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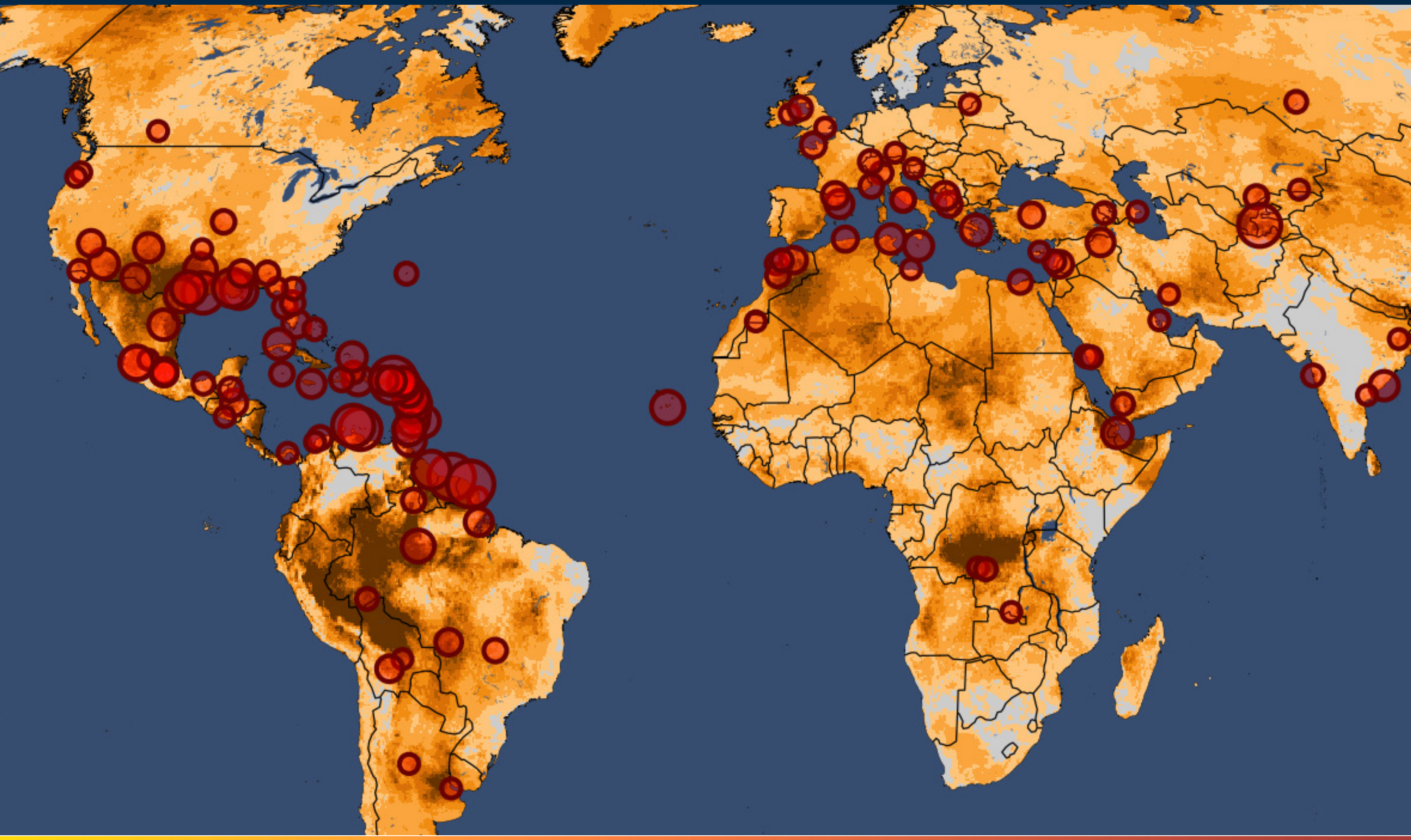

November 9, 2023

CLIMATE CENTRAL

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Key Facts

Leading up to COP28, Climate Central scientists assessed worldwide air temperatures for climate fingerprints over the past 12 months (November 1, 2022 to October 31, 2023).

Analysis using the Climate Shift Index (CSI) — Climate Central's daily local temperature attribution system — indicates that human-caused climate change significantly elevated temperatures over the last 12 months. The analysis looks at daily average temperatures and heat waves and includes data for 175 countries, 154 states/provinces, and 920 major cities.

With an average warming of more than 1.3°C, the past 12 months were the hottest on record. El Niño is just beginning to boost temperatures, but based on historical patterns, most of the effect will be felt next year. Rapidly reducing carbon pollution every year is required to halt the warming trend.

Over the entire year-long period, 90% percent of people (7.3 billion) experienced at least 10 days of temperatures very strongly affected by climate change, and 73% (5.8 billion) experienced more than a month's worth of these temperatures. These days had a CSI of 3 or higher; CSI level 3 indicates that human-caused climate change made those temperatures *at least three times more likely*.

We also examined exposure to dangerous, extreme temperatures, especially where conditions persisted for at least 5 days. We found that **1 in 4 people (1.9 billion) experienced a five-day heat wave (at minimum) that was strongly influenced by carbon pollution.** These multi-day heat streaks had a CSI of 2 or higher, indicating that human-caused climate change made those temperatures *at least two times more likely*.

Our findings confirm that climate burdens are both inequitable and emerging everywhere around the world. Least developed countries and small island nations had higher exposure to climate-driven heat, but climate change touched every country, and intense heat waves occurred in the U.S., Europe, India, and China.

➢ **Download data:** for 175 countries, 154 states/provinces, and 920 global cities

INTRODUCTION

The past 12 months were hot — by the data, and by lived human experience around the world.

More heat translates to more heat waves, the deadliest of weather-related hazards. Their rising global frequency and intensity is consistent with the well-established scientific understanding of the consequences of carbon pollution — mainly from burning coal, oil, and natural gas.

Climate change attribution science uses observations, computer models, and statistical methods to quantify whether and to what extent human-caused climate change altered the likelihood of specific weather events. Climate Central's daily attribution system, the Climate Shift Index, or CSI, applies the latest peer-reviewed methodology to map the influence of human-caused climate change on daily local temperatures and multi-day extreme heat events across the globe.

RESULTS

1. The past 12 months were the hottest on record with an average temperature above 1.3°C

Prior to this year, the previous record for the warmest 12-month period was 1.29°C above the pre-industrial baseline (1850-1900) and was set over the period October 2015-September 2016. The 12-month period ending in September 2023 tied this record, and it was eclipsed by the most recent 12-month period (November 2022-October 2023). **We estimate that the global average temperature for the last 12 months was 1.32°C above the pre-industrial baseline**.

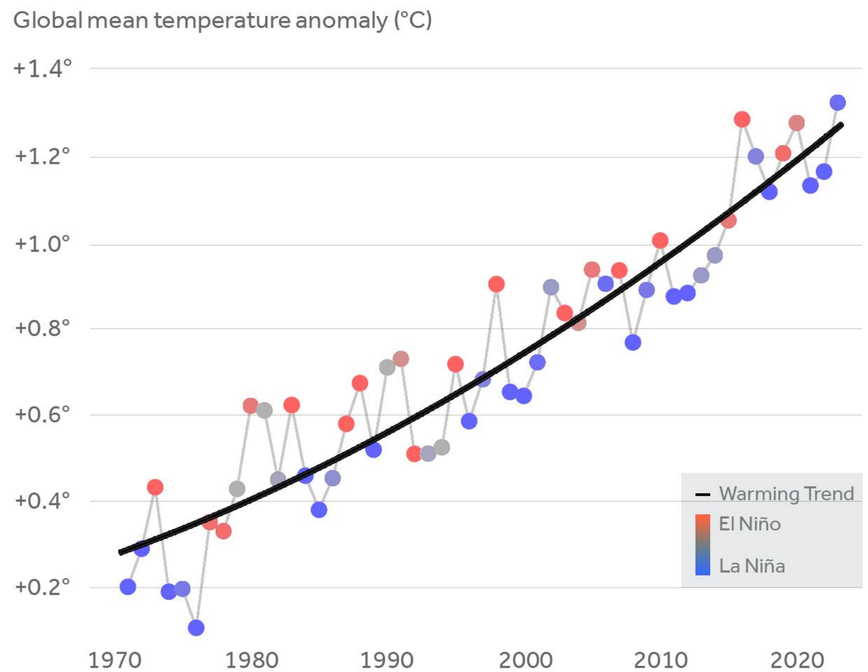
Influence of El Niño on recent global temperatures

Year-to-year, global temperatures vary within a range around the long-term trend. The El Niño Southern Oscillation (ENSO) is one of the best-known natural factors that influence global temperatures. NOAA developed the Oceanic Niño Index (ONI) to quantify ENSO. Historically, November-October global temperatures are most strongly influenced by ENSO conditions during the Northern Hemisphere winter (December-February). In early 2023, La Niña conditions were fading and the ONI was -0.7. This would be expected to have a slight cooling effect on November-October global mean temperature.

The ONI for July-September is currently 1.3, indicating a shift to El Niño conditions. Statistically, summer ENSO conditions have little relationship with November-October global temperatures, suggesting that the developing El Niño does not explain the current new record. However, NOAA predicts that El Niño conditions will persist through the winter. Based on historical relationships, it is highly likely that the next 12 months will be even hotter, possibly exceeding 1.4°C.

There is a strong trend in global average temperatures (Figure 1). This trend is primarily driven by global warming caused by excess greenhouse gasses released by human actions, like burning coal, oil, and natural gas. This trend does not appear steady; rather, the trend line curves upward confirming that warming is accelerating. The most recent and record-breaking 12-month period is highly consistent with the trend. Rising emissions of heat-trapping gasses are the main driver of the trend, followed by some reduction in aerosol pollutants with cooling effects.

Figure 1. Global mean temperature trend



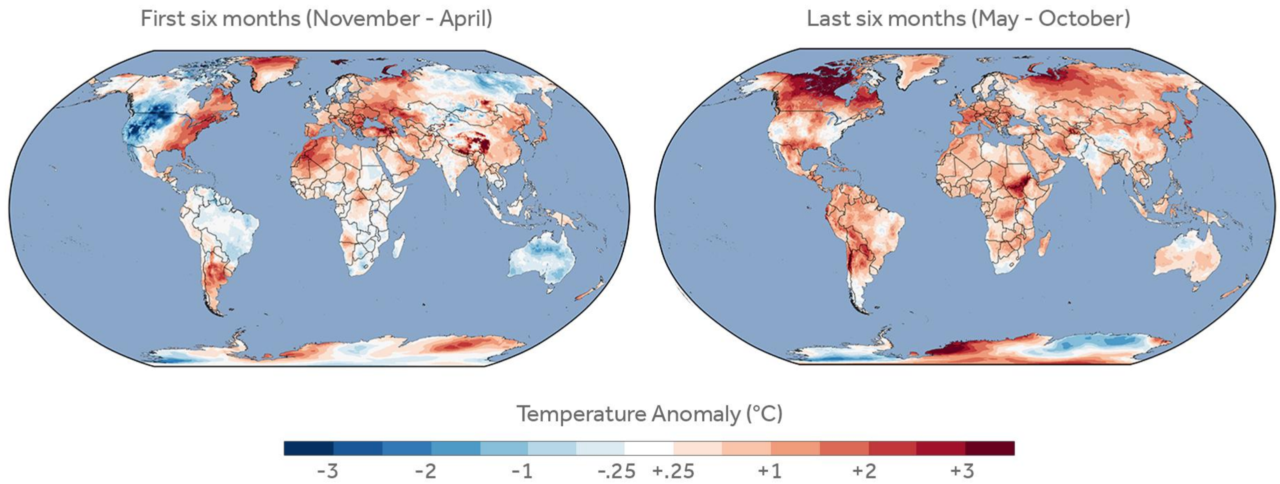
November-October average global temperatures. The gray curve depicts the long-term warming trend. The colors indicate the ENSO state (red = El Niño, blue= La Niña) from the previous December-February. See Methods for details.

2. Most people on the planet experienced temperatures very strongly affected by climate change

➢ **Download data**: Climate Shift Index (CSI) levels for 175 countries

The impacts of the record global temperatures were not distributed evenly in time and space. During the first half of the November-to-October year, several places, including western North America, northern South America, southern Africa, and Australia, had below-average temperatures (relative to 1991-2020) (Figure 2). In total, 67% of the land surface and 83% of people experienced warmer-than-average conditions. Conditions became even warmer during the most recent six months, with 90% of the land surface and 92% of people experiencing above-average temperatures.

Figure 2. Global temperature anomalies



Global temperature anomalies for the first half (November 2022-April 2023) and second half (May 2023-October 2023) of the last 12-month period. Anomalies are relative to the 1991-2020 standard normal period.

The Climate Shift Index (CSI) allows us to quantify how climate change has changed the likelihood of a daily temperature anywhere in the world. From last November to April, 58% of people were exposed to 10 or more days at a very strong CSI level of 3 (Figure 3), meaning that those days' temperatures were made at least three times more likely by climate change. This number rose to 82% of people during the most recent six months. **Over the full year, 90% of people (7.3 billion) experienced at least 10 days — and 73% (5.8 billion) experienced more than a month — of temperatures with very strong climate fingerprints.**

The number of days with climate fingerprints was generally higher near the equator. While temperature anomalies tend to be low near the equator, day-to-day changes in temperature are also low in equatorial climates, which makes it easier to detect the influence of climate change at these locations.

The Climate Shift Index (CSI)

Humans have caused global average temperatures to increase, per this report's analysis, by 1.3°C since 1850. But people do not experience global average temperatures. Instead, we mainly experience climate change through shifts in the daily temperatures and weather patterns where we live.

Climate Central's Climate Shift Index (CSI) system quantifies the local influence of climate change on daily temperatures around the world.

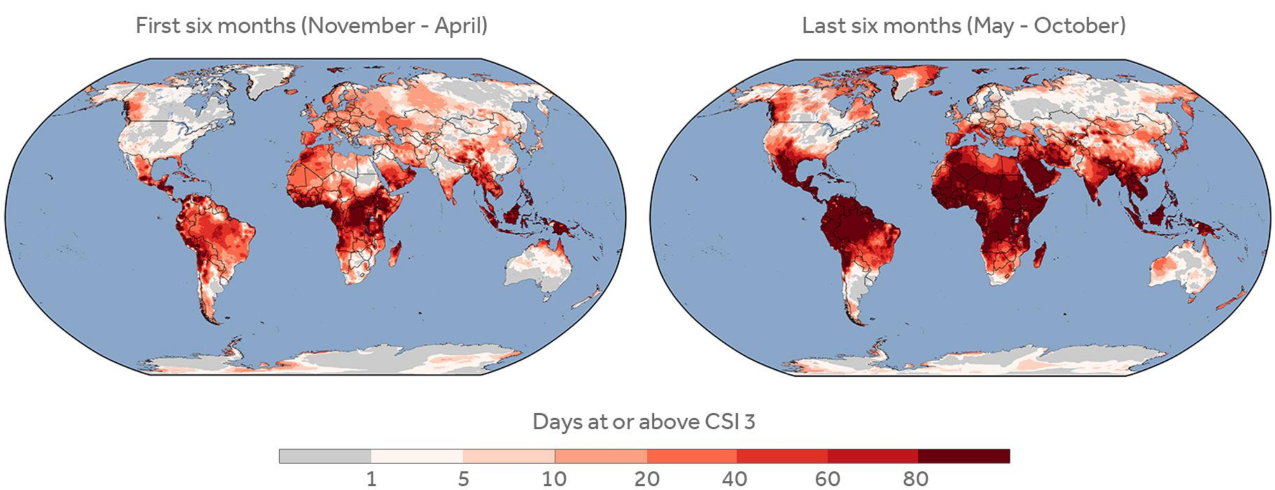
The CSI quantifies how much human-caused climate change has shifted the odds of daily temperatures that people experience locally. The CSI is grounded in peer-reviewed attribution science and was launched by Climate Central in 2022. Local CSI levels are accessible via our free map tool.

The CSI scale is centered on zero. A CSI level of 0 means that there is no detectable influence of human-caused climate change. In other words, that day's temperature is equally likely in both the modern climate and one without global warming.

Positive CSI levels 1 to 5 indicate conditions that are increasingly likely in today's climate. A CSI level of 1 means that climate change is detectable (technically, the temperature is at least 1.5x more likely). CSI levels 2 and higher correspond with the multipliers (2 = at least 2x more likely, 3 = at least 3x more likely, etc.). The CSI scale is currently capped at level 5, which means that a CSI of 5 includes higher values and thus should be read as *at least 5*. CSI level 5 events would be very difficult to encounter in a world without climate change — not impossible, but extremely unlikely.

The CSI can also be applied to temperatures that are unusually cool. For instance, a CSI level of -2 means that the temperature in question is two times *less* likely (equivalently 1/2 as likely) due to human-caused climate change.

Figure 3. Days with very strong climate fingerprints: CSI at 3 or higher



Number of days at CSI level 3 or higher during the first and last halves of the study period. These are days with temperatures made at least three times more likely by climate change.

We computed the daily average CSI for 175 countries (see Methods for inclusion rationale) (Table 1).

The country with the highest average CSI was Jamaica. Its average CSI over the last 12 months was 4.5 out of a maximum of 5. This means that climate change had an extraordinary impact on temperatures: on the average day, the average person in Jamaica experienced temperatures made more than four times more likely by human-caused climate change. Two other countries, Guatemala (4.4) and Rwanda (4.1), also had 12-month average CSI values above 4.

These three countries each represent regions that had especially strong climate fingerprints in the last 12 months. Of the seven Caribbean countries we analyzed, all of them had annual average CSI values above 1, indicating that climate change was detectable in the average day's temperatures. Annual average CSI at or above 1 occurred in 13 out of 16 countries in eastern Africa and 7 out of 8 countries in Central America. Overall, there were 108 countries with annual CSI above 1. The list is dominated by smaller countries, especially islands in the Caribbean and Indo-Pacific.

Table 1. Countries with annual average CSI of 1 or higher

Continent	Countries with annual average CSI ≥ 1	Country with the highest CSI	CSI of the most populous country	CSI of the country with the highest GDP	CSI of the country with the lowest GDP
Africa	44 out of 52	Rwanda (4.1)	Nigeria (2.3)	Egypt (1.3)	Sao Tome and Principe (3.5)
Asia	32 out of 47	Brunei (4.0)	India (1.0)	India (1.0)	East Timor (2.1)
Europe	4 out of 38	Spain (1.4)	Italy (1.2)	Italy (1.2)	Slovenia (1.0)
North America*	14 out of 17	Jamaica (4.5)	Mexico (2.1)	Mexico (2.1)	Belize (2.7)
Oceania	6 out of 8	Samoa (3.8)	Papua New Guinea (3.5)	Papua New Guinea (3.5)	Vanuatu (1.8)
South America	8 out of 13	Ecuador (3.2)	Colombia (2.2)	Colombia (2.2)	Suriname (2.8)

Summary of countries with annual average CSI of 1 or higher (others not included). All values are average CSI values.
**Includes Central America and the Caribbean*

This analysis underscores the pattern that climate impacts fall hardest on the countries that have contributed least to the problem. The small island developing states had unusually high average CSI values (2.7) as did the least developed countries (2.0). In contrast, the G20 countries had an average CSI of 0.8. The 10 countries with the highest historical emissions had an average CSI of 0.7, while the 10 lowest emitters had an average CSI of 2.7. For more information, see the full country data.

While climate impacts are stronger in the developing world, impacts among the richest countries are accelerating. This was especially noticeable during the last six months. During the first half of the most recent year-long period (November-April), Saudi Arabia, Indonesia, and Mexico were the only G20 countries with an average CSI greater than 1. **During the second half of the year (May-October), nine G20 countries — Saudi Arabia, Mexico, Indonesia, India, Italy, Japan, Brazil, France, and Turkey — experienced comparably significant climate-driven heat**. In the second half of the year, the mean CSI increased in all G20 countries except Germany, Russia, Canada, and Argentina.

Table 2. Mean CSI for G20 countries

G20 Country	Mean CSI over past 12 months (Nov 2022-Oct 2023)	Mean CSI over Nov 2022-Apr 2023	Mean CSI over May 2023-Oct 2023
Saudi Arabia	2.3	1.2	3.5
Mexico	2.1	1.2	2.9
Indonesia	2.4	1.9	2.9
India	1.0	0.3	1.6
Italy	1.2	0.9	1.5
Japan	1.0	0.4	1.5
Brazil	0.7	0.1	1.4
France	0.9	0.6	1.1
Turkey	0.8	0.5	1.1
United Kingdom	0.7	0.6	0.8
South Korea	0.6	0.4	0.8
China	0.5	0.3	0.7
United States	0.4	0.2	0.6
Germany	0.5	0.6	0.5
South Africa	0.3	0.1	0.5
Australia	0.2	0.0	0.3
Russia	0.4	0.5	0.3
Canada	0.2	0.2	0.2
Argentina	0.4	0.6	0.2

Mean CSI for the G20 countries over the 12-month period and the first six months and last six months. Data are sorted by the values from the last half of the study period. Full data are available here.

The large area of many of the G20 countries tends to mask the climate signal when looking at country-wide averages. While the CSI averaged across the U.S. population was relatively low, several U.S. states had high average CSI values. During the second half of the year, six states — Hawaii (2.8), Louisiana (1.9), Texas (1.9), Florida (1.8), New Mexico (1.8), and Arizona (1.3) — had average CSI values that exceeded 1.

China, Brazil, and India each had an increase in the number of state-equivalent administrative districts with a CSI value greater than 1 during the second half of the year.

- **Brazil**: Amapá (4.6), Pará (4.0), Amazonas (3.7), Roraima (3.7), Ceará (3.2), Acre (2.7), Rondônia (2.6), Rio Grande do Norte (2.5), Maranhão (2.5), Pernambuco (2.1), Alagoas (1.9), Paraíba (1.8), Sergipe (1.8), Bahia (1.7), Mato Grosso (1.5), Minas Gerais (1.2), Goiás (1.0), Espírito Santo (1.0), Distrito Federal (1.0)
- **China**: Hainan (2.1), Fujian (1.7), Guangdong (1.6), Hong Kong (1.6), Yunnan (1.6), Xizang (1.4), Guangxi (1.2), Liaoning (1.0),
- **India**: Kerala (3.6), Goa (3.4), Andaman and Nicobar (3.3), Puducherry (3.2), Mizoram (3.0), Karnataka (3.0), Meghalaya (2.9), Manipur (2.8), Tripura (2.8), Dadra and Nagar Haveli (2.6), Andhra Pradesh (2.4), Assam (2.2), Arunachal Pradesh (2.1), Nagaland (2.1), West Bengal (2.0), Jharkhand (1.9), Odisha (1.9), Tamil Nadu (1.9), Bihar (1.8), Maharashtra (1.7), Chhattisgarh (1.6), Telangana (1.5), Uttar Pradesh (1.4), Madhya Pradesh (1.1), Gujarat (1.0), Uttarakhand (1.0)

CSI: Tools, Data, Custom Maps, and Local Alerts

Here are four ways to use this attribution analysis from Climate Central:

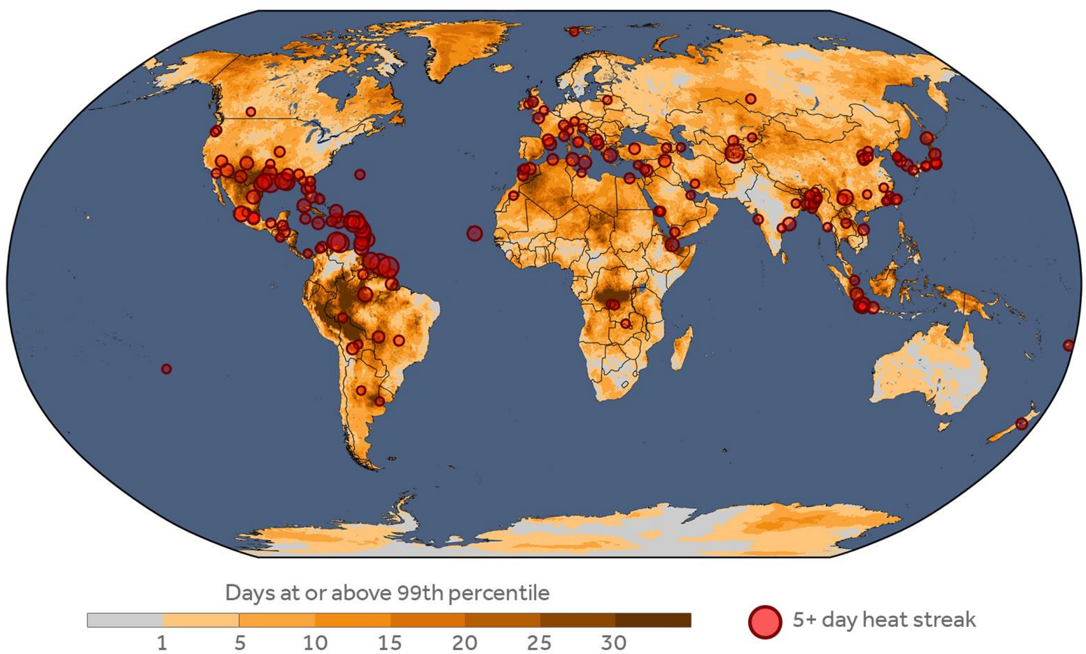
1. **Use the tools.** Climate Central's Climate Shift Index map tool shows which parts of the world are experiencing high CSI levels, every day. Explore the global CSI map for today, tomorrow, and any day this past year.
2. **Download the data.** Summary data from this report are available to download and explore in more detail how human-caused climate change has affected people around the world this year.
3. **Create custom CSI maps.** The Climate Shift Index is now available in KML format. Fill out this form to join our pilot project, receive the KML links, and start creating custom CSI maps.
4. **Sign up for alerts.** Sign up here to receive custom email alerts when strong CSI levels are detected in your local area.

3. 1 in 4 people faced extreme heat waves driven by climate change this year

The country- and state-level CSI averages highlight the distribution of climate-fueled heat across the planet. However, the CSI allows us to look at conditions on an even finer scale. We focused on extreme heat — temperatures that are expected to occur less than 1% of the time at a location based on the 1991-2020 reference period. Temperatures at this level would be noticeably hot for that location. They would also be well above the minimum mortality temperature, indicating conditions that would be dangerous to many people experiencing them.

The analysis shows that 4.9 billion people (61% of the global population) experienced more than five total days of locally extreme temperatures (Figure 4). These temperatures are especially dangerous if they persist over several days, reducing the opportunity of people and plants and animals to recover. Additionally, 2.1 billion people (26%) experienced five or more consecutive days of these extremes, and **1.9 billion (24%) experienced a five-day heat streak with a clear climate fingerprint:** a CSI level of 2 or higher, indicating that human-caused climate change made those temperatures *at least two times more likely*.

Figure 4. Heat streaks



Number of days with locally extreme temperatures. The circles indicate cities with at least one 5+ day streak of extreme temperatures that is attributable (CSI>=2). The size of the circles reflects the length of the longest heat streak.

We analyzed the occurrence of extreme temperatures in 700 cities of at least 1 million people around the world. **With a 22-day streak of extreme heat, Houston, Texas, stands out with the longest streak among these cities** (Table 3)**.** The United States had 12 cities with streaks of five or more days. Most were in the South (Texas, Florida, and Louisiana) or the Southwest (Arizona and Nevada). With the exception of Portland, Oregon (mean CSI=4.6), each of these streaks had an average CSI of 5 , meaning that climate change boosted the likelihood by at least a factor of five. The CSI is a daily metric and does not consider the probability of getting several days of extreme temperatures. Accounting for the probability of getting a multi-day streak of extreme temperatures would almost certainly lead to higher estimates for how climate change has boosted the odds of these events.

A total of 156 cities had extreme heat streaks of five days or more. Among these cities, 144 had streaks with an average CSI of 2 or higher (Table 4). These attributable streaks were distributed over 37 countries and included some of the largest cities in the world such as Tokyo; Jakarta, Indonesia; Mumbai, India; Mexico City; and London.

Impacts beyond heat: a global retrospective of extreme weather impacts this year

Economic impacts
In the U.S., 24 extreme weather events killed at least 383 people and led to financial losses exceeding $67 billion USD to date. Human-induced climate change impacted large parts of South America: the heat-boosted drought in Argentina led to an estimated 3% GDP reduction, while in the Amazon River region, the water level reached its lowest point ever recorded, affecting water and food distribution to half a million people in October alone. In the Panama Canal, which operates an estimated 5% of global trade, the 2-year-long drought disrupted the world's busiest trade passage for months.

Deadly and displacing flooding
Human-induced climate change also increases the severity and frequency of extreme rainfall and, consequently, of fatal flooding events. Over the past year, thousands have been killed and millions have been displaced around the world: in New Zealand during Cyclone Gabrielle; in Malawi, Mozambique, and Madagascar during Cyclone Freddy; in China during Typhoon Haikui; and in Libya, Greece, Bulgaria, and Turkey during Storm Daniel — Africa's deadliest storm ever, with over 4,000 victims. A recent investigation shows that extreme weather has killed at least 15,700 people in Africa this year so far. In April, unprecedented flooding in Rwanda and the Democratic Republic of the Congo killed over 400 people; by September, flooding washed away farmlands in Ghana and displaced nearly 26,000 people — most of whom are women and children. Meanwhile, the drought in the Horn of Africa, intensified by climate-fueled heat, continues to claim new victims, having left over 23 million people acutely food insecure while displacing another 2.7 million.

Heat, wildfires, and health
In what is now considered the deadliest U.S. fire of the century, 93 people died in Hawaii. In Canada, 1 person out of every 200 was forced to evacuate their homes due to wildfires that burned over 45 million acres and lasted for months. Heat waves that approached the human survivability threshold stretched from East and South Asia to Europe and North Africa, killing at least 264 people in India and over 2,000 people in Spain, at a time when parts of the country also faced their driest period in 500 years. In Italy, as temperatures surpassed 40°C in August and September, hospitals were unable to accommodate the number of people seeking care for heat-related illnesses, with Covid-era admission levels reported in emergency units.

CONCLUSION

At the global scale and in countries, states, and cities around the world, the last 12 months were remarkably hot, and the CSI indicates that climate change boosted this heat for billions. More than 9 in 10 people encountered heat that was made much more likely by human-caused climate change. The highest exposures to climate-driven heat were in the tropics, concentrating the impact on developing countries. However, every country experienced some level of climate driven heat; and streaks of intense heat occurred in the U.S., Europe, India, and China.

While the last year has set records, it is also not surprising — we are in the midst of a warming trend fueled by carbon pollution. As long as humanity continues to burn coal, oil, and natural gas, temperatures will rise and impacts will accelerate and spread. The analysis presented here underscores how efforts to reduce emissions and limit warming will benefit people around the world.

Table 3. Summary of longest extreme heat streaks among largest cities

City	Country	Number of days in the heat streak	Start date
Houston	United States	22	2023-07-31
Jakarta	Indonesia	17	2023-10-07
New Orleans	United States	17	2023-07-30
Tangerang	Indonesia	17	2023-10-07
Qujing	China	16	2023-05-20
Austin	United States	16	2023-07-31
San Antonio	United States	15	2023-08-04
Zapopan	Mexico	15	2023-06-12
Bekasi	Indonesia	15	2023-10-07
Guadalajara	Mexico	15	2023-06-12

The average CSI for each streak is 5. Download full city data.

Table 4. Summary of attributable extreme temperature streaks of 5 days or more by country

Country	Number of analyzed cities*	Number of cities with heat streaks	Number of cities with attributable heat streaks	Largest city with attributable heat streak	Mean CSI of the largest city's heat streak
China	314	48	48	Tianjin	3.8
United States	50	12	12	Miami	5.0
Mexico	13	11	11	Mexico City	5.0
Japan	12	9	9	Tokyo	4.7
Indonesia	14	9	9	Jakarta	5.0

India	51	9	5	Mumbai	5.0
South Korea	10	6	6	Seoul	2.8
Bangladesh	3	3	2	Dhaka	2.1
Argentina	3	3	2	Buenos Aires	5.0
Brazil	18	3	3	Manaus	5.0
Congo (Kinshasa)	4	3	3	Kananga	5.0
Morocco	3	3	3	Casablanca	4.7
Colombia	6	2	2	Barranquilla	5.0
Kazakhstan	3	2	2	Almaty	2.2
Dominican Republic	2	2	2	Santo Domingo	5.0
Taiwan	5	2	2	Taipei	5.0
Italy	2	2	2	Rome	5.0
Saudi Arabia	4	2	2	Jeddah	5.0
Yemen	1	1	1	Sanaa	5.0
Iran	8	1	1	Shīrāz	5.0
Tunisia	1	1	1	Tunis	5.0
Honduras	3	1	1	San Pedro Sula	5.0
Armenia	1	1	1	Yerevan	5.0
Libya	1	1	1	Tripoli	5.0
Canada	5	1	1	Calgary	3.2
United Kingdom	2	1	1	London	5.0
Germany	4	1	1	Munich	5.0
Iraq	3	1	1	Mosul	5.0
Bolivia	2	1	1	Santa Cruz	5.0
Syria	2	1	1	Damascus	5.0
Myanmar	3	1	1	Rangoon	5.0
Egypt	4	1	1	Alexandria	5.0
Spain	2	1	1	Barcelona	5.0
Cuba	1	1	1	Havana	5.0
Azerbaijan	1	1	1	Baku	5.0
Algeria	1	1	1	Algiers	5.0
Vietnam	7	1	1	Quảng Hà	5.0

**Out of 920 cities. See why we included the cities we did in the Methods under City Analysis.*

METHODS

Global Mean Temperature Analysis

We began with two standard estimates of global mean temperature, NASA's GISSTEMP and the UK Met Office's HadCRUT. We used HadCRUT, which has data starting in 1850, to establish the pre-industrial baseline 1850-1900. We then used the means of the two datasets over 1961-1990 to re-baseline GISSTEMP, which begins in 1880, to the pre-industrial period.

Our global mean temperature times series is based on 2m air temperature anomalies (relative to 1991-2020) from ERA5. We estimated daily global mean temperature by taking the area-weighted average and then calculated rolling 12-month means. We regressed the GISSTEMP global mean against the 12-month ERA5 means from 1970-present ($R^2 = 0.96$). This allowed us to transform the ERA5 global mean into temperatures comparable to GISSTEMP using the equation:

$$\text{Corrected} = 0.9253\ \text{ERA5} + 0.8682.$$

We fit a series of linear models to characterize the trend and quantify the influence of ENSO on global mean temperatures. We focused on the 12-month means for November-October. We found that the linear trend is significant (R^2=0.88, $p<0.01$).

We used NOAA's Oceanic Nino Index (ONI) data as our ENSO index. We fit a series of models:

$$\text{GMT} = a*\text{Year}+b*\text{Year}^2+c*\text{ONI\_q}+d$$

where ONI_q is the 3-month average ONI from the period ending q months before October. We tested q ranging from 0 to 24 and we compared models with and without the quadratic Year^2 term. The quadratic model with December-February mean ONI (q=9) was the best (R^2=0.94, ΔAIC=-29.4). Notably, models using ONI from summer were not better than the trend alone.

Calculating the Climate Shift Index

All Climate Shift Index (CSI) levels reported in this brief are based on daily average temperatures and ERA5 data from November 1, 2022 to October 31, 2023. See the frequently asked questions for details on computing the Climate Shift Index, including a summary of the multi-model approach described in Gilford et al. (2022).

Daily Global Population Exposure

For each day, we identified the grid cells with CSI values of 3 or higher and summed over the first six months, last six months, and the full 12-month period. We then used the proportion of population based on the Gridded Population of the World v4 estimate for 2020 living in each cell meeting the specific threshold (for example, 10 days), summed over the globe, and then multiplied by the estimated global population of 8.025 billion.

Country Analysis

The country-level analysis focuses on 175 countries. The countries are a subset of those used in the upcoming Lancet Countdown report that had CO2 emissions and GDP data available through Our World in Data (original data sources from IEA and World Bank, respectively).

To build up to national figures, we computed the population-weighted daily temperature anomaly and CSI were weighted using gridded local population estimates from Gridded Population of the World v4 (estimate for 2020). Each national average is thus the temperature anomaly or CSI for a typical person living in that country. We summarized the experience in each country by averaging over the first and last halves of the last 12 months as well as the full year-long period. We also calculated the proportion of each country's population that was exposed to CSI>=3 for more than 5, 10, 30, or 100 days. To compute the averages for groups of countries (i.e. the G20), we multiplied the per-capita means by the population in each country, summed, and then divided by the total population in the group.

City Analysis

We selected a list of 920 cities that either have more than 1 million inhabitants or are a national capital. We also included administrative capitals in the U.S., India, or Brazil. For each city, we found the CSI and temperature anomaly time series from the nearest 0.25° grid cell. We then computed the mean temperature and CSI, the number of days with CSI>=2, 3, or 5. For the comparisons and rankings in the report, we focused on 700 of these cities having more than 1 million people.

Extreme Heat Analysis

For each ERA5 grid cell, we calculated the 99th percentile temperature based on daily temperatures from 1991-2020. This temperature would be recognized as extraordinarily hot by people living at a particular location. It is also considerably warmer than the minimum mortality threshold temperature, which is usually estimated as the 90th percentile or even lower.

We then calculated the number of days in the study period that were above this threshold and used the procedure described above to estimate the number of people experiencing different numbers of extreme heat days.

We also looked for streaks of 5 or more days where each day was above the 99th percentile level. For each streak, we calculated the mean CSI over the streak. We used CSI=2 as our threshold for attributability, but most streaks had much higher average CSIs. For each city, we recorded the number of days in its longest streak, the start date of that streak, and the maximum mean CSI of any of its streaks.

We note that the CSI considers the attributability of individual days. The probability of a streak of several days is lower than the probability of a single day, and studies of multi-day heat events typically calculate probability ratios that would correspond with CSI levels above our current maximum of 5. In other words, the average CSI is a very conservative estimate of the attributability of a multi-day heat streak.

Climate Central is an independent group of scientists and communicators who research and report the facts about our changing climate and how it affects people's lives. Climate Central is a policy-neutral 501(c)(3) nonprofit.