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The June 2026 heatwave established a new benchmark for early-summer heat in Germany

Monica Ionita[1] and Viorica Nagavciuc[1]
[1]Alfred Wegener Institute Helmholtz Center for Polar and Marine Research, Paleoclimate Dynamics, Bremerhaven, Germany

Correspondence: Monica Ionita (Monica.Ionita@awi.de)

Abstract. The June 2026 heatwave established a new benchmark for early-summer heat in Germany, producing the highest temperatures observed since instrumental records began and culminating in a new provisional national temperature record of 41.8°C. Here, we quantify the extremeness of this event using high-resolution gridded observations, long-term station records extending back nearly two centuries, and ERA5 reanalysis, and investigate the relative contributions of atmospheric circulation and background climate warming. Across the 1951–2026 gridded record, the event ranks first in peak daily maximum temperature, cumulative heatwave intensity, and the number of days with daily maximum temperature exceeding 30°C. Daily maximum temperature anomalies reached 12–16°C locally, while regional peak temperatures exceeded the 1971–2000 climatology by up to 4.9 standard deviations and long-term station records by up to 3.7 standard deviations. At the national scale, heatwave duration and frequency have increased significantly since 1951, providing the long-term climatic context in which this event occurred. Flow-analogue analysis shows that the heatwave was generated by a persistent omega-type blocking anticyclone, but that comparable circulation patterns from the recent past would have produced 3–4°C lower temperatures than those observed in 2026, indicating substantial thermodynamic amplification associated with background warming. Our results show that the June 2026 event represents a new class of intensity-dominated, record-shattering early-summer heatwaves in Germany, in which persistent atmospheric blocking acts upon a substantially warmer climate to produce unprecedented temperatures.

Keywords: Heatwave, atmospheric blocking, flow-analogue method, climate trends, Germany

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1. Introduction

Heatwaves are among the deadliest and most disruptive weather extremes in Europe, with impacts on human health, agriculture, infrastructure, ecosystems, and energy demand (Boboc et al., 2025; Ionita et al., 2024; Perkins-Kirkpatrick and Lewis, 2020; Seneviratne et al., 2021; Vaideanu et al., 2025; Vautard et al., 2023). Their frequency, intensity, and duration have increased in recent decades, reflecting the combined influence of natural variability and anthropogenic warming (Barriopedro et al., 2023; Vautard et al., 2023). As the climate continues to warm, the probability of record-shattering heat extremes is also rising, making it increasingly important to understand not only the magnitude of individual events, but also the mechanisms that produce them (Fischer et al., 2021). Europe is especially vulnerable to extreme heat because it is warming rapidly and because major summer heatwaves often arise from the persistence of blocking anticyclones and subtropical ridges (Chan et al., 2022; Ionita et al., 2025a; Kautz et al., 2022; Pfahl and Wernli, 2012). These circulation patterns suppress cloud formation, promote subsidence, and allow hot air masses to remain over the same region for several days, thereby intensifying near-surface heat (Sousa et al., 2018; Zschenderlein et al., 2019). Heatwave severity is further amplified when atmospheric circulation interacts with dry soils, which reduce evaporative cooling and increase sensible heating at the surface (Barriopedro et al., 2023; Lorenz et al., 2010; Miralles et al., 2014). For this reason, separating the dynamic contribution of circulation from the thermodynamic contribution of background warming is central to the interpretation of European heat extremes (Jézéquel et al., 2018).

The late-June 2026 heatwave was an exceptional pan-European event that affected much of Western and Central Europe and culminated in record-breaking temperatures in several countries (WMO, 2026). In Germany, the event reached extraordinary intensity between 25 and 29 June, when provisional national temperature records were broken on successive days, and many stations exceeded 40°C (DWD, 2026). According to preliminary measurements, the all-time record for Germany was broken on the 28 June, with a temperature of 41.8°C recorded in Möckern-Drewitz (Brandenburg) (DWD, 2026). The event was notable not only for its peak temperature, but also for its spatial extent and its persistence across consecutive days, indicating an unusually strong and broadly organized heat episode. In France, Météo-France reported that 23 June was the hottest day recorded since observations began in 1947. Temperatures reached 44.3 °C in Pissos, 42.1 °C in Bordeaux, and a June record of 40.9 °C in Paris. In the United Kingdom, temperatures climbed to 37.7 °C (WMO, 2026). The extremeness of this heatwave event and its early onset (i.e., June) makes it an important case study for understanding how an extreme circulation event interacts with a warmed background climate to produce record-breaking heat.

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Germany provides a particularly relevant setting for this analysis because it lies in a region where European heat extremes have intensified markedly in recent decades (Barriopedro et al., 2023; Boboc et al., 2025; Ionita et al., 2026; Vautard et al., 2023). Long instrumental records show that heatwave characteristics in Central and Western Europe have shifted toward stronger and more frequent extremes, with recent decades standing out as the warmest in the historical record (Beckett and Sanderson, 2022; Fischer et al., 2021; Ionita et al., 2025b; Perkins-Kirkpatrick and Lewis, 2020). Nevertheless, many heatwave studies remain focused either on synoptic dynamics or on statistical record-breaking, rather than on a combined observational diagnosis of event extremeness, long-term trend context, and circulation-based decomposition (Barriopedro et al., 2023; Fischer et al., 2021; Han et al., 2022; Luo et al., 2023; Vautard et al., 2019, 2023). Thus, a detailed case study of the June 2026 event can help bridge that gap by showing how unusual the event was in Germany, how it fits into longer-term changes, and how much of its intensity can be linked to circulation versus background warming. The timing of the event further enhances its significance. Extreme temperatures occurring in late June are generally associated with larger societal impacts than comparable events later in the summer because ecosystems, agriculture, infrastructure, and the population are less acclimatized to prolonged heat. In addition, many sectors, including public health and water management, typically prepare for the most severe heat later in July and August. Consequently, record-breaking heat occurring already in June represents an important indicator of the ongoing seasonal shift toward earlier occurrence of extreme temperatures.

In this study, we present a multi-scale observational analysis of the late-June 2026 heatwave, with a focus on Germany, while situating it within its broader European context. Specifically, we address three questions: how extreme was the event relative to the German observational record across regions and metrics; how do its characteristics compare with long-term trends in heatwave behavior since 1951; and what were the relative roles of atmospheric circulation and thermodynamic warming in shaping its peak intensity? To answer these questions, we combine gridded temperature data, long-term station records, ERA5 reanalysis fields, and a flow-analogue decomposition of the event peak. By doing so, we aim to provide a physically grounded assessment of one of the most severe heatwaves to affect Germany in the instrumental era and to clarify what it reveals about the evolving nature of European heat extremes.

2. Data and methods

2.1 Data

Gridded daily maximum temperature (TX) over Germany is taken from the HYRAS-DE dataset (version 6.1) of the Deutscher Wetterdienst (DWD), which provides daily fields on a 1km x 1km grid over the period for 1951–2026. HYRAS-DE data is derived from quality-controlled station

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observations and is based on a combination of nonlinear temperature profiles with non-Euclidean residual interpolation (Razafimaharo et al., 2020). Area averages for the 16 German federal states (Table 1 and Figure 1) and for Germany as a whole are computed using administrative boundary masks (GADM level-1 polygons).

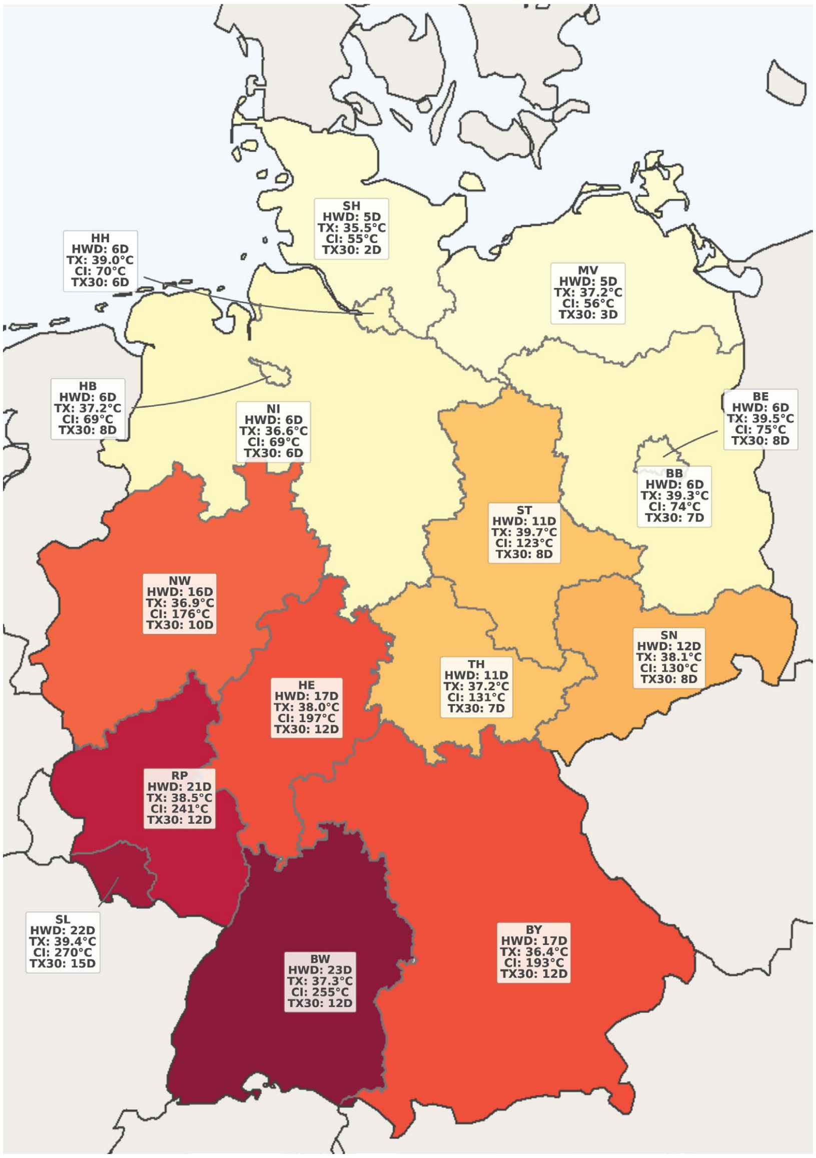

Figure 1. Location of the federal states and the statistics for the June 226 HW event. HWD – heatwave duration; CI – cumulative intensity, TX30 – number of days with the daily TX>30°C. The different colors are a simplified version of the heatwave duration, to emphasize the most affected federal stated. Dark red indicate the regions with the highest duration. The long name of each federal state can be found in *Table 1*.

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Table 1. Name of the Federal States, their abbreviations and the 2026 heatwave statistics.

Federal state	Abbr.	HW Days	Max TX	CI	TX>30°C
Baden-Württemberg	BW	23	37.3	254.7	12
Bavaria / Bayern	BY	17	36.4	193.4	12
Berlin	BE	6	39.5	74.7	8
Brandenburg	BB	6	39.3	74.2	7
Bremen	HB	6	37.2	69.0	8
Hamburg	HH	6	39.0	70.3	6
Hesse / Hessen	HE	17	38.0	197.0	12
Mecklenburg-Western Pomerania	MV	5	37.2	56.2	3
Lower Saxony / Niedersachsen	NI	6	36.6	69.4	6
North Rhine-Westphalia	NW	16	36.9	175.5	10
Rhineland-Palatinate	RP	21	38.5	240.6	12
Saarland	SL	22	39.4	270.1	15
Saxony / Sachsen	SN	12	38.1	130.5	8
Saxony-Anhalt	ST	11	39.7	122.7	8
Schleswig-Holstein	SH	5	35.5	54.6	2
Thuringia / Thüringen	TH	11	37.2	131.0	7

To extend the temporal perspective beyond the gridded record, we also use daily TX series from 18 long-term DWD climate stations with records reaching back to the mid-19th century (Table 2).

Table 2. Names of the long-term stations used in this study

No.	Station name	Federal state	Altitude (m.a.s.l.)	Record
1	Berlin-Dahlem	BE	51 m.	1876 - 2026
2	Bremen	HB	4 m.	1890 - 2026
3	Brocken	ST	1135 m.	1896 - 2026
4	Cottbus	BB	68 m.	1887 - 2026
5	Fichtelberg	SN	1213 m.	1890 - 2026
6	Görlitz	SN	239 m.	1860 - 2026
7	Göttingen	NI	167 m.	1858 - 2026
8	Heinersreuth	BY	350 m.	1879 - 2026
9	Hohenpeißenberg	BY	977 m.	1879 - 2026
10	Jena	TH	155 m.	1824 - 2026
11	Leipzig	SN	138 m.	1864 - 2026
12	Magdeburg	ST	79 m.	1881 - 2026
13	Oberstdorf	BY	806 m.	1910 - 2026
14	Plauen	SN	387 m.	1882 - 2026
15	Potsdam	BB	81 m.	1893 - 2026
16	Putbus	MV	40 m.	1857 - 2026
17	Schwerin	MV	59 m.	1890 - 2026
18	Zugspitze	BY	2956 m.	1901 - 2026

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Large-scale atmospheric fields (i.e., the 500 hPa geopotential height (Z500) and the 850 hPa temperature (T850)) are taken from the ERA5 reanalysis (Hersbach et al., 2020) at daily resolution over a European domain, having a 0.25° X 0.25° grid. Unless stated otherwise, anomalies are computed relative to the 1971–2000 calendar-day climatology.

2.2 Heatwave detection and metrics

Heatwaves (HW) are detected with a percentile-based algorithm equivalent to the widely used framework of (Hobday et al., 2016), applied here to the daily maximum temperature (Perkins and Alexander, 2013). Heatwaves are identified relative to a calendar-day-dependent threshold, defined at each grid point (or for each area-averaged regional series) as the 90th percentile of daily maximum temperature (TX) computed over the 1971–2000 reference period using a 15-day window centered on each calendar day. A heatwave event is defined as a period of at least five consecutive days during which TX exceeds this threshold. The short summer season May–June (MJ) is considered for the gridded and station-based analyses. The present analysis is restricted to May–June (MJ) because, at the time of writing, complete and quality-controlled observational datasets for July and August 2026 were not yet available. Restricting the analysis to the available period ensures a consistent comparison between the 2026 event and the historical record. As the June heatwave accounts for the overwhelming majority of the early-summer temperature extremes in 2026, this restriction does not affect the interpretation of the event itself but should be considered when comparing seasonal heatwave metrics with previous years. From the detected events we derive different HW metrics: the number of heatwave events (frequency), the number of heatwave days (duration), peak TX, and the cumulative intensity, (i.e., defined as the sum over all heatwave days of the daily exceedance of TX above the calendar-day climatological mean).

To compare the extremeness of 2026 across regions and stations on a common scale, we define a standardized exceedance ("warming ratio") of the 2026 maximum May–June TX as $(TX_{2026} - P90) / \sigma$, where P90 is the 90th percentile and σ the standard deviation of the daily temperature maximum series over the 1971–2000 baseline. In addition, empirical percentiles and ranks of the 2026 values of each heatwave metric are computed relative to all previous years of the respective record.

2.3 Trend analysis

Linear trends of the heatwave metrics over 1951–2026 are estimated by ordinary least squares. Two-sided p-values are obtained from the *t-test* statistic of the regression slope, and the 95% confidence intervals of the slope are shown. Trends are computed both for Germany-average time-series as well as for the gridded data. Given the skewed nature of some heatwave metrics, the robustness of the Germany-average trends was additionally confirmed with the non-parametric

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Mann–Kendall test and Sen's slope estimator (Hamed and Ramachandra Rao, 1998; Sen, 1968), which are less sensitive to outliers and do not assume normally distributed residuals. For the gridded trend maps, statistical significance was evaluated using the modified Mann–Kendall test (Hamed and Ramachandra Rao, 1998), which corrects for the inflation of apparent significance caused by serial autocorrelation in annual time series, with trend magnitudes given by the Theil–Sen median slope estimator (Sen, 1968).

2.4 Flow-analogue decomposition

The dynamic and thermodynamic contributions to the June 2026 event peak (i.e., 25–29 June 2026) are separated with a flow-analogue approach (Cattiaux et al., 2010; Jézéquel et al., 2018; Yiou et al., 2012). For each event day, the N = 25 days with the most similar Z500 patterns over a European domain are selected from the period 1970–2025 (excluding 2026), restricting candidates to a ±15 day calendar window around the event date to preserve the seasonal cycle. Pattern similarity is measured by the latitude-weighted Euclidean distance of Z500 anomaly fields. The dynamic contribution to the event-day temperature anomaly is estimated as the composite area-mean T850 anomaly of the selected analogues over a Germany-centered target region (5–16° E, 47–56° N). Thus, the thermodynamic contribution is the residual between the observed and the analogue-composite anomaly. Uncertainty of the dynamic component is quantified by bootstrap resampling of the analogue sets (1000 resamples; 95% confidence intervals). To isolate thermodynamic warming under near-identical circulation, the analogue selection is additionally restricted to an early (1970–2000) and a late (2001–2025) epoch, and the corresponding composites are compared. The quality of the analogues is verified against randomly drawn days from the same calendar window (Supplementary Figure S1).

3. Results

3.1 Maximum temperature and synoptic evolution of the June 2026 event

Figure 2 shows the observed daily TX fields (top row) and the corresponding anomalies relative to the 1971–2000 climatology (bottom row) for the peak days of the HW event, namely 26 to 28 June 2026. On 26 June, the most intense heat was concentrated over southwestern and western Germany, with observed TX exceeding 39°C in the Upper Rhine region. The heat subsequently expanded and shifted east and northeastward. On 27 and 28 June, large parts of central and eastern Germany experienced TX values above 37–40 °C, and daily anomalies locally reached +12 to +16°C. This spatio-temporal evolution is fully consistent with the station-based record sequence, in which the provisional all-time national record migrated from Saarbrücken-Burbach (41.3 °C, 26 June,

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western part of Germany) to Möckern-Drewitz (41.8 °C, 27 June) and Neißemünde-Coschen (41.7 °C, 28 June, eastern part of Germany) (DWD, 2026).

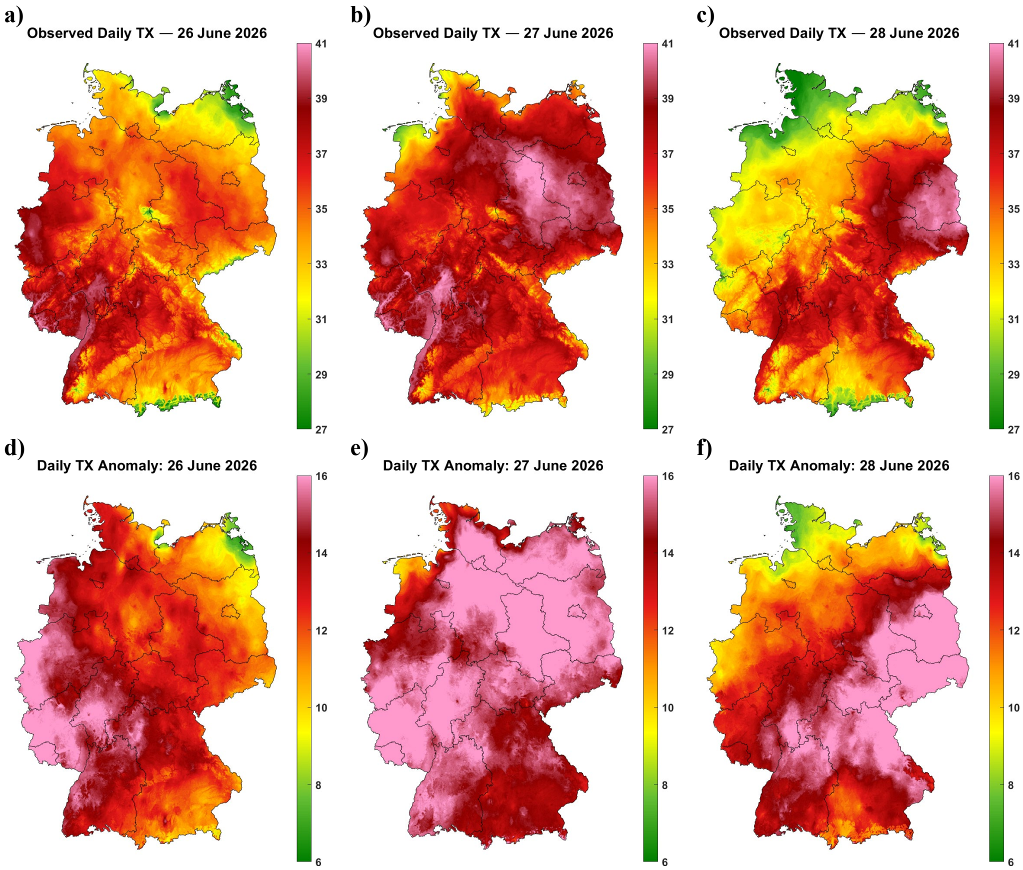

Figure 2. Surface analysis of the late-June 2026 heatwave over Germany. (a–c, top row) Observed daily maximum temperature (TX, °C) on 26, 27 and 28 June 2026, and (d–f, bottom row) the corresponding daily TX anomalies (°C) relative to the 1971–2000 climatology.

The synoptic drivers of the event are shown in Figure 3. A pronounced positive Z500 anomaly (i.e., an omega-type blocking ridge embedded in a heat-dome configuration extending from the subtropical Atlantic into Central Europe) dominated the mid-troposphere during the peak phase. The anticyclonic anomaly amplified and propagated slowly eastward from the 20 to 28 June (Figure 3), steering the low-level heat plume across Germany in phase with the surface temperature evolution (Figure 2). The core of the surface anomaly shifted from western Germany on the 26 June to central and eastern Germany by 27 – 28 June, spanning several hundred kilometers while the blocking ridge remained centered over Central Europe. On the 27 – 28 June, the record-breaking footprint covered virtually all of Germany, indicating that the event was both spatially extensive and vertically coherent in lower-tropospheric temperature and mid-tropospheric geopotential height.

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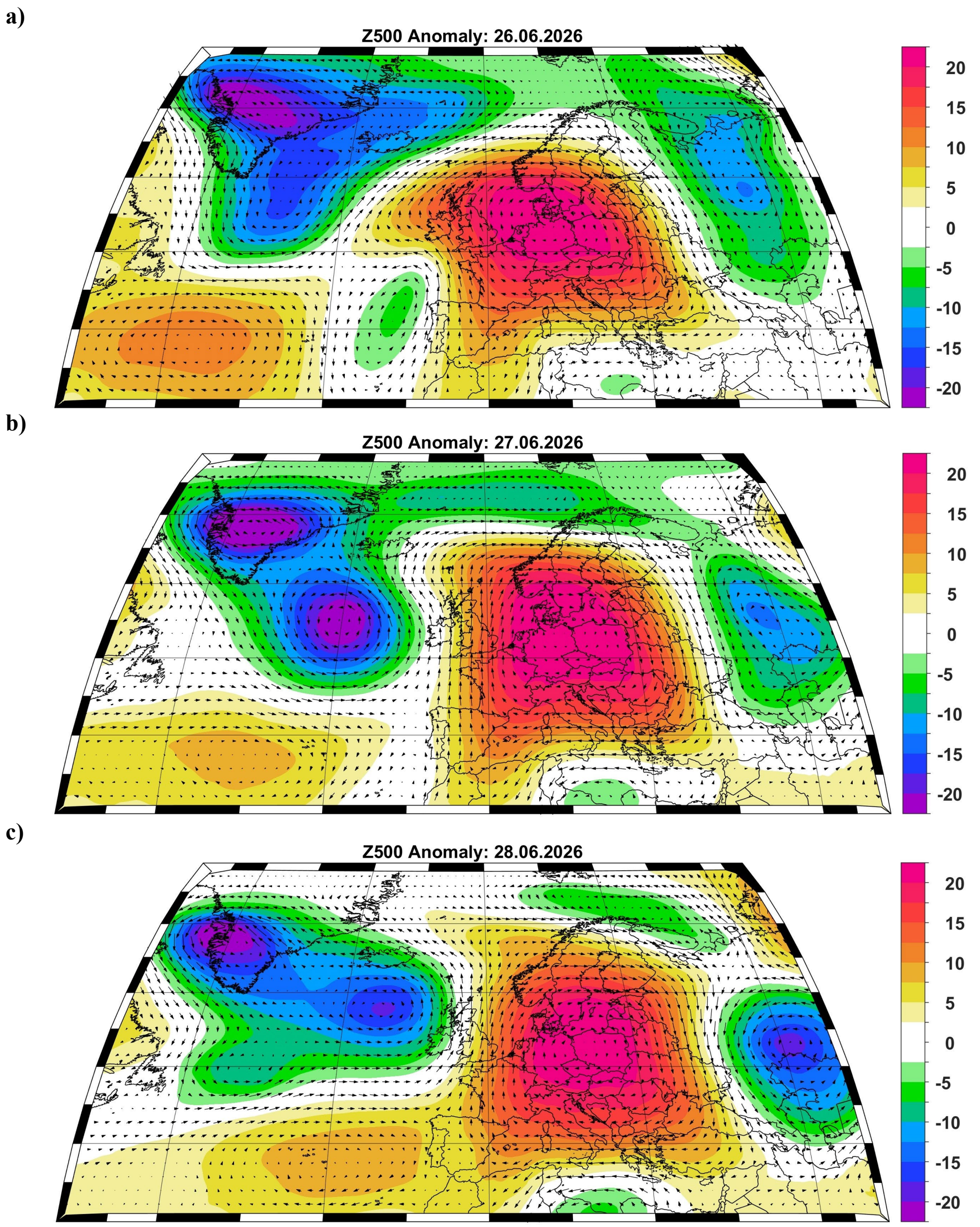

Figure 3. Synoptic evolution during the event peak. 500 hPa geopotential height (Z500) anomalies (shading, m) relative to the 1971–2000 climatology on a) 26 June, b) 27 June, and c) 28 June 2026, with vectors indicating the associated 500 hPa wind field (ERA5).

Such persistent blocking ridges are the canonical dynamic precondition for major European heatwaves (Boboc et al., 2025; Faranda et al., 2023b; Kautz et al., 2022; Pfahl and Wernli, 2012), while eastward propagation explains the day-by-day displacement of the temperature maxima from the western part of Germany towards the east. While in Figures 2 and 3 we focus on the three most intense days of the event and on the surface temperature at country level; the full five-day evolution, including the flanking days of 25 and 29 June, are shown in Figures S2 and S3. For the extended event analysis, we use the T850 to have a better indication of the temperature anomalies at European level. Both the T850 warm anomaly and the Z500 blocking ridge were already well established over Central Europe on 25 June and persisted through 29 June, while the compensating cut-off low over the eastern North Atlantic deepened and shifted southward as the event progressed, consistent with the omega-block configuration described above. The stippling in Supplementary Figure S2 and S3 marks grid points where the T850 and Z500 anomaly, respectively, was the highest value on record for that calendar day since 1970, and on the 27 and 28 June this record-breaking footprint covers virtually all of Germany and adjacent parts of Central Europe in both fields simultaneously. The spatial co-occurrence of unprecedented lower-tropospheric temperature and mid-tropospheric geopotential-height anomalies over the same region and days indicates that the event was extreme not only in terms of area-mean intensity, as shown in Section 3.2, but also at individual grid points in both T850 and Z500.

3.2 How exceptional was 2026? A regional perspective

Figure 4 places the 2026 May–June maximum TX in the context of the full 1951–2026 gridded record for the 16 federal states and the Germany average. The 2026 regional values span from 31.4 to 35.9 °C with an ensemble mean of 33.3 °C, well above the 90th percentile of the 1971–2000 baseline (31.7 °C), and the decadal distributions reveal a systematic upward shift of the annual-maximum distribution, with the 2021–2026 sub-decade clearly the warmest of the record. The 2026 May–June maximum TX exceeded the baseline P90 by more than one standard deviation in all but one region (Figure 5a), with values ranging from 1.8σ (Schleswig-Holstein) to 4.9σ (Saarland) and the strongest normalized departures in the southwest and west (Saarland, Baden-Württemberg, Rheinland-Pfalz, Hessen) and in Sachsen-Anhalt, mirroring the evolution of the daily maximum temperature in Figure 2.

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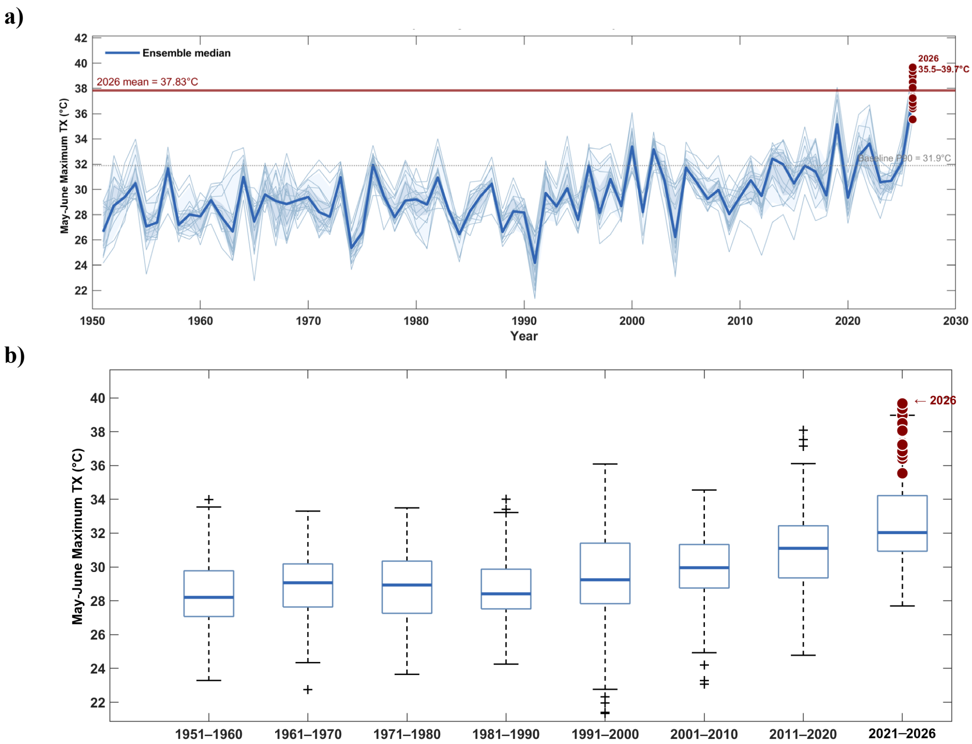

Figure 4. a) Maximum May–June daily maximum temperature (TX, °C) for the 16 German federal states and the Germany area-averaged series. Thin blue lines show the individual regional time series, the thick blue line the ensemble median, and the shaded bands the interquartile (25th–75th percentile, dark) and 10th–90th percentile (light) ranges across regions. Red dots mark the 2026 values of the individual regions (range: 31.4–35.9 °C), and the horizontal red line indicates the 2026 ensemble mean (33.3 °C). The dotted gray line denotes the 90th percentile of the 1971–2000 baseline period (31.7 °C) and b) Decadal distributions of the maximum May–June TX (°C), pooled over all 16 federal states and the Germany average, for the decades 1951–1960 to 2021–2026. Boxes span the interquartile range, the blue line marks the median, whiskers extend to the most extreme non-outlier values, and crosses denote outliers. Red dots show the 2026 values of the individual regions.

The regional spread of the 2026 annual maximum reflects a marked southwest-to-east gradient, with the strongest departures in Saarland, Baden-Württemberg, Rheinland-Pfalz, Hessen, and Sachsen-Anhalt. In all federal states, the event exceeded the 1971–2000 P90 by more than 1σ, confirming that the exceptional heat was nationwide rather than confined to a few hotspots. For the two federal states with the highest standardized exceedance (Saarland and Baden-Württemberg), daily temperatures in 2026 repeatedly exceeded the pre-2026 record maximum envelope during the peak of the event (Figure 5b and 5c).

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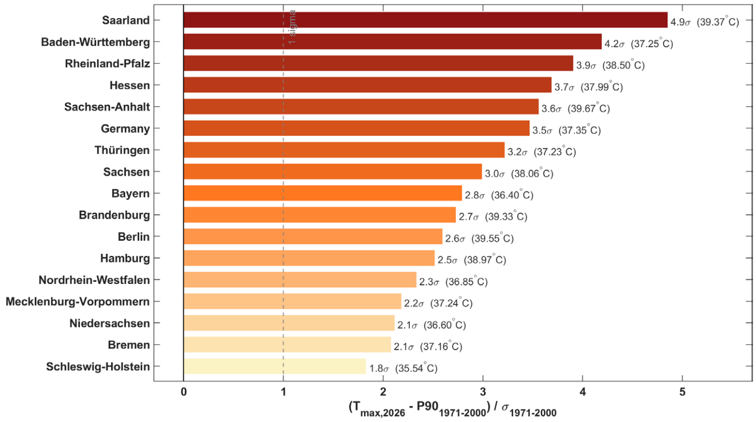
a)



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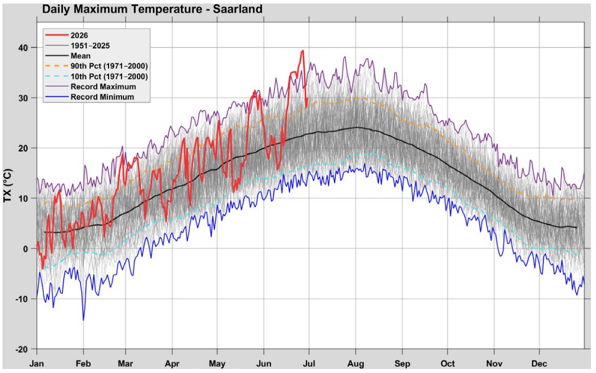

c)

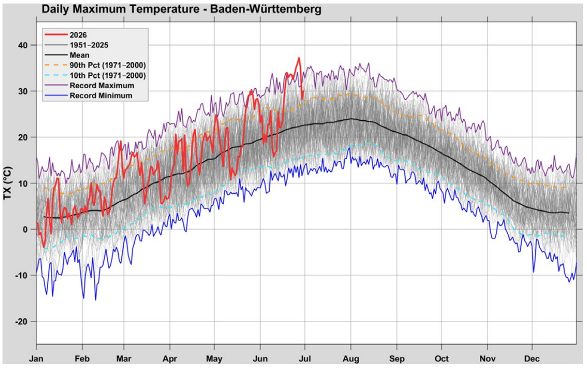

Figure 5. a) Standardized exceedance (warming ratio) of the 2026 maximum May–June TX, defined as (TX,2026 − P90(1971–2000)) / σ, where P90 is the 90th percentile and σ the standard deviation of the regional annual-maximum series over 1971–2000. Regions are ranked in descending order; the value in parentheses gives the absolute 2026 annual maximum (°C) and the dashed line marks the 1σ level; b) Daily maximum temperature area-averaged for Saarland federal state for the year 2026 and c) as in b) but for Baden-Württenberg. In b) and c) the red line represents the daily maximum temperature for 2026. The black line represents the mean of the daily maximum temperature, the blue line the lowest and the magenta line the highest daily values of the maximum temperature over the period 1951 - 2025. The period 1971–2000 was used to compute the daily maximum temperature climatology (i.e., black line).

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Moreover, the daily maximum temperature recorded at the peak of the heatwave exceeded all daily maximum temperatures observed since 1951, including those in July and August, when such extremes are typically more likely. The multi-metric assessment for the Germany-average daily maximum temperature time-series (Figure 6) shows that the exceptional character of 2026 was concentrated in intensity rather than persistence: the peak daily TX (37.3 °C), the cumulative heatwave intensity (139.5 °C), and the number of days with TX > 30 °C (8 days) all rank first among the 76 years of the record, whereas the number of heatwave days (12, rank 6/76) and the number of events (1, rank 6/76) are high, but not unprecedented. The late-June 2026 heatwave was thus a comparatively compact, but extraordinarily intense event and is consistent with the emergence of record-shattering, margin-breaking extremes in a rapidly warming climate (Fischer et al., 2021).

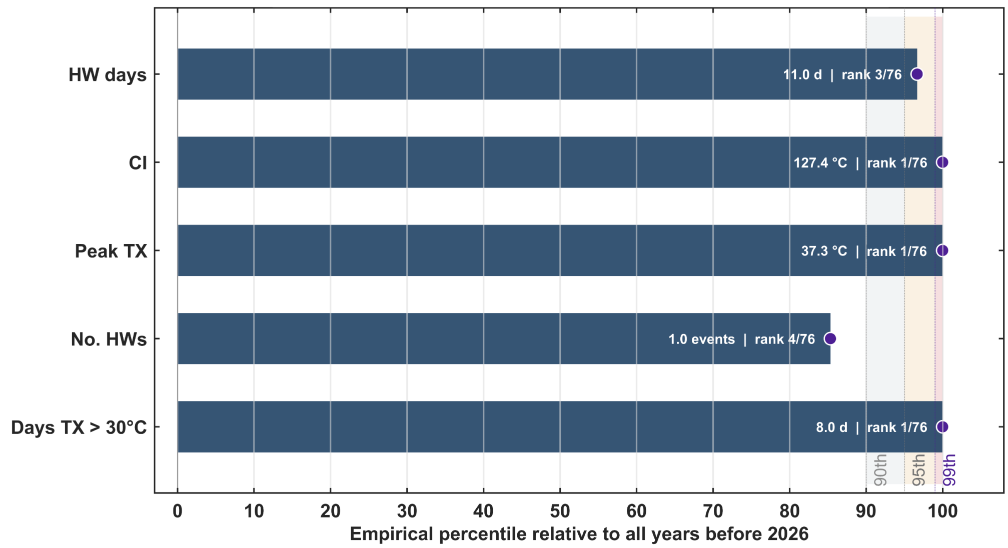

Figure 6. Multi-metric extremeness of 2026 for the Germany area-average daily TX time-series. For each heatwave metric, number of heatwave days (HW days), cumulative intensity (CI), peak daily TX, number of heatwave events (No. HWs), and number of days with TX > 30 °C, the marker shows the empirical percentile of the 2026 value relative to all years of the record before 2026 (1951–2025). Labels give the absolute 2026 value and its rank among the 76 years of the full record. Peak TX (37.3 °C), cumulative intensity (139.5 °C) and days above 30 °C (8 d) rank 1st.

3.3 A long-term station perspective

Because the gridded dataset begins only in 1951, Figure 7 extends the perspective of the June 2026 HW event using the ensemble of 18 long-term DWD stations, whose May–June maximum TX series reach back to ~ 1824 in the case of the longest meteorological station (i.e., Jena). The exact length of each station are given in Table 2. The 2026 values stand at or near the top of these ~180-year records at the majority of stations. Station-level standardized exceedances relative to the 1971–

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2000 baseline range from approximately 2.5 to 3.4 standard deviations, with the largest normalized departures occurring at stations in central and eastern Germany, including Magdeburg (40.1°C, 3.7 σ), Leipzig (40.0°C, 2.8 σ), Jena (39.2°C, 2.9 σ) and Cottbus (40.7°C, 2.8 σ).

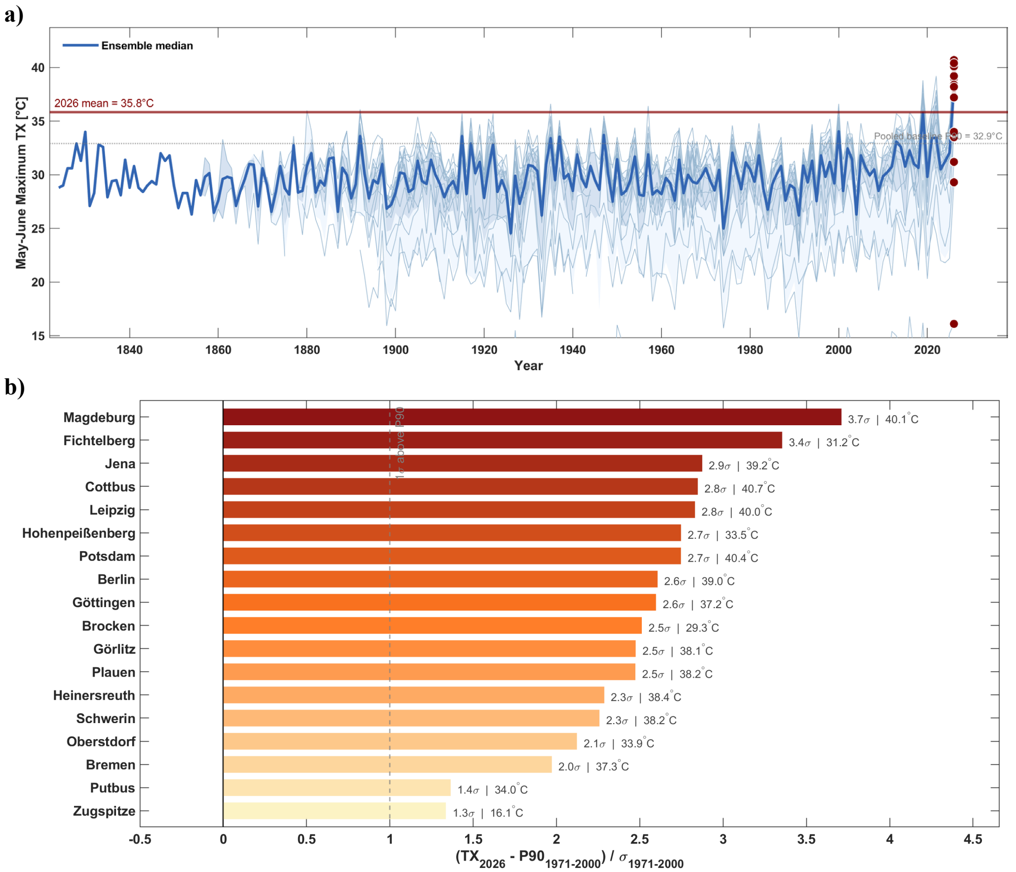

Figure 7. Long-term station perspective. a) Maximum May–June TX of the 18 long-term DWD stations (thin gray lines) and their ensemble median (blue), from the beginning of the individual records (see Table 2 for the length of each station) to 2026; the 2026 values are highlighted and b) Station-level 2026 warming ratio, defined as in Figure 5a, but relative to the 1971–2000 baseline of each station's annual-maximum series; stations are ranked in descending order, and labels give the warming ratio and the absolute 2026 TX (°C).

This pattern again reflects the eastern culmination of the event. Substantial exceedances were also observed at mountain stations, including Brocken (29.3°C, 2.5 σ), Fichtelberg (31.2°C, 3.4 σ) and Hohenpeißenberg (33.5°C, 2.7 σ), indicating that the anomaly was vertically coherent and not confined to the boundary layer. This consistency between lowland and mountain stations strengthens the conclusion that the event reflected a broad atmospheric anomaly rather than a purely local surface effect. Moreover, the consistency between the century-scale station perspective and the gridded

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analysis underlines that late June 2026 was not merely rare in a 76-year context, but exceptional on the scale of the full instrumental era.

3.4 Long-term trends of heatwave characteristics, 1951–2026

Figure 8 summarizes the long-term evolution of heatwave characteristics (i.e., duration and frequency) at country level, over the period 1951 - 2026. The trend maps of heatwave days and heatwave frequency over the period 1951–2026 show statistically significant increases over virtually all of Germany, with the strongest trends in the west and southwest.

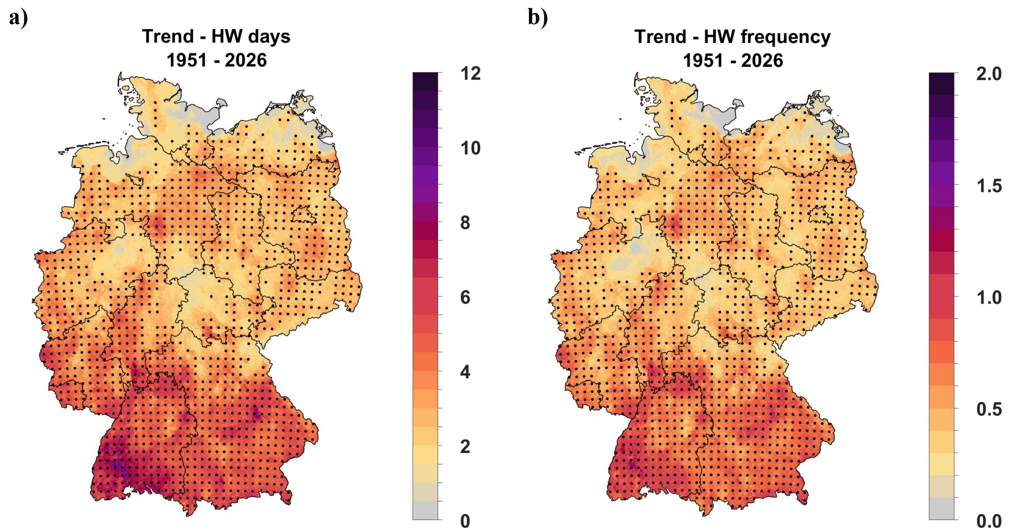

Figure 8. Long-term trends of heatwave characteristics over Germany, over the period 1951–2026. a) HW days and b) HW frequency. Trend slopes are estimated using the Theil–Sen median estimator, with statistical significance assessed using the modified Mann–Kendall test. Grid cells with significant trends at $p < 0.05$ are stippled.

For example, for Baden-Württemberg, the HW duration has increased by +0.70 days per decade and the cumulative heatwave intensity by +7.09 °C per decade. The 2026 values (duration: 23 days; CI: 255 °C degree-days) are the highest of the 1951–2026 record (Supplementary Figure S4). Similar findings are found if we consider Bayern, where we observed that the HW duration has increased by +0.67 days per decade and the cumulative heatwave intensity by +6.40 °C per decade. The 2026 values (duration: 17 days; CI: 193 °C degree-days) are also the highest of the 1951–2026 record (Supplementary Figure S5). These trends are consistent in sign and magnitude with pan-European assessments (Boboc et al., 2025; Perkins-Kirkpatrick and Lewis, 2020; Seneviratne et al., 2021) and with the finding that the western and central European heat extremes are intensifying at the upper end of, or beyond, model expectations (Vautard et al., 2023). Overall, the trend analysis suggests that the long-term evolution of German heatwaves is being driven mainly by longer and more intense events, rather than by frequency alone. The positive trends in both duration and

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cumulative intensity indicate a systematic shift toward more persistent and more severe heat extremes across Germany since 1951.

To emphasize the spatial extent of the June 2026 HW events, Figure 9 compares the spatial heatwave-day pattern of 2026 and the numbers of days with to TX > 30°C, with two other benchmark early summer HWs, namely 1953 and 1976 (i.e., selected based on a similar statistic like in Figure 6). While 1953 was comparatively limited in both extent and extreme temperatures (Figure 9a), 1976 produced a widespread, long-lasting episode reaching 10–15 heatwave days across much of western Germany (Figure 9b).

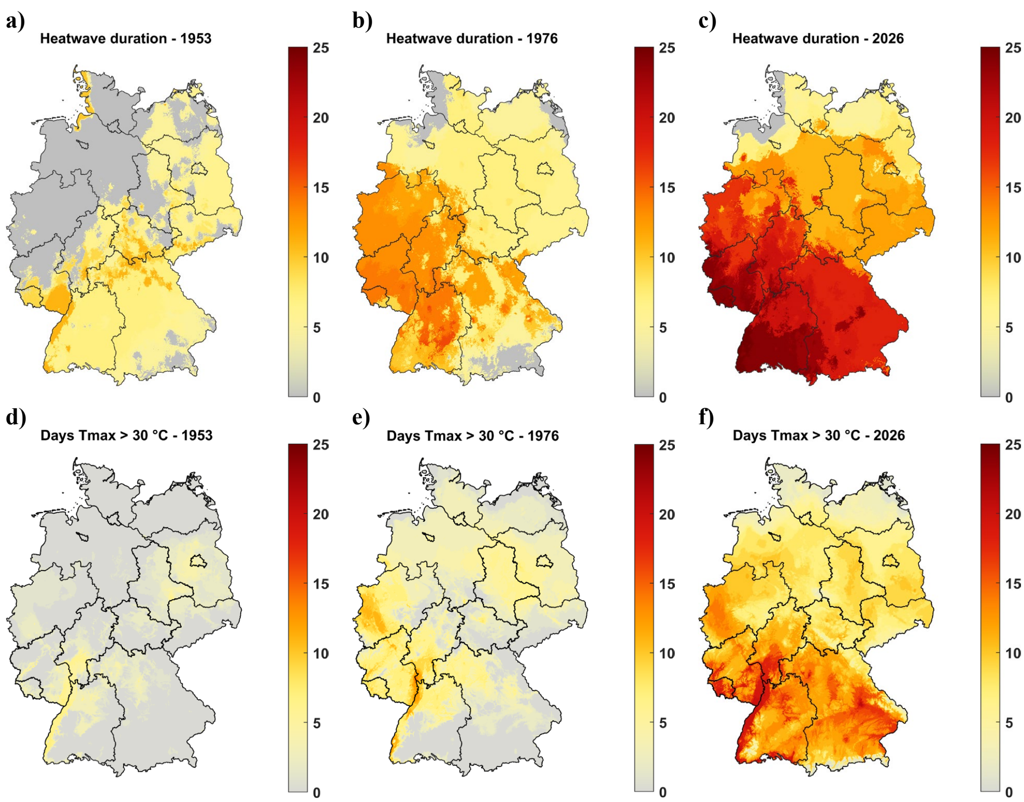

Figure 9. Heatwave days (upper panels) and the number of days with daily TX> 30°C (lower panels) in selected extreme heatwave years over the instrumental record: 1953, 1976 and 2026. Units: Days.

The 2026 pattern is spatially more extensive and locally more intense (Figure 9c), with totals exceeding 20 days in duration across large parts of the south and southwest, corroborating the intensity-dominated character diagnosed in Figure 6. The number of days with daily TX > 30 °C (Figures 9d–f) shows an even sharper contrast: in 1953 such days were essentially absent nationwide, and in 1976 they remained confined to a modest belt along the Rhine Valley and the southwest part of the country, rarely exceeding 10 days. In 2026, by contrast, these days became widespread across

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almost the entire country and reached 15 to 20 days over large parts of the south and southwest, underscoring that the 2026 event pushed not just heatwave duration, but also extreme heat days counts to unprecedented spatial coverage. We retain this comparison in the main text because it demonstrates that an individual historical summer (i.e.,1976) can rival 2026 in spatial extent, but neither 1953 nor 1976 combined this extent with the peak intensities observed for the June 2026 event.

3.5 Dynamic and thermodynamic contributions to the event peak

Having established that the June 2026 heatwave was exceptional both in its short-term context (Section 3.2) and in the long-term trend context (Section 3.3), a key remaining question is how much of its peak intensity reflects the specific atmospheric circulation pattern of the event itself, as opposed to the general warming of the background climate on which it occurred. Disentangling these two contributions matters for interpretation: a heatwave driven mainly by an unusual, low-probability circulation pattern is largely a matter of atmospheric chance, whereas one in which even a comparatively ordinary circulation pattern now produces record-breaking heat points to a systematic, ongoing shift in the climate baseline with direct implications for how such events should be expected to evolve in the future. We address this question using the flow-analogue approach (Jézéquel et al., 2018), which decomposes the observed temperature anomaly into a dynamic component attributable to the atmospheric circulation and a thermodynamic component reflecting the warming that persists even when circulation is held approximately constant.

The flow-analogue decomposition (Figure 10) shows that, on each of the five peak days (25–29 June 2026), the circulation-congruent (dynamic) component accounts for the majority of the observed T850 anomaly averaged over the Germany: the composite of the N = 25 closest Z500 analogues yields strongly positive T850 anomalies on all days, confirming that this circulation type is intrinsically generating high temperatures. However, a substantial positive thermodynamic residual of ~3 – 4°C remains on every event day and lies well outside the 95% bootstrap range of the dynamic component, indicating that the observed temperatures were systematically warmer than historical weather, with essentially the same circulation. The positive residual therefore indicates that the same circulation pattern now produces systematically higher temperatures than in the historical record, but it should not be interpreted as a purely thermodynamic effect alone.

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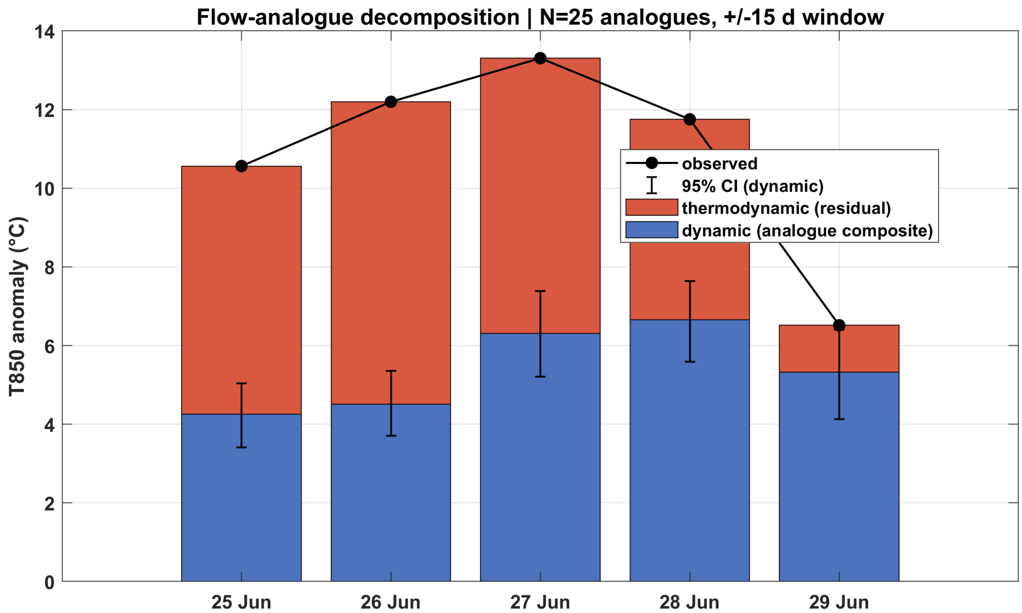

Figure 10. Flow-analogue decomposition of the late-June 2026 heatwave over Germany. Stacked bars show, for each event day (25–29 June 2026), the dynamic contribution (blue; mean T850 anomaly of the N = 25 closest Z500 circulation analogues drawn from 1970–2025) and the thermodynamic contribution (red; residual between observed and analogue-composite anomalies) to the observed area-mean 850 hPa temperature anomaly over the target region (5–16° E, 47–56° N). Error bars denote the 95% bootstrap confidence interval (1000 resamples) of the dynamic component. All anomalies are relative to the 1971 – 2000 climatology.

The spatial decomposition (Figure 11) confirms this finding. The analogue composite reproduces the observed anticyclonically-forced warm anomaly pattern over Central Europe in both structure and position, while the residual (thermodynamic) field consists of a broad, spatially smooth warming that is not tied to the circulation anomaly, which can be regarded as the fingerprint of background warming rather than of a particular weather configuration (Cattiaux et al., 2010; Jézéquel et al., 2018). Restricting the analogue selection to an early (1970–2000) and a late (2001–2025) epoch isolates the thermodynamic warming under near-identical circulation (Figure 12). The late-epoch analogue composite is systematically warmer than the early-epoch composite on all event days, quantifying the warming realized for the same circulation states over roughly three decades. Strikingly, the observed 2026 anomalies exceed even the late-epoch composite by a further 3–4 °C, indicating that the event was extreme even relative to the recent warm climate, plausibly reflecting the exceptional amplitude and persistence of the 2026 atmospheric blocking (Supplementary Figure S3), dry antecedent land-surface conditions, and the continued warming trend within the late epoch itself. The pooled epoch composites (Figure 13) show that the analogue circulation patterns of the two epochs are nearly indistinguishable, while their temperature difference constitutes a coherent warming of the entire domain, except the British Isles.

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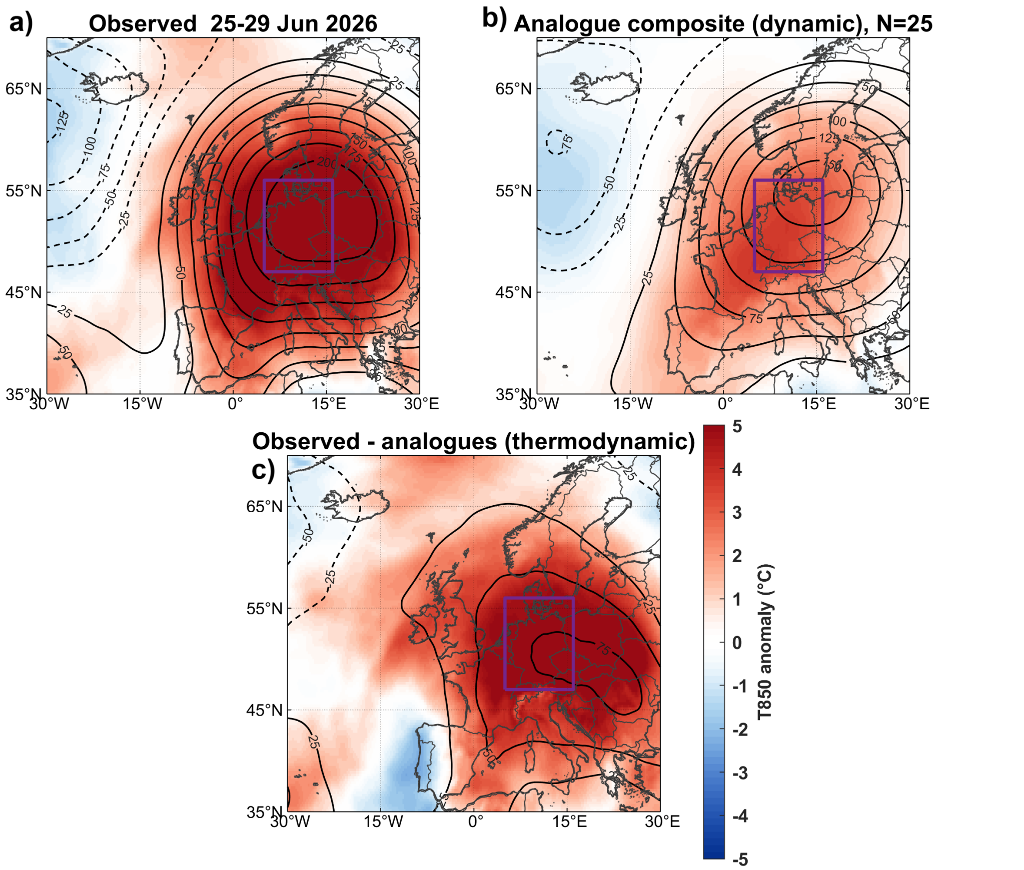

Figure 11. Spatial flow-analogue decomposition, averaged over 25–29 June 2026. a) Observed T850 anomaly (shading, °C) and Z500 anomaly (contour lines, m) relative to the 1971–2000; b) Composite of the daily N = 25 circulation analogues, representing the dynamic component and c) Difference (a) minus (b), representing the thermodynamic component.

The larger number of qualifying analogues in the late epoch (n = 87 vs. n = 38) additionally hints at an increased recent occurrence of such blocking-like circulation patterns, consistent with reported changes in European summer circulation (Bakke et al., 2023; Boboc et al., 2025; Faranda et al., 2023a; Rousi et al., 2022). Because the number of qualifying analogues is larger in the late epoch, the analysis is also consistent with a recent increase in the frequency of blocking-like atmospheric circulation states, although this cannot by itself distinguish forced change from internal variability. The persistent omega-type blocking pattern that characterized the June 2026 event is also relevant from a forecasting perspective. Persistent large-scale circulation regimes associated with European heatwaves can exhibit enhanced predictability on sub-seasonal timescales compared with rapidly evolving synoptic disturbances, providing useful windows for early warning (Lemburg and Fink, 2024; Pyrina and Domeisen, 2023). Consequently, although the precise magnitude of near-surface

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temperatures remains difficult to predict, the large-scale dynamical setting favorable for prolonged heat can often be anticipated several days to weeks in advance. Continued improvements in sub-seasonal forecasting therefore represent an important opportunity to reduce the societal impacts of future extreme heat events through earlier warning and preparedness (Rouges et al., 2024).

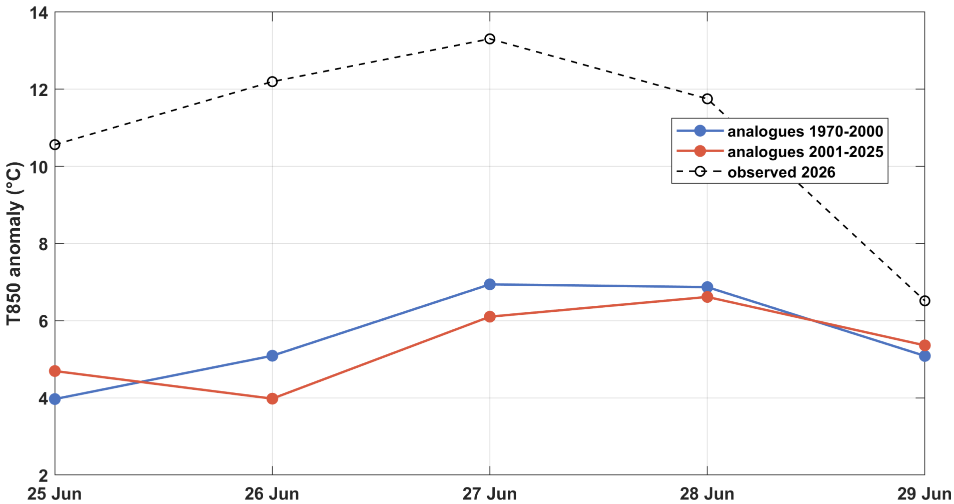

Figure 12. Thermodynamic warming under fixed circulation. Area-mean T850 anomaly of the analogue composite when the analogues of each event day are restricted to the early epoch 1970–2000 (blue) and the late epoch 2001–2025 (red), compared with the observed 2026 anomalies (black dashed). The systematic offset between the two epochs quantifies the warming that has occurred for near-identical circulation states, while the observed 2026 anomalies exceed even the late-epoch composite by ~3-4°C.

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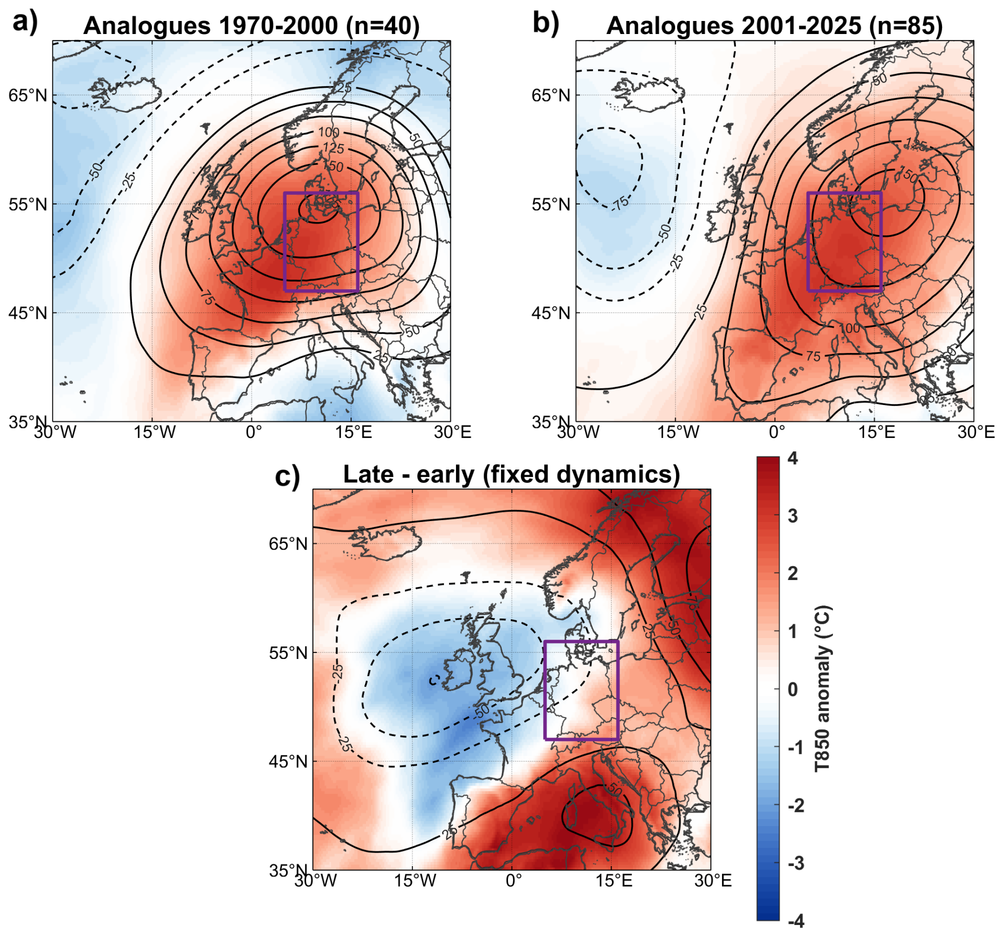

Figure 13. Analogue composites by epoch, pooled over the analogues of all five event days. a) T850 anomaly (shading, °C) and Z500 anomaly (contour lines, m) composited over all analogues from 1970–2000 (n = 38); b) As in a), but for analogues from 2001–2025 (n = 87) and c) Difference (b) minus (a): the warming realized under essentially unchanged circulation.

4. Conclusions

The June 2026 heatwave constitutes a timely case study for examining how an individual record-shattering extreme relates to the longer-term evolution of heat in a region already identified as a hotspot of European warming. Characterizing this relationship, rather than documenting the event's magnitude in isolation, is essential for anticipating how such extremes will evolve under continued warming and for informing the adaptation planning and early-warning systems required to mitigate impacts on health, infrastructure, and ecosystems during future events of comparable severity. Although the summers of 2003 and 2019 remain benchmarks for extreme heat in Central Europe (Black et al., 2004; Sousa et al., 2020), the June 2026 event differs in two important respects. First, the highest temperatures occurred exceptionally early in the season, before the climatological peak of

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summer. Second, despite its comparatively short duration, the event exceeded previous June extremes over large parts of Germany, illustrating that future record-breaking events need not be long-lasting to produce unprecedented impacts.

Overall, from this study three main conclusions emerge. First, the late-June 2026 heatwave was among the most extreme of the entire instrumental era: rank 1 of 76 years in peak TX, cumulative intensity, and days with TX > 30 °C at country level, standardized exceedances of up to 4.9σ at the federal-state level (i.e., Saarland and Baden-Württemberg) and up to 3.7σ at individual long-term stations (i.e., Magdeburg), and a new provisional all-time national temperature record broken on three consecutive days (DWD, 2026). Its compact duration distinguishes it from other long-lasting HWs, especially at the beginning of the summer season (e.g., 1953, 1976) and exemplifies the class of short, record-shattering extremes whose probability increases disproportionately under sustained warming (Fischer et al., 2021).

Second, the long-term context indicates that the event occurred against a strongly altered background climate: total heatwave duration and cumulative intensity over Germany have roughly tripled since the mid-20th century, with field-consistent positive trends across the entire country (Ionita et al., 2026; Luo et al., 2023; Petrovic et al., 2024; Tomczyk and Sulikowska, 2018). These findings agree with the acceleration of European heat extremes documented by (Antonescu et al., 2023; Boboc et al., 2025; Ionita et al., 2024; Luo et al., 2023; Vautard et al., 2023) and with global assessments of intensifying heatwave regimes (Adeyeri et al., 2025; Han et al., 2022; Perkins-Kirkpatrick and Lewis, 2020; Seneviratne et al., 2021).

Third, the flow-analogue decomposition attributes the amount of the day-to-day temperature anomaly structure to an exceptionally strong omega-type blocking ridge (i.e., which is the classic dynamic driver of European mega-heatwaves (Kautz et al., 2022; Pfahl and Wernli, 2012; Zschenderlein et al., 2019), while simultaneously demonstrating a large and growing thermodynamic increment. Similar large-scale atmospheric circulation states, now produce systematically higher temperatures than three decades ago, and the 2026 observations exceeded even the recent-epoch analogue expectation by 3–4 °C. This decomposition is methodologically conservative, as analogue composites average over N = 25 patterns and therefore damp the tails of the analogue temperature distribution. The quoted thermodynamic residuals should thus be regarded as combining background warming with the contribution of the event's extraordinary circulation amplitude and antecedent land-surface state. Dry soils, which reduce evaporative cooling and enhance sensible heating, are a well-established amplifier of European heatwaves (Lorenz et al., 2010; Miralles et al., 2014; Seneviratne et al., 2010) and were likely relevant in 2026 given the anomalously warm and dry preceding spring (Copernicus Climate Change Service, 2026). It should be noted that the analogue method depends on

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the choice of domain, distance metric, analogue number, and epoch boundaries. Sensitivity tests (e.g., analogue quality diagnostic, bootstrap confidence intervals) indicate that the qualitative conclusions are robust, but the exact partitioning between dynamic and thermodynamic contributions carries methodological uncertainty (Jézéquel et al., 2018). Whether the apparent increase in the frequency of blocking-like analogue states reflects a forced circulation trend or internal variability cannot be resolved from a single event analysis; the evidence for forced changes in European summer circulation, including double-jet regimes, remains an active research area (Rousi et al., 2022). The analogue-based separation of dynamic and thermodynamic contributions should be interpreted as an observationally constrained approximation rather than a unique partition. The exact magnitudes depend on the selected domain, analogue number, calendar window, and reference epoch, although the qualitative conclusion of a strong dynamical precondition combined with substantial thermodynamic amplification is robust to the tested sensitivities.

Although the present analysis focuses primarily on atmospheric circulation and background warming, land–atmosphere interactions likely provided an additional amplification mechanism. Reduced soil moisture limits evaporative cooling, thereby increasing sensible heat fluxes and promoting higher near-surface temperatures. Previous studies have shown that this feedback is particularly important during major European heatwaves (Barriopedro et al., 2023; Lorenz et al., 2010; Miralles et al., 2014). Given the exceptionally warm and dry spring preceding the June 2026 event (Copernicus Climate Change Service, 2026), soil-moisture depletion probably enhanced the observed surface temperature anomalies, although quantifying this contribution requires dedicated land-surface analyses beyond the scope of the present study.

Summarizing, the late-June 2026 heatwave was the most intense heat event on record in Germany, especially since it occurred at the beginning of the summer, whose peak temperatures and cumulative intensity are unprecedented in the last 76 years (i.e., based on the HYRAS-DE length) and stand at the top of station records extending back nearly two centuries. It was produced by the superposition of (i) an exceptionally strong and persistent omega-type blocking anticyclone, which our flow-analogue analysis identifies as the dominant driver of the daily anomaly structure, and (ii) a thermodynamic background warming that renders present-day circulation analogues systematically warmer than their historical counterparts and that the 2026 event exceeded by a further 3–4 °C. Combined with the robust upward trends in heatwave duration at country level, these results imply that the HW event In June 2026 must be expected to recur with increasing frequency and intensity, and that adaptation planning in Germany should explicitly account for short, record-shattering heat extremes in early summer, when physiological and infrastructural acclimatization is lowest. Beyond its climatological significance, the June 2026 heatwave also illustrates the growing challenge posed by early-season extreme heat. Adaptation measures in Germany have traditionally focused on the

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climatological peak of summer; however, the occurrence of record-breaking temperatures already in June suggests that preparedness plans, public-health interventions, and early-warning systems should increasingly account for severe heat episodes occurring substantially earlier in the season. For example, provisional data from the German Federal Statistical Office (Destatis) indicate that all-cause mortality in Germany was approximately 30% above the four-year median during calendar week 26 (22–28 June 2026), the week most fully overlapping with the heatwave, corresponding to roughly 23,700 deaths nationwide, about 6,800 more than two weeks earlier. A detectable rise in mortality was already apparent in calendar week 25 (15–21 June), coinciding with the onset of the event (Statistisches Bundesamt, 2026). Taken together, these results show that late-June 2026 was an exceptional heat event in Germany, combining record peak intensity, widespread regional exceedances, and a strong blocking-driven dynamical setting on a markedly warmer background climate. The event was compact in duration but extreme in intensity, illustrating how persistent circulation anomalies and long-term warming now interact to produce short, record-shattering heatwaves in early summer.

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Data availability. The data that support the findings of this study are available from the corresponding data sources referenced in the paper (see Data and Methods section).

Author contributions. MI conceived the ideas and designed the methodology together with VN. MI analyzed the data and drafted and led the writing of the manuscript with significant input from VN. All authors contributed critically to the writing of the manuscript. All the figures in the manuscript and the supplementary file were created by the authors.

Competing interests. The contact author has declared that none of the authors has any competing interests.

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