A Look at 2021

Takeaway Points from the State of the Climate

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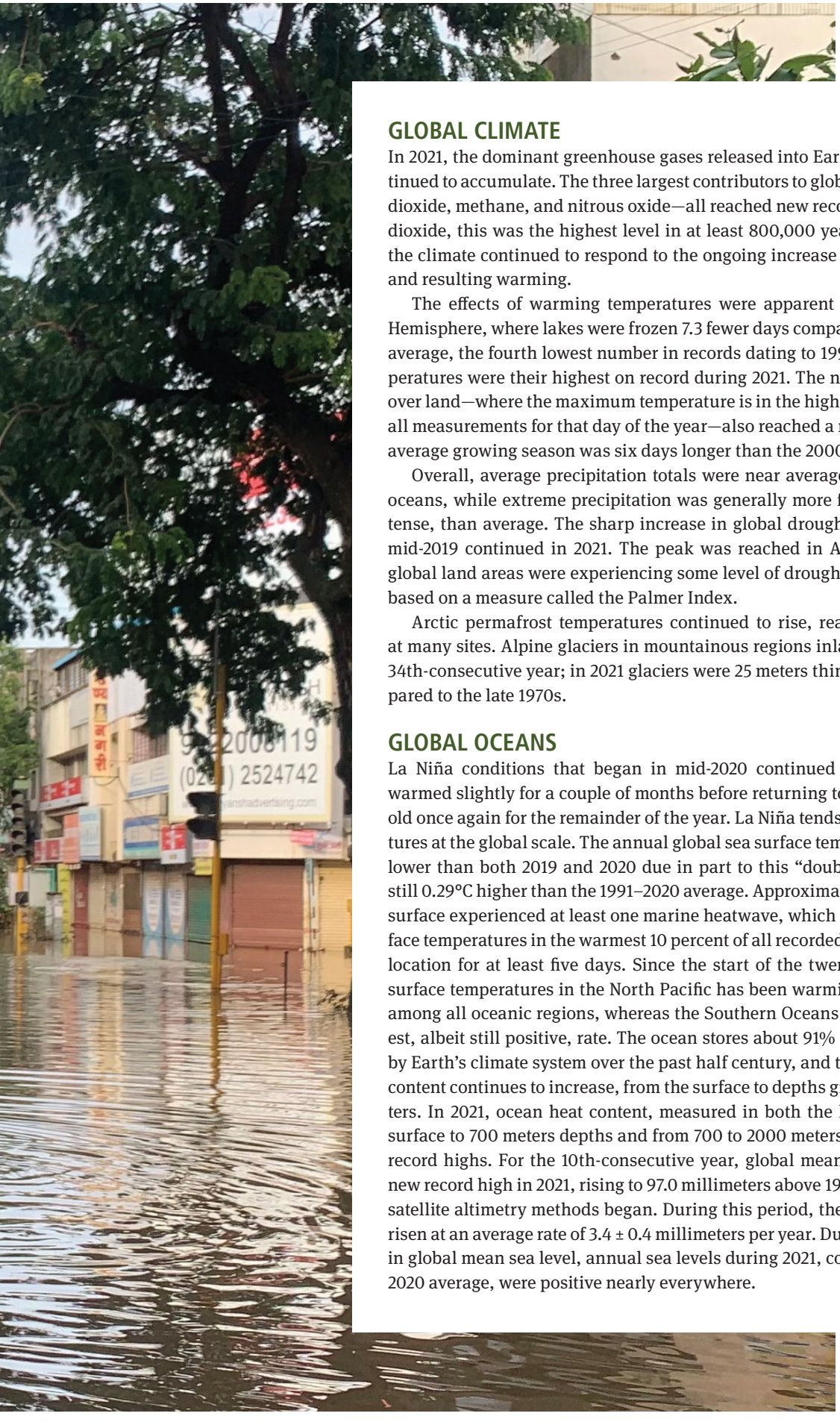
July 2021, the market area in Kolhapur, Maharashtra, India flooded by the Panchganga River. Maharashtra was affected by a series of extreme rainfall events in 2021.
(Image: Sayali Pashte, iStock)



GLOBAL CLIMATE

In 2021, the dominant greenhouse gases released into Earth's atmosphere continued to accumulate. The three largest contributors to global warming—carbon dioxide, methane, and nitrous oxide—all reached new record highs. For carbon dioxide, this was the highest level in at least 800,000 years. During the year, the climate continued to respond to the ongoing increase in greenhouse gases and resulting warming.

The effects of warming temperatures were apparent across the Northern Hemisphere, where lakes were frozen 7.3 fewer days compared to the 1991–2020 average, the fourth lowest number in records dating to 1991. Lake surface temperatures were their highest on record during 2021. The number of warm days over land—where the maximum temperature is in the highest 10 percent among all measurements for that day of the year—also reached a new record high. The average growing season was six days longer than the 2000–20 base period.

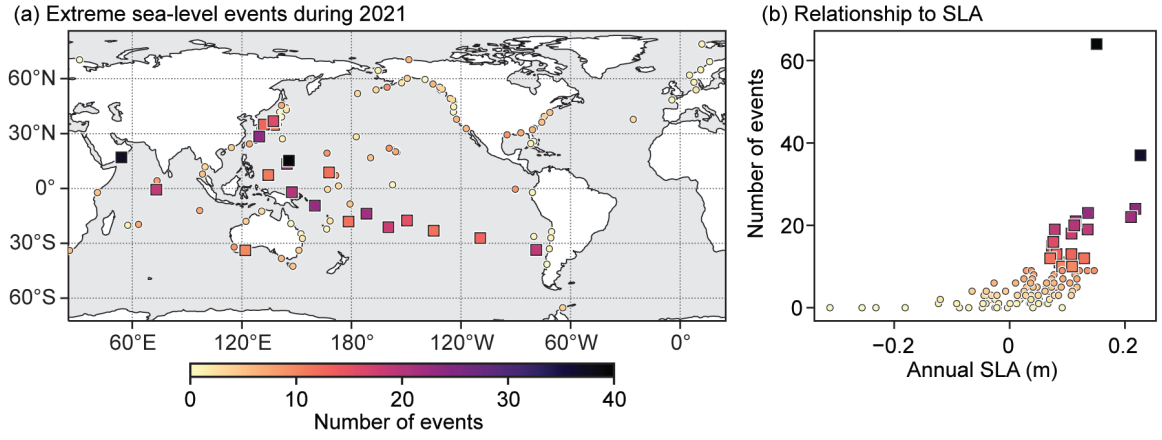
Overall, average precipitation totals were near average over land and over oceans, while extreme precipitation was generally more frequent, but less intense, than average. The sharp increase in global drought area that began in mid-2019 continued in 2021. The peak was reached in August, when 32% of global land areas were experiencing some level of drought, a new record high, based on a measure called the Palmer Index.

Arctic permafrost temperatures continued to rise, reaching record values at many sites. Alpine glaciers in mountainous regions inland lost mass for the 34th-consecutive year; in 2021 glaciers were 25 meters thinner on average compared to the late 1970s.

GLOBAL OCEANS

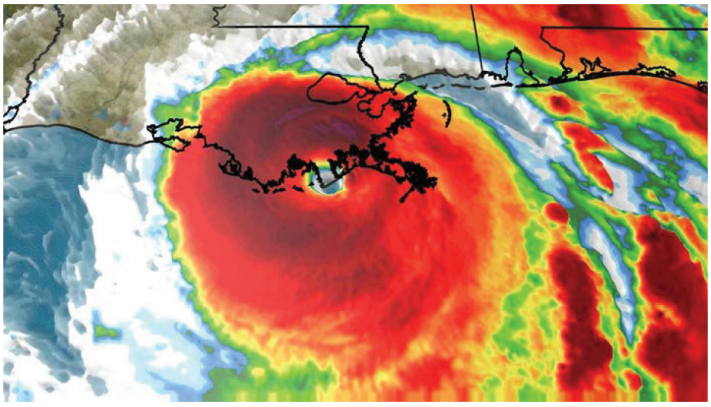
La Niña conditions that began in mid-2020 continued into mid-2021, then warmed slightly for a couple of months before returning to the La Niña threshold once again for the remainder of the year. La Niña tends to dampen temperatures at the global scale. The annual global sea surface temperature in 2021 was lower than both 2019 and 2020 due in part to this "double-dip" La Niña, but still 0.29°C higher than the 1991–2020 average. Approximately 57% of the ocean surface experienced at least one marine heatwave, which is defined as sea surface temperatures in the warmest 10 percent of all recorded data for a particular location for at least five days. Since the start of the twenty-first century, sea surface temperatures in the North Pacific has been warming at the fastest rate among all oceanic regions, whereas the Southern Oceans warmed at the slowest, albeit still positive, rate. The ocean stores about 91% of the energy gained by Earth's climate system over the past half century, and the global ocean heat content continues to increase, from the surface to depths greater than 4000 meters. In 2021, ocean heat content, measured in both the layers of the ocean's surface to 700 meters depths and from 700 to 2000 meters depth, reached new record highs. For the 10th-consecutive year, global mean sea level reached a new record high in 2021, rising to 97.0 millimeters above 1993, the year in which satellite altimetry methods began. During this period, the global sea level has risen at an average rate of 3.4 ± 0.4 millimeters per year. Due to long-term trends in global mean sea level, annual sea levels during 2021, compared to the 1993–2020 average, were positive nearly everywhere.

Extreme sea levels events across the South Pacific



The map on the left shows the number of extreme sea level events measured at 114 tide gauges during 2021. The graph on the right shows the relationship between the number of extreme events at each location and the annual sea level departure from average from that location. Twenty of the 114 locations experienced more than 10 extreme sea level events during 2021 (represented by squares), and were especially concentrated in the tropical western Pacific and in a diagonal region of the South Pacific near where annual sea levels were the highest compared to their long-term averages. Extreme sea level is defined as a daily sea level measurement in its highest 1% compared with all measurements for that particular location. Over time, the median number of extreme sea level events per year and location increased from one during 1993–97 to four during 2017–21. (Figs. 3.17a,b in State of the Climate in 2021; see discussion in section 3f.)

Hurricane Ida becomes second Category 4 storm to impact Louisiana in two years



Category 4 Major Hurricane Ida was the most impactful storm in the Atlantic basin in 2021. Ida struck the U.S. coast near Port Fourchon, Louisiana, with maximum 1-minute sustained winds of 130 kt on 29 August, causing tremendous destruction in south-central and southeastern Louisiana. This intensity at landfall ties the Last Island Hurricane (1856) and Hurricane Laura (2020) for the strongest maximum sustained winds for a Louisiana landfalling hurricane on record. Ida's landfall pressure of 931 hPa was the second lowest for a Louisiana hurricane on record, trailing only Katrina (920 hPa), which struck on the same date 16 years prior to Ida. After moving further inland and becoming extra-tropical, Ida's remnants interacted with a frontal system to cause significant flash flooding across the coastal plains of Pennsylvania, New Jersey, New York, and Connecticut. At $75 billion (U.S. dollars) in damage, Ida was the costliest U.S. disaster of 2021 and the fifth most expensive hurricane on record (since 1980). (Fig. SB4.1 in State of the Climate in 2021; see discussion in Sidebar 4.1.)

THE TROPICS

Weak-to-moderate La Niña conditions—average sea surface temperatures 0.5 to 1.0°C below the 1991–2020 average—were present in the central and eastern equatorial Pacific Ocean during most of 2021, a climate phenomenon that began in August 2020. In July, a negative Indian Ocean dipole event became established, with above-average temperatures in the east Indian Ocean and below-average temperatures in the west. This was the first negative event since 2016. La Niña impacts climate patterns around the globe, while the phase of Indian Ocean dipole primarily affects the weather of the surrounding continents in the Southern Hemisphere.

In total, 97 named tropical cyclones were observed during the combined Northern Hemisphere and Southern Hemisphere storm seasons. This number was well above the 1991–2020 average of 87 but also well below the record 104 named storms of 1992. Seven tropical cyclones across the globe reached Saffir–Simpson Hurricane Wind Scale Category 5 intensity level—four in the western North Pacific and one each in the South Indian Ocean (Faraji), Australian region (Niran), and the Southwest Pacific (Yasa). Super Typhoon Rai was the third costliest typhoon in the history of the Philippines, causing about $1 billion

(U.S. dollars) in damages and more than 400 deaths. The North Atlantic hurricane basin recorded 21 named storms, the third most for the basin, behind the record 30 cyclones in 2020 and 28 in 2005. Seven of those storms became hurricanes, which is on par with the 1991–2020 average of 7.2.

THE ARCTIC

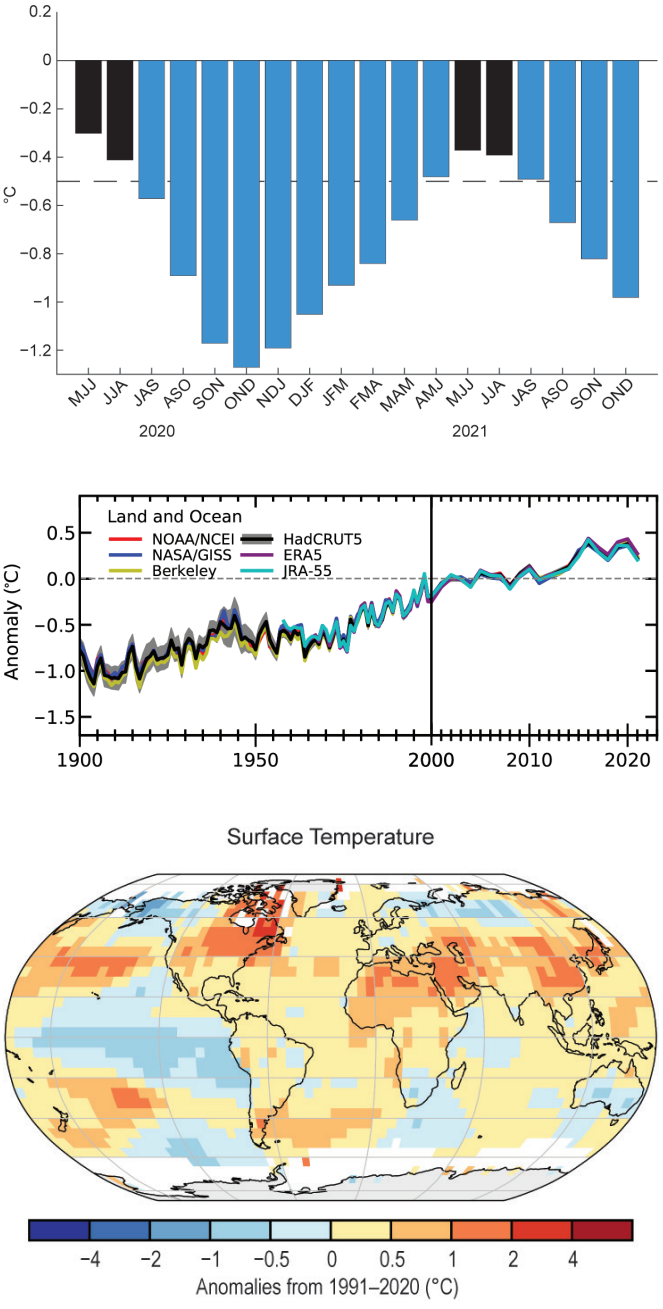
The Arctic had its coolest year since 2013, but 2021 was still the 13th-warmest year in the 122-year record. Extreme heat events occurred during the summer. Related to the heat waves in western North America, a temperature of 39.9°C was recorded at Fort Smith, Northwest Territories, Canada, on 30 June; this was the highest temperature ever recorded north of 60°N. A widespread melt event on the Greenland Ice Sheet on 14 August—the latest on record—coincided with the first observed rainfall in the 33-year record at the Summit Station, which sits at more than 3200 meters above sea level.

The Arctic minimum sea ice extent—the area of ice measured during the peak of the melt season—was the 12th-smallest extent in the 43-year record. The amount of multiyear ice—that is, ice that survives one or more summer melt seasons—remaining in the Arctic at this time was the second lowest on record. This indicates the Arctic's sustained transition to a younger, thinner ice cover, which is more likely to fully melt in the future. The oldest ice, more than four years old, has declined by 94% since the start of the record. While the rate of decline in minimum sea ice extent over the 2010–21 period has slowed compared to previous decades, Arctic sea ice volume continues to rapidly shrink. In 2021, the East Greenland Sea was nearly ice-free during much of the summer.

ANTARCTICA AND THE SOUTHERN OCEAN

The 2021 Antarctic ozone hole was larger than average, but it was smaller than ozone holes in the late 1990s and 2000s when the levels of ozone depleting substances were near their maximum. The smaller size indicates that ozone recovery due decreasing ozone depleting substances continues. Even so, the Antarctic ozone hole in 2021 did not close until 23 December; this was the second longest period of time on record that it remained, shorter only than 2020. A strong and stable polar vortex—a low pressure system with very cold polar air above the region—contributed to this long-lived ozone hole. The cold air within the polar vortex also contributed to the coldest winter (from April through September) on record at the South Pole. It was a different story on the Antarctic Peninsula. Two stations in that region received persistent warm northerly winds that contributed to their warmest (tied) and second-warmest years on record.

Despite La Niña during most of 2021, the global annual surface temperature was among the six highest on record



In the eastern tropical Pacific Ocean, sea surface temperatures reached the La Niña threshold (at least 0.5°C below the 1991–2020 average) during the July–September (JAS) period in 2020 and continued to remain in this phase throughout most of 2021. Typically, La Niña tends to dampen global surface temperatures, but even in this phase, the annually averaged temperature across land and ocean surfaces in 2021 was still among the six highest in records dating as far back as the mid-1800s. (Figs. 4.1, 2.1a, and Plate 2.1a in State of the Climate in 2021; see discussion in sections 4.1 and 2b1, respectively.)

Melting sea ice and warming Arctic waters are leading to more ship activity, along with more pollution and debris

Changes in sea ice seasonality and warming ocean ecosystems allow for expanded Arctic maritime activity, increasing pollution in the region. The remote coastal communities of this region are ethnically diverse and reliant on the non-commercial acquisition of marine resources for their nutritional, cultural, and economic well-being. During the summer of 2020, the Bering Strait region of Alaska—the only marine corridor from the Pacific to the Arctic Ocean—experienced a novel marine debris event, unusual in terms of the amount and the types of garbage observed. This event was not due to foreign debris of commercial fishing equipment, but rather the widespread everyday garbage, including plastics, food items, and hazardous materials. The items found were not weathered, meaning they had recently entered the water. (Fig. SB5.1 in State of the Climate in 2021; see discussion in Sidebar 5.1.)

The continent as a whole continued to lose ice mass. On balance, 50 billion metric tons of mass was lost from December 2020 to December 2021; however, the loss in 2021 was far less than the average rate of annual mass loss of 140 billion metric ton per year since 2003. Still, for perspective, this is equivalent to the amount of water in 20 million Olympic size swimming pools, and spread across the world's ocean, this is equal to approximately 0.14 mm of global sea level rise.

In the ocean waters surrounding Antarctica, the size of the extent of sea ice varied dramatically compared to average throughout 2021, similar to previous years. The year began with below-average extent before abruptly shifting to above normal at the end of February. The extent of measured sea ice remained above average through September, but by December a new record low for the month was set.

REGIONAL CLIMATES

North America. Canada, the contiguous United States, and Mexico each observed their fourth-warmest year on record. For Mexico, its four warmest years have all occurred since 2017. Even with the overall warmth, including the record-breaking summer heatwave in western North America, a major cold snap in February affected eastern Canada, the southeastern United States, and northern Mexico. February temperatures from –35°C to –50°C were reported in parts of the Canadian Arctic and Prairies; these extreme low temperatures broke minimum temperature records that dated back more than 50 years. The prolonged Arctic air also caused widespread power outages for nearly 10 million people in Texas, as well as other southern U.S. states and northern Mexico.

Drought conditions prevailed across much of the West and northern Plains of the United States throughout the year. Excessive spring and summer dryness, combined with record heat in June and July, rapidly intensified drought in the Pacific Northwest. Extreme and exceptional drought—the two worst categories—covered about 26.8% of the contiguous United States on 17 August and marked the largest extent of these drought intensities since the start of the U.S. Drought Monitor in 2000. The widespread and long-lasting dry period across western Canada from June to August 2021 broke many records, with some areas facing their driest

summer since the start of the record in 1948. From 16 June to 6 August, Vancouver Airport recorded 53 consecutive days without a measurable rainfall event (0.2 mm or more)—the longest interval without rainfall in 35 years.

Central America and the Caribbean. In Central America, stations in Panama and Costa Rica had below-average temperatures for the year, while stations in Honduras and Guatemala reported above-average temperatures. The Caribbean reported its fifth warmest year since the start of the record in 1891. Annual temperatures have been increasing at an average rate of 0.22°C per decade over the past half century. Over the same time period, the annual rainfall total has been decreasing at an overall rate of 1.1 mm per decade, although there can be large differences from year to year.

Hurricane Elsa impacted St. Lucia, Barbados, St. Vincent and the Grenadines, Haiti, and Jamaica during 2–6 July. In St. Lucia, strong winds damaged buildings and telecommunications along with water infrastructure. Agriculture and fisheries were also impacted. Elsa was the first hurricane to impact Barbados in 66 years, since Hurricane Janet. Hurricane Grace impacted Haiti on 16–17 August, causing flooding in more than 600 houses. Grace also impacted Jamaica on 17–18 August as a tropical storm. Initial damage estimates were $1.1 million (U.S. dollars). Jamaica and Cuba were impacted by Tropical Storm Ida on 26–28 August. While no tropical storms affected Central America in 2021, there were still 59 fatalities reported due to hydro-meteorological events, such as floods and landslides, and 19 deaths by lightning strikes during the rainy season.

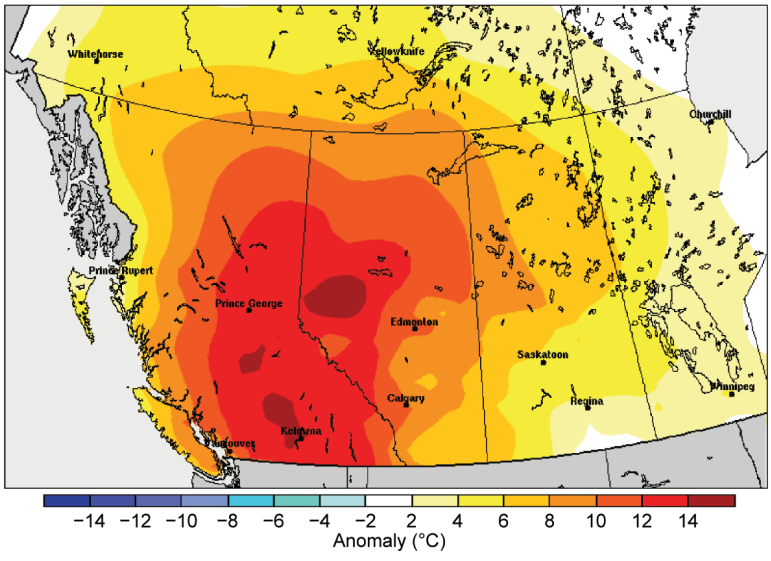
South America. The 2021 mean temperature was the sixth highest on record for northern South America and seventh highest for central South America. Parts of central and southern Brazil were record warm for the year. Southern South America, Argentina, and Chile each reported their fifth warmest year on record. Even so, significant cold waves affected central South America during June and July; some locations reported minimum temperatures that were up to 29°C below average. In Argentina, a new national record for minimum temperature was set in Presidencia Roque Saénz Peña with –7.4°C on 29 July, its lowest since 1961.

Drought spanned parts of central South America, including regions of the Amazon, during the austral summer and autumn. The Paraguay River shrank to its lowest levels in half a century. In central Chile, a "mega-drought" continued for the 12th consecutive year, becoming the longest drought in the historical record in the region. It was the fifth driest year in the 108-year record for Santiago, the capital of Chile, with a population of 5.6 million residents.

Following months of above-average rain, the Rio Negro River at Manaus (central Brazilian Amazon) rose and remained above its emergency threshold for a total of 91 days, reaching its highest level of 30.02 meters in more than 100 years of recordkeeping on 16 June. The overflow of the river caused damaging floods that surpassed the "once-in-a-century" Amazon flood in 2012. By the end of June, the flood in the Brazilian Amazonia caused economic losses of $40 million (U.S. dollars) and affected more than 450,000 people.

Africa. In 2021, temperatures over much of Africa were

Intense heat dome parks itself over northwestern North America in summer 2021



In the final week of June and first week of July 2021, a high-pressure ridge built over western North America, stretching from California to the Arctic Circle. A new Canadian maximum temperature record of 49.6°C was set at Lytton, British Columbia, on 29 June, breaking the previous national record by over 4°C and was higher than any temperature ever reached in Europe or South America. In the United States (not shown here), Furnace Creek in Death Valley, California, reached 54.4°C on 9 July—equaling the temperature measured at that location in 2020, which was the hottest temperature measured on Earth since 1931. Overall, thousands of temperature records were broken and the heat, combined with dry conditions, sparked massive wildfires. Hundreds of people in Canada and the United States lost their lives, and millions more were impacted. (Fig. SB7.1 in State of the Climate in 2020; see discussion there in section 7b and Sidebar 7.1.)

Extreme wet and dry areas across Central America and the Caribbean during May–June 2021

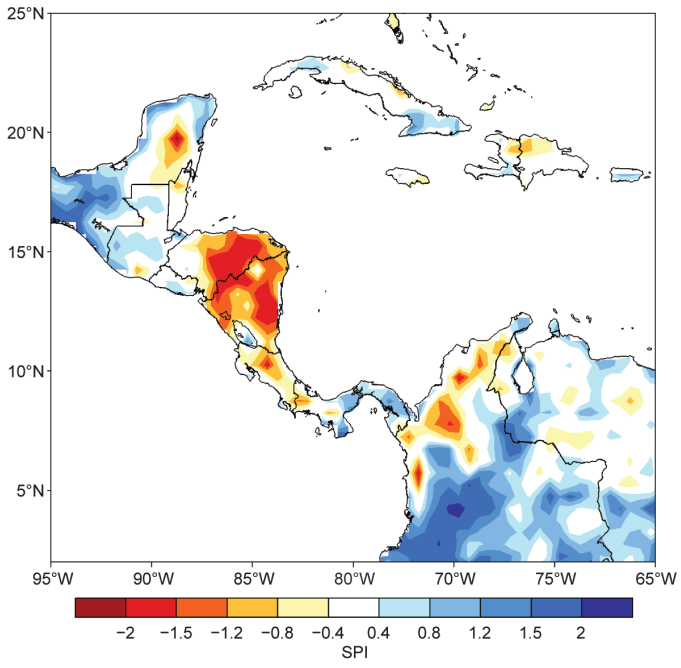


Fig. SB7.3. Both extreme dry (red) and wet (blue) conditions occurred over Central America during the two months of May and June 2021, as shown by the Standard Precipitation Index (SPI), which is an index to characterize meteorological drought or wetness. Rainfall deficits of more than 100 mm in Nicaragua and Honduras contributed to reduced soil moisture that degraded vegetation health and impacted Primera season cropping activities. Elsewhere, severe weather during 21–24 May brought flash floods, landslides, coastal flooding, and high winds to several regions in Guatemala, affecting more than 10,000 people. In mid-June, flash floods caused three fatalities when the Quibá River overflowed in Sololá. (Figs. SB7.3 in State of the Climate in 2021; see discussion in Sidebar 7.2)

above normal. In July, temperatures exceeding 40°C were reported from several areas of Morocco, with more than 60% of stations reporting heat waves. A temperature of 49.6°C was reported from Sidi-Slimane station in Morocco on 10 July, equaling the highest temperature on record for the country. In Southern Africa, annual temperatures were up to 2°C below average over southern Angola, Namibia, and northwestern Botswana, ranking 2021 among the top 5% of the coldest years on record in these areas.

In the Sahel, rainfall totals during July–September generally account for much of the annual cumulative rainfall; totals during this period were above average in 2021 for the third consecutive year. In parts of equatorial East Africa, the annual total rainfall was the lowest on record, leading to three consecutive failed rainy seasons that resulted in one of the worst threats to food security in 35 years for more than 20 million people in the region. And the 2020/21 below-average rainfall season over southern and southwestern Madagascar prolonged an unprecedented six-year drought, resulting in widespread food insecurity and malnutrition for over 1.1 million people over the Grand Sud in Madagascar.

Tropical Storm Chalane made landfall over eastern Madagascar near the end of December 2020, while Tropical Cyclone Eloise made landfall as a tropical storm over Antalaha in northeastern Madagascar in mid-January. After crossing Madagascar, Eloise made landfall over central Mozambique four days later. More than 30 fatalities were reported from these storms.

Europe and the Middle East. Europe as a whole reported an annual temperature 0.2°C higher than the 1991–2020 average; nationally, Armenia reported its third warmest year on record, Türkiye (Turkey) its fourth-warmest year, and West Kazakhstan its fifth warmest. Winter temperatures were above average across most of the region. It was so warm in Sweden that Lake Erken had 61 days less ice cover compared to its 1991–2020 normal. However, there were some cold air outbreaks; in Spain, a new all-time national minimum temperature record of –34.1°C was set on 6 January at Clot del Tuc de la Llança in the Pyrenees. Following a cool spring in most areas, Europe reported its second-hottest summer on record. Only the summer of 2010 was warmer. A provisional new European maximum temperature record of 48.8°C was set in Sicily on 11 August. During 18–19 November, Denmark observed a nighttime minimum temperature of 10°C, the highest night temperature ever recorded in the country that late in the year.

Most of the Middle East, from Türkiye to Pakistan, saw an intensification of drought conditions. In the South Caucasus, June was exceptionally dry in Armenia with average precipitation total only 27% of normal, and severe droughts were observed in the last week of the month.

In mid-July, a strong storm brought heavy rainfall to Central Europe, which led to extreme flooding, particularly in western Germany where several towns were completely flooded. Water levels in rivers far exceeded historical records, 7 to 8 meters above normal in some places. In Germany, 179 people were killed, marking one of the deadliest weather events on record for the country. On 4 October, a new European 12-hour rainfall record was set in Rossiglione (northwest Italy), with a total of 740.6 mm, which was more than half of its annual average of 1270 mm.

Asia. China and Hong Kong reported their warmest years since the start of records in 1951 and 1884, respectively, and South Korea and Mongolia observed their second warmest

since their records began in 1973. For Hong Kong, 61 hot nights—daily minimum temperatures at least 28.0°C—and 54 very hot days—daily maximum temperature at least 33.0°C—were reported, both of which were the highest annual totals on record. India reported its fifth-warmest year in its 121-year record. Seasonally, Russia observed a winter among its coldest 30% since the start of the record in 1936, which was later followed by its hottest summer on record. In Kyoto, Japan, full bloom dates for a native cherry tree species, *Prunus jamasakura*, were the earliest in the entire record, which began in AD 801, breaking the previous earliest date set in the year 1409.

Hong Kong was exceptionally dry during the first five months of 2021, its second driest such period on record. Iran reported its driest year since 1991. Drought intensified and expanded along a large stretch of northeastern Siberia and the Far East region of Russia, which led to unprecedented wildfires. In Afghanistan, large rainfall deficits occurred during spring and autumn. Wheat harvest was estimated to be about 20% less compared to the previous year, and the U.S. Agency for International Development projected that more than half of the country's population would be food insecure by winter 2021.

Tropical Cyclone Seroja brought heavy rain to Indonesia in April, with daily rainfall totals of more than 200 mm recorded in places. Extremely Severe Cyclonic Storm Tauktae claimed 144 lives, mainly in western India. In May, Severe Cyclonic Storm Yaas crossed the north Odisha coast and caused nine fatalities. Over 1.3 million people were affected by floods from the storm. Cyclonic Storm Gulab crossed the north Andhra Pradesh/south Odisha coasts on 26 September, claiming 19 lives. In December, Typhoon Rai passed over Song Tu Tay station in Vietnam; the wind speed of 88.6 kt was the highest observed in the Vietnam observation system in the last 40 years.

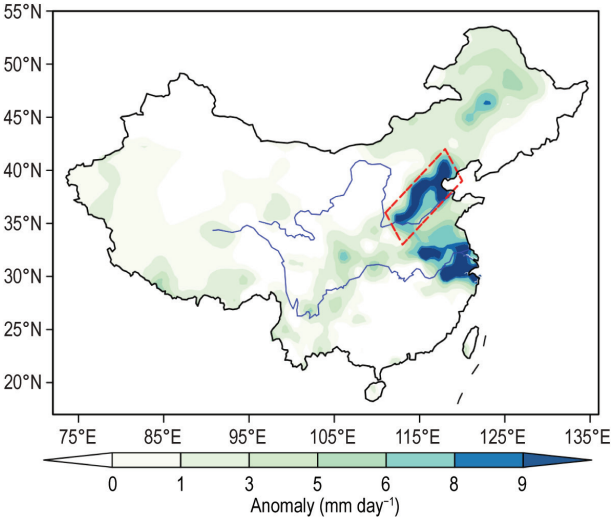
Oceania. La Niña typically leads to stark regional differences across the Oceania region. This was indeed the case in 2021 with La Niña present most of the year, with drier conditions for some southwest Pacific islands near the equator in the central and eastern part of the region and wetter conditions for eastern Australia. The Micronesia region had a quiet year for typhoon activity, also typical of a La Niña influence. And while La Niña conditions contributed to Australia's coldest year since 2012, New Zealand reported its warmest year on record. Higher-than-normal air pressure and winds from the northwest contributed to the record warmth. On top of these patterns, which can shift over weeks or months, New Zealand is experiencing overall increasing temperatures at a rate of 1.07 ±0.24°C per century.

Another factor that influences weather in the region—the Indian Ocean dipole, which measures the difference between ocean surface water temperatures in the eastern and western Indian Ocean—also contributed to above-average austral winter and spring rainfall over parts of southern Australia, as it entered its negative phase for the first time since 2016.

In early March, Cyclone Niran—the second Category 5 storm of the 2020/21 South Pacific cyclone season—caused damage to Australia and New Caledonia estimated at greater than $200 million (U.S. dollars). Severe Tropical Cyclone Seroja brought heavy rains and damaging winds to areas around Kalbarri and Geraldton in Western Australia during April. This was the farthest south a tropical cyclone has crossed the Western Australian coast since the 1950s.

In Micronesia, abundant rainfall over the island of Kapingamarangi late in 2021 helped the island recover from the effects of long-term drought earlier in the year. On Guam, a large deficit of rainfall, during a very dry period from January to September, was completely erased with record rainfall during October.

Unprecedented extreme rainfalls over East Asia in July and August 2021



In China, the Meiyu/Baiu/Changma rainy season was eight days shorter than the 1991–2020 average. However, the rainy season in North China (shown by the red box) lasted 59 days, the second longest since the start of the record in 1961, with average total rainfall 203% of normal, the third highest on record. On 20 July, a 1-hour precipitation total of 201.9 mm was recorded in Zhengzhou—capital of Henan province in central China and home to more than 10 million people—the highest hourly precipitation on record for mainland China. The disastrous rainstorms inundated the city, leading to 380 fatalities or missing people. Typhoon In-fa brought heavy rain to the Yangtze River Delta, as shown by the dark blue shading to the southeast of North China. (Fig. SB7.6 in State of the Climate in 2021; see discussion in section 7g.)