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

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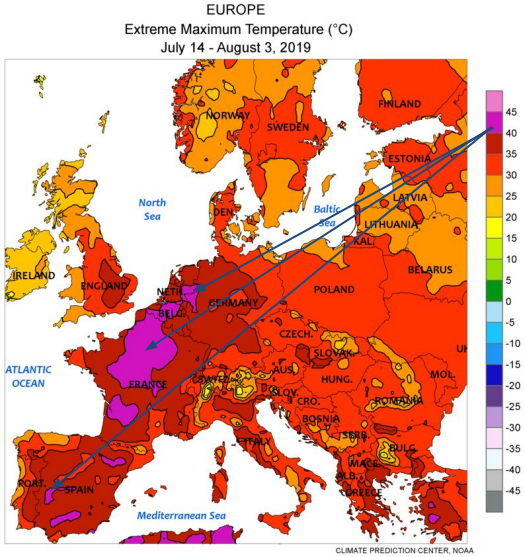
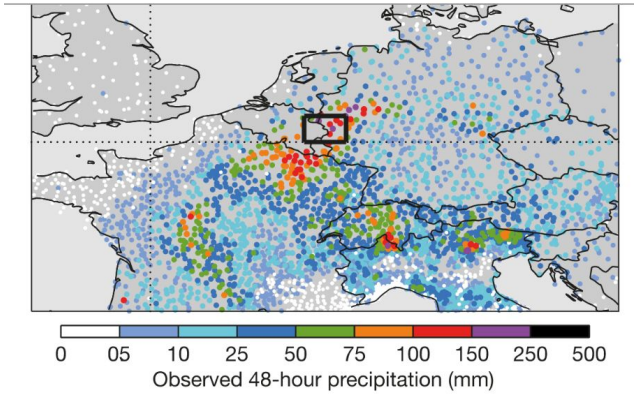
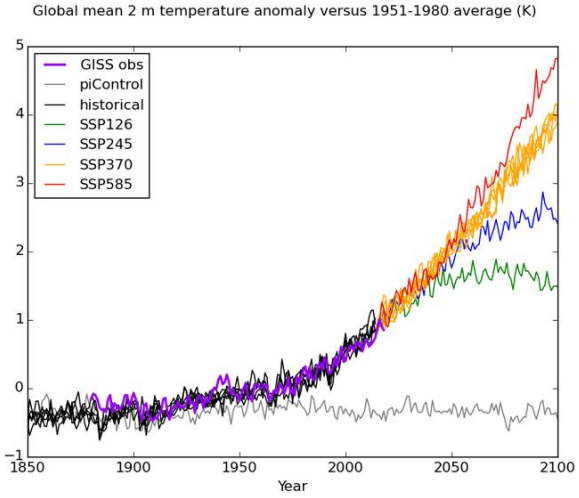
Recent extreme weather events in Europe





ECMWF, 2021



Semmler et al., 2020

How would these extreme events look like in the past and in the future?

Spectral Nudging experiments

How would these extreme events look like in the past and in the future?

Approach: Spectral Nudging experiments

Large scale observed (ERA5) winds

AWI-CM
AWI Climate Model

Storyline of the event

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

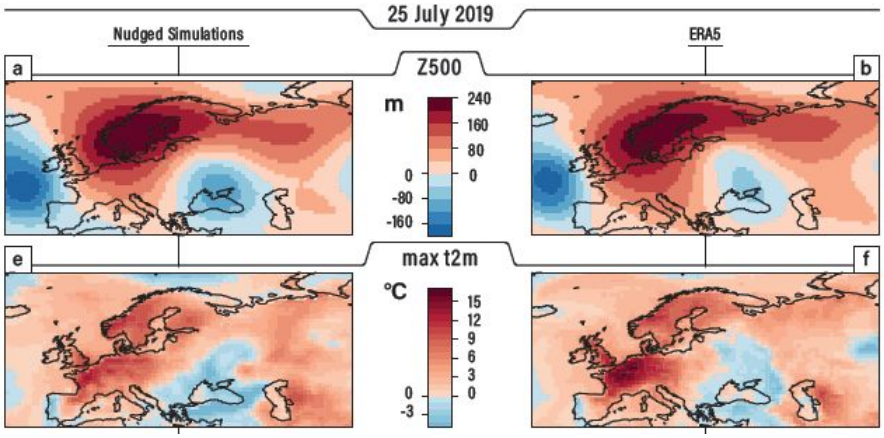
$$\frac{\partial X_n^m(\eta,t)}{\partial t} = F_n^m(\eta,t) + G_n^m(\eta)\left[X_n^{m(reana)}(\eta,t) - X_n^m(\eta,t)\right]$$

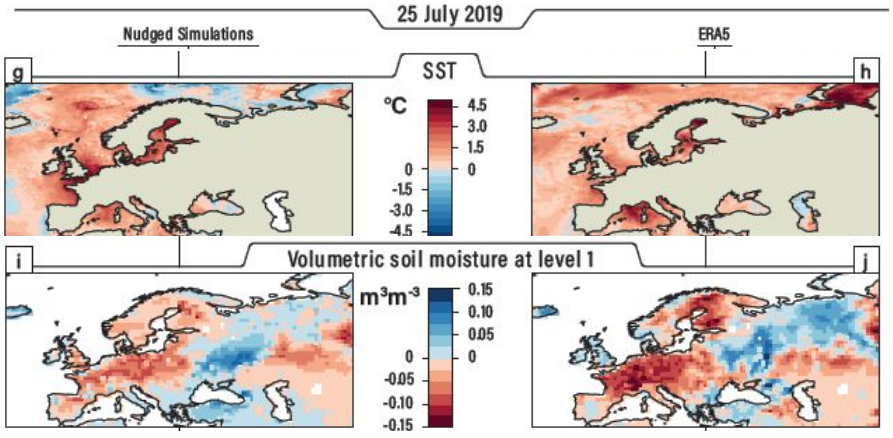
Model forcing

Nudging

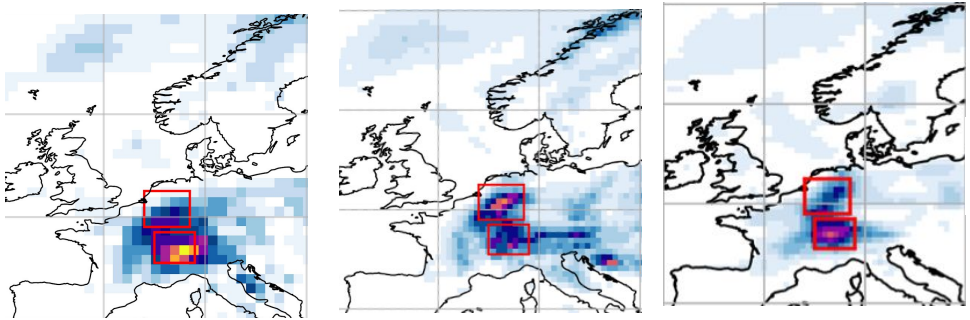
Analogue for heatwave and flood

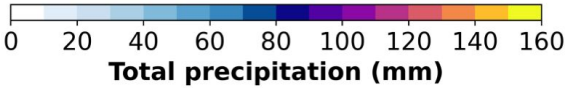
AWI-CM-1-1





AWI-CM-1-1 | ERA5 | AWI-CM-3

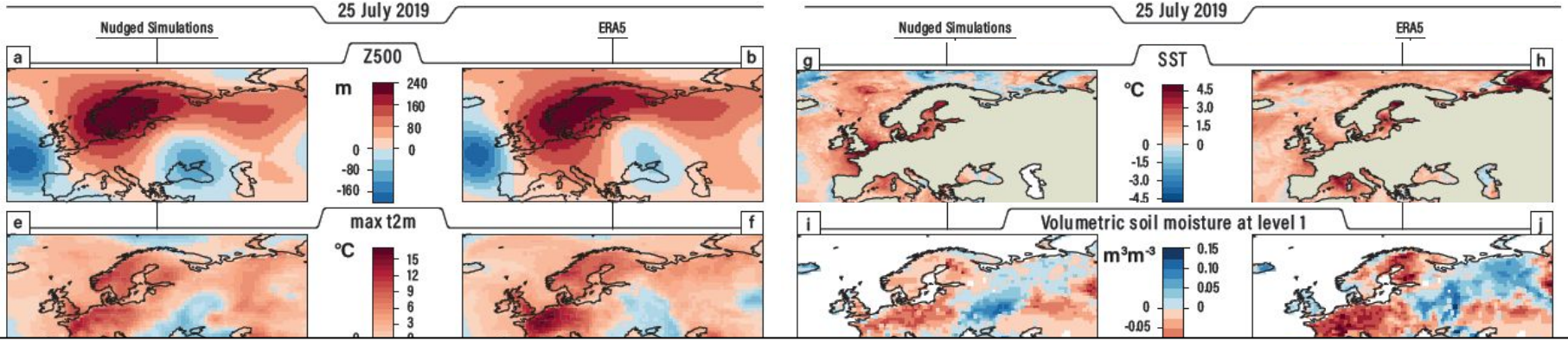




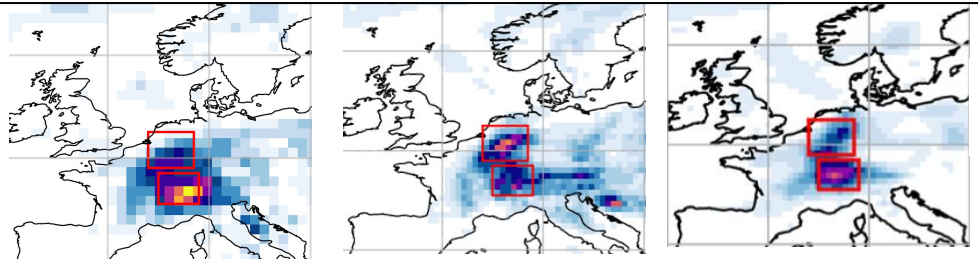
Total precipitation accumulated over the 12-17 July 2021

Analogue for heatwave and flood

AWI-CM-1-1



Our approach generate excellent analogues for **unconstrained variables**

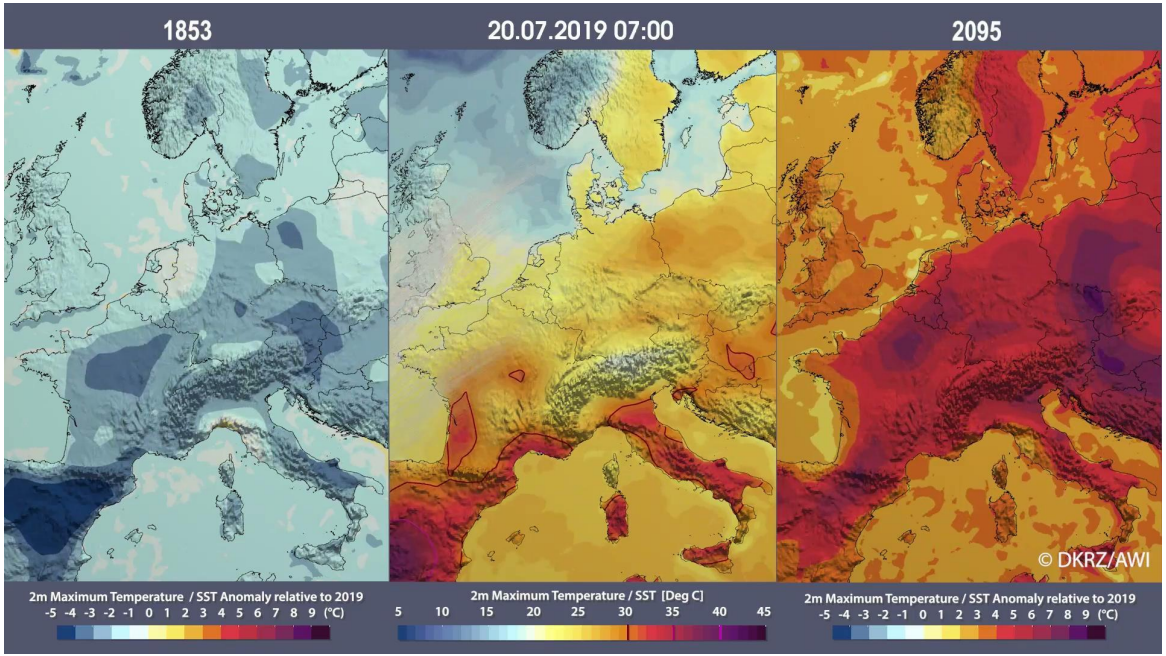


Total precipitation accumulated over the 12-17 July 2021

Ensemble mean

Regional differences

AWI-CM-1-1

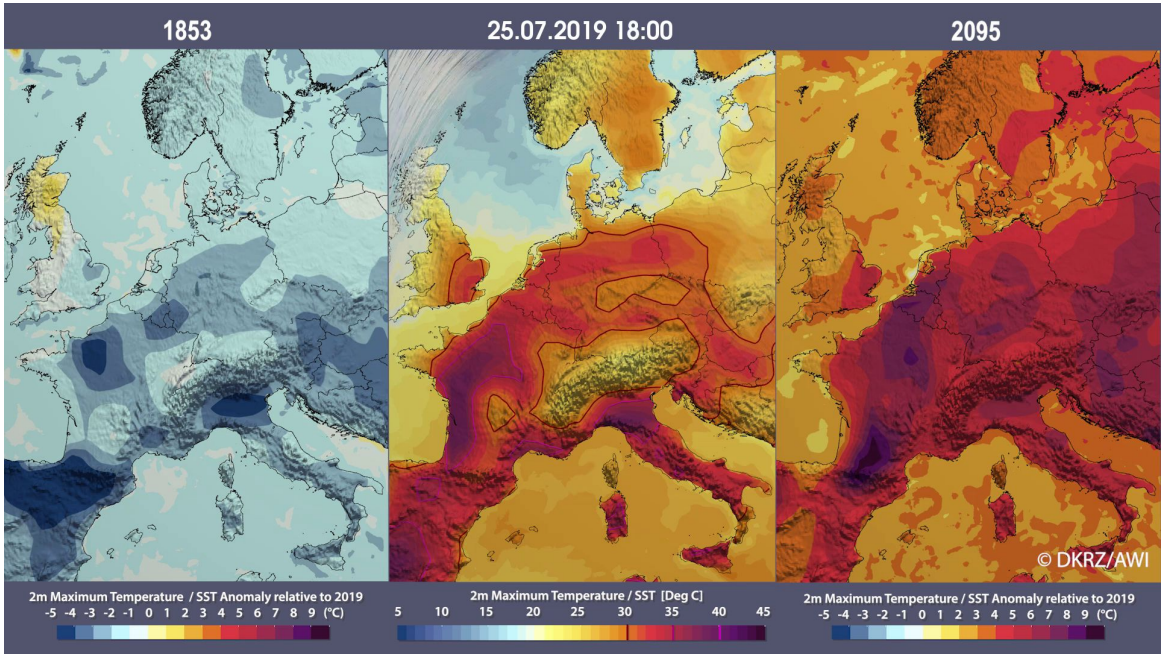


Up to **6ºC warmer** now than in the preindustrial climate

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

Regional differences

AWI-CM-1-1



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Conclusions

- We have built storyline scenarios for recent extreme events (the European July 2019 heat wave or July 2021 floods) using spectral nudging in state-of-the-art AOGCMs.
- This approach allows us to generate excellent analogues not only for constrained parameters but also for t2m, SST, soil moisture, precipitation...
- Strong and generalised global warming amplification
- On the July 2019 heatwave peak, temperatures would not have reach 40 ºC in the preindustrial climate and would reach close to 50 ºC in a 4 ºC warmer climate
- We are currently exploiting this methodology to explore different extreme events, including floods, marine heatwaves,...

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

Sánchez-Benítez, A., Goessling, H., Pithan, F., Semmler, T., and Jung, T. (2022). The July 2019 European Heat Wave in a Warmer Climate: Storyline Scenarios with a Coupled Model Using Spectral Nudging. *Journal of Climate*, **35,** 2373-2390, https://doi.org/10.1175/JCLI-D-21-0573.1.

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Extra slides

Method and models overview

AWI-CM
AWI Climate Model

AWI-CM-1-1-MR

ECHAM 6.3.04p1 + FESOM 1.4

Five members ensembles from 1st January 2018 to 31st July 2021 in preindustrial, present, 2 and 4ºC warmer climates

+

AWI-CM3

OpenIFS + FESOM 2

Five members ensembles from 1st January 2018 to 31st July 2021 in present climate

+

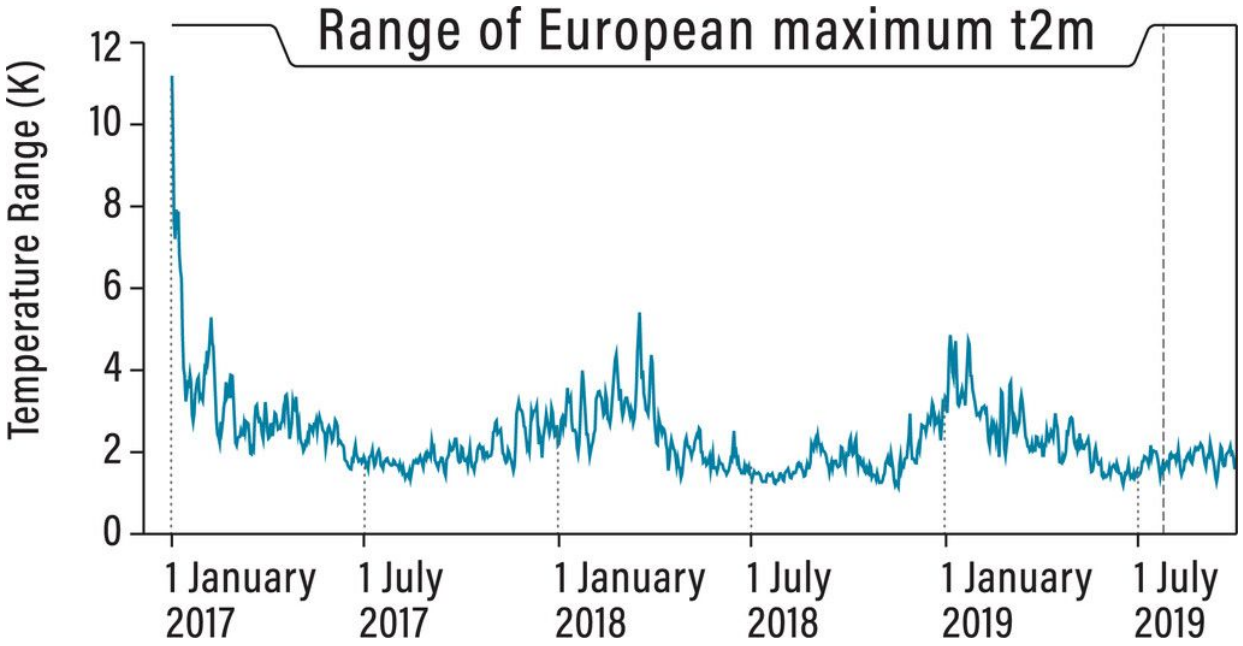
"Long control nudged run" from 1st January 1979 to 31st December 2014 in present climate

Daily or sub-daily (for some fields) temporal resolution.

Data are available upon request

Small ensemble spread

AWI-CM-1-1

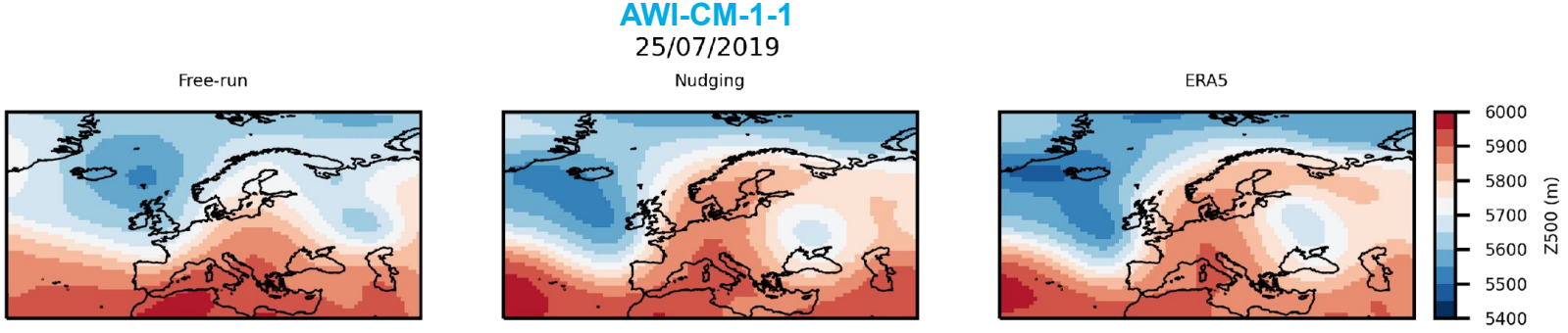


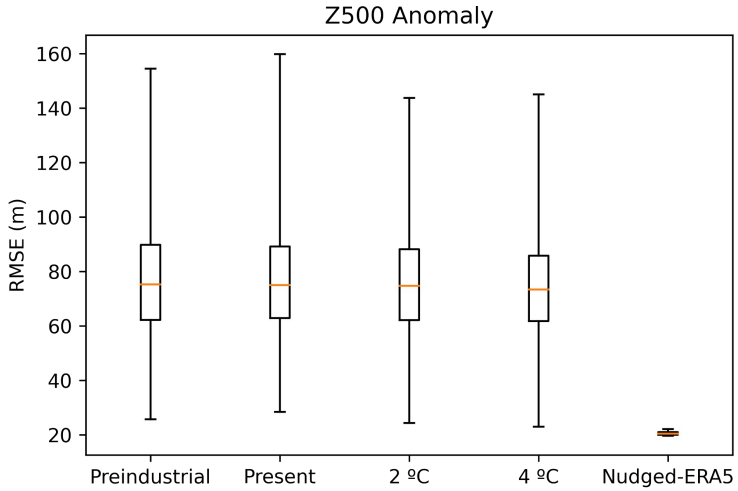
Temporal evolution of the range of daily maximum t2m for Europe. The range is computed as the difference between the daily maximum and minimum values of the five ensemble members for each day

One year of spinup time is enough to reach a stabilization

Small ensemble spread (~1K) in summer

The best analogues!





Our approach generates better analogues than using long free-runs

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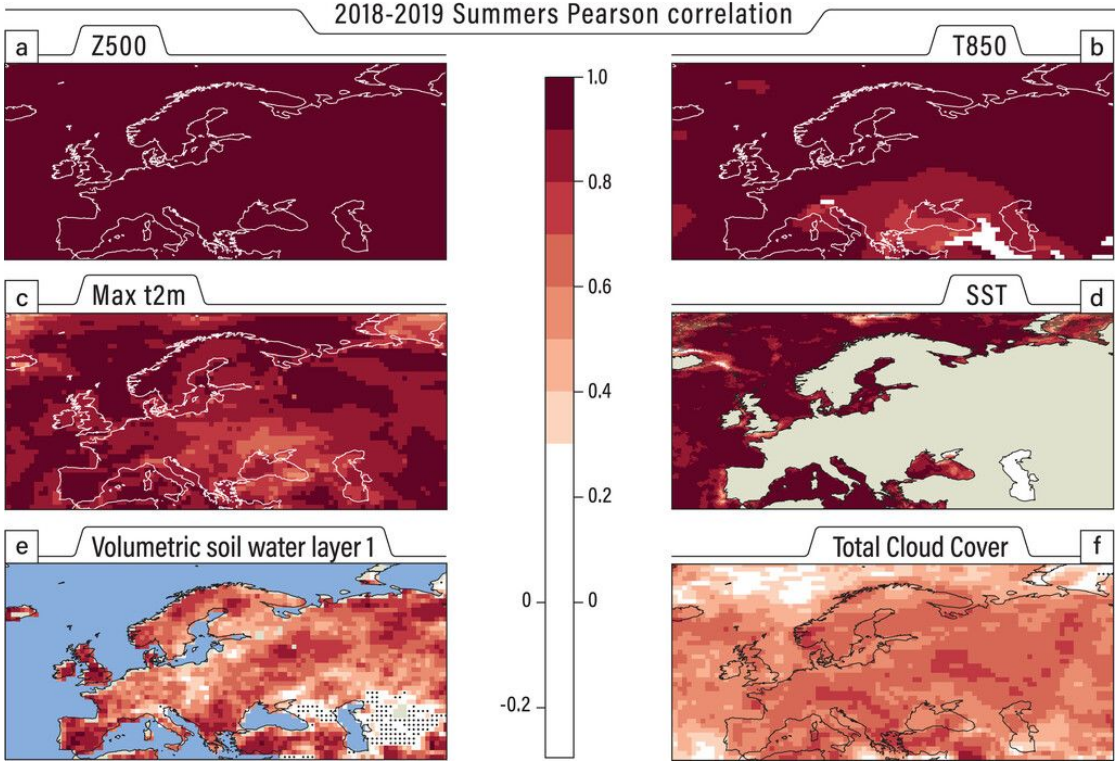
The previous evolution is captured

Distribution of Z500 RMSE between the free-run and nudged 25th July in different climates and between the five nudged simulations and ERA5 25th July 2019 (right). The boxplots extend from the 25th to the 75th percentile, with the median in between, and the whiskers represent the maximum and minimum values

Significant correlations

AWI-CM-1-1

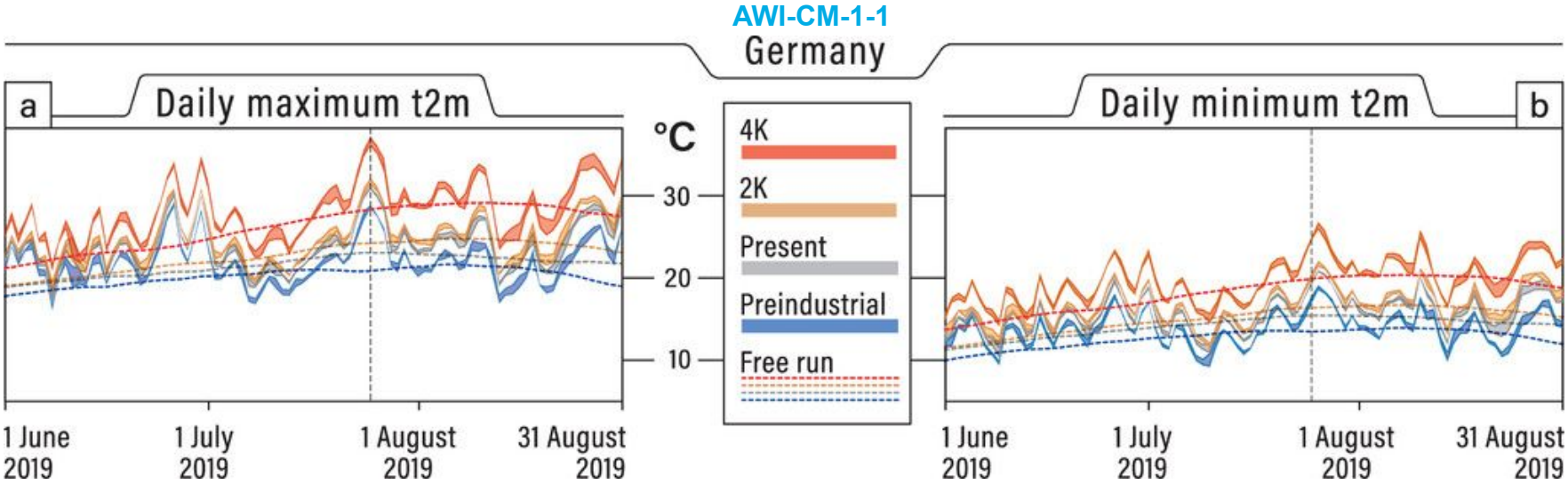


Sizeable correlations are obtained for critical variables that are not nudged in our simulations

Our method not only works well for single extreme cases but, more generally, also captures daily-to-seasonal variability in Europe during summertime

Pearson correlation between present-day simulations and ERA5 for the summers of 2018 and 2019 using daily fields. Grid points with nonsignificant correlation ($p > 0.05$) computed using the probability density function of the sample are stippled.

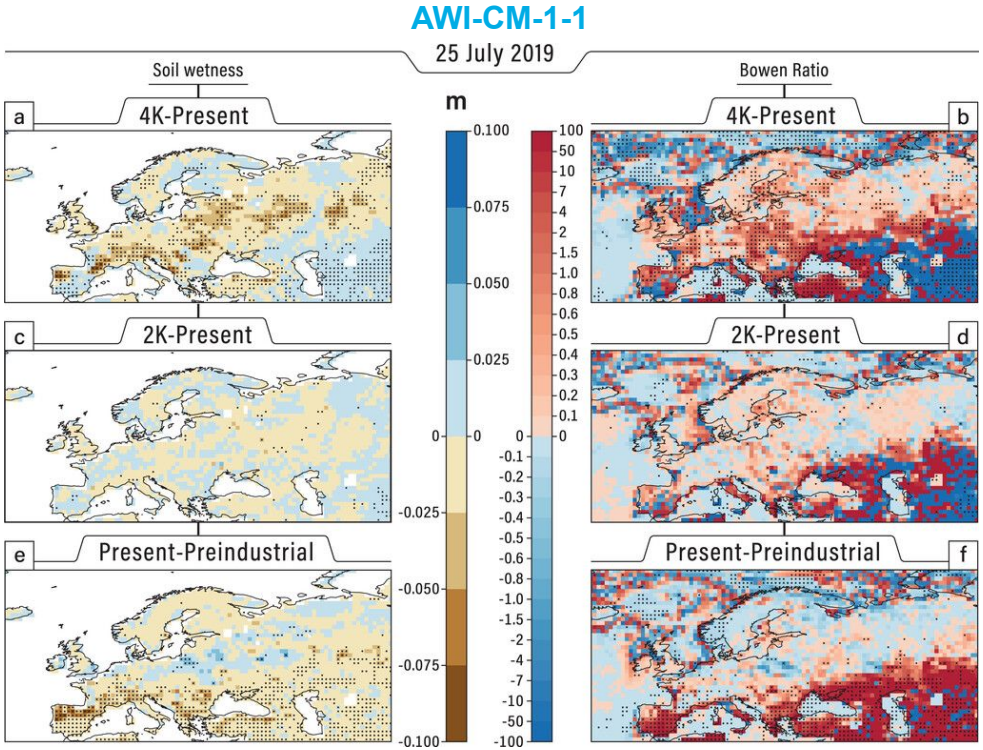
Are nights the new days?



Robust differences among ensembles in the different climates.

Nighttime t2m (minimum t2m) in Germany in a 4-K-warmer world are projected to become comparable to typical daytime maxima (maximum t2m) in preindustrial times, at least for the heat waves that occurred in late July and August 2019

Northward extension of drying



(left) Soil wetness and (right) Bowen ratio differences between (a),(b) 4 K warmer and present; (c),(d) 2 K warmer and present; and (e),(f) present and preindustrial climates on 25 Jul 2019. Locations where the two ensembles do not overlap are indicated by stippled.

From the preindustrial to present-day climates, there is a strong and robust drying in the Mediterranean region that is accompanied by a dramatic increase in the Bowen ratio.

When considering future changes (i.e., +4 K minus present-day) the drying of the soil and the increase in Bowen ratio peak in midlatitude regions, including central Europe.