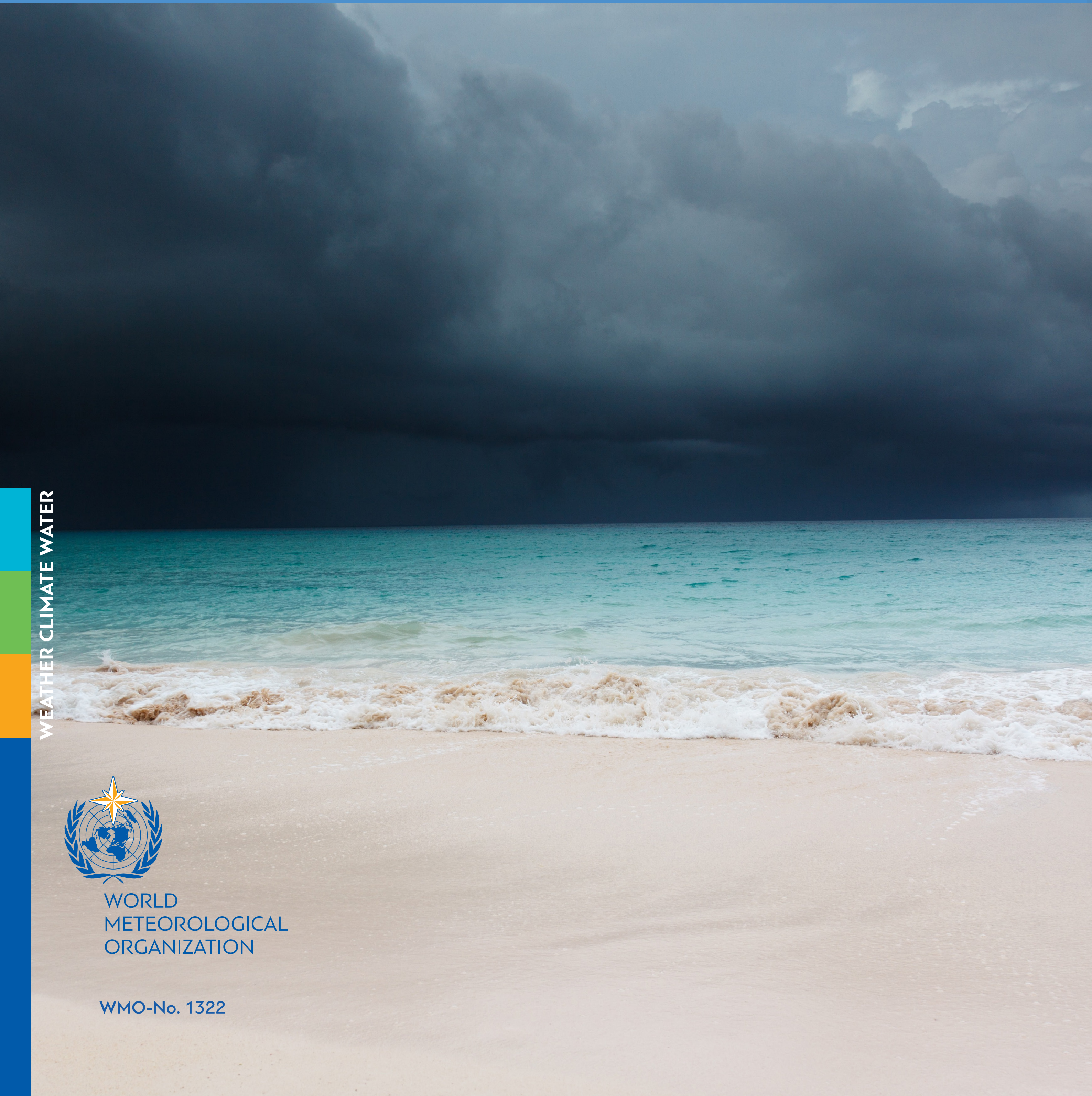
State of the Climate in Latin America and the Caribbean

2022



WEATHER CLIMATE WATER

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WMO-No. 1322

We need your feedback

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

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Contents

Key messages

In Latin America and the Caribbean, 2022 was not as warm as 2021. However, the period from 1991 to 2022 showed an average warming trend of about 0.2 °C/decade (and higher in Mexico and the Caribbean), which was the strongest on record since the start of the 30-year climatologies in 1900.

Sea levels continued to rise at a higher rate in the South Atlantic and the subtropical North Atlantic compared to the global mean, threatening the continental coastal areas of several Latin American and Caribbean countries and small island developing States (SIDS).

Tropical storms, in particular, Hurricanes *Fiona*, *Lisa* and *Ian*, caused severe damage in Central America and the Caribbean. Hurricane *Fiona* ranks as the third costliest hurricane on record (since 1980), leading to an estimated US$ 2.5 billion in damages in badly hit Puerto Rico.

Floods and landslides triggered by heavy rainfall led to hundreds of fatalities and billions of US dollars in economic losses across the region. Over the span of just a few weeks, on 15 February and 20 March, two rain-related disasters devastated Petropolis, Rio de Janeiro state, Brazil, leading to more than 230 deaths.

Prolonged drought conditions contributed to negative impacts on several economic sectors in the region, including agriculture, energy, transportation and water supply. In Brazil, the agricultural production index dropped by 5.2% in first quarter of 2022, compared with same period in 2021, due to a decline in the production of soy and corn.

Exceptionally high temperatures, low air humidity and severe drought led to periods of record wildfires in many South American countries. In January and February, Argentina and Paraguay recorded an increase of 283% and 258%, respectively, in the number of hotspots detected compared to the 2001–2021 average, and January to March wildfire CO_2 emissions were the highest in the last 20 years.

In the Parana–La Plata Basin, the drop in hydropower production in 2022 due to low river flows forced countries to replace hydroelectric energy sources with fossil fuels, hampering efforts for energy transition towards net-zero emissions.

Renewable energy capacity in the region increased by 33% between 2015 and 2020. However, the pace needs to accelerate as electricity demand is expected to increase by 48% from 2020 to 2030. In addition to the significant hydropower potential in Latin America and the Caribbean, there are untapped solar and wind resources, which accounted for 16% of total renewable energy generation in 2020.

In order to more efficiently adapt to the consequences of climate change and the resulting increase in the intensity and frequency of many extreme weather and climate events, the Latin American and Caribbean population must be made more aware of climate-related risks, and early warning systems in the region must employ improved multidisciplinary mechanisms.

Foreword

The WMO *State of the Climate in Latin America and the Caribbean 2022* report is the third in an annual series, following the successful reports published for 2020 and 2021.

This report summarizes the 2022 state of the climate and the extreme and high-impact weather and climate events in Latin America and the Caribbean (LAC), placed in the context of long-term climate variability and change, as well as the associated socioeconomic impacts. Tropical cyclones, heavy precipitation and flooding events, and severe multi-year droughts continued to cause significant human and economic losses in the region throughout 2022.

An analysis of the Nationally Determined Contributions (NDC) of the parties to the Paris Agreement shows that the top priority areas for climate change adaptation and mitigation are agriculture and food security, and energy. The report addresses these key topics, highlighting the impacts of the persistent droughts in the region on agricultural production and the unexploited potential of renewable energy, especially solar and wind resources.

There are major gaps in the weather and climate observing networks, especially in the least developed countries (LDCs) and small island developing States (SIDS); these gaps represent an obstacle to effective climate monitoring, especially at the regional and national scales, and to the provision of early warnings and adequate climate services. WMO works with its Members and partners to improve climate observations through the Global Climate Observing System (GCOS) and by ensuring adequate financial mechanisms for weather and climate observations through the Systematic Observations Financing Facility (SOFF).

Early warnings are fundamental for anticipating and reducing the impacts of extreme events. WMO is leading the United Nations Early Warnings for All initiative and its Executive Action Plan launched by United Nations Secretary-General António Guterres during the World Leaders Summit at the United Nations 2022 Climate Change Conference, COP27. The Action Plan will strengthen Earth system observations and monitoring and predictive and warning capabilities, ensuring that every person on Earth is covered by early warning services.

I wish to congratulate and thank the lead authors, contributing experts, scientists and organizations for their collaboration and input into the production and timely delivery of this publication. I am also grateful to the WMO Member National Meteorological and Hydrological Services, Regional Climate Centres and United Nations agencies for their continuous commitment to supporting WMO activities.

Prof. Petteri Taalas
Secretary-General, WMO

Global climate context

The global annual mean near-surface temperature in 2022 was 1.15 °C [1.02 °C to 1.28 °C] above the 1850–1900 pre-industrial average. The year 2022 was either the fifth or the sixth warmest year on record according to six data sets,[1] despite the cooling effect of La Niña. The years 2015 to 2022 were the eight warmest years on record in all data sets.[2]

Atmospheric concentrations of the three major greenhouse gases reached new record observed highs in 2021, the latest year for which consolidated global figures are available, with levels of carbon dioxide (CO_2) at 415.7 ± 0.2 parts per million (ppm), methane (CH_4) at 1 908 ± 2 parts per billion (ppb) and nitrous oxide (N_2O) at 334.5 ± 0.1 ppb – respectively 149%, 262% and 124% of pre-industrial (before 1750) levels (Figure 1). Real-time data from specific locations, including Mauna Loa[3] (Hawaii, United States of America) and Kennaook/Cape Grim[4] (Tasmania, Australia) indicate that levels of CO_2, CH_4 and N_2O continued to increase in 2022.

Over the past two decades, the ocean warming rate has increased, and the ocean heat content in 2022 was the highest on record. Ocean warming and accelerated loss of ice mass from the ice sheets contributed to the rise of the global mean sea level by 4.62 mm per year between 2013 and 2022, reaching a new record high in 2022. Between 1960 and 2021, the ocean absorbed about 25% of annual anthropogenic emissions of CO_2 into the atmosphere,[5] and CO_2 reacts with seawater and lowers its pH. The limited number of long-term observations in the open ocean have shown a decline in pH, with a reduction of the average global surface ocean pH of 0.017–0.027 pH units per decade since the late 1980s. This process, known as ocean acidification, affects many organisms and ecosystem services,[6] and threatens food security by endangering fisheries and aquaculture.

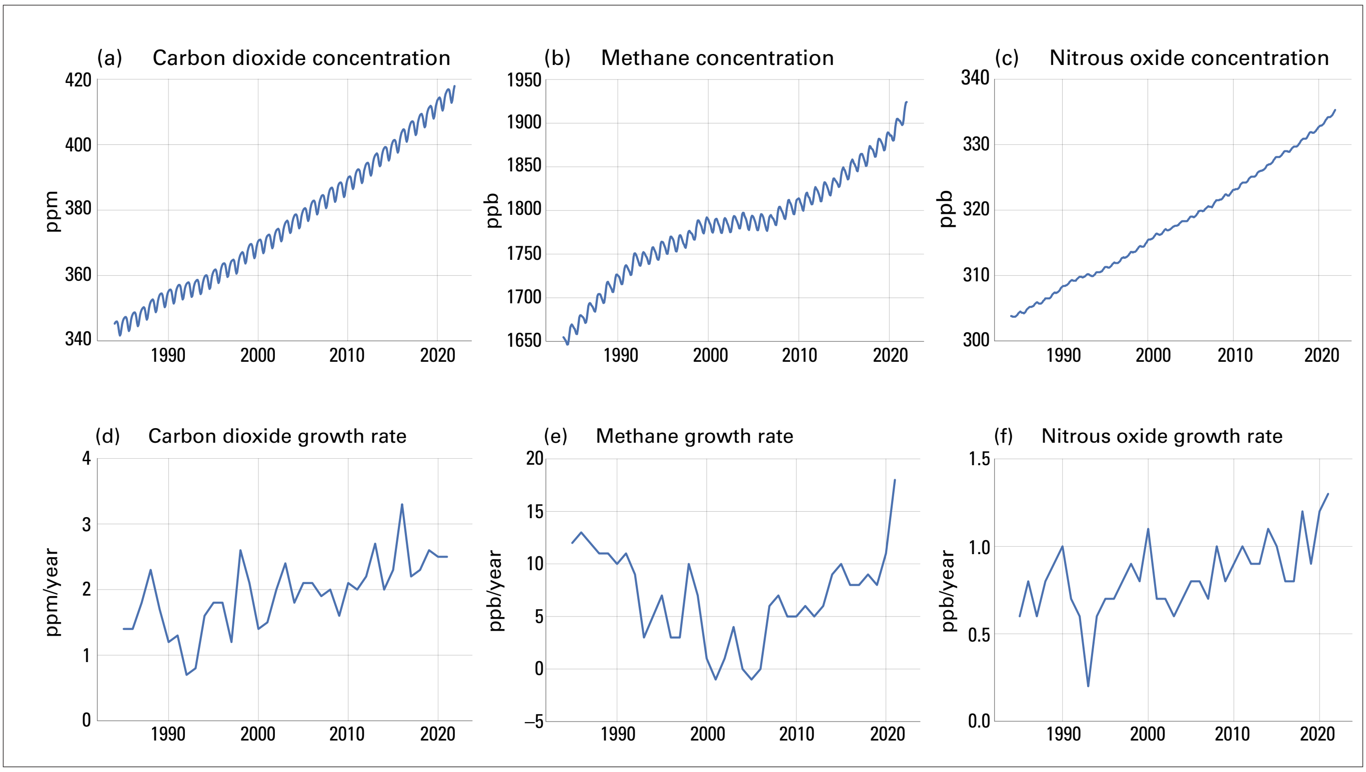


Figure 1. Top row: Monthly globally averaged mole fraction (measure of atmospheric concentration), from 1984 to 2021, of (a) CO_2 in parts per million, (b) CH_4 in parts per billion and (c) N_2O in parts per billion. Bottom row: the growth rates representing increases in successive annual means of mole fractions for (d) CO_2 in parts per million per year, (e) CH_4 in parts per billion per year and (f) N_2O in parts per billion per year.

Regional climate

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

MAJOR CLIMATE DRIVERS

LAC is surrounded by the Pacific and the Atlantic Oceans, and the climate in the region is largely influenced by the prevailing sea-surface temperatures (SSTs) and associated large-scale atmosphere–ocean coupling phenomena, such as the El Niño–Southern Oscillation (ENSO). Central and eastern tropical Pacific SST conditions are especially crucial for identifying the onset of El Niño and La Niña and their influence on climate patterns and extremes, both worldwide and in the LAC region.

La Niña conditions, which began in September 2020 and continued for most of 2021, with a brief break in the boreal summer of 2021, evolved to a moderate strength event that prevailed throughout 2022 (Figure 2), transitioning to ENSO neutral around March 2023. This marked the third consecutive year of La Niña and the third time such an event, informally referred to as a “triple dip” La Niña, has occurred in the last 50 years (following 1973–76 and 1998–2001).

ENSO strongly influences rainfall and temperature patterns over large parts of the region.[8] The 2022 La Niña event was associated with higher air temperatures and precipitation deficits over northern Mexico, a prolonged period of drought conditions over much of south-eastern South America, and increased rainfall in parts of Central America and northern South America and in the Amazon region.

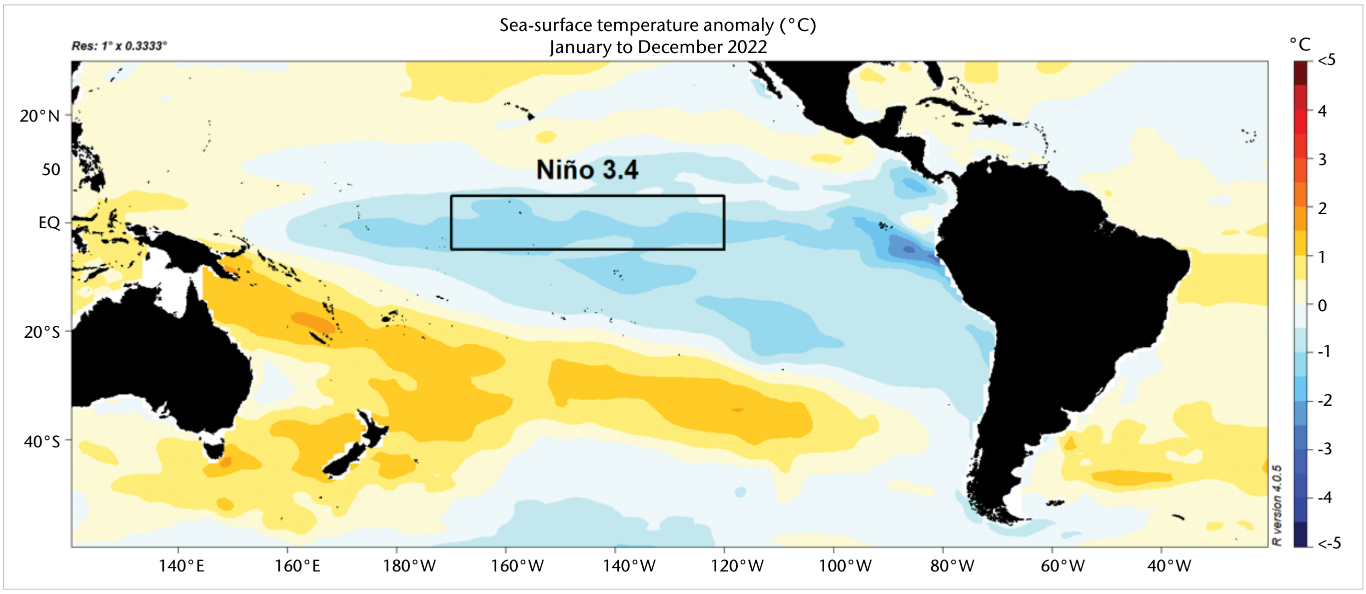

Sea-surface temperature anomaly (°C)
January to December 2022

Figure 2. Annual SST anomalies in 2022 (reference period: 1991–2020). The box represents the Niño 3.4 SST Index region (5°N–5°S, 120°W–170°W). *Source:* National Oceanic and Atmospheric Association (NOAA) National Centers for Environmental Prediction (NCEP) Global Ocean Data Assimilation System (GODAS), Processing: International Research Centre on El Niño (CIIFEN)

TEMPERATURE

The 2022 mean temperature in LAC was between the 12th and 21st highest on record, depending on the data set used, close to the 1991–2020 average (-0.06 °C to 0.10 °C) and 0.55 °C [0.46 °C to 0.70 °C] above the 1961–1990 average (Table 1). The annual mean temperature anomalies relative to 1991–2020 across the LAC region are shown in Figure 3 and Table 1 (see details regarding the data sets in the Data sets and methods section). Warming was less pronounced in the region in 2022 compared to 2021, and especially when compared to 2020 (which was one of the three warmest years on record). The 1991–2022 period shows the highest warmest trend (about 0.2 °C or higher per decade) since 1900 in the LAC region (compared with the previous 30-year periods of 1900–1930, 1931–1960, 1961–1990). Of the four subregions, Mexico experienced the largest degree of warming, almost 0.3 °C/decade, in the 1991–2022 period (Figure 4).

Table 1. 2022 temperature ranking (1900–2022) and anomalies for LAC (°C, difference from the 1991–2020 and 1961–1990 averages)

Region	*Temperature ranking*	*Anomaly (°C)*	
		1991–2020	*1961–1990*
Mexico	6th–15th warmest	0.23 [0.12–0.34]	0.96 [0.61–1.07]
Central America	10th–16th warmest	0.09 [0.02–0.16]	0.59 [0.46–0.73]
Caribbean	15th–31st warmest	-0.02 [-0.13–0.06]	0.50 [0.20–0.65]
South America	12th–25th warmest	-0.04 [-0.09–0.08]	0.50 [0.39–0.67]
LAC	12th–21st warmest	0.00 [-0.06–0.10]	0.55 [0.46–0.70]

Source: Data are from the following six data sets: Berkeley Earth, ERA5, GISTEMP, HadCRUT5, JRA-55, NOAAGlobalTemp. For details regarding the data sets, see Temperature in the Data sets and methods section.

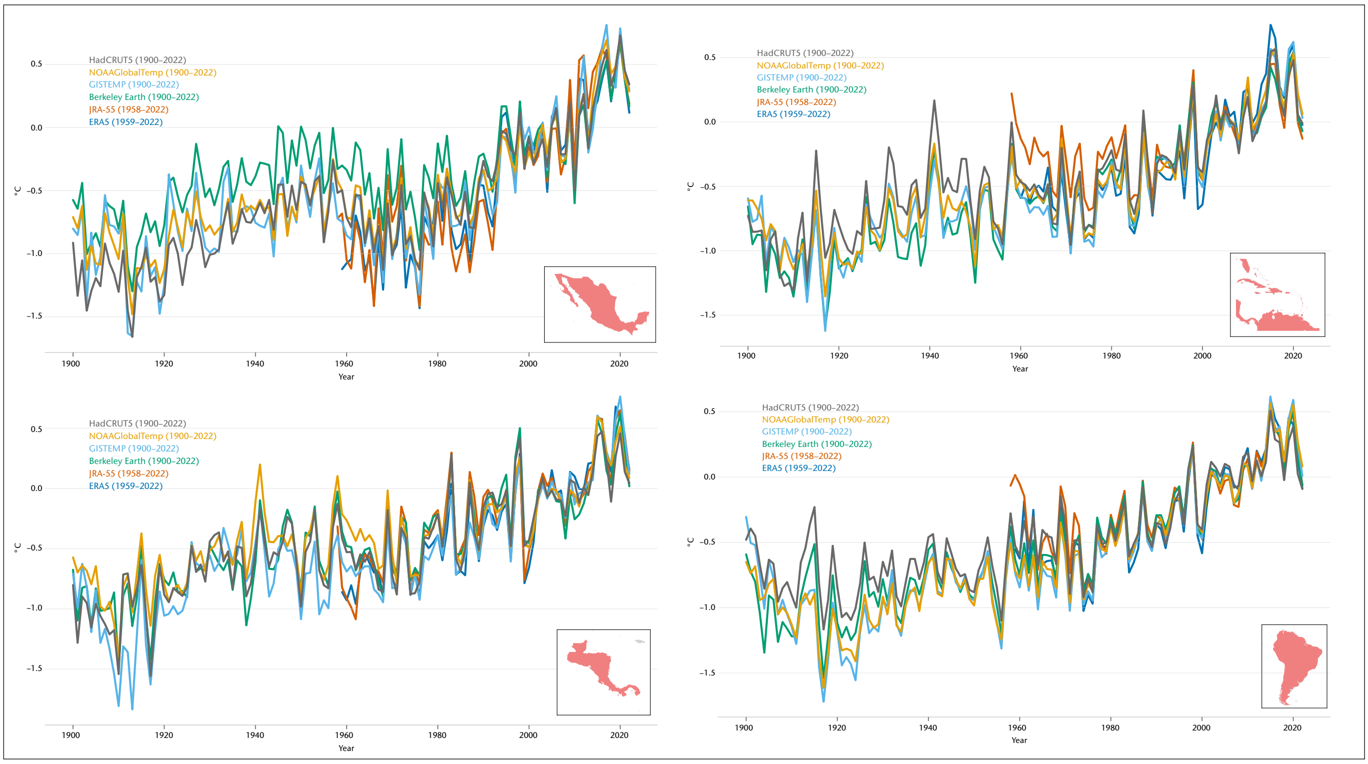


Figure 3. Annual mean temperature anomalies, 1900–2022, difference relative to the 1991–2020 average for Latin America and the Caribbean: Mexico, Central America, the Caribbean and South America. Data are from six different data sets, as indicated in the legend: HadCRUT5, NOAAGlobalTemp, GISTEMP, Berkeley Earth, ERA5 and JRA-55. The inset maps show the regions for which the averages are calculated.

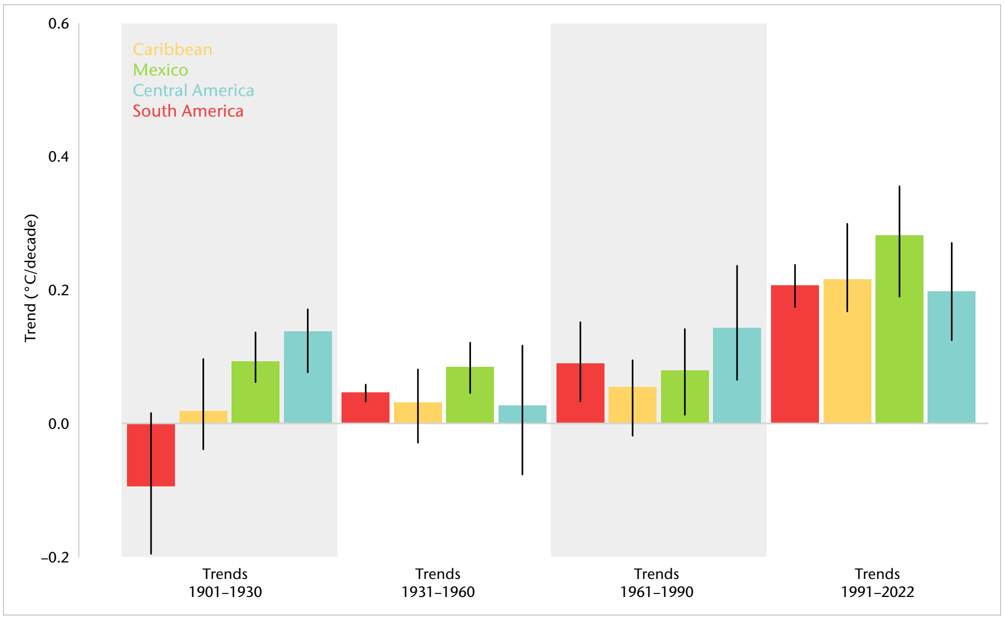


Figure 4. Regional temperature trends for the Caribbean, Mexico, Central America and South America for 30-year periods. The coloured bars show the average trend calculated over each period for the six data sets: HadCRUT5, NOAAGlobalTemp, GISTEMP, Berkeley Earth, ERA5 and JRA55. The black vertical lines indicate the ranges of the six estimates.

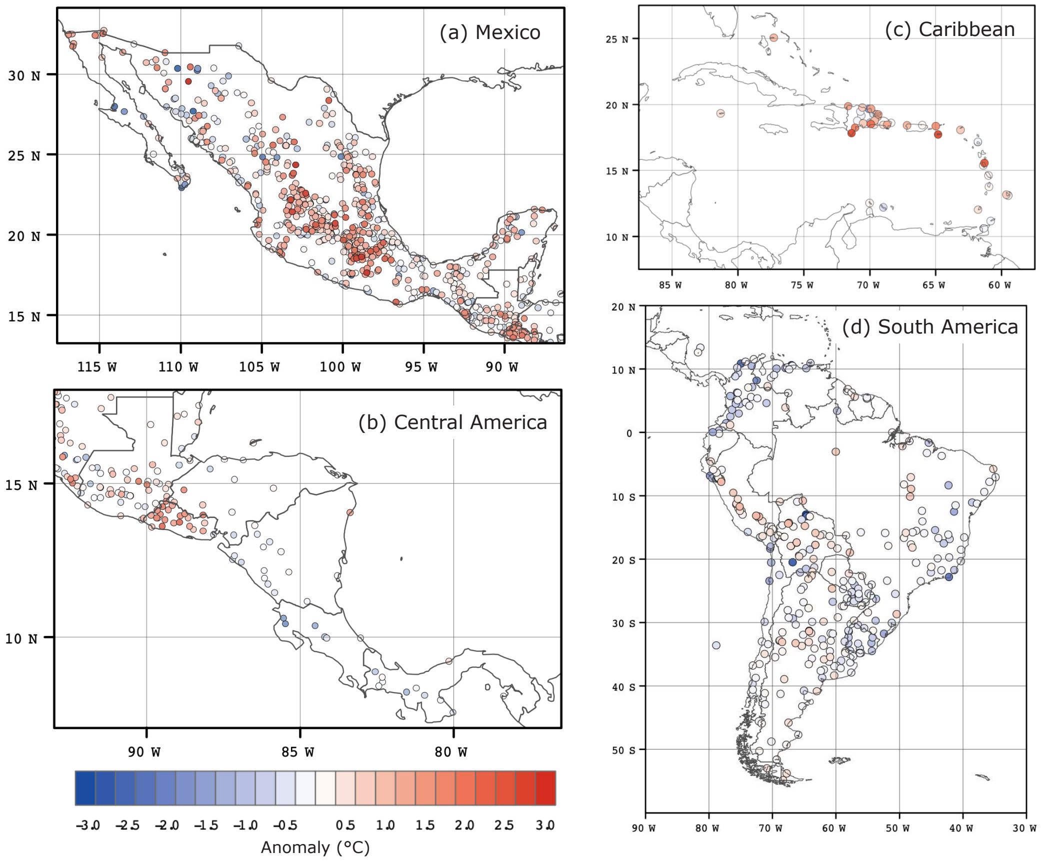


Figure 5. In situ mean air temperature (2 m) anomalies for 2022 (relative to 1991–2020) for a) Mexico, b) Central America, c) the Caribbean and d) South America, in °C. The colour scale is shown at the bottom left of the figure.
Source: CIIFEN, from National Meteorological and Hydrological Services data

In most land areas of the region, station data-based anomalies for 2022 relative to 1991–2020 (Figure 5a to 5d) show that anomalies of +1 °C to +3 °C were recorded in central and eastern Mexico and in the Yucatán Peninsula, and anomalies of +1 °C to +2 °C were recorded in Guatemala and El Salvador (Figure 5a, 5b), while negative anomalies were recorded in the rest of Central America. In the Caribbean, positive temperature anomalies of +1 °C to +2 °C were recorded in the Dominican Republic, Puerto Rico, and the small Caribbean islands (Figure 5c). In South America, above-normal temperature anomalies of +1 °C to +1.5 °C were observed in eastern Amazonia, the central and southern Andes of Peru, Bolivia, central Chile and central Argentina. Negative temperature anomalies of -0.5 °C to 1.0 °C were observed in the extreme north of Venezuela, Guyana, northern Colombia, north-eastern Chile, and Uruguay.

PRECIPITATION

The annual rainfall anomalies for 2022 (percentage relative to the 1991–2020 climatological standard normal) are shown in Figure 6. Rainfall in central and eastern Mexico was around 40%–60% below normal, while in north-west Mexico and the Yucatán Peninsula, rainfall was 40% above normal (Figure 6a). Baja California recorded precipitation that was around 20% below normal in the extreme south, and around 10% to 20% above normal in the rest of the region. In most of Central America, except for some locations in Guatemala, precipitation was between 10% and 40% above normal. In the Caribbean region, below-normal rainfall was recorded in Cuba and in some areas of the Dominican Republic and the small Caribbean islands (Figure 6c). In the Caribbean islands of Venezuela, precipitation was 10%–50% above normal.

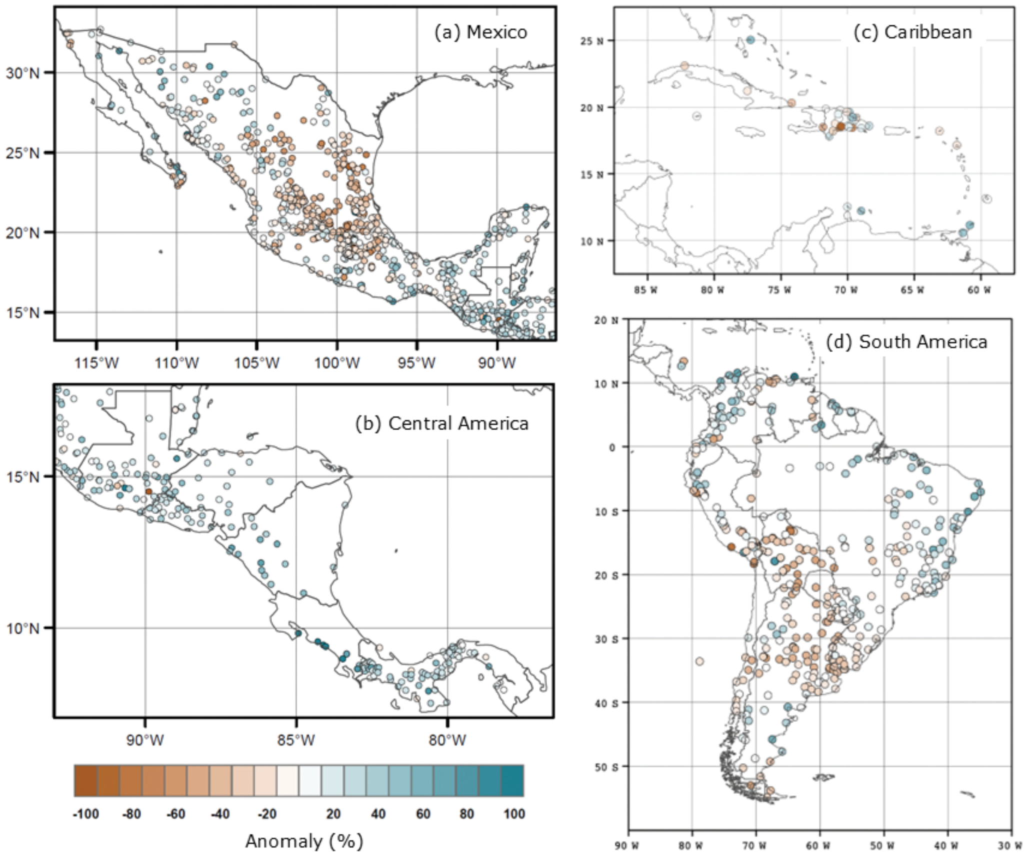


Figure 6. In situ rainfall anomalies for 2022 (percentage with respect to the 1991–2020 reference period) in a) Mexico, b) Central America, c) the Caribbean and d) South America.
Source: CIIFEN, from National Meteorological and Hydrological Services data

In South America (Figure 6d), below-normal rainfall was recorded in the central and southern regions of Chile (between 20% and 60% below normal) and in the central and south-western Andes of Peru and in Bolivia (between 30% and 50% below normal). As in 2021, below-normal rainfall was dominant over the Paraná–La Plata Basin in south-eastern Brazil, northern Argentina, Paraguay and Uruguay, suggesting a late onset and weak South American monsoon. Above-normal precipitation anomalies (10%–20%) dominated the semiarid region of north-eastern Brazil, southern Argentina, the northern coast of Peru, central and coastal Colombia, central South America and eastern Amazonia, French Guiana, Suriname and Guyana. Positive precipitation anomalies in south-east Brazil were related to heavy precipitation events concentrated in a few days (see Extreme events). Some of the observed rainfall patterns were consistent with the typical rainfall patterns associated with La Niña conditions (see Major climate drivers).

GLACIERS

Glaciers are shrinking throughout the region overall, although their behaviour depends on the regional climate and local topography.[9] Based on data from the World Glacier Monitoring Service (WGMS),[10] the surface mass balance of the glaciers in the Tropical Andes had a negative trend of around -0.96 m water equivalent (m w.e.) per year during the available monitoring period of 1990–2021. Remote sensing observations show that surface area reduction in the tropics has fluctuated from 25% to 50% since the 1950s, moving into a period of significant ice mass loss since the late 1970s.[11] This may be associated, at least partly, with increasing temperatures and decreasing solid precipitation at high elevations. Further south, in the Andes of Chile and Argentina, glaciers have been losing mass for the last two decades, at a rate of around -0.79 m w.e. per year in the dry Andes and around -0.69 m w.e. per year in the southern Andes. In the dry Andes, the longest mass balance series in this region reported by WGMS comes from the Echaurren Norte glacier (Figure 7), which lost about 29 m w.e. from 1975 to 2021 (-0.63 m w.e. per year), with the largest part of the loss, about 20 m w.e. (-0.95 m w.e. per year), occurring since 2000.[12]

An analysis of Sentinel satellite imagery shows that in 2022, the central Andes glaciers of Argentina and Chile experienced a near total loss of snowpack in January due to early summer warmth, leading to dirty/dark glaciers. The dark surface absorbed more solar radiation and warmed and melted more. Some

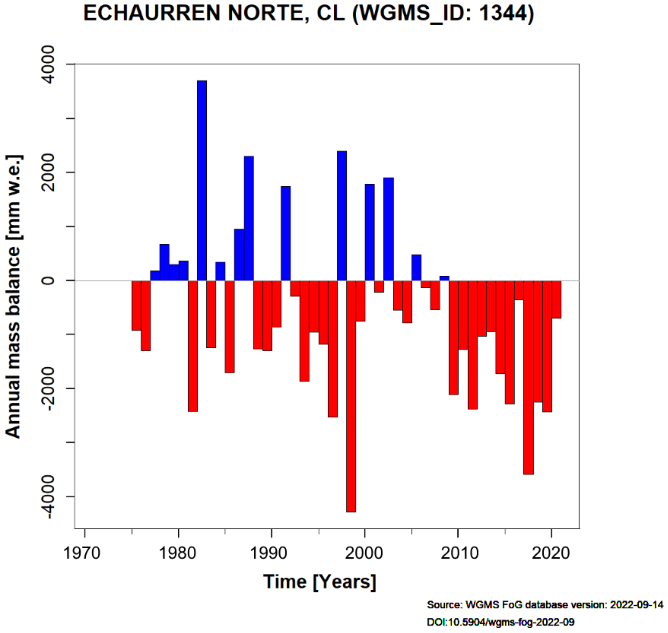


Figure 7. Annual mass balance of the Echaurren Norte reference glacier, Andes (Chile), 1975–2021
Source: World Glacier Monitoring Service (WGMS) *Fluctuations of Glaciers Database*

glaciers remained largely bare for two months and others melted faster, leading to more rapid ice loss with subsequent fragmentation and the rapid expansion of bedrock areas amidst the glacier.[13]

SEA LEVEL

In 2022, the global mean sea level (GMSL) continued to rise. The average GMSL rise is estimated to be 3.4 mm ± 0.3 mm per year over the 30 years (1993–2022) of the satellite altimeter record; however, the rate doubled between the first decade of the record (1993–2002) and the last (2013–2022), during which the rate exceeded 4 mm per year.

The sea level in the Latin America and Caribbean region has increased at a higher rate than the global mean in the South Atlantic and the subtropical North Atlantic, and at a lower rate than the global mean in the eastern Pacific over the last three decades.[14] Sea-level rise threatens a large portion of the Latin American and Caribbean population who live in coastal areas by contaminating freshwater aquifers, eroding shorelines, inundating low-lying areas, and increasing the risks of storm surges.[15]

High-precision satellite altimetry data covering the period from January 1993 to June 2022 indicate that during this period, the rates of sea-level change on the Atlantic side of South America were higher than those on the Pacific side (Figure 8 (right) and Table 2).[16] In the South American Pacific region, the rate of change was 2.21 mm ± 0.1 mm per year, and along the west coast of Mexico and Central America, it was 1.92 mm ± 0.1 mm per year, both lower than the global average of 3.37 mm ± 0.32 mm per year during this period. The sea level on the Pacific side of South America is highly influenced by ENSO, and smaller increases are observed during La Niña. Along the Atlantic coast of South America, south of the equator, the rate of change from January 1993 to June 2022, 3.66 mm ± 0.1 mm per year, was higher than the global average. A comparable rate was also observed in the subtropical North Atlantic and the Gulf of Mexico (3.60 mm ± 0.1 mm per year). In the tropical North Atlantic, around Central America and the southern Caribbean, the rate was 3.23 mm ± 0.1 mm per year during this period (Figure 8 (left) and Table 2).

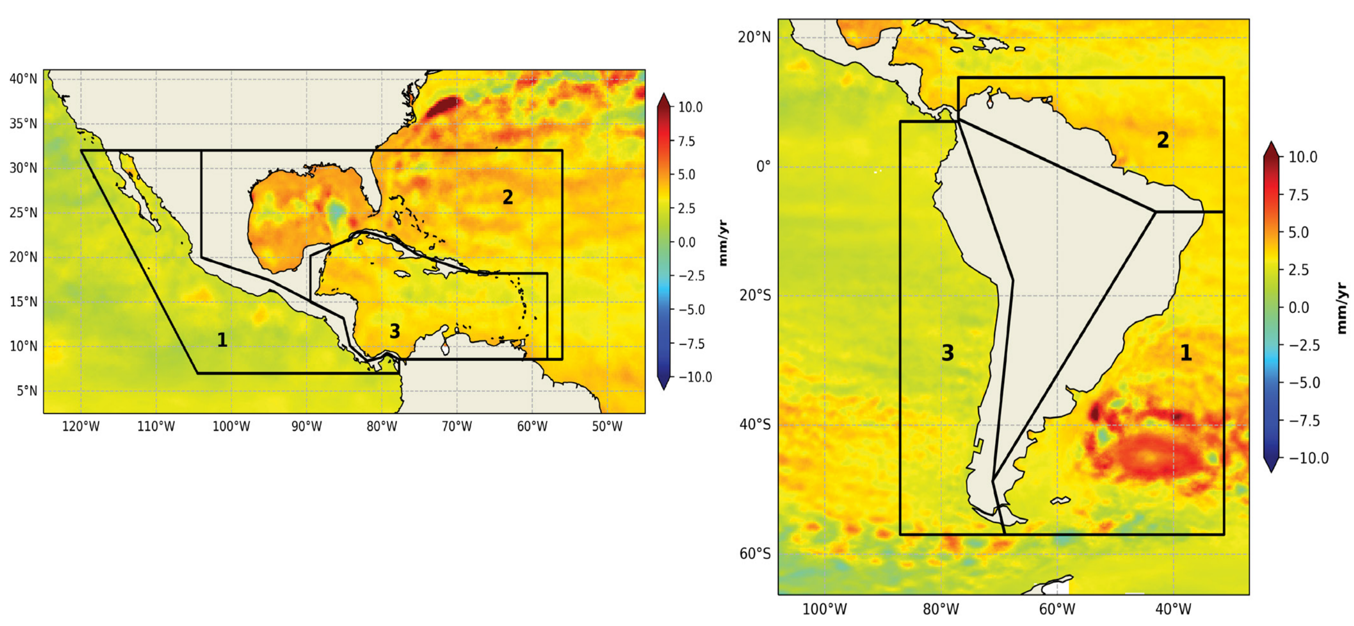


Figure 8. Sea-level trends based on satellite altimetry, in Mexico, Central America and the Caribbean (left), and in South America (right), over the period from January 1993 to June 2022. The transition from green to yellow corresponds to the 3.4 mm/year global mean averaged trend. The boxes represent the subregions where the rates of area-averaged sea-level change are provided in Table 2.
Source: Copernicus Climate Change Service (C3S)

Table 2. Rate of area-averaged coastal sea-level change over the period from January 1993 to June 2022 based on satellite altimetry. Subregions are defined in Figure 8.

Region	*Subregion (See Figure 8)*	*Area*	*Trends in rate of sea-level rise (in mm per year)*
Mexico, Central America and the Caribbean	1	Central America Pacific	1.92 ± 0.1
	2	Subtropical North Atlantic and Gulf of Mexico	3.60 ± 0.1
	3	Tropical North Atlantic	3.23 ± 0.1
South America	1	South Atlantic	3.66 ± 0.1
	2	South America tropical North Atlantic	3.39 ± 0.1
	3	South America Pacific	2.21 ± 0.1

Source: Based on gridded C3S altimetry data averaged from 50 km offshore to the coast by the Laboratory of Space Geophysical and Oceanographic Studies (LEGOS).

Extreme events

The IPCC AR6 Report[17] confirms that global warming is altering the intensity and frequency of many extreme weather events, leading to or exacerbating other high-impact events such as flooding, landslides, wildfires, and avalanches. The wider socioeconomic risks and impacts associated with these events are described in Climate-related impacts and risks. The IPCC AR6 report also shows that for all of Central and South America, the observed trends indicate a *likely* increase in the intensity and frequency of hot extremes, and a *likely* decrease in the intensity and frequency of cold extremes, as well as an increase in mean and heavy precipitation in south-eastern South America. The following sections only highlight the most extreme events of 2022; details on all reported events can be found in an interactive online map.[18]

TROPICAL CYCLONES

The 2022 Atlantic hurricane season had a near-average number of storms, ending with 14 named storms (there was an average of 14 named storms for the period 1991–2020).[19] La Niña usually favours high hurricane activity in the Atlantic Basin, but that was not the case in 2022; nevertheless, there were nine tropical storms affecting land areas in the LAC region (Table 3), including seven hurricanes, of which two, *Fiona* and *Ian*, were major hurricanes. Some of the reported impacts are described below.

Table 3. Summary of the 2022 hurricane season in the Atlantic Basin. The table includes only tropical storms, hurricanes and major hurricanes that most affected land areas in the LAC region (in chronological order). Major hurricanes are identified with the acronym MH.

Hurricane or tropical storm	*Period*	*Affected regions*
Tropical storm *Alex*	5–6 June	Yucatan Peninsula, Bermuda, Cuba
Hurricane *Bonnie*	1–9 July	South-western Caribbean, Nicaragua, Costa Rica, El Salvador
Hurricane *Earl*	2–10 September	Puerto Rico and the US Virgin Islands
Hurricane *Fiona* (MH)	14–23 September	Puerto Rico, Dominican Republic and the Turks and Caicos Islands
Hurricane *Ian* (MH)	23–30 September	Western Caribbean and Cuba
Hurricane *Julia*	7–10 October	Central Nicaragua and El Salvador
Tropical storm *Karl*	11–14 October	South-west Gulf of Mexico, Guatemala, Belize
Hurricane *Lisa*	31 October–5 November	Belize
Hurricane *Nicole*	7–11 November	Puerto Rico and the US Virgin Islands

Source: Based on data from NOAA/National Hurricane Center (NHC)

Hurricane *Fiona*[20] was an extremely long-lasting tropical cyclone that made several landfalls in the eastern and northern Caribbean islands. In Puerto Rico, Hurricane *Fiona* made landfall as a Category 1 storm on 18 September, caused hundreds of thousands to lose access to water service and, according to Puerto Rico's Department of Health, led to at least 22 deaths. Fiona caused an estimated US$ 2.5 billion of damage in Puerto Rico, making it the third costliest hurricane on record there, after *Maria* (2017) and *Georges* (1998).[21]

Hurricane *Ian* progressed over the sea south of Jamaica but produced around 785 mm–1 500 mm of rainfall, as well as storm surges and swells that affected coastal communities, with localized flooding in some areas of the island. *Ian*'s rapidly changing track posed challenges for preparedness and response operations on the island, with preliminary assessments showing relatively minor flood-related impacts, especially in low-lying coastal areas. *Ian* moved south-west of the Cayman Islands as a Category 1 hurricane and emerged into the Gulf of Mexico, after passing through Cuba, as a Category 3 major hurricane, resulting in significant agricultural damage in the affected areas, with over 20 000 hectares of land for food production destroyed.[22]

Hurricane *Lisa* affected around 172 000 people in Belize, close to 39% of the population. No fatalities were reported; however, 500 houses were destroyed, and an additional 5 000 homes were damaged. The initial damage estimates to the housing sector were approximately US$ 10 million, with most of this damage recorded within the Belize District. It should be noted that losses from natural hazards exceed an average of US$ 46 million per year in Belize.[23]

Other tropical storms also caused damage and casualties in the Caribbean, Central America and Mexico. Tropical Storm *Alex* produced heavy rainfall and flooding in portions of Cuba, and four related fatalities were reported. Tropical Storm *Earl* triggered landslides and flash flooding across the US Virgin Islands. Tropical Storm *Karl* partially originated from the remnants of Hurricane *Julia* and meandered over the south-western Gulf of Mexico. *Karl* degenerated into a remnant low before skirting the coast of the Mexican state of Tabasco; three people died due to flooding related to *Karl* in the state of Chiapas. Hurricane *Nicole* triggered landslides and localized flooding in Puerto Rico and the US Virgin Islands.[24]

The 2022 eastern Pacific hurricane season was fairly active, with 19 named storms, including two that crossed over from the Atlantic (there was an average of 15 named storms for the period 1991–2020). Most of these storms remained offshore. Hurricane *Bonnie* developed over the southern Caribbean Sea (Atlantic Basin) and entered the Pacific Basin on 2 July, a rare Atlantic-to-Pacific Basin crossing.[25] As *Bonnie* progressed over Central America (Nicaragua, Costa Rica, and El Salvador), the associated heavy rainfall led to five deaths and significantly impacted livelihoods (damaging staple crops, vegetables, and livestock) and infrastructure.[26, 27] In Costa Rica, 150 mm–250 mm of rain fell along the north-western coast and more than 3 000 people were evacuated due to the resulting flooding and mudslides. More than 10 000 people were also reported to have lost power in Nicaragua. About three months later, on 9 October, *Julia* became the second tropical storm in 2022 to cross over between the Atlantic and Pacific Basins, leading to 35 direct deaths related to flash flooding and destruction in many Central American countries.[28]

HEAVY PRECIPITATION AND FLOODING

In Central America and the Caribbean, abundant precipitation and subsequent flooding episodes were reported. In this region, La Niña typically is associated with above-normal rainfall from June to October.[29] On 17 September, in the Cambronero mountainous area of Costa Rica, a landslide occurred after heavy rainfall, leading to 10 fatalities. In Puerto Rico, the Cooperative Observer station at the Maricao Fish Hatchery (the time series began in 1955), located along the western slopes of the Cordillera Central, recorded 3 356 mm of rainfall, making 2022 the second wettest year on record (after 1998, during which 3 412 mm of rainfall was recorded). Additionally, several stations recorded their all-time highest daily precipitation amount in 2022. Most of these were associated with Hurricane *Ian* on 28 and 29 September. A number of communities were declared disaster areas by the Government of Suriname on 25 May after the country experienced widespread flooding beginning in March 2022.[30]

In central South America, episodes of extreme rainfall triggered flooding and landslides that affected thousands of people. In the state of São Paulo, Brazil, at least 19 people died due to landslides and flooding after heavy rainfall on 28 January. Earlier, on 11 January, heavy rainfall of more than 200 mm in 24 hours led to flooding and landslides in Minas Gerais (Brazil), in which at least 15 people died.[31]

On 15 February, in Petropolis in the state of Rio de Janeiro, Brazil, 258 mm of rain fell in three hours (greater than the monthly average of 210 mm) and a total of 530 mm of rain was recorded in 24 hours, leading to more than 230 fatalities.[32] Heavy rainfall occurred again on 20 March, 415 mm in 10 hours, leading to landslides and flooding.[33] On 2–3 April, in Paraty and Angra dos Reis (about one hundred kilometres south-west of Petropolis), at least 16 people died after a record amount of rainfall, over 800 mm in 48 hours, triggered floods and landslides.[34]

Exceptionally heavy rains fell in the states of Pernambuco, Alagoas, and Paraíba (north-east Brazil). In Recife, in state of Pernambuco, the intense rainfall from 25 to 30 May, 551 mm (the monthly average is 411 mm), led to 130 deaths, impacted about 130 000 people, and caused the city to declare a state of emergency.[35] In Rondônia, in western Brazilian Amazonia, heavy rain from early February increased the levels of rivers, causing flooding in the municipality of Cacoal.[36] The Rio Negro at Manaus reached the severe flood level (29 m) in early May and 29.37 m by 23 May, the fourth highest level since 1903.

In northern South America, the influence of La Niña on rainfall patterns extends from June to March and is usually associated with above-normal rainfall.[37] Heavy rainfall affected most of Colombia in 2022 (particularly the Andean and Pacific regions) at the beginning of the first rainy season (which lasts from mid-March to June) and in August, when several landslides triggered by heavy rainfall were reported across Antioquia department (north-west Colombia), leading to casualties.[38] Floods, landslides, and flash floods resulted in 266 fatalities and impacted 864 municipalities and 645 930 people. In total, 5 207 houses were destroyed and 106 574 were damaged, and 289 cities were declared to be in a state of public calamity.[39] Colombia declared a situation of national disaster and the government allocated aid of US$ 500 million.[40]

Many parts of Venezuela were affected by floods after heavy rains in October and November. In the worst single incident, 50 deaths were reported, with 56 people missing after a landslide in Las Tejerías on 8 October.

On 20 February, two people died and 20 went missing in the Bolivian Tarija department after heavy rainfall that caused a two-metre-high torrent of water, mud, and debris to slide down a narrow ravine, destroying the homes, crops, and livestock of various Guarani communities.[41]

DROUGHTS

Drought affected several countries in the LAC region during 2022. In Central America, Costa Rica reported unusually dry conditions, mainly along the southern Caribbean coast (with associated meteorological drought conditions).[42] In Mexico, the north-east states of Nuevo León and Tamaulipas were the most affected by drought in 2022. According to the Drought Monitor,[43] around 30% of Mexico experienced moderate to extreme drought during the whole of 2022, which is in agreement with the Integrated Drought Index (IDI) maps presented in Figure 9. By May 2022, about 56 % of Mexico was affected by moderate to exceptional drought.

Droughts in the LAC region are classified according to the IDI drought monitoring categories.[44] Figure 9 shows the intensity of the drought according to the IDI in four main affected countries/regions: north-east Mexico, central Chile, the central and southern Andes and the Parana–La Plata Basin.

The drought conditions in 2022 across the La Plata Basin in south-eastern South America were the worst since 1944. Below-normal rainfall was dominant in south-eastern Brazil, northern Argentina, Uruguay, Paraguay and eastern Bolivia, suggesting an early ending of the South American Monsoon.[45,46] The third La Niña year in a row caused a prolonged period of drought conditions, mainly in south-eastern South America.[47] In 2022, central Argentina recorded its driest year since records began in 1960.

El Alto, in the Bolivian Andes, registered the lowest precipitation in October–December since 1956 (a -109 mm anomaly relative to the 1991–2020 reference period). This drought has been particularly harsh for the rural sectors and indigenous populations of Bolivia, where it is estimated to have affected approximately 230 000 hectares of crops, at least 8 000 of which have been lost.[48] In total, 164 municipalities in Bolivia were affected by drought, including 3 151 communities, 171 000 families, and 247 000 hectares of land.[49]

In spring 2022, in the southern Andes of Peru, the drought was the most severe since instrumental measurements first began in 1965. Negative precipitation anomalies were between 60% and 100% and were related to the persistence of La Niña.[50] Drought also affected the west coast of subtropical South America, including Chile, where the last year with above average rainfall was 2006.[51] The year 2022 was

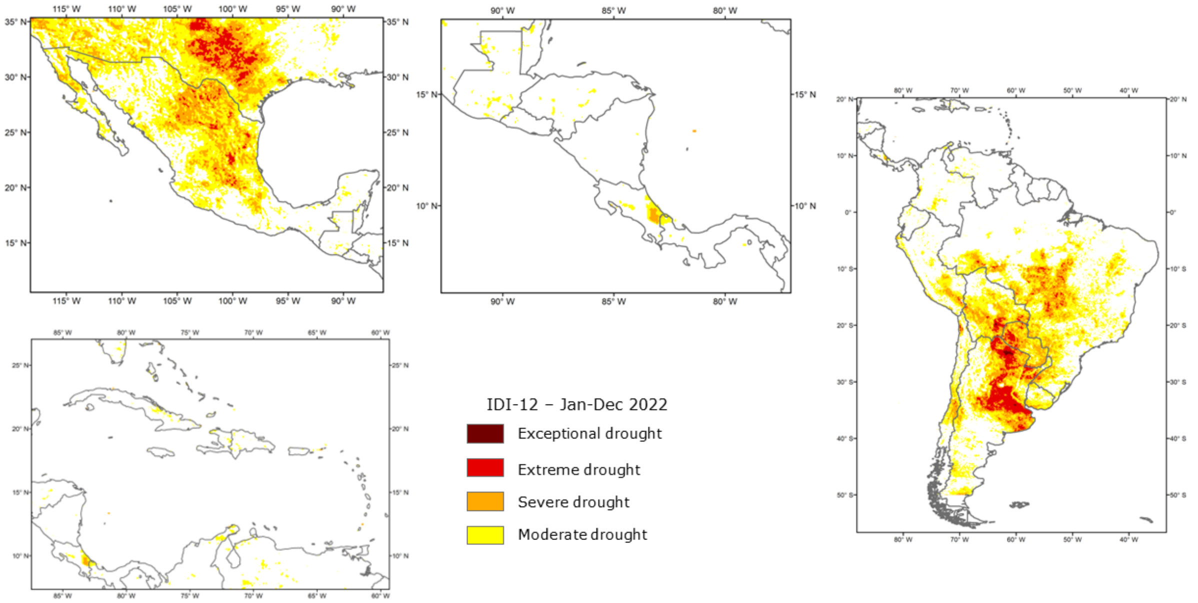


Figure 9. IDI for January–December 2022 (IDI-12) in Mexico, Central America, the Caribbean and South America
Source: Standardized Precipitation Index (SPI), calculated from Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS) and Vegetation Health Index data from the Center for Satellite Applications and Research (STAR/NOAA). The calculation was based on Cunha, A.P.M.A.; Zeri, M.; Deusdará Leal, K. et al. Extreme Drought Events over Brazil from 2011 to 2019. Atmosphere 2019, 10 (11), 642. https://doi.org/10.3390/atmos10110642.

the fourth-driest year on record for Chile, which is experiencing a 14-year-long megadrought, the region's longest and most severe drought in more than 1 000 years.

Drought affected Puerto Rico, and by mid-June, 68% of the territory was experiencing a moderate to severe drought; this was the largest area of drought for the island in the 23-year US Drought Monitor (USDM) record. Drought intensity reached a peak in the United States Virgin Islands (USVI) in mid-July, when St. Croix and St. John were in extreme drought and St. Thomas was in severe drought.[52]

A sandstorm affected northern Chile on 17 March, leaving around four thousand people without energy in the city of Diego de Almagro. Instability associated with a segregated low-pressure system triggered the storm near the city.[53] Human exposure to sand and dust storms is associated with adverse health impacts, and infrastrutures may also be impacted, as occurred in this case. These storms are also a safety hazard of concern to road transportation and aviation.[54]

HEATWAVES AND WILDFIRES

In mid-January, the southern tip of South America suffered from a long and intense heatwave.[55] In Argentina, in the period from 6 January to 26 January, temperatures in more than 50 cities rose to above 40 °C, more than 10 °C warmer than the typical average temperature. Buenos Aires had two days above 40 °C for the first time.[56] From 13 to 26 January, a heatwave occurred in 90% of the meteorological stations of Paraguay.[57] The warmest day was 24 January, with temperatures reaching 43.0 °C in Concepción (the 1991–2020 mean monthly maximum was 34.2 °C). The longest heatwave, lasting 14 consecutive days, was detected in Encarnación.

A large area centred around the central-northern part of Argentina, southern Bolivia, central Chile, and most of Paraguay and Uruguay experienced record-breaking temperatures during two consecutive heatwaves in late November and early December 2022. In Chile, forest fires caused significant damage to the flora and fauna after the burning of the Chilean Palm, a species native to the Valparaíso region.[58] In the Bolivian Amazon, during the heatwave from 25 to 30 November, the city of Cobija recorded 37.7 °C on 28 November (the mean monthly maximum is 30.8 °C).[59] The region is also experiencing a prolonged drought that started in 2019 and has worsened over the years. From 4 to 12 December, temperature records tumbled across Argentina, as 24 weather stations recorded temperatures above 40 °C. Rivadavia station, located near the border with Bolivia and Paraguay, recorded a maximum temperature of 46 °C on 7 December.[60]

The prolonged dry conditions associated with high temperatures led to record wildfires in January and February in Argentina and Paraguay. There was an increase of 283% and 258%, respectively, in the number of hotspots detected when compared to the 2001–2021 average.[61] From January to March 2022, wildfire emissions were the highest in the last 20 years in Paraguay and northern Argentina. In Bolivia and Chile, the heatwaves in November and December, together with the persistent drought conditions, resulted in record-breaking wildfires and an increase of 214% and 256%, respectively, in the number of hotspots detected when compared to the 2001–2021 average.[62] Most of these wildfires were driven by persistent low humidity and an increase in daytime temperature due to drought, which is typical of drought–heat compound events. The estimated carbon emissions from wildfires in Paraguay were approximately five megatons, and the estimated carbon emissions for Argentina during the same period were nearly 12 megatons. Other countries, such as Colombia and Venezuela, also had increases in their wildfire emissions at the end of January and February. In Brazil, the overall emissions in the Brazilian Amazon were near the 2003–2021 average during the fire season between July and October; however, the state of Amazonas experienced the highest July–October total fire emissions of the last 20 years at just over 22 megatons, almost five megatons more than the previous record high emissions, set in 2021.[63,64]

COLD WAVES

Unusually low temperatures and cold waves were reported in parts of Latin America in 2022. In the southern Peruvian Andes (Yunguyo (Puno)), cold events occurred between 12–19 April, with minimum temperatures of -1.8 °C to -1.4 °C (climatology of 2.2 °C). On 17–30 July, a cold wave affected the Patagonia region, and in Calafate (southern Argentina), the minimum temperature reached -16.5 °C. In Chile, from 28 May to 1 June, a cold wave occurred in Chillan, where the minimum temperature reached -6.3 °C on 1 June, the lowest June temperature in 55 years (the 1991–2020 mean monthly minimum for June was 5 °C).

On 16 May, a subtropical storm over the South Atlantic favoured the intensification of an intense cold air surge that reached most of subtropical South America east of the Andes.[65] In Brazil, a cold event from 16 to 23 May (the longest in 2022) affected most of the country, including western Amazonia; this event also affected Bolivia. On 18 May, the city of Sao Paulo recorded the third lowest temperature for the month of May in 32 years, 6.6 °C (the mean monthly minimum is 13.1 °C). In Gama (Brasilia), the minimum temperature reached 1.4 °C on 19 May, the lowest temperature recorded for May since 1963 (the mean monthly minimum is 15.6 °C).

Cold events affected the Bolivian Altiplano from May to December, and the El Alto station recorded the lowest May temperature recorded in Bolivia in 24 years, 9.8 °C, on 23 May (the mean monthly minimum is -0.6 °C).[66]

Observational basis for climate monitoring

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

In 1992, the Global Climate Observing System (GCOS) was established by WMO, the Intergovernmental Oceanographic Commission (IOC) of the United Nations Educational, Scientific and Cultural Organization (UNESCO), the United Nations Environment Programme (UNEP) and the International Science Council (ISC) to coordinate and facilitate the development and improvement of global climate observations. GCOS has identified a set of Essential Climate Variables (ECVs) that together provide the information necessary to understand, model and predict the trajectory of the climate as well as plan mitigation and adaptation strategies (Figure 10). The status of the observational basis for these ECVs is published in regular status reports. GCOS also identifies in implementation reports what is needed to improve the system.

In 2022, GCOS released its latest Implementation Plan[67] in response to the findings of the 2021 GCOS Status Report, to the implications arising from the IPCC Sixth Assessment Report and to recent scientific studies on the climate cycles. The publication provides recommendations for a sustained and fit-for-purpose Global Climate Observing System.

In addition to observations provided by the GCOS-coordinated Global Surface Network (GSN) and Global Upper-Air Network (GUAN), National Meteorological and Hydrological Services (NMHSs) of WMO Members provide a more comprehensive and widespread network of observations, acquired primarily for operational weather prediction. The WMO Global Basic Observing Network (GBON), a globally-designed network with prescribed capabilities and observing schedules, and for which

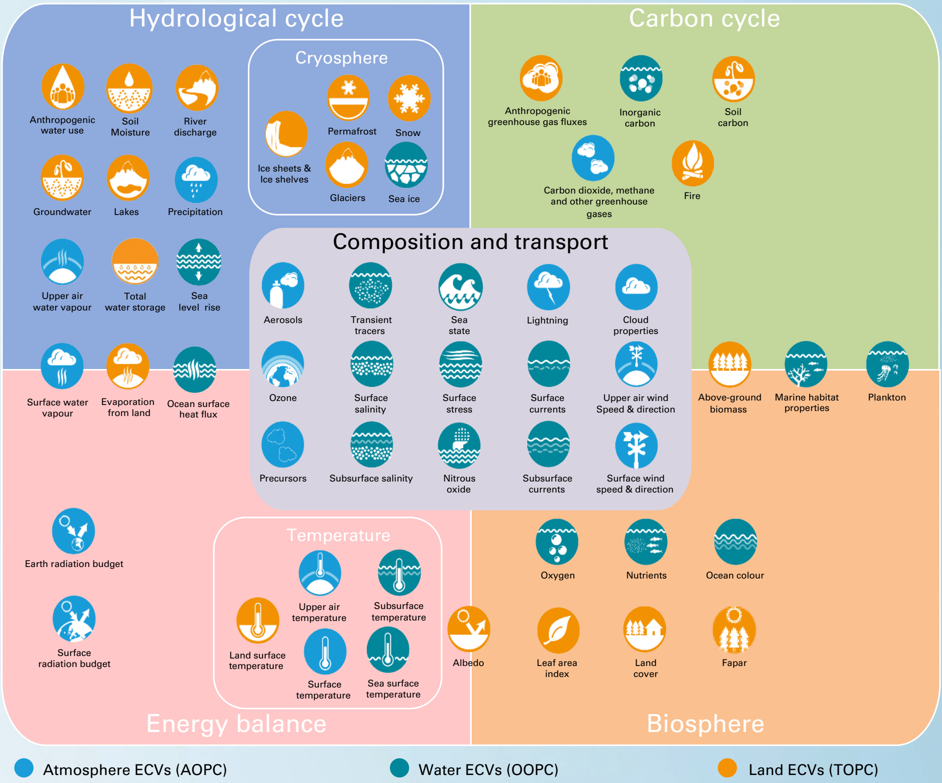


Figure 10. ECVs identified by GCOS and the climate cycles. Many ECVs contribute to understanding several different cycles – this figure only indicates the main links.

international data exchange is mandatory, will provide critically needed observations for numerical weather prediction and will help substantially strengthen climate reanalysis.

In order to provide the necessary financial and technical assistance for the implementation and operation of GBON in the poorest and most poorly observed areas of the globe, WMO, the United Nations Development Programme (UNDP) and UNEP have established the Systematic Observations Financing Facility (SOFF). SOFF has raised significant funds for supporting observations in least developed countries and small island developing States and commenced its implementation phase in 2023.

Complementing the observations of the physical and dynamic properties of the atmosphere, the WMO Global Atmospheric Watch (GAW) coordinates atmospheric composition measurements, ensuring that reliable and accurate data are obtained from measurements made by WMO Members, research institutions and/or agencies and other contributing networks.

Observations of ocean physics, biogeochemistry, biology and ecosystems are coordinated through the Global Ocean Observing System (GOOS). The GOOS Observations Coordination Group (OCG) monitors the performance of these observations[68] and produces an annual Ocean Observing System Report Card. Ocean observations are generally made widely available to international users.

In the terrestrial domain, there is a wider group of observing networks. Hydrological observations are generally operated by NMHSs and coordinated through WMO. A number of specialized Global Terrestrial Networks (GTNs), for example, on hydrology (including lakes and rivers), permafrost, glaciers, land use, and biomass, also contribute to GCOS. Data exchange agreements are generally less developed for the terrestrial networks, and many important observations are not made available to international users.

The Committee on Earth Observation Satellites/Coordination Group for Meteorological Satellites (CEOS/CGMS) Joint Working Group on Climate (WGClimate) bases the development of satellite observations for climate on the ECV requirements established by GCOS. It has produced an ECV Inventory that includes records for 766 climate data records for 33 ECVs covering 72 separate ECV products, with more planned. WGClimate is also working on actions arising from the Implementation Plan. Satellite observations have near-global coverage. Used with ground-based observations, either as complementary data sets, or for validation and calibration, they form an invaluable part of the global observing system.

Climate-related impacts and risks

Climate-related impacts in LAC are associated not only with hazardous events, but also with a complex scenario of increased exposure and vulnerability, generally linked to high levels of poverty and low levels of governance.[69] Until 2018, 76% of the population lived in informal urban settlements – two thirds of urban growth in LAC is unplanned.[70] It is estimated that 340 million people live in medium and small urban areas, where 80% of climate-related disasters occur.[71] Added to this complex scenario are high and rising food inflation, increasing poverty in the context of the COVID-19 pandemic, high levels of income inequality, and increasing levels of hunger, food insecurity, and obesity. In 2023, the Caribbean's small island developing States are expected to face increased vulnerability due to climate-related migration and food insecurity.[72]

The discussions in this section are relevant to some of the United Nations Sustainable Development Goals (SDGs). Achieving food security and improved nutrition and promoting sustainable agriculture will help reduce hunger and will help SDG 2 to be met. Meeting SDGs 6 and 7 will ensure the availability and sustainable management of water and sanitation and will ensure that everyone has access to affordable, reliable, sustainable and modern energy.

AFFECTED POPULATION AND DAMAGES

This section complements the Extreme events section. Based on information from the Centre for Research on the Epidemiology of Disasters (CRED) Emergency Events Database (EM-DAT),[73] in 2022, 78 meteorological, hydrological and climate-related hazards were reported in the Latin America and the Caribbean region; of these, 86% were storm and flood related events and accounted for 98% of the 1 153 fatalities documented in this database (Figure 11). The US$ 9 billion economic damages reported to EM-DAT were mainly due to drought (40%) and storms (32%). The real figures related to the impacts of extreme events are presumed to be worse because of under-reporting and because data on impacts are not available for some countries.[74]

AGRICULTURE AND FOOD SECURITY

In Latin America and the Caribbean, the number of people affected by undernourishment is projected to remain stable until 2030 at around 56 million, corresponding to about eight percent of the population.[75] The

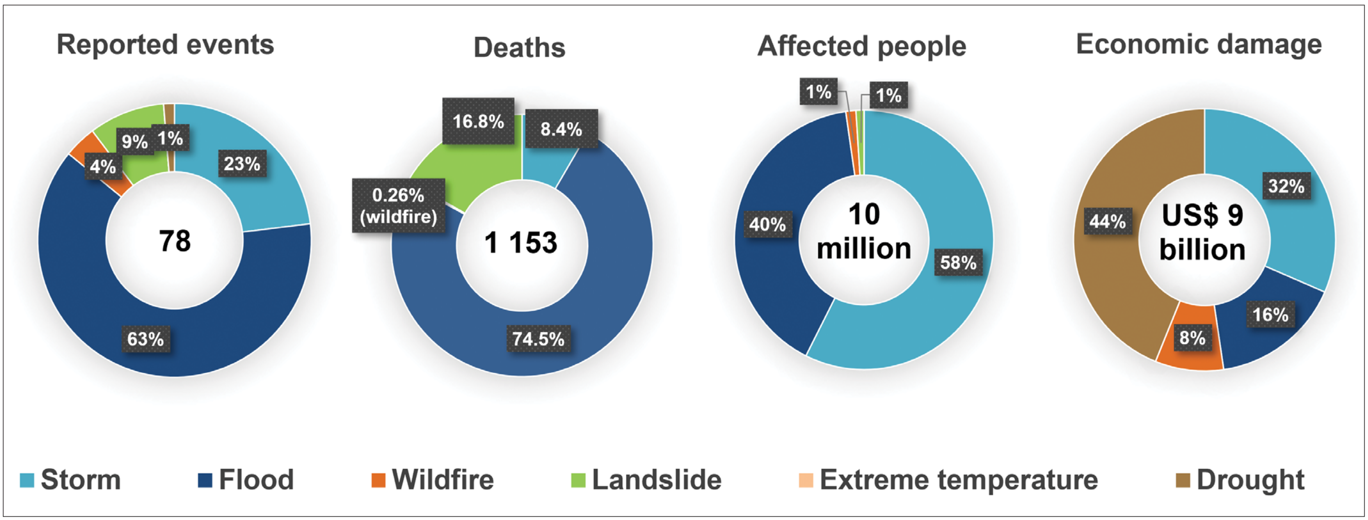


Figure 11. Weather-, climate- and water-related disasters in Latin America and the Caribbean in 2022. Note: Impact numbers for some disaster occurrences may be lacking due to data unavailability.
Source: CRED EM-DAT

region plays a vital role in producing food and ecosystem services that benefit not only the region itself, but the entire planet. As food systems are very diverse, there is enormous variation among the region's countries in terms of their scale, sophistication, and economic importance.

Drought conditions in 2022 led to damages to agriculture and reduced crop yields, affecting global crop markets. In Brazil, a lack of rain and high temperatures were associated with large agricultural losses during the year. Brazil is one of the world's breadbaskets; agriculture amounts to nearly 7% of its annual gross domestic product (GDP). For the first quarter of 2022, there was a reduction of 5.2% in Brazil's agricultural production index compared to the first quarter of 2021.[76] This was largely due to poor harvests of soy and corn associated with drought (it was the third consecutive dry year in parts of the country). Coffee yields were also affected and are expected to be the lowest since 2014; Brazil is the world's largest coffee bean producer.[77]

Gran Chaco[78] is experiencing its most severe drought in the last 80 years; 80% of families in this area have suffered losses of over 75% with respect to their agricultural production for self-consumption.

In Argentina, over 60% of the total damages and loses concerning agricultural production systems were related to cattle production. At the peak of the dry conditions in January 2022, about 6.9 million heads of cattle were negatively affected not only by less forage availability, but also by a lack of drinking water and intense heat, which have a significant impact on the health and well-being of animals. The north-eastern provinces were the most affected by the dry conditions.[79]

Chile has experienced an uninterrupted sequence of drier than average years since 2010, a drought with unprecedented longevity and large spatial extent in the historical record.[80] For the first time in its history, Chile declared an "agricultural emergency" in December 2022 in the Magallanes region and in the Chilean Antarctic due to the water deficits in those areas. To alleviate the problems caused by the drought, the government will grant aid to agricultural and livestock producers.[81,82]

By December 2022, in Central America and the Caribbean, Segunda/Postrera season[83] cereals were developing under favourable conditions despite localized damage from Tropical Storm *Julia* and Hurricane *Lisa*. In Haiti, the harvesting of second season cereals was finalized with slightly below-average yields.[84]

WATER RESOURCES AND ENERGY PRODUCTION

The megadrought in central Chile continued in 2022. More than half of Chile's population of 19 million live in areas suffering from severe water scarcity. In April 2022, the Government of Chile announced an unprecedented water rationing plan for its capital city, Santiago. Central Chile (33°S–45°S) was the most affected region, with moderate to severe drought, and by December 2022, 58.4% of the national territory was affected by some degree of drought. The long-lived "Central Chile Mega Drought", put Chile at the forefront of the LAC region's water crisis.

The Paraná River, on which Argentina relies to export 80% of its agricultural products, was affected by low water flow due to the Paraná–La Plata Basin (LPB) drought (see Droughts and Figure 12). Levels of the Paraguay River at Ladario reached 64 cm below normal (the annual average level for 1900–2022 was about 280 cm). This situation can partially be attributed to dry conditions related to the La Niña event that started in 2020 and extended into 2022.[85] In the LPB in 2022, the drop in hydropower productivity did not lead to an energy crisis but led countries to turn to less sustainable energy sources, such as thermoelectric sources, which use fossil fuels, making energy more expensive.[86] The drought and associated low river flows caused problems for energy production at the hydroelectric plants in the region. Electricity production in the two binational power plants in the LPB – Yacyretá (Argentina and Paraguay) and Itaipú (Paraguay and Brazil) – has been drastically affected by the low levels of water. Itaipú has shown a steady decrease in water levels since 2018. A similar pattern has been seen for Yacyretá, although the decrease in hydropower generation began a little later than in Itaipú.[87]

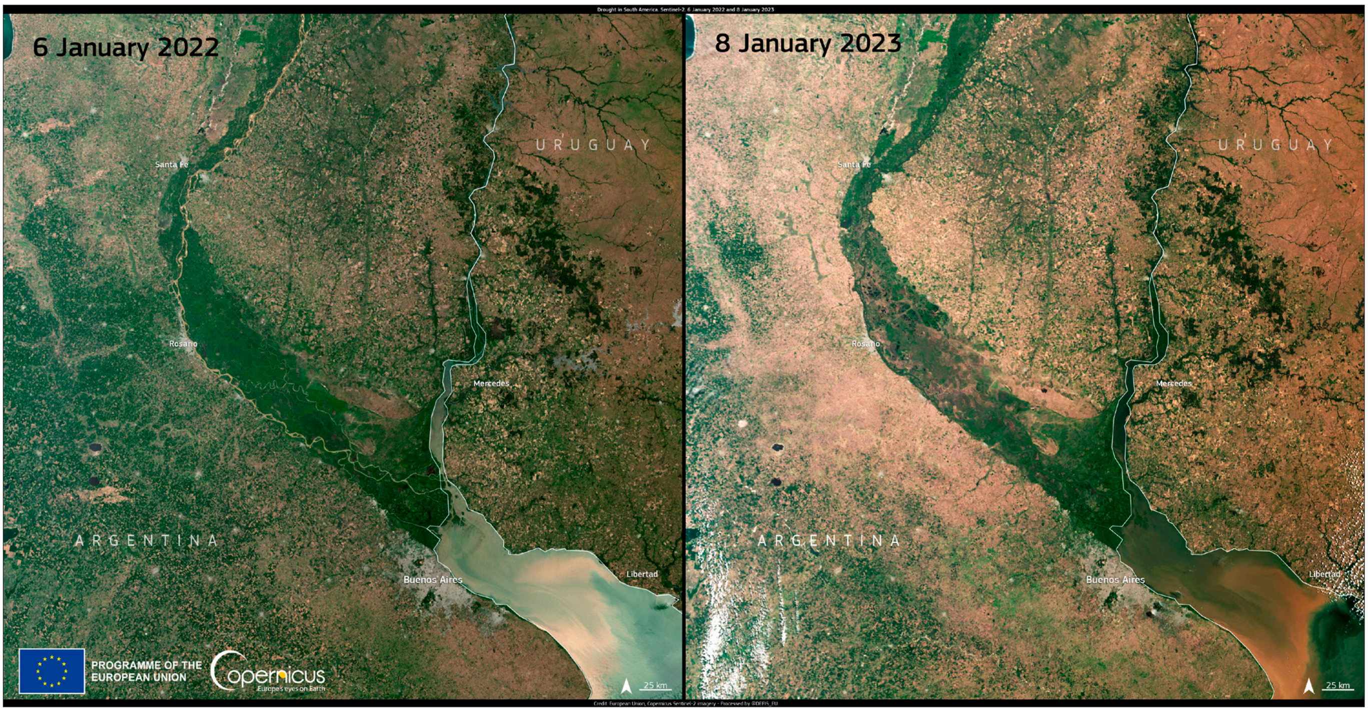


Figure 12. Impact of the drought on the Paraná River Basin region in January 2022 (left) and January 2023 (right)
Source: Copernicus Sentinel-3 satellites (https://www.copernicus.eu/en/form/image-of-the-day-download?image_id=/system/files/2023-01/image_day/20230110_Drought_South_America.jpg)

In Mexico, drought affected the water supply in one of the biggest metropolitan regions, Monterrey, and two of the three dams that provide water for the city, La Boca and Cerro Prieto, reached extreme low levels, with 13% and 7% of full capacity, respectively. In Costa Rica, drought affected the potable water supply in the North Pacific and central country regions.

Enhancing climate resilience and adaptation policies

As part of their efforts to mitigate and adapt to climate change, parties to the Paris Agreement in the LAC region have submitted ambitious Nationally Determined Contributions (NDCs). As of February 2023, a total of 30 parties from LAC have submitted their NDCs, and 93% of these have submitted updated NDCs.

SECTORAL PRIORITIES UPDATE OF THE REGION

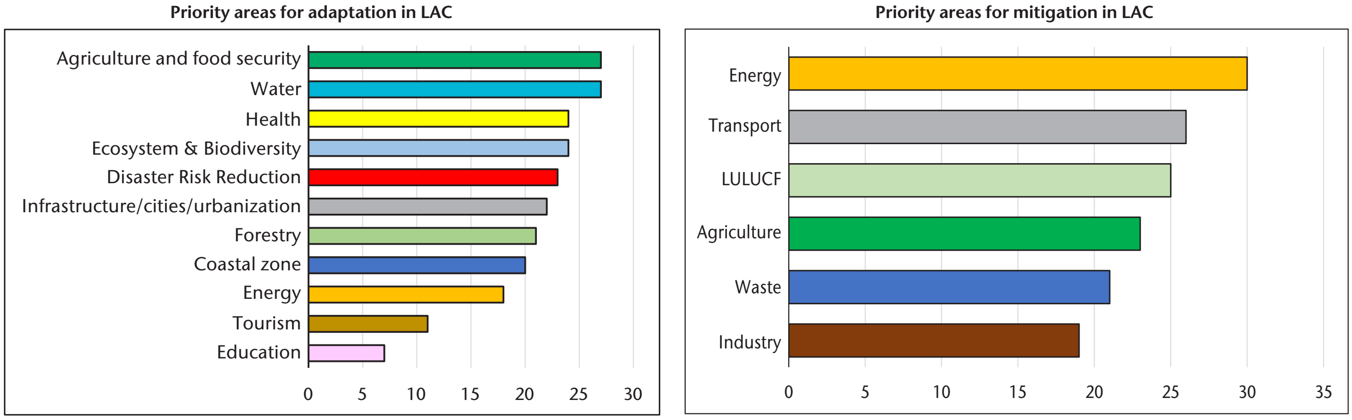
Most parties to the Paris Agreement in the LAC region have enhanced their efforts in adaptation and have set clear priorities and goals. The top priority areas for adaptation in the region are agriculture and food security, water, health, and ecosystems (Figure 13). The top priority areas for reducing greenhouse gas (GHG) emissions in the region are energy; transport; and land use, land use change, and forestry (LULUCF).

ENHANCING THE ROLE OF NATIONAL METEOROLOGICAL AND HYDROLOGICAL SERVICES IN SUPPORTING RESILIENT AGRICULTURE

The agricultural sector in LAC plays an essential role in producing food that feeds the region and the entire planet.[88] However, the sector is highly vulnerable to the impacts of climate change. Climate services have demonstrably improved agricultural production and reduced food insecurity; however, such services are still lagging in the region.

According to the data provided by National Meteorological and Hydrological Services (NMHSs) and collected by WMO, 66% of WMO Members in LAC reported providing climate services for agriculture and food security. However, fewer than 50% of Members reported providing climate projections and tailored products for the sector (Figure 14). These findings demonstrate that there is a gap regarding information from NMHSs and that there is room for improvement with respect to the potential to support climate-smart decisions. It is imperative that these emerging gaps be addressed as the LAC NDCs emphasize the importance of agriculture in promoting economic and rural development, employment, and food security in the region.

According to the IPCC AR6 Working Group II (WG2) report,[89] there is high confidence that drought severity and intensity will increase and that soil moisture will decline in south-western South America, south-western North America, Central America and the Amazon Basin. These regions are expected to become drier due to both reduced precipitation and increases in evaporative demand.


Priority areas for adaptation in LAC

Priority areas for mitigation in LAC

Figure 13. Priority areas for adaptation (left) and for mitigation (right) for Latin America and the Caribbean
Source: 2023 WMO analysis of the NDCs of 30 parties to the Paris Agreement in Latin America and the Caribbean from 2016 to February 2023

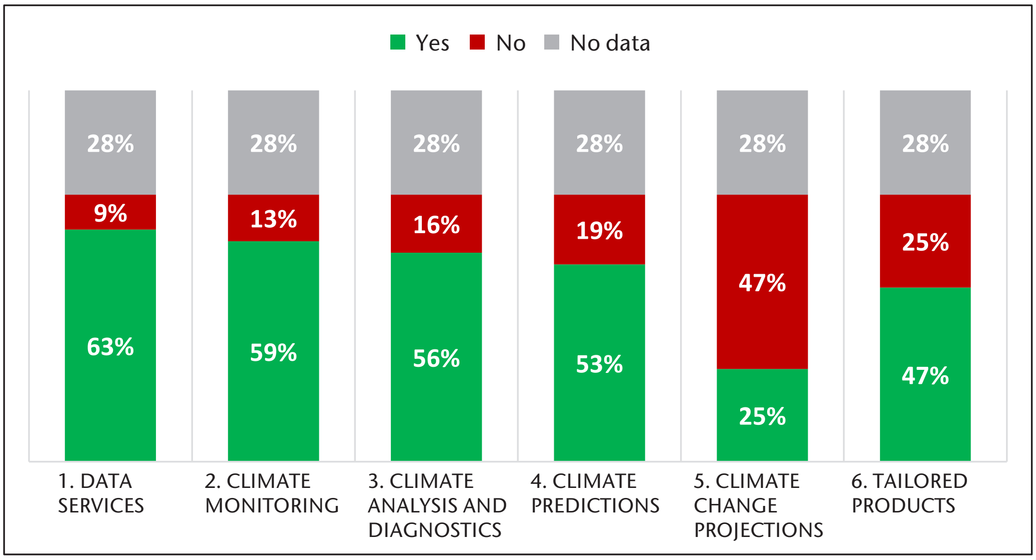


Figure 14. Percentage of Latin America and the Caribbean meteorological services providing climate services to the agriculture and food security sector by type of product
Source: WMO Climate services checklist data

NMHSs and Regional Climate Centres (RCCs) in the region have a leading role to play in providing historical data and prediction information for early preparedness and the future planning of agricultural activities. This includes, inter alia:

(1) Providing long-term time series to analyse trends and extreme values associated with drought frequency, intensity, and duration. This will allow for a better identification of drought risks and indices in support of informed decisions for adaptation;[90]

(2) Providing seasonal forecasts and organizing Regional Climate Outlook Forums (RCOFs);

(3) Strengthening RCC products, in particular, improving downscaled climate projections;

(4) Implementing climate watch systems, aiming to enhance science-based decision-making and countermeasures against extreme weather/climate events and anomalous climate states.[91]

IMPROVING MULTI-HAZARD RISK INFORMATION AND EARLY WARNING SYSTEMS, CLIMATE POLICY AND CLIMATE SERVICES

As defined by the United Nations General Assembly, multi-hazard early warning systems (MHEWS) address several hazards and/or impacts of similar or different types in contexts where hazardous events may occur alone, simultaneously, in cascade or cumulatively over time, and taking into account the potential interrelated effects. A multi-hazard early warning system with the ability to warn of one or more hazards increases the efficiency and consistency of warnings through coordinated and compatible mechanisms and capacities, involving multiple disciplines, for updated and accurate hazard identification and monitoring for multiple hazards.[92] The LAC region experiences considerable early warning challenges. For example, in South America only 60% of people are covered by MHEWS according to 2020 data available from nine countries, representing 75% of the total. A WMO-led workshop on impact-based forecast and warning services in 2018 identified gaps relating to the need for more effective multidisciplinary exchanges among producers and users and better communication with the media and the public.

In the LAC region, urbanization expansion into hills and steep slope hazard areas of cities has increased the risk to hydrometeorological hazards such as landslides. It is therefore essential to educate the decision makers, population, and relevant non-governmental organizations (NGOs) about the deadly risks of climate-related disasters and to reinforce public perceptions of the need to react to natural hazard alerts and warnings issued by national institutions. The ultimate goal is to ensure that responsibilities, roles and behaviours are well described and made known to everyone involved in the identification and analysis of risks related to weather, water and climate extremes and the early warning providers and recipients.[93] These educational efforts should be an integrated and sustained part of an efficient and proactive multi-hazard early warning system.

Even though most of the NDCs of the parties to the Paris Agreement include climate services as a requirement for managing climate risks in climate-sensitive sectors, WMO data indicate that climate service provision in the region is lacking. In fact, one WMO Member in the LAC region is at a less-than-basic capacity level for providing climate services, six are at a basic level, and ten have an essential capacity level only. Seven WMO Members fall into the full or advanced capacity categories, while eight Members do not report information on climate services at all (Figure 15). In 2022, the situation was the same as in 2021, with nine of 19 Members for which data are available from the region indicating that their capacity level for providing end-to-end drought forecasting and warning services was inadequate.

Enhanced efforts to communicate with national governments are needed from institutions dealing with climate change assessment, mitigation, and adaptation at the national and regional levels. Specifically, efforts are needed to help decision-making by demonstrating the costs and benefits of strengthening multi-hazard early warning systems and climate services for climate adaptation.

End-to-end multi-hazard early warning systems and sustainable investments require multiple components, including innovative financing solutions, in order to reduce the impacts of weather- and climate-related disasters and ensure that every person on Earth is protected by early warning systems by the end of 2027. Collaboration among key players to ensure resource mobilization at the national and international level is essential to promote MHEWS, including making funds available through international mechanisms for climate adaptation. These investments in MHEWS, climate services and related infrastructures, and organizational components are essential to better prepare to deal with the increasing frequency and intensity of extreme weather and climate events, which are severely impacting populations and economies, especially in LDCs and SIDS, where the vulnerability and exposure of populations and economies to these events are on the rise.

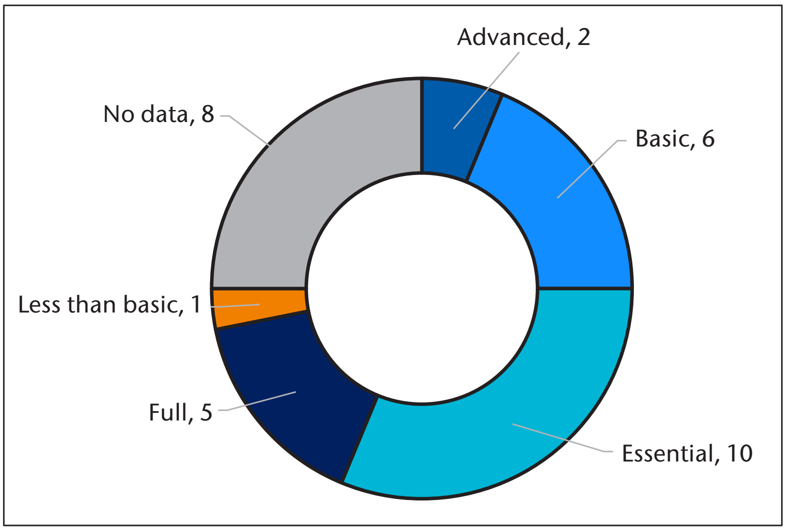


Figure 15. Overview of LAC climate policy priorities and capacities for climate services and early warning systems: Capacity level for the provision of climate services
Source: WMO Climate services checklist data

LEVERAGING RENEWABLE ENERGY FOR RESILIENT AND SUSTAINABLE DEVELOPMENT

LAC is the region with the highest share of modern renewables in total final energy consumption, mainly because of its hydropower potential.[94] In Latin America, hydropower is the main source for electricity generation in most countries, accounting for 45% of the total electricity supply in the region. LAC countries strengthened efforts to reduce emissions starting in 2015. As a result, renewable energy capacity in the region increased by 33% between 2015 and 2020; however, the pace needs to improve.[95] From 2020 to 2030, the electricity demand is expected to increase by 48%, pushed by economic and population growth.[96] This corresponds to an average annual rate of around 3.9% (compared to a rate of 2.3% in 2010–2019). According to the International Renewable Energy Agency (IRENA), the region hosts some of the world's most dynamic renewable energy markets, building on the historical role of hydropower and liquid biofuels, driven by Brazil's early determination to diversify its transport fuel mix.[97] However, there is also the potential to tap into the region's solar and wind resources, which accounted for only 16% of the total renewable generation in 2020, according to IRENA.[98] By 2050, LAC will fall short of achieving net-zero emissions without significant changes in energy mixes and expansion plans.

IMPROVING CLIMATE SERVICES FOR THE ENERGY TRANSITION TO NET ZERO EMISSIONS

Climate services play a key role in the global energy transition to achieve net zero emissions. Climate services are essential for renewable energy, including for site selection, resource assessment and financing, operations, the maintenance and management of energy systems, electricity integration into the grid, and impact assessments of energy systems. Climate services are needed to ensure that energy systems are resilient with respect to climate-related shocks and to inform measures to increase energy efficiency. Risk assessments addressing planning for and early warnings related to extreme events affecting energy supply and demand can help the industry to anticipate, absorb, accommodate, and recover from adverse impacts.

According to data provided by NMHSs and collected by WMO, 59% of Members in Latin America and the Caribbean reported providing climate data services for the energy sector, with fewer than 40% of Members indicating that they provide climate projections and tailored products for the sector (Figure 16). The results highlight the untapped potential of NMHSs to assist with energy transition and the challenge of addressing the emerging needs of the sector in this region.

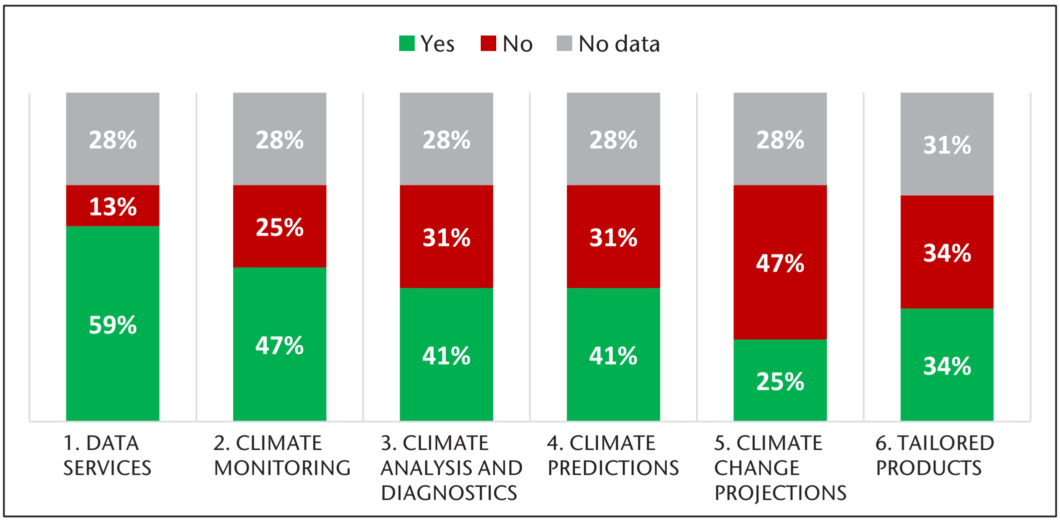


Figure 16. Percentage of Latin American and the Caribbean Meteorological Services providing climate services to the energy sector by type of product
Source: WMO Climate services checklist data

Data sets and methods

TEMPERATURE

Six data sets (cited below) were used in the calculation of regional temperature. Regional mean temperature anomalies were calculated relative to the 1961–1990 and 1991–2020 baselines using the following steps:

1. Read the gridded data set;

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

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

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

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

6. Subtract the 30-year period average from each year to get anomalies relative to that base period.

The following six data sets were used:

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

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

GISTEMP v4 – GISTEMP Team, 2022: *GISS Surface Temperature Analysis (GISTEMP), version 4*. NASA Goddard Institute for Space Studies, https://data.giss.nasa.gov/gistemp/. Lenssen, N.; Schmidt, G.; Hansen, J. et al. Improvements in the GISTEMP Uncertainty Model. *Journal of Geophysical Research: Atmospheres* **2019**, *124* (12), 6307–6326. https://doi.org/10.1029/2018JD029522. The data are available here.

HadCRUT.5.0.1.0 – Morice, C. P.; Kennedy, J. J.; Rayner, N. A. et al. An Updated Assessment of Near-Surface Temperature Change From 1850: The HadCRUT5 Data Set. *Journal of Geophysical Research: Atmospheres* **2021**, **126** (3), e2019JD032361. https://doi.org/10.1029/2019JD032361. The data are available here.

JRA55 – Kobayashi, S.; Ota, Y.; Harada, Y. et al. The JRA55 Reanalysis: General Specifications and Basic Characteristics. *Journal of the Meteorological Society of Japan*. Ser. II **2015**, *93* (1), 5–48. https://doi.org/10.2151/jmsj.2015-001. The data are available here.

NOAAGlobalTemp v5 – Zhang, H-M. ; Huang, B.; Lawrimore, J. et al. NOAA Global Surface Temperature Data set (NOAAGlobalTemp), Version 5.0. *NOAA National Centers for Environmental Information*. doi: 10.25921/9qth-2p70. Huang, B.; Menne, M. J.; Boyer, T. et al. Uncertainty Estimates for Sea Surface Temperature and Land Surface Air Temperature in NOAAGlobalTemp Version 5. *Journal of Climate* **2020**, *33* (4), 1351–1379. https://journals.ametsoc.org/view/journals/clim/33/4/jcli-d-19-0395.1.xml. The data are available here.

Temperature in situ data from National Meteorological and Hydrological Services were also used.

PRECIPITATION

Precipitation in situ data from National Meteorological and Hydrological Services were used.

GLACIERS

Glacier mass balance data for 22 monitored glaciers in the Andes were obtained from the World Glacier Monitoring Service (WGMS), https://www.wgms.ch.

SEA-SURFACE TEMPERATURE

Sea-surface temperature anomalies were processed by CIIFEN using data from the NOAA/NCEP Global Ocean Data Assimilation System (GODAS).

SEA LEVEL

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

DROUGHT

The integrated drought index (IDI) uses Standardized Precipitation Index (SPI) data calculated using Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS) and the Vegetation Health Index from the Center for Satellite Applications and Research (STAR/NOAA)

Drought data were also provided by the US Drought Monitor (USDM) https://droughtmonitor.unl.edu/.

WILDFIRES

Data on burned areas in the Pantanal come from NASA satellite images (NPP-VIIRS) processed by the ALARMES warning system from the Laboratory for Environmental Satellite Applications (LASA-UFRJ).

Active fire data for South America come from NASA satellite images (MODIS-AQUA) processed by the Brazilian National Institute for Space Research (INPE).

Data on carbon emissions from wildfires come from the Copernicus Atmosphere Monitoring Service (CAMS) Global Fire Assimilation System (GFAS) analysis.

Data from the WMO Vegetation Fire and Smoke Pollution Warning Advisory and Assessment System (VFSP-WAS) were also used.

COLD WAVES

In situ data from National Meteorological and Hydrological Services were used.

EMERGENCY EVENTS DATABASE

The Emergency Events Database (EM-DAT) is a global database on natural and technological triggered disasters containing essential core data on the occurrence and effects of more than 21 000 disasters around the world, from 1900 to the present. EM-DAT is maintained by the Centre for Research on the Epidemiology of Disasters (CRED) at the School of Public Health of the Université catholique de Louvain, located in Brussels, Belgium.

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

CLIMATE SERVICES

2022 State of Climate Services: Energy (WMO-No. 1301).

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

WMO analysis of the NDCs of the parties to the Paris Agreement, complemented by the United Nations Framework Convention on Climate Change (UNFCCC) synthesis report: *Nationally Determined Contributions Under the Paris Agreement: Synthesis Report by the Secretariat*.

Checklist for Climate Services Implementation (Climate services dashboard)

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Endnotes

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