INSTITUTE FOR ATMOSPHERIC AND CLIMATE SCIENCE

The substructure of extremely hot summers in the Northern Hemisphere

Matthias Röthlisberger, Michael Sprenger, Emmanouil Flaounas, Urs Beyerle and Heini Wernli

Institute for Atmospheric and Climate Science, ETH Zürich, Zürich, Switzerland

Reference

IAC Institute for Atmospheric and Climate Science

erc

Röthlisberger, M., Sprenger, M., Flaounas, E., Beyerle, U., and Wernli, H.: The substructure of extremely hot summers in the Northern Hemisphere, *Weather Clim. Dynam.*, **1**, 45–62, https://doi.org/10.5194/wcd-1-45-2020, 2020.

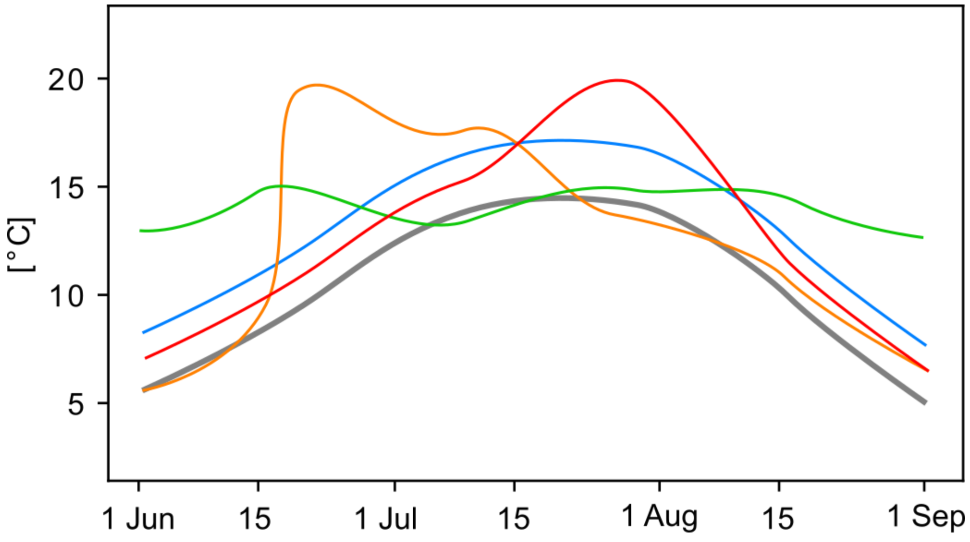
The substructure of an (extreme) summer

IAC Institute for Atmospheric and Climate Science

Hot temperature extremes on close to seasonal time scales can have severe ecological, public health and economic effects that sometimes go beyond (or are distinct from) the effects of temperature extremes on synoptic (e.g., multi-day) time scales.

An extremely hot summer (hereafter extreme summer) may be defined in the upper tail of the June–August (JJA) seasonal mean T2m distribution. However, when doing so it is unclear whether a particular summer is extreme because of an unusual heat wave (i.e., hottest summer days hotter than climatologically), a suppression of cool summer days, a shift in the entire temperature distribution or any combination of the above.

However, these different extreme summer substructures conceivably shape the societal impact of an extreme summer. In this study we therefore assess which part of the local T2m distribution contributes how much to extreme summers defined in the upper tail of the JJA seasonal mean T2m distribution.



Archetypical substructures:
Heat wave during an otherwise benign summer
Milder than normal cool summer days
Shift in the entire T2m distribution
Any combination of the above
Gray line = climatological temperature evolution

Data and data pre-processing

ERA-Interim data (Dee et al., 2011): JJA seasonal mean T2m values from 1979-2018; linear trend removed at each grid point; 40 JJA seasonal mean values at each grid point. Five hottest summers (12.5%) at each grid point are considered extreme summers hereafter.

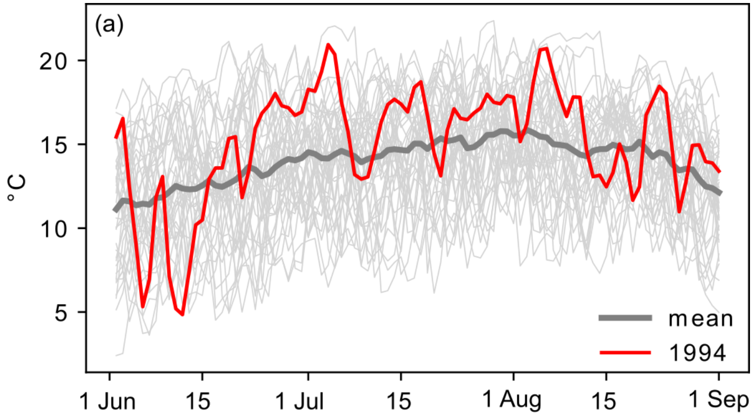
Defining seasonal extremes with just 40 values at each grid point is elusive, therefore we simulate a large number of JJA seasons under present day climate conditions with the Community Earth System Model one (CESM1) in a set up very similar to that of the CESM large ensemble (CESM-LE) project (Kay et al., 2015).

CESM data: 70 member ensemble simulation of the period 1990-1999; JJA seasonal mean T2m values; linear (10yr) trend removed in each ensemble member at each grid point; 700 JJA seasonal mean values at each grid point. The 35 hottest summers (5%) at each grid point are considered extreme summers hereafter. [see reference on slide 2 for details of the CESM data]

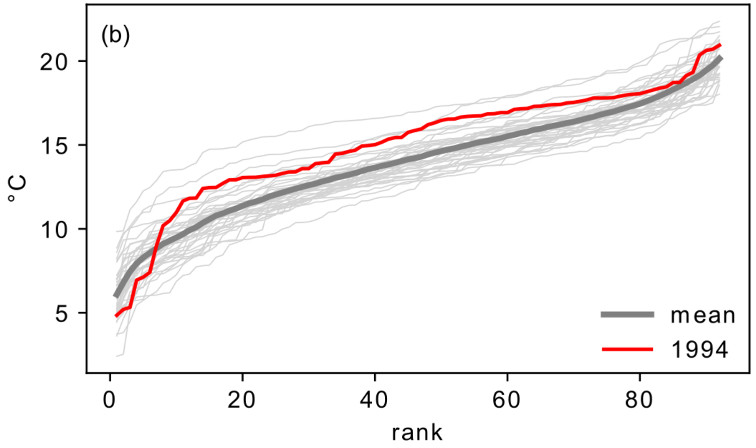
Method to assess the substructure of an (extreme) summer

example from ERA-I grid point at 9°E/47°N

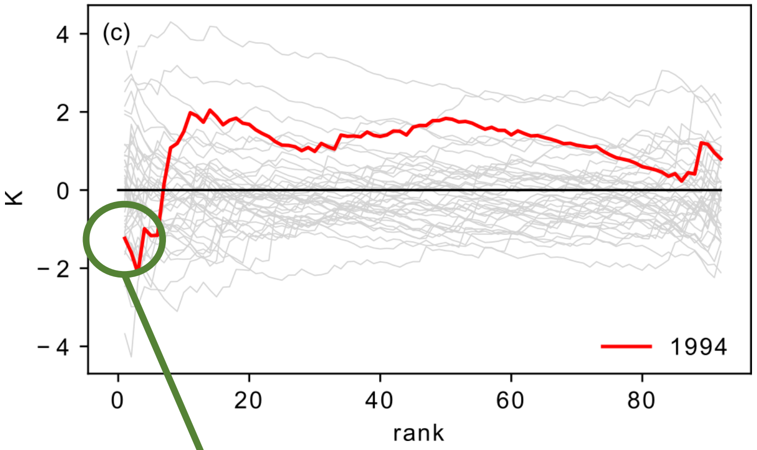
Time evolution of T2m at 9°E/47°N for all summers in 1979–2018



Daily mean T2m values ranked within their respective summer



"Rank day anomaly" of each rank day in each season



Step 1: Rank all T2m values within their respective season

Step 2: Compute "rank day means"

Step 3: Compute "rank day anomalies"

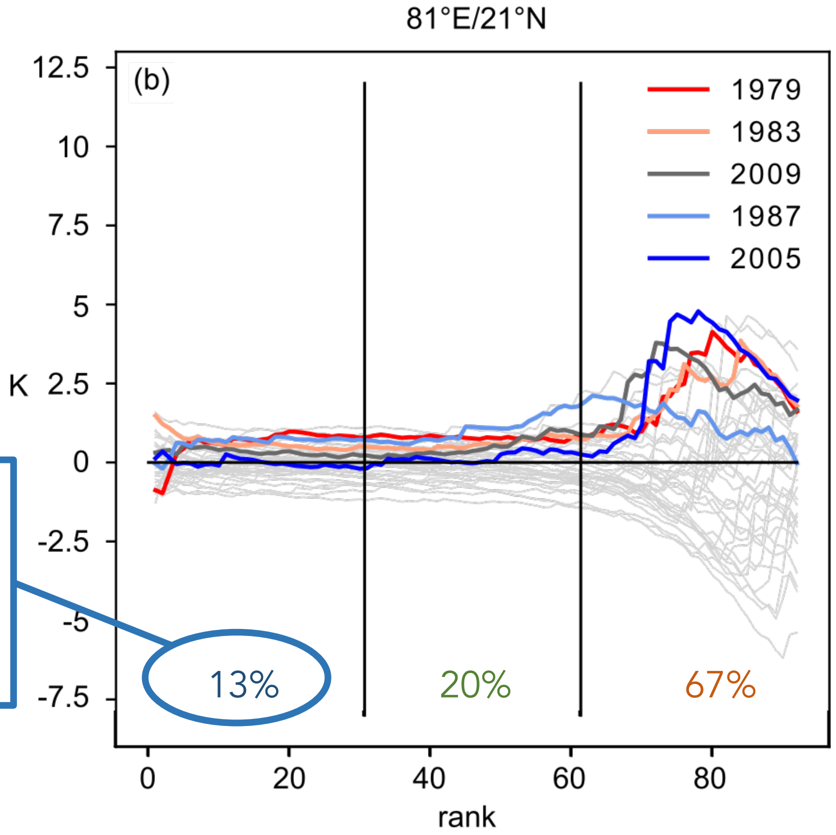
The coldest day of the 1994 summer was 1.2 K colder than the average coldest summer day at this grid point.

Integrating the rank day anomalies over the coldest, middle and hottest tercile of summer days exactly quantifies the contributions from these three thirds of the summer days to the seasonal mean anomaly.

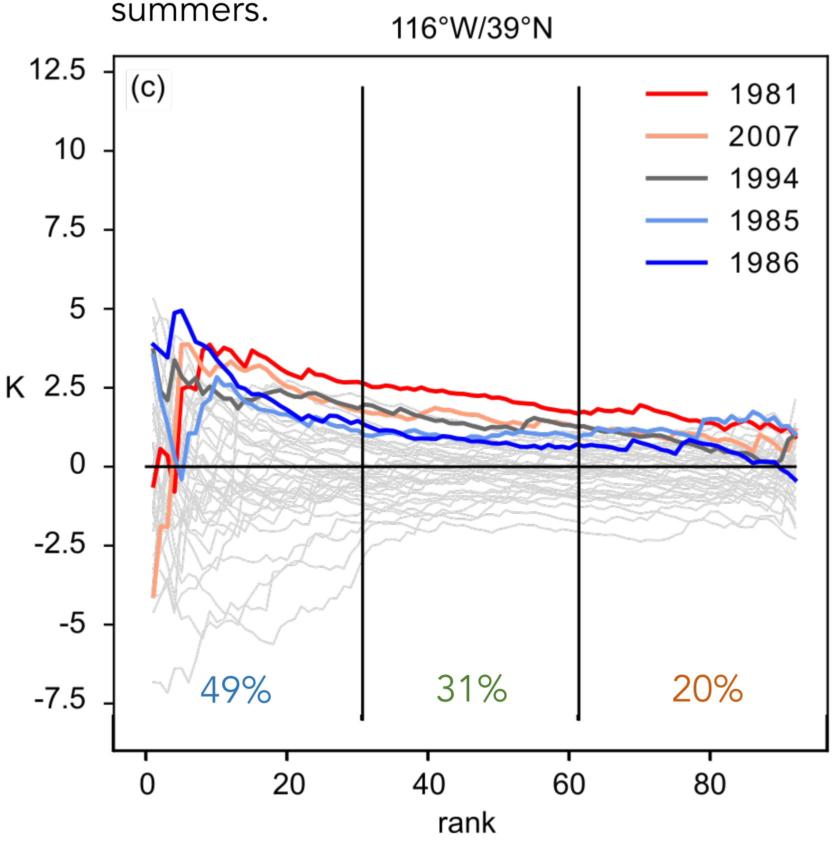
Applying this decomposition to extreme summers allows for quantifying their substructures.

Two example grid points; five hottest ERA-I summers are highlighted in colour

Grid point in eastern India: Hottes summer days responsible for extreme summers.



Grid point in Nevada: Milder than normal cool summer days contribute substantially to extreme summers.



Contributions from the coldest, middle and hottest third to the average extreme summer anomaly. The next slide depicts maps of these quantities.

Spatial variability in ERA-I extreme summer substructures

IAC Institute for Atmospheric and Climate Science

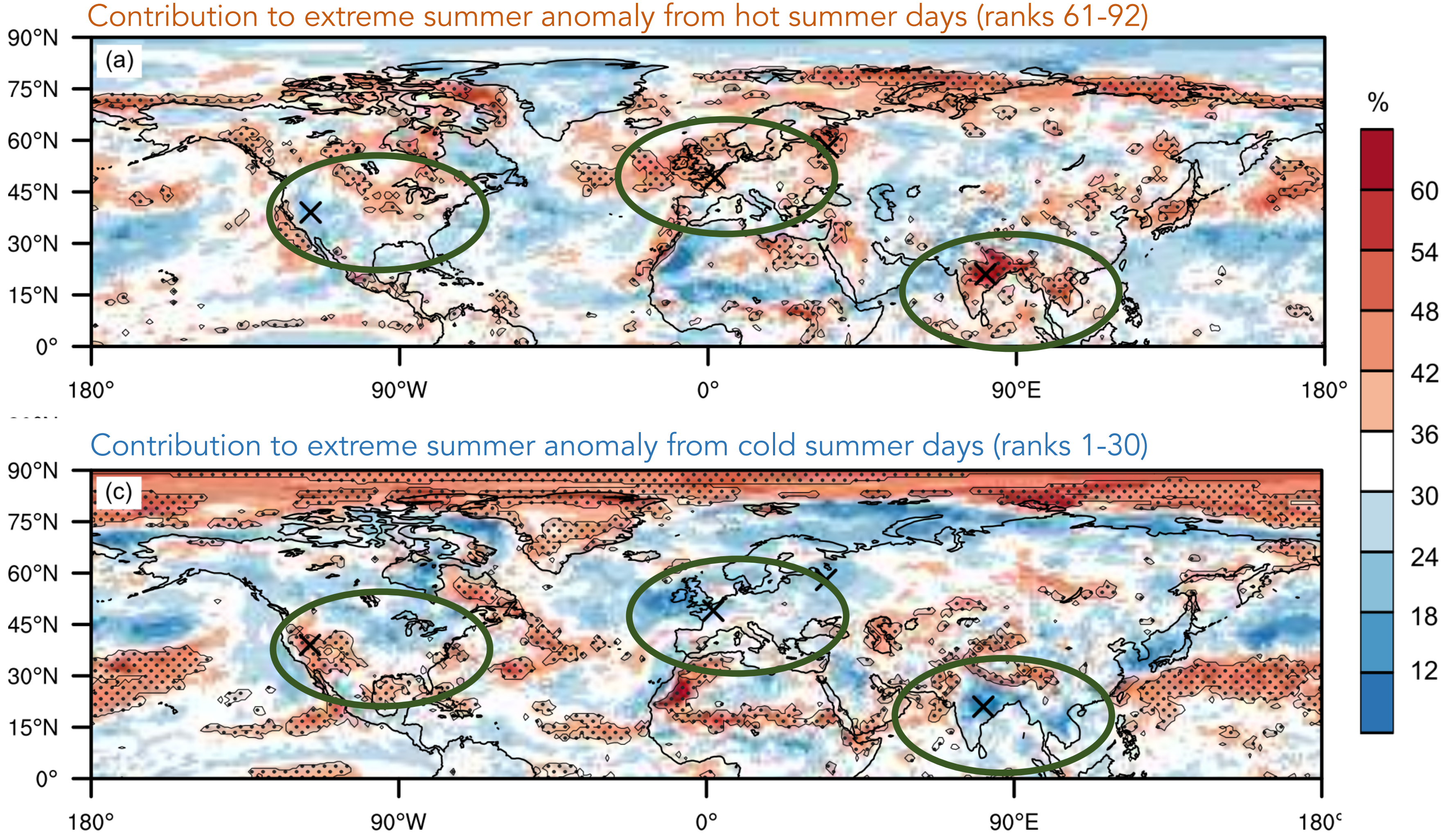
erc

1. Contribution from hottest third > 60% in India & Southeast Asia

2. In Europe, contribution from hottest third slightly increased (i.e., > 33%)

3. Dipole structure over US, hot days more important over the central/eastern US, cold days more important over the southwest.

4. Contribution from cold summer days is substantial in many regions, including the high Arctic .

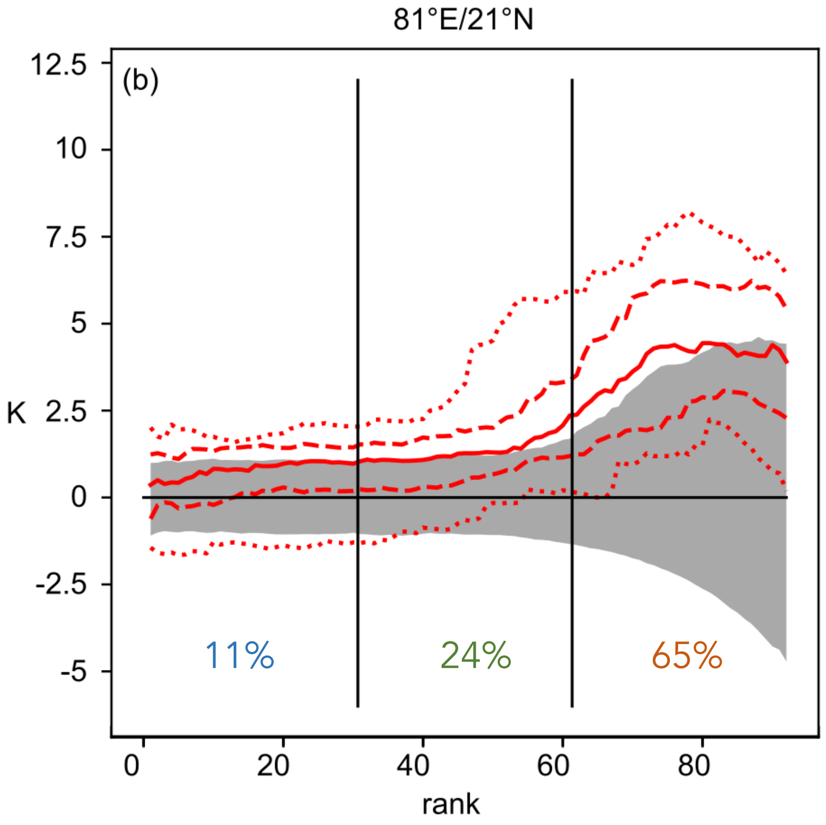


These results are derived from very short data records. How do CESM extreme summer substructures look like?

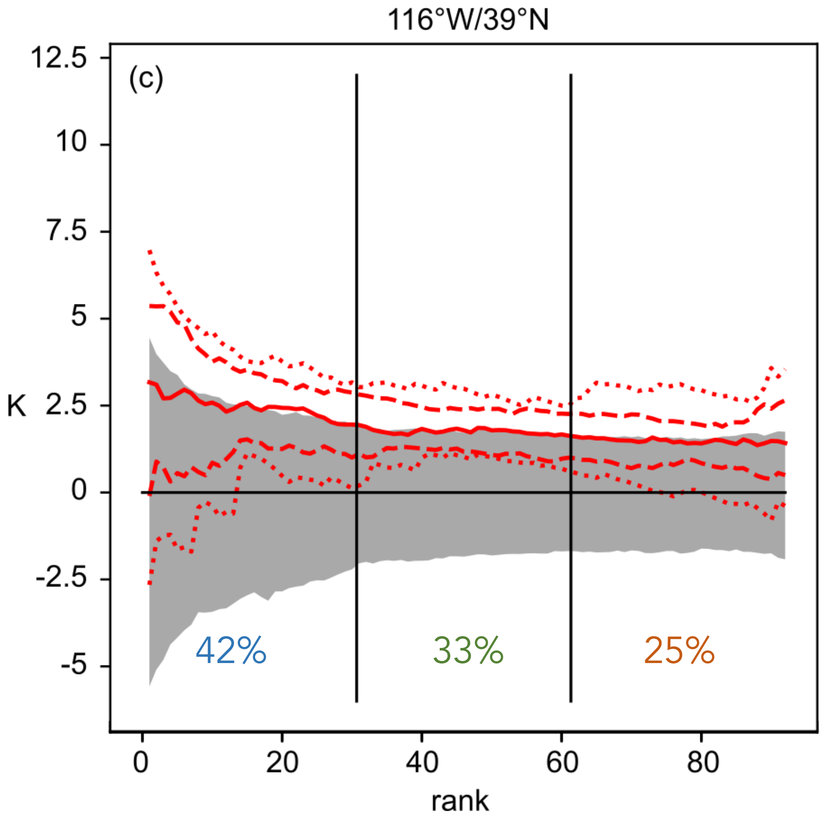
Same example grid points in CESM

Gray: 5th to 95th percentile of all JJA seasons
Red dotted: max, min of exseas
Red dashed: q10, q90 of exseas
Red solid: median of exseas

Grid point in eastern India: Hottest summer days responsible for extreme summers also in CESM.



Grid point in Nevada: Milder than normal cool summer days contribute substantially to extreme Summers also in CESM.



Excellent qualitative and quantitative agreement in extreme summer substructures between the two data sets at these two grid points. How about other regions?

Spatial variability
ERA-I vs. CESM

Remarkable qualitative (and partly even quantitative) agreement between ERA-I and CESM extreme summer substructures!

Implications of this agreement:

1. ERA-I extreme summer substructures are not an artefact of the short data records but rather result from physical processes that shape the local extreme summer substructure (more on that in the paper).

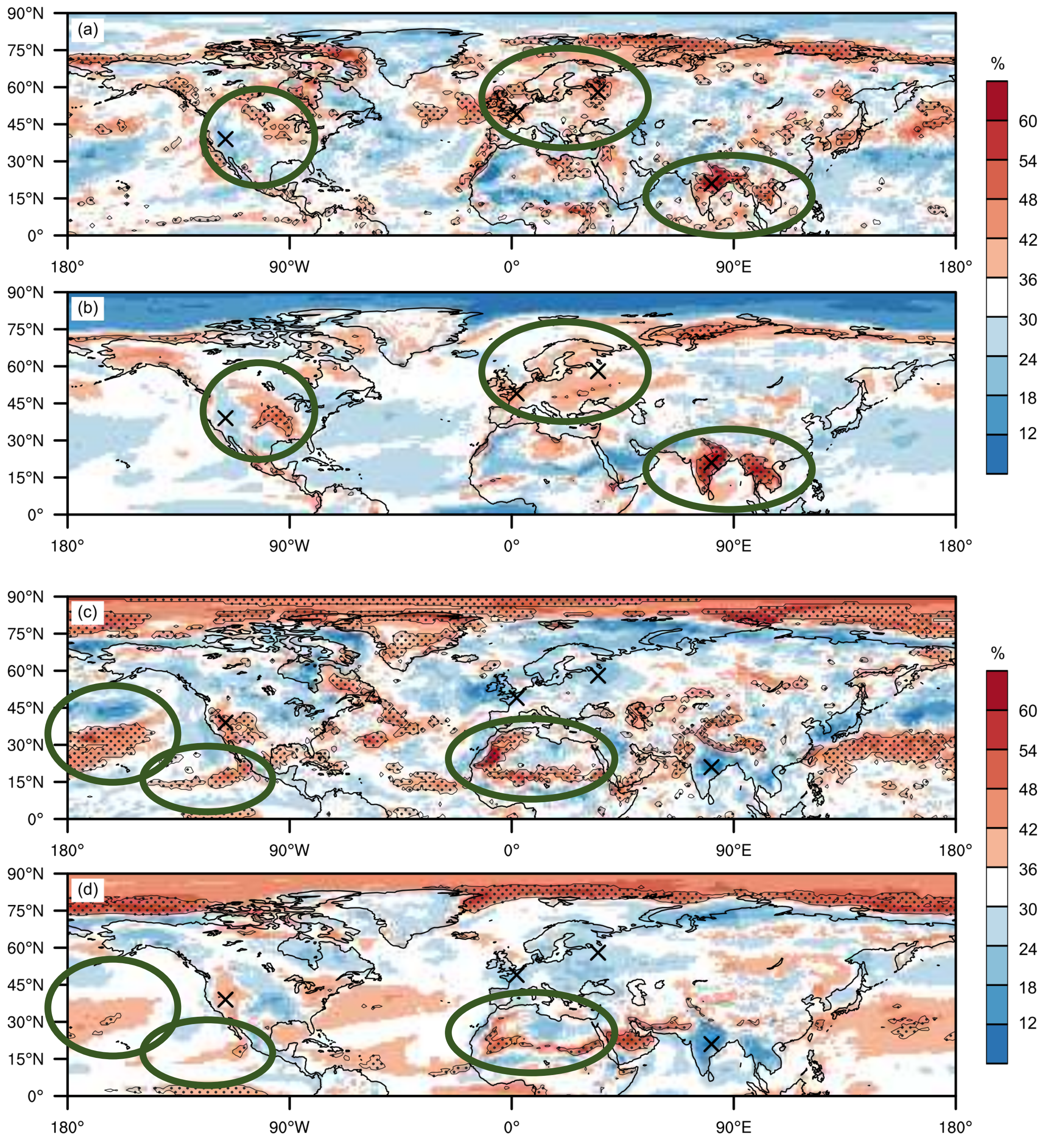
2. CESM reproduces these processes surprisingly well.

Hot summer days ERA-I

Hot summer days CESM

Cold summer days ERA-I

Cold summer days CESM



Summary and conclusions

- The substructure of extreme summers is assessed by decomposing the seasonal mean anomaly into the contributions from all rank days.
- Large spatial variability in extreme summer substructures.
- Suppression of cool summer days is fundamentally important for seasonal (JJA) temperature extremes.
- CESM reliably reproduces the ERA-I extreme summer substructures and may therefore be used to assess changes in extreme summer substructures with climate change.
- Physical processes that shape the local extreme summer substructure differ widely in space, and may be related to e.g., monsoons, physical boundaries such as sea ice edges, orography and Rossby wave dynamics or the location of climatological temperature gradients [more on that in the paper].

Questions and comments are very much appreciated and may be directed to matthias.roethlisberger@env.ethz.ch

Acknowledgements: This work was funded by the European Research Council under the European Union's Horizon 2020 research and innovation programme (INTEXseas project, grant nr. 787652). Moreover, Maxi Böttcher and Lukas Papritz (both ETH Zürich) are acknowledged for helpful discussions during different stages of this work and Gary Strand and Clara Deser (both NCAR) for providing CESM restart files.