

## Significant weather and climate events in 2023

This is a supplement to the WMO provisional State of the Climate 2023 report. It expands on the summary of significant high-impact events in the main report, with a broader range of events included, including some events which were climatically extreme but had limited immediate impacts.

In general, this supplement includes events up to mid-October. A full report for the year will be included as a supplement to the final 2023 State of the Climate report to be published during 2024.

### Tropical cyclones – overall assessment

2023 to date has seen a slightly below average total number of tropical cyclones globally, but an above average number of intense tropical cyclones, and a number of notably long-lived tropical cyclones, including Cyclone Freddy in the South Indian Ocean, which was one of the longest-lived tropical cyclones on record<sup>1</sup>.

In total, there have been 69 tropical cyclones in the season<sup>2</sup> to date (as of 15 October), slightly below the average at this point of the year. This largely reflects below-average tropical cyclone numbers in the 2022-23 Southern Hemisphere season, particularly in the South Pacific. Northern Hemisphere numbers have been very close to average, with well above average numbers in the North Atlantic offset by well below average numbers in the western North Pacific. The North Indian Ocean has had above average activity, and the Northeast Pacific slightly below average. Both the North Atlantic and Northeast Pacific anomalies are opposite to those which would normally be experienced during an El Niño event.

The intensity and longevity of cyclones in 2023 is reflected in the Accumulated Cyclone Energy (ACE) index, which merges cyclone intensity and duration. With the exception of the South Pacific, ACE has been above average in all basins, including the western North Pacific where cyclone numbers have been well below average. In the South Indian Ocean, largely as a result of Cyclone Freddy, the ACE value was the second-highest this century despite cyclone numbers being slightly below average.

Notable individual cyclones are discussed in the relevant regional sections.

### Africa

In terms of loss of life, the most significant event was the Mediterranean cyclone, referred to locally as 'Storm Daniel', in September. After affecting Greece, Bulgaria and Türkiye (see Europe section), the storm was slow-moving in the eastern Mediterranean for several days before the main rainbands associated with it impacted north-eastern Libya on 10 and 11 September. Extreme rainfalls affected the coast and nearby mountains, with 414.1 mm falling in 24 hours at Al-Bayda on 10-11 September. The intense rainfalls resulted in extreme flooding in the region. The most extreme impacts were in the city of Derna (about 50 km east of Al-Bayda), where much of the central city was destroyed by flooding, exacerbated by the failure of two dams. At least 4 345 confirmed deaths in Libya have been attributed to the flooding with 8 500 still missing (as of 17 October).

Tropical Cyclone Freddy in February and March was one of the world's longest lived tropical cyclones. It formed on 6 February off the western coast of Australia and moved westwards across the Indian

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<sup>1</sup> A WMO committee is currently evaluating whether Cyclone Freddy surpassed existing records (held by Hurricane/Typhoon John in 1994) for the longest duration and longest track of a tropical cyclone.

<sup>2</sup> For these purposes, the 'season' is defined as the combination of the 2022-23 Southern Hemisphere season (1 July 2022 to 30 June 2023) and the 2023 Northern Hemisphere season (starting 1 January 2023).

Ocean, intensifying to reach maximum wind gusts of 175 kt on 19 February, passing north of Mauritius and Réunion on 20 February before making its first landfall on the east coast of Madagascar on 21 February. Freddy crossed Madagascar and reintensified before a second landfall in Mozambique on 24 February. Although it dropped below cyclone intensity, the system remained organised over land and re-emerged over the Mozambique Channel on 1 March, reintensifying to become a cyclone again. It remained slow-moving over the Mozambique Channel before moving northwest and making its final landfall in Mozambique on 11 March, then moving inland as a remnant low. The major impacts of Freddy came as a result of flooding during the final landfall, both in Mozambique and Malawi, as extremely heavy rain fell (up to 672 mm in Mozambique). Malawi was especially hard hit with at least 679 deaths reported<sup>3</sup>. A further 165 deaths were reported in Mozambique. Casualties were also reported in Madagascar and Zimbabwe. This catastrophic event submerged extensive agricultural areas and inflicted severe damage on crops.

A major episode of severe flooding with associated landslides affected central Africa in early May, focused on the Lake Kivu region on the border between Rwanda and the Democratic Republic of the Congo. 182.6 mm of rain fell on 2 May at Mushubati, a national daily record for Rwanda, with records also set at several other Rwandan stations. At least 574 deaths were associated with this event, 443 in the Democratic Republic of the Congo<sup>4</sup> and 131 in Rwanda<sup>5</sup>. High rainfalls in the early months of 2023 extended north to the Lake Victoria basin, further prolonging flooding downstream in South Sudan which has persisted for much of the period since 2020. The White Nile in White Nile State (South Sudan) reached record high levels in February. This prolonged flooding rendered basic needs such as food, clean water, and healthcare difficult to access and contributed to the near collapse of local livelihoods.

Extreme heat affected northern Africa on a number of occasions during July and August, a southward extension of the persistent heat which impacted southern Europe (see Europe section). In the July heatwave, all-time records included those at Tunis (Tunisia) (49.0 °C on 24 July) and Algiers (49.2 °C on 23 July), while a second heatwave brought a temperature of 50.4 °C to Agadir (Morocco) on 11 August, the first time that 50 °C has been reached in Morocco. Northwestern Africa was also affected by drought, with rainfall in Morocco for the 2022-23 rainy season 28% below average, the fourth successive year with rainfall at least 20% below average and the country's driest four-year period on record. However, average to above average rainfall in some areas during the March-May rainy season resulted in an easing of long-term drought conditions which had persisted since late 2020 in the Greater Horn of Africa.

## Asia

Tropical Cyclone Mocha, in May, was one of the most intense cyclones ever observed in the Bay of Bengal, reaching peak 10-minute sustained winds of 115 kt. It formed on 11 May and became more intense as it moved north, reaching a peak of intensity early on 14 May, then weakening somewhat before making landfall near the Bangladesh-Myanmar border a few hours later. There were significant impacts, particularly in Rakhine State of Myanmar, with substantial wind damage and inundation, both from storm surge and freshwater flooding. There were also major impacts on settlements of refugees and internally displaced people, both in Myanmar and Bangladesh. In total at least 145 lives were lost in Myanmar and over 270 000 buildings damaged or destroyed<sup>6</sup>.

Typhoon Doksuri (Egay) crossed the northern Philippines in late July, passing across the Luzon Strait and the northeastern part of the South China Sea before making landfall in Fujian province of China. It caused substantial flooding both in the Philippines and China, with some of the most significant

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<sup>3</sup> EM-DAT

<sup>4</sup> UNICEF (via ReliefWeb) EM-DAT quotes 2970 for DRC but this appears to include 2500 initially reported missing.

<sup>5</sup> EM-DAT

<sup>6</sup> <https://ahacentre.org/situation-update/situation-update-no-8-tropical-cyclone-mocha-myanmar-26-may-2023/>.

flooding occurring in the Beijing region from the remnants of the storm. A 24-hour total of 744.8 mm was observed at Wangjiayuan Reservoir, in the hills near Beijing. At least 56 deaths were attributed to Doksuri in China, and 45 in the Philippines<sup>7</sup>. In early September, Typhoons Saola and Haikui both had significant impacts in southern China. The remnants of Haikui contributed to record-breaking rainfall intensities in Hong Kong on 7-8 September, with Hong Kong receiving 158.1 mm of rain in an hour and 605.8 mm in 12 hours.

A major and prolonged heatwave affected much of south-eastern Asia in April and May, extending as far west as Bangladesh and eastern India and north to southern China. The most exceptional temperatures occurred in Thailand, Lao PDR and Vietnam. In Thailand, 44.6 °C at Tak on 15 April was the equal-highest temperature on record in the country's main observation network, while 41.0 °C at Bangkok Metropolis on 7 May was the highest on record in metropolitan Bangkok. Luang Prabang (Lao PDR) reached 43.5 °C on 6 and 7 May, and Thong Duong (Viet Nam) 44.2 °C on 7 May. Ang Mo Kio (37.0 °C on 13 May) equalled Singapore's national record. There was also significant drought in the first half of the year in southern China, with the drought intensity in Yunnan province the most significant of the post-1961 period.

Later in the year, persistent heat in Japan, particularly in Hokkaido and northern Honshu, resulted in the country having its hottest summer on record with national mean temperatures 1.76 °C above the long-term average. 106 of 915 reporting stations experienced their highest temperature on record. September was also the hottest on record. It was also an exceptionally hot July in much of Kazakhstan.

Extreme cold occurred in parts of northeast Asia in the second half of January. In the far northeast of China temperatures fell below -50 °C, with Mohe reaching -50.8 °C on 22 January, the lowest there since 1969, and automatic weather stations in the area as low as -53 °C, while Tonguloh (Russian Federation) reached -62.7 °C on 18 January, the country's lowest since 2002. Heavy snow fell during this period in Japan and the Republic of Korea.

The Indian southwest monsoon season was relatively dry, as is characteristic of El Niño years, with All-India rainfall for June to September 6% below the long-term average. There were still some significant flood and storm episodes, with at least 599 deaths reported from flooding, associated landslides and lightning in June and July across India, Pakistan and Nepal<sup>8</sup>. Further west, near-average cool-season rainfall in eastern Turkey eased long-term drought in the Tigris and Euphrates, but rainfall for the 12 months ending in June 2023 was 40% to 60% below average in an area east of the Caspian Sea encompassing parts of Turkmenistan, Uzbekistan and Afghanistan.

Afghanistan experienced another poor crop season due to a substantial reduction in snowmelt and rainfall, despite significant and locally destructive flash floods in some areas during the summer. This led to widespread acute food insecurity, particularly in the north and northeastern regions.

### South America

Long-term drought continued in subtropical South America, focused on northern Argentina and Uruguay. Rainfall from January to August was 20 to 50% below average over much of northern and central Argentina, with some regions experiencing their fourth successive year of significantly below average rainfall. There were major crop losses in Argentina with wheat production in 2022-23 more than 30% below the five-year average. In Uruguay, water storages reached critically low levels, badly affecting the quality of supplies to major centres including Montevideo, although there was some improvement in the situation from August.

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<sup>7</sup> EM-DAT

<sup>8</sup> EM-DAT

Extreme heat occurred in South America on numerous occasions during the year. One of the most significant heatwaves occurred in late September and early October, with many locations experiencing record high temperatures in a broad region of the tropics east of the Andes. A territorial record high temperature was set in French Guiana (38.8 °C at Saint-Laurent on 25 September), while in Brazil locations where record high temperatures occurred included Belo Horizonte (38.6 °C on 25 September). In Peru, Tingo de Ponaza reached 41.4 °C on 27 September. Earlier in the year, March was exceptionally hot in Argentina and Uruguay, with temperatures 8-10 °C above average over much of northern Argentina from 1-19 March.

Drought became increasingly widespread in the northern half of South America during the year. June-September rainfall was well below average in much of the Amazon basin and rivers fell to well below average levels, with the Rio Negro at Manaus falling to its lowest level on record on 17 October<sup>9</sup>. Further south, after significant rainfall deficiencies in the southern eastern mountains of Peru, including the driest January since 1964, Lake Titicaca (Peru/Bolivia) also fell to its lowest level since 1996<sup>10</sup>. Significant agricultural losses are expected in many parts of the region.

### North America, Central America and the Caribbean

Canada's wildfire season was well beyond any previously recorded. Significant fire activity began in late April, expanded during a very warm and dry May, and continued throughout the summer and into early autumn. The total area burned nationally as of 15 October was 18.5 million hectares, more than six times the 10-year average (2013-2022) and far above the previous record seasonal total of 7.1 million hectares in 1995<sup>11</sup>. Many parts of the country were affected, with 5.2 million hectares burned in Quebec and at least 2 million in each of the Northwest Territories, British Columbia and Alberta, while Nova Scotia had the largest fires in its history in late May and early June. The city of Yellowknife was evacuated for several weeks in August and September, and many remote communities were evacuated for significant periods. Many of the fires were in remote areas, but in Nova Scotia more than 200 structures were lost in the Halifax area on 1 June, and nearly the same number were destroyed around Kelowna, British Columbia, in August. The fires also resulted in significant and widespread smoke pollution, particularly in the heavily populated areas of eastern Canada and the north-eastern United States in the first half of June. Six deaths were directly attributed to fires, although the broader health impacts of the smoke are yet to be fully assessed.

Drought extended over many areas of Canada (including most of the significantly fire-affected areas), covering most areas within 500 km of the southern border from Lake Superior westwards, and also extending north into parts of the Northwest Territories and east into western Quebec, as well as southwards into northern parts of the midwestern United States.

A second major region of drought, which gradually worsened through the year, extended from the southern United States to cover much of Mexico and other parts of central America. By the end of August, parts of eastern Texas and Louisiana were classified as being in exceptional drought. Rainfall for 2023 has been below average through most of central America. Low water levels restricted traffic in the Panama Canal from August onwards. The return of El Niño in 2023 is expected to have adverse consequences in the entire crop cycle of maize in Central America and northern parts of South America, where water deficits could curtail both planting area and yields with compounding negative impacts on final production. The initial impacts of El Niño are becoming evident in Haiti, where irregular rainfall is disrupting the first season harvest.

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<sup>9</sup> <https://www.portodemanaus.com.br/?pagina=niveis-maximo-minimo-do-rio-negro>

<sup>10</sup> <https://www.gob.pe/institucion/senamhi/noticias/840699-puno-lago-titicaca-presenta-niveles-de-agua-mas-bajos-desde-hace-27-anos>

<sup>11</sup> Canadian Interagency Fire Centre

In contrast, a very wet winter and spring eased or eliminated drought in much of the western United States, particularly in California, which experienced significant flooding. 345 mm of rain fell in San Francisco from 26 December to 10 January, and state average precipitation for the period from December to May was 53% above the 1901-2000 average and the second-highest of the 21st century. The normally dry Tulare Lake, in the southern San Joaquin Valley, filled for the first time since 1998, and snow depths reached levels amongst their highest of the last 50 years in many parts of the Sierra Nevada. There was further unseasonable rain in parts of the region in August as a result of Hurricane Hilary, the first tropical cyclone to reach California since 1997. In marked contrast to the situation further north, it was a relatively inactive wildfire season in the United States with the seasonal area burned among the lowest this century.

It was an exceptionally hot summer through most of the southern United States from Arizona eastwards. Phoenix had its hottest month on record in July, with a monthly mean temperature of 39.3 °C and a record 31 consecutive days of 110 °F (43.3 °C) or above from 30 June to 30 July. In August the most relatively extreme heat was near the Gulf of Mexico, with many locations from Texas to Florida experiencing their hottest month on record. Numerous locations reached record high temperatures, including New Orleans (40.6 °C on 27 August) and Houston Hobby Airport (42.8 °C on 27 August).

A short-lived intense cold outbreak affected the northeastern United States and adjacent areas of eastern Canada in early February, accompanied by strong winds and very low wind-chill temperatures. Temperatures in Boston fell to -23.3 °C on 4 February, the lowest since 1957. On Mount Washington the temperature fell to -43.9 °C with wind chills of -78 °C, amongst the lowest ever observed in the United States outside Alaska. Despite this event, overall winter temperatures were well above average. Baltimore and Atlantic City had their least snowy winters on record, and New York did not receive its first snow until 1 February, the latest date on record.

Severe storm activity in the United States for 2023 to date has been above average, particularly early in the year, with the January-March period having the largest number of tornadoes on record. The most significant outbreak was on 31 March, when over 150 tornadoes were observed across southern and central states, the largest single outbreak on record for March. There were further major storm outbreaks earlier in March, and in April and June.

### South-West Pacific

The North Island of New Zealand suffered repeated extreme rainfall and flooding events in January and February. The most significant was on 13-14 February, when Cyclone Gabrielle passed just east of the North island as a post-tropical system. Daily rainfalls exceeded 500 mm in parts of the eastern North Island and Auckland (971.5 hPa) had its lowest air pressure on record. Extreme flooding occurred in the Gisborne and Hawke's Bay regions, and Northland, Auckland and the Coromandel Peninsula were also badly affected. A more localised event in the Auckland area on 27-28 January brought record rainfalls at all durations from 1 to 48 hours, with the central Albert Park site receiving 211 mm in 6 hours and 280 mm in 24 hours. 11 deaths were reported as a result of Gabrielle and 4 from the Auckland floods, with total economic losses from the two events estimated at US\$5.3 to 8.6 billion<sup>12</sup>, by far the most costly non-earthquake natural disaster recorded in New Zealand.

The deadliest single wildfire of the year globally occurred in Hawaii, on the western side of the island of Maui. Extreme fire weather conditions, with low humidity and strong, gusty winds driven by a pressure gradient between strong high pressure to the north and the circulation of Hurricane Dora well to the south, combined with pre-existing drought to favour the development and rapid spread

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<sup>12</sup> NZ Treasury, <https://www.treasury.govt.nz/sites/default/files/2023-04/impacts-from-the-north-island-weather-events.pdf>

of intense fires. The most badly affected region was around the town of Lahaina, which was largely destroyed with over 2,200 structures lost. At least 97 deaths were reported<sup>13</sup>, the most in a wildfire in the United States for more than 100 years. Wildfires of such intensity and speed of movement are extremely rare in the tropics.

Parts of northern Australia experienced major flooding during the early months of 2023. The remnants of Tropical Cyclone Ellie, which made landfall on 22 December 2022 in the western Northern Territory, brought major flooding to the Kimberley region of northern Western Australia and adjacent parts of the Northern Territory in late December and early January. Dimond Gorge received 355.6 mm on 2 January and 830.2 mm in the week from 28 December to 3 January. The Fitzroy River at Fitzroy Crossing exceeded its previous record level by more than a metre, and the main road bridge was destroyed, severing the only road links between the east Kimberley and areas further south and west for several months. A second major flood affected the far northwest of Queensland and eastern Northern Territory in early March. The Gregory River reached record levels and the town of Burketown was evacuated, although it ultimately escaped full inundation. Several Indigenous communities were also evacuated for extended periods. Later in the year, Tropical Cyclone Ilsa became the first category 5 landfall in Australia since 2009 when it crossed the coast east of Port Hedland on 13 April, in a sparsely populated area with limited impacts on land apart from the destruction of a roadhouse. However, much of Australia outside the tropics has had average to below average rainfall in 2023 to date, after widespread wet conditions in 2021 and 2022, and winter crop production is forecast to be slightly below the 10-year average, with a forecast 34% fall from record high levels in 2022<sup>14</sup>. September was especially dry and was the country's driest month on record averaged over the continent.

## Europe

A major Mediterranean cyclone (known locally as storm 'Daniel') impacted the eastern Mediterranean in early September. In its first phase, the storm brought exceptional rainfalls, with the most extreme totals in the Thessaly region of Greece north of Athens. There were also extreme rainfalls and flooding in parts of southern Bulgaria and Türkiye, while at the same time a second system further west resulted in significant flash flooding in Spain. In Greece, Zagora Pelion received 759.6 mm on 5 September and a 5-day total of 1096.2 mm from 4 to 8 September, while in Bulgaria, 329 mm fell in 16 hours at Kosti on 4-5 September. Major flooding resulted, with 19 deaths reported in Greece and Bulgaria. In Greece, the main north-south road and rail routes were cut for extended periods, and there were also severe agricultural losses, with many areas of highly productive land covered with silt. The storm went on to produce extreme impacts in Libya (see [Africa](#) section).

There were numerous other flood events in southern Europe during 2023, which resulted in major economic losses and some loss of life. In May, two intense rain events two weeks apart, on 1-3 May and 16-18 May, affected the Emilia-Romagna region of northern Italy, with two-day totals exceeding 250 mm in the second event and a record total of 260.8 mm in 48 hours at Monte Albano. The second event also extended to Croatia with a record daily total of 256.4 mm on 15 May at Gračac. There was major flooding in both countries, particularly in Italy, with total losses estimated at US\$9.7 billion<sup>15</sup>, the most costly weather disaster globally of 2023 to date. Further episodes of extreme rainfall, severe thunderstorms and giant hail affected northern Italy, Slovenia and adjacent countries on several occasions in July and August. In Slovenia, following a very wet July, falls of over 200 mm of rain in 10 hours on 3-4 August, resulted in record flooding on several rivers. It was the country's most

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<sup>13</sup> Events | Billion-Dollar Weather and Climate Disasters | National Centers for Environmental Information (NCEI) (noaa.gov) [https://www.ncei.noaa.gov/access/billions/events/US/2023?disasters\[\]=wildfire](https://www.ncei.noaa.gov/access/billions/events/US/2023?disasters[]=wildfire)

<sup>14</sup> <https://www.agriculture.gov.au/abares/research-topics/agricultural-outlook/australian-crop-report/overview>

<sup>15</sup> EM-DAT

costly weather-related disaster with total losses estimated at US\$5 billion. Relatively wet conditions in July and August in much of central and north-western Europe eased drought in those areas, with some flooding, particularly in Norway. Ireland had its wettest July on record

Multiple major heatwaves affected southern Europe, especially in the second half of July where severe and exceptionally persistent heat occurred. Italy was particularly affected, with temperatures reaching 48.2 °C on 24 July at the Sardinian sites of Lotzorai and Jerzu, only 0.6 °C below the European record set in Sicily in 2021. Record high temperatures also occurred further east in locations including Izmir (Türkiye) (43.2 °C on 26 July). The extreme heat shifted to southeast Europe in late July. Further heatwaves affected west-central Europe in late August and early September. Numerous locations in southern France, northern Spain and western Switzerland set records during the late August event, including Toulouse (42.4 °C on 23 August), Lyon (41.4 °C on 24 August) and Bilbao (44.0 °C on 23 August), while the September event brought seven consecutive days which reached 30 °C in the United Kingdom and six consecutive days above 25 °C in Ireland, both September records. There was also extensive wildfire activity during the summer, particularly in Greece (both on the mainland and on islands). A fire in north-eastern Greece in late August and early September burned 93 000 hectares, the largest fire ever observed in the European Union since comprehensive records began in 2000. The heatwaves also affected northern Africa (see Africa section).