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Wildfire synchronicity across European regions is favored by specific weather regimes



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Synchronous wildfires (wildfires occurring in multiple locations within a week) pose challenges to coordinated firefighting efforts between European countries. Despite their potentially severe impacts, their occurrence and relationship with predictable atmospheric circulation patterns are poorly understood. We analyze synchronous wildfires across ten European regions over the past two decades and attribute their seasonal occurrences to seven year-round weather regimes. We find that weather regimes modulate the occurrence and spatial extent (the number of regions involved) of synchronous wildfires primarily by driving warm and dry meteorological anomalies, suggesting that these events may become more frequent in a warming world. Specifically, Atlantic Ridge promotes wildfire synchronicity between multiple pairs of European regions in summer, and European Blocking is the most likely regime co-occurring with synchronous wildfires spanning large spatial domains (or involving more than five regions) in spring and fall. Our findings could support early warning systems for synchronous wildfire emergencies in Europe because these weather regimes are predictable on subseasonal timescales.

Wildfires pose severe threats to both society and the environment. Mitigating their impacts requires timely emergency responses and international cooperation¹. In Europe, such cooperation is facilitated by the European Union Civil Protection Mechanism², which is activated during wildfire emergencies to provide cross-border firefighting support. An example is the 2018 extreme wildfire season in Scandinavia, where central and southern European countries, including Germany, France, and Italy, deployed firefighting equipment and personnel to support wildfire suppression in Sweden³. However, sharing resources becomes increasingly difficult when multiple wildfires occur synchronously across regions⁴. These synchronous events can overwhelm firefighting capacities, potentially leading to more severe impacts than isolated incidents. The increase in extreme wildfire seasons in recent decades has intensified pressure on firefighting capacities⁵, not only affecting traditionally fire-prone Mediterranean countries⁶ but also raising concerns in less fire-prone regions, such as central and northern Europe^{7–9}. Climate change is projected to substantially increase the frequency and intensity of extreme fire weather conditions across Europe¹⁰. This shift can lead to more frequent synchronous fire weather across larger spatial areas than under current climate conditions^{11–13}. Yet, to the best of our knowledge, observation-based evidence of synchronous wildfire

occurrences across Europe does not exist, significantly limiting our ability to understand, predict, and prepare for these events. In this work, we address these critical knowledge gaps by linking seasonal synchronous wildfire observations in Europe to so-called weather regimes, which are large-scale, quasi-stationary, recurrent, and persistent atmospheric circulation patterns. These weather regimes are more predictable on subseasonal timescales (several weeks in advance) than local daily weather conditions^{14,15}, offering a promising avenue for developing early warning systems and enhancing societal preparedness for synchronous wildfire emergencies in the future.

The development of synchronous wildfires is shaped by climatic and meteorological processes on different timescales. On annual to multi-decadal timescales, wildfire synchronicity is modulated by climate variability^{16–18}. This relationship is well understood in North America, where tree ring-based fire chronologies show that the warm phase of the Atlantic Multidecadal Oscillation promotes subcontinental synchronicity¹⁷, while the El Niño Southern Oscillation and the Pacific Decadal Oscillation jointly modulate regional synchronicity^{17,19,20}. On seasonal timescales, the overlap in fire weather seasonality can increase the probability of spatially compounding fire weather, as shown between Australia and North America, threatening the feasibility of firefighting cooperation between these two

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regions²¹. In Europe, regional wildfire activity exhibits strong and distinct seasonality. For example, Mediterranean regions typically experience wildfires in summer (JJA)²², while the UK sees peak wildfire activity in spring (MAM)²³. Thus, we hypothesize that European regions with overlapping wildfire seasonality should be more prone to synchronous wildfires. On weekly to daily timescales, regional wildfires are mainly driven by hot and dry meteorological anomalies, and sometimes by strong winds²⁴. Therefore, we hypothesize that the concurrent formation of such conditions across regions, which are typically shaped by large-scale weather patterns²⁵, can trigger synchronous wildfires. In Europe, atmospheric blocking events frequently induce heatwaves and droughts under their high-pressure conditions²⁶, providing favorable weather conditions for wildfires in the Mediterranean summer^{27–30}. The variability of these large-scale patterns in the Atlantic-European sector can be captured by seven year-round weather regimes^{14,31,32}. They are European Blocking (EuBL), Scandinavian Blocking (ScBL), Greenland Blocking (GL), Atlantic Ridge (AR), Atlantic Trough (AT), Scandinavian Trough (ScTr), and Zonal Regime (ZO)³¹. These regimes characteristically modulate near-surface conditions relevant for fire weather development (temperature, relative humidity, precipitation, and wind speed^{31,33,34}), and may thus play a critical role in shaping wildfire synchronicity across Europe. While previous studies have illuminated the modulating effects of synoptic weather conditions on wildfires at local to regional scales^{27–30}, the spatial patterns of synchronous wildfires across the European continent and their relationship with predictable weather regimes remain to be studied.

Here, we present a systematic analysis of synchronous wildfires in Europe from 2001 to 2020 to understand the meteorological conditions and large-scale weather regimes favoring the development of these events. We identify synchronous wildfires involving at least two European regions within a week based on satellite fire observations, and analyze these events following three steps: (a) We use complex network theory to quantify seasonal wildfire synchronicity between ten European regions; (b) We use atmospheric reanalysis data to characterize meteorological conditions that favor the occurrence of synchronous wildfires; and (c) We use the aforementioned year-round weather regime classification scheme to identify regimes that modulate the occurrence and spatial extent (i.e. the number of regions involved) of synchronous wildfire events in different seasons. We find that specific weather regimes can significantly increase the probability of inter-regional synchronous wildfires and modulate the spatial extent of these events across the continent by driving warm, dry, and/or windy meteorological anomalies. The relationship between synchronous wildfires and predictable weather regimes can support more effective firefighting cooperation and enable faster responses to synchronous wildfire emergencies in Europe.

Results

Wildfire synchronicity between European regions is enhanced by overlapping fire seasons

To quantify wildfire synchronicity, we map the spatial and seasonal occurrences of inter-regional wildfire connections by counting the total number of synchronous events with a maximum time lag of six days between each pair of the ten European regions (Fig. 1; Methods). We identify significant ($p < 0.05$ and $p < 0.01$) connections based on block permutations and quantify regional wildfire connectivity using degree centrality (the number of significant connections a region has divided by the maximum number of possible connections, Methods). We show that in Europe synchronous wildfires occur year-round with seasonally varying frequencies (Fig. 1). The strongest wildfire synchronicity across the ten regions is found when considering all meteorological seasons (12 significant connections, Fig. 1a). Seasonally, spring (MAM) shows the highest number of significant connections (11), particularly involving central Europe (CE), northeastern Europe (NEE) and southeastern Europe (SEE), with each region showing equally high connectivity (degree centrality of 0.44 in Fig. 1b). Summer (JJA) shows six significant connections, mainly involving the Alps (AL), western Mediterranean (WMD), and SEE (degree centrality

of 0.33 in Fig. 1c). A similar set of significant connections between southern regions is observed in fall (SON, Fig. 1d), while winter (DJF) shows the fewest significant connections across all seasons (only three, Fig. 1e). These inter-regional connections are generally robust to different choices of the maximum time lag used in the synchronicity definition (Methods, Figures S1–S5). Furthermore, the overall patterns of spatial connections remain comparable when the synchronicity analysis is performed based on countries instead of the ten regions (Figure S6).

As firefighting cooperation operates at the country level^{1,3}, we calculate the cross-border event fraction for each region. We define this metric as the fraction of cross-border events (wildfires occurred in more than one country within a region) across all inter-regional synchronous events involving this region (Fig. 1, shown by the edge color of nodes). We observe relatively high fractions of cross-border events (≥ 0.3) in NEE, SEE, Iberian Peninsula (IP) and eastern Mediterranean (EMD) during spring, in IP and EMD from summer to fall, and in CE and SEE during winter. This indicates that countries within these regions potentially have reduced capacities to provide inter-regional firefighting support in the respective season, because regional cross-border events may already exhaust firefighting resources.

As shown above, wildfire synchronicity exhibits seasonally varying spatial patterns, which may reflect overlaps in regional fire seasonality. To further examine the relationship between fire seasonality and synchronicity, we interpret inter-regional wildfire connections using averaged regional wildfire seasonality during 2001–2020 (Methods). We find that regional fire seasonality (Fig. 2a–j) governs the potential for synchronous wildfire occurrences across Europe. Regional wildfire activity peaks can increase a region's wildfire connectivity during a season. For instance, SEE shows stronger inter-regional connections in spring and summer than in other seasons due to wildfire activity peaks in March and August (Figs. 1b–e and 2h). AL exhibits limited connectivity in spring, aligning with its low wildfire activity in this season, but becomes more connected in summer and fall due to enhanced wildfire activities in August and October (Figs. 1b–d and 2i). In addition, overlapping fire seasons can increase the occurrence of synchronous events among regions. Synchronicity among the British Isles (BI), CE, and NEE is the highest in spring (Fig. 1b), when their fire seasons overlap during March–April (Fig. 2e–g). Similarly, synchronicity is the highest among IP, WMD, EMD, and Scandinavia (SC) in summer (Fig. 1c), because their fire seasons overlap during July–August (Fig. 2a–d). These observations highlight the role of wildfire seasonality in shaping synchronous wildfire occurrences between regions. Although wildfire synchronicity and seasonality are often aligned, synchronous events are still possible during periods when both regions or one of the two regions experiences low fire activity. For example, France (FR) and IP are connected in winter (Fig. 1e) even though fire activity in IP is only slightly enhanced in this season (Fig. 2d).

Synchronous wildfires occur under warm and dry conditions

Next, we study which meteorological conditions are associated with synchronous and regional wildfires across different seasons using the global atmospheric reanalysis dataset ERA5³⁵. Specifically, we analyze meteorological anomalies (temperature, relative humidity, precipitation, wind speed and the Canadian fire weather index (FWI)³³) on two types of days: (a) synchronous wildfire days, that is, days when one region co-experienced wildfires with any other region(s); (b) regional wildfire days, that is, days when wildfire(s) occur within a single region (Methods).

This analysis shows that synchronous wildfire days consistently co-occur with warm and dry conditions, characterized by positive temperature anomalies and negative anomalies in precipitation and relative humidity, across all European regions (Fig. 3a–c; Methods). Warm and dry anomalies are also evident on regional wildfire days. They are generally comparable to the anomalies on synchronous wildfire days. However, positive temperature anomalies are markedly stronger in NEE, CE, BI, AL, and FR on synchronous wildfire days compared to regional wildfire days (Fig. 3a). For wind speed anomalies, we see a regionally varied picture with negative wind speed anomalies on synchronous and

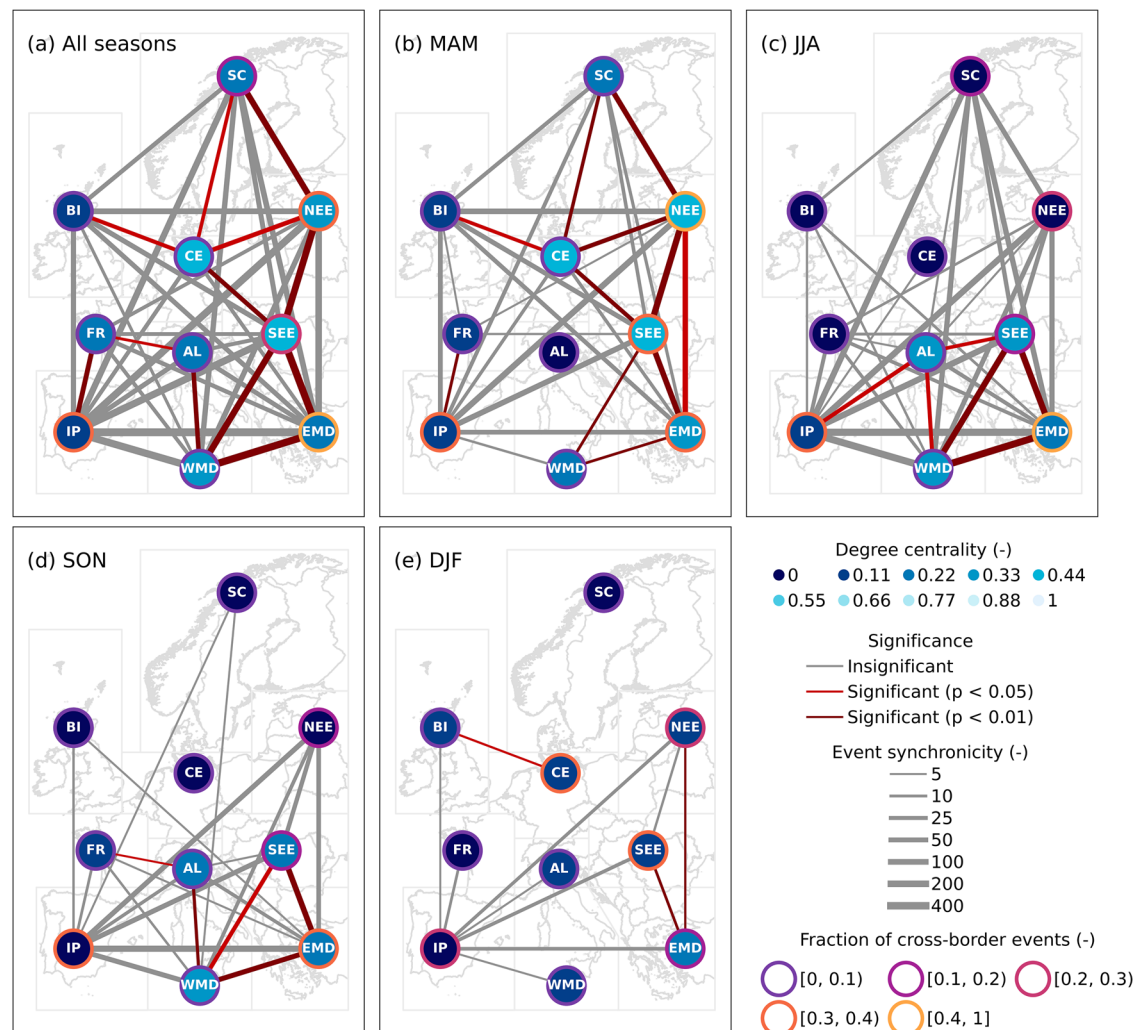


Fig. 1 | Seasonal patterns of European wildfire synchronicity. **a** All seasons, **b** spring (MAM), **c** summer (JJA), **d** fall (SON), and **e** winter (DJF). Each region is represented by a node (or a colored circle with the region abbreviation). The filled color of a node represents its degree centrality, that is the number of significant connections a region has divided by the maximum number of possible connections (i.e. 9), ranging between 0 (no significant connections) and 1 (significant connections to all other nodes). The edge color of a node represents the fraction of cross-border events (wildfires occurred in more than one country within a region) across all inter-regional synchronous events involving the region. The edge (or the

connection) between two regions represents the value of event synchronicity (the ES value, that is, the total number of synchronous wildfires between two regions over a time period) on a natural logarithmic scale. The thicker the line, the stronger the event synchronicity. For visual clarity, $ES < 10$ are not shown for all seasons (a), and $ES < 5$ are not shown for individual seasons (b–e). The color of the connection represents the statistical significance of wildfire synchronicity (red: significant, gray: insignificant). Significant connections are identified at two levels based on one-sided tests: the ES value is higher than the 95th percentile ($p < 0.05$, light red) and the 99th percentile ($p < 0.01$, dark red) of the block permutation ensemble.

regional wildfire days in northern and western regions (SC, CE, BI, FR, and IP), small anomalies in eastern regions (NEE, SEE, and EMD), and positive anomalies in AL and WMD (Fig. 3d).

Regional and synchronous wildfire days, driven by concurrent warm and dry conditions, consistently exhibit positive anomalies in the FWI across all regions (Fig. 3e). The FWI reflects meteorologically driven wildfire potential³³, highlighting that synchronous wildfires across multiple European regions can be explained by concurrent atmospheric anomalies that favor wildfires.

Weather regimes modulate the occurrence and spatial extent of synchronous wildfires

The concurrent anomalous meteorological conditions (particularly the concurrent warm and dry conditions) occurring during synchronous wildfire days, as discussed above, are often a result of persistent atmospheric circulation patterns, so-called weather regimes. From the perspective of early warning, it is thus important to understand under which kind of weather regimes synchronous wildfires and their associated meteorological

conditions occur. We analyze the relationship between weather regimes and wildfire synchronicity (Fig. 4) using an ERA5-based daily weather regime classification scheme (Methods). For each region pair with at least 20 seasonal synchronous events, we calculate a relative conditional probability describing the likelihood of synchronous wildfires given a specific weather regime relative to the likelihood of wildfire synchronicity overall (Equation (3)). We assess the significance of this probability measure based on block permutations ($p < 0.05$, Methods). We find that weather regimes modulate the occurrence and spatial extent (i.e., the number of regions involved) of synchronous wildfires in spring, summer, and fall (Fig. 4). These modulating effects are mainly attributable to the warm and dry meteorological anomalies they drive, and in some cases (for example, AR in summer) to positive wind speed anomalies (Fig. 5).

We show that EuBL, ScBL, and ZO contribute the most to pairwise wildfire synchronicity (Fig. 4a–d). In spring, EuBL significantly enhances wildfire synchronicity between northern and western regions (such as BI–SC, BI–NEE, and BI–IP). Synchronicity between the three northern regions (SC, BI and NEE) is enhanced by both EuBL and ScBL, two anticyclonic

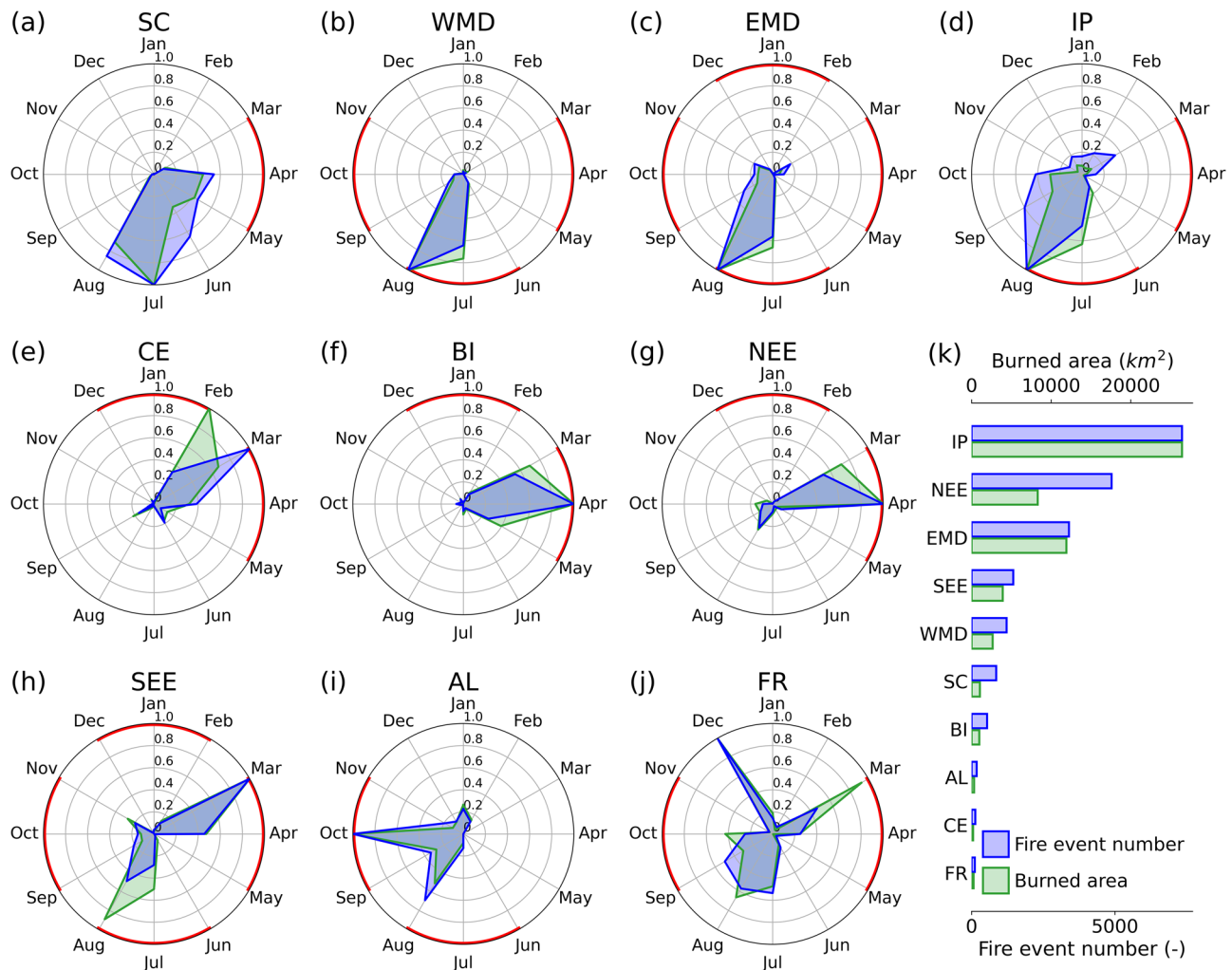


Fig. 2 | Wildfire seasonality and activity for the ten European regions considered. a–j Radar charts show the 20-year (from 2001 to 2020) averaged fire seasonality, calculated based on fire event number (blue) and burned area (green). Monthly values are rescaled to the monthly maximum over the 20 years. A season is highlighted in red if a region shows significant wildfire synchronicity with any other

region in this season (according to the light and dark red connections in Fig. 1). k Bar chart shows the total number of fire events (blue) and cumulative burned area (km^2 , green) for each region over the 20 years. An unscaled version of regional wildfire seasonality can be found in Figure S18.

regimes associated with stable weather conditions, consistent with our observation that wildfire days in these regions are characterized by negative wind speed anomalies (Fig. 3d). The ZO regime enhances synchronicity between eastern regions (SEE, NEE, and EMD) and between IP and NEE (Fig. 4a). In summer, multiple weather regimes promote synchronicity (Fig. 4b), among which AR and ScBL enhance north-south synchronicity, and the AT enhances synchronicity between southeastern regions (WMD, EMD and SEE). In fall, wildfire synchronicity is enhanced by the ScTr between southern regions (WMD-IP, WMD-EMD) and by the ZO regime between eastern regions (EMD-SEE, EMD-NEE) (Fig. 4c).

Using the same probability measure (Equation (3)), we resolve the modulating effects of weather regimes on the spatial extent of synchronous wildfires by classifying wildfire observations within a seven-day rolling window into five levels based on the number of regions involved (Methods). In spring and fall, there is a positive relationship between the spatial extent of synchronous wildfires and the relative conditional probability of these events to co-occur with EuBL (Fig. 4e, g). A similar positive relationship is found for ZO in the fall season, while a negative relationship is found for GL in spring and fall. The activity of GL is usually anti-correlated with ZO due to the largely reversed patterns of their geopotential height anomalies^{14,31}, which explains their opposing relationships with the spatial extent of synchronous wildfires in the fall season (Fig. 4g).

To explain the modulating effects of weather regimes on synchronous wildfires, we further investigate the meteorological anomalies under each weather regime using the ERA5 reanalysis³⁵ (Figures S7–S14, Methods). We find that weather regimes modulate the occurrence and spatial extent of synchronous wildfires by driving anomalous meteorological conditions that favor wildfires (Fig. 5; Methods). EuBL, ScBL, ZO, AT, and ScTr generally drive concurrent warm, dry, and positive FWI anomalies in regions where they significantly promote wildfire synchronicity (Fig. 5a–e and Figure S7–S11). Consistent with these observations, regions where wildfire synchronicity is enhanced by EuBL, ZO, AT, and ScBL (spring only) generally experience high pressure conditions under these regimes^{14,31}. Positive wind speed anomalies appear to be a secondary meteorological driving force of wildfire synchronicity, as such conditions are only observed in regions where synchronicity is promoted by ScTr and AR (Fig. 5e, f and Figure S11–S12). GL drives widespread cold and humid anomalies across the European continent (Fig. 5g and Figure S14), impeding the development of synchronous wildfires (Fig. 4e, g).

Discussion

In this study, we resolve the spatial and seasonal patterns of synchronous wildfires between European regions over the past two decades using satellite fire observations. We find that synchronous wildfire events are favored by

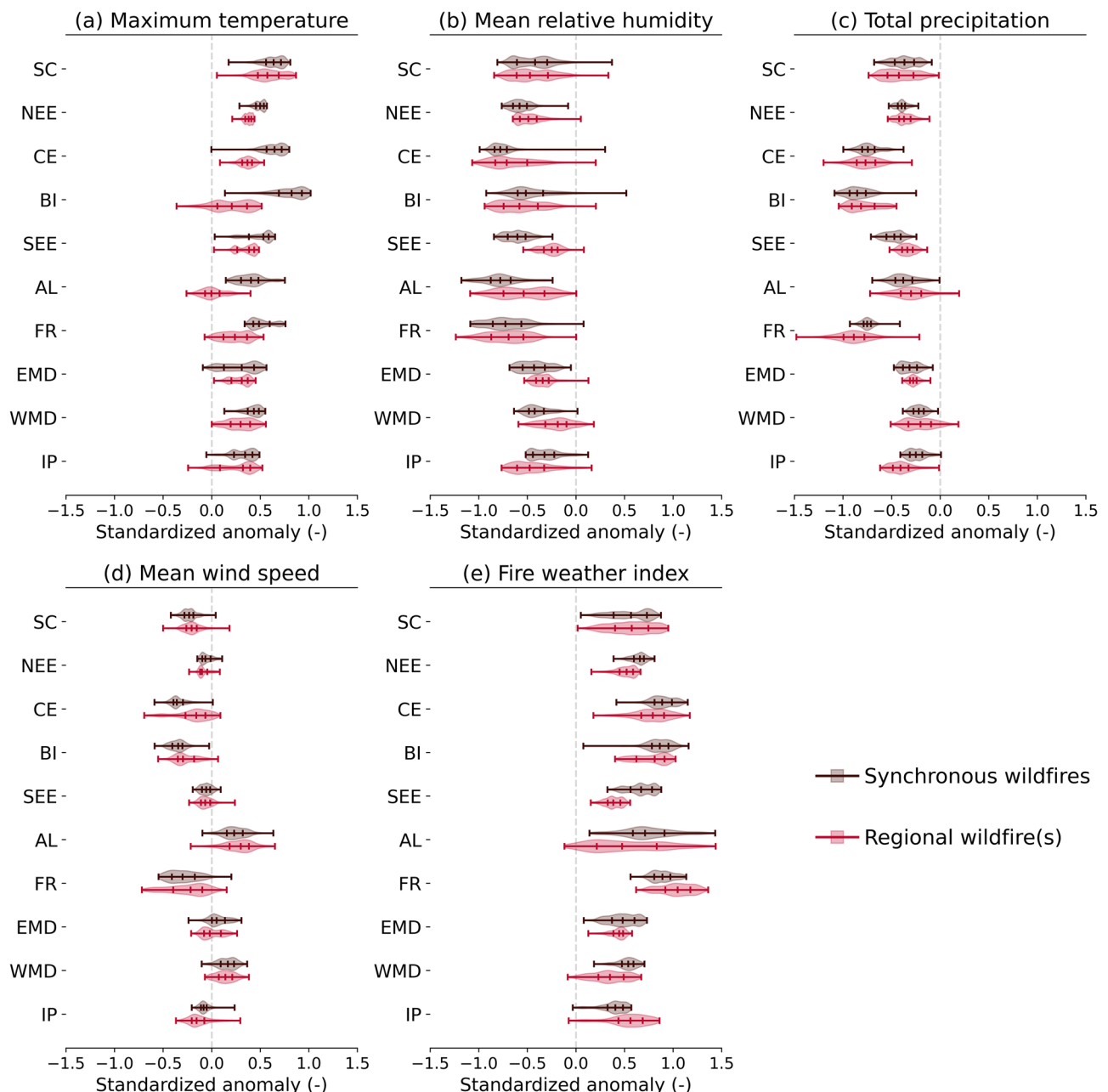


Fig. 3 | Meteorological conditions on regional and synchronous wildfire days. Standardized anomaly of (a) maximum temperature, (b) mean relative humidity, (c) total precipitation, (d) mean wind speed, and (e) Canadian fire weather index on days with regional wildfires (red) and days with synchronous wildfires (black) for

each region. The violin plots show the spatial variability of meteorological anomalies (min, 25th percentile, median, 75th percentile, max, as shown by the vertical dashes) and their distributions (shades) for each region. The sample size of regional and synchronous wildfire days for each region can be found in Table S1.

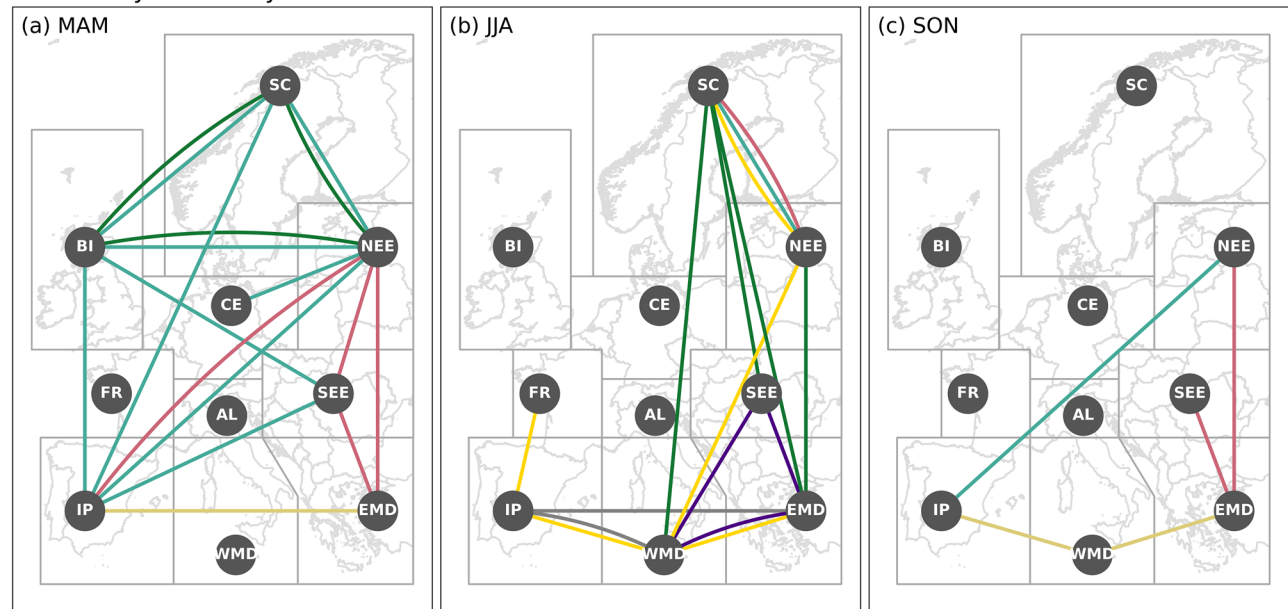
overlapping fire seasons (Figs. 1 and 2) and by weather regimes that drive fire-conductive weather conditions in the respective regions, i.e., concurrent warm, dry, and/or wind anomalies (Figs. 3, 4, 5). These synchronous events reflect the combined contributions of these two processes, with weather regimes acting as subseasonal atmospheric modulators, increasing or decreasing the likelihood of synchronous wildfires within overlapping fire seasons. Our findings provide observational evidence supporting earlier studies based on the FWI or climate model burned area simulations, which show that synchronous fire weather over large spatial scales can be favored by overlapping fire weather seasons²¹, and that fire synchronicity in the Northern Hemisphere is enhanced by high-pressure conditions³⁶.

We establish spatially and seasonally explicit links between wildfire synchronicity and weather regimes, and identify European Blocking (EuBL), Scandinavian Blocking (ScBL), and the Zonal regime (ZO) as the

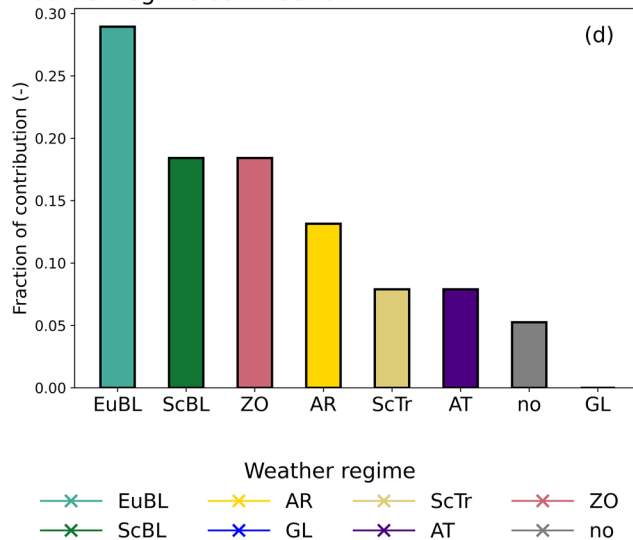
three most important weather regimes favoring pairwise wildfire synchronicity (Fig. 4a–d) due to their high-pressure conditions over large parts of Europe¹⁴. Persistent atmospheric high-pressure conditions have previously been associated with increased fire activity in various regions of Europe^{27,28,30,37}. Our findings extend this understanding by demonstrating that high-pressure conditions can promote wildfire synchronicity at a continental scale.

We identify concurrent warm and dry conditions caused by persistent atmospheric high-pressure conditions as a dominant driver of wildfire synchronicity in Europe (Figs. 3 and 5). This finding is consistent with studies showing that warm and dry conditions are important drivers of individual wildfire events^{24,38–41}. Observational evidence and climate model projections show an increasing frequency of such compound warm and dry events in Europe^{42,43}, which will likely lead to an increase in synchronous fire

Pair-wise synchronicity



Weather regime contribution



Continental synchronicity

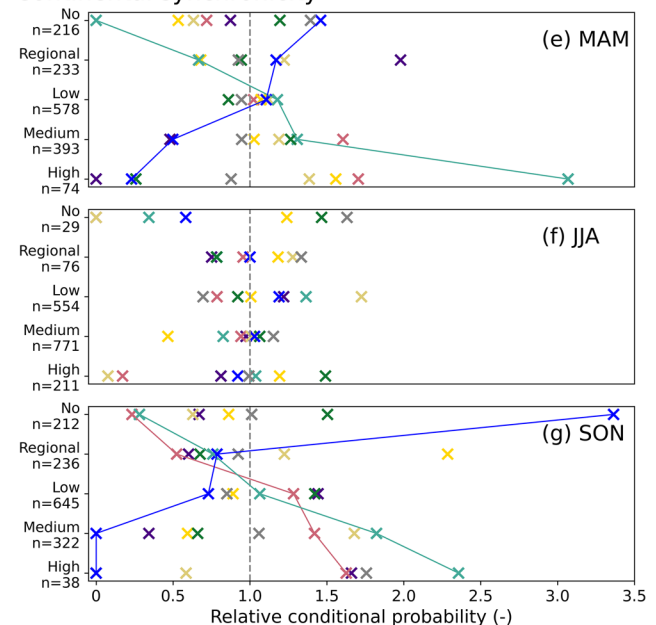


Fig. 4 | Relationship between weather regimes and synchronous wildfires. a–c The weather regimes that significantly enhance pairwise wildfire synchronicity for MAM, JJA, and SON. Significant relationships are identified when the relative conditional probability of synchronous wildfires between any two regions co-occurring with a weather regime (including no regime) is higher than the 95th percentile of the value calculated based on the block permutation ensemble (one-sided tests). Such probability is calculated for region pairs with at least 20 seasonal synchronous events (winter excluded due to insufficient sample sizes). **d** shows the relative contribution of the seven regimes and the no-regime to pairwise wildfire synchronicity, which is calculated as the number of wildfire connections significantly promoted by a weather regime divided by the total number of wildfire

connections significantly promoted by all regimes (including the no-regime). **e–g** show the relative conditional probability of synchronous wildfire events of different spatial extents within a seven-day sliding window co-occurring with the seven weather regimes and no regime for MAM, JJA, and SON. The spatial extents of these events are divided into five levels: No (no wildfires), Regional (wildfires within a single region), Low (two or three regions co-experience wildfires), Medium (four or five regions co-experience wildfires), and High (more than five regions co-experience wildfires). In (**e–g**), a weather regime is connected by lines if its relative conditional probability measure increases or decreases in a monotonic way with the increasing spatial extent of synchronous wildfire events.

danger under climate change¹¹. This expected increase will likely result from both thermodynamic effects, such as the greenhouse-gas-induced warming of the climate system, and dynamic effects, such as the changing frequency of weather regimes that can intensify the drying in specific regions⁴⁴. Our results suggest that an improved understanding of future changes in the frequency and intensity of these regimes can help to robustly project the

trend and variability of synchronous fire danger in Europe under climate change.

Though we do observe anomalous meteorological conditions favoring wildfires in most of the regions affected by weather regimes (Figs. 4 and 5), there are two exceptions. First, in summer, ScBL significantly promotes synchronicity among five regions, while

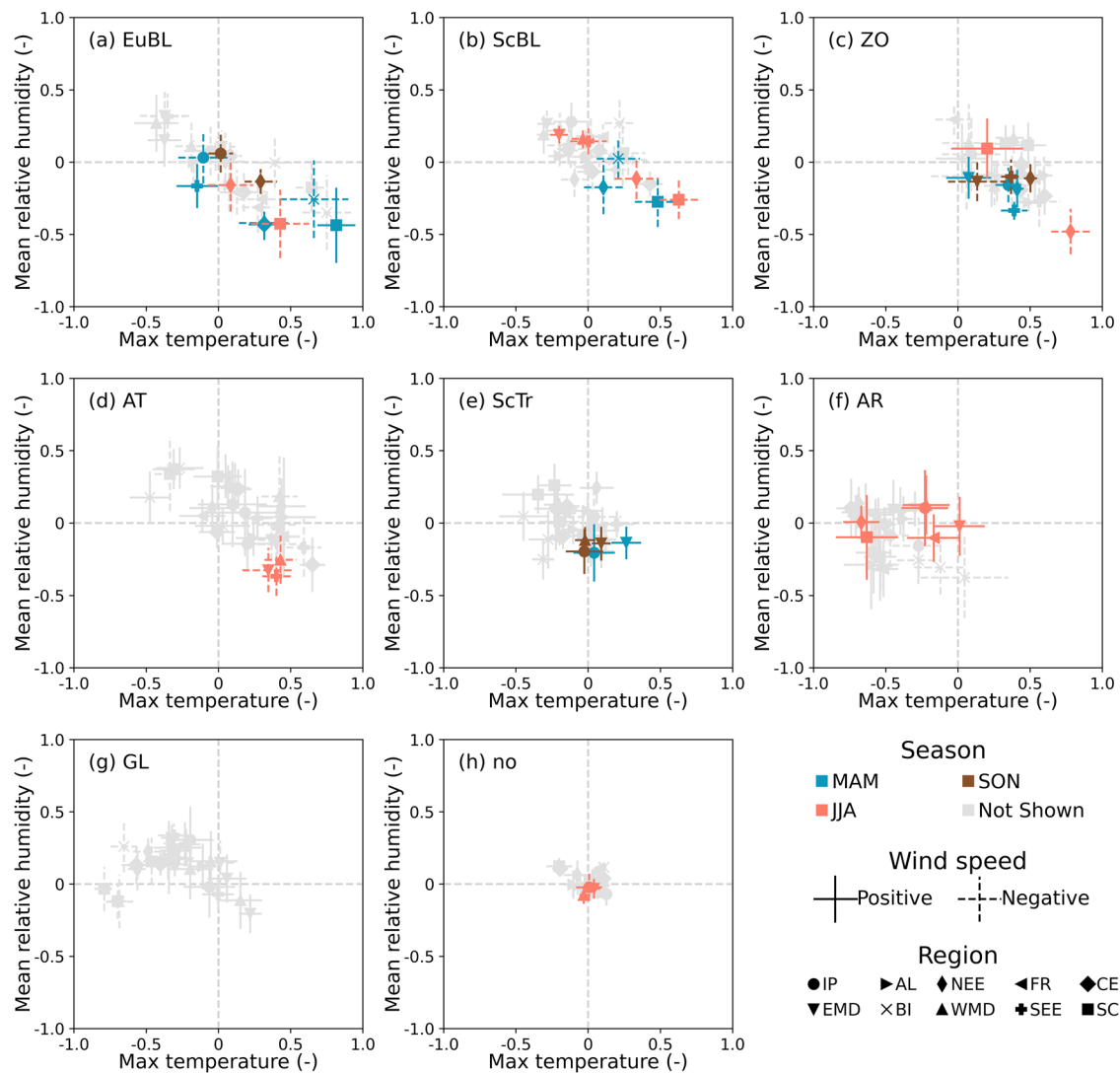


Fig. 5 | Regional meteorological anomalies driven by weather regimes. Each region is shown by a different shape. **a–h** represent European Blocking (EuBL), Scandinavian Blocking (ScBL), Zonal Regime (ZO), Atlantic Trough (AT), Scandinavian Trough (ScTr), Atlantic Ridge (AR), Greenland Blocking (GL), and no regime. The position of the dot shows the mean value (averaged across time and space for a region, latitude-weighted), and the uncertainty cross shows one standard deviation of the spatial variability (latitude-weighted) within the region of standardized daily maximum temperature (x) and daily mean relative humidity (y). The

sign of daily mean wind speed anomalies is provided as binary information (magnitude not shown): the solid and dashed uncertainty crosses represent positive and negative wind speed anomalies, respectively. In (**a–h**), region pairs between which wildfire synchronicity is significantly promoted by weather regimes are colored by the season of such effects according to Fig. 4a–c, while region pairs between which wildfire synchronicity is not promoted by any weather regime in a season are shown in gray. The number of days classified as each weather regime in each season can be found in Table S2.

anomalous fire-conductive conditions are only present in the northern regions (SC and NEE), but not in the southern regions involved (SEE, WMD, EMD) (Figs. 4b, 5b, and Figure S8). This suggests that due to the commonly fire-conductive conditions in the three southern regions in summer, the synchronicity between the southern and northern regions is rather determined by fire activity in the north, which is enhanced by ScBL. Second, synchronous wildfires between IP-EMD and IP-WMD are significantly promoted under the no regime in summer (Figs. 4b and 5h), likely because the high climatological mean fire danger in southern Europe in this season can lead to wildfires under less pronounced meteorological anomalies²⁴.

Studying wildfire synchronicity based on satellite wildfire detection has several limitations related to the available fire information. First, satellite fire observations do not provide information on the cause of fires, and it is impossible to eliminate anthropogenic impacts on these observations, such as factors that influence ignition, firefighting efficiency, and other wildfire management policies including prescribed burning⁴⁵. While we tried to

reduce such anthropogenic influence by excluding cropland fires from our analysis, our dataset may still include intentional biomass burnings if they occurred on natural vegetation. Second, the number of synchronous events may have been underestimated for 2001 and the first half of 2002, because Terra was the only operational satellite providing the required observations during that time⁴⁶. However, our key results show limited sensitivity to this satellite detection inhomogeneity. Most of the significant inter-regional wildfire connections are preserved when these two years are excluded (compare Fig. 1 to Figure S15). Similarly, the effects of EuBL, ZO and GL on the spatial extent of synchronous wildfires in spring and fall remain unchanged when excluding these two years, while a moderate number of significant promoting effects of weather regimes on pairwise synchronicity are lost (compare Fig. 4 to Figure S16). Third, the limited temporal coverage of satellite burned area detections (25 years) does not yet allow for analyzing the impact of climate regime shifts on wildfire synchronicity in a robust way. However, we believe that recent temporal extensions of global fire event datasets, such as the Global Fire Atlas^{47,48}, might in the near future facilitate

studies on the relationship between climate change and wildfire synchronicity.

In addition, several methodological limitations need to be considered in the interpretation of our results. First, synchronous wildfire identification inevitably depends on how the region boundaries are set. Different ways of regionalization can affect the identification of synchronous events. Nevertheless, we believe that the regionalization we use is suitable for the analysis of wildfire synchronicity because it captures the main latitudinal and longitudinal climate gradients of Europe and can well distinguish between different types of fire seasonality. Dominant spatial features of the country-level synchronicity analysis are generally represented in the region-level synchronicity analysis (compare Figure S6 to Fig. 1), demonstrating that the spatial pattern of synchronicity only shows moderate sensitivity to different ways of regionalization. Second, the significance of wildfire synchronicity is hard to establish via block permutations between two time series with frequent wildfire events, leading to strong but insignificant connections, such as those observed for IP-EMD during summer and fall (Fig. 1c, d). The following three factors can contribute to this: (a) Counts of synchronous wildfire events between time series with frequent events have less inter-annual variability than between time series with infrequent events; (b) The condition under which two wildfire dates are identified as synchronous can be stricter for time series with frequent than infrequent events (Methods); (c) Random synchronicity (or synchronicity by coincidence) may occur. This issue could be mitigated by, for example, only focusing on days with fire numbers or burned area above a certain regional percentile threshold. However, we refrain from doing so because a regional percentile-based threshold does not help to address the highly imbalanced regional wildfire activity, but significantly reduces the number of wildfire observations, making it difficult to stratify the analyses seasonally due to a limited sample size. Third, we have focused on the influence of meteorological conditions relevant to wildfire synchronicity controlled by weather regimes. We acknowledge that wildfires also depend on land surface processes acting on longer timescales, such as fuel load and long-term drought conditions during the fire season^{49,50}, which can also be influenced by anomalous weather regime occurrence over extended periods⁵¹.

We describe the spatial and seasonal patterns of synchronous wildfires in Europe over the past two decades and link their occurrence as well as spatial extent to weather regimes. We identify high-pressure conditions as a key circulation characteristic promoting synchronous wildfires, and also resolve the underlying meteorological driving forces, that is, warm and dry anomalies, and in specific cases also wind anomalies. The implications of these results are two-fold: (a) The warming and (in some regions) drying of the climate system, as well as potential changes in the frequencies and intensities of weather regimes⁴⁴ can lead to extended fire seasons in the future. This indicates that under climate change, synchronous wildfires are likely to occur in previously unaffected seasons and may involve more regions than historical observations, which may challenge the current mode of firefighting cooperation in Europe. (b) Since these analyzed weather regimes tend to be better predictable on subseasonal timescales than local daily weather^{14,15}, their relationships with synchronous wildfires illustrated here can contribute to improved operational early warnings and preparedness for these wildfire emergencies. Based on our findings, different European regions and countries can coordinate firefighting resources more effectively, taking into account the likelihood of synchronous wildfires between them in the respective season and under the dominant weather regime.

Methods

Study area

We adjust the PRUDENCE regionalization⁵² and divide the European continent (−10.5°W–32.0°E, 34.8°N–71.2°N) into ten regions (Figure S17): Iberian Peninsula (IP), western Mediterranean (WMD), eastern Mediterranean (EMD), France (FR), the Alps (AL), southeastern Europe (SEE), British Isles (BI), central Europe (CE), northeastern Europe (NEE), and Scandinavia (SC). The regionalization represents a transition from the

Mediterranean climate in the south to the subarctic climate in the north, and a transition from an oceanic influence in the west to a continental influence in the east.

Wildfire observations and event synchronicity detection

We select 20103 observed wildfire events (Figure S17a) in Europe in the period 2001–2020 from the global fire event dataset FRY_v2.0_FireCCI51_6D⁵³ (hereafter FRY dataset). The FRY dataset delineates fire events by applying a spatio-temporal aggregation algorithm to two satellite fire products: FireCCI51 250 m burned area⁴⁶ and MODIS MCD14ML 1 km active fire⁵⁴. For each fire event, it provides information on location, size, shape, start date, etc. When available, we use the first detection date of an active fire as the start date of a fire event to reduce the temporal uncertainty related to burned area detection⁵⁵. For only 5% of fire events, active fire temporal information is missing, in which case we use the first detection date of the burned area instead. The selection of fire events is based on two criteria: (a) To reduce the influence of anthropogenic activities, we only consider fires that occurred in near-natural vegetation. This requires that at least 80% of the burned pixels are classified as natural vegetation in a fire polygon, including tree cover, shrubland, grassland, and/or sparse vegetation based on land cover maps⁵⁶. (b) To account for the high detection uncertainty of small fires (< 13 hectares) in MODIS burned area products⁵⁷, we only consider fire events larger than three 250 m × 250 m pixels (or 18.75 hectares).

Based on the preprocessed FRY dataset, we calculate the total number of fire events and cumulative burned area (km^2) over the 20 years for each region (Fig. 2k). To analyze fire seasonality, we calculate the regional monthly climatology of burned area and fire event number over the 20 years (Figure S18). For each region, these values are rescaled to [0, 1] by dividing each of them by the maximum of the 12 monthly averages (Fig. 2a–j).

To detect wildfire synchronicity, we use the event synchronicity (ES) statistical framework, which is based on complex network theory^{58,59}. Specifically, we extract daily binary fire time series (1: fires starting within a region, 0: no fires starting within a region) for each of the ten regions. As we binarize the fire time series, a single count of synchronous events between two regions may correspond to different numbers of wildfires on each side (Figure S19). The wildfire event m in region i and event n in region j are synchronized if the absolute time lag between their start dates $|\Delta t_{m,n}^{i,j}| = |t_m^i - t_n^j|$ satisfies a dynamical threshold described by Equation (1):

$$|\Delta t_{m,n}^{i,j}| \leq \min \left\{ \left| \min \left\{ \frac{t_m^i - t_{m-1}^i, t_{m+1}^i - t_m^i, t_n^j - t_{n-1}^j, t_{n+1}^j - t_n^j}{2} \right\}, \tau_{\max} \right| \right\} \quad (1)$$

where t_{m-1}^i, t_{m+1}^i are the fire start dates before and after event m in region i , and t_{n-1}^j, t_{n+1}^j are the fire start dates before and after event n in region j (Figure S20). $\tau_{\max}$ representing the maximal time lag between two events, is set to 6 days, which means that we focus on synchronicity within a week. This is because (a) a one-week threshold is generally in line with the timescale of weather regimes, and (b) synchronous wildfires within a week are likely to challenge firefighting resource distribution. This dynamical threshold (Equation (1)) helps reduce subjectivity in the definition of synchronicity, separate synchronous events, and avoid double counting. The event synchronicity (ES) value is the total number of synchronized wildfire events between two regions during a season or the entire study period, which is mapped on a logarithmic scale as the connection between them in the complex network (Fig. 1). To test the statistical significance of the ES value between each region pair, we perform 2000 block permutations of the binary fire time series by random permutation of the order of years without replacement, while retaining the temporal sequence of wildfire events within a year. This enables retaining the serial dependence of the ten regional wildfire time series in the permutation ensemble, which leads to a more robust significance test than random permutation (i.e., breaking the serial dependence). We report two levels of significance based on one-sided

tests in this analysis: $p < 0.05$ and $p < 0.01$ when the observed ES value is higher than the 95th and the 99th percentile of the ES distribution of the permutation ensemble, respectively.

To quantify the connectedness of fire activity in one region, we calculate the degree centrality as follows:

$$D_i = \frac{n_{i,\text{sig}}}{N - 1} \quad (2)$$

where $n_{i,\text{sig}}$ is the number of significant connections region i has, N is the total number of nodes in the network, and $N - 1$ is the maximal number of significant connections region i could have (in this case 9).

We replicate the synchronicity network analysis with different τ_{max} values (9, 12, 15, 18, 21 days) to test the sensitivity of the network structure to this parameter (Figures S1–S5). We also replicate this analysis without the years 2001 and 2002 to test the sensitivity of the network structure to satellite detection inhomogeneities caused by the single operation of Terra during these years⁴⁶ (Figure S15). Our results show limited sensitivity to both changes. To inform cross-border firefighting collaboration in Europe, we perform a country-level synchronicity analysis based on the same synchronous event identification method described above (Figure S6). We do not perform the block permutation statistical test for the country-level analysis, as from an operational perspective, the actual number of synchronous events is more relevant than the statistical significance.

Daily weather regime classification

To link synchronous wildfires to weather regimes, we use a weather regime classification scheme for the Atlantic European sector³¹, which was updated as well as adapted to the ERA5 reanalysis³². These seven regimes are a refinement of the more classical but seasonally defined four regimes^{60,61}. The underlying classification scheme applies k-means clustering to the leading empirical orthogonal function (EOF) modes of 10-day low-pass filtered and seasonally normalized daily geopotential height anomalies at 500 hPa (Z500) from ERA5 to identify seven weather regimes. These weather regimes thus represent quasi-stationary, persistent, and recurrent large-scale circulation patterns in the atmosphere, which characteristically modulate regional surface weather conditions relevant for wildfire occurrence. They can be grouped into two types: four blocking regimes, European Blocking (EuBL), Scandinavian Blocking (ScBL), Atlantic Ridge (AR) and Greenland Blocking (GL), in which positive geopotential height anomalies associated with high pressure conditions near the surface dominate; three cyclonic regimes, Zonal Regime (ZO), Scandinavian Trough (ScTr) and Atlantic Trough (AT), in which the negative geopotential height anomalies associated with low pressure conditions near the surface dominate. During the 20-year study period, each day is either assigned to one of the seven weather regimes or classified as no regime, representing the climatological mean state of geopotential height anomalies at 500 hPa. In principle, this assignment is done as follows: (a) A specific regime is active on a timestep if its so-called regime index is the highest among all seven regime indices (the regime index is a scalar quantifying the similarity between the Z500 anomaly of any given timestep and the mean Z500 pattern of a specific regime) and equal to or above a minimum threshold of 1.0 for at least 5 days. If these conditions are not fulfilled, no regime is active on that timestep. (b) We use the ERA5 3-hourly weather regime class of the first timestep (at 00:00) for each day, under the assumption that the weather regime at the beginning of the day provides the meteorological preconditions for potential wildfires during the day. In most cases (89% of the days during the study period), weather regimes do not change during any given day and the eight 3-hourly classes are the same.

Statistical relationships between synchronous wildfires and weather regimes

We use a relative conditional probability measure⁶² to quantify the modulating effect of weather regimes on (a) pairwise wildfire synchronicity and

(b) synchronicity across the continent:

$$\frac{P(\text{SynFire}|\text{WR})}{P(\text{SynFire})} = \frac{\frac{P(\text{SynFire} \cap \text{WR})}{P(\text{WR})}}{P(\text{SynFire})} \quad (3)$$

where $P(\text{SynFire}|\text{WR})$ represents the conditional probability of synchronous wildfires occurring under a certain weather regime, and $P(\text{SynFire})$ is the probability of synchronous wildfires independent of weather regimes. $P(\text{WR})$, representing the weather regime frequency, is dynamically adjusted based on the season (Figure S21). If the presence of a weather regime favors the occurrence of synchronous wildfires, this measure will be larger than one, and vice versa.

In the pairwise perspective (Fig. 4a–c), we analyze region pairs with at least 20 observations of synchronous wildfires identified by the ES framework for spring (MAM), summer (JJA), and fall (SON), respectively. The winter season is excluded from this analysis because there are insufficient synchronous wildfire observations between any region pair. We assign a unique weather regime to each observation of synchronous wildfires between two regions. If weather regime transitions occur within two fire start dates, the weather regime of the earlier date is used. Our results are unlikely to be affected by this choice because these two wildfire dates usually lie within a time span short enough that weather regime transitions rarely occur (only 3% of the pairwise synchronous wildfire events have different weather regimes on the first and second wildfire dates). Combined with the weather regime daily classification, we calculate the relative conditional probability of synchronous wildfires between each region pair co-occurring with each weather regime and no regime. We perform 2000 block permutations of the weather regime daily sequence to estimate the distribution of this measure between each region pair. A weather regime is said to significantly promote wildfire synchronicity between two regions (and mapped as a colored link connecting the two regions in Fig. 4a–c) if the relative conditional probability measure is higher than the 95th percentile of the distribution (one-sided tests).

In the continental perspective (Fig. 4e–g), we first classify the spatial extent (i.e. the number of regions involved) of all wildfire observations within a seven-day sliding window into five levels (Figure S17): no wildfire (No, no wildfire occurred across all regions), regional wildfire(s) (Regional, wildfire(s) occurred within any single region), low synchronicity (Low, two to three regions co-experienced wildfires), medium synchronicity (Medium, four to five regions co-experienced wildfires), and high synchronicity (High, more than five regions co-experienced wildfires). We assign the most frequent weather regime to each seven-day time window. Since weather regime transitions are likely to occur within seven days, if more than one weather regime occurred at the maximal frequency during a seven-day window, the event is attributed to all of them. Using the same probability measure (Equation (3)), we calculate the relative conditional probability of these five levels of synchronous wildfire events co-occurring with each weather regime and the no-regime.

We replicate the analyses described in this section without the years 2001 and 2002 to test the sensitivity of the relationship between weather regimes and wildfire synchronicity to satellite detection inhomogeneities caused by the single operation of Terra during these years⁴⁶ (Figure S16). We show that this has a limited influence.

Standardized meteorological anomalies based on ERA5 atmospheric reanalysis

We use the following four meteorological variables: 2 m maximum air temperature (daily maximum in K, converted to °C for FWI calculation), 10 m wind speed (daily mean in m/s, converted to km/h for FWI calculation), 2 m relative humidity (daily mean in %), and total precipitation (daily sum in mm, converted to mm for FWI calculation) from the global atmospheric reanalysis ERA5³⁵. Based on these variables, we calculate the daily Canadian fire weather index³³, which is a widely used numerical descriptor of fire danger based on weather conditions. Since these five variables have different units, we standardize them empirically to a normal distribution over the 20

years to represent the magnitude of anomaly in unit variance and allow for meaningful comparison (or calculate the z-score). This is done in two steps for each pixel and each month separately: (a) We estimate the percentile rank $P(x)$ of each daily value x using the empirical cumulative distribution function (Equation (4)); (b) We use the inverse cumulative distribution function ($\Phi^{-1}(p)$) to transform these percentile ranks to a standard normal distribution (Equation (5)). A value above zero means a positive anomaly relative to monthly mean climatology over the 20 years in any given pixel, and vice versa. Since total precipitation is left-tied to zero, we add a normally distributed random noise ($\mu = 0, \sigma = 1 \times 10^{-27}$) to all 0 values of this variable before the standardization procedure.

$$P(x) = \frac{1}{n+1} \sum_{i=1}^n I(x_i \leq x), \text{ where } I(x_i \leq x) = \begin{cases} 1, & \text{if } x_i \leq x \\ 0, & \text{otherwise} \end{cases} \quad (4)$$

$$z(x) = \Phi^{-1}(P(x)) \quad (5)$$

To resolve meteorological conditions favoring regional and synchronous wildfires, for each region, we distinguish between two types of days: (a) days with regional wildfires (when wildfires occurred only in this region), and (b) days with synchronous wildfires (when this region co-experienced wildfires with any other region). Based on this classification, we calculate the averaged fields of the five standardized meteorological variables on these two types of days across all seasons (Fig. 3). Lastly, we calculate latitude-weighted regional mean (across space and time) and standard deviation (representing spatial variability) of meteorological anomalies under each weather regime and under no regime in spring (MAM), summer (JJA) and fall (SON), focusing on maximum temperature, mean relative humidity and mean wind speed (Fig. 5).

Data availability

The FRY_v2.0_FireCCI51_6D global fire event dataset is available at <https://osf.io/rjvz5/>. Land cover maps developed by the climate change initiative of European Space Agency are available at <https://climate.esa.int/en/projects/land-cover/>. The ERA5 reanalysis data is available at <https://doi.org/10.24381/cds.adbb2d47>. Weather regime data based on ERA5 is available at <https://zenodo.org/records/17080146>. The source data used to generate main figures in this study is available at <https://doi.org/10.5281/zenodo.20734895>.

Code availability

Python scripts to reproduce this study are available at <https://doi.org/10.5281/zenodo.21700164>. We use Python version 3.11.8 to perform analyses.

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References

- Bloem, S., Cullen, A. C., Mearns, L. O. & Abatzoglou, J. T. The Role of international resource sharing arrangements in managing fire in the face of climate change. *Fire* **5**, 88 (2022).
- Parker, C. F., Persson, T. & Widmalm, S. The effectiveness of national and EU-level civil protection systems: evidence from 17 member states. *J. Eur. Public Policy* **26**, 1312–1334 (2019).
- Berchtold, C. et al. Barriers and facilitators in interorganizational disaster response: identifying examples across Europe. *Int. J. Disaster Risk Sci.* **11**, 46–58 (2020).
- Abatzoglou, J. T., Juang, C. S., Williams, A. P., Kolden, C. A. & Westerling, A. L. Increasing synchronous fire danger in forests of the Western United States. *Geophys. Res. Lett.* **48**, e2020GL091377 (2021).
- Fernandez-Anez, N. et al. Current wildland fire patterns and challenges in Europe: a synthesis of national perspectives. *Air Soil Water Res.* **14**, 11786221211028185 (2021).
- Turco, M. et al. Climate drivers of the 2017 devastating fires in Portugal. *Sci. Rep.* **9**, 13886 (2019).
- Cunningham, C. X., Williamson, G. J. & Bowman, D. M. J. S. Increasing frequency and intensity of the most extreme wildfires on Earth. *Nat. Ecol. Evol.* **8**, 1420–1425 (2024).
- Krikken, F., Lehner, F., Haustein, K., Drobyshev, I. & Van Oldenborgh, G. J. Attribution of the role of climate change in the forest fires in Sweden 2018. *Nat. Hazards Earth Syst. Sci.* **21**, 2169–2179 (2021).
- Miller, J., Böhnisch, A., Ludwig, R. & Brunner, M. I. Climate change impacts on regional fire weather in heterogeneous landscapes of Central Europe. *Nat. Hazards Earth Syst. Sci.* **24**, 411–428 (2024).
- El Garroussi, S., Di Giuseppe, F., Barnard, C. & Wetterhall, F. Europe faces up to tenfold increase in extreme fires in a warming climate. *npj Clim. Atmos. Sci.* **7**, 30 (2024).
- Torres-Vázquez, M. N. et al. Large increase in extreme fire weather synchronicity over Europe. *Environ. Res. Lett.* **20**, 024045 (2025).
- Yin, C. et al. Increasing synchronicity of global extreme fire weather. *Sci. Adv.* **12**, ead8813 (2026).
- Gauthier, E. & Bevacqua, E. Human-induced climate change intensifies spatially compounding fire weather extremes across European countries. *npj Nat. Hazards* **3**, 39 (2026).
- Büeler, D., Ferranti, L., Magnusson, L., Quinting, J. F. & Grams, C. M. Year-round sub-seasonal forecast skill for Atlantic-European weather regimes. *Q. J. R. Meteorol. Soc.* **147**, 4283–4309 (2021).
- Osman, M., Beerli, R., Büeler, D. & Grams, C. M. Multi-model assessment of sub-seasonal predictive skill for year-round Atlantic-European weather regimes. *Q. J. R. Meteorol. Soc.* **149**, 2386–2408 (2023).
- Gincheva, A. et al. The interannual variability of global burned area is mostly explained by climatic drivers. *Earth's Future* **12**, e2023EF004334 (2024).
- Kitzberger, T., Brown, P. M., Heyerdahl, E. K., Swetnam, T. W. & Veblen, T. T. Contingent Pacific-Atlantic Ocean influence on multicentury wildfire synchrony over western North America. *Proc. Natl. Acad. Sci.* **104**, 543–548 (2007).
- Cardil, A. et al. Climate teleconnections modulate global burned area. *Nat. Commun.* **14**, 427 (2023).
- Heyerdahl, E. K. et al. Climate drivers of regionally synchronous fires in the inland Northwest (1651 – 1900). *Int. J. Wildland Fire* **17**, 40–49 (2008).
- Yocom Kent, L. L. et al. Climate drives fire synchrony but local factors control fire regime change in northern Mexico. *Ecosphere* **8**, e01709 (2017).
- Richardson, D. et al. Increasing fire weather season overlap between North America and Australia challenges firefighting cooperation. *Earth's Future* **13**, e2024EF005030 (2025).
- Turco, M. et al. On the key role of droughts in the dynamics of summer fires in Mediterranean Europe. *Sci. Rep.* **7**, 81 (2017).
- Perry, M. C., Vanvyve, E., Betts, R. A. & Palin, E. J. Past and future trends in fire weather for the UK. *Nat. Hazards Earth Syst. Sci.* **22**, 559–575 (2022).
- Miller, J., Touma, D. & Brunner, M. I. Compounding preconditions of wildfires vary in time and space within Europe. *Commun. Earth Environ.* **6**, 1005 (2025).
- Giaquinto, D., Di Capua, G., Marzocchi, W. & Kurths, J. Spatio-temporal evolution of compound hot and dry extremes synchronizations in Europe. *Clim. Dyn.* **63**, 146 (2025).
- Kautz, L.-A. et al. Atmospheric blocking and weather extremes over the Euro-Atlantic sector – a review. *Weather Clim. Dyn.* **3**, 305–336 (2022).
- Ruffault, J., Moron, V., Trigo, R. M. & Curt, T. Daily synoptic conditions associated with large fire occurrence in Mediterranean France: evidence for a wind-driven fire regime. *Int. J. Climatol.* **37**, 524–533 (2017).

28. Duane, A. & Brotons, L. Synoptic weather conditions and changing fire regimes in a Mediterranean environment. *Agric. For. Meteorol.* **253–254**, 190–202 (2018).
29. Papavasileiou, G. & Giannaros, T. M. Synoptic-scale drivers of fire weather in Greece. *Sci. Total Environ.* **925**, 171715 (2024).
30. Pereira, M. G., Trigo, R. M., Da Camara, C. C., Pereira, J. M. & Leite, S. M. Synoptic patterns associated with large summer forest fires in Portugal. *Agric. For. Meteorol.* **129**, 11–25 (2005).
31. Grams, C. M., Beerli, R., Pfenninger, S., Staffell, I. & Wernli, H. Balancing Europe's wind-power output through spatial deployment informed by weather regimes. *Nat. Clim. Change* **7**, 557–562 (2017).
32. Hauser, S., Teubler, F., Riemer, M., Knippertz, P. & Grams, C. M. Life cycle dynamics of Greenland blocking from a potential vorticity perspective. *Weather Clim. Dyn.* **5**, 633–658 (2024).
33. Wagner, C. E. *Development and Structure of the Canadian Forest Fire Weather Index System* (CABI, 1987).
34. Wang, S. S., Qian, Y., Leung, L. R. & Zhang, Y. Identifying key drivers of wildfires in the contiguous US using machine learning and game theory interpretation. *Earth's Future* **9**, e2020EF001910 (2021).
35. Hersbach, H. et al. The ERA5 global reanalysis. *Q. J. R. Meteorol. Soc.* **146**, 1999–2049 (2020).
36. Bui, H. X. et al. Summer midlatitude stationary wave patterns synchronize northern hemisphere wildfire occurrence. *Geophys. Res. Lett.* **49**, e2022GL099017 (2022).
37. Giannaros, T. M. & Papavasileiou, G. Changes in European fire weather extremes and related atmospheric drivers. *Agric. For. Meteorol.* **342**, 109749 (2023).
38. Ruffault, J. et al. Increased likelihood of heat-induced large wildfires in the Mediterranean Basin. *Sci. Rep.* **10**, 13790 (2020).
39. Fan, X. et al. Escalating hot-dry extremes amplify compound fire weather risk. *Earth's Future* **11**, e2023EF003976 (2023).
40. Sutanto, S. J., Vitolo, C., Di Napoli, C., D'Andrea, M. & Van Lanen, H. A. Heatwaves, droughts, and fires: Exploring compound and cascading dry hazards at the pan-European scale. *Environ. Int.* **134**, 105276 (2020).
41. Monteiro Dos Santos, D. et al. Compound dry-hot-fire events connecting Central and Southeastern South America: an unapparent and deadly ripple effect. *npj Nat. Hazards* **1**, 32 (2024).
42. Manning, C. et al. Increased probability of compound long-duration dry and hot events in Europe during summer (1950–2013). *Environ. Res. Lett.* **14**, 094006 (2019).
43. Bevacqua, E., Zappa, G., Lehner, F. & Zscheischler, J. Precipitation trends determine future occurrences of compound hot-dry events. *Nat. Clim. Change* **12**, 350–355 (2022).
44. Fischer, L. J. et al. How relevant are frequency changes of weather regimes for understanding climate change signals in surface precipitation in the North Atlantic-European sector? A conceptual analysis with CESM1 large ensemble simulations. *Weather Clim. Dyn.* **6**, 1027–1043 (2025).
45. Rabin, S. S., Gérard, F. N. & Arneth, A. The influence of thinning and prescribed burning on future forest fires in fire-prone regions of Europe. *Environ. Res. Lett.* **17**, 055010 (2022).
46. Lizundia-Loiola, J., Otón, G., Ramo, R. & Chuvieco, E. A spatio-temporal active-fire clustering approach for global burned area mapping at 250 m from MODIS data. *Remote Sens. Environ.* **236**, 111493 (2020).
47. Andela, N. & Jones, M. W. Update of: the Global Fire Atlas of individual fire size, duration, speed and direction. <https://doi.org/10.5281/zenodo.11400062> (2024).
48. Andela, N. et al. The Global Fire Atlas of individual fire size, duration, speed and direction. *Earth Syst. Sci. Data* **11**, 529–552 (2019).
49. Qu, Y., Miralles, D. G., Veraverbeke, S., Vereecken, H. & Montzka, C. Wildfire precursors show complementary predictability in different timescales. *Nat. Commun.* **14**, 6829 (2023).
50. McNorton, J., Moreno, A., Turco, M., Keune, J. & Di Giuseppe, F. Hydroclimatic Rebound Drives Extreme Fire in California's Non-Forested Ecosystems. *Glob. Change Biol.* **31**, e70481 (2025).
51. Savary, O., Ardilouze, C. & Cattiaux, J. Linking European droughts to year-round weather regimes. *Weather Clim. Dyn.* **7**, 223–245 (2026).
52. Christensen, J. H. & Christensen, O. B. A summary of the PRUDENCE model projections of changes in European climate by the end of this century. *Climatic Change* **81**, 7–30 (2007).
53. Van der Werf, G. & Mouillot, F. ESA CCI ECV Fire Disturbance: D5.1 Product Validation and Intercomparison Report, version 4.0. (2024).
54. Giglio, L., Schroeder, W. & Justice, C. O. The collection 6 MODIS active fire detection algorithm and fire products. *Remote Sens. Environ.* **178**, 31–41 (2016).
55. Boschetti, L., Roy, D. P., Justice, C. O. & Giglio, L. Global assessment of the temporal reporting accuracy and precision of the MODIS burned area product. *Int. J. Wildland Fire* **19**, 705 (2010).
56. Copernicus Climate Change Service, Climate Data Store. Land Cover Classification Gridded Maps From 1992 to Present Derived From Satellite Observation (2019).
57. Giglio, L., Loboda, T., Roy, D. P., Quayle, B. & Justice, C. O. An active-fire based burned area mapping algorithm for the MODIS sensor. *Remote Sens. Environ.* **113**, 408–420 (2009).
58. Quian Quiroga, R., Kreuz, T. & Grassberger, P. Event synchronization: a simple and fast method to measure synchronicity and time delay patterns. *Phys. Rev. E* **66**, 041904 (2002).
59. Boers, N. et al. Complex networks reveal global pattern of extreme-rainfall teleconnections. *Nature* **566**, 373–377 (2019).
60. Michelangeli, P.-A., Vautard, R. & Legras, B. Weather regimes: recurrence and Quasi Stationarity. *J. Atmos. Sci.* **52**, 1237–1256 (1995).
61. Vautard, R. Multiple weather regimes over the North Atlantic: analysis of precursors and successors. *Monthly Weather Rev.* **118**, 2056–2081 (1990).
62. Brunner, L., Schaller, N., Anstey, J., Sillmann, J. & Steiner, A. K. Dependence of present and future European temperature extremes on the location of atmospheric blocking. *Geophys. Res. Lett.* **45**, 6311–6320 (2018).
63. Li, X. Python scripts for wildfire synchronicity across European regions is favored by specific weather regimes. <https://doi.org/10.5281/zenodo.21700165> (2026).

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Author contributions

X.L., J.M., R.R.W., and M.I.B. conceptualized the study. X.L. processed the fire and atmospheric reanalysis data. D.B. helped with using the weather regime data and with the interpretation of the results. X.L. conducted the statistical analyses under the supervision of R.R.W. and M.I.B. X.L. wrote the first draft of this paper with input from M.I.B. and R.R.W. All authors contributed to the scientific discussions, writing, and revisions of this work. M.I.B. secured funding for this work.

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The authors declare no competing interests.

Additional information

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