Anthropogenic changes in internal climate variability can cause the most extreme climate extremes

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EGU, 8 May 2020

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Take-home messages

1| The frequency and intensity of climate extremes is, on average, much more extreme when the change is caused by an increased variability than when caused by a shift in the mean climate.

2| Attribution on a stakeholder-relevant scale shows that the changed frequency and intensity of temperature and wind extremes are primarily driven by changes in the mean state, while those of precipitation extremes are primarily driven by changes in internal variability. Our results reconcile contrasting findings of previous studies on the relevance of internal variability for changes in extremes.

3| A reduced vulnerability and a strengthened socioeconomic resilience of society are required to address a) the more frequent heat extremes caused by the mean temperature increase especially in the tropics, and b) the more intense precipitation extremes caused by changes in precipitation variability especially in the densely populated southern and eastern Asia.

4| Limiting global warming to 1.5ºC would largely prevent the exposure of the future global population to the unprecedented frequency and intensity of climate extremes.

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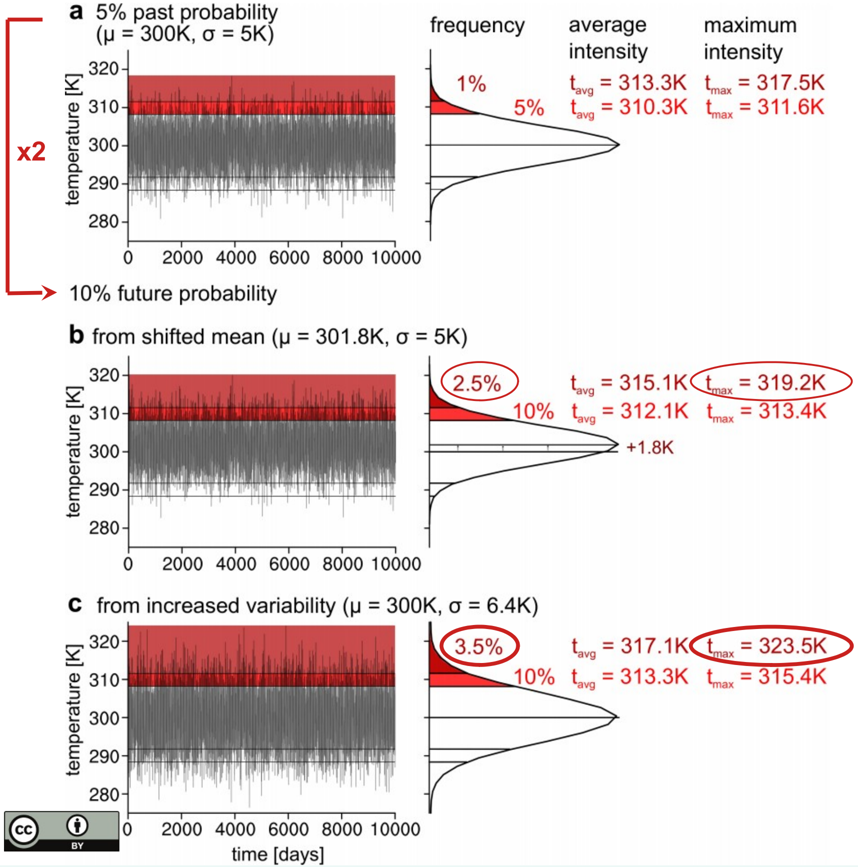
The cause-dependent severity of climate extremes

White-noise time series



- For a doubling of the frequency of past extreme events very extreme extremes occur much more frequent and intense when the change in frequency is caused by an increased variability (c) than when caused by a shift in the mean climate (b).

- If the frequency of extreme heat ($p < 0.05$) doubles because of a shift of the distribution in a warming climate, very extreme events ($p < 0.01$) become 2.5 times more likely. If, however, the frequency of extreme events doubles because of an increase in internal variability, very extreme events become 3.5 times more likely.

- In addition, the maximum intensity of the most extreme event during a time period triples when an event is caused by internal variability compared to a shift in the mean climate.

→ Knowing the cause of future extreme events is necessary to estimate probabilities and intensities of very extreme extremes that are outside the envelope of climate-model simulations.

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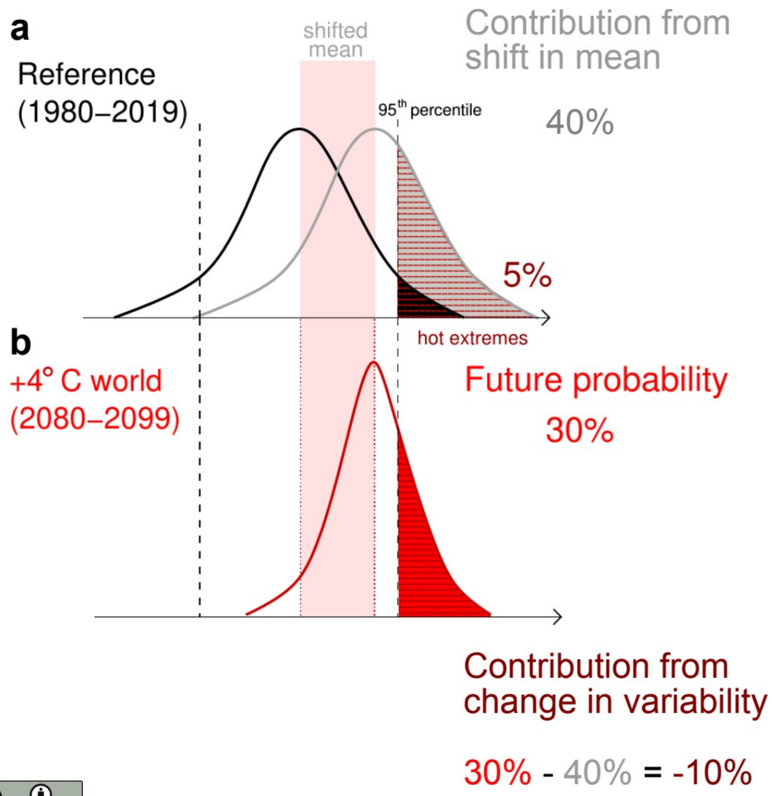
Empirical threshold approach that accounts for internal variability



- We extend an established empirical threshold approach (Stott et al, 2004; Stott, 2016) to specifically account for changes in internal variability on a local scale.
- We apply this approach to the CMIP5 models that provide daily output and ensemble simulations (see table below).
- We use the ensemble simulations of each model to isolate the change in internal variability by removing the yearly-averaged forced signal in all simulations (compare Olonscheck & Notz, 2017; Frankcombe et al, 2018).

→ Allows us to robustly estimate the fraction of future extremes caused by anthropogenic global warming versus the fraction caused by the warming-induced changes in internal variability.

Model name	Spatial resolution latitude x longitude	Number of historical + RCP8.5 simulations for SAT / 10-m wind speed / total precipitation
CanESM2	2.79° x 2.81°	5 / 5 / 5
CCSM4	0.94° x 1.25°	3 / - / 3
CSIRO-Mk3-6-0	1.865° x 1.875°	10 / 10 / 10
EC-EARTH	1.125° x 1.125°	10 / 5 / 10
HadGEM2-CC	1.25° x 1.875°	3* / 3* / 3*
HadGEM2-ES	1.25° x 1.875°	4* / 4* / 4*
IPSL-CM5A-LR	1.89° x 3.75°	4 / 4 / 4
MIROC5	1.40° x 1.41°	3 / 3 / 3
MPI-ESM-LR	1.865° x 1.875°	3 / 3 / 3

* end in year 2098

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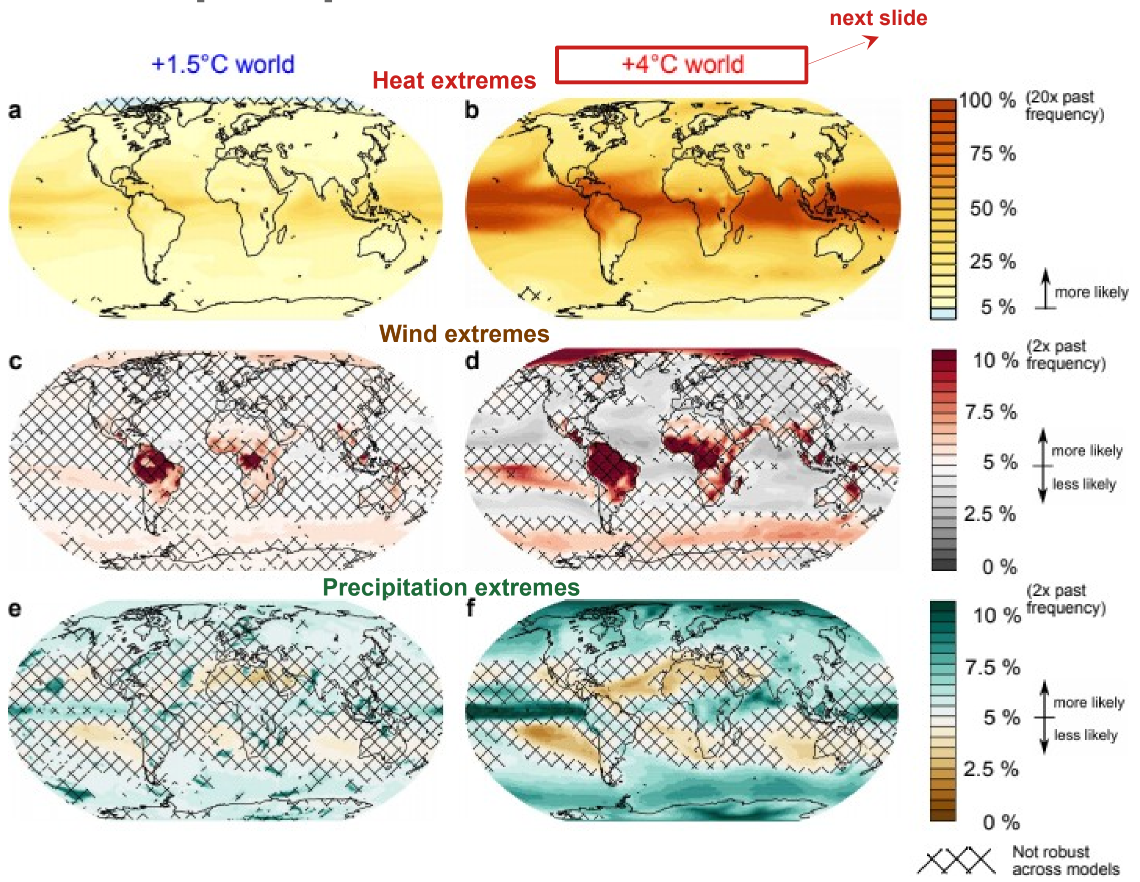
Future probability of heat, wind and precipitation extremes

- We provide multimodel-mean estimates of changes in the frequency of heat, wind and precipitation extremes for a 1.5ºC (left) and a 4ºC warmer world (right) compared to preindustrial.

- In a 4ºC warmer world,
  - heat extremes will be much more frequent everywhere, with an up to 20-fold increase in the heat-extreme frequency (b),
  - wind extremes are twice as frequent on the Arctic Ocean, and are substantially increased in regions where tropical forests are converted to bare land (d),
  - precipitation extremes increase in many high-latitude and tropical regions (f).

- These substantial changes in the frequency of climate extremes can be largely prevented by limiting global warming to 1.5ºC (a, c, e).



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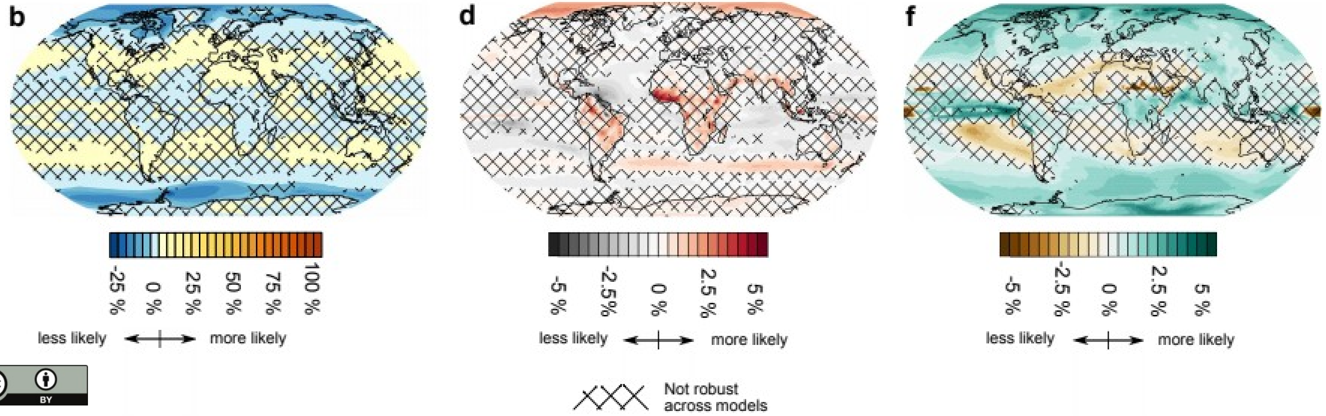
Attribution of the probability of extremes in a 4°C warmer world

Future change in the frequency of

heat extremes | wind extremes | precipitation extremes

caused by a shift in the mean

caused by a change in variability



- We find that the changed frequency of temperature and wind extremes are primarily driven by changes in the mean state, while those of precipitation extremes are primarily driven by changes in internal variability.

- The multimodel-consistent contribution from changes in internal variability impacts the patterns of the future frequencies of extremes.

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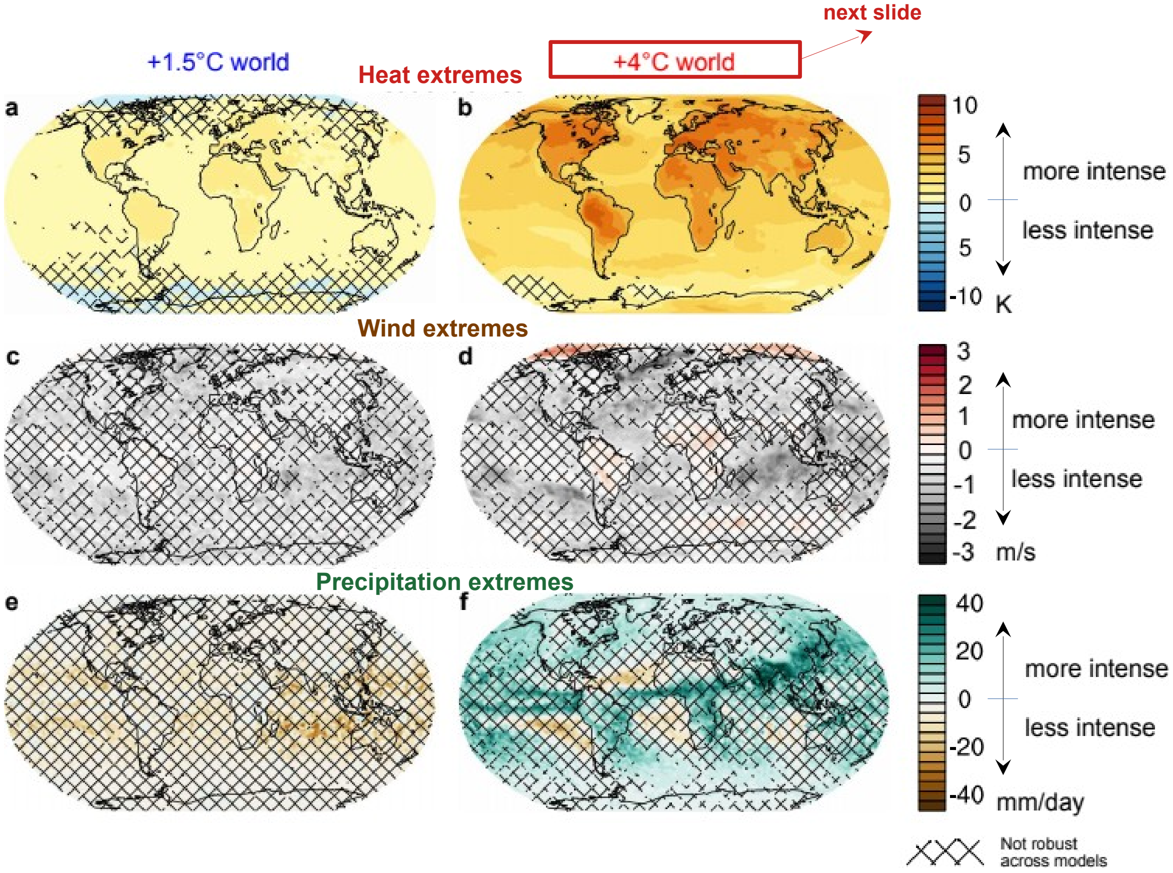
Future intensity of heat, wind and precipitation extremes

- In a 4ºC warmer world,
  - heat extremes will be up to 6ºC more intense especially in Eurasia, North America and the Amazonian region (b),
  - the maximum intensity of wind extremes will mainly decrease especially over the mid-latitude oceans (d)
  - the maximum intensity of precipitation extremes will substantially increase by up to 40 mm day^{-1} in Southern and Eastern Asia (f).

- These substantial changes in the intensity of climate extremes can be largely prevented by limiting global warming to 1.5ºC (a, c, e).



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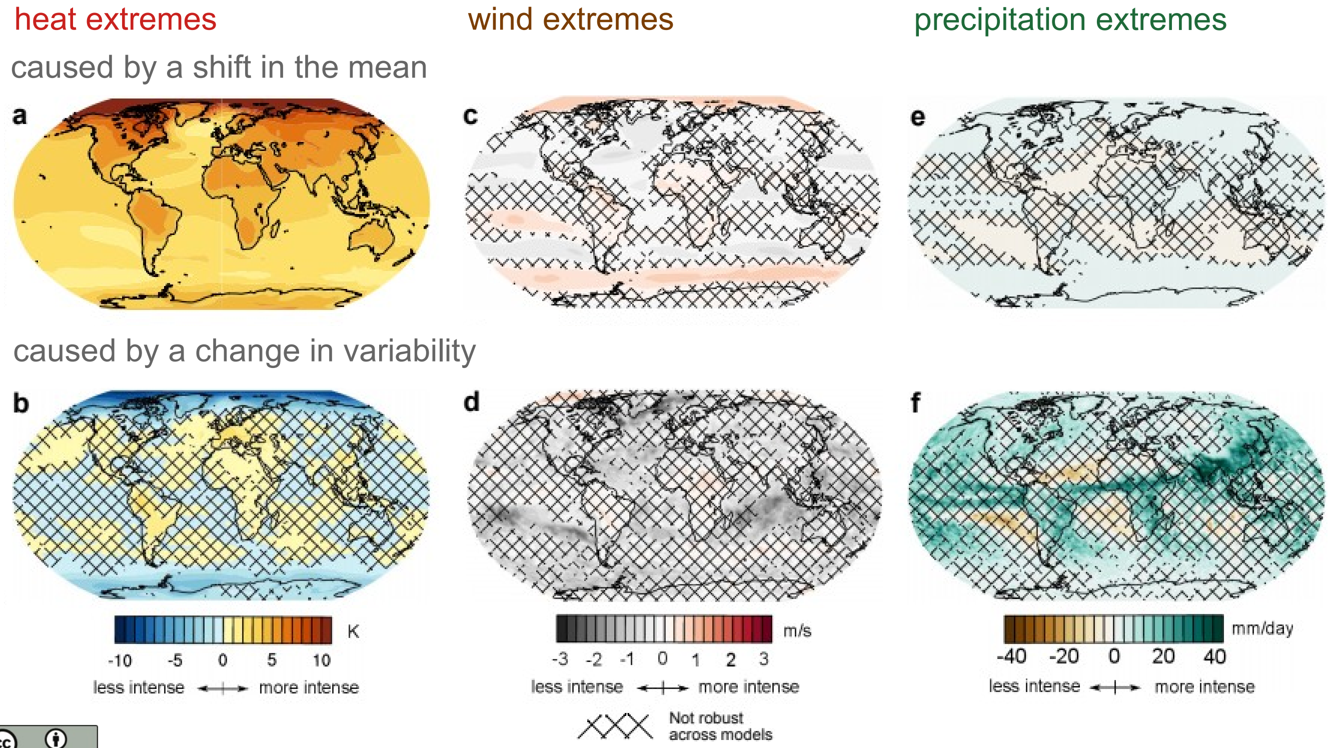
Attribution of the intensity of extremes in a 4°C warmer world

Future change in the intensity of



- We find that the intensity of heat extremes is primarily increased by the mean climate shift, most strongly in northern high latitudes (a), while the reduced intensity of wind extremes over many ocean basins is primarily driven by decreases in wind variability (d).

- The patterns of change in extreme precipitation intensity are predominantly caused by changes in precipitation variability (f), with a minor contribution from the shift in mean precipitation (e).

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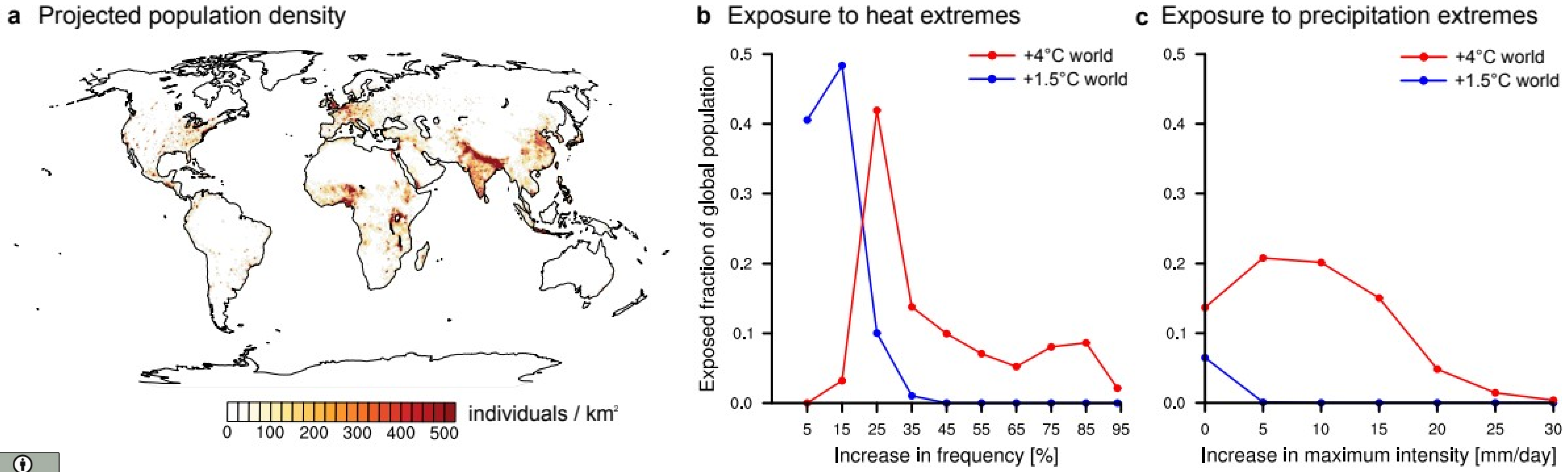
Future population exposure to climate extremes

- The changed frequencies and intensities of climate extremes have substantial impacts on the future global population projected for 2080-2099 (SSP5-8.5, a).

- Limiting global warming to 1.5ºC would prevent the exposure of half of the future global population to more than sixfold more frequent heat extremes projected for in a 4ºC warmer world (b). Complying with the 1.5ºC target would further prevent the exposure of half of the future global population to more than 8 mm day^{-1} more intense precipitation extremes (c).



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