Global Water Monitor

2023 SUMMARY REPORT

Global Water Monitor Consortium

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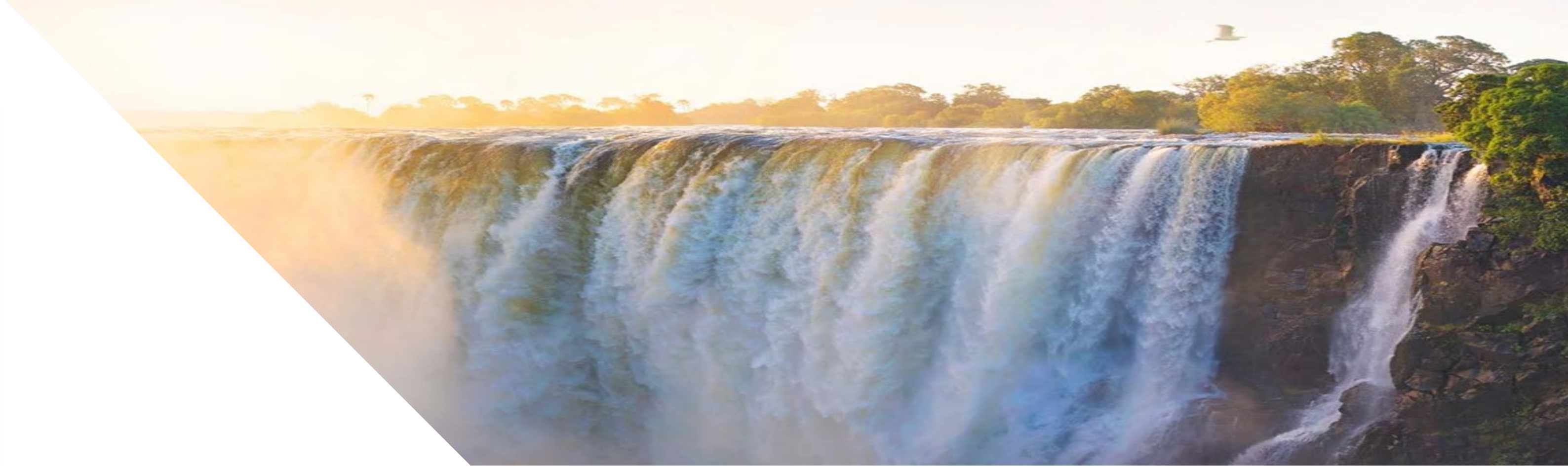
Front cover image: satellite image of cyclone Freddie, likely the longest-lived cyclone in recorded history, strengthening over the Mozambique Channel



Preface

Our global water resources are under pressure. The growing world population needs more and more water for agriculture, industry and households, while global warming is changing both rainfall patterns and the water requirements of plants, people and ecosystems.

2023 was the hottest year on record and this also affected the water cycle in various ways, from intensifying cyclones and other rainfall systems, to exacerbating drought and fire activity.

More than ever, we need information on the current state of the water cycle. Unfortunately, the global measurement network is in decline, and much of the remaining observations are not publicly available. Earth-observing satellites help fill gaps in our knowledge by measuring the atmosphere and the Earth's surface.

The Global Water Monitor Consortium brings together several public and private research and development organisations that share a goal of providing free, rapid and global information on climate and water resources.

Over the years, the partners have developed methods to combine and interpret water measurements made at thousands of ground stations and dozens of satellites orbiting the Earth. They use these to produce up-to-date information on different components of the water cycle.

Recently, they teamed up to provide comprehensive climate and water information via the Global Water Monitor (www.globalwater.online), an online data explorer that unlocks an extraordinary trove of climate and water data to anyone interested, free of charge. The development of the Monitor makes it possible to report on the state of our global water resources within a few days of the event. We produced this second annual report to use and demonstrate that capacity.

Last year's report included information on precipitation, air temperature and humidity, soil water availability, river flows and water volumes in natural and artificial lakes. This year, we have also added information on daily extreme precipitation and temperatures, terrestrial water storage, surface water extent, and vegetation condition.

This report summarises the state and any trends in the global water cycle in 2023. It also examines the most important hydrological events of the year. These included a relatively high number of natural disasters, many of which were found to be exacerbated by global warming. The events of 2023 show how ongoing climate change is impacting our planet and lives more with every passing year and reinforce the urgent need to dramatically reduce fossil fuel emissions.

7 January 2024

Albert van Dijk

Professor of Water Science and Management, Australian National University
Chair, Global Water Monitor Consortium

Summary

Record temperatures across most of the world in 2023 also affected water resources and water-related hazards. Heatwaves contributed to deepening and new droughts in South America and Canada. There were many extreme rainfall events including several tropical cyclones.

About this report

The Global Water Monitor provides free, rapid and global information on climate and water resources. This summary report contains information on rainfall, air temperature, humidity, soil and groundwater conditions, vegetation access to water, river flows, flooding, and lake volumes in 2023. Trends in the water cycle and some of the most important hydrological events of 2023 are interpreted and discussed.

Global summary

Key aspects of the water cycle in 2023 over the global land area were:

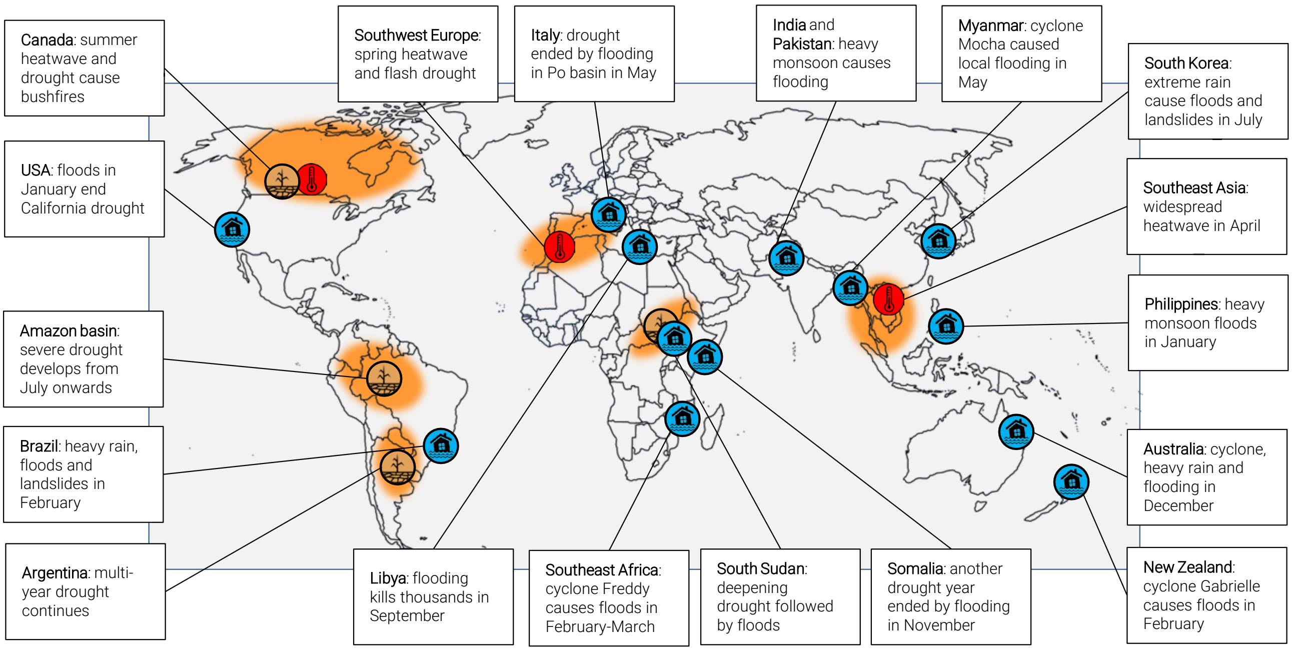
- *Precipitation* was close to average. There does not appear to be a clear trend towards more monthly high or low rainfall extremes.
- Average *temperature* was the highest recorded globally and in 77 countries. The frequency of record-warm months was also the highest observed.
- Relative *air humidity* was the second lowest on record, continuing a trend towards drier average and extreme conditions. Drier-than-normal conditions prevailed nearly everywhere.
- Despite warmer and drier conditions, high annual *soil water* conditions were observed in many regions.
- *Vegetation vigour* was the highest since 2001, continuing a steady increase over the last decades
- *Surface water* occurrence from water bodies and flood events was the second lowest in two decades, but months with record high water occurrence appear to be increasing globally.
- *River flows* were slightly lower than the previous year. Record high river flows appear to be getting more common, and record low flows less common.
- *Lake volumes* have been increasing over recent decades. High storage records are broken more often.
- Many dry and wet records in *terrestrial water storage* - combining all parts of the terrestrial water cycle - were broken in 2023, despite several missing months of missing data.

Regions in Focus

The global water cycle in 2023 was influenced by a change in circulation and ocean water temperatures in the Pacific Ocean from La Niña to El Niño conditions but against a backdrop of overall increasing sea surface temperatures due to global warming. The higher temperatures increase the strength and rainfall intensity associated with storm systems such as tropical cyclones. There were a relatively large number of such events in 2023, and the human and economic toll was large.

The year started with continuing heavy rain and flooding in the Philippines and the western USA. In February, cyclonic storm systems hit Madagascar, Malawi and Mozambique in southeast Africa, while heavy rain caused floods and landslides in southeastern Brazil. In April, southeast Asia was hit by a large-scale heatwave, followed by cyclone Mocha in Myanmar. The first half of the year also saw extremely dry conditions in northern Argentina and nearby regions and in southwestern Europe.

Major water-related events in 2023



In May, record dry conditions in northern Italy were abruptly ended by heavy rainfall and flooding. An extremely wet season in South Korea, India and Pakistan brought landslides and flooding between June and August, while in Canada, very dry and hot conditions caused a record wildfire activity. From July onwards, very dry and recurrent hot conditions across South America led to a rapidly developing drought in the Amazon basin that intensified during the second half of the year.

In September, a Mediterranean cyclone or 'medicane' brought heavy rainfall to Greece and caused reservoir dams to fail in Libya, killing thousands. In November, several years of deepening drought in Somalia were interrupted by heavy rainfall and flooding, while nearby South Sudan largely remains in drought. The final weeks of 2023 brought severe storm systems with heavy rains and flooding to the northeast coast of Australia.

Outlook for 2024

At the start of 2024, the greatest risk of developing or intensifying drought appears to be in Central and South America (except southern Brazil and Uruguay), southern Africa and western Australia. Regions unlikely to develop drought for at least several months include the Sahel region and the Horn of Africa, northern Europe, India, China and southeast Asia, and southern Brazil and Uruguay.

Contents

Measuring and Interpreting Change

How do satellites measure water?

Since the first Earth-observing satellite was launched sixty years ago, satellite remote sensing has become a crucial part of weather observation and forecasting systems worldwide. In more recent decades, the use of satellites to observe water at and below the Earth's surface has developed into practical solutions. Ideally, satellite measurements are calibrated to on-ground measurements where they exist to increase their accuracy. Once calibrated, they can provide information much faster, over much larger areas and with much greater detail than the on-ground measurement network alone.

All data discussed in this report were developed using methods that have been published:

Precipitation and **weather** data are estimated by combining the latest satellite observations with all globally available weather station data and information from weather forecasting models[1]

Soil water is interpreted from measurements by passive and active satellite microwave (radar) instruments and made available by the EU Copernicus Climate Data Store[2]

Surface water occurrence, including lakes, rivers and other forms of (temporary) inundation was mapped using NASA's MODIS satellite imagery[3].

River flows are estimated by automated measurement of river width in satellite imagery[4]

Lake and reservoir storage data are estimated by combining satellite measurements of surface water level and extent with topography[5].

[1] Beck et al., Bulletin American Meteorological Society, 2022 (link)
[2] Copernicus Climate Data Store (link, v202012 combined product)
[3] NASA and USGS Earth Data (link)
[4] Hou et al., Remote Sensing of Environment, 2022 (link)

Vegetation vigour (NDVI) responds to water availability and is observed by NASA's MODIS satellites[3].

Terrestrial water storage, including groundwater, soil water, surface water, snow and land ice, are derived from gravity measurements by the GRACE satellites[6].

The Global Water Monitor data explorer

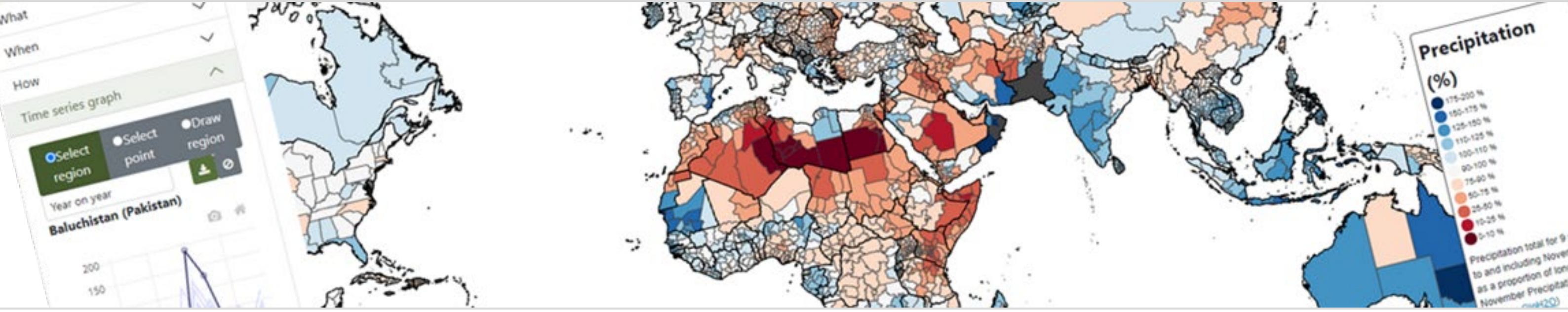
The key objective of the Global Water Monitor is to make up-to-date, global and accurate climate and water information freely available and easily accessible. We developed a visual data explorer, the Global Water Monitor (www.globalwater.online). All data shown in this report are directly derived from that website and, therefore, can be reproduced or examined in more detail. Users can retrieve and visualise maps or time series for any location, administrative hydrological region or hand-drawn area. Some background on the calculations and interpretations available and as used in this report is provided below.

Understanding Anomalies

The 'normal' range of climate and water conditions varies worldwide, from arid deserts to tropical monsoon regions and frozen poles. Percentages and anomalies are insightful ways of comparing actual values to the distribution of values for the same area and time of year in the historical record. The metrics available in the Global Water Monitor and used in this report are:

Anomaly or absolute difference from mean provides information on the departure from long-term average conditions. For example, rainfall in a particular period (e.g., March to September) may be 100 mm more than the average for the same period in all previous years.

[5] Hou et al., Hydrology and Earth System Sciences, 2022 (link)
[6] Boergens et al. (2019) (link), also available from GraVIS (link)



Percentage of the mean puts the same information in a relative context. For example, the same 100 mm difference would be 110% of (or 10% above) a longer-term average value of 1000 mm.

Standardised anomaly or sigma value is a useful means to compare the actual conditions to previous years in a way that accounts for the year-to-year variation experienced historically. It is calculated by dividing the actual anomaly by the standard deviation of values in previous years. Below is a general interpretation of the colour scale used in most maps in this report. Extremely high or low values often coincide with record values in the time series, but that is not automatically the case.

Sigma (σ)	Description*
> 4.0	*extremely high*
3.0 – 4.0	*extremely high*
2.0 – 3.0	*unusually high*
1.0 – 2.0	*high*
0.50 – 1.00	*above average*
-0.50 – 0.50	*near average*
-1.0 – -0. 50	*below average*
-2.0 – -1.0	*low*
-3.0 – -2.0	*unusually low*
-4.0 – -3.0	*extremely low*
< -4.0	*extremely low*

*Colour legend and interpretation of standard anomalies. *) colours are reversed for air temperature to be more intuitive*

Summarising by country or catchment

Summaries were calculated by **country** as defined by the International Organisation for Standardization (ISO 3166-1). They include fully independent countries and dependent administrative regions with varying degrees of autonomy. In the Global Water Monitor, summary data are also available for the next lower level of administrative regions within each country provided by ISO (e.g., states and provinces). We imply no political statement by using the current ISO list.

Many of the world's **river basins** cover more than one country. In those cases, country statistics do not provide a complete picture of water resource conditions across the river basin. Conversely, large countries may contain multiple river basins with different conditions. Therefore, summaries were also calculated by river basin. In the case of islands and coastal regions with multiple small catchments, river 'basins' can be a series of bordering catchments. In the Global Water Monitor, summary data are also available for individual smaller catchments within basins.

Limitations

Where there are no gaps in the data, averages across countries or catchments can be calculated without problems. Where there are some missing data, they can be estimated. However, where most data is missing, calculated averages can be misleading.

Summarising storage in lakes by country or basin is straightforward in principle, as they can be added up. However, not all water bodies are measured all the time, and gaps in the data need to be estimated.

Summarising river flows by country or catchment is challenging. For example, many countries contain multiple rivers. We selected the fifteen river observation locations with the largest long-term average flows within the country or catchment and calculated a weighted average value. By its very nature, averaging over years and regions can hide locally severe conditions or extreme events that occur over short periods. This should be kept in mind when interpreting the information.

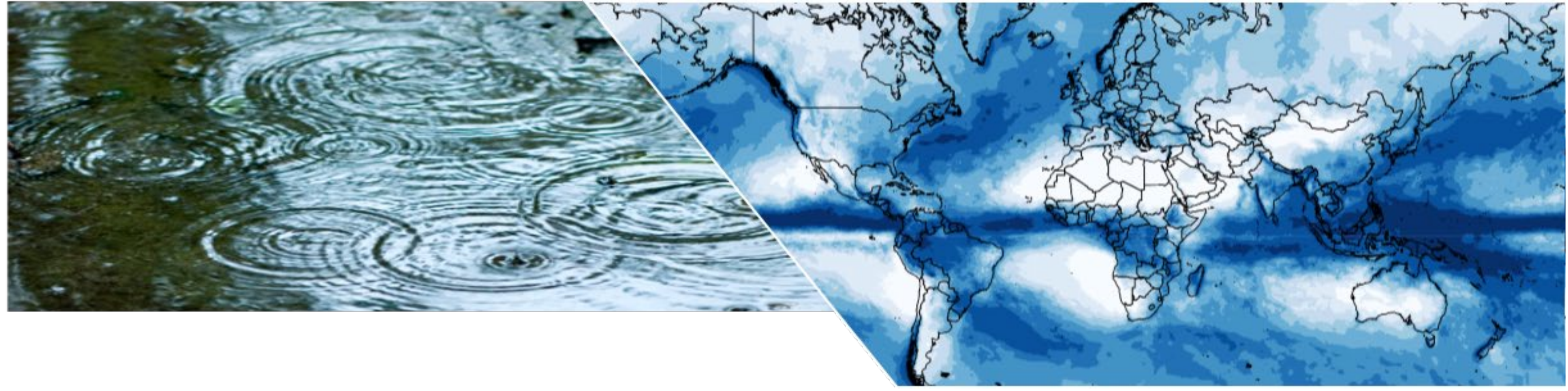
Satellite instruments can provide a near-immediate global overview of climate and water conditions, but they are not perfect. Where they are available, onsite observations are usually more accurate and necessary to calibrate remote sensing approaches like those used here. Protecting and expanding the remaining water measurement station network should be a priority.

Record length, frequency and spatial detail vary between data sources. For example, climate data are available from 1979, water body data from 1984, soil water data from 1991, river flow data from 2000, and terrestrial water storage data from 2002 onwards.

Even satellite observations are unavailable in some regions and at some times. For example, soil water observations are only possible if the soil is not frozen or covered with dense forest, and surface water and vegetation observations require daylight and clear skies. In the case of climate data, data gaps are filled by weather models with their own uncertainties.

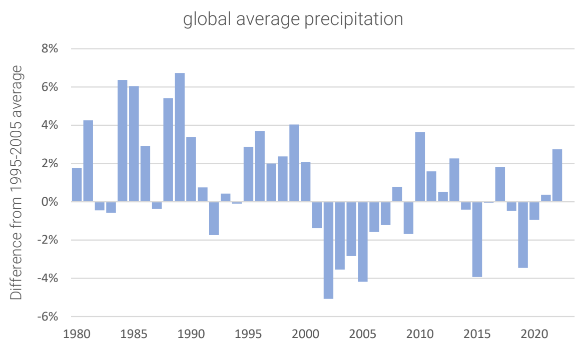
Efforts were made to confirm the interpretation of the data using background research, but the above limitations should be kept in mind when reading this report. Anyone inclined to take action based on the information presented here should first consult the relevant local or national agencies.

Global Summary

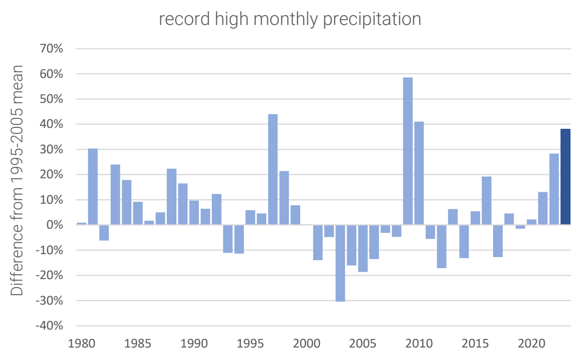


Precipitation

Global precipitation was close to average. There does not appear to be a clear trend towards more monthly high or low rainfall extremes.



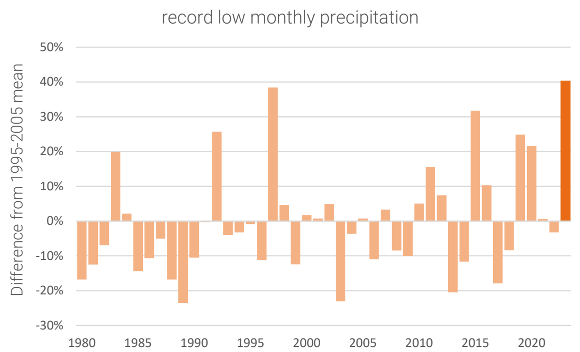
Annual precipitation over land relative to the average for 1995-2005



The number of times high monthly precipitation records were broken compared to the average for 1995-2005

Average precipitation over the global land area was identical to the average for 1995-2005. There does not appear to be evidence for a trend in global average precipitation.

The number of record high monthly precipitation totals in the 4687 river catchments worldwide was the highest since 2010 and 38% higher than around 2000 (1995-2005). Nonetheless, there is little evidence for a long-term global trend towards more high monthly rainfall records. However, research has found that increasing trends in extreme precipitation over shorter periods (five days or less) have become more common than decreasing trends[7]. This would be expected to increase the risk of local flash floods.



The number of times low monthly precipitation records were broken compared to the average for 1995-2005

The number of record low monthly precipitation totals was the highest on the record and 40% higher than the average around 2000. There does not appear to be a strong long-term trend at global scale.

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[7] *Seneviratne et al. (2021) Weather and Climate Extreme Events in a Changing Climate. In: Climate Change 2021: The Physical Science Basis, pp. 1513-1766, doi:10.1017/9781009157896.013*

Global patterns

Global precipitation patterns were dominated by high sea surface temperatures and a change from neutral to El Niño conditions in the second half of the year[8]. Total precipitation in 2023 was unusually high in some regions at high northern latitudes (including Arctic Canada and parts of northern Europe), the Arabian Peninsula, the Horn of Africa, south Asia and the Himalayas, and some smaller regions. Rainfall was unusually low in the southern half of Canada, Central America, the north and east of South America, the western Mediterranean, and Central Asia.

Precipitation by country

Annual rainfall was unusually low in Mexico, Turkmenistan and Marocco (∝-2). Annual rainfall was also well below average in Canada, western North Africa, and in Central Asia.

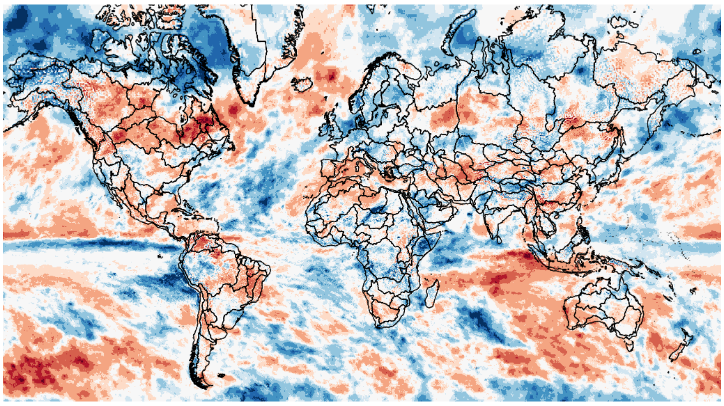
The highest annual rainfall total since 1979 was recorded for four countries and territories in Europe (including Denmark in Austria). Unusually wet conditions also occurred in elsewhere in Europe, and in Gabon and Sierra Leone in Africa, as well as some smaller island territories.

Precipitation by river basin

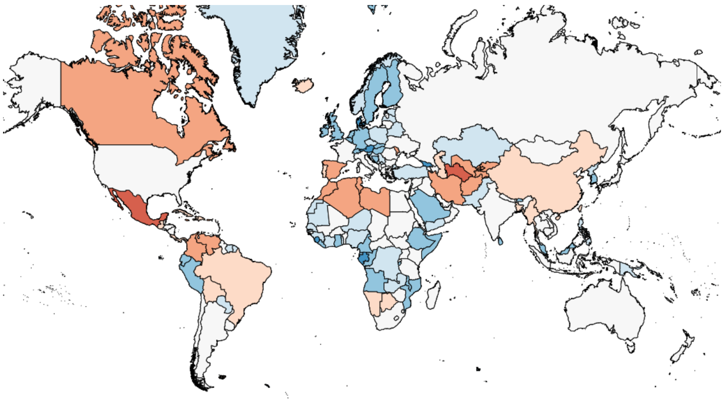
The lowest annual rainfall since 1979 was recorded for six river basins in Canada (including the Mackenzie, Nelson and Churchill Rivers), the Sao Francisco River in eastern Brazil, along the Central American coast, the Aral Basin in Central Asia. Rainfall was also unusually low along the eastern Caspian Sea coast.

Record high annual precipitation was observed in several Arctic basins, as well as river catchments in Sweden and the Tibet Plateau. Rainfall was also unusually high in coastal catchments in Central Africa, the Horn of Africa and the northern Arabian Peninsula.

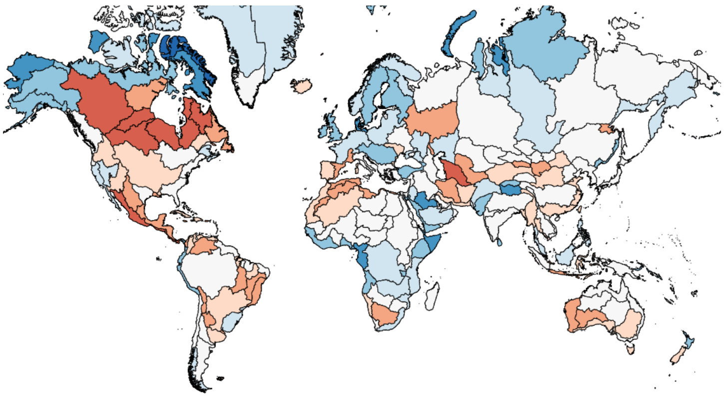
Standardised anomaly in annual precipitation (see p.8 for legend)



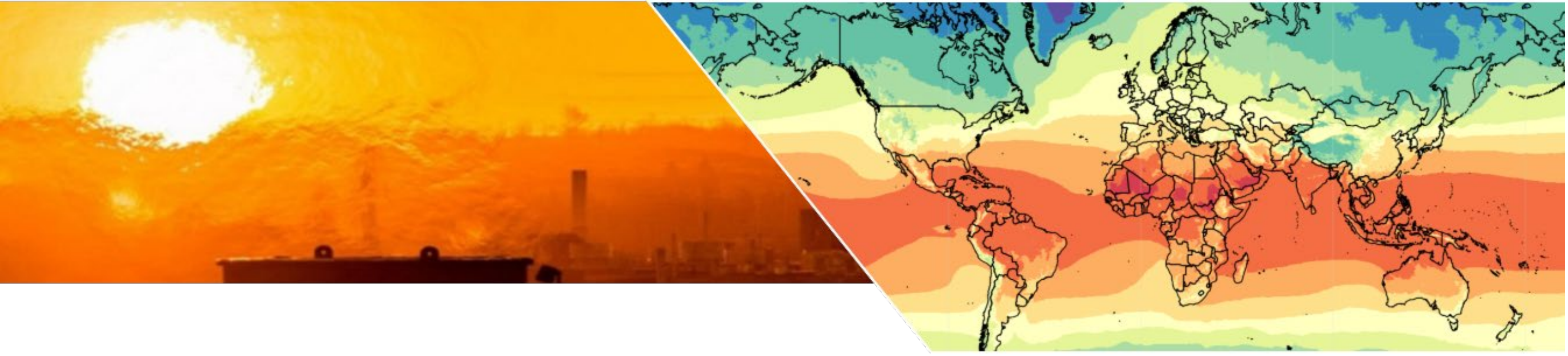
By country



By river basin

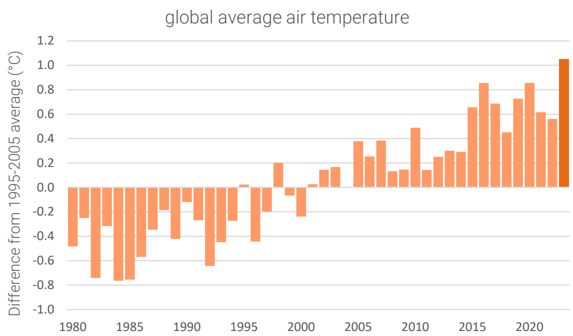


[8] NOAA, 2023 (link)

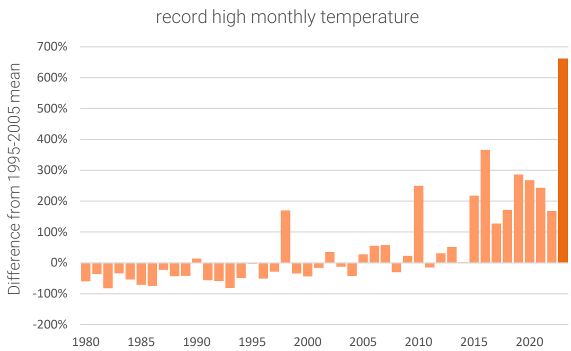


Air temperature

Average temperature over land was the highest recorded globally and in 77 countries. The frequency of record warm months was also the highest observed.



Annual average temperature over the global land area compared to the average for 1995-2005.

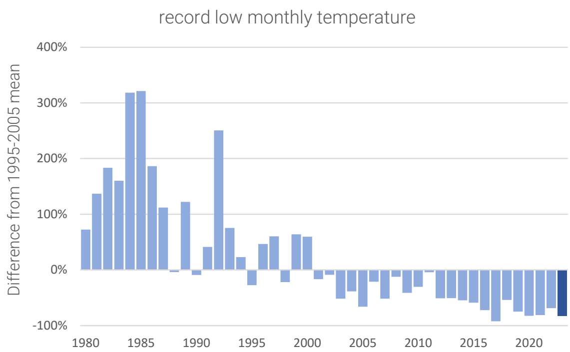


The number of times high monthly average temperature records were broken compared to the average for 1995-2005.

Globally, 2023 was the hottest year on record. Air temperature across the global land area was 1.1°C above the 1995-2005 average.

The number of record high monthly average temperatures in the 4687 river catchments worldwide was the highest in 45 years – almost eight times (+662%) the 1995-2005 average. Record high average temperatures were observed across all seasons. There is a very clear and rapid trend towards more record-breaking monthly average temperatures globally.

The number of record low monthly average temperatures was much (-82%) below the 1995-2005 average for the 23rd year in a row. There is a clear long-term trend with few record-breaking low monthly average temperatures globally in recent years.



The number of times low monthly temperature records were broken compared to the average for 1995-2005.

Global Patterns

Annual average temperature was unusually high almost everywhere. Among the few exceptions were the western USA, Scandinavia, western India, northern Australia, the far south of South America and parts of the Arctic region.

By country

More than 77 countries experienced the highest average annual temperature in 45 years. Extremely high average annual temperatures were recorded for Bolivia in South America, Djibouti in the Horn of Africa and some island territories in the Caribbean and Pacific Ocean.

The strongest absolute temperature deviation was measured for Canada, where the average annual temperature was 2.2°C above the long-term (1979-2022) average.

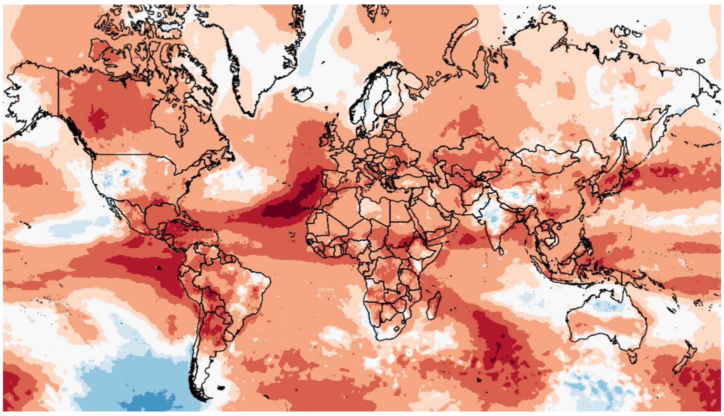
New Caledonia was the only countries to experience very slightly (0.06°C) below-average temperatures in 2023.

By river basin

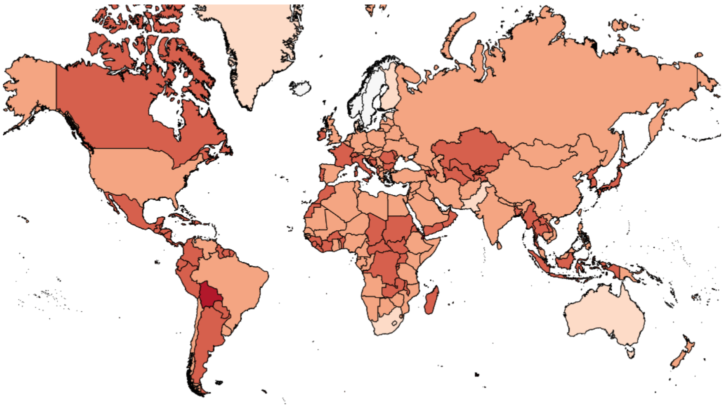
Average annual temperatures in 2022 were unusually high in almost all catchments worldwide. Average temperature was extremely high in the Salinas Grande basin in central South America and the Canary Islands.

Temperatures were only near or slightly below average in the western USA, the southern cone of South America, the Sabarmati Basin in India, the Tibet Plateau and in Scandinavia.

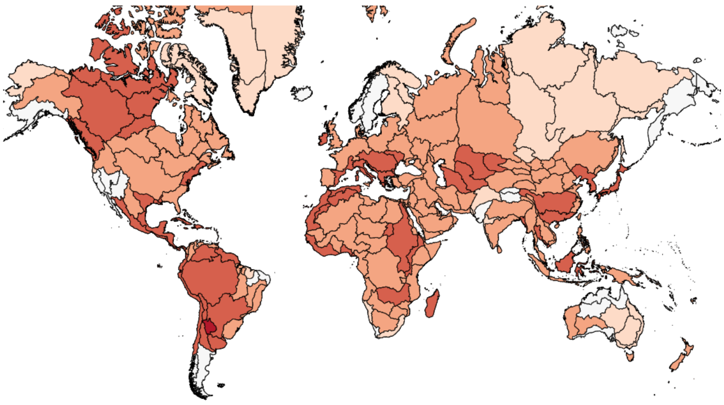
Standardised anomaly in annual average air temperature (see p.8 for legend - note the colour scale is reversed for temperature, with red showing higher temperatures)



By country

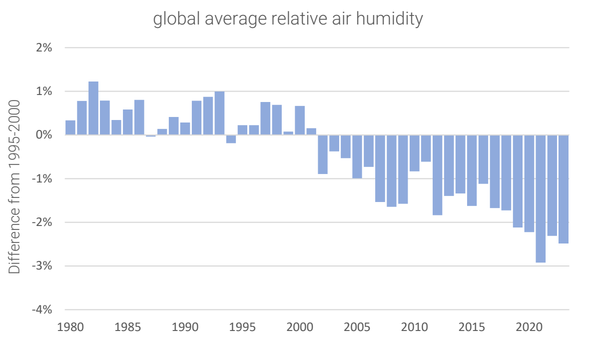


By river basin



Air humidity

Air humidity over land was the second lowest on record, continuing a trend towards drier average and extreme conditions. Dry conditions prevailed nearly everywhere.

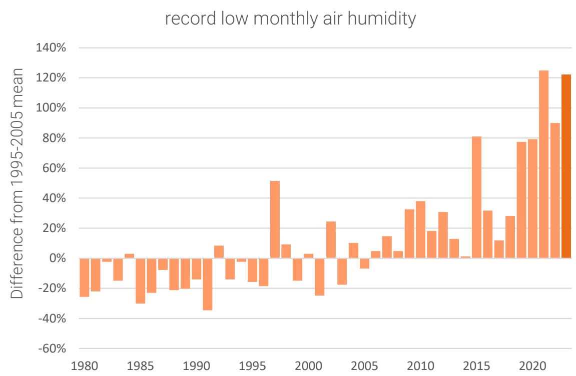


Annual average air humidity over the global land area compared to the average for 1995-2005

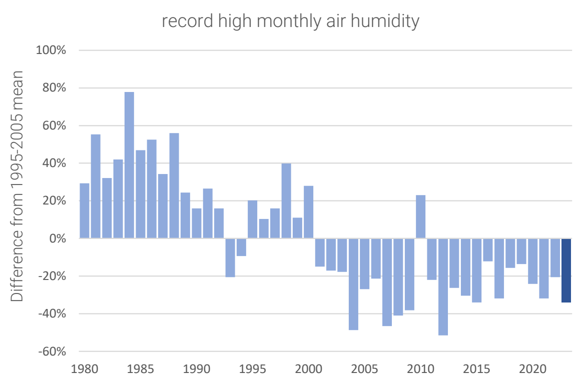
Relative air humidity over the global land surface in 2023 was the second driest on record after 2021 and 2.5% lower than the 1995-2005 average value. There has been a steady trend towards drier air, attributed to a more rapid rise in air temperature over land than over sea[9].

Months with record low average air humidity in the 4687 river catchments worldwide were the most numerous in 45 years, and 2.2 times (+122%) more frequent than the 1995-2000 average. There appears to be a strong trend towards more months with record-low relative air humidity. Low air humidity exacerbates the impacts of drought on ecosystems and people and increases the risk and severity of bushfires.

In contrast, the number of months with record high average air humidity was below the 1995-2005 average for the 23rd year in a row, by 34%. There is evidence for a decline in record-high humidity.



The number of times low monthly air humidity records were broken compared to the average for 1995-2005



The number of times high monthly air humidity records were broken compared to the average for 1995-2005

[9] *Seneviratne et al. (2021) Weather and Climate Extreme Events in a Changing Climate. In: Climate Change 2021: The Physical Science Basis, pp. 1513-1766, doi:10.1017/9781009157896.013*

Global patterns

Annual average air humidity was below average across most of the land area. Exceptions occurred in parts of North America, Africa, the Middle East and South Asia. The lowest humidity was observed over the Amazon, Spain and western North Africa, Central Asia and parts of Russia and Indonesia

By country

A total of 20 countries and territories experienced unusually low air humidity (σ<-2) in 2022. They include Russia, Turkmenistan and Uzbekistan in Central Asia, five countries and territories in the Caribbean, five in South America (including Brazil), three in North-Africa, Sudan and South Sudan in Eastern Africa. Extremely low humidity (σ<-3) was observed in Panama in Central America.

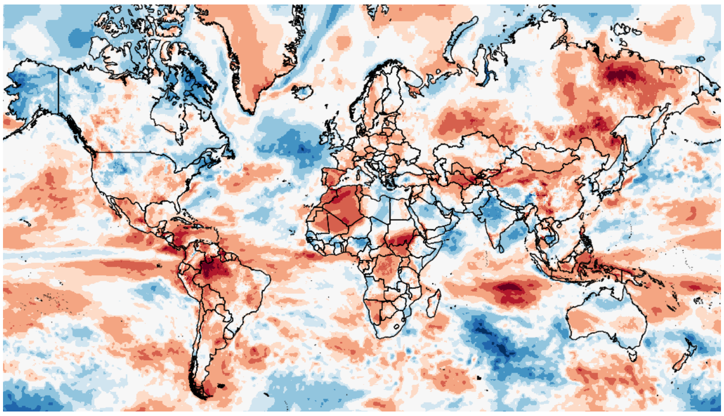
In contrast, record high humidity occurred in Sri Lanka, while unusually high humidity was also observed Cambodia.

By river basin

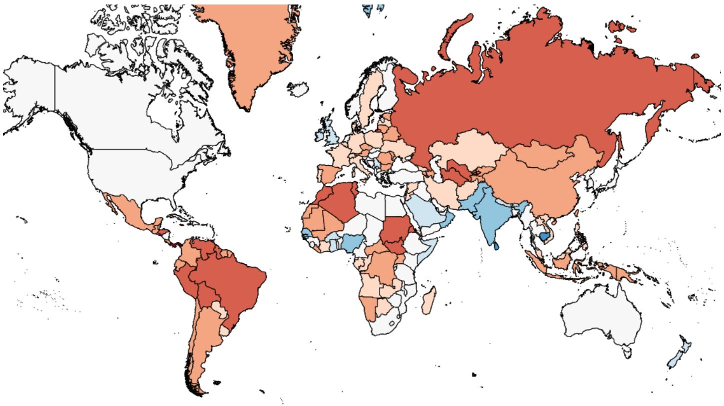
Annual average relative air humidity in 2023 was extremely low in the Amazon River basin, along the southwestern Mediterranean coast and along the northeast coast of Siberia. Air humidity was also unusually low in the Orinoco, Nile and Lena rivers basins, in and around the Caribbean, in western North Africa and the interior of China.

The highest humidity in the time series was recorded for Sri Lanka, the Sabarmati River basin in India, the island of Socotra near the Horn of Africa and along the Arctic coast of Alaska. Humidity was also unusually high in some catchments along the northern coat of Canada and the North Island of New Zealand.

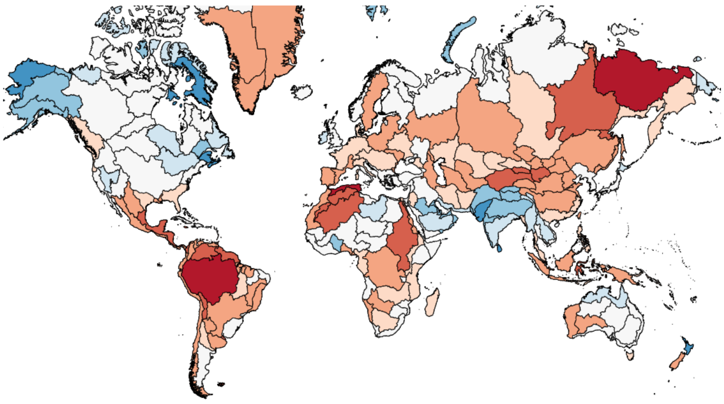
Standardised anomaly in annual average air humidity (see p.8 for legend)

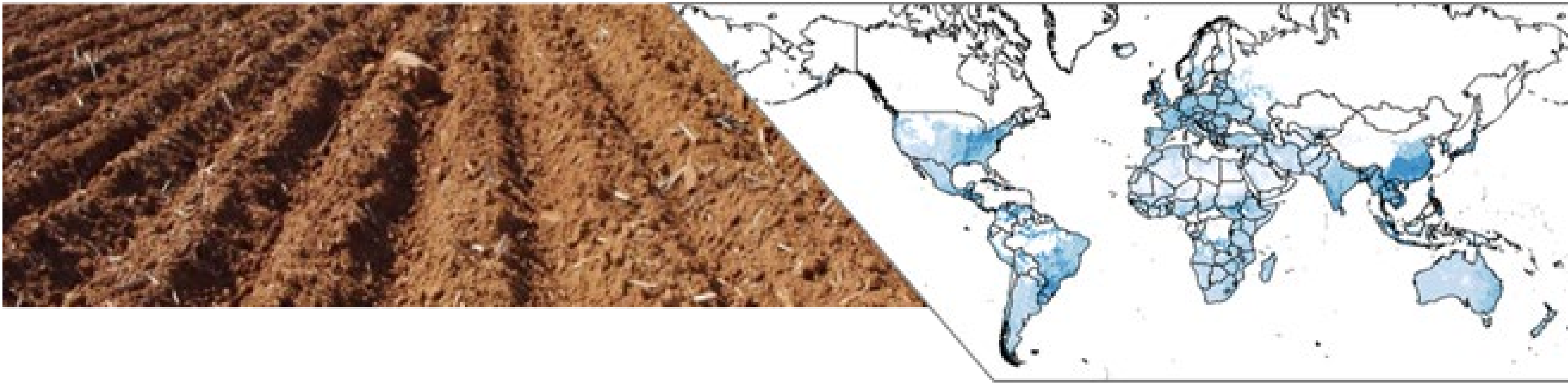


By country



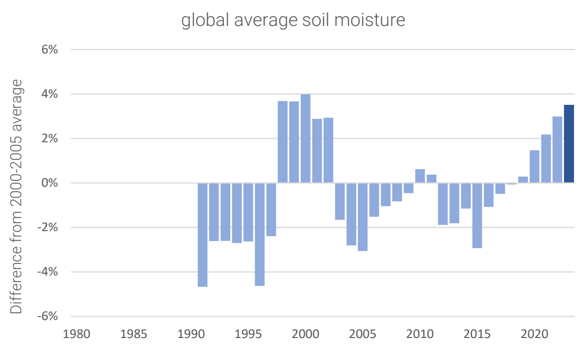
By river basin





Soil water

Despite warmer and drier conditions, high annual soil water conditions were observed in many regions.

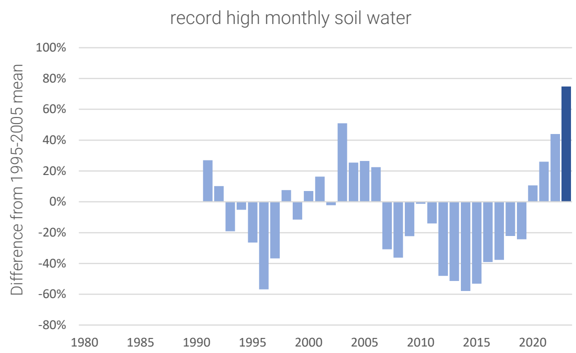


Annual soil water content over the global land area compared to the average for 1998-2021.

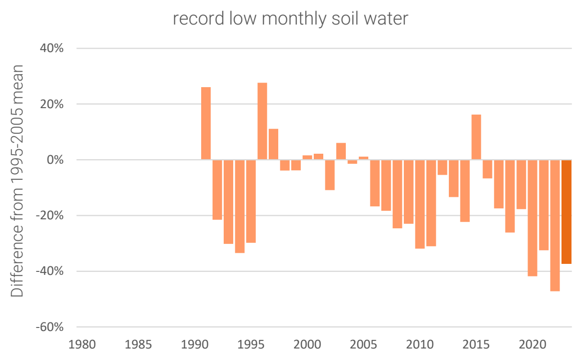
Soil water content over the land area was 3.5% above the 1998-2005 average. The change towards wetter global soil water conditions during the last three La Niña years continued in 2023. Global average soil water conditions appear to oscillate slightly over time, without a clear long-term trend.

The number of months with record high average soil water conditions in 4687 river catchments was 75% above the 1998-2005 average and the highest since observations started in 1991. There appears to be emerging evidence for a long-term increasing trend since around 2014. Countries contributing most to the increasing trend include India, China, Turkey and several Sahel countries. These trends do not always coincide with annual rainfall trends. However, satellite instruments measure soil water near to the surface only, which can respond more to rainfall frequency than total amount and can also be affected by agriculture and vegetation changes.

Conversely, months with record low soil water were 37% below average. There appears to be a trend towards fewer record dry soil observations. This trend does not correspond with declining trends in rainfall and air humidity but does correspond with increasing river flows and lake storage and vegetation in many regions (see next sections)[10]. The record combines a series of satellite instruments and inconsistencies between sensors may cause some of the shifts.



The number of times high monthly soil water records were broken compared to the average for 1995-2005.



The number of times low monthly soil water records were broken compared to the average for 1995-2005.

10 *e.g., Liu et al. (2015) Nature Climate Change 5, 470-474*

Global patterns

Spatial patterns in annual soil water anomalies in 2023 mostly reflected rainfall patterns, with relatively wet soils across Europe, South and Eastern Asia, the western USA and Northern Australia. There may be a connection with recent increases in vegetation cover and agricultural expansion in some of these regions.

Very dry soil conditions occurred in Central Asia, the western Mediterranean, the south of South America and in some regions in high northern latitudes.

By country

Annual average soil water content was unusually low ($\sigma<-2$) and/or the lowest since 1991 in Tunesia in North Africa and in Turkmenistan in Central Asia.

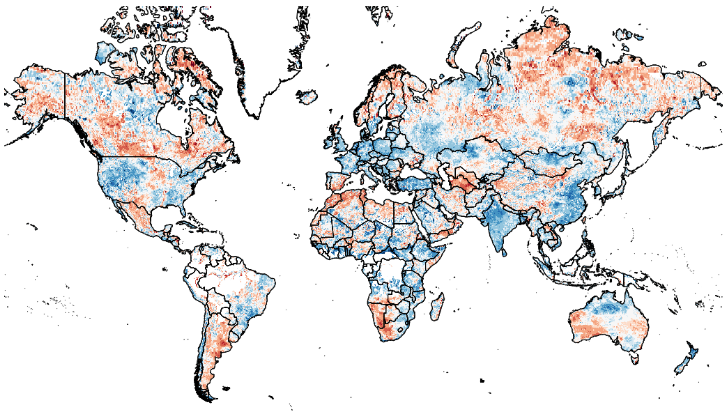
Extremely high soil water conditions ($\sigma>3$) were recorded in Turkey and Kuwait. Unusually wet soil conditions ($\sigma>2$) occurred in 27 countries: five countries in south and southeast Asia (including India and Bangladesh), 13 in Africa, five in Europe, three in the Middle East, and New Zealand.

By river basin

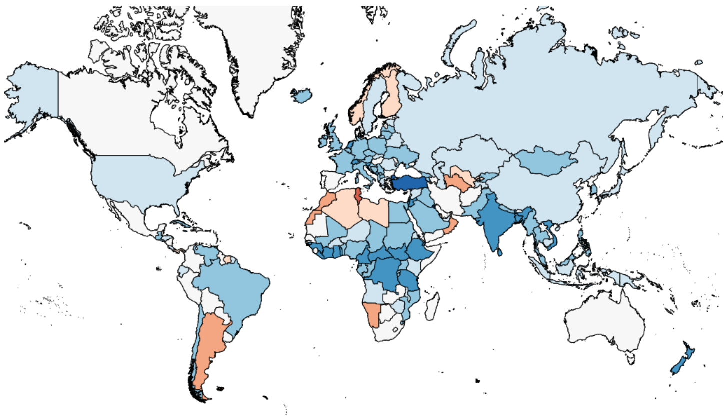
Unusually dry average soil water conditions ($\sigma<-2$) were only recorded in catchments on Baffin Island in Canada.

Extremely high soil water content ($\sigma>3$) was observed along in catchments in Turkey and the eastern Mediterranean, the Huang He River basin in China, and the Galapagos Islands. Unusually high soil water conditions were also recorded in the large Ganges-Brahmaputra and Congo basins, and several other several river basins in South Asia, the Middle East, Central and West Africa, the west coast of North America, northern Europe and the coast of China.

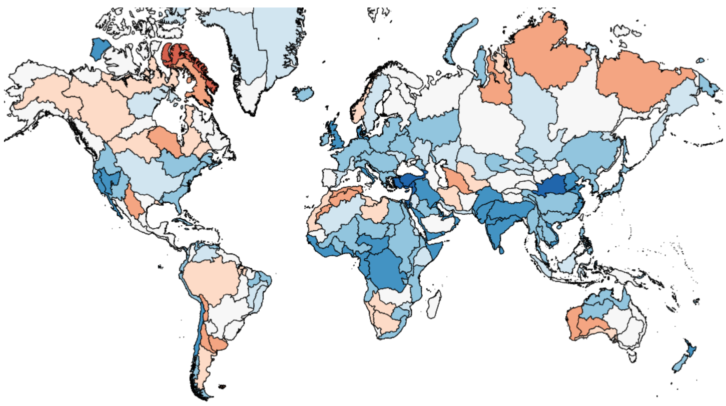
Standardised anomaly in annual average soil water content (see p.8 for legend)



By country

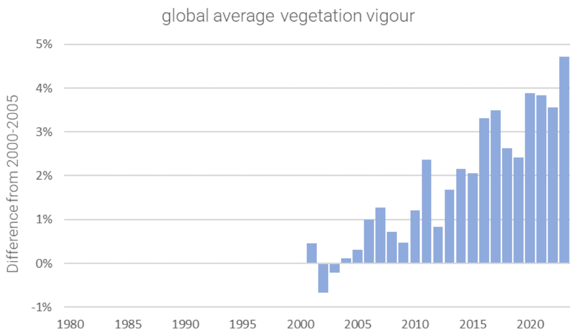


By basin



Vegetation vigour

Globally, vegetation greenness was the highest since 2001, continuing a steady increase over the last decades



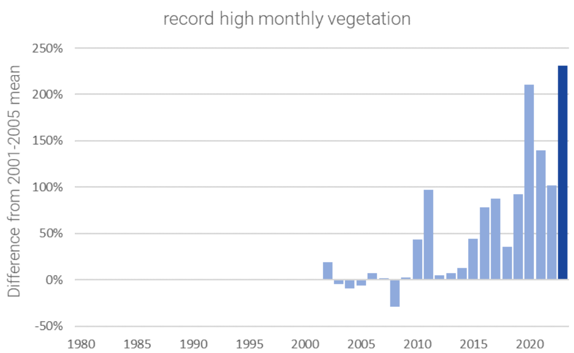
Annual vegetation vigour over the global land area compared to the average for 2001-2005.

Vegetation vigour over the land area was 4.7% above the 2001-2005 average and the highest recorded. Global vegetation vigour has been increasing steadily, due to a combination of increasing temperatures in cold regions, agricultural expansion, and fertilisation from increasing CO_2 and other anthropogenic sources.

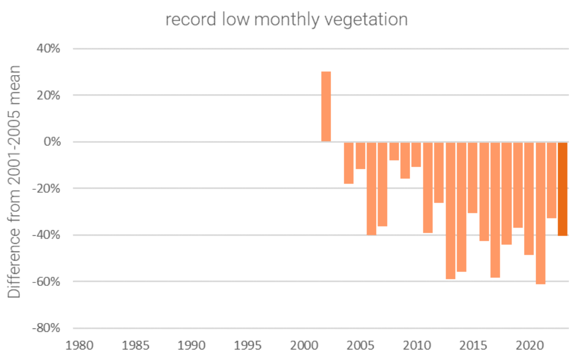
The number of months with record high vegetation vigour in 4687 river catchments was 3.3 times (+231%) the 2001-2005 average and the highest recorded. Regions contributing most to the increasing trend since 2002 include South Asia, China, Eastern Europe and the African Sahel region.

Conversely, months with record low vegetation vigour occurred 40% below the average frequency and were less than in 2022. Months with record low vegetation were observed in parts of Canada, the western USA, South America, the western Mediterranean, northern Scandinavia, and western Russia.

After an initial decreasing trend in record minimum vegetation until 2014 there does not appear to be a strong trend in low vegetation records in recent years.



The number of times high monthly soil water records were broken compared to the average for 2001-2005.



The number of times low monthly soil water records were broken compared to the average for 2001-2005.

Global patterns

Spatial patterns in annual vegetation vigour anomalies in 2023 mostly reflected average rainfall anomalies.

Vegetation cover was unusually high in northern Canada, parts of Russia, most of the African Sahel region and the Arabian Peninsula. Vegetation cover was also relatively high in parts of the USA, Kazakhstan, and northern Australia.

Very low vegetation vigour occurred in parts of the Amazon and the far north of Scandinavia. Low annual vegetation cover also occurred in southern South America, Northern Africa and parts of southern Africa.

By country

Extremely high vegetation cover (σ>3) was observed in Canada, Saudi Arabia, Ethiopia and the Central African Republic. Unusually high vegetation cover (σ>2) occurred in five other countries on the Arabian Peninsula, seven other countries in Central Africa and the Sahel, and six Asian countries (including Pakistan, Japan and South Korea).

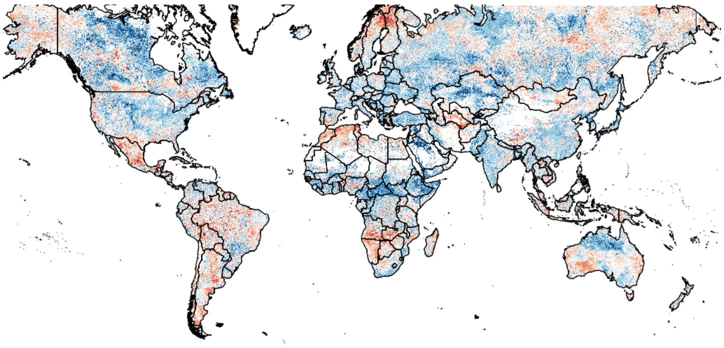
Annual average vegetation cover was unusually low in Tunesia, the Solomon Islands and the Falkland Islands.

By river basin

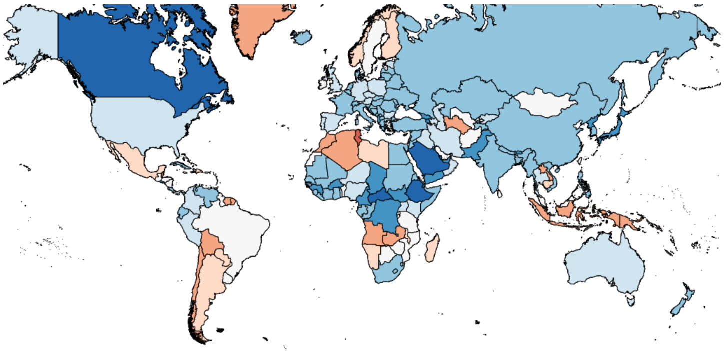
Unusually high vegetation cover was observed in several of the largest river basins (Mississippi, Congo, Nile and Indus Rivers), in northern Canada and in the Sahel region. Extremely high vegetation cover (σ>3) was observed in the Canadian Mackenzie basin, on the Arabian Peninsula and the Lake Chad basin in central Africa.

Unusually low vegetation conditions (σ<-2) were recorded in the Amazon and Belém River basins, as well as catchments along the southwest Mediterranean, parts of Papua New Guinea and far north Canada.

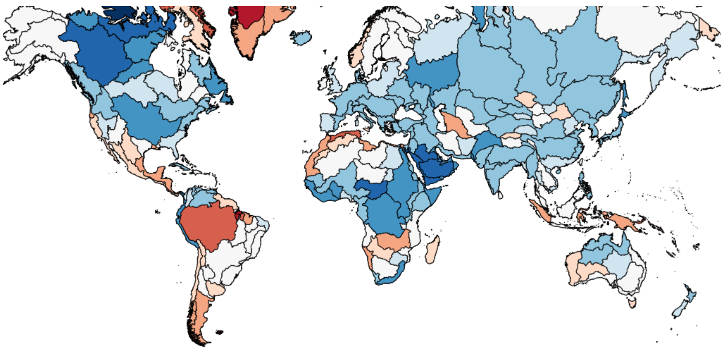
Standardised anomaly in annual average vegetation vigour (see p.8 for legend)

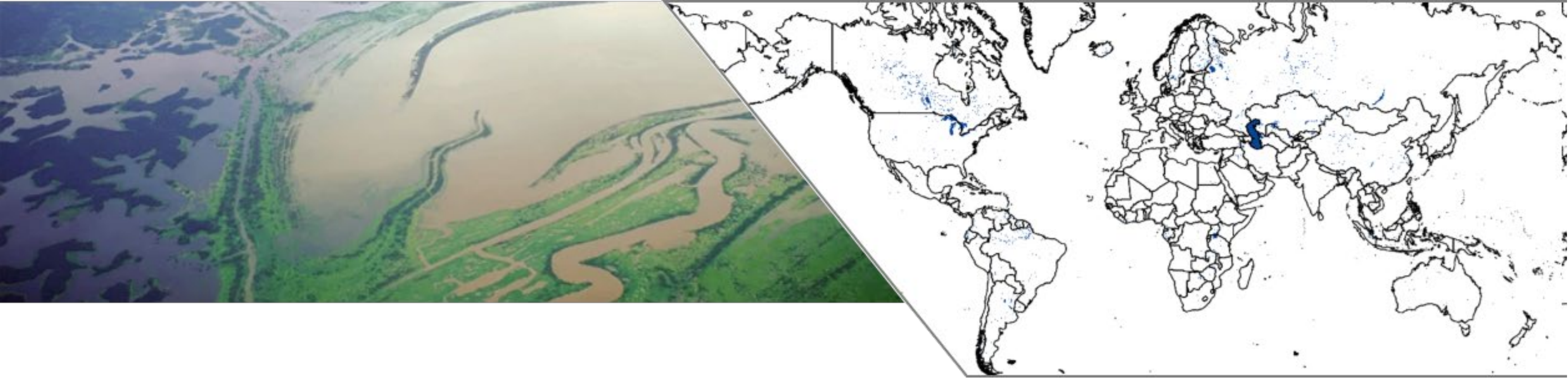


By country



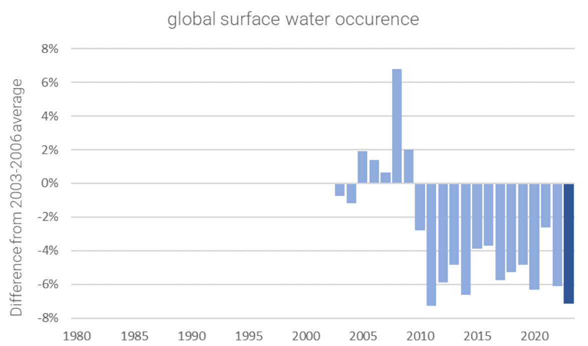
By basin





Surface water occurrence

Global surface water occurrence was the second lowest in two decades, but months with record high water occurrence appear to be increasing globally.



Global surface water occurrence compared to the 2003-2006 average.

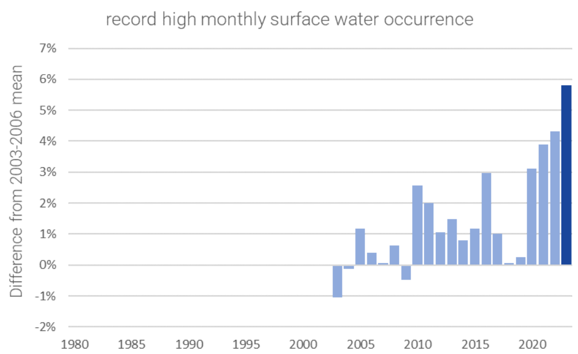
Year to year variations in surface water occurrence are dominated by the extent of large wetlands and lakes and seasonal flooding of large rivers.

Global surface water occurrence was 7% below the 2003-2006 average, the lowest since 2011 and the second lowest measured during the last 21 years. Surface water occurrence declined from 2008 to 2011, with lesser fluctuations since.

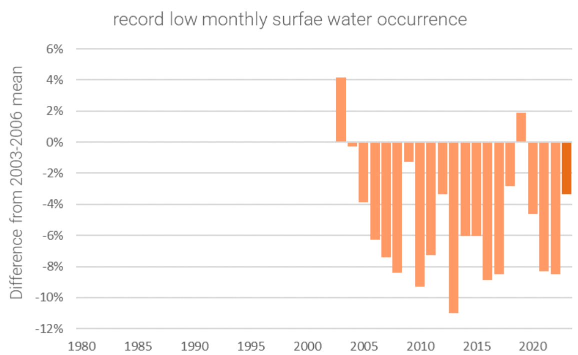
The number of months surface water reached record extent in 4687 river catchments was 6% above the 2003-2006 average. There appears to be a trend towards more water extent records.

Low monthly water extent records were broken 3% less than around 2003-2006. After an initial decrease in low water extent records until around 2011 there does not appear to have been a clear trend since.

Some changes in record water occurrence may be attributed to the construction of new dams, especially in China, India and Brazil. The remainder is associated with natural floodplains, water bodies and wetlands.



The number of times high monthly water occurrence records were broken compared to the average for 2003-2006.



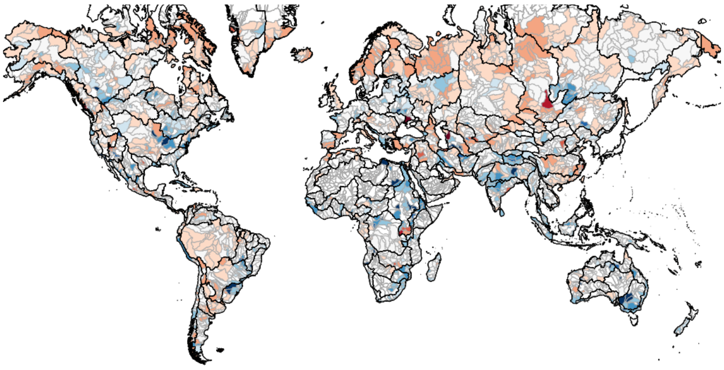
The number of times low monthly water occurrence records were broken compared to the average for 2003-2006.

Global Patterns

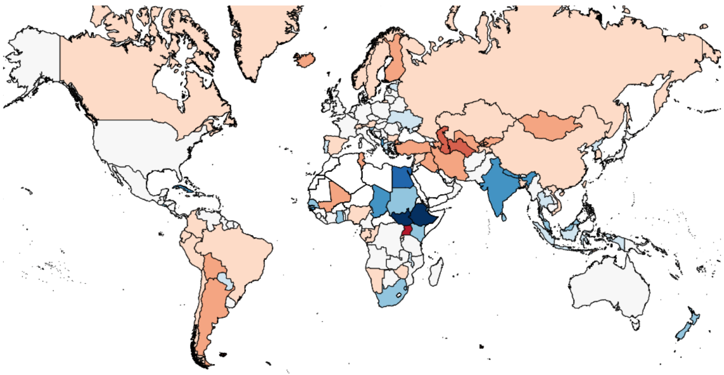
Annual average surface water occurrence was below average in most of the world in 2023 Extremely low water occurrence was reported for smaller catchments along the shores of the Caspian Sea and the lower Dnipro River in war-affected Ukraine.

Annual average water occurrence was extremely high in some catchments in the USA and Mexico - especially along the Pacific Coast- and on the coast of Libya. Water occurrence was also extremely high along some reaches of the Uruguay River in South America, the Nile River in Africa, the Ganges River in India and the Darling River in Australia.

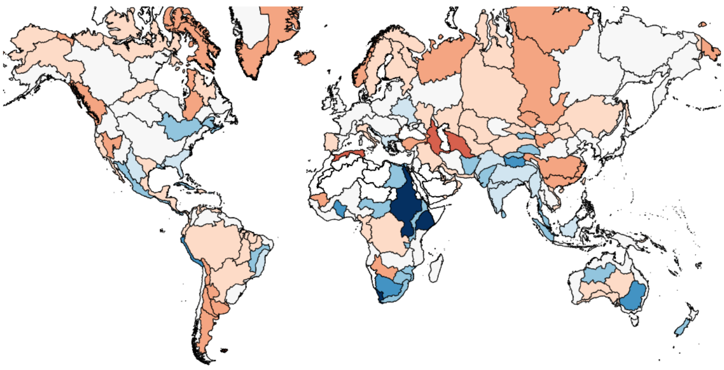
Standardised anomaly in annual average river flows in the major river(s) (see p.8 for legend; estimates are not available in some smaller and arid regions.)



By country



By river basin



By country

Annual water occurrence was average or below average in most countries. Water extent was unusually low for Turkmenistan due to ongoing water level declines in the Caspian Sea and in the Falkland Islands[11].

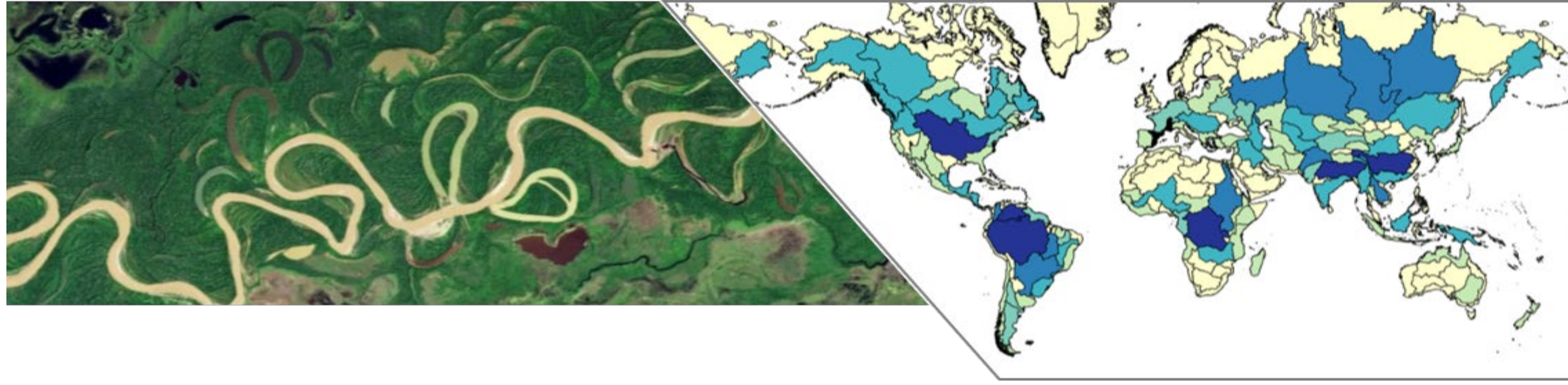
Water occurrence was extremely high in Ethiopia, South Sudan and Egypt due to high rainfall in the Upper Nile, filling wetlands and reservoirs. Water occurrence was also unusually high in 14 other countries, including India and Nepal in Asia, Guinea-Bissau and Chad in Africa, Cuba and several smaller island states.

By basin

Unusually low water occurrence was observed in river catchments along the Caspian Sea, the Southwest Mediterranean, and the Falkland Islands.

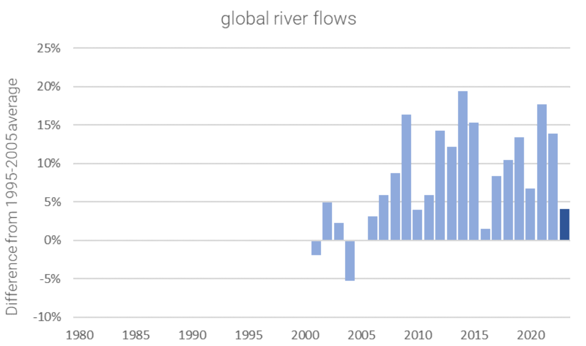
Water occurrence was extremely high in the Nile River and the Shebelli-Juba river basins in the Horn of Africa, and along the South African southwest coast. Water occurrence was also unusually high in the African Volta and Orange River basins and along the East African coast; the Tibet Plateau in China, the Murray-Darling Basin in Australia, and the coast of Peru.

[11] water occurrence also appeared extremely low in Uganda, but this was due to a measurement error



River flows

Global river flows were slightly lower than the previous year. Record high river flows appear to be getting more common and record low flows less common.



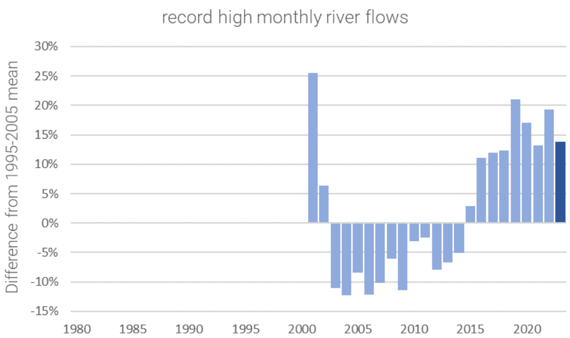
Global river flows compared to the average for 2001-2005.

Global average river flows are dominated by rivers in the world's wettest tropical and temperate regions. Global average river flows, estimated as the sum of river flows in all river basins, were 4% above the 2001-2005 average. There does not appear to be a strong trend in global average river flows. Globally, river flows were the lowest since 2016.

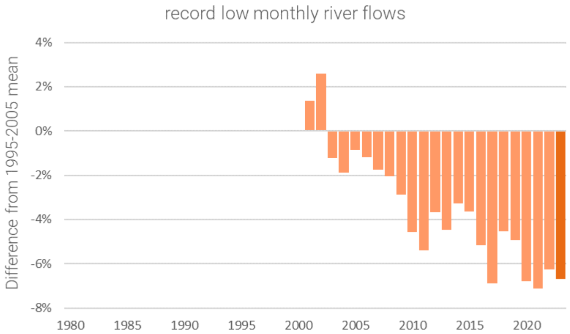
The number of times high monthly river flow records were broken at the 67,630 satellite river gauges was 14% above the 2001-2005 average. There appears to be a trend towards more record high river flows.

Low monthly average river flow records were broken 7% less often than around 2000 (2001-2005). There appears to be a clear trend towards fewer record-low river flows.

There are several possible explanations[12], including increased regulation of river flows, the impact of global warming in cold regions, and the fact that low flow records cannot be broken where zero flows have previously already occurred in that month. Further research is needed to test these explanations.



The number of times high monthly river flow records were broken compared to the average for 2001-2005.



The number of times low monthly river flow records were broken compared to the average for 2001-2005.

[12] Gudmonsson et al. (2021) Science 371, 1159-1162

Global patterns

By country

Annual average flows in the main river(s) were around average in most countries. River flows were extremely high in both Congo's and unusually high and/or the highest since 2003 in Nigeria, the Central African Republic and Ethiopia in Africa, the UK, Ireland and Denmark in Europe, El Salvador and Ecuador in the Americas, Iran and Azerbaijan in Asia, and in New Zealand.

Annual average river flows were unusually low and/or the lowest since 2003 in Georgia, Bhutan and Myanmar in Asia and Colombia in South America.

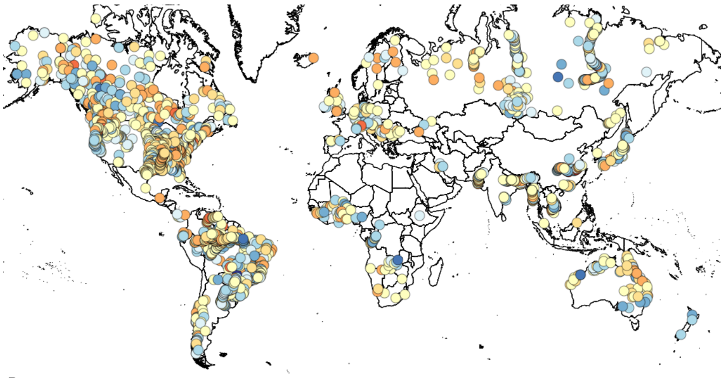
By basin

Both high and low average 2023 river flows were observed in river basins worldwide.

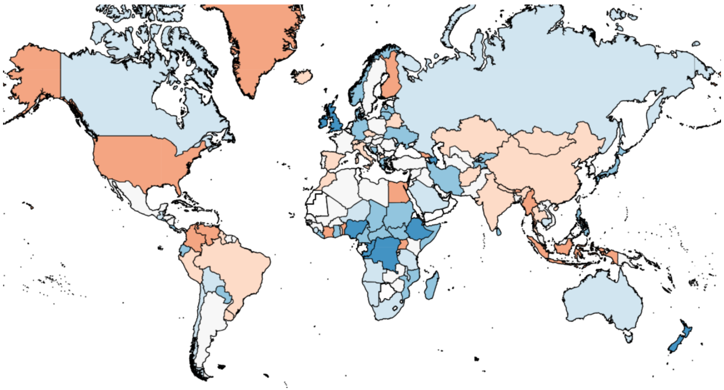
Unusually high annual flows and/or the lowest flows since 2003 were observed in the Niger, Lake Chad and Congo River basins in Africa, the Tocantins River in South America, the Arabian Interior and along the western Caspian Sea coast.

Unusually low flows and/or the lowest flows since 2003 were observed in the USA Colorado River, the Lake Titicaca and Venezuelan coast catchments in South America, the East Mediterranean coast and the Salween River and Sumatran catchments in southeast Asia.

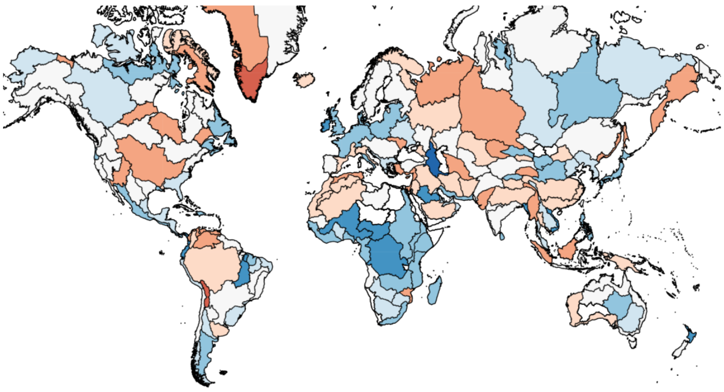
Standardised anomaly in annual average river flows in the major river(s) (see p.8 for legend; estimates are not available in some smaller and arid regions.)

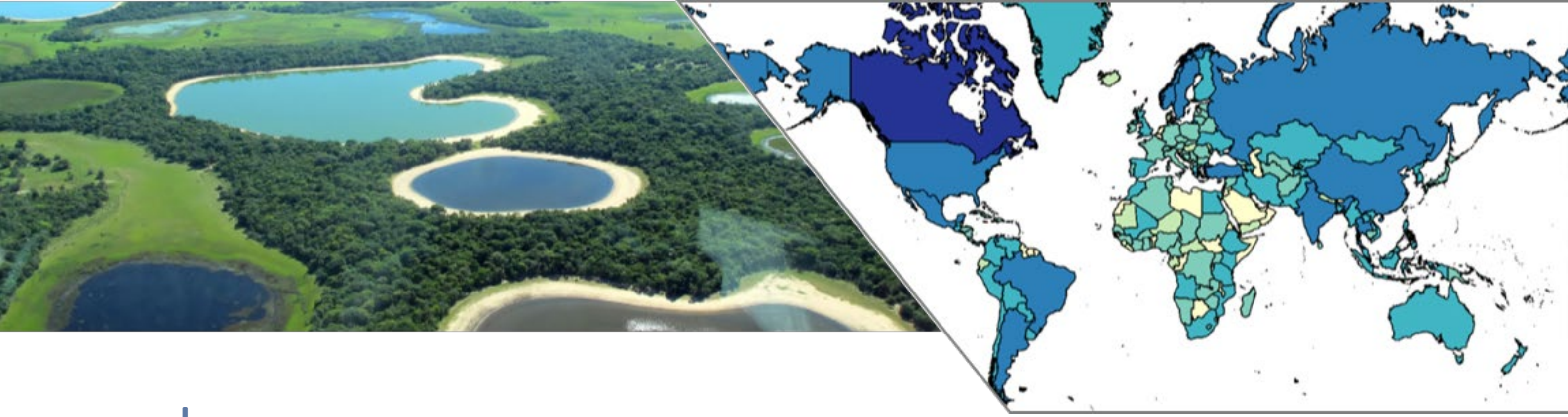


By country



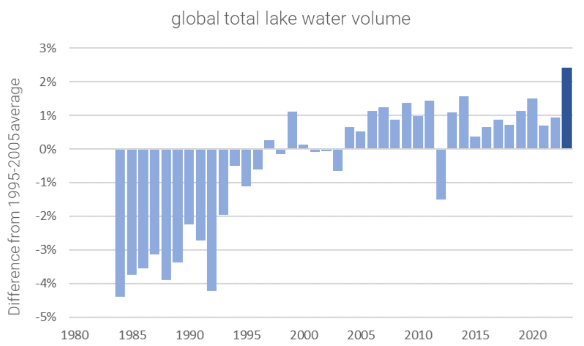
By river basin





Lake volume

Global water volumes in lakes are gradually increasing and high storage records are broken more often.

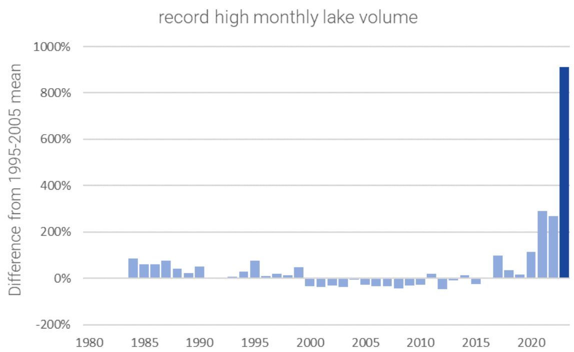


Combined water storage in lakes compared to the average around 2000 (1995-2005).

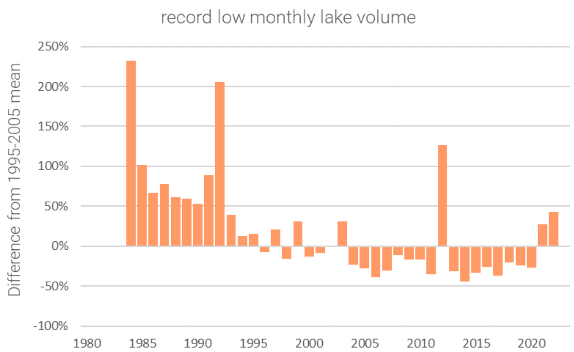
About two-thirds (64%) of all water in natural and artificial lakes worldwide are found in just six countries: Canada, the USA, China, Russia, Brazil and India (in descending order). The largest number of (often relatively small) lakes are found at high latitudes. Water storage in lakes increased by 1.5% from 2022 and reached the highest value in the time series, having increased by 7% since 1984. The increase can be mainly attributed to new and expanded reservoir lakes, especially in China, India and the Nile River Basin.

The number of times annual average lake storage records were exceeded in the 27,879 observed lakes was more than ten times (+913%) greater than the average around 2000. The number of times low lake storage values were broken was 43% above the 1995-2005 average.

The increase in record-high volumes and the initial decrease in record-low volumes before 2000 can be attributed to a combination of human and natural factors. Small and very large lakes are all counted equally. Dams continue to be built and expanded worldwide to secure water, and their filling explains some of the trends. In addition, most natural lakes are found in the Arctic region, where greater and earlier snowmelt can contribute to increased lake volumes.



The number of times high monthly lake storage records were broken compared to the average for 1995-2005.



The number of times low monthly lake storage records were broken compared to the average for 1995-2005.

Global patterns

By country

Storage in natural and artificial lakes was unusually high in China, in Ghana, Niger and Kenya in Africa, in Chile and Ecuador in South America, and in Sweden in Europe.

Lake water storage unusually low in Austria, Macedonia and Moldova in Europe, but this was based on only a small number of lakes.

A way to highlight the impact of 2022 climate conditions is to consider changes in stored volume. Lake volume decreased from the previous year in 37 countries, increased in 73, and could not reliably be measured or was zero in the remaining 192 (typically small or arid) countries and territories.

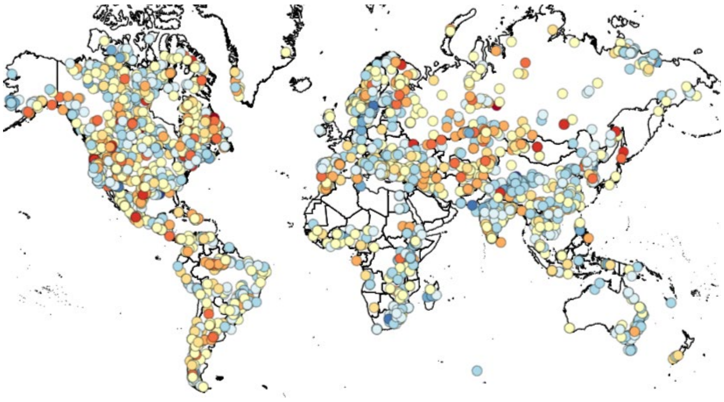
In descending order, the greatest absolute decreases in surface water storage occurred in Canada, India, Turkmenistan, Mexico and Iraq. The greatest increases occurred in USA, Brazil, China and Ghana. In relative terms, the most notable decreases from the previous year were in Iraq (-12%) and Sri Lanka (-11%). The greatest increases were in Congo (+59%), Pakistan (+19%), Afghanistan (+18%), Uruguay and Cambodia (+17%)[13].

By river basin

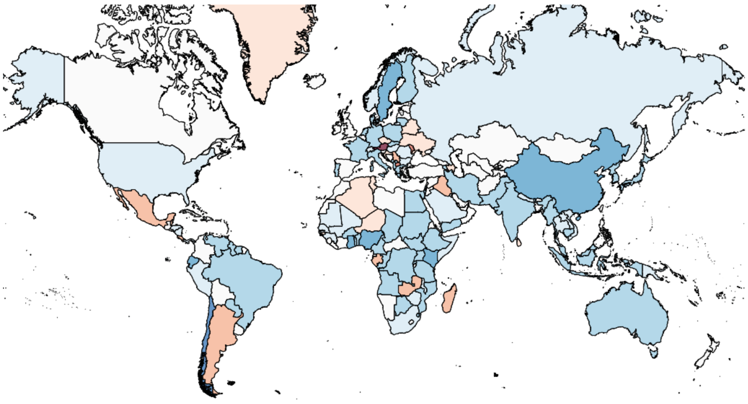
Unusually high lake volumes were observed in Africa along the east Mediterranean coast, in the Niger River basin, the Rift Valley in Eastern Africa and the interior of southern Africa; in Asia in the Indian Sabarmati region, the Tibetan Plateau and Gobi Interior; in Europe along the Danish and north German coast; in Northern Australia and in several Arctic coastal catchments.

Lake volumes were extremely low in the Don River basin due to the destruction of reservoir dams in the Ukraine, and unusually low in the Salinas River basin in South America due to ongoing drought.

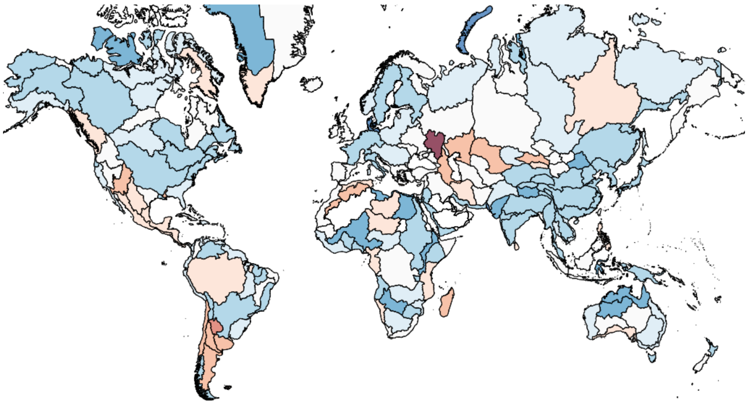
Standardised anomaly in annual average lake water storage (see p.8 for legend; estimates are not available in some smaller regions).



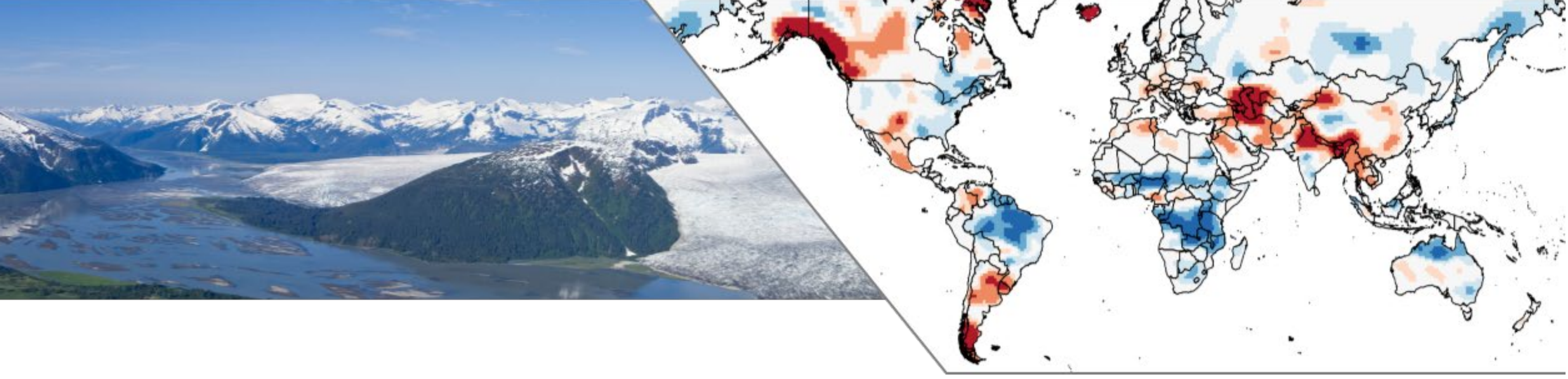
By country



By river basin

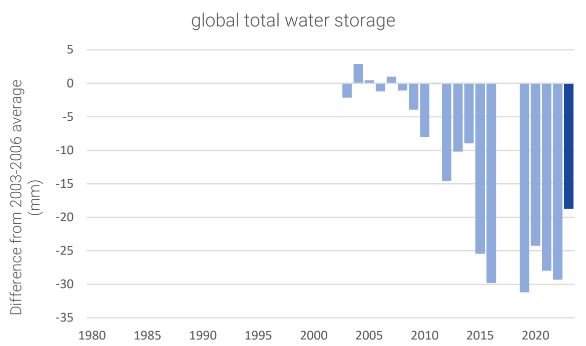


[13] Only countries or river basins with a combined lake capacity exceeding 10,000 GL were considered, as satellite-estimate storage may be less acurrate for smaller storages.



Terrestrial water storage

Many dry and wet records in terrestrial water storage were broken in 2023, despite several missing months



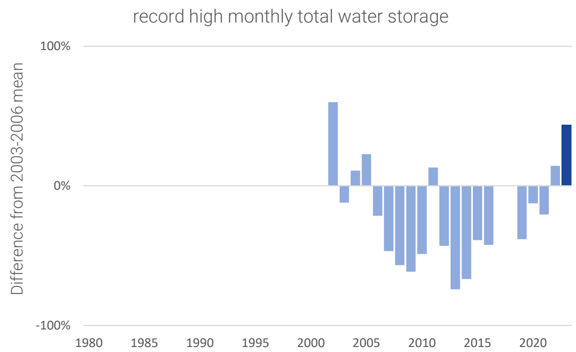
January-May average terrestrial water storage over the global land area compared to the average for 2003-2006.

Terrestrial water storage is the sum of all water on the continents, including soil water, groundwater and surface water as well as snow and ice. The average storage for January-September was 19 mm below the 2003-2006 average[14]. Land-based water storage was lower than the previous two years. Global terrestrial water storage on land declined rapidly between 2006 and 2016 but appears to have stabilised since.

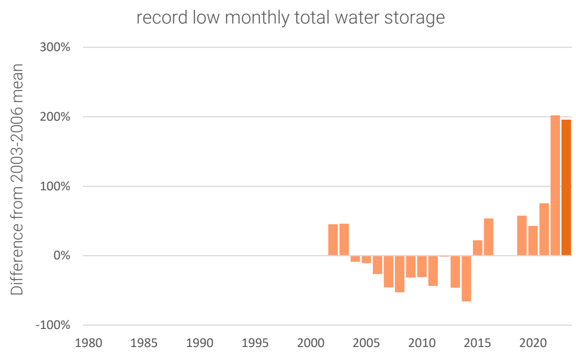
The number of months with record high terrestrial water storage in 4687 river catchments was 44% above the 2003-2006 average in 2023, noting that data was not available for all months. [15]

Months with record low soil water were almost three times (+196%) more frequent than the 2003-2006 average, once again despite incomplete data for 2023. Most of these records will be attributable to progressively disappearing ice cover and the steady decline in Caspian Sea water level since 1995.

There appear to be increasing trends in both record high and low water storage months since around 2013, suggesting an intensification and/or increased duration of unusually dry and wet conditions. However, the data record is relatively short and has gaps.

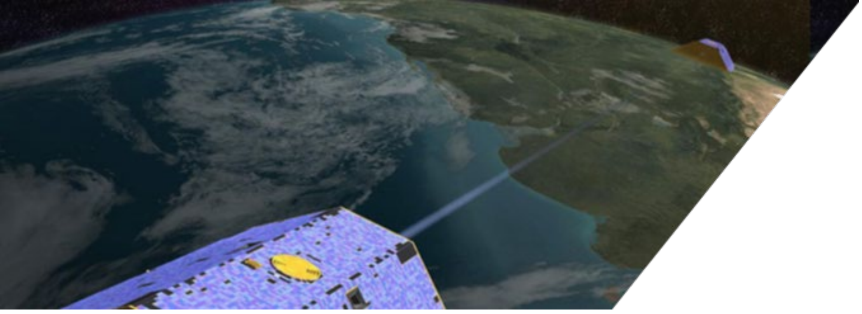


The number of times high monthly terrestrial water storage records were broken compared to the average for 2003-2006 (note months for 2023 and the years shaded grey are incomplete)



The number of times low monthly terrestrial water storage records were broken compared to the average for 2003-2006 (note months for 2023 and the years shaded grey are incomplete)

[14] Greenland and Antarctica are not included in the calculations. Data for 2017 and 2018 were considered too incomplete to use. Estimates for June-September 2023 are provisional based on the DDK-filtered data from the processing center GFZ.
[15] Provisional estimates for June-September 2023 were not included.



Global patterns

Calculating standardised anomalies emphasises recent changes and reduces the influence of strong long-term trends in terrestrial water storage (e.g., due to ice melt), while not entirely removing them.

Spatial patterns for January-September 2023 anomalies show the prevailing dry conditions in many northern mid-latitude regions. Terrestrial water storage was unusually low in much of North and Central America, the Mediterranean region, North Africa, Central Asia, and parts of China and South Asia. Long-term declines in Caspian Sea level and retreating mountain glaciers play a role in some of these regions.

Terrestrial water storage was unusually high in most of the northern high latitudes, as well as isolated parts of South America, Africa and Oceania.

By country

Average January-September terrestrial water storage was very low for China, the USA, Mexico, Oman and the United Arab Emirates on the Arabian Peninsula, and Algeria in North Africa.

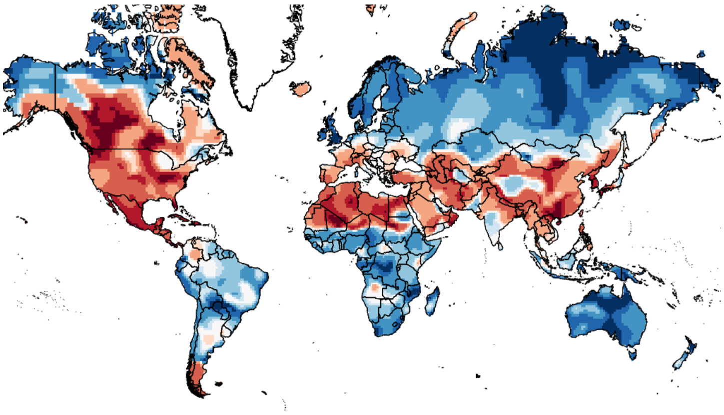
Very wet conditions occurred in Scandinavia, the UK and Ireland, and Australia and New Zealand.

By river basin

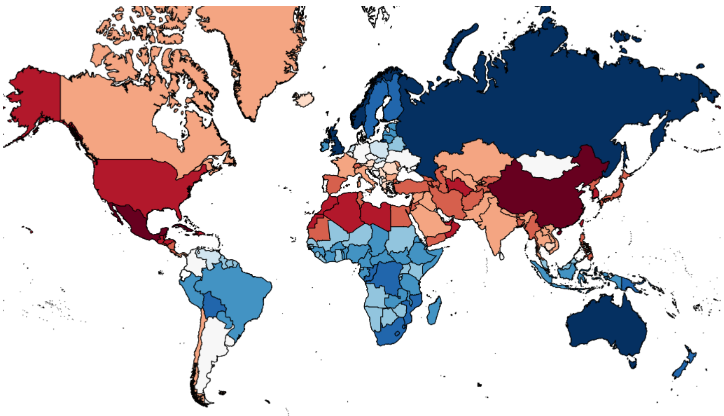
Very low average terrestrial water storage conditions were recorded in 15 river basins, most of them in North and Central America, northwest Africa, Central Asia and China, including the Yangtze River basin.

Very high terrestrial water storage was observed in 29 river basins, including many basins along the Arctic Sea, in Australia, and along the coast of South Africa.

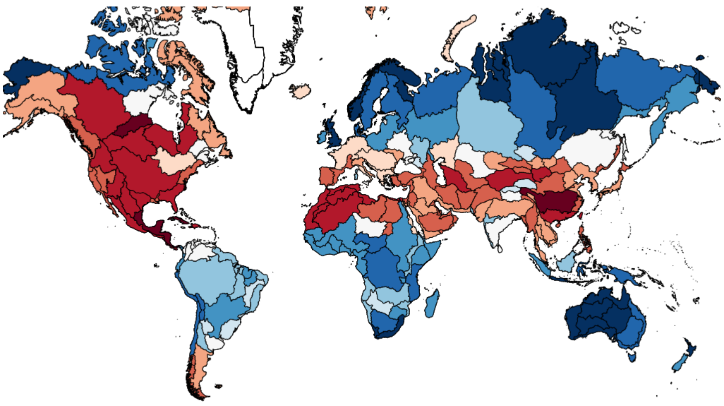
Standardised anomaly in January-September average total water storage (see p.8 for legend). Note: data for Greenland not included.



By country



By basin



Regions in Focus

Philippines

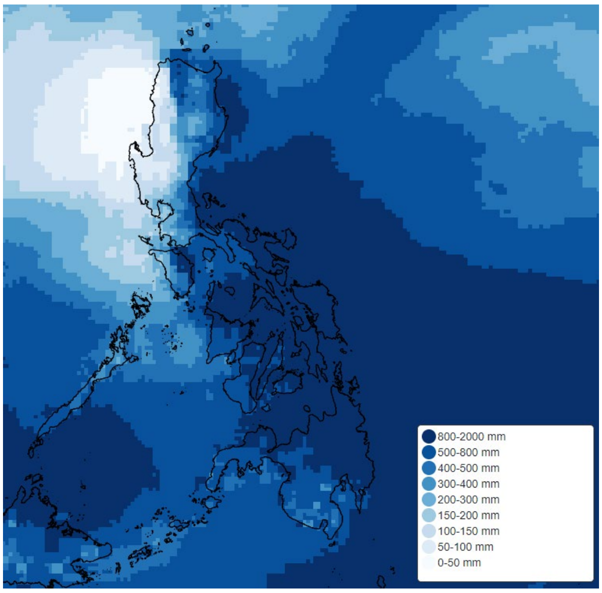
Flooding and landslides

The Philippine floods, which began in December 2022 and continued into early 2023, were triggered by a shear line collision located within the regions of Visayas and Mindanao. The widespread rains led to severe flooding and landslides.

Ongoing severe weather since the start of the year caused at least 38 fatalities and displaced 170,000 people. As many as 2 million people were impacted across 14 of the country's 17 regions[16]. Many of the affected areas were still recovering from the spate of severe weather in late December 2022, when at least 52 people died.

A total of 687 flood incidents and 31 landslides were reported[17]. More than 548 houses were destroyed, and more than 1,200 were damaged. By 23 January, there were still around 90,000 people housed in 350 evacuation centres, more than half of them in Northern Samar.

There has been an increasing trend in rainfall across much of the Philippines, especially during the December-February wet season[18]

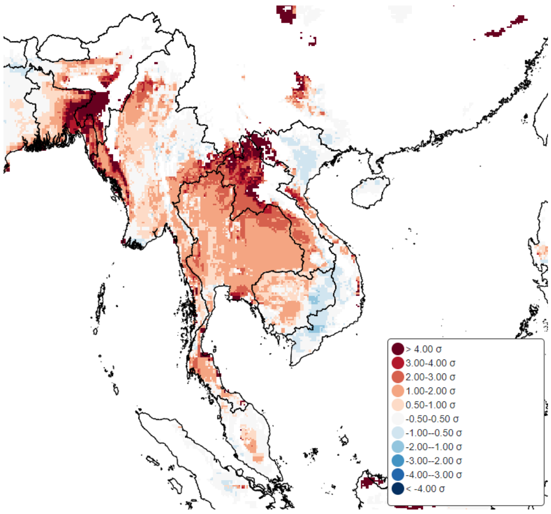


Total precipitation total for 3 months up to and including February 2023

[16] Floodlist, 23 January 2023 (link)
[17] WorldsAid, 16 January 2023 (link)
[18] PAGASA (2018) (link)

Southeast Asia

The April ‘monster’ heatwave



Number of days with maximum temperature above 35°C for April 2023 compared to long-term average for April, calculated in number of standard deviations (σ)

Starting in April 2023, a record-breaking heatwave affected many countries in southeast Asia, from India to Cambodia. April is historically a hot month but in 2023 the heat was uniquely oppressive. Highest-ever temperatures of more than 40 °C were recorded in Thailand and Lao. The heatwave was made more damaging by the prevailing humid conditions.

The humid heat caused extreme heat stress in people and animals, resulting in deaths and hospitalisations for heat strokes and a strong surge in electricity demand for cooling. Casualties were reported in India and Thailand, but the true death toll of heat waves is notoriously hard to establish.

The economic impacts were also substantial. In India and Bangladesh, schools were closed for several weeks due to the heat. The heat also affected agricultural production and the health of crops and livestock.[19]

An international group of scientists established that climate change made a strong contribution to the event, making it more than 30 times more likely to occur. [20]

[19] Arab News, 30 April 2023 (link)
[20] World Weather Attribution, 17 May 2023 (link)

Myanmar

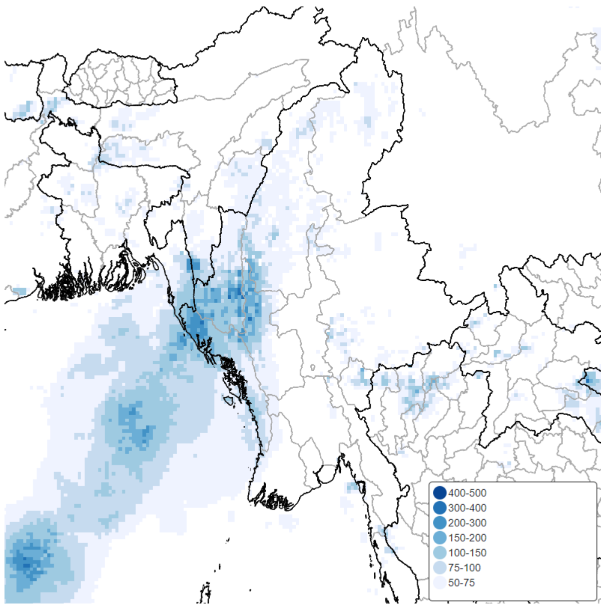
Tropical cyclone Mocha

Cyclone Mocha made landfall in Rakhine State, Myanmar on May 14. It was one of the strongest cyclones recorded in the country with wind speeds exceeding 250 kilometres per hour.

The cyclone, along with the storm surge and flooding, affected an estimated 7.9 million people. In Rakhine State alone, 1.9 million people were impacted. The state has the second-highest poverty rate in the country. The Myanmar authorities reported at least 145 deaths due to the cyclone, but other reports suggest a death toll of 460. The cyclone affected the Rohingya refugee community particularly hard. [21,22]

In Sittwe, the state's capital, most buildings were damaged, bridges collapsed, and fishing boats, healthcare facilities, and schools destroyed. The cyclone caused flooding over an area of about 1,182 square kilometres, leading to livestock deaths and contamination of drinking water and farmland. The estimated total direct damage caused by Cyclone Mocha was $2.24 billion in damage to buildings, property, agriculture, and infrastructure, equivalent to 3.4% of Myanmar's GDP. [23]

Research has found that the strength of tropical cyclones in East and Southeast Asia has been increasing dramatically. Compared to 1980, storms now last 2-9 hours longer and reach 30-190 km further inland[24].

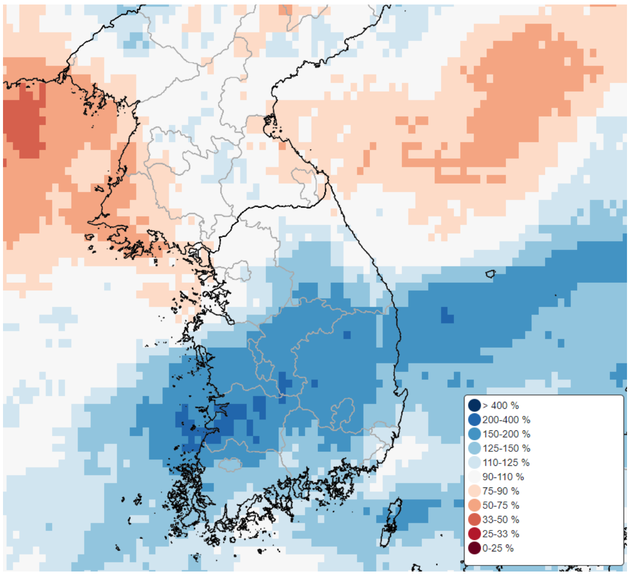


Maximum daily precipitation for May 2023, showing the path of cyclone Mocha

[21] UNDP Reliefweb, 6 June 2023 (link)
[22] Radio Free Asia, 17 May 2023 (link)
[23] World Bank, 7 August 2023 (link)
[24] Chen et al. (2021) (link)

South Korea

Floods and landslides



Total precipitation total for 2 months up to and including July 2023 as a proportion of long term average June-July total precipitation.

Floods occurred between 25 June and 26 July after heavy rainfall during the East Asian rainy season. The downpour was the heaviest in South Korea in 115 years and the third heaviest on record[25].

The rains resulted in severe flooding and landslides across the country, primarily affecting residents in the provinces of North Chungcheong and North Gyeongsang.

At least 47 people were killed. The floods had a significant impact on water resources. The overflow of a dam in North Chungcheong led to the evacuation of over 9,200 homes and over 14,400 people nationwide.

The economic damage was large. There was damage to 6,064 public and 2,470 private properties due to flooding and landslides triggered by the heavy rains. Over 340 square kilometres of farmland were damaged or flooded and over 825,000 livestock were killed.[26]

Experts noted that climate change likely contributed to the event, with rains coming in more intense bursts rather than spread out over a longer period.[27]

[25] Yonhap News Agency, 26 July 2023 (link)
[26] Yonhap News Agency, 22 July 2023 (link)
[27] New York Times, 14 July 2023 (link)

India

Monsoon floods

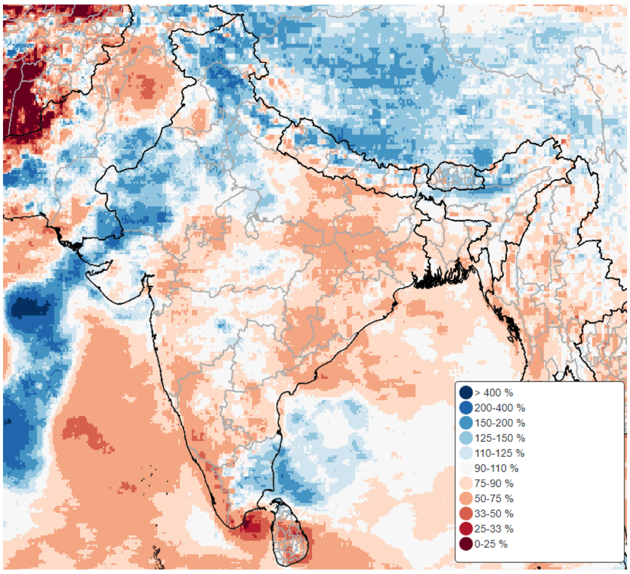
In late August 2023, Himachal Pradesh and Uttarakhand experienced devastating cloudbursts, exacerbating the damage from earlier heavy monsoon rains in June. The cloudbursts, occurring around August 19, unleashed rapid, massive volumes of water, triggering flash floods and landslides.

The affected areas included the Kedarnath valley in Uttarakhand and the Kullu Manali districts of Himachal Pradesh, which were already severely impacted by the early monsoon.[28]

The downpours caused renewed flooding and landslides, displacing thousands and severely damaging roads, bridges, houses, and agricultural land.

The combined toll of the monsoon and subsequent cloudbursts resulted in over 227 fatalities in Himachal Pradesh and over 50 deaths in Uttarakhand.

The combination of the monsoon surge and moisture brought by the western disturbance contributed to the intensive rainfall.

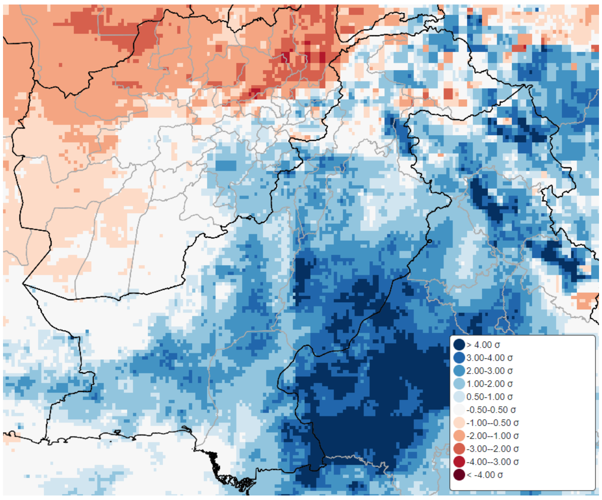


Total precipitation total for 3 months up to and including August 2023 as a proportion of long term average June-August total precipitation

[28] Reliefweb, 1 September 2023 (link)

Pakistan

Monsoon floods



Total precipitation total for 5 months up to and including July 2023 compared to long term average March-July total precipitation, calculated in number of standard deviations (σ)

Nine months after the severe floods of 2022, heavy monsoon rains and floods returned to Pakistan. Intense rainfall events caused both isolated and ongoing flood emergencies throughout the monsoon season.

On 10 June, heavy rains and rain-related incidents resulted in the loss of at least 33 lives and injuries to around 150 people in Khyber Pakhtunkhwa and Punjab provinces.

A month later, severe weather-related incidents due to pre-monsoon rainfall continued to affect central and northern Pakistan, resulting in mounting casualties and damage and affecting mostly the provinces of Punjab, Khyber Pakhtunkhwa, Balochistan and Azad Jammu and Kashmir.

By August, 196 people had perished, more than 200 were injured and thousands of houses damaged across the country, particularly in Balochistan. Later in August, 16 more died in central Punjab Province in eastern Pakistan where several hundred villages have been inundated due to floods of the Sutlej River. More than 378,000 people and over 20,000 animals were evacuated to secure locations. The flooding river destroyed levees and villages at several places, submerging 620 square kilometres of cropland. Malaria outbreaks were also reported.

Between June and September, authorities reported a total of 226 fatalities 349 injured people, more than 547,400 evacuated and 5,800 damaged houses.[29]

[29] Reliefweb, 28 September 2023 (link)

Southeast Africa

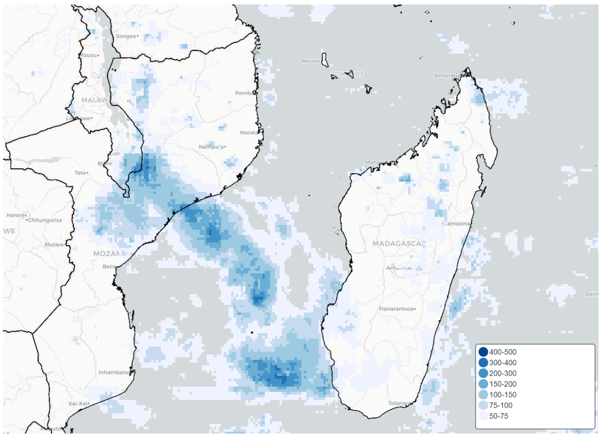
Tropical Cyclone Freddy

Tropical Cyclone Freddy was an exceptionally long-lived, powerful, and deadly tropical cyclone that wandered over the southern Indian Ocean and southeast Africa for more than five weeks, between 5 February and 14 March 2023. This makes it most likely the longest-lived tropical cyclone in recorded history.[30]

The system developed near Indonesia and moved across the Indian Ocean developing into a Category 5 cyclone. It made landfall on the central east coast of Madagascar. The storm rapidly weakened overland but once it crossed the island re-strengthened over the Mozambique Channel before making a second landfall in southern Mozambique. Despite being weaker at landfall, the cyclone caused widespread flooding across parts of Mozambique after stalling near the coast, moving backwards and forwards between Madagascar and Mozambique again, picking up energy from the warm ocean. The cyclone brought heavy rainfall to parts of Mozambique and Malawi.

The hardest hit was southern Malawi, which received half of its annual rainfall during six days in the first weeks of March[31]. An estimated 2,2 million people were affected by the rains, floods, mudslides and wind damage, including 660,000 people who were displaced[32]. The nation's power grid was crippled, with its hydroelectric dam rendered inoperable. The total cost of recovery and reconstruction was estimated at $680 million.

In total, the cyclone killed at least 1,434 people: 1,216 in Malawi, 198 in Mozambique, 17 in Madagascar, two in Zimbabwe, and one in Mauritius, making it the deadliest cyclone since 2019.

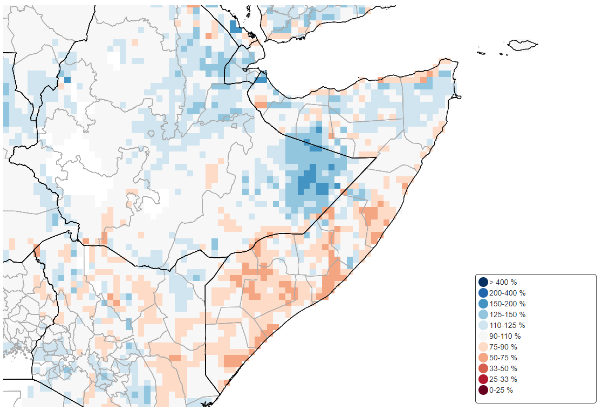


Maximum daily precipitation for March-April 2023

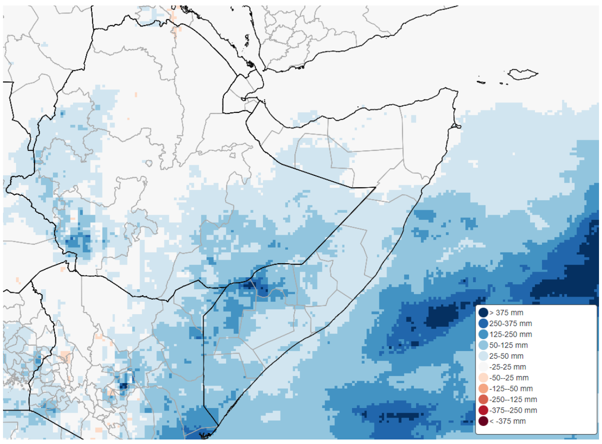
[30] Washington Post, 7 March 2023 (link)
[31] Floodlist, 17 March 2023 (link)
[32] Government of Malawi, 30 April 2023 (link)

Somalia

A third drought year, then floods



Soil water for 10 months January-October 2023 as a proportion of long term average January-October soil water



Total precipitation for November-December 2023 compared to long term average November-December total precipitation

Until October 2023, Somalia and nearby parts of Ethiopia and Kenya remained in the grip of severe drought that started in late 2020 and led to five consecutive failed cropping seasons. Rainfall was close to normal, but temperatures were high and the humanitarian situation remained challenging. By early 2023, 3.5 million livestock had died, 1.4 million people were displaced and 8 million needed aid.[33]

Conditions started to improve when more normal conditions returned in March. However, high rainfall in Ethiopia caused the Shebelle River to burst its banks in downstream Somalia in May, impacting almost half a million people and displacing 247,000, many losing their food stores, livestock and water supplies.[34]

As predicted, due to a change to an El Niño climate phase, further flooding ensued later in 2023. In November, Somalia received its highest monthly rainfall since 1997. Torrential rains caused widespread flooding in the southern half of the country, impacting more than 2.4 million people, displacing one million and killing 110 people.

It was estimated that the ongoing drought was made 100 times more likely due to human climate change, with global warming predicted to reduce rainfall during the first half of the year and increasing it during the second half[35]. Combined with higher temperatures, this means more drought-like conditions and poorer vegetation, which in turn can also enhance flash floods during intensive rain events[36]

[33] United Nations, 8 February 2023 (link)
[34] United Nations, 6 June 2023 (link)
[35] World Weather Attribution, 27 April 2023 (link)
[36] Guardian, 27 April 2023 (link)

Libya

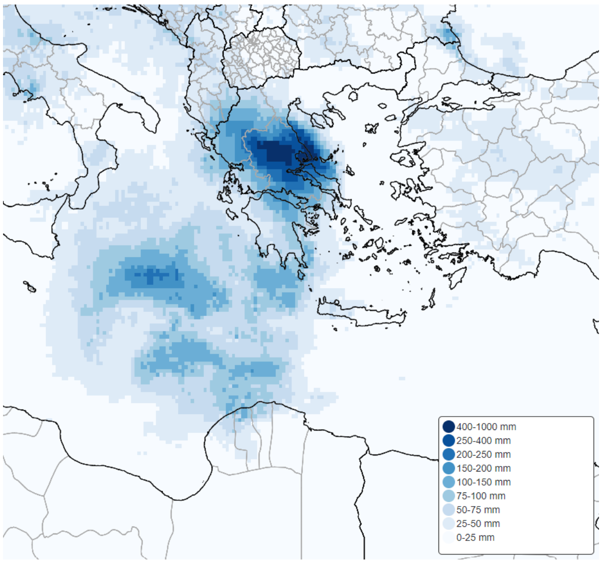
Storm Daniel

Storm Daniel, a powerful mid-latitude cyclone, developed over the Ionian Sea and Greece in early September 2023. The storm was fuelled by high Mediterranean Sea temperatures. It delivered torrential rains and high winds to the southern Balkan peninsula and western Turkey.

In Greece, flooding caused more than two billion euros in damage, making it the most costly recorded storm for the country. Homes were swept away by torrents, bridges collapsed, roads were made impassable, power lines fell and crops were wiped out. Authorities confirmed 10 casualties, with 1,700 people rescued from the floodwaters.[37]

Storm Daniel subsequently crossed the Mediterranean, striking the northeastern coast of Libya on 10 September. The impacts were devastating. Major dams collapsed, releasing vast quantities of water into an already inundated Derna city. The storm impacted about 250,000 people and destroyed 10,000 buildings. The flooding left 4,300 dead, 8,500 missing presumed dead, and 40,000 displaced.[38]

So-called 'medicanes' - storms in the Mediterranean resembling tropical hurricanes - have occurred before, but historically have been smaller. The unusually warm sea surface temperature caused the storm to strengthen rapidly and are a direct result of global warming.[39]

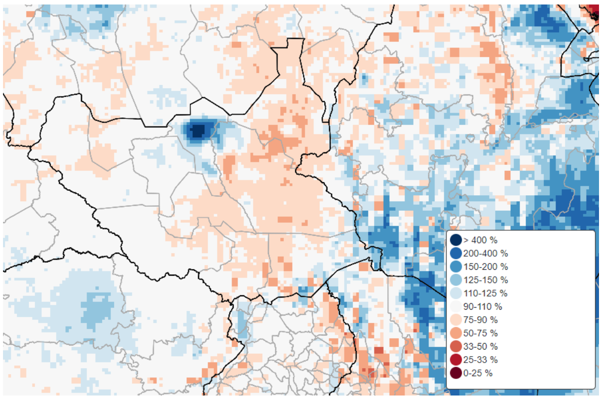


Total precipitation for September 2023

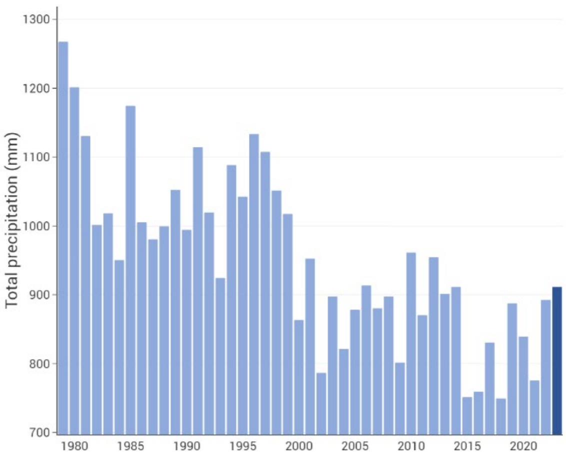
[37] Reuters, 9 September 2023 (link)
[38] UNDP, 19 October 2023 (link)
[39] The Guardian, 15 September 2023 (link)

South Sudan

Floods despite a long-term decline in rainfall



Total precipitation total for 2023 as a proportion of long-term average annual precipitation



Annual rainfall for South Sudan since 1979

In early 2023, South Sudan experienced the worst drought conditions in four decades following five years of below-average rainfall and high temperatures.

Later in the year, river flooding occurred for the fourth year in a row in early 2023 due to high inflows from the White Nile upstream since 2019.

The combination of drought and flood events pose serious challenges to peacebuilding, development, and resilience in South Sudan, which is still recovering from a civil war that ended in 2018. There were an estimated 7.8 million people facing severe acute food insecurity during the 2023 lean season.[40] The floods also undermine the efforts of humanitarian agencies and donors to aid the affected populations.

There is evidence for a long-term decline in rainfall over South Sudan over the last four decades.

[40] Unicef, 3 November 2023 (link)

Southwest Europe

Deepening drought

In June, a third of the European continent was classified as being in drought conditions, with 10 per cent of the area in a state of crisis[41].

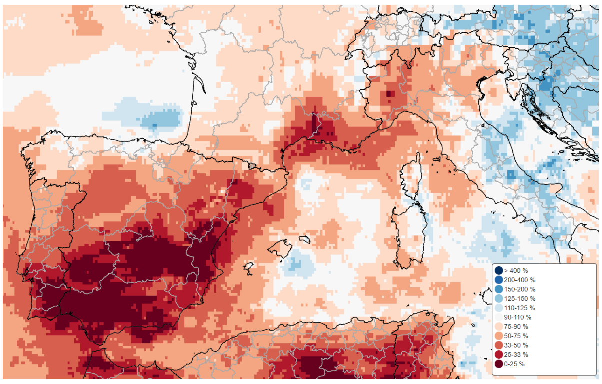
Southwestern Europe experienced the driest and warmest spring on record. The Iberian Peninsula experienced significant deficits in soil moisture, with most of the area recording the driest values on record. [42]

Drought conditions in Spain reduced water supplies to 50% of capacity by May, and agricultural production was expected to be the worst in decades.[43]

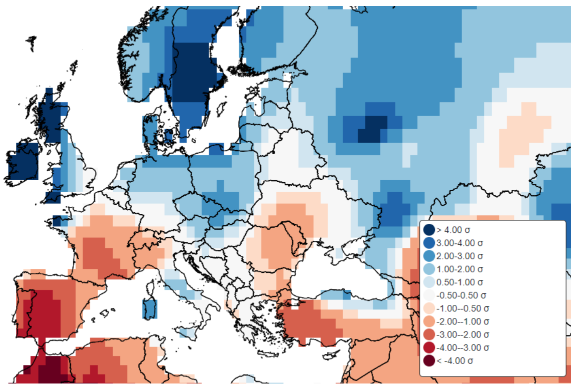
In Southern France, 30,000 residents were left without reliable water sources by August. The driest winter in six decades combined with warm temperatures compromised fresh water supplies across the country.

Wildfires sprung up across the region, with especially bad outbreaks in Portugal, Spain and Greece.

More frequent and severe droughts in the Mediterranean region are in line with climate change predictions.



Total precipitation total for January-April 2023 as a proportion of long term average January-April total

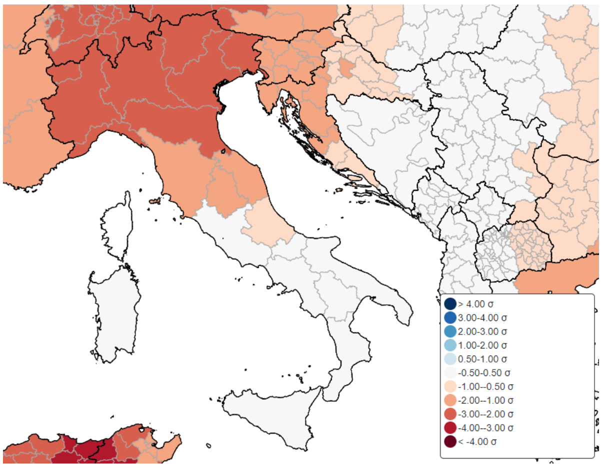


Total water stored in water bodies, soil, aquifers and ice for May 2023 compared to long term average May, calculated in number of standard deviations (σ)

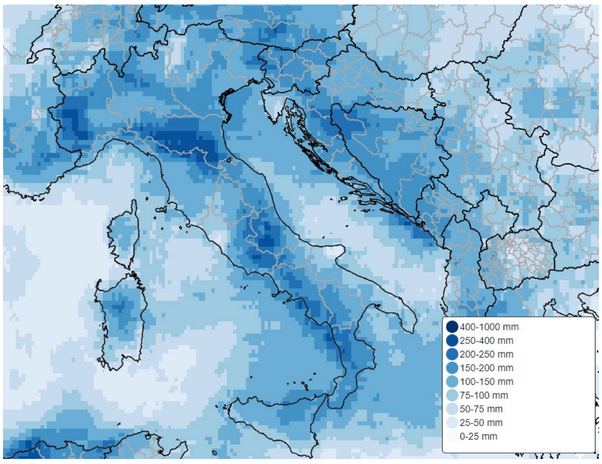
[41] European Drought Observatory, June 2023 (link)
[42] Copernicus Climate Change Service, 27 June 2023 (link)
[43] Reuters, 18 May 2023 (link)

Italy

Drought then floods in Northern Italy



Terrestrial water storage for January-April 2023 compared to long term average January-April, calculated in number of standard deviations (σ)



Total precipitation for May 2023

Similar to southwestern Europe, northern Italy also experienced a dry and warm winter, with reduced snow cover in the Alps. By May, lakes and reservoirs such as Lake Garda and the Po River were much below normal conditions.

In the Emilia-Romagna region of northern Italy, the dry conditions were abruptly reversed in May by heavy rainfall and floods. Some areas received half of their average annual rainfall in 36 hours.[44]

The rainfall caused up to 300 landslides, 23 overflowing rivers, some 400 roads damaged or destroyed and 42 flooded municipalities. The floods resulted in at least 13 deaths, 10,000 people displaced, and 5,000 farms under water.[45]

The floods caused billions of euros damage. The agriculture sector was hit particularly hard, with damages to crops estimated at about €1.5 billion.[46]

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[44] Cima research foundation, 19 May 2023 (link)
[45] Reutrers, 19 May 2023 (link)
[46] Bloomberg, 19 May 2023 (link)

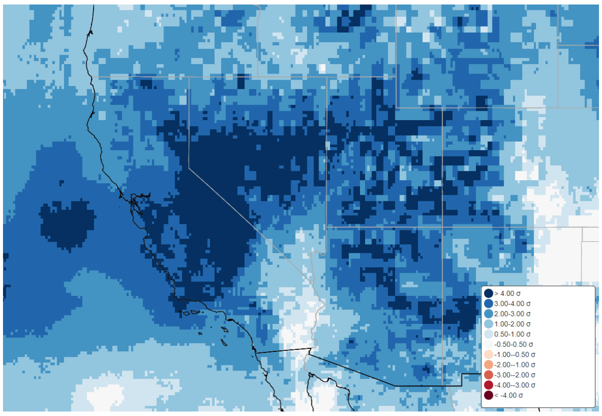
United States of America

Atmospheric rivers flood California

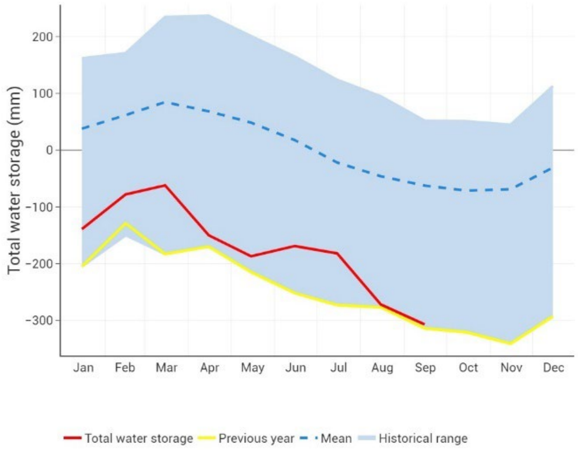
After three dry years, extreme drought conditions in California were abruptly ended by a series of moisture-laden cloud bands or 'atmospheric rivers' bringing high rainfall between December 26, 2022, and March 25, 2023.

The floods affected parts of California and Nevada. Record or near-record daily rainfall more than 120 mm was recorded in the San Francisco region. The violent storm and floods resulted in property damage and at least 22 fatalities. The economic damage was estimated to be $4.6 billion.[47]

It has been predicted that the intensity and frequency of extreme weather and floods from atmospheric rivers will increase due to global warming.[48]



Total precipitation total for December 2022- March 2023 compared to long term average December-March total precipitation, calculated in number of standard deviations (σ)

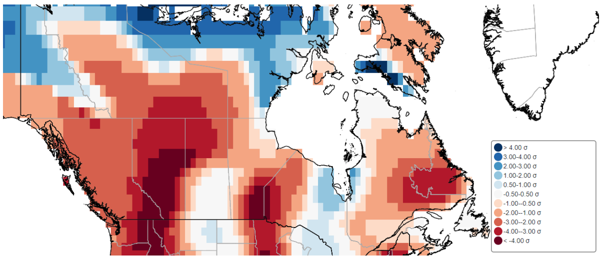


Year-on-year pattern in terrestrial water storage for California, showing a return from severe drought in 2022 (yellow) to slightly better conditions in the first half of 2023 (red)

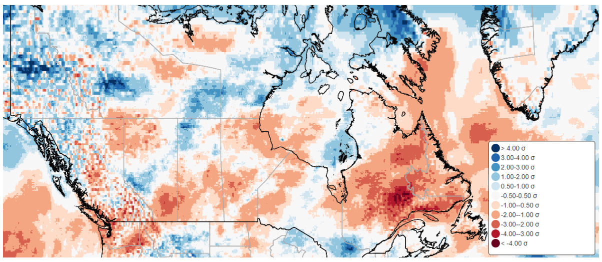
[47] NOAA, 10 January 2023 (link)
[48] Corringham et al., 2022 (link)

Canada

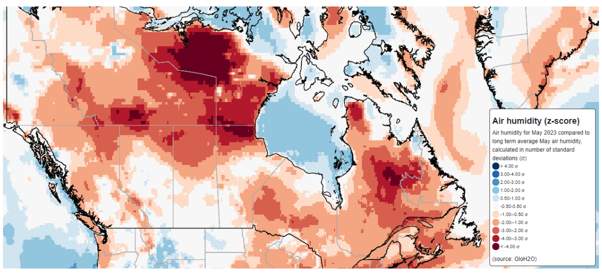
Heatwaves, drought and wildfire



Total water stored in water bodies, soil, aquifers, snow and ice for May 2023 compared to long term average for May, calculated in number of standard deviations (σ)



Total precipitation total for 6 months up to and including June 2023 compared to long term average January-June total precipitation, calculated in number of standard deviations (σ)



Air humidity for May 2023 compared to long term average May air humidity, calculated in number of standard deviations (σ)

From May to June, hot and dry conditions across Canada rapidly exacerbated already dry conditions. New records were set on Canada's west coast. The heat also accelerated snow melt in mountain ranges, causing flooding and mudslides.

The drought and hot, dry conditions directly contributed to record forest fires. The fires started in Nova Scotia on May 27 after extremely low rainfall in the preceding weeks and grew to become the largest wildfire in recorded history of the province. Fires subsequently erupted coast to coast, from British Columbia to Quebec. By autumn, fires had consumed a staggering 180,000 square kilometres, about 5% of Canada's forest area and multiple times any extent since records started in 1983.[49]

There were 17 casualties, more than 150,000 people were evacuated and 200 houses and other buildings were damaged. The fires also caused considerable economic damage, with oil production, mining and forestry disrupted by the fires. Smoke from the fires caused air quality alerts and evacuations in Canada and the United States, including in New York and Washington D.C.

It has been estimated that climate change more than doubled the likelihood of the extreme fire weather conditions that occurred. They were caused by a combination of increased temperature and decreasing humidity, both driven by global warming. The effect was compounded by unusually low precipitation in the months leading up to the fires.[50]

[49] CIFFC (link)
[50] World Weather Attribution, 22 August 2023 (link)

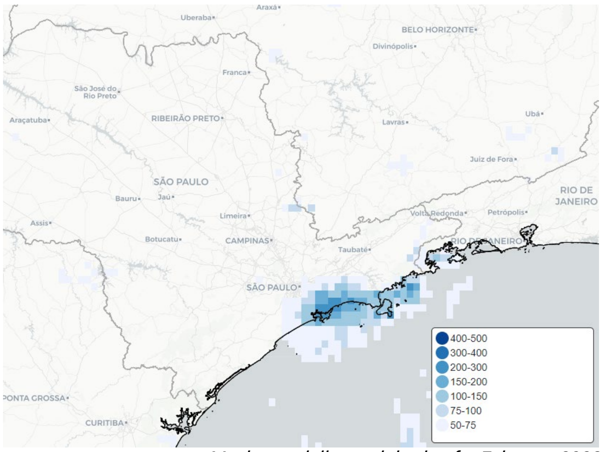
Brazil

Floods in February and a heatwave in November in Southern Brazil

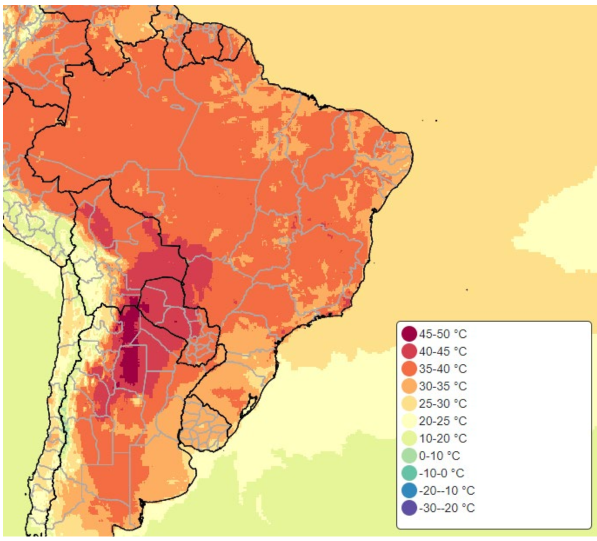
In February, São Paulo was hit by more than 600mm rain in one day, the most intense storm not associated with a cyclone in Brazil's recorded history.[51] The torrential rain caused flooding and landslides, with the city of São Sebastião hit hardest. At least 49 lives were lost, more than 50 homes destroyed and more than 2,500 people displaced.[52] Rescue and relief operations were hindered by damaged highways and continued rainfall.

Later in the year, Brazil experienced several heat waves - in August, September, October, and, worst of all, November. The November heat wave was designated the worst in the country's history by the Brazilian meteorological service. Temperatures in Mato Grosso do Sul and Minas Gerais exceeded 43°C for many consecutive days, mainly between 12-19 November 2023. The city of Araçuaí in Minas Gerais reached 44.8°C on 19 November; the highest temperature in Brazil ever recorded by the meteorological service.

The high relative humidity of the air exacerbated the impact of the heat on human health. The so-called 'apparent temperature' is indicative of health impacts and exceeded 59°C. The heatwave caused increased mortality among the vulnerable, which included a concert-goer in Rio de Janeiro who succumbed to overheating.



Maximum daily precipitation for February 2023

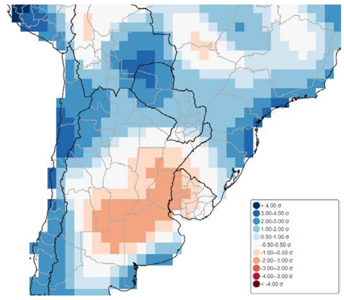


Maximum daily temperature for November 2023

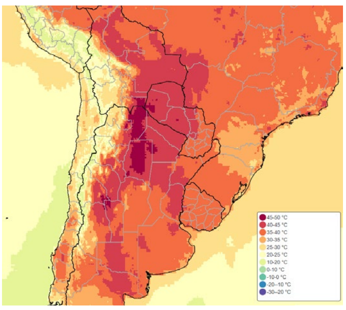
51 Folha de S.Paulo, 20 February 2023 (link)
52 Floodlist, 21 February 2023 (link)

Argentina

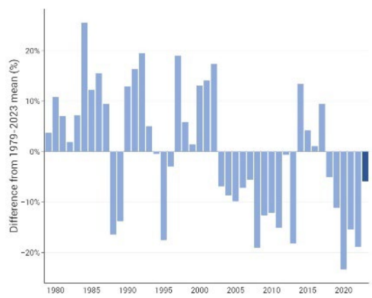
A multi-year drought intensified further



Total water stored in water bodies, soil, aquifers, snow and ice for January-May 2023 compared to long term average, calculated in number of standard deviations (σ)



Maximum temperature for 2023



Percentage variations in annual rainfall over Argentina for 1984-2023

Northern Argentina and adjoining countries suffered extreme drought conditions in 2023. The drought started in 2019 and intensified to become the worst drought in decades. The drought was accompanied by recurrent heatwaves. December-February was by far the hottest summer on record, with hot conditions persisting into March.

The heat had major impacts on agriculture. Soybean production was less than half of the preceding year and the lowest in over 20 years. Overall drought losses were estimated at $ 20 billion or 3% of GDP.[53] The agricultural crisis further compounded Argentina's economic problems, including hyperinflation. The drought and heat gave rise to widespread wildfires. In Corrientes province, between Paraguay and Uruguay, more than 1000 square kilometres were destroyed by fire in early 2023.[54]

Heatwaves returned later in the year, with an extraordinary heatwave in the winter month of August. Temperatures were more than 10 to 20 °C above average, approaching actual values of 40°C even in the Andes mountains. The previous temperature record in Buenos Aires was broken by more than 5°C.

The record winter temperatures were caused by a combination of dry land surface conditions, high sea surface temperatures in the Atlantic Ocean and a developing El Niño in the Pacific Ocean.[55] Scientists concluded that climate change was not the main driver of the lack of rainfall, but did cause increased temperatures in the region, exacerbating its severity and impacts.[56]

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[53] Buenos Aires Times, 4 July 2023 (link)
[54] AFP, 14 March 2023 (link)
[55] ABC, 4 August 2023 (link)
[56] World Weather Attribution, 16 February 2023 (link)

Amazon basin

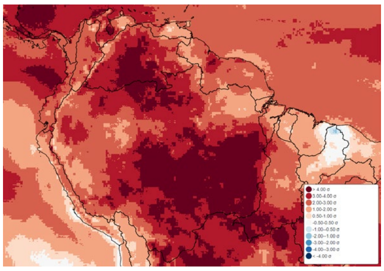
Heat and flash drought cause extremely low river levels

Starting in June, very low rainfall and high temperatures caused the rapid development of a drought in the Amazon basin. Some areas received less than a quarter of average June-November rainfall, along with several heatwaves. Air humidity reached record lows. The hot, dry air dried out forests, soils and rivers.

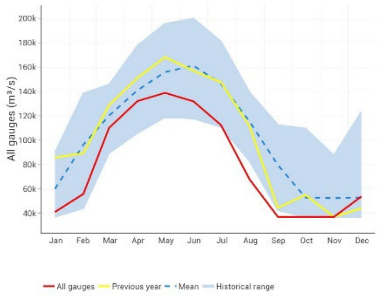
By November, the Rio Negro reached its lowest level in 120 years. More than 150 endangered river dolphins died, most likely because of water temperatures approaching 40 °C. The drought had profound impacts on communities in the Amazon, which rely on navigable rivers for food, transport and trade. Brazil's fourth-largest hydroelectric dam stopped operations because of record low flow, while shipping on the Amazon River itself was also affected.

Drought development coincided with a change to El Niño conditions and unusually warm waters in the northern Atlantic Ocean. Global warming and rainforest clearing have been implied in further exacerbating drought impacts.[57]

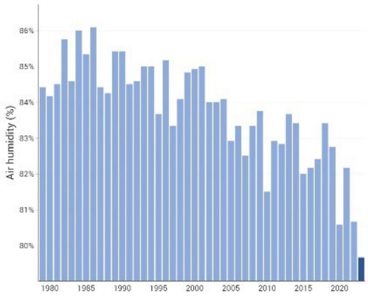
The 2023 drought is the fourth extreme drought in 15 years, increasing concerns about irreversible degradation of the vast Amazon forests by drought and fire, which could release vast amounts of carbon and speed up global warming.[58] Fire activity was close to average in 2023 but expected to increase in early 2024 if dry and warm conditions persist.[59]



Average temperature for November 2023 compared to long term average November average temperature, in standard deviations (σ)



Year-on-year pattern in streamflow in Amazon River near Manaus, showing extreme low flows from September to November 2023 (red)

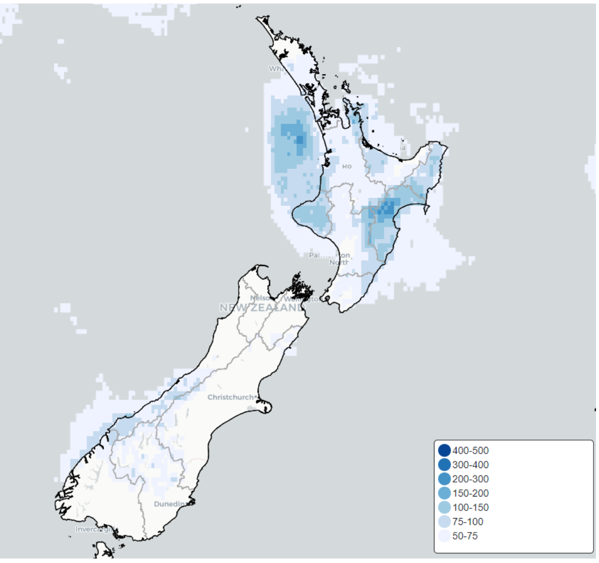


Time series of annual average relative humidity over the Amazon basin

[57] Nature, 14 November 2023 (link)
[58] Reuters, 3 December 2023 (link)
[59] INPE,31 December 2023 (link)

New Zealand

Cyclone Gabrielle



Maximum daily rainfall for February 2023

Tropical Cyclone Gabrielle formed in early February 2023 south of the Solomon Islands and made landfall on New Zealand's North Island on 12 February. The cyclone brought rainfalls of 300-400mm, wind gusts of 130-140km/h and waves as high as 11 metres, causing widespread devastation.[60]

The cyclone caused 12 fatalities, making it the deadliest weather event in New Zealand since 1968. The rain caused severe flooding and landslides, impacting water resources and damaging infrastructure. At least 10,000 people were displaced [61]

With total damages estimated at US$8.4 billion, Cyclone Gabrielle was the costliest tropical cyclone in the Southern Hemisphere and he costliest natural disaster to hit the country.

Tropical cyclones only form over sea surface temperatures above 26°C. When the cyclone formed ocean sea surface temperature was warmer than normal along the corridor from the Coral Sea to New Zealand, which likely helped to maintain its strength and rainfall potential[60].

The number of ex-tropical cyclones affecting New Zealand is expected to remain about the same or perhaps even decline, but to become more severe as the planet continues to warm. [60]

[60] NZ MetService (2023) (link)
[61] BBC, 19 March 2023 (link)

Australia

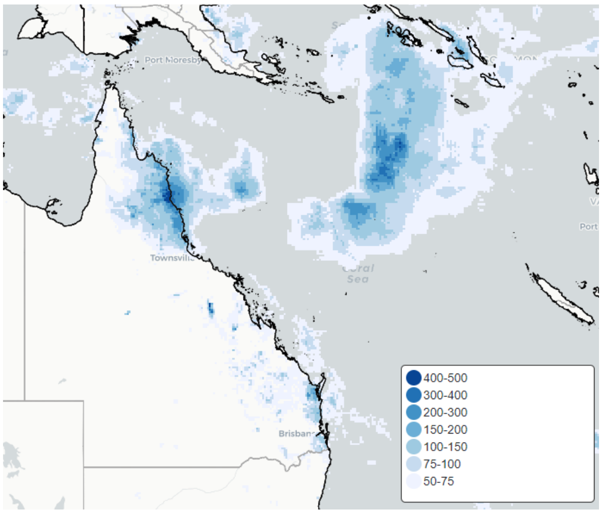
Storms and flooding in Queensland

On 17 December, ex-Tropical Cyclone Jasper produced torrential rains in the region of Cairns on the north Queensland coast, with some sites recording more than 800 mm.

The torrential rains caused widespread flooding, with river levels reaching heights not seen in over 50 years.

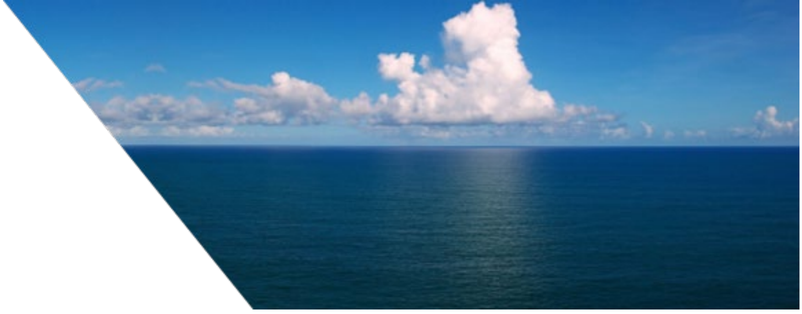
The rains left 40,000 homes and businesses without power. Emergency services moved 106 people to evacuation centres and rescued 12 people from floodwater. Several roads were closed due to flooding or debris.[62]

On 25 December, the densely populated south Queensland coast was hit by a mini tornado that caused seven casualties and left more than 150,000 homes without power. Subsequent record rainfall from 31 December onwards caused flooding, further hampering recovery efforts.



Maximum daily rainfall for December 2023

[62] Floodlist, 18 December 2023 (link)



Outlook for 2024

A look at hydrological conditions at the end of 2023 can help assess the risk of droughts developing in 2024. This is less true for floods, as the change from drought to flood conditions can happen more rapidly following intense rainfall.

Precipitation during the second half of 2023 was extremely low in the Amazon region and southern Canada. Precipitation was also low across much of the USA, Mexico, Brazil, northwest Africa, Central Asia, parts of Siberia, interior China and western Australia.

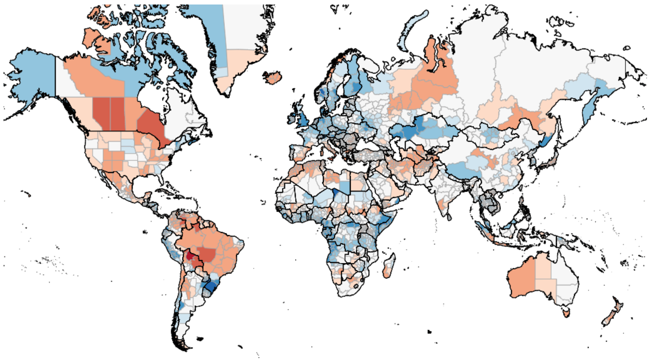
Soil wetness for October-December was also below average in most of these regions, as well as in Scandinavia and southern Africa.

Lake volumes were unusually low in the Amazon basin, Argentina, Central America and along the coast of Central Africa.

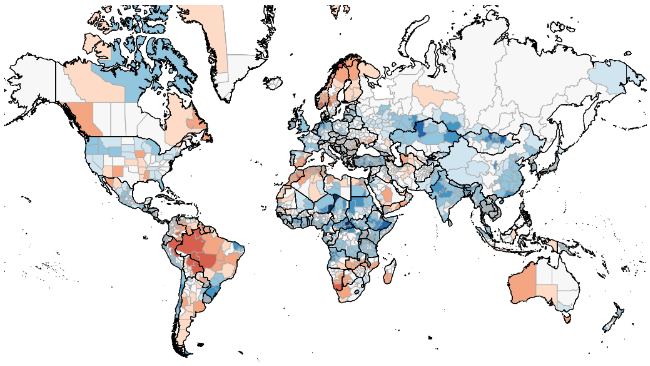
As of January 2024, El Niño conditions appear to have peaked but will persist into early 2024, with higher-than-average precipitation expected for eastern Africa and most of Asia, and lower precipitation for the western half of South America, the Caribbean, southern Africa, and northern and western Australia.[63] The greatest risk of developing or intensifying drought therefore appear to be in Central and South America (except southern Brazil and Uruguay), southern Africa and western Australia.

Regions that are unlikely to develop drought conditions for at least several months include the Sahel region and the Horn of Africa, northern Europe, India, China and southeast Asia, and southern Brazil and Uruguay. In these regions, the greater risk may be flooding, landslides and other challenges related to excessive wetness, should high rainfall return.

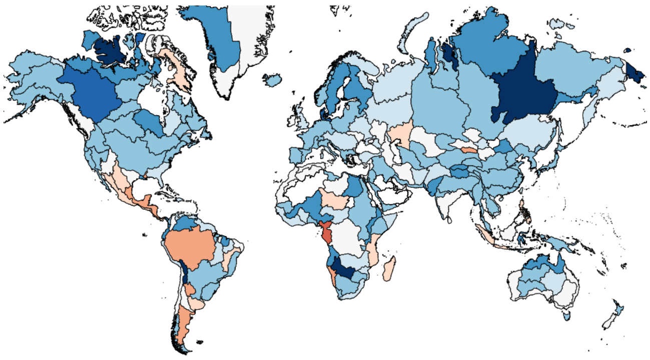
A likely return to neutral conditions is forecasted between April-June with potential for another La Niña by late 2024.



*Standardised anomaly for total precipitation for July-December 2023 by administrative region**



*Standardised anomaly in October-December by administrative region **



*Standardised anomaly in October-December total lake water storage by river basin**

** see p.8 for legend*

[63] APCC, 15 December 2023 (link)

About Us

The Global Water Monitor Consortium is a partnership of several individuals and organisations who share a mission to make global water information more current and available for public interest and debate. Together, they have developed the Global Water Monitor (www.globalwater.online), a web-based data explorer where users can find detailed current and past climate and water information.

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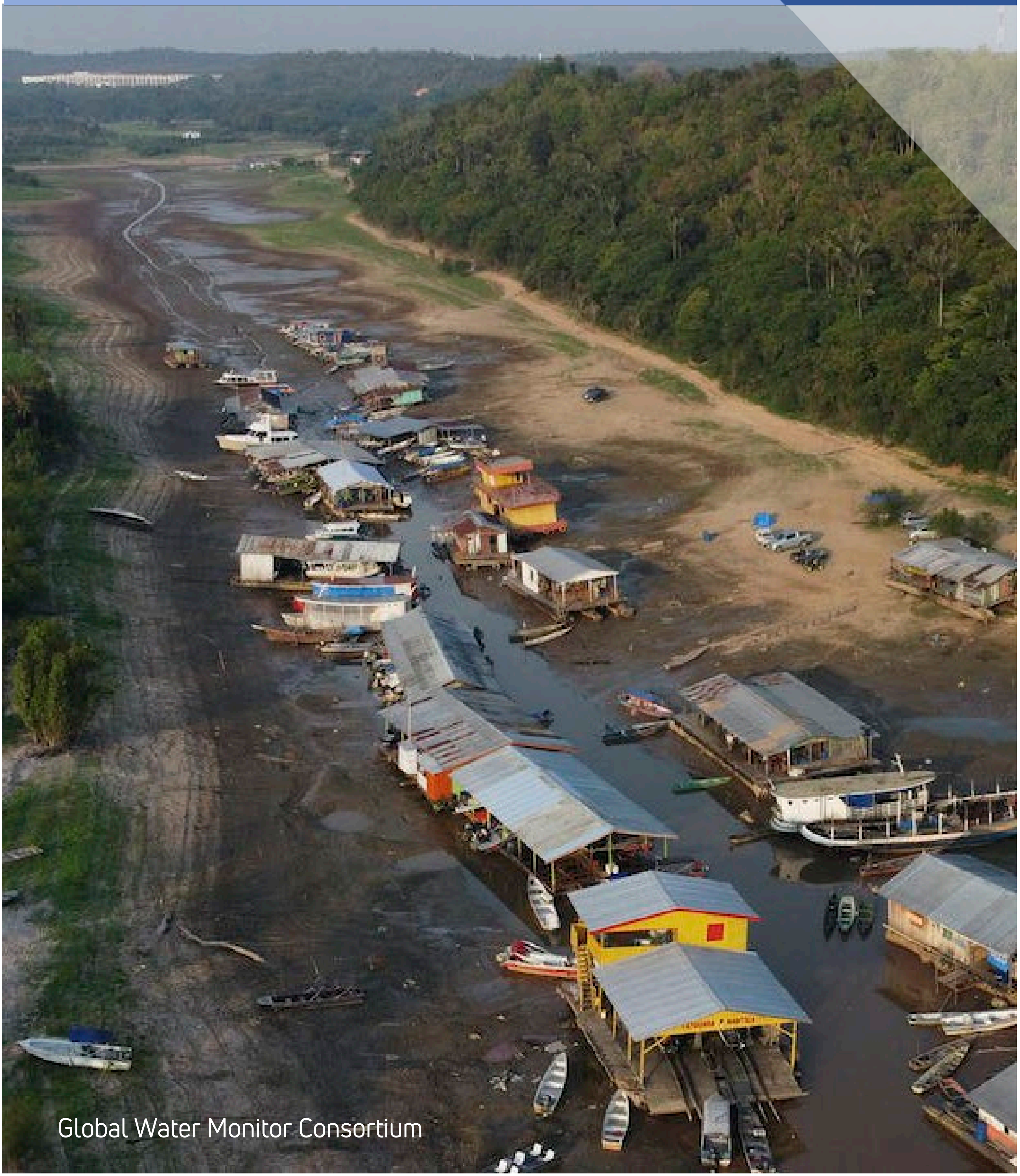

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