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Extremes cluster in a warmer world

An assessment of low-probability, high-impact events using the MPI Grand Ensemble

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High-impact hazards such as extreme precipitation, heat stress and drought will occur more closely together, both in time and in space, as the world becomes warmer.

This clustering of extreme conditions year after year brings even larger risks to the already vulnerable affected regions, further threatening societal and ecological resilience.

MPI-GE: the ideal tool to precisely sample rare events

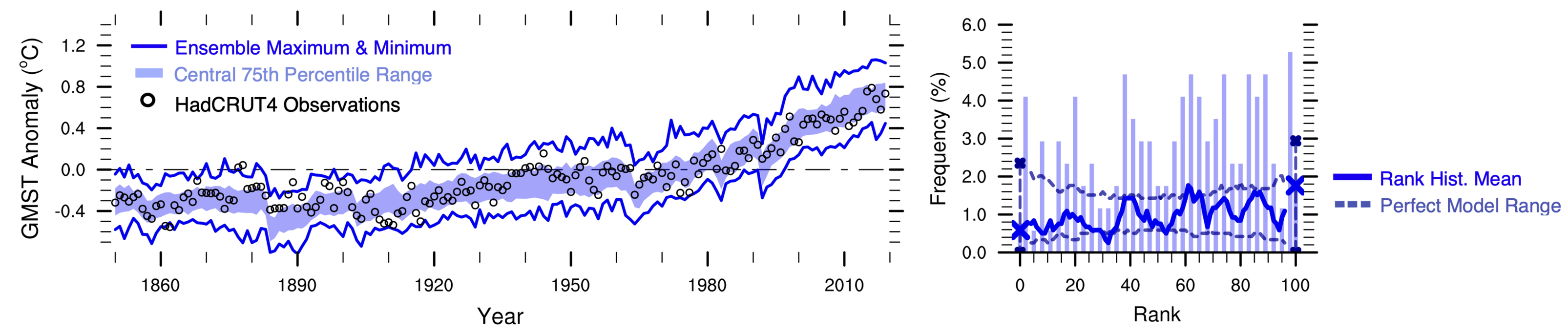
Paper on evaluation of different Large Ensembles:
Suarez-Gutierrez et al. 2021, Clim. Dyn.

The 100-member **Max Planck Institute Grand Ensemble** (MPI-GE; [1]) simulates **large samples of low-probability extreme events**, based on a **precise sampling of the chaos in the climate system** arising due to internal variability.

MPI-GE is the **largest ensemble** from a comprehensive Earth System Model (MPI-ESM, CMIP5 forcing), and offers one of the **best representations of forced changes and variability** in historical temperatures among all available large ensembles [2].

This makes MPI-GE the ideal tool to assess **changes in the characteristics and likelihood of low-probability, high-impact extreme and compound events** in a warming world.

Here, we use historical and **moderate warming** (RCP4.5) MPI-GE simulations, with **2,25C of global mean temperature rise** by the end of the 21st Century.



MPI-GE captures forced changes and variability in observed temperatures well. Time series of MPI-GE (blue) annual Global Mean Surface Temperature (GMST) anomalies wrt. the period of 1961-1990 compared to HadCRUT4 observations (black circles). Rank histogram of HadCRUT4 observations as a member of MPI-GE (full line) against perfect model rank histogram range (dashed lines). Model captures observations well if rank hist. of observations falls mostly within perfect model range.

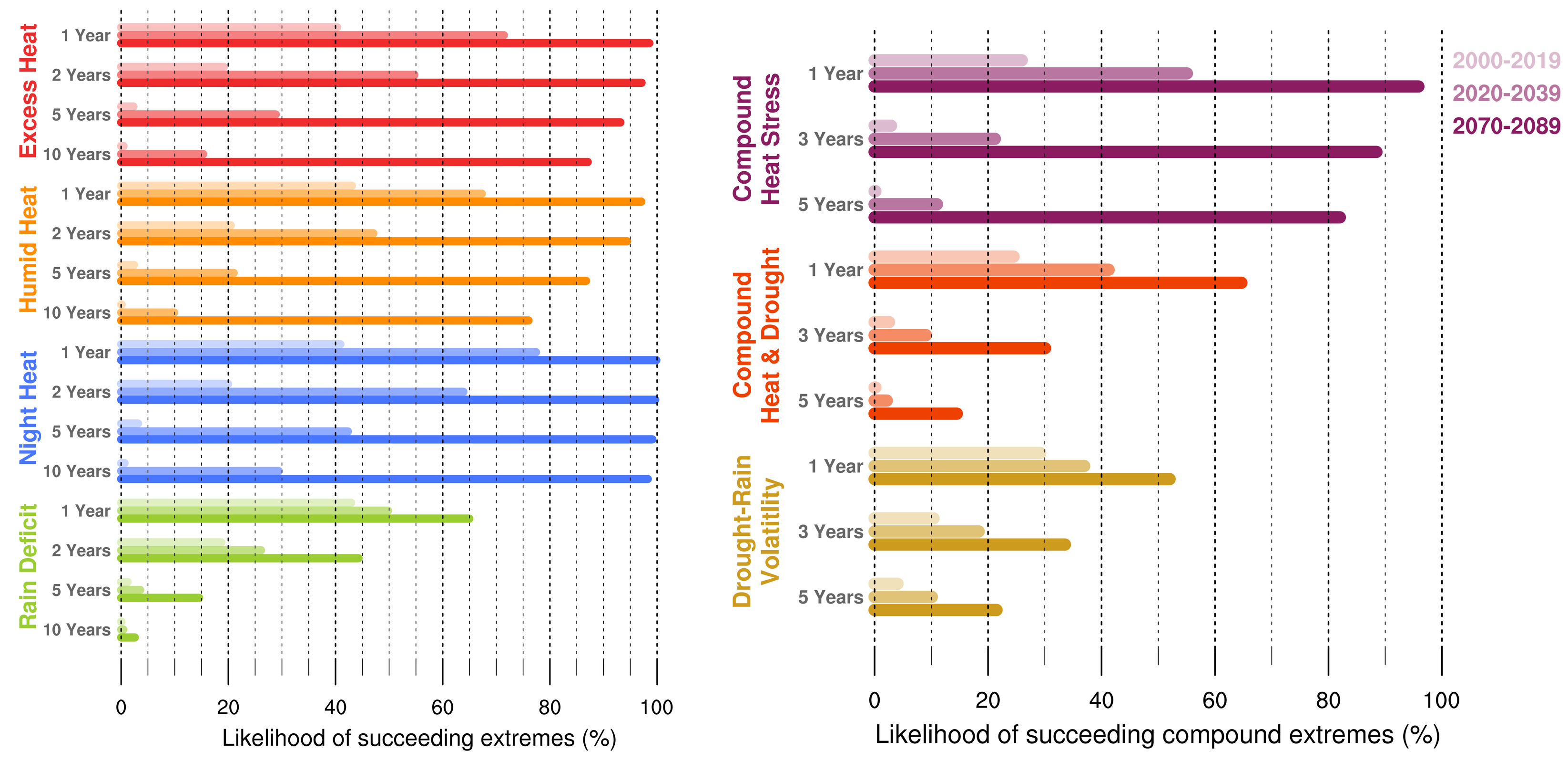
Increasing likelihood of succeeding extreme heat and drought stress over Europe [3]

The likelihood of a **whole decade of year-after-year extreme heat over Europe goes from virtually impossible to 10-30%** in just the next two decades. Lack of nighttime cooling becomes the most persistent form of heat stress over Europe.

The likelihood **of two succeeding years with extreme Rain Deficit goes from 20 to over 40%** by the end of the century, but the likelihood of 5-10 years of drought years remains relatively low.

Compound Heat Stress likelihood doubles in the next 20 years, and reaches over 95% by the end of the century. Rare or **virtually impossible succeeding Compound Heat and Drought becomes likely already in the next 20 years**, and 3 times more likely by the end of the century,

The likelihood of rare or **virtually impossible 3-5 years of succeeding compound extremes reaches 10-20% in the next 20 years** for all metrics.



Likelihood of year-after-year succeeding extremes under increasing global warming for different single and compound excess metrics, for the periods of starting between the years 2000-2019 (light colors), 2020-2039 (medium colors) and 2070-2089 (dark colors). Extreme years are defined as those equal to or larger to the 2000-2019 average in each metric.

These **novel Excess Metrics** illustrate excess heat and/or drought stress beyond certain thresholds accumulated over whole seasons.

Excess Heat, Humid Heat, and Night Heat are defined as the difference between the actual temperature reached (maximum daily temperature, Wet Bulb temperature, or minimum daily temperature for each metric respectively) minus the given temperature threshold over said grid cell, summed over all grid cells and days per summer.

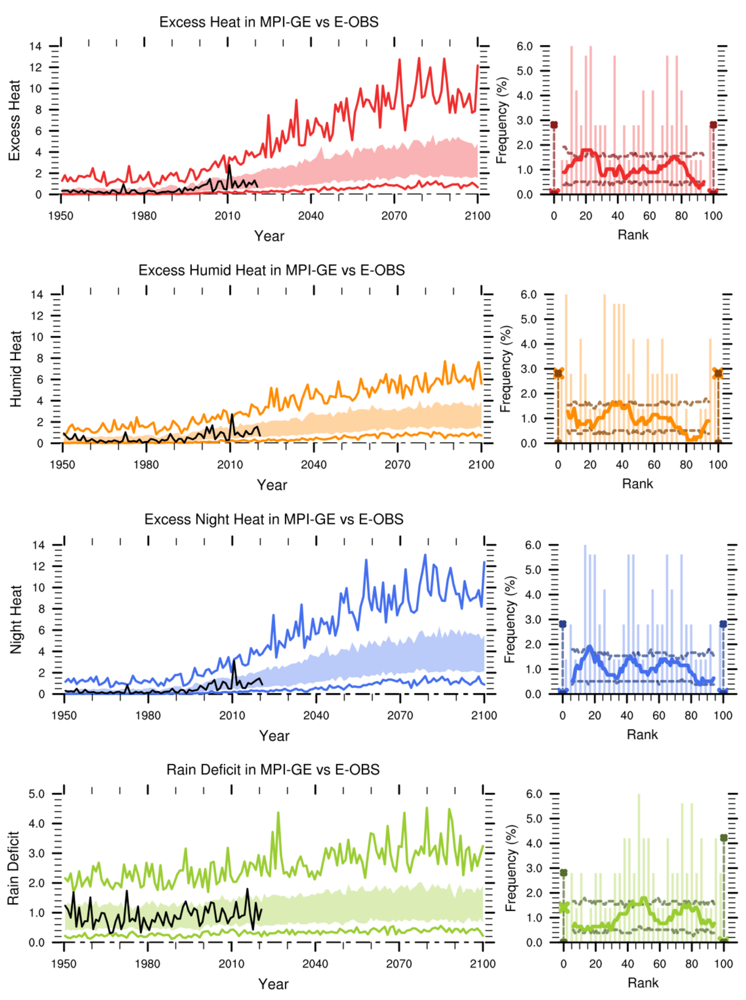
Excess Rain Deficit is defined as the difference between the 10th percentile monthly precipitation-threshold minus the actual precipitation, summed for each grid cell and month in the whole year.

Thresholds are defined as the 10th/90th percentile under historical conditions defined by the period of 1950-1999.

Compound Heat Stress reflects all three Excess Heat, Humid Heat and Night Heat extreme conditions occurring together.

Compound Heat and Drought reflects simultaneous extreme Excess Heat and Rain Deficit conditions.

Drought-Rain volatility reflects years of extreme Rain Deficits followed or preceded by years of extreme rain excess, defined as the difference in monthly precipitation minus the 90th percentile precipitation-threshold for each month summed for the whole year.



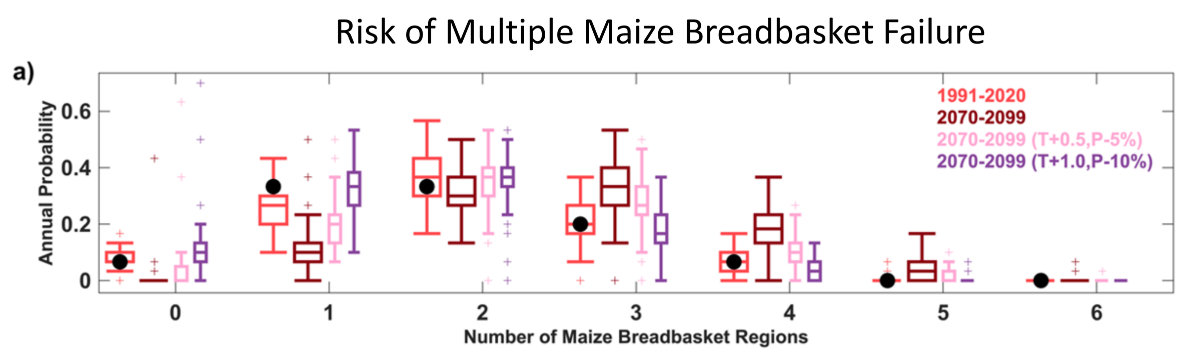
Heat and Drought Stress Excess Metrics for MPI-GE against E-OBS. Time series (left) show excess metrics anomalies simulated by MPI-GE (color) and E-OBS observations (black), as ratios with respect to their average over the period of 2000-2019. Rank histograms (right) represent the frequency of each place that E-OBS annual values take in a list of ensemble members ordered by ascending metrics values. Model captures observations well if rank hist. of observations falls mostly within perfect model range.

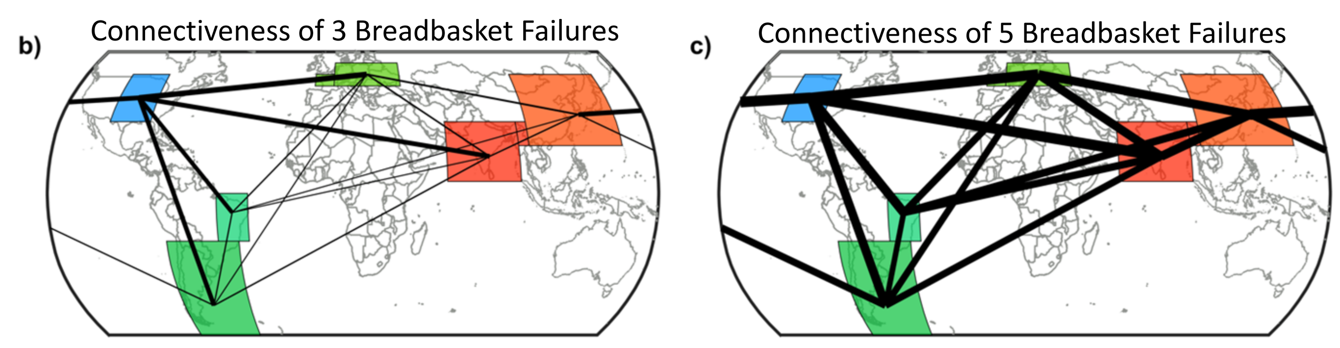
Increasing spatiotemporal proximity in global heat, drought, and precipitation extremes [4]

Paper on spatiotemporal proximity of extremes:
Raymond et al. 2022, Environ. Res. Lett.

The chance of **concurrent extreme heat and drought** leading to simultaneous maize **failures in 3 or more breadbaskets doubles,** from 28.7% to 57.3%; while the frequency of **5-breadbasket-failure years increase from 0.6% to 5.4%.**

The region **most likely to suffer failure in years with 3 breadbasket failures is the Central US;** connected most closely to Central Europe.



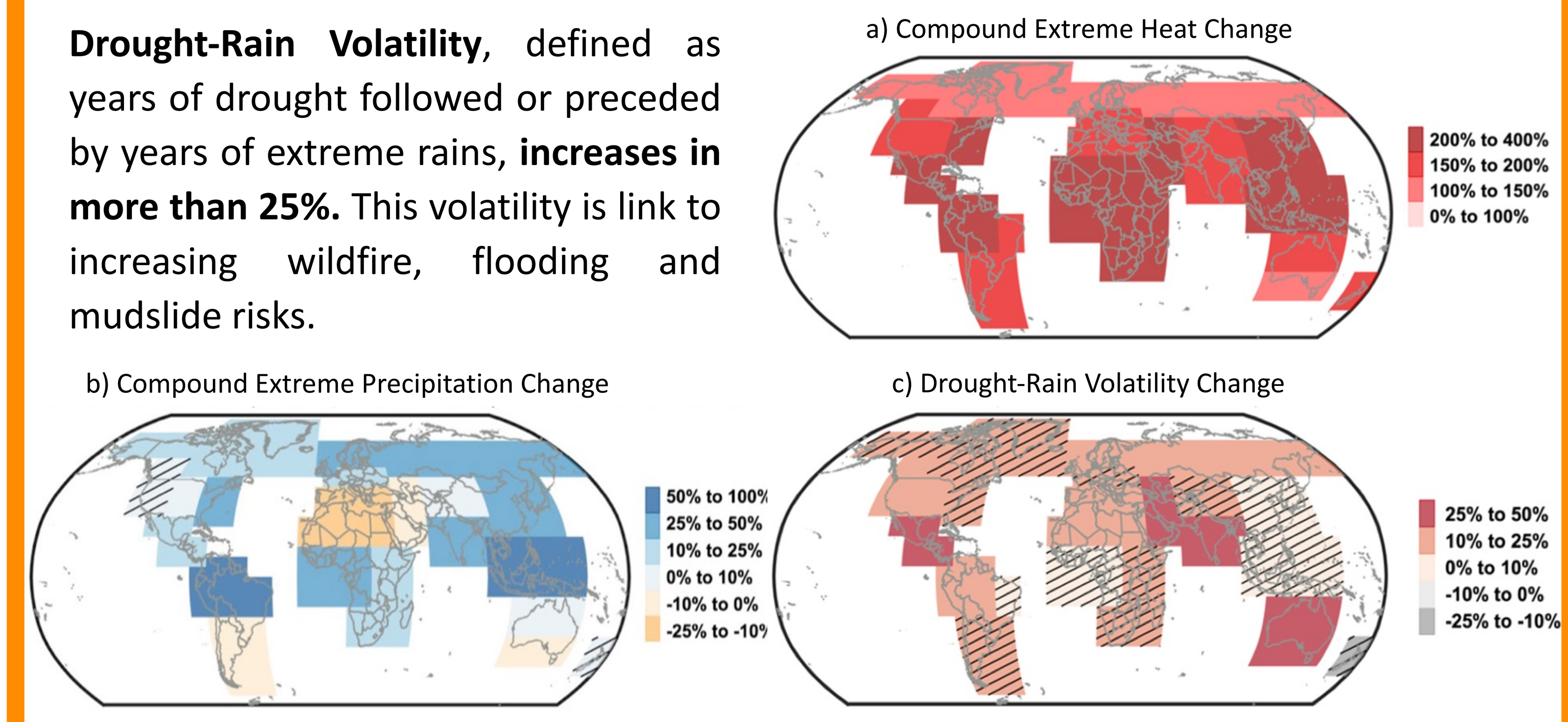


Changing risk of multiple-breadbasket failure for maize. (a) Probability of a year having X breadbaskets experiencing a failure. Scenarios are 1991–2020 (light red), 2070–2099 (dark red), and two potential future CO2-fertilization effects: crop failure threshold at 0.5C warmer and 5% drier than current (pink), and at 1.0C warmer and 10% drier (purple). Circles show equivalent probabilities using reanalysis. (b) For years with 3 breadbasket failures, wider lines indicate higher probability that the two regions connected are among those experiencing failures, varying here from 9% to 44%. (c) As in (b) but for years with 5 breadbasket failures, with probabilities here varying from 45% to 86%.

Temporally-compounding **Extreme Heat increases in frequency by 100%–300%** from recent decades to the end of the 21st century.

Temporally-compounding **Extreme Precipitation becomes 50-100% more frequent** in large mid and low latitude areas.

Drought-Rain Volatility, defined as years of drought followed or preceded by years of extreme rains, **increases in more than 25%.** This volatility is link to increasing wildfire, flooding and mudslide risks.



Projected median percent change in (a) temporally compound extreme heat, (b) temporally compound extreme precipitation and (c) extreme drought-rain volatility between 1991–2020 and 2070–2099. Hatching marks least than 67member% of ensemble s agree on the sign of the change. Compound Extreme Heat and precipitation is counted over three or more consecutive extreme days exceeding the 95th percentile of daily values (considering all seasons together) of daily-maximum temperature and daily-total precipitation at the grid cell level. Drought-Rain Volatility is defined as an extreme drought year having an extreme rain year either one year before or after. Drought and Rain years are defined as those below/above the 10th/90th percentile of total precipitation, respectively.

References

[1] Maher et al. (2019). The Max Planck Institute Grand Ensemble — Enabling the Exploration of Climate System Variability. *JAMES.*

[2] Suarez-Gutierrez et al. (2021). Exploiting large ensembles for a better yet simpler climate model evaluation. *Climate Dynamics.*

[3] Suarez-Gutierrez et al. (In Preparation). The Decadal Variability of Extreme European Heat and Drought Stress

[4] Raymond et al. (2022). Increasing spatiotemporal proximity of heat and precipitation extremes in a warming world quantified by a large model ensemble. Environ. Res. Lett.

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