emission scenarios and event attribution studies. Robust inference about these differences is impossible based on individual model simulations, but requires the sample size of SMILES. Not accounting for these changes could lead to a dramatic misrepresentation of future climate risks from heat events. Our findings therefore confirm the

importance of studies specifically targeting very extreme events.