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Storylines of past and plausible future climates for recent extreme weather events with coupled climate models

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Under the ongoing climate change, extreme weather events are becoming more prolonged, intense, and frequent; and this trend is expected to continue in a future warmer climate. Several studies have found that the synoptic atmospheric circulation at the time of the event is the main contributing factor in most cases. Moreover, they are shaped by slower processes, including sea-surface temperature and soil moisture, in turn influenced by the history of preceding weather patterns, and by the background climate. The separation of influencing components is exploited by the storyline approach, where an atmosphere model is nudged toward the observed dynamics using different climate boundary conditions. Thus, the storyline approach focuses on the less uncertain thermodynamic influence of climate on extreme events, disregarding the somewhat controversial dynamical changes. This approach provides a very efficient way of making the impacts of climate change more tangible to experts and non-experts alike as events fresh in the people's memory are reproduced in different plausible climates with just moderate computational resources.

Spectral nudging experiments have been run with two coupled climate models, AWI-CM-1 and AWI-CM-3. In these simulations, the large-scale free-troposphere dynamics are constrained toward ERA5 data and the model is run for different boundary conditions. Here, the ocean and sea-ice state are consistently simulated, unlike previous studies which employed atmosphere-only models. Our setups reasonably reproduce daily to seasonal observed anomalies of relevant unconstrained parameters, including near-surface temperature, soil moisture or cloud cover. In particular, our configurations showed satisfactory skills in reproducing two different extreme events: the July 2019 European heat wave, and the July 2021 European extreme rainfall. Therefore, this methodology has been applied to study several extreme events in different climates. To do so, nudged simulations are branched off CMIP6 historical and scenario simulations of the same model. For the particular July 2021 extreme rainfall event, we have run five ensemble members for AWI-CM-1-1-MR for dynamical conditions from 1st January 2017 to 31st July 2021 in pre-industrial, present-day, +2K, and +4K climates. These simulations are complemented with similar experiments for AWI-CM-3.

The most outstanding finding of these studies is a global warming amplification associated with

some events, which exacerbates their exceptionality, especially in a high emission scenario.