European Commission

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THE 2023 ANNUAL CLIMATE SUMMARY

Global Climate Highlights 2023

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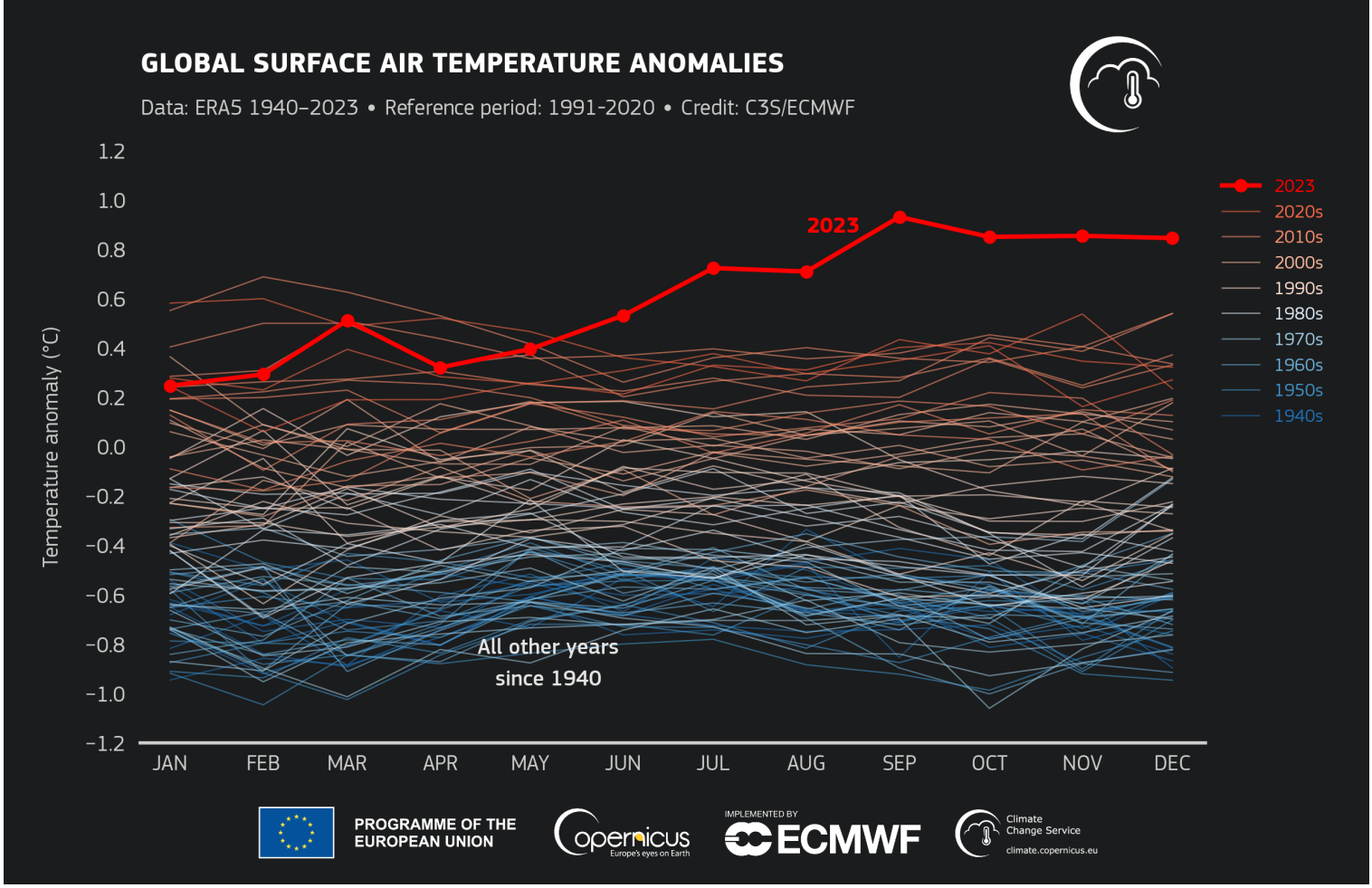

Monthly global surface air temperature [1] *anomalies (°C) relative to 1991–2020 from January 1940 to December 2023, plotted as time series for each year. 2023 is shown with a thick red line while other years are shown with thin lines and shaded according to the decade, from blue (1940s) to brick red (2020s). Data source: ERA5. Credit: C3S/ECMWF.*

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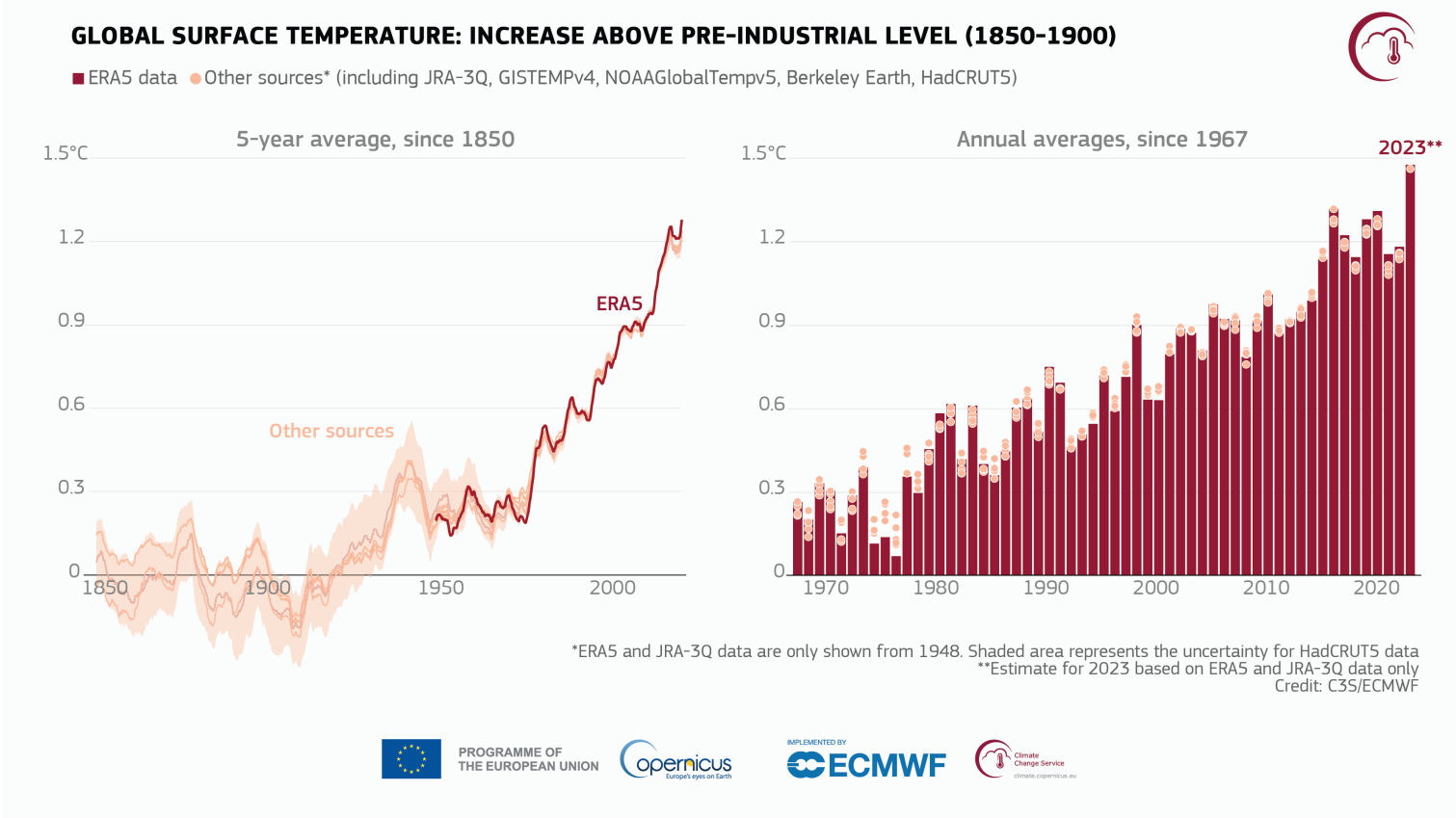
2023 has replaced 2016 as the warmest calendar year on record. According to the ERA5 dataset, the global-average temperature for 2023 was 14.98°C, 0.17°C higher than recorded for 2016.



Global surface air temperature (°C) increase above the average for 1850-1900, the designated pre-industrial reference period, based on several global temperature datasets shown as 5-year averages since 1850 (left) and as annual averages since 1967 (right). -.Credit: C3S/ECMWF.

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KEY MESSAGES

- 2023 is confirmed as the warmest calendar year in global temperature data records going back to 1850
- 2023 had a global-average temperature of 14.98°C, 0.17°C higher than the previous highest annual value in 2016
- 2023 was 0.60°C warmer than the 1991-2020 average and 1.48°C warmer than the 1850-1900 pre-industrial level
- It is likely that a 12-month period ending in January or February 2024 will exceed 1.5°C above the pre-industrial level
- Each month from June to December in 2023 was warmer than the corresponding month in any previous year
- July and August 2023 were the warmest two months on record. Boreal summer (June-August) was also the warmest season on record
- In September 2023, the temperature deviation above the 1991–2020 average was larger than in any month in any year in the ERA5 dataset (0.93°C higher than the 1991-2020 average)
- October, November and December 2023, each with a temperature of 0.85°C above average, ranked all joint second-largest in terms of temperature deviation above the 1991–2020 average

The year-to-year increase in global-average temperature was exceptionally large from 2022 to 2023. It follows a transition from three years of La Niña in 2020–2022 to El Niño conditions in 2023, although other factors appear to have also played a role. Further discussion is given in the section on sea surface temperature as well as in the highlight box: Was the unusual warmth of 2023 expected.

i

Global datasets show consistent picture for 2023

2023 is the warmest year on record according to ERA5. 2023 is also the warmest year on record according to the JRA-3Q dataset, for which the average temperature relative [2] to 1991-2020 is 0.02°C smaller than that of ERA5. The absolute value from JRA-3Q is 0.02°C larger than the ERA5 value. Other routinely examined datasets (Berkeley Earth, GISTEMPv4, HadCRUT5 and NOAAGlobalTempv5) are also expected to report 2023 to be the warmest year on record once their December values become available. Their temperatures relative to 1991-2020 are expected from earlier months of 2023 to range from 0.02 to 0.06°C below that of ERA5. All these datasets would then place 2023 within the range from 1.4°C to 1.5°C warmer than the 1850-1900 level, assuming an offset of 0.88°C between 1850-1900 and 1991-2020 levels. The implications of uncertainty in this offset are discussed separately here in the context of the Paris Agreement.

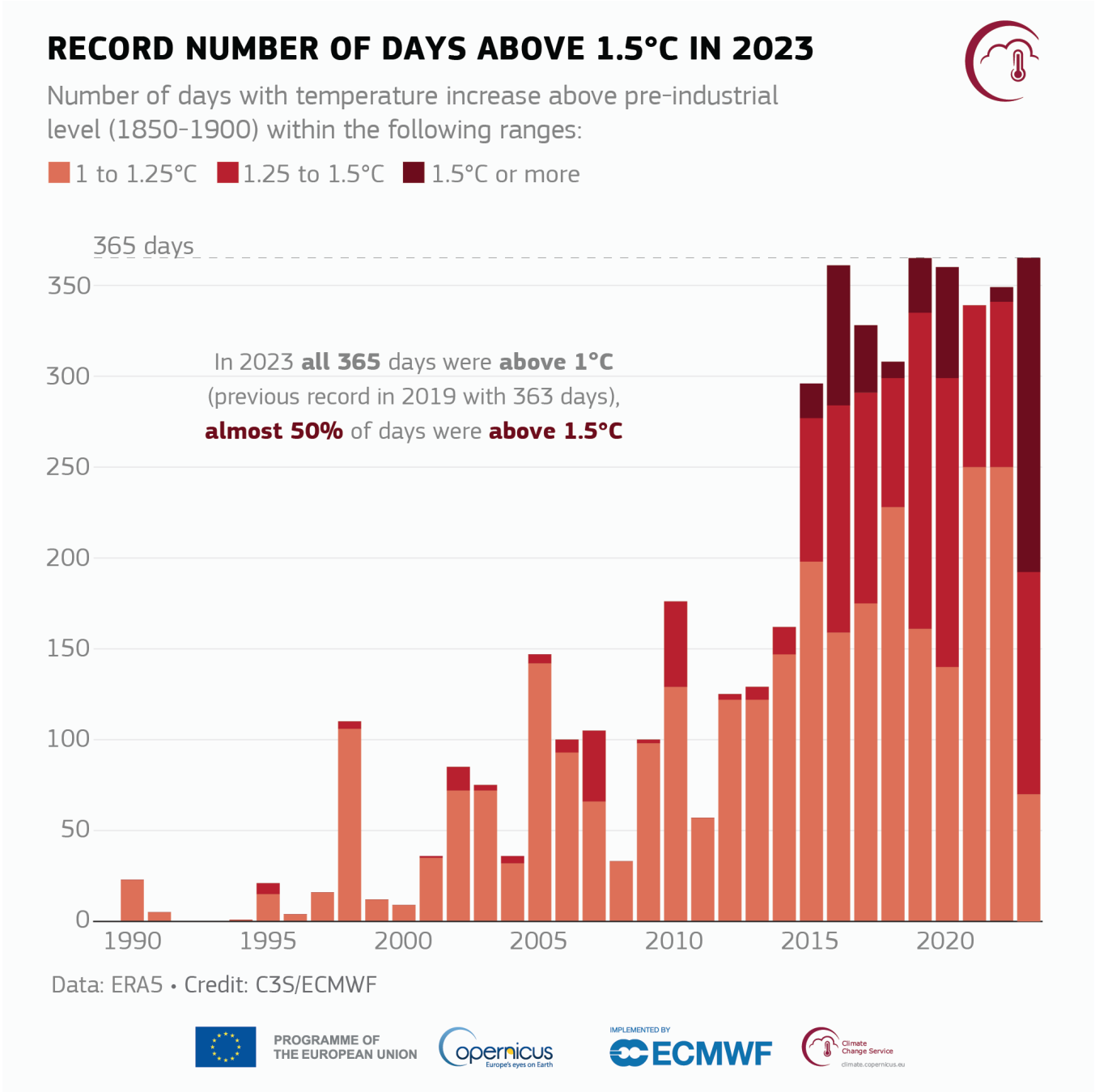
The evolution of the daily global-average temperature shows that 2023 is noteworthy for the occurrence of the highest global temperatures on record, both in absolute terms, during July, and relative to the annual cycle, during November. Almost all days from the beginning of June were the warmest in the ERA5 data record for that particular day of the year.

All days in 2023 were more than 1°C above the pre-industrial level

KEY MESSAGES

- 2023 marks the first time on record that every day within a year has exceeded 1°C above the 1850-1900 pre-industrial level for that time of year. Close to 50% of days were more than 1.5°C warmer than the 1850-1900 level, and two days in November were, for the first time, more than 2°C warmer.

Record number of days above 1.5C | Daily global temperature increase



The number of days during which the temperature exceeded the average for 1850-1900, the designated pre-industrial reference period, by more than 1°C, from the years 1990 to 2023. The plot highlights temperature increases within three ranges: 1–1.25°C (orange), 1.25–1.5°C (red), and 1.5°C or more (crimson). Source: ERA5. Credit: C3S/ECMWF

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The approach of the climate system towards the 1.5°C and 2°C limits of the Paris Agreement is usually discussed for temperatures that have been averaged globally and over each year of one or more decades. Observational datasets whose coverage includes the 1850-1900 reference period have monthly resolution, however, enabling estimates to be made of the annual variation in the warming from 1850-1900 to the recent past. This provides a basis for monitoring the accumulation of daily exceedances of the warming limits using reanalysis datasets such as ERA5.

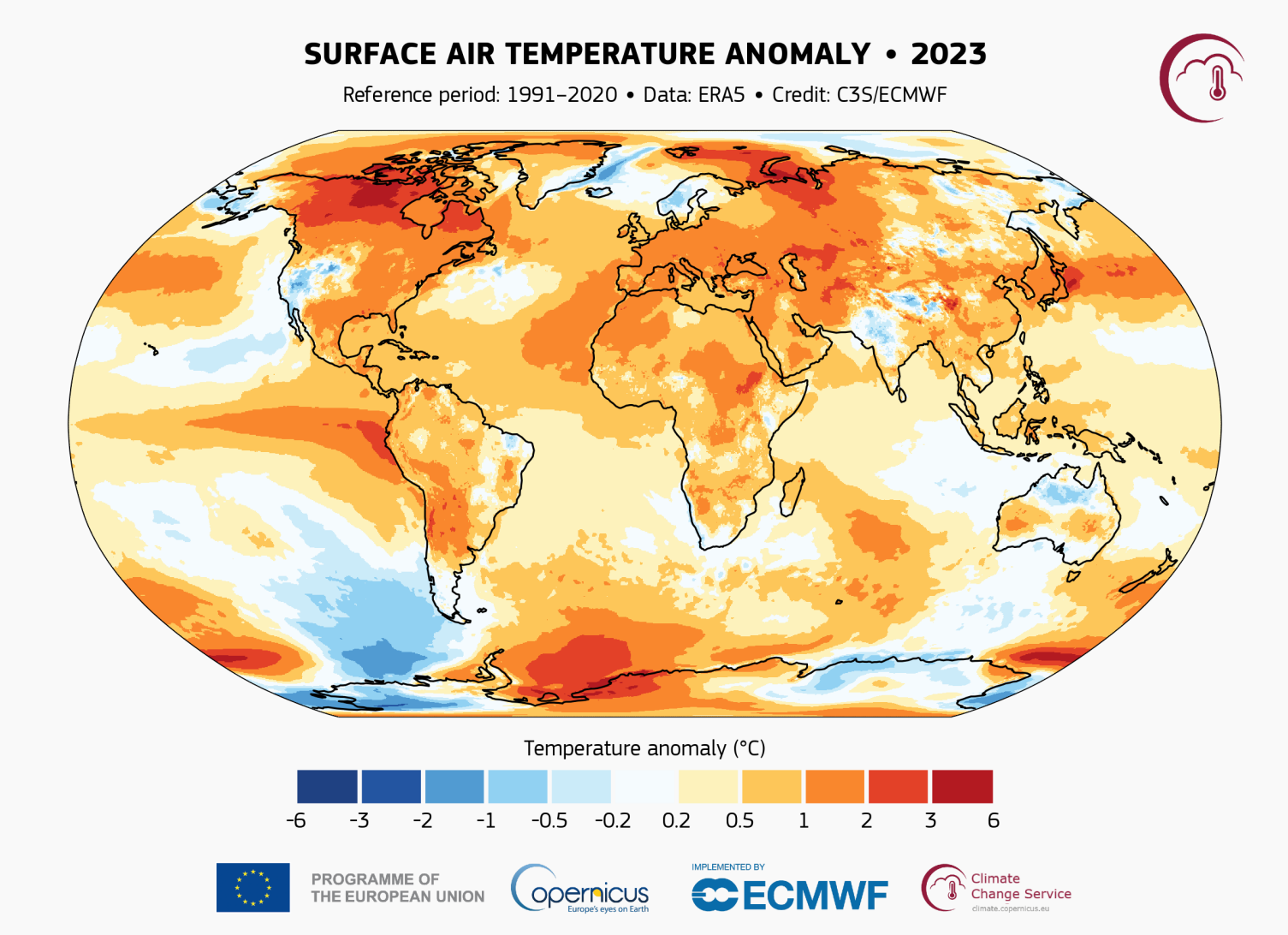
Using ERA5, this monitoring shows that all days of 2023 had global temperatures more than 1°C warmer than the 1850-1900 level for that time of year. Two days were more than 2°C warmer than 1850-1900, the first time the 2°C level has been exceeded. Close to 50% of days in 2023 were in excess of 1.5°C warmer than 1850-1900. This was the case for just over 20% of days in

2016, the previous warmest year on record. The earliest period in ERA5 with daily temperatures successively at least 1.5°C warmer than 1850-1900 is 2-15 December 2015.

Regional variations

Surface air temperature anomaly - 2023

Surface air temperature anomaly - 2022



Surface air temperature anomaly for 2023 relative to the average for the 1991–2020 reference period. Data: ERA5. Credit: C3S/ECMWF.

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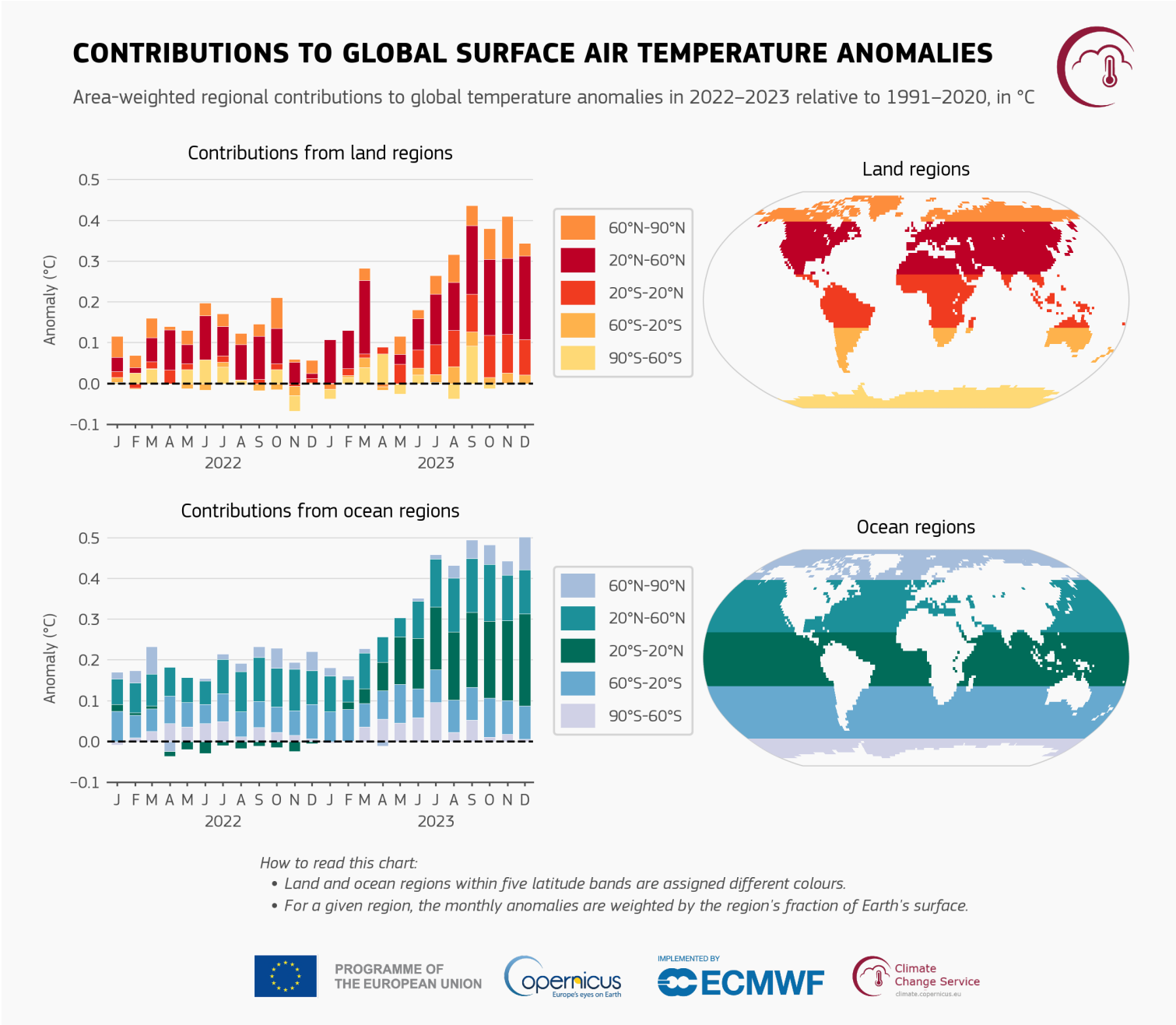
KEY MESSAGES

- Average air temperatures for 2023 were the warmest on record, or close to the warmest, over sizeable parts of all ocean basins and all continents except Australia

The distribution of surface air temperature anomalies across the globe in 2023 shows a marked contrast with that of 2022. Almost all land areas experienced above-average temperatures in 2023. Annual temperatures were more than 1°C higher than the 1991-2020 average over much of Europe and North America, and over several other regions.

Marine air temperatures were also the warmest on record for several regions in 2023. This is the case for much of the North Atlantic and Caribbean, northern, tropical and southern parts of the Pacific, and parts of the South Atlantic and Indian Oceans. The air temperature anomalies for these and other regions are tied closely to anomalies in sea surface temperatures (SSTs). The only sizeable region where marine air temperatures were the coldest on record was southwest of South America. The contrast in temperatures over the tropical and southern subtropical eastern Pacific Ocean between 2022 and 2023, from coldest to close-to-warmest on record, illustrates the transition from La Niña to El Niño conditions discussed further below.

How did different regions contribute to the global temperature anomaly?



Latitudinal contributions to the monthly global surface air temperature anomalies relative to the 1991–2020 reference period, shown separately for land and ocean regions. The contribution from each region is weighted by its area on the Earth's surface and is highlighted with a specific colour in the bar charts. Source: ERA5. Credit: C3S/ECMWF

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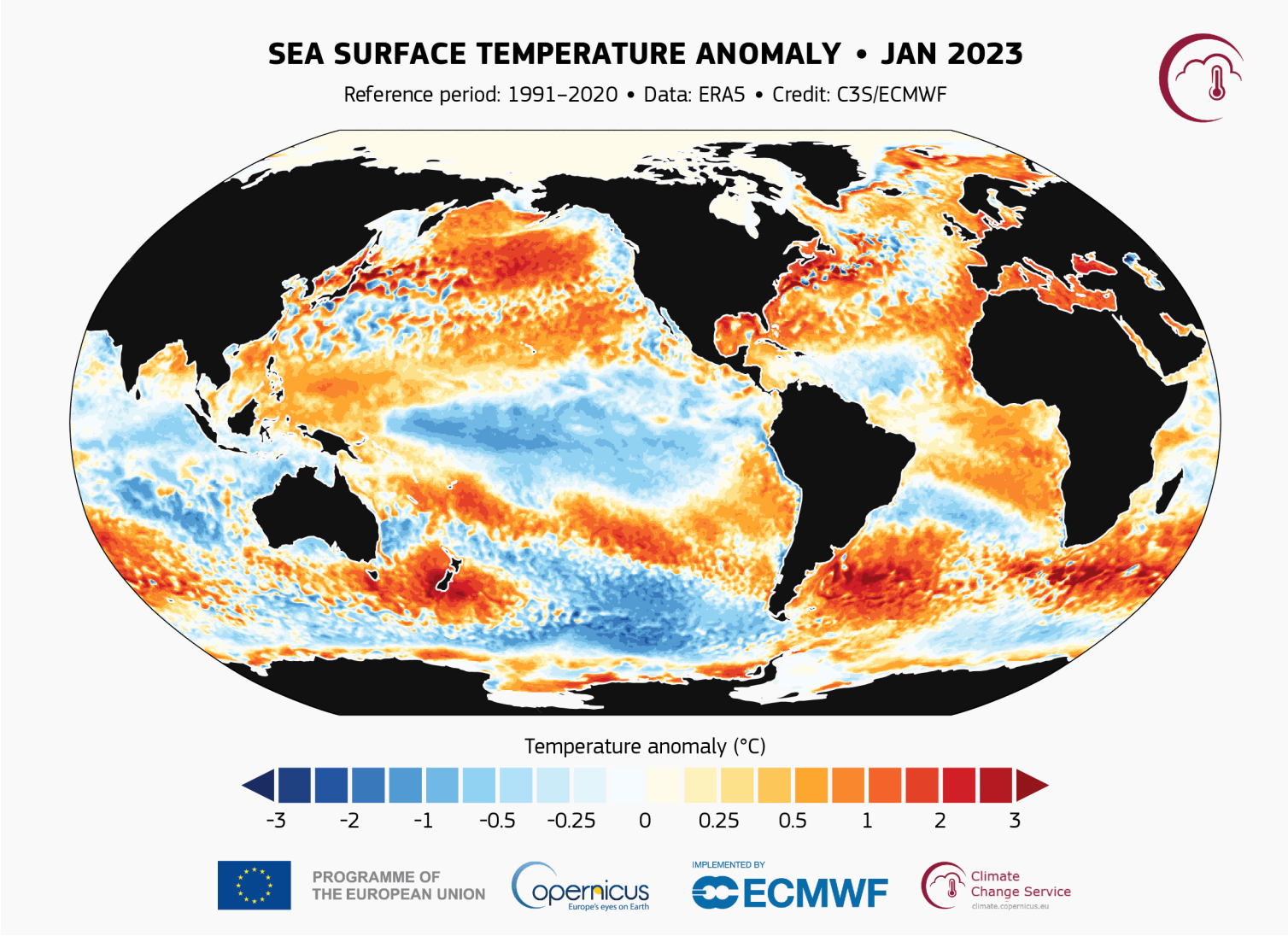
The rise in air temperature since the mid-1970s has been about twice as large over land as over ice-free ocean, but each surface accounts for about half of the rise in global-average air temperature, as the area of the Earth's surface covered by ocean is much larger than the area covered by land. The monthly evolution of the contribution of various regions to the global temperature anomaly in 2022 and 2023 is illustrated above. The increase in temperature anomaly from May to August 2023 was associated with a relatively large contribution from warm temperatures over the ocean. Temperatures anomalies over the tropical ocean shifted from negative in 2022 to positive in 2023, associated both with the transition from La Niña to El Niño over the Pacific Ocean and with generally warmer temperatures over the Atlantic and Indian Oceans. The particularly large anomalies in the final four months of 2023 are associated with significant contributions from both ocean and land, primarily from the tropics (especially over ocean) and the northern extratropics (especially over land).

Sea surface temperatures: transition to El Niño and record global values

KEY MESSAGES

- Global-average SSTs [3] were persistently and unusually high, reaching record levels for the time of year, from April through December.
- 2023 saw a transition to El Niño. In spring 2023, La Niña came to an end and El Niño conditions began to develop, with the WMO declaring the onset of El Niño in early July.
- High SSTs in most ocean basins, and in particular in the North Atlantic, played an important role in the record-breaking global SSTs.
- The unprecedented SSTs were associated with marine heatwaves around the globe, including in parts of the Mediterranean, Gulf of Mexico and the Caribbean, Indian Ocean and North Pacific, and much of the North Atlantic.



Monthly sea surface temperature anomalies in 2023 relative to the averages for the 1991–2020 reference period for the corresponding months. Data: ERA5. Credit: C3S/ECMWF

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2023 has seen record-breaking SSTs around the globe, including the highest daily global SST in the ERA5 record, and every month from April through to December saw global SSTs reach record levels for the time of year. Typically, SSTs reach their highest level for the year in March and then begin to fall, before a slight increase again during July and August. In 2023, global-average SSTs rose sharply in March, with a slight dip in April and May, but continued to rise throughout the boreal summer months to reach the highest value in ERA5 of 21.02°C on 23 and 24 August, which is higher than the previous record of 20.95°C, set in March 2016 towards the end of a strong El Niño event. Throughout the rest of the year, global-average SSTs remained unusually high and well above the previous warmest years.

Last year also marked a shift in the El Niño Southern Oscillation (ENSO). The start of 2023 saw the end of a rare 'triple-dip' La Niña, where the cool phase of ENSO persisted for three years from 2020 until Spring 2023. Later in Spring, the first signs of a transition to El Niño appeared, with WMO declaring the onset of El Niño in early July. While this El Niño event continued to strengthen and contributed to the warmth of 2023, it has not been as strong as those events experienced in 2015 and 1997.

High SSTs outside of the equatorial Pacific also played an important role in the record-breaking global SSTs. This is particularly true in the North Atlantic, which has seen exceptional SSTs

throughout June to December, with monthly anomalies well above average for the time of year and daily SST records broken. The previous highest daily SST for the North Atlantic was 24.81°C, set in September 2022, and on 31 August 2023 the SST reached 25.19°C. The boreal summer months saw marine heatwaves across large sectors of the North Atlantic. The warm tropical Atlantic SSTs also contributed to an above-normal hurricane season, ranking 4th for the most named storms in a year since 1950, and seeing the most named storms of any El Niño influenced year. Marine heatwaves were also observed in parts of the North Pacific and Indian Oceans, around New Zealand, in the Gulf of Mexico and the Caribbean and in the Mediterranean. These can have significant and sometimes devastating impacts on ocean ecosystems and biodiversity, and lead to socio-economic impacts.

Was the unusual warmth of 2023 expected?

Yes and no. Yes, in the sense that a year as warm as 2023 was seen as being inevitable in due course due to a combination of continued climate warming and an occurrence of El Niño. This trend could be inferred by extrapolating observation-based time series or by examining the range of possibilities indicated by climate projections used in the Sixth Assessment Report of the IPCC. More specifically, the WMO reported in 2022 that decadal forecasts estimated there was a 48% chance that the global temperature would exceed 1.5°C above the pre-industrial level in at least one year between 2022 and 2026. That chance was increased to 66% for the period 2023-2027 in an updated report published in 2023.

No, in the sense that there was an unforeseen factors - some of which are still under scientific investigation - that contributed to the extremity of global temperatures in 2023. Forecasts from ten climate prediction centres were indicating late in 2022 that there was only a very low probability that the annual temperature for 2023 would be as high as it was.

The temperatures observed in the later months of 2023 were not only record high relative to the average for 1991-2020, but also relative to a climatological average adjusted to the present day, considering the average rate of temperature increase of about 0.2°C/decade recorded since 1979. The change in annual temperature from 2022 to 2023 was larger than any change from one year to the next in the ERA5 data record. 2023 is also unusual in that its record temperature is for a year in which the El Niño was building up rather than declining.The latter was the case in 2016 and 1998, for example. Moreover, the El Niño in 2023 was weaker than in the build-up phases of the strong 1997/98 and 2015/16 events.

This all shows that the record temperatures in 2023 are not only due to El Niño and general global warming. A comprehensive attribution for the year as a whole is not yet available, but the warmth of SSTs across the globe, the record low extent of Antarctic sea-ice and extremes over land are evident factors, even if the relative contributions of natural variability and climate change are less obvious. Several changes in forcing factors have also been identified as likely minor contributors: enhanced stratospheric water vapour due to the eruption in January 2022 of the Hunga Tonga–Hunga Ha‘apai volcano, reduced aerosols due to lower sulfur dioxide emissions by shipping, and the approach of the current solar cycle to its peak.

What are the expectations for 2024? A recently released forecast for the year suggests that it could be warmer still than 2023, with a reasonable probability that the calendar year will end with an average temperature in excess of 1.5°C above the pre-industrial level according to multiple datasets. More immediate is the possibility that the twelve consecutive months ending in January and/or February 2024 will exceed the 1.5°C level according to ERA5, as January and February 2023 were not especially warm months.

Extreme events around the world

KEY MESSAGES

- A large number of extreme events were recorded across the globe, including heatwaves, floods, droughts and wildfires.
- Estimated global wildfire carbon emissions in 2023 increased by 30% with respect to 2022, driven largely by persistent wildfires in Canada

Extreme events around the world in 2023 had significant impacts on human health, ecosystems, nature and infrastructure. Among the most exceptional were flooding, wildfires, drought and extreme heat.

Impactful flooding events ranged from flash floods caused by intense rainfall, to large-scale flooding due to the passage of atmospheric rivers (such as in California in January and March, and over Chile in July), monsoon rainfall, large low-pressure systems and tropical cyclones. Cyclone Freddy impacted southeast Africa (February, March), Cyclone Mocha south and southeast Asia (May), Hurricane Hilary Mexico and the western USA (August), Hurricane Otis Mexico, (October), Storm Daniel the Mediterranean (September), and post-tropical cyclone Jasper Australia, (December), among others. In some cases, such as in the Horn of Africa during Autumn, flooding may have been exacerbated by particularly low soil moisture levels that favoured and accelerated runoff.

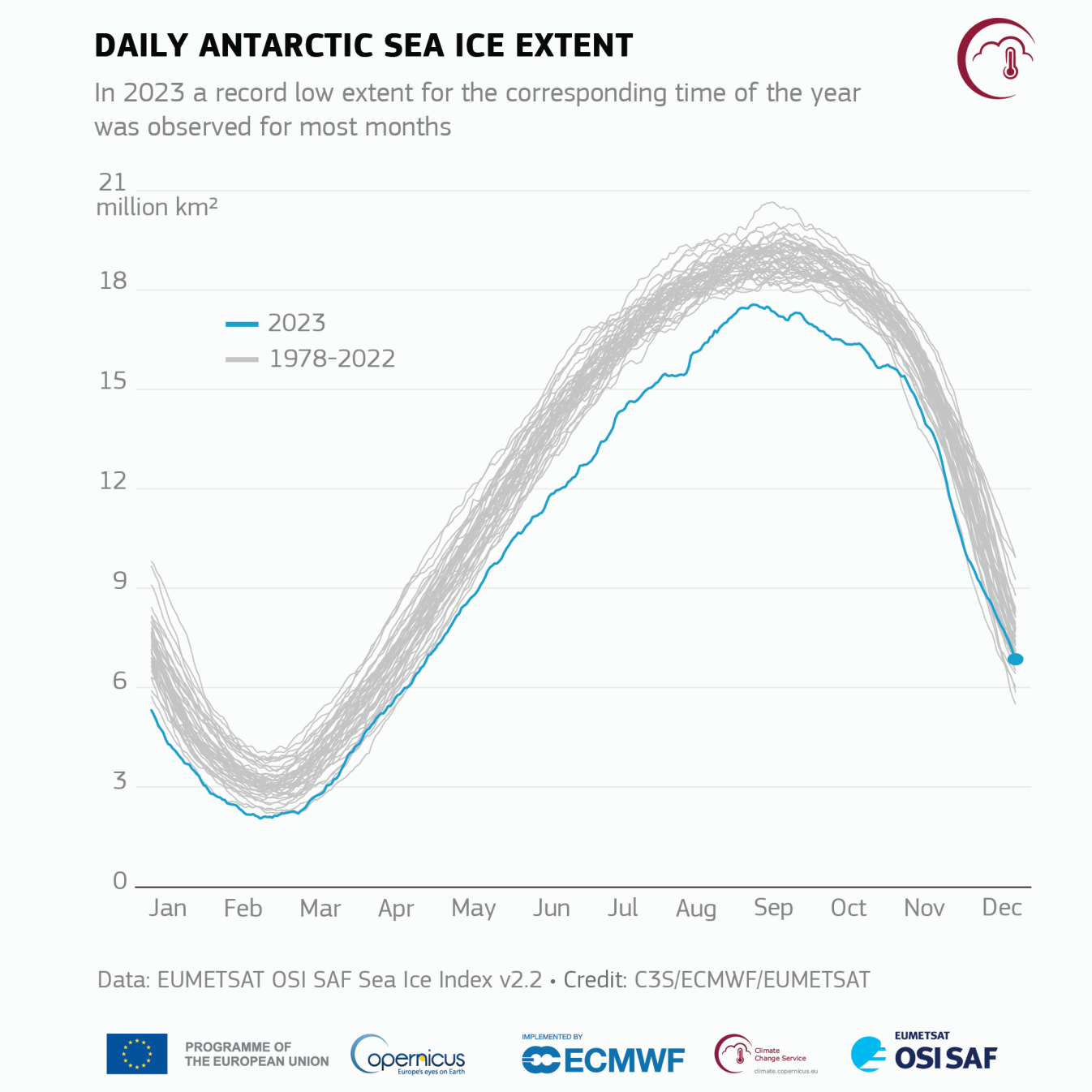
Many other regions across the globe suffered from prolonged lack of precipitation, in particular in North (Mexico) and South America (Amazon basin, Pantanal wetlands, Argentina, Uruguay) and western Africa. Heatwaves occurred around the world during 2023, often breaking national or local temperature records. Significant occurrences in southern Europe, North Africa, and parts of North America and Asia, were followed in seasonal progression by occurrences over parts of South America, southern Africa and Australia.

Hot and dry conditions in some regions also contributed to extensive wildfires, notably in southern Europe, Canada (in particular the Northwest Territories, and with significant contribution to global carbon emissions), South America, Australia and Hawaii, among others.

Sea ice: record low extents around Antarctic

KEY MESSAGES

- 2023 was remarkable for Antarctic sea ice: it reached record low extents for the corresponding time of the year in 8 months. Both the daily and monthly extents reached all-time minima in February 2023
- Arctic sea ice extent at its annual peak in March ranked amongst the four lowest for the time of the year in the satellite record. The annual minimum in September was the sixth-lowest.



Daily Antarctic sea ice extent from October 1978 to December 2023 in million square kilometers. The year 2023 is shown with a blue line, all other years with grey lines. Data source: EUMETSAT OSI SAF Sea Ice Index v2.2. Credit: C3S/ECMWF/EUMETSAT.

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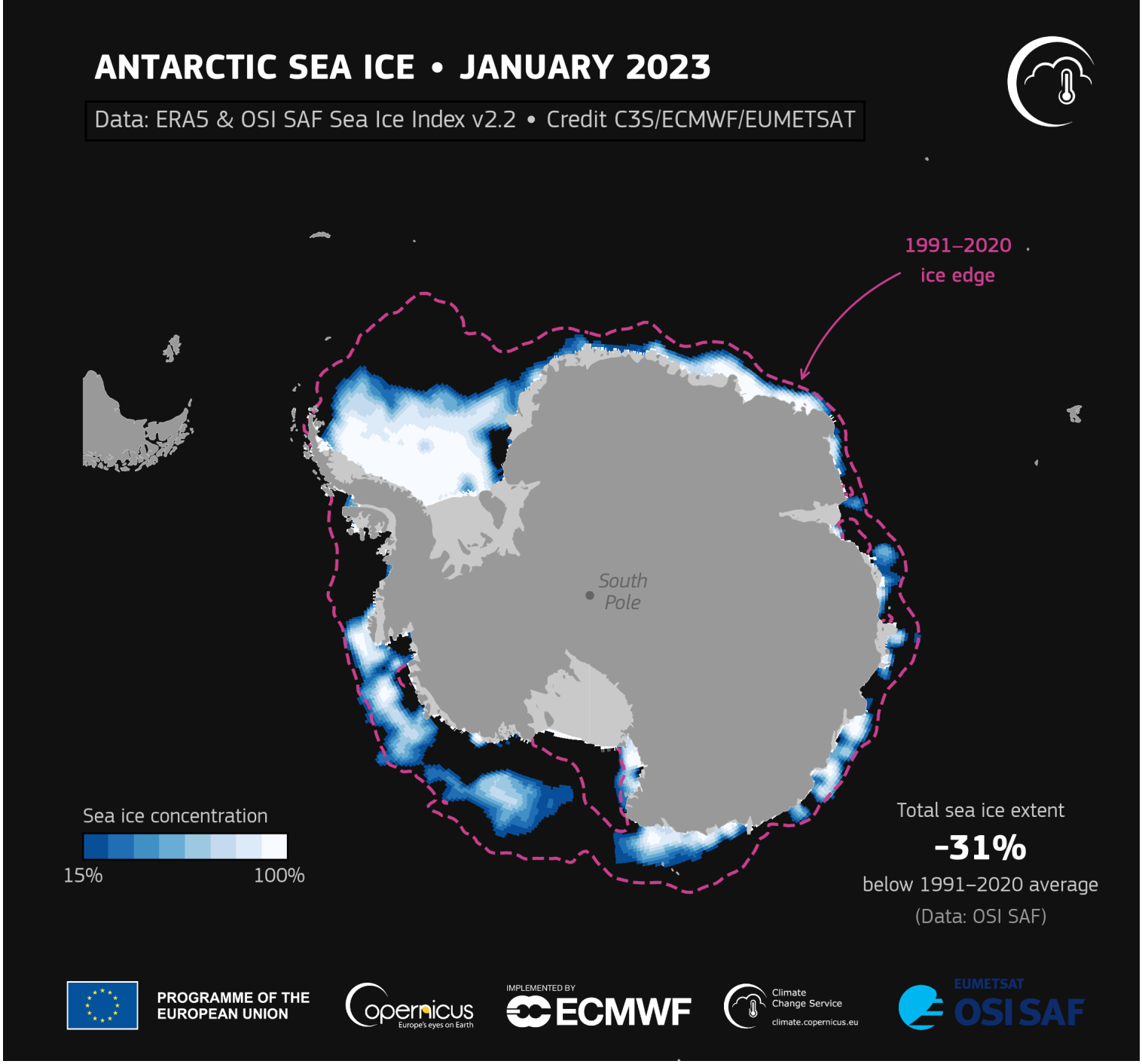
Antarctic Sea Ice | Arctic Sea Ice



Monthly mean sea ice concentrations around Antarctica in 2023. The average sea ice edge for each month during the 1991–2020 reference period is shown with a dashed magenta line. The monthly anomaly for the total Antarctic sea ice extent is indicated in the lower-right corner. Data: ERA5 (sea ice concentration), EUMETSAT OSI SAF Sea Ice Index v2.2 (sea ice extent anomaly). Credit: C3S/ECMWF/EUMETSAT

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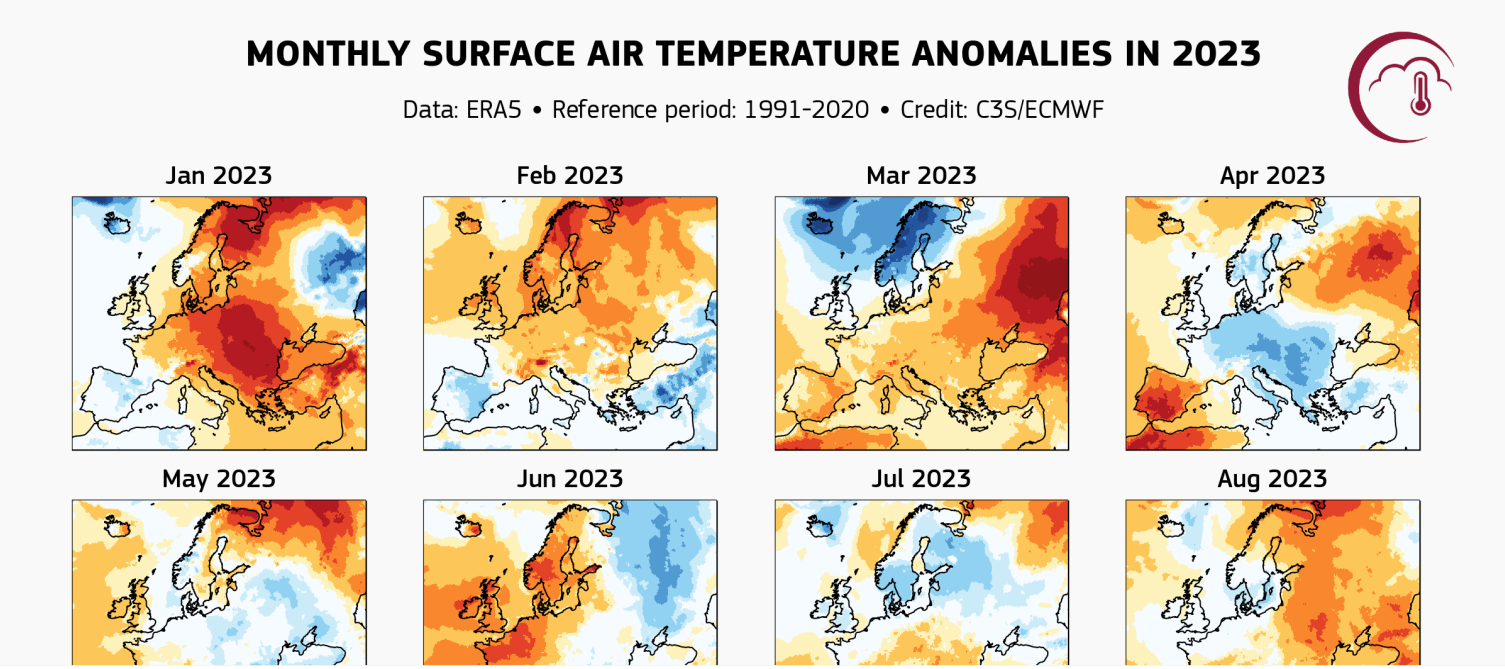
Europe: high variability and many extreme events

KEY MESSAGES

- 2023 was the second-warmest year for Europe, at 1.02°C above the 1991-2020 average, 0.17°C cooler than 2020, the warmest year on record
- Temperatures in Europe were above average for 11 months during 2023 and September was the warmest September on record
- European winter (December 2022 – February 2023) was the second-warmest winter on record

- The average temperature for the European summer (June-August) was 19.63°C; at 0.83°C above average, it was the fifth-warmest on record. During the season, Europe experienced heatwaves, including marine heatwaves, with multiple daily temperature records broken and widespread drier-than-average conditions on land
- European autumn (September-November) had an average temperature of 10.96°C, which is 1.43°C above average. This made autumn the second-warmest on record, just 0.03°C cooler than autumn 2020
- Heavy precipitation triggered significant flood events across the continent, from spring onwards



Surface air temperature monthly anomalies for Europe in 2023, relative to the corresponding averages for the 1991-2020 reference period. Data source: ERA5. Credit: C3S/ECMWF.

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Seasonal anomalies in precipitation for Europe, relative to the corresponding seasonal averages for the 1991-2020 reference period, for boreal winter 2022-2023 and spring, summer and autumn 2023. The anomalies are expressed as a percentage of the seasonal averages for 1991–2020. Data source: ERA5 Credit: C3S/ECMWF.

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Seasonal anomalies in the volumetric moisture content of the top 7 cm of soil for Europe, relative to the corresponding seasonal averages for the 1991-2020 reference period, for boreal winter 2022-2023 and spring, summer and autumn 2023. The anomalies are expressed as a percentage of the seasonal averages for 1991–2020. The darker grey shading denotes arid areas where soil moisture anomalies are not shown. Data source: ERA5-Land Credit: C3S/ECMWF.

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Temperatures were highly variable across Europe, especially in spring and summer when a stark contrast in conditions was observed across the continent. In both seasons, Europe as a whole saw above-average temperatures, but not record breaking; spring 2023, although clearly warmer than the two previous years, was not among the ten warmest in the data record. It saw Iberia and northeastern Europe experiencing well above-average temperatures and drier conditions for the season, whereas in a northwest-to-southeast band across Europe, temperatures were near-average and wetter-than-average conditions prevailed. May was the only month in the year with average conditions slightly below the climatological mean.

Summer was ranked fifth-warmest, with an average temperature of 19.63°C, 0.83°C above the 1991-2020 climatology, a year after the warmest European summer of 2022. June was hot and dry in northern Europe and colder than average in the south, whereas July and August were colder and wetter than average in northern Europe, while southern (July) and southwestern (August) Europe experienced heatwaves which resulted in multiple daily temperature records broken. This included marine heatwaves which affected both the Atlantic and the Mediterranean. Significant wildfires also occurred.

Particularly cold conditions occurred from October to December across Scandinavia, whereas the rest of the continent experienced above-average temperatures, making it the second-warmest autumn on record. The European-average temperature was 10.96°C, at 1.43°C above average, just 0.03°C cooler than autumn 2020.

Europe also experienced considerable storms and flooding. Significant flood events triggered by heavy, or record-breaking precipitation, occurred in Emilia-Romagna, Italy, in May; in Norway and Sweden (storm Hans) and Slovenia in August. In autumn, there were multiple storms and associated flooding including: in Greece in September (Storm Daniel, also behind devastating flooding in Libya); in October in northern and western Europe (Storm Babet); across the Iberian Peninsula (storm Aline); and across most of western Europe (Storm Ciarán). Further storms affected central (Storm Ciro) and northwestern Europe (Storms Elin, Fergus, Pia, Gerrit and Geraldine) in December.

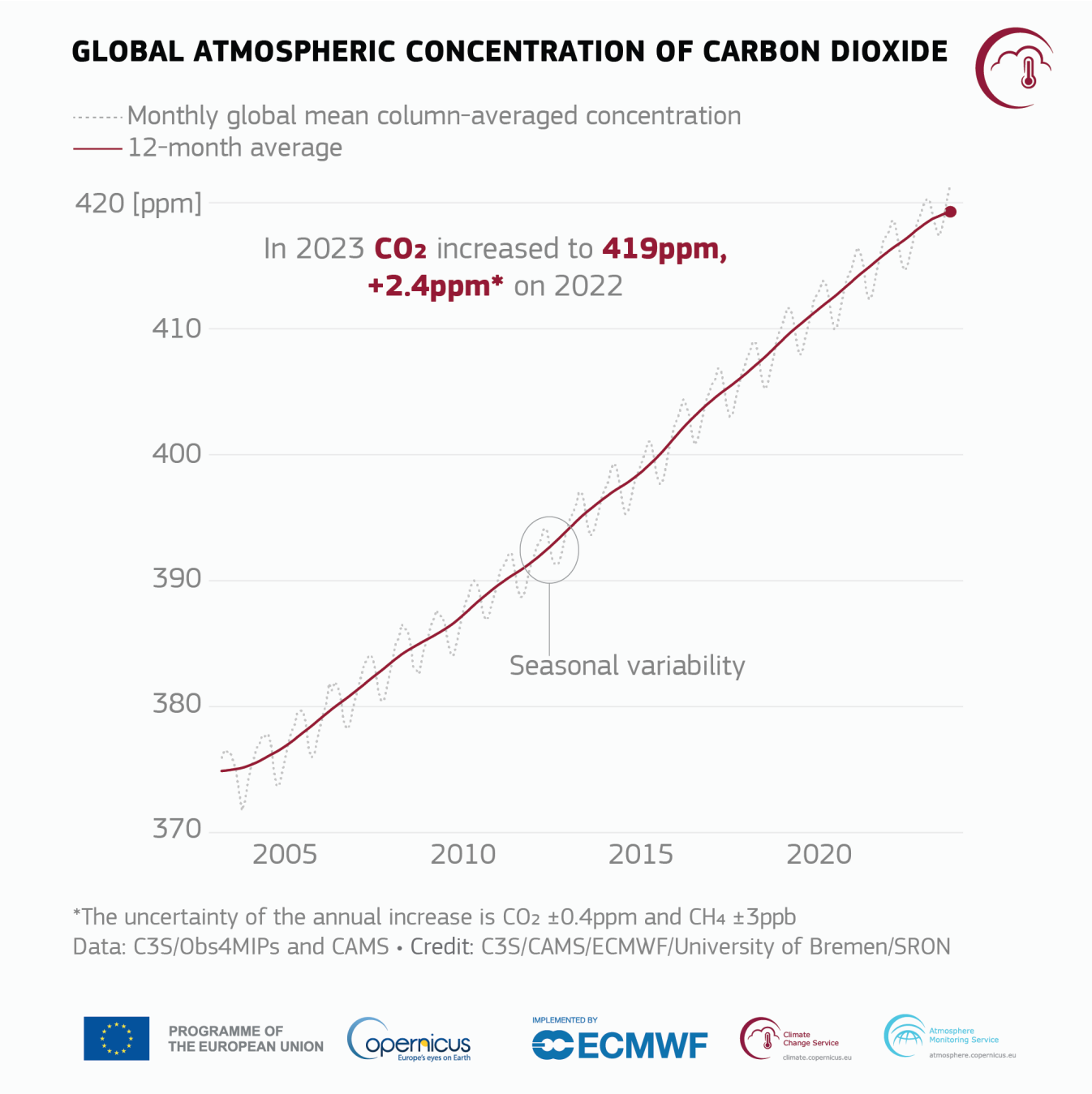
The widespread heavy precipitation of 2023 only partly alleviated the persistent drier-than-average conditions over southern Iberia and France, part of the Alps, the eastern Balkans and a large region of eastern Europe.

Greenhouse gas concentrations: continued increase

KEY MESSAGES

- The atmospheric concentrations of carbon dioxide and methane continued to increase and reached record levels in 2023, reaching 419 ppm and 1902 ppb respectively. Carbon dioxide concentrations in 2023 were 2.4 ppm higher than in 2022 and methane concentrations increased by 11 ppb.

Carbon dioxide | Methane



Monthly global mean atmospheric CO2 column-averaged concentration from satellites for 2003-2023 and 12-months average, expressed in parts per million. Data source: C3S/Obs4MIPs (v4.5) consolidated (2003–2022) and CAMS preliminary near real-time data (2023) GOSAT-2 records. Spatial range: 60°S - 60°N over land. Credit: C3S/CAMS/ECMWF/University of Bremen/SRON.

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The atmospheric concentration of the greenhouse gases carbon dioxide and methane continued to increase in 2023. Preliminary analysis of satellite data averaged over the whole atmospheric column, shows that carbon dioxide concentrations are approximately 2.4 ppm (+/- 0.4 ppm) higher in 2023 compared to 2022, while methane rose by around 11 ppb (+/- 3 ppb). This resulted in an annual average for 2023 of approximately 419.3 ppm for carbon dioxide and 1902 ppb for methane. The increase of CO_2 is similar to the increase observed in recent years.

The increase of methane remains high but is not as high as for the last three years. Atmospheric concentrations of methane had substantially grown throughout the 20th century, to stall from 2000 to 2006. Based on additional data sources, including in situ and measurements from ice

cores, the atmospheric CO_2 concentrations were higher in 2023 than at any time in at least 2,000,000 years. Atmospheric concentrations of CH_4 in 2023 were higher than at any time in at least 800,000 years.

Further Reading

Footnotes

[1] When we use the term 'temperature' here, we mean the temperature close to the Earth's surface, hence the term 'surface air temperatures.' For land surfaces, this usually refers to the air temperature at a 2m height above the surface. For the ocean, this can either refer to the same 2m air temperature, or to the temperature of the ocean or sea surface layer. This is dependent on the dataset used.

[2] This has been estimated using JRA-3Q analysis data over land and JRA-3Q background forecast data over sea, to avoid possible problems arising from biases in temperature observations from ships. This is equivalent to what is done in ERA5, which analyses surface air temperature observations only over land.

[3] The findings about global sea surface temperatures (SSTs) presented here are based on SST data from ERA5 averaged over the 60°S–60°N domain. Note that ERA5 SSTs are estimates of the ocean temperature at about 10m depth (known as foundation temperature). The results, e.g. date of the highest value in 2023, may differ from other SST products providing temperature estimates at different depths, such as 20cm depth for NOAA's OISST.

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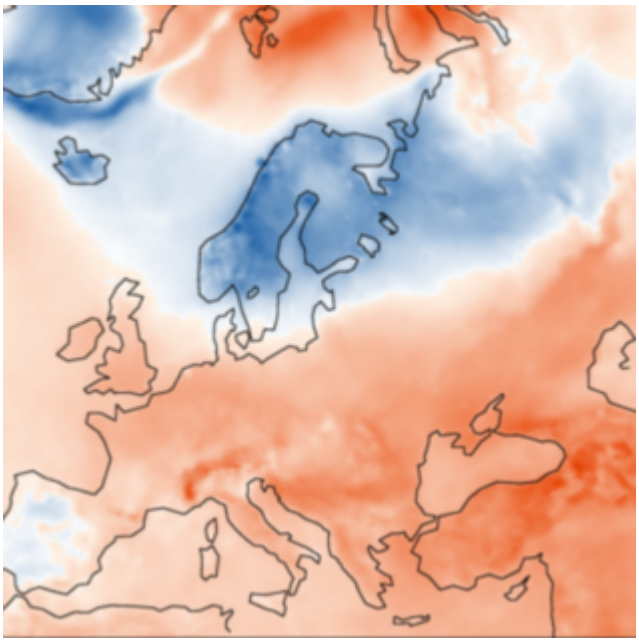
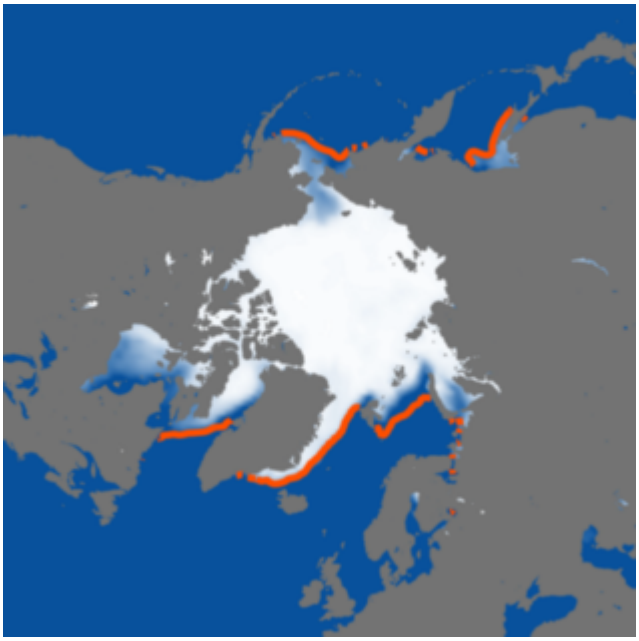
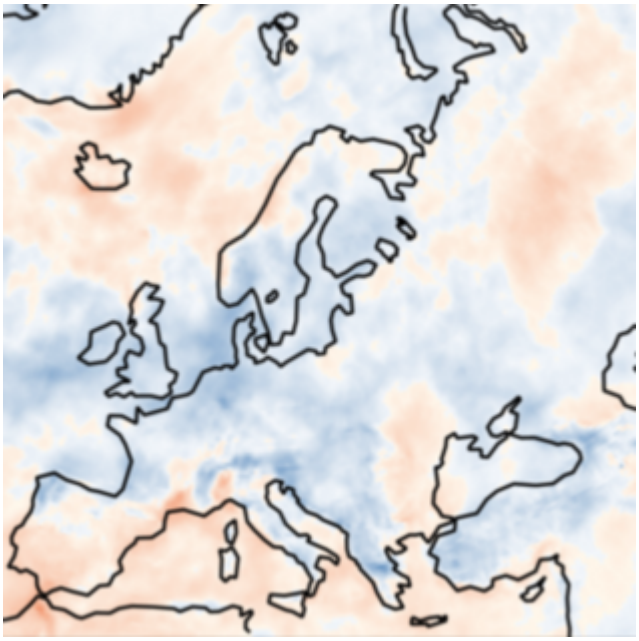


Surface air temperature for December 2023



Sea ice cover for December 2023



Precipitation, relative humidity and soil moisture for December 2023

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