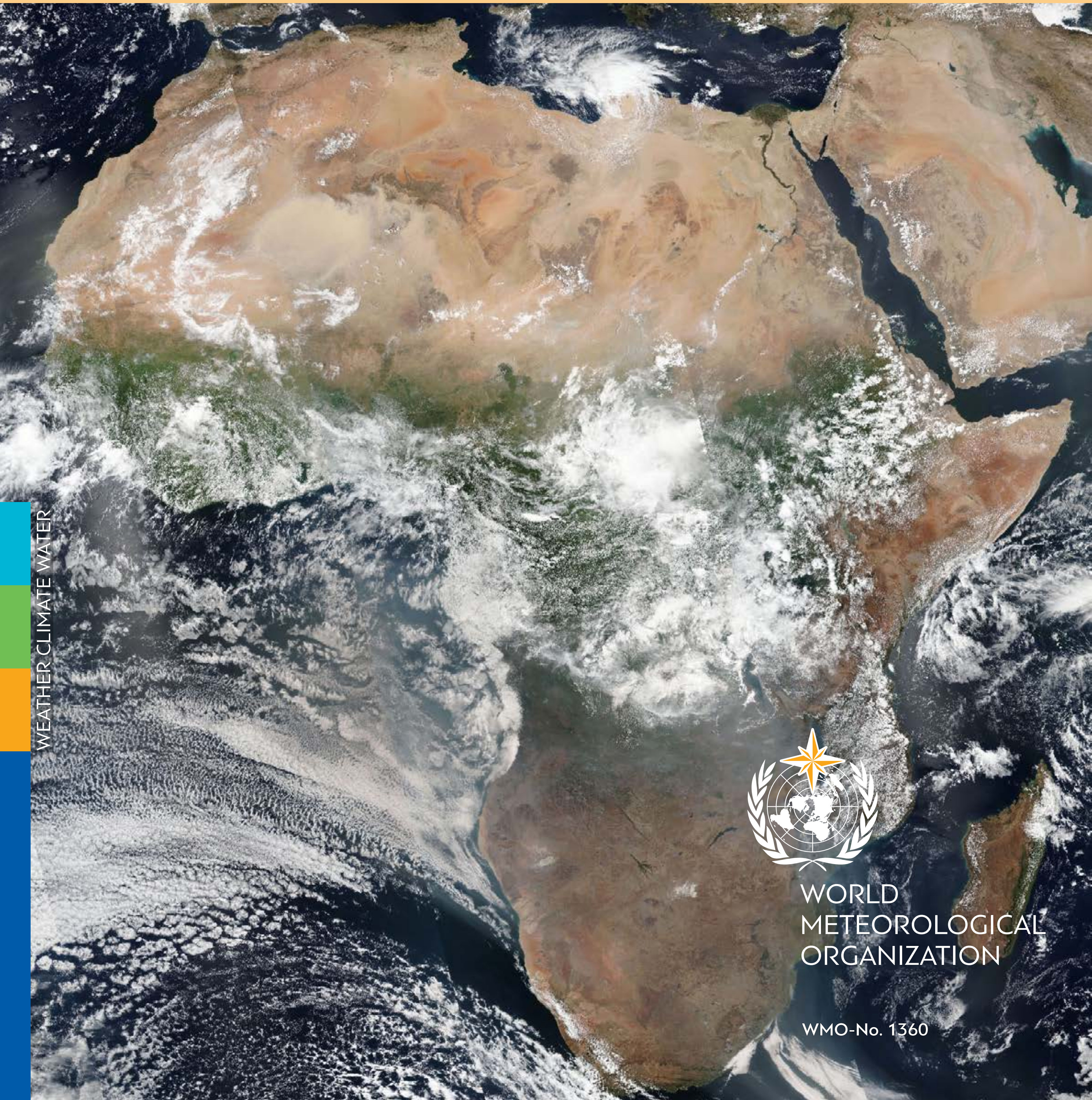
State of the Climate in Africa

2023



WEATHER CLIMATE WATER

WORLD METEOROLOGICAL ORGANIZATION

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Cover illustration: Satellite image of 10 September 2023. Credit: NASA Worldview
Key messages page:
Beautiful Baobab trees at sunset at the avenue of the baobabs in Madagascar. N 163235373. Credit: dennisvdwater Generative AI. Source: Adobe Stock

Contents

We need your feedback

This year, the WMO team has launched a process to gather feedback on the State of the Climate reports and areas for improvement. Once you have finished reading the publication, we ask that you kindly give us your feedback by responding to this short survey. Your input is highly appreciated.

Key messages

In Africa, 2023 was one of the three warmest years in the 124-year record, depending on the dataset used. The mean temperature was 0.61 °C higher than the 1991–2020 average and 1.28 °C higher than the 1961–1990 average.

The African continent warmed at a rate of +0.3 °C/decade between 1991 and 2023, a slightly faster rate than the global average.

2023 was the warmest year on record in many countries, including Mali, Morocco, the United Republic of Tanzania, and Uganda. Morocco experienced the highest temperature anomaly, 1.25 °C above the 1991–2020 reference period.

Extreme heatwaves in July and August affected northern Africa, with Tunis, Tunisia reaching a new maximum temperature of 49.0 °C, and Agadir, Morocco reaching a new maximum temperature of 50.4 °C.

The rate of sea-level rise around Africa was close to or slightly higher than the global mean rate of 3.4 mm/year. The highest rate of sea-level rise, 4.1 mm/year, was observed in the Red Sea.

Precipitation was notably higher than normal in Angola and coastal areas north of the Gulf of Guinea. Regions with a marked rainfall deficit included the western part of North Africa, the Horn of Africa, portions of Southern Africa, and Madagascar.

Parts of Morocco, Algeria, Tunisia, Nigeria, Cameroon, Ethiopia, Madagascar, Zambia, Angola, and the Democratic Republic of the Congo experienced severe drought in 2023.

At least 4 700 confirmed deaths in Libya have been attributed to the flooding that followed the Mediterranean cyclone Storm Daniel in September, with 8 000 people still missing.

Parts of Kenya, Somalia and Ethiopia experienced widespread and severe flooding, with more than 350 deaths and 2.4 million people displaced during the April–June period.

Climate extremes are becoming more frequent and severe and are disproportionately affecting African economies and societies. On average, climate-related hazards cause African countries to lose 2%–5% of their gross domestic product (GDP) annually, with many diverting up to 9% of their budgets to respond to climate extremes.

In Tunisia, widespread drought conditions in 2023 resulted in cereal production being 80% below average. Rainfall deficits in Nigeria, Benin, and Ghana also led to localized shortfalls in agricultural production.

In sub-Saharan Africa, it is estimated that climate adaptation will cost US$ 30 billion to US$ 50 billion per year over the next decade, 2%–3% of the regional GDP.

Investing in National Meteorological and Hydrological Services and early warnings and early actions is a priority for saving lives, promoting economic development, valuing development gains and livelihoods and reducing the cost of disaster responses.

Foreword

The WMO report on the State of the Climate in Africa 2023 is the fifth annual report on the climate in WMO Regional Association I (Africa). It provides an assessment of past and current climate trends across the African continent using the latest data and information on extreme weather and climate events and their socioeconomic impacts.

Over the past 60 years, Africa has recorded a warming trend that has become more rapid than the global average. In 2023, the continent experienced heatwaves, heavy rains, floods, tropical cyclones, and prolonged droughts. While many countries in the Horn of Africa and north-western Africa continued to suffer from exceptional multi-year drought, others experienced extreme precipitation events leading to flooding with significant casualties. These extreme events had devastating impacts on communities, with serious economic implications.

Climate data are critical for the development of climate services to support informed decision-making. Nevertheless, significant gaps in basic weather and climate observations remain over Africa. WMO and its partners initiated the Systematic Observations Financing Facility (SOFF) to close these observational gaps, thereby strengthening the underpinning data required for effective climate services, including early warnings. SOFF is a key element in the push to achieve the ambitious goal of the Early Warnings for All initiative, which was announced by the United Nations Secretary-General in 2022 and which aims to ensure that everyone on Earth is protected by early warning systems by 2027.

The State of the Climate in Africa 2023 is the result of a multi-agency effort, with contributions from African National Meteorological and Hydrological Services (NMHSs), WMO Regional Climate Centres (RCCs), specialized United Nations agencies and international organizations, the African Development Bank, the Accelerating Impacts of CGIAR Climate Research for Africa (AICCRA) project, and numerous experts and scientists.

I take this opportunity to congratulate the authors for the quality of this report and thank the WMO Members, our sister United Nations agencies, and the experts and scientists who have supported its production and review.

(Prof. Celeste Saulo)
Secretary-General, WMO

Preface

The 2023 edition of the State of Climate in Africa report addresses the urgent need to invest in meteorological services and early warning systems to adapt to climate change and build resilience in Africa. As the impacts of climate change continue to manifest globally, the African continent stands at a critical juncture, facing both the challenges and opportunities associated with a changing climate.

Africa, with its diverse ecosystems, rich cultural heritage, and growing populations, faces disproportionate burdens and risks arising from climate change-related weather events and patterns, including prolonged droughts, devastating floods, out-of-season storms, and wildfires. These events cause massive humanitarian crises with detrimental impacts on agriculture and food security, education, energy, infrastructure, peace and security, public health, water resources, and overall socioeconomic development across the continent.

It is important to capitalize on the commitment of the highest African leadership to strengthen early warning systems and climate information services and to take early action to protect lives, livelihoods, and assets and inform long-term decision-making related to climate change risks. This report accordingly sets the stage for a comprehensive exploration of the essential role that meteorological services and early warning systems play in enabling African nations to adapt to the realities of climate change. African countries need to prioritize addressing the pressing need for enhanced investment in these critical areas as a means of mitigating risks, building adaptive capacity, and fostering resilience at the local, national, and regional levels. Emphasis must be placed on the transformative potential of proactive initiatives aimed at strengthening meteorological services and early warning systems; these measures can empower decision makers, inform public awareness, and guide sustainable development strategies.

In this report, the reader will encounter a tapestry of knowledge, experiences, and insights that underscore the imperative of investing in meteorological services and early warning systems as a cornerstone of climate adaptation and resilience-building efforts. I invite readers to embark on this enlightening journey, acquainting themselves with the intrinsic links between weather, water and climate, and the collective imperative to safeguard Africa's sustainable future in the face of a changing climate.

As the climate narrative unfolds, we are reminded of the interconnectedness of humanity and the natural world and the responsibility we share in nurturing a resilient and harmonious coexistence amidst the challenges of a changing climate. Through collective action, informed decisions, and unwavering commitment, Africa can forge a path towards a climate-resilient future, where meteorological services and early warning systems serve as pillars of preparedness, adaptation, and sustainable progress.

As we embark on understanding the climate indicators and embrace the insights of this report, let us navigate the evolving climate landscape and work towards a future where African communities thrive in the face of climate change.

H.E. Ambassador Josefa Leonel Correia Sacko
Commissioner for Agriculture, Rural Development,
Blue Economy and Sustainable Environment
African Union Commission

Global climate context

The global annual mean near-surface temperature in 2023 was 1.45 °C [1.32 °C to 1.57 °C] above the 1850–1900 pre-industrial average and 1.09 °C [1.05 °C to 1.12 °C] above the 1961–1990 baseline. The year 2023 was the warmest year globally on record according to six datasets[1] despite the cooling effect of La Niña at the start of the year. The years 2015 to 2023 were the nine warmest years on record in all six datasets.[2]

Atmospheric concentrations of the three major greenhouse gases reached new record observed highs in 2022, the latest year for which consolidated global figures are available, with levels of carbon dioxide (CO_2) at 417.9 ± 0.2 parts per million (ppm), methane (CH_4) at 1 923 ± 2 parts per billion (ppb) and nitrous oxide (N_2O) at 335.8 ± 0.1 ppb – respectively 150%, 264% and 124% of pre-industrial (before 1750) levels (Figure 1). Real-time data from specific locations, including Mauna Loa[3] (Hawaii, United States of America) and Kennaook/Cape Grim[4] (Tasmania, Australia) indicate that levels of CO_2, CH_4 and N_2O continued to increase in 2023.

Over the past two decades, the ocean warming rate has increased; the ocean heat content in 2023 was the highest on record. Ocean warming and accelerated loss of ice mass from the ice sheets contributed to the rise of the global mean sea level by 4.77 mm per year between 2014 and 2023, reaching a new record high in 2023. The ocean is a sink for CO_2. It absorbs around one quarter of the annual emissions of anthropogenic CO_2 into the atmosphere.[5] CO_2 reacts with seawater and alters its carbonate chemistry, resulting in a decrease in pH, a process known as "ocean acidification". Ocean acidification affects organisms and ecosystem services,[6] including food security, by reducing biodiversity, degrading habitats, and endangering fisheries and aquaculture.

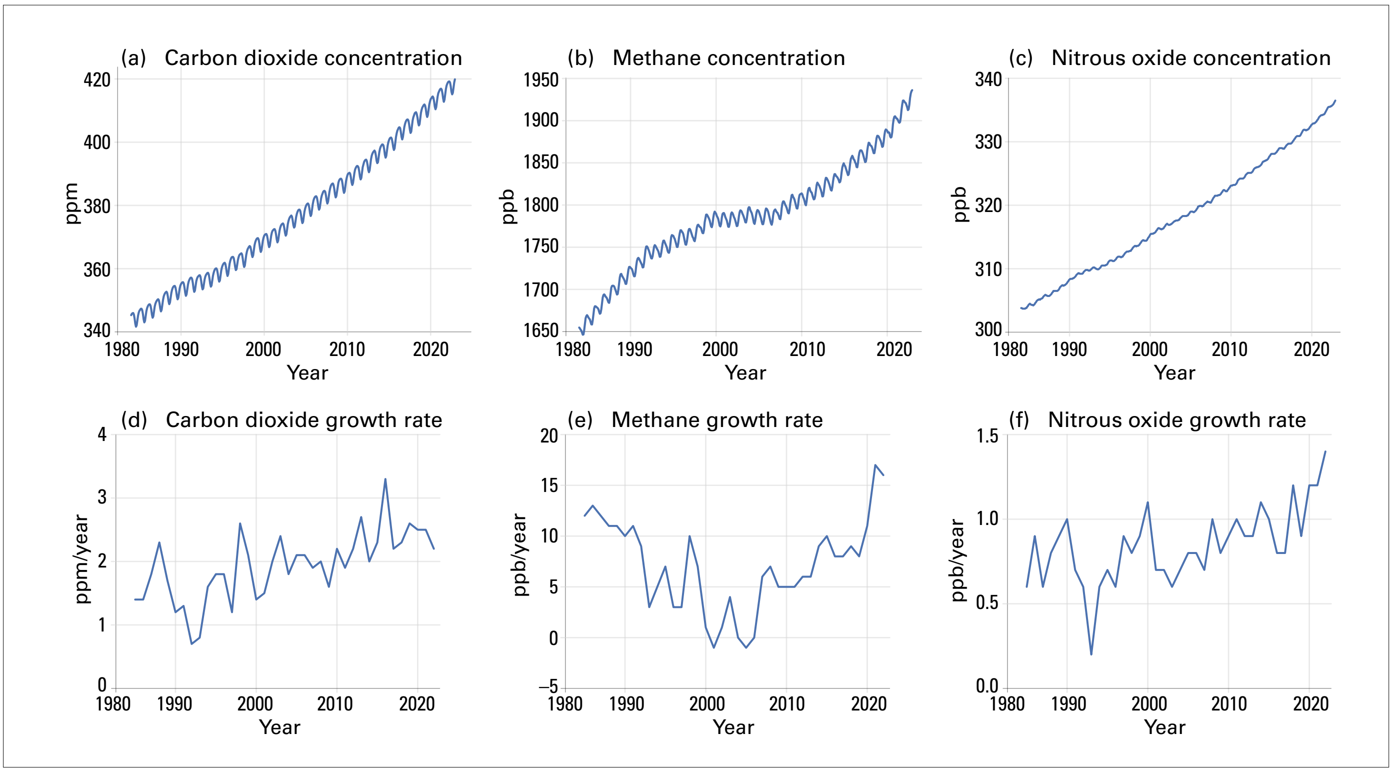


Figure 1. Top row: Monthly globally averaged mole fraction (measure of atmospheric concentration), from 1984 to 2022, of (a) CO_2 in parts per million, (b) CH_4 in parts per billion and (c) N_2O in parts per billion.
Bottom row: Growth rates representing increases in successive annual means of mole fractions for (d) CO_2 in parts per million per year, (e) CH_4 in parts per billion per year and (f) N_2O in parts per billion per year.

Regional climate

The following sections analyse key indicators of the state of the climate in Africa during 2023. One indicator that is particularly important, temperature, is described in terms of anomalies, or departures from a reference period. For global mean temperature, the Sixth Assessment Report (AR6) of the Intergovernmental Panel on Climate Change (IPCC)[7] uses the reference period 1850–1900 for calculating anomalies in relation to pre-industrial levels. However, this pre-industrial reference period cannot be used in all regions as a baseline for calculating regional anomalies due to insufficient data for calculating region-specific averages prior to 1900. Instead, the 1991–2020 climatological standard normal reference period is used for computing anomalies in temperature and other indicators. Regional temperature anomalies can also be expressed relative to the reference period 1961–1990. This is the reference period recommended by WMO for assessing long-term temperature change. In the present report, exceptions to the use of these baseline periods for the calculation of anomalies, where they occur, are explicitly noted.

TEMPERATURE

LONG-TERM TEMPERATURE ANOMALIES IN AFRICA

The African mean near-surface air temperature in 2023 was 0.61 °C [0.47 °C–0.81 °C] above the long-term average of the 1991–2020 climatological standard normal (Figure 2) and 1.28 °C [1.18 °C–1.40 °C] above the 1961–1990 average.

Depending on the dataset used, 2023 was one of the three warmest years for Africa in the 124-year record.

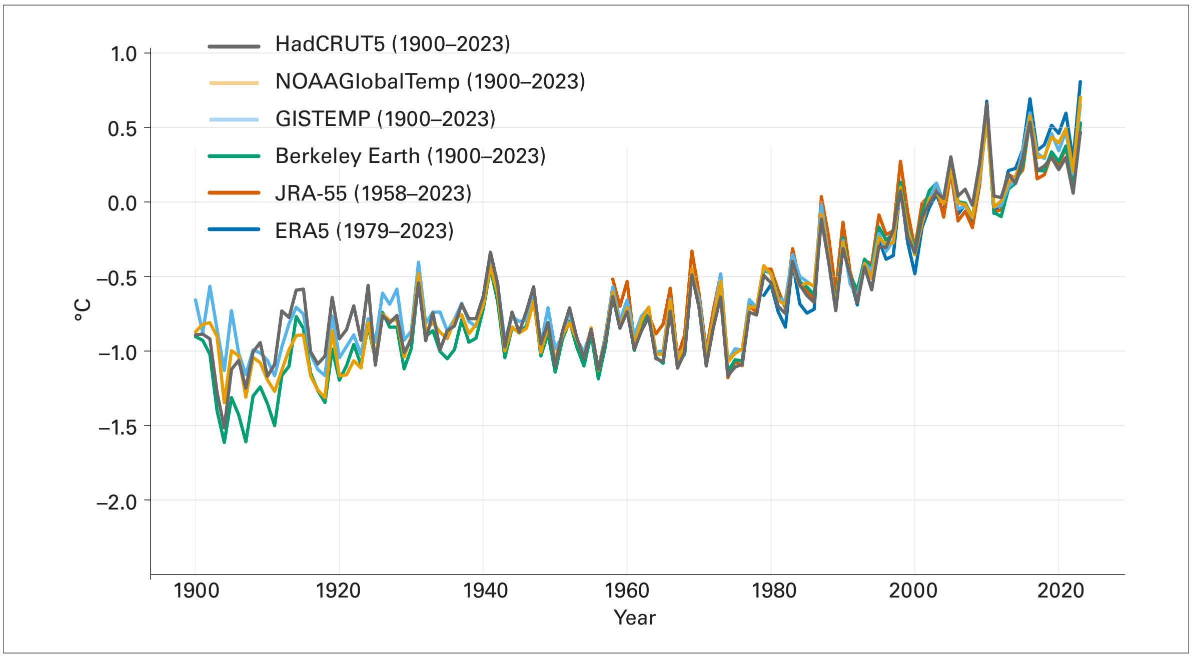


Figure 2. Temperature difference in °C with respect to the 1991–2020 climatological period for Africa (WMO Regional Association I) from 1900 to 2023, based on six datasets, including observational datasets.

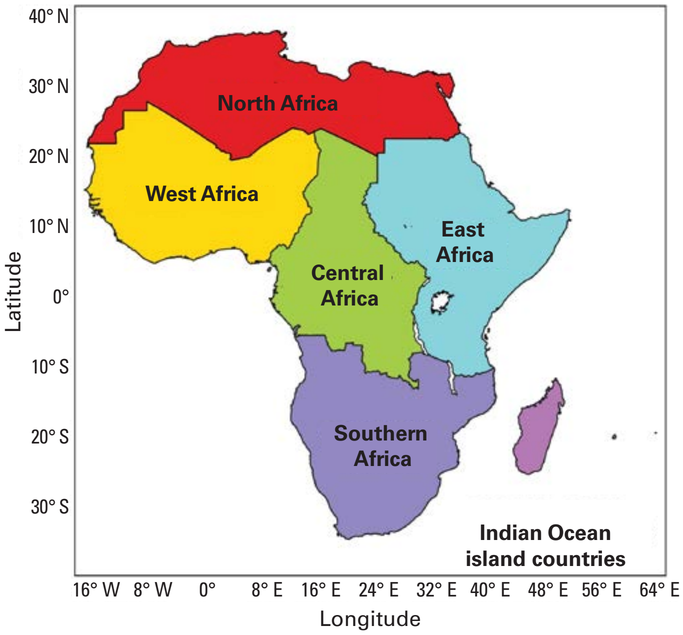
Source: Data are from the following six datasets: Berkeley Earth, ERA5, GISTEMP, HadCRUT5, JRA-55, NOAAGlobalTemp.

TEMPERATURE IN THE AFRICAN SUBREGIONS

Temperature trends are also analysed by subregion, considering overall geographic and climatic patterns, for North Africa, West Africa, Central Africa, East Africa, Southern Africa, and the Indian Ocean island countries (Figure 3).

Temperature trends

The African continent continued to observe a warming trend, with an average rate of change of around +0.3 °C/decade between 1991 and 2023, compared to +0.2 °C/decade between 1961 and 1990. The recent trend is slightly higher than the global average warming trend (land/ocean) of around +0.2 °C/decade for the 1991–2023 period.



All six African subregions have experienced an increase in the temperature trend over the past 60 years, compared to the period before 1960. The warming has been most rapid in North Africa, around +0.4 °C/decade between 1991 and 2023, compared to +0.2 °C/decade between 1961 and 1990. Southern Africa has experienced the lowest warming trend compared to the other subregions, around +0.2 °C/decade between 1991 and 2023 (Figure 4).

Figure 3. The six African subregions referred to in this report: North Africa (red), West Africa (yellow), Central Africa (green), East Africa (light blue), Southern Africa (dark blue), and the Indian Ocean island countries (purple)

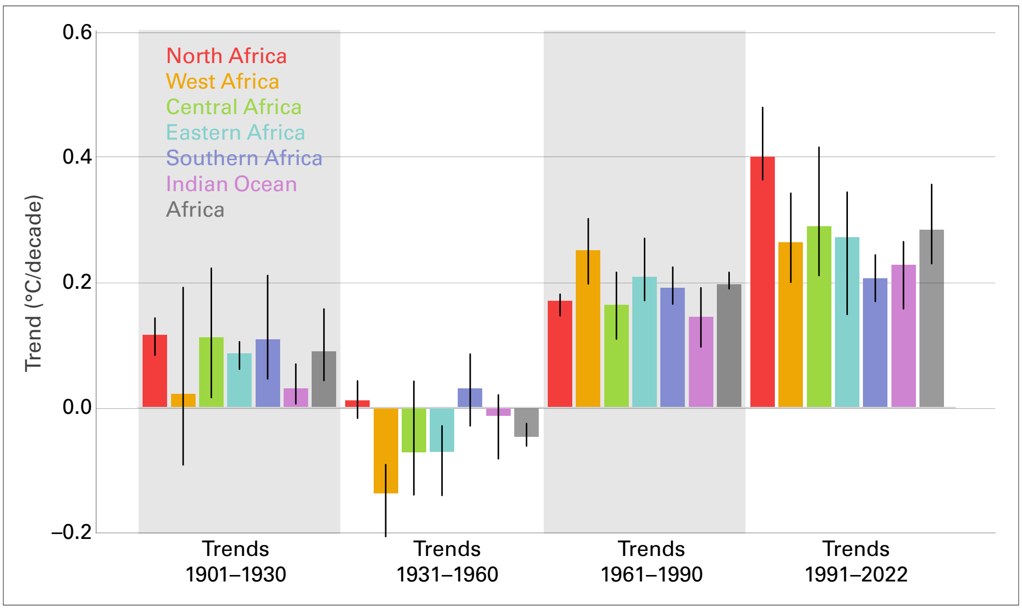


Figure 4. Trends in the area average temperature in °C/decade for the six African subregions: North Africa (red), West Africa (yellow), Central Africa (green), East Africa (light blue), Southern Africa (dark blue), the Indian Ocean island countries (purple), and the whole of Africa (grey) over four 30-year sub-periods: 1901–1930, 1931–1960, 1961–1990, and 1991–2023. The trends were calculated using different datasets, including observational datasets (HadCRUT5, NOAAGlobalTemp, GISTEMP, and Berkeley Earth) and reanalyses (JRA-55 and ERA5). The black vertical lines indicate the range of the six estimates.

Temperature anomalies

In 2023, temperatures were above the 1991–2020 average across Africa (Figure 5, left). However, there are many data-sparse regions across the continent, where uncertainties are relatively high (Figure 5, right).

The highest temperature anomalies were recorded across north-western Africa, especially in Morocco, costal parts of Mauritania and north-west Algeria. North Africa recorded the highest 2023 temperature anomaly compared to the other African subregions: 0.84 °C [0.69 °C–1.00 °C] above the 1991–2020 average and 1.68 °C [1.52 °C–1.86 °C] above the 1961–1990 average (see the table).

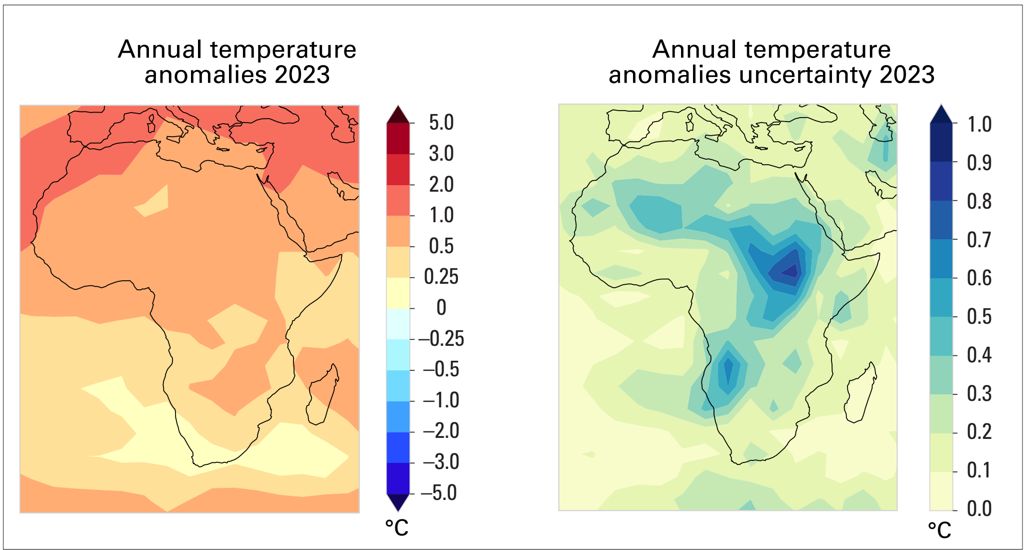


Figure 5. Near-surface air temperature anomalies for 2023 relative to the 1991–2020 average (left) and estimated uncertainty in temperature anomalies for 2023 (right). Anomalies are calculated as the median of six datasets, including observational datasets (HadCRUT5, NOAAGlobalTemp, GISTEMP, and Berkeley Earth) and reanalyses (JRA-55 and ERA5). Each dataset has been averaged onto a consistent 5° latitude by 5° longitude grid then plotted using a standard contouring algorithm that interpolates between the grid averages.

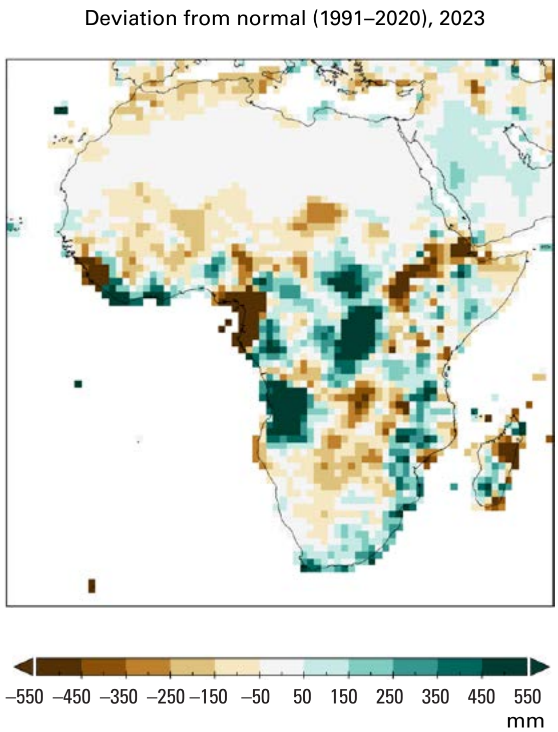
Table. Near-surface air temperature anomalies in °C for 2023 relative to the 1991–2020 and 1961–1990 reference periods. Anomalies for the whole African continent and for each of the African sub-regions were calculated using six different data sets, including observational data sets (HadCRUT5, NOAAGlobalTemp, GISTEMP, and Berkeley Earth) and reanalyses (JRA-55 and ERA5). The range of anomalies among these data sets is given in the brackets.

	1991–2020	*1961–1990*
North Africa	**0.84 °C** [0.69 °C–1.00 °C]	**1.68 °C** [1.52 °C–1.86 °C]
West Africa	**0.64 °C** [0.43 °C–0.80 °C]	**1.29 °C** [0.99 °C–1.48 °C]
Central Africa	**0.59 °C** [0.37 °C–0.86 °C]	**1.17 °C** [0.96 °C–1.34 °C]
East Africa	**0.61 °C** [0.38 °C–0.86 °C]	**1.29 °C** [1.18 °C–1.46 °C]
Southern Africa	**0.40 °C** [0.20 °C–0.58 °C]	**0.98 °C** [0.86 °C–1.09 °C]
Indian Ocean island countries	**0.54 °C** [0.49 °C–0.64 °C]	**1.08 °C** [0.98 °C–1.19 °C]
Africa	**0.61 °C** [0.47 °C–0.81 °C]	**1.28 °C** [1.18 °C–1.40 °C]

The regional averages mask some notable averages in individual countries. In 2023, several countries, including Mali, Morocco, the United Republic of Tanzania, and Uganda experienced their highest recorded temperatures, with Morocco having the highest temperature anomaly, at 1.25 °C above the 1991–2020 average. In contrast, Namibia and South Africa had the lowest temperature anomalies. The Southern Africa region registered the lowest 2023 temperature anomalies compared to the 1991–2020 average: 0.40 °C [0.20 °C–0.58 °C].

PRECIPITATION

In 2023, many regions of Africa experienced precipitation levels comparable to those in 2022, except over the Sahel, where most areas recorded dry conditions. Precipitation anomalies were slightly above the 1991–2020 average in north-eastern Africa, large parts of East Africa and most coastal parts of Southern Africa. High precipitation anomalies were observed over Angola, large parts of central and eastern Central Africa, and coastal areas north of the Gulf of Guinea. Regions with a marked rainfall deficit included the western part of North Africa, the Horn of Africa, portions of Southern Africa, and Madagascar (Figure 6, right).



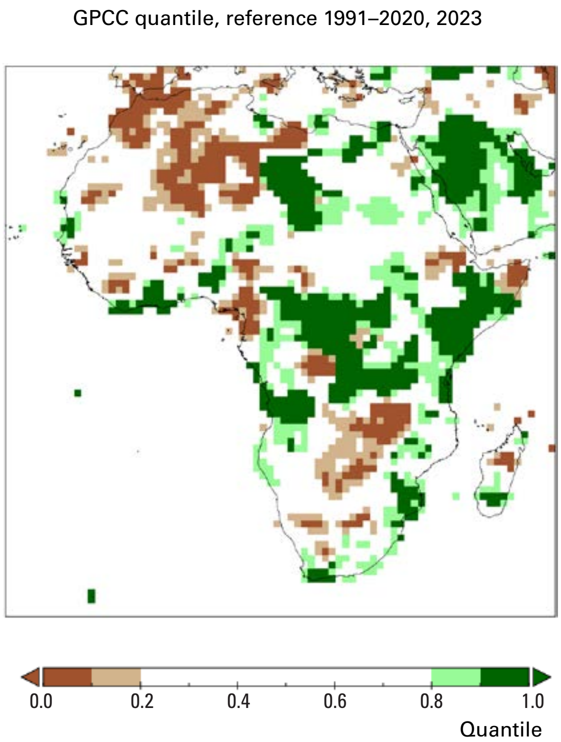


Figure 6. Precipitation anomalies in mm for 2023 (left): Blue areas indicate above-average precipitation, and brown areas indicate below-average precipitation. The reference period is 1991–2020. Precipitation quantiles for 2023 (right): Green areas indicate unusually high precipitation totals (light green indicates the highest 20%, and dark green indicates the highest 10% of the observed totals). Brown areas indicate abnormally low precipitation totals (light brown indicates the lowest 20%, and dark brown indicates the lowest 10% of the observed totals). The reference period is 1991–2020.

Source: Global Precipitation Climatology Centre (GPCC), Deutscher Wetterdienst (DWD), Germany

Below-normal annual rainfall prevailed over much of North and north-western Africa, especially Morocco, Algeria, Tunisia, and western Libya (Figure 6, left), where the precipitation deficits exceeded 150 mm (the lowest 10% of the observed totals during the 1991–2020 climatology period). Conversely, northern Egypt and the Jebel Akhdar in north-east Libya experienced above-average precipitation, with excesses of over 150 mm (the highest 10% of the observed totals during the climatology period).

West Africa experienced a normal to early onset of its monsoon rainy season, which was characterized by mostly average to above-average conditions. The western part of the region (southern-western Mauritania, north-western Senegal, western Guinea-Bissau and western Sierra Leone), and the eastern part of the region (south-western Nigeria), as well as southern coastal parts of Liberia, Côte d'Ivoire, Ghana, and Togo, benefited from wetter-than-average conditions (Figure 6, right). Southern Mauritania, western Senegal, central Mali, western Burkina Faso, south-eastern Niger, southern Ghana, southern Togo, eastern Benin and parts of Nigeria received enhanced rainfall. Conversely, northern Mali, south-eastern Guinea, parts of Côte d'Ivoire and portions of Nigeria observed suppressed precipitation (Figure 6, right).

In Central Africa, wetter-than-normal conditions prevailed in most of the region, with precipitation anomalies exceeding 400 mm above average in many parts of Democratic Republic of the Congo and Angola and eastern Central African Republic (Figure 6, left).

In East Africa, central Sudan, northern Ethiopia and Uganda suffered from below-normal precipitation. Wetter-than-normal conditions, with extreme rainfall in some areas were recorded in south-west Sudan, southern parts of Ethiopia, Somalia, Kenya, Burundi and Rwanda, and most parts of the United Republic of Tanzania. Heavy rainfall led to extensive flooding in Somalia, Ethiopia, and Kenya in October and November. These floods followed the most prolonged drought on record over the Horn of Africa – from late 2020 to early 2023.

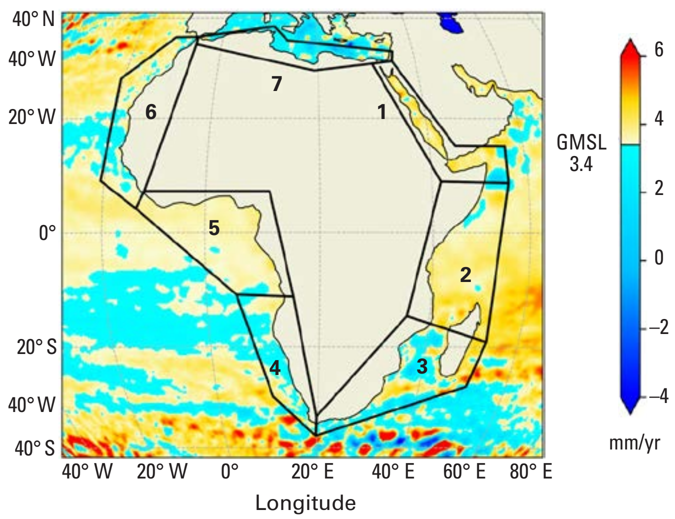
In Southern Africa, positive rainfall anomalies of over 300 mm were found across central and western Angola (Figure 6, left). Most of Malawi and Mozambique, Eswatini and coastal parts of South Africa observed enhanced rainfall, with some areas in the highest 10% of the observed totals during the climatology period. Conversely, rainfall deficits reaching 100 mm were observed across Zambia, Botswana, and most of Namibia, as well as limited areas in the central part of South Africa and some areas in Zimbabwe (Figure 6, right).

In the West Indian Ocean, suppressed rainfall resulted in negative anomalies of over 200 mm in northern and extreme southern Madagascar and Seychelles. In contrast, a rainfall surplus was recorded in Comoros and most areas in southern Madagascar (Figure 6, left).

SEA LEVEL

Sea level around the African continent continues to rise. Figure 7 shows altimetry-based regional sea-level trends from the coast to 50 km offshore from January 1993 to June 2024. The transition from blue to yellow corresponds to the global mean sea-level rise over the same timespan, amounting 3.4 +/- 0.3 mm/year. The map shows some regional variability in the sea-level trend patterns on both the Atlantic and Indian Ocean sides of the continent. The rates of sea-level rise from January 1993 to June 2024 have been computed along the coastlines from the data shown in the boxes in Figure 7. The table in Figure 7 indicates the coastal sea-level trends that are computed for all seven regions for the same period.

The rate of sea-level rise, which is estimated in bands 50 km wide around the coast, is close to or slightly higher than the global mean in all the regions except for the southern Mediterranean Sea, where it is lower (3.0 mm/year). The largest rate of observed sea-level rise is in the Red Sea (4.1 mm/year).



Box number	Ocean	Sea level rise rate (mm/year)
1	Red Sea	4.1 ± 0.2
2	Western Indian Ocean	4.0 ± 0.2
3	South-west Indian Ocean	3.8 ± 0.1
4	South-east Atlantic	3.5 ± 0.1
5	Tropical Atlantic	3.7 ± 0.1
6	North-east Atlantic	3.6 ± 0.1
7	Southern Mediterranean Sea	3.0 ± 0.2
	Global	3.4 ± 0.3

Figure 7. Left: Spatial sea-level trends in the seven coastal regions of Africa covering the period from January 1993 to June 2024: Red Sea (1), Western Indian Ocean (2), South-west Indian Ocean (3), South-east Atlantic Ocean (4), Tropical Atlantic Ocean (5), North-east Atlantic Ocean (6) and Southern Mediterranean Sea (7). Right: Table indicating the sea-level rise in mm/year for the seven coastal regions of Africa and the global ocean.

Source: Copernicus Climate Change Service (C3S). See C3S Climate Data Store for more information on the datasets and methodology used to measure sea-level rise.

Major drivers of climate variability affecting the region

The El Niño–Southern Oscillation (ENSO) phases (El Niño and La Niña) and the sea-surface temperature (SST) anomaly patterns in the tropical Atlantic Ocean and Indian Ocean usually constitute the main drivers of rainfall variability in Africa.

La Niña conditions emerged in mid-2020 and continued through 2021 and 2022, finally coming to an end in March 2023. It is the third time that such a multi-year La Niña event has occurred in the last 50 years. La Niña was at moderate strength through the end of 2022, but El Niño conditions developed in mid-2023 and persisted to the end of the year (Figure 8a). The Tropical Northern Atlantic (TNA) index was positive for most of 2022 and throughout 2023, reflecting positive SSTs in the eastern tropical North Atlantic Ocean (Figure 8b). The Tropical Southern Atlantic (TSA) index was also positive for most of the year, reflecting the positive SSTs in the eastern

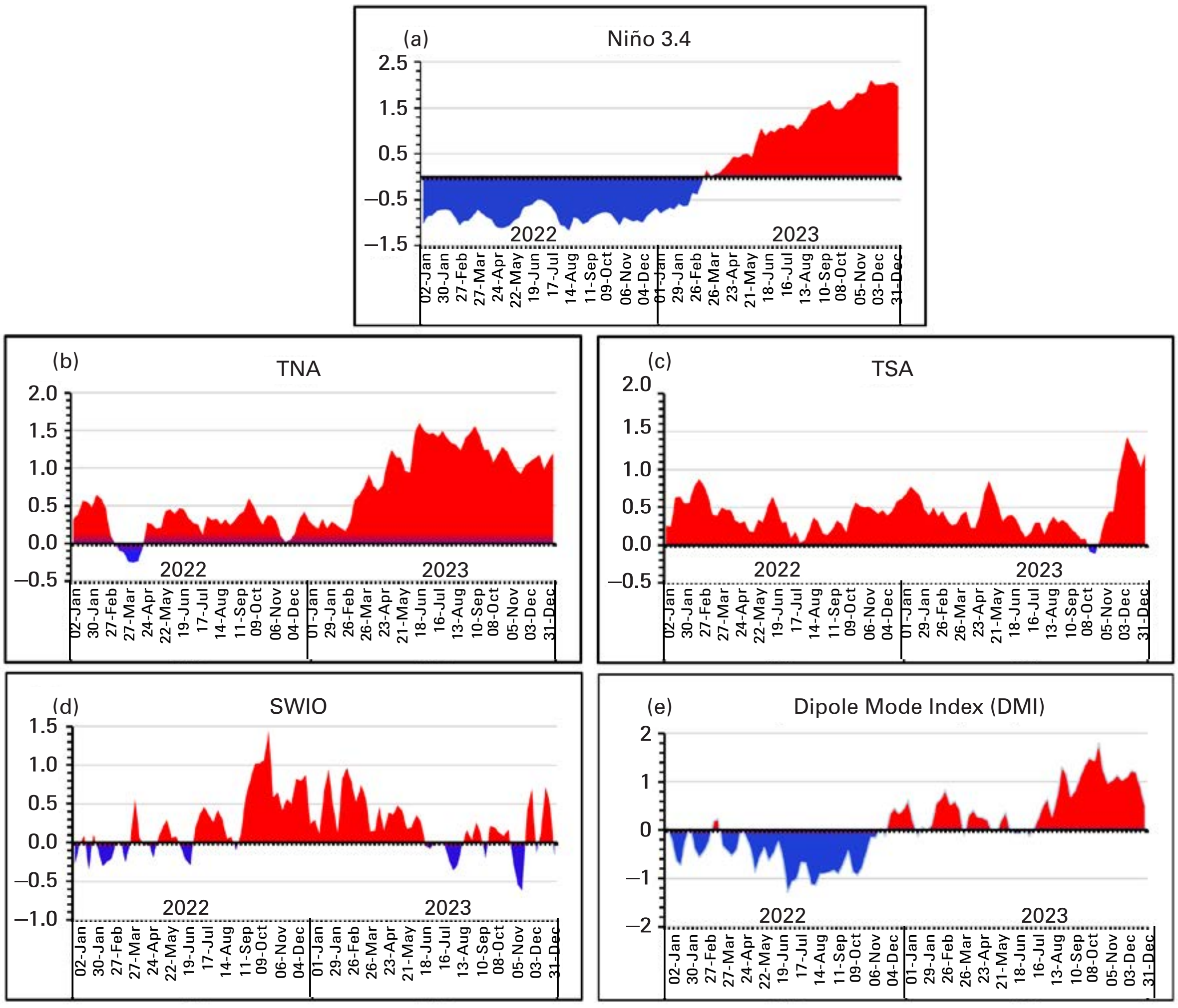


Figure 8. Time series of climate indices for 2022 and 2023:
(a) Niño 3.4 index [SST anomalies averaged over 5°S–5°N; 170°W–120°W];
(b) TNA index [SST anomalies averaged over 5.5°N–23.5°N; 15°W–57.5°W];
(c) TSA index [SST anomalies averaged over 0–20°S; 10°E–30°W];
(d) SWIO index [SST anomalies averaged over 32°S–25°S; 31°E– 45°E];
(e) Indian Ocean DMI – the difference between the SST anomalies over the tropical western Indian Ocean [10°S–10°N; 50°E–70°E] and the tropical eastern Indian Ocean [10°S– 0; 90°E–110°E].
Anomalies are deviations from the 1982–2005 mean.

tropical South Atlantic Ocean, except in October, when it was closer to neutral (Figure 8c). The South-western Indian Ocean (SWIO) index fluctuated and was positive for most of 2023, except in June, July and November (Figure 8d). The Indian Ocean Dipole Mode Index (DMI) was positive during most of 2023, except in June, when it was closer to neutral (Figure 8e). Positive TNA and TSA indices were favourable for above-average summer rainfall over West Africa. The positive SWIO index favoured well-above-average austral summer precipitation in many parts of South Africa and southern Madagascar. The warmer-than-average SSTs in the western Equatorial Indian Ocean (adjacent to the East African coastline), coupled with lower-than-average SSTs over the eastern Equatorial Indian Ocean (adjacent to Australia), constituted a positive Indian Ocean Dipole (IOD) which, although weak between January and June 2023, was favourable for enhanced rainfall over most of East Africa.

Extreme climate events

In 2023, many extreme climate events were reported across Africa. The continent was affected by heavy rainfall, floods, tropical cyclones, droughts, heatwaves, wildfires, and sandstorms. The extreme events in this section are described with respect to how they affected the different subregions.

FLOODS

EXTREME FLOODING IN LIBYA AND ELSEWHERE

In terms of loss of life, the most significant event was the Mediterranean cyclone, referred to locally as Storm *Daniel*, in September 2023. After affecting Greece, Bulgaria and Türkiye, the storm was slow-moving in the eastern Mediterranean for several days before the main rainbands impacted north-eastern Libya on 10 and 11 September. Extreme rainfall affected the coast and nearby mountains, with 414 mm falling in 24 hours at Al-Bayda on 10–11 September. The intense rainfall resulted in extreme flooding in the region. The most severe impacts were in the city of Derna (about 50 km east of Al-Bayda), where much of the central city was destroyed by flooding (Figure 9), exacerbated by the failure of two dams. At least 4 700 confirmed deaths in Libya have been attributed to the flooding with 8 000 still missing (as of 15 December 2023).[8]

Tropical Cyclone *Freddy*, a long-lived cyclone in February and March 2023, formed off Australia's western coast and moved west across the Indian Ocean. It passed north of Mauritius and Réunion before making its first landfall on the east coast of Madagascar. *Freddy* re-intensified before making its second landfall in Mozambique. Although it dropped below cyclone intensity, it re-emerged over the Mozambique Channel and made its final landfall in Mozambique.

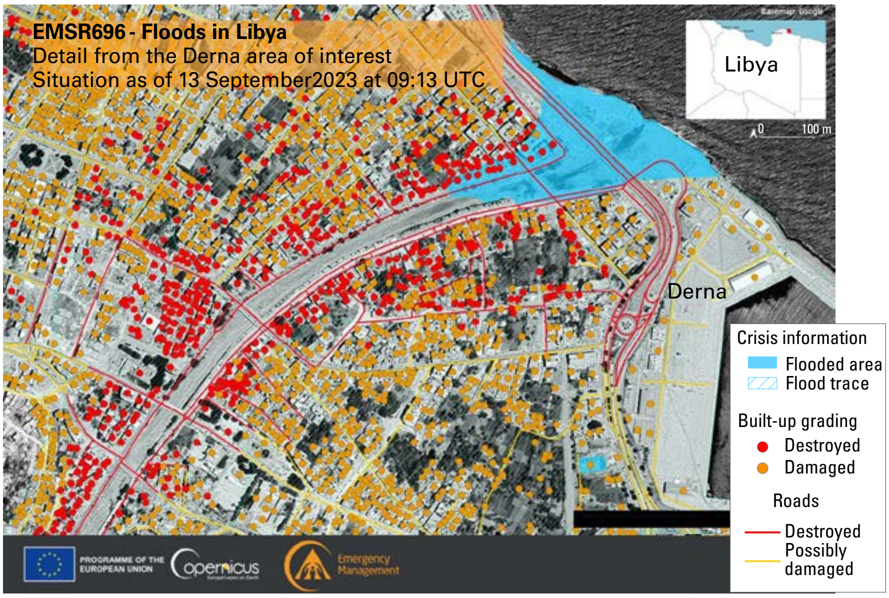


Figure 9. Flooded areas and destroyed buildings (red circles) in Derna, Libya on 10 September 2023

Source: European Union, Copernicus Sentinel image

The major impacts of *Freddy* resulted from flooding that occurred during its final landfall in Mozambique, with extremely heavy rainfall affecting both Mozambique and Malawi (up to 672 mm in Mozambique). Malawi was especially hard hit by the flooding, with at least 679 deaths reported.[9] A further 165 deaths were reported in Mozambique. Casualties were also reported in Madagascar (17 deaths) 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, mainly the Lake Kivu region, on the border between Rwanda and the Democratic Republic of the Congo. On 2 May, Mushubati recorded 183 mm of rain, 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[10] and 131 in Rwanda.[11] Heavy rainfall in the early months of 2023 extended north to the Lake Victoria basin, further prolonging the flooding downstream in South Sudan which has persisted for much of the time since 2020. The White Nile River 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. In September and October, approximately 300 000 people were affected by flooding across 10 countries, with Niger, Benin, Ghana and Nigeria the most heavily impacted. Nearly 12 000 people in five countries in West and Central Africa were newly displaced due to flooding in July and August, bringing the total number of countries facing flood-related displacement in 2023 to nine. On 7 October, heavy rainfall in the north of the Democratic Republic of the Congo triggered the flooding of several hectares of agricultural land and basic infrastructure, and in Ghana, heavy rainfall on 15 October forced the Volta River Authority to initiate the spillage of excess water to address rising levels threatening the Akosombo and Kpong dams, resulting in flooding downstream along the banks of the Volta River and leading to the destruction of homes and farmlands (Figure 10).

Figure 10. Flooding in Ghana on 20 October 2023

Source: A. Kaledzi

The Greater Horn of Africa region, which, prior to 2023, had endured a long-term drought, experienced substantial flooding in 2023, particularly later in the year with the onset of heavy rains associated with El Niño and the positive IOD. The most severely affected area was the region encompassing the southern half of Somalia, south-eastern Ethiopia and north-eastern Kenya. During the *Deyr* rainy season (October and November), monthly rainfall in this region generally ranged from 100 mm to 200 mm, and in some areas exceeded 200 mm, several times the long-term averages. This followed widespread above-average rainfall during the *Gu* rainy season (April to June). There was extensive and severe flooding, with at least 352 deaths and 2.4 million displaced people reported across all three countries, although the wet conditions did lead to some recovery in pasture and crop conditions after the extended drought. Landslides and flooding in early December also resulted in at least 89 deaths in northern parts of the United Republic of Tanzania.

DROUGHTS

EXTREME DROUGHT IN SEVERAL PARTS OF AFRICA

In 2023, severe droughts, exceeding historical severity levels, occurred mainly in the coastal lands of northern Morocco, Tunisia and Algeria, but they also affected southern Cameroon, the Ethiopian highlands, northern Madagascar, and areas encompassing Zambia, eastern Angola and the southern Democratic Republic of the Congo (Figure 11).

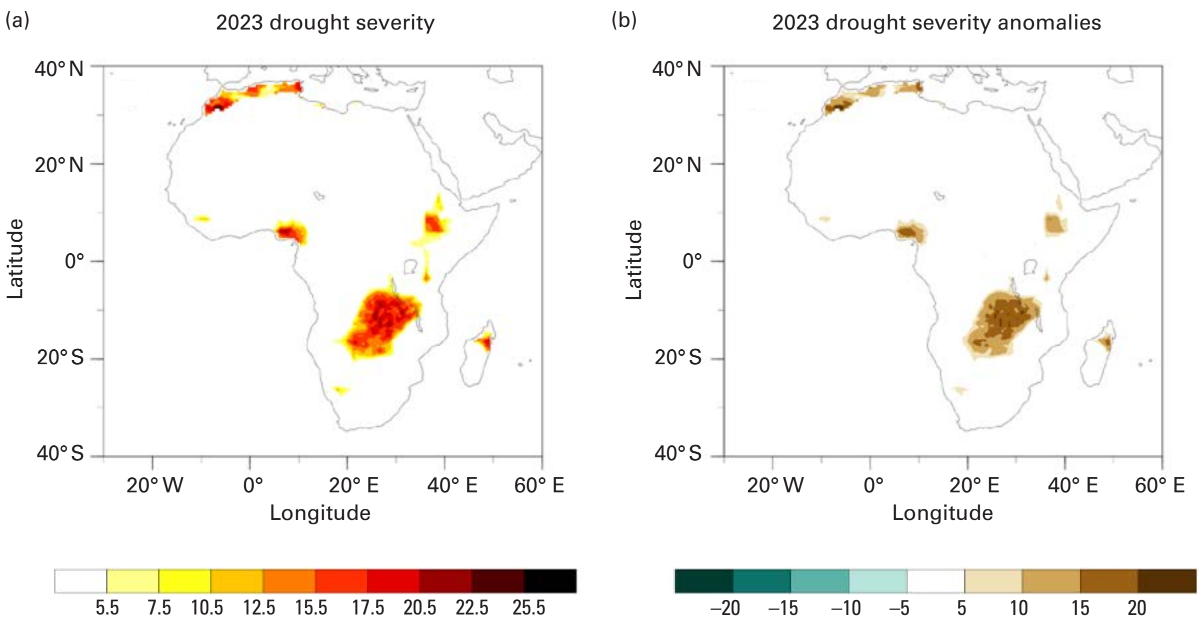


Figure 11. Spatial distribution of (a) drought severity for 2023 and (b) the anomalies of drought severity for 2023 with respect to the reference period 1991–2020 based on the 12-month standardized precipitation index (SPI12) applied to GPCC (see https://opendata.dwd.de/climate_environment/GPCC/html/fulldata-monthly_v2020_doi_download.html). Drought severity is calculated as the absolute value of the sum of all SPI12 values lower than -1 from January to December 2023.

Figure 12. Photograph of Al Massira Dam in 2023 showing its lowest fill level, approximately 5.6%. Upper right: Satellite image indicating the water storage extent in 2013 and 2023.

Source: Main photograph: 2M TV, Morocco. Satellite image: Landsat Image Gallery.

While some regions, such as the Horn of Africa, are emerging from severe drought, others, such as north-western Africa, continue to face high precipitation deficits which impact water resources. For example, Al Massira Dam – Morocco's second largest dam after Al-Wahda Dam – which has a storage capacity of more than 2.65 billion cubic meters, registered its lowest fill level since its construction in 1976, at less than 6%, compared to almost 99% in May 2013 (Figure 12). Rainfall in Morocco for the 2022/2023 rainy season was 28% below average, the fourth consecutive year with rainfall at least 20% below average, and the country's driest four-year period on record. Rainfall was also well below average in the early part of the 2023/2024 rainy season.

HEATWAVES AND WILDFIRES

The extreme heat that impacted southern Europe also affected northern Africa on multiple occasions during July and August. The July heatwave broke records in Tunis, Tunisia, where the temperature reached a high of 49.0 °C. In August, the heatwave set a new record of 50.4 °C in Agadir, Morocco, marking the first time that 50.0 °C was reached in Morocco.

Figure 13 shows that many countries in Africa experienced heatwaves[12] in 2023. North African countries, including Morocco and Algeria, as well as East and Central African countries, including Sudan, South Sudan, the Democratic Republic of the Congo and the Central African Republic, experienced the highest number of heatwaves, with more than 14 events. Countries in Southern Africa, including Namibia, Botswana, Zambia, Angola and Madagascar also experienced a comparable number of heatwaves across most of their territories. In all these countries, the number of heatwaves in 2023 exceeded the climatological mean of 10 events. However, the amplitudes were maximal and surpassed the climatological mean only along the coastal regions of Morocco and Algeria, along the border of Sudan and South Sudan, and in north-western Ethiopia, although the latter regions are subject to large uncertainties with respect to temperature data.

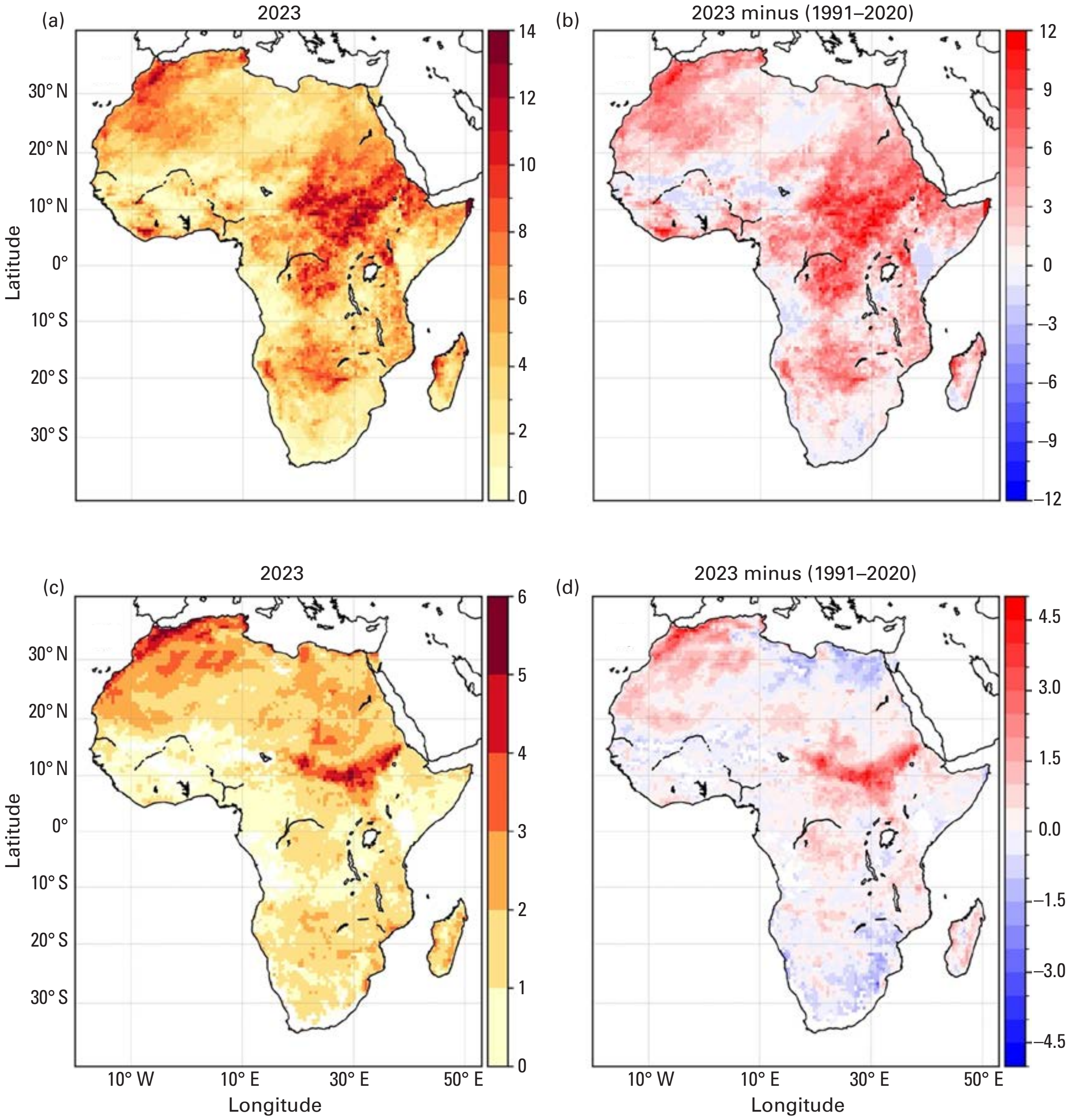


Figure 13. Spatial distribution of (a) the heatwave number (HWN) for 2023, (b) the anomalies of the HWN for 2023 with respect to the climatology of the reference period 1991–2020, (c) the heatwave amplitude (HWA), the peak daily value of the hottest heatwave for 2023 and (d) the anomalies of the HWA for 2023 with respect to the climatology of the reference period 1991–2020 using ERA5 (see https://cds.climate.copernicus.eu/cdsapp#!/dataset/reanalysis-era5-complete?tab=overview).

Drier conditions, combined with higher temperatures, contributed to increased fire weather conditions in North Africa. A number of wildfires were recorded in 17 prefectures in July in central and eastern Algeria, leading to at least 44 deaths, the evacuation of more than 1 500 people from their villages, and the burning of 32 000 hectares of forest.

Climate-related impacts to agriculture and food security

In 2023, extreme weather conditions caused widespread floods and below-average rainfall, leading to significant food production and supply shortages in the Central African Republic, Kenya, and Somalia.

North Africa's cereal production in 2023 was estimated at 33 million tonnes, similar to the previous year's already drought-stricken harvest and about 10% below the five-year average. The largest production decrease occurred in Tunisia, where the cereal output was estimated at 300 000 tonnes, over 80% below the annual average due to widespread drought conditions. A decline was also reported in Algeria, where the cereal output was estimated at 3.6 million tonnes, 12% less than in 2022 and 20% below the five-year average. In Morocco, the 2023 cereal output, estimated at 5.6 million tonnes, recovered from the drought-affected 2022 harvest but was still about 30% below the average. In Egypt and Libya, the 2023 cereal harvests were near average.

Rainfall deficits between July and September affected parts of north-eastern and north-western Nigeria, northern Benin, and north-eastern Ghana, resulting in localized shortfalls in agricultural production. In most producing areas, cumulative rainfall amounts between June and September were average to above average, favouring crop establishment and development. In Niger, cereal production was forecast at a below-average level, as dry spells constrained yields mainly in the southern and south-western areas, and a delayed onset of seasonal rains and persisting insecurity resulted in a reduced planted area. Localized shortfalls in agricultural production were expected in the conflict-affected areas of the Liptako-Gourma region (overlapping Mali, Niger and Burkina Faso), the Lake Chad Basin and northern Nigeria, due to constrained access to cropland and agricultural inputs.

Erratic rainfall and insecurity kept cereal production at below-average levels in northern parts of the Greater Horn of Africa, including Sudan, South Sudan, the Karamoja region in Uganda, Eritrea, Ethiopia, and central and western Kenya. In Sudan, seasonal rains were below average and temporally erratic, with prolonged dry spells. The production of sorghum and millet was forecast to decrease by about 25% and 50%, respectively, compared to 2022. In South Sudan, seasonal rainfall was near average over the western half of the country, and below average over the eastern half. The rainfall deficits were more severe in the south-eastern areas, causing shortfalls in crop production, which affected the first season harvest. In Ethiopia, the overall production prospects for the main *meher* crops were favourable, as above-average rainfall amounts boosted yields in the key western growing areas of the Amhara and Benishangul Gumuz regions. However, insecurity due to conflict in some areas of the Amhara and Oromia regions, along with insufficient rains in some central and southern areas of the Oromia and former Southern Nations, Nationalities and People's (SNNP) regions, likely resulted in localized shortfalls in cereal production. In key unimodal rainfall growing areas of the Central, Rift Valley and Western provinces of Kenya, long-rains crops benefited from average to above-average rainfall amounts. However, the aggregate long-rains maize production was estimated at 5% to 10% below the five-year average, as erratic rainfall in bimodal rainfall agropastoral and marginal agriculture areas resulted in reduced harvests in these locations. In Ethiopia, the *Deyr* and *Hageya* rains concluded with some of the highest cumulative totals in the 40-year historical record, leading to extensive flooding in the Somali, Oromia, and southern Ethiopia regions and resulting in the loss of main season crops among agropastoral communities, mainly in riverine areas along the Shebelle and Omo rivers. Nearly 27 000 livestock died and over 72 000 hectares of planted crops were destroyed.[13] In Somalia, normal rainfall was received in the northern part and above-normal rainfall was received in the southern and central parts of the country during the *Deyr* season. Flooding events led to the loss of livestock and cropland.[14] In Kenya, the rains were well above the 40-year average across most of the country. Enhanced pasture, forage, and water resources supported livestock production. Increased agricultural production and labour opportunities were also reported. However, in northern and north-eastern Kenya, flooding affected around 640 600 hectares of land, of which around 18 300 hectares were cropland.[15]

Favourable weather conditions in Southern Africa resulted in good cereal yields, though periods of rainfall deficits and tropical cyclones (for example, Tropical Cyclone *Freddy*) resulted in localized shortfalls in several areas. The total cereal production in 2023 was estimated at 41.2 million tonnes, about 12% above the previous five-year average.[16] Bumper harvests were recorded in South Africa and Zimbabwe. In Malawi and Mozambique, cyclones and rainfall deficits caused extensive crop damage. Dry weather conditions late in the season in Angola and Namibia kept production levels unchanged year-on-year, but cereal harvests were nevertheless above the five-year average. El Niño conditions underpinned unfavourable 2023/2024 cereal production in Southern Africa. The onset of the October to December rains was delayed by three to four weeks in central parts of the region, resulting in delayed planting and potential shortening of the crop-growing window. Rainfall was below average in the southern half of the region, affecting early season crop development. The period from November through early December was particularly dry, resulting in the permanent wilting of some crops that were planted in October.[17] In addition, despite the recent easing of international fertilizer prices, access of farmers to agricultural inputs was being constrained by weak national currencies in multiple countries, which kept domestic prices elevated.[18]

Climate policy and strategic perspectives

INVESTMENT NEEDED FOR ADAPTATION AND RESILIENCE-BUILDING IN AFRICA

The increasing frequency and severity of weather and climate extremes disproportionately affect African economies and societies, leading to natural disasters and disrupting economic, ecological and social systems. Climate-related hazards, including droughts, floods, cyclones and heatwaves, exacerbate food insecurity, water scarcity, and displacement, and cause African countries to lose, on average, 2% to 5% of their gross domestic product (GDP) annually, with many countries diverting up to 9% of their budgets into unplanned expenditures to respond to extreme weather events. By 2030, it is estimated that up to 118 million extremely poor people (those living on less than US$ 1.90/day) will be exposed to drought, floods and extreme heat in Africa if adequate response measures are not put in place. This will place additional burdens on poverty alleviation efforts and significantly hamper growth. Figure 14 shows the types of hazards of greatest concern in Africa based on an analysis of the nationally determined contributions (NDCs) of 53 African countries.

Climate-resilient development in Africa requires investments in hydrometeorological infrastructure and early warning systems to prepare for escalating high-impact hazardous events. In sub-Saharan Africa alone, it is estimated that climate adaptation will cost US$ 30 billion to US$ 50 billion (2%–3% of the regional GDP) per year over the next decade.

Investments in National Meteorological and Hydrological Services (NMHSs) in Africa are needed to enhance data collection and improve forecasting capabilities in order to strengthen the ability of these institutions to issue early warnings and advisories for extreme events. There is a particular need to invest in cutting-edge technologies and systems to enhance the accuracy and lead time of weather, climate, and hydrological forecasts.

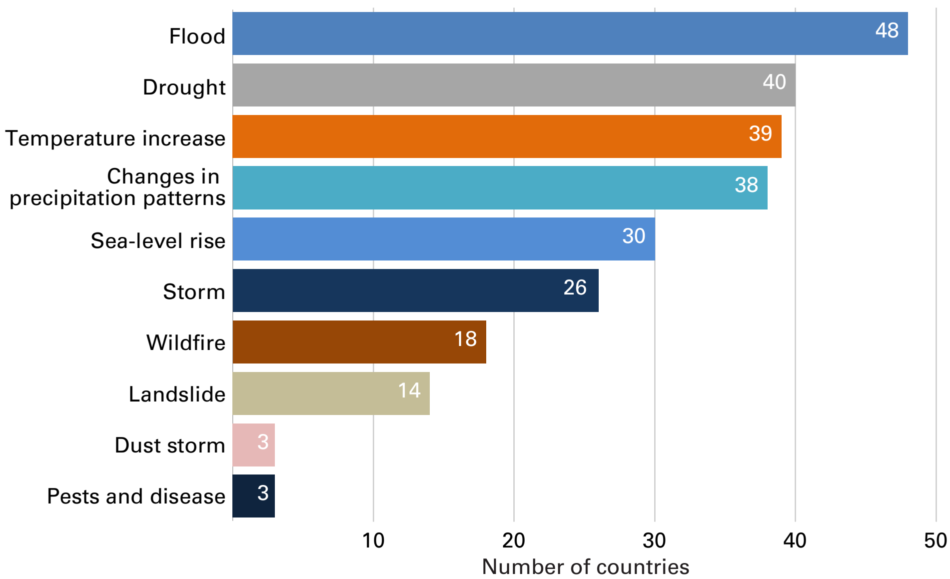


Figure 14. Hazards of greatest concern for the African region. This graph was generated by WMO using the NDCs of 53 countries in Africa based on the active NDCs submitted as of June 2024.

These investments in NMHSs and early warning systems in Africa can be targeted to enhance and modernize observational networks with advanced weather monitoring instruments, to upgrade forecasting and modelling capabilities to improve the accuracy and timeliness of predictions, to establish robust communication channels to disseminate warnings to vulnerable communities, to integrate advanced technology, such as remote sensing and satellite imagery, for accurate predictions and risk assessment, to enhance training and capacity-building for meteorologists and hydrologists, and to foster collaboration and partnerships for knowledge exchange and resource sharing among African countries and international organizations. These investments are crucial for building resilience against weather-related disasters, safeguarding lives and livelihoods, and promoting sustainable development across the continent.

CLIMATE SERVICES CAPACITIES

Climate services refer to the provision and use of climate data, information, and knowledge with the aim of helping people make better informed decisions. The effectiveness of these services depends on good communication between the service provider and the recipient, as well as a reliable access system that enables quick and effective action. Based on data collected from 52 WMO Members in the region, 58% of Members in Africa (31 in total) currently provide climate services at either “essential” or “full” capacity, as shown in Figure 15.

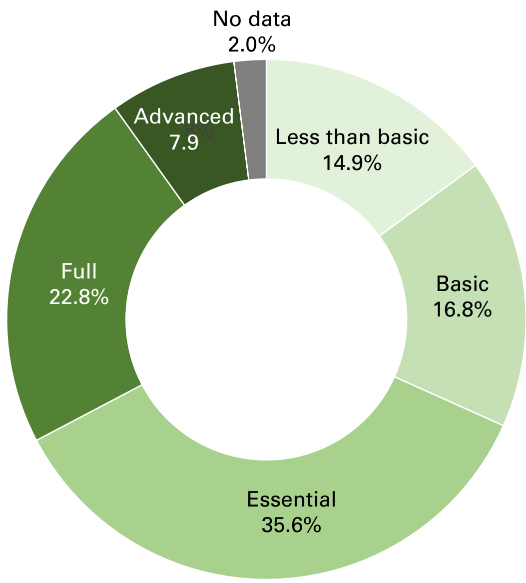


Figure 15. Overview of generalized (not sector-specific) climate services capacities based on the data collected from 52 WMO Members in Africa

Source: WMO Checklist for Climate Services Implementation, as of June 2024

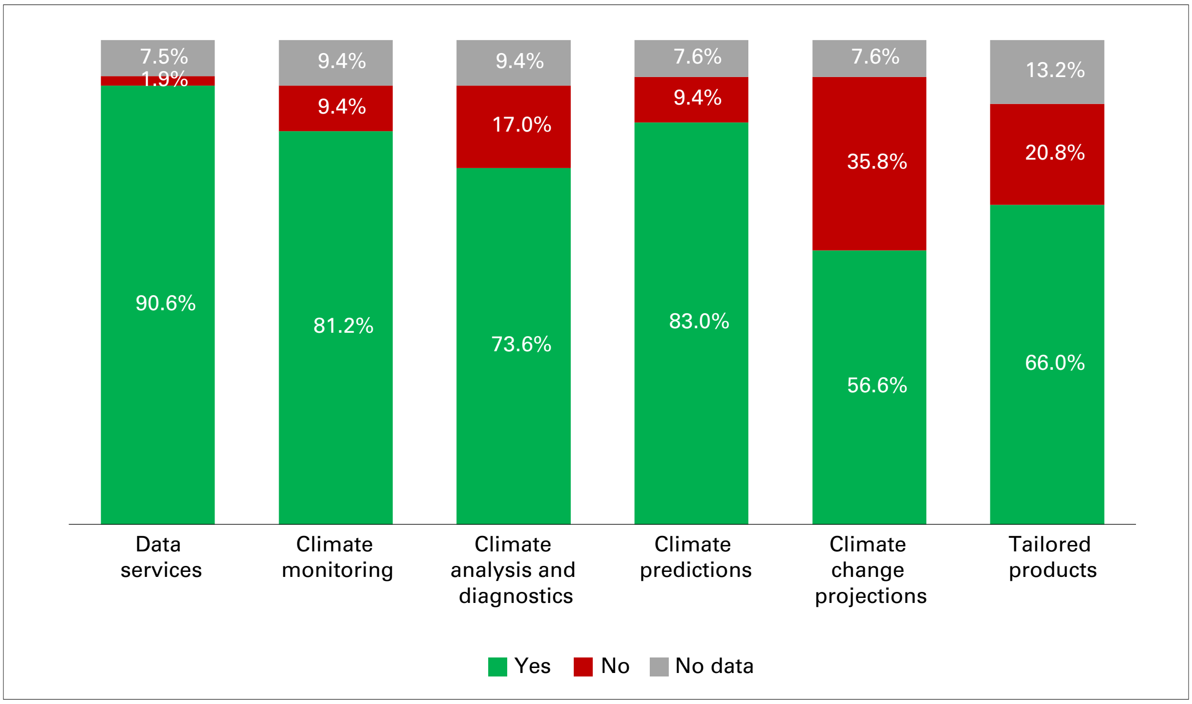


Figure 16. Climate services provided by NMHSs in Africa to the agriculture and food security sector. The percentages are based on the information provided by 53 African Members.

Source: WMO Checklist for Climate Services Implementation, as of June 2024

Figure 16 shows that 91% of WMO Members in Africa provide climate data services to the agriculture and food security sector. However, 66% provide tailored products and 57% provide climate change projections for this sector. The NMHSs self-reported their level of service provision on a scale of 1 to 6, where 1 represents initial engagement and 6 represents full engagement. The average score for the region was 3.3 out of 6, indicating that most of the engagement is in the initial stages. This suggests that the focus is primarily on identifying needs (1 to 3 on the scale) rather than on providing tailored products and services (4 to 6 on the scale).[19]

STRATEGIC PERSPECTIVES

NMHSs are responsible for providing early warning services to reduce disaster risks and for supporting national development and life-supporting activities that are sensitive to weather, climate and water. They conduct systematic observations and data gathering, which form the foundation for monitoring and predicting weather, climate, water and related environmental conditions, including issuing warnings, alerts and advisories. Delivering weather, climate, water information effectively and efficiently, collaborating with the media to ensure that forecasts and warnings reach last-mile communities, and fostering international cooperation through the exchange of meteorological data and products are fundamental for NMHSs to maintain their relevance and visibility.

African countries and their respective policymakers should adopt holistic and integrated approaches to navigate the complexities of climate change negotiations, building resilience and a sustainable future for the next generations. In this regard, they should:

i) **Systematically invest in the climate information system and early warning system components.** Effective weather and climate services are critical to better manage risks due to climate variability and longer-term changes in climate-sensitive sectors. The overall cost-to-benefit ratio of these investments is one to 10.[20] However, the benefits of systematically investing in strengthening the operational regional-national hydrometeorological system needed for climate services outweigh the costs by about 80 to one.[21]

ii) **Explore innovative financing mechanisms.** Africa should explore innovative financing mechanisms, including private sector investments, debt-for-nature swaps, and debt-for-climate swaps to secure predictable climate financing for climate action, sustainability, and job creation.

iii) **Capitalize on the continent's right to just energy transition.** According to the United Nations Economic Commission for Africa, Africa needs investment of at least US$ 2 trillion by 2050 in the power sector alone to drive green growth on the continent.[22]

iv) **Embrace initiatives aimed at building Africa's climate resilience.** Policymakers should continue supporting regional initiatives, such as the recently launched African Development Bank Climate Action Window, which aims to mobilize up to US$ 14 billion to support adaptation in 37 low-income countries, the Early Warnings for All (EW4ALL) initiative launched by the United Nations Secretary-General, the Climate for Development in Africa (ClimDev-Africa) Programme, the Africa Climate Resilient Investment Facility (AFRI-RES), the Accelerating Impacts of CGIAR Climate Research for Africa (AICCRA) project, the Intra-African, Caribbean and Pacific (ACP) Climate Services and related Applications Programme (ClimSA), and others.

v) **Ensure that adaptation remains the priority.** Although Africa should continue to call for scaling up climate finance to make up for the shortfall caused by the failure to deliver US$ 100 billion per year by 2020 and through 2025, its group of negotiators should, in addition to soliciting the doubling of adaptation finance, also solicit the finalization of the New Quantified Goal on Climate Finance.

vi) **Actively engage in the global stocktake.** The global stocktake (GST), as enshrined in Article 14 of the Paris Agreement, takes place every five years to review collective efforts and results in all areas of the Paris Agreement. In October 2023, at the Twenty-eighth Conference of the Parties to the United Nations Framework Convention on Climate Change (UNFCCC) (COP28), in Dubai, the Parties adopted a decision on the GST that recognizes the need for enhanced resiliency and deep, rapid, and sustained reductions in greenhouse gas emissions in line with 1.5 °C pathways. NMHSs should ensure that climate data and information are included in the next generation of NDCs and have the goal of enhancing resiliency and adaptive capacity in line with rising temperatures.

vii) **Promote partnership and collaboration.** Promoting community participation, indigenous knowledge systems, and gender-responsive approaches can foster social cohesion, empower marginalized groups, and enhance adaptive capacities at the grassroots level. Regional cooperation, knowledge-sharing, and South-South partnerships should also be promoted to facilitate the exchange of best practices, resources, and expertise to address common climate challenges collaboratively. In this regard, establishing and operationalizing the continental and national-level working groups on loss and damage (L&D) is critical to enabling access to the newly established L&D Fund.

INVESTMENTS IN CLIMATE RESEARCH AND INNOVATION TO DRIVE AFRICA'S GREEN TRANSITION AGENDA

One of the goals of Agenda 2063 of the African Union (AU) is the creation of environmentally sustainable and climate-resilient economies and communities. Research and innovation are identified as key drivers to achieve sustained growth, competitiveness, and economic transformation throughout the continent. The inaugural 2023 Africa Climate Summit convened experts, policymakers, and practitioners in Nairobi to discuss overarching climate issues and strategies, emphasizing the role of science, technology, and industry in socioeconomic development. Through the Nairobi Declaration,[23] African Heads of State and Government committed to, inter alia, building effective partnerships to meet the needs for financial, technical, and technological support and knowledge-sharing for climate change adaptation. They also committed to strengthening early warning systems and climate services to protect lives, livelihoods, and assets.

The Nairobi Declaration reinvigorates previous initiatives and commitments, such as the African Union Climate Change and Resilient Development Strategy and Action Plan (2022–2032),[24] which outlines specific interventions and actions to address climate change impacts on the continent. The strategy emphasizes the need to enhance capacity in the generation, uptake, and effective use of climate services through, inter alia, training courses, experiential learning, and inter-institutional partnerships. Accordingly, targeted investment is required to sustain the gains made in, and hasten the march towards, socializing climate science and translating research into scaled-up climate action. This calls for more research to develop climate actions, including approaches to effective climate change financing and technology transfer to support local communities in adapting to the ever-changing impacts of climate change in order to ultimately achieve the desired outcomes.

Datasets and methods

All datasets and their use are subject to licence or permission even if from an open source. Please consult the data download pages for appropriate support

TEMPERATURE DATA

GRIDDED DATA

Six datasets (cited below) were used in the calculation of regional temperature.

Regional mean temperature anomalies were calculated relative to 1961–1990 and 1991–2020 baselines using the following steps:

1. Read the gridded dataset;

2. Regrid the data to 1° latitude × 1° longitude resolution. If the gridded data are higher resolution, take a mean of the grid boxes within each 1° ×1° grid box. If the gridded data are lower resolution, copy the low-resolution grid box value into each 1° ×1° grid box that falls inside the low-resolution grid box;

3. For each month, calculate the regional area average using only those 1° ×1° grid boxes whose centres fall within the region;

4. For each year, take the mean of the monthly area averages to obtain an annual area average;

5. Calculate the mean of the annual area averages over the periods 1961–1990 and 1991–2020;

6. Subtract the 30-year period average from each year.

Note that the range and mean of anomalies relative to the two different baselines are based on different sets of data.

The following six datasets were used:

Berkeley Earth: Rohde, R. A.; Hausfather, Z. The Berkeley Earth Land/Ocean Temperature Record. *Earth System Science Data* **2020**, *12*, 3469–3479. https://doi.org/10.5194/essd-12-3469-2020. The data are available here.

ERA5: Hersbach, H.; Bell, B.; Berrisford, P. et al. The ERA5 Global Reanalysis. *Quarterly Journal of the Royal Meteorological Society* **2020**, *146* (730), 1999–2049. https://doi.org/10.1002/qj.3803.

ERA5: Hersbach, H.; Bell, B.; Berrisford, P. et al. *Complete ERA5 from 1940: Fifth generation of ECMWF atmospheric reanalyses of the global climate*. Copernicus Climate Change Service (C3S) Data Store (CDS), 2017. https://doi.org/10.24381/cds.143582cf.

ERA5.1: Simmons, A.; Soci, C.; Nicolas, J. et al. *ERA5.1: Rerun of the Fifth generation of ECMWF atmospheric reanalyses of the global climate (2000-2006 only)*. Copernicus Climate Change Service (C3S) Data Store (CDS), 2020. https://doi.org/10.24381/cds.143582cf.

ERA5.1: Bell, B., Hersbach, H., Simmons, A. et al. The ERA5 Global Reanalysis: Preliminary Extension to 1950. *Quarterly Journal of the Royal Meteorological Society* **2021**, *147* (741), 4186–4227. https://doi.org/10.1002/qj.4174.

GISTEMP v4: Lenssen, N.; Schmidt, G.; Hansen, J. et al. Improvements in the GISTEMP Uncertainty Model. *Journal of Geophysical Research: Atmospheres* **2019**, *124* (12), 6307–6326. https://doi.org/10.1029/2018JD029522.

GISTEMP v4: GISTEMP Team, 2022: *GISS Surface Temperature Analysis (GISTEMP), version 4*. NASA Goddard Institute for Space Studies, https://data.giss.nasa.gov/gistemp/.
Lenssen, N.; Schmidt, G.; Hansen, J. et al. Improvements in the GISTEMP Uncertainty Model. *Journal of Geophysical Research: Atmospheres* **2019**, *124*, 6307–6326. https://doi.org/10.1029/2018JD029522. The data are available here.

HadCRUT.5.0.2.0: Morice, C. P.; Kennedy, J. J.; Rayner, N. A. et al. An Updated Assessment of Near-Surface Temperature Change From 1850: The HadCRUT5 Data Set. *Journal of Geophysical Research: Atmospheres* **2021**, *126*, e2019JD032361. https://doi.org/10.1029/2019JD032361.

HadCRUT.5.0.1.0 data were obtained from http://www.metoffice.gov.uk/hadobs/hadcrut5 on 19 March 2024 and are © British Crown Copyright, Met Office 2023, provided under an Open Government Licence, http://www.nationalarchives.gov.uk/doc/open-government-licence/version/3/.

JRA-55: Kobayashi, S.; Ota, Y.; Harada, Y. et al. The JRA-55 Reanalysis: General Specifications and Basic Characteristics. *Journal of the Meteorological Society of Japan*. Ser. II **2015**, *93*, 5–48. https://doi.org/10.2151/jmsj.2015-001. The data are available here.

NOAAGLOBALTEMP: Huang, B.; Menne, M. J.; Boyer, T. et al. Uncertainty Estimates for Sea Surface Temperature and Land Surface Air Temperature in NOAAGlobalTemp Version 5. *Journal of Climate* **2020**, *33* (4), 1351–1379. https://doi.org/10.1175/JCLI-D-19-0395.1.

NOAAGLOBALTEMP: Zhang, H.-M.; Lawrimore, J. H.; Huang, B. et al. Updated Temperature Data Give a Sharper View of Climate Trends. *Eos*, 19 July 2019. https://doi.org/10.1029/2019EO128229.

IN SITU DATA

Temperature in situ data are provided by National Meteorological and Hydrological Services.

PRECIPITATION DATA

GRIDDED DATA

Schneider, U.; Becker, A.; Finger, P. et al. GPCC Monitoring Product: Near Real-time Monthly Land-Surface Precipitation from Rain-gauges based on SYNOP and CLIMAT data; Global Precipitation Climatology Centre (GPCC), 2020. http://dx.doi.org/10.5676/DWD_GPCC/MP_M_V2020_100.

Schneider, U.; Becker, A.; Finger, P. et al. GPCC Full Data Monthly Product Version 2020 at 1.0°: Monthly Land-surface Precipitation from Rain-gauges built on GTS-based and Historical Data, 2020. http://dx.doi.org/10.5676/DWD_GPCC/FD_M_V2020_100.

IN SITU DATA

Temperature in situ data are provided by National Meteorological and Hydrological Services.

SEA-SURFACE TEMPERATURE DATA

Reynolds, R. W.; Rayner, N. A.; Smith, T. M. et al. An Improved in Situ and Satellite SST Analysis for Climate. *Journal of Climate* **2002**, *15* (13), 1609–1625. https://doi.org/10.1175/1520-0442(2002)015<1609:AIISAS>2.0.CO;2.

Data: NOAA NCEP EMC CMB GLOBAL Reyn_SmithOIv2 monthly sst (columbia.edu)

SEA LEVEL DATA

Guérou, A., Meyssignac, B., Prandi, P. et al. Current Observed Global Mean Sea Level Rise and Acceleration Estimated from Satellite Altimetry and the Associated Uncertainty, *EGUsphere* **2022** [preprint]. https://doi.org/10.5194/egusphere-2022-330.

EM-DAT DATA

EM-DAT data (www.emdat.be) were used for historical climate impact calculations. EM-DAT is a global database on natural and technological disasters, containing essential core data on the occurrence and effects of more than 21 000 disasters in the world from 1900 to the present. EM-DAT is maintained by the Centre for Research on the Epidemiology of Disasters (CRED) at the School of Public Health of the Université catholique de Louvain, located in Brussels, Belgium.

The indicators used for mortality, number of people affected and economic damage were total deaths, number affected and total damages (in thousands of US dollars), respectively.

CLIMATE SERVICES

WMO analysis of nationally determined contributions

Checklist for Climate Services Implementation (Members' climate services capacities, based on responses to this Checklist, can be viewed here)

WMO Climate Services Dashboard

List of contributors

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Endnotes

[1] Data are from the following datasets: Berkeley Earth, ERA5, GISTEMP v4, HadCRUT.5.0.1.0, JRA-55, NOAAGlobalTemp v5. For details regarding these datasets, see the Datasets and methods section in the *State of the Global Climate 2023* (WMO-No. 1347).

[2] World Meteorological Organization (WMO). *State of the Global Climate 2023* (WMO-No. 1347). Geneva, 2024.

[3] http://www.esrl.noaa.gov/gmd/ccgg/trends/mlo.html

[4] https://www.csiro.au/greenhouse-gases/

[5] Friedlingstein, P.; O'Sullivan, M.; Jones, M. W. et al. Global Carbon Budget 2022. *Earth System Science Data* **2022**, *14* (11), 4811–4900. https://doi.org/10.5194/essd-14-4811-2022.

[6] Intergovernmental Panel on Climate Change (IPCC). *IPCC Special Report on the Ocean and Cryosphere in a Changing Climate*; Pörtner, H.-O.; Roberts, D. C.; Masson-Delmotte, V. et al., Eds.; Cambridge University Press: Cambridge, UK and New York, USA, 2019. https://www.ipcc.ch/srocc/.

[7] Intergovernmental Panel on Climate Change (IPCC). *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*; Masson-Delmotte, V.; Zhai, P.; Pirani, A. et al., Eds.; Cambridge University Press: Cambridge, UK and New York, USA, 2021. https://www.ipcc.ch/report/ar6/wg1/.

[8] https://reliefweb.int/report/libya/libya-flood-response-humanitarian-update-15-december-2023-enar

[9] EM-DAT (https://www.emdat.be/)

[10] EM-DAT (https://www.emdat.be/) quotes 2 970 for the Democratic Republic of the Congo, but this appears to include 2 500 initially reported missing.

[11] EM-DAT (https://www.emdat.be/)

[12] A heatwave is defined as a period of three consecutive days during which the 90th percentile of the maximum temperature threshold is exceeded. This is measured using an index called Excess Heat Index Significance (EHIsig = [(Ti + Ti−1 + Ti−2)/3] – T90, where Ti is the 2 m daily maximum temperature for day i, and T90 is the climatological 90th percentile of the maximum temperature for each calendar day of the year based on a moving window of 15 days, computed for the 1991–2020 climatological period).

[13] https://reliefweb.int/report/ethiopia/east-africa-food-security-outlook-december-2023

[14] https://fews.net/east-africa/somalia/seasonal-monitor/december-2023

[15] https://fews.net/east-africa/kenya/food-security-outlook-update/december-2023

[16] https://openknowledge.fao.org/server/api/core/bitstreams/40d4a160-c5be-47e8-a6de-3f8edb1081f1/content

[17] https://fews.net/sites/default/files/2023-12/SADC%20Agromet%20Update%20Issue-02-2023-2024_Season_Final_2212023.pdf

[18] https://openknowledge.fao.org/server/api/core/bitstreams/40d4a160-c5be-47e8-a6de-3f8edb1081f1/content

[19] The NMHSs ranked their level of service provision using the following scale: 1 = Initial engagement with the sector; 2 = Definition of needs; 3 = Co-design of products; 4 = Tailored products accessible for use; 5 = Climate services guide policy decisions and investment plans in sectors; 6 = Documentation of socioeconomic benefits.

[20] https://wmo.int/news/media-centre/benefits-of-investments-climate-services-agriculture-and-food-security-outweigh-costs

[21] https://wmo.int/news/media-centre/benefits-of-investments-climate-services-agriculture-and-food-security-outweigh-costs

[22] https://www.uneca.org/stories/africa%E2%80%99s-top-six-priorities-at-cop28#:~:text=Findings%20by%20the%20UN%20Economic,in%20the%20power%20sector%20alone.

[23] https://bit.ly/3unqrYN

[24] https://bit.ly/42uC50A

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