European State of the Climate 2024

ECMWF Communication Section - Copernicus Team
European Centre for Medium-Range Weather Forecasts, ECMWF
Robert-Schuman-Platz 3
53175 Bonn, Germany
copernicus-press@ecmwf.int

Chair, Publications Board
World Meteorological Organization (WMO)
7 bis avenue de la Paix
PO Box 2300
CH-1211 Geneva 2, Switzerland
+41 (0) 22 730 8403
publications@wmo.int

This document was produced with funding from the European Union. Views and opinions expressed are however those of the author(s) only. The European Commission, ECMWF or WMO cannot be held responsible for any use which may be made of the information contained herein.

The data behind the art

The cover art of the European State of the Climate 2024 report is an eye-catching data visualisation designed to capture attention and offer a visual representation of climate conditions in Europe at a glance.

The temperature anomaly data for Europe, when plotted, resemble a mountainscape. Using ERA5 data, the visualisation shows the annual temperature anomaly for European land, relative to the pre-industrial level, over the last five decades (1975–2024). Sequential shades of orange were chosen to visually identify each decade, with more vibrant shades indicating warmer average temperatures. The largest annual anomaly per decade is shown, resembling altitude markers. The sun and clouds at the top represent the distinct east-west contrast in climate conditions seen across Europe in 2024.

A special acknowledgement to Simon Scherrer (MeteoSwiss) whose work inspired the idea of representing data as a mountainscape.

PROGRAMME OF THE EUROPEAN UNION · Copernicus Europe's eyes on Earth · Climate Change Service · IMPLEMENTED BY ECMWF · WORLD METEOROLOGICAL ORGANIZATION

Welcome to the 2024 European State of the Climate (ESOTC) report, compiled by the Copernicus Climate Change Service (C3S) and the World Meteorological Organization (WMO). C3S provides climate monitoring for the globe, Europe and the Arctic; the WMO is the UN authoritative organisation that collates, monitors and predicts weather, climate and water resources, and provides related services at national, regional and global scales through its 193 Members, the National Meteorological and Hydrological Services.

doi.org/10.24381/14j9-s541

The ESOTC provides descriptions and analyses of climate conditions in Europe[1] in 2024, covering variables from across the Earth system, key events and their impacts, and a discussion of climate policy and action with a focus on resilience of the built environment. It also provides an overview of climate conditions across the Arctic, and updates to the long-term evolution of key Climate Indicators. It is the result of a collaborative effort by around 100 scientists and colleagues across Europe and the rest of the world to analyse around 40 datasets, report on around 40 different climate variables or indices, and review, design and publish the ESOTC 2024.

“At ECMWF, we are grateful for the European Commission’s continued support towards the Copernicus programmes for Climate Change and Atmosphere Monitoring Services, as well as their support of our contribution to the Copernicus Emergency Management Service. The 2024 ESOTC report is a testament to the dedication of our staff and collaborators, whose excellent work makes it possible to produce such a high-quality and well-regarded publication.”
Florence Rabier, Director-General, ECMWF

"WMO collaborates with the Copernicus Climate Change Service and other partners to strengthen the provision of climate information and services. These are essential to increase resilience to extreme weather and climate impacts. WMO is committed to expanding early warning systems. We are making progress but need to go further and faster."
Celeste Saulo, Secretary-General, WMO

[1] C3S supports the adaptation and mitigation policies of the European Union, while the WMO Regional Office for Europe serves its 50 Member States, covering Europe, Greenland, the South Caucasus and part of the Middle East. They therefore cover overlapping but slightly different geographical domains. The size and climatic zones of the two domains differ, so variations in statistics are expected. Some statistics are reported for both domains. Maps showing the domains are on page XX.

Globally, 2024 was the warmest year on record, following on from the remarkable warmth of 2023. It became the first year with a global average temperature exceeding 1.5°C above the pre-industrial level[2]. The 1.5°C target of the Paris Agreement refers to the average temperature exceeding this threshold over a 20-year period. The latest five-year average temperature is 1.3°C. The last 10 years have been the warmest ten years on record.

Ocean temperatures were also exceptionally high in 2024, influenced by the residual effects of the strong El Niño that peaked in late 2023, and higher-than-average or record-high temperatures in most ocean basins. The annual average sea surface temperature over the non-polar ocean reached a record high, as did global ocean heat content. Ocean warming and accelerated loss of ice from glaciers and ice sheets contributed to rising sea levels, and the global average sea level reached a new record high in 2024.

Atmospheric concentrations of the greenhouse gases carbon dioxide and methane continued to increase.

Since the 1980s, Europe has been warming twice as fast as the global average, making it the fastest-warming continent on Earth. This is due to several factors, including the proportion of European land in the Arctic, which is the fastest-warming region on Earth, changes in atmospheric circulation that favour more frequent summer heatwaves, and a reduction in aerosol emissions.

Heatwaves are becoming more frequent and severe, and southern Europe is seeing widespread droughts. Glaciers in all European regions continue to melt. Changes in the pattern of precipitation, including an increase in the intensity of the most extreme events, have been observed. This can lead to increased flooding and likely contributed to some of the most catastrophic events seen in 2024.

As well as this PDF version, the report is available online with interactive charts, a key events map, a summary with infographics, and a graphics gallery that also includes a range of additional figures and data download options: *climate.copernicus.eu/ESOTC/2024*

To cite this report:

[2] Based on a consensus of datasets exceeding 1.5°C; some variation between datasets is expected.

Copernicus Climate Change Service (C3S) and World Meteorological Organization (WMO), 2025: European State of the Climate 2024, climate.copernicus.eu/ESOTC/2024, doi.org/10.24381/14j9-s541

Contents

Flooding

Key messages

- 2024 saw the most widespread flooding since 2013, with river flows in 30% of the European river network exceeding the 'high' flood threshold and 12% exceeding the 'severe' flood threshold.
- In September, as a result of Storm Boris, flows reached at least twice the average annual maximum along 8500 km of rivers. For comparison, the Danube is around 2850 km long.
- In October, severe flooding affected Valencia, Spain. National records were broken for total rainfall over 1, 6 and 12 hours, although not the 24-hour record.

Flooding can result in damage, displacement, economic losses and loss of life.

This section provides an overview of flooding across Europe in 2024 and discusses the precipitation and river flow associated with two of the major flood events: Storm Boris affecting much of central and eastern Europe in September, and the extreme flooding that impacted the Valencia region of Spain in October. There is also a discussion of trends related to flooding in Europe.

For more information on significant events across Europe in 2024, visit the interactive 'Key events map' online.

Flooding in 2024

Intense or prolonged precipitation are key drivers of flooding. In 2024, storms and flooding affected an estimated 413,000 people, resulting in the loss of at least 335 lives. Damage from storms and flooding across Europe during the year is estimated to have cost at least €18 billion.

Much of western Europe saw wetter-than-average conditions, with some areas experiencing their wettest year on record. River flows for the year as a whole were higher than average across much of central and northwestern Europe.

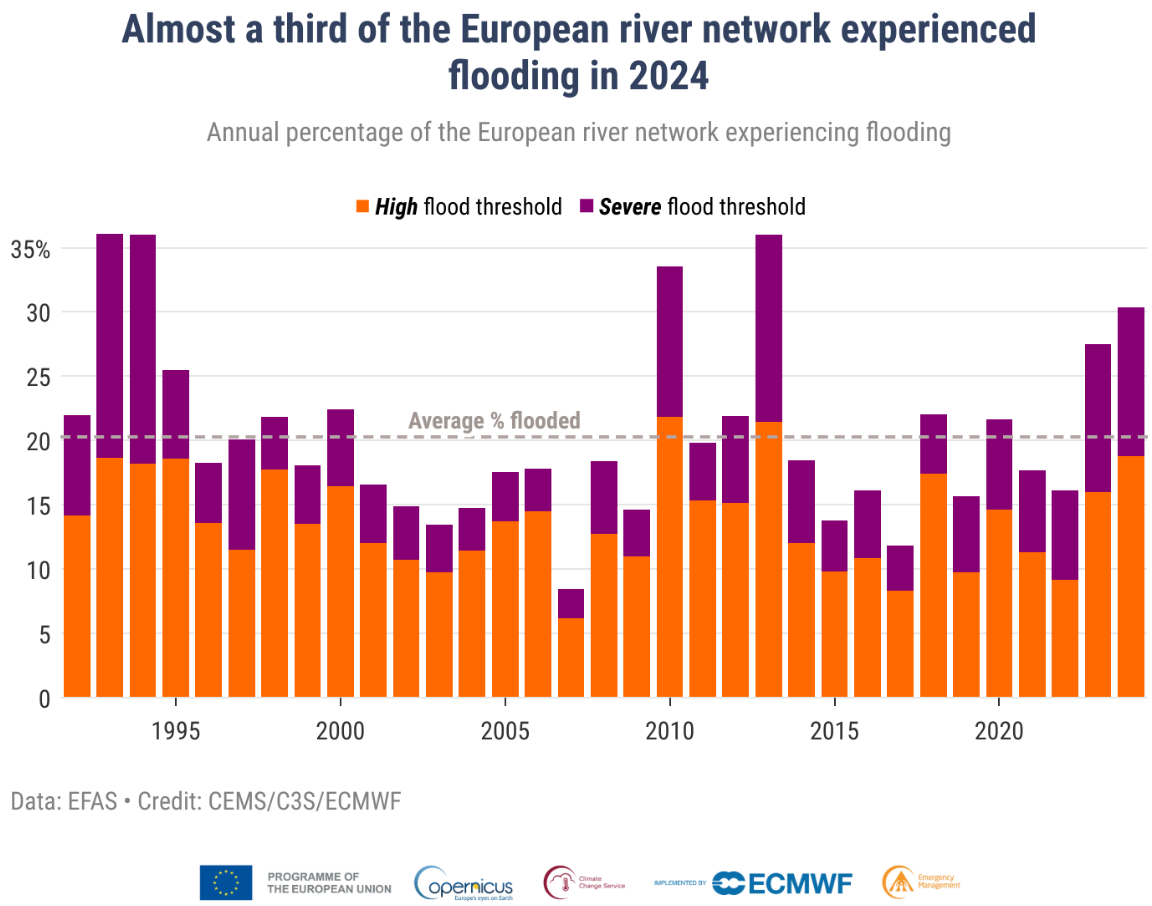


Figure 1.1. Percentage of the European river network that exceeded the 'high' (orange) and 'severe' (purple) flood thresholds during 1992–2024. The average annual percentage of the river network exceeding at least the 'high' threshold (grey line) is around 20%. Data: EFAS. Credit: CEMS/C3S/ECMWF.

Over the course of the year, 30% of the river network experienced flows exceeding the 'high' flood threshold[3], while 12% of the river network saw flows exceeding the 'severe' flood threshold. The percentage of the river network that flooded was the fifth largest in a record going back to 1992 and the largest since 2013.

[3] In this report, the 'high' flood threshold is based on the five-year return period and the 'severe' flood threshold the 20-year return period. A return period describes how often an event of a given magnitude will occur on average.

Notable events[4] began in January, with Storm Henk bringing heavy precipitation to parts of northern France, and to England and Wales, where it caused flooding along the Severn and Thames. In February, heavy rainfall led to flooding in northern Spain and in March, much wetter-than-average conditions in France led to multiple floods. A series of storms during May caused several floods across eastern France, western Germany, Belgium and the Netherlands. In June, southern Germany experienced widespread flooding and Switzerland saw flooding and landslides. One of the most damaging widespread floods on record in Europe occurred in September due to Storm Boris, affecting eight countries in central and eastern Europe. The worst flood in Bosnia and Herzegovina since 2014 occurred in early October. At the end of the month, a cut-off low-pressure system—a storm system that becomes isolated from the main wind flow and typically moves very slowly—brought intense and, in some cases, record-breaking rainfall causing catastrophic flooding in eastern Spain, particularly in the region of Valencia.

Storm Boris, central and eastern Europe

In the second week of September, Storm Boris developed. Moving from western Europe into the Mediterranean, the above-average air temperatures in the region, and sea-surface temperatures in the Mediterranean and Black Sea, favoured the evaporation of large amounts of moisture into the atmosphere, which was subsequently transported into central Europe. This resulted in extreme precipitation over central and eastern Europe, with flooding in parts of Germany, Poland, Austria, Hungary, Czechia, Slovakia, Romania and Italy. There were fatalities and widespread damage, severely affecting local communities. Similar weather conditions also led to flooding in 1997, 2002, 2005 and 2013, for example.

Storm Boris remained sandwiched between areas of high pressure, which resulted in rainfall persisting for several days. Parts of Poland, Germany, Czechia and northeastern Romania, which were among the most impacted areas, saw up to three months' worth of rain from 12 to 16 September. For the upper Danube basin, this was by far the largest five-day rainfall total on record.

Flooding during Storm Boris was extensive, producing flood peaks at least twice the average annual maximum along 8500 km of rivers–twice as many rivers as those affected by the widespread floods of 2002 in the same region [R1]. For comparison, the Danube is around 2850 km long. Severe river flooding was seen in the upper and middle Danube, the Elbe and the Oder basins, with peak river flow occurring several days after the precipitation fell, especially in the lower river sections. The flooding passed through the whole Danube, peaking on 15 September in the middle Danube, near Budapest in Hungary. The most severe floods on the Elbe were in the upper

[4] A summary of notable flood events across Europe in 2024 can be found in the bulletins of the Copernicus Emergency Management Service (CEMS) European Flood Awareness System.

part of the basin (Czechia and eastern Germany), peaking on 17 September. Floods were seen in large parts of the Oder basin (in western Poland and its border with Czechia and Germany) and peaked on 20 September in the lower Oder.

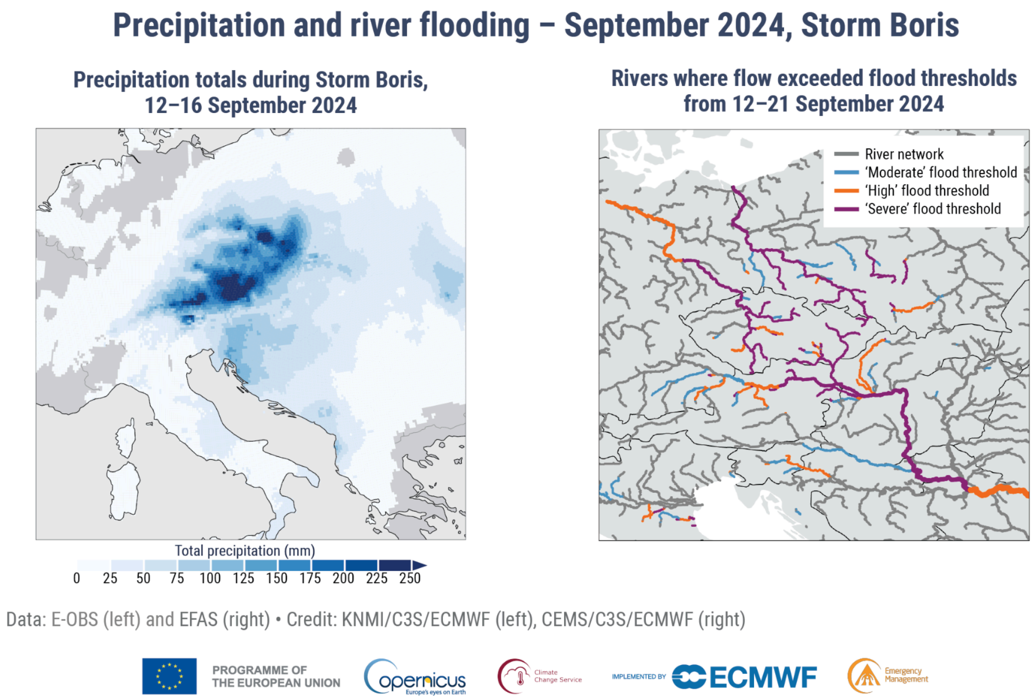


Figure 1.2. (Left) Total precipitation (mm) during Storm Boris from 12–16 September 2024. Data: E-OBS. Credit: KNMI/C3S/ECMWF. (Right) Map showing rivers with upstream areas larger than 1000 km^2 (grey), and those where the river flow exceeded the 'high' (five-year return period) (orange) and 'severe' (20-year return period) (purple) flood thresholds on any day from 12–21 September 2024. Data: EFAS. Credit: CEMS/C3S/ECMWF.

Severe flooding in Spain

Between 28 October and 4 November, a prolonged period of intense rainfall affected Spain's Mediterranean and adjacent provinces. On 29 October, the combined rainfall and river flooding led to devastating impacts[R2] in the province of Valencia, where at least 232 people lost their lives. Fatalities also occurred in the provinces of Albacete, Cuenca and Malaga. Infrastructure damage and economic losses were severe, totalling around €16.5 billion.

The weather system associated with this event was a cut-off low-pressure system, sometimes referred to in Spanish as a 'dana' ('depresión aislada en niveles altos'). Warm, moist air from the Mediterranean Sea was pushed toward the Spanish coast, creating powerful storms. A detailed description of the event, including the storm structure, chronology, observed rainfall and historical context, is available from the Spanish national meteorological service, AEMET[R2].

The storms persisted for several hours[R2], breaking national records for total rainfall in 1 (184.6 mm), 6 (620.6 mm) and 12 hours (720.4 mm) . The one-hour rainfall total of 184.6 mm more than triples AEMET's threshold defining 'torrential rain', of 60 mm. On 29 October, 771.8 mm of rain in 24 hours was seen at Turís Mas de Calabarra. This is the second highest 24-hour rainfall total on record for Spain, after 817.0 mm observed in Oliva, Valencia during a similar event in 1987.

The heavy precipitation triggered severe flooding in sections of the Turia and Júcar rivers. Flood waters moved quickly through the network towards coastal towns and river flows peaked on 29 October in the rivers Turia, Cabriel and Magro.

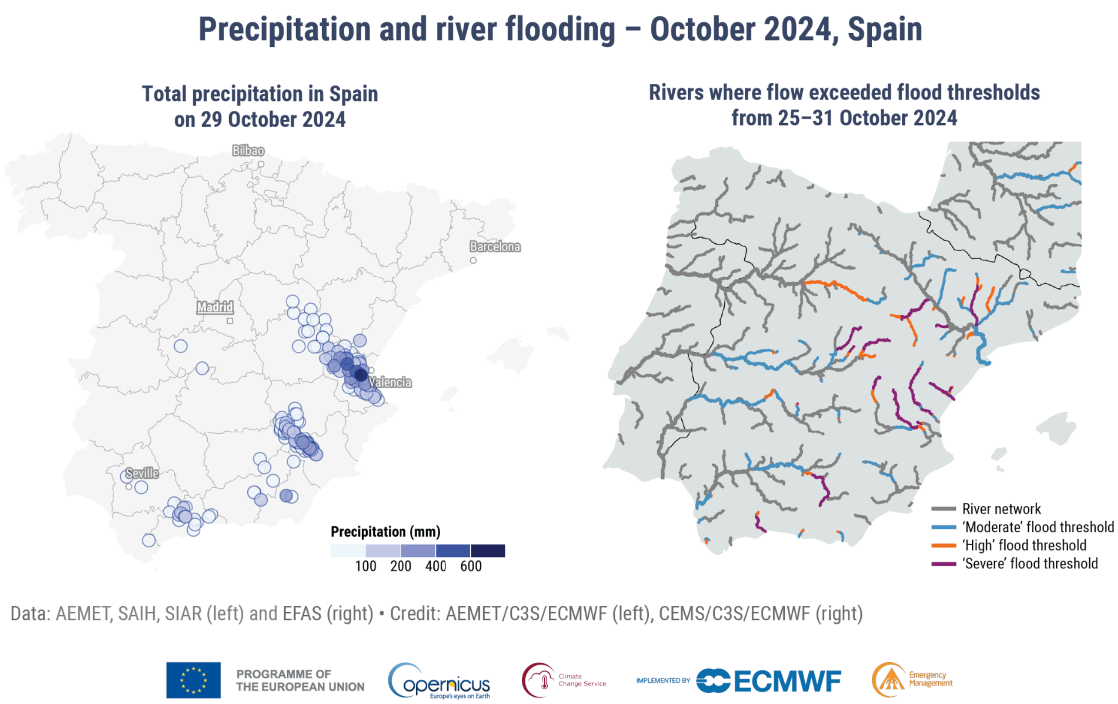


Figure 1.3. (Left) Total precipitation (mm) in Spain on 29 October 2024. Data: AEMET, SAIH and SIAR. Credit: AEMET/C3S/ECMWF. (Right) Map showing rivers with upstream areas larger than 1000 km^2 (grey), and those where the river flow exceeded the 'high' (five-year return period) (orange) and 'severe' (20-year return period) (purple) flood thresholds on any day from 25–31 October 2024. Data: EFAS. Credit: CEMS/C3S/ECMWF.

Flood trends in Europe

What does the Intergovernmental Panel on Climate Change (IPCC) say about expected changes in precipitation and flooding?

The Intergovernmental Panel on Climate Change (IPCC) published the Sixth Assessment Report (AR6) in stages between 2021 and 2023. Compiled by hundreds of scientists around the globe, AR6 looks at past, present and future climate change, and its impacts, across more than 66,000 sources published before January 2021.

The IPCC AR6[5] reports that extreme precipitation and surface water flooding are projected to increase in all regions of Europe. Observed precipitation trends have both seasonal and regional patterns. In recent decades, there has been an increase in average precipitation over northern, western, central and eastern Europe. In northern and eastern Europe, precipitation extremes have also increased, but the observed trend varies across western and central Europe.

Between 1960 and 2010, river flood hazards increased in western and central Europe and the United Kingdom by 11% per decade and decreased in eastern and southern Europe by 23% per decade. The most recent three decades had the highest number of floods in the past 500 years. Projections indicate a continued increase in river flood hazards in western and central Europe, and a decrease in northern and southern Europe. Europe is one of the regions with the largest projected increase in flood risk.

[5] The AR6 chapter on Europe is also summarised in a regional fact sheet and a fact sheet on climate change impacts and risks.

Heat and drought in southeastern Europe

Key messages

- July 2024 saw the longest heatwave on record for southeastern Europe.
- There were record-breaking numbers of ‘strong heat stress’ days and tropical nights in southeastern Europe during summer. The numbers of heat stress days and tropical nights are increasing in this region.
- In southeastern Europe, the year-to-year variability in the number of wet days in summer is increasing.

In recent years, much of Europe has experienced heatwaves. In 2024, however, while most of Europe saw above-average temperatures for the year as a whole, the most extreme heat was in southeastern Europe[6]. This section summarises the conditions in this region during summer—June, July and August—2024, and discusses the trends in heat and drought.

Summer 2024 in southeastern Europe

Following a warmer-than-average spring, there were six heatwaves[7] during summer 2024, including the region’s longest and second most severe heatwave on record. The severity and ranking of heatwaves are derived from the temperature anomaly, the duration and the area affected. Based on this, the most severe heatwave on record for

39°–46°N, 15°–30°E, for consistency with previously published

hresholds for issuing heatwave advisories. Here, a heatwave
emperature exceeding the 98th percentile of the 1961–1990

southeastern Europe was in July 2007, when a 10-day heatwave with an average temperature anomaly of 9.7°C affected 72% of the region. In 2024, the most severe heatwave lasted 13 days with an anomaly of 9.2°C, affecting 55% of the region. This was one of a series of heatwaves during summer and early autumn, with two in June lasting 5–6 days each and three in August lasting 5–8 days each. In the 97 days from 1 June to 5 September there were 43 days with heatwaves. In August, there were as few as three days between heatwaves. The maximum temperature was above average for all but two days during summer.

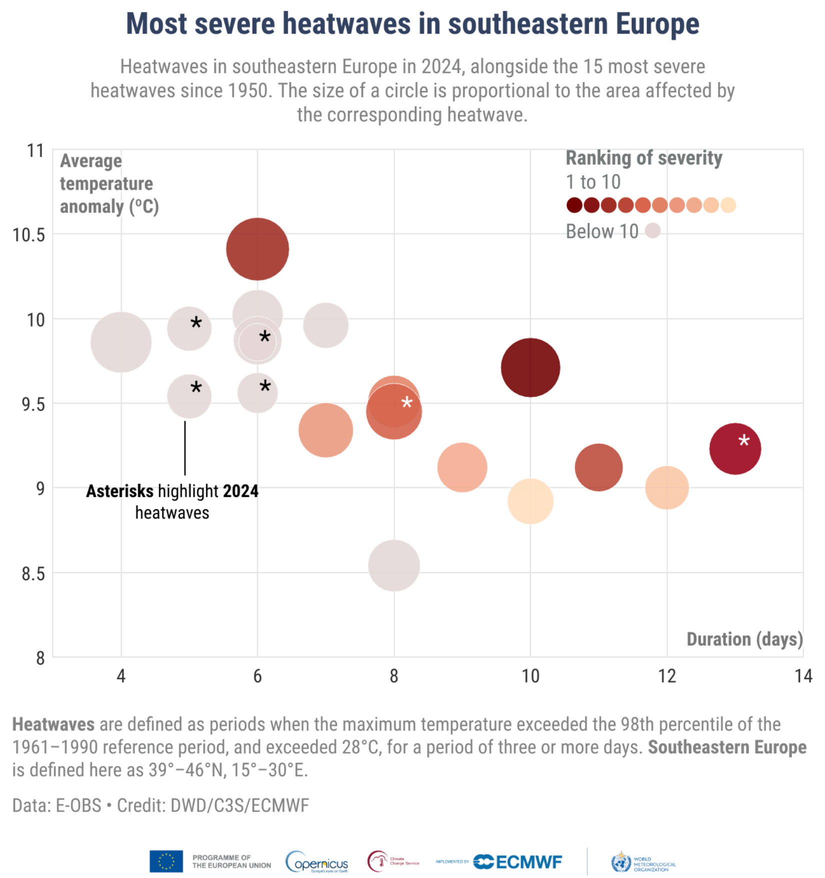


Figure 2.1. Heatwaves in southeastern Europe in 2024, alongside the 15 most severe heatwaves in southeastern Europe since 1950. The circle size is proportional to the area affected by the corresponding event. The 10 most severe heatwaves are indicated by darker colours and grey indicates those with a ranking of severity below 10. Southeastern Europe is defined here as 39°–46°N, 15°–30°E. Data: E-OBS. Credit: DWD/C3S/ECMWF.

Heat can put the body under stress, influenced not only by temperature but also by other environmental factors. The Universal Thermal Climate Index (UTCI) measures the effect of the environment on people, accounting for temperature, humidity, wind, sunshine and radiation. It reflects how the body responds to thermal environments and is expressed as a ‘feels like’ temperature, divided into ten thermal stress categories. For heat stress, the focus is on the maximum daily feels-like temperature.

In southeastern Europe, the UTCI for the summer as a whole was 3.3°C above average. There were 66 days of at least 'strong heat stress' (a feels-like temperature of 32°C or higher), which is the highest number on record and well above the average of 29 days. At the peak of the heat stress, on 13 August, 99% of the region was affected by at least 'strong heat stress', and 53% by at least 'very strong heat stress' (a feels-like temperature of 38°C or higher).

High nighttime temperatures can also affect health, offering little respite from daytime heat stress. Tropical nights—when the minimum daily temperature does not fall below 20°C—are an indicator of this. In summer 2024, southeastern Europe experienced a record 23 tropical nights, far exceeding the average of eight and the previous record of 16, in 2012.

The region saw lower-than-average rainfall from spring, which intensified during the summer, coinciding with the heat. Rainfall increased from early September, but drought conditions persisted. The Copernicus Emergency Management Service (CEMS) European Drought Observatory had warnings in place throughout the summer for persistent and stable drought conditions in southern and eastern Europe. The 'drought index'[R3], a measurement of severity, showed that southeastern Europe recorded its driest summer conditions in a 12-year data record. There were more lakes in the region with below-average water levels than in summer 2023, and summer-average river flows were 'notably' or 'exceptionally low' in 35% of rivers, especially in the southeast.

During the 2024 wildfire season, the period in which at least 80% of the total annual burnt area occurs, the European Commission's Emergency Response Coordination Centre (ERCC) was activated in response to 13 wildfires across Europe. 11 of these occurred in southeastern Europe, during summer and autumn. The largest was near Athens, Greece, in August, burning almost 11,000 ha (110 km^2), with around 1600 people evacuated. The ERCC reported that 'our focus was mainly on eastern Europe and the Balkans where the combination of factors such as drought, heatwaves and wind episodes among others have caused the number of fires and area burnt to be well above the average of recent years'.

Heat and drought trends

What does the Intergovernmental Panel on Climate Change (IPCC) say about expected changes in southeastern Europe?

The Sixth Assessment Report (AR6) of the IPCC was published in stages between 2021 and 2023. Compiled by scientists around the globe, AR6 looks at past, present and future climate change and its impacts based on data from more than 66,000 sources published before January 2021.

AR6[8] reports that temperatures will rise across Europe at a faster rate than the global average, and the frequency and intensity of hot extremes will increase. Resulting agricultural losses are projected for most European areas. Although 'evidence of higher heat tolerance is also emerging', AR6 states that, for Europe as a whole, a 'global warming level of 1.5°C could result in 30,000 annual deaths due to extreme heat', with up to three times this at 3°C of global warming. The risk of heat stress, both discomfort and mortality, also depends on the level of socioeconomic development. The number of heat-related deaths[9] is projected to be highest, and to increase most rapidly, in southeastern Europe.

The frequency and severity of lower-than-average river flows are also projected to increase in the region, alongside the risks for soil moisture drought. This will make streamflow drought and challenges of water supply and demand more severe and persistent. Based on 1.5°C of global warming, the number of days with water scarcity and drought is projected to increase slightly in southeastern Europe, resulting in 18% of the population exposed to 'at least moderate water scarcity'. This would increase to 54% with 2°C of global warming.

Are these changes already being seen in ESOTC datasets?

Monitoring of long-term climate indicators confirms that, since the 1980s, Europe has been warming twice as fast as the global average, making it the fastest-warming continent. In recent decades, heat has been the leading cause of reported deaths due to extreme weather and climate events in Europe. There are estimated to have been around 47,700 heat-related deaths in Europe in 2023 and around 61,700 in 2022. An estimate for 2024 is not yet available. In the World Health Organization (WHO) European Region, heat-related mortality has increased by around 30% in the past 20 years.

In summer in southeastern Europe, there is an increasing number of days with at least 'strong heat stress' and an increasing number of tropical nights, particularly since the 1980s. The summer average maximum feels-like temperature is also increasing, while the amount of rainfall in the region each summer varies. Analysis of three datasets suggests that the year-to-year variability in the number of wet days—where the total 24-hour precipitation is at least 1 mm—during the season is increasing, particularly since the 2000s.

[8] The AR6 chapter on Europe is also summarised in a regional fact sheet and a fact sheet on climate change impacts and risks.

[9] For a discussion of climate policy and action related to extreme weather and human health, and climate resilience in the health sector, see the 2023 ESOTC report.

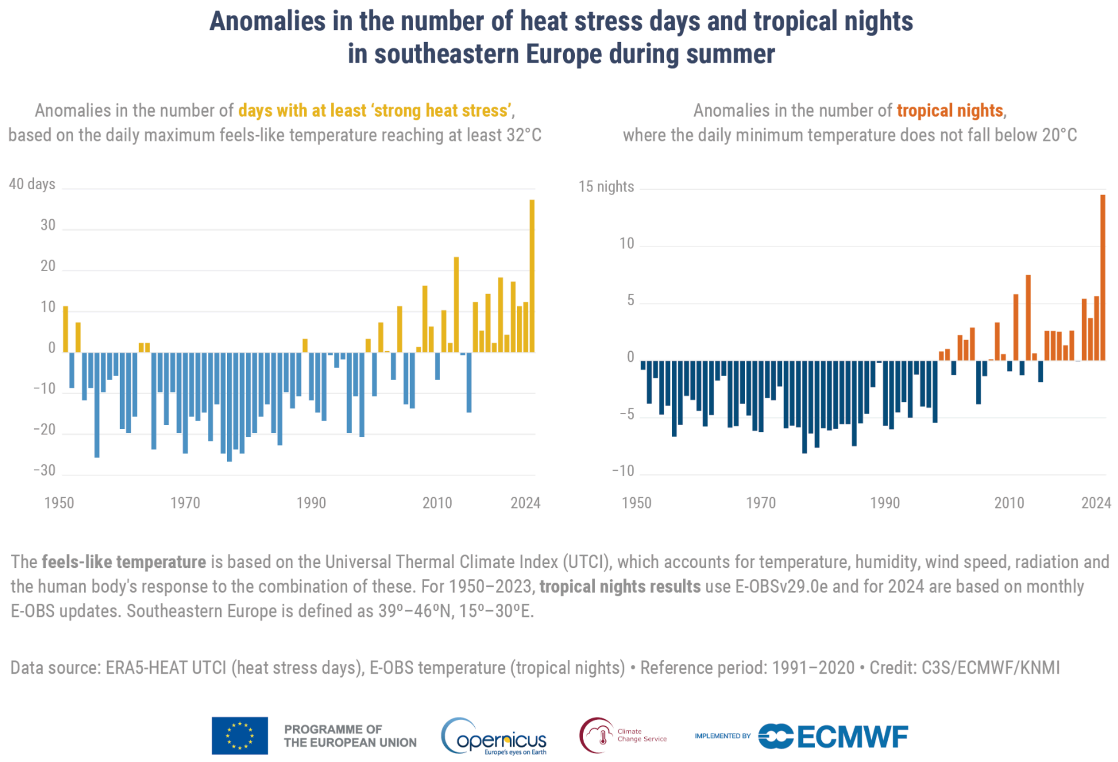


Figure 2.2. Anomalies in the number of days with at least 'strong heat stress' and the number of tropical nights in southeastern Europe, for each summer for the period 1950–2024. Southeastern Europe is defined here as 39°–46°N, 15°–30°E. For 1950–2023, the indices based on E-OBSv29.0e are used and for 2024 the indices based on the monthly E-OBS updates. Data: ERA5-HEAT, E-OBS. Credit: C3S/ECMWF/KNMI.

Temperature

Key messages

- 2024 was the warmest year on record for Europe, with record annual temperatures in central, eastern and southeastern Europe.
- Averaged over Europe, 45% of days were much warmer than average and around 12% of days were the warmest on record.
- Around 69% of the European land area saw fewer than three months (90 days) of frost days. This is the largest area on record to see so few days.

Surface air temperature, measured at around 2 m above the surface and referred to in this section as 'temperature', has impacts on both human and natural systems. It affects health, agriculture and energy demand, for example, as well as biodiversity and natural environments.

This section gives an overview of temperature anomalies and extremes in 2024 across the continent, explores variations throughout the year, and provides historical context for the findings.

2024 was the warmest year on record for Europe for all datasets considered, with record-high annual temperatures in nearly half (around 48%) of the continent[10]. The area with record temperatures mainly covered central, eastern and southeastern Europe, but also northern Scandinavia and southeastern Spain. In other parts of Europe, temperatures were generally warmer than average, with around 85% of the region being much warmer than average. Iceland was the only country with much cooler-than-average temperatures. A large part of Greenland and a few small areas in southwestern Europe saw near-average temperatures. The largest positive temperature anomalies, of 2–3°C above average, were over eastern and southeastern parts of Europe.

[10]Six datasets are considered for the annual average temperature for the WMO RA VI domain for Europe. For other statistics and descriptions, two datasets, ERA5 and E-OBS, are used and refer to the C3S domain for Europe unless explicitly indicated otherwise. 2024 was also the warmest year on record for this domain. The percentages referred to in this paragraph are derived from ERA5. In some of the spatial detail, for example over Sicily and in the easternmost part of the region, ERA5 and E-OBS show differences. Read more in the dataset discussion section of 'About the data' online.

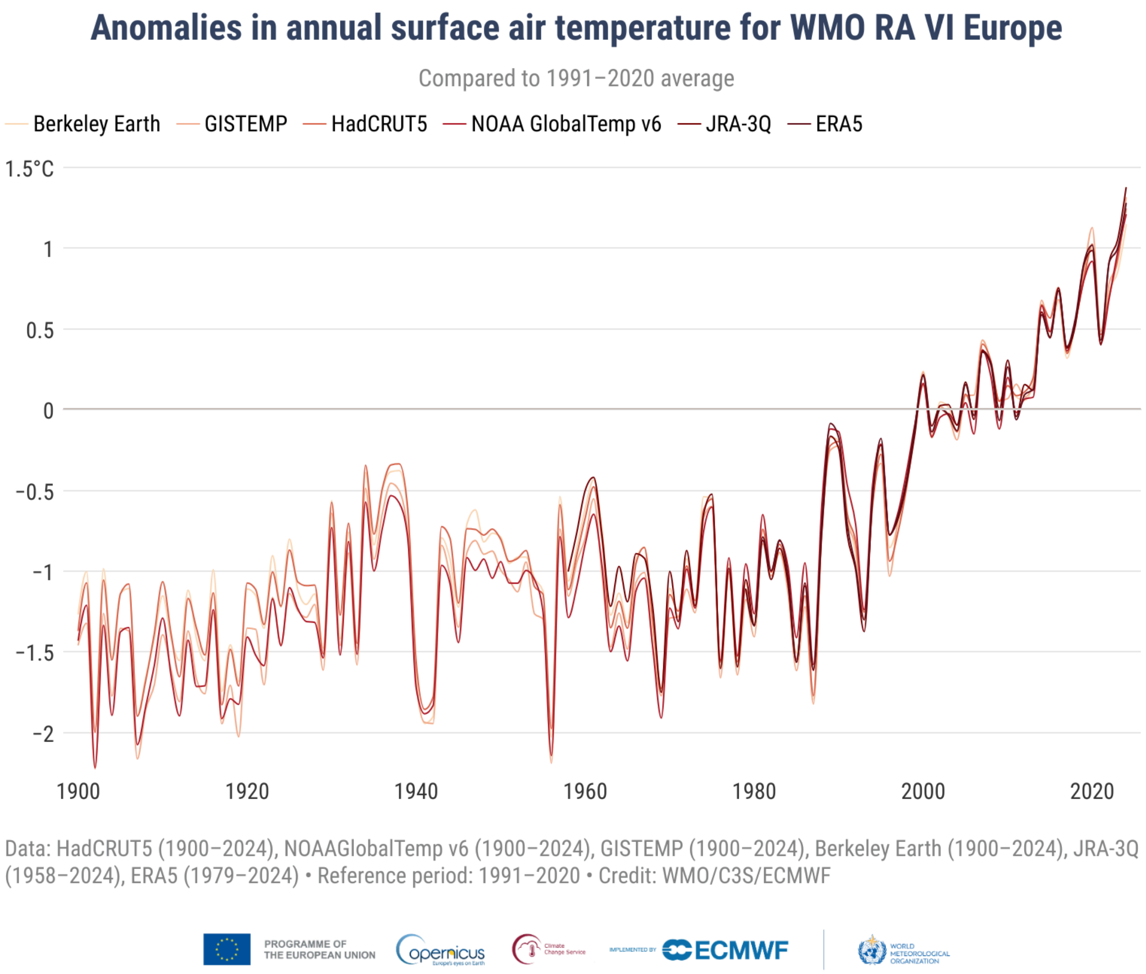


Figure 3.1. Annual surface air temperature anomalies over European (as defined by the WMO Regional Association VI) land, from a range of datasets, for 1900–2024 (start year varies by dataset), relative to the average for the 1991–2020 reference period. Data: HadCRUT5, NOAAGlobalTemp, GISTEMP, Berkeley Earth, JRA-3Q, ERA5. Credit: C3S/ECMWF/WMO. Data can be downloaded and information on the methodology can be found on the [WMO Regional Dashboard for Europe](#).

Temperatures for Europe show long-term warming trends. The trends are not uniform over time, however, and generally show little change, or weak cooling, from the 1950s to the 1980s, with the 1980s being slightly cooler than the 1930s. Most of the warming has happened since the 1980s. The three warmest years on record for Europe have all occurred since 2020 and the ten warmest since 2007.

Temperature variations throughout the year

The year was generally characterised by above- to well-above-average and sometimes record-high temperatures. Averaged over European land[11], only one day saw well-below-average temperatures for the time of year and only 51 days saw below-average temperatures. Around 45% of days saw well-above-average temperatures and around 12% of days were the warmest on record.

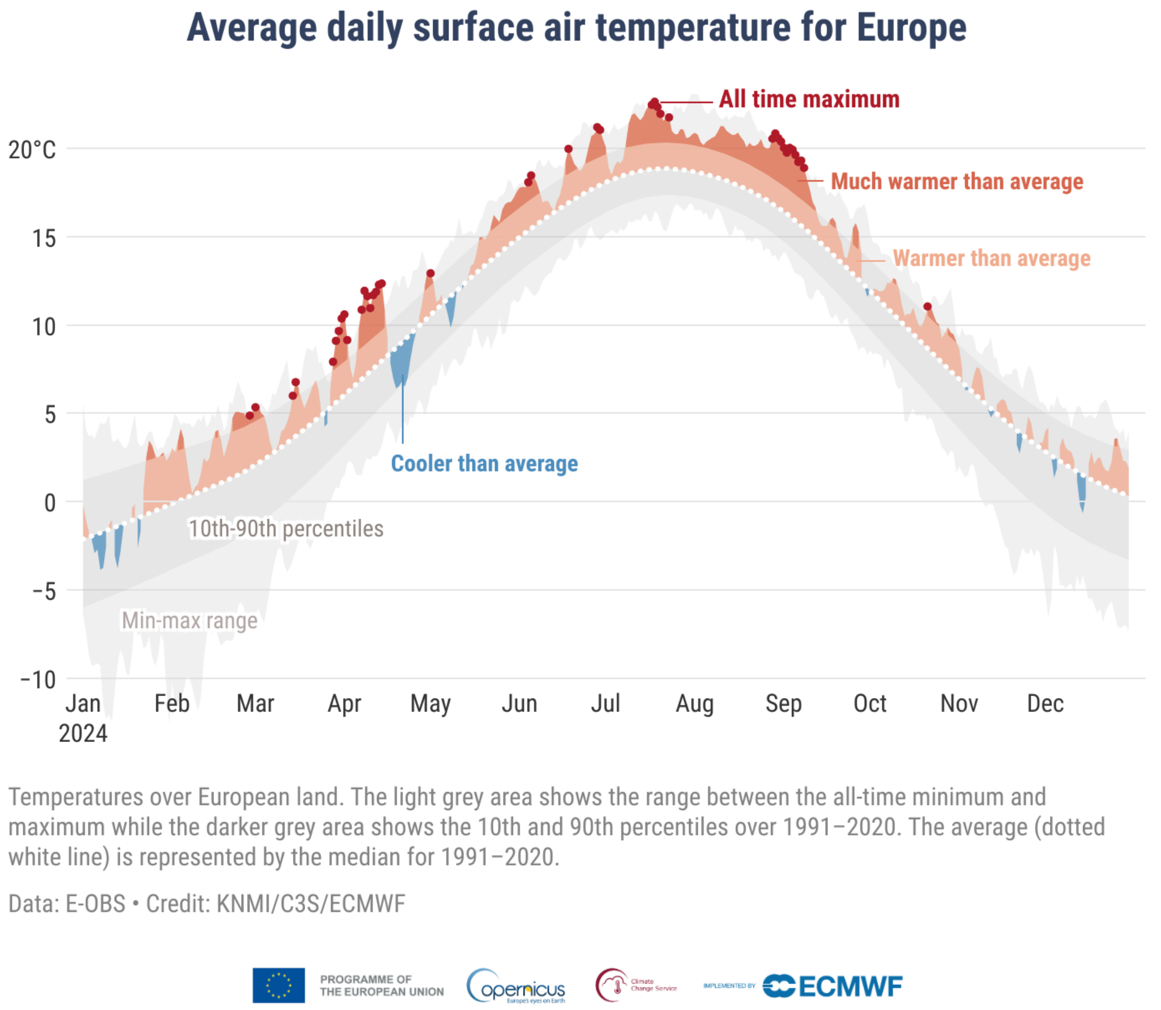


Figure 3.2. Average daily surface air temperature (°C) for European (as defined by C3S) land for 2024, showing warmer-than-average (orange shading), much warmer-than-average (red shading) and all-time maximum (red dots) temperatures, and cooler-than-average (blue shading) temperatures, alongside the 10th and 90th percentiles (outside of which temperatures are considered to be much below/much above average) (grey shading) of the daily surface air temperature for 1991–2020 and the average (dashed line). Data: E-OBS. Credit: C3S/ECMWF/KNMI.

The year started with a north–south contrast in temperatures, continuing from the [end of 2023](). During January, temperatures were cooler than average over parts of

[11] Daily statistics based on E-OBS.

Greenland, much of the Nordic region, the Baltic States and western Russia, while temperatures in southern and eastern parts of Europe were near or above average. The north-south contrast persisted into February, but with the near-average temperatures shifted further north and with most of Europe south of Scandinavia seeing much above-average temperatures. During February, a large region of record-high temperatures was seen over central and eastern Europe, and northern parts of southeastern Europe.

Winter as a whole reflected this north-south contrast, being the only season during the year for which a large part of Europe saw negative temperature anomalies. However, much above-average temperatures in the south and southeast, with positive anomalies of around 3°C around the Black Sea, led to the second warmest winter on record for Europe, after 2020. When extending the region to include Greenland, the Caucasus and parts of the Middle East, winter ranked seventh warmest on record.

For the other seasons, a relatively persistent pattern was established, with above-average temperatures for most of Europe and an east-west contrast with generally larger positive temperature anomalies in eastern Europe. Both spring and summer were the warmest on record for Europe.

During spring, the region of largest positive anomalies moved from central Europe during March to southern Europe, Russia, the Caucasus and Türkiye in April. Another move in May saw well-above-average and in some parts even record-breaking monthly temperatures over the United Kingdom, Ireland, and all land areas around the Baltic Sea.

During summer and into September, the pattern became even more established, with parts of southeastern Europe consistently seeing record-high monthly temperatures, while temperatures in western Europe generally varied between cooler than average in June and September and warmer to much warmer than average during July and August. Due to exceptional warmth in eastern Europe in September, autumn for Europe was the third warmest on record.

From October to the end of the year, temperatures were still generally above average, but the total area of much above-average temperatures was smaller and there were no large regions of record-high temperatures.

The temperature variations throughout the year generally reflect changes in atmospheric circulation, with the strength of the correlation varying from month to month. The clearest association includes January, when there was low pressure over the regions in northern Europe with cooler-than-average temperatures, and September, which saw high pressure over warmer-than-average areas in central and eastern Europe.

Temperature extremes

Both minimum and maximum temperatures for the year as a whole were above average across all of Europe. Maximum temperatures were most above average in eastern and southeastern areas, where there was a large region of temperatures 2–3°C above average, and in southern Spain. Minimum temperatures were also well above average in these areas, as well as over parts of central and western Europe, though the east-west contrast was less distinct than for maximum temperatures.

2024 saw a large number of heatwaves and high levels of heat stress, while there were no large regions with record-cold monthly, seasonal or annual average temperatures. This is in line with the overall warming trend, which leads to warm records being broken more often than cold records. Nevertheless, during a cooler-than-average period affecting Scandinavia and Finland in early January, one station in Sweden and several stations in Norway saw record-cold temperatures.

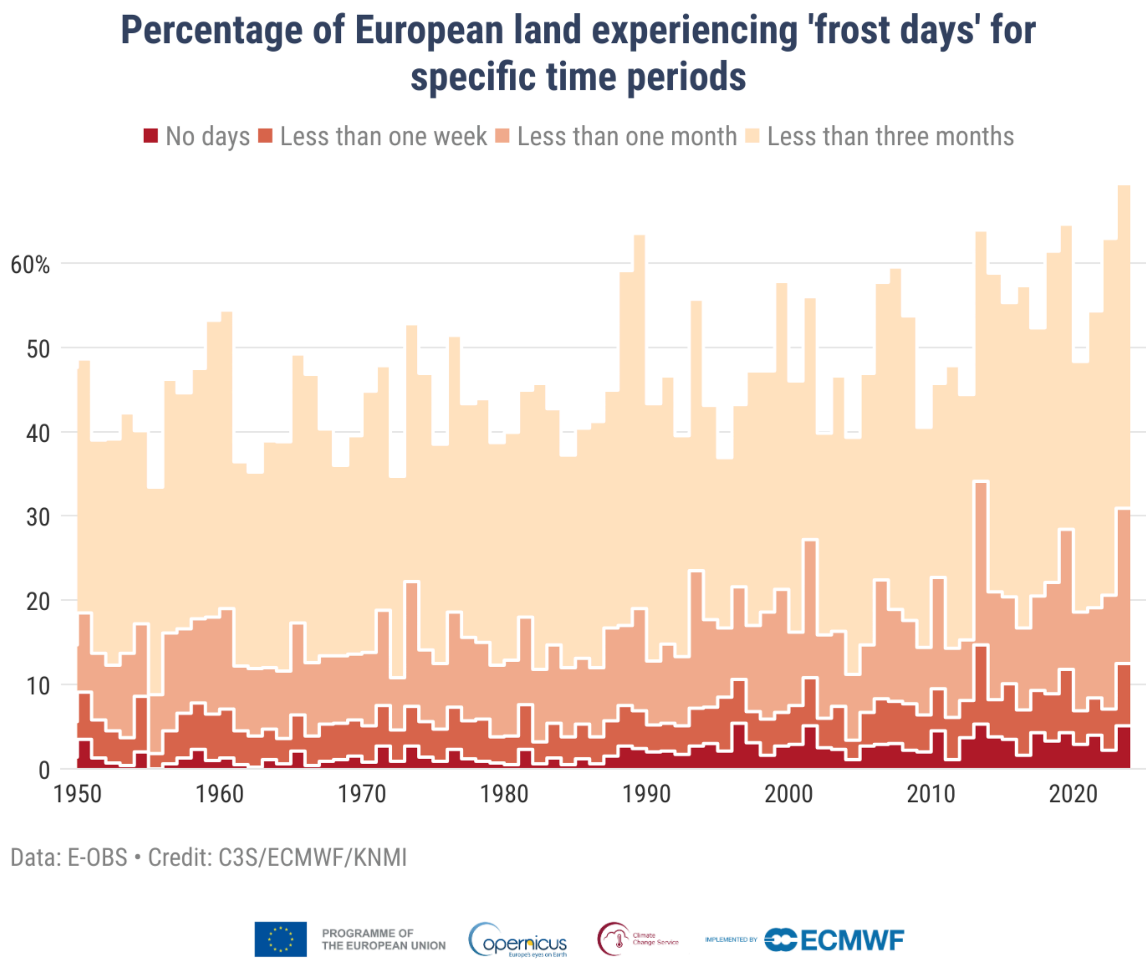


Figure 3.3. The percentage of European land experiencing 'frost days' (days with a minimum temperature of 0°C or lower) for specific time periods (shades of red): No days, less than

one week, less than a month (31 days), fewer than three months (90 days). Data: E-OBS. Credit: C3S/ECMWF/KNMI.

One way to consider cold extremes is to look at the number of days during which the minimum temperature is 0°C or lower ('frost days') and the maximum temperature is 0°C or lower ('ice days'). Generally, the fraction of Europe that experiences neither of these types of days is increasing. In other words, the area of Europe that experiences days with temperatures below freezing is shrinking. During 2024, the declining number of frost days was particularly notable. The area of European land[12] that experienced fewer than three months (90 days) of frost days was the largest on record (around 69%), while the areas experiencing less than a month and less than a week were both the second largest on record, at 31% and 13% respectively. For comparison, the average areas are 50%, 19% and 8% of European land, for fewer than three months, less than a month and less than a week, respectively. The percentages of Europe that experienced ice days for fewer than three months, less than a month, less than a week, or not at all, were larger than average, but not exceptionally so. More on cold stress can be read below, in the 'Thermal stress' section.

Thermal Stress

Key messages

- In 2024, the numbers of days with 'strong', 'very strong' and 'extreme heat stress' were all the second highest on record.
- The number of tropical nights was the second highest on record.
- The number of cold stress days was the lowest on record, but the ones that did occur were in the more severe categories.

Extreme temperatures, alongside other environmental factors, can impact human health. There were estimated to be around 47,700 heat-related deaths in Europe in 2023, and around 61,700 in 2022. An estimate for 2024 is not yet available.

Thermal comfort indices can be used to represent the effect of the environment on people. The Universal Thermal Climate Index (UTCI), for example, takes into account temperature, humidity, wind speed, sunshine and heat emitted by the surroundings, and how the body responds to different thermal environments. The UTCI has units of °C, representing a 'feels like' temperature, divided into ten heat and cold stress categories. For heat stress, the focus is on the maximum daily feels-like temperature (UTCI), and for cold stress, the minimum daily feels-like temperature.

[12] Frost day and ice day statistics derived from E-OBS.

High nighttime temperatures can also affect health, offering little respite from daytime heat stress. Tropical nights—those during which the temperature does not fall below 20°C—are an indicator of this.

This section provides an overview of heat stress, tropical nights and cold stress across Europe in 2024. Detailed information about regional heatwaves can be found in the 'Heat and drought in southeastern Europe' section.

Heat stress

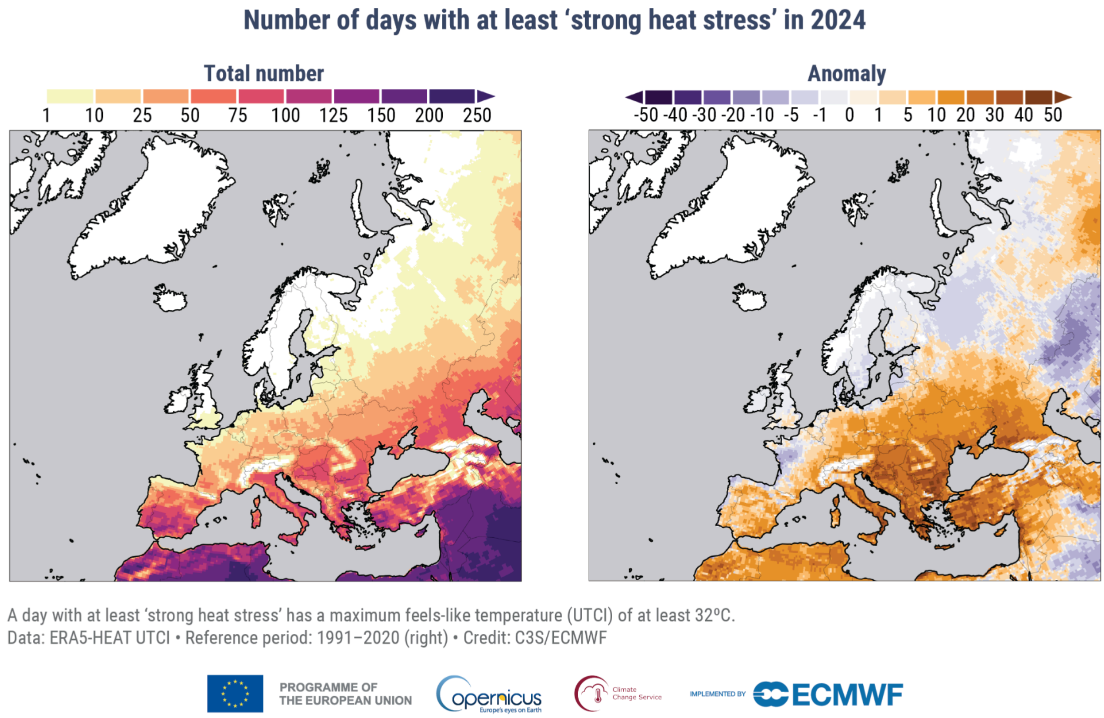


Figure 4.1. Number of days with at least 'strong heat stress' in 2024, and associated anomalies, relative to the average for the 1991–2020 reference period. A day with 'strong heat stress' has a maximum feels-like temperature, based on the Universal Thermal Climate Index (UTCI), of at least 32°C. Data: ERA5-HEAT. Credit: C3S/ECMWF.

In 2024, 60% of Europe (excluding Greenland and Svalbard) saw more days than average with at least 'strong heat stress', where the feels-like temperature is 32°C or higher. Around 30% of Europe, however, mostly in northern and northwestern regions, saw fewer days than average with this level of heat stress. Much of southern and eastern Europe saw more days than average with at least 'very strong heat stress', where the feels-like temperature is 38°C or higher. Central and northeastern Europe saw fewer days than average with at least 'very strong heat stress'. It was mostly during summer that much of Europe saw more heat stress days than average, extending into autumn for central and southeastern regions.

On 17 July 2024, 20% of Europe experienced at least 'very strong heat stress'. This is the joint largest area for a single day since records began in 1950, alongside 7 August 2010, during Europe's most severe heatwave.

There were few days with 'extreme heat stress', where the feels-like temperature is 46°C or higher, but up to two days were seen in some small areas of southern and eastern Spain, Azerbaijan and Türkiye. For southern Portugal, southwestern Spain and parts of southeastern Europe, there was a below-average number of 'extreme heat stress' days.

For Europe, the numbers of days with 'strong' to 'extreme heat stress', have been increasing since the 1980s. In 2024, this was the second highest on record for 'strong' and 'very strong heat stress', behind 2010. For 'extreme heat stress', 2024 ranked behind 2010 and 2023, which had the joint highest number of days.

Tropical nights

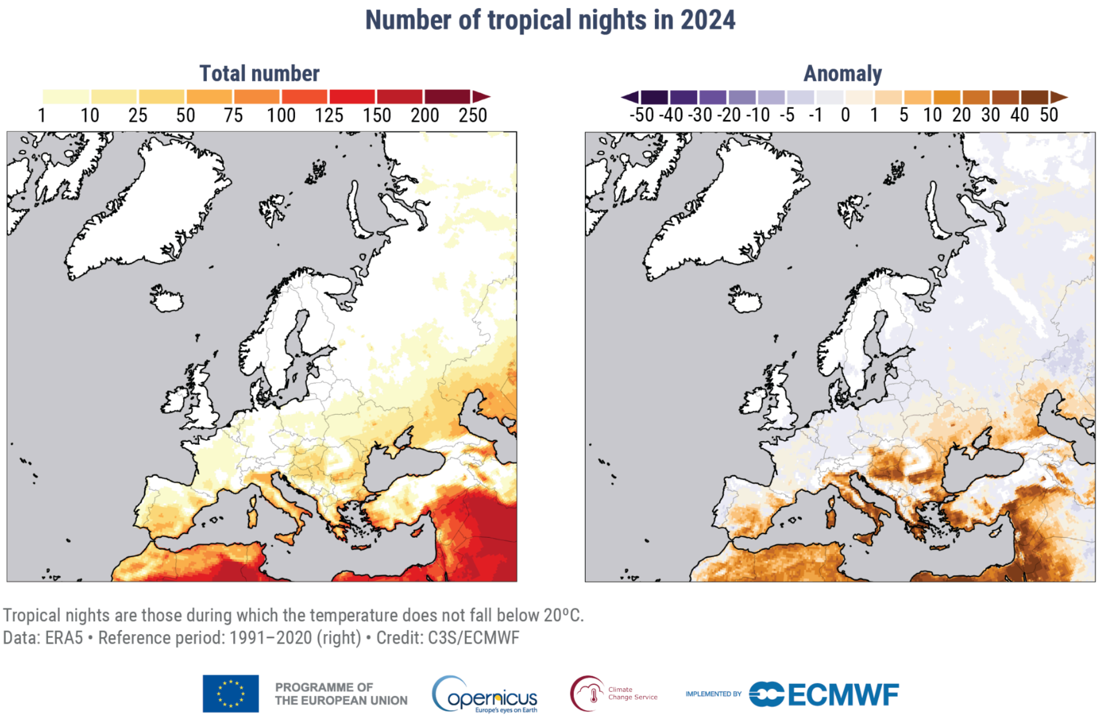


Figure 4.2. Number of tropical nights in 2024 and associated anomalies relative to the average for the 1991–2020 reference period. Tropical nights are those during which the temperature does not fall below 20°C. Data: ERA5. Credit: C3S/ECMWF.

In 2024, 37% of Europe saw more tropical nights than average, especially in the southeast. In southern Greece, some areas saw up to 55 more tropical nights than average, much of Italy up to 50 more, western Türkiye up to 40 more, and parts of Croatia, Serbia, Hungary, Romania and Bulgaria up to 35 more. Meanwhile, 38% of Europe saw a slightly below-average number of tropical nights, with the largest negative anomalies in small areas of southern Spain, where there were 10 fewer nights than average, and in Portugal, with as many as 5 fewer nights.

As well as the number of days with heat stress, the number of tropical nights for Europe has been increasing since the 1980s, with 2024 seeing the second highest number on record, behind 2010. The area experiencing tropical nights has also been increasing, from an average of around 20% of Europe seeing at least one tropical night per year in the 1970s, to around 34% in the 2010s and 35% so far in the 2020s. In southeastern Europe, the number of tropical nights in summer 2024 was the highest on record, at 23—nearly triple the previous record of eight in 2012.

Cold stress

While the number of heat stress days for Europe as a whole is increasing, the number of cold stress days[13] is decreasing. 2024 saw a record low number of days with at least ‘strong cold stress’, where the feels-like temperature reaches -13°C or lower. A high proportion (around 80%) of cold stress days, however, fell into the more severe categories: ‘very strong cold stress’ (feels-like -27°C or lower) and ‘extreme cold stress’ (-40°C or lower). This means that in 2024, the cold stress days that did occur were generally more severe.

Apart from Fennoscandia, Iceland, parts of Greenland and parts of northern Russia (23% of Europe), most of the region (73%) saw fewer days than average with ‘very strong cold stress’. A large part of Europe, particularly western, central and southern Europe, does not typically see ‘extreme cold stress’. For the year as a whole, despite the increasing number of heat stress days and decreasing number of cold stress days, areas of northern and northeastern Europe saw around an average number of ‘extreme cold stress’ days. In total, around half of Europe saw fewer ‘extreme cold stress’ days than average and 20% saw more than average.

Wildfires

Key messages

[13] Cold stress statistics are based on the daily (24-hour) minimum UTCI values, so a cold stress ‘day’ may see its coldest feels-like temperatures during the nighttime.

- Fire danger remained average or slightly above average in Europe during 2024, with the highest values observed in September, due to conditions in Portugal and parts of Spain.
- In September, fires burning in Portugal contributed to a total of around 110,000 ha (1100 km^2) burnt in Europe in one week, around a quarter of the total annual area.
- While fire emissions in Europe remained below average for most of the year, they increased significantly in September due to large-scale fires in Portugal.

Wildfires, or wildland fires, are fuelled by combustible vegetation and triggered by ignition sources, such as lightning or human activity. They are influenced by a range of factors, both natural and anthropogenic, including vegetation type and structure, moisture, topography and wind. The increased frequency and intensity of extreme wildfires may result in habitat destruction and air quality deterioration. In recent years, European summers have seen increased wildfire potential[R4][R5], expressed here as fire danger, with a growing number of larger fires and an extended fire season—the period of the year in which at least 80% of the total annual burnt area occurs.

In this section[14], wildfire burnt areas are estimated through satellite observations and emissions of carbon and pyrogenic pollutants are estimated fire radiative power (FRP).

Fire danger

Where fuel is available, weather plays a pivotal role in determining the risk of fires. Fire danger is estimated using the Fire Weather Index (FWI) to understand how weather conditions influence flammability and to evaluate potential spread and intensity of a fire. While the FWI does not account for ignition, it generally correlates well with actual fire activity in terms of burnt area.

In 2024, fire danger levels in summer were generally average to slightly above average across most of Europe. The highest values occurred in September, because of a combination of dry conditions and strong winds, especially in Portugal and parts of Spain. Southeastern Europe also experienced above-average fire danger in June and August due to extreme temperatures. The most significant deviations of fire danger from the average, though with lower overall values, were seen at the end of summer in parts of eastern Europe, particularly northeast of the Black Sea, where soil moisture levels were much lower than average. The fire season was not extreme but was relatively long. For example, southeastern Spain, the eastern Balkans,

[14] The definition of Europe may differ depending on the variable being discussed. When not otherwise specified, Europe follows the C3S definition.

Greece and western Türkiye recorded up to 20 more days of extreme fire danger (FWI of 50 or above) than average, while parts of Ukraine and southwestern Russia had around 25 more days.

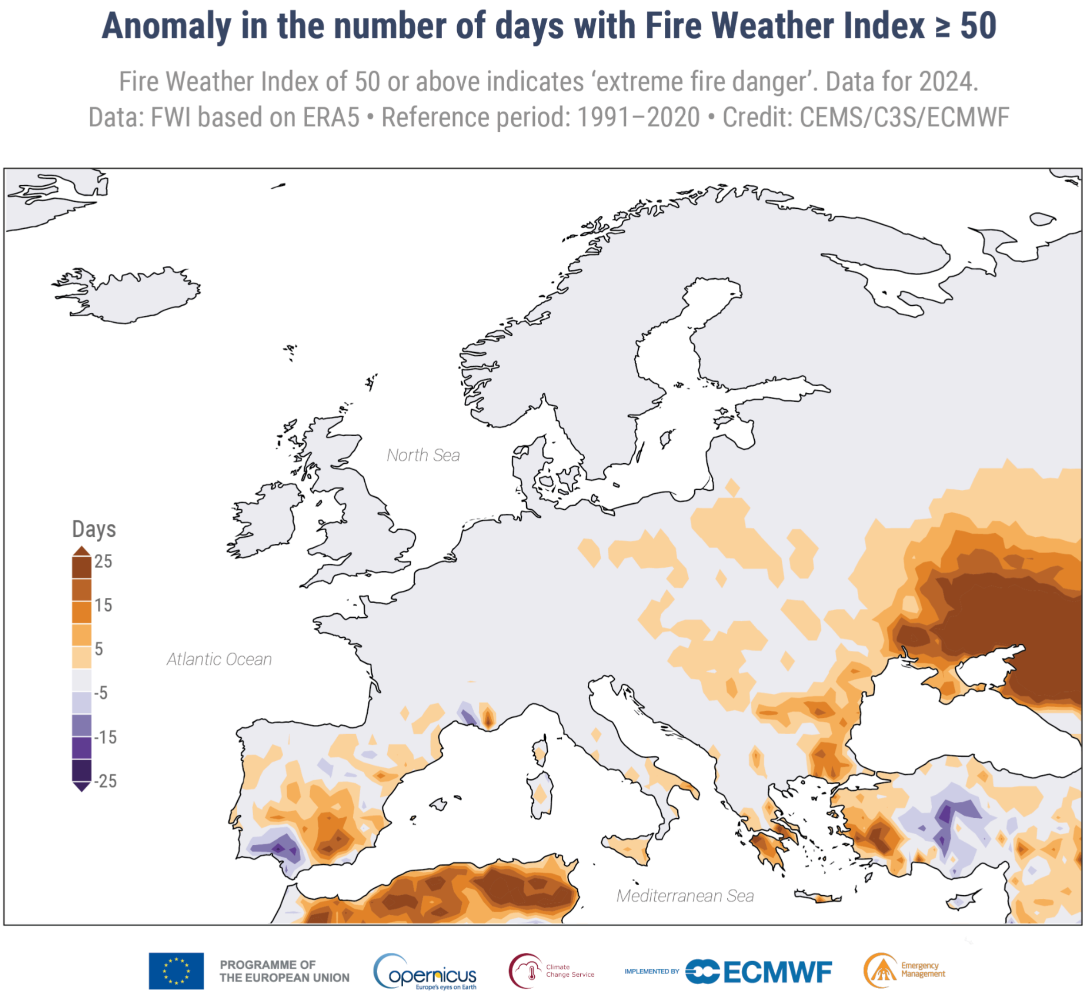


Figure 5.1. Anomalies in the number of days with a Fire Weather Index of 50 or above (indicating 'extreme' fire danger) in Europe in 2024, relative to the average for the 1991–2020 reference period. These conditions are when 'critical' fires, those above 10,000 ha, can develop. Data: FWI based on ERA5. Credit: CEMS/C3S/ECMWF.

Burnt areas

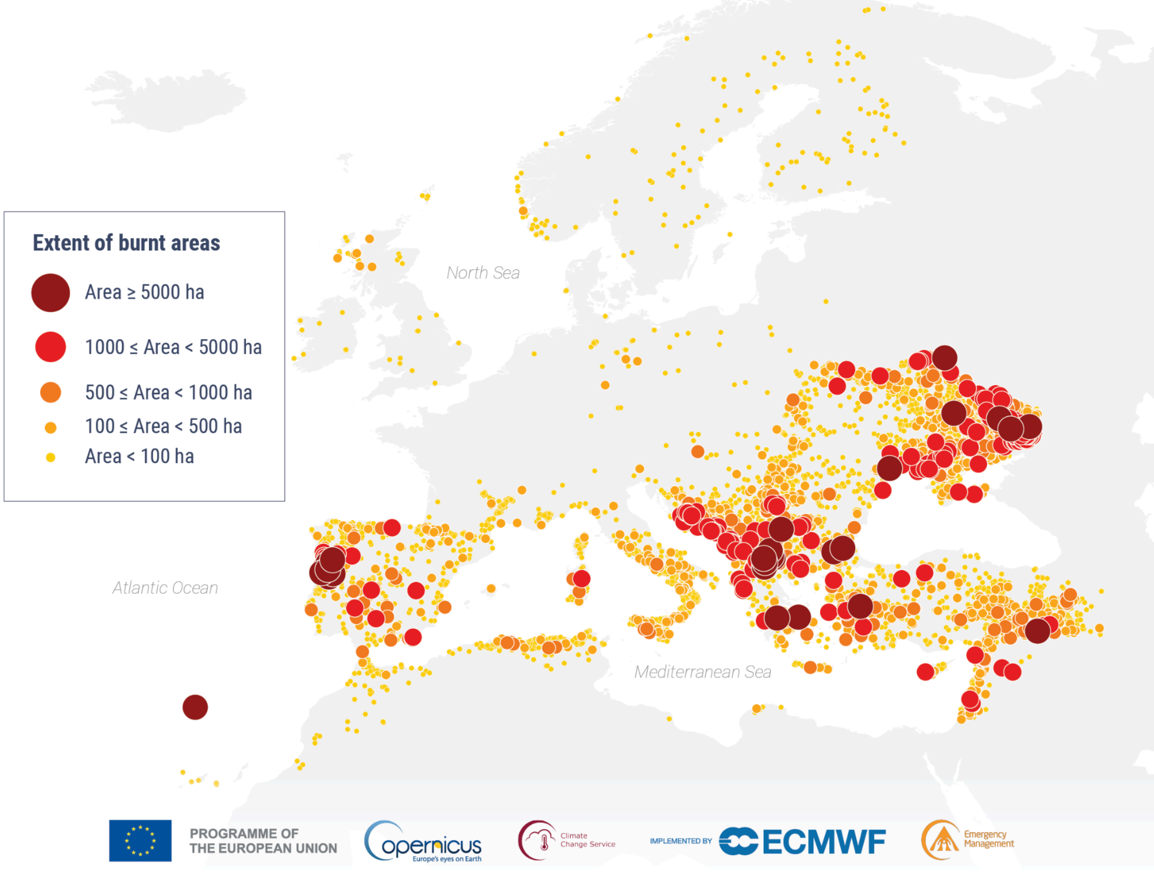
For most of the fire season, which runs from June to September, Europe[15] saw an extent of burnt area that was average or below average[R6]. However, there were substantial wildfires in July in Greece, where a large fire in eastern Attica burned

[15] The definition of Europe used here is that of the European Union (EU27): Austria, Belgium, Bulgaria, Croatia, Cyprus, Czechia, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, the Netherlands, Poland, Portugal, Romania, Sweden, Slovakia, Slovenia and Spain.

around 11,000 ha (110 km^2), and in Madeira. Intense wildfire activity occurred in July and August in the Balkans, where Romania and Bulgaria saw an above-average number of fires. In September, when the year-to-date burnt area for Europe was below average, a number of large fires were ignited within a short period in Portugal, with around 110,000 ha burnt in one week. This increased the total burned area in the country from around 13,000 ha before September to around 130,000 ha by the end of the month. This represents 32% of the total burnt area in Europe in 2024, which reached around 400,000 ha. The estimated burnt area is slightly above average but 66% less than the record of 1,200,000 ha in 2017. Notably, a high concentration of wildfires was seen throughout the fire season in a large region north of the Black Sea, particularly along Ukraine's border with Russia and Belarus[16].

Burnt areas across Europe and the Mediterranean in 2024

Data: European Forest Fire Information System (EFFIS) • Credit: EFFIS/CEMS/C3S/ECMWF



[16] As with all wildfires, the ignition source is an important component. In this region, it is likely that many instances of ignition are related to the ongoing conflict. In addition, insufficient fire management could exacerbate the impact of fires.

Figure 5.2. Distribution and extent of burnt areas across Europe and the Mediterranean[17] in 2024. Data: European Forest Fire Information System (EFFIS). Credit: EFFIS/CEMS/C3S/ECMWF.

Wildfire emissions

Wildfires release a complex mixture of gases and aerosols, including large amounts of carbon dioxide and 'black carbon'. Monitoring these emissions is one way to assess the scale of fire activity in a region.

In 2024, the total annual emissions for northern and southern Europe were near average. However, when looking at individual months, fire emissions for Europe[18] as a whole—and for southwestern and southeastern Europe—were below average for every month except September. In southeastern Europe, some Balkan countries—notably North Macedonia, Bulgaria and Serbia—experienced above-average emissions for July and August. Emissions were also above average for Greece in September, although not on the same scale as in 2023. In southwestern Europe, large-scale fires in northern Portugal in mid-September generated well-above-average emissions.

Snow and glaciers

Key messages

- Glaciers in all European regions saw a net loss of ice in 2024.
- Glaciers in Scandinavia and Svalbard experienced their highest rates of mass loss on record and saw the largest annual glacier mass loss of any glacier region globally.
- Much of Europe experienced fewer days with snow than average, except for northern Europe during winter.

[17] This domain encompasses, besides the EU27 countries: Albania, Bosnia and Herzegovina, Kosovo under UNSCR 1244, Montenegro, North Macedonia, Norway, Serbia, Switzerland, Türkiye, the United Kingdom and Ukraine; and Algeria, Israel, Lebanon, Libya, Morocco, Palestinian Territory, Syria and Tunisia.

[18] The region of Europe used to investigate wildfire emissions encompasses Austria, Czechia, Denmark, Estonia, Finland, Germany, Hungary, Ireland, Latvia, Lithuania, the Netherlands, Poland, Sweden, Slovakia, and the United Kingdom (northern Europe) as well as Bulgaria, Croatia, Cyprus, France, Greece, Italy, Portugal, Romania, Slovenia, Spain (southern Europe). Southwestern Europe comprises France, Italy, Portugal and Spain; southeastern Europe comprises Bulgaria, Croatia, Cyprus, Greece, Romania and Slovenia.

The cryosphere encompasses all parts of the Earth system where water is in solid form, including ice sheets, glaciers, snow cover, permafrost and sea ice.

Snow plays an important role in weather and climate. Changes in snow cover can impact many other aspects of the Earth system, influencing temperatures, glacier mass balance, river flow, flooding and droughts.

A lack of snow during winter and spring has implications for conditions later in the year. For example, together with heatwaves and higher-than-average temperatures, it can contribute to drought conditions. Snowmelt during spring and summer is an important source of water for many of Europe's rivers. Positive anomalies in the number of snow days can be beneficial for hydropower and soil moisture, for example, but rapid snowmelt due to rising temperatures can increase the risk of flooding and avalanches.

Snow is also an important factor influencing glacier melt. In Europe, glaciers accumulate snow during winter and spring, and snow cover can delay melting of glacier ice in the warmer months. A lack of snow at the start of the year combined with warmer-than-average temperatures can result in increased mass loss from glaciers.

Changes in glacier mass balance—the balance between accumulation and melting of snow and ice—are directly linked to climate change and are important to monitor. For example, glacier melt contributes to runoff and to sea level rise. Over the last few decades, glaciers around the globe have been experiencing mass loss, and the European Alps is one of the regions where glaciers are shrinking the most.

In this section, we focus on snow days and glaciers across Europe. More information about sea ice can be found in the 'Arctic Ocean' section, and long-term trends in sea ice, ice sheets and glaciers are also covered in the climate indicators.

Snow days

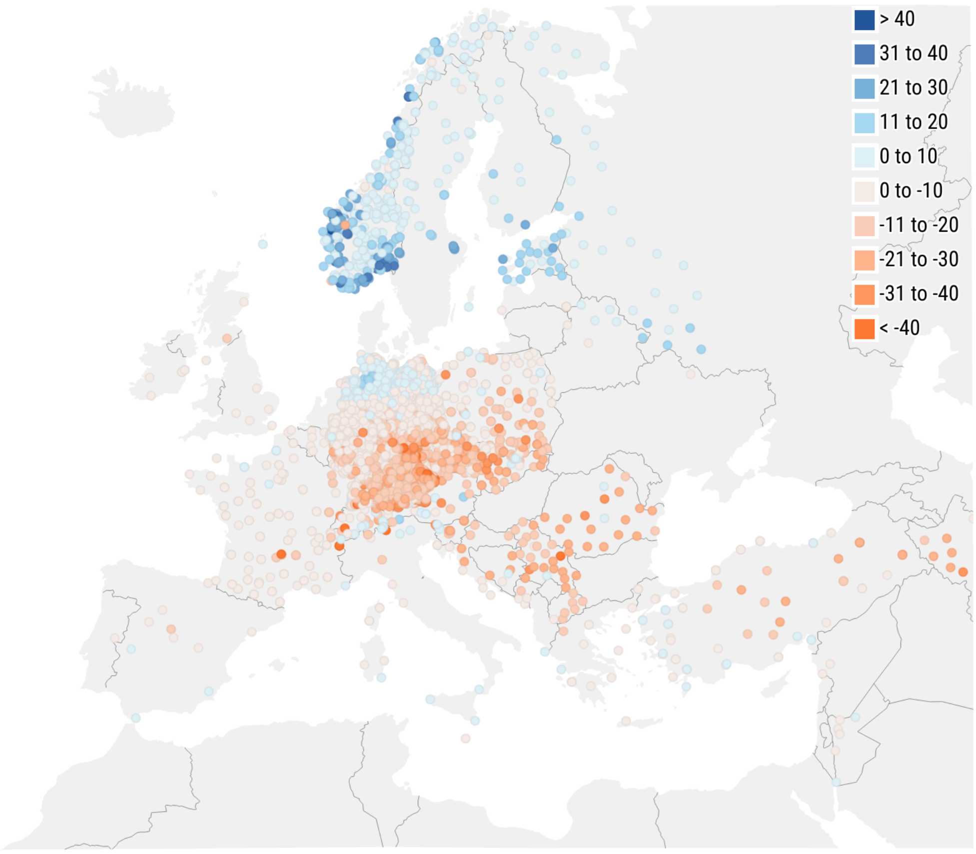
During winter, much of northern Europe—including Fennoscandia, Estonia, northwestern Russia and northern Germany—saw more snow days (when the depth is at least 1 cm) than average. For the season as a whole, this region also experienced cooler-than-average conditions. The largest positive snow day anomalies generally coincided with areas that were both cooler than average and saw more precipitation than average. Many locations in Norway saw 10–20 more snow days than average, but in southern Norway there were up to 40, and one location recorded 45 more snow days.

Most of the rest of Europe saw above-average temperatures during winter and, therefore, although there was above-average precipitation, there were fewer snow days than average. Anomalies ranged from -5 to -45 days, with the largest negative anomalies over southern Germany, southern Poland and the Balkans. Several locations in central Europe saw almost 50 fewer snow days than average.

In spring, almost all of Europe saw fewer snow days than average, except for high elevations in southern Norway and a few other locations in Fennoscandia, where there were up to 10 days more than average. Across central Europe there were as many as 20 fewer snow days than average, while much of Norway saw as many as 30, and in some locations up to 50 days fewer. This coincides with the areas that saw above-average temperatures and, in most cases, below-average precipitation during spring.

Anomalies in the number of snow days during winter 2024

Days when the snow depth is at least 1 cm



Data from December 2023 to February 2024.

Data: ECA&D • Reference period: 1991–2020 • Credit: C3S/ECMWF/KNMI

Figure 6.1. Anomalies in the number of snow days during winter 2024, relative to the average for the 1991–2020 reference period, showing more snow days than average (blue) and fewer snow days than average (orange). Winter covers the period December 2023 to February 2024. Data: ECA&D. Credit: C3S/ECMWF/KNMI.

Glaciers

Glacier changes are measured in hydrological years, accounting for the seasons of accumulation and melt. In Europe, the hydrological year begins on 1 October with the start of winter accumulation and finishes on 30 September of the following year with the end of the summer melt season. During the 2023–24 hydrological year, glaciers in all European regions lost ice.

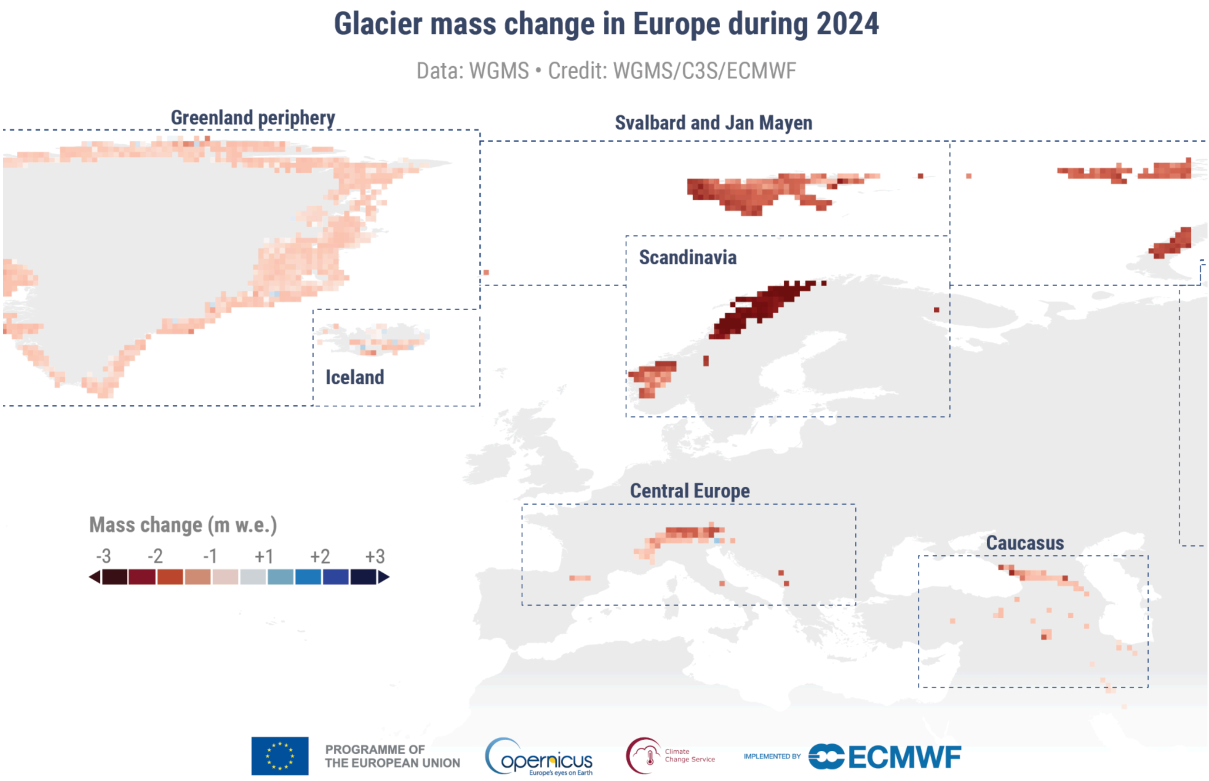


Figure 6.2. Mass change of glaciers across Europe for the 1 October 2023–30 September 2024 hydrological year, showing positive balances (increase of ice) (blue) and negative balances (loss of ice) (red). Annual mass change values are given in the unit 'metre water equivalent (m w.e.)', representing a glacier-wide average of 1000 kg m^{-2} and, accounting for ice density, corresponding to 1.1 m of ice thickness. For Greenland, peripheral glaciers are shown, but the Ice Sheet is not included in this dataset. Data: WGMS. Credit: WGMS/C3S/ECMWF.

Glaciers in Scandinavia and Svalbard experienced their highest rates of mass loss on record in 2024, with an average ice thickness loss of 1.8 m in Scandinavia and 2.7 m in Svalbard. These regions also saw the largest annual mass loss of all glacier regions globally. This is likely due to enhanced summer melt, with the region seeing much warmer-than-average temperatures throughout the summer, with record-breaking temperatures in August and September. Much of Scandinavia also saw a below-average number of snow days in spring. This could be an indicator of an extended melt season.

Over the last decade, central Europe is one of the regions of the world where glaciers are receding the fastest, alongside Iceland, the southern Andes, Alaska, western Canada and the USA. 2024 was another exceptional year in the Alps, with an average ice thickness loss of 1.2 m. Although large, this is considerably less than the extreme losses observed in 2022 (3.6 m) and 2023 (2.4 m).

During winter and spring, precipitation in the Alps was much above average. However, most locations saw an average number of snow days. This implies that, despite above-average temperatures, precipitation was still able to contribute to snow cover in the upper mountain ranges, having a compensating effect and resulting in a slightly smaller amount of glacier ice loss in the Alps compared to previous years. 2024 was the warmest year on record in Europe, and the Alps saw above- or much above-average temperatures in every month except April and September. Record-breaking temperatures in August probably contributed to high glacier melt rates at the end of summer, likely linked to the overall glacier mass loss for the year.

In Iceland, the only country in Europe to observe much cooler-than-average temperatures in 2024, glaciers still experienced an overall ice thickness loss of 0.8 m, but this was around half the rate of glacier loss seen in 2023 (1.4 m).

Precipitation

Key messages

- In 2024, there was a clear east-west contrast in conditions across Europe.
- It was one of the ten wettest years on record for western Europe, with the most above-average precipitation observed in France, northern Italy, Belgium, the Netherlands, Luxembourg, Denmark and northern Fennoscandia.

- Across eastern and southeastern Europe, conditions were drier than average. When considering a period from 1979 onwards, parts of Ukraine and Russia saw their driest year.

Precipitation is a key component of the global water cycle. It is important for public water supply, food production, the health of the natural environment and inland waterway transport. Above-average or below-average precipitation can be a precursor to floods or droughts.

This section gives an overview of anomalies and extremes in annual precipitation across the continent in 2024, variations throughout the year, the number of wet days, and provides historical context for the findings.

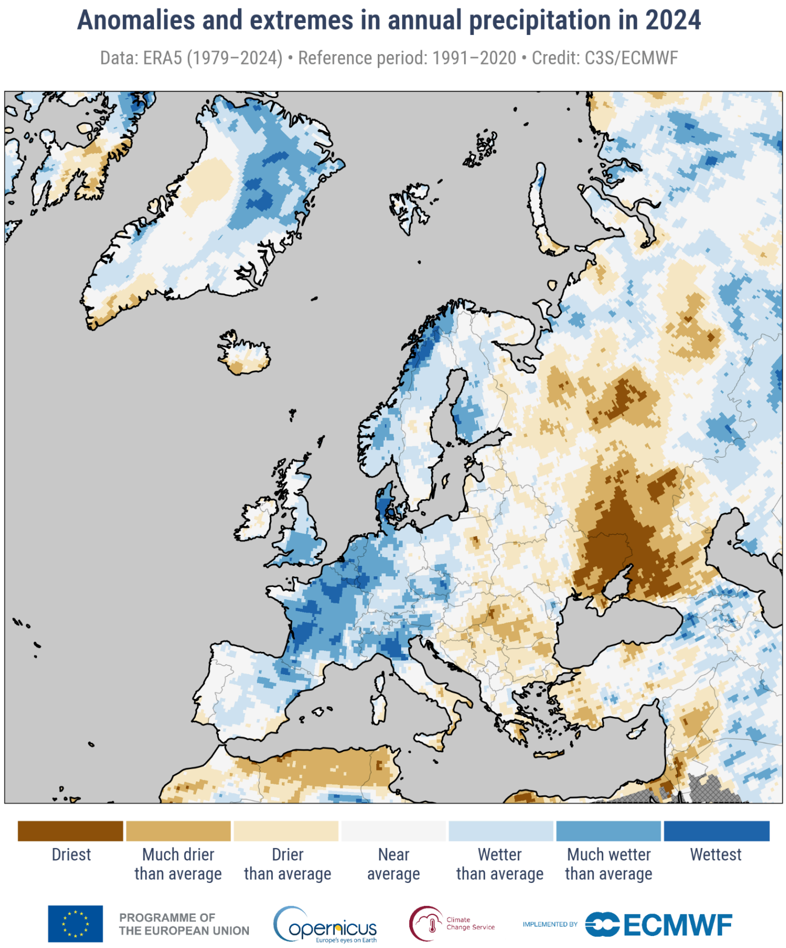


Figure 7.1. Anomalies and extremes in annual precipitation in 2024. The extreme categories ('wettest and 'driest) are based on rankings for 1979–2024. The other categories describe how precipitation compares to the distribution during the 1991–2020 reference period. 'Much wetter/drier than average' - wetter/drier than 90% of precipitation values. 'Wetter/drier than

average' - than 66% of precipitation values. 'Near average' - within the middle 33%. Data: ERA5. Credit: C3S/ECMWF.

In 2024, Europe experienced above-average precipitation overall[19], with around 34% of the land area[20] seeing above-average annual precipitation.

There was a pronounced east-west contrast in conditions. Western Europe saw widespread wetter-than-average conditions, with some areas in a swathe from Spain and Italy to northern Fennoscandia experiencing their wettest year in the period since 1979[21]. For western Europe, excluding Iceland, it was one of the ten wettest years[22] in the analysed period since 1950.

Across most of eastern Europe, conditions were drier than average, with eastern Ukraine and parts of southwestern Russia having their driest year in the same period.

[19] Overall precipitation for Europe was 1.9% above average based on ERA5 and 5% above average based on E-OBS. When including Greenland, the Caucasus and parts of the Middle East, it was 0.5% above average based on ERA5 and 3.2% above average based on GPCC.
[20] Based on ERA5.
[21] In some of the spatial detail, ERA5, E-OBS and GPCC show differences. Read more in the dataset discussion within the 'About the data' section online.
[22] Due to differences between datasets that require further analysis, establishing a definitive ranking so soon after the end of the year can be challenging. Two datasets, ERA5 and E-OBS, indicate that 2024 was the wettest year on record for western Europe, excluding Iceland, with precipitation at 13-14% above average. The GPCC dataset (based on the 'Monitoring' product for 2021–2024), however, indicates that 2024 was the tenth wettest year in the period since 1950, with 1960 being the wettest at around 16% above average. At the time of publication, the consensus is that 2024 was one of the ten wettest years for western Europe in the analysed period since 1950.

Monthly variations

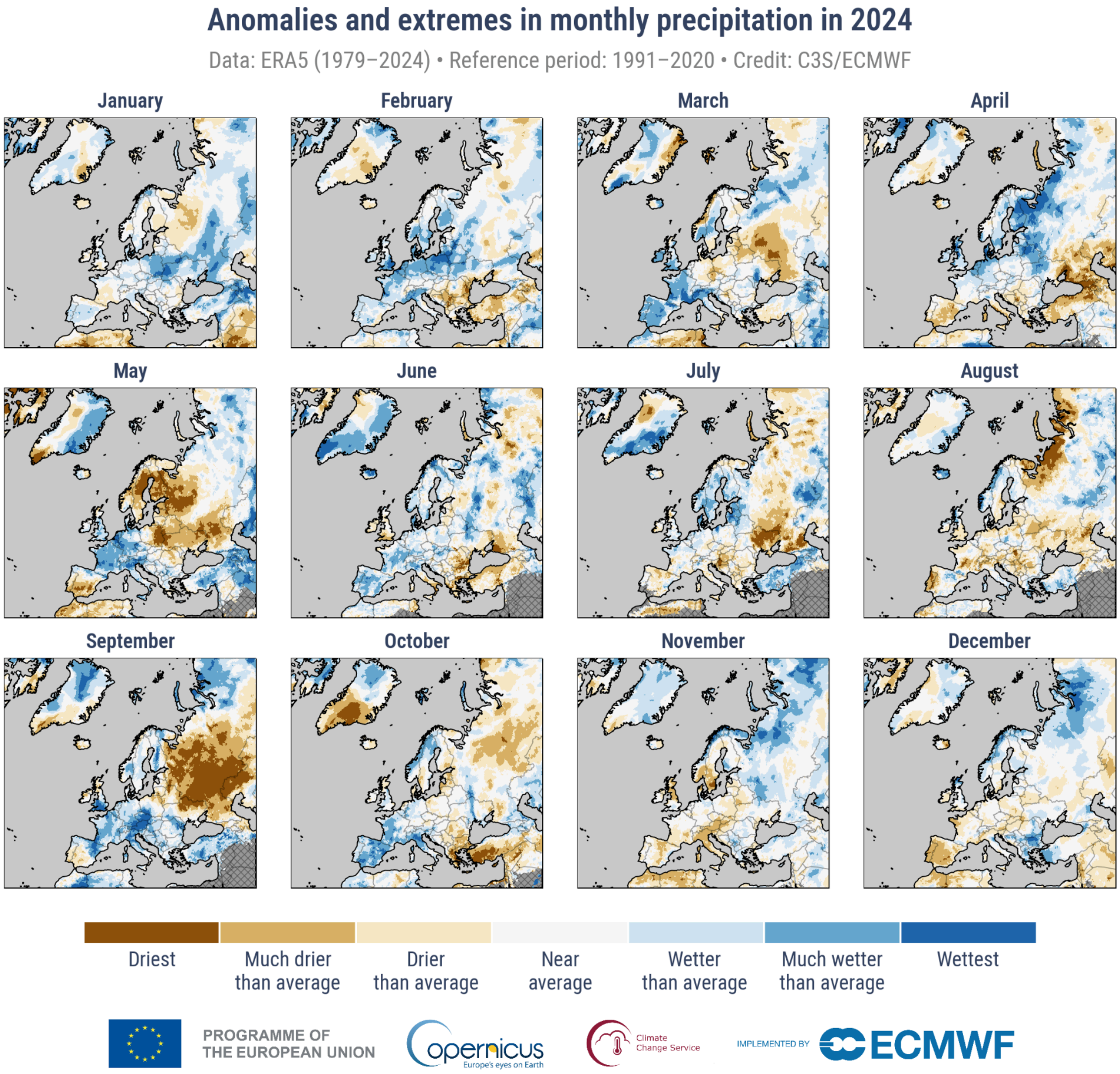


Figure 7.2. Anomalies and extremes in monthly precipitation in 2024. The extreme categories (‘wettest and ‘driest) are based on rankings for 1979–2024. The other categories describe how precipitation compares to the distribution during the 1991–2020 reference period. ‘Much wetter/drier than average’ - wetter/drier than 90% of precipitation values. ‘Wetter/drier than average’ - than 66% of precipitation values. ‘Near average’ - within the middle 33%. Data: ERA5. Credit: C3S/ECMWF.

Monthly-averaged maps show more detail about the variation in precipitation throughout the year, with some of these anomalies linked to notable severe weather events.

Winter and spring
Wetter-than-average conditions were seen across northern and western Europe during winter and spring. Some areas, such as eastern Fennoscandia and northwestern Russia, had their wettest April in the period since 1979. Conversely, drier-than-average conditions occurred in eastern Europe, including widespread areas in northeastern Europe that saw their driest May in the period since 1979.

Summer
Wetter-than-average conditions continued across western Europe in June, and some parts of Greenland experienced large wet anomalies during June and July. Southeastern Europe saw the most prominent dry conditions and had its driest summer in a 12-year record, according to the 'drought index'[R3] measure of drought severity.

Autumn
September saw its wettest conditions in central Europe in the period since 1979, due to extreme precipitation over central and eastern Europe from Storm Boris, resulting in widespread severe flooding. This contrasted with widespread dry conditions across eastern Europe and western Russia.

October saw wetter-than-average conditions across western Europe. In particular, extremely wet conditions occurred in eastern Spain that were related to devastating flooding in the Valencia region. In November, northern Russia had wetter-than-average conditions, whereas western and central Europe were mostly drier than average.

Wet days in 2024

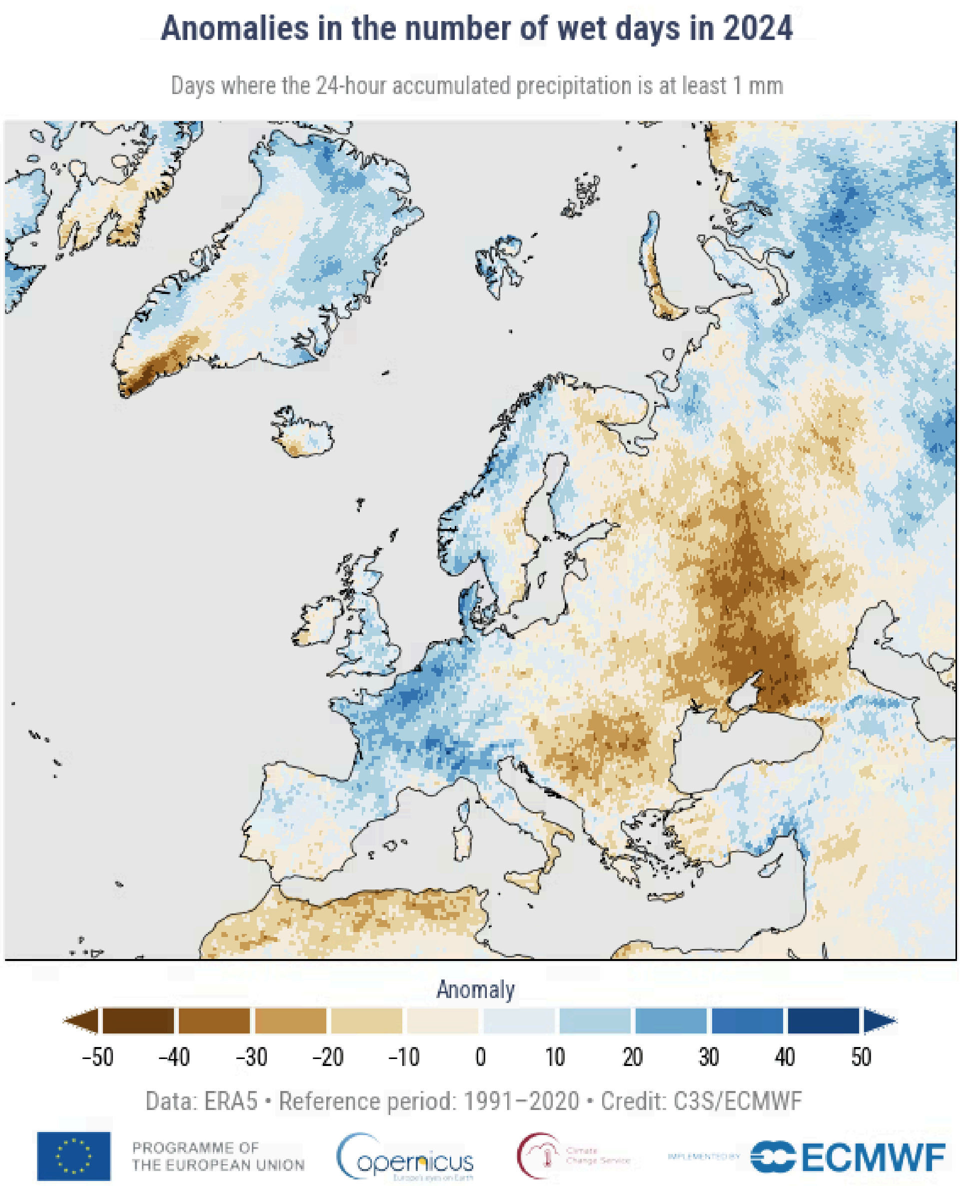


Figure 7.3. The anomaly in the number of wet days, where the 24-hour accumulated precipitation is at least 1 mm, in 2024, from -50 days (dark brown) to +50 days (dark blue), relative to the average for the 1991–2020 reference period. Data: ERA5. Credit: C3S/ECMWF.

The general east-west contrast in conditions was also clearly reflected in the number of wet days—those where the 24-hour accumulated precipitation is at least 1 mm. The year was characterised by more frequent precipitation in larger amounts than average in western areas and less frequent precipitation in smaller amounts in eastern areas.

In particular, the number of wet days was higher than average across western Europe, most notably over France, Belgium, the Netherlands and Denmark, where there were 30–40 more wet days than average. Northern and eastern Greenland, most of Norway and a region from northern Kazakhstan to northern Russia also had more wet days than average. In contrast, a broad region covering the Balkans, Ukraine and western Russia had fewer wet days than average, with some areas having up to 50 fewer days.

Soil moisture

Key messages

- In 2024, surface soil moisture was drier than average for Europe as a whole.
- There was a clear east-west contrast, with eastern Europe experiencing drier-than-average conditions and western Europe being wetter than average.

Soil moisture is a key component of Earth's climate and hydrological systems. It plays a crucial role in the exchange of water and energy between the land surface and the atmosphere, influencing weather patterns, temperature regulation and the water cycle. Soil moisture affects atmospheric processes and climate predictability. Prolonged soil moisture deficits can lead to drought conditions, reducing crop yields and increasing the risk of wildfires. Both high and low soil moisture can contribute to flooding, soil erosion and land degradation.

In this section, the data represent conditions in the first few centimetres (~0–7 cm) of the soil.

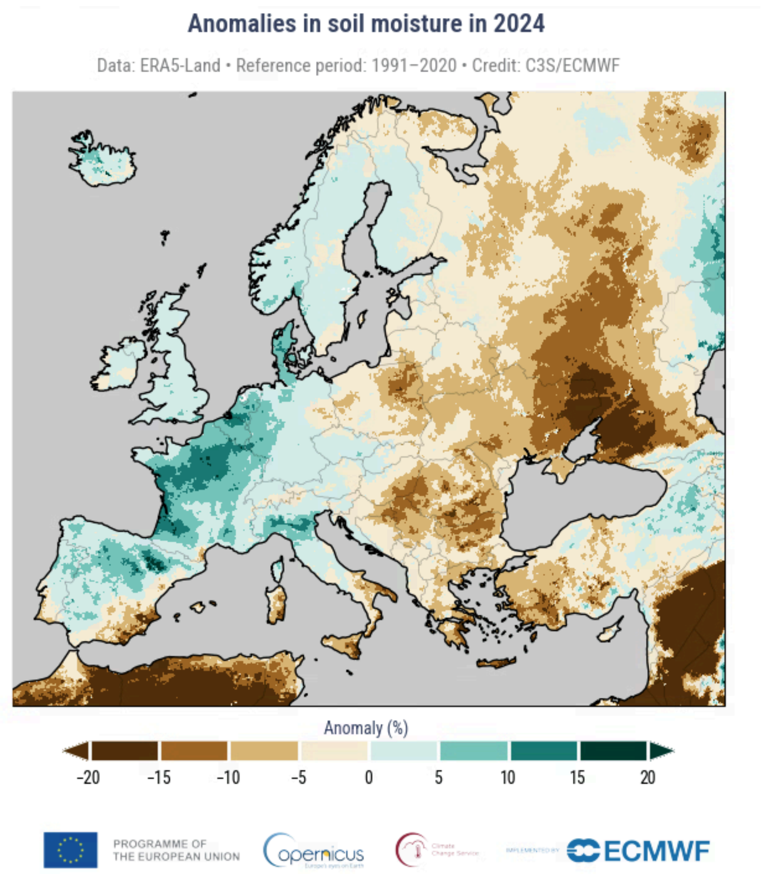


Figure 8.1. Annual surface soil moisture anomalies (%) in 2024, showing positive (green) and negative (brown) anomalies, expressed as a percentage of the annual average for the 1991–2020 reference period. Data: ERA5-Land. Credit: C3S/ECMWF.

Averaged over Europe, a trend towards increasingly dry surface soil moisture conditions has been observed over the past two decades, with the annual soil moisture anomaly for 2024 also indicating drier-than-average conditions.

Despite this, there was a clear east-west contrast, with eastern Europe experiencing widespread drier-than-average conditions and some areas facing severe droughts. Western Europe, however, had slightly higher-than-average surface soil moisture. The contrast was particularly evident in the summer and autumn months, with negative and positive anomalies of around 10% in the east and west, respectively.

Soil moisture extremes

Denmark had an exceptionally wet summer, with some regions experiencing record-high soil moisture conditions of 30–40% above average during both June and July, based on records dating back to 1950. Together with above-average precipitation during summer, this led to localised flooding.

In contrast, eastern Ukraine and western parts of Russia faced extremely low soil moisture conditions, of around 50% below average, which began in the summer months and intensified through autumn. The most severe and widespread dry anomalies occurred in September.

Similarly, during summer and autumn, southeastern Europe experienced lower-than-average surface soil moisture conditions and endured multiple heatwaves. During heatwaves, dry soils reduce evaporative cooling, thus amplifying increases in temperature and intensifying heat extremes. This effect is particularly strong in regions that are already warm and dry.

At the beginning of October, Storm Kirk swept across France. The associated flooding was worsened by already saturated soils, following higher-than-average precipitation in September.

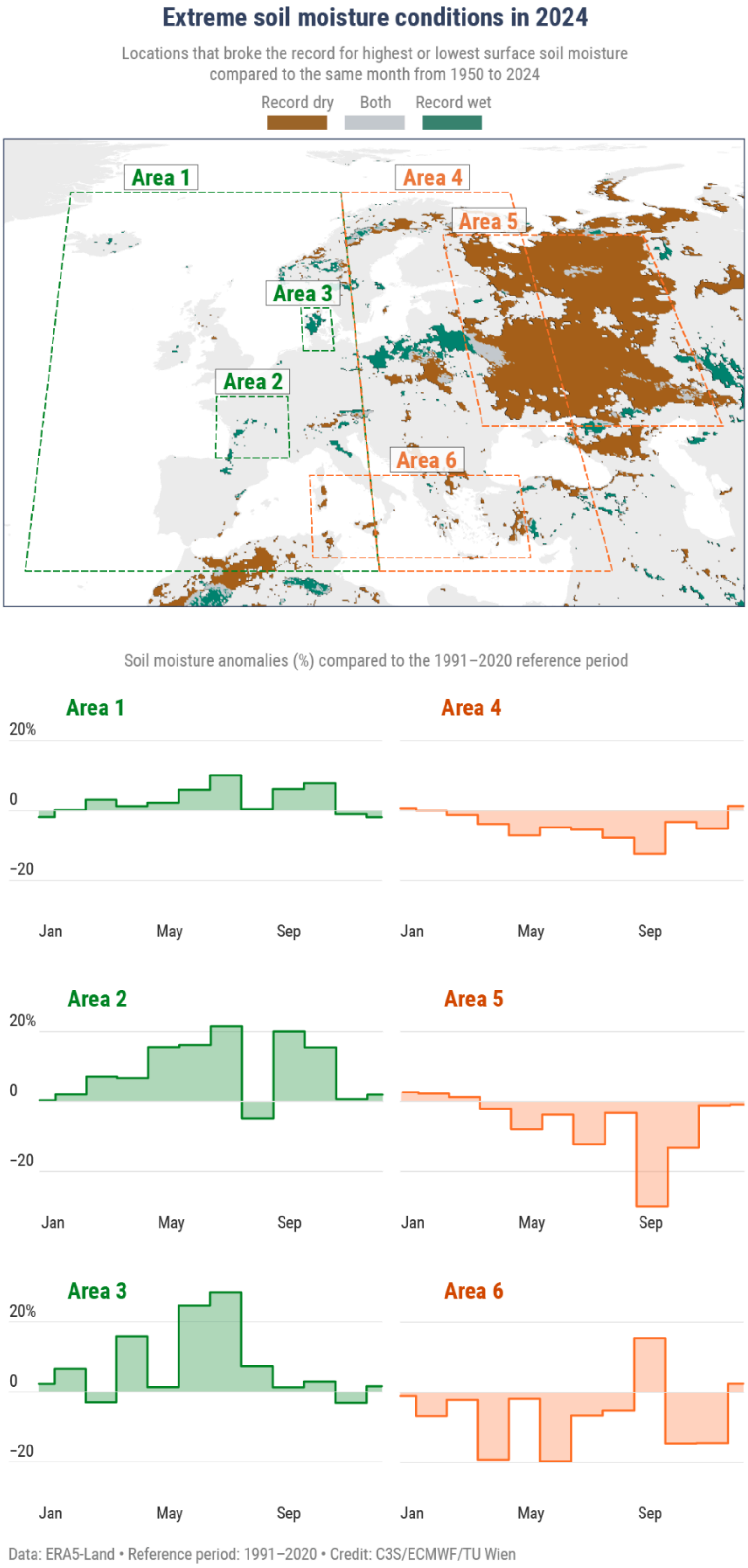

Extreme soil moisture conditions in 2024
Locations that broke the record for highest or lowest surface soil moisture compared to the same month from 1950 to 2024
Record dry
Both
Record wet
Area 1
Area 2
Area 3
Area 4
Area 5
Area 6
Soil moisture anomalies (%) compared to the 1991–2020 reference period
20%
0
-20
Jan
May
Sep
Data: ERA5-Land • Reference period: 1991–2020 • Credit: C3S/ECMWF/TU Wien

Figure 8.2. Areas of Europe with record wet or dry monthly conditions in 2024, showing positive (green) and negative (brown) anomalies, compared to the same month from 1950–2024. Time series of 2024 monthly anomalies, showing positive (light green) and negative (light orange) anomalies, relative to the average for the 1991–2020 reference period. Data: ERA5-Land. Credit: C3S/ECMWF/TU Wien.

River flow

Key messages

- In 2024 there was a clear east-west contrast in river flow conditions across Europe.
- Western Europe saw widespread higher-than-average river flows, with some catchments, such as the Thames in the United Kingdom and the Loire in France, experiencing their highest flows in a 33-year record in four months of spring and autumn.
- Eastern Europe saw lower-than-average river flows for much of the year, with the lowest November flows on record.

River flow is the volume of water flowing through a river channel, as measured at a given point, in cubic metres per second. High river flow can lead to flooding, while low river flow can negatively impact species dependent on freshwater and riverside ecosystems. In extreme cases, low river flow can develop into a hydrological drought, affecting public water supply, hydroelectric power generation and commercial river transport, for example.

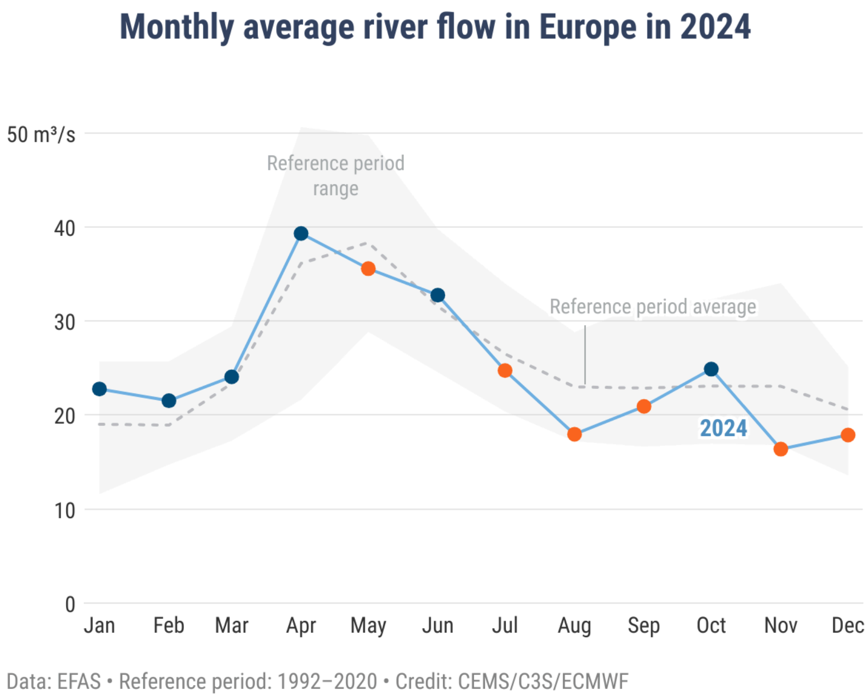


Figure 9.1: Monthly average river flow (m^3/s) for Europe, showing below-average (orange dots) and above-average (blue dots) river flow, with the range between monthly minimum and maximum flows, based on the 1992–2020 reference period (grey shading), and the average for the reference period (dashed grey line). Data: EFAS. Credit: CEMS/C3S/ECMWF.

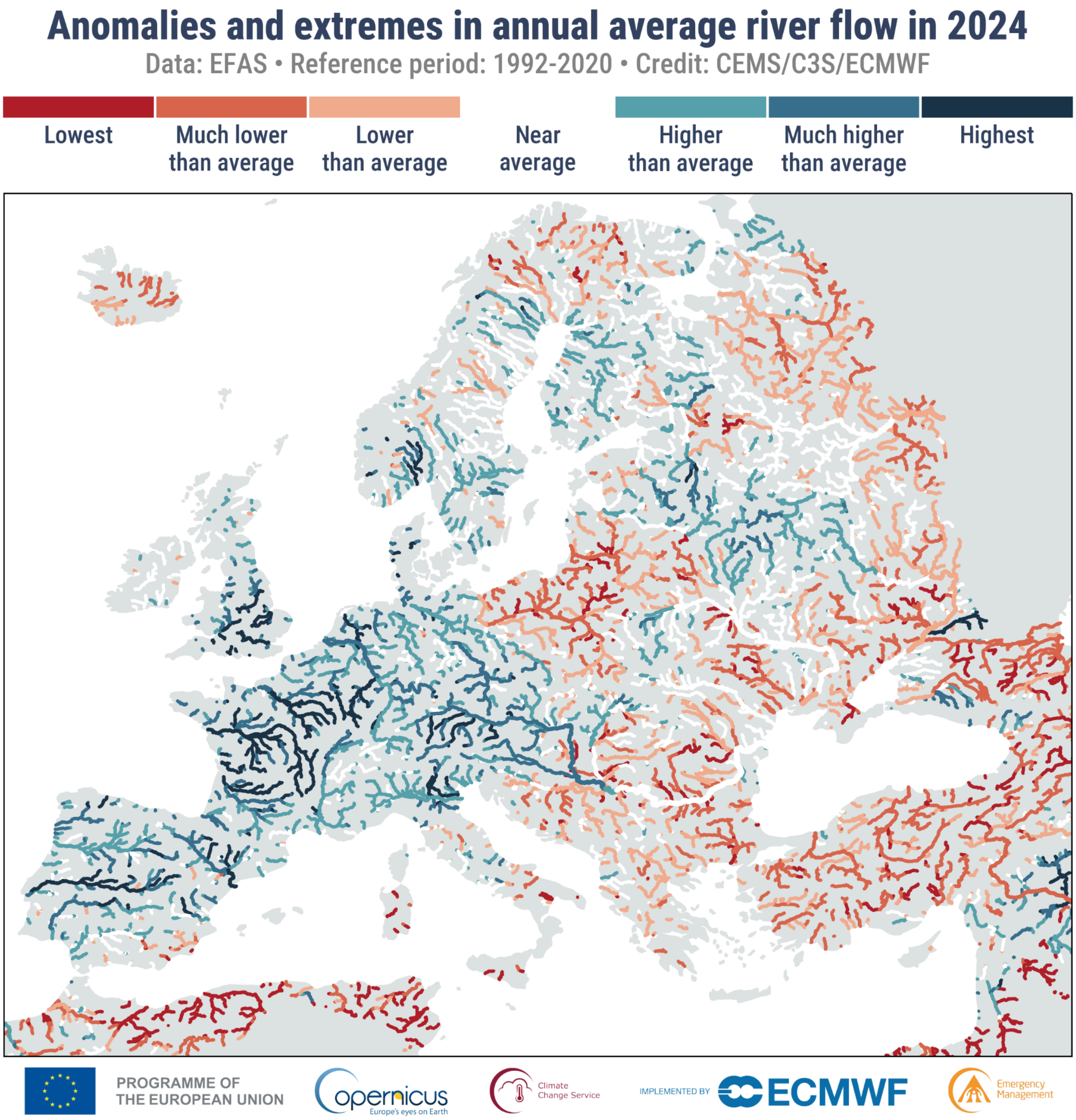


Figure 9.2: Anomalies and extremes in annual average river flow in 2024. The extreme categories (highest' and 'lowest') are based on rankings for 1992–2024. The other categories describe how river flow compares to the distribution during the 1992–2020 reference period. 'Much higher/lower than average' - higher/lower than 90% of river flow values. 'Higher/lower than average' - than 66% of river flow values. 'Near average' - within the middle 33%. Only rivers with drainage areas greater than 1000 km^2 are shown. Data: EFAS. Credit: CEMS/C3S/ECMWF.

For Europe as a whole, river flows in 2024 were generally around average, but with a pronounced east-west contrast. Western areas saw above-average flows, while 40% of the river network, mainly in the east, saw below-average flows. The spatial pattern largely reflects those of precipitation and soil moisture, however, the above-average flow region extends further east in the Danube catchment, as the flow drains towards the Black Sea. Flows were above average from January to April and in June and

October, and below average in May, July to September, and in November and December. The most below-average flows were seen in August and November. August saw the third lowest flows on record for the month while November saw the lowest flows for the month, based on a record starting in 1992.

Monthly variations

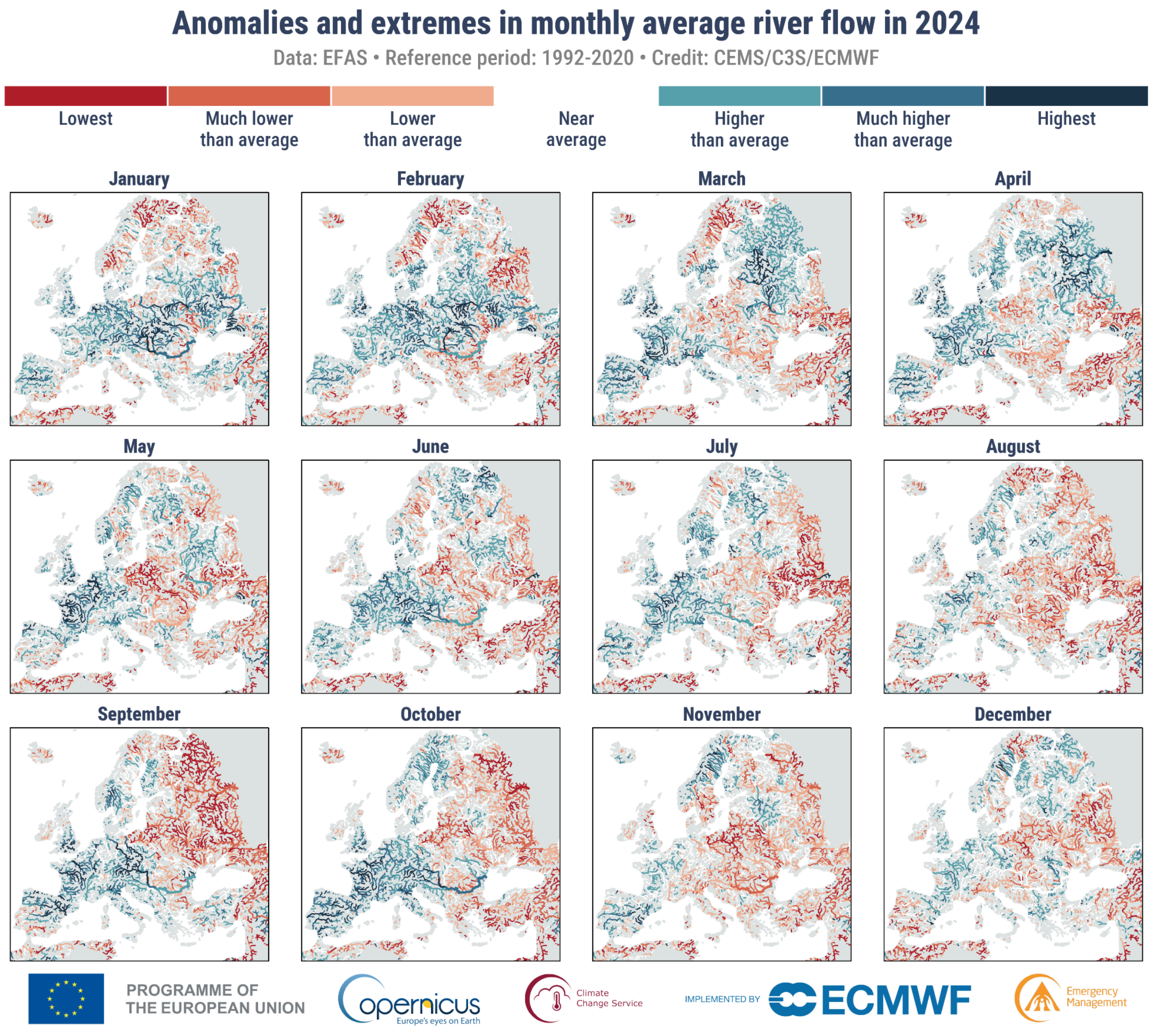


Figure 9.3: Anomalies and extremes in monthly average river flow in 2024. The extreme categories (highest' and 'lowest') are based on rankings for 1992–2024. The other categories describe how river flow compares to the distribution during the 1992–2020 reference period. 'Much higher/lower than average' - higher/lower than 90% of river flow values. 'Higher/lower than average' - than 66% of river flow values. 'Near average' - within the middle 33%. Only rivers with drainage areas greater than 1000 km^2 are shown. Data: EFAS. Credit: CEMS/C3S/ECMWF.

From January to April, most rivers across Europe had above-average monthly flows. In February, 44% of European rivers saw at least higher-than-average flow, the largest proportion of the year, and several regions, mainly in eastern and central Europe, saw their highest river flows on record.

River flows in western Europe remained above average in March, April and May. The Thames, in the United Kingdom, saw much above-average flows for most of the year, with record-high flows[23] for the time of year in March, May, September and October. In the Loire, in France, flows remained above average for the whole year, with record-high flows for the time of year in April, May, September and October.

During the summer, anomalies in flows in many rivers began to decrease and by August 53.9% of rivers were experiencing lower-than-average flows for the time of year. The most-affected areas were those surrounding the Black Sea in eastern Europe. Many large rivers in central Europe, including the Danube River basin, also saw either near- or below-average flows, with some smaller tributaries showing record-low flows for August.

A widespread flood affected central and eastern Europe in September due to Storm Boris, but there remained a strong east-west contrast in river flow. Lower-than-average flows were seen across around 50% of the river network, mainly in the east, and higher-than-average flows in central and western Europe. Many rivers in central Europe transitioned from lower-than-average to record-high flows for the time of year during the month.

In October, river flows in the Iberian Peninsula transitioned from near or below average to much higher than average, and even record high, as seen for the Tagus River, which flows from Spain into Portugal. October also saw devastating local flooding in Valencia, in eastern Spain.

November saw a record 54.4% of rivers with below-average flow for the month. This included rivers in southeastern Europe that were affected by extreme heat and drought. The Evros, for example, which flows from southern Bulgaria through northeastern Greece and northwestern Türkiye, experienced record or near-record low flow for all months in 2024. The Vistula in eastern Poland had record or near-record low flows from May to December.

Lakes

Key messages

- 2024 was the warmest year on record for European lakes.

[23] Based on the EFAS dataset for the full European river network, which starts in 1992. Observational data may be available with longer-term records of river height and other measurements for some locations, such as the Thames.

- The surface water temperature of European lakes was 0.77°C above average during their warm season, which runs from July to September, and is increasing at a rate of about 0.34°C per decade.
- During June to September, lake water level anomalies largely reflected the anomalies seen in precipitation and soil moisture. Southern Europe showed a stark east-west contrast with below-average values in the east and above-average values in the west.

Lakes act as both indicators and regulators of climate variability and change and, as such, are vulnerable to their impacts. For example, shorter periods of ice cover provide a changing environment for species populating the lake and, in some cases, changing temperatures may impact survival thresholds[24]. Nutrient and oxygen distributions may also change, which could have consequences for the ecosystem.

Lake levels directly respond to changes in climate variables such as precipitation, temperature and relative humidity. Anthropogenic activities, such as land use, can also influence them.

As well as responding to climate change, lakes also influence the local weather and climate.

This section focuses on lake surface water temperature (LSWT) and lake water levels (LWL) during the warm season (July to September and June to September, respectively) in Europe in 2024. LSWT is the temperature of the lake water at the surface while LWL is the water level above Earth's surface. Both are estimated using satellite observations.

Lake surface water temperatures

[24] More information on the impact of warming waters on lake ecosystems can be found in the review paper by Woolway et al. (2020), for example.

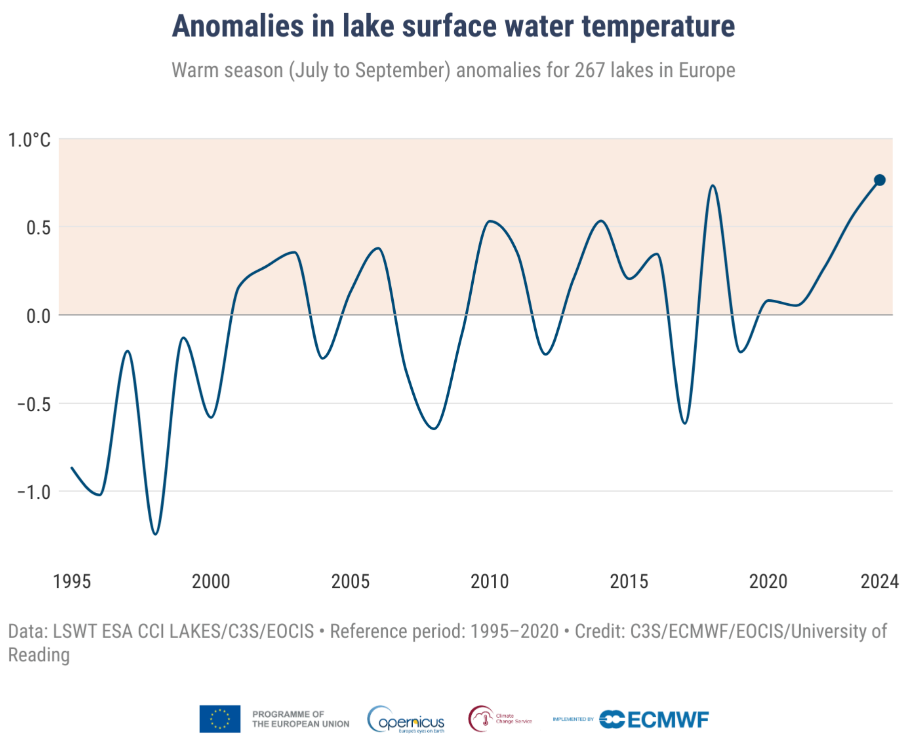


Figure 10.1. Lake surface water temperature anomalies (°C), relative to the average for the 1995–2020 reference period, for 1944 lakes globally and for 267 European lakes. Values are averages for the warm season in the Northern (July–September) and Southern Hemisphere (January–March) with annual averages for tropical lakes. The dashed lines indicate the estimated linear trend. Data: LSWT ESA CCI LAKES/C3S/EOCIS. Credit: C3S/ECMWF/EOCIS/University of Reading.

The average LSWT for the warm season of the 267 European lakes was the highest on record, at 0.77°C above the average for 1995–2020.

In southern Europe, lakes were warmer than average in July (+0.72°C) and in August (+1.36°C), but cooler than average in September (-0.27°C). This meant that, for the warm season as a whole, the LSWT was only slightly above average. In eastern Europe, the LSWT was consistently above average throughout July, August and September. In Iceland, the United Kingdom and Ireland, the LSWT was below average in June and July and near average in August. For the rest of Europe, the LSWT was more variable during the season. In the Alpine region of Switzerland, for example, the LSWT was moderately above average, resulting from high positive anomalies in August (+1.45°) and slightly negative anomalies in September (-0.80°C).

European lakes are warming at a rate of around 0.34°C per decade, which is faster than the global rate of around 0.22°C per decade.

Lake water levels

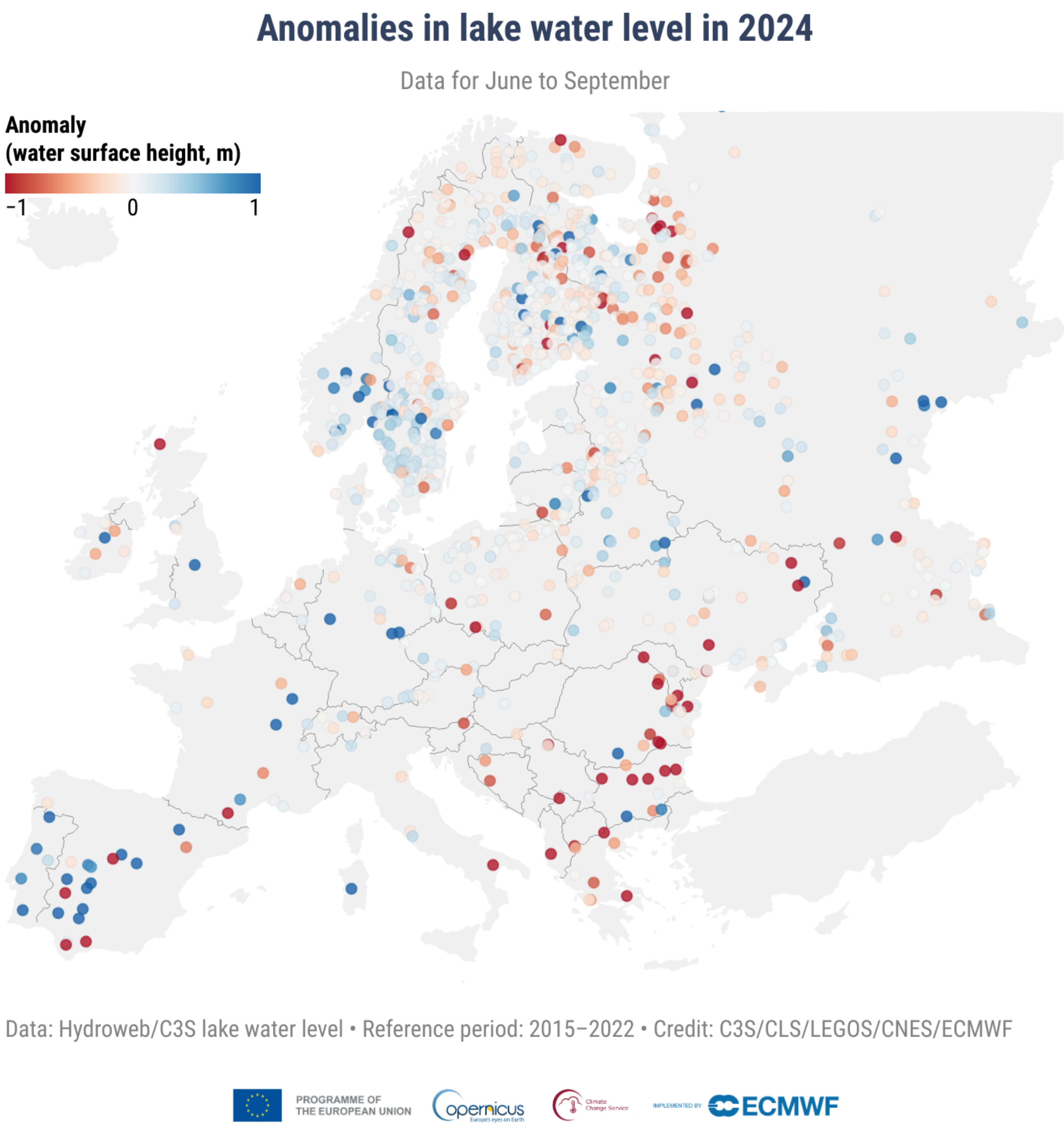


Figure 10.2. Lake water level (coloured dots) anomalies (metres) in Europe for June–September, relative to the average for the 2015–2022 reference period. Data: Hydroweb/C3S lake water level. Credit: C3S/CLS/LEGOS/CNES.

The warm season saw contrasts in LWL anomalies across different parts of Europe, largely reflecting the predominant precipitation and soil moisture conditions. The Iberian Peninsula, much of northern Europe and some parts of eastern Europe had higher-than-average LWLs relative to the 2015–2022 reference period, associated with wetter-than-average conditions. Southeastern Europe, however, which experienced lower-than-average precipitation and below-average soil moisture levels with persistent drought conditions, saw below-average LWLs.

In addition to environmental conditions, human activities can also affect the water levels of both natural and artificial lakes. In some cases, water management, particularly associated with agricultural irrigation, plays a significant role in lowering lake levels, especially when conditions are drier than average. This is the case for Lake Prespa, a natural lake, on the border of North Macedonia, Albania and Greece, and the artificial Guadalhorce reservoir in Spain.

European Ocean

Key messages

- The annual average sea surface temperature for the European region in 2024 was the highest on record, slightly above the previous record set in 2023.
- The Mediterranean Sea as a whole recorded its highest annual sea surface temperature, significantly exceeding the previous record set in 2023. In August, it also reached its highest daily sea surface temperature, surpassing the previous record set in July 2023.
- Sea surface temperatures (SSTs) were above average across most of the region, except in the Iceland Sea and southwest of Greenland. Record-high annual SSTs were observed in the central North Atlantic, Mediterranean, Black, Norwegian and Barents Seas.

Covering around 71% of Earth's surface, the ocean plays a crucial role in the climate system as a heat store. It has absorbed 90% of the excess heat caused by anthropogenic greenhouse gas emissions. Rising ocean temperatures can lead to significant impacts, such as shifting habitats, coral bleaching and mass mortality of marine species.

Sea surface temperatures (SST) are a key indicator for understanding energy exchanges between the ocean and atmosphere, as well as the ocean's role in shaping weather and climate.

Marine heatwaves—periods of unusually high ocean temperatures—can have severe impacts on marine ecosystems and biodiversity. They also have socio-economic consequences, particularly for industries such as fisheries, aquaculture and tourism.

Primary production is the process by which organic compounds are produced, mainly through photosynthesis. It is an indicator of ocean health and its response to climate change. Primary production can be monitored via satellite measurements of chlorophyll a, a photosynthetic pigment in phytoplankton.

This section provides an overview of annual sea surface temperatures across the European region and variations throughout the year, and discusses marine heatwave conditions in the Mediterranean Sea. It also provides information on anomalies in Chlorophyll a concentrations.

Sea surface temperature

Alongside a long-term warming trend since records began in 1979, the average sea surface temperature (SST) across the European region[25] has been significantly warmer over the past three years than in any previous year on record. During 2024, the annual SST for the European region as a whole reached a new high of 13.73°C. This was 0.69°C above average and 0.06°C warmer than the previous record set in 2023.

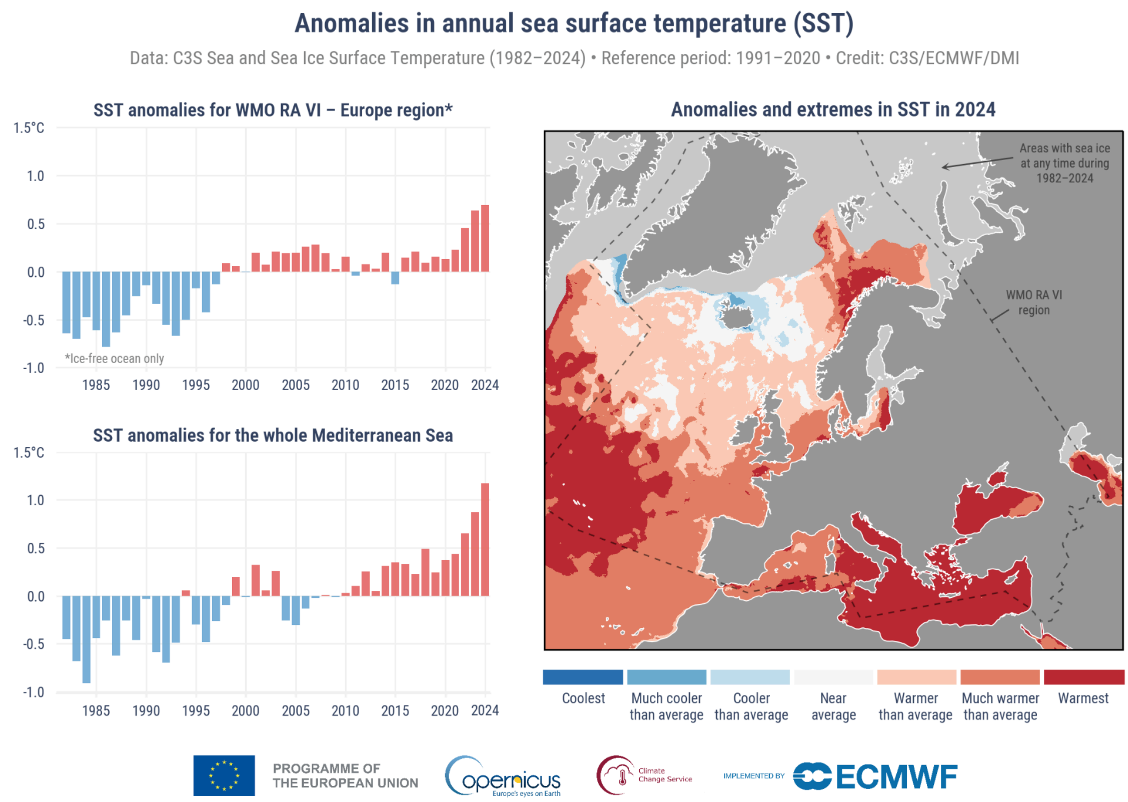


Figure 11.1. (Left) Annual average sea surface temperature (SST) anomalies (°C) for 1982–2024, relative to the average for the 1991–2020 reference period, for (top) the WMO

[25] In this section, the European region refers to all seas and the ocean contained within the WMO RA VI (Europe) domain. Figure 11.1 includes a map of this region.

RA VI (Europe) region and (bottom) the whole Mediterranean Sea. (Right) Anomalies and extremes in annual SST in 2024. The extreme categories ('coolest' and 'warmest') are based on rankings for 1982–2024. The other categories describe how the temperatures compare to their distribution during the 1991–2020 reference period. 'Much cooler/warmer than average' - cooler/warmer than 90% of temperatures. 'Cooler/warmer than average' - than 66% of temperatures. 'Near average' - within the middle 33%. Data: C3S Sea and Sea Ice Surface Temperature v1.0. Credit: C3S/ECMWF/DMI.

Annual SSTs were above average across most of the region, except in the Iceland Sea and southwest of Greenland. Record-high annual SSTs were observed in three ocean sectors: the central North Atlantic; the eastern Mediterranean Sea and Black Sea; and the Norwegian Sea and the eastern Barents Sea.

The Mediterranean Sea as a whole also experienced its warmest year on record, at 21.5°C. This was 1.2°C above average and 0.3°C higher than the previous record set in 2023.

For much of January and April, southern areas of the European region saw much warmer-than-average or record-breaking SSTs, while the North Sea, Baltic Sea and Gulf of Bothnia saw cooler-than-average SSTs. Large parts of the Mediterranean Sea experienced well-above-average SSTs for most of the year, particularly in eastern areas, where SSTs reached record highs from January to April and June to September.

High SSTs in the Mediterranean have been linked to more intense storms and more extreme rainfall. For example, during the devastating Storm Daniel in 2023, high SSTs likely provided additional energy and moisture[R7], contributing to the storm's intensification. In 2024, above-average SSTs in the Mediterranean may have been a factor in the extreme rainfall associated with Storm Boris, which led to flooding in central and eastern Europe in September and with severe flooding in the Valencia region[R8] in Spain in October. The 'Flooding' section provides more information on these events.

Mediterranean marine heatwave

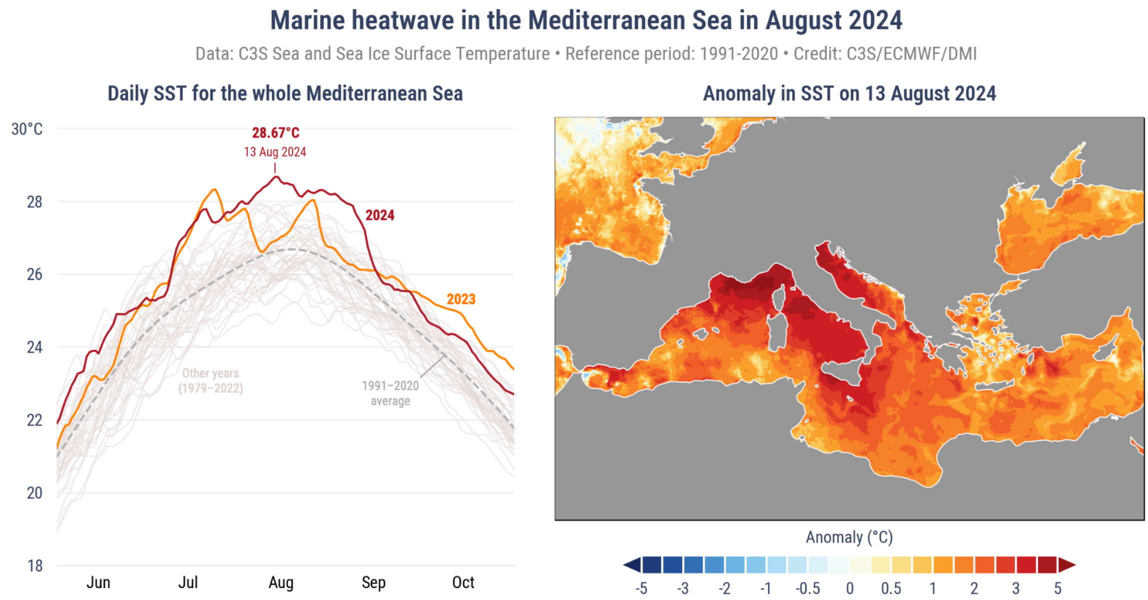


Figure 11.2. (Left) Daily sea surface temperatures (°C) for the Mediterranean Sea as a whole during 2023 (orange) and 2024 (red), and previous years since 1982 (grey). (Right) Daily sea surface temperature anomalies (°C) on 13 August 2024, the day of the highest SST across the Mediterranean Basin, relative to the average for the 1991–2020 reference period. Data: C3S Sea and Sea Ice Surface Temperature v1.0. Credit: C3S/ECMWF/DMI.

Daily SSTs averaged across the entire Mediterranean Sea reached their highest recorded values in mid-August, peaking at 28.7°C on 13 August. This surpassed the previous record of 28.3°C set in July 2023. While record SSTs during the summer were primarily observed in the Adriatic Sea and the eastern Mediterranean basin, SSTs on 13 August were most above average in the western Mediterranean, with anomalies reaching up to 4°C in the Ligurian Sea and northern Adriatic Sea, and up to 6°C in the Gulf of Lion. These large positive anomalies corresponded to a Category 3[26] ('severe') marine heatwave and coincided with a heatwave affecting the surrounding land areas.

Ocean colour

The presence of Chlorophyll a (Chl a) directly affects ocean colour, as it contributes to the greenish hue typically associated with regions abundant in phytoplankton.

[26] Marine heatwaves are often categorised based on their intensity. A Category 3 marine heatwave has an SST that exceeds the average by at least three times the difference between the average SST and the 90th percentile.

Ocean colour can be used to monitor water quality, the health of aquatic ecosystems and the uptake of carbon dioxide by phytoplankton—an important carbon sink.

Variations in Chl a concentrations are linked to the availability of sunlight and nutrients, and to the grazing of zooplankton on the phytoplankton. While more Chl a can be an indicator of increased primary productivity and a healthier marine ecosystem, it can also be a sign of environmental stress and imbalances. The relationship between Chl a and climate change is influenced by various factors, such as temperature, light availability and nutrient levels. Chl a concentrations can also indicate the occurrence of algal blooms, which are seasonal. Changes in the patterns of these blooms can indicate changes in the ecosystem, although this may not only be linked to climate but also to nutrient availability.

In 2024, particularly from April to July, highly variable positive and negative anomalies in Chl a concentrations were observed across the European region. In the Atlantic north of the United Kingdom and Ireland, Chl a concentrations were above average in May, but showed strong negative anomalies of as much as 90% in June and July. Further north, the Norwegian and Greenland Seas saw strong positive anomalies in May and June, of up to 200–600% above average in some areas, followed by negative anomalies of as much as 65% below average in July. Most of the Mediterranean Sea recorded below-average Chl a concentrations from April to July. Only a few areas in the western Mediterranean saw above-average concentrations, particularly in June. Many of the Chl a concentration patterns in the European region resemble those observed in 2023. The Mediterranean Sea is a notable exception; positive anomalies were less pronounced and less widespread than in 2023.

Winds and circulation

Key messages

- For 2024 as a whole, there was lower-than-average pressure over northwestern Europe and higher-than-average pressure over eastern Europe.
- This pattern was particularly prominent in February, March and during the summer, leading in general to wetter, cooler conditions in western Europe and warmer, drier conditions in eastern Europe.
- Annual mean surface wind speeds were generally near or below average across most of the continent.

In the Northern Hemisphere, winds move clockwise around areas of high pressure and anticlockwise around areas of low pressure. Atmospheric circulation refers to this large-scale movement of air. It is the process by which thermal energy—responsible for temperature within a system—and moisture are redistributed across Earth. In general, high pressure brings stable conditions while low pressure brings cloud and precipitation. In this way, circulation drives weather patterns, which play an important role in shaping anomalies in many climate variables, and it can itself be influenced by climate change.

This section provides an overview of the monthly atmospheric circulation patterns observed over Europe and the North Atlantic Ocean in 2024.

Anomalies in atmospheric circulation can be characterised using the 850-hPa geopotential height. Here, 'geopotential height' is referred to as 'height'. This variable is defined as the distance required to travel up in the atmosphere for the air pressure to drop to 850 hPa, usually about 1.5 km above sea level. It is related to the mean sea level pressure often displayed on weather maps: positive height anomalies usually correspond to areas of higher-than-average pressure (anticyclones) and lower heights to areas of lower-than-average pressure (depressions). The 850-hPa level has been chosen because it is high enough to avoid surface friction and terrain/topography effects in most areas but low enough to capture important weather patterns like temperature changes, wind shifts and moisture transport.

Geopotential height anomalies and the associated changes in the prevailing wind direction are visualised with different colours and wind arrows on the maps below. Temperature anomalies at 850 hPa are also discussed to highlight the presence and movement of warm and cold air masses at altitude, which influence the air temperature anomalies at the surface.

Atmospheric circulation

On average, conditions during 2024 showed an east-west contrast, with low pressure over northwestern Europe and high pressure over eastern Europe. This prevailing circulation pattern was associated with northerly winds (winds blowing from the north) and cooler temperatures in far western areas, and southerly winds and warmer temperatures in central and eastern areas. This east-west contrast during the year is evident in several climate variables, including surface air temperatures, precipitation, cloud cover, sunshine, and solar radiation.

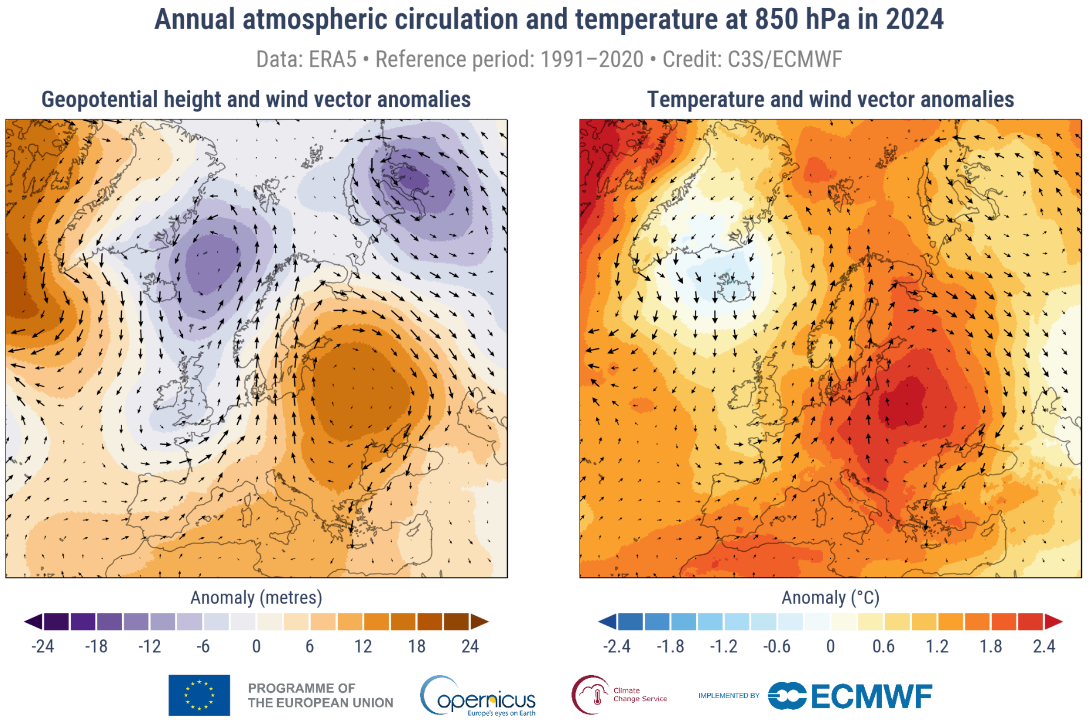


Figure 12.1. (Left) Annual average anomalies (purple and orange shades) in geopotential height (metres) and wind vectors at 850 hPa for 2024. (Right) Annual average anomalies (blue and orange shades) of temperature (°C) and wind vectors at 850 hPa for 2024. All anomalies are relative to the average for the 1991–2020 reference period. The 850 hPa level is about 1.5 km above sea level. Data: ERA5. Credit: C3S/ECMWF.

Winter and spring

Below-average heights were seen over northwestern and western Europe in February and March, respectively, bringing storms and wetter-than-average conditions. This circulation was associated with westerly winds which also led to warmer-than-average surface and 850 hPa temperatures across most of Europe.

In May, Fennoscandia saw above-average heights which led to drier conditions and warmer-than-average temperatures. This also led to pronounced cooler-than-average 850 hPa temperature anomalies over northwestern Russia due to northerly airflow east of the high-pressure area.

Summer

The summer was dominated by below-average heights over the northeastern North Atlantic Ocean. Based on the locations of the centres of low pressure and associated wind patterns, this led to slightly cooler-than-average temperatures over western Europe in June, and warmer-than-average temperatures in July and August, except over the United Kingdom. In addition, in August, a combination of much below-average heights over Iceland and above-average heights over the Barents and Kara Seas was associated with sustained southerly winds towards the Barents

Sea. This led to much warmer-than-average temperatures over the region at the surface and at 850 hPa.

Autumn and winter
In September, above-average heights across eastern Europe brought drier-than-average conditions and warmer-than-average temperatures at the surface and at 850 hPa. This high-pressure system partly contributed to the severe impacts of Storm Boris in central Europe by blocking the storm's movement, resulting in persistent precipitation in the affected area over several days.

In November, western Europe saw above-average heights, which brought drier-than-average conditions and lower-than-average wind speeds. Conversely, below-average heights and higher-than-average wind speeds prevailed over the Barents Sea, bringing moist air to northern European Russia, leading to wetter-than-average conditions.

In December, above-average heights across the North Atlantic Ocean caused drier-than-average conditions in western Europe. While lower-than-average heights resulted in a few storms over western Europe, higher-than-average heights dominated through most of the month.

Surface wind speed

Wind speeds were above average across much of the continent in January, February, April and September. Although they were below average during other months, in June and August, record-high wind speeds for the period since 1979 occurred over the Norwegian Sea and the northeastern Atlantic. For the year as a whole, wind speeds were generally near or below average across most of the continent.

In some months, the above-average wind speeds indicate an active storm season[27], particularly over northwestern Europe in, for example, January, April, August and December, and in southeastern Europe in January, April, June, July, October and November. However, variations in wind conditions within a month can reduce the influence of individual storms on monthly averages. Information on some individual storms can be found in the 'Key events map' online.

[27] The 2023/24 storm season (which runs from September to August) saw the highest number of named storms in a season since storm-naming was introduced in 2015. Lists of storms are available from the UK MetOffice and the Irish Meteorological Service, Met Éireann.

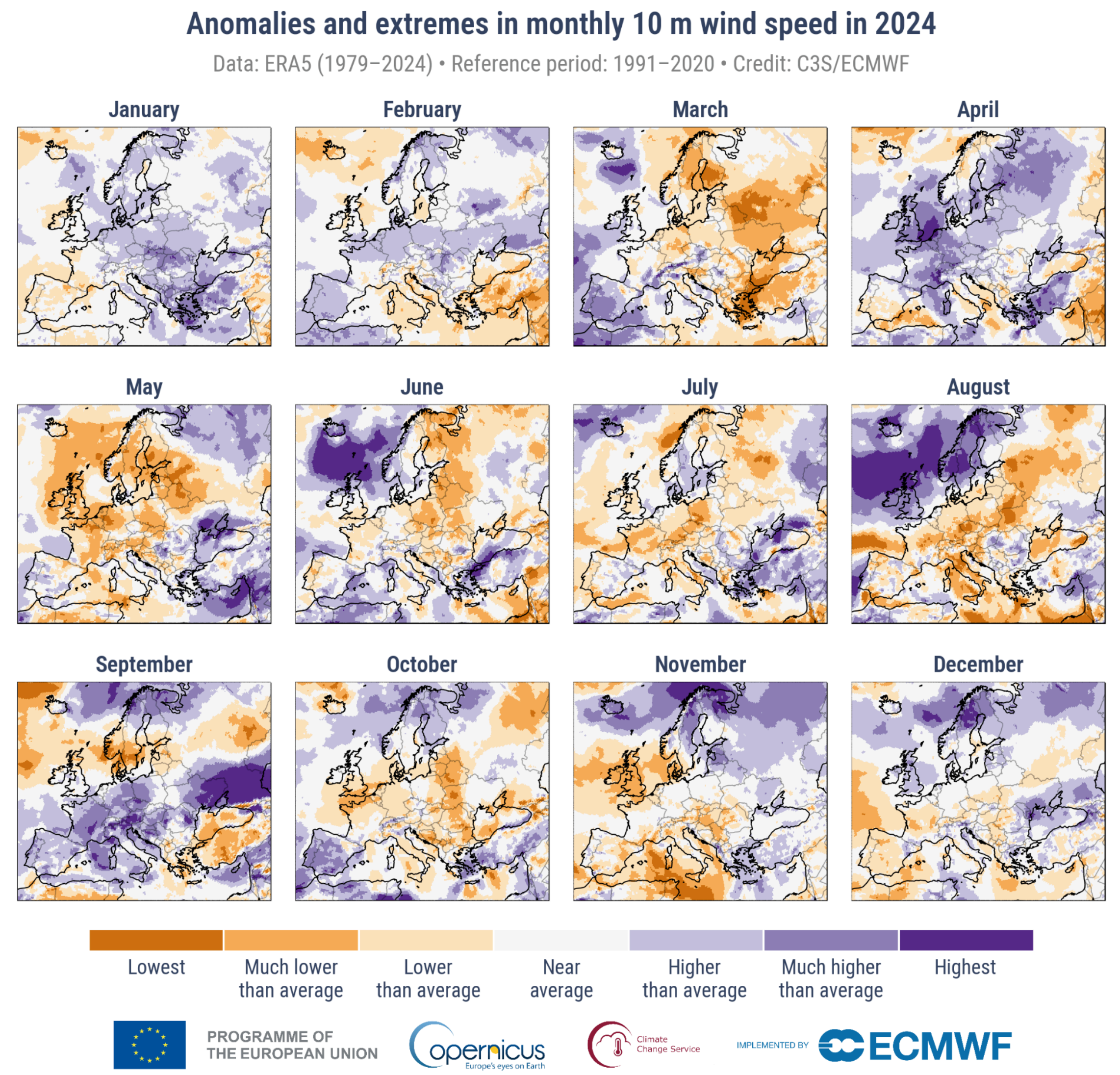


Figure 12.2. Anomalies and extremes in monthly 10 m wind speed in 2024. The extreme categories ('lowest' and 'highest') are based on rankings for 1979–2024. The other categories describe how the wind speeds compare to their distribution during the 1991–2020 reference period. 'Much lower/higher than average' - lower/higher than 90% of temperatures. 'lower/higher than average' - than 66% of temperatures. 'Near average' - within the middle 33%. Data: ERA5. Credit: C3S/ECMWF.

Clouds and sunshine

Key messages

- There was a distinct east-west contrast, with more hours of sunshine and higher surface solar radiation in the east, and fewer hours of sunshine and lower solar radiation in the west. This was most striking in May.
- Spring saw the largest positive anomalies in sunshine duration and surface solar radiation, of up to 180 hours and 70 W/m^2, respectively.

Cloud cover and sunshine duration are relevant to many sectors of society, including renewable energy and tourism. Both variables have been observed since the late 19th century, initially by eye and by simple instruments on the ground. Since the early 1980s, satellite observations have been used to obtain spatially complete estimates of cloud cover, surface solar radiation[28] and sunshine duration.

This section provides an overview of anomalies in sunshine duration, solar radiation and cloud cover across Europe in 2024.

Sunshine and solar radiation

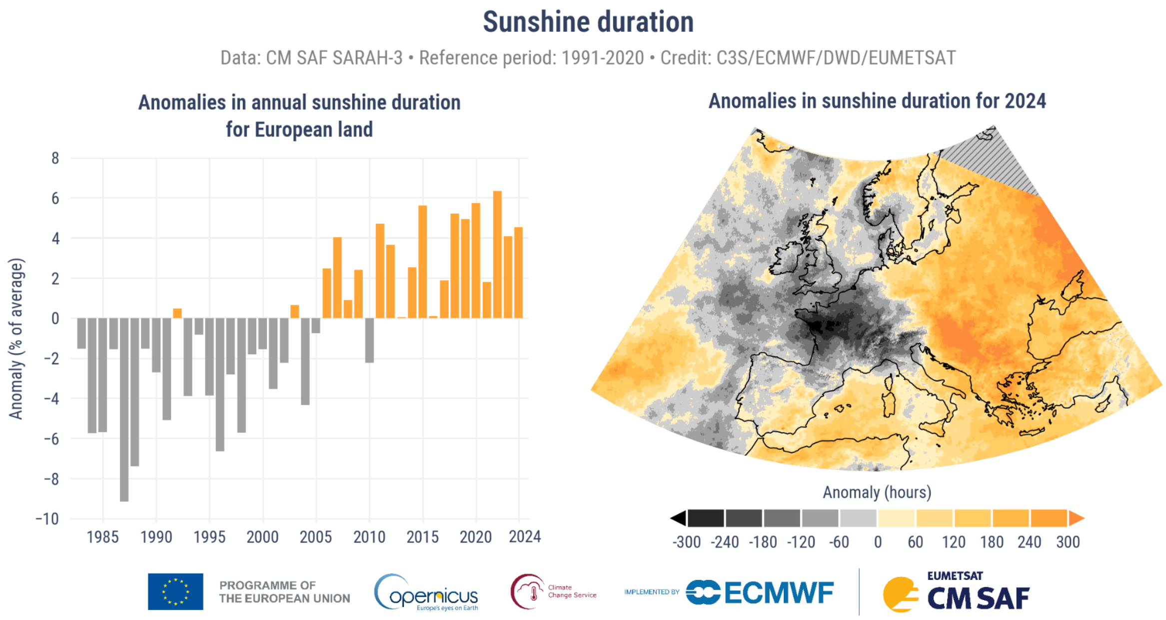


Figure 13.1. (Left) Annual sunshine duration anomalies (%) for Europe for 1983–2024, showing positive (orange) and negative (grey) anomalies. The anomalies are for land areas only and expressed as a percentage of the average. (Right) Sunshine duration anomalies (hours) over Europe for 2024, showing positive (shades of orange) and negative (shades of grey) anomalies. Grey hatching in the top right corner of the map indicates missing data. All anomalies are relative to the average for the 1991–2020 reference period. Data: CM SAF SARAH-3 CDR and ICDR. Credit: C3S/ECMWF/DWD/EUMETSAT.

---

[28] A measure of how much solar energy within the 2.0-4.0 µm wavelength (or shortwave) region reaches Earth's surface per unit area.

For Europe as a whole, sunshine duration in 2024 was around 4% above average. This continues a tendency of positive anomalies seen since 2006, with the exception of 2010. The 2024 annual average, however, masks a strong east-west contrast, centred on Germany. Eastern Europe saw widespread positive anomalies in sunshine duration and surface solar radiation, with the highest anomalies in the Balkans, ranging from 100 to 300 hours, and in some areas up to around 350 hours. In contrast, widespread negative anomalies in sunshine duration and surface solar radiation were seen across western Europe, reaching up to 350 hours below average across France, although parts of Spain and the Mediterranean experienced slightly above-average sunshine duration. May had the clearest east-west contrast, with positive anomalies in sunshine duration across eastern Europe and negative anomalies over western Europe, which reflects the pattern seen in the precipitation anomalies.

Cloud cover

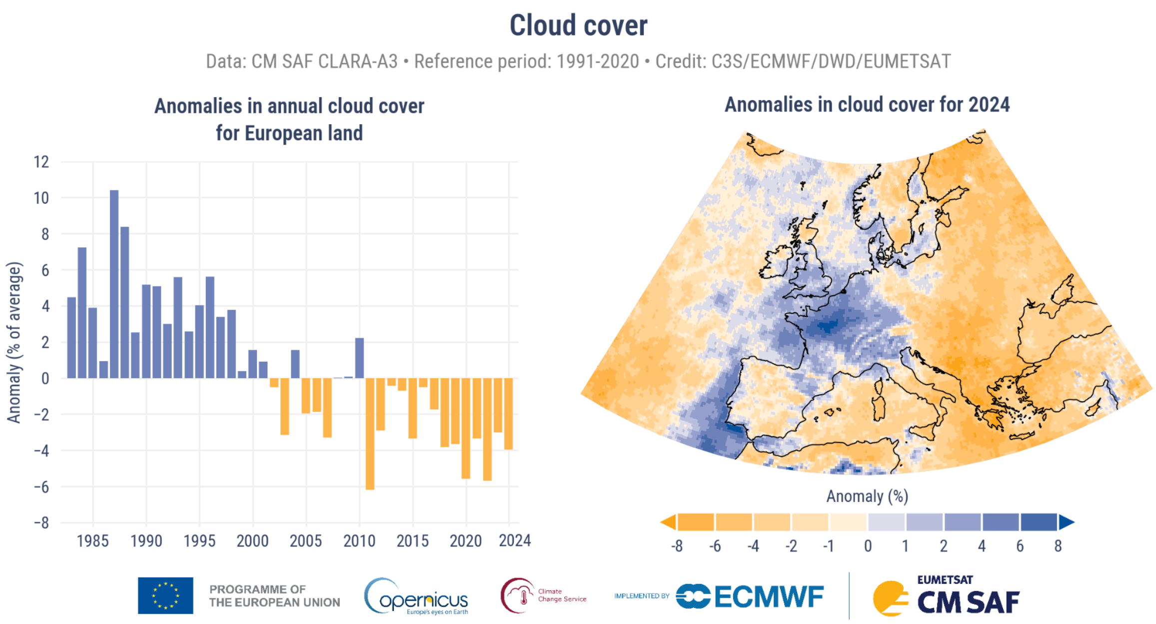


Figure 13.2. (Left) Annual cloud cover anomalies (%) for Europe for 1983–2024, showing positive (blue) and negative (orange) anomalies. The anomalies are for land areas only and expressed as a percentage of the average. (Right) Average annual cloud cover anomalies (%) over Europe for 2024, showing positive (shades of blue) and negative (shades of orange) anomalies. All anomalies are relative to the average for the 1991–2020 reference period. Data: CLARA-A3 CDR/ICDR. Credit: C3S/ECMWF/DWD/EUMETSAT.

In general, positive anomalies in sunshine duration and surface solar radiation correspond to negative anomalies in cloud cover. This was the case for 2024. Cloud cover over European land as a whole was below average, but there was a strong east-west contrast in anomalies, with negative anomalies mainly across eastern Europe and positive anomalies over large parts of western Europe. In line with what was observed for sunshine duration, positive anomalies in cloud cover across France reached about 10%, while negative anomalies of about -10% were seen over the Balkans. The largest negative anomalies in cloud cover were seen in September, reaching up to -50% across eastern Europe. This was related to a high-pressure system over the same region and associated record dry conditions.

Renewable energy resources

Key messages

- 2024 saw a record proportion of actual electricity generation by renewables in Europe, at 45%.
- There was an east-west contrast in the climate-driven potential for power generation from solar photovoltaic, with above-average potential in the east, and below-average potential in the west.
- Climate-driven potential power generation from wind was generally below average, reflecting below-average wind conditions across the continent.

Power generation from renewable energy sources is essential to Europe's transition to a decarbonised energy system. Reports indicate that since 2019, the number of EU countries where renewables generate more electricity than fossil fuels has nearly doubled, rising from 12 to 20, driven by a surge in wind and solar capacity.

Renewable power generation and electricity demand are highly sensitive to environmental conditions, which are shaped by phenomena occurring across different timescales, from short-term weather events to long-term climate trends. As Europe increasingly relies on renewables, understanding their temporal and spatial variability in a changing climate is vital. This includes assessing how these variations affect electricity demand and the potential for renewable power generation.

This section reviews Europe's actual electricity generation in 2024 and the influence of climate conditions on potential power generation from onshore wind and solar photovoltaic (PV), as well as on electricity demand. Non-climatic factors, such as technological efficiency improvements, are not considered.

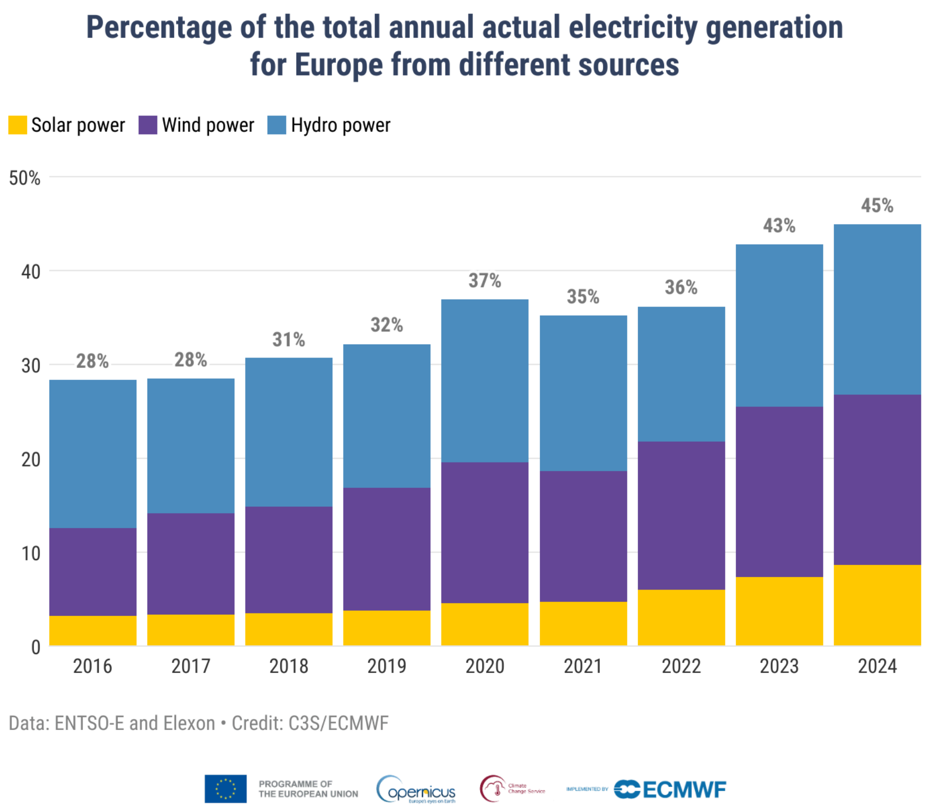


Figure 14.1. Percentage of the total actual annual electricity generation for Europe, from solar (yellow), wind (purple) and hydro (blue) power, for 2016–2024. Data: ENTSO-E and Elexon[29]. Credit: C3S/ECMWF.

The proportion of actual electricity generation by renewables in Europe reached a record high in 2024, at 45%, compared to the previous record of 43% in 2023. Of the 45%, around 18% was produced by wind power, around 9% by solar power and around 18% by hydropower. The combined contribution from wind and solar power reached its maximum in April, at almost a third of the total share of electricity generated, while in most other months solar and wind contributed around 25%. The contribution from hydropower remained relatively steady throughout the year, between around 22% in May and 15% in December.

[29] Elexon data for Great Britain are combined with ENTSO-E data for the EU to give the totals shown.

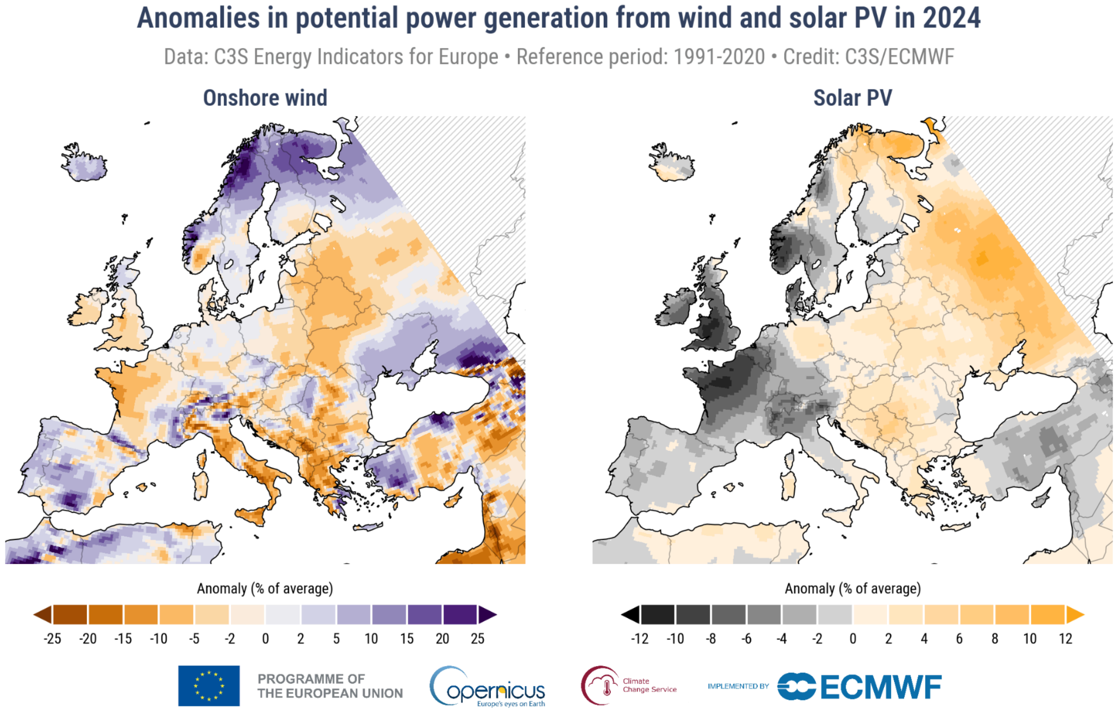


Figure 14.2: Annual anomalies (%) in potential power generation from two renewable sources in Europe in 2024: onshore wind capacity factor (left), and solar photovoltaic (PV) capacity factor (right). All anomalies are relative to the average for the 1991–2020 reference period and expressed as a percentage of this average. Grey hatching in the top right corner of the map indicates areas outside of the dataset domain. Data: C3S Energy Indicators for Europe. Credit: C3S/ECMWF.

In 2024, potential power generation from wind in Europe was generally below average, reflecting below-average wind conditions across the continent. This was particularly the case in southern Europe, including Italy and the Balkan countries along the Adriatic Sea. However, there were a few exceptions, notably in the Iberian Peninsula, the Alps and Fennoscandia, where the potential for power generation from wind remained near average or above average.

Across Europe, there was an east-west contrast in the potential for solar PV power generation, with above-average potential in eastern Europe and much below-average potential in western Europe. Northwestern Europe and southern Scandinavia saw the most below-average potential. This east-west contrast reflects the cloud cover and solar radiation conditions across the continent.

The much below-average potential for solar PV power generation made 2024 an unusual so-called ‘dark year’ for Europe and highlights some of the challenges faced by the continent’s solar energy sector. However, it was reported to be a record year for additions to total EU solar PV capacity. This meant that, despite the below-average climate-driven potential for solar PV power generation, the year as a whole saw an increase in actual solar electricity generation compared to 2023.

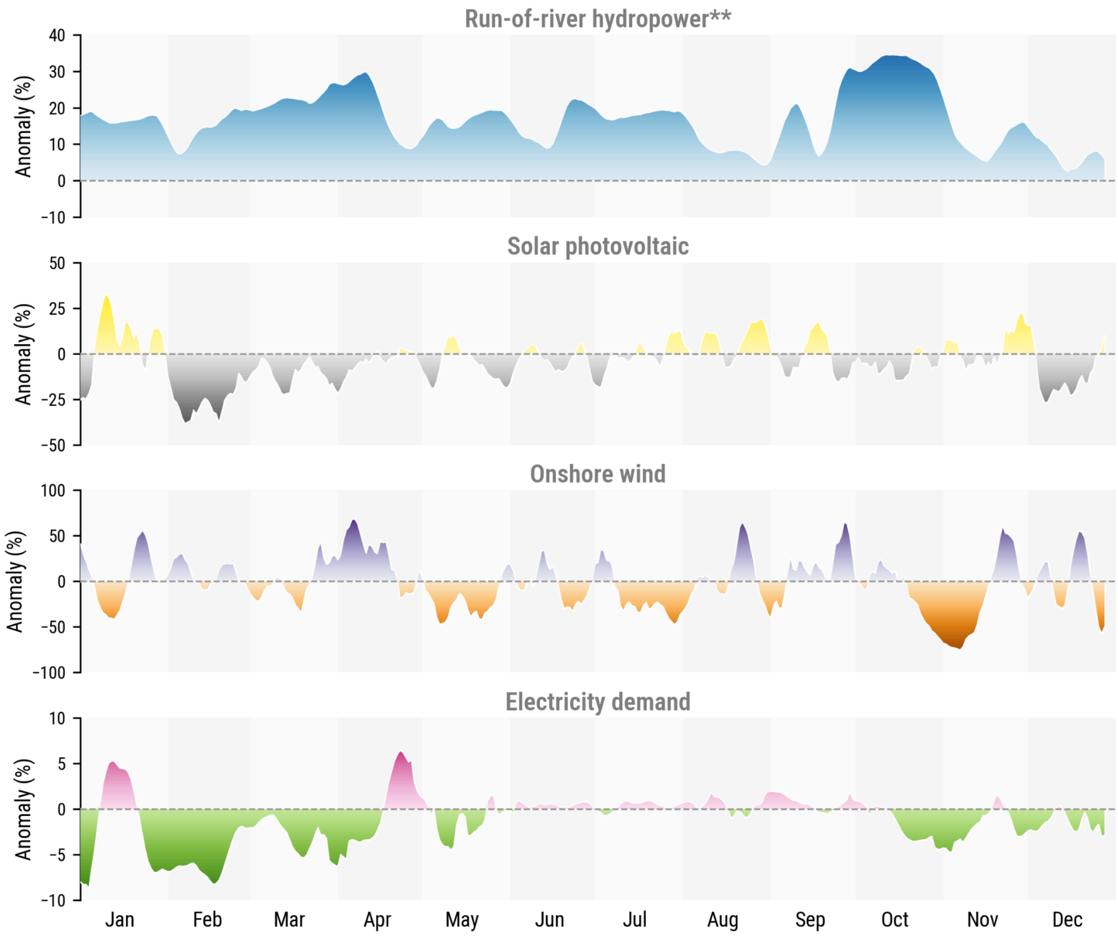
Variability throughout the year

Potential power generation from renewable sources and climate-driven electricity demand vary throughout the year, due to weather and climate fluctuations. Climate-driven electricity demand is linked to factors such as a reduced need for heating during warmer-than-average winters and increased need for air conditioning during warmer-than-average summers.

While climate conditions can drive additional electricity demand, they can also partially compensate through increased renewable power generation. For example, in summer, higher demand can be balanced out by additional solar PV power generation.

Daily anomalies in energy indicators for northwestern Europe* in 2024

Data: C3S Energy Indicators for Europe • Reference period: 1991-2020 • Credit: C3S/ECMWF



*Included countries: Belgium, Denmark, France, Germany, Ireland, Luxembourg, Netherlands, Switzerland, and United Kingdom.
**For hydropower, only 3 countries are included: France, Germany, and Switzerland.

PROGRAMME OF THE EUROPEAN UNION   Copernicus Europe's eyes on Earth   Climate Change Service   IMPLEMENTED BY ECMWF

Figure 14.3. Daily anomalies (seven-day running average) in the potential for power generation from run-of-river hydropower, solar photovoltaic and onshore wind, and anomalies in climate-driven electricity demand, averaged over northwestern Europe (Belgium, Denmark, France, Germany, Ireland, Luxembourg, Netherlands, Switzerland and the United Kingdom). The anomalies are expressed as a percentage of the 1991–2020 reference period. Potential for power generation is based on the capacity factor. Data: C3S Energy Indicators for Europe. Credit: C3S/ECMWF

Variability in northwestern Europe

Comparing regional energy statistics can highlight links and compensation between climate-driven electricity demand and renewable power resources at a larger scale than that of individual countries. Here, statistics are reported for 'northwestern Europe', a region defined as Belgium, Denmark, France, Germany, Ireland, Luxembourg, the Netherlands, Switzerland and the United Kingdom. These countries are chosen because of their relatively similar climatic conditions in 2024.

Averaged across these nine countries, there was a peak in the climate-driven electricity demand in early January before it dropped below average from late January through spring, except for a brief increase in the second half of April. This reflects the above-average temperatures during winter and spring, and particularly the record-breaking warm anomalies for much of this region in February. During summer, climate-driven electricity demand was near average, again reflecting the near-average temperatures, before returning to below average from mid-October through to the end of the year.

The potential for solar PV power generation fluctuated but was below average for much of the year, reflecting the below-average solar radiation in this region for the year as a whole. Notably, there were large negative anomalies in the potential for solar PV power generation between early February and mid-April, reaching up to 38% below average, and in December, reaching up to 27% below average. From April to December anomalies were smaller, with some fluctuations to small positive anomalies of up to around 20% in August, September and at the end of November.

Potential power generation from run-of-river hydropower remained above average throughout the year, due to higher-than-average river flows during most of 2024. This also reflected the much wetter-than-average year for precipitation in this region.

Autumn wind drought

Solar PV and wind power generation typically follow a complementary seasonal cycle[R9], with solar PV power generation peaking in spring and summer, while wind power generation is greater in autumn and winter. This pattern was observed in 2024 in Europe.

In northwestern Europe, however, there was a 'wind drought'—a prolonged period of below-average wind speeds—in late October and early November, with the potential for wind power generation dropping to 75% below average. This coincided with slightly below-average potential for solar PV power generation. Wind droughts in northwestern Europe usually occur when a high-pressure system over central Europe reduces wind strengths, and are often accompanied by above-average wind speeds elsewhere in Europe, particularly in northern Scandinavia[R10][R11]. This was the case in 2024, highlighting the complementarity of renewable energy sources and the importance of a well-connected European transmission network, as excess energy from windier regions can help to compensate for below-average wind speeds elsewhere, improving overall energy stability.

Arctic temperature

Key messages

- 2024 was the third warmest year on record for the Arctic as a whole and the fourth warmest for Arctic land.
- Svalbard experienced its warmest summer on record for the third consecutive year, with a temperature well above that of 2023.
- In contrast, the Greenland Ice Sheet recorded its third-lowest mass loss since 2001, a period otherwise marked by an overall trend of accelerating ice loss, due to limited summer surface melt and above-average snowfall.

Since the 1990s, the Arctic has been warming at a rate far exceeding the global average, a phenomenon known as 'Arctic amplification'. This rapid warming directly affects the Arctic cryosphere, causing reductions in snow and ice coverage. This loss further accelerates warming through reduced surface reflectivity ('albedo'). This process, known as the temperature-albedo feedback loop, is one of the physical mechanisms[R12] responsible for Arctic amplification. The impacts of this warming extend beyond the cryosphere, affecting ecosystems, indigenous communities, economic activities and geopolitics. Superimposed on the long-term warming trend are short-term fluctuations in weather and climate patterns, which influence the magnitude and distribution of temperature anomalies. This section focuses on near-surface air temperature, referred to from here on as 'temperature'.

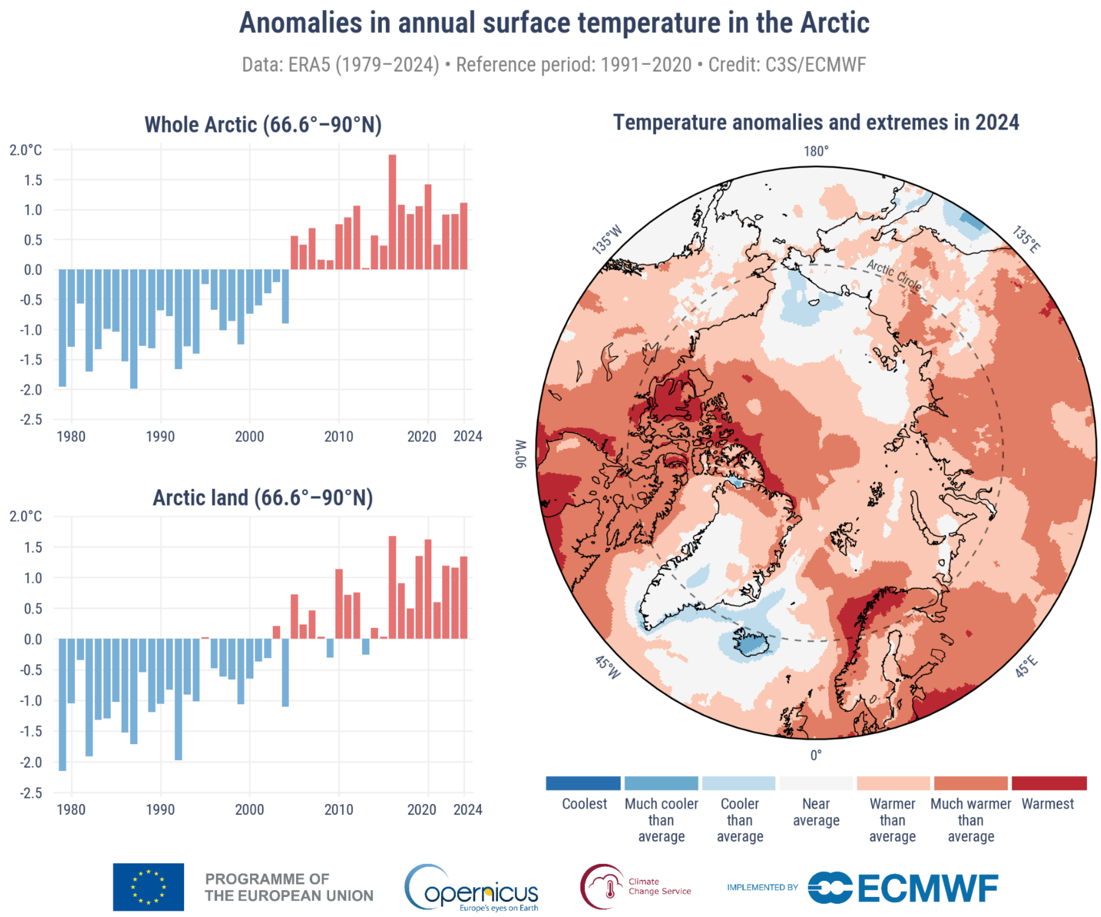


Figure 15.1. (Left) Annual average surface air temperature anomalies (°C) from 1979–2024, relative to the average for the 1991–2020 reference period, (top) for the Arctic as a whole (66.6°–90°N) and (bottom) over all Arctic land areas. (Right) Anomalies and extremes in annual surface air temperature in 2024. The extreme categories ('coolest' and 'warmest') are based on rankings for 1979–2024. The other categories describe how the temperatures compare to their distribution during the 1991–2020 reference period. 'Much cooler/warmer than average' - cooler/warmer than 90% of temperatures. 'Cooler/warmer than average' - than 66% of temperatures. 'Near average' - within the middle 33%. Data: ERA5. Credit: C3S/ECMWF.

In 2024, the annual average temperature for the Arctic as a whole (all areas north of the Arctic Circle) was 1.11°C above average, making it the third warmest year on record for the region. Over Arctic land, the temperature was 1.34°C above average, making it the fourth warmest year, just below 2019 (1.35°C), the third-warmest year. For both regions, 2016 and 2020 remain the warmest and second-warmest years, respectively. For the Arctic as a whole, the ten warmest years have all occurred since 2011. For Arctic land, the five warmest years have all occurred since 2016. For more information on long-term temperature trends in the Arctic, see the 'Temperature' Climate Indicator.

Most areas in the northern high latitudes experienced above-average temperatures for the year as a whole. Record-high temperatures were observed in parts of Canadian Arctic Archipelago, northern Scandinavia and the adjacent Norwegian Sea. In Arctic Canada, as in 2023, annual temperatures reached around 3–3.7°C above average, some of the largest positive anomalies globally. In contrast, two main regions experienced near-average or below-average annual temperatures: one covering Iceland, nearby seas and southern Greenland, and the other surrounding the Chukchi Sea.

Monthly variations

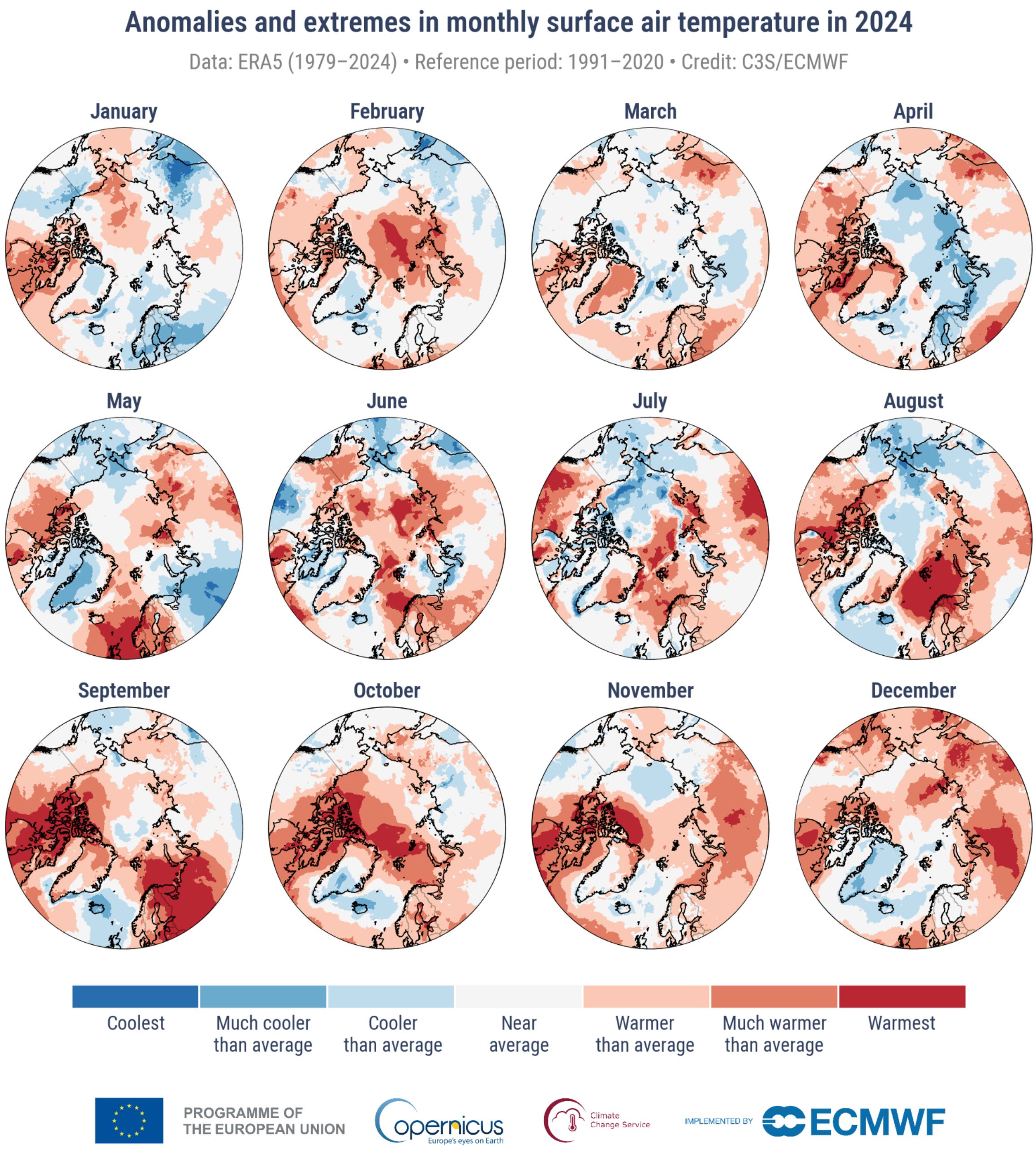


Figure 15.2. Anomalies and extremes in surface air temperature over the north polar region for each month of 2024. The extreme categories ('coolest' and 'warmest') are based on rankings for 1979–2024. The other categories describe how the temperatures compare to their distribution during the 1991–2020 reference period. 'Much cooler/warmer than average' - cooler/warmer than 90% of temperatures. 'Cooler/warmer than average' - than 66% of temperatures. 'Near average' - within the middle 33%. Data: ERA5. Credit: C3S/ECMWF.

From January to May, temperatures across the Arctic were generally near average or below average. February was an exception, with parts of the central Arctic Ocean and northern Siberia experiencing much warmer-than-average conditions. For the rest of the year, much above-average or record-high temperatures were more widespread across the region. The anomalous warmth was particularly evident in two areas: the eastern European Arctic (Norwegian Sea, Barents Sea and northern Scandinavia) from June to October, and northeastern Canada from August to December. These warm conditions were associated with, and likely contributed to, much below-average sea ice cover in the two sectors in the autumn and early winter.

The warmth in the eastern European Arctic was most pronounced in August and September, when most of the area experienced record-high temperatures. In contrast, over Iceland and parts of Greenland during the same period, temperatures were generally near average or below average.

Summer temperatures in the European Arctic

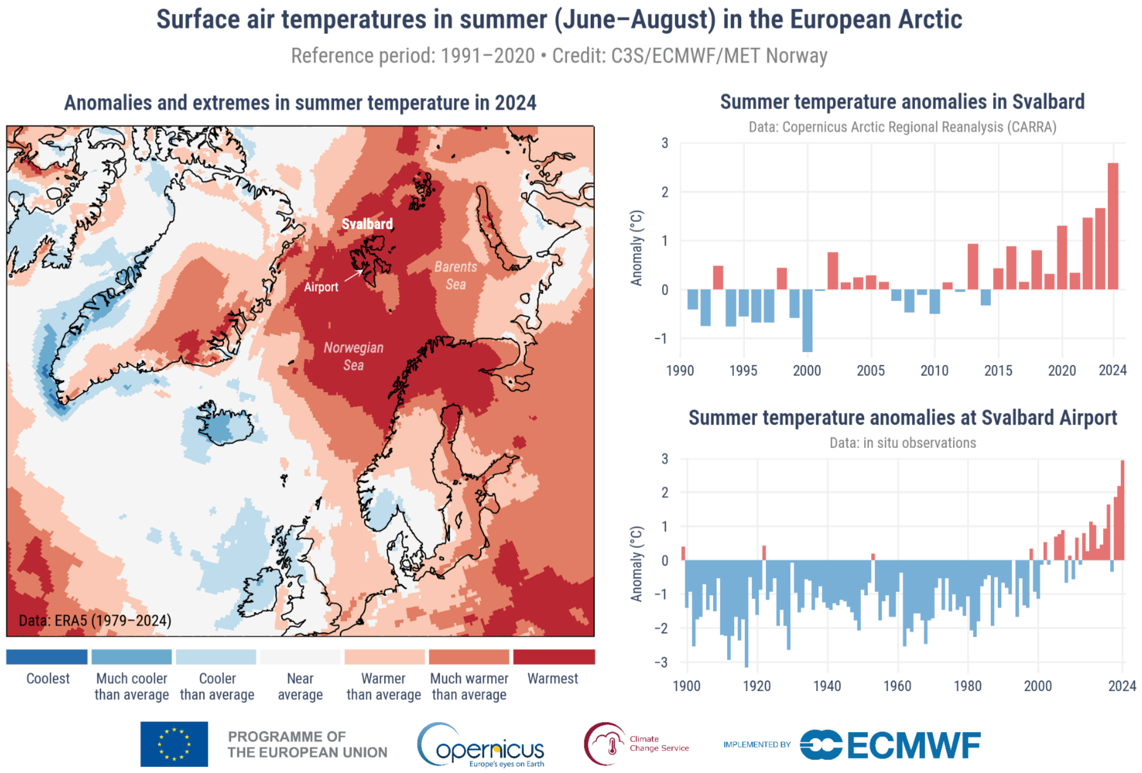


Figure 15.3. (Left) Anomalies and extremes in surface air temperature in summer (June to August) 2024. The extreme categories ('coolest' and 'warmest') are based on rankings for 1979–2024. The other categories describe how the temperatures compare to their distribution during the 1991–2020 reference period. 'Much cooler/warmer than average' - cooler/warmer than 90% of temperatures. 'Cooler/warmer than average' - than 66% of temperatures. 'Near average' - within the middle 33%. (Right) Surface air temperature anomalies for summer for Svalbard (land only; top) and at Svalbard Airport from 1899–2023 (bottom). All anomalies are relative to the average for the 1991–2020 reference period. Data: ERA5, Copernicus Arctic Regional Reanalysis (CARRA) and in situ observations at Svalbard Airport. Credit: C3S/ECMWF/MET Norway.

As outlined above, summer (June to August) 2024 saw contrasting temperature anomalies across the European Arctic. Temperatures were much above average, and often record high, in the eastern part of the region, including over the Barents, Norwegian and Greenland Seas, Svalbard, Franz Joseph Land and northern Fennoscandia. These warm conditions contributed to record mass loss from glaciers in Scandinavia and Svalbard. In contrast, further west, temperatures were mostly near average or below average over Iceland and surrounding seas, as well as across the western and northern parts of Greenland. In Iceland, Reykjavik recorded its coldest summer since 1992.

Record warm summer in Svalbard

For the third consecutive summer, the average temperature in Svalbard reached a new record high, at 2.6°C above average, well above 2023's record of 1.7°C. At

Svalbard Airport, a location where temperature measurements[R13] extend back to 1899, the summer was also the warmest on record, at 2.9°C above average, significantly warmer than in 2023 (2.2°C). As in 2022 and 2023, the region's warm summer coincided with well above-average sea surface temperatures over the Barents Sea. In recent decades, this region has been one of the fastest-warming places on Earth[R14].

Limited ice loss in Greenland
For the 2023–2024 hydrological year, which begins on 1 September, the Greenland Ice Sheet recorded its third smallest mass loss since 2001[30]. In 2024, the near-average temperatures observed across most of Greenland explain the lack of major summer melt events. Above-average snowfall in spring and summer also contributed to the limited ice loss. As a result of limited snowmelt and abundant snowfall, the ice sheet's surface mass balance (the difference between mass gained from snowfall and mass lost through surface melting and sublimation) was the third most positive since 2001, slightly above 2022. More on the Greenland Ice Sheet can be found in the 'Ice sheet' Climate Indicator.

The role of atmospheric circulation
The contrast in summer temperatures across the European Arctic can be linked to a persistent atmospheric circulation pattern, which in 2024 was characterised by low pressure over Iceland and high pressure over the Barents and Kara Sea. This pattern promoted warm southerly winds towards the Barents Sea and cool northerly winds over western Greenland. This circulation pattern was most pronounced in August. The record temperatures seen over the Barents Sea were not directly linked to reduced sea ice cover as the area is typically ice-free during the summer months.

Arctic wildfires

Key messages

- In 2024, the total wildfire carbon emissions from high northern latitudes were the sixth highest in the 22-year satellite record, while emissions north of the Arctic Circle were the third highest.
- Most high-latitude wildfires were in Canada's Northwest Territories and Russia's Sakha Republic.

As Earth's climate continues to warm, and with the Arctic warming more rapidly than the global average, conditions at high northern latitudes are becoming more conducive to wildfires[R15]. This increases the risk of positive feedback loops with a range of climate impacts. For example, the high carbon content of peat and boreal soils means that wildfires can release significant amounts of carbon into the atmosphere, potentially accelerating the rise in global greenhouse gas

[30]To rank Greenland's surface and total mass balance in 2024, the period 2001–2024 was chosen as it corresponds to a phase of high mass loss for the ice sheet following an acceleration in the early 2000s. This period also saw a significant rise in Arctic surface air temperatures and a pronounced decline in sea ice cover.

concentrations. Furthermore, the deposition of aerosols, such as fine particulates of pure carbon (‘black carbon’) and soot, emitted by wildfires can darken snow and ice surfaces, reducing their reflectivity (‘albedo’) and causing them to absorb more solar energy, making them more prone to melting. These processes, in combination with other complex environmental interactions related to Arctic wildfires, highlight the importance of monitoring wildfires and associated carbon emissions as part of ongoing efforts to track climate changes in the region.

Wildfire emissions

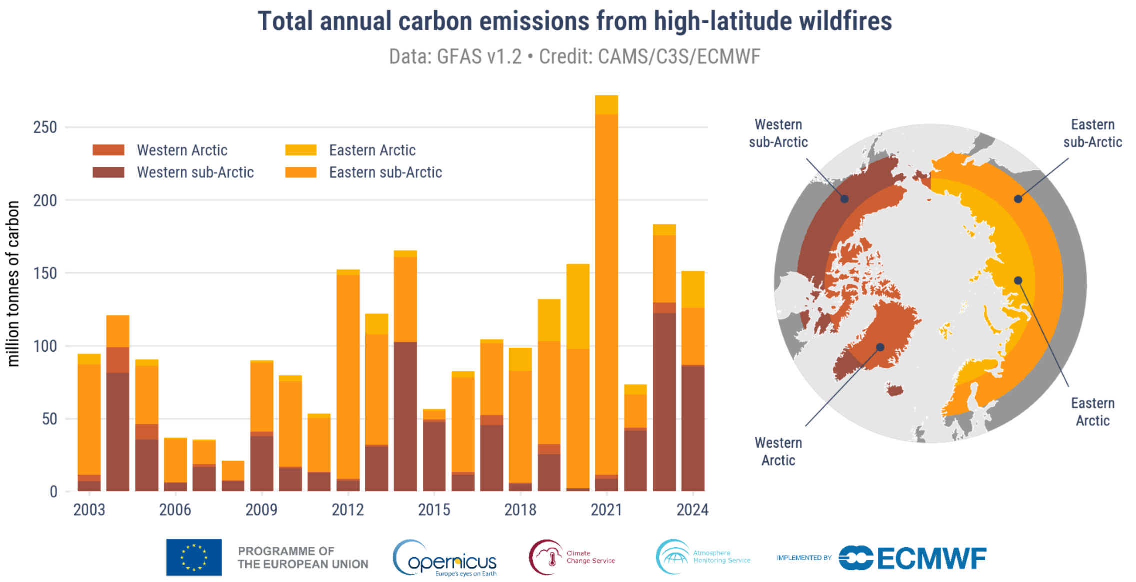


Figure 16.1. (Left) Annual total estimated carbon emissions (million tonnes) from wildfires from all land areas in northern high latitudes (north of 60°N) from 2003–2024. The colours indicate the regions contributing to the emissions. (Right) Map showing the four regions: western sub-Arctic (dark brown), western Arctic (light brown), eastern sub-Arctic (dark orange) and eastern Arctic (light orange). Data: CAMS GFAS v1.2 wildfire data. Credit: CAMS/C3S/ECMWF.

Wildfire carbon emissions from across the sub-Arctic and Arctic regions, which encompass all land areas north of 60°N, reached an estimated total of 151 million tonnes in 2024, based on the 22-year Global Fire Assimilation System (GFAS) dataset from the Copernicus Atmosphere Monitoring Service (CAMS). This was the sixth-highest level of total annual emissions for the region since records began in 2003. Compared to recent years, it was lower than in 2023, which was the second highest on record at 183 million tonnes, and significantly below the record of 271 million tonnes in 2021.

As in previous years, the sub-Arctic accounted for most of the year’s total emissions from high latitude wildfires, at 125 million tonnes (83%), the fifth-highest amount since 2003. Emissions north of the Arctic Circle reached 26 million tonnes (17%), the third-highest amount since 2003. These relatively high emissions from the Arctic were linked to the return of large-scale, persistent fires in the northern parts of Russia's Sakha Republic, a level of activity not seen since the record seasons of 2019 and 2020.

As in 2022 and 2023, the majority of emissions (58% in 2024) came from the western high latitudes due to widespread, prolonged wildfires across Canada. According to GFAS data published by CAMS, the country experienced its second-highest annual wildfire carbon emissions, well above average and second only to the record wildfire season of 2023.

Wildfire locations

During summer 2024, wildfire activity in the high northern latitudes was primarily concentrated in Canada's Northwest Territories and Russia's Sakha Republic. The most intense fires—those with a fire radiative energy of 5 MJ/m^2 or higher—were generally located in areas where soils were unusually dry, a condition that significantly increases fire risk.

In the Northwest Territories, wildfire activity initially developed in mid-July and rapidly intensified in early August, driven by prolonged heatwave conditions. Some of these fires are thought to have been 'zombie' or 'holdover' fires, remnants of the record-breaking 2023 Canadian wildfire season that survived the winter and were reignited by warm, dry weather. As in 2023, the Northwest Territories accounted for the largest share of carbon emissions among Canadian provinces.

Wildfires in the Arctic sector of Russia's Sakha Republic began in mid-June, coinciding with a period of much higher-than-average surface air temperatures. The region last experienced such severe wildfire activity in 2020, contributing to what was then an exceptionally intense wildfire season for the Arctic. In July, strong wildfire activity also spread further south, prompting authorities in the Republic to declare a state of emergency.

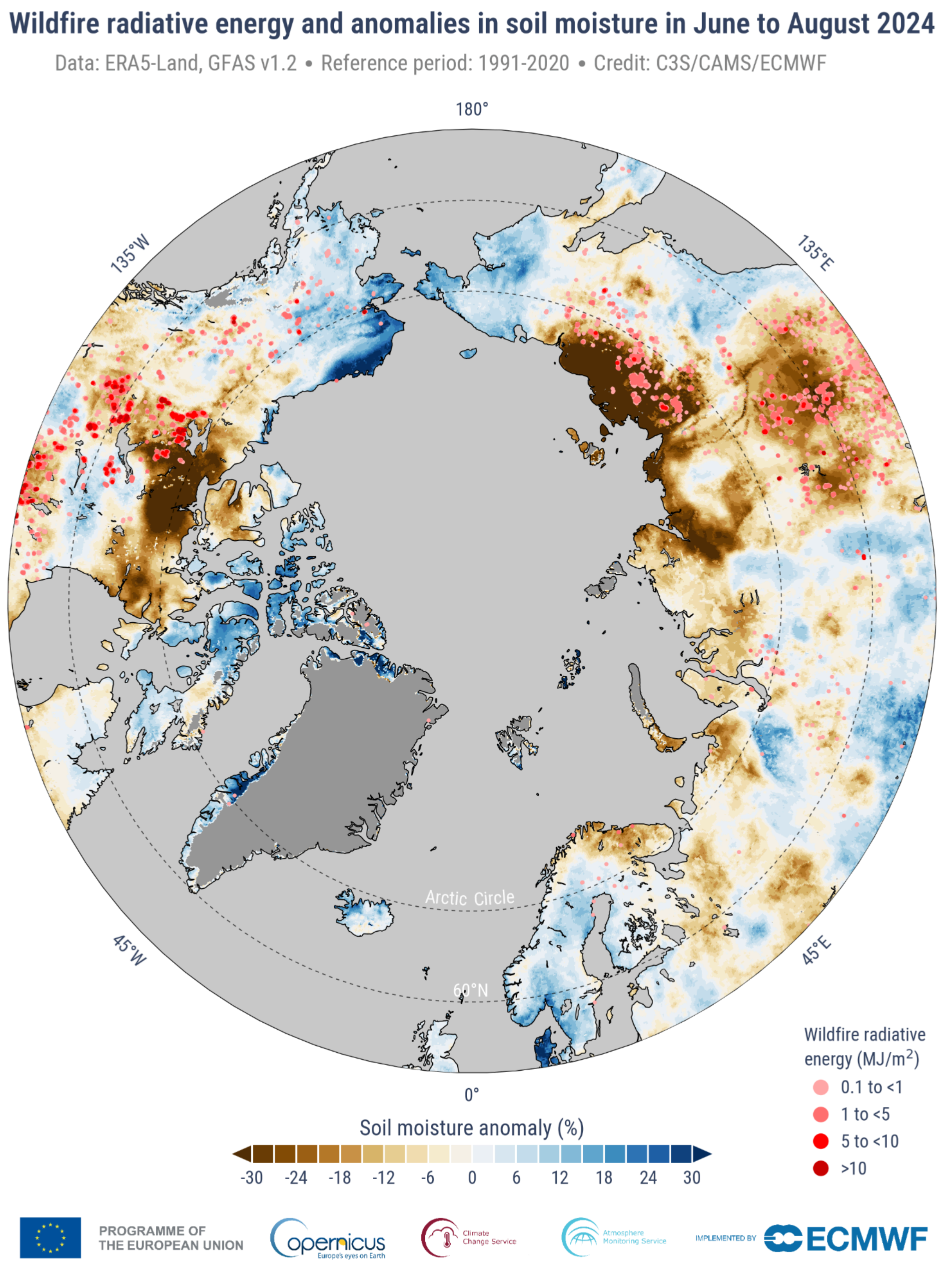


Figure 16.2. Map showing soil moisture anomalies, locations[31] and total wildfire radiative energy (megajoules per m^2) (red dots) of wildfires in June–August 2024. The soil moisture anomalies are relative to the average for the 1991–2020 reference period and expressed as a percentage of this average. Data: ERA5-Land soil moisture and CAMS GFAS v1.2 wildfire data. Credit: C3S/ECMWF/CAMS.

[31] In Figure 16.2, wildfire locations are shown only where the GFAS-estimated wildfire radiative energy is at least 0.1 MJ/m^2.

Arctic ocean

Key messages

- During 2024, Arctic sea ice extent was relatively close to average until June, but fell well below average in the following months. At its annual minimum in September, the monthly extent ranked fifth lowest in the satellite record.
- The annual average sea surface and sea ice temperature north of the Arctic Circle was the third warmest on record. The Norwegian and Barents Seas saw record warm sea and sea ice temperatures in August and September, contrasting with below-average temperatures in the North Atlantic sector.
- The Barents Sea and Hudson Bay saw well below average sea ice in late 2024, with freeze-up occurring much later than average and record late, respectively.

The Arctic region and the Arctic Ocean in particular are highly sensitive and vulnerable to changes in temperature. The long-term decline in sea ice has further contributed to the warming by reducing surface reflectivity (‘albedo’). Besides the warming trend, short-term changes in weather and climate also influence the magnitude and distribution of temperature anomalies, impacting local ecosystems.

This section examines the evolution of Arctic sea ice cover, as well as surface temperatures (ocean waters and sea ice), complemented by observations of Chlorophyll a concentrations in spring and summer.

Sea ice cover

In 2024, Arctic sea ice extent remained close to average until June. At its annual maximum in March, the monthly extent was only 1% below average. From July onward, the sea ice extent dropped significantly below average. At its annual minimum in September, the monthly extent was 19% below average, ranking fifth lowest in the satellite record. This value is in line with the anomalies of -10% to -20% often observed in September since 2007 and well above the record low of -32% in 2012. The annual minimum for the daily extent was the sixth lowest[32] on record and the year ended with the lowest December extent on record.

[32] A satellite data outage of six days occurred between 12 and 17 September around the time when Arctic sea ice extent was reaching its annual minimum. Therefore, there is some uncertainty about the magnitude and ranking of the minimum extent.

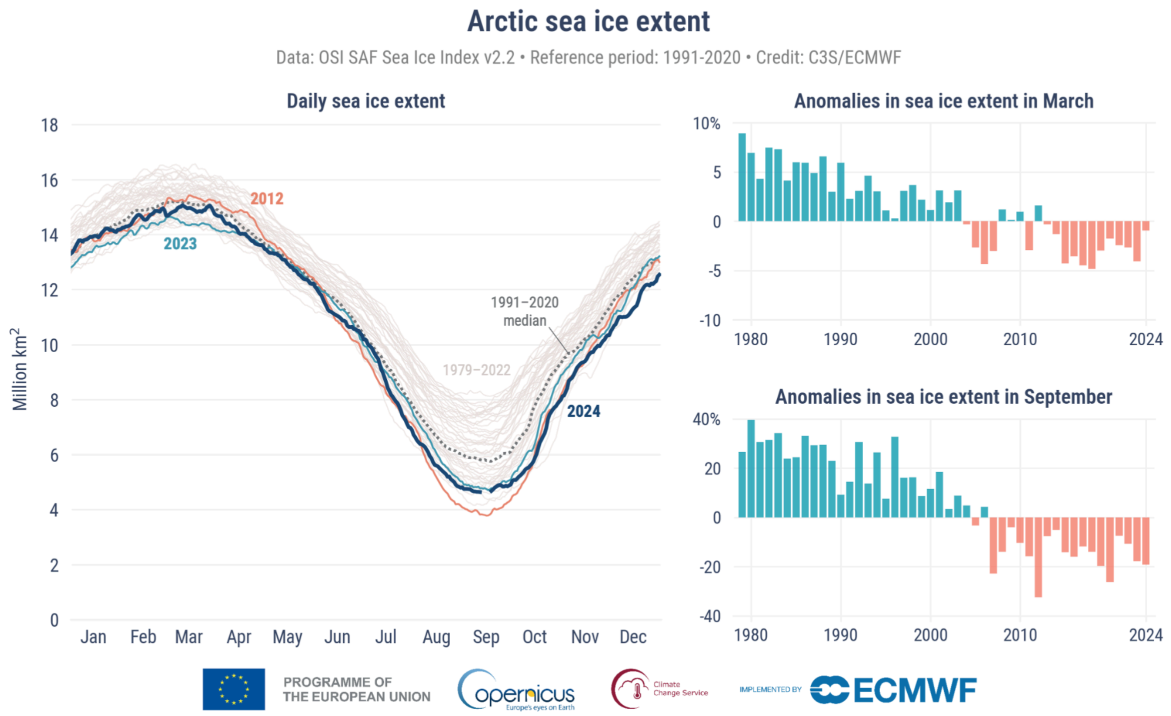


Figure 17.1. (Left) Daily Arctic sea ice extent from 1979–2024, highlighting 2024 (dark blue line), 2023 (teal line), and 2012 (salmon line; year of the lowest daily sea ice extent). (Right) Monthly anomalies (%) in Arctic sea ice extent for March (top) and September (bottom) from 1979–2024. The anomalies are relative to the respective monthly averages for the 1991–2020 reference period and expressed as a percentage of these averages. Data: OSI SAF Sea Ice Index v2.2. Credit: C3S/ECMWF/EUMETSAT.

From January to April, sea ice concentrations across the Arctic were relatively close to average. In the Greenland Sea, concentrations remained above average, continuing a trend observed throughout 2023. This was linked to southward sea ice drift from the central Arctic Ocean through the Fram Strait, which lies between Greenland and Svalbard. In May and June, sea ice extent in Hudson Bay fell to record lows for the time of year, as strong, persistent winds pushed the ice away from the eastern shore. From July onward, below-average concentrations became more widespread, corresponding to a decline in total Arctic sea ice extent to well below average. From August to October, below-average concentrations were most pronounced in the Northeast Atlantic sector (the Greenland, Barents and Kara Seas) and in the Beaufort Sea. This partly coincided with record-high surface air temperatures and sea surface temperatures in the Barents Sea region. In November and December, sea ice cover in the Barents Sea remained well below average, causing freeze-up in this area to occur around 1.5 months later than average. Hudson Bay experienced a record late freeze-up, delayed by almost a month and so remaining virtually ice-free in December. These two sectors were major contributors to the record-low sea ice extent seen in December.

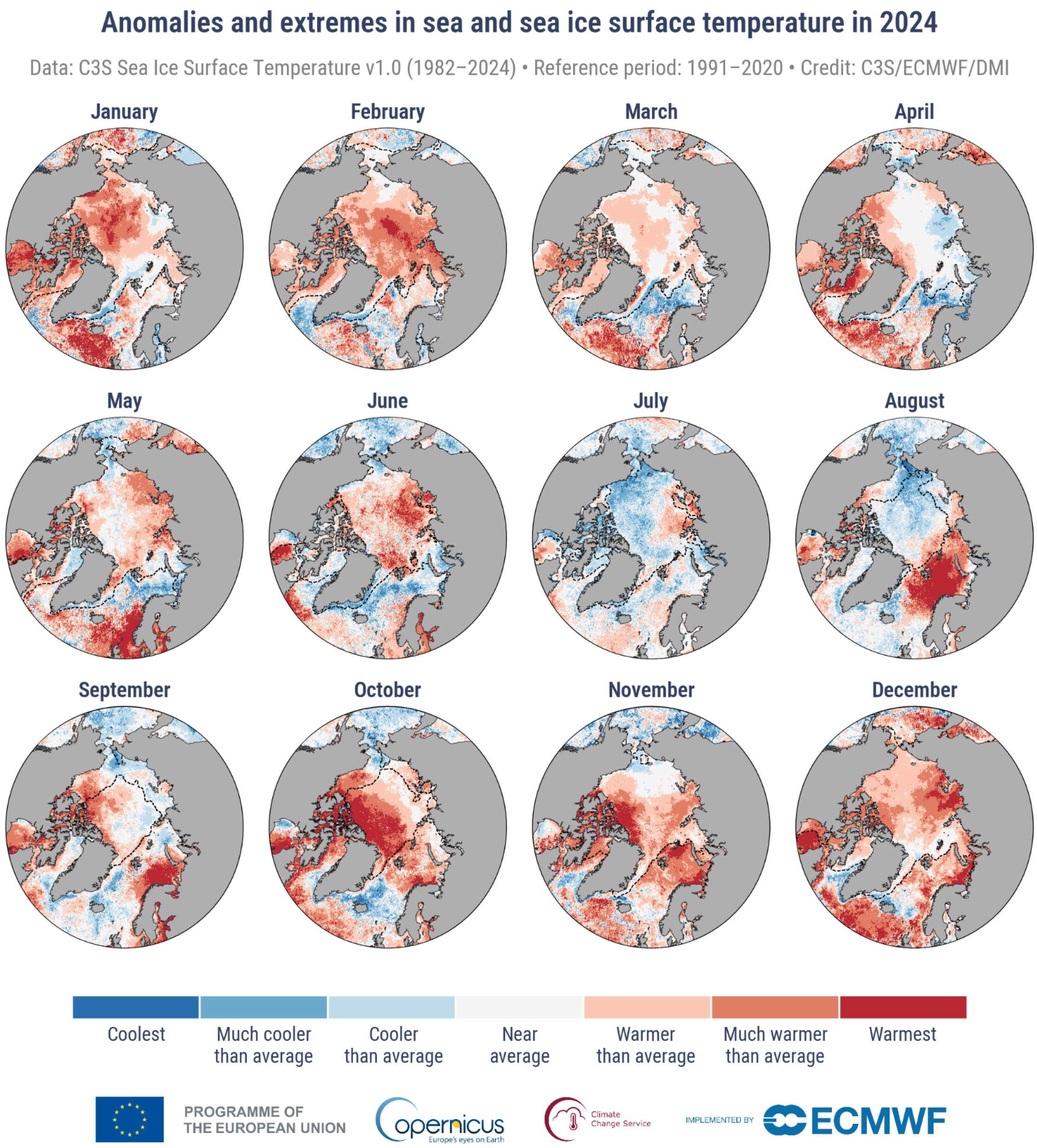


Figure 17.2. Monthly average sea ice concentration anomalies (%) in 2024, relative to the average for the 1991–2020 reference period. Data: OSI SAF Global Sea Ice Concentration v3.0. Credit: C3S/ECMWF/EUMETSAT.

Sea surface and sea ice surface temperature

The temperature at the ocean's surface plays an essential role in heat and water exchange with the atmosphere, as well as in sea ice processes. Sea surface temperature (SST) can be estimated from satellite observations. Where sea ice is present, SST is typically assumed to be -1.8°C, the freezing point of seawater. Here, however, SST over ice-free water is combined with satellite-derived estimates of the ice surface temperature (IST) over ice-covered areas to assess the surface temperature of the Arctic Ocean as a whole. IST exhibits fluctuations that are often much larger than those of SST. This is due to differences in physical properties between seawater and the air immediately above the ice surface.

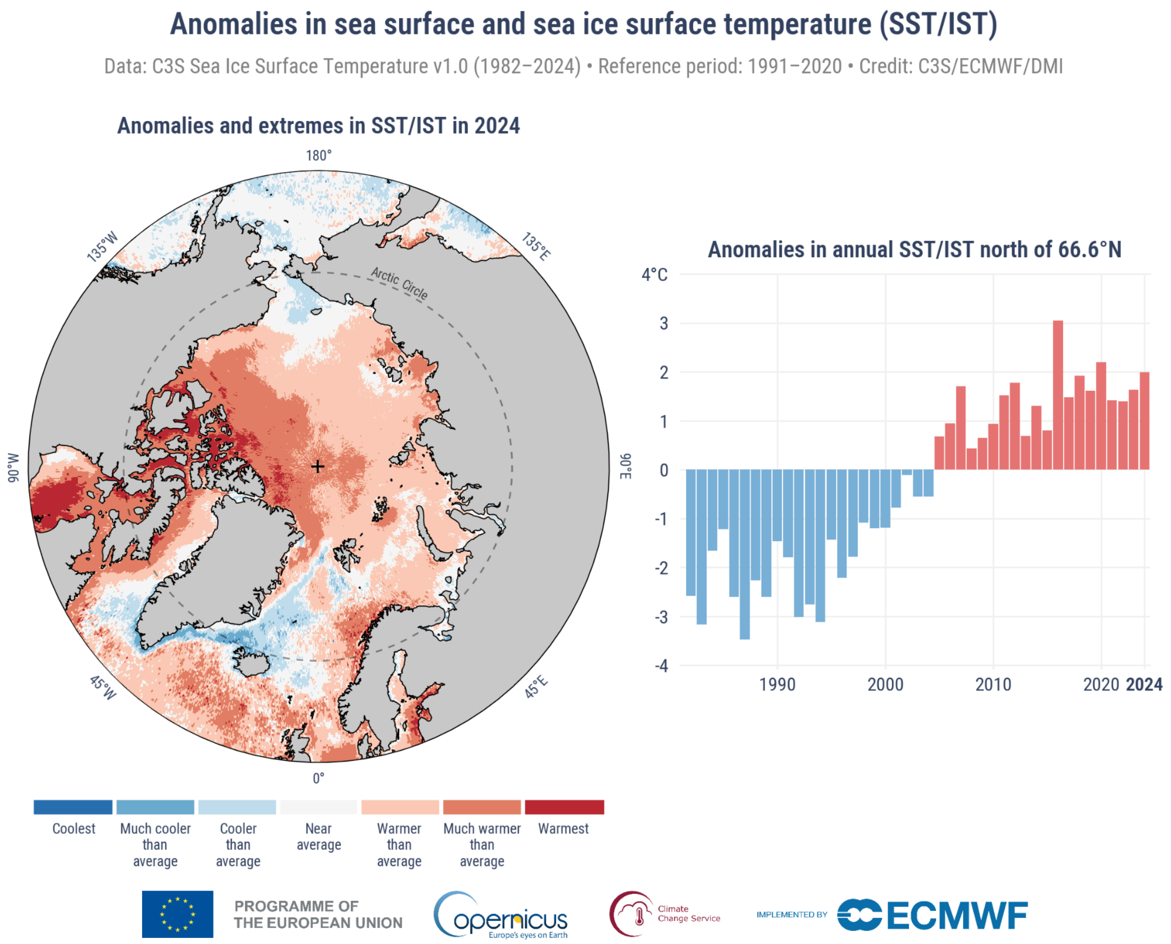


Figure 17.3 Anomalies and extremes in annual sea surface temperature (SST) and sea ice surface temperature (IST) in 2024. The extreme categories ('coolest' and 'warmest') are based on rankings for 1982–2024. The other categories describe how the temperatures compare to their distribution during the 1991–2020 reference period. 'Much cooler/warmer than average' - cooler/warmer than 90% of temperatures. 'Cooler/warmer than average' - than 66% of temperatures. 'Near average' - within the middle 33%. (Right) Annual SST/IST anomalies for the ocean north of the Arctic Circle relative to the 1991–2020 reference period. Data: C3S Sea Ice Surface Temperature v1.0. Credit: C3S/ECMWF/DMI.

Spatial averages

In 2024, the annual SST/IST north of the Arctic Circle was 1.99°C above average, making it the third warmest in the satellite record, behind 2016 (+3.05°C) and 2020 (+2.20°C). This positive anomaly aligns with a strong warming trend observed since the 1980s. As in 2023, daily temperatures were much warmer than average outside the melt season, which runs from April to August. The anomalies were particularly high early in the year, especially in February. From April to September, temperatures generally remained close to average, but dropped well below average from mid-July to early August. A second period of positive temperature anomalies was experienced from October to December, reaching up to around 10°C above average. For around a month, from the beginning of October, temperatures reached record levels for the time of year.

Regional variations

Temperatures for the year as a whole were above average across most of the Arctic Ocean and much above average in large parts of the western Arctic. Parts of Hudson Bay and the Canadian Archipelago saw record highs, with annual temperatures in eastern Hudson Bay reaching up to 4–5°C above average. In contrast, below-average temperatures prevailed in parts of the North Atlantic sector (Greenland and Labrador Seas, Denmark Strait) and the Chukchi Sea.

During the year, the anomalously warm conditions in Hudson Bay were most pronounced in January, May–June, October and December, and partly linked to much-reduced sea ice cover described above. Record-high temperatures occurred in the Norwegian and Barents Seas in August and September, peaking at around 4–5°C above average in August. These seas are typically ice-free during these two months. Therefore, below-average sea ice cover was unlikely to be a key contributing factor to the record-warm conditions. Instead, atmospheric influences, such as sustained warm winds from the south, probably played an important role.

Nearly half of the central Arctic Ocean experienced much warmer-than-average temperatures in October, coinciding with similarly warm conditions over land in the Canadian Arctic. It is likely these warm conditions contributed to the below-average sea ice thickness observed in the same part of the Arctic Ocean.

In the Greenland Sea and Denmark Strait, above-average sea ice cover from January to April may have contributed to the cooler temperatures, as described above. However, the persistence of these cooler temperatures during the rest of the year suggests that other factors, such as atmospheric conditions, were likely involved.

Ocean colour

Chlorophyll a (Chl a) is a photosynthetic pigment in phytoplankton that is estimated by satellite measurements of ocean colour, which varies depending on what is dissolved or suspended in the water. As the abundance of phytoplankton is linked to the availability of sunlight and nutrients, Chl a can help assess the health of marine ecosystems. In polar waters, Chl a concentration is used to identify sea ice retreat in spring, which increases the availability of sunlight, and melting sea ice, which releases nutrients in the water.

In May, Chl a concentrations were higher than average in the Greenland Sea and along the northern coast of Norway. In June, a region of the southern Greenland Sea also saw a strong positive anomaly. Elsewhere, values were mostly near or below average during the month. In July, above-average concentrations occurred across the Greenland, Barents and Kara Seas. The summer months also saw positive Chl a anomalies in the Chukchi and East Siberian Seas.

Resilience of the built environment to climate extremes

Key messages

- European cities have become more resilient, but continued efforts will unlock even greater potential to effectively tackle the challenges associated with climate change.
- Extreme weather events pose increasing risks to Europe's built environment and infrastructure and the services they support, and urgent action is needed, especially on flood risks.
- Current adaptation measures in European cities are mostly physical and technological, followed by nature-based and governance solutions. Encouragingly, 51% of European cities now have dedicated adaptation plans in place, representing significant progress from 26% in 2018.

As climate challenges increase, cities are leading global action, acting as hubs of innovation and transformation. Home to around 55% of the world's population[R16] and responsible for 70% of carbon emissions[R17], urban areas are major drivers of environmental degradation. In Europe, however, around 70% of climate mitigation and 90% of adaptation efforts take place in urban areas, positioning them as key leaders in the fight against climate change[R18]. European cities have also committed to reducing carbon emissions by 55% by 2030 and achieving net-zero emissions by 2050[R18]. By integrating climate action with nature restoration, cities are redefining the role of urban areas in fostering resilience and sustainability.

This section provides an overview of the risk of weather and climate extremes to the built environment and infrastructure in Europe, in the context of climate policy and action.

In 2024, the EEA published the first European Climate Risk Assessment (EUCRA), showing that 34 of 36 major climate risks across five risk clusters (ecosystems, health, infrastructure, food and economy and finance) could reach critical or even catastrophic levels during this century under high warming scenarios.

An increase in the frequency and intensity of many extreme weather events is posing increased risks to the built environment and infrastructure in Europe, and to the services they provide. Aging structures and rising demand for housing in urban areas are further exacerbating the risks. As infrastructure assets are often part of an interconnected network, disruptions to one asset can cascade across sectors. Human health is also negatively affected by extreme weather events because of the poor condition of infrastructure in some regions. The vulnerability of population groups living in poorly maintained and insulated buildings is exacerbated during extreme heat and heatwaves, and particularly in dense urban areas where there is a strong urban heat island effect.

Identified climate risks for the infrastructure cluster

Climate risks for 'Infrastructure' cluster	Urgency to act	Risk severity			Policies	
		Current	Mid-century	Late century (low/high warming scenario)	Horizon	Readiness
Pluvial and fluvial flooding	Urgent action needed	Substantial •••	Critical •••	Critical/Catastrophic ••	Long	Medium
Coastal flooding	More action needed	Substantial •••	Critical •••	Catastrophic •••	Long	Advanced
Damage to infrastructure and buildings*	More action needed	Substantial ••	Substantial ••	Substantial/Critical ••	Long	Medium
Energy disruption due to heat and drought (hotspot region: southern Europe)	More action needed	Substantial ••	Critical ••	Critical ••	Medium	Medium
Energy disruption due to heat and drought	Further investigation	Limited ••	Substantial ••	Substantial/Critical •	Medium	Medium
Energy disruption due to flooding	Further investigation	Substantial ••	Critical ••	Critical ••	Long	Advanced
Marine transport	Further investigation	Limited ••	Substantial ••	Substantial/Critical ••	Medium	Medium
Land-based transport	Further investigation	Limited ••	Substantial ••	Substantial ••	Medium	Medium

Low confidence (•) Medium confidence (••) High confidence (•••)
* Urgency based on high warming scenario (late century)

Data: EUCRA • Credit: EEA/C3S/ECMWF

Figure 18.1. Identified climate risks for the infrastructure cluster, including urgency to act, projected severity in the current, mid- and late-century and related policy characteristics. [Source: EUCRA[R19]]

There are clear indications that impacts from climate change may increase in the future. Damage to the built environment from extreme weather is projected to increase by as much as tenfold by the end of the 21st century due to climate change alone. In particular, urgent action is needed on pluvial and fluvial[33] flooding risks, which are expected to reach 'critical'[34] risk severity by the mid-century, or

[33] Pluvial flooding occurs when intense rainfall leads to surface water buildup, for example because the ground can't absorb it fast enough or drainage systems are overwhelmed. Fluvial flooding occurs when rivers overflow due to heavy rain or snowmelt.
[34] 'Critical' risk severity is defined as large and frequent damage, large extent and high pervasiveness, long-term disturbance of system functionality, cascading effects beyond system boundaries.[R19]

'catastrophic'[35] risk severity by the late century under a high warming scenario (with global warming of 3.5°C). Coastal flooding is also expected to reach 'catastrophic' risk severity by the late century and, under a high warming scenario, damage to infrastructure, energy disruption and marine transport challenges associated with vulnerability of infrastructure to extreme events and other challenges such as sea level rise, are all expected to reach at least 'critical' risk severity.

European cities are increasingly feeling the impacts of climate change. The effects of events such as heatwaves and floods are often exacerbated in urban areas due to their dense infrastructure, population levels and infrastructure layouts. Investing in urban resilience is crucial to mitigating these impacts.

Urban areas are particularly vulnerable to flooding due to increased surface run-off during storms and other heavy precipitation events, especially where there are artificial or sealed surfaces. Since 2000, the overall proportion of sealed land in Europe has grown by around 6%. Between 2011 and 2021, an estimated 26.9% of urban areas saw a significant rise in population living within existing floodplains. In addition, the urban heat island effect can cause surface temperatures to be up to 10–15°C warmer than in surrounding areas. Other increasing risks include water scarcity, declining water quality, the spread of disease-carrying vectors, storms, wildfires, landslides and coastal flooding due to sea level rise. The sectors most impacted by climate change in larger urban areas are water, buildings, health and transport.

What cities are already doing

Cities play an essential role in implementing adaptation measures, which must consider local conditions and vulnerabilities. Cities across Europe vary in context, such as geography; capacity, including finance; and experience of past events, and readiness to adapt, but almost all are taking some form of action. In 2022, around 19,000 adaptation actions were reported[R20], mainly addressing adaptation needs in the water (17%), buildings (13.6%), environment (11.7%), land (10.8%), agriculture (9.3%) and health (7.6%) sectors.

The Key Type Measure classification can help with reporting and monitoring of progress on adaptation actions. Based on this classification, physical and technological measures were the most common action across Europe (35.4%), followed by nature-based solutions (26.6%), governance (20.3%) and knowledge-based (14.3%). Economic measures were the least reported (3.4%).

Physical and technological measures, as the most common action, include water recycling, separation of rain and greywater, climate-resilient building design, risk mapping and early warning systems.

Due to the magnitude of current and predicted future climate impacts, it may be necessary to combine these approaches with complementary types of adaptation

[35] 'Catastrophic' risk severity is defined as very large and frequent damage, very large extent or very high pervasiveness, irreversible loss of system functionality, systemic risk. [R19]

actions. Nature-based solutions, for example, promote the maintenance and re-integration of nature. Green (vegetation) and blue (water) elements provide water regulation, cooling and other benefits, for example. 91% of local climate action plans across Europe include nature-based solutions in their adaptation measures.

Governance and institutional measures are also widely reported. These include policies and regulations that can assist in increasing overall climate resilience. A comprehensive local climate action plan is essential for achieving adaptation goals. Targeted spatial planning and building regulations can help limit urban expansion, especially in high-risk areas, and maintain and create space for green infrastructure. Updating specific building codes and design regulations can promote circularity in material use and improve energy and water efficiency. Economic instruments and finance can encourage the uptake of adaptation measures, such as green roofs, rainwater collection or energy-efficient renovations, while supporting the enforcement of climate-related policies. Affordable insurance measures that account for further climate resilience are also essential in reducing the impact of climate-related economic losses. Additionally, measures that improve knowledge and support behavioural change, such as awareness campaigns, can enhance individual and societal resilience.

Many cities and other urban settlements are implementing specific measures to become more climate resilient. Examples highlighted in the EUCRA report include measures to address climate extremes, particularly heatwaves and floods. For details of actions taken across various European cities, see the Climate Resilience section of the ‘Key events map’ online, and the infographic on page XX for some examples.

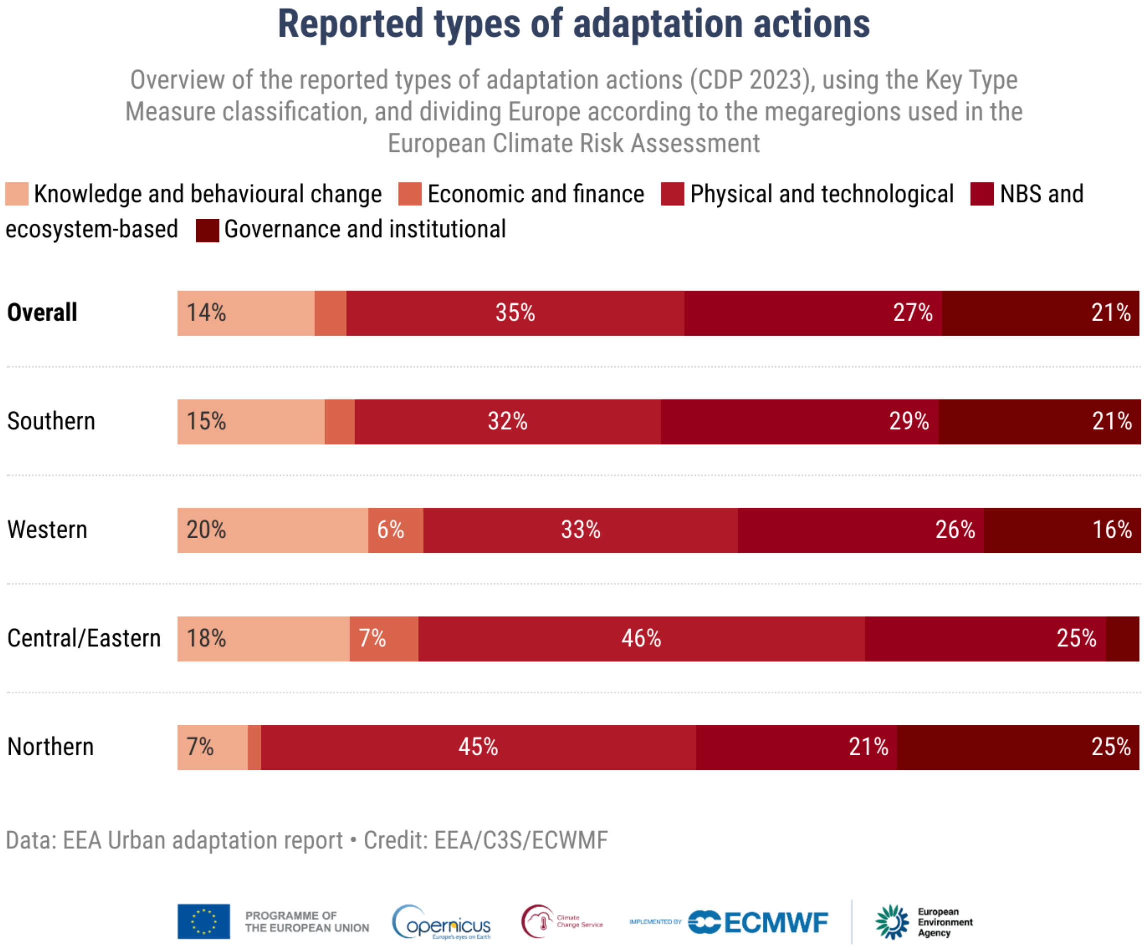


Figure 18.2: Overview of the reported types of adaptation actions[R21], using the Key Type Measure classification, and dividing Europe[36] according to the megaregions used in the European Climate Risk Assessment. [Source: Urban adaptation report[R22]]

Enabling successful adaptation

Citizen engagement is the most frequently reported enabler of adaptation actions. Involving citizens in planning, implementation and maintenance is vital as they can provide valuable insights into the local impacts of climate change and the suitability of specific measures. Engaging vulnerable groups is particularly important to ensure equitable outcomes of climate adaptation activities.

[36] Countries covered (reporting adaptation actions to CDP within the four EUCRA megaregions): Northern: Denmark, Finland, Iceland, Ireland, Latvia, Lithuania, Norway and Sweden; Southern: Croatia, Greece, Italy, Portugal, Slovenia, Spain, Türkiye, Albania, Bosnia and Herzegovina, and Montenegro; Western: Belgium, France, Germany, the Netherlands and Switzerland; Central-eastern: Bulgaria, Czechia, Hungary and Poland.

The most reported barriers to implementation of adaptation actions are the availability of sufficient and sustained funding, often linked to the absence of long-term political commitment with a clear vision. Ensuring sufficient long-term financial resources is key to success.

Measuring progress towards climate resilience

The importance of supporting and facilitating local adaptation to climate change is increasingly acknowledged in policies at both national and European level, with cities playing a key role in implementation. Local authorities are well positioned to put adaptation strategies and plans into practice and are increasingly required to do so by law. Municipal-level adaptation projects can be tailored to locally observed climate impacts and to the needs of specific stakeholders, including citizens.

European institutions have raised their ambitions, creating policies designed to accelerate local action. The 2021 EU adaptation strategy aims to ensure resilience, while the European Climate Law sets the 'net-zero' climate neutrality target for 2050 into binding legislation. These directives are supported by increased funding for the adaptation actions needed. New implementation mechanisms, such as the 2023 Mission on Adaptation, have been established to help scale up actions. These EU initiatives are complemented by local, regional and national governance in member states.

Adaptation planning is becoming more widespread, with an estimated 51% of European cities now having dedicated plans, marking significant progress from 26% in 2018. The development of local climate and energy plans are influenced by factors such as city size (with smaller municipalities having more limited technical and resource capacity), national legislation on local climate planning and participation in city networks and initiatives. In 2020, an estimated 123 million people in the EEA-38 countries lived in areas with an adaptation commitment[R19]. By early 2024 that figure had reached 202.5 million.

Adaptation is required across all sectors and governance levels, and actions must address both current climate impacts and protect against future risks. However, to effectively upscale actions at the local level, tangible targets are needed to measure progress.

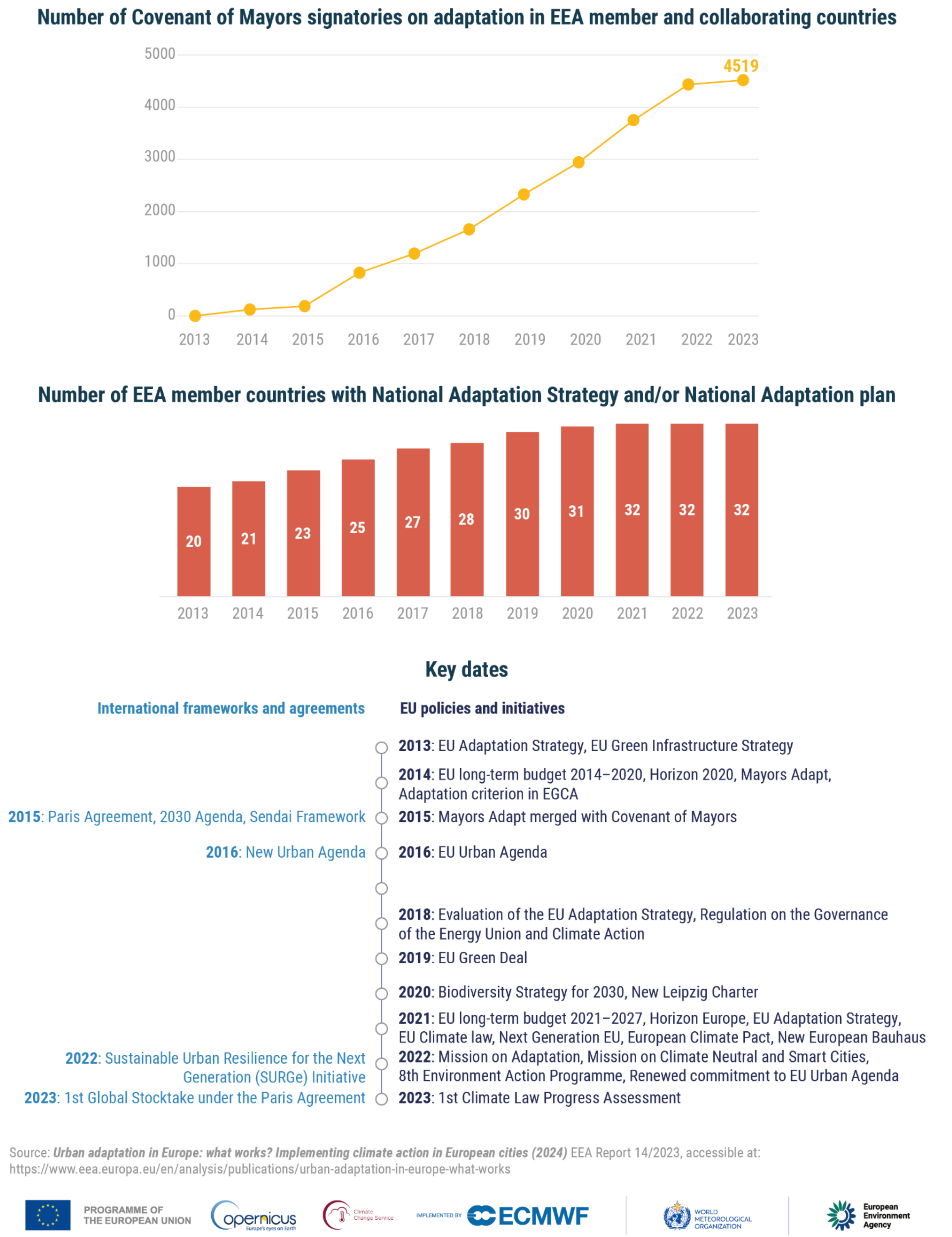


Figure 18.3. Evolution of European policy relevant to adaptation, national adaptation plans and strategies, and number of signatories to the Covenant of Mayors with adaptation commitments for 2013–2023.[Source: EEA Urban Adaptation report 2024[R22]]

Trends in Climate Indicators

Climate Indicators show the long-term evolution of key variables used to evaluate global and regional trends in our changing climate. While the focus of this report has been on the climate of 2024 across Europe, this section provides a summary[37] of long-term changes at global and regional levels. For more information on each of the variables summarised here, visit the 'Climate Indicators Dashboard'.

Increasing temperatures over land and ocean

The Paris Agreement aims to hold the increase in global average temperature to well below 2°C above pre-industrial levels and preferably below 1.5°C. The five-yearly Global Stocktake assesses the collective progress in the implementation of the Paris Agreement. The first was completed at the end of 2023.

Monitoring surface air and sea surface temperatures globally and regionally contributes to the stocktake. Global average values for these variables have increased significantly since the pre-industrial era, by around 1.3–1.4°C* and 1.0°C, respectively.

Temperature
In recent decades, temperatures over land have risen around twice as fast as those over the ocean. Europe is the fastest warming of all the WMO regions, at around twice the global average. Temperatures over the Arctic have risen more rapidly than those over most of the rest of the globe, with an estimated warming of around 3°C since the 1970s. The trend map illustrates both the overall warming trend and the differences in the rate of warming in different regions of the globe.

Since 1850–1900, an increase in surface air temperature of around:
Globe: +1.3°C
WMO RA VI: +2.5°C
Europe: +2.4°C
Arctic: +3.3°C
**Latest five-year averages. Values for Europe, WMO RA VI and the Arctic are over land only.*
Data: ERA5

[37] In this report, long-term trends are summarised by highlighting the best estimate of key statistics. The uncertainty associated with these estimates are due to factors such as measurement uncertainties and differences between datasets. These uncertainties do not impact the conclusions or clear long-term trends. For more detailed information on each variable, datasets and methodologies, visit the dedicated Climate Indicators website.

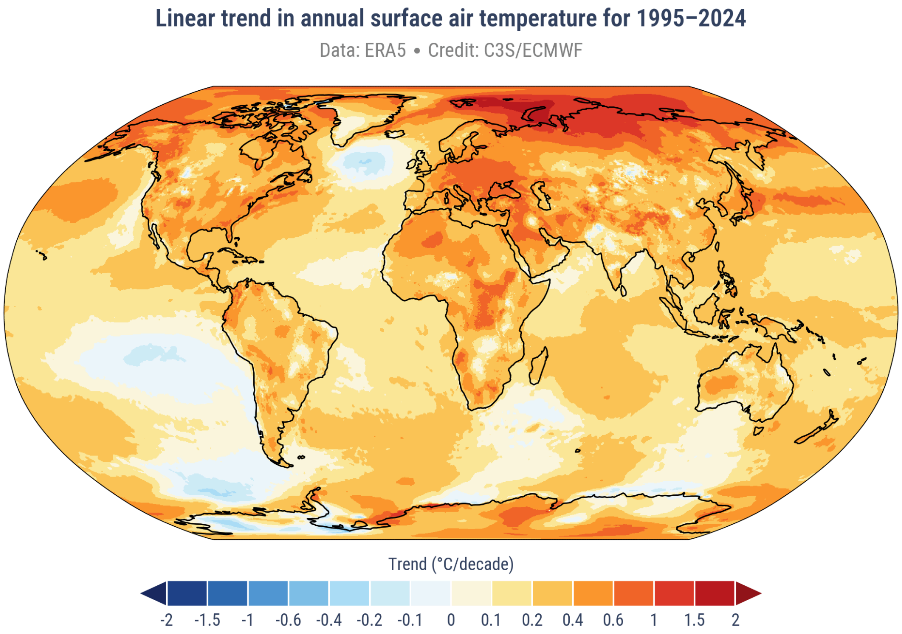


Figure 19.1. Trend[38] in annual surface air temperature (°C/decade) for 1995–2024. Data: ERA5. Credit: C3S/ECMWF.

Sea Surface Temperature

A key modulator of global SSTs on interannual timescales is the El Niño Southern Oscillation (ENSO), which sees periods of warmer (El Niño) or cooler (La Niña)-than-average conditions in the central and eastern tropical Pacific. These changes in SST influence circulation patterns and surface air temperatures around the globe. For example, the record-high SSTs over the non-polar ocean in 2024 were influenced by the residual effects of the El Niño that peaked in late 2023, and a transition towards neutral ENSO conditions.

Since the 1980s, an increase in SST of around:
Globe (non-polar ocean, 60°S–60°N) +0.6°C
WMO Regional Association VI (Europe) +1.0°C
Mediterranean Sea +1.3°C
Latest five-year averages
Data: HadSST4.1.0.0, COBE2, ERSSTv5, ERA5, C3S Sea and Sea Ice Surface Temperature v1.0

[38] The linear trends are calculated using ordinary least-square regression. This does not imply that the temperature changes are themselves linear.

The ocean is impacted by and regulates the climate

The ocean absorbs and stores up to 90% of the excess heat that is associated with human-induced greenhouse gas emissions, playing a crucial role in regulating the climate.

Large-scale ocean circulation redistributes heat from low to mid and high latitudes, and between the surface and deeper layers. The balance between heat absorption and release results in variations in ocean heat content.

Change in mean sea level is an essential indicator of the evolving climate. It reflects both the thermal expansion of the ocean in response to its warming and the increase in ocean mass due to the melting of ice sheets and glaciers.

Sea level

Since 1999, global mean sea level has risen by around 9.4 cm. The rate of rise is accelerating, averaging 4.2 mm per year over the last ten years compared to 2.9 mm per year between 1999 and 2009. Regionally, there can be variation. For example, across Europe, sea level changes differ between the open ocean and coastal areas due to various oceanic and geophysical processes.

Since 1999, an average annual sea level rise of around:
Global: +3.7mm
Europe: +2–4mm
February 1999 to July 2024.
Data: CMEMS monitoring indicator and C3S sea level product.

Ocean heat content

Long-term trends in ocean heat content indicate that most of the heat gain is in the upper 700 m of the ocean. This heat is slowly being transferred to the 700–2000 m layer. Even small changes in temperature correspond to large changes in energy, due to the ocean's immense volume. In 2024, global ocean heat content was the highest on record.

Since 1993, an increase[39] of:
Global: +0.16°C
Northeastern Atlantic: +0.03°C
in the upper 2000 m
Data: ORAS5

[39] Ocean heat content is traditionally expressed in joules, as it represents the total energy stored in the ocean. However, to provide a more intuitive understanding of temperature-related changes, this report presents these statistics in °C. The conversion from joules to °C accounts for the specific heat capacity of seawater—approximately 4,000 joules per kilogram per degree Celsius—and the vast mass of the ocean.

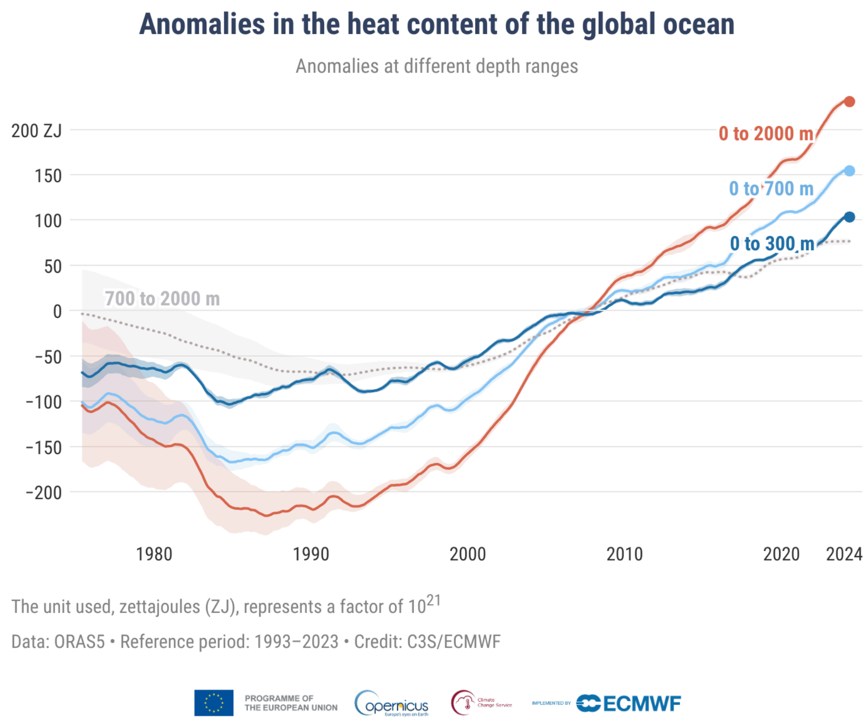


Figure 19.2. Time series of anomalies in the heat content of the global ocean from 1975–2024 in the upper 300 m (dark blue), 700 m (light blue), 2000 m (red) and 700–2000 m (grey dashed line), relative to the average for the 1993–2023 reference period. Showing five-member ensemble means (solid lines) and ensemble spread (shading). Data: ORAS5. Credit: C3S/ECMWF.

The cryosphere in a changing climate

The cryosphere encompasses all parts of the Earth system where water is in solid form, including ice sheets, glaciers, snow cover, permafrost and sea ice.

The cryosphere and the climate exert a strong influence on each other. Due to its high surface reflectivity ('albedo'), changes in the cryosphere impact the amount of solar energy taken up by the planet's surface, and consequently temperatures.

As temperatures rise, glaciers and ice sheets melt, releasing vast amounts of water, which contributes to global sea level rise. The changing cryosphere therefore has many further environmental and societal implications.

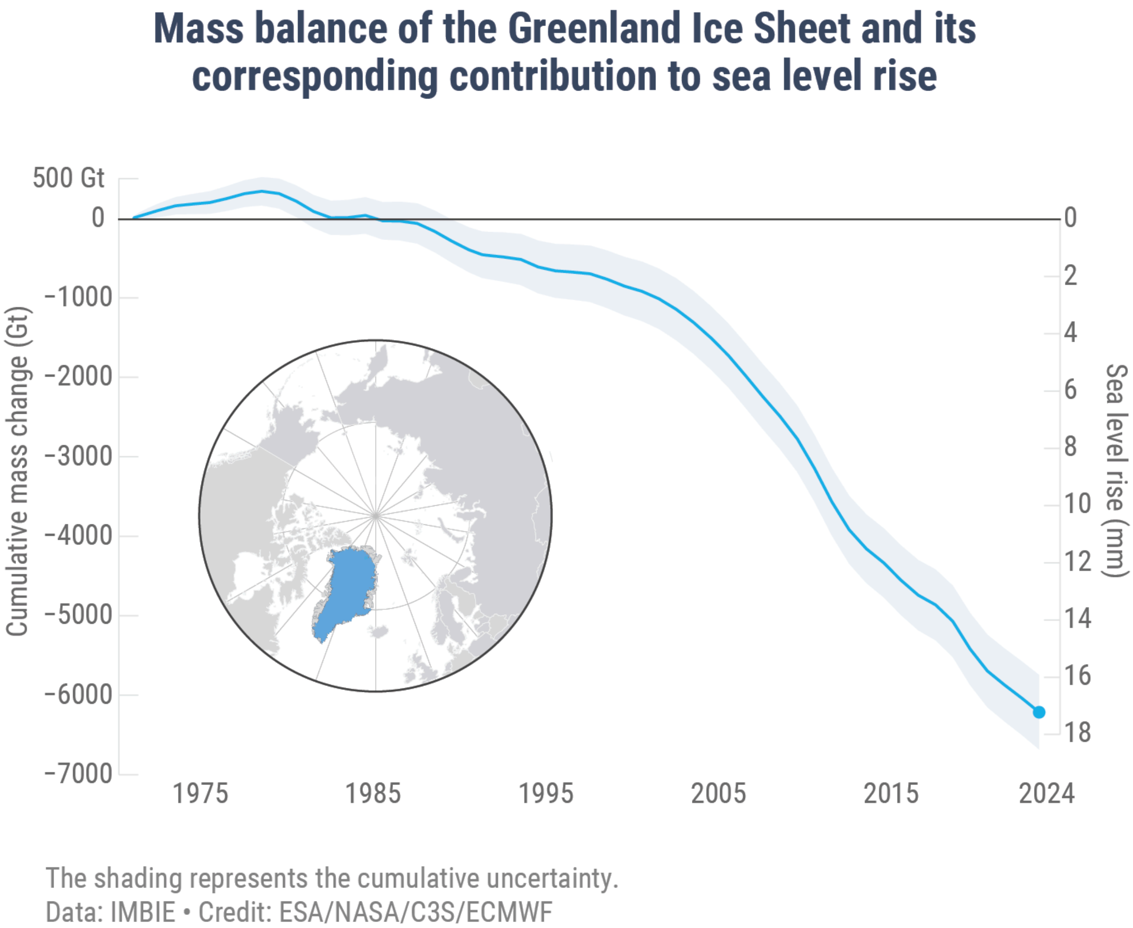
Glaciers

Globally, around 275,000 glaciers cover an area of approximately 700,000 km^2. Glaciers have seen a substantial and prolonged loss of ice mass since the mid-19th century, both globally and across Europe. An average of about 16 m reduction in ice thickness has been observed since global records began in 1976, and glaciers have contributed about 1 mm per year to global mean sea level rise during the last decade. In 2023, this contribution peaked at 1.5 mm due to record global glacier mass loss, and in 2024 remained high at 1.2 mm. The five years with the largest global glacier mass loss have all occurred within the past six years.

Since 1976, a loss of glacier ice of around:
Global: -9200 km^3
Europe: -915 km^3
Ice loss for Europe does not include peripheral glaciers in Greenland.
Data: WGMS

Ice sheets
Earth's polar ice sheets cover most of Greenland and Antarctica, and store about 68% of the planet's freshwater resources. If the ice sheets were to melt entirely, they would raise global mean sea level by around 7.4 m for the Greenland Ice Sheet and around 57.9 m for the Antarctic Ice Sheet. Since the 1970s, melting of these ice sheets has caused sea level to rise by around 3 cm. It is estimated that for every centimetre of sea level rise, around six million people across the planet are exposed to coastal flooding. The rate of ice loss has increased by around three times (Antarctica) to five times (Greenland) since the 1980s.

Since the 1970s, a loss of ice sheet of around:
Greenland: -6776 km^3
Antarctica: -5253 km^3
Data for 1972–2023 for Greenland, and 1979–2023 for Antarctica.
Data: IMBIE



PROGRAMME OF THE EUROPEAN UNION | Copernicus Europe's eyes on Earth | Climate Change Service | IMPLEMENTED BY ECMWF

Figure 19.3. Cumulative mass change of the Greenland Ice Sheet since 1972 and its corresponding contribution to sea level rise. The shading represents the cumulative uncertainty. Data: IMBIE. Credit: ESA/NASA/C3S/ECMWF.

Sea ice

Arctic sea ice extent has declined markedly since satellite records began in the late 1970s. The decline is largest around the annual minimum in September, with widespread retreat across the region. In the Antarctic, although the long-term trend remains uncertain, sea ice extent has often reached much lower-than-average values since around 2017, with successive record lows at its annual minimum in February in 2022 and 2023, and near-record lows in 2024 and 2025.

Ice loss since the 1980s:
Arctic (September): -2.7 million km^2 (-36%)
Antarctic (February): -0.7 million km^2 (-20%)
Last five years, relative to 1980s
Data: EUMETSAT OSI SAF

Greenhouse gases driving climate change

Greenhouse gases (GHGs) in the atmosphere trap heat close to Earth's surface.
As concentrations increase, the near-surface temperature also rises, with significant impacts. Human activities lead to the emission of GHGs in various ways, including the combustion of fossil fuels for energy, deforestation, the use of fertilisers in agriculture, livestock farming and the decomposition of organic material in landfills. Of all the long-lived GHGs that are emitted by human activities, carbon dioxide (CO2), methane (CH4) and nitrous oxide (N2O) have the largest impact on the climate.

Greenhouse gas concentrations

The amount of a gas contained in a certain volume of air.
Atmospheric concentrations of the two most important anthropogenic greenhouse gases, carbon dioxide (CO2) and methane (CH4), continued to increase in 2024, reaching record levels.

Since 2020, an increase in the concentrations of greenhouse gases, per year, of:
CO2: +2.4 ppm
CH4: +12 ppb
Concentrations (column-averaged mixing ratios) for CO2 and CH4, averaged over the whole atmospheric column for 60°S-60°N.
Data: C3S/Obs4MIPs (2003-2023) and CAMS near real-time data (2024).

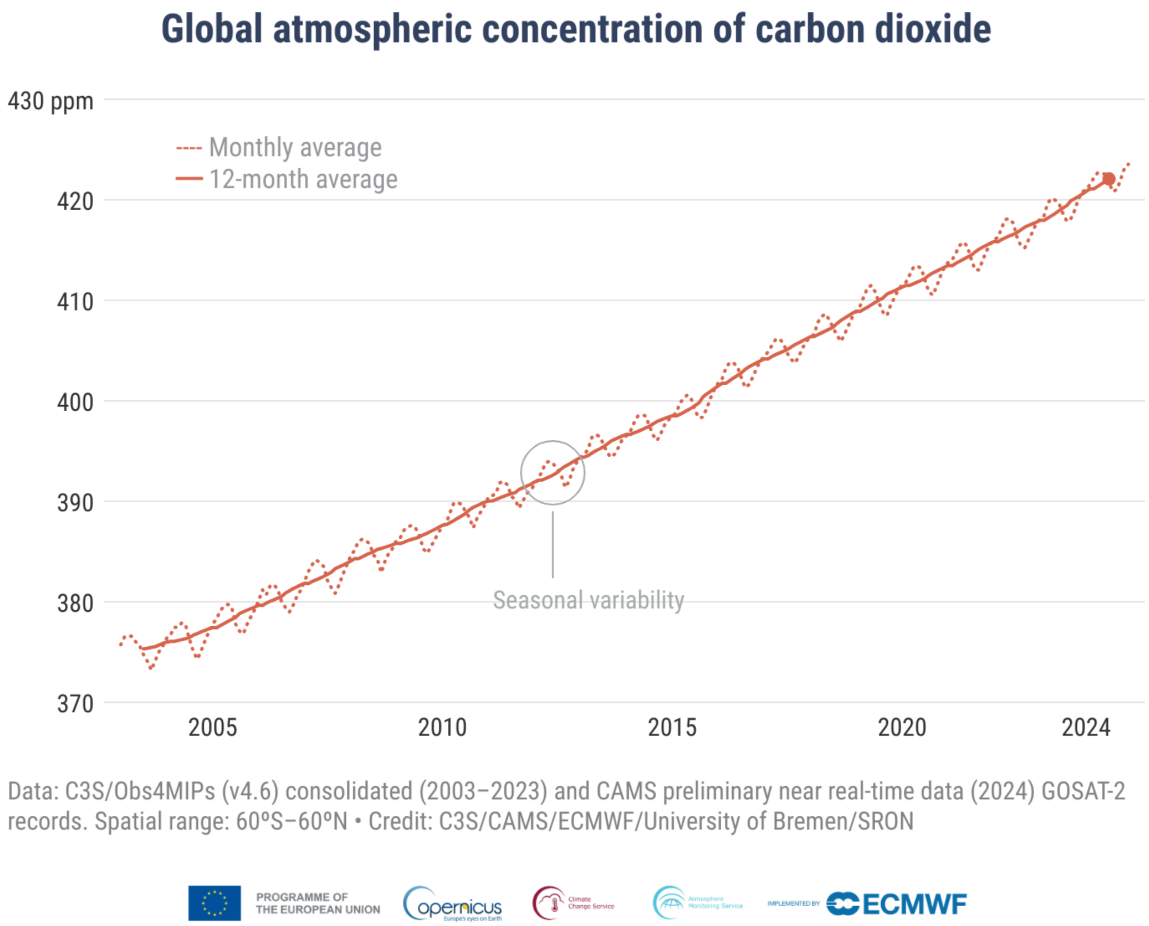


Figure 19.4. Global concentration of atmospheric column-averaged CO2 (ppm) as measured by satellites for 2003–2024, showing monthly values (dotted line) and the trend obtained by 12-month averaging (solid line). Data: C3S/Obs4MIPs (v4.6) consolidated (2003–2023), CAMS preliminary near real-time data (2024) GOSAT-2 records. Spatial range: 60°S–60°N over land. Credit: C3S/CAMS/ECMWF/University of Bremen/SRON.

Greenhouse gas fluxes
The net difference between the amount of a gas added to the atmosphere by emissions from ‘sources’ and the amount taken up by ‘sinks’.
Estimated net surface fluxes of CO2, CH4 and N2O have been increasing during recent decades. Around half of anthropogenic emissions of CO2 have been absorbed by land vegetation and the ocean and around half remains in the atmosphere.

Over the last decade, net fluxes of greenhouse gases at Earth’s surface, per year, of around:
CO2: +5000 TgC
CH4: +420 TgC
N2O: +16 TgN
Data cover 1979–2024 for CO2, 1983–2023 for CH4, 1996–2022 for N2O.
Data: CAMS

About the report

Acknowledgements

The ESOTC's findings are based on expertise from across the C3S and WMO communities, as well as other Copernicus services and external partners.

The report is authored by C3S, ECMWF, the WMO and data providers from institutions across Europe, and edited by the ECMWF ESOTC editorial team.

This report is reviewed by colleagues across the Copernicus network, the WMO, WMO ET-CMA and representatives from national meteorological and hydrological services.

Contributions are as follows:

ESOTC editorial team (ECMWF):
Lead editor and coordination: Rebecca Emerton
Scientific editorial: Julien Nicolas, Francesca Guglielmo, Freja Vamborg, David Lavers, Shaun Harrigan, Samantha Burgess
Copy editing and proofreading: Annabel Cook
Graphic and visual design: Anna Lombardi

ESOTC editorial team (WMO): Sari Lappi (WMO), Andrew Ferrone (MECB), Peer Hechler (WMO), Stefan Rösner (DWD/WMO RCC)

Communications (ECMWF): Isabelle Boscaro-Clarke, Elisabeth Mittelbach, Eva Remete, Maximilian Lingen, Nuria Lopez, Rafael Cereceda, Francesca Fusco

Communications (WMO): Clare Nullis, Jesse Cruz

Contributors (alphabetical order):
Signe Aaboe (Met Norway), Giovanni Aldrigo (ICS), Natalia Havelund Andersen (DTU), Omar Baddour (WMO), Jacqueline Bannwart (WGMS/Uni Zurich), Julie Berckmans (EEA), Else van den Besselaar (KNMI), Peter Bissolli (DWD/WMO RCC), Eric de Boisseson (ECMWF), Penny Boormarn (WEMC), Andrew Bower (UNDRR), Jason Box (GEUS), Michael Buchwitz (Universitat Bremen), Carlo Buontempo (ECMWF), Samantha Burgess (ECMWF), Chiara Cagnazzo (ECMWF), Gabriel Calassou (Group CLS), Beatriz Calmettes (Group CLS), Laura Carrea (University of Reading), Matthieu Chevallier (ECMWF), Frederic Chevallier (LSCE), Annabel Cook, Francesca Di Giuseppe (ECMWF), Claudia Di Napoli (ECMWF), Matteo De Felice (Rabobank), Wouter Arnoud Dorigo (TU Wien), Alena Dostolova (EODC), Gorm Dybkjær (DMI), Laurent Dubus (RTE), Inés Dussaillant (WGMS / Uni Zurich), Rebecca Emerton (ECMWF), Andrew Ferrone (MECB), Nube Gonzales-Reviriego (ECMWF), Francesca Guglielmo (ECMWF), Hanane Hafraoui (UNEP),

Shaun Harrigan (ECMWF), Peer Hechler (WMO), Stefan Hendricks (AWI), Chris Hewitt (WMO), Benjamin Hickman (UNEP), Ketil Isaksen (Met Norway), Ioanna Karagali (DMI), Athul Kaitheri (University of Northumbria), Frank Kaspar (DWD), John Kennedy (Consultant), Andrea Kreis (DWD), Blaz Kurnik (EEA), Sari Lappi (WMO), David Lavers (ECMWF), Johanna Lems (TU Wien), Roderick van der Linden (DWD), Anna Lombardi (ECMWF), Letizia Lusito (ICS), Aleksandrina Mavrodieva (UNDRR), Benoit Meyssignac (LEGOS), Anna Christina Mikalsen (DWD), Luis Munuera (UNEP), Thomas Nagler (ENVEO), Julien Nicolas (ECMWF), Morten Ødegaard (Met Norway), Yigyeong Oh (UNDRR), Inès Otosaka (University of Northumbria), Marika Palosaari (UNEP), Florian Pappenberger (ECMWF), Mark Parrington (ECMWF), Frank Paul (WGMS / Uni Zurich), Uwe Pfeifroth (DWD/EUMETSAT CM SAF), Wolfgang Preimesberger (TU Wien), Christel Prudhomme (ECMWF), Pierre Prum (EEA), Victor Quet (Group CLS), Elena Restivo (ICS), Kornelia Radics (WMO), Claire Ransom (WMO), Lily Riahi (UNEP), Maarit Roebeling (DWD/WMO RCC), Stefan Rösner (DWD/WMO RCC), Joaquín Muñoz Sabater (ECMWF), Peter Salamon (EC JRC), Jesus San-Miguel (EC JRC), Gerard van der Schrier (KNMI), Andy Shepherd (University of Northumbria), Thomas Sikorski (DWD/EUMETSAT CM SAF), José Álvaro Silva (IPMA), Adrian Simmons (ECMWF), Tom Slater (University of Northumbria), Kerstin Stelzer (Brockmann Consult), Blair Trewin (BoM), Alberto Troccoli (ICS), Freja Vamborg (ECMWF), Ine Vandecasteele (EEA), Margherita Vargiu (UNEP), Ksenia Vysotska (UNEP), Jan Wuite (ENVEO), Matthia Zaramella (ICS), Michael Zemp (WGMS/Uni Zurich), Markus Ziese (DWD), Volker Zins (DWD), Hao Zuo (ECMWF)

Other organisations: Adria Congrex, Blossom, Eau de Web, HBI

The data behind ESOTC 2024

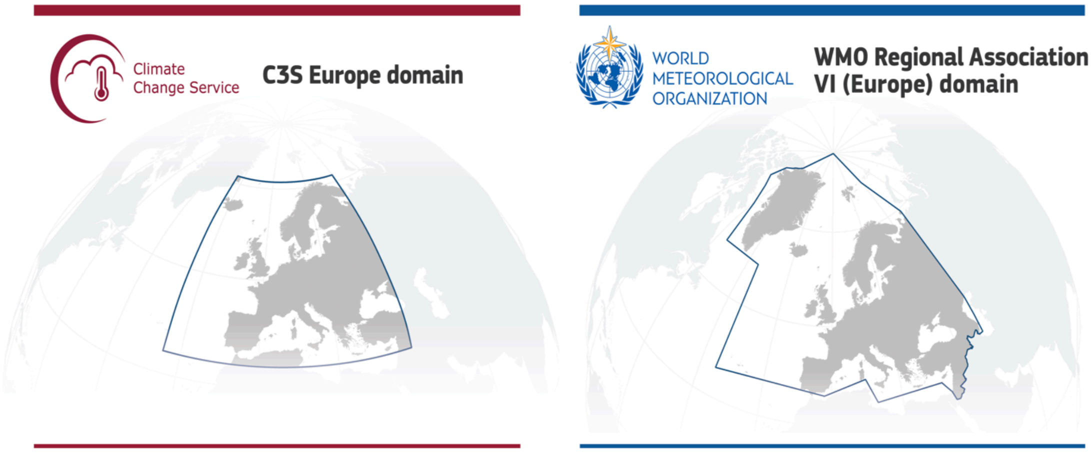
The ESOTC 2024 relies extensively on datasets provided operationally and in near real-time by the Copernicus Services. The operational data are freely accessible via data catalogues such as the C3S Climate Data Store (CDS). Explore the full ESOTC online to download data and explore other resources.

The 'About the data' section online describes the datasets and methods used in the ESOTC 2024, with links to download the original data and documentation for each dataset.

For near real-time updates of temperature and SST, see pulse.climate.copernicus.eu

Averages Throughout the report, use of the word 'average' refers to the mean, unless stated otherwise.
Reference periods By comparing 2024 against the average for a reference period, it can be seen how the year fits within a longer-term context. Generally, the reference period used is 1991–2020, but where less extensive data records are available, other periods may be used and these

will be stated in the associated figures. Some variables are compared to the pre-industrial level, for which the reference period used is 1850–1900.



ESOTC 2024 is jointly produced by C3S and the WMO. C3S supports the adaptation and mitigation policies of the European Union, by providing consistent and authoritative information about climate change, while the WMO Regional Office for Europe serves its 50 Member States, covering Europe, Greenland, the South Caucasus and part of the Middle East. They therefore cover overlapping geographical domains, indicated on the maps above. The size and climatic zones of each domain differ, so variations in the statistics are expected. The ESOTC makes use of a wide range of datasets, for which geographical coverage varies. Several sections of the report provide information for both the C3S and WMO RA VI domains, where possible based on the geographical coverage of the data.

About us

Copernicus Services implemented by ECMWF

Vital environmental information for a changing world

The European Centre for Medium-Range Weather Forecasts (ECMWF) has been entrusted by the European Commission to implement two of the six services of the Copernicus programme: the Copernicus Climate Change Service (C3S) and the Copernicus Atmosphere Monitoring Service (CAMS). In addition, ECMWF provides support to the Copernicus Emergency Management Service (CEMS).

The Copernicus Climate Change Service (C3S)

The C3S mission is to support adaptation and mitigation policies of the European Union by providing consistent and authoritative information about climate change. C3S adds value to environmental measurements by providing free access to quality-assured, traceable data and applications, all day, every day. We offer consistent information on the climate anywhere in the world, and support policymakers, businesses and citizens in preparing for future climate change impacts.

World Meteorological Organization (WMO)

The WMO is the United Nations system's authoritative voice on the state and behaviour of Earth's atmosphere, its interaction with the land and oceans, the weather and climate it produces and the resulting distribution of water resources.

As weather, climate and the water cycle know no national boundaries, international cooperation at a global scale is essential for the development of meteorology and operational hydrology as well as to reap the benefits from their application.

The WMO provides the framework for such international cooperation for its 193 Member States and Territories, and plays a leading role in international efforts to monitor and protect the climate and the environment.

WMO regional office for Europe and RCC network
The Regional Office for Europe is responsible for achieving the WMO's long-term goals and strategic objectives for the 50 WMO Regional Association VI (Europe) Member Countries.

Regional Climate Centres are operational entities of the Global Framework for Climate Services' Climate Services Information System. They serve the members of the WMO through their respective National Meteorological and Hydrological Services (NMHSs), supporting NMHSs in meeting their national climate-related duties.

List of figures

Below is a complete list of figures included in ESOTC 2024. Head to the ESOTC 'graphics gallery' online to view all the figures and download the associated data. For some figures in this PDF, additional versions are available in the online version of the full report, indicated with letters, for example to provide the same figure for additional datasets. Figures with an 'S' in the reference are only available from the graphics gallery.

Flooding

Heat and drought in southeastern Europe

Temperature

Thermal stress

Wildfires

Snow and glaciers

Precipitation

Soil moisture

River flow

Lakes

European Ocean

Winds and circulation

Clouds and sunshine

Renewable energy resources

Arctic temperature

Figure 15.2. Anomalies and extremes in surface air temperature over the north polar region for each month of 2024. Data: ERA5.
Figure 15.3. Anomalies and extremes in surface air temperature in summer 2024, surface air temperature anomalies for summer for Svalbard and at Svalbard Airport from 1899–2023. Data: ERA5, CARRA and in situ observations at Svalbard Airport.
Figure S15.1. Annual average surface air temperature anomalies over the north polar region in 2024. Data: ERA5.
Figure S15.2. Average surface air temperature anomalies over the north polar region for each month of 2024. Data: ERA5.
Figure S15.3. Average surface air temperature anomalies in summer 2024 over the Barents Sea and Svalbard region. Data: CARRA.
Figure S15.4. Time series of total annual mass balance and annual surface mass balance for the Greenland Ice Sheet from 1987–2024. Data: PROMICE.

Arctic wildfires
Figure 16.1. Annual total estimated carbon emissions from wildfires from all land areas in northern high latitudes from 2003–2024. Data: CAMS GFAS v1.2 wildfire data.
Figure 16.2. Map showing high-latitude soil moisture anomalies, locations and total wildfire radiative energy of wildfires in June–August 2024. Data: ERA5-Land and CAMS GFAS v1.2 wildfire data.

Arctic ocean
Figure 17.1. Daily Arctic sea ice extent from 1979–2024 and monthly anomalies in Arctic sea ice extent for March and September from 1979–2024. Data: OSI SAF Sea Ice Index v2.2.
Figure 17.2a. Monthly average sea ice concentration anomalies in 2024. Data: OSI SAF Global Sea Ice Concentration v3.0.
Figure 17.2b. Monthly average sea ice concentration and sea ice drift in 2024. Data: OSI SAF Global Sea Ice Concentration v3.0, OSI SAF Global Low-Resolution Sea Ice Drift, C3S Sea Ice Edge v3.0.
Figure 17.3 Anomalies and extremes in annual sea and sea ice surface temperature in 2024 and annual SST/IST anomalies for the ocean north of the Arctic. Data: C3S Sea Ice Surface Temperature v1.0.
Figure S17.1. Daily average sea surface and ice surface temperature for the Arctic Ocean north of 66.6°N in 2024. C3S Ocean and Sea Ice Surface Temperature v1.0.
Figure S17.2 Arctic anomalies and extremes in sea- and sea-ice surface temperature in 2024. Data: C3S Sea Ice Surface Temperature v1.0.
Figure S17.3. Arctic monthly chlorophyll a concentrations for April, May, June and July 2024. Data: C3S Ocean Colour CDR/ICDR v6.0.
Figure S17.4. Arctic monthly chlorophyll a concentration anomalies (%) for April, June and July 2024. Data: C3S Ocean Colour v6.0.
Figure S17.5 Arctic sea ice thicknesses and anomalies for April and October 2024. Data: CryoSat-2/SMOS.

Resilience of the built environment to climate extremes
Figure 18.1. Identified climate risks for the infrastructure cluster, including urgency to act, projected severity in the current, mid- and late-century and related policy characteristics. Source: EUCRA
Figure 18.2: Overview of the reported types of adaptation actions. Source: EEA Urban adaptation report 2024
Figure 18.3. Evolution of European policy relevant to adaptation, national adaptation plans and strategies, and number of signatories to the Covenant of Mayors with adaptation commitments for 2013–2023. Source: EEA Urban Adaptation report 2024

Long-term trends in climate indicators
Figure 19.1. Trend in annual surface air temperature for 1995–2024. Data: ERA5.
Figure 19.2. Time series of anomalies in the heat content of the global ocean from 1980–2024. Data: ORAS5.
Figure 19.3. Cumulative mass change of the Greenland Ice Sheet since 1972 and its corresponding contribution to sea level rise. Data: IMBIE.
Figure 19.4. Global concentrations of atmospheric column-averaged carbon dioxide and methane as measured by satellites for 2003–2024. Data: C3S/Obs4MIPs (v4.6) consolidated (2003–2023), CAMS preliminary near real-time data (2024) GOSAT-2 records.

References

[R1] Ulbruch, U. et al., 2003: The central European floods of August 2002: part 1 - Rainfall periods and flood development. *Weather*, **58** (11), 371–377. doi.org/10.1256/wea.61.03A

[R2] AEMET (2024) Estudio sobre la situación de lluvias intensas, localmente torrenciales y persistentes, en la Península Ibérica y Baleares entre los días 28 de Octubre y 4 de Noviembre de 2024. Agencia Estatal de Meteorología, 23 de diciembre. aemet.es/en/conocermas/recursos_en_linea/publicaciones_y_estudios/estudios/detalles/episodio_dana_oct_nov24 [Accessed: 5 February 2025]

[R3] Ziese, M. et al., 2014: The GPCC Drought Index - a new, combined and gridded global drought index, *Earth System Science Data, **6**, 285–295. doi.org/10.5194/essd-6-285-2014*

[R4] Rogers, B. M. et al., 2020: Focus on changing fire regimes: interactions with climate, ecosystems and society, *Environmental Research Letters,* **15**, 030201. doi.org/10.1088/1748-9326/ab6d3a

[R5] EEA, 2021: Forest fires in Europe, *European Environment Agency Indicators,* available online at: eea.europa.eu/en/analysis/indicators/forest-fires-in-europe [Accessed 12 February 2025]

[R6] San-Miguel-Ayanz, J. et al.: Advance report on Forest Fires in Europe, Middle East and North Africa 2024, Publications Office of the European Union, Luxembourg, 2025. doi:10.2760/1264626, JRC141505.

[R7] Argüeso, D. et al., 2024: Storm Daniel fueled by anomalously high sea surface temperatures in the Mediterranean, *npj Clim Atmos Sci*, **7**, 307. doi.org/10.1038/s41612-024-00872-2

[R8] CEAM, 2024: Analysis of the meteorological situation associated with flooding in the province of Valencia on Tuesday, October 29, 2024. Meteorology and Climate Research department, Mediterranean Centre for Environmental Studies. ceam.es/wp-content/uploads/2024/10/DANA_2024_10_29_CEAM_FINAL_ingles.pdf [Accessed 30 January 2025]

[R9] Kaspar, F. et al., 2019: A climatological assessment of balancing effects and shortfall risks of photovoltaics and wind energy in Germany and Europe, *Advances in Science and Research*, **16**, 119–128. doi.org/10.5194/asr-16-119-2019

[R10] Drücke, J. et al., 2021: Climatological analysis of solar and wind energy in Germany using the Grosswetterlagen classification, *Renewable Energy*, **164**, 1254–1266. doi.org/10.1016/j.renene.2020.10.102

[R11] DWD (Kaspar, F. et al), 2024: Klimatologische Einordnung der “Dunkelflaute” im November 2024. dwd.de/DE/leistungen/besondereereignisse/verschiedenes/20241217_Dunkelflaute_im_November.pdf?__blob=publicationFile&v=2 [Accessed 7 February 2025]

[R12 Previdi, M. et al, 2021: Arctic amplification of climate change: a review of underlying mechanisms, *Environmental Research Letters*, **16**(9), 093003. doi.org/10.1088/1748-9326/ac1c29

[R13] Isaksen, K. et al., 2022: Exceptional warming over the Barents area, *Scientific Reports*, **12**, 9371. doi.org/10.1038/s41598-022-13568-5

[R14] Nordli, Ø. et al., 2020: Revisiting the extended Svalbard Airport monthly temperature series, and the compiled corresponding daily series 1898–2018, *Polar Research*, **39**. doi.org/10.33265/polar.v39.3614

[R15] McCarty, J. L., et al., 2021: Reviews and syntheses: Arctic fire regimes and emissions in the 21st century, *Biogeosciences*, **18**, 5053–5083. doi.org/10.5194/bg-18-5053-2021.

[R16] United Nations Environment Programme (2024). Cities Unit - UN Environment Programme. wedocs.unep.org/20.500.11822/46372

[R17] World Bank Group (2023): Thriving: Making Cities Green, Resilient, and Inclusive in a Changing Climate. Mukim, Megha; Roberts, Mark, editors. hdl.handle.net/10986/38295

[R18] EUROCITIES. (2025). Empowering cities to win Europe’s climate battle. eurocities.eu/latest/empowering-cities-to-win-europes-climate-battle

[R19] European Environment Agency, 2024: European Climate Risk Assessment, EEA Report 01/2024, ISBN: 978-92-9480-627-7.
eea.europa.eu/en/analysis/publications/european-climate-risk-assessment

[R20] EC-JRC, 2023, GCoM — MyCovenant, 3rd Release — September 2022, European
Commission, Joint Research Centre (JRC) (Dataset) PID.
data.jrc.ec.europa.eu/dataset/9cefa6ca-1391-4bcb-a9c8-46e029cf99bb [Accessed 23 March 2025]

[R21] CDP, 2022, '2022 Cities Adaptation Actions by Action Group | CDP Open Data Portal'
data.cdp.net/Adaptation-Actions/2022-Cities-Adaptation-Actions-by-Action-Group/wai8-pzfv [Accessed 13 February 2025]

[R22] European Environment Agency, 2024: Urban adaptation in Europe: what works? Implementing climate action in European cities, 2024, EEA Report 14/2023.
eea.europa.eu/en/analysis/publications/urban-adaptation-in-europe-what-works