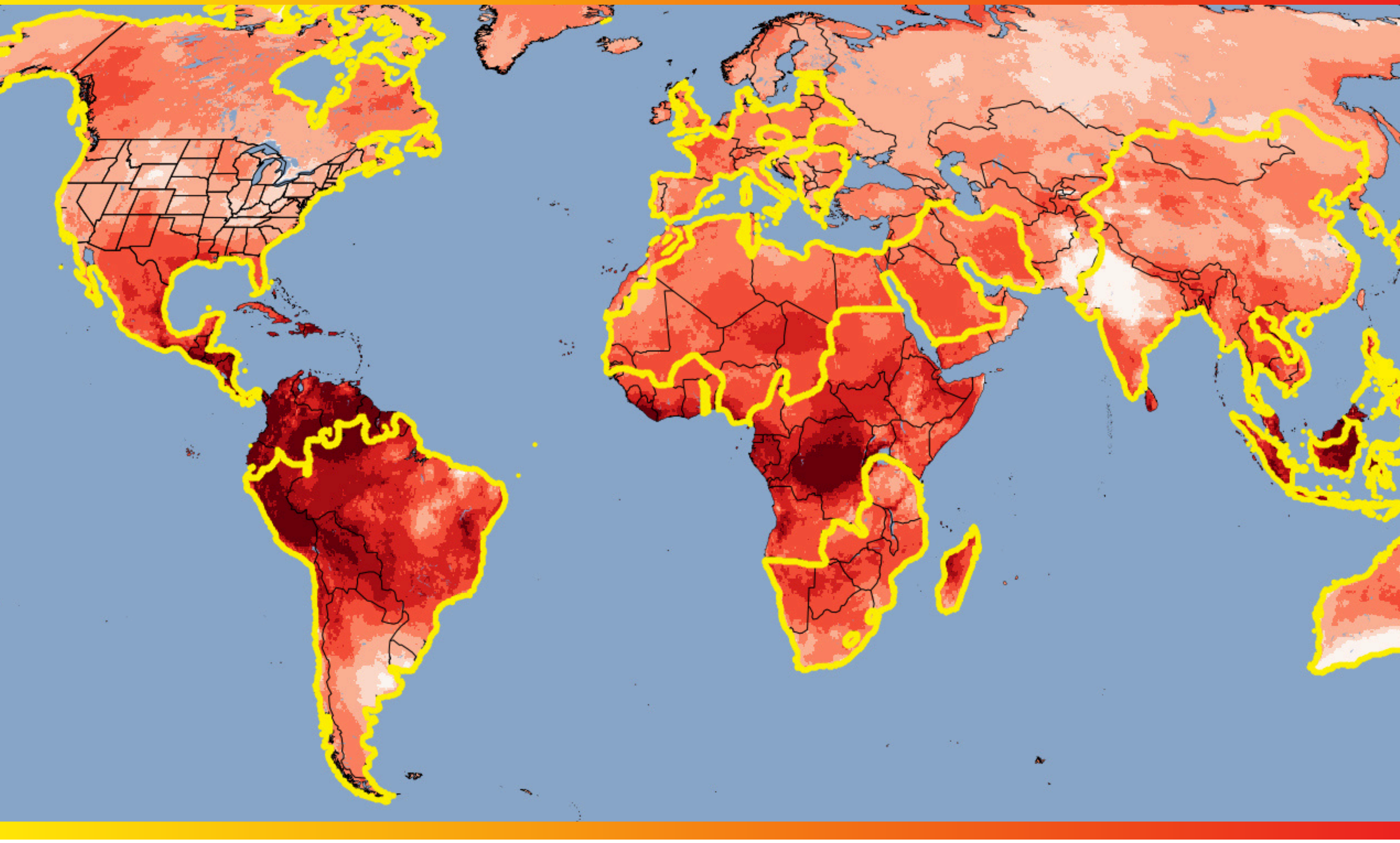
Climate Change and the Escalation of Global Extreme Heat: Assessing and Addressing the Risks

A look at global extreme heat over the past 12 months, how climate change has influenced this heat, and strategies to prevent increasingly frequent and intense heat from claiming lives worldwide.

May 28, 2024



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World Weather Attribution

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A look at global extreme heat over the past 12 months, how climate change has influenced this heat, and strategies to prevent increasingly frequent and intense heat from claiming lives worldwide.

What's inside the report:

Ahead of Heat Action Day, this new report from scientists at World Weather Attribution, the Red Cross Red Crescent Climate Centre, and Climate Central assesses the influence of human-caused climate change on dangerous heat waves over the past 12 months (May 15, 2023 to May 15, 2024).

The period of analysis spans Earth's hottest year on record (2023) and 11 consecutive months of record-breaking global temperatures (June 2023-April 2024). The report found that human-caused climate change is boosting dangerous extreme heat for billions, and making heat events longer and more likely.

Key findings from the report include:

- Using World Weather Attribution criteria, the study identified **76 extreme heat waves that span 90 different countries**. These events put billions of people at risk, including in densely populated areas of South and East Asia, the Sahel, and South America.
- Over the 12-month period, **6.3 billion people (about 78% of the global population)** experienced at least 31 days of extreme heat (hotter than 90% of temperatures observed in their local area over the 1991-2020 period) that was made at least two times more likely due to human-caused climate change.
- Over the last 12 months, human-caused climate change **added an average of 26 days of extreme heat** (on average, across all places in the world) than there would have been without a warmed planet.

This report also demonstrates the crucial role of tracking and reporting on impacts in extreme heat assessment, and offers actionable solutions to heat risk.

➢ **Download data:** for May 15, 2023-May 15, 2024 for 168 countries and all U.S. states

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1. Introduction

The year 2023 was the hottest year on record. July 2023 was the hottest month ever recorded and July 6, 2023 was the hottest day ever. Since then, each one of the last 12 months have broken their previous monthly record for highest average temperature.

This is not a surprise or an accident — the causes are well known and the impacts devastating. The continuous burning of coal, oil and gas has released enough greenhouse gasses to warm the planet by 1.2°C since pre-industrial times. Year after year, human-induced climate change manifests through more intense and frequent extreme weather events, with heat waves being the most dramatically affected.

In the last decades, climate science has come a long way in understanding the role of climate change in fueling extreme temperatures and heat waves. Thanks to developments in attribution science and climate models, we can now quantify how much heat climate change has added to an extreme temperature event, how much more frequent and intense heat waves will become if we don't stop emitting greenhouse gasses, and how many people have died because of the extreme heat brought about by human-induced climate change.

One of the most consistent findings is that every heat wave happening today has been made more likely, more intense, and longer-lasting due to humans burning fossil fuels (Clarke et al., 2022). In the last few years, we have also identified many deadly extreme heat events that would have been virtually impossible without human-induced climate change. Although floods and cyclones make more headlines, heat is arguably the deadliest extreme event, with thousands of extreme heat-related deaths reported each year and many more that go unreported.

World Weather Attribution (WWA), an international group of scientists that analyzes the role of climate change in extreme weather, monitors heat waves and other events across the world. Using a set of fixed criteria, they identify the most damaging extreme events and decide whether to analyze them based on their impacts and the team's capacity to undertake the study.

Unlike what happens with floods or droughts, where the human impacts are rapidly felt and acknowledged, the consequences of extreme heat often go unnoticed. Countries seldom declare emergency states or appeal for humanitarian support because of a heat wave. That is why the criteria WWA uses to detect the most potentially impactful heat waves has to be different than for other extreme events. Currently, the team will consider conducting studies on heat waves if they meet one of these two criteria:

1. Record-breaking or unseasonably high temperatures over a large geographic area, for a prolonged period (3+ days), are either forecasted or observed in global data products.
2. Media reports of ≥10 heat-related deaths or major disruptions to critical sectors (notably transportation, energy, and manufacturing) are found.

And provided they also meet at least one of these:

3. The heat identified is occurring during the first 3-6 weeks of the hot season (due to heightened vulnerability of early season extreme temperatures).
4. The heat is occurring in a densely populated area (≥200 people/km^2).
5. The heat is occuring in a highly vulnerable area (using ≥4.8 on the INFORM index as an indicator) and/or high lack of coping capacity (≥6.0 INFORM).

Using these criteria, 76 extreme heat events were triggered between May 15, 2023 and May 15, 2024 in 90 different countries across all continents, excluding Antarctica. These extreme heat events had the potential to affect billions of people in densely populated areas such as South and East Asia, the Sahel, and the megacities in South America. For most of the triggered events that fell outside of Europe and North America, we do not have any information on how many people were actually affected and how. What is increasingly clear, however, is that when we do have information on impacts, they are dire and are mostly affecting the most vulnerable people in every country.

Out of the 76 triggered extreme heat events, the WWA team studied seven in depth:

- The extreme humid heat in South and Southeast Asia in May 2023
- The extreme heat in Southern Europe, North America and China in July 2023
- The early and prolonged heat that affected millions of people across Argentina, Brazil, Paraguay, and Bolivia in September 2023
- The hottest-ever October (2023) in Madagascar
- Dangerous humid heat in the coastal regions of West Africa in February 2024
- The deadly heat in the Sahel region during Ramadan 2024
- The most recent extreme heat that affected all of Asia, from Israel, Palestine, Lebanon and Syria in the west, to Myanmar, Thailand, Vietnam and the Philippines in the east during April 2024.

In all these studies, human-induced climate change was found to be a key driver of the extreme heat. In many cases, including in Southern Europe, the southern United States and Mexico, the Sahel region, West Africa, Thailand, Lao PDR, and the Philippines, the high temperatures observed would never have occurred without human-induced climate change.

While these studies only give a snapshot of all the extreme heat waves occurring, they all tell the same story: climate change is an absolute game-changer when it comes to extreme heat, and threatens, in combination with the urban heat island effect, rapidly growing urban settlements worldwide (Tuholske et al., 2021). Below, we assess the role of climate change in heat extremes over the last year across the world, including the distinct 76 heatwaves identified using WWA criteria. We combine this with an in-depth assessment of the different ways these heat extremes have impacted society. We conclude with concrete actions that can be undertaken at different scales to prevent heat-related impacts, most acutely fatalities.

World Weather Attribution is a collective of scientists who use weather observations and climate models to understand how climate change influences the intensity and likelihood of extreme weather events. Their studies also assess the role of vulnerability and exposure in the extent of the impacts.

2. Attribution analysis of heat waves

To build off of WWA's work, Climate Central scientists conducted an analysis of attributable heat over the past year (attributable to human-induced climate change), including all 76 extreme heat events triggered by WWA's criteria. We compared these events with locations that experienced climate-altered temperatures, using our Climate Shift Index (CSI) system.

Below, we describe conditions across the planet between May 15, 2023 and May 15, 2024. We also provide detailed data on 168 countries.

The CSI uses peer-reviewed methodology (Gilford et al., 2022) and quantifies the influence of climate change on daily temperatures. We typically express this influence as a change in the likelihood of the observed temperature due to climate change (for an example, see the CSI global map). The system also estimates the temperature that would have occurred in a world without human-caused climate change. We refer to these as the counterfactual temperatures.

For this study, we focused on days with temperatures that people would consider hot based on their local experience. For each location in our dataset, we calculate the temperature that is warmer than 90% of temperatures observed at that site over the 1991-2020 period (also referred to as temperatures above the 90th percentile). We then counted the number of days with temperatures above this threshold and where the CSI said climate change made the temperatures at least twice as likely (Figure 1).

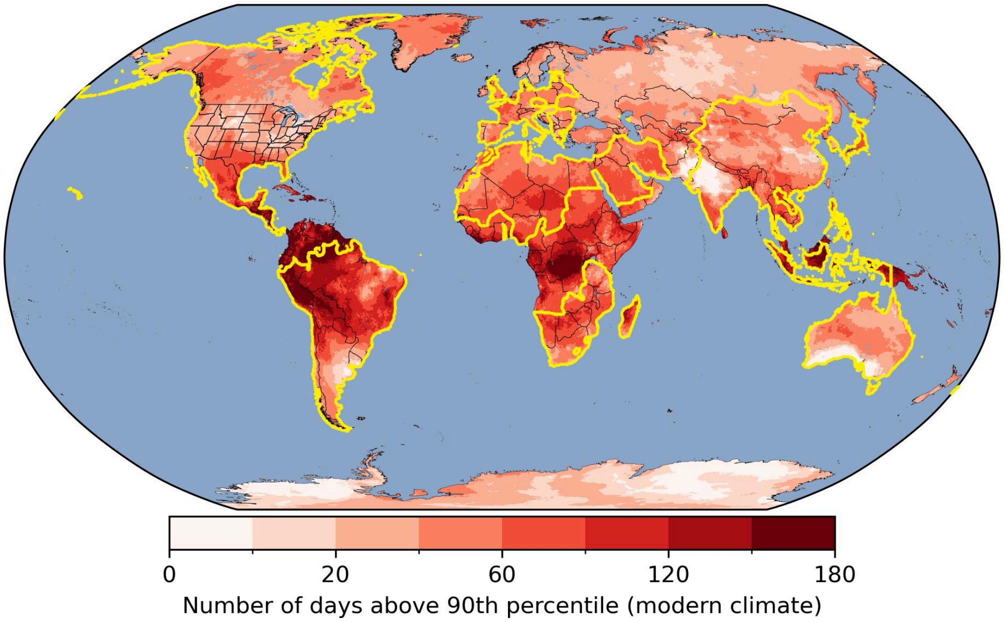

Figure 1. Number of days above the 90th percentile with a Climate Shift Index (CSI, see section 2) level 2 or higher. The yellow outlined regions represent countries with heat wave events identified by World Weather Attribution that occurred over May 15, 2023 to May 15, 2024. Analysis based on ECMWF ERA5 data. Produced May 22, 2024.

We also used the counterfactual temperatures to make a more direct estimate of how climate change influenced the experience of people with extreme temperatures during the last 12 months. Specifically, we count the number of days above the 90th percentile level and then subtract the number of times the counterfactual temperatures exceeded this level. This shows that human-induced climate change added an average of 26 days of unusually warm temperatures over the last 12 months (Figure 2).

Key findings:

- More than six billion people (6.3 billion) experienced at least 31 days with heat above the 90th percentile and at a CSI level of 2 or higher.
- The five countries where the average person experienced the most days with extreme heat[1] above their local heat level were Suriname with 182 days, Ecuador with 180 days, Guyana with 174 days, El Salvador with 163 days, and Panama with 149 days.
- Without human-induced climate change, the average person in Suriname would have experienced 24 such days. That number was 10 days for Ecuador, 33 days for Guyana, 15 days for El Salvador, and 12 days for Panama.

Next, we specifically estimated the influence of climate change on each of the 76 extreme heat events triggered by WWA criteria. To do so, we calculated the Probability Ratio (PR) of each event using the Climate Shift Index system (see Methods for an explanation of the calculation). The PR indicates the increase in likelihood of an event occurring as a result of climate change (a PR of 5 means that human-caused climate change made the event 5 times more likely). Each event was defined as the five days following the identified onset of the heat wave in the WWA criteria. For each identified event, the entirety of affected countries were treated as part of the heat wave. It is important to highlight that because we use a consistent definition of these heat waves for each country (a length of six days), rather than characterizing the heat waves based on the impacts as done in WWA studies (van Oldenborgh et al., 2021), the changes in likelihood differ quantitatively from studies undertaken by WWA. However, they all show qualitatively the same thing: human-induced climate change strongly increased the likelihood of these heat waves.

Key findings:

- The event with the highest PR was experienced in Oceania: the Marshall Islands and Micronesia experienced an event from March 7-12, 2024 with a PR of 35. Two heat waves covering both Indonesia and the Philippines had the second and third highest PRs. The first of these events (October 26-31, 2023) had a PR of 25. The second one (April 2-7, 2024) had a PR of 29.
- In Africa, the event with the highest PR occurred in Tanzania from February 21-26, 2024 with a PR of 11.

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[1] Defined as days above the 90th percentile and at a CSI level of 2 or higher

- In North/Central America, the event with the highest PR covered the Dominican Republic, Costa Rica, Guatemala, Panama, and Honduras from March 22-27, 2024 with a PR of 13.
- In Europe, an event covering Spain and Portugal from August 7-12, 2023 had a PR of 8.
- In South America, the event with the highest PR covered Brazil, Argentina, Paraguay, and Bolivia from November 8-13, 2023, with a PR of 7.

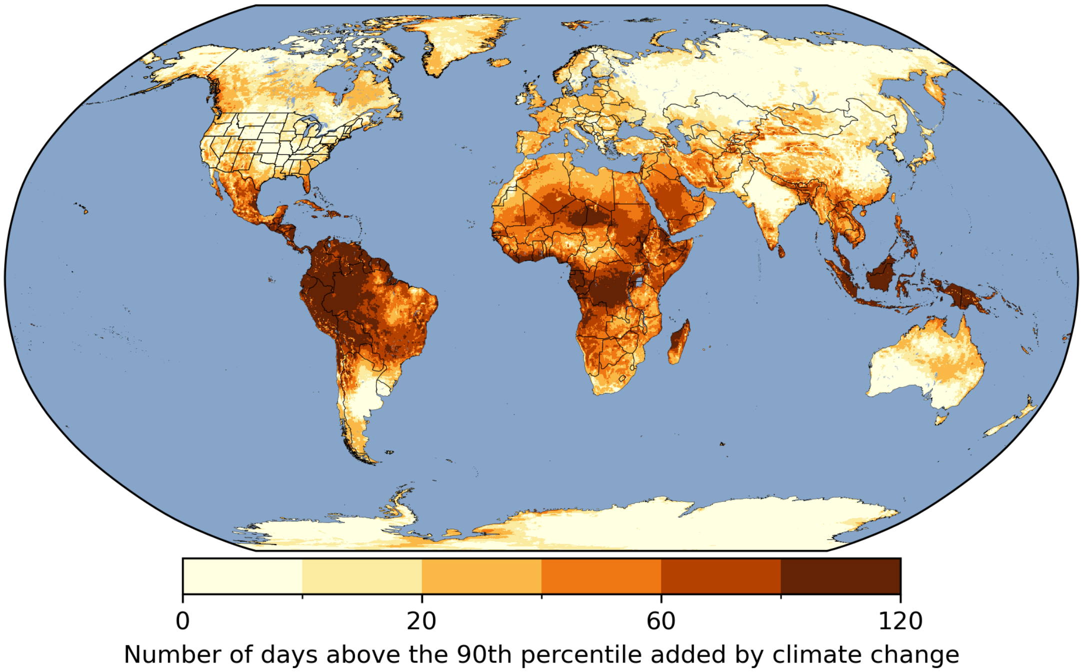

Figure 2. Additional days with temperatures above the 90th percentile in the current climate over May 15, 2023 to May 15, 2024, added by the burning of fossil fuels. Produced May 21, 2024.

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.

3. The crucial role of impacts in extreme heat assessment

Globally, extreme heat is among the deadliest natural hazards, with thousands of people dying from heat-related causes each year (The Lancet, 2021). For example, in the summer of 2022, an estimated 61,672 heat-related fatalities occurred across Europe (Ballester et al., 2023).

While Europe is a fast-warming continent with infrastructure that is not built to withstand rising temperatures, plus an aging population highly vulnerable to extreme heat, it is not the only region vulnerable to extreme heat impacts. However, with some notable exceptions that also include North America and India among others, impacts of extreme heat are only sporadically reported in the media across all regions. The full impact of extreme heat is often not known until weeks or months afterward, once death certificates are collected or scientists can analyze excess deaths. In many cases, the full extent of its impact on human health is never truly known because heat-related deaths are often attributed to other causes like kidney failure or cardiac arrest, even though those deaths may not have occurred had the high temperatures not exacerbated someone's pre-existing condition. Often, they are not counted at all. While excess deaths should show this, many countries are lacking full death records. Limited reporting on heat-related impacts greatly hampers our ability to understand the true scale and full spectrum of impacts associated with extreme heat.

Extreme heat brings multifaceted impacts that compound and cascade across various sectors, as illustrated in the interconnected pathways in Figure 3. These impacts are most evident for (but not limited to) health, water, agriculture, economy, livability, critical infrastructure, and the environment.

In the environment, extreme heat increases the risk of wildfires, air pollution, and the loss of biodiversity. Extreme heat also strains healthcare services due to heat-related illnesses. Health impacts include increased morbidity and mortality, exacerbation of mental health issues, and strain on emergency medical facilities. These health effects are compounded by critical infrastructure failures, such as electricity blackouts and transportation disruptions, which impede access to essential services.

Water resources are heavily impacted, with reduced water quality and increased demand leading to potential shortages and a higher risk of waterborne diseases. Extreme temperatures and water stress adversely affects agriculture, causing crop damage, reduced yields, and heightened food insecurity. The agricultural impacts then ripple through the economy, reducing food production, affecting livelihoods, and disrupting industrial activities. Water is also a critical component of energy production; thermoelectric plants use it to cool equipment and hydroelectric plants rely on water flow to spin turbines. A reduction in energy production can have knock-on effects, increasing power cuts when electricity is most needed.

Livability is compromised as extreme heat intensifies discomfort in indoor and outdoor spaces, increases aggression, and heightens social conflict. The compounded effects across sectors underscore the systemic nature of extreme heat impacts, where disruptions in one area can cascade, amplifying challenges in others, ultimately stressing the social, economic, and environmental fabric of communities.

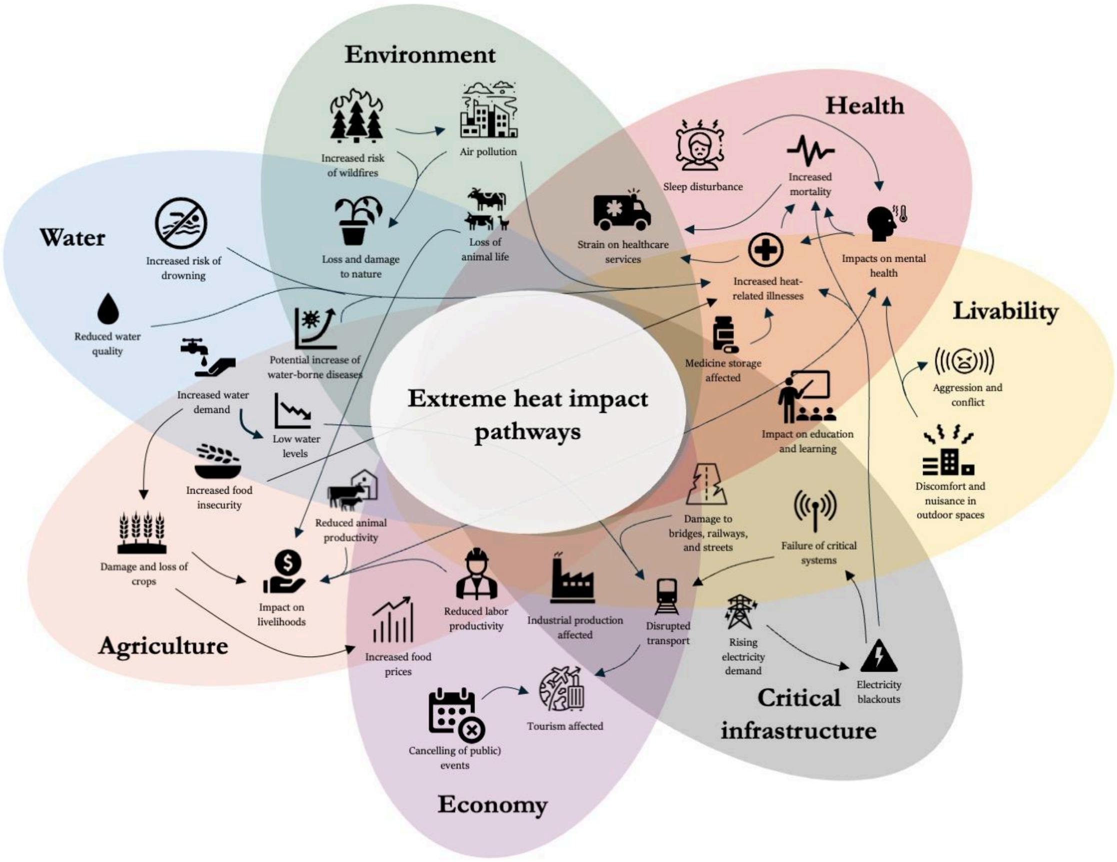

Figure 3. Interrelated and compounding impacts resulting from extreme heat.

Despite the occurrence of severe heat-related emergencies across the world in recent years, reliable data and comprehensive reporting on impacts are often lacking, with the largest gaps across many developing countries in Africa, Asia, and Latin America (Campbell et al., 2018). For example, for many of the heat events that have triggered based on the WWA trigger methodology since last year, we are only aware of extreme temperature records. Information about impacts to human health, agriculture, or other systems are not available. In fact, few countries keep comprehensive records of heat waves and the impacts they cause, such as excess mortality. Notably, this means currently available global mortality figures are likely a severe underestimate (see e.g. Zhu et al., 2024; Zhao et al., 2021).

Conceptualizing, monitoring, detecting, documenting, and communicating heat-related events and impacts face numerous challenges and barriers, ultimately impeding effective public health responses and a realistic estimate of financial requirements, and thus flows of finance. A primary challenge is the absence of standardized heat wave definitions and thresholds (Awashti et al., 2022), complicating systematic monitoring and cross-regional reporting of heat-related impacts. Additionally, comprehensive and standardized data collection systems to track heat-related illnesses, deaths, and disruptions across sectors are lacking, leading to underreporting and misdiagnosis of heat-related cases. This issue is exacerbated by limited data integration and sharing among health, meteorological, and emergency services (PAHO, n.d.), and the absence of robust surveillance systems (IFRC, 2022), particularly in developing countries, where tracking heat impacts is less feasible due to resource constraints.

Existing monitoring systems often fail to provide nationally representative data, underestimating the true burden of heat-related impacts. For instance, reliance on emergency department visits alone skews data, as not all cases are captured (see e.g. Vaidyanathan et al., 2024; Schramm et al., 2021). This is especially prevalent among developing countries with limited health system coverage. Further, attributing excess mortality to heat is particularly challenging for people with underlying health conditions, due to difficulties in isolating heat as the sole cause of death when comorbidities and older age increase vulnerability to heat-related illness and mortality (Kristie et al., 2021). This also means that heat-related health impacts may be misdiagnosed or attributed to other causes. Resource and capacity constraints, including limited funding, inadequate infrastructure for real-time data collection, and a shortage of trained personnel, further hinder effective monitoring and analysis of heat-related data (Murage et al., 2024; IFRC, 2022).

Coordination and communication barriers present additional obstacles. Responsibilities among various agencies involved in heat monitoring and response notably are often fragmented, leading to ineffective communication and dissemination of heat-related information and alerts. Public awareness of heat-related risks remains low (Eady et al., 2020; WHO, 2018; Howe at al., 2018; Beckmann & Hiete, 2020), impacting the reporting and management of heat-related incidents. Coordination between meteorological services and health sectors is crucial yet insufficiently implemented, reducing the potential for meteorological data to inform health and emergency response decision-making.

Vulnerable populations, such as the elderly, low-income, and marginalized communities, often have less access to healthcare systems. Differences in heat exposure, acclimatization, and adaptation strategies across regions further complicate the attribution of impacts to heat events, especially when considered alongside other environmental stressors and the overarching challenge of climate change.

Addressing these multifaceted barriers to fully understand, and in turn prevent, the human toll of extreme heat requires a concerted effort to improve data and reporting systems, enhance coordination, and increase public awareness and resources dedicated to heat-related monitoring and response.

The Red Cross Red Crescent Climate Centre is a climate reference center supporting the global Red Cross Red Crescent humanitarian movement and its partners to reduce the impacts of extreme weather events on the most vulnerable people.

4. Actionable solutions to heat risks

Deaths from extreme heat are preventable. There are a myriad of options available to reduce exposure to extreme heat that range from low or no-cost individual actions, to population-scale interventions that decrease the urban heat island effect.

For example, at the individual level, actions can include behavioral adaptations such as spending less time outdoors during the hottest time of the day, or drinking water at regular intervals. People can use cooling devices to cool the air (fans, A/Cs, evaporative coolers, etc.) or use low-tech cooling methods that directly reduce body temperature such as self-dousing with water. People can modify their built environment by increasing shade on exterior surfaces or windows (e.g. shutters, solar shades, awnings, shade trees), improving ceiling and roof insulation, or increasing the reflectivity of their roofs by painting them white. All of these are evidence-based interventions that can reduce the impacts of heat risk, which should be communicated to people widely. But individual actions are often not enough. Access to water, electricity, and shade when needed is a luxury for the most vulnerable, and the scale of the issue requires collective action — at the community, city, regional, and country levels.

Cities are hotspots of heat risk, but can also be drivers of action to protect the people living in them from extreme temperatures through the development of City Heat Action Plans (HAPs). City Heat Action Plans integrate actions across timescales — from the imminent extreme heat to seasonal preparedness — and long-term urban planning. They provide a plan for different municipal departments and non-governmental actors to work together, outlining roles and responsibilities such as communication, emergency response, and health system strengthening. While many cities in North America, Europe, Australia, and now in India have HAPs, there is a large gap in Africa, the Middle East, South America, and in Small Island Nations. Rapidly rising temperatures necessitate that these regions quickly bolster their planning for extreme heat. Without adaptation measures, the impacts across all sectors, especially human health, are certain to increase (IPCC, 2023).

Additional measures to reduce extreme heat impacts at the population level include:

- Strengthening crucial service provision systems, such as ensuring emergency health services are able to expand and absorb increased demand for treatment during extreme heat events.
- Incorporating cooling needs into social protection programs that supplement energy costs of the most vulnerable.
- Ensuring water and electricity systems are able to meet increased demands without being overwhelmed.
- Bolstering transport systems to ensure they remain operational and accessible during extreme heat events.

- Strengthening early warning system coverage and efficacy.
- Legislating building codes to encourage passive and active cooling measures.
- Passing and enforcing worker safety laws.
- Enhancing cold storage to reduce agriculture supply chain losses.
- Designing towns and cities with cool spaces in close proximity to all residents.

There is evidence that many of the measures mentioned above are effective. A review of assessments reported that in a majority of places where there was extreme heat, there was a reduction of adverse effects where preventive measures had been implemented (Boekmann & Rohn, 2014). Despite the availability of actions to reduce heat risks, these are not equally available to everyone everywhere. Many developing countries are playing catch up on adaptation while also facing the highest rates of increase in temperatures and population-level vulnerability, putting them at higher risk (IPCC, 2023). It is imperative that in addition to adapting to extreme heat, we must reduce greenhouse gas emissions to net zero in order to put the brakes on further rising temperatures. ■

Methods

Calculating the Climate Shift Index (CSI)

Calculating the CSI begins with high-resolution daily temperatures (high, low, and daily average). For this report, Climate Central scientists (we) use ERA5 data from May 15, 2023 to May 15, 2024. We estimate how often the temperature at a particular location is likely to occur in the current climate using both historical observations (ERA5) and 24 climate models. We also estimate the likelihood in a climate without human-caused climate change. The CSI is built from the ratio of these two likelihoods.

Based on the multi-model approach described in Gilford et al. (2022), the CSI combines several different techniques for estimating the frequency of a given temperature occurring in the current climate and in a climate without human-caused climate change. Two of the techniques use 70 years of historical temperature reconstructions. The other technique uses 24 state-of-the-art global climate models run with and without carbon dioxide emitted by human activities over the historical period.

Calculating days above the 90th percentile

To calculate the number of days with temperatures above the 90th percentile in the modern climate with a climate change fingerprint, we compiled ERA5 data from 1991 to 2020. We then calculated the 90th percentile temperature of all average daily temperatures for each ERA5 grid cell over this time period. For each average daily temperature from May 15, 2023 to May 15, 2024, we found the days where temperatures exceeded their associated 90th percentile temperature threshold from the 1991-2020 period and experienced a CSI greater than or equal to 2. The number of days that fulfilled these criteria were added up to compute a final number for days above the 90th percentile with a climate fingerprint in the modern climate.

To calculate the number of days with temperatures above the 90th percentile in the counterfactual climate (the climate in a world where climate change hasn't occurred), we calculated the likelihood as a percentile of daily average temperatures occurring from May 15, 2023 to May 15, 2024 in the modern climate. Next, we applied that percentile to the counterfactual climate to compute what the equivalent temperature would have been in the counterfactual climate. We found those days where counterfactual temperatures exceeded their associated 90th percentile temperature threshold from the 1991-2020 period, and experienced a CSI value greater than or equal to 2. The number of days that fulfilled these criteria were added up to compute a final number for days above the 90th percentile with a climate fingerprint in the counterfactual climate.

To find the number of days above the 90th percentile added by climate change, the number of days above the 90th percentile in the counterfactual climate was subtracted from the number of days above the 90th percentile in the modern climate.

To find the average values per country for these values, we averaged final values (number of days) across the country by weighting based on population density in each ERA5 grid cell.

Calculating probability ratios for triggered heat events

For each triggered heat wave identified by World Weather Attribution from May 15, 2023 to May 15, 2024, we compiled the onset date of that event as well as the affected countries. We used an event length of six days. Next, for each event, we found the daily climate factors (a value derived to generate the Climate Shift Index that is a measurement of the increase in likelihood due to climate change of a temperature occurring). To find the climate factor of the event as a whole, we found the variance associated with the daily temperatures in each location for days within the event from 1991-2020. We then calculated the yearly means for those same daily temperatures from 1991-2020, before calculating the variance of these yearly means. By multiplying the ratio of the two (the daily temperature variance to the yearly temperature variance) by the mean climate factor, we calculated variance-scaled climate factors. This translates a sequence of changes in likelihoods to a single comprehensive value. To find the mean climate factor of an event, we found the spatial mean of the variance-scaled climate factors across the affected countries. Finally, we converted climate factors to Probability Ratios.