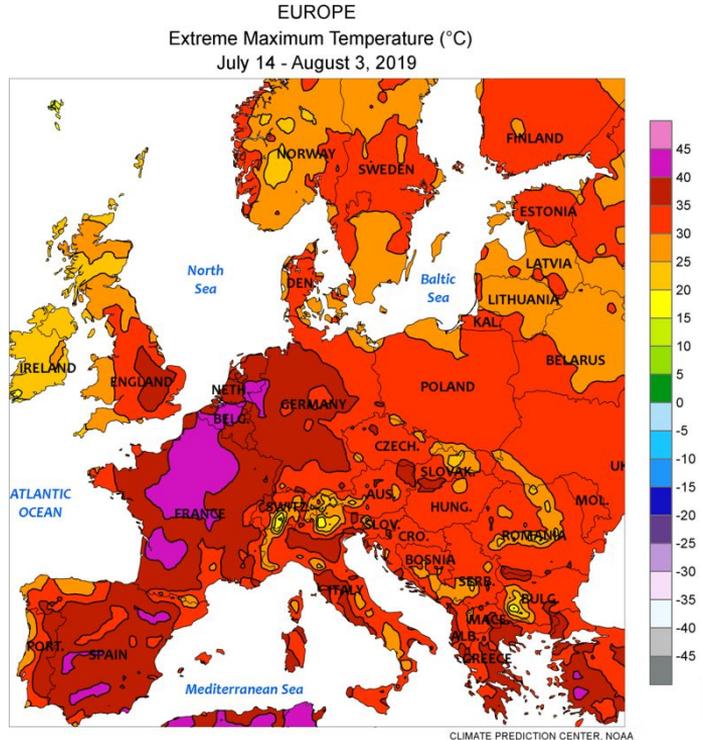


Storylines of plausible past and future climates for the July 2019 European Heatwaves

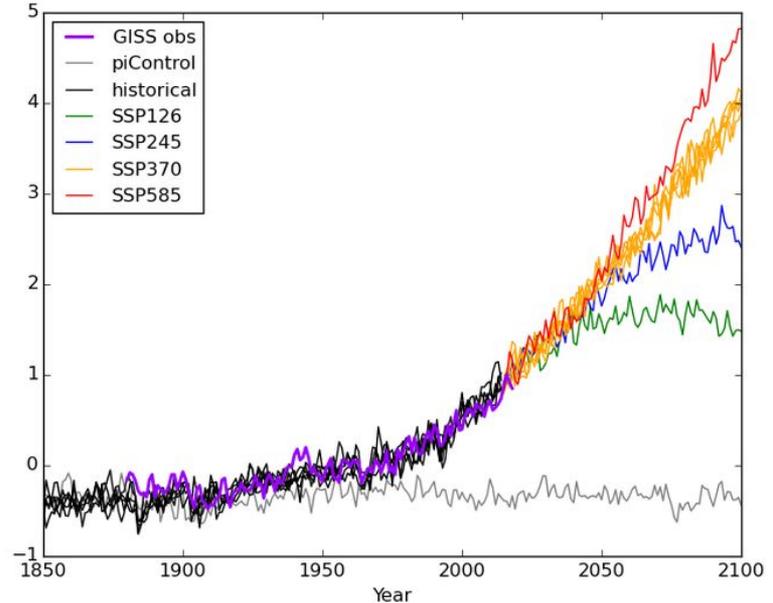
Antonio Sánchez Benítez (1), Thomas Jung (1,2), Helge
Goessling (1), Felix Pithan (1), Tido Semmler (1)

- (1) Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research,
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Global mean 2 m temperature anomaly versus 1951-1980 average (K)



Semmler et al., 2020

**How would this heatwave look like
in the past and in the future?**



Thermodynamic changes → changed CO₂, SSTs etc. → low uncertainty

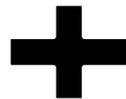
Dynamical changes → jet stream → high uncertainty

Approach: Spectral
Nudging
experiments

Large-scale dynamics are prescribed using
ERA5

Climate model with different “boundary
conditions” for past and future time slices

Observed divergence
and vorticity



AWI-CM
AWI Climate Model

+impact modelling
+Greenland polynyas
+...



Storyline of
the event

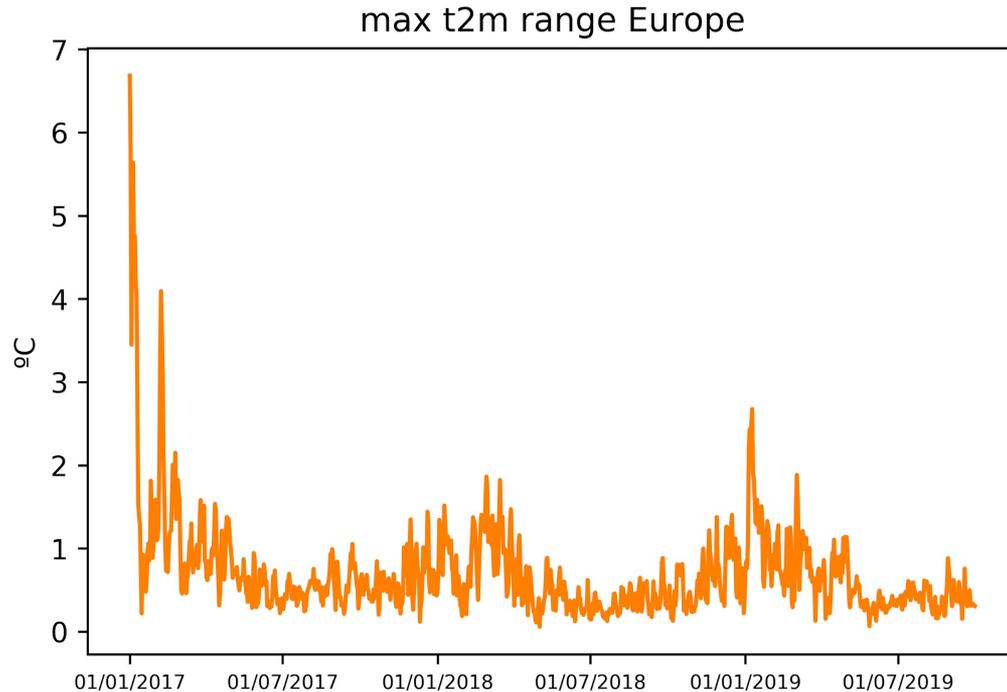
$$\frac{\partial X_n^m(\eta, t)}{\partial t} = \underbrace{F_n^m(\eta, t)}_{\text{Model forcing}} + \underbrace{G_n^m(\eta) \left[X_n^{m(\text{reana})}(\eta, t) - X_n^m(\eta, t) \right]}_{\text{Nudging}}$$

The following parameters have been used in our simulations:

- **T20** triangular truncation (~2000 km wavelength)
- Only mid and high troposphere is constrained (**100-700 hPa**)
- Weak nudging intensity (**24 h e-folding time**)

Five members ensemble between **1st January 2017 to 30th April 2020**

Simulations in **preindustrial, present, 2 and 4 °C warmer climates**



Five nudging simulations (starting from different initial conditions) have been run.

Stabilisation in few months!

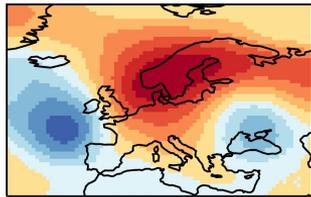
As we are interested in summer events, the **first year** was used as **spin-up**

Useful global simulations (AOGCM) between **1st January 2018 and 30th April 2020** for different purposes!

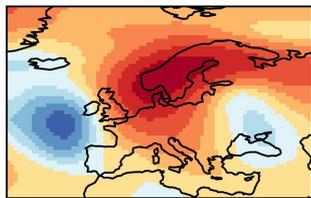
Temporal evolution of European maximum t2m range (computed as the difference between the maximum-minimum values of the five ensemble members)



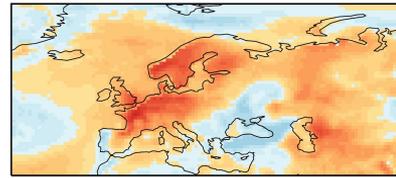
Z500 Anomaly 25 th July 2019
AWI-CM



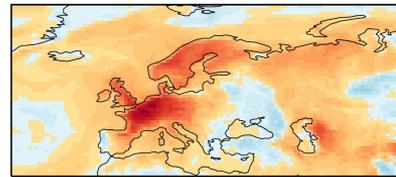
ERA5



Maximum t2m Anomaly 25th July 2019
AWI-CM

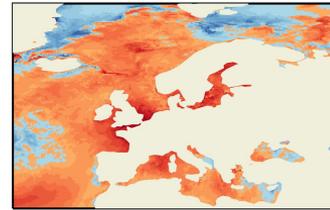


ERA5

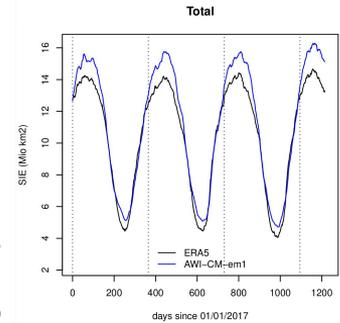
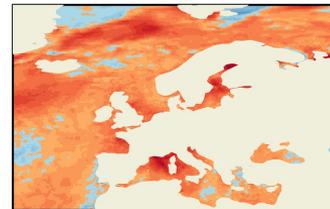


SST Anomaly 25th July 2019

AWI-CM

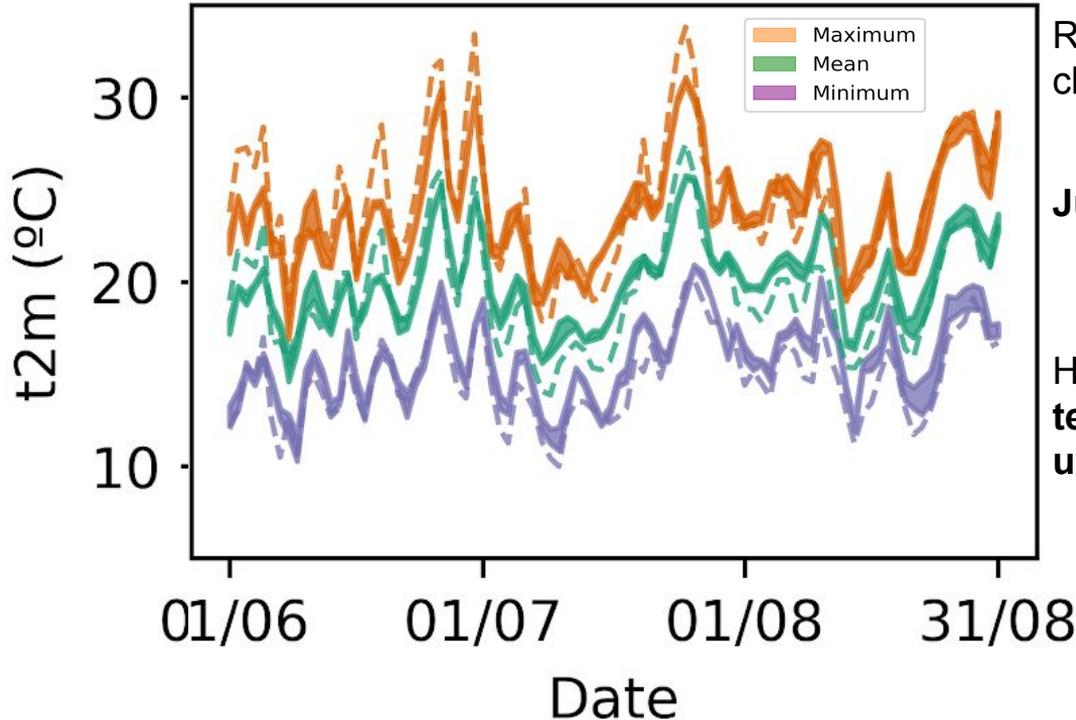


ERA5



Our approach allows us to generate **excellent analogues** in **atmosphere, land, ocean and sea ice** in **AWI-CM (AOGCM)** not just in **space** but also in **time**.

2019



Really **high correlation** between our present climate simulations and ERA5

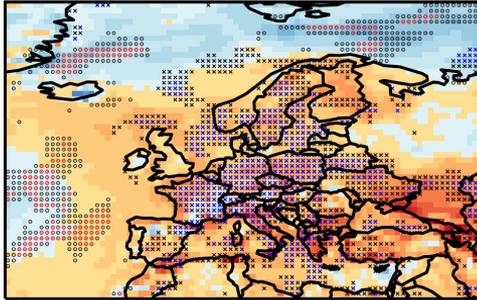
June and July 2019 heatwaves are **well captured**

However the really **exceptional maximum 2m temperatures** reached in **these events** are **underestimated**.

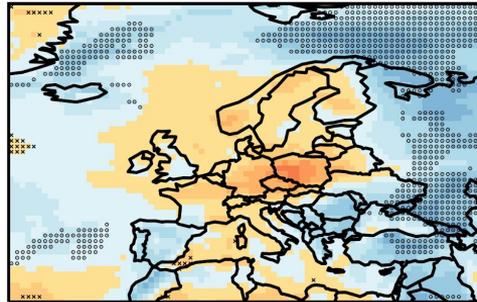
Seasonal evolution of daily minimum (blue), mean (green) and maximum (orange) 2m temperature in Germany from 1st June to 31st August 2019 for the present-time nudging experiments (shading) and ERA5 (dashed lines). Shading spans the min/max range of values obtained by the respective 5-member ensembles.



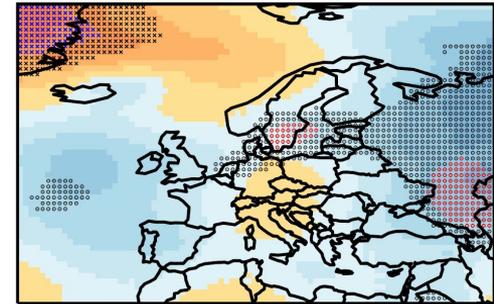
Warmest 10 Germany



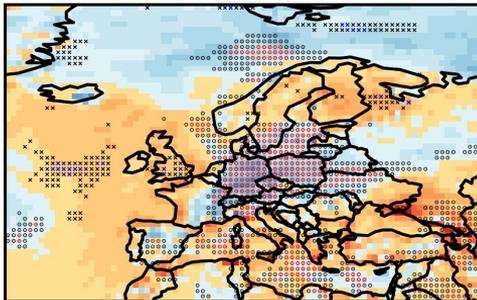
Top 10



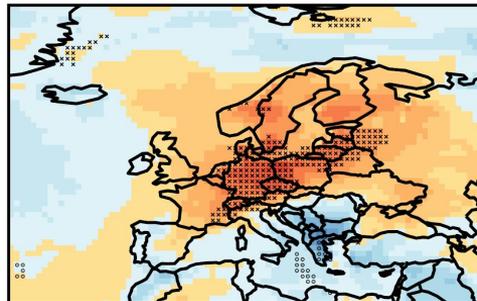
Warmest 10



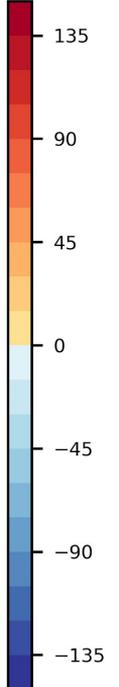
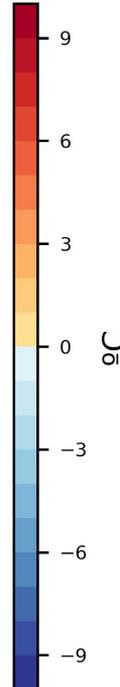
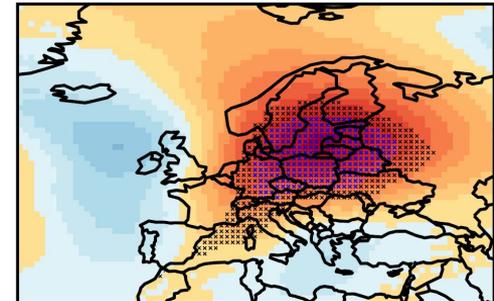
Coldest 10 Germany



Bottom 10



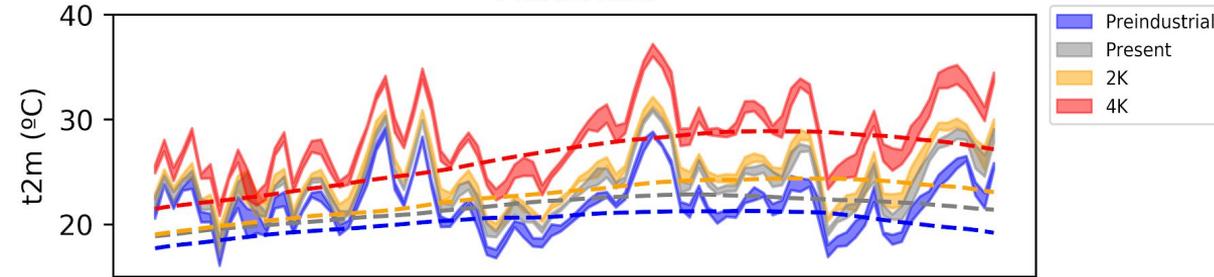
Coldest 10



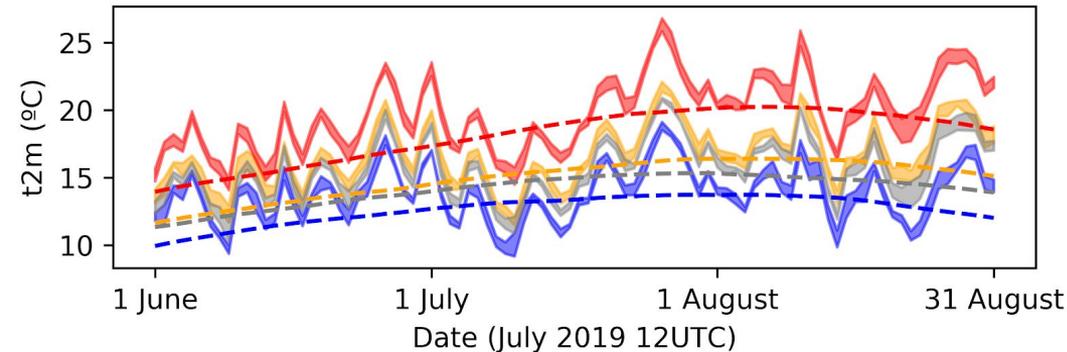
(Left) max t2m differences between the present-time simulations and ERA5, (middle) max t2m and (right) Z500 anomalies (relative to model free-run) for the ten days with (top) warmest and (bottom) coldest Germany maximum t2m differences between the present-time simulations and ERA5. 2018 and 2019 summer were included. Black (blue)Crosses/(red)Dots indicate where the values are significant higher/lower at $p < 0.05$ (0.01) level.



Maximum



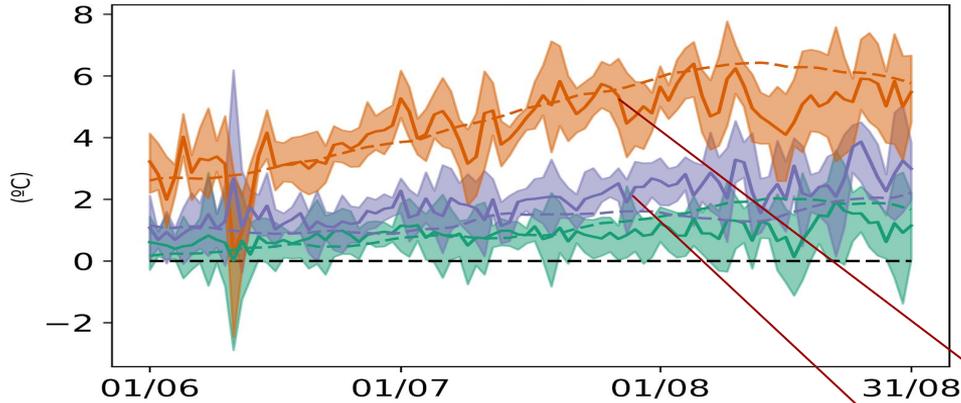
Minimum



Robust warming from preindustrial to present and from present to 4 °C warmer climates

High-summer nighttime temperatures in the 4 °C warmer climate would be similar to daytime temperatures in the preindustrial climate.

Seasonal evolution of daily maximum (top) and minimum (bottom) t2m averaged for Germany in different climates (preindustrial in blue, present in gray, 2 °C warmer in orange and 4 °C warmer in red). Shading spans the min/max range of values obtained by the respective 5-member ensembles.



Seasonal evolution of daily maximum t2m differences averaged for Germany between different climates (present-preindustrial in blue, 2 °C warmer-present in green and 4 °C-present in orange). Shading spans the min/max range of values obtained by the respective 5-member ensembles. Solid and dashed lines show the ensemble mean and the climatology (from the free-run) respectively.

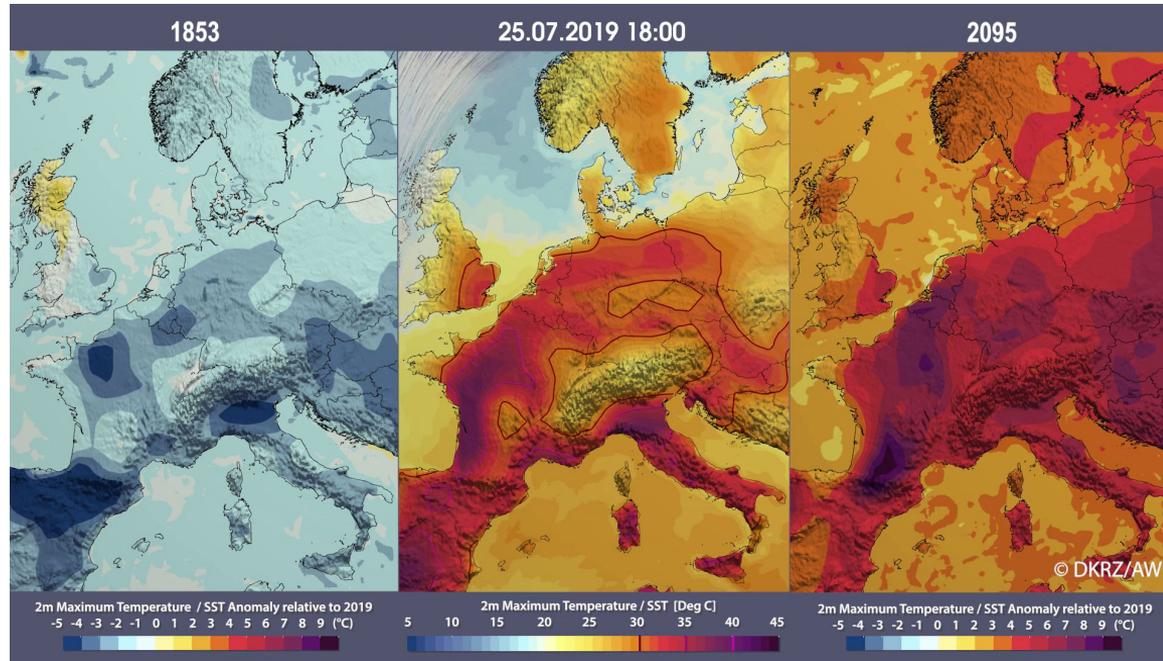
Clear seasonal cycle

~Global warming in early summer

Strong global warming amplification of daily max t2m in high and late summer

+5.5°C from present to 4 °C warmer climates
(vs 2.6 °C global warming)

+2.0°C from preindustrial to present climates
(vs 1.4 °C global warming)

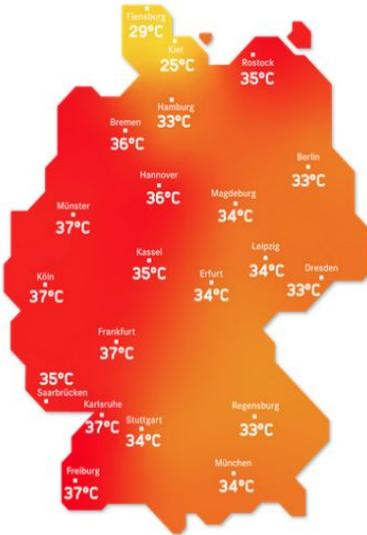


Up to **6°C warmer** now than in the preindustrial climate

Up to **10°C warmer** in the 4°C warmer climate than now!

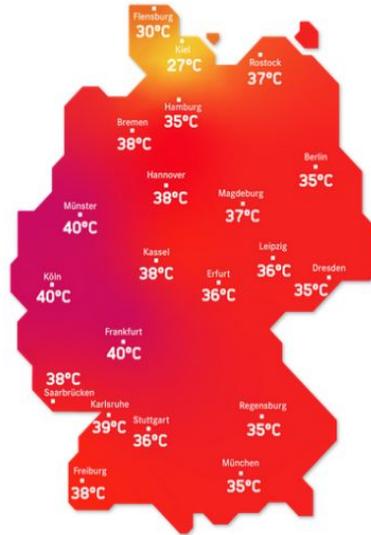
25th July 2019

Pre-industrial

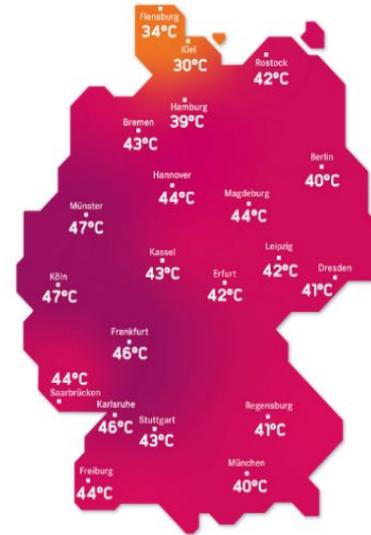


<40°C

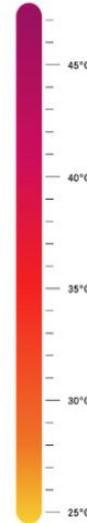
Present



+4°C warmer climate



47°C! (~European record)



- Our approach allows us to generate excellent analogues not only for constrained parameters but also for t2m, SST, SIC...
- Some flow dependant biases seem to appear. Method can help to improve the model
- Robust warming from preindustrial to present and from present to 4 °C warmer climates
- Strong and generalised global warming amplification in high and late summer. Stronger amplification in the 4 °C warmer climate
- High-summer Nighttime temperatures in the 4 °C warmer climate would be similar to daytime temperatures in the preindustrial one
- On the July 2019 heatwave peak, temperatures would not have reach 40°C in the preindustrial climate and would reach more than 45°C in a 4 °C warmer climate

We thank Sebastian Rast (MPI-M) for support with the spectral nudging in ECHAM, and Michael Böttinger (DKRZ) for the visualization

Storylines of plausible past and future climates for the July 2019 European Heatwaves

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