

State of the Climate in Africa

2021



WEATHER CLIMATE WATER



WORLD
METEOROLOGICAL
ORGANIZATION

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Foreword



The *State of the Climate in Africa* report has become a flagship report for the continent, providing authoritative scientific information on climate trends, observed high-impact weather and climate events, and their associated impacts in key sensitive sectors. It also highlights information on climate policies and mitigation and adaptation strategies implemented in Africa to cope with climate-related impacts. The 2021 report is the third in the series and places a special emphasis on water resources, a pivotal sector for human and ecosystem health and sustainable socioeconomic development of Africa.

Africa's climate has warmed more than the global average since pre-industrial times (1850–1900). In parallel, the sea-level rise along African coastlines has also been faster than the

global mean, contributing to increases in the frequency and severity of coastal flooding, erosion, and salinity in low-lying cities. Continental water bodies are steadily drying up, especially Lake Chad, leading to significant adverse impacts on the agricultural sector, ecosystems, biodiversity and the socioeconomic development of the surrounding nations. 2021 was either the third or the fourth warmest year on record for Africa depending on the data set used.

In 2021, Africa was hit by a number of high-impact events. Lingering droughts, extensive floods and tropical cyclones, compounded by protracted conflicts, economic slowdowns and downturns, as well as the impact of the COVID-19 pandemic, jeopardized food security, drove population displacement, and led to devastating losses and damages impairing socioeconomic development. It is imperative for the continent to accelerate efforts to establish robust regional and national early warning systems and climate services for climate-sensitive sectors in order to strengthen climate resilience and adaptation capacities.

In June 2022, at its seventy-fifth session, the WMO Executive Council approved a strategy and measures for enhancing the visibility, effectiveness and implementation of the Global Framework for Climate Services (GFCS). The strategy and measures are designed to address adaptation priorities in African countries' Nationally Determined Contributions (NDCs) to the Paris Agreement, including agriculture and food security, disaster risk reduction, water resource management, health and energy. Through a partnership with the Green Climate Fund, WMO will support African countries to increase their access to climate finance by ensuring that adaptation investments incorporate climate science information and measures to strengthen hydrometeorological systems and services.

The information in this report is taken from observing systems coordinated by WMO and its partner organizations. The WMO Integrated Global Observing System (WIGOS) provides basic weather and climate information and the Global Climate Observing System (GCOS) defines a broader set of Essential Climate Variables (ECVs) that are needed to monitor the global climate and support climate mitigation and adaptation efforts. While the evidence for climate change in Africa is unequivocal, the most recent Intergovernmental Panel on Climate Change (IPCC) reports show that there remain significant gaps in the observation of some variables over the continent, particularly precipitation, but also the basic variables defined in the WMO Global Basic Observing Network (GBON). GBON and the Systematic Observations Financing Facility that supports it will provide critically needed observations for numerical weather prediction and will help substantially strengthen climate monitoring and early warning systems.

Approximately 60% of the African population is not covered by early warning systems to cope with extreme weather and climate change. Recognizing the value of early warnings and early action, the Secretary-General of the United Nations has tasked WMO with leading the effort to achieve the ambitious goal of having sufficient early warning services in place to cover the global population within the next five years. WMO will spearhead this effort in close collaboration with key partners by seeking to close observation gaps and by helping to build and strengthen Members' capacities to issue early warnings and to act on those warnings.

I take this opportunity to congratulate the experts from the region and worldwide for leading the scientific coordination and authorship of this report and thank WMO Members and our sister United Nations agencies for their continuous commitment to supporting this publication by providing input and by contributing to the report review process.

A handwritten signature in blue ink, consisting of a long, sweeping horizontal stroke with a small loop at the end, and a shorter, curved stroke below it.

Prof. Petteri Taalas
Secretary-General, WMO

Preface



State of the Climate in Africa reports are annual snapshots of science-based information for climate policy and decision-making in Africa. The African Union uses these reports in its leadership role to support member states in the implementation of weather- and climate-related strategic frameworks in Africa. The reports also provide relevant information to inform Parties to the United Nations Framework Convention on Climate Change (UNFCCC) of the climate situation, climate impacts, and gaps and needs for improving climate services in the region.

Temperature increases, heatwaves, extensive floods, tropical cyclones, prolonged droughts, and rising sea levels resulting in the loss of lives, property damage, and population

displacement undermine Africa's ability to achieve its commitments to meet the targets of the United Nations Sustainable Development Goals (SDGs) and the African Union's *Agenda 2063: The Africa We Want*, which outlines Africa's path for attaining inclusive and sustainable economic growth and development.

Building and strengthening synergies among all stakeholders is critical for achieving sustainable water resources in Africa. Continental frameworks such as the *Africa Water Vision for 2025: Equitable and Sustainable Use of Water for Socioeconomic Development* are designed to avert and minimize the disastrous consequences of climate variability and change.

Member states are encouraged to consider establishing sustainable frameworks, such as a National Framework for Climate Services (NFCS), to support their Nationally Determined Contributions (NDCs), especially with respect to weather, climate, and water-related hazards. To this effect, the key actions of external and internal resource mobilization, capacity development, and technology transfer must be undertaken as matter of urgency.

This third edition of the *State of the Climate in Africa* report is the result of a collaboration involving the African Union Commission (AUC), WMO, and other specialized agencies of the United Nations. This multi-agency effort provides informed climate analysis, identifies notable hydrometeorological events, impacts and risks, and suggests climate actions to build the resilience of African nations.

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

Key messages



Africa continued to record a warming trend, with an average increase of approximately +0.3 °C/decade between 1991 and 2021; this is faster than the warming of +0.2 °C/decade which occurred between 1961 and 1990. 2021 was either the third or the fourth warmest year on record for Africa depending on the data set used. All six sub-regions of Africa recorded an increase in the temperature trend, with North Africa recording the largest temperature anomaly.



The rate of sea-level rise along the African coastlines is higher than the global mean rate, in particular along the Red Sea and south-west Indian Ocean, where the rate is close to 4 mm/year. Relative sea-level rise is likely to continue in the future, contributing to an increase in the frequency and severity of coastal flooding in low-lying cities and an increase in the salinity of groundwater due to sea-water intrusion. By 2030, 108–116 million people in Africa are expected to be exposed to sea-level rise risk.



Increasing water consumption combined with more frequent droughts and heat events will increase water demand and put additional pressure on already scarce water resources. Disruptions in water availability will impede access to safe water. In addition, limited water availability and water scarcity are expected to trigger conflicts among people who are already contending with economic challenges.



East Africa suffered the effects of cumulative failed rainy seasons combined with heightened conflict endemic in the region, related population displacement, and COVID-19 restrictions. High food prices impeded food availability and access, leaving more than 58 million people in conditions of acute food insecurity.



Tropical Cyclone *Eloise* severely affected the Southern African region, including Mozambique and Madagascar. Mozambique was the hardest hit, as populations in several locations were still recovering from Cyclone *Idai*, which struck the country in 2019. Over 43 000 people were internally displaced.



The total surface area of Lake Chad, which is located close to the Sahara desert and borders Chad, Cameroon, Nigeria, and Niger, shrunk from 25 000 km² in the 1960s to 1 350 km² in the 2000s; it has remained stable from the 2000s to the present.



Increased temperature has contributed to a 34% reduction in agricultural productivity growth in Africa since 1961. This is more than any other region. This trend is expected to continue in the future, increasing the risk of acute food insecurity and malnutrition. A global warming of 1.5 °C is projected to be accompanied by a decline of 9% of the maize yield in West Africa and a decline of 20%–60% of the wheat yield in Southern and North Africa.



Climate-related hazards continued to be a major driver of new displacement in Africa. Hydrometeorological hazards continued to fuel patterns of protracted, prolonged and repeated displacement. While most disaster displacement is internal, displacement across borders also occurs and may be linked to conflict or violence, with climate change acting as a vulnerability multiplier.



In Africa, the rate of implementation of Multi-hazard Early Warning Systems (MHEWSs) is lower than in other regions. There is a need to fill the capacity gap in collecting data for basic hydrometeorological variables which underpin better climate services and early warning systems in order to mitigate deaths as well as loss and damage.



While there was an improvement from 2017–2018, there is still a need to further improve the level of provision of climate services in Africa. Currently, 28 countries provide these services at a basic to essential level, and only nine provide climate services at a full level.

Observational basis for climate monitoring

Climate monitoring is performed by a network of observing systems covering the atmosphere, the ocean, hydrology, the cryosphere and the biosphere. Each of these areas is monitored in different ways by a range of organizations. Cutting across all these areas, satellite observations provide major contributions to global climate monitoring.

In 1992, the Global Climate Observing System (GCOS) was established jointly by WMO, the Intergovernmental Oceanographic Commission (IOC) of the United Nations Educational, Scientific and Cultural Organization (UNESCO), the United Nations Environment Programme (UNEP) and the International Science Council (ISC) to coordinate and facilitate the development and improvement of global climate observations. GCOS has identified a set of Essential Climate Variables (ECVs) that together provide the information necessary to understand, model and predict the trajectory of the climate as well as plan mitigation and adaptation strategies.

ECVs are physical, chemical or biological variables or a group of linked variables that critically contribute to the characterization of the Earth's climate system and include atmospheric, oceanic and terrestrial components. GCOS currently specifies 54 ECVs (see the table below).

ECV data sets provide the empirical evidence needed to understand and predict the evolution of the climate, to guide mitigation and adaptation measures, to assess risks and enable the attribution of climate events to underlying causes, and to underpin climate services. They are required to support the work of UNFCCC and IPCC.

2016 Essential Climate Variables (ECVs)				
Atmospheric	Surface	Oceanic	Physical	Hydrology
	Precipitation, surface pressure, surface radiation budget, surface wind speed and direction, surface temperature, surface water vapour			Groundwater, lakes, river discharge, soil moisture
	Upper air			Cryosphere
	Earth radiation budget, lightning, upper-air temperature, upper air water vapor, upper-air wind speed and direction			Glaciers, ice sheets and ice shelves, permafrost, snow
Terrestrial	Composition	Biogeochemical	Biological/ecosystems	Biosphere
	Aerosol properties, carbon dioxide, methane and other greenhouse gases, cloud properties, ozone, aerosol and ozone precursors			Above-ground biomass, albedo, fire, fraction of absorbed photosynthetically active radiation, land cover, land surface temperature, latent and sensible heat fluxes, leaf area index, soil carbon
				Human use of natural resources
				Anthropogenic greenhouse gas fluxes, anthropogenic water use

Global climate context

The global mean temperature in 2021 was $1.11\text{ }^{\circ}\text{C} \pm 0.13\text{ }^{\circ}\text{C}$ above the 1850–1900 pre-industrial average, less warm than in some recent years owing to La Niña conditions at the start and end of the year. 2021 was between the fifth and seventh warmest year on record globally according to the six data sets used (Figure 1). The past seven years, 2015 to 2021, were the seven warmest years on record. The year 2016, which started during a strong El Niño, remains the warmest year since the mid-nineteenth century according to most data sets.

Atmospheric concentrations of the three major greenhouse gases (GHGs) – carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) – reached new record highs in 2020: respectively 149% (413.2 ± 0.2 parts per million (ppm)), 262% ($1\,889 \pm 2$ parts per billion (ppb)), and 123% (333.2 ± 0.1 ppb) of pre-industrial (before 1750) levels.

Real-time data from specific locations, including Mauna Loa (Hawaii) and Cape Grim (Tasmania), indicate that levels of CO_2 , CH_4 and N_2O continued to increase in 2021. Increasing GHG concentrations lead to an accumulation of heat in the climate system, much of which is stored in the ocean.

Over the past two decades, the ocean warming rate has strongly increased, and the ocean heat content in 2021 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 4.5 mm/yr between 2013 and 2021, reaching a new record high in 2021. The ocean absorbs about 23% of annual anthropogenic emissions of CO_2 into the atmosphere, leading to overall warming.¹ CO_2 reacts with seawater, however, and lowers its pH. This process, known as ocean acidification, affects many organisms and ecosystem services and threatens food security by endangering fisheries and aquaculture.²

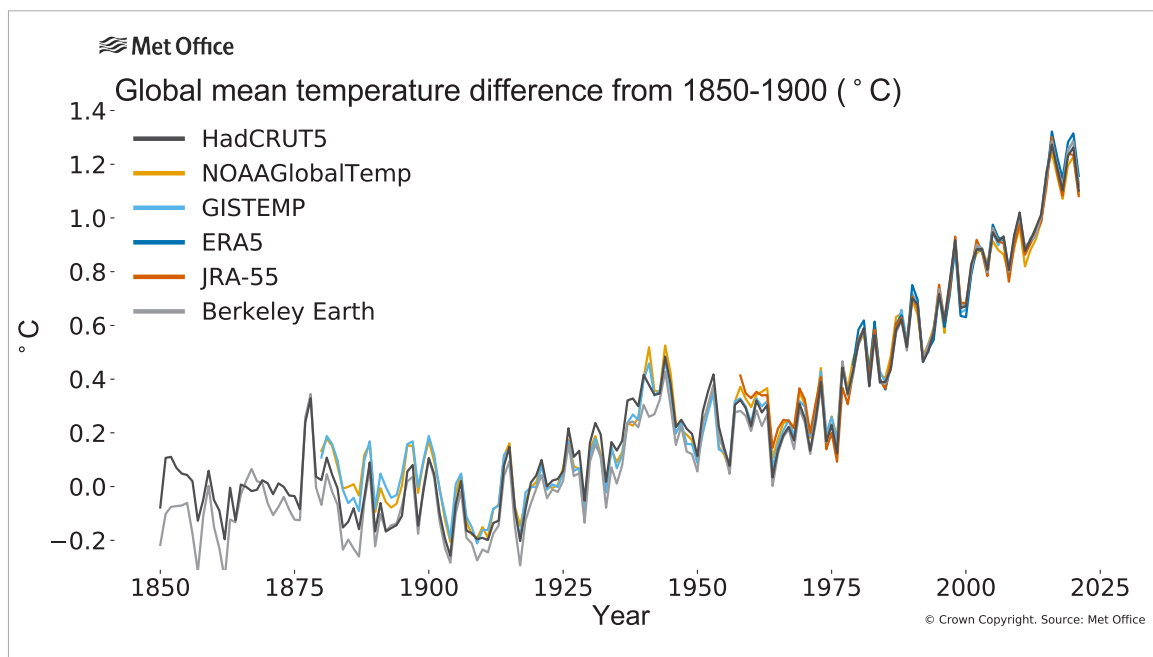


Figure 1. Global (combination of land and ocean) annual mean temperature anomalies in $^{\circ}\text{C}$ from 1850 to 2021 relative to the pre-industrial average (1850–1900) based on six data sets, including observational data sets (HadCRUT5 [black], NOAA GlobalTemp [yellow], GISTEMP [light blue], and Berkeley Earth [grey]) and reanalyses (ERA5 [dark blue] and JRA-55 [orange]). For further explanations and details of the data sets, see [State of the Global Climate 2021](#) (WMO-No. 1290).

Source: Met Office, United Kingdom of Great Britain and Northern Ireland

Regional climate

The following section assesses the past and current climate of Africa by describing temperature and rainfall patterns, the evolution of ice melt on mountain glaciers, the trends of sea-level rise along African coastlines, and the spatiotemporal variations of continental water bodies.

One important climate indicator, temperature, is described in terms of anomalies, or departures from a reference period. For global mean temperature, the reference period used in the Sixth Assessment Report (AR6) of the Intergovernmental Panel on Climate Change (IPCC), 1850–1900, is used for calculating anomalies in relation to pre-industrial levels. This period cannot be used as a baseline for calculating regional anomalies, however, due to insufficient data for calculating region-specific averages prior to 1900.

Regional temperature increase is therefore computed and expressed relative to the 30-year 1961–1990 reference period, which is the fixed reference period recommended by WMO as a consistent and stable reference period for assessing long-term climate change, especially for temperature.

The 1981–2010 climatological standard normal period is also used for computing anomalies in temperature and other indicators with reference to more recent climate average conditions. The use of 1981–2010 for computing temperature anomalies provides a more recent benchmark for operational climate monitoring and applications in various sectors, such as adaptation planning and decision-making. Exceptions to the use of these baseline periods for the calculation of anomalies, where they occur, are explicitly noted.

TEMPERATURE

TEMPERATURE TRENDS IN AFRICA IN COMPARISON WITH OTHER CONTINENTS

Africa continued to observe a warming trend, with an average rate of change of around $+0.3$ °C/decade between 1991 and 2021, compared to $+0.2$ °C/decade between 1961 and 1990, -0.04 °C/decade between 1931 and 1960, and $+0.08$ °C/decade between 1901 and 1930. The warming has been more rapid in Africa than the global average (Figure 2).³ Increasing mean temperature trends across Africa are attributable to human-induced climate change according to IPCC AR6.

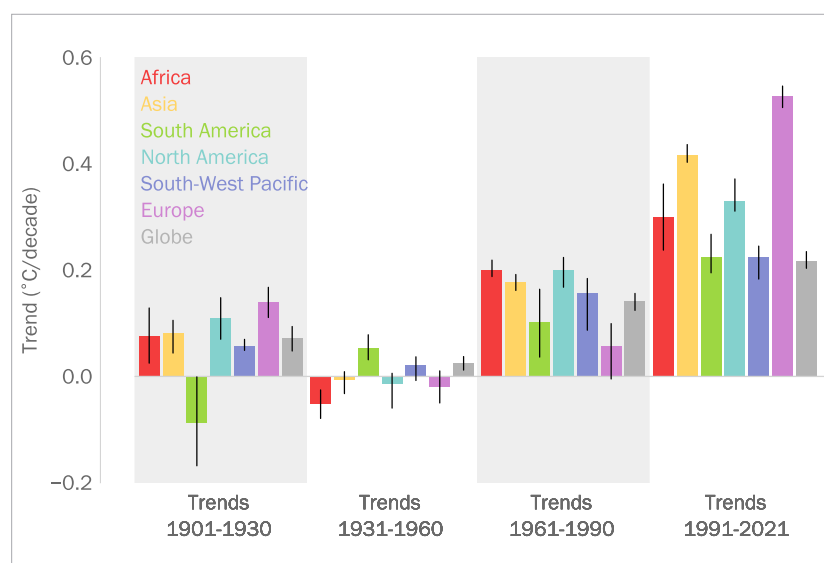


Figure 2. Trends in the area average temperature in °C/decade for Africa (red), Asia (yellow), South America (green), North America (light blue), Oceania (dark blue), Europe (purple), and the global average (grey) over four periods: 1901–1930, 1931–1960, 1961–1990, and 1991–2021. The trends have been calculated using different data sets,⁴ including observational data sets (HadCRUT5, NOAA GlobalTemp, GISTEMP, and Berkeley Earth) and reanalyses (ERA5 and JRA-55). The black vertical line indicates the estimated range.
Source: Met Office, United Kingdom

LONG-TERM TEMPERATURE ANOMALIES IN AFRICA

The African near-surface mean air temperature in 2021 was estimated to be 0.68 °C [0.55 °C -0.88 °C] above the 1981–2010 average. Computed with respect to the WMO reference period for climate change, the African mean surface temperature increased by 1.12 °C [1.03 °C – 1.23 °C] relative to 1961–1990. The spread between data sets was wider in 2021 than in other recent years, reflecting some uncertainty in the data sets. The lowest temperature anomaly estimate was produced by HadCRUT5, and the highest by ERA5 (Figure 3). The largest differences between the data sets occur in Central and East Africa, where there is a lack of sufficient long-term in situ measurements.

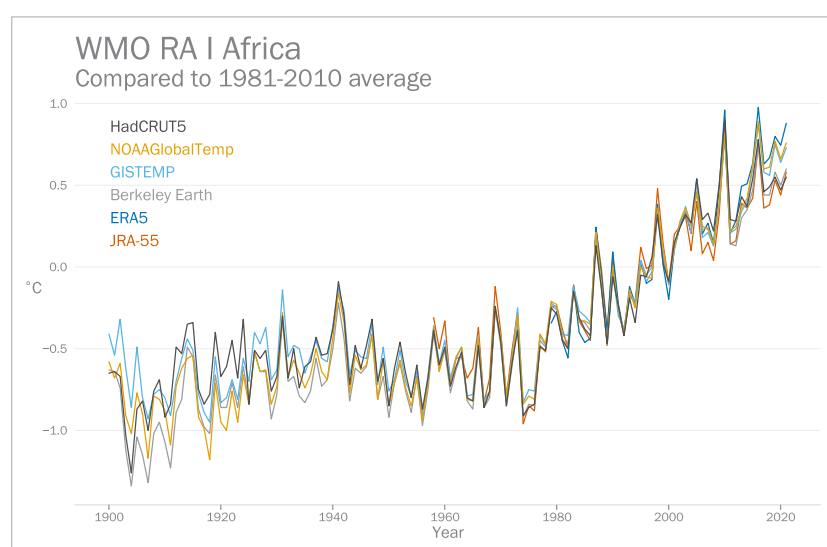


Figure 3. Temperature difference in °C with respect to the 1981–2010 climatological period for Africa (WMO Regional Association I) based on six data sets, including observational data sets (HadCRUT5 [black], NOAA GlobalTemp [yellow], GISTEMP [light blue], and Berkeley Earth [grey]) and reanalyses (ERA5 [dark blue] and JRA-55 [orange]).

Source: Met Office, United Kingdom

The year 2021 tied with 2019, placing it as either the third or the fourth warmest year on record in Africa depending on the data set used.

TEMPERATURE IN THE AFRICAN SUB-REGIONS

In this section, Africa is divided into six sub-regions based on economic and political groupings (Figure 4):

- North Africa – Union du Maghreb Arabe
- West Africa – Economic Community of West African States (ECOWAS)
- Central Africa – Economic Community of Central African States (ECCAS)
- East Africa – Intergovernmental Authority on Development (IGAD)
- Southern Africa – Southern African Development Community (SADC)
- Indian Ocean island countries – Indian Ocean Commission (IOC).

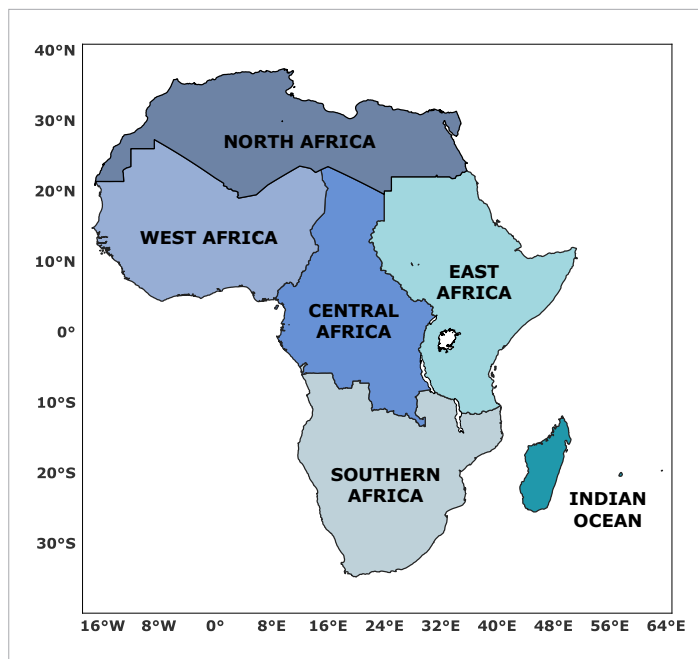


Figure 4. The six African sub-regions based on economic and political groupings: North Africa, West Africa, Central Africa, East Africa, Southern Africa, and Indian Ocean island countries.

Source: WMO

Temperature trends

All six African sub-regions experienced an increase in the temperature trend from the period 1901–1930 to the period 1991–2021. Notably, the warming trend for North Africa, around 0.41 °C/decade between 1991 and 2021, was higher than the warming trend for all the other African sub-regions (Figure 5) and was more than twice the warming trend for North Africa for the decades between 1961 and 1990 (around 0.19 °C/decade) and almost twice the global rate (around 0.22 °C/decade) for the same period.

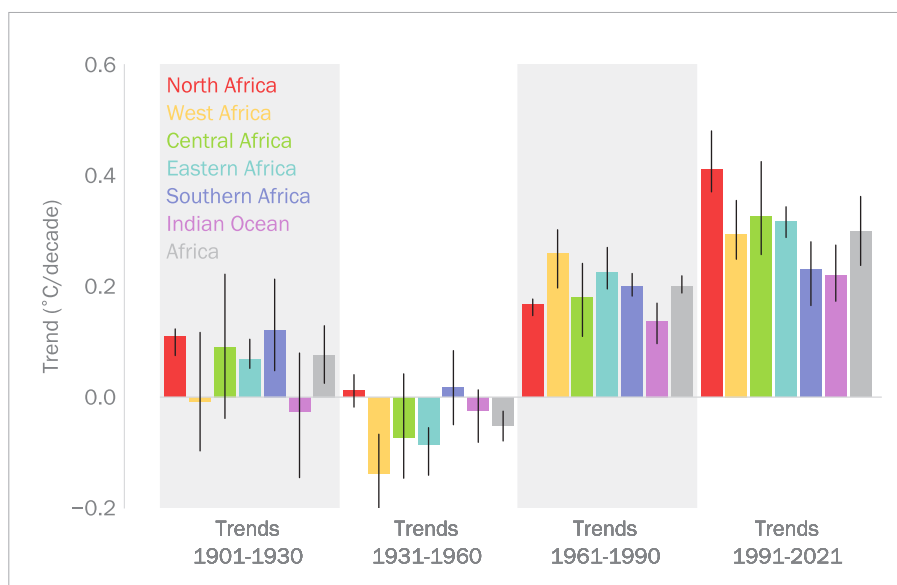


Figure 5. Trends in the area average temperature in °C/decade for the six African sub-regions: North Africa (red), West Africa (yellow), Central Africa (green), East Africa (light blue), Southern Africa (dark blue), and Indian Ocean island countries (purple), and the whole of Africa (grey) over four 30-year sub-periods: 1901–1930, 1931–1960, 1961–1990, and 1991–2021. The trends were calculated using different data sets,⁵ including observational data sets (HadCRUT5, NOAA GlobalTemp, GISTEMP, and Berkeley Earth) and reanalyses (ERA5 and JRA-55). The black vertical line indicates the range of the six estimates.⁶

Source: Met Office, United Kingdom

Temperature anomalies

In 2021, most of Africa recorded temperatures above the 1981–2010 average. The exception was Southern Africa, which experienced slightly below-average temperatures (Figure 6 left). The highest temperature anomalies were recorded across North Africa, followed by West Africa.

Large uncertainties in temperature anomalies exceeding 0.7 °C were present over the area encompassing South Sudan, eastern Central African Republic (CAR), and northern and central Democratic Republic of the Congo (DRC). Portions of south-western Algeria also observed uncertainties of around 0.4 °C – 0.5 °C (Figure 6 right). ERA5 provided higher temperature values than other data sets across Central to north-east Africa and into the Middle East. Cold temperature anomalies in HadCRUT5 were more localized in the Central and East Africa regions.

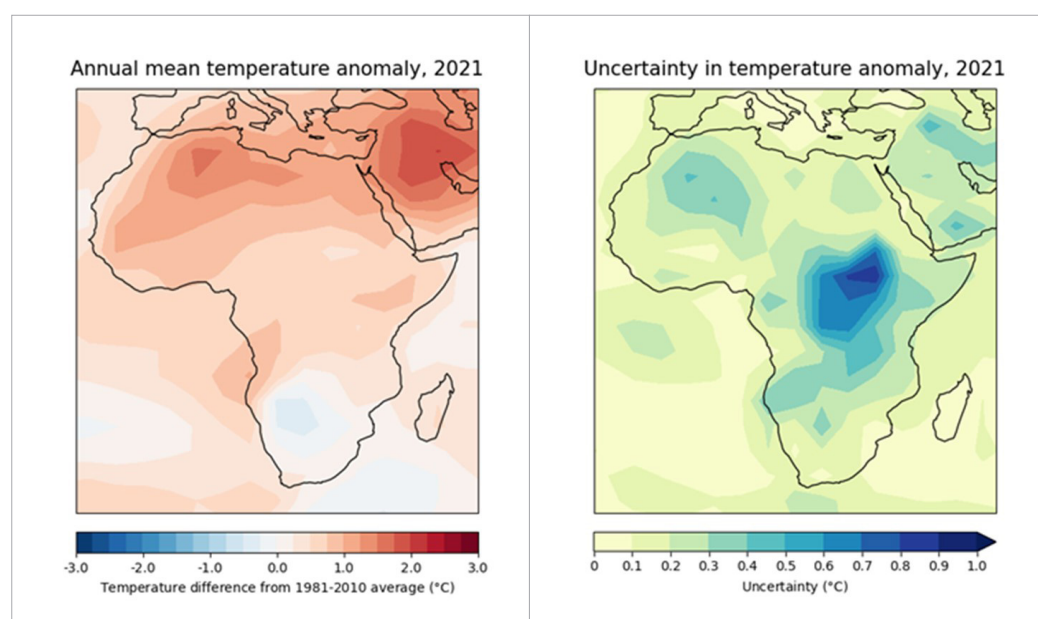


Figure 6. Near-surface air temperature anomaly for 2021 relative to the 1981–2010 average (left) and estimated uncertainty in temperature anomaly for 2021 (right). The anomaly is calculated as the median of five data sets, including observational data sets (HadCRUT5, NOAA GlobalTemp, GISTEMP, and Berkeley Earth) and one reanalysis (ERA5). Each data set 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.
Source: Met Office, United Kingdom

2021 temperatures across North Africa were 1.22 °C above the 1981–2010 average and 1.76 °C above the 1961–1990 average. For West Africa, temperatures were 0.91 °C above the 1981–2010 average and 1.39 °C above the 1961–1990 average (Table 1). In both regions, 2021 was among the three warmest years on record.

Table 1. Mean temperature anomalies in °C for 2021 relative to the 1981–2010 and 1961–1990 reference periods. Anomalies for the whole African continent and sub-regions have been calculated using different data sets,⁷ including observational data sets (HadCRUT5, NOAA GlobalTemp, GISTEMP, and Berkeley Earth) and reanalyses (ERA5 and JRA-55).

	North Africa	West Africa	Central Africa	East Africa	Southern Africa	Indian Ocean island countries	Africa
1981–2010	1.22 °C	0.91 °C	0.69 °C	0.60 °C	0.17 °C	0.45 °C	0.68 °C
1961–1990	1.76 °C	1.39 °C	1.01 °C	1.04 °C	0.59 °C	0.74 °C	1.12 °C

Source: Met Office, United Kingdom

EXTREME TEMPERATURES

An upward trend in the number of extreme warm days⁸ has been clearly identified over continental Africa since 1979. According to IPCC AR6, increases in extreme temperatures and decreases in cold extremes are projected to continue throughout the twenty-first century. In 2021, Africa recorded 10 extreme warm days at the continental scale (Figure 7).

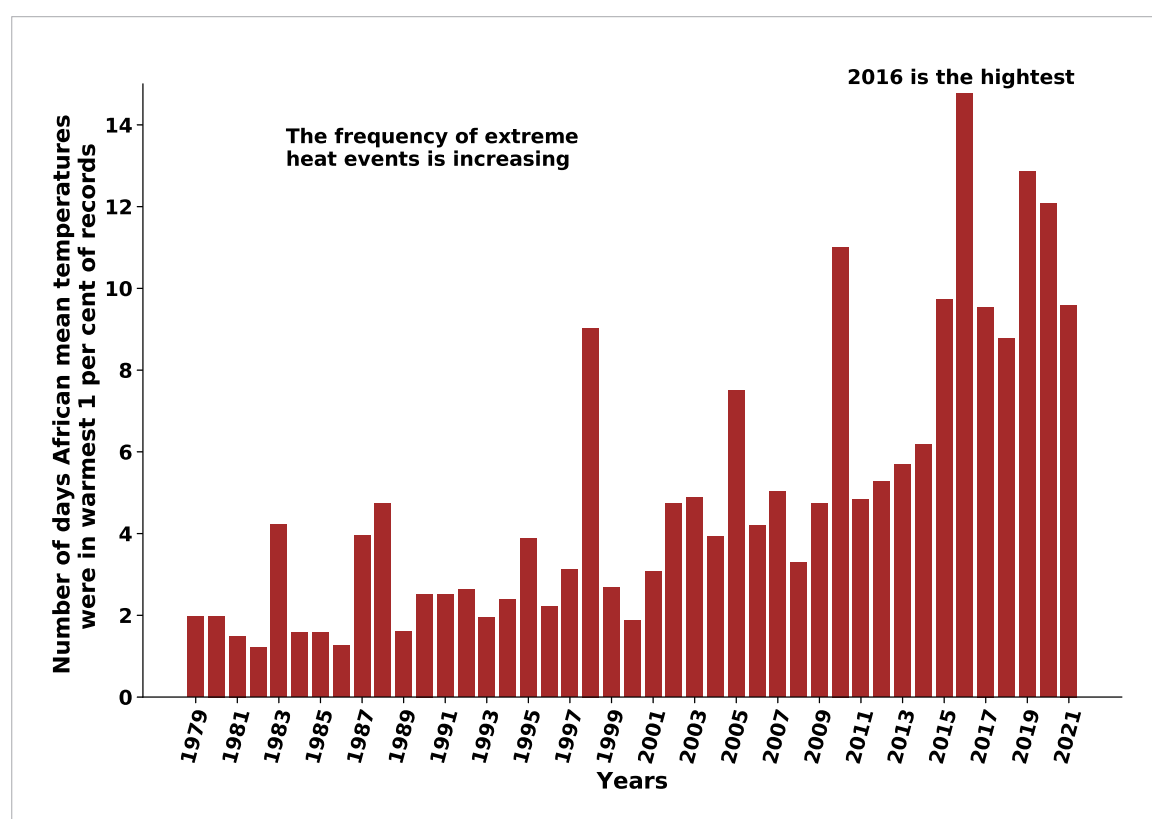


Figure 7. Annual number of extreme warm days in Africa from 1979 to 2021.

Source: African Center of Meteorological Applications for Development (ACMAD), based on ERA5

PRECIPITATION

In 2021, rainfall patterns included a large and contrasting geographical distribution of precipitation anomalies (Figure 8).

Below-normal rainfall conditions prevailed over much of North Africa, especially in the coastal areas of Morocco, Tunisia, and north-western Libya, where negative anomalies exceeded 160 mm (the lowest 10% of totals during the 1951–2010 climatology period). Conversely, north-eastern Egypt experienced above-average precipitation, with positive anomalies of over 40 mm (ranking among the highest 10% of observed totals during the climatology period).

West Africa experienced a delayed onset and early cessation of its rainy season, and most of the rains were received during July and August. Overall, local areas in Côte d'Ivoire, Burkina Faso, Ghana, and eastern Niger received enhanced rainfall (the highest 10% of the observed totals), while much of Mauritania, Liberia, Togo, and Nigeria observed suppressed precipitation (the lowest 10% of the totals during the climatology period).

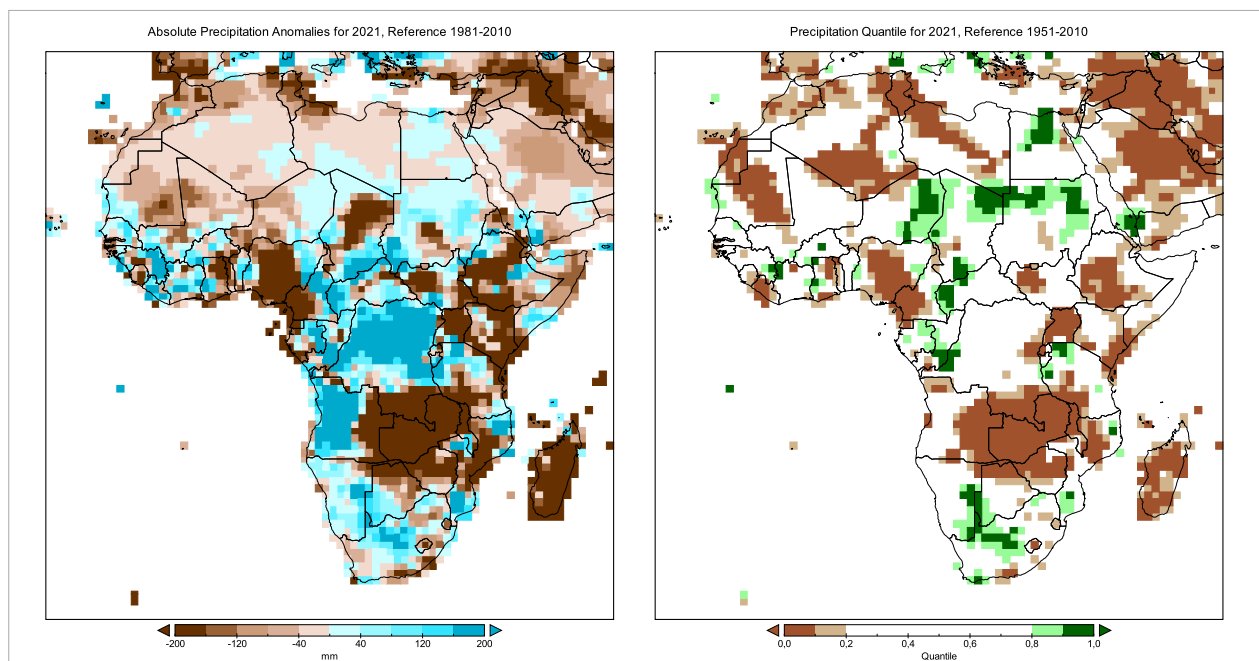


Figure 8. Absolute precipitation anomalies in mm for 2021 (left): Blue areas indicate above-average precipitation, while brown areas indicate below-average precipitation. The reference period is 1981–2010. Precipitation quantiles for 2021 (right): Brown areas indicate abnormally low precipitation totals (light brown indicates the lowest 20%, and dark brown indicates the lowest 10% of the observed totals). Green areas indicate unusually high precipitation totals (light green indicates the highest 20%, and dark green indicates the highest 10% of the observed totals). The reference period is 1951–2010.

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

In Central Africa, the largest positive anomalies (more than 160 mm above the average) were recorded in southern Chad, northern Cameroon, parts of CAR, portions of Congo, and much of DRC. Negative precipitation anomalies of over 160 mm were observed across south-western Cameroon, central Chad, and southern DRC.

In East Africa, northern Sudan and north-western Tanzania recorded wetter than normal conditions, with areas with the highest percentile (10%) of the climatology period (1981–2010) indicated in Figure 8, while Ethiopia, Uganda, and portions of South Sudan, southern Somalia, Kenya, and Tanzania recorded drier than normal conditions, with areas with the lowest percentile (10%) of the climatology period indicated in Figure 8. The severity of dry conditions worsened in the fourth quarter of 2021 (October–November–December) over Somalia, southern and south-eastern Ethiopia, central and northern Uganda and northern parts of Kenya.

In Southern Africa, remarkable rainfall deficits of over 160 mm were observed across eastern Angola, Zambia, Zimbabwe, central Mozambique, and pockets along the coast of South Africa, with areas with the lowest 10% of the climatology period indicated in Figure 8, while large moisture surpluses of over 160 mm were found across central and western Angola, eastern Namibia, western Botswana, central South Africa, and northern and southern Mozambique, with areas with the highest 10% of the climatology period indicated in Figure 8.

In the West Indian Ocean, suppressed rainfall resulted in negative anomalies of over 160 mm in Madagascar and Comoros, with areas with the lowest 10% of the climatology period indicated in Figure 8.

MOUNTAIN GLACIERS

Climate change has profound and irreversible consequences for the Earth system, including the receding of glaciers in equatorial East Africa; these include the glaciers on Mount Kenya (Kenya), Mount Kilimanjaro (Tanzania), and the Rwenzori Mountains (Uganda). African glaciers are retreating at a faster rate than the global mean.⁹

The total glacial area on Mount Kenya decreased by 121 000 m², the equivalent of approximately 44% of the mountain's ice cover, between 2004 and 2016.¹⁰ The total glacial area on the Rwenzori Mountains decreased from around 2 km² in 1987 to around 1 km² in 2003.¹¹ Glaciers on Kilimanjaro retreated from their former extent of 11.40 km² in 1912 to 1.76 km² in 2011, a total loss of about 85% of the ice cover over the last 100 years.¹²

Glaciers on the Rwenzori Mountains and on Mount Kenya are projected to disappear by 2030, while those on Kilimanjaro, a major tourism attraction, are projected to disappear by 2040. The decline in the surface area of the glaciers on the Rwenzori Mountains is due to rising air temperatures, while the retreat of the glaciers on Mount Kenya and Kilimanjaro is due to reduced precipitation and atmospheric moisture.¹³

Whether or not glaciers fully disappear in East Africa depends on the amount of future precipitation that falls in the East Africa region, which, as noted, is a crucial climatic driver of these glaciers. The glaciers on the three massifs, and especially on Kilimanjaro, provide an excellent opportunity to study linkages in the climate system and how large-scale climatic changes are propagated to high mountains. The direct local driver of glacier shrinkage has been a lack of snowfall at least since the late nineteenth century. The remote driver has mainly been the supply of moisture from the Indian Ocean, which, at least in the most recent decades, has been affected by global warming.

COASTAL SEA LEVEL

Since the early 1990s, sea level has been routinely measured globally and regionally by high-precision altimeter satellites. During this period, global mean sea level has risen at an average rate of 3.3 ± 0.4 mm/yr (a total global increase of about 8 cm), and has even accelerated in response to ocean warming and land ice melt. The rate of rise is not geographically uniform, however, mostly due to non-uniform ocean thermal expansion and regional salinity variations.¹⁴

The sea level was measured in the 12 coastal regions of Africa from January 1993 to August 2021 (Figure 9).¹⁵ Overall, the rate of sea-level rise around Africa is higher than the global mean, as highlighted in IPCC AR6.¹⁶

The highest rate of sea-level rise around Africa has been observed along the coastal areas of the Red Sea (Figure 9, box 9), with a rate of 4.4 mm/yr, followed by the Tanzania and Mozambique coasts (box 7), and the eastern coast of South Africa (box 6), where the rate exceeds 3.9 mm/yr. The rate of sea-level rise is also much higher than the global average along the western coasts of South Africa and Namibia (box 5), reaching nearly 3.8 mm/yr. It exceeds 3.6 mm/yr along the Atlantic coasts of North-West Africa (box 1), the Gulf of Guinea region (box 3), from Gabon to Angola (box 4) and Somalia (box 8). Western Africa coastlines (box 2) have experienced a rate of sea-level rise close to the global mean, with a rate of 3.3 mm/yr. The rate of sea-level rise is lower than the global mean over the Mediterranean Sea (boxes 10, 11, and 12), ranging from 2.5 mm/year to 3.1 mm/year.

Relative sea-level¹⁷ rise is likely to continue around Africa, contributing to increases in the frequency and severity of coastal flooding in low-lying areas and along most sandy coasts.¹⁸

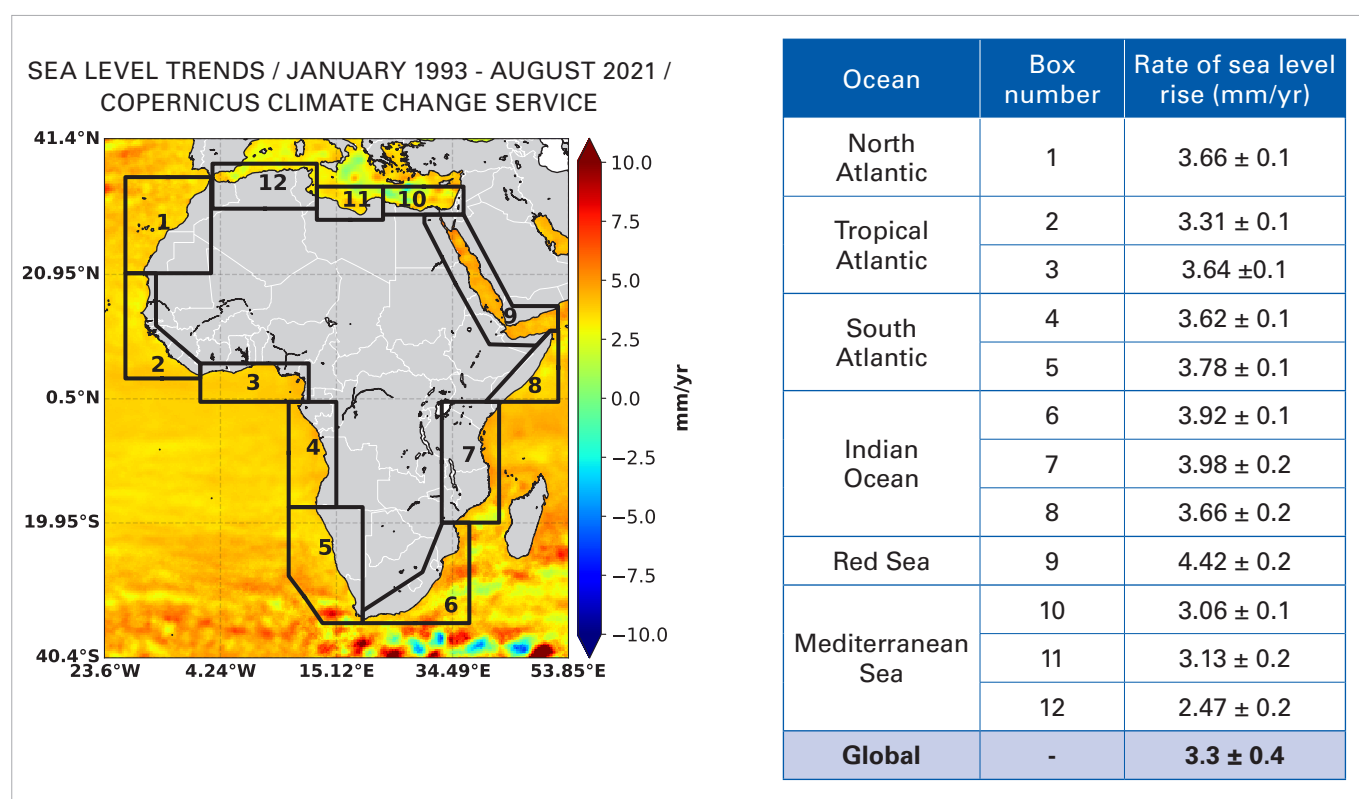


Figure 9. Left: Sea-level trends at the 12 coastal regions of Africa covering the period from January 1993 to August 2021: the North Atlantic (1), the Tropical Atlantic (2 and 3), the South Atlantic (4 and 5), the Indian Ocean (6, 7, and 8), the Red Sea (9), and the Mediterranean Sea (10, 11, and 12). Right: Table indicating the sea-level rise in mm/yr for the 12 coastal regions of Africa and the global ocean.
Source: Copernicus Climate Change Service (C3S). See [C3S Climate Data Store](#) for more information on the data sets and methodology used to measure sea-level rise.

CONTINENTAL WATER BODIES

WATER LEVELS IN MAJOR LAKES

Africa is home to several major lakes, including Lake Victoria and Lake Chad. Continuous monitoring of those lakes is paramount, as they have crucial implications for the agricultural sector as well as the socioeconomic development, ecosystem health, and biodiversity of the continent.

Lake Victoria is the largest freshwater lake of the continent, spanning areas of Kenya, Tanzania, and Uganda. Given that around 80% of the lake refill comes from direct rainfall and only 20% from basin discharge, changes in the water level mainly reflect precipitation patterns.¹⁹ The lake has exhibited large water level variations, with sharp rises in 1997/1998 and 2019–2021, and a decline in 2006 (Figure 10). High water levels registered in 1997/1998 were attributed to the extreme precipitation associated with the El Niño episode during the same period. From 1998 to 2006, the water level decreased drastically and in 2006 reached its lowest level since 1961.²⁰ The low water level in 2006 coincided with the occurrence of severe drought in equatorial East Africa and a strong negative Indian Ocean Dipole (IOD) phase. Intense precipitation in late 2019 and early 2020 caused a huge increase in water storage and led to considerable flooding in adjacent areas, population displacement, power interruption, and infrastructure and crop damage.²¹ This excessive precipitation was associated with the positive IOD phase in early 2019.²² Since May 2021, the water level has been receding again; however, this has coincided with a negative IOD phase.

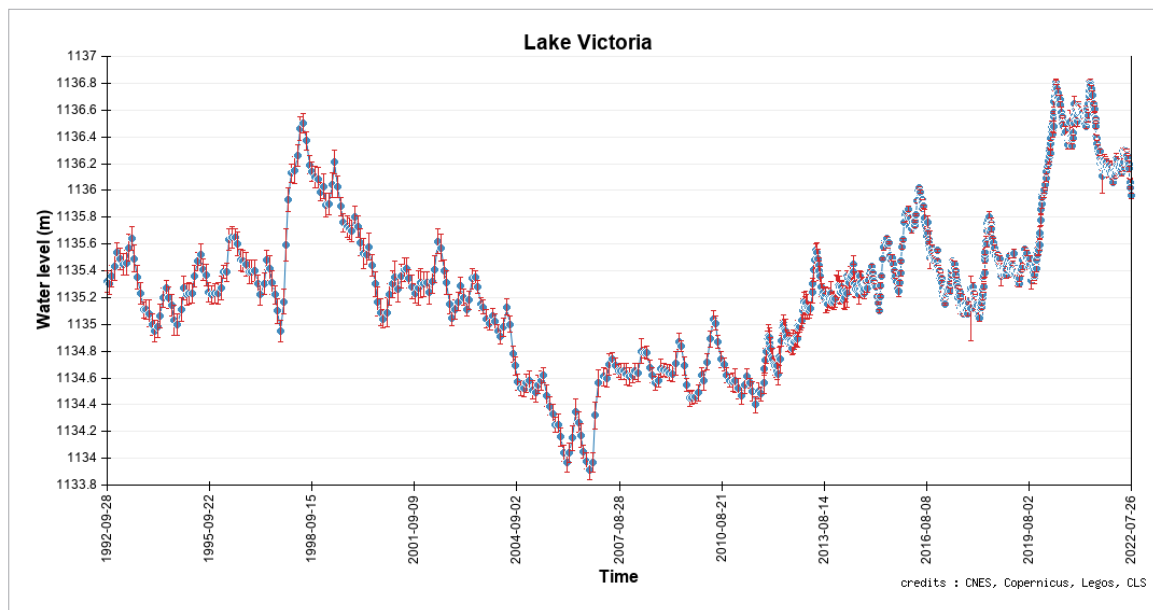


Figure 10. Time series of the monthly water level of Lake Victoria from September 1992 to May 2022. Satellite altimetry is used to measure the water level. Monthly water level values are indicated by blue dots and the associated uncertainties are depicted with red bars.
Source: [Hydroweb portal](#)

Lake Chad is located close to the Sahara desert, bordering Chad, Cameroon, Nigeria, and Niger. Its total surface area shrunk by 90%²³ from the 1960s (25 000 km²) to the 2000s (1 350 km²) and has remained stable from the 2000s to the present day.²⁴ This dramatic shrinkage reflects the combined effect of climate variability and change and intense anthropogenic pressure on water. Droughts in the 1970s and 1980s contributed to split the lake into a northern pool and a southern pool (Figure 11). Over the last two decades, the southern pool has remained quite stable and has even slightly increased due to stable local rainfall and an increase in the Chari-Logone River discharge; however, the northern pool has experienced a descending trend in water extent due to an increase in evaporation and vegetation cover and a decrease in discharge from the Komadugu-Yobe River (Figure 12). The shrinking of the lake was accompanied by a reduction in the area of cultivable land and grazing sites, a decline in fish production, a loss of biodiversity, and the consequent

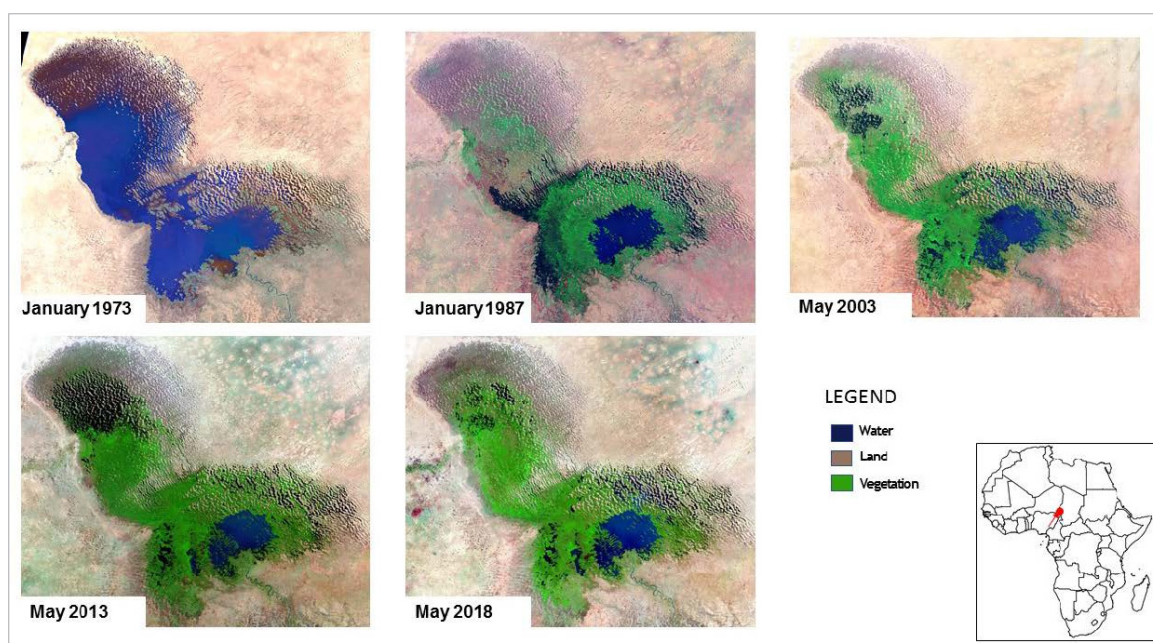


Figure 11. Declining water levels of Lake Chad from January 1973 to May 2018
Source: United Nations University Institute for Water, Environment and Health (UNU-INWEH), based on Landsat images from the United States Geological Survey

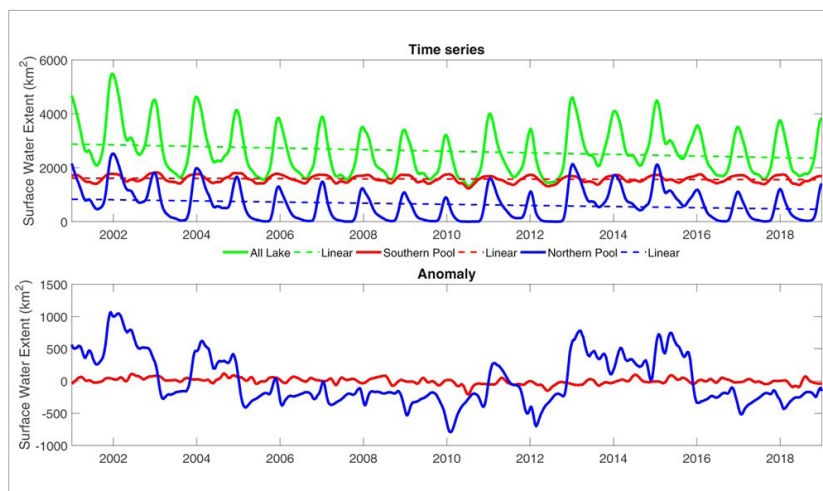


Figure 12. Time series of the total (top) and anomaly (bottom) of surface water extent of the northern pool (blue), southern pool (red), and Lake Chad (green) in km² for the period 2001–2018. The trends are plotted as dashed curves.

Source: Pham-Duc, B. et al., 2020²⁶

deterioration of population livelihoods in the Lake Chad basin. Despite the slight decline of the northern pool, the total surface area of Lake Chad has remained stable since the 2000s due to infilling of groundwater resources by the Chari, Logone and Komadugu-Yobe Rivers, the main tributaries of the lake.²⁵

RIVER DISCHARGE

The Niger River recorded its highest discharge during 2020/2021. This period corresponds to the worst flood in Niger's history, which affected over half a million people across the country.²⁷ The discharge exceeded 3 000 m³/s in September–October 2020, which was much higher than the 1991–2020 hydrological normal of 1 400 m³/s, and continued to be well above average until June 2021. From June to October 2021, the discharge returned to close to normal, with local fluctuations reflecting the rainy season in the region. The lowest discharge on record was in 1984/1985, mirroring the nationwide drought during that period (Figure 13).

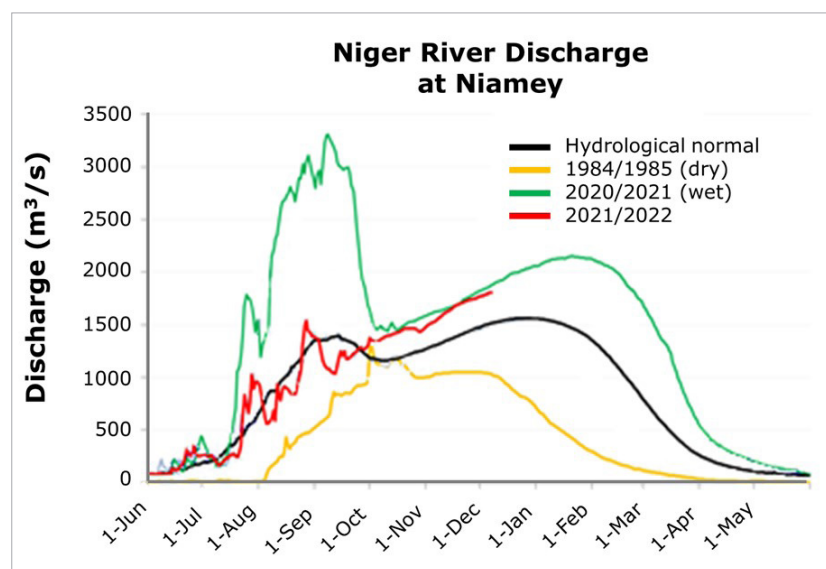


Figure 13. Discharge of the Niger River in m³/s for different time periods at Niamey station, Niger. The hydrographs compare the dry year of 1984/1985 (yellow), the wet year of 2020/2021 (green), the year 2021/2022 (red), and the hydrological normal of 1991–2020 (black).

Source: Regional Training Centre for Agrometeorology and Operational Hydrology and their Applications (AGRYMET).

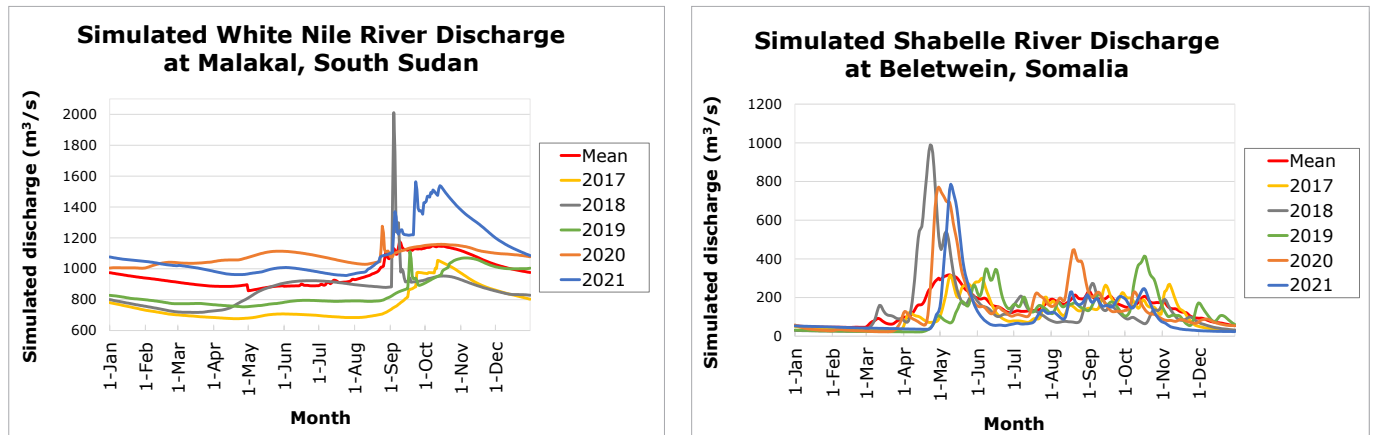


Figure 14. Simulation based on the observed river discharge of the White Nile River at Malakal, South Sudan (left) and the Shabelle River, Somalia (right) in m^3/s for the years 2017 (yellow), 2018 (grey), 2019 (green), 2020 (orange), and 2021 (blue). The 1993–2021 climatological normal is represented by the red curve.

Source: ICPAC, based on output from the GeoSFM Model

The 2021 White Nile River discharge was higher than the long-term average and higher than the 2020 discharge from October onwards (Figure 14 left). This was mainly driven by near-to-above-normal rainfall in the upstream basin. The high peak discharge in September 2018 was caused by localized heavy rains around Makalal. For the Shabelle River discharge, below-normal conditions were observed, except during a short period between May and June, during which heavy *Gu* rains triggered riverine flooding (Figure 14 right).²⁸

The monthly flow of the Congo-Oubangui River from January 2017 to May 2022 does not present significant changes compared to average values, except during the peak months of October and November. The 2021 flow was near-to-below average (Figure 15).

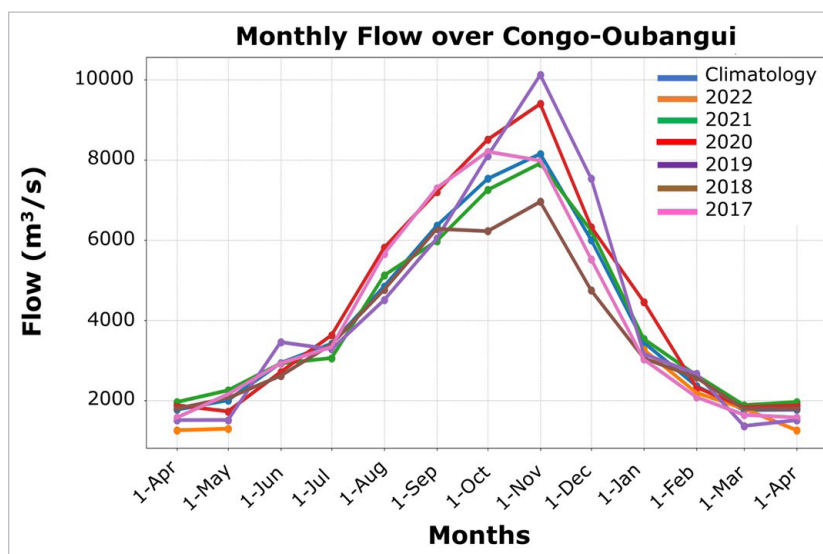


Figure 15. Monthly flow of the Congo-Oubangui River flow in m^3/s for the years 2017 (pink), 2018 (brown), 2019 (purple), 2020 (red), 2021 (green), and 2022 (orange). The 2008–2021 climatology is represented by the blue curve.

Source: Hydroweb portal

Major drivers of climate variability affecting the region

Rainfall variability is affected not only by the phases of the El Niño Southern Oscillation (ENSO), but also by sea-surface temperature (SST) anomalies in the tropical Atlantic Ocean and Indian Ocean. Indeed, La Niña episodes are typically associated with above-average summer precipitation over the Sahel.²⁹ Positive SST anomalies over the tropical Atlantic Ocean are also usually favourable for above-average summer rainfall over West Africa.³⁰ Warmer SSTs over the south-western Indian Ocean (SWIO) tend to be associated with above-average rainfall across Southern Africa.³¹ Usually, a positive IOD phase contributes to increased convection over the western Indian Ocean and leads to wetter-than-normal conditions over East Africa.³²

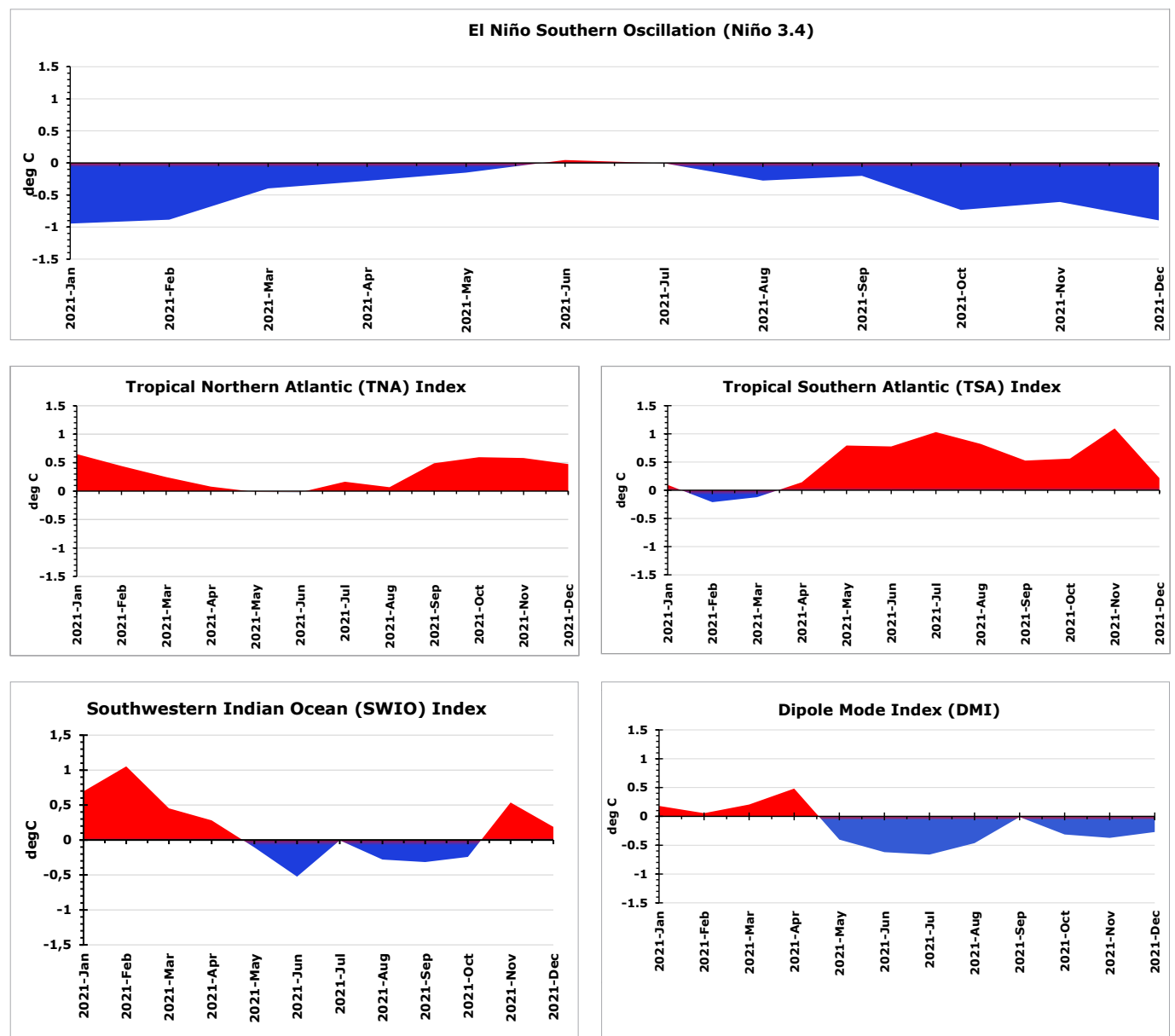


Figure 16. Time series of climate indices for 2021 relative to 1981–2010: (a) Niño 3.4 index [5°S–5°N; 170°W–120°W]; (b) Tropical Northern Atlantic index [5.5°N–23.5°N; 15°W–57.5°W]; (c) Tropical Southern Atlantic index [0°–20°S; 10°E–30°W]; (d) South-western Indian Ocean index [32°S–25°S; 31°E–45°E]; (e) Dipole Mode Index (DMI)³³.

Source: ACMAD, based on data from the State of the Ocean Climate and NOAA National Centers for Environmental Prediction (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](https://doi.org/10.1175/1520-0442(2002)015<1609:AIISAS>2.0.CO;2).)

The ENSO signal measured using the Niño 3.4 index, which tracks SSTs in the tropical Pacific, varied throughout the year, with moderate strength La Niña conditions early in the year evolving to an ENSO-neutral state during June and July then returning back to a stronger La Niña situation from October onwards (Figure 16a). The Tropical Northern Atlantic (TNA) index was positive during most of the year, reflecting positive SSTs in the eastern tropical North Atlantic, except during April–May–June (Figure 16b). The Tropical Southern Atlantic (TSA) index was negative at the beginning of the year and positive from April to the end of the year (Figure 16c). The SWIO index was positive from January to May, negative from May to October, then positive from October to December (Figure 16d). A positive IOD phase developed until mid-April, followed by a negative IOD phase lasting for the remainder of the year (Figure 16e).

The La Niña signal coupled with negative IOD values contributed to drier-than-normal conditions in East Africa. Indeed, Ethiopia, Kenya, and Somalia experienced the failure of the Gu rains (April–May–June) and the *Deyr* rains (October–November–December), leading to an exceptional multi-seasonal drought. An active start of the 2020/2021 rainy season and the occurrence of tropical cyclones across the southern part of Africa were the result of the La Niña event and a positive SWIO index. Although ENSO-neutral conditions prevailed during June–September, above-average SSTs in the TNA contributed to enhanced rainfall later during the West African monsoon.

Extreme and high-impact events

In 2021, many extreme and high-impact events were reported across Africa. The continent was affected by heavy rainfall, floods, land-falling tropical cyclones, droughts, heatwaves, wildfires, and sandstorms. These events led to disastrous impacts on socioeconomic sectors, which are reported in the section on [Climate-related risks and socioeconomic impacts](#) below.

FLOODS

In 2021, South Sudan experienced a third straight year of extreme floods. Lakes and rivers in the Nile Basin upstream of South Sudan remained at elevated levels due to the intense rainfall in 2020 and 2021. The June–September main rainy season started 10–20 days earlier than usual in South Sudan due to a faster-than-normal northward progression of the Intertropical Convergence Zone (ITCZ) from April to June.³⁴ Although the seasonal rainfall was not well above average, the standing water from past years, which had not fully receded, contributed to increase the Nile flows into South Sudan and caused widespread floods.³⁵ The wetter-than-normal conditions persisted into the typical dry season, which also contributed to sustained localized flooding in the country at the end of the year.

Although the rainy season in West Africa started late and ended early,³⁶ most of the rain fell over a short period from mid-July to August, leading to localized flooding. Several stations in Niger registered accumulated precipitation of over 100 mm in 24 h, including one station in Niamey that recorded 140 mm of rain on 10 August 2021. In Benin, excessive rainfall caused high river levels that resulted in flooding. Nigeria experienced high-intensity rainfall that led to flooding across many parts of the country, contributing to the spread of cholera. On 1 August, Katsina State registered 100.4 mm of rain, the second highest daily precipitation total ever recorded in that state. The highest amount of rainfall in 2021 in Nigeria was recorded in Jalingo, Taraba State, where rainfall totals reached 201 mm in 24 h on 16 August. On 10 August, parts of Bauchi State observed a rainfall amount of about 80 mm.

In Congo, in November 2021, rains raised the water level of rivers above the riverbanks, inundating the neighbouring areas, especially the departments of Likouala, Sangha, Cuvette, and Plateaux in the central-north part of the country, as well as several districts in the cities of Pointe-Noire and Brazzaville in the southern part of the country.

At the beginning of the year, torrential rains elevated the water level of Lake Tanganyika, which reached a height of 776.4 m above sea level, around 3.7 m higher than the normal average level in April, exposing lakeside communities of DRC and Burundi to major flooding (Figure 17).

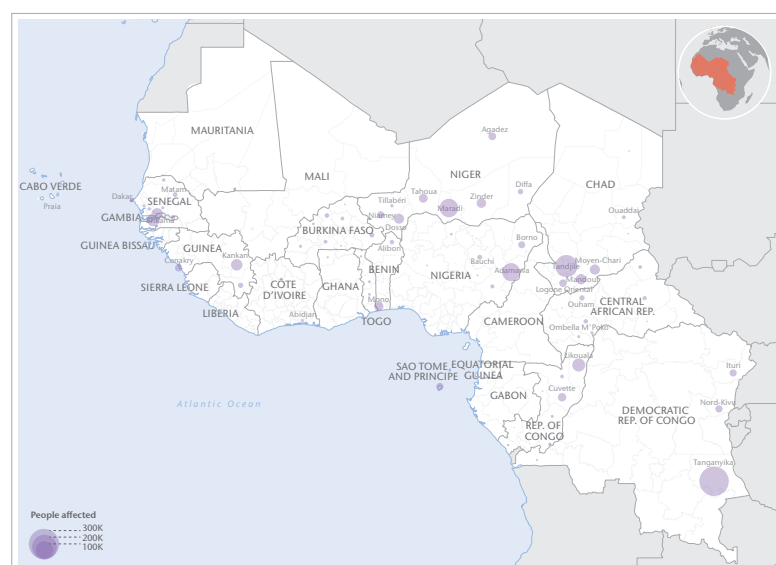


Figure 17. West and Central Africa: Flooding situation overview (January–December 2021)
Source: OCHA

TROPICAL CYCLONES

After being hit by Tropical Storm *Chalane* in December 2020, the Southern African region was hit by Tropical Cyclone *Eloise* in January 2021 (Figure 18). On 19 January, *Eloise* made landfall in northern Madagascar, near Antalaha, Antsiranana Province, as a moderate tropical storm.³⁷ *Eloise* contributed to making rainfall totals in January up to 150% of the average in the northern part of Madagascar. After crossing Madagascar, *Eloise* moved towards the Mozambique Channel and intensified into a Category 1 storm, with maximum sustained winds of 120 km/h. On 23 January, it reached peak intensity as a Category 2 cyclone and made landfall in central Mozambique, near Beira city, Sofala Province. The cyclone was accompanied by maximum sustained winds of 140 km/h and wind gusts of up to 160 km/h. According to the Mozambique's National Institute of Meteorology (INAM), Beira city received 250 mm of rain in 24 hours. Following landfall, *Eloise* was downgraded to a tropical storm and moved westward across Southern Africa, causing heavy rainfall in its path.

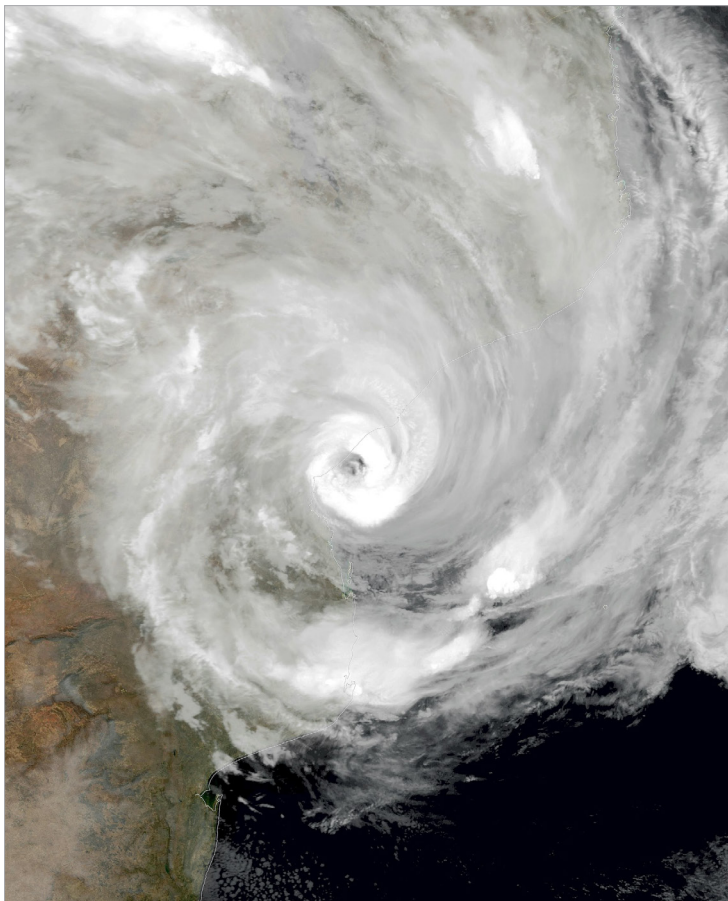


Figure 18. Tropical Cyclone Eloise on 22 January 2021
Source: NASA

DROUGHTS

The Sahel experienced below-average rainfall at the beginning (May–June) and end (September–October) of the rainy season. Between May and June, parts of Senegal, southern Mauritania, central Mali, northern Nigeria, and much of Niger experienced dry spells of over 21 days. Between September and October, southern Mauritania, central Mali, northern Burkina Faso, Niger, and northern Nigeria experienced dry spells of over 19 days.³⁸

East Africa experienced three consecutive below-average rainy seasons (October–November–December 2020, March–April–May 2021, and October–November–December 2021). The severity of dry conditions worsened in October–November–December 2021, especially over southern Ethiopia, much of Somalia, central and northern Uganda, northern Kenya, and central and southern Tanzania, where rainfall deficits were over 200 mm. The equatorial and southern parts of East Africa experienced a delay of at least 28 days of the onset of the October–November–December rainy season. Delayed rainfall onset combined with below-average rainfall seasons resulted in one of the worst droughts for the region in the past 40 years.

The southern part of Madagascar continued to endure the severe drought that has persisted for at least two years. The October–November–December 2021 period that marked the beginning of the main rainy season in Madagascar (from October to March), was one of the driest starts to the season in the 40-year historical record. During this period, rainfall deficits were more pronounced in the southern and eastern parts of the country. Toliara Province received 165 mm of rain, around 50% of normal rainfall during this time.³⁹ Negative 12-month Standardized Precipitation Index (SPI)⁴⁰ values depict long-term dry conditions across southern and south-eastern Madagascar in October (Figure 19a). In particular, the Tananarive region observed high negative SPI values, below -2.5, during most of 2021, which was well below the 2020 and 2019 SPI (Figure 19c), and the lowest since 2013 (Figure 19b).

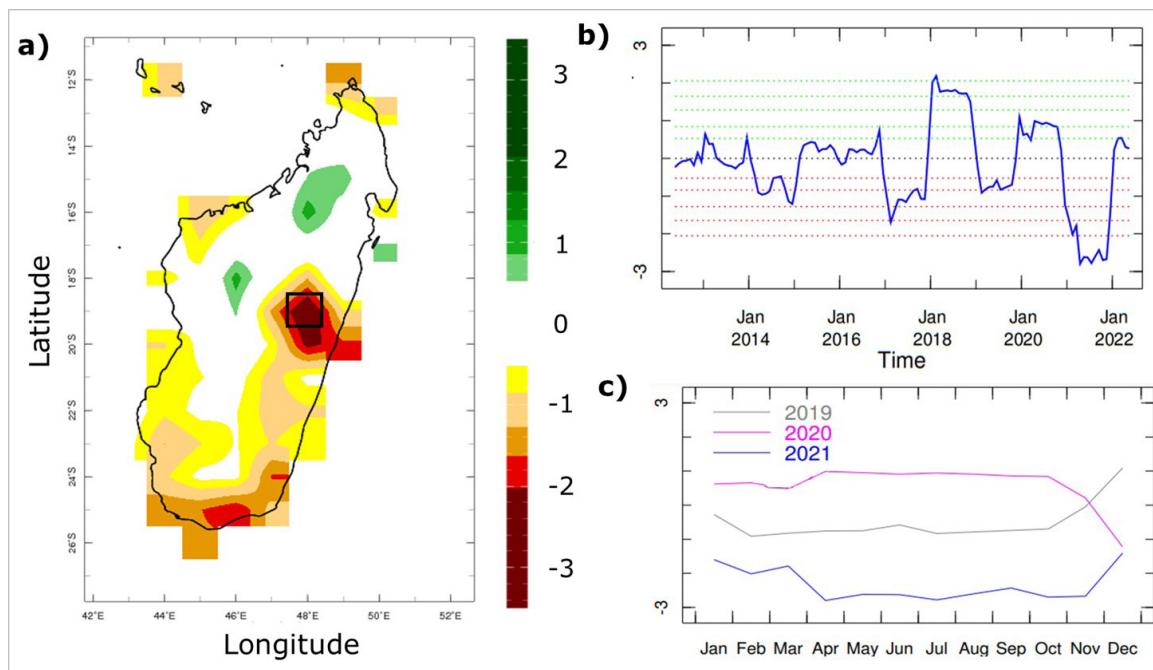


Figure 19. Madagascar SPI: a) 12-month SPI ending October 2021. Green shading indicates long-term wet conditions and yellow-to-red shading depicts long-term dry conditions. b) Time series of the 12-month SPI from 2013 to 2021 for the selected area [19.5°S–18.5°S; 47.5°E–48.5°E] (the green dashed lines correspond to the wet categories; the red dashed lines correspond to the dry categories). c) Time series of the 12-month SPI for 2019 (grey), 2020 (pink), and 2021 (blue) for the selected area [19.5°S–18.5°S; 47.5°E–48.5°E]. The SPI is based upon observed monthly precipitation totals from the Climate Prediction Center’s (CPC) Gauge – Outgoing Longwave Radiation (OLR) blended daily precipitation analysis.

Source: International Research Institute for Climate and Society (IRI) Data Library

HEATWAVES AND WILDFIRES

Several episodes of heatwaves and record high temperatures occurred in North Africa during the 2021 summer. The summer of 2021 was the hottest summer in Tunisia since 1950, with an average temperature anomaly of 2.65 °C above the 1981–2010 average. The country was affected by two heatwaves. The first lasted eight consecutive days in June and affected the southern part of the country, where maximum temperatures reached 49.9 °C in Tozeur. The second lasted five consecutive days in August in the Kairouan and Sidi Bouzid regions. Kairouan registered a record temperature of 50.3 °C on 11 August. In June, a severe heatwave affected the western part of Libya, where monthly temperatures were 10 °C above the 1981–2010 average. Morocco was subjected to an exceptional heatwave in which several temperature records were broken on 10 July 2021. A heatwave episode also occurred in Algeria, where a maximum daily temperature of 49.7 °C was reported in August in Bouchegouf.

The hot and dry weather contributed to making vegetation more flammable. Although some fires were linked to arson, the combination of high temperatures, reduced precipitation, and windy conditions strongly contributed to amplifying them. Algeria was affected by a series of major wildfires, including 43 fires in Oum el Bouagui in June and 22 fires in Tizi-Ouzou in August (Figure 20). Wildfires also occurred in Morocco (Chefchaouen) and Tunisia (Touiref and Kasserine).



Figure 20. Wildfire in Tizi Ouzou, Algeria on 12 August 2021
Source: Mousaab Rouibi/Anadolu Agency

SANDSTORMS AND DUST STORMS

On 5 February 2021, strong winds close to the surface in northern Algeria lifted a large amount of sand and dust that was then transported in a southerly flow towards south-east Spain. On 6 February, dust reached southern and central Europe, turning the sky yellow, coating buildings and cars, and affecting air quality in cities such as Barcelona and Marseilles. Dust also reached the Alps and covered the snow (Figure 21).

In March 2021, the central and south-western parts of Libya were also hit by a severe sandstorm that originated from a deep air depression of 996 mbar. This depression was accompanied by strong south-westerly winds of 65 km/h.⁴¹ It led to car crashes and downed power lines.

In December 2021, in Egypt, a sandstorm accompanied by strong winds and high waves prompted local authorities to close four ports in the Red Sea: Alexandria, Dekheila, Burullus, and Suez. In addition to disrupting marine navigation, sandstorms led to the suspension of classes in schools, universities, and other educational institutions in Alexandria and in the provinces of Matrouh, Kafr El-Sheikh, and Beheira.

Dust storms were also reported in Nigeria in March and Sudan in June. Dust storms delayed air and ground transportation and caused flight cancellations. Dust reduced the visibility to as low as 200 m over some cities in northern Nigeria (Kano, Katsina, and Maiduguri) and central Nigeria (Abuja).

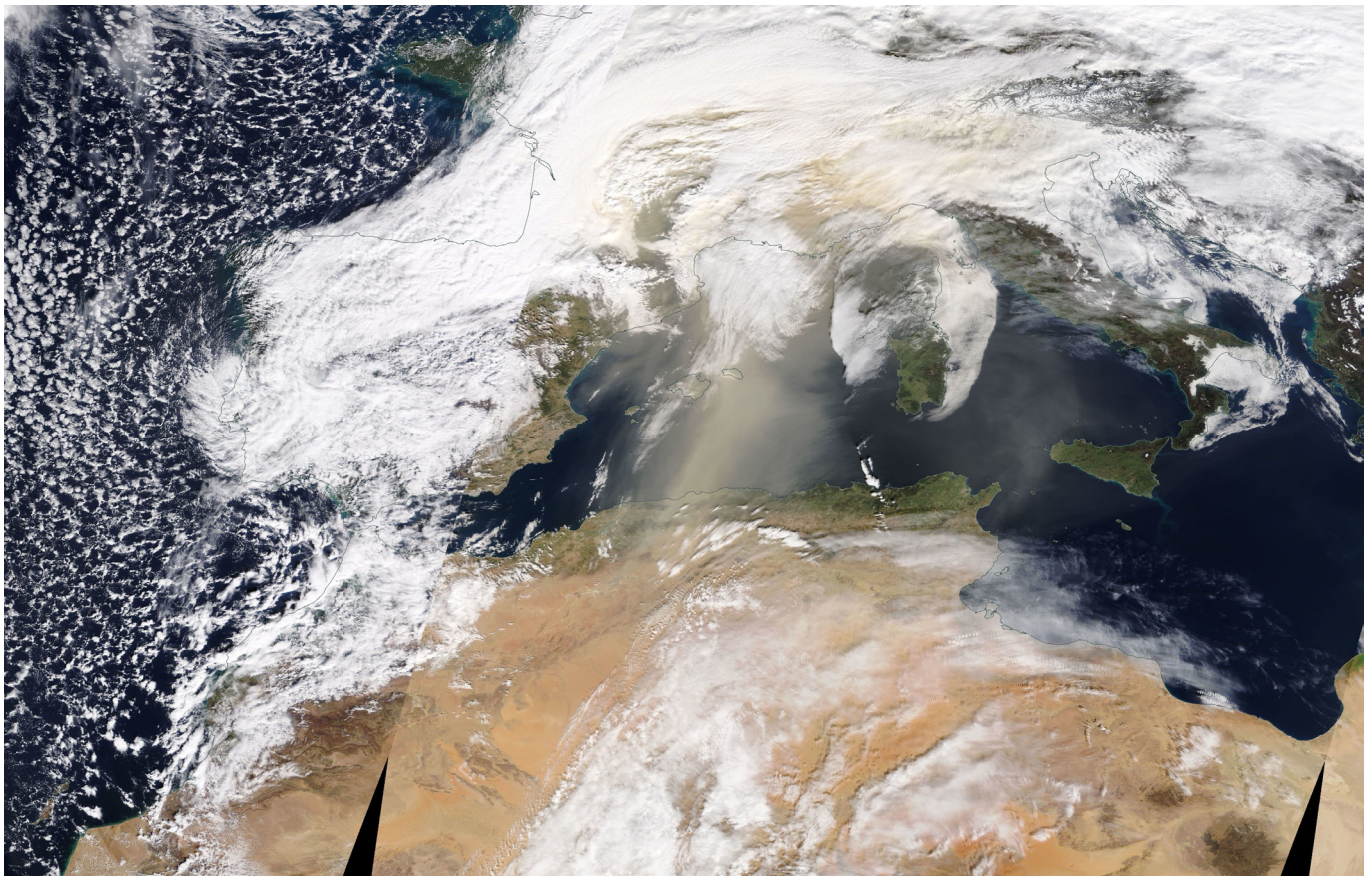


Figure 21. Drift of Saharan dust across the Mediterranean Sea into Europe on 6 February 2021

Source: NASA Worldview

Climate-related risks and socioeconomic impacts

The extreme and high-impact weather events described in the previous section affected diverse climate-sensitive sectors in Africa, including agriculture and food security, water resources, population displacement, health, and transportation. This section provides an analysis of the socioeconomic impacts associated with the extreme events that occurred in 2021 and relates them to the Sustainable Development Goals (SDGs) as defined in the 2030 Agenda for Sustainable Development.

AGRICULTURE AND FOOD SECURITY

In 2021, withering droughts and extensive floods, compounded by protracted conflicts, economic slowdowns and downturns, and the lingering impacts of the COVID-19 pandemic, drove hunger and malnourishment across Africa. All these factors jeopardize food security and impair Africa's progress towards meeting the commitment to reach zero hunger and end malnutrition in all its forms by 2030 as envisioned by SDG 2.

NORTH AFRICA

During the summer of 2021, multiple intense fires ravaged parts of North Africa and burned thousands of hectares of land, damaging orchards and affecting livestock. In Algeria, more than 40 000 hectares of land of Tizi-Ouzou burned, about 14% of the total area, more than 5 000 hectares of fruit trees were lost, and more than 19 000 farm animals were killed, according to the Agriculture Services Directorate in Tizi-Ouzou.⁴² Twelve fire engines and more than 900 firefighters were mobilized by the Algerian government to fight the fires and protect people and property across the country. The fires killed at least 90 people. In Tunisia, fires destroyed 100 hectares of forest in Touiref and hundreds of hectares of land in Kasserine.⁴³

WEST AFRICA

The 2021 rainy season was characterized by late onset rains and long dry spells in September and October, a critical period for crops and pasture development. Erratic rains negatively affected cereal production, contributing to driving up prices of food and agricultural inputs. 2021/2022 West African cereal production, estimated at 73.3 million tons, dropped by 1.8% compared to the previous year but was up by 3.2% from the average of the past five years.⁴⁴ Niger and Burkina Faso recorded reductions in cereal production of 36% and 10% compared with the previous five-year average, respectively. In Burkina Faso, maize prices increased by 50% compared to the five-year average,⁴⁵ while in Niger, the price of sorghum was 40% above the five-year average and the price of millet increased by 30%.⁴⁶

Between October and December 2021, around 23.7 million people in the Sahel and West Africa were estimated to be in crisis or worse according to the Integrated Food Security Phase Classification (IPC) standardized scale⁴⁷ (IPC Phase 3 and above). This situation was due not only to reduced domestic production and high food prices, but also to worsening security incidents driving population displacement.⁴⁸ This figure is well above the 16.7 million people estimated at the end of 2020.

EAST AFRICA

East Africa, in particular Ethiopia, Somalia, and Kenya, faced an exceptionally long drought as a result of three consecutive below-average rainy seasons (October–November–December 2020, March–April–May 2021, and October–November–December 2021). The effect of cumulative failed rainy seasons combined with heightened conflict endemic in the region, related population displacement, COVID-19 restrictions, and high food prices impeded food availability and access, leaving more than 58 million East Africans in acute food insecurity.⁴⁹

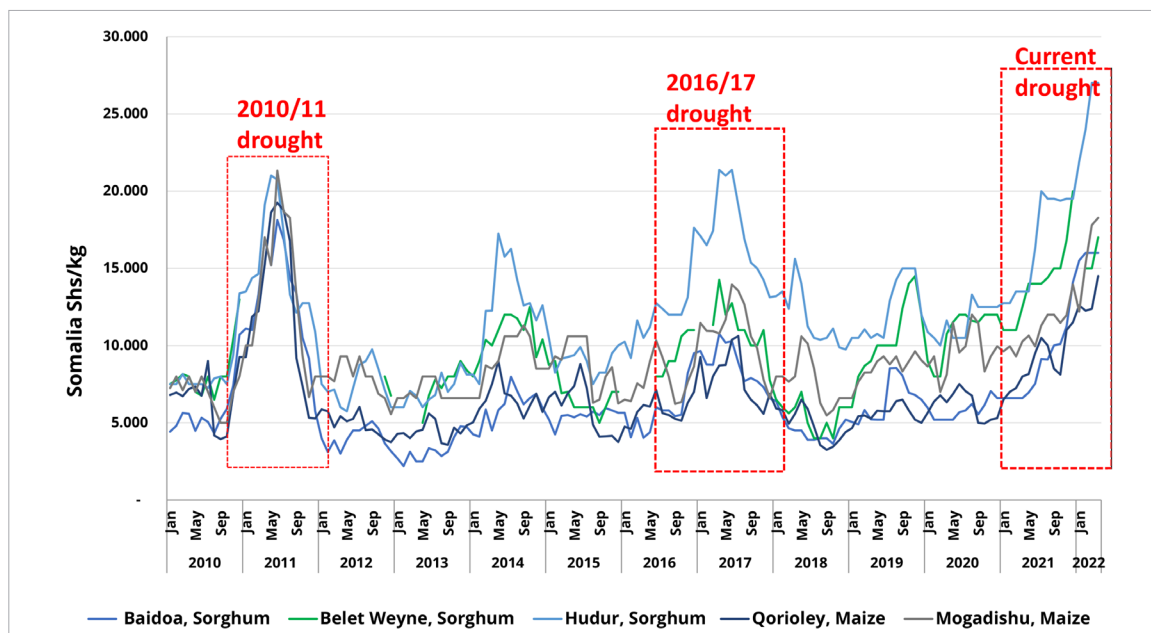


Figure 22. Time series of sorghum and maize prices in Somali shilling (the official currency for Somali) per kg for selected markets in Somalia (Baidoa, Qorioley, Belet Weyne, Hudur, and Mogadishu) from January 2010 to January 2022.

Source: World Food Programme (WFP)

In Ethiopia, between May and June 2021, around 16.8 million people in the *Meher*- and *Belg*-dependent areas⁵⁰ were in crisis or worse (IPC Phase 3 and above), including 5.5 million people in the northern part of the country. In the extreme north of Ethiopia, over 350 000 people were in catastrophe (IPC Phase 5), the highest number of people in this situation in a single country since the 2011 famine in Somalia.⁵¹ The rate of child malnutrition reached 17.1% in February and worsened to 22.7% in September.⁵²

In Somalia, *Deyr*⁵³ season cereal production was estimated to be 58% below the 1995–2020 average, making it the third lowest *Deyr* harvest since 2010. This shortage caused a sharp spike in food prices. In December 2021, sorghum and maize prices rose by 66% compared to the previous year, reaching levels witnessed during the severe 2016/2017 drought and 2011 famine (Figure 22). Nearly 3.5 million people endured acute hunger (IPC Phase 3 or worse) between October and December 2021.⁵⁴ Water shortages and parched landscapes drove a decline in livestock health and productivity due to drought-induced diseases, abortions, low milk production and extensive livestock deaths.⁵⁵ This situation was reminiscent of the devastating 2016/2017 drought that led to massive livestock losses, from which most herders have not yet been able to fully recover.

In Kenya, depressed March–April–May *long rains* contributed to a reduction of 42% of the maize output in the south-eastern agricultural areas and 70% in the coastal areas. Around 1.5 million livestock died in 15 counties. In the northern and north-eastern pastoral areas, September milk production was 55% below average. The price of livestock decreased due to the dismal body conditions of the animals. Goat retail prices were 18% below the long-term average.⁵⁶ About 2.1 million people in Arid and Semi-arid Land (ASAL) counties experienced acute food insecurity (IPC Phase 3 and above) between July and October 2021. This is 700 000 people more than the same period in 2020, an increase of 34%. In September, the Kenyan Government declared the drought a national disaster and released USD 18 million to mitigate the impact of the drought and USD 15.3 million for food assistance.⁵⁷

SOUTHERN AFRICA

In 2021, the Grand South region of Madagascar faced its worst drought since 1981, leaving the population on the brink of famine throughout the year. To make matters worse, favourable rains combined with high temperatures in the first half of the year created ideal conditions for fall armyworm. A fall armyworm outbreak contributed to the loss of 60% of crops, while Malagasy locusts infested more than 48 000 hectares of land, adversely affecting the off-season crops planted earlier.⁵⁸ Tiokamena (sandstorms) occurred during the agricultural campaign, affecting cassava and maize crops. According to the Famine Early Warning Systems Network (FEWS NET), the 2021 crop production in the southern part of Madagascar was 10–30% below the 2020 production and 50–70% below the five-year average. The decline in crop production, compounded by COVID-19 and related restrictions, led to an increase of 20–70% in the price of cassava and an increase of 10–80% in the price of maize compared to last year.⁵⁹ Around 1.14 million people experienced high levels of acute food insecurity (IPC Phase 3 or above), including 14 000 people in catastrophe (IPC Phase 5) between April and September 2021.⁶⁰ During this period, over 26% of children under the age of five in Ambovombe suffered from acute malnutrition, compared to 8.5% in November 2020.⁶¹

WATER RESOURCES

By December 2021, approximately 90% of Somalia was afflicted by persistent drought conditions of varying severity, with the southern and central parts of the country being the worst affected.⁶² More than 3.2 million people, in 66 out of the 74 country's districts, were affected by this multi-seasonal drought. The Shabelle and Juba River basins experienced the lowest rainfall totals on record since 1981,⁶³ and many wells, boreholes, and berkads⁶⁴ dried up. By October, around 82% of berkads in Galmudug, around 89% of berkads in Mudug, and more than 90% of berkads in Puntland had dried up according to the national authorities.⁶⁵ The limited water availability forced communities, including herders, to walk long distances in search of water and pastures. This led to competition for, and the quick depletion of, scant water resources, with approximately 169 000 people displaced in search of food, water, pastures, and humanitarian services.⁶⁶

The ongoing drought in southern Madagascar, the worst in over 40 years, caused rivers to dry up in 2021 and water prices to soar, pushing communities to desperate measures just to survive. As of the end of the year, 70% of people in southern Madagascar were without access to basic drinking water and 50% of the region was in urgent need of water, sanitation and hygiene assistance.

POPULATION DISPLACEMENT

Climate change is the defining crisis of our time, and disaster-related population displacement is one of its most recurrent consequences. The entire African continent is already suffering from climate change impacts. The most acute consequences of climate change disproportionately affect vulnerable people living in the most fragile and conflict-affected locations. Refugees and Internally Displaced People (IDPs) in Africa are on the frontlines of the climate emergency.⁶⁷ In 2021, around 14.1 million people were internally displaced in sub-Saharan Africa, including around 11.5 million due to conflict and violence and around 2.5 million due to disasters (Figure 23). Many are living in climate “hotspots”, where they typically lack the resources to adapt to an increasingly hostile environment. This can also exacerbate pre-existing tensions among communities relying on increasingly scarce resources, deepen existing inequalities (SDG 10), especially gender inequalities⁶⁸ (SDG 5), and further entrench poverty (SDG 1), thereby compromising the attainment of multiple SDGs in Africa.

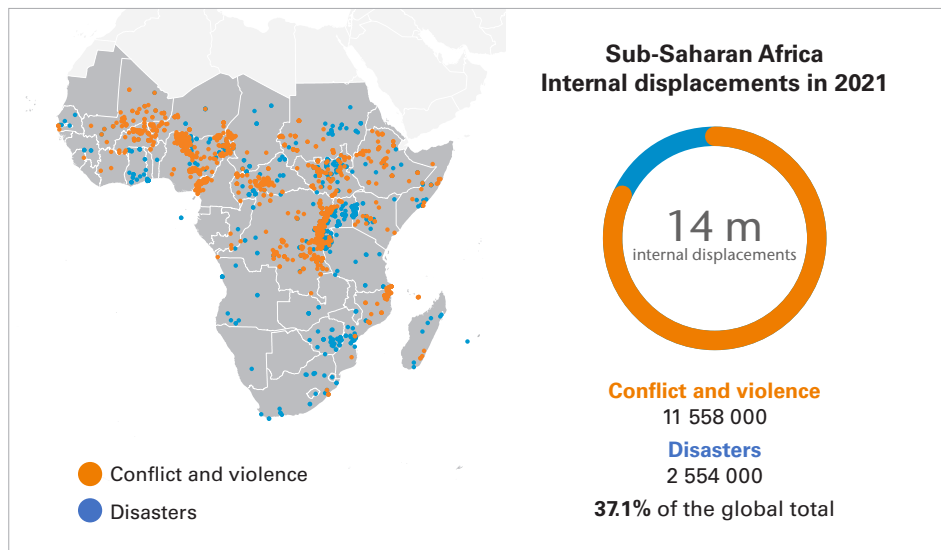


Figure 23. Internal displacements in 2021 in Africa due to conflict and violence (orange dots) and disasters (blue dots).
Source: Infographics modified from IDMC GRID 2022

WEST AFRICA

In Niger, torrential rainfall and floods affected more than 230 000 people.⁶⁹ More than 12 000 houses were destroyed, nearly 6 000 hectares of cultivable land were flooded, and more than 10 000 livestock were lost.⁷⁰ In a region where frequent attacks by armed groups have pushed 250 000 refugees, most from Mali and Nigeria, to seek safety in Niger, and where violence within its own borders has forced a further 264 000 IDPs from their homes, disasters contributed to increase population vulnerability in 2021.⁷¹ Further south, in Benin, heavy rainfall and the release of water at the Nagbeto dam caused widespread floods in the neighbouring municipalities in September. More than 35 000 people were affected, with 10 000 people displaced. Houses and buildings were damaged or destroyed, including 50 schools and a dozen colleges.

In Mauritania, the frequency of bush fires related to temperature rise has increased at an alarming rate, posing a serious threat to pastoralist refugees and host communities that keep large herds of livestock.⁷² Lake Mahmouda, a vital source of water and food for refugees and local communities in Mauritania, is under threat of depletion.⁷³

CENTRAL AFRICA

Between January and May 2021, a series of floods in the province of Tanganyika, Democratic Republic of the Congo, affected more than 280 000 people (more than 8% of the total population), killed 16 people, and damaged more than 26 000 houses, 116 schools, 50 health centres, and 5 000 hectares of crops.⁷⁴ In addition, the eruption of Mount Nyiragongo on 22 May affected nearly 30 000 people, killed more than 30 people, and destroyed more than 3 000 houses. Altogether, the heavy rains and floods accounted for more than 200 000 displacements in Tanganyika Province, and the volcanic eruption triggered almost 600 000 displacements, leading thousands to cross the border into Rwanda and Uganda.⁷⁵

In the Congo, torrential rains and subsequent flooding in November 2021 affected more than 46 000 people, mainly in the departments of Likouala, Sangha, Cuvette, and Plateaux. Likouala alone had more than 34 500 affected people. More than 6 500 people had to be relocated in the departments of Cuvette and Plateaux.⁷⁶

Population displacement is also a consequence of long-term effects of climate change that exacerbate competition for water and other resources. Water levels in Lake Chad have decreased by as much as 90% in the past 60 years, and the effects are felt by communities that rely on the Logone and Chari Rivers, which feed the lake on Cameroon's far northern border. Climate-related resource scarcity has precipitated the clashes in Far North Cameroon, displacing thousands inside the country and forcing more than 30 000 people to flee to neighbouring Chad in December 2021, according to the United Nations High Commissioner for Refugees (UNHCR).⁷⁷

EAST AFRICA

In Burundi, the rising water level of Lake Tanganyika exposed the adjacent communities to major flooding, leading to property destruction and population displacement. According to the United Nations Office for the Coordination of Humanitarian Affairs (OCHA), more than 33 000 people were displaced. Local villages in the Mutimbuzi commune, in the western part of Burundi, were the hardest hit with more than 3 300 displaced people in Gatumba and over 3 000 displaced people in Rukaramu.⁷⁸

Between May and December 2021, South Sudan battled widespread flooding that affected around 835 000 people, with Jonglei, Unity, and Upper Nile States the worst affected areas.⁷⁹ The flooding left 35 000 South Sudanese refugees in need of urgent assistance.⁸⁰ Many people were forced to move to higher grounds, which were rapidly overcrowded with makeshift structures.⁸¹ Many displaced people were not able to return to their homes until early 2022. Flood impacts, combined with ongoing conflicts, resulted in internal and cross-border displacements. In 2021, it was estimated that around 2 million South Sudanese were internally displaced, while an additional 2.3 million were refugees in neighbouring countries.⁸²

SOUTHERN AFRICA

In January 2021, Tropical Cyclone Eloise affected more than 467 000 people in the Southern African region.⁸³ In Mozambique, the provinces of Sofala, Manica, Zambezia, Inhambane, and Gaza were the hardest hit by Tropical Cyclone *Eloise*, as they were still recovering from Cyclone *Idai*, which struck in 2019. Strong winds and rains damaged over 8 700 shelters in more than 60 resettlement sites established in the aftermath of Cyclone *Idai*.⁸⁴ Over 43 000 people were internally displaced, and more than 34 500 people were evacuated. In Madagascar, the storm affected more than 1 000 people in the districts of Antalaha, Maroantsetra, Vavatenina, and Toamasina and displaced more than 500 people in the commune of Maroantsetra.⁸⁵

HEALTH

A cholera outbreak was declared in Niger and Nigeria during the summer of 2021. This outbreak resulted from flooding compounded by inadequate waste management, poor sanitary and sanitation practices, lack of drainage systems, and consumption of contaminated water.

From June 2021, Nigeria's cholera cases spread rapidly across the country, impacting 32 out of the 36 states. The outbreak affected more than 94 000 people, especially children between the ages of 5 and 14 years, and 3 300 people died. The case fatality rate was 3.5% higher than the annual outbreaks in the past four years.⁸⁶

In Niger, the first cases were observed in August 2021, in the Maradi region, close to the border with Nigeria. Between August and December 2021, more than 5 500 cases and more than 160 deaths were reported, with a case fatality rate of 2.9%.⁸⁷ Although cholera is endemic to the region, no cases had been observed in Niger since 2018. This incidence of cholera, therefore, reflects halted or possibly reversed progress towards the realization of healthy life targets (SDG 3).

Climate and socioeconomic development challenges

The African climate is already changing, and its impacts, already experienced by the population, will continue and increase without urgent adaptation and mitigation measures. Climate impacts delay and hinder progress on the continent in achieving economic prosperity (SDGs 1, 8, and 11), eradicating poverty and hunger (SDGs 1 and 2), and ensuring healthy lives (SDGs 2, 3, and 6).

AGRICULTURE AND FOOD SECURITY

Increased temperature has contributed to a 34% reduction in agricultural productivity growth in Africa since 1961. This is more than any other region in the world. This trend is expected to continue in the future, increasing the risk of acute food insecurity and malnutrition. A global warming of 1.5 °C is projected to be accompanied by a decline of 9% of the maize yield in West Africa, 20%–60% of the wheat yield in Southern and North Africa, and more than 12% of the catch potential of marine fisheries in several West African countries.⁸⁸

Climate change will have serious implications on jobs and work productivity. In the sub-Saharan region, 55%–62% of the labour force is employed in agriculture, largely rainfed-based. In this region, with a global warming of 3 °C, the work capacity in agriculture is projected to be reduced by 30–50% relative to the 1986–2005 period.⁸⁹

WATER RESOURCES

Climate change and variability lead to high fluctuations in lake levels and affect river discharge and groundwater recharge rates. In West Africa, the long-term decline in river flow is attributed to an increase in temperature, drought, and increased water demand.⁹⁰ This trend has severe implications for water-dependent sectors, such as hydroelectric power production, agriculture, and health, and for access to safe water.⁹¹ Limited water availability and water scarcity have also already shown to be sources of conflicts.

POPULATION DISPLACEMENT

The drivers of population displacement are complex and multi-faceted, and climate change is one of many interacting risk factors. Chronic floods and droughts, sea-level rise, and extreme weather events are all major drivers that influence displacement patterns within borders and across international borders. High water stress is estimated to affect about 250 million people in Africa and is expected to displace up to 700 million people by 2030.⁹² Climate-induced migration is likely to increase population density, create overcrowded areas, and contribute to the growth of informal settlements.⁹³ These factors escalate the risk of tensions and intercommunal conflicts.

It is essential to invest more in protection, prevention, preparedness, disaster risk reduction (DRR), adaptation, mitigation, resilience, policy engagement, legal guidance, and data collection and analysis, and also to reduce the environmental impact of refugee settlements and ensure sustainable responses. This includes supporting the implementation of the Agenda for the Protection of Cross-border Displaced Persons in the Context of Climate Change and Disasters, the Free Movement Protocols, the Paris Agreement, the Sendai Framework for Disaster Risk Reduction, the Global Compact on Refugees (GCR), and the Global Compact on Migration (GCM).

CITIES AND SETTLEMENTS

High population growth and the rapid urbanization of Africa have increased the exposure of people, assets, and infrastructure to climate and hydrological hazards.

By 2030, 108–116 million people in Africa are expected to be exposed to sea-level rise.⁹⁴ Sea-level rise will lead to more frequent coastal flooding, coastal erosion, and soil salinization due to seawater intrusion, thereby raising risks for Africa's coast settlements, economies, and ecosystems. Damages associated with sea-level rise in sub-Saharan countries could amount to 2–4% of the Gross Domestic Products (GDPs) by 2050.⁹⁵

Climate policy

The following section discusses the current status of African Nationally Determined Contributions (NDCs) to the Paris Agreement and the cost of their implementation. It also emphasizes the nexus between water resources and climate change and the need to implement water-related services, water management strategies and early warning systems to strengthen the resilience of African nations.

NATIONALLY DETERMINED CONTRIBUTIONS

The Paris Agreement is implemented through the NDCs, which guide national climate change responses and actions. As of March 2022, 194 Parties to the Agreement, 53 from Africa, had submitted an NDC. Out of those 53 African Parties, 43 had submitted an updated and revised NDC reflecting more substantial ambitions and more significant commitments for adaptation and mitigation to climate change.⁹⁶

ADAPTATION

A climate science-based approach to adaptation includes a country's capacity for climate analysis and delivery of climate services through institutions such as National Meteorological and Hydrological Services (NMHSs); this approach also helps a country to identify and select climate action priorities. In addition, monitoring the past, present, and projected future status of the climate enriches a country's ability to track climate conditions in local contexts. A climate science-based approach also contributes to formulating and implementing climate-related national policies, including the climate-sensitive objectives of the SDGs and the Sendai Framework for Disaster Risk Reduction.⁹⁷

In Africa, the majority of the Parties have mentioned agriculture and food security, water, health, and disaster risk reduction as top priority areas for adaptation (Figure 24 left). Revised NDCs have prioritized the health sector more than before and included gender mainstreaming issues. For example, Malawi has identified the need to integrate gender in climate change adaptation measures and to collect gender disaggregated data to track progress.⁹⁸

Most African Parties have aligned their adaptation efforts and activities with SDGs⁹⁹ related to ending poverty (SDG 1), zero hunger (SDG 2), good health and well-being (SDG 3), clean water (SDG 6), economic growth (SDG 8), responsible consumption and production (SDG 12), climate action (SDG 13), sustainable use of ocean, sea, and marine resources (SDG 14), and the terrestrial ecosystem (SDG 15) in their NDCs.

For example, the Ethiopian NDC is built on its Climate Resilience and Green Economy Strategy (CRGE), which has a goal of helping the country reach lower middle-income status (SDG 8). Kenya has strengthened the Blue Economy within its NDC to capitalize on its extended coastline and the inland water bodies and ecosystems within the country (SDG 14).

MITIGATION

Although Africa accounts for 2% to 3% of global greenhouse gas emissions,¹⁰⁰ 83% of the African NDCs submitted have included GHG reduction targets in their NDC mitigation component, according to a WMO analysis.

The commitments on emission reduction range from 22% for Uganda to 68.8% for Ethiopia, with reference to pre-defined baseline figures, mostly from 2010. Zimbabwe has increased its commitment from a 33% to a 40% reduction in per capita emissions compared to business as usual by 2030, conditional on international support. The sectors of energy, agriculture, waste, and land use, land-use change and forestry (LULUCF) have been defined as focus areas for mitigation (Figure 24 right).

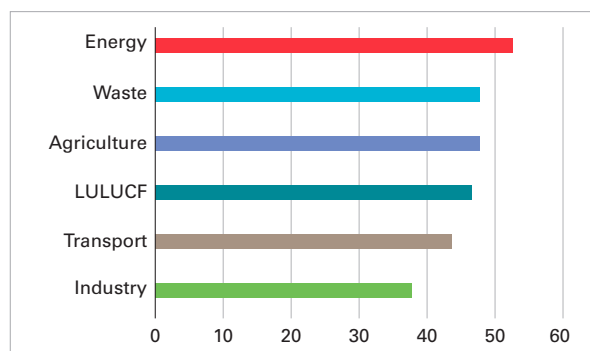
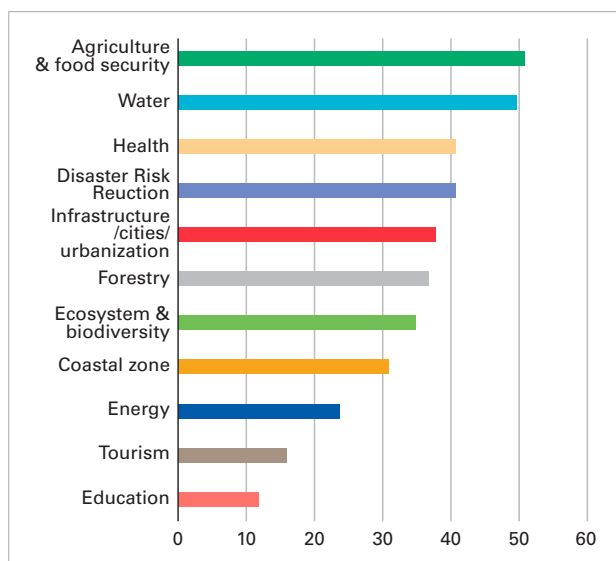


Figure 24. Priority areas for adaptation (left) and priority sectors for mitigation (right) in African countries' NDCs. LULUCF = land use, land-use change and forestry.
Source: WMO

The African continent has a significant and growing role in the global carbon cycle, with potentially important climate change implications. However, the sparse observation network in and around Africa shows that Africa is one of the weakest links in understanding the global carbon cycle. Deforestation is the largest contributor when it comes to tropical land use emissions,¹⁰¹ with Africa accounting for 25% to 35% of total tropical land clearing from deforestation in the last decades.^{102, 103} Furthermore, carbon losses through deforestation tend to be permanent in Africa, as afforestation and reforestation rates are modest, at less than 5% of annual deforestation.¹⁰⁴ Deforestation in Africa exacerbates the effects of climate change. It worsens the water crisis, intensifies the frequency and the impacts of floods, and significantly reduces rain as well as the ability of forests to absorb carbon dioxide, resulting in stored carbon being released into the atmosphere and further intensifying the ongoing global warming.

COST OF NATIONALLY DETERMINED CONTRIBUTIONS

Over 80% of African countries have identified a need for financial support from the international community to fully implement their NDCs. These resources are expected to materialize through capacity building and technology transfer, grants, and concessional loans, among other sources.

Based on the Africa NDC Hub, the total cumulative adaptation costs for the period 2020–2030 are estimated to be up to USD 407 billion for adaptation, and around USD 715 billion for mitigation.¹⁰⁵

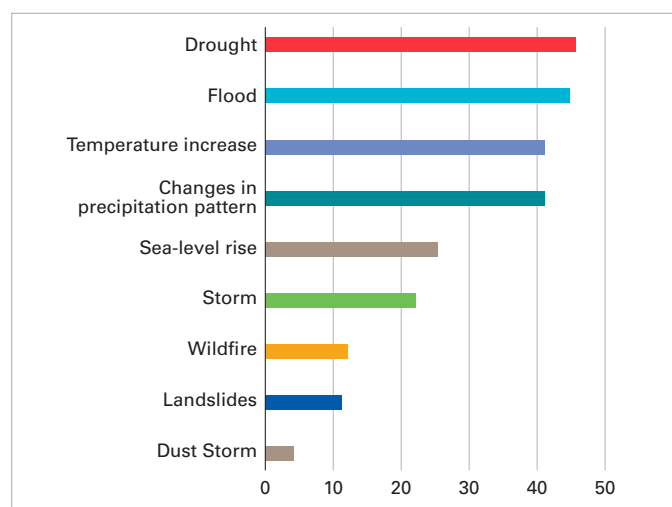


Figure 25. Hazards of highest concern as highlighted in the 53 African NDCs during the period 2016–2022
Source: WMO

HAZARD TYPES OF HIGHEST CONCERN

According to the NDCs, droughts and floods are the hazard types of highest concern for African Parties (Figure 25). Indeed, in the past 50 years, drought-related hazards have claimed the lives of over half a million people and led to economic losses of over USD 70 billion in the region.¹⁰⁶ More than 1 000 flood-related disasters have been reported, involving more than 20 000 deaths in Africa over this period.¹⁰⁷ It is estimated that by 2050, climate impacts could cost African nations USD 50 billion annually.¹⁰⁸

WATER-RELATED CLIMATE SERVICES CAPACITIES

As of June 2022, 44 African countries had completed the climate services checklist. Among these 44 countries, two provide climate services at an advanced level, nine at a full level, 17 at an essential level, 11 at a basic level, and five at a less-than-basic level. Some improvements can be seen compared to the 2017–2018 period. Indeed, three member countries moved from basic to essential, one from essential to full, and one from full to advanced.

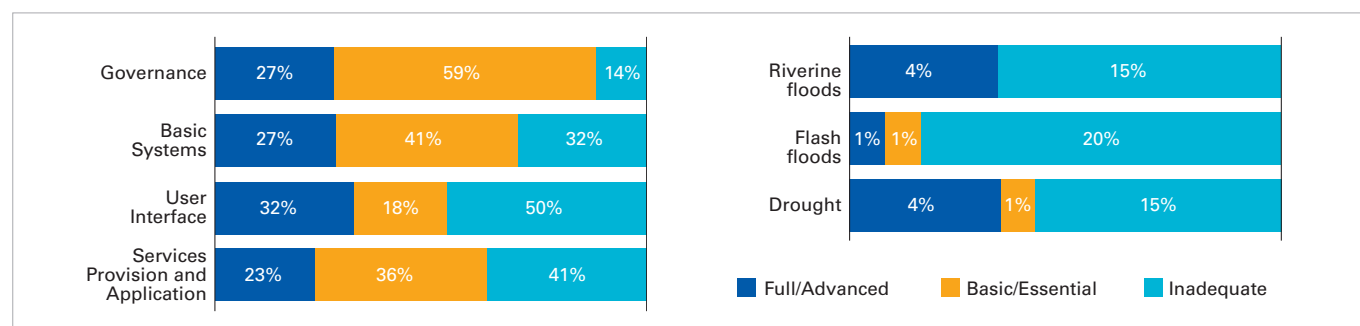


Figure 26. Percentage of WMO Members in Africa satisfying the components of the value chain (governance, basic systems, user interface, and services provision and application) (a total of 22 countries) (left). Number of WMO Members in Africa with early warnings available to the population at risk by hazard type (riverine floods, flash floods, and drought) (right). Note: For each hazard, the category Inadequate includes Members with no (0%) end-to-end early warning systems in place as well as Members with end-to-end early warning systems reaching no more than 33% of the population at risk; the category Basic/Essential includes Members with end-to-end early warning systems reaching 34–66% of the population at risk; and the category Full/Advanced includes Members with end-to-end early warning systems reaching 67–100% of the population at risk.
Source: WMO

Regarding the water sector, Africa still faces numerous capacity gaps in high-quality and reliable water-related climate services. Only 27% of African countries (22 countries) provide water-related climate services across the entire value cycle at a full/advanced level and only four countries provide end-to-end drought forecasting or warning services at a full/advanced capacity level (Figure 26).¹⁰⁹

Twenty-seven out of 51 African countries for which data are available have inadequate capacity to implement integrated water resource management (IWRM) elements effectively, and in 2020, many activities were undertaken on an ad hoc basis with unsustainable financing.¹¹⁰ Despite improvements over the past three years, four out of five African countries are unlikely to have sustainably managed water resources by 2030.¹¹¹

Around 418 million people still lack even a basic level of drinking water service, 779 million people lack basic sanitation services (including 208 million who still practice open defecation) and 839 million people still lack basic hygiene services. Achieving the SDG 6 targets in Africa will require a 12-fold increase in current rates of progress on safely managed drinking water, a 20-fold increase for safely managed sanitation and a 42-fold increase for basic hygiene services.¹¹²

Strategic perspectives

TOWARDS THE SUSTAINABLE USE OF WATER

Africa is already experiencing high levels of water stress and climate change, including changes in rainfall and temperature patterns likely to affect the availability of water resources.¹¹³ The chances of achieving the SDGs in Africa appear to be receding further unless concrete actions are taken to address key water-related concerns.

In rapidly growing African economies, increasing demands for freshwater supply to sustain population growth and the needs of the agriculture and industrial sectors now pose significant threats to water resource sustainability. Increased water stress and meeting future water demands will require increasingly difficult decisions about how to ensure access to water and sanitation (SDG 6). Securing water for communities, economies, and ecosystems is critical for poverty alleviation (SDG 1), green energy (SDG 7), and disaster risk reduction (SDG 11), as highlighted by targets of the Africa Water Vision 2025.¹¹⁴

Environmental alterations, such as detrimental land use practices, groundwater stress, and deforestation, along with political conflicts, tensions over management of transboundary rivers, inadequate infrastructure, and low adaptive capacity in many areas, make the African population particularly vulnerable to hydroclimatic variability and future changes in the water cycle.

Transboundary cooperation in mitigation and water resource management adaptation is crucial to prevent the negative impacts of unilateral measures and maladaptation. Transboundary cooperation can make mitigation and adaptation more effective through data exchange, enlarging the range and location of available measures, and sharing costs and benefits. Crop diversification and adopting more drought-resistant crop varieties are important adaptation strategies, bearing in mind the production technology adjustments that may be required. Developing countries and least developed countries (LDCs) should consider developing policies that encourage cost recovery, provide economic incentives to manage water efficiently, and induce private sector investment. Climate finance for water resource management and sanitation (for example, blue bonds and blue loans) support community climate resilience and job creation at the local level and help improve sustainable development outcomes.

IMPLEMENTING EARLY WARNING SYSTEMS

The [2021 State of Climate Services: Water](#) (WMO-No. 1278)¹¹⁵ report makes five strategic recommendations for improved water resources management and the implementation of early warning systems:

- In Africa, the rate of Multi-hazard Early Warning System (MHEWS) implementation overall is lower than the rate in other regions, and the last mile delivery of early warning systems needs attention, with only four out of 10 people covered.¹¹⁶
- Invest in end-to-end drought and flood early warning systems in at-risk LDCs, especially for drought warnings in Africa.
- Invest in Integrated Resources Water Management (IRWM) as a solution to better manage water stress, as 27 countries in Africa have inadequate capacity to effectively implement IRWM elements according to SDG 6 data from 2020.
- Fill the capacity gap in collecting data for basic hydrological variables which underpin climate services and early warning systems, as Africa is the WMO region with lowest coverage.
- Improve the interaction among national level stakeholders to co-develop and operationalize climate services with users to better support adaptation; for example, in the water sector 50% of WMO Members have an inadequate level of services. There is also a pressing need for better monitoring and evaluation of socioeconomic benefits, which will help to showcase best practices.

In addition, according to the [State of the Climate in Africa 2019](#) (WMO-No. 1253)¹¹⁷ report, standard operating procedures (SOPs) should be established to guide operational aspects in a clear and consistent manner prior to, during and after the disaster. SOPs should ensure that NMHSs and other government agencies responsible for disaster management and dealing with emergency situations and humanitarian issues have clearly defined roles and responsibilities. Warning messages need to be user-oriented and targeted to various audiences, clearly indicating potential impacts.

ESTABLISHMENT OF NATIONAL FRAMEWORKS FOR CLIMATE SERVICES

A National Framework for Climate Services (NFCS) is a coordination mechanism for consolidating and sustaining collaboration among national stakeholders and providers of climate information to co-produce and co-design user-tailored climate services at the national level and document their benefits. To date, 30 African countries have established, or are establishing, an NFCS. The current status of implementation varies from step 1 to step 5.¹¹⁸

Among these 30 countries, 21 are in the final stage of implementation (step 5), one is endorsing a strategic plan and costed action plan (step 4), seven are developing a national strategic plan and costed action plan (step 3), and one is in the first stage of assessment of the baseline on climate services capacities (step 1). Six other countries are planning to start the first step of assessing climate services capacities at the national level.¹¹⁹

Accelerating the establishment of NFCSs will strengthen stakeholder engagement and improve the development and delivery of climate services in support of governmental policies and strategies for dealing with climate change. Such climate services are crucial to support informed decision-making, spur growth in socioeconomic sectors, and enhance the resilience of African countries to cope with climate-related risks and impacts. These services could include regular climate monitoring, operational climate prediction and the provision of early warnings at the national and sub-national levels.

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Method and data sets

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TEMPERATURE

• *Gridded data*

Six data sets (cited below) were used in the calculation of regional temperature. Regional mean temperature anomalies were calculated relative to 1961–1990 and 1981–2010 baselines using the following steps:

1. Read the gridded data set;
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 over land 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 1981–2010;
6. Subtract the 30-year period average from each year to obtain anomalies relative to that base period.

Note that the range and mean of anomalies relative to the two different baselines are based on different sets of data, as anomalies relative to 1961–1990 cannot be computed for ERA5, which starts in 1979.

The following six data sets were used:

HADCRUT5 ANALYSIS

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HadCRUT.5.0.1.0 data were obtained from <http://www.metoffice.gov.uk/hadobs/hadcrut5> on 24 October 2021 and are © British Crown Copyright, Met Office 2021, provided under an Open Government License, <http://www.nationalarchives.gov.uk/doc/open-government-licence/version/3/>.

NOAAGLOBALTEMP

Zhang, H.-M.; Huang, B.; Lawrimore, J. et al., NOAA Global Surface Temperature Dataset (NOAAGlobalTemp), Version 5.0. NOAA National Centers for Environmental Information. doi:10.7289/V5FN144H. 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://journals.ametsoc.org/view/journals/clim/33/4/jcli-d-19-0395.1.xml>.

GISTEMP V4

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

PRECIPITATION

- ***Gridded data***

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- ***In situ data***

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

SEA-SURFACE TEMPERATURE

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*, 1609-1625. [https://doi.org/10.1175/1520-0442\(2002\)015<1609:AIISAS>2.0.CO;2](https://doi.org/10.1175/1520-0442(2002)015<1609:AIISAS>2.0.CO;2).
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SEA LEVEL

Regional sea level trends are based on gridded C3S altimetry data averaged from 50 km offshore to the coast by the Laboratory of Space Geophysical and Oceanographic Studies (LEGOS).

DROUGHT

Drought data are provided by retrospective and real-time NOAA NCEP Climate Prediction Center (CPC) Gauge - OLR Blended (GOB) daily precipitation analysis

CLIMATE SERVICES

WMO Analysis of NDCs

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

[WMO Hydrology Survey, 2020](#)

[2020 State of Climate Services: Risk Information and Early Warning Systems](#) (WMO-No. 1252)

[2021 State of Climate Services: Water](#) (WMO-No. 1278)

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- 6 The uncertainty in the trends is larger for the earlier two periods than for the latter two periods; this is not necessarily well described by the spread of the data sets.
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