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The challenge of estimating high return levels with short records under large internal variability

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The scientific understanding of changes in climate extremes is mostly limited to moderate definitions of extreme events occurring every few years, due to a lack of long-term observational daily data sets. In order to estimate return levels beyond observed time periods and event magnitudes, extreme events are typically modelled statistically based on extreme value theory. This is challenging since the short observational record may be affected by low-frequency natural internal variability and limits the block size that can be used.

Here we test some common assumptions in the statistical modelling of extremes based on indices of climatic extremes (Tx7d, Rx1d, Rx5d) using long pre-industrial control runs and initial-condition large ensembles with thousands of years of model data.

The tail of a distribution fitted to temperature and precipitation maxima is known to be highly sensitive to the compliance with statistical assumptions and choices such as the block size. Typically, 1-year block maxima are extracted from observational time series due to short record length. It is unclear whether these maxima are already in the domain of true extremes suitable for an extreme value analysis. Furthermore, the observational record is too short to sample low-frequency regional variability and potential transient changes in the mean climate. Standard uncertainty estimates (confidence intervals and hypothesis tests) are generally not accounting for potential biases introduced by a dominant mode of climate variability or violated modelling assumptions.

Based on a 4700-year pre-industrial control simulation and an 84-member ensemble performed with CESM 1.2.2 model, we systematically extend the statistical modelling of temperature and precipitation extremes to larger block-sizes and longer synthetic observational periods. This analysis reveals a considerable influence of climate variability on tail estimates. Furthermore, the use of too small block sizes can induce substantial random as well as systematic biases. Statistical model complexity and thus uncertainty further increases for extremes retrieved from transient large-ensemble members, as non-stationarity has to be accounted for in the model formulation. Thus, the potential of spatial pooling or conditioning on further climatic variables as proxies for a specific climatic mode to derive more robust tail estimates is also evaluated. Findings based on the CESM ensemble are compared with pre-industrial control runs performed with other models in CMIP6 and other initial-condition large ensembles of the CLIVAR large ensemble working group.