2023 was Earth's hottest year on record

It was the warmest year on record for 29% of the global population, 77 countries, and 3 continents; 21 nations or territories set an all-time extreme heat record.

The world broke the record set in 2016 for the warmest year on record in 2023 by a large margin: 1.18 degrees Celsius (2.12°F) above the 20th-century average, NOAA reported Jan. 12. NASA, the European Copernicus Climate Change Service, Berkeley Earth, the UKMET Office, and the Japan Meteorological Agency also rated 2023 as the warmest on record.

Compared to temperatures in the preindustrial era of the late 1800s, last year's global average temperature as computed by the first five of these groups was between 1.34 degrees Celsius and 1.54 degrees Celsius warmer. (These differences arise largely from using different baseline years for pre-industrial climate, such as 1850 versus 1880, and from slight differences in how researchers

account for data-sparse areas such as the Arctic, especially prior to 1900.)

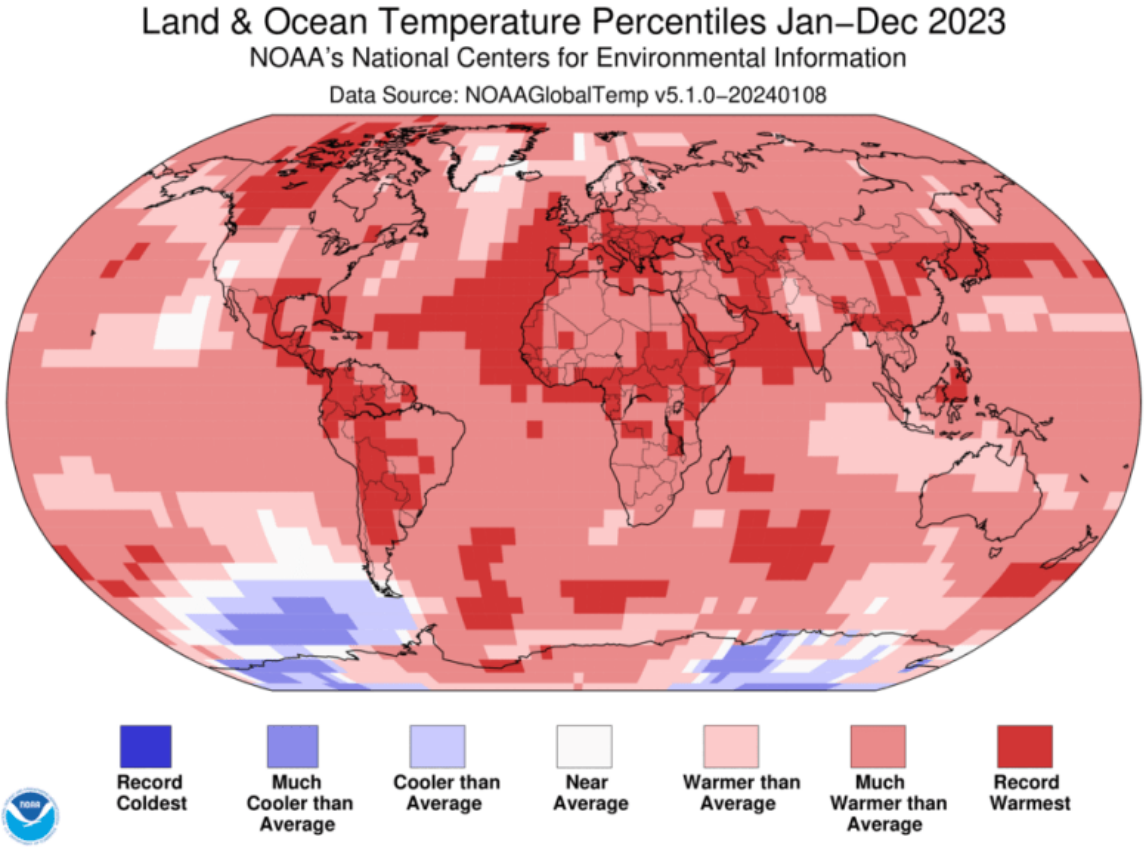

Figure 1. Departure of temperature from average for 2023. North America, South America, and Africa all had their warmest year on record. Asia and Europe had their second-warmest year on record, while Oceania had its 10th-warmest year on record. No regions experienced record cold. (Image credit:
NOAA)

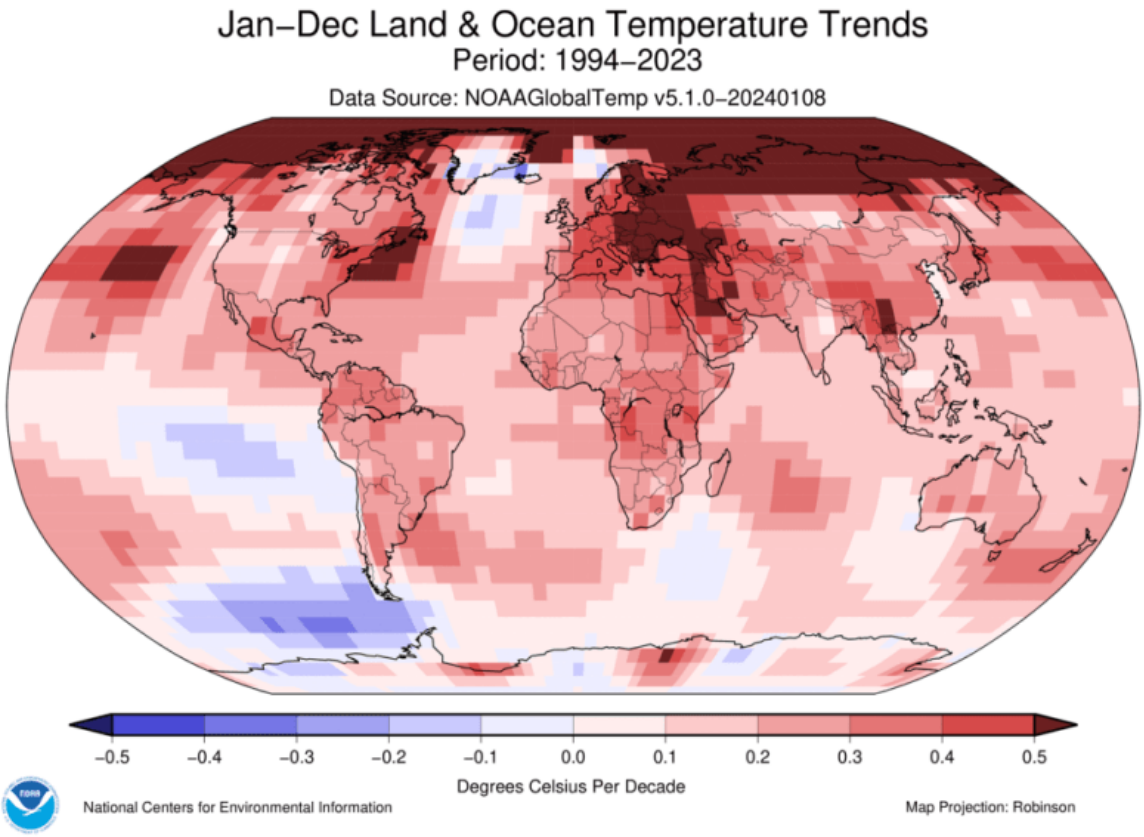

Figure 2. Change in average yearly temperature from 1994 to 2023. The regions with the strongest warming have been the Arctic, Eastern Europe, the Middle East, and the waters off the Northeast and Western U.S. coasts. (Image credit: NOAA)

According to NOAA, the 10 warmest years on record since 1880 were the most recent 10 years — 2014 through 2023. This year vaulted to the top largely on the strength of an extraordinary burst of record warmth in the second half of the year (see embedded post from the European Commission below). The previous warmest year on record was 2016.

Global ocean temperatures and land temperatures in 2023 were both the warmest on record, said NOAA. According to Berkeley Earth, 2023 was the first year the global average land temperature was more than 2 degrees Celsius above pre-industrial levels, and it was also the first year that global average ocean surface

temperatures were more than 1 degree Celsius above pre-industrial levels.

Global satellite-measured temperatures in 2023 for the lowest eight kilometers of the atmosphere were the warmest in the 45-year satellite record by a large margin, according to the University of Alabama Huntsville. The previous record was set in 2016. According to Berkeley Earth, 17% of the Earth's surface experienced a locally record-high annual average temperature in 2023. Local record annual averages impacted an estimated 2.3 billion people — 29% of the global population — with 77 countries setting new national records for their annual average, including China, Japan, Bangladesh, Germany, Ukraine, Mexico, and Brazil.

As detailed in our Jan. 9 post, for the United States, 2023 was the fifth-warmest year in history going back to 1895. It was the warmest year on record for five states in the Southern Plains and New England: Massachusetts, New Hampshire, Mississippi, Louisiana, and Texas. Every state from the Mississippi Valley eastward had a top-ten warmest year, and none of the contiguous states were cooler than average.

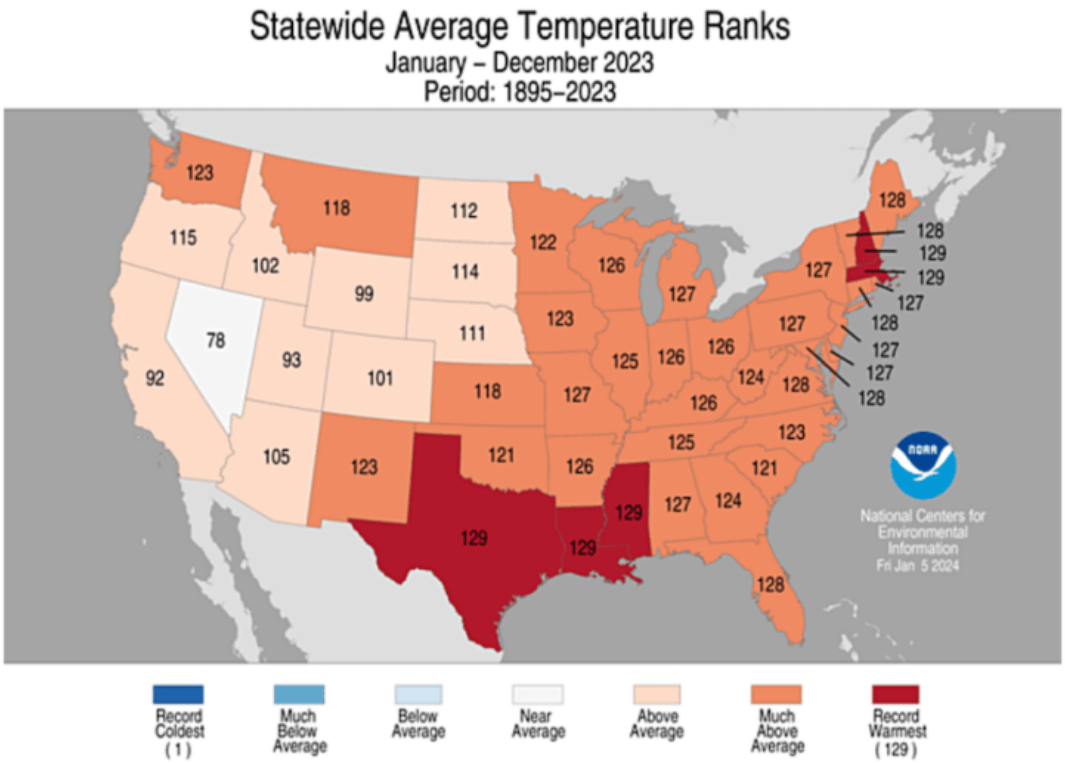

Figure 3. Rankings of average temperature in 2023 for each contiguous U.S. state across records going back to 1895. Higher numbers (from 1 to 129) denote warmer values. (Image credit: NOAA/NCEI)

The two main human-emitted heat-trapping gases — carbon dioxide and methane — both reached all-time highs in 2023, with the methane growth rate hitting its highest level on record. Although CO2 concentrations have hit a new high each year for decades, the increase in methane has been more irregular: There was an unexpected leveling off in the 2000s, followed by a sharp increase in the 2010s and 2020s.

Warmest year on record for total ocean heat content

The total heat content of the world's oceans in 2023 was the warmest in data going back to the 1950s, according to a Jan. 11, 2024, paper by Cheng et al., New Record Ocean Temperatures and

Related Climate Indicators in 2023, published in the journal Advances in Atmospheric Sciences. In the uppermost 2,000 meters of the oceans, there were approximately 15 zettajoules more heat in 2023 than in 2022, which held the previous record (a zettajoule is one sextillion joules — 10 to the 21st power). To put those numbers into context, understand that humans use a total of about 0.5 zettajoules of energy per year.

More than 90% of the increasing heat from human-caused global warming accumulates in the ocean as a result of its large heat capacity. The remaining heating manifests as atmospheric warming, a drying and warming landmass, and melting land and sea ice. Increasing ocean heat content causes sea level rise through thermal expansion of the water and melting of glaciers in contact with the ocean, resulting in higher coastal erosion and more damaging storm surges. Ocean heat content also produces stronger and more rapidly intensifying hurricanes; causes more intense precipitation events that can lead to destructive flooding; contributes to “marine heat waves” that damage or destroy coral reefs; and disrupts atmospheric circulation patterns.

An unexpected global temperature record

At the beginning of 2023, it was not expected that 2023 would set a new global temperature record. In January 2023, NOAA gave less than a 7% chance that 2023 would be the warmest year on record. As Tweeted last week by climate scientists Zeke Hausfather and Gavin Schmidt (see below), annual-average global temperatures can usually be predicted from the long-term trend caused by global warming, combined with an adjustment for the state of ENSO (the El Niño Southern Oscillation, or whether or not an El Niño or La Niña event was present). However, this method failed to anticipate that 2023 would be a record-breaking year, and it is unclear why.

Some possible explanations for the unusual warmth of 2023 have been given:

A recent decrease in aerosol pollution (in part, from recent regulations to reduce pollution from commercial ships), which has led to more sunlight being absorbed by the surface. Climate scientist James Hansen championed this explanation in a January 4 post. He made the concerning prediction that the unusual global warmth of 2023 will persist: "By May the 12-month running-mean global temperature relative to 1880-1920 should be +1.6-1.7°C and not fall below +1.4 ± 0.1°C during the next La Nina minimum. Thus, given the planetary energy imbalance, it will be clear that the 1.5°C ceiling has been passed for all practical purposes."

Natural variability, brought on, in part, by the rapid switch-over to a strong El Niño event in late 2023 from a three-year-long La Niña event. Regarding the unusual global oceanic warmth in 2023, atmospheric dynamics expert Paul Roundy at SUNY-Albany had this to say on Twitter in October 2023:

"The main reason for the very strong warming this year above the long-term trend is that three years of La Niña warmed the extratropics by reducing wind-driven evaporation and by increasing incoming solar radiation. Normally the midlatitude warmth would have had time to moderate through a neutral year or two before El Niño emerged, but 3 years of compounded extratropical warming occurred, then El Niño emerged almost immediately, so the tropical warmth **and the midlatitude warmth occurred simultaneously.**"

The eruption of the Hunga Tonga volcano in 2022, which shot a large amount of water vapor into the stratosphere, potentially causing global warming. One study estimated that the water vapor could lead to several years of enhanced global warming, thus

raising the odds that at least one year will temporarily breach the 1.5°C threshold. However, the aerosol particles also emitted during the eruption may have actually made the volcano's net effect on the Earth a *cooling* rather than a warming.

NOAA is giving a 33% chance that 2024 will surpass 2023 as the warmest year on record; climate scientist Gavin Schmidt puts the odds at 55%, assuming that the usual prediction method (which failed in 1992 and 2023) works. "What happens in 2024 will be important," Schmidt commented. "Does it go back to being predictable based on ENSO (in which case 2024 is expected to just be a little warmer than 2023), or does the positive anomaly persist?"

Global tropical cyclones below average in number, but with many major storms and a Category 5 in every basin

A total of 78 named tropical cyclones occurred across the globe in 2023, which was below the 1980-2023 average, according to the Colorado State Real-Time TC Activity page. Of those, 45 reached the equivalent of hurricane strength (winds of 74 mph or higher), and 30 reached the equivalent of major hurricane strength (winds of 111 mph or higher). This was the seventh-highest number of major storms since 1980. The global accumulated cyclone energy, or ACE — an integrated metric of the strength, frequency, and duration of tropical storms — was near average. However, for the first time on record, all seven of the world's cyclone-spawning oceanic basins produced at least one storm equivalent to a category 5 hurricane. The widespread record oceanic warmth of 2023 likely helped raise the intensity of many of this year's storms.

El Niño continues but is expected to end by May

Strong El Niño conditions persisted during December, but neutral conditions are expected to emerge by the Northern Hemisphere spring (73% chance in April-May-June), NOAA reported in its January monthly discussion of the state of the El Niño/Southern Oscillation, or ENSO.

Long-range ENSO predictions are typically not reliable until after northern spring. However, the odds of La Niña in late 2024 are rising. Cooler-than-average waters are strengthening below the surface of the western tropical Pacific, and there is increasing long-range model support for a transition to La Niña later this year. There is also some climatological support: In records going back to 1950, all four of the El Niño events that were as strong as the current one transitioned to La Niña conditions in the following year. The January NOAA and Columbia University's International Research Institute for Climate and Society forecast have raised the odds from the previous month, now calling for La Niña to be the most likely outcome as soon as June-August 2024. For the upcoming Atlantic hurricane season (August-September-October), the forecast called for a 64% chance of La Niña, a 30% chance of ENSO-neutral, and a 6% chance of El Niño. El Niño conditions tend to suppress Atlantic hurricane activity through an increase in wind shear, but La Niña conditions tend to have the opposite effect.

Arctic sea ice: 9th-lowest December extent on record

Arctic sea ice extent during December 2023 was the ninth-lowest in the 45-year satellite record, according to the National Snow and Ice Data Center. They commented that in 2023, "sea ice extent followed a pattern typical of the past decade, with persistently below-average extent in the northernmost Atlantic (Barents and Norwegian Seas) and large summer retreat along the eastern Siberian coast. However, the pace of sea ice decline (e.g. summer minimums or monthly average extents) has slowed since 2012, and

the 2012 record low summer minimum has not been surpassed. While explanations have been offered to account for this 'hiatus,' notably involving variations on ocean heat transport to the Arctic Ocean, questions remain.

Antarctic sea ice: a record-low year

Antarctic sea ice extent in December was the second-lowest on record, behind the record low set in 2016. For the year, Antarctic sea ice extent set new records for the lowest yearly average extent and lowest minimum extent; each month from May through October had a new record-low monthly extent. According to the 2023 "State of the cryosphere" report from the International Cryosphere Climate Initiative, "The unprecedented reduction in Antarctic sea ice extent since 2016 represents a regime shift to a new state of inevitable decline caused by ocean warming." Carbon Brief has a good summary of the report, which says that a 2-degree Celsius rise in global temperatures above preindustrial levels would commit the world to truly alarming levels of sea level rise of "between 12 and 20 meters" (39 to 66 feet) over a period of centuries. The report said that with current emissions, one meter (3.3 feet) of sea level rise could occur by 2070, with three meters (9.8 feet) possible by the early 2100s.

A slew of heat records in 2023

International weather records researcher Maximiliano Herrera monitors the pulse of the planet in remarkable detail, and he logged 21 nations or territories that set or tied their all-time *reliably measured* heat records in 2023; three nations set an all-time cold record in 2023. Six nations or territories — the U.S. Virgin Islands, Chad, Saba, Vietnam, Barbados, and Peru — beat or tied their old all-time heat record twice in 2023; French Guiana beat their previous all-time heat record three times; and Laos beat

its previous all-time heat record an astounding four times. According to Herrera, the record for most national/territorial all-time heat records in a year is 24, set in 2019. In 2022, 12 such records were set.

Among global weather stations having at least 40 years of record-keeping, Herrera documented 595 that exceeded (not just tied) their all-time heat record in 2023 and 35 that set an all-time cold record. For comparison, 762 stations set their all-time heat record in 2022, and 404 in 2021.

The 21 places that set or tied an all-time national/territorial heat record in 2023

Thailand: 45.4°C (113.7°F) at Tak Agromet, April 15
Laos: 42.7°C (108.9°F) at Luang Prabang, April 18; beaten one day later with 42.9°C (109.2°F) at Sayaburi, April 19; beaten again on May 6 and May 7 with 43.5°C (110.3°F) at Luang Prabang
Vietnam: 44.1°C (111.4°F) at Hoi Xuan, May 6; beaten again with 44.2°C (111.6°F) at Tuong Duong, May 7
Singapore: 37.0°C (98.6°F) at Ang Mo Kio, May 13 (tie)
Chad: 48.0°C (118.4°F) at Faya, May 25; tied again on June 16
China: 52.2°C (126°F) at Sabao, July 16
Vatican City: 42.9°C (109.2°F) at Roma Macao, July 18
Cayman Islands: 35.3°C (95.5°F) at Owen Roberts airport, July 22
Albania: 44.0°C (111.2°F) at Kucova, July 25
Morocco: 50.4°C (122.7°F) at Agadir, August 11
U.S. Virgin Islands (U.S.): 35.6°C (96.1°F) at St. Croix, August 14 (tie); beaten on September 9 with 36.1°C (97°F) at St. Croix
Dominica: 36.6°C (97.9°F) at Canefield Airport, August 27
Aruba: 36.5°C (97.7°F) at Queen Beatrix Airport, August 28 (tie)
Saba: 34.4°C (93.9°F) at Juancho Yrausquin Airport, August 29; tied again on September 8
Martinique (France): 36.6°C (97.9°F) at Ducos, September 15

St. Barthelemy (France): 35.5°C (95.9°F) at Gustavia, September 15 (tie)
French Guiana (France): 38.1°C (100.6°F) at Grand Santi, September 15; beaten on September 25 with 38.8°C (101.8°F) at St. Laurent do Moroni; beaten again with 39.1°C (102.4°F) at Grand Santi, October 14
Guyana: 40.1°C (104.2°F) at Ebini, September 26
Peru: 41.4°C (106.5°F) at Tingo de Ponaza, September 27; beaten again with 41.6°C (106.9°F) at Inapari, October 7
Suriname: 38°C (100.4°F) at Zanderj Airport, September 30 (tie)
Barbados: 35.6°C (96.1°F) at Bridgetown, September 30; tied on October 1 at the same station

The 3 places that set or tied an all-time national/territorial cold record in 2023

Myanmar: -6.0°C (21.2°F) at Hakha, Jan. 17 (tied)
China: -53.0°C (-63.4°F) at Jintao, Jan. 22
Cyprus: -12.8°C (9°F) at Trodos Mt. Station, Feb. 8 (tied)

A total of 175 monthly national/territorial heat records beaten or tied in 2023

In addition to the 21 all-time national/territorial records listed above (plus seven, for the records set in two different months in Laos, Chad, Saba, French Guiana, Peru, Barbados, and the U.S. Virgin Islands), 147 nations or territories set monthly all-time heat records in 2023, for a total of 175 monthly all-time records. Here are the additional 147 monthly heat records set in 2023:

- Jan. (13): Czech Republic, Liechtenstein, Netherlands, Denmark, Poland, Belarus, Lithuania, Latvia, Romania, Moldova, Ukraine, Cyprus, Nigeria
- Feb. (4): Chile, Taiwan, Pakistan, Cyprus

- March (3): Botswana, Vietnam, Taiwan
- April (12): Cabo Verde, Botswana, Turkmenistan, Mauritius, Antigua and Barbuda, Spain, Morocco, Portugal, Andorra, Saba, St. Barthelemy, Laos
- May (9): Mauritius, Solomon Islands, Botswana, Cambodia, Cocos Islands, Panama, Saba, Maldives, French Guiana
- June (15): Botswana, Vietnam, Tuvalu, Hong Kong, Mauritius, Aruba, Saba, Senegal, Costa Rica, China, Chad, Solomon Islands, Morocco, French Guiana, Guyana
- July (11): Mauritius, Liechtenstein, U.S. Virgin Islands, Dominica, Italy, Malta, El Salvador, Tanzania, St. Barthelemy, Martinique, Guyana
- August (17): Qatar, Niger, Mauritius, Chile, St. Barthelemy, Turkey, Thailand, Botswana, France, Bolivia, Paraguay, Martinique, Chad, Suriname, French Guiana, U.S. Virgin Islands, Kenya
- September (9): Saba, Mauritius, Chad, Norway, St. Barthelemy, Djibouti, French Guiana, Peru, Ireland
- October (22): Spain, Andorra, Saba, Guyana, France, Austria, Poland, Taiwan, Oman, Iran, Slovenia, Mauritius, Singapore, Colombia, U.S. Virgin Islands, Dominican Republic, Belize, Honduras, Senegal, Moldova, Paraguay, Dominica
- November (20): Mongolia, North Korea, South Korea, Bangladesh, Cyprus, Malta, Tunisia, Philippines, Greece, Cayman Islands, Dominica, Taiwan, Spain, Mauritius, South Africa, French Southern Territories, Maldives, Paraguay, Martinique, U.S. Virgin Islands
- December (12): Croatia, Maldives, Hong Kong, North Korea, Taiwan, Papua New Guinea, Gibraltar, Spain, Thailand, Congo Brazzaville, Costa Rica, Dominica

A total of nine monthly national/territorial cold records beaten in 2023

In addition to the three all-time cold records listed above, six nations or territories set a monthly all-time cold record in 2023, for a total of nine monthly cold records for the year:

- Feb. (1): Montenegro
- March (2): St. Eustatius, Martinique
- June (1): Finland
- August (2): French Polynesia, Montenegro

Notable global heat and cold records for 2023

- Hottest temperature in the Northern Hemisphere: 53.9°C (129.0°F) at Saratoga Spring, Calif. (USA), July 16
- Coldest temperature in the Northern Hemisphere: -62.7°C (-80.9°F) at Tongulah, Russia, January 18
- Hottest temperature in the Southern Hemisphere: 49.5°C (121.1°F) at Roebourne, Australia, December 31
- Coldest temperature in the Southern Hemisphere: -83.2°C (-117.8°F) at Concordia, Antarctica, July 25
- Highest 2023 average temperature in the Southern Hemisphere: 29.7°C (85.5°F) at Surabya AP, Indonesia
- Highest 2023 average temperature in the Northern Hemisphere: 32.2°C (90.0°F) at Matam, Senegal

Earth's all-time record for hottest yearly average temperature was 32.9°C (91.2°F) at Makkah, Saudi Arabia, in 2010 and 2016.

Fifteen notable hemispherical and continental temperature records set in 2023

- Lowest temperature reliably recorded in January in the Southern Hemisphere: -51.2°C (-60.2°F) at Concordia, Antarctica, Jan. 31;
- Highest temperature ever recorded in April in Europe: 38.8°C (101.8°F) at Cordoba, Spain, April 27;
- Highest minimum temperature ever recorded in Africa for any month: 39.6°C (103.3°F) at Adrar, Algeria, July 6;
- Highest temperature ever recorded in July in Europe: 48.2°C (118.8°F) at Jerzu and Lotzorai, Italy, July 24;
- Highest minimum temperature ever recorded in July in Europe: 36.2°C (97.2°F) at Palermo, Italy, July 24;
- Highest temperature ever recorded in Africa in August (tie): 50.4°C (122.7°F) at Agadir, Morocco, August 11;
- Highest temperature ever recorded in the Southern Hemisphere in August (tie): 45.0°C (113°F) at Villamontes, Bolivia, August 23;
- Highest minimum temperature ever recorded in Oceania and in the whole Southern Hemisphere in August: 28.8°C (83.8°F) at Funafuti, Tuvalu, August 31 (previous record: 28.7°C at August Nui, Tuvalu, on August 14);
- Highest minimum temperature ever recorded in South America and the Southern Hemisphere in September: 30.6°C (87.1°F) at Base Aerea Jara, Paraguay, September 3;
- Highest minimum temperature ever recorded in the world in October: 33.9°C (93.0°F) at Abu al Bukoosh (United Arab Emirates), October 6;
- Highest minimum temperature ever recorded in South America in October: 31.6°C (88.9°F) at Nueva Asuncion (Paraguay), October 23;
- Highest minimum temperature ever recorded in the Northern Hemisphere in November: 30.8°C (87.4°F) at Das Island, United Arab Emirates, November 1;

- Highest temperature ever recorded in Europe in November: 35.1°C (95.2°F) at Sisi, Crete, November 4;
- Highest minimum temperature ever recorded in South America: 34.6°C (94.3°F) at Mariscal Estigarribia, Paraguay, November 18; and
- Highest temperature ever recorded in Africa in November: 46.7°C (116.1°F) at Augrabies Falls, South Africa, November 27.

December 2023: Earth's warmest December on record

December 2023 was the warmest December since global record-keeping began in 1850, NOAA's National Centers for Environmental Information reported January 12, as did NASA. In the NASA database, December 2023 had the third-highest departure above average of any month in the 144-year database, behind only September 2023 and November 2023.

Notable global heat and cold marks for December 2023

– Hottest temperature in the Northern Hemisphere: 41.0°C (105.8°F) at Tambacounda, Senegal, and Mayes, Mali, December 3;
– Coldest temperature in the Northern Hemisphere: -59.8°C (-75.6°F) at Summit, Greenland, December 26;
– Hottest temperature in the Southern Hemisphere: 49.5°C (121.1°F) at Roebourne, Australia, December 31; and
– Coldest temperature in the Southern Hemisphere: -43.9°C (-47.0°F) at Concordia, Antarctica, December 8.

Major weather stations' new all-time heat or cold records in December 2023

Among global stations with a record of at least 40 years, seven stations set (not just tied) all-time heat records in December 2023, and nine stations set an all-time cold record:

Maumere (Indonesia) max. 37.2°C, December 4;
Mendoza (Argentina) max. 41.8°C, December 16;
Mendoza Airport (Argentina) max. 44.9°C, December 16;
Xiaodian (China) min. -24.0°C, December 17;
Qinghe (China) min. -22.6°C, December 17;
Datong (China) min. -31.9°C, December 17;
Halls Creek (Australia) max. 46.1°C, December 19;
Yunzhou (China) min. -33.2°C, December 20;
Yangqu (China) min. -27.0°C, December 20;
Baoding (China) min. -23.3°C, December 20;
Shunping (China) min. -22.0°C, December 20;
Qingshuihe (China) min. -31.3°C, December 21;
Rongcheng (China) min. -23.4°C, December 21;
Agalega Island (Mauritius) max. 35.4°C, December 26;
Tanah Merah (Indonesia) max. 37.9°C, December 26; and
Winton (Australia) max. 47.2°C, December 30.