Earth System Dynamics

Supplement of

The European summer heatwave of 2019 – a regional storyline perspective

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Supplementary material for Klimiuk et al., 2024

This document includes one table and 17 figures

Table S1: List of DWD stations used for validation of present-day storylines with their coordinates and names, sorted by latitude.

| ST_ID	ST_LON	ST_LAT	ST_NAME
01550	11.0621	47.4830	Garmisch-Partenkirchen
01346	8.0038	47.8748	Feldberg/Schwarzwald
01262	11.8134	48.3477	München-Flughafen
15444	9.9216	48.4418	Ulm-Mähringen
04177	8.3301	48.9726	Rheinstetten
03667	11.2539	49.4258	Nürnberg-Netzstall
03904	6.3789	49.5354	Perl-Nennig
07341	8.7862	50.0900	Offenbach-Wetterpark
00867	10.9679	50.3066	Lautertal-Oberlauter
02667	7.1575	50.8645	Köln-Bonn
01050	13.8470	51.0221	Dresden-Hosterwitz
04763	9.9266	51.0607	Sontra
02932	12.2396	51.4347	Leipzig/Halle
00617	6.8863	51.8730	Borken in Westfalen
03987	13.0622	52.3812	Potsdam
02014	9.6779	52.4644	Hannover
00691	8.7981	53.0451	Bremen
03196	11.9321	53.3222	Marnitz
01981	9.8957	53.4776	Hamburg-Neuwiedenthal
05097	12.7655	54.0654	Tribsees
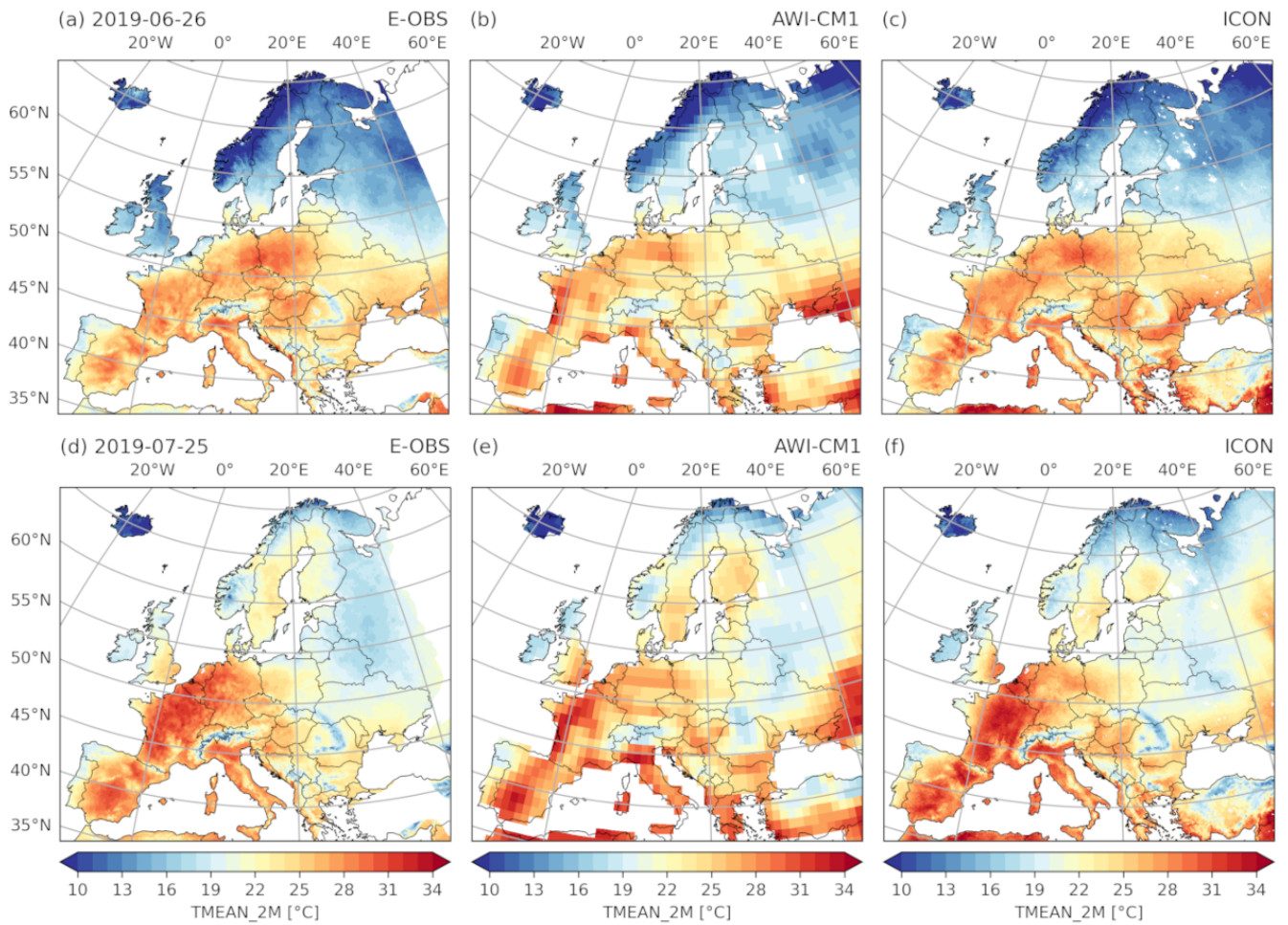
Figure S1: Mean 2m temperature on 26.06.2019 (first peak of the June heatwave) and 25.07.2019 (peak of the July heatwave) for E-OBS (left), AWI-CM1 (middle), and ICON EUR-12 (right).
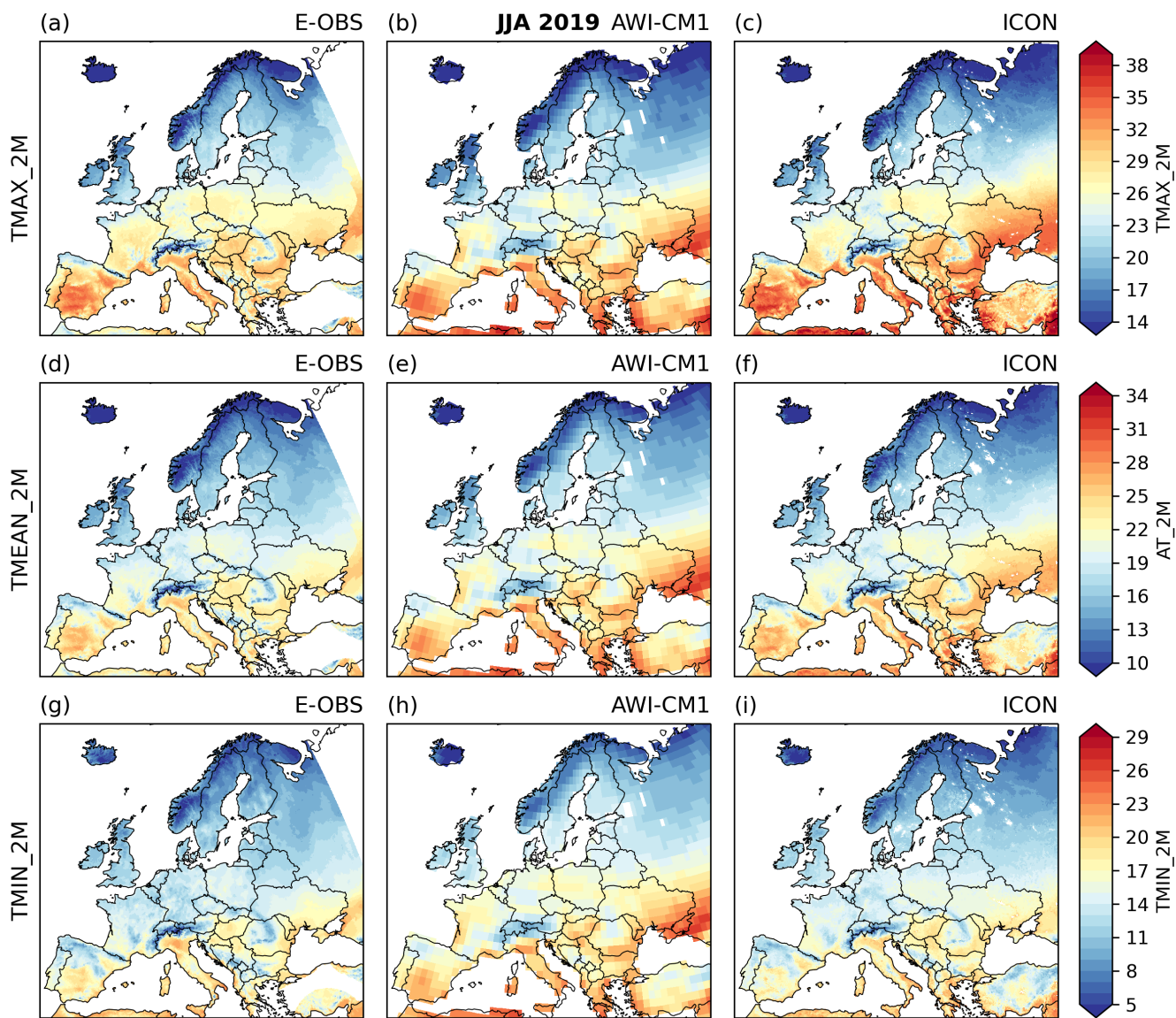
Figure S2: Seasonally averaged maximum, mean, and minimum 2m temperature in June - August 2019 as of (left) E-OBS, (middle) AWI-CM1, (right) ICON EUR-12.
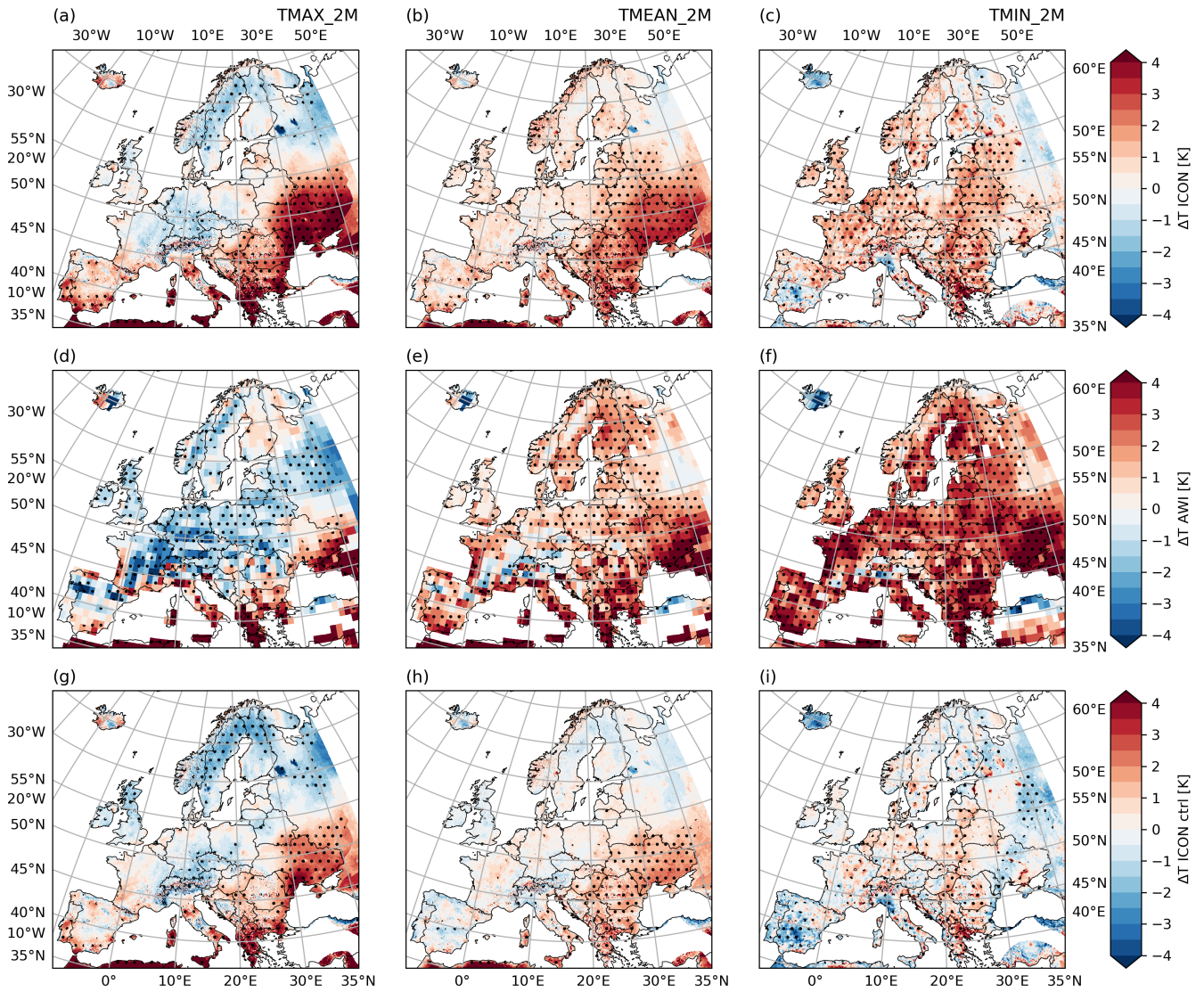
Figure S3: Seasonal mean bias of 2m temperature w.r.t. E-OBS in 2019 for (a-c) ICON EUR-12 simulation, (d-f) AWI-CM1 simulation, (g-i) ICON EUR-12 control simulation driven by ERA5. Hatched areas indicate regions where the bias to E-OBS is statistically significant with a p-value threshold of 0.05
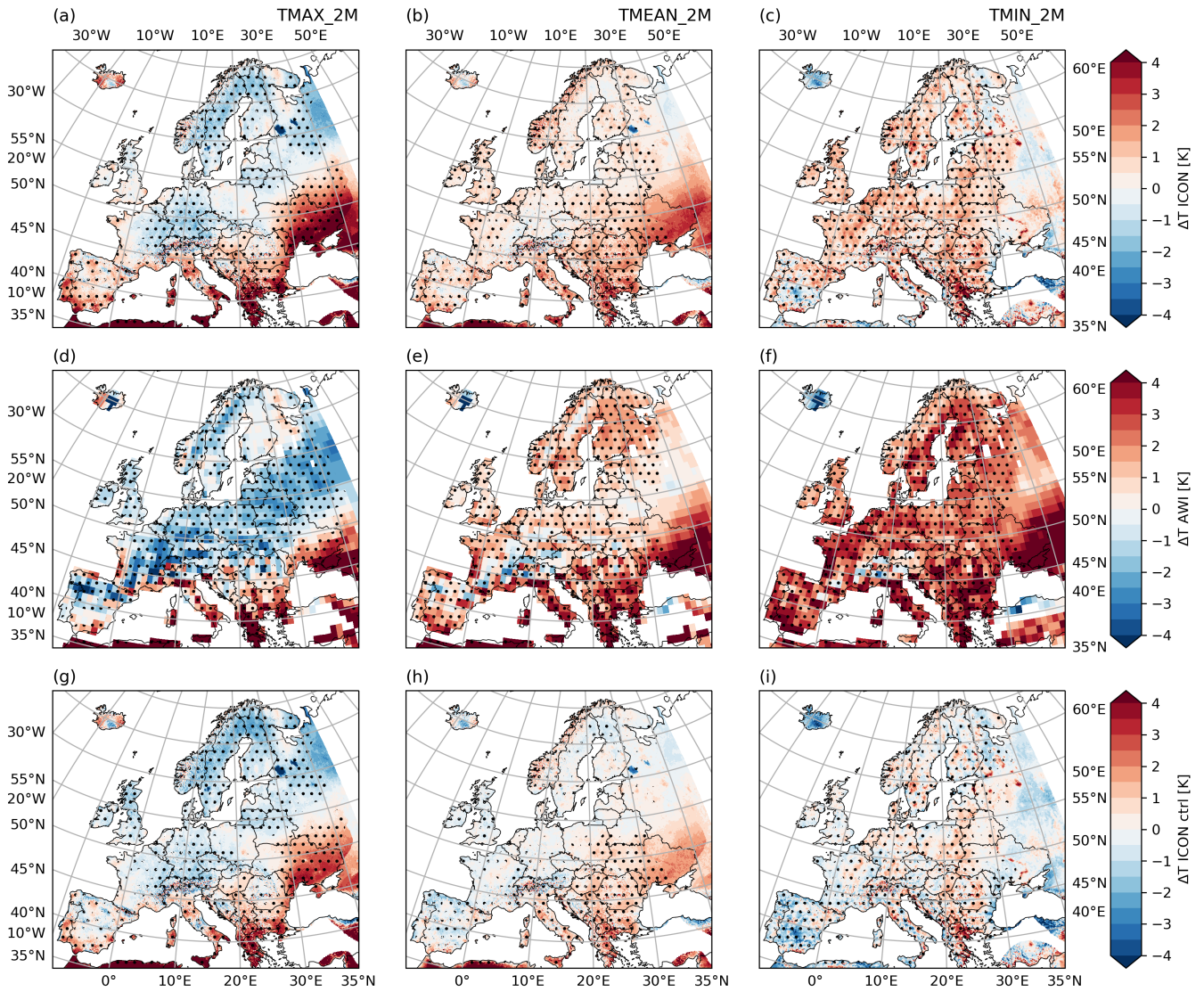
Figure S4: Seasonal mean bias of 2m temperature w.r.t. E-OBS in 2018-2022 for (a-c) ICON EUR-12 simulation, (d-f) AWI-CM1 simulation, (g-i) ICON EUR-12 control simulation driven by ERA5. Hatched areas indicate regions where the bias to E-OBS is statistically significant with a p-value threshold of 0.0
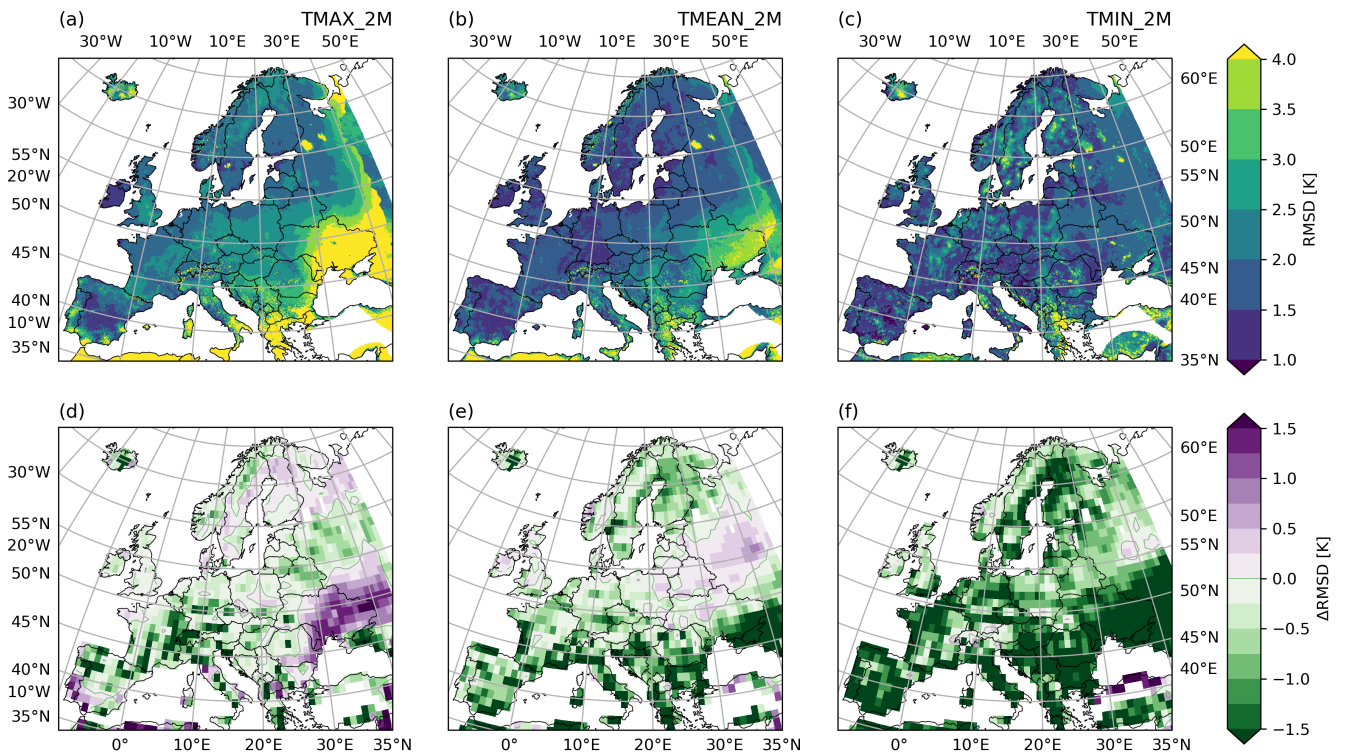
Figure S5: Added value assessment of the ICON EUR-12 simulation for June, July, August 2018-2022 for daily maximum (left column), mean (middle column), and minimum (right column) 2m temperature. (a-c): root mean square difference (RMSD) of the simulated daily 2m temperatures by ICON EUR-12 to E-OBS. (d-f): Change in RMSD achieved by dynamical downscaling; the green colours correspond to the reduced squared error of daily temperatures.
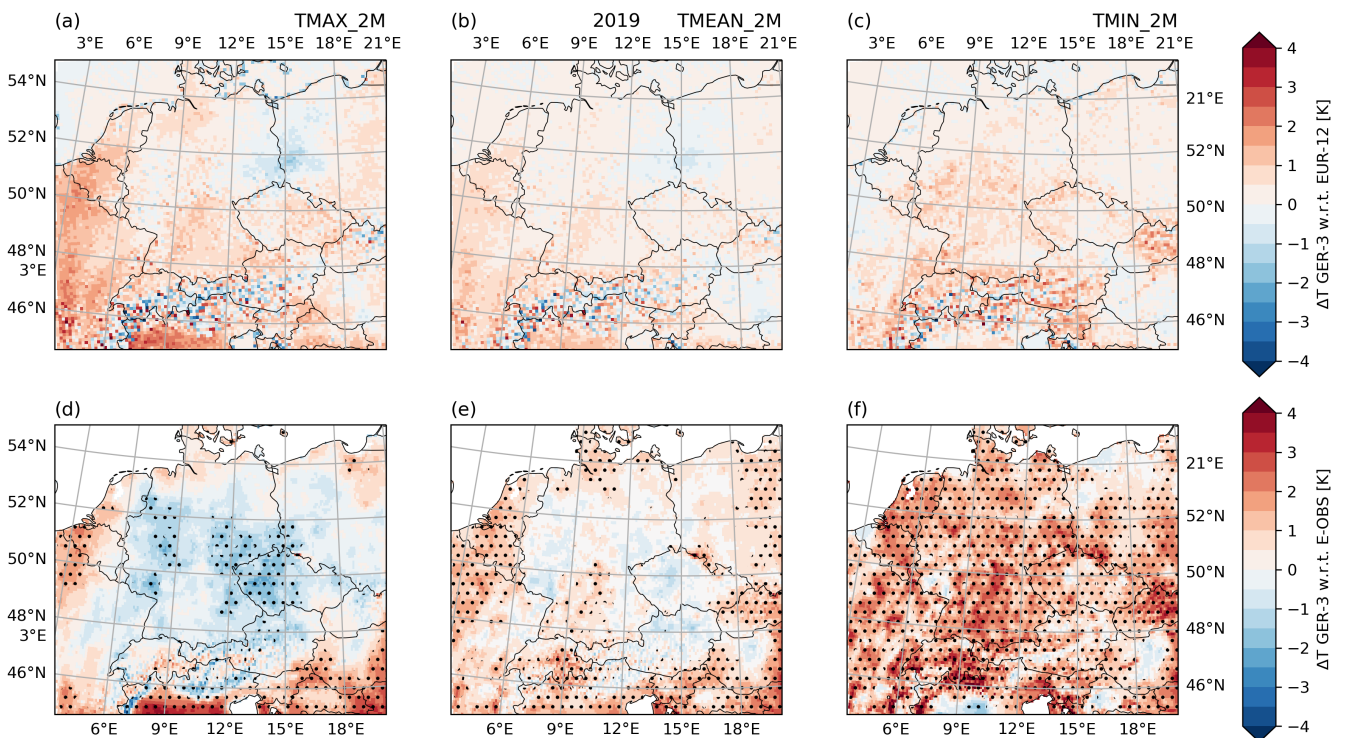

Figure S6: Mean JJA bias of 2m temperature of the nested convective permitting GER-3 simulation in 2019 (a-c) with respect to EUR-12, (d-f) with respect to E-OBS; hatched areas indicate regions where the bias to E-OBS is statistically significant with a p-value threshold of 0.05
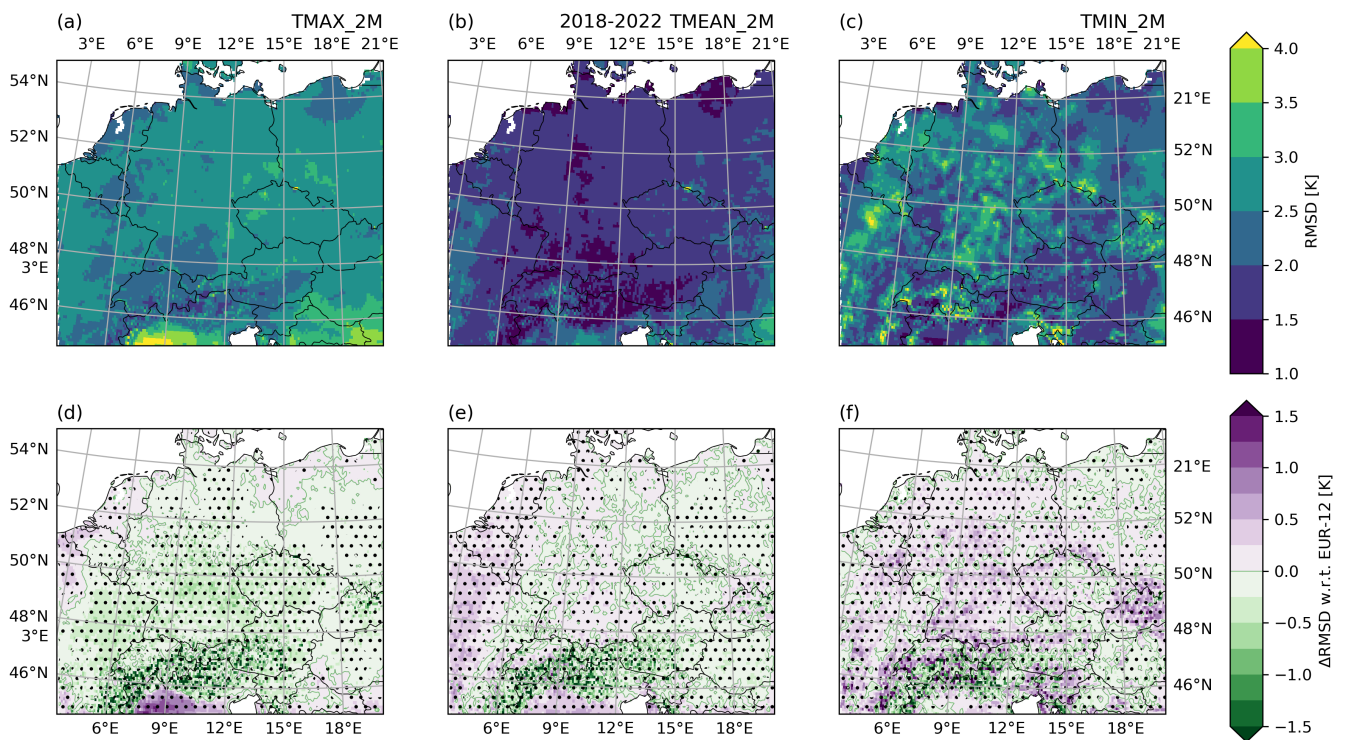
Figure S7: Added value assessment of the ICON GER-3 simulation for June, July, August 2018-2022 for daily maximum (left column), mean (middle column), and minimum (right column) 2m temperature. (a-c): root mean square difference (RMSD) of the simulated daily 2m temperatures by ICON GER-3 to E-OBS. (d-f): Change in RMSD w.r.t. EUR-12 simulation achieved by dynamical downscaling; the green colours correspond to the reduced squared error of daily temperatures.
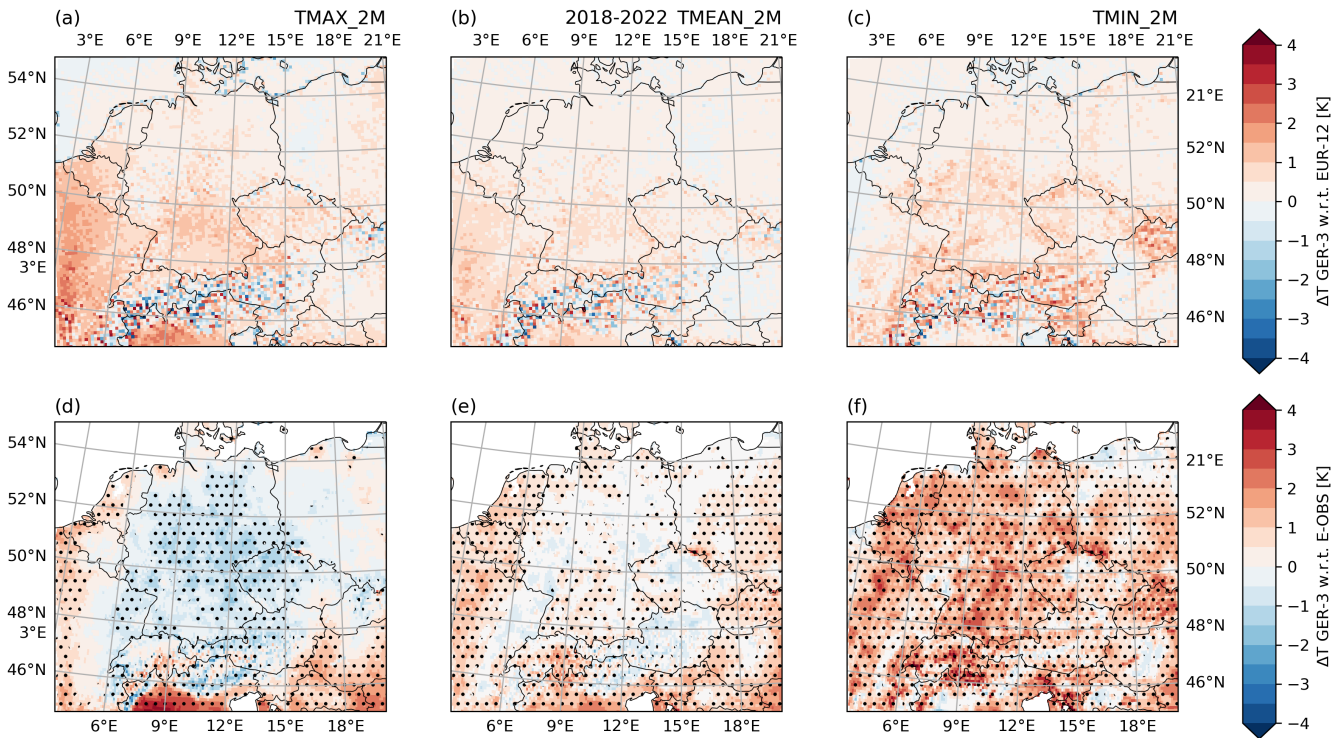
Figure S8: Mean JJA bias of 2m temperature of the nested convective permitting GER-3 simulation in 2018-2022 (a-c) with respect to EUR-12, (d-f) with respect to E-OBS; hatched areas indicate regions where the bias to E-OBS is statistically significant with a p-value threshold of 0.05
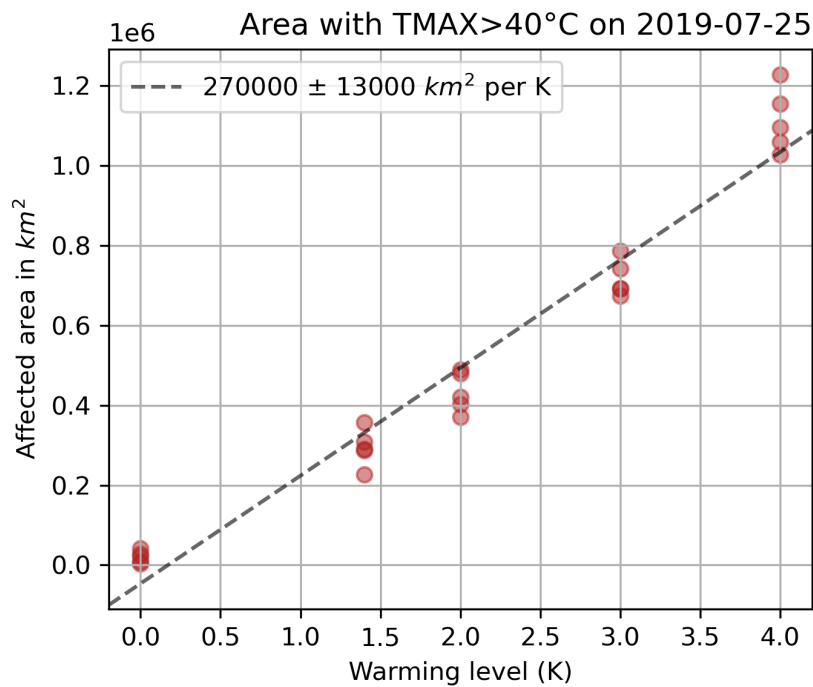

Figure S9: The European area affected by the daily maximum temperatures over 40 °C on 25.07.2019 against the warming level, based on the EUR-12 simulation. The number in the legend is the increase of the area per 1 K of global warming if approximated linearly.
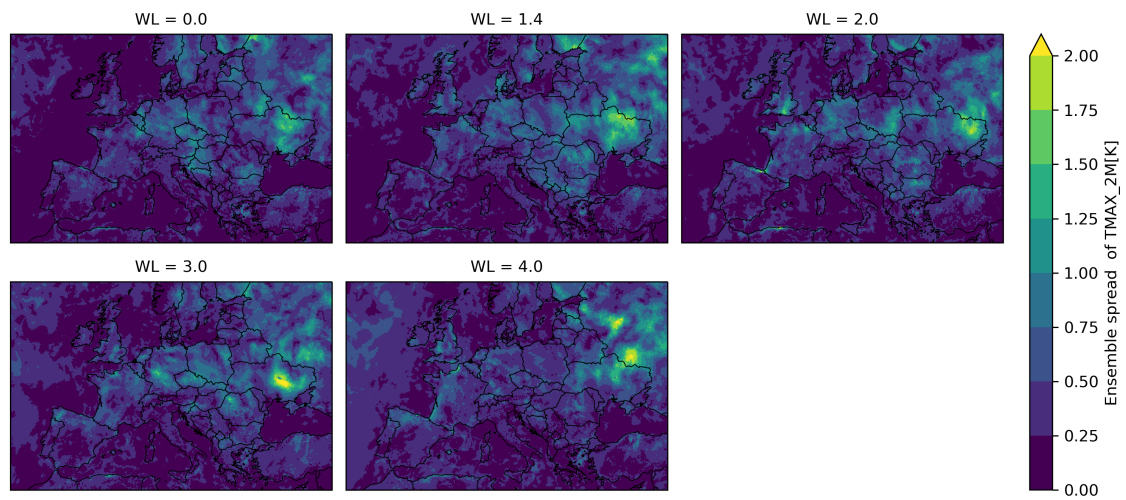
Figure S10: Ensemble spread of 5-day mean daily maximum temperature of the EUR-12 simulation for the period from 23.07 to 27.07 of the dynamical year 2019 at each warming level.
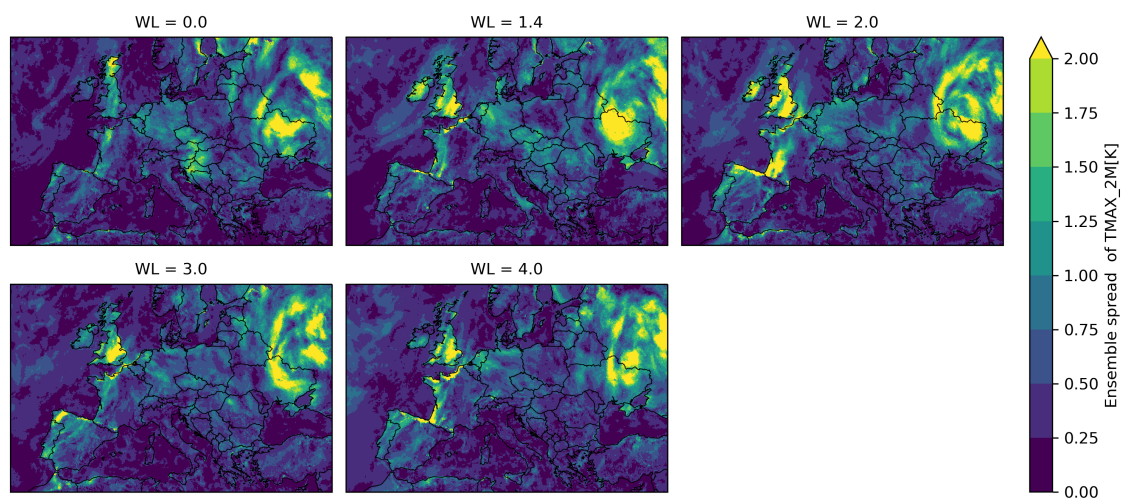

Figure S11: Ensemble spread of 5-day mean daily maximum temperature of the EUR-12 simulation on 25.07 of the dynamical year 2019 at each warming level.
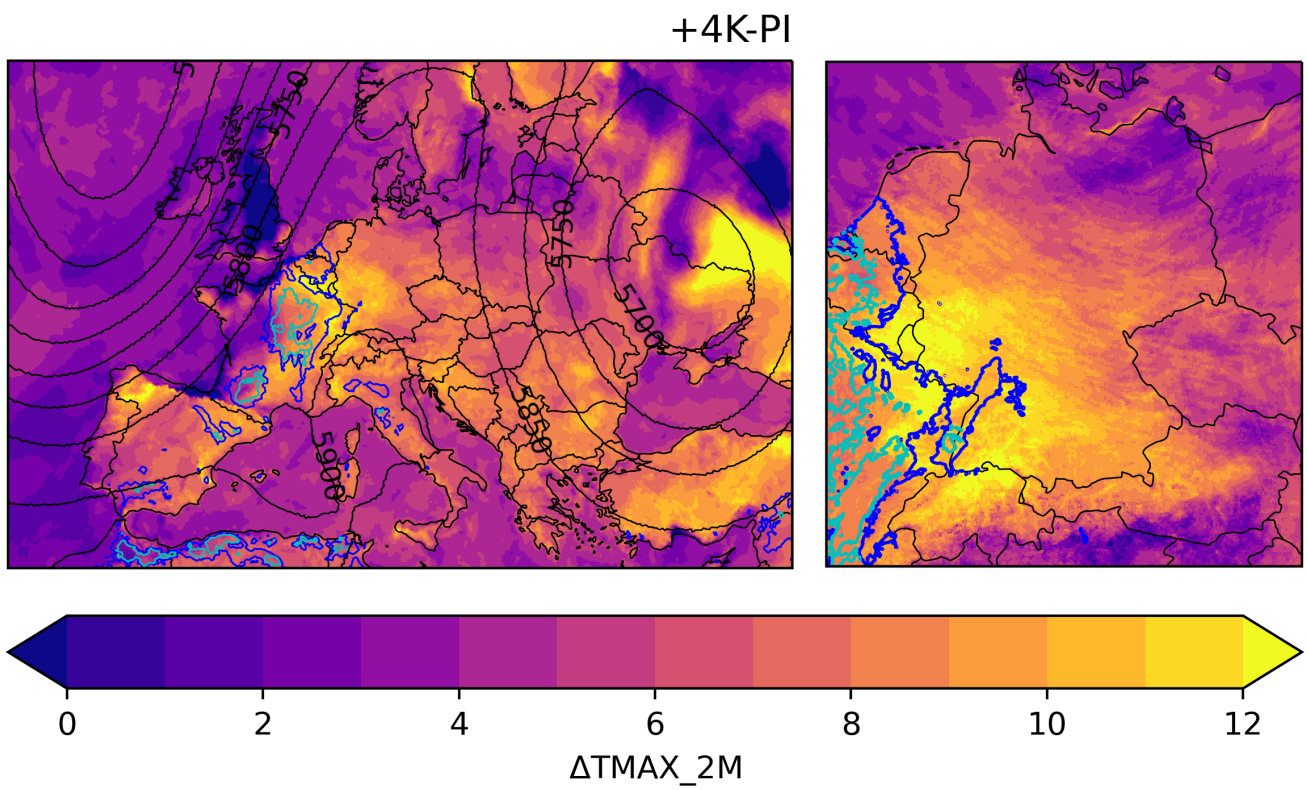
Figure S12: Difference of the maximum 2m temperature on 25.07.2019 between the +4 K warmer world and the pre-industrial climate (ensemble member 1). Contour lines represent the maximum 2m temperature in the present-day ICON (left) EUR-12 and (right) GER-3 simulations; blue contour: 40°C, Cyan contour: 42°C
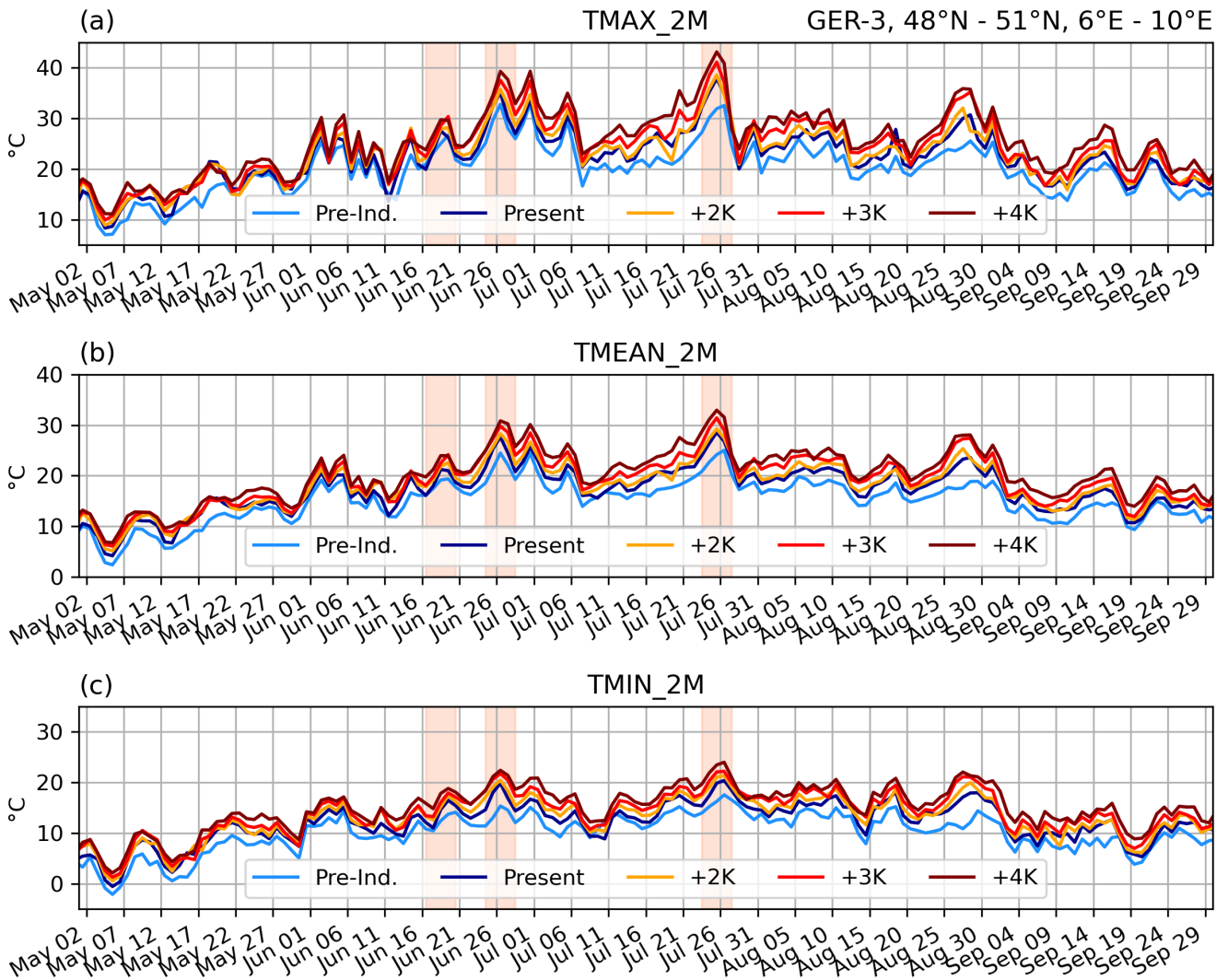
Figure S13: Daily (a) maximum, (b) mean, and (c) minimum temperatures averaged over the longitude/latitude box with boundaries 48° N - 51° N and 6° E - 10° E (see Fig. 1b) over the MJJAS period of the year 2019 based on the GER-3 storyline simulations. The three highlighted periods (orange) are discussed in detail in section 3.3.
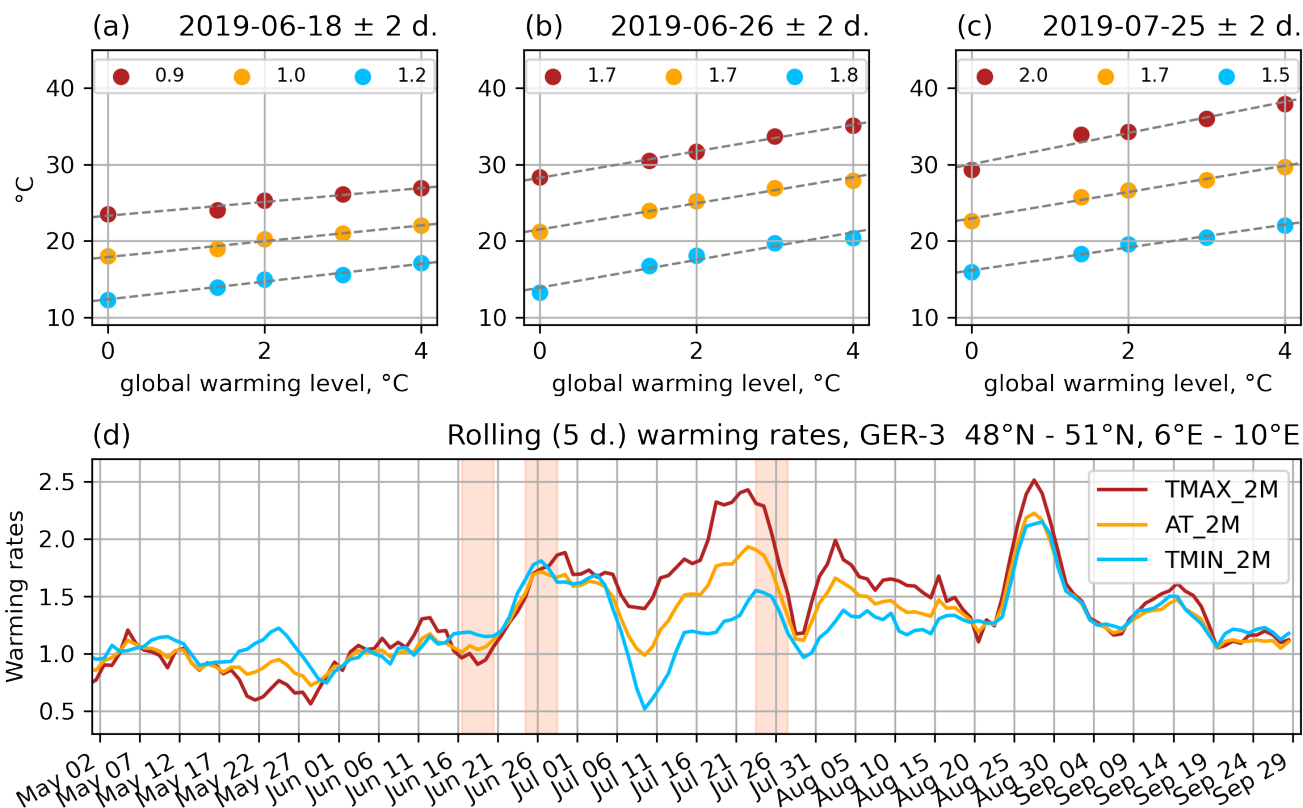
Figure S14: (a-c) Daily maximum (red), mean (orange), and minimum (blue) 2m temperature over the longitude/latitude box 48° N - 51° N, 6° E - 10° E averaged over three 5-day periods plotted against the global warming level. The numbers in the legend represent the slopes of the respective lines; (d) warming rates for the rolling average (5-day window) of daily maximum, mean, and minimum temperatures over the same box. The three highlighted periods are discussed in detail in section 3.3. Based on the GER-3 simulation.
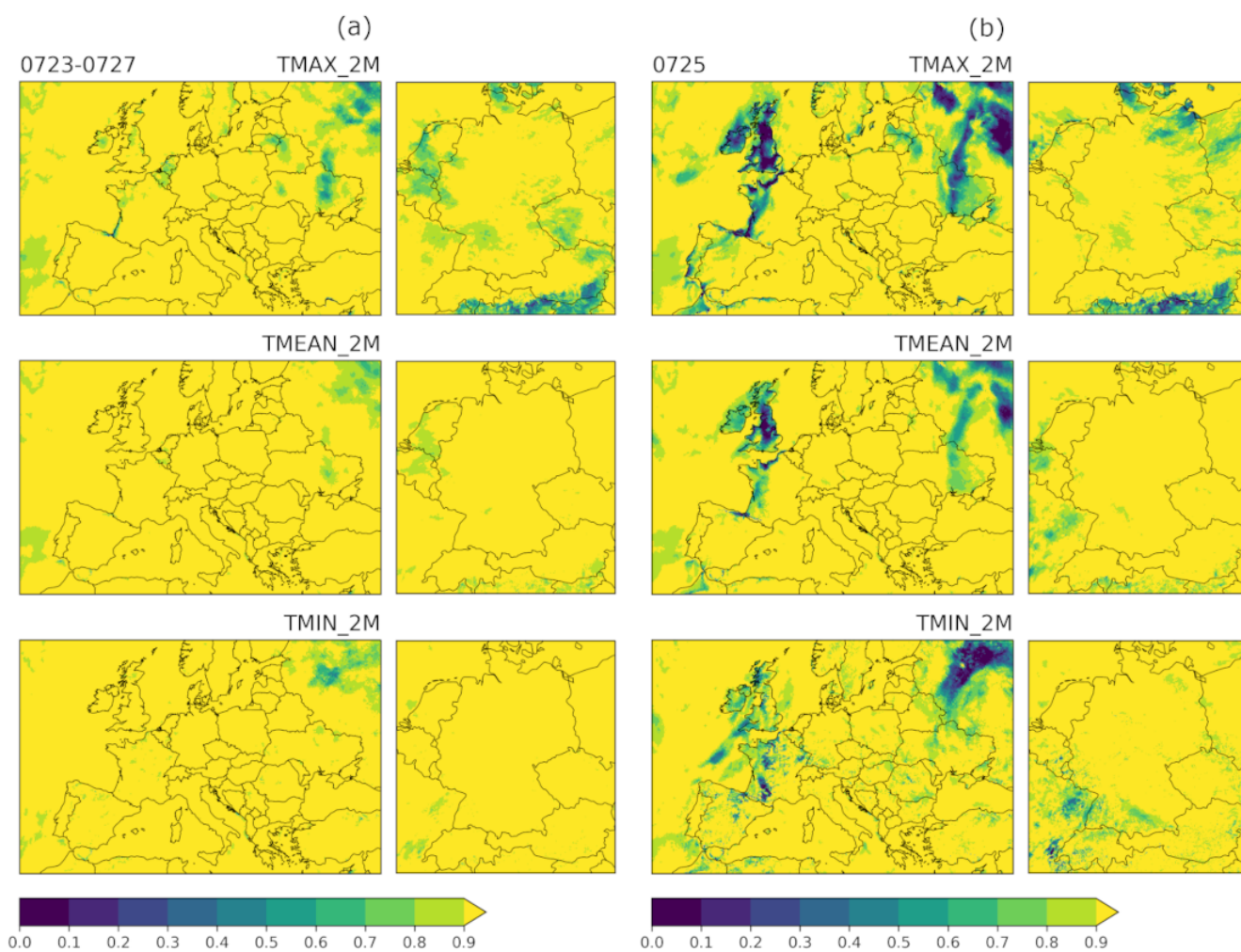
Figure S15: Goodness of linear fit (R-squared) for warming rates of maximum, mean, and minimum 2m temperatures (a) over the period from 23.07.2019 to 27.07.2019, (b) on 25.07.2019.
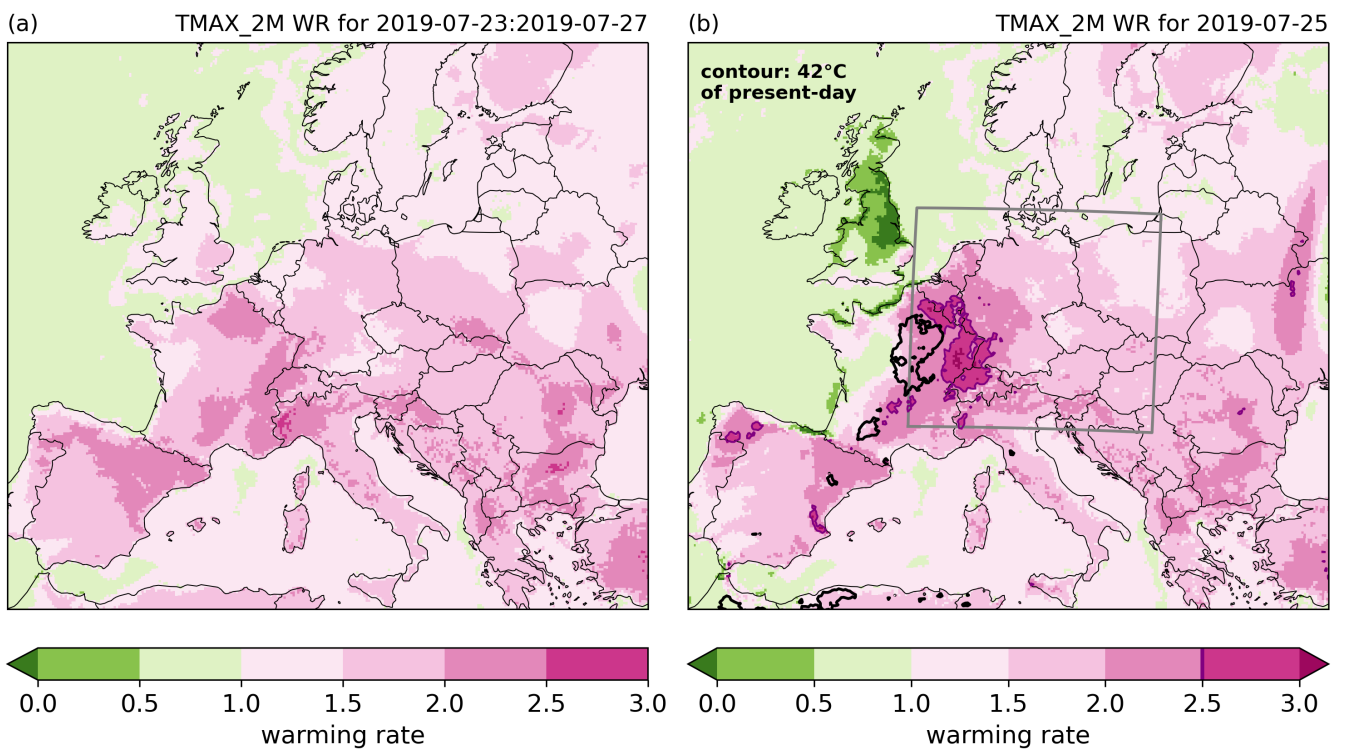
Figure S16: (a) Mean warming rates over the period from 23.07.2019 to 27.07.2019; (b) Warming rates for the 25.17.2019. Black contour in (b) surrounds the core area of the heatwave in the present-day climate. The gray box in (b) shows the boundaries of the GER-3 domain.
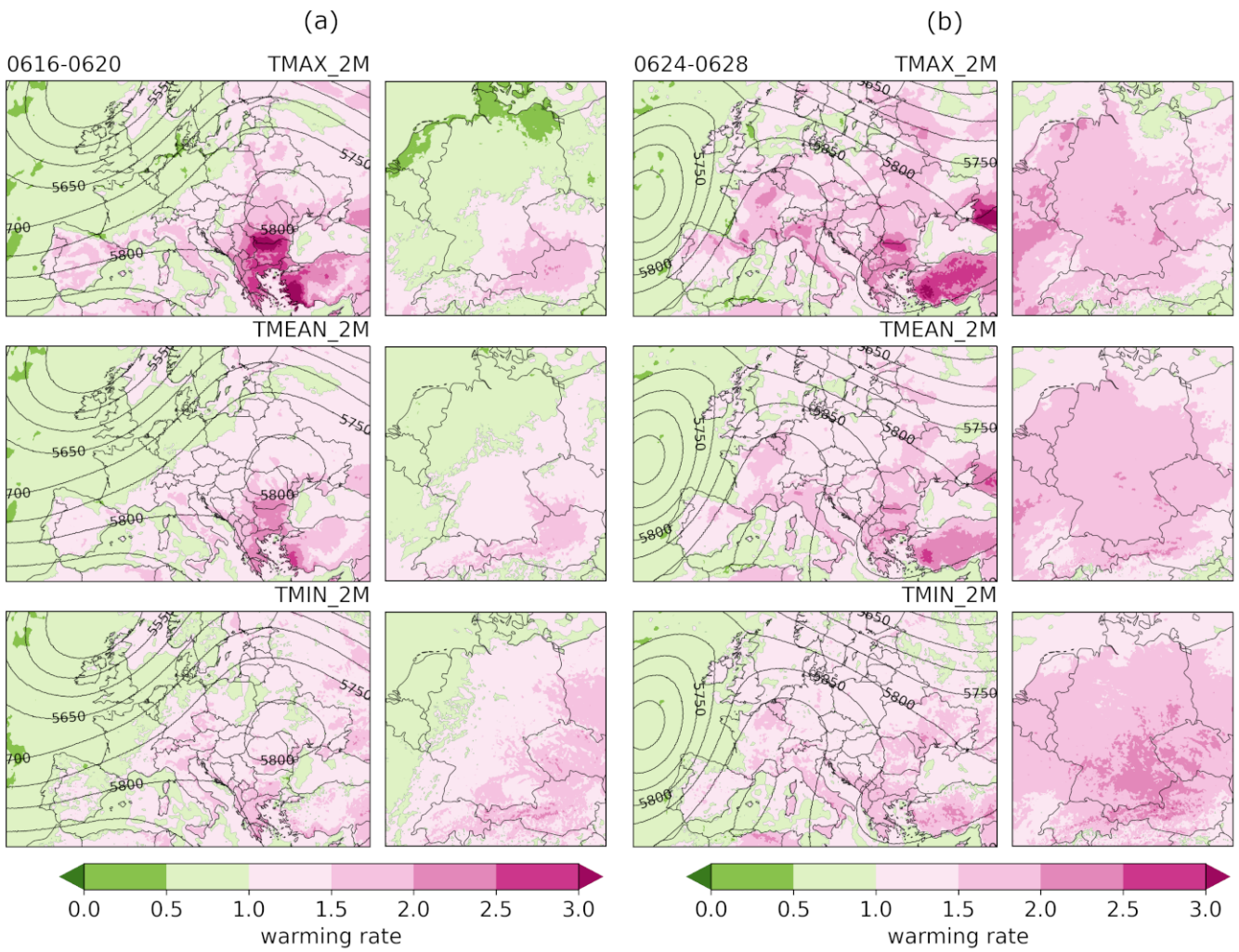
Figure S17: (a) Warming rates for the period from 16.06.2019 to 20.06.2019. (b) Warming rates for the period from 24.06.2019 to 28.06.2019. Contours: geopotential height as of the EUR-12 present-day simulation (ensemble member 1).