State of the Climate in Latin America and the Caribbean

2021

WEATHER CLIMATE WATER

WORLD
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Key messages

The warming trend continued in 2021 in Latin America and the Caribbean. The average rate at which temperatures increased was around 0.2 °C per decade between 1991 and 2021, compared to 0.1 °C per decade between 1961 and 1990.

In 2021 the temperature was above the 1981–2010 average in all subregions, with the highest anomaly value of +0.59 (±0.1 °C) in the Mexico and Central America domain, corresponding to +0.97 (±0.1 °C) above the WMO 1961–1990 reference period for climate change.

Glaciers in the tropical Andes have lost at least 30% of their area since the 1980s, with a negative mass balance trend of –0.97 m water equivalent per year during the 1990–2020 monitoring period. Glacier retreat and the corresponding ice-mass loss has increased the risk of water scarcity for the Andean population and ecosystems.

Sea levels in the region continued to rise in 2021 at a faster rate than globally, notably along the Atlantic coast of South America south of the equator, and the subtropical North Atlantic and Gulf of Mexico. Sea-level rise threatens a large proportion of the population, which is concentrated in coastal areas – by contaminating freshwater aquifers, eroding shorelines, inundating low-lying areas and increasing the risks of storm surges.

The "Central Chile Mega-drought" continued in 2021, at 13 years to date constituting the longest in one thousand years, exacerbating a drying trend and putting Chile at the forefront of the region's water crisis. A multi-year drought in the Paraná–La Plata Basin, the worst since 1944, affected central-southern Brazil, parts of Paraguay and the Plurinational State of Bolivia.

In the Paraná–La Plata Basin, drought-induced damage to agriculture reduced crop production, including of soybeans and corn, affecting global crop markets. In South America overall, drought conditions led to a decline of 2.6% in the 2020–2021 cereal harvest compared with the previous season.

The 2021 Atlantic hurricane season was the third-most active Atlantic hurricane season on record with 21 named storms, including seven hurricanes, and was the sixth consecutive above-normal Atlantic hurricane season.

Extreme rainfall (with record values in many places), floods and landslides induced substantial losses in 2021, leading to hundreds of lives lost, tens of thousands of homes destroyed or damaged and hundreds of thousands of people displaced. Floods and landslides in the Brazilian states of Bahia and Minas Gerais led to an estimated loss of US$ 3.1 billion.

Deforestation in the Brazilian Amazon rainforest doubled compared to the 2009–2018 average, reaching its highest level since 2009. Compared to 2020, 22% more forest area was lost in 2021.

A total of 7.7 million people, in Guatemala, El Salvador and Nicaragua experienced high levels of food insecurity in 2021, with contributing factors including continuing impacts from Hurricanes *Eta* and *Iota* in late 2020 and COVID-19 pandemic economic impacts.

South America is among the regions with the greatest documented need for strengthening of early warning systems. Multi-hazard early warning systems (MHEWS) are essential tools for effective adaptation in areas at risk from weather, water and climate extremes.

Foreword

After the successful publication of the first WMO report on the State of the Climate in Latin America and the Caribbean (LAC) last year, I am pleased to see the timely publication of this second edition. This second report has involved National Meteorological and Hydrological Services (NMHSs), WMO Regional Climate Centres (RCCs), and several research institutions, as well as an increased number of contributing United Nations agencies, and international and regional organizations.

The report shows that hydrometeorological hazards, including droughts, heatwaves, tropical cyclones and floods, have unfortunately led to the loss of hundreds of lives, caused severe damage to crop production and infrastructure, and induced population displacement.

Increasing sea-level rise and ocean warming are expected to continue to affect coastal livelihoods, tourism, health, food, energy and water security, particularly on small islands and in Central American countries. For many Andean cities, melting glaciers represent the loss of a significant source of fresh water currently used for domestic use, irrigation and hydroelectric power. In South America, the continued degradation of the Amazon rainforest is still being highlighted as a major concern, not only for the region but also for the global climate, considering the role of the forest in the carbon cycle.

In addition to describing climate trends, extreme events and associated impacts, the report identifies knowledge gaps and areas for improvement for better supporting climate action in the LAC region. Despite the continuous efforts in strengthening multi-hazard early warning systems, the report points out clearly that there are still significant gaps to be addressed to strengthen these systems to reduce adverse impacts of hydrometeorological hazards in the region.

The information in this report is built on observing systems coordinated by WMO and its partner organizations. The WMO Integrated Global Observing System (WIGOS) provides basic weather and climate information, and the Global Climate Observing System (GCOS) defines a broader set of Essential Climate Variables (ECVs) that are needed to monitor the global climate, and support mitigation and adaptation.

While the evidence for climate change is unequivocal, the most recent reports of the Intergovernmental Panel on Climate Change (IPCC) show that there remain significant gaps in the observation in developing countries. The WMO Global Basic Observing Network (GBON) and the Systematic Observations Financing Facility that supports it will provide critically needed observations for numerical weather prediction and will help substantially strengthen climate monitoring.

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

(Prof. Petteri Taalas)
Secretary-General

Preface

The Latin America and the Caribbean region is home to some of the widest biodiversity on the planet. From Caribbean marine and coastal oases to the Amazon rainforest and down to the southern-most reaches of Patagonia, the region is filled with natural wealth.

However, the increasing impact of climate change and climate variability, compounded by the effects of the COVID-19 pandemic have not only undermined the productivity of ecological systems in the region, but have also stalled decades of advancement against poverty, inequality and food insecurity in the region. Rising sea levels and warming oceans are threatening the health of marine and coastal ecosystems. Drought, landslides, saltwater intrusion, extreme heat and human-induced land use changes have contributed to deforestation rates reaching their highest levels in 15 years. This trend is impacting terrestrial ecosystems, near-shore urban developments and other human settlements, as well as sustainable livelihoods, soil productivity and tourism opportunities. In the meantime, melting glaciers, mega-droughts, extreme rainfall and flooding are putting food production and water security at risk for both rural and urban populations across the region. The devastation caused by the frequency and ferocity of extreme hydro-climatic events in the Caribbean is especially overwhelming for the small island, low-lying and coastal States of the subregion.

Addressing such interrelated challenges and multidimensional vulnerabilities will require a well-articulated, prioritized and integrated effort. The coral reef restoration projects ongoing in the Caribbean and Pacific are good examples of this. They seek to re-establish self-sustaining, functioning reef ecosystems affected by ocean warming and acidification, among other stressors, while demonstrating the advantages of effective collaboration between academia and practitioners for collective problem-solving.

Strengthening partnerships and alliances with diverse stakeholders can also create long-term and regional and national solutions. For example, the Climate Action Platform for Agriculture in Latin America and the Caribbean (PLACA), launched at the twenty-fifth session of the Conference of the Parties to the United Nations Framework Convention on Climate Change (COP25), is as a voluntary regional collaboration mechanism on climate action in agriculture. PLACA promotes collaboration among LAC countries to implement mitigation and adaptation measures that can support regional and national strategies regarding climate change impacts and climate variability in the agricultural sector. The platform brings together representatives from twelve ministries of agriculture in the region, so far, along with six partner organizations and several United Nations organizations, including the Economic Commission for Latin America and the Caribbean (ECLAC), the Food and Agricultural Organization of the United Nations (FAO) and WMO.

The report on the State of the Climate in Latin America and the Caribbean, the second of its kind, is a critical source of science-based information and data. Informed by science, this report serves to support climate-related policy design and decision-making. ECLAC will continue to play an active role through the provision of policy support, capacity building, and the improved dissemination of weather, climate-change and climate variability data and information services. This dedicated support will serve to better foster decisive action and continue promoting more effective climate change mitigation and adaptation policies with all stakeholders across Latin America and the Caribbean.

Mario Cimoli
ECLAC Acting Executive Secretary

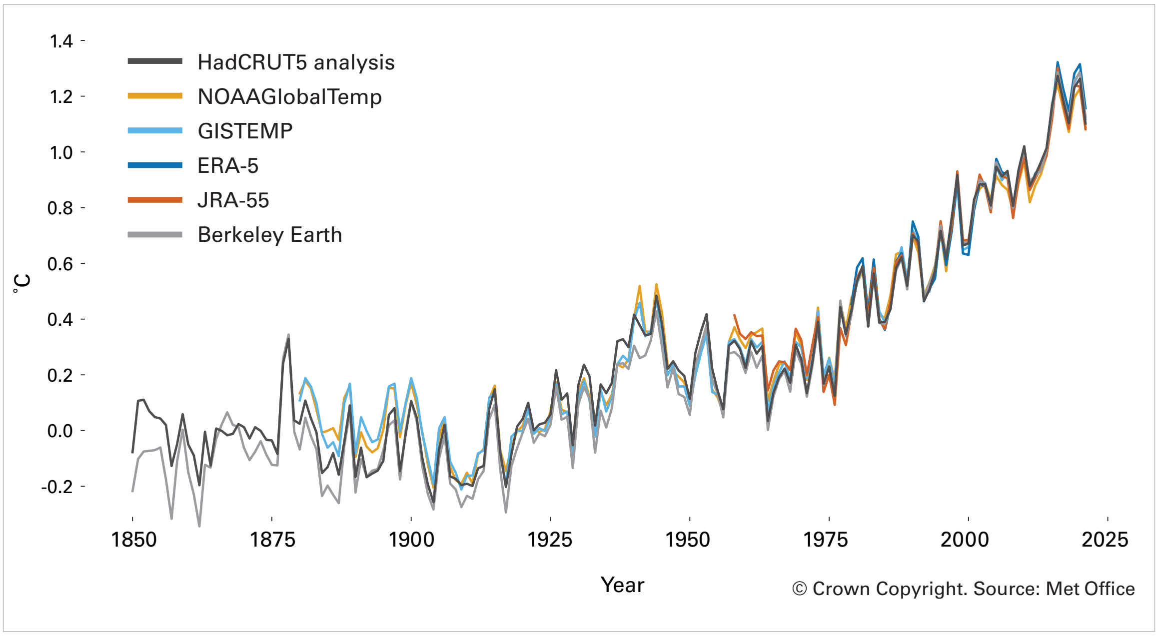
Global climate context

The global annual mean temperature in 2021 was 1.11 ± 0.13 °C above the 1850–1900 pre-industrial average – less warm than in some recent years owing to cooling La Niña conditions at the start and end of the year. The year 2021 was between the fifth and seventh warmest year on record according to six data sets (Figure 1).[1] The past seven years, 2015 to 2021, were the seven warmest years on record. The year 2016, which started during a strong El Niño, remains the warmest year on record in most data sets.

Atmospheric concentrations of the three major greenhouse gases reached new record highs in 2020, with levels of carbon dioxide (CO_2) at 413.2 ± 0.2 parts per million (ppm), methane (CH_4) at 1 889 ± 2 parts per billion (ppb) and nitrous oxide (N_2O) at 333.2 ± 0.1 ppb – respectively 149%, 262% and 123% of pre-industrial (before 1750) levels. Real-time data from specific locations, including Mauna Loa (Hawaii) and Cape Grim (Tasmania) indicate that levels of CO_2, CH_4 and N_2O continued to increase in 2021. Increasing greenhouse gas concentrations lead to an accumulation of heat in the climate system, much of which is stored in the ocean.

Over the past two decades, the ocean warming rate strongly increased, and the ocean heat content in 2021 was the highest on record. Ocean warming and accelerated loss of ice mass from the ice sheets contributed to the rise of the global mean sea level by 4.5 mm per year between 2013 and 2021, reaching a new record high in 2021. The ocean absorbs about 23% of annual anthropogenic emissions of CO_2 into the atmosphere, thereby helping to alleviate overall warming; however, CO_2 reacts with seawater and lowers its pH. This process, known as ocean acidification, affects many organisms and ecosystem services, and threatens food security by endangering fisheries and aquaculture.[2,3]

Figure 1. Global annual mean temperature difference from pre-industrial conditions (1850–1900) for six global temperature data sets: HadCRUT5, NOAAGlobalTemp, GISTEMP, Berkeley Earth, ERA5 and JRA55. *Source:* Met Office, United Kingdom of Great Britain and Northern Ireland.



Regional climate

The following sections analyse key indicators of the state of the Latin America and Caribbean regional climate. One important such indicator, temperature, is described in terms of anomalies, or departures from a reference period. For global mean temperature, the reference period used in the Sixth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC),[4] 1850–1900, is used for calculating anomalies in relation to pre-industrial levels. The pre-industrial period cannot be used as a baseline for calculating regional anomalies, however, due to insufficient data for calculating region-specific averages prior to 1900. Regional temperature anomalies are therefore expressed relative to the 30-year 1961–1990 reference period, which is the fixed period recommended by WMO as a consistent and stable reference for assessing long-term climate change, especially for temperature. The 1981–2010 climatological standard normal period is also used, for computing anomalies in temperature and other indicators with reference to more recent climate average conditions. Exceptions to the use of these baseline periods for the calculation of anomalies, where they occur, are explicitly noted.

TEMPERATURE

Despite being cooler than recent years due to the influence of a moderate La Niña, 2021 was, according to the six data sets,[5] between the sixth and the tenth warmest year in Mexico/Central America, between the seventh and the seventeenth warmest in the Caribbean and between the sixth and the sixteenth warmest in South America.

The warming trend continued in 2021 in Latin America and the Caribbean. The average rate of temperature increase in the region was around 0.2 °C per decade between 1991 and 2021, compared to 0.1 °C per decade between 1961 and 1990 (Figure 2). The warming rate in Mexico and Central America, 0.27 [0.22–0.30] °C per decade, suggests that this subregion likely warmed faster in 1991–2021 than the Caribbean and South America, which warmed at 0.24 [0.19–0.30] °C and 0.23 [0.21–0.26] °C per decade, respectively (Figure 2).

Observed temperature anomaly relative to 1961–1990

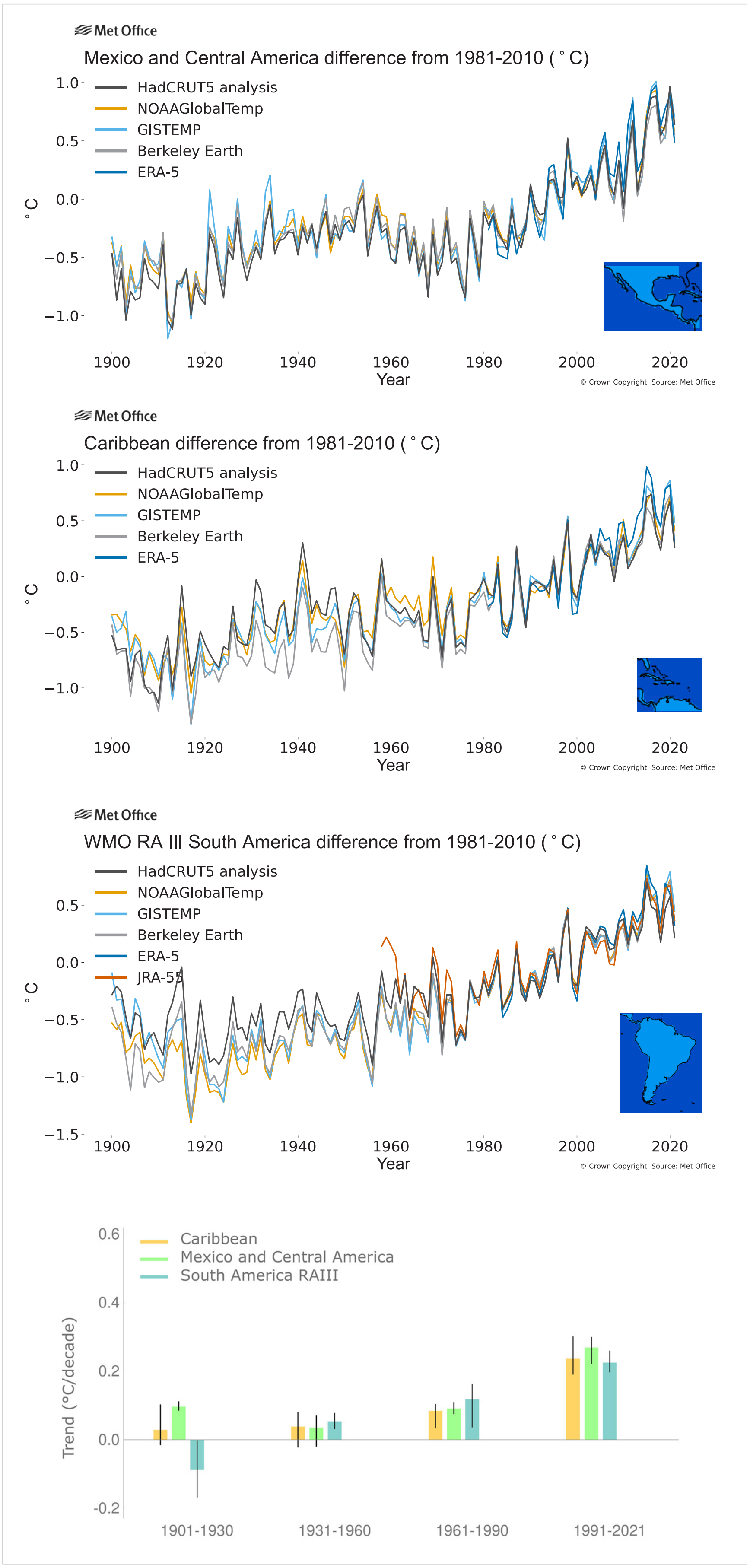
Average temperatures in 2021 were 0.97 [0.87–1.08] °C,[6] 0.68 [0.56–0.79] °C and 0.69 [0.50-0.83] °C above the 1961–1990 average in Mexico and Central America, the Caribbean and South America, respectively.

Observed temperature anomaly relative to a recent climatological standard normal

The use of 1981–2010 for computing temperature anomalies provides a more recent benchmark for operational climate monitoring and applications in various sectors, such as adaptation planning and decision-making. Average temperatures were 0.59 [0.49–0.70] °C, 0.35 [0.26–0.48] °C and 0.36 [0.21–0.45] °C above the 1981–2010 average in Mexico and Central America, the Caribbean and South America, respectively.

In most land areas of the region, annual temperatures were warmer than the 1981–2010 average. Anomalies of +1 °C to +3 °C were recorded in central Mexico, the Yucatán peninsula, Guatemala, Honduras and El Salvador (Figure 3a, 3b), and +0.5 °C in Nicaragua, while some relative cooling was recorded in Costa Rica and Panama. In the Caribbean, positive temperature anomalies were recorded in the Dominican Republic, Jamaica and the small Caribbean islands (Figure 3c). In South America, above-normal temperature anomalies prevailed over the entire continent, with +1 °C to +2 °C in north-east Brazil, Colombia, central Brazil, central Chile, and central and southern Argentina (Figure 3d). Anomalies of +0.5 °C were also recorded in central Amazonia, northern Argentina, Paraguay and Peru. Negative temperature anomalies were observed in the extreme north of the Bolivarian Republic of Venezuela, Guyana, north-east of Chile, west of Uruguay and extreme north of Brazil.

Figure 2. Average temperature anomalies (relative to 1981–2010) for (a) Mexico and Central America, (b) the Caribbean and (c) South America. Data are from six different data sets: HadCRUT5, NOAAGlobalTemp, GISTEMP, Berkeley Earth, ERA5 and JRA55. Panels (a) and (b) do not include the JRA55 data set. Panel (d): trends for four 30-year periods as indicated on the x-axis. Coloured bars are the average trend calculated over each period for each of six data sets: HadCRUT5, NOAAGlobalTemp, GISTEMP, Berkeley Earth, ERA5 and JRA55. The black vertical line indicates the range of the six estimates. *Source:* Met Office, United Kingdom.



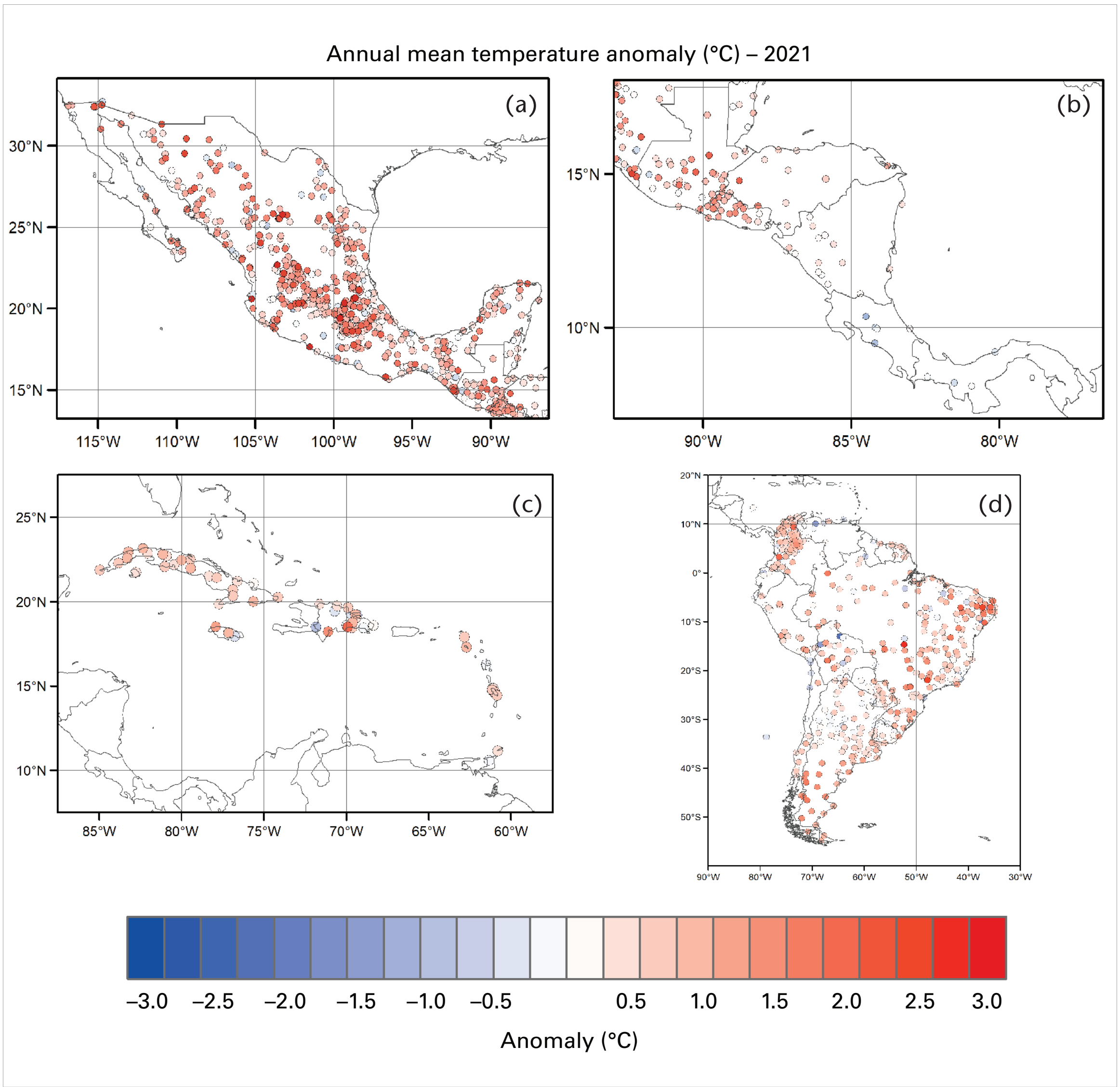


Figure 3. Air temperature (2 m) anomalies for 2021 (relative to 1981–2010) for (a) Mexico, (b) Central America, (c) the Caribbean and (d) South America, in °C. *Source:* International Research Centre on El Niño (CIIFEN), from National Meteorological and Hydrological Services data.

PRECIPITATION

In this section the 1981–2010 climatological standard normal is used for computing 2021 rainfall anomalies, expressed as a percentage above or below normal.

Rainfall in central Mexico was around 40%–60% above normal, while north-west Mexico and Baja California recorded rainfall around 20% below normal (Figure 4a). In the north Atlantic coast and over the Yucatán peninsula, Guatemala and El Salvador, rainfall anomalies ranged from 50% below normal to 20% above normal (Figure 4b). Below-normal rainfall was recorded in Belize and Nicaragua, while Costa Rica and much of Panama recorded above-normal rainfall.

In the Caribbean region, below-normal rainfall was recorded in Cuba, the Dominican Republic and the small Caribbean islands (Figure 4c). For example, in much of Guadeloupe, annual rainfall was 10%–50% below normal.

In South America (Figure 4d), rainfall anomalies of between 20% and 60% below normal were recorded over the central and southern regions of Chile, and 30% to 50% below normal over the south-western Andes of Peru. 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. Below-normal rainfall conditions dominated the semiarid region of north-east Brazil and the Caribbean coast of the Bolivarian Republic of Venezuela.

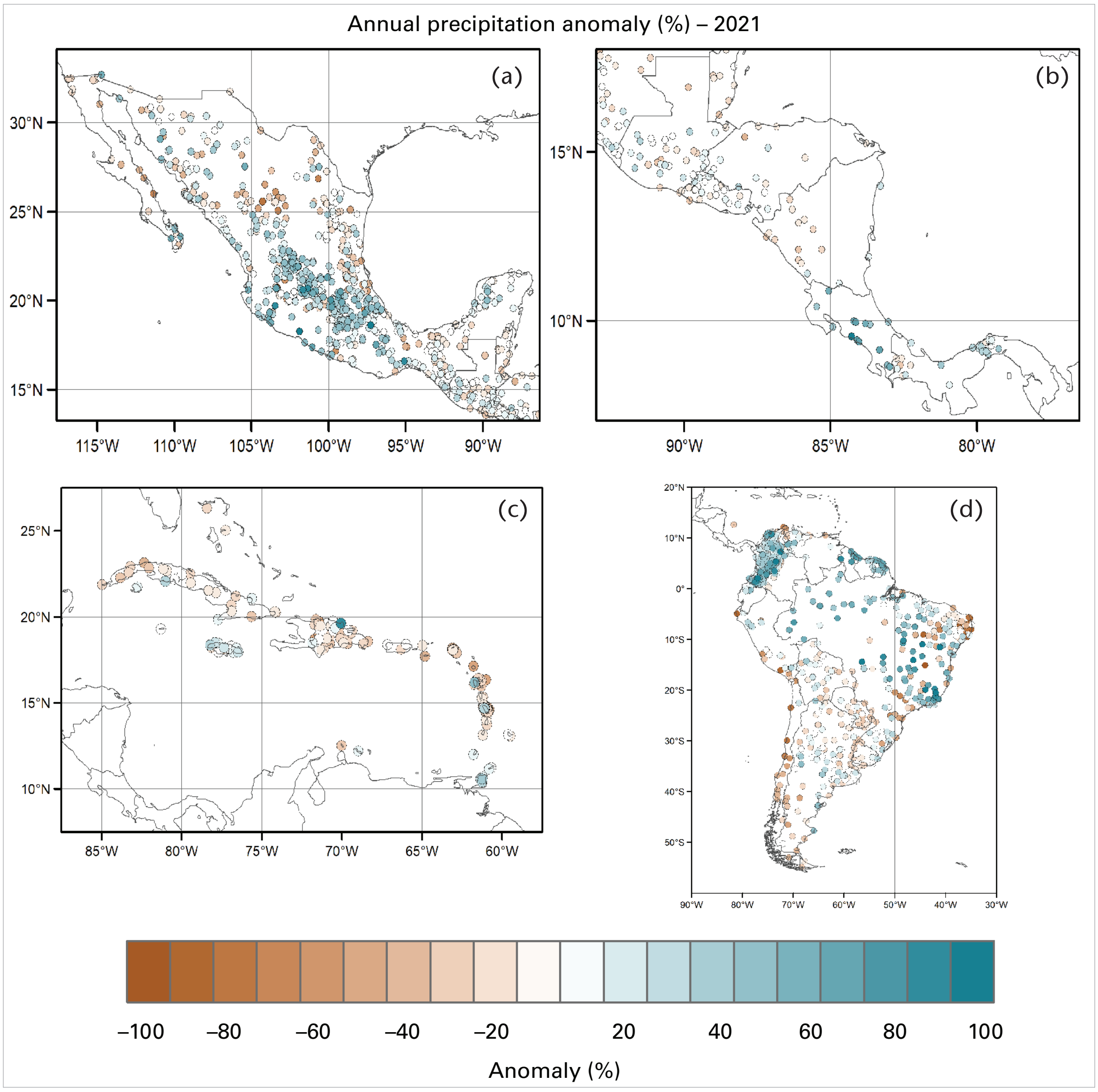


Figure 4. Rainfall anomalies for 2021 (% with respect to the 1981–2010 reference period) in (a) Mexico, (b) Central America, (c) the Caribbean and (d) South America. *Source:* CIIFEN, from National Meteorological and Hydrological Services data.

Conversely, the western side of Colombia, central Amazonia, French Guyana, Suriname and Guyana recorded above-normal rainfall for the year. Some of the observed rainfall patterns were in line with the typical rainfall patterns associated with La Niña conditions (verified during most of 2021, see Sea-surface temperature).

GLACIERS

Assessment of the recent evolution of the ice masses in the Andes region[7] is based on the mass balance time series from the World Glacier Monitoring Service. In the tropics, glacier mass balance has a negative trend of around –0.97 m water equivalent (w.e.) per year during the monitoring period (1990–2020) (Figure 5a). Remote sensing observations show that surface area reductions in the tropics have fluctuated from 25% to 50% since the 1950s, with significant ice-mass loss occurring since the late 1970s.[8] Further south, in the Andes of Chile and Argentina, glaciers have also been retreating for decades, with a differential rate of around –0.72 m w.e. per year for the 2004–2021 period in the dry Andes and –0.56 m w.e. per year from 1976 to 2021 in the southern Andes (Figure 5b and Figure 5c, respectively). These observed glacier mass loss rates are among the highest regional mass loss rates globally.[9]

On average, the tropical Andes glaciers have lost at least 30% of their area since the 1980s.[10] The current glacier area has shrunk rapidly since the 1970s in Peru (losses of 54%, 56% and 64% for the Cordilleras Vilcanota, Vilcabamba and Urubamba, respectively), with low-lying glaciers receding the most across all regions.[11] The corresponding ice-mass loss has increased the risk of water scarcity for the Andean population and ecosystems.[12]

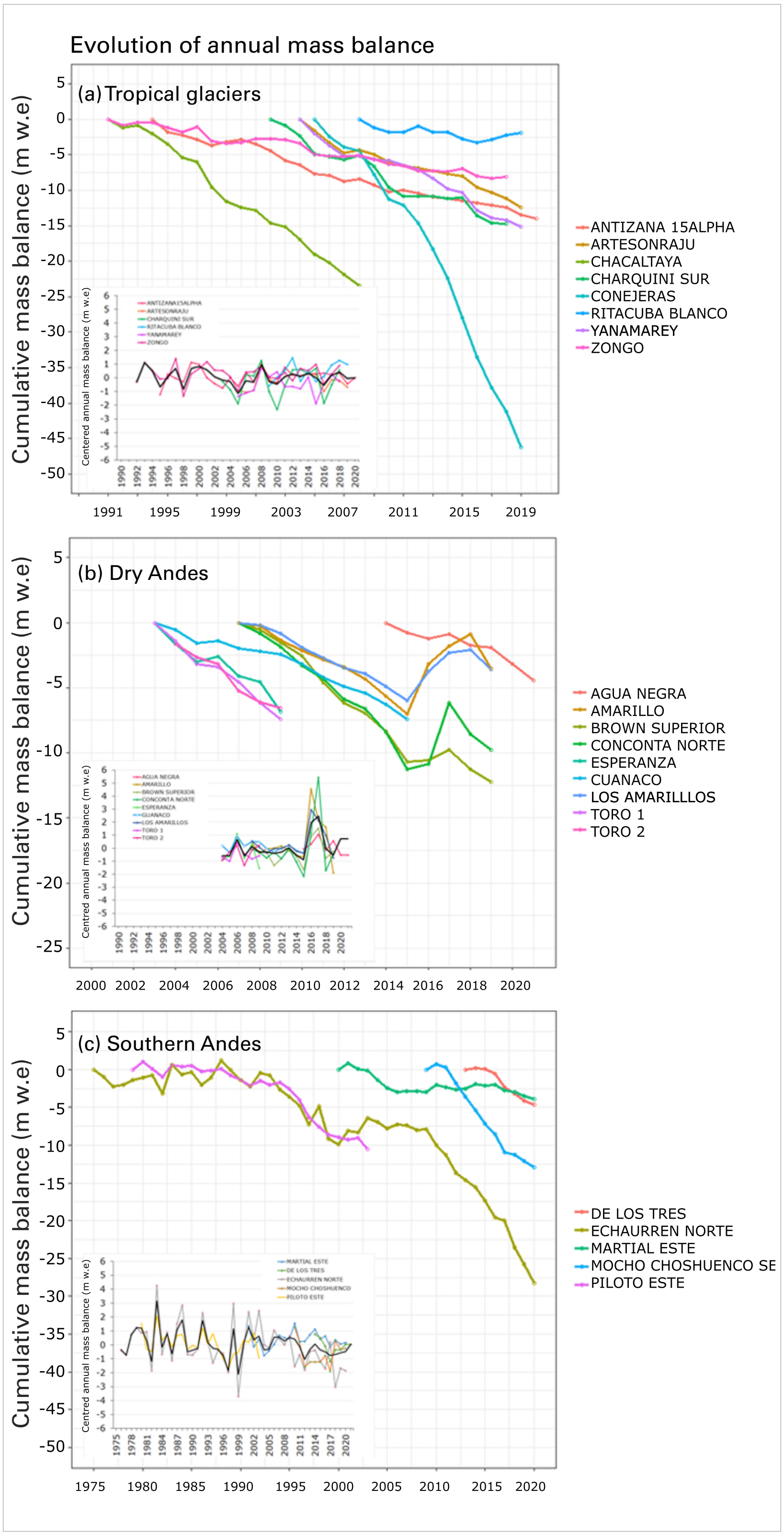


Figure 5. Cumulative mass balance of 22 monitored glaciers showing the evolution of the Andean ice masses in the three main regions: (a) tropics, 1990–2020; (b) dry Andes, 2004–2021 and (c) southern Andes, 1976–2021. The inset in each panel shows the centred mass balance of the time series; the average centred balance is shown by a black line. *Source:* data from World Glacier Monitoring Service (WGMS).

SEA-SURFACE TEMPERATURE

Sea-surface temperature (SST) is the mean temperature in the top few metres of the ocean.[13] It is a vital component of the climate system as it exerts a major influence on the exchanges of energy, momentum and moisture between the ocean and atmosphere. The SST largely controls the atmospheric response to the ocean on both weather and climate timescales. Spatial patterns in SST reveal the structure of the underlying ocean dynamics, such as ocean fronts, eddies, coastal upwelling and exchanges between the coastal shelf and open ocean.[14] In a warmer world, warmer SSTs lead to more frequent marine heatwaves, coral bleaching, and damage to reefs and related fisheries.[15,16]

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 particular in the LAC region. El Niño and La Niña together with the Southern Oscillation, defined as the atmospheric pressure difference between Tahiti and Darwin, comprise the El Niño Southern Oscillation (ENSO). La Niña conditions emerged in mid-2020 and peaked in the October–December period at moderate strength. La Niña weakened through the first half of 2021, reaching an ENSO-neutral state in May, according to both oceanic and atmospheric indicators. However, SSTs cooled after mid-year, reaching La Niña thresholds once again by the July–September period. By the October–December period, average SSTs once again reached moderate strength, at 1.0 °C below normal.[17]

La Niña typically leads to increased rainfall in northern Brazil, Colombia and other northern parts of South America and is associated with reduced rainfall in Uruguay and parts of Argentina. Drier-than-normal conditions are generally observed along coastal Ecuador and in north-western Peru.[18,19] Rainfall anomalies in 2021 in South America were comparable to these typical La Niña rainfall patterns (see Precipitation).

The tropical North Atlantic and adjacent ocean areas were cooler than normal from February to August 2021, and warmer from September to December, reaching 0.5 °C above average (1981–2010) in November 2021. The SST anomaly in the Caribbean Sea was +0.69 °C above the average, lower than the 2020 value of +0.98 °C. In the Gulf of Mexico, SST anomalies reached +0.43 °C, also lower than the 2020 values of +0.78 °C (Figure 6).

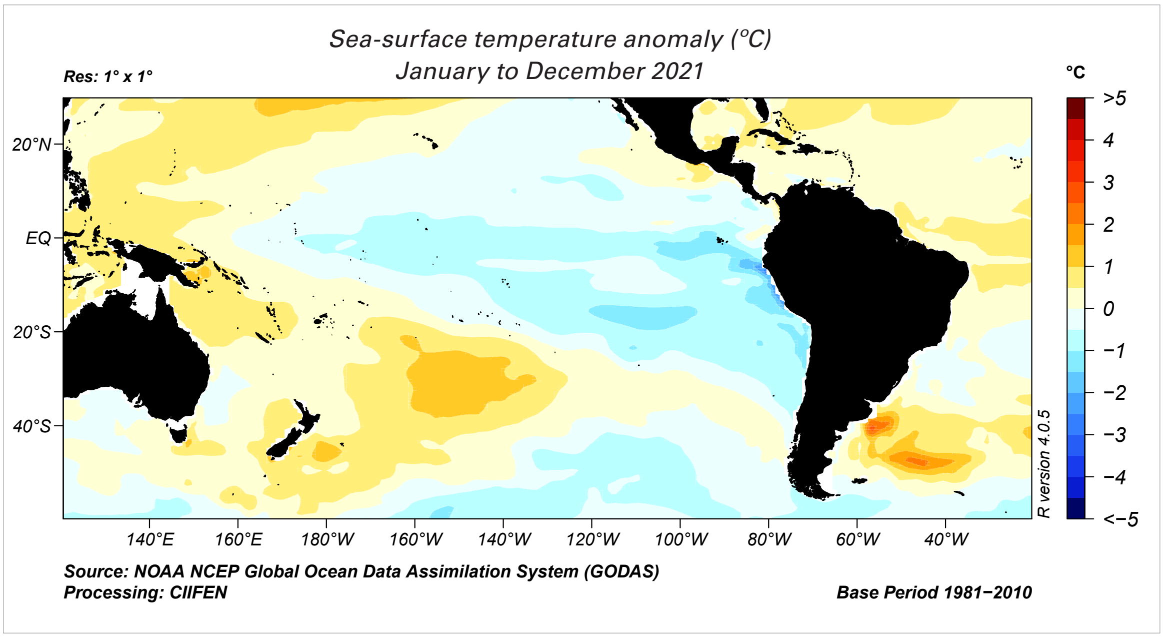


Figure 6. Annual SST anomalies in 2021. Reference period is 1981–2010. *Source:* CIIFEN.

SEA LEVEL

The abundance of heat-trapping greenhouse gases in the atmosphere once again reached a new record in 2020, with the annual rate of increase above the 2011–2020 average, a trend that continued in 2021.[20] Most of the excess energy that accumulates in the Earth system due to increasing concentrations of greenhouse gases is taken up by the ocean. The added energy warms the ocean, and the consequent thermal expansion of the water leads to sea-level rise, to which is added melting land ice.

Compared to global mean sea level, over the last three decades relative sea level has increased at a higher rate than global mean in the South Atlantic and the subtropical North Atlantic, and at a lower rate in the East Pacific.[21] Sea-level rise threatens the large portion of the Latin American and Caribbean population which lives in coastal areas – by contaminating freshwater aquifers, eroding shorelines, inundating low-lying areas and increasing the risks of storm surges.[22] Figure 7 shows sea-level trends in two LAC subregions – South America (panel a) and Mexico, Central America and the Caribbean (panel b) – each of which is divided into three domains.[23]

Based on high-precision satellite altimetry data covering the period 1993 to 2022, the rates of sea-level change on the Atlantic side of South America are higher than on the Pacific side (Figure 7a). In the South America Pacific region, rate of change is 2.45 ± 0.1 mm per year, less than the global average, 3.33 ± 0.4 mm per year. Along the Atlantic coast of South America, south of the equator, the rate of change is 3.52 ± 0.0 mm per year, and along the tropical North Atlantic coast of South America it is 3.28 ± 0.1 mm per year. Comparable rates are also recorded in the subtropical North Atlantic, around the Caribbean and the Gulf of Mexico, with 3.48 ± 0.1 mm per year, and in the tropical North Atlantic, around Central America and the southern Caribbean, with 3.23 ± 0.1 mm per year (Figure 7b). The sea level on the Pacific side is rising at a lower rate than on the Atlantic side, with an increase of 2.23 ± 0.2 mm per year. Sea level on the Pacific side is highly influenced by ENSO, with more significant increases in sea level occurring during strong El Niño events and smaller increases during La Niña events.

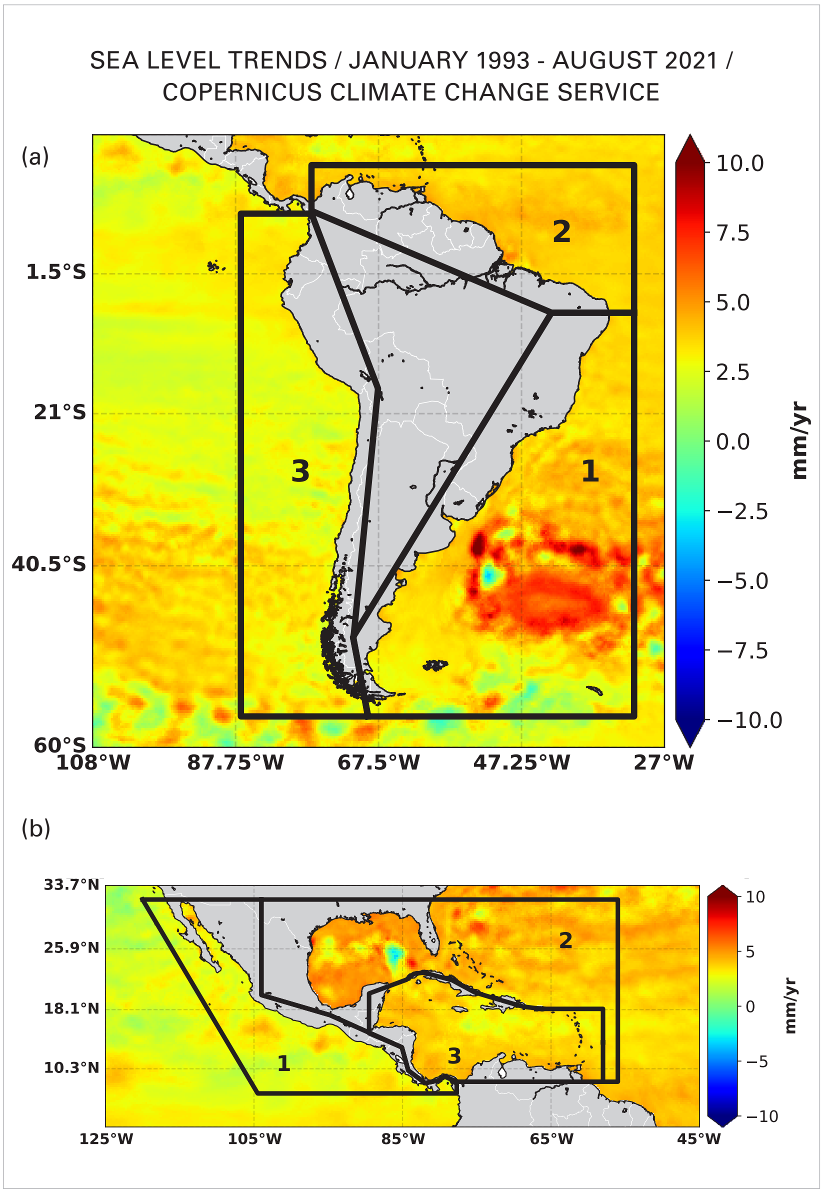


Figure 7. Regional sea-level trends in three domains for South America (a) and Mexico, Central America and the Caribbean (b), where the coastal sea-level trends from January 1993 to December 2021 were computed (based on satellite altimetry). Domain designations: a1 – South Atlantic, a2 – South America tropical North Atlantic, a3 – South America Pacific, b1 – Central America Pacific, b2 – subtropical North Atlantic and Gulf of Mexico, b3 – tropical North Atlantic.
Source: Copernicus Climate Change Service (C3S), https://climate.copernicus.eu/sea-level.

Extreme events

Although understanding broad-scale changes in the climate is important, the acute impacts of weather and climate are most often felt during extreme meteorological events such as heavy rain and snow, droughts, heatwaves, cold waves and storms, including tropical storms and cyclones. These can lead to or exacerbate other high-impact events such as flooding, landslides, wildfires and avalanches. This section provides an overview of the characteristics and selected impacts of these events, based largely on input from WMO Members. Additional information on socioeconomic impacts and risks associated with these events is provided in the section on Socioeconomic impacts.

The Working Group I contribution to the IPCC Sixth Assessment Report[24] indicated that global warming is altering the intensity and frequency of extreme weather, water and climate events. The report shows that for Central and South America the observed trends indicate a *likely* increase in the intensity and frequency of hot extremes and decrease in the intensity and frequency of cold extremes, as well as a significant intensification of total and heavy precipitation in south-eastern South America. As for droughts and dry spells, the report identified mixed trends in different subregions of the Caribbean and Central America, while in Mexico, central Chile and the Paraná–La Plata Basin there is some evidence of increased frequency and severity of meteorological droughts.

The following sections highlight the most impactful extreme events of the year. Additional reported events are included in an interactive online map provided separately.[25] The 1981–2010 climatological standard normal is used as reference, with any exceptions explicitly noted.

TROPICAL CYCLONES

The 2021 Atlantic hurricane season was very active, with 21 named storms – well above the 1981–2010 average of 14 – including seven hurricanes, of which four were major hurricanes. With about US$ 80 billion in damage (much of which occurred in the United States of America, associated with Hurricane *Ida*), it was also one of the costliest seasons. It was the sixth consecutive above-normal Atlantic hurricane season and the seventh consecutive year with a named storm forming before the official start to the season on 1 June (Tropical Storm *Ana* formed on 22 May). On 30 June, Tropical Storm *Elsa* (later Hurricane *Elsa*) became the earliest fifth named storm on record. Hurricane *Elsa* would become the first hurricane of the season on 2 July, and affected several territories in the Caribbean, including Barbados, Saint Lucia, Saint Vincent and the Grenadines, Martinique, the Dominican Republic, Haiti, Jamaica, the Cayman Islands and Cuba, before moving into Florida/United States.[26]

Three tropical cyclones were simultaneously active in the North Atlantic on 16 August, namely, Tropical Storm *Fred*, Tropical Storm *Grace* (later Hurricane *Grace*), and Tropical Storm *Henri* (later Hurricane *Henri*) (Figure 8). Tropical Storm *Fred* affected portions of the Greater Antilles (from 11 to 15 August), producing strong winds, some storm surge flooding, and heavy rainfall. Hurricane *Grace* made landfall on the Yucatán Peninsula of Mexico on 18 August, and after a trajectory over the south-western Gulf of Mexico, made a second landfall on the mainland coast of Mexico as a category 3 hurricane (on the Saffir-Simpson scale) on 20 August, making it the strongest hurricane on record to make landfall in the state of Veracruz.[27] At the time it was still a tropical storm, it affected the Leeward Islands, Puerto Rico, the Dominican Republic, Haiti (just days after a 7.2 magnitude earthquake), Jamaica and the Cayman Islands. The heavy rainfall and strong winds led to flash floods, landslides and damage to crops and infrastructure.

Hurricane *Ida* made landfall in western Cuba on 27 August with category 1 strength before rapidly intensifying into a category 4 hurricane on its track to Louisiana/United States. Before it developed into a tropical cyclone, rainfall associated with *Ida* caused significant flooding in the Bolivarian Republic of Venezuela.[28]

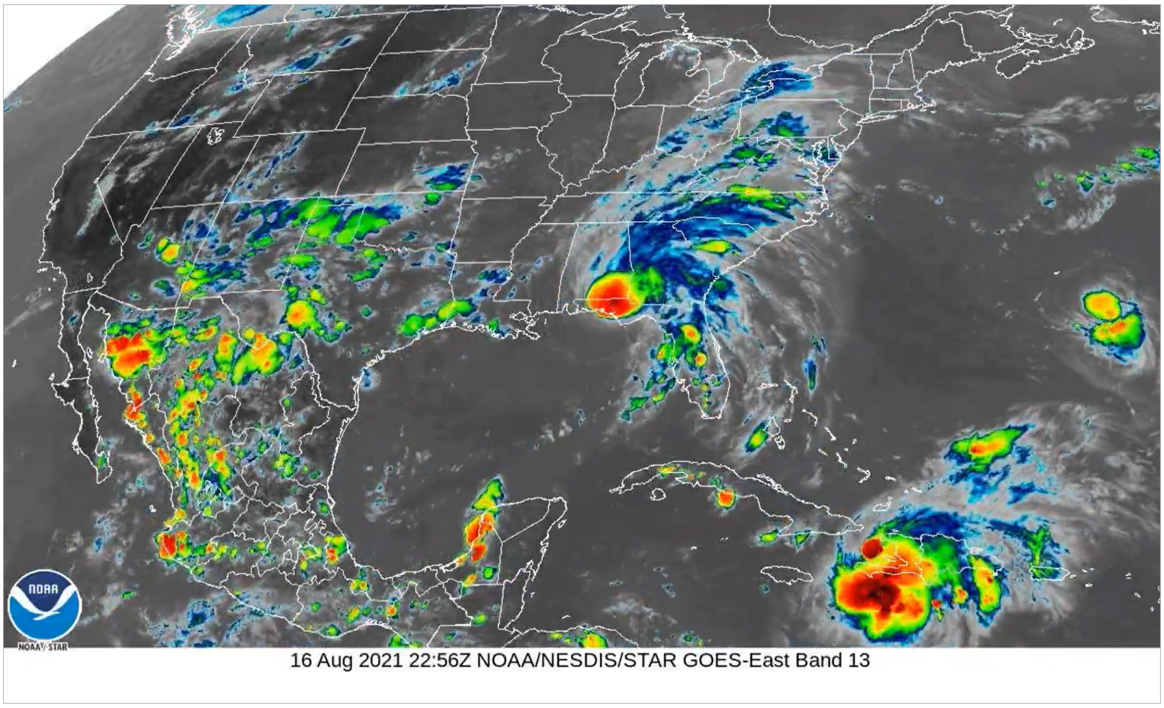


Figure 8. NOAA/NESDIS/STAR GOES-East Band 13 image of tropical cyclones simultaneously active in the North Atlantic on 16 August, 22:56 UTC: Tropical Storm *Fred* (centre), nearing landfall in the Florida Panhandle; Tropical Storm *Grace* (later Hurricane *Grace*) (bottom-right), south of Hispaniola; and Tropical Storm *Henri* (later Hurricane *Henri*) (centre-right), southeast of Bermuda. *Source:* National Oceanic and Atmospheric Administration (NOAA).

HEAVY PRECIPITATION AND FLOODING

Central America and the Caribbean experienced abundant precipitation and subsequent flooding episodes associated with tropical cyclones. On Hispaniola, floods occurred on 1 July due to Tropical Storm *Elsa*, and later, on 12–19 August, Tropical Storms *Fred* and Grace caused additional floods. Tropical Storm *Grace* (later Hurricane *Grace*) passed over Haiti on 16 and 17 August, bringing heavy rain and strong wind to the country during the rescue efforts that followed the 7.2 magnitude earthquake on 14 August. The storm caused flash floods and landslides as it moved west past Haiti[29] and into the rest of the Caribbean.[30] Heavy rainfall in late November led to flooding in Cuba's eastern province of Holguín. The city of Moa, in Holguín, received 137 mm in 24 hours.[31] In Central America, flood events were reported in many places, at multiple times during the year, some associated with record short-term rainfall. Countries affected included Honduras, Guatemala, El Salvador, Costa Rica and Panama. In Turrialba, Costa Rica, on 22 and 23 July it rained 545 mm in 36 hours, a new record for such a period and almost double the average monthly rainfall for July (285 mm).[32] In Mexico, from 20 to 24 August, Tropical Storm *Grace* affected the Yucatán Peninsula and the state of Veracruz,[33] leaving 95% of the people of Poza Rica without electricity. A series of floods in Panama affected 27 500 people.

In South America, episodes of extreme rainfall triggered flooding and landslides that affected thousands of people, in particular in the state of Santa Catarina (southern Brazil), the state of Pernambuco (north-eastern Brazil), the northern section of the state of Minas Gerais and the southern part of the state of Bahia. The precipitation was about 200–250 mm above normal (1981–2010) in central Amazonia in December 2020–February 2021.[34] In the Brazilian Amazon, in Manicoré, in March, 583.8 mm of precipitation fell (normal is 300 mm), and in Tucuruí, 604 mm fell (normal is 436.7 mm).[35] As a result of these rainfall excesses, the Rio Negro at Manaus (central Brazilian Amazon) reached the highest water levels in 102 years of records in June 2021 (Figure 9). Since the late 1990s, nine extreme floods have occurred, while only eight events were reported from 1903 to 1998. The water level of the Rio Negro in Manaus was above 29 m (the emergency threshold) for 91 days. It reached 30.02 m on 16 June, breaking the previous record of 29.97 m in June 2012 (Figure 9). In Pedra Azul, state of Mato Grosso, accumulated precipitation in December was 707.5 mm, a new record for this station (the previous highest monthly value, recorded in 1961, was 488.3 mm, and the average value for December is 187.2 mm).[36] In French Guyana rainfall in 2021 was between 100% and 150% above normal. In Cayenne on 13 March it rained 70.4 mm in 1 hour, a once-in-a-hundred-year event,[37] and on 14 March it rained 134 mm in 3 hours in Matoury. Heavy rainfall and widespread floods hit all regions of Guyana towards the end of May, affecting more than 25 000 families and damaging at least 7 900 houses.[38]

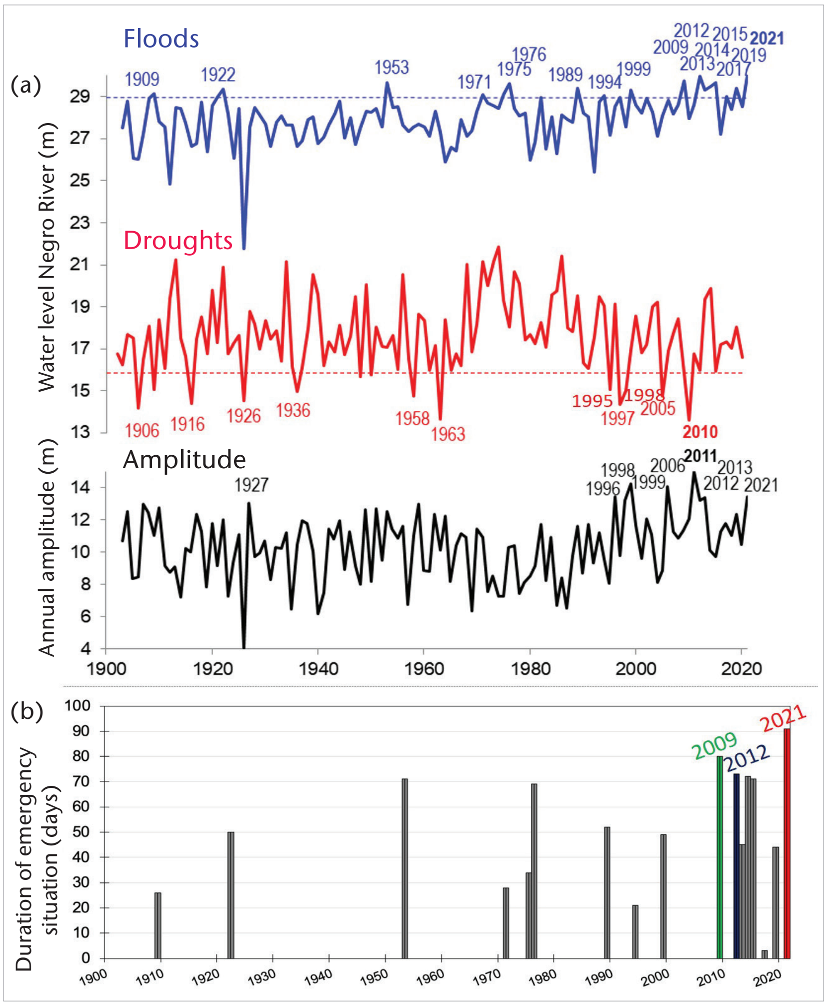


Figure 9. (a) Maximum (blue line) and minimum (red line) annual water level of Rio Negro at Manaus (1903–2021). Years corresponding to extreme flood with water level surpassing 29 m are indicated in blue, and years in red refer to severe hydrological droughts with minimum water level under 15.8 m. The annual water level amplitude (maximum minus minimum) is indicated by a black line (calendar years indicate extreme values with annual amplitudes >13 m) (adapted from Schöngart and Junk (2020));[39] (b) duration of the emergency in Manaus (water level ≥29.0 m). All data obtained from the platform Hidroweb, available on the National Water Resources Information System (SNIRH) operated by the Brazilian National Water and Sanitation Agency (ANA) and the Geological Survey of Brazil (CPRM). *Source:* Adapted from Espinoza et al. (2022).

In the Bolivarian Republic of Venezuela, on 23 August, the passage of tropical waves generated heavy rains that caused floods and landslides in the states of Mérida, Táchira, Bolívar, Apure, Zulia, Delta Amacuro, Carabobo, Yaracuy, Portuguesa and Sucre (Figure 10). The International Federation of Red Cross and Red Crescent Societies (IFRC)[40] reported that the impacts at the national level included nearly 55 000 people affected in 10 states and 85 municipalities, 116 roads and 10 bridges damaged, associated with 79 instances of rivers overflowing and 40 large-scale landslides. In the state of Mérida, heavy rainfall caused landslides and overflowing of rivers and streams, affecting 11 out of 23 municipalities.

Extreme rainfall and floods also occurred in other locations in southern South America, including in Dolores, Buenos Aires province, Argentina, where 276 mm of rain fell in 24 hours on 5 January, an unprecedented event which led to severe floods.[41] In the Juan Fernández Islands, administrative region of Valparaíso, Chile, 124 mm of rain fell on 19 April, the second highest 24-hour value for this station.[42]

In Colombia, floods were reported during 9–30 June and 19–24 September along the Magdalena River, 13–18 June along the Putumayo River, and 12–15 April in Cartagena affecting nearly 40 000 people.[43] In Llalli in the department of Puno in the southern Peruvian Andes, at 3980 m above sea level, a record daily rainfall of 58.8 mm was recorded on 9 February, surpassing the previous record of 45.7 mm on 26 February 2010 (average normal for February is 152.5 mm).

Floods during 13–20 February were reported in the Peruvian Amazon, and the flow of the Iñapari River reached 29 601.6 m³/s on 20 February, surpassing the previous record of 18 357.2 m³/s on 3 March 2017. Flooding was recorded on 13 February along the Pukiri and Colorado Rivers, and along the Tahuamanu River on 15 February. In Naranjitos, in the state of Amazonas, the flow of the Utcubamba River reached 673.8 m³/s on 12 February, surpassing the flood limit value of 394.3 m³/s.

Figure 10. Aerial view of flooded farms and houses in La Fortuna, state of Zulia, Bolivarian Republic of Venezuela, on 10 September 2021, two weeks after torrential rains hit the country. *Source:* Photo by Federico Parra/AFP via Getty Images.

DROUGHTS

Drought affected several countries in the LAC region during 2021. Drought categories based on the Integrated Drought Index (IDI)[44] have been used to describe the intensity of the drought in the three main affected countries/regions, Mexico, Chile and the Paraná–La Plata Basin. The IDI categories are D0: abnormally dry, D1: moderate drought, D2: severe drought, D3: extreme drought and D4: exceptional drought.[45,46]

According to the Drought Monitor of Mexico,[47] more than 50% of the country was affected by severe to exceptional drought in 2021, the second largest percentage after 2011/2012 (Figures 11 and 12). The area affected by drought since July 2020 reached 87.5% by the end of April 2021, leading to a water crisis and impacts on agriculture.[48] In 2020 and the first half of 2021, La Niña and a warmer tropical North Atlantic favoured increased precipitation in southern Mexico and drier conditions in the northern part of the country. The drought situation in northern Mexico in 2021 was due mostly to a weak monsoon season starting in July 2020. The negative rainfall anomalies in this region of Mexico shown in the annual rainfall map of Figure 4 are a result of warm and dry conditions that persisted until May 2021. After May 2021 the drought conditions gradually diminished (Figure 12).

By the middle of the year some parts of Central America were affected by weak-to-moderate drought. In the Caribbean, several countries experienced some level of moderate drought, particularly Haiti, the Dominican Republic, Puerto Rico and some parts of Cuba. Saint Croix, in the United States Virgin Islands, had its fourth driest year on record, with annual precipitation the lowest recorded since 1965, and groundwater levels were at record lows, similar to those of 2016.

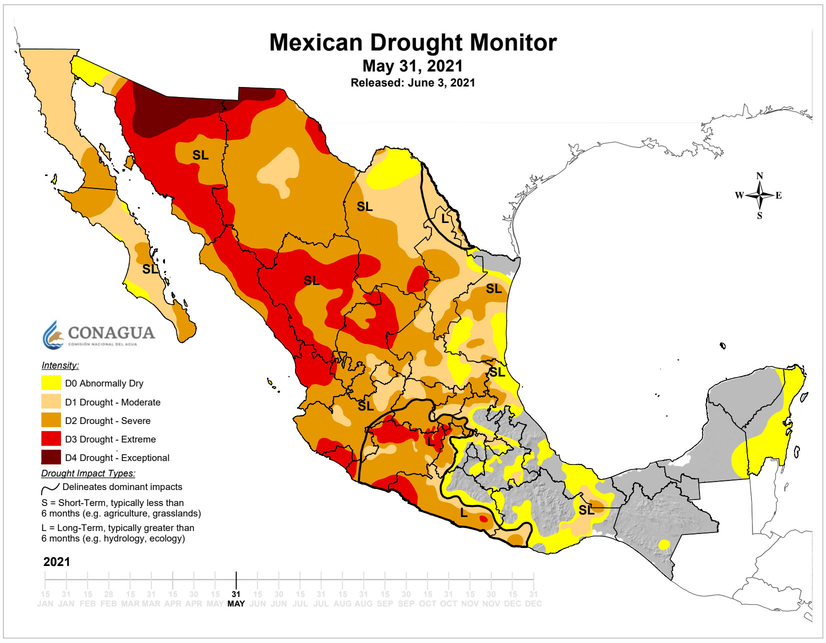


Figure 11. Drought conditions in Mexico, 31 May 2021.
Source: Drought Monitor of Mexico, National Water Commission (CONAGUA).

Drought also affected the west coast of subtropical South America, continuing an unprecedented, uninterrupted sequence of drier-than-average years in Chile. The ongoing "Central Chile Mega-drought", which has lasted for 13 years to date, is the longest and most severe in 1 000 years, putting Chile at the forefront of a regional water crisis (Figure 13).[49] The IPCC states that there is medium confidence that the drying trend in central Chile and severe droughts in south-western South America can be attributed to human influence.[50]

In the Paraná–La Plata Basin, the multi-annual drought affecting central-southern Brazil, parts of Paraguay and the Plurinational State of Bolivia continued in 2021 (Figure 13). The lack of rainfall, mainly in the upper part of the basin, has led to a considerable decrease in the flow of the Paraguay and Paraná Rivers (Figure 14). These drought conditions across the Paraná–La Plata Basin in Brazil and Argentina have been the worst since 1944.[51] In 2021 Brazil's south and south-east regions faced their worst droughts in nine decades, raising the spectre of possible power rationing given the grid's dependence on hydroelectric plants.[52] The drought situation in Paraná–La Plata Basin countries affected many sectors, including agriculture, inland water navigation, energy production, and water supply as well as ecosystems. Argentina, Brazil and Paraguay declared formal drought emergencies during 2021. On 24 July 2021, the Government of Argentina declared a state of water emergency valid for 180 days and encompassing seven provinces with territory along the Paraná, Paraguay and Iguazu Rivers. On 8 July 2021, the Government of Paraguay declared a state of emergency for navigation on the Paraná, Paraguay and Apa Rivers.[53]

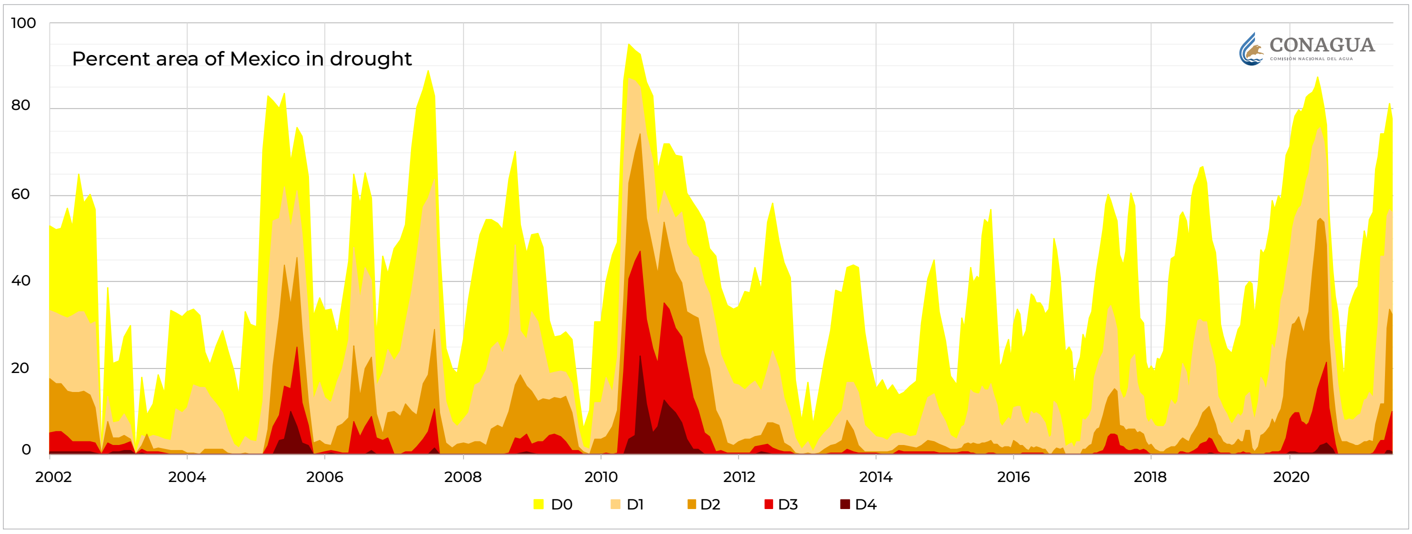


Figure 12. Percentage of territory affected by drought
(D0 – abnormally dry, D1 – moderate drought, D2 – severe drought, D3 – extreme drought, D4 – exceptional drought), in Mexico from 2003 to 2021.
Source: Drought Monitor of Mexico, CONAGUA.

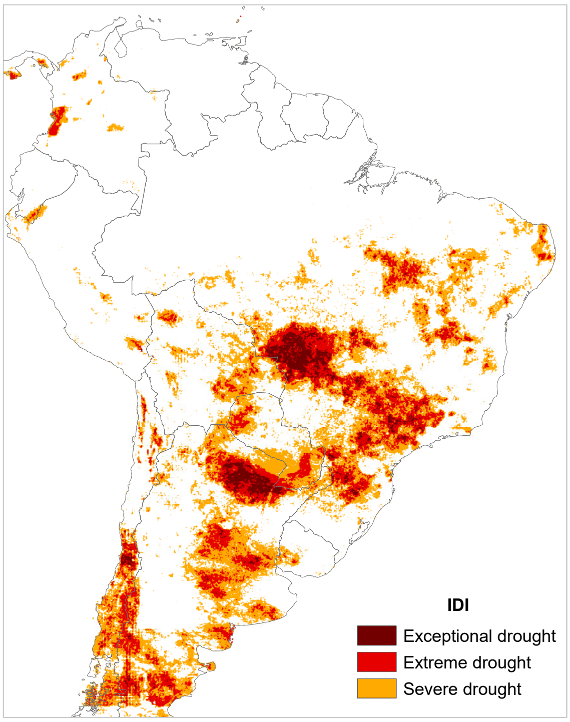


Figure 13. Integrated Drought Index (IDI) for September 2020–August 2021, in South America. *Source:* Standardized Precipitation Index (SPI) calculated from Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS) and Vegetation Health Index from Center for Satellite Applications and Research (STAR/NOAA). Calculation based on Cunha et al. (2019).

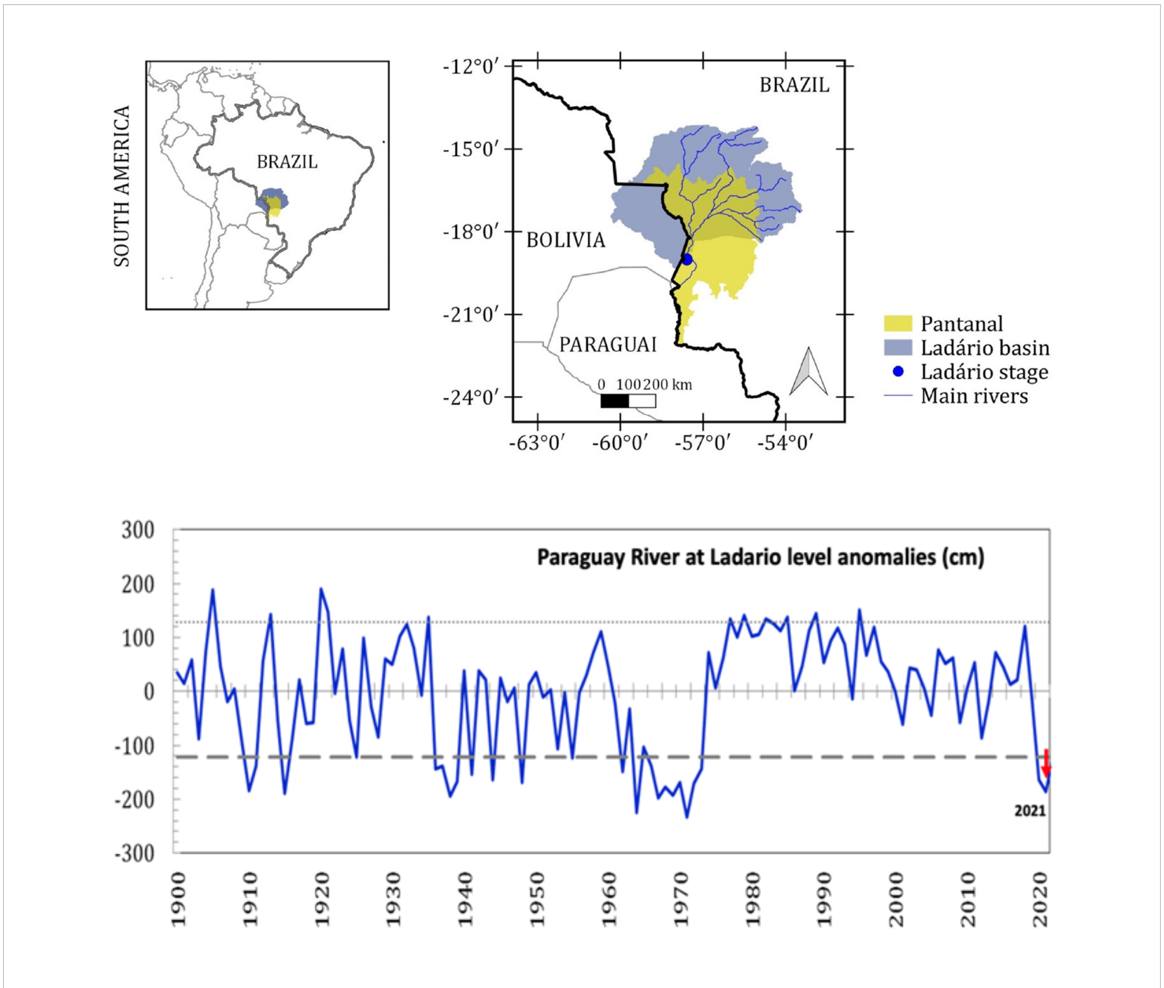


Figure 14. Level anomalies of the Paraguay River at Ladário (cm). Locations of the Ladário station and the Ladário Basin are shown in the right side of the panel. *Source:* Marengo et al. (2021).[54]

SANDSTORMS

On 1 October, sandstorms, rare in Brazil, hit several cities in various states of central and south-eastern Brazil, areas already affected by drought. In Três Lagoas (central Brazil), winds reached almost 70 km/h and were accompanied by a drop in temperature, from 41 °C to 24 °C, and low visibility caused by airborne sand. On 26 October, another large sandstorm, as well as smoke, hit the interior of São Paulo and areas of Mato Grosso. Within a week, this second dust storm left cities in São Paulo without power and in a state of emergency.

HEATWAVES AND WILDFIRES

Heatwaves were reported in many parts of the LAC region. In Argentina, several locations recorded 6–8 days in a row with heatwave conditions. An all-time temperature record was set in Cipolletti (43.8 °C) and Maquinchao (38.9 °C) on 22 January.[55] In west-central Brazil, in August 2021, exceptionally high temperatures were reported[56] over several days. For example, in Cuiabá, in the state of Mato Grosso, maximum temperatures reached 41 °C on 24 and 25 August (about 7 °C above normal), accompanied by critically low humidity levels, mainly in the central regions (relative humidity of approximately 8%–11%). On 21 September, Aragarças/Goiás reached 43.0 °C, the highest value for September at this station (the previous highest value was 41.5 °C on 14 September 2019). In Chile, up to 18 heatwave episodes during the year affected different regions of the country.[57] Some of them were very intense, including those that affected the Santiago region from 11 to 13 April (with a maximum temperature of 31.4 °C), and Valdivia from 2 to 5 February (37.3 °C) and then from 7 to 10 February (35.1 °C). On 27 February, Puerto Williams, Chile (considered the southern-most town in the world), registered its highest temperature on record, since 1961, of 26.1 °C (the previous record being 26.0 °C on 22 December 1984).[58] In Paraguay, a heatwave occurred from 18 to 20 September, with temperatures reaching 38.2 °C in Pedro Juan Caballero. In Peru, on 13 April, Jepelacio (northern Amazonia) reached 34.2 °C (the previous highest temperature was 33.6 °C on 23 November 2016).

Wildfires occurred all over South America during 2021 (Figure 15).[59] In Peru, on 5 August, forest fire driven by the low persistent humidity and the increase in the daytime temperature resulted in 2 200 hectares of natural vegetation

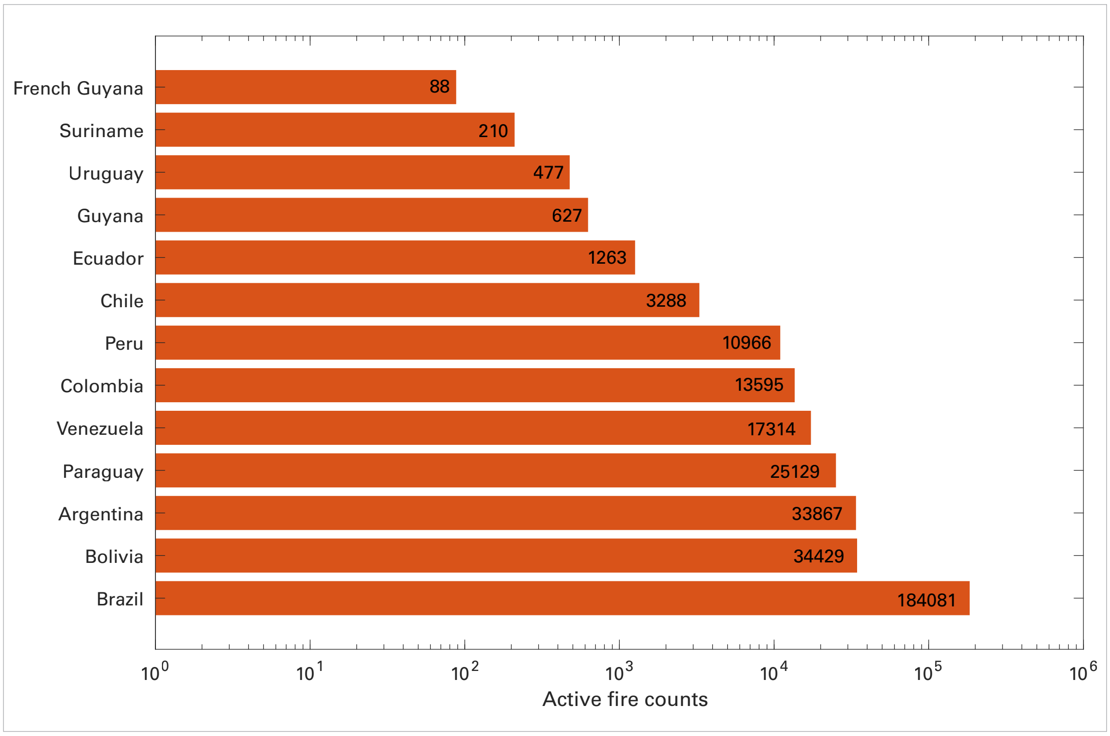


Figure 15. Number of active fires detected by MODIS-AQUA satellite in South America in 2021, by country or territory, displayed on a logarithmic scale.

cover being destroyed in the province of Quispicanchi, with 1 400 hectares and 800 hectares being destroyed in the districts of Lucre and Andahuaylillas, respectively.[60] Brazil reported approximately 184 000 fire outbreaks (of which 75 000 occurred just in the Brazilian Amazon). In August alone, more than 1 million hectares were burned in the Brazilian section of the Pantanal.[61] Most fires occurred in the Pantanal region of the state of Mato Grosso do Sul during compound drought and heatwave events, which enhanced vegetation flammability (Figure 16). It is estimated that wildfires burned more than 1 950 000 hectares across the Pantanal region during 2021 (Figure 16). Although these values correspond to a reduction of approximately 50% compared to 2020, the year 2021 still ranks as the second highest year since 2012 in terms of burned area.[62] Natural fires are rare in Brazil, and most fire outbreaks are associated with human activity, such as deforestation and pasture maintenance.[63]

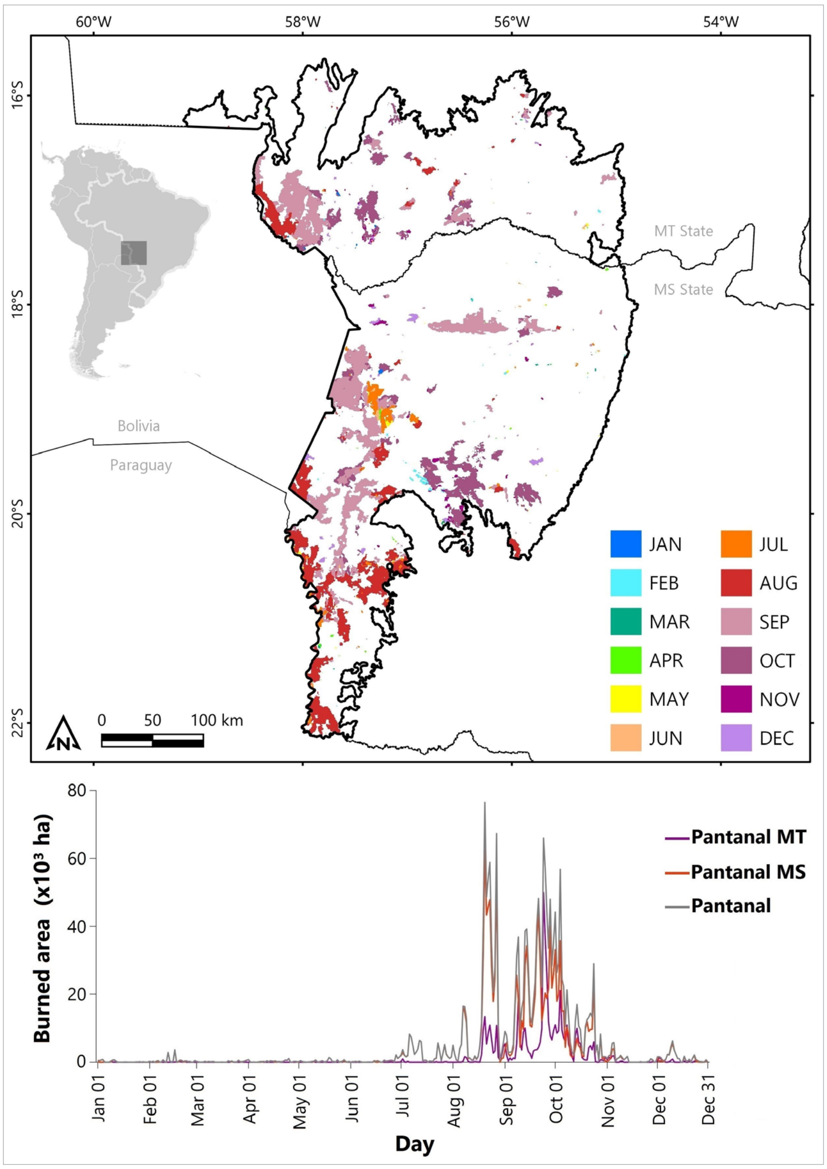


Figure 16. Burned areas in the Pantanal biome, Brazil, in 2021 (MT: state of Mato Grosso; MS: state of Mato Grosso do Sul).
Source: LASA-UFRJ.

COLD WAVES

Intense cold wave or cold spell episodes occurred during June and through August in many locations in southern South America. One of the most intense cold waves occurred in the last week of June into July, extending from western Amazonia and intensifying towards south-eastern Brazil, and with greater intensity in southern Brazil,[64] Paraguay, the Plurinational State of Bolivia, northern Argentina and central and southern Chile. In Argentina, on 28 June, Catamarca recorded its lowest minimum temperature of –6.2 °C (the previous record of –5.8 °C being on 15 June 1961).[65] On 29 July, minimum temperatures of –7.4 °C and –2.5 °C were detected in Presidente Roque Sáenz Peña and Formosa. These represent new monthly historical records, with the previous ones being –7.1 °C on 18 July 2017 and –2.3 °C on 1 July 1976, respectively. In the Plurinational State of Bolivia the all-time lowest temperatures were recorded in some stations of the Chiquitania and Pantanal regions and new historical minimum temperature records were set on 30 June. In Brazil, on 28 June , the temperature in Vilhena, in the state of Rondônia, reached 8.2 °C (compared with a 1981–2010 monthly average of 19.2 °C). In the Itatiaia National Park, in the highlands of Rio de Janeiro, the minimum temperature reached –9.9 °C on 1 July, about 25 °C below normal (14.4 °C), likely constituting one of the lowest minimum temperatures in Brazil in 2021. In Paraguay, between 28 and 30 June, the lowest temperatures on record were logged in Mariscal Estigarribia, where it reached –2.6 °C, and in Pedro Juan Caballero, where it reached 1.0 °C (the normal averages for June are 13.6 °C and 13.4 °C, respectively).

Climate-related impacts and risks

The COVID-19 pandemic negatively affected the economies of the countries in the region, especially the most vulnerable economies in the Caribbean small island developing states (SIDS). The state of the public finances, already weakened by the COVID-19 pandemic,[66] increased the risks to the countries of other disasters. The combined effect of COVID-19 and hydrometeorological hazards contributed to a slowing of progress towards achieving the Sustainable Development Goals (SDGs), and especially SDGs 1 and 2, no poverty and zero hunger.

AGRICULTURE AND FOOD SECURITY

According to the Food and Agriculture Organization of the United Nations (FAO),[67] negative impacts on harvests and/or changes in planting season (such as starting later than normal) were reported, due to below-average rainfall during the last quarter of 2021 in Chile, Brazil, Uruguay and Paraguay. The South American 2021 cereal harvest declined by an estimated 2.6% compared with the previous year. In the Caribbean, rice crops in some areas of Cuba were adversely affected due to rainfall deficits starting in April. In Haiti, irregular rainfall distribution in central areas affected crop growing conditions. Below-average rainfall between April and May 2021 in almost all of Haiti resulted in low agricultural production. Since late 2018, the number of Haitian people experiencing high levels of acute food insecurity (that is, Integrated Food Security Phase Classification (IPC) Phase 3 or above) has nearly doubled to about 4.3 million in September 2021–February 2022. Insecurity, poor production, natural disasters and inflation are key drivers of the current levels of acute food insecurity.[68]

In Central America, in 2021, the compound effect of the COVID-19 pandemic and hydro-meteorological hazards – in particular, drought and flooding – had significant impacts on food security (see Figure 17). A total of 7.7 million people experienced acute food insecurity in El Salvador, Guatemala and Nicaragua.

Agriculture in Brazil, Chile, Paraguay and Uruguay was also affected due to the delay in the planting season as a result of below-average rainfall during the last quarter of 2021.[69] This shift in precipitation patterns was partly related to La Niña (see Precipitation and Sea-surface temperature).

In Brazil, the larger-producing summer crop suffered severe impacts from lack of rain during critical development stages and periods of frost (Figure 18) (see also Precipitation and Cold waves).

Paraguay is the world's fourth-largest exporter of soybeans, and this crop contributes greatly to the country's gross domestic product (GDP). Predictions of soybean production in Paraguay for 2020/2021 were reduced from 10 million tons to about 8 million tons. This was due to the lack of rainfall associated with La Niña. Rainfall in the Canindeyú and Itapúa departments during September and October 2020 was about 30% of normal.[70] The lack of rainfall affected the yields of short-cycle soybean, sown at the beginning of 2021. In the department of Alto Paraná, short-cycle soybean was expected to be almost completely lost. A similar decrease in the sown area and yields of short-cycle

Figure 17. Corn field affected by drought (left) and damage to corn cob (right) in Jocotán, Chiquimula, Guatemala, 12 July 2015. Recurrent droughts leading to crop losses in the Central American Dry Corridor, comprised of El Salvador, Guatemala, Honduras and Nicaragua, severely affect rural livelihoods and increase food insecurity in the region. Photo credit: Rubí López. *Source:* FAO Americas, https://www.flickr.com/photos/faoalc/27117133485/in/album-72157668276602532/.

soybean also occurred during the previous 2019/2020 cropping cycle.[71]

In Argentina, lack of February rains, as well as high temperatures affected the late-planted crop (usually the smaller season) during critical developmental stages. Many crop sowings had shifted to the late-planted season, making the two seasons about the same size in 2021. The Grain Exchange (Bolsa de Cereales) of Buenos Aires (Argentina) stated that the production of soybean in the 2020/2021 cropping cycle was about 43.5 million tons, about 3 million tons below forecasts. The decrease in production – 11% lower than in 2019/20 – was tied to low rainfall during February and March 2021, critical periods for yield definition of this crop. Nationally averaged soybean yields for Argentina were about 10% lower than the 2019/2020 cycle.[72] Reduced soybean production prospects in South America are contributing to the sharp increase in the FAO vegetable price index.[73]

Reduced precipitation and altered rainfall seasons are also affecting rainfed subsistence farming, particularly in the Dry Corridor in Central America and in the tropical Andes, compromising food security in this region.[75]

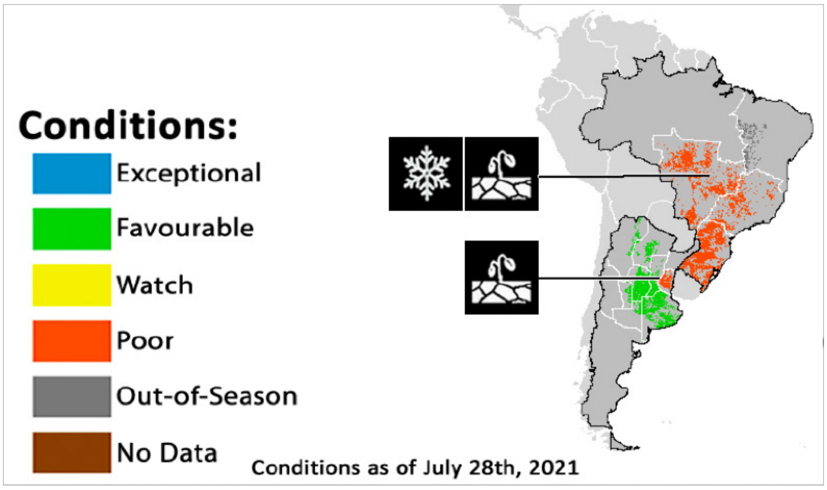


Figure 18. Maize crop conditions in main growing areas are based upon a combination of national and regional crop analysis inputs along with Earth observation data. Condition information is based upon information as of 28 July. Where crops are in other than favourable conditions, the climatic drivers responsible for those conditions are displayed.[74]

In Chile, the continuing drought and loss of surface and underground water resources severely affected dozens of rural communities, requiring water to be supplied by trucks.

According to the IPCC, 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, south-western Australia, Central America and the Amazon Basin. These regions are expected to become drier due to both reduced precipitation and increases in evaporative demand.[78]

WATER RESOURCES

Glacier retreat, temperature increase and precipitation variability, together with land-use change, have affected ecosystems, water resources and livelihoods, throughout the LAC region, including through landslides and flood-related disasters.[76] Mexico continues to be affected by recurrent droughts in large parts of its territory. Several countries of the Caribbean have dealt with severe lack of water (see Droughts).

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 drought.[77] Electricity production was also affected due to drought-induced low water levels at the Yacyretá and Itaipú Dams in Paraguay. The worst drought situation in decades in Brazil's south and south-east regions also negatively affected hydroelectric power generation (see Droughts).

FOREST AND ECOSYSTEM SERVICES

Central and South American ecosystems are highly exposed and vulnerable to climate change. The combined effect of anthropogenic land-use changes and climate change has increased the vulnerabilities of terrestrial ecosystems. Extreme heat and drought, leading to wildfires, damage the forest and related ecosystems.

The Amazon forest was exposed to unprecedented droughts and higher temperatures in 1998, 2005, 2010 and 2015/2016, mainly attributed to El Niño. Cumulative drought impacts have adversely affected forest health. Deforestation in the Brazilian Amazon rainforest area was 12 000 km^2 in 2021, reaching its highest value since 2009 (Figure 19). The deforested area increased by 22% from 2020 to 2021 and doubled compared to the annual average of deforested area during the 10-year period 2009–2018.

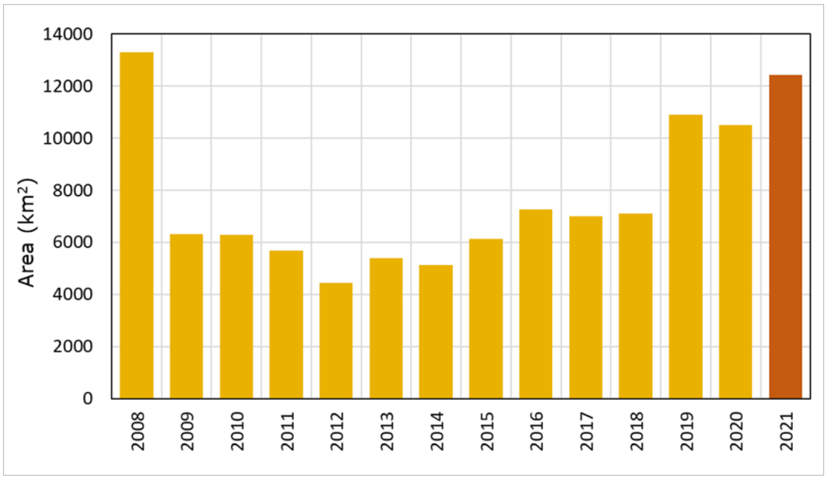


Figure 19. Annual deforestation rate in the Brazilian Amazon from 2008 to 2021. *Source:* PRODES-INPE[79] -National Institute for Space Research.

Similarly, ocean and coastal ecosystems such as coral reefs, estuaries, salt marshes, mangroves and sandy beaches are negatively affected by climate change and associated hazards in the region.[80]

Much of the coastal area surrounding the Mesoamerican Reef and nearby islands is low-lying and exposed to sea-level rise. Eroding shorelines have already been documented, which can affect nesting and reproductive success of marine turtles. In addition, the warming of seawaters is responsible for the observed increase in episodes of coral bleaching, which is devastating to reefs and the wildlife that depend on them.

Ongoing coral reef restoration projects in Spanish-speaking countries in the Caribbean and eastern Tropical Pacific are being developed. These aim to provide alternative, sustainable livelihood opportunities for local populations, and to promote coral reef conservation for re-establishing a self-sustaining, functioning reef ecosystem.[81] This may have strong positive impacts on tourism, local economies, fisheries and food security for local populations.

MIGRATION AND POPULATION DISPLACEMENT

Migration and displacements have multiple causes. Climate change and extreme events are amplifying factors, which exacerbate social, economic and environmental drivers. According to the Working Group II contribution to the IPCC Sixth Assessment Report,[82] changes in climate and extreme events have severely affected the LAC region. The Andes, north-east Brazil and the northern countries in Central America are among the regions most sensitive to climatic-related migrations and displacements, a phenomenon that has increased in the last eight years, compared with the situation described in the IPCC Fifth Assessment Report (2014).[83] On small islands, the vulnerability of communities, especially those relying on coral reef systems for livelihoods, may exceed adaptation limits well before 2100. The impacts of climate change on vulnerable low-lying and coastal areas present serious threats to the ability of land to support human life and livelihoods. Although the drivers and outcomes are highly context-specific, climate-related migration is expected to increase on small islands, including in the Caribbean region.

The southern and coastal areas of Suriname bore the brunt of heavy rainfall recorded in 2021, with flooding displacing some 1 000 households and creating priority food security needs[84] (see Precipitation and Heavy precipitation and flooding). The 2021 Atlantic hurricane season triggered fewer displacements than the 2020 season. However, thousands of people in Cuba were evacuated in July and August 2021 as Hurricanes *Elsa* and *Ida* affected the island.[85] Protracted weather- and climate-related displacement remains a major concern in the region. Cross-border migration has been reported in Central America subsequent to the impacts of Hurricanes *Eta* and *Iota* in late 2020.

According to the National Oceanic and Atmospheric Administration (NOAA) National Hurricane Center,[86] the flooding resulting from Tropical Storm *Fred* affected the Dominican Republic. The floods left 47 communities across the country cut off, and damaged or destroyed over 800 homes, as well as displacing over 4 000 people. In Haiti, strong winds, heavy rainfall and flooding associated with Hurricane *Grace* worsened the ongoing humanitarian crisis that followed the 7.2 magnitude earthquake on 14 August, by destroying makeshift shelters and interrupting rescue and recovery efforts.[87]

According to the latest analysis by the International Organization for Migration (IOM), extreme climate events and slow onset climatic change influenced human mobility patterns throughout 2021.[88] In December 2021, more than 90 000 people were evacuated and displaced in the states of Bahia and Minas Gerais in Brazil, as a consequence of extreme flooding that led to the collapse of two dams[89] (see Heavy precipitation and flooding).

Several countries in the LAC region adopted/updated their nationally determined contributions (NDCs) to the Paris Agreement to incorporate human mobility issues.[90] For instance, the 2021 updated NDC from Antigua and Barbuda calls for the "potential adoption of Organization of Eastern Caribbean States (OECS) regional agreements, frameworks and policies on forced displacement and human mobility caused by climate change within the OECS region". The 2021 Belize updated NDC suggests enhancing the protection of "climate refugees". The Paraguay 2021 NDC requests an enhanced involvement with the IOM to address hazards that cause "forced displacement and migration".

SOCIOECONOMIC IMPACTS

According to the latest analysis[91] of the Economic Commission for Latin America and the Caribbean (ECLAC), extreme events, in particular persistent drought, have exacerbated the damaging impact of the COVID-19 pandemic on the social and economic prospects of the countries in the region, especially the Caribbean small island developing states (SIDS). The tourism sector, a key driver of economic growth in those countries, came to a complete halt across the economy. The accumulated losses of this sector in the Caribbean are anticipated to range between US$ 53 billion and US$ 75 billion during the period 2020 to 2023. This subregion will be, relatively, the most affected in the LAC region, given its smaller population and the weight of tourism in its economies, and the losses will have negative consequences on the level of employment in the sector, with a gender bias.

Brazil was severely damaged by extreme weather and climate at various times of the year, leading to several US$ billions of losses and disruption of roads and schools. According to the Instituto de Desenvolvimento Agropecuário e Florestal Sustentável do Estado do Amazonas (IDAM),[92] the flood in the Brazilian Amazon led to an estimated economic loss of US$ 40 million for the rural sector and affected more than 450 000 people in the state of Amazonas.

The flood disaster in the states of Bahia and Minas Gerais in Brazil resulted in an estimated loss of US$ 3.1 billion. The total affected population is estimated at more than 800 000.[93, 94, 95]

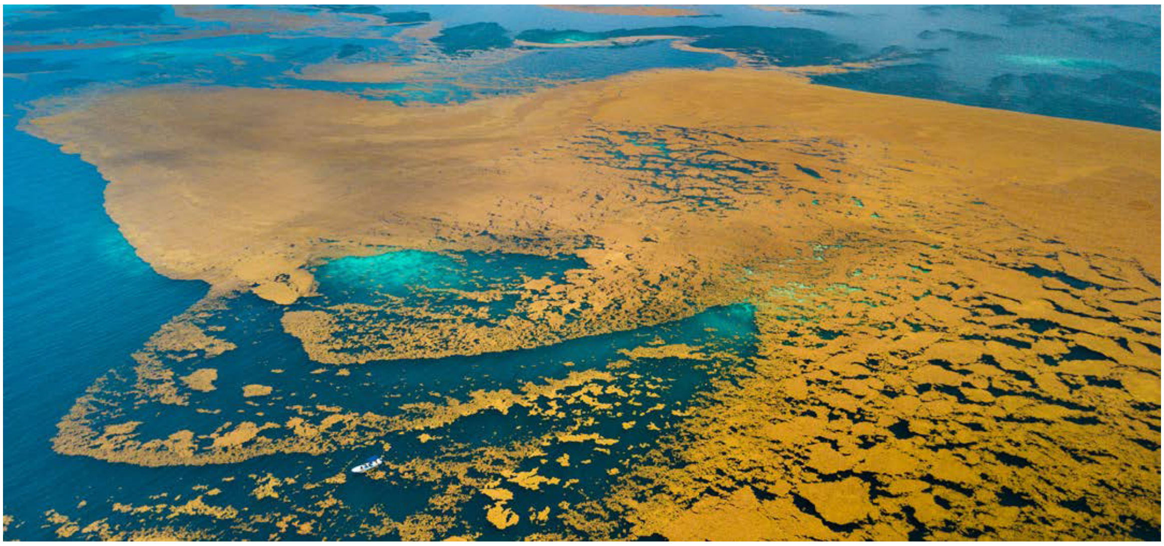
Preliminary estimates from the Brazilian government's food supply agency (CONAB)[96] indicate that extreme cold conditions and frosts (see Extreme events) affected 150 000 to 200 000 hectares – about 11% of the country's total arabica crop area. Frost-related losses, together with accumulated losses from the 2021 drought, ranked among the biggest disasters for Brazilian farmers in recent years. CONAB estimates that coffee production in Brazil in 2022 will be 120 000 tons lower than what was forecast in May 2021, due to three cold waves and drought in 2021. The sugar-energy sector had also already been accumulating losses since 2020 due to drought. CONAB estimates the 2022 sugarcane harvest at 574.8 million tons, 4.6% lower than the previous harvest.

Sargassum, climate change and the impact on tourism in the Caribbean

Sargassum is brown algae which originates in the Sargasso Sea of the western Atlantic Ocean. It grows up to several metres and can float in the open ocean. Seawater warming due to climate change is among the factors responsible for its spread in the Caribbean.[97]

Floating sargassum is beneficial at sea, mainly as a unique pelagic habitat. However, its drifting to and accumulation on the coastlines has significant negative impacts on tourism and other biophysical and socioeconomic sensitive sectors. This issue therefore represents an emerging hazard for the Caribbean

Figure 20. Drone photograph of a vast mat of sargassum near Silk Cayes, Belize, 4 September 2018. Photo credit: Tony Rath. *Source:* UNEP-CEP, 2021.



countries, which are already subject to numerous others. Indeed, various countries in the Caribbean have declared national states of emergency with respect to sargassum influxes (Figure 20).[98]

The year 2021 witnessed another washing up of massive quantities of sargassum in the Caribbean region. Warming oceans due to climate change and other environmental conditions, including undetermined potential factors, lead to massive quantities of sargassum being transported to coastlines in the Caribbean (West Africa is also affected).[99] This in turn reduces economic activities in climate-sensitive sectors such as tourism, maritime transport and fisheries, and adversely affects ocean biodiversity and human well-being.[100]

Enhancing climate resilience and adaptation policies

REASONS FOR CONCERN AND KNOWLEDGE GAPS

The IPCC Sixth Assessment Report Working Group I[101] and Working Group II[102] reports conclude that the LAC climate is changing. Precipitation patterns are shifting, temperatures are rising and some areas are experiencing changes in the frequency and severity of weather extremes, such as heavy rains. The effects range from melting Andean glaciers to devastating floods and droughts. The two great oceans that flank the continent – the Pacific and the Atlantic – are warming and becoming more acidic, while sea level also rises. Unfortunately, greater impact is likely in store for the region as both the atmosphere and oceans continue to rapidly change. Food and water supplies will be disrupted. Towns and cities and the infrastructure required to sustain them will be increasingly at risk. Human health and welfare will be adversely affected, along with natural ecosystems. Amazonia, north-eastern Brazil, Central America, the Caribbean and some parts of Mexico will see increased drought conditions, while hurricane impacts may increase in Central America and the Caribbean. Climate change is threatening vital systems in the region, such as the glaciers in the Andes, the coral reefs in Central America and the Amazon forest, which are already approaching critical conditions under risk of irreversible damage.

In addition to impacts from the COVID-19 pandemic, the United Nations Office for Disaster Risk Reduction (UNDRR) registered a total of 175 disasters in the LAC region during the 2020–2022 period.[103] Of these, 88% have meteorological, climatological and hydrological origins. These hazards accounted for 40% of recorded disaster-related deaths and 71% of the economic losses. The UNDRR *GAR Special Report on Drought 2021*[104] documents the severity of impacts of recurrent droughts in the Caribbean, in the years 2009–2010, 2014–2016 and 2019–2020. Those droughts have had severe, long-term and cascading health and sanitation, economic, social and environmental impacts, and have also generated secondary hazards, such as wildfires.

The tourism sector is highly vulnerable to climate change and at the same time contributes to the emission of greenhouse gases which cause global warming. Accelerating climate action in tourism is therefore of utmost importance for the resilience of the sector. Climate action is understood as the efforts to measure and reduce greenhouse gas emissions and strengthen adaptive capacity.

The IPCC has indicated (2022)[105] that the most reported obstacle for adaptation in terrestrial, freshwater, ocean and coastal ecosystems in the region is financing, but other challenges exist. For example, adaptation barriers in the water sector include institutional instability, fragmented services and poor management of services, inadequate governance structures, and insufficient data and analysis of adaptation experience.

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

The intense rainfall and floods in the states of Bahia and Minas Gerais in Brazil during the last week of December 2021 were properly monitored, and alerts helped minimize related damage and protect human lives and property. Loss of life in this disaster was lower than in previous disasters despite higher accumulated rainfall.[106] This example highlights the importance of having appropriate early warning services.

The importance of strengthening climate services, including but not limited to early warnings, is increasingly recognized in the region. NDCs submitted by countries as part of implementation of the Paris Agreement outline efforts by each country to reduce national emissions and adapt to the changing climate. In the LAC region, 30 Parties to the United Nations Framework Convention on Climate Change (UNFCCC) had submitted NDCs as of March 2022. Of those, 24 have submitted a new, updated or second NDC.

Most Parties have highlighted agriculture and food security, water, health and ecosystem and biodiversity as their top areas for adaptation (Figure 21a). Over 80% of Parties in the region have prioritized climate services in their NDCs. Climate services capacity development

(40%), modelling and forecasting (36%), data and data management (32%), observing network (32%), monitoring and evaluation (31%) and research (20%) were the topics most mentioned among those NDCs (Figure 21a). Over 60% of Parties in the region have included gender-related issues in their NDCs.

Over 60% of NDCs from the region mention early warning (EW) in their NDCs – for droughts, floods, storms and heat and cold waves. For example, Belize[107] highlighted the need to enhance early warning systems for drought and extreme weather events to support farmers in planning for and responding to the impacts of climate change by 2025. Floods, tropical cyclones, droughts, sea-level rise, temperature increases and changes in precipitation patterns have been mentioned by most Parties as hazards of the highest concern (Figure 21b).

MEMBERS' CAPACITIES: CLIMATE SERVICES AND EARLY WARNING

Disasters expose inequalities in natural and managed systems and human systems as they disproportionately affect poor and marginalized communities including ethnic and racial minorities, indigenous people, women and children. Therefore, disaster risk reduction is fundamental for climate justice and climate-resilient development. In Central and South America, climate change will increase water and food security risks due to frequent/extreme droughts, and damages to life and infrastructure due to floods, landslides, sea-level rise, storm surges and coastal erosion. Floods and landslides pose a risk to life and infrastructure; a 1.5 °C temperature increase would increase the population affected by floods by 100%–200% in Colombia, Brazil and Argentina, by 300% in Ecuador and by 400% in Peru. Increased water scarcity and competition over water are projected with high confidence by the IPCC.[108]

In the context of significant weather and climate hazards under climate change scenarios, some extreme weather events increase in frequency and/or severity because of climate change.[109] Disasters associated with these hazards demonstrate the immediate societal and political implications of rising risks, and provide windows of opportunity to raise awareness about climate change and to implement disaster reduction policies and strategies. Meeting the SDG 11 (sustainable cities and communities) targets of reduced loss of life and economic losses will require reducing climate-related disaster impacts.

To reduce adverse impacts of climate-related disasters and support resource management decisions and improved outcomes, climate services, end-to-end early warning systems and sustainable investments are required but are not yet adequate.

Although climate services are explicitly mentioned in most Parties' NDCs as a requirement for managing climate risks in climate-sensitive sectors, WMO data indicate that one WMO Member in the LAC region is at a less-than basic capacity level for the provision of climate services, six are at a basic level, and eleven Members have an essential capacity level only. Just five WMO Members fall into the full or advanced capacity categories (Figure 21c).[110]

As defined by the UNDRR, multi-hazard early warning systems (MHEWS) are:

> an integrated system of hazard monitoring, forecasting and prediction, disaster risk assessment, communication and preparedness activities systems and processes that enables individuals, communities, governments, businesses and others to take timely action to reduce disaster risks in advance of hazardous events.[111]

MHEWS data from WMO Members suggest that the LAC region faces several EW capacity gaps.[112] According to data from 19 WMO Members in the LAC region that responded to the 2020 WMO Hydrology Survey, 16 provide forecast and warning services for riverine floods, 12 for flash floods, and 13 for droughts. However, 12 Members out of the 19 WMO LAC Members that provided data reported having inadequate end-to-end flash flood forecasting and warning services and 8 Members reported having inadequate riverine floods forecasting/warning services, even though floods are frequent in the region (Figure 21f). Moreover, 9 Members from the region provide end-to-end drought forecasting and warning services at an inadequate capacity level. More investment – and more precisely targeted investment – in climate services is needed to strengthen MHEWS and decision support for adaptation in climate-sensitive sectors prioritized in the NDCs of Parties to the UNFCCC.

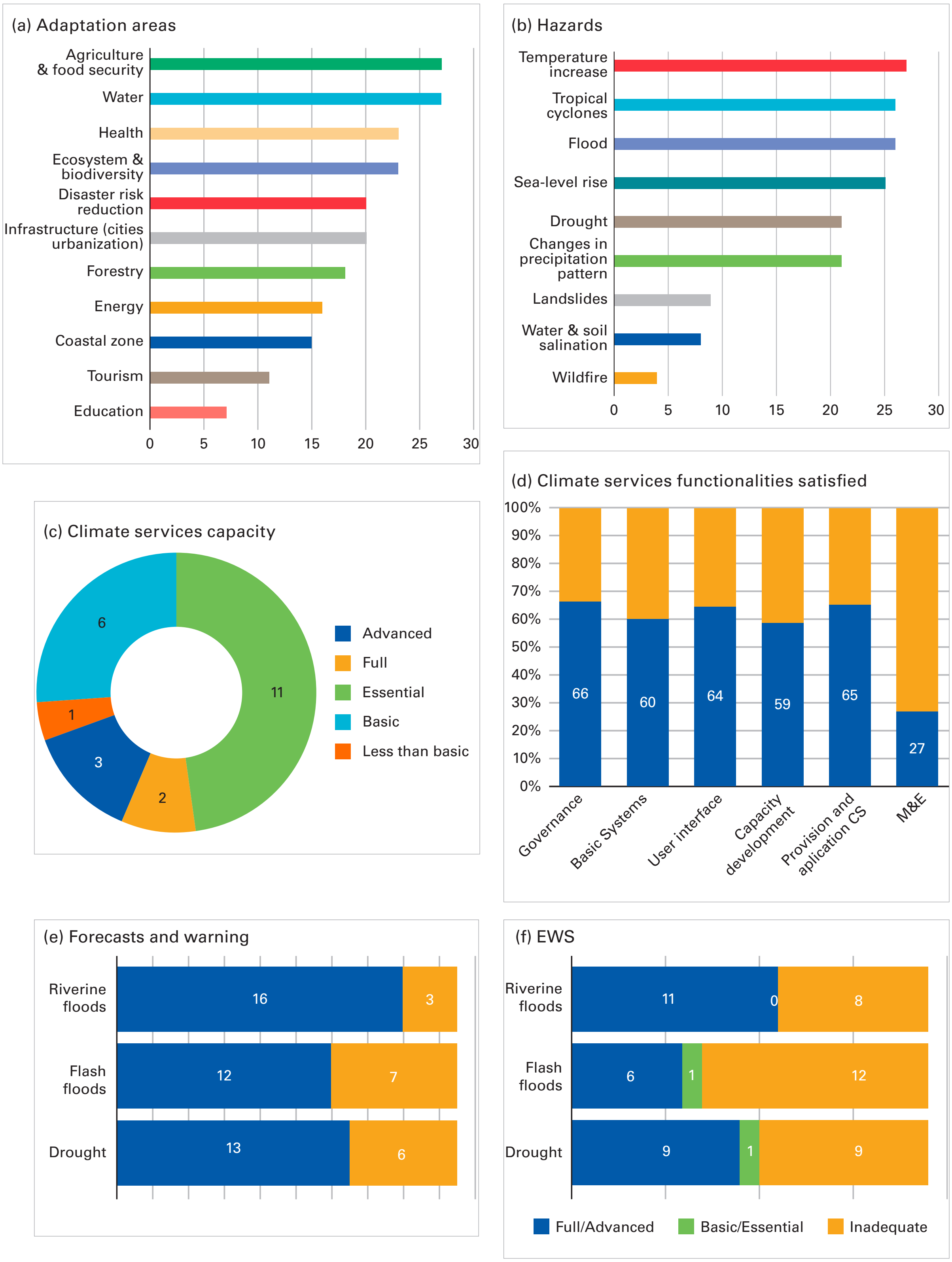


Figure 21. Overview of LAC climate policy priorities and capacities for climate services and early warning systems. Note to Figure 21(d): the results are representative of ten SIDSs that provided data. M&E: Monitoring and Evaluation of socioeconomic benefits. Note to Figure 21 (e): the results are representative of seven SIDSs that provided data. Grey represents WMO Members indicating no EWS in place.[113] Note to Figure 21(f): Member capacities are categorized as Inadequate (0%–33%), Basic/Essential (34%–66%) and Full/ Advanced (67%–100%), according to the estimated percentage of the at-risk population that receive EW. For each hazard, the Inadequate category includes Members (providing data) reporting that no end-to-end EWS for the hazard is in place, as well as those whose end-to-end EWSs do not reach more than 33% of the at-risk population. The results are representative of seven SIDSs that provided data.[114]

Observational basis for climate monitoring

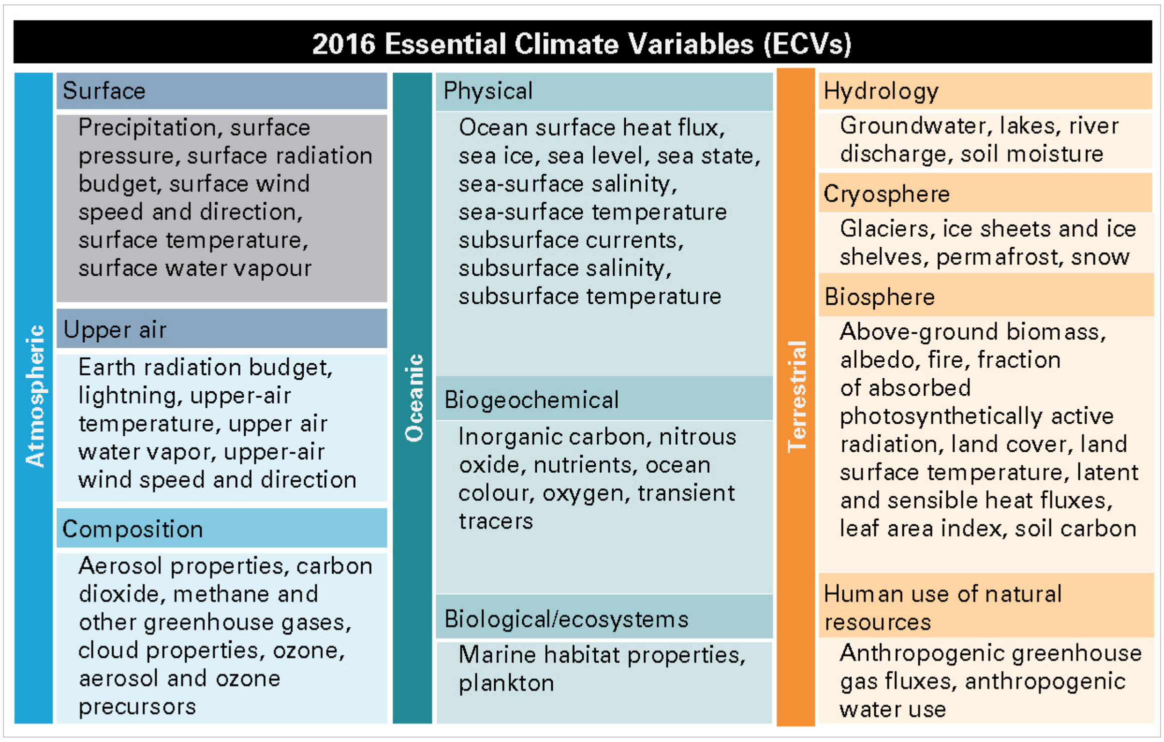
Climate monitoring is performed by a network of observing systems covering the atmosphere, the ocean, hydrology, the cryosphere and the biosphere. Each of these areas is monitored in different ways by a range of organizations. Cutting across all these areas, satellite observations provide major contributions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

In 1992, the Global Climate Observing System (GCOS) was established jointly by WMO, the Intergovernmental Oceanographic Commission (IOC) of the United Nations Educational, Scientific and Cultural Organization (UNESCO), the United Nations Environment Programme (UNEP) and the International Science Council (ISC) to coordinate and facilitate the development and improvement of global climate observations. GCOS has identified a set of Essential Climate Variables (ECVs)[115] that together provide the information necessary to understand, model and predict the trajectory of the climate as well as plan mitigation and adaptation strategies.

ECVs are physical, chemical or biological variables or a group of linked variables that critically contribute to the characterization of Earth's climate system, and include atmospheric, oceanic and terrestrial components. GCOS currently specifies 54 ECVs (see Figure 22).

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

Figure 22. Essential Climate Variables (ECVs) identified by GCOS



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 1961–1990 and 1981–2010 baselines using the following steps:

1. Read the gridded data set;
2. Regrid the data to 1° latitude × 1° longitude resolution. If the gridded data are higher resolution, then take a mean of grid boxes within each 1°×1° grid box. If the gridded data are lower resolution, then 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 1981–2010;
6. Subtract the 30-year period average from each year to get anomalies relative to that base period.

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

The following six data sets were used:

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

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.

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.

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.

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, https://www.jstage.jst.go.jp/article/ jmsj/93/1/93_2015-001/_article.

NOAAGlobalTemp v5 – Zhang, H-M. ; Huang, B.; Lawrimore, J. et al. NOAA Global Surface Temperature Dataset (NOAAGlobalTemp), Version 5.0. *NOAA National Centers for Environmental Information*. doi: 10.25921/9qth-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.

Temperature in situ data from National Meteorological and Hydrological Services.

PRECIPITATION

Precipitation in situ data from National Meteorological and Hydrological Services.

GLACIERS

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

SEA-SURFACE TEMPERATURE

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

SEA LEVEL

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

DROUGHT

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

Standardized Precipitation Index (SPI) in situ data from National Meteorological and Hydrological Services.

WILDFIRES

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

Active fire data for South America (Figure 15): NASA satellite images (MODIS-AQUA) processed by the Brazilian National Institute for Space Research (INPE).

CLIMATE SERVICES

WMO Analysis of NDCs

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

WMO Hydrology Survey, 2020

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

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

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ORGANIZATIONS

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Endnotes

1 Data are from six different data sets: HadCRUT5, NOAAGlobalTemp, GISTEMP, Berkeley Earth, ERA5 and JRA55. For details of the data sets and processing see Data sets and methods.

2 World Meteorological Organization (WMO). *WMO Greenhouse Gas Bulletin (GHG Bulletin), No. 17*: The State of Greenhouse Gases in the Atmosphere Based on Global Observations through 2020; WMO: Geneva, 2021.

3 World Meteorological Organization (WMO). *State of the Global Climate 2021* (WMO-No. 1290). Geneva, 2022.

4 Masson-Delmotte, V.; Zhai, P.; Pirani, A. et al., Eds. *Climate Change 2021: The Physical Science Basis*; Intergovernmental Panel on Climate Change (IPCC), 2021. https://www.ipcc.ch/report/ar6/wg1/.

5 The temperature data sets are described at the end of the report (see Data sets and methods)

6 The anomaly values in square brackets correspond to the data sets with the lowest and the highest regional average temperature value

7 Masiokas, M. H.; Rabatel, A.; Rivera, A. et al. A Review of the Current State and Recent Changes of the Andean Cryosphere. *Front Earth Sci* **2020**, *8*, 99. https://doi.org/10.3389/feart.2020.00099.

8 Rabatel, A.; Francou, B.; Soruco, A. et al. Current State of Glaciers in the Tropical Andes: a Multi-century Perspective on Glacier Evolution and Climate Change, *The Cryosphere* **2013**, *7*, 81–102. https://doi.org/10.5194/tc-7-81-2013.

9 Masson-Delmotte, V.; Zhai, P.; Pirani, A. et al., Eds. *Climate Change 2021: The Physical Science Basis*; Intergovernmental Panel on Climate Change (IPCC), 2021. https://www.ipcc.ch/report/ar6/wg1/.

10 Masson-Delmotte, V.; Zhai, P.; Pirani, A. et al., Eds. *Climate Change 2021: The Physical Science Basis*; Intergovernmental Panel on Climate Change (IPCC), 2021. https://www.ipcc.ch/report/ar6/wg1/.

11 Taylor, L. S.; Quincey, D. J.; Smith, M. W. et al. Multi-decadal Glacier Area and Mass Balance Change in the Southern Peruvian Andes. *Front Earth Sci* **2022**, *10*. https://doi.org/10.3389/feart.2022.863933.

12 Caro, A.; Condom, T.; Rabatel, A. Climatic and Morphometric Explanatory Variables of Glacier Changes in the Andes (8–55°S): New Insights from Machine Learning Approaches. *Front Earth Sci* **2021**, *9*. https://doi.org/10.3389/feart.2021.713011.

13 Matthews, J. B. R.; Babiker, M.; De Coninck, H. et al. Glossary. In *Climate Change 2021: The Physical Science Basis*; Masson-Delmotte, V.; Zhai, P.; Pirani, A. et al., Eds.; Intergovernmental Panel on Climate Change (IPCC), 2021.

14 https://gcos.wmo.int/en/essential-climate-variables/sst

15 Bertrand, A.; Lengaigne, M.; Takahashi, K. et al. *El Niño Southern Oscillation (ENSO) Effects on Fisheries and Aquaculture*; FAO Fisheries and Aquaculture Technical Paper No. 660; Food and Agriculture Organization of the United Nations: Rome, 2020. https://doi.org/10.4060/ca8348en.

16 Masson-Delmotte, V.; Zhai, P.; Pirani, A. et al., Eds. *Climate Change 2021: The Physical Science Basis*; Intergovernmental Panel on Climate Change (IPCC), 2021. https://www.ipcc.ch/report/ar6/wg1/.

17 World Meteorological Organization (WMO). *State of the Global Climate 2021* (WMO-No. 1290). Geneva, 2022.

18 https://public.wmo.int/en/about-us/frequently-asked-questions/el-ni%C3%B1o-la-ni%C3%B1a

19 https://iri.columbia.edu/wp-content/uploads/2016/05/LaNina_Rainfall.pdf

20 World Meteorological Organization (WMO). *WMO Greenhouse Gas Bulletin (GHG Bulletin), No. 17*: The State of Greenhouse Gases in the Atmosphere Based on Global Observations through 2020; WMO: Geneva, 2021.

21 Masson-Delmotte, V.; Zhai, P.; Pirani, A. et al., Eds. *Climate Change 2021: The Physical Science Basis*; Intergovernmental Panel on Climate Change (IPCC), 2021. https://www.ipcc.ch/report/ar6/wg1/.

22 Masson-Delmotte, V.; Zhai, P.; Pirani, A. et al., Eds. *Climate Change 2021: The Physical Science Basis*; Intergovernmental Panel on Climate Change (IPCC), 2021. https://www.ipcc.ch/report/ar6/wg1/.

23 Regional sea-level trends based on Copernicus Climate Change Service (C3S) altimetry data averaged from 50 km offshore to the coast by the Laboratory of Space Geophysical and Oceanographic Studies (LEGOS)

24 Masson-Delmotte, V.; Zhai, P.; Pirani, A. et al., Eds. *Climate Change 2021: The Physical Science Basis*; Intergovernmental Panel on Climate Change (IPCC), 2021. https://www.ipcc.ch/report/ar6/wg1/.

25 https://wmo.maps.arcgis.com/apps/instant/interactivelegend/index.html?appid=43b371aeb7af4c8b9e9c77a4370a13ed

26 https://www.noaa.gov/news-release/active-2021-atlantic-hurricane-season-officially-ends and https://www.nhc.noaa.gov/data/tcr/index.php?season=2021&basin=atl

27 https://www.nhc.noaa.gov/data/tcr/AL072021_Grace.pdf

28 World Meteorological Organization (WMO). *State of the Global Climate 2021* (WMO-No. 1290). Geneva, 2022.

29 Government of Haiti; United Nations (UN); European Union (EU) et al. Executive Summary. In *Post-Disaster Needs Assessment in Haiti: Earthquake of 14 of August 2021 in the Southern Peninsula*; Government of Haiti, 2021. https://www.ilo.org/wcmsp5/groups/public/---ed_emp/documents/publication/wcms_831127.pdf.

30 https://disasterscharter.org/web/guest/activations/-/article/flood-large-in-haiti-activation-730-

31 http://www.acn.cu/cuba/87641-afectan-intensas-lluvias-al-municipio-de-moa-en-el-este-de-holguin

32 National contribution, Costa Rica

33 National contribution, Mexico

34 Espinoza, J.-C.; Marengo, J. A.; Schongart, J. et al. The New Historical Flood of 2021 in the Amazon River Compared to Major Floods of the 21st Century: Atmospheric Features in the Context of the Intensification of Floods. *Weather and Climate Extremes* **2022**, *35*. https://doi.org/10.1016/j.wace.2021.100406.

35 National contribution, Brazil

36 Espinoza, J.-C.; Marengo, J. A.; Schongart, J. et al. The New Historical Flood of 2021 in the Amazon River Compared to Major Floods of the 21st Century: Atmospheric Features in the Context of the Intensification of Floods. *Weather and Climate Extremes* **2022**, *35*. https://doi.org/10.1016/j.wace.2021.100406.

37 National contribution, France

38 https://caring4others.org/flooding-crisis-in-guyana-june-2021/

39 Schöngart, J.; Junk, W. J. Clima e hidrologia nas várzeas da Amazônia Central. In *Várzeas Amazônicas: Desafios para um Manejo Sustentável*; Junk, W. J.; Piedade, M. T. F.; Wittmann, F. et al., Eds.; Editora INPA: Manaus, pp. 44–65.

40 https://adore.ifrc.org/Download.aspx?FileId=443722

41 National contribution, Argentina

42 National contribution, Chile

43 Institute of Hydrology, Meteorology and Environmental Studies (IDEAM)

44 IDI combines a meteorological-based drought index and remote sensing-based index to assess the drought events. Cunha, A. P. M.; Zeri, M.; Deusdará, L. K. et al. Extreme Drought Events over Brazil from 2011 to 2019. *Atmosphere* **2019**, *10*, 642–649. https://doi.org/10.3390/atmos10110642.

45 https://www.drought.gov/explaining-drought-category-maps

46 In Central America and the Caribbean, drought was characterized using the Standardized Precipitation Index (SPI) calculated from station data (not shown). The SPI data are available from Members' NMHSs. For more information about this index, see: World Meteorological Organization (WMO). *Standardized Precipitation Index: User Guide* (WMO-No. 1090). Geneva, 2012.

47 https://smn.conagua.gob.mx/es/climatologia/monitor-de-sequia/monitor-de-sequia-en-mexico

48 https://www.bbc.com/mundo/noticias-america-latina-57163233

49 Garreaud, R. D.; Clem, K.; Veloso, J. V. The South Pacific Pressure Trend Dipole and the Southern Blob. *J. Clim.* **2021**, *34*, 7661–7676. https://doi.org/10.1175/JCLI-D-20-0886.1.

50 Masson-Delmotte, V.; Zhai, P.; Pirani, A. et al., Eds. *Climate Change 2021: The Physical Science Basis*; Intergovernmental Panel on Climate Change (IPCC), 2021. https://www.ipcc.ch/report/ar6/wg1/.

51 Naumann, G.; Podestá, G.; Marengo, J. et al. *El Episodio de Sequía Extrema de 2019–2021 en la Cuenca del Plata*, EUR 30833 ES, Oficina de Publicaciones de la Unión Europea: Luxemburgo, 2022, doi:10.2760/346183.

52 Getirana, A.; Libonati, R.; Cataldi, M. Brazil Is in Water Crisis — It Needs a Drought Plan. *Nature* **2021**, *600* (7888), 218–220. https://www.nature.com/articles/d41586-021-03625-w.

53 Naumann, G.; Podestá, G.; Marengo, J. et al. *El Episodio de Sequía Extrema de 2019–2021 en la Cuenca del Plata*, EUR 30833 ES, Oficina de Publicaciones de la Unión Europea: Luxemburgo, 2022, doi:10.2760/346183.

54 Marengo, J.A.; Cunha, A. P.; Cuartas, L. A. et al. Extreme Drought in the Brazilian Pantanal in 2019–2020: Characterization, Causes, and Impacts. *Front. Water* **2021**, *3*. 639204. doi: 10.3389/frwa.2021.639204.

55 National contribution, Argentina

56 National contribution, Brazil

57 National contribution, Chile

58 National contribution, Chile

59 Brazil National Institute for Space Research (INPE): https://queimadas.dgi.inpe.br/queimadas/portal-static/estatisticas_paises/

60 National contribution, Peru

61 ALARMES warning system, Laboratory for Environmental Satellite Applications, Universidade Federal do Rio de Janeiro (LASA-UFRJ), https://lasa.ufrj.br/alarmes

62 Libonati, R.; Rodrigues, J. A.; Sena, C. A. P. et al. *Sistema ALARMES – Alerta de área Queimada Pantanal, Situação Final de 2021*, Nota Tecnica 01/2022; Laboratório de Aplicações de Satélites Ambientais – UFRJ: Rio de Janeiro, 2022. https://www.researchgate.net/publication/360023971_Nota_Tecnica_012022_LASA-UFRJ_Queimadas_Pantanal_2021.

63 Menezes, L. S.; de Oliveira, A. M.; Santos, F. L. M. et al. Lightning Patterns in the Pantanal: Untangling Natural and Anthropogenic-induced Wildfires. *Science of the Total Environment* **2022**, *820* (19), 153021. https://www.sciencedirect.com/science/article/abs/pii/S0048969722001103.

64 https://portal.inmet.gov.br/uploads/notastecnicas/LEVANTAMENTO_MASSA-DE-AR-FRIO-FINAL-DE-JULHO_vCGMADP.pdf#page=1&zoom=auto,-100,842

65 National contribution, Argentina

66 Economic Commission for Latin America and the Caribbean (ECLAC). *Special Report COVID-19, No. 13*; ECLAC: 2022. https://www.cepal.org/en/publications/47721-how-finance-sustainable-development-recovery-effects-covid-19-latin-america-and.

67 Food and Agriculture Organization of the United Nations (FAO). *Crops Prospects and Food Situation – Quarterly Global Report No. 1*; FAO: Rome, March 2022. https://www.fao.org/3/cb8893en/cb8893en.pdf.

68 https://www.ipcinfo.org/fileadmin/user_upload/ipcinfo/docs/IPC_Haiti_Acute_Food_Insecurity_2021Sept2022June_Snapshot_English_wholecountry.pdf

69 Food and Agriculture Organization of the United Nations (FAO). *Crops Prospects and Food Situation – Quarterly Global Report No. 1*; FAO: Rome, March 2022. https://www.fao.org/3/cb8893en/cb8893en.pdf.

70 National contribution, Paraguay. See https://www.meteorologia.gov.py/publicaciones/, and more specifically, https://www.meteorologia.gov.py/wp-content/uploads/2021/10/boletin_climatico_2021.pdf.

71 Group on Earth Observations Global Agricultural Monitoring (GEOGLAM). *Crop Monitor for AMIS No. 86*; GEOGLAM: August 2021. https://cropmonitor.org/index.php/cmreports/reports-archive/.

72 Bolsa de Cereales de Buenos Aires. *Cierre de Campaña – Soja 2020/21*; Instituto de Estudios Económicos: 2021. https://www.bolsadecereales.com/download/informes/documento1/165.

73 https://www.fao.org/newsroom/detail/fao-food-price-index-rises-to-record-high-in-february/en

74 Group on Earth Observations Global Agricultural Monitoring (GEOGLAM). *Crop Monitor for AMIS No. 86*; GEOGLAM: August 2021. https://cropmonitor.org/index.php/cmreports/reports-archive/.

75 Pörtner, H-O.; Roberts, D. C.; Adams, H. et al. *Climate Change 2022: Impacts, Adaptation and Vulnerability*; Intergovernmental Panel on Climate Change (IPCC): 2022. https://www.ipcc.ch/report/ar6/wg2/.

76 Masson-Delmotte, V.; Zhai, P.; Pirani, A. et al., Eds. *Climate Change 2021: The Physical Science Basis*; Intergovernmental Panel on Climate Change (IPCC), 2021. https://www.ipcc.ch/report/ar6/wg1/.

77 Naumann, G.; Podestá, G. P.; Marengo, J. A. et al. *El Episodio de Sequía Extrema de 2019–2021 en la Cuenca del Plata*; EUR 30833 ES; Oficina de Publicaciones de la Unión Europea: Luxemburgo, 2022. doi:10.2760/346183. https://www.researchgate.net/publication/358734930_El_episodio_de_sequia_extrema_de_2019-_2021_en_la_Cuenca_del_Plata_Un_informe_conjunto_del_JRC_de_la_Comision_Europea_el_CEMADEN_el_SISSA_y_la_OMM.

78 Masson-Delmotte, V.; Zhai, P.; Pirani, A. et al., Eds. *Climate Change 2021: The Physical Science Basis*; Intergovernmental Panel on Climate Change (IPCC), 2021. https://www.ipcc.ch/report/ar6/wg1/.

79 http://terrabrasilis.dpi.inpe.br/app/dashboard/deforestation/biomes/legal_amazon/increments

80 Masson-Delmotte, V.; Zhai, P.; Pirani, A. et al., Eds. *Climate Change 2021: The Physical Science Basis*; Intergovernmental Panel on Climate Change (IPCC), 2021. https://www.ipcc.ch/report/ar6/wg1/.

81 Bayraktarov, E.; Banaszak, A. T.; Montoya Maya, P. et al. Coral Reef Restoration Efforts in Latin American Countries and Territories. *PLoS ONE* **2020**, *15* (8), e0228477. https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0228477.

82 Pörtner, H-O.; Roberts, D. C.; Adams, H. et al. *Climate Change 2022: Impacts, Adaptation and Vulnerability*; Intergovernmental Panel on Climate Change (IPCC): 2022. https://www.ipcc.ch/report/ar6/wg2/.

83 Pachauri, R. K.; Allen, M. R.; Barros, V. R. et al. *Climate Change 2014: Synthesis Report*; Core Writing Team; Pachauri, R. K.; Meyer, L. A.; Eds. Intergovernmental Panel on Climate Change (IPCC): Geneva, 2014. https://www.ipcc.ch/report/ar5/syr/.

84 United Nations Office for the Coordination of Humanitarian Affairs (OCHA). Latin America & the Caribbean – Monthly Situation Snapshot – As of 6 July 2021; OCHA: 2021. https://reliefweb.int/report/antigua-and-barbuda/latin-america-caribbean-monthly-situation-snapshot-6-july-2021.

85 https://es.euronews.com/2021/08/28/huracan-ida-impacta-en-cuba-dejando-intensas-lluvias-a-su-paso-y-miles-de-evacuados

86 https://www.nhc.noaa.gov/data/tcr/AL062021_Fred.pdf

87 https://www.nhc.noaa.gov/data/tcr/AL072021_Grace.pdf

88 https://environmentalmigration.iom.int/events/migration-and-climate-change-central-american-region

89 https://reliefweb.int/report/brazil/latin-america-caribbean-weekly-situation-update-27-december-2021-2-january-2022-3.

90 https://unfccc.int/NDCREG

91 https://www.cepal.org/en/topics/covid-19

92 www.idam.am.gov.br. See also https://www.ft.com/content/b799ebe8-5eec-4185-ac92-ce9593d4ad12.

93 https://reliefweb.int/disaster/fl-2021-000204-bra

94 United Nations Children's Fund (UNICEF). *Brazil Country Office – Bahia Humanitarian Flash Note No. 1, 07 January 2022*; UNICEF: 2022. https://www.unicef.org/media/114251/file/Brazil%20Flash%20Situation%20Report,%2008%20January%202022.pdf.

95 International Charter Space and Major Disasters. *Flooding in Brazil*; 30 December 2021, https://disasterscharter.org/web/guest/activations/-/article/flood-large-in-brazil-activation-742-;.

96 Companhia Nacional de Abastecimento (CONAB), www.conab.gov.br

97 https://wedocs.unep.org/bitstream/handle/20.500.11822/37016/SargPM.pdf?sequence%E2%80%A6

98 United Nations Environment Programme (UNEP) - Caribbean Environment Programme. *Sargassum White Paper – Turning the Crisis into an Opportunity. Ninth Meeting of the Scientific and Technical Advisory Committee (STAC) to the Protocol Concerning Specially Protected Areas and Wildlife (SPAW) in the Wider Caribbean Region*; UNEP-CEP: Jamaica, 2021. https://www.unep.org/cep/resources/publication/sargassum-white-paper-turning-crisis-opportunity.

99 United Nations Environment Programme (UNEP) - Caribbean Environment Programme (CEP). *Sargassum White Paper – Turning the Crisis into an Opportunity. Ninth Meeting of the Scientific and Technical Advisory Committee (STAC) to the Protocol Concerning Specially Protected Areas and Wildlife (SPAW) in the Wider Caribbean Region*; UNEP-CEP: Jamaica, 2021. https://www.unep.org/cep/resources/publication/sargassum-white-paper-turning-crisis-opportunity.

100 United Nations Environment Programme (UNEP). *Sargassum: Brown Tide or Golden Jewel?*; UNEP: 2021. https://wedocs.unep.org/bitstream/handle/20.500.11822/36315/FB024.pdf.

101 Masson-Delmotte, V.; Zhai, P.; Pirani, A. et al., Eds. *Climate Change 2021: The Physical Science Basis*; Intergovernmental Panel on Climate Change (IPCC), 2021. https://www.ipcc.ch/report/ar6/wg1/.

102 Pörtner, H-O.; Roberts, D. C.; Adams, H. et al. *Climate Change 2022: Impacts, Adaptation and Vulnerability*; Intergovernmental Panel on Climate Change (IPCC): 2022. https://www.ipcc.ch/report/ar6/wg2/.

103 United Nations Office for Disaster Risk Reduction (UNDRR). *Regional Assessment Report of Disaster Risk in Latin America and the Caribbean: Challenges in Disaster Risk Reduction and Progress Towards the Sendai Framework for Disaster Risk Reduction (2015–2030)* Targets; UNDRR, 2021. https://www.undrr.org/publication/undrr-roamc-regional-assessment-report-disaster-risk-latin-america-and-caribbean-rar. See also the International Disaster Database (EM-DAT), https://public.emdat.be/.

104 United Nations Office for Disaster Risk Reduction (UNDRR). *GAR Special Report on Drought 2021*; UNDRR: Geneva, 2021. https://www.undrr.org/media/49386/download.

105 Pörtner, H-O.; Roberts, D. C.; Adams, H. et al. *Climate Change 2022: Impacts, Adaptation and Vulnerability*; Intergovernmental Panel on Climate Change (IPCC): 2022. https://www.ipcc.ch/report/ar6/wg2/.

106 United Nations Children's Fund (UNICEF). *Brazil Country Office – Bahia Humanitarian Flash Note No. 1, 07 January 2022*; UNICEF: 2022. https://www.unicef.org/media/114251/file/Brazil%20Flash%20Situation%20Report,%2008%20January%202022.pdf.

107 Belize Updated NDC, https://unfccc.int/NDCREG

108 Pörtner, H-O.; Roberts, D. C.; Adams, H. et al. *Climate Change 2022: Impacts, Adaptation and Vulnerability*; Intergovernmental Panel on Climate Change (IPCC): 2022. https://www.ipcc.ch/report/ar6/wg2/.

109 Masson-Delmotte, V.; Zhai, P.; Pirani, A. et al., Eds. *Climate Change 2021: The Physical Science Basis*; Intergovernmental Panel on Climate Change (IPCC), 2021. https://www.ipcc.ch/report/ar6/wg1/.

110 Based on 23 Members from the LAC region that provided climate services data in 2021

111 De San Pablo, M. *CREWS Commits Additional Funding to Strengthen Early Warning Systems in the Caribbean*; UNDRR: 24 February 2022. https://www.undrr.org/news/crews-commits-additional-funding-strengthen-early-warning-systems-caribbean.

112 World Meteorological Organization (WMO). *2020 State of Climate Services: Risk Information and Early Warning Systems* (WMO-No. 1252). Geneva, 2020.

113 World Meteorological Organization (WMO). *2021 State of Climate Services: Water* (WMO-No. 1278). Geneva, 2021.

114 World Meteorological Organization (WMO). *2021 State of Climate Services: Water* (WMO-No. 1278). Geneva, 2021.

115 https://gcos.wmo.int/en/essential-climate-variables/

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