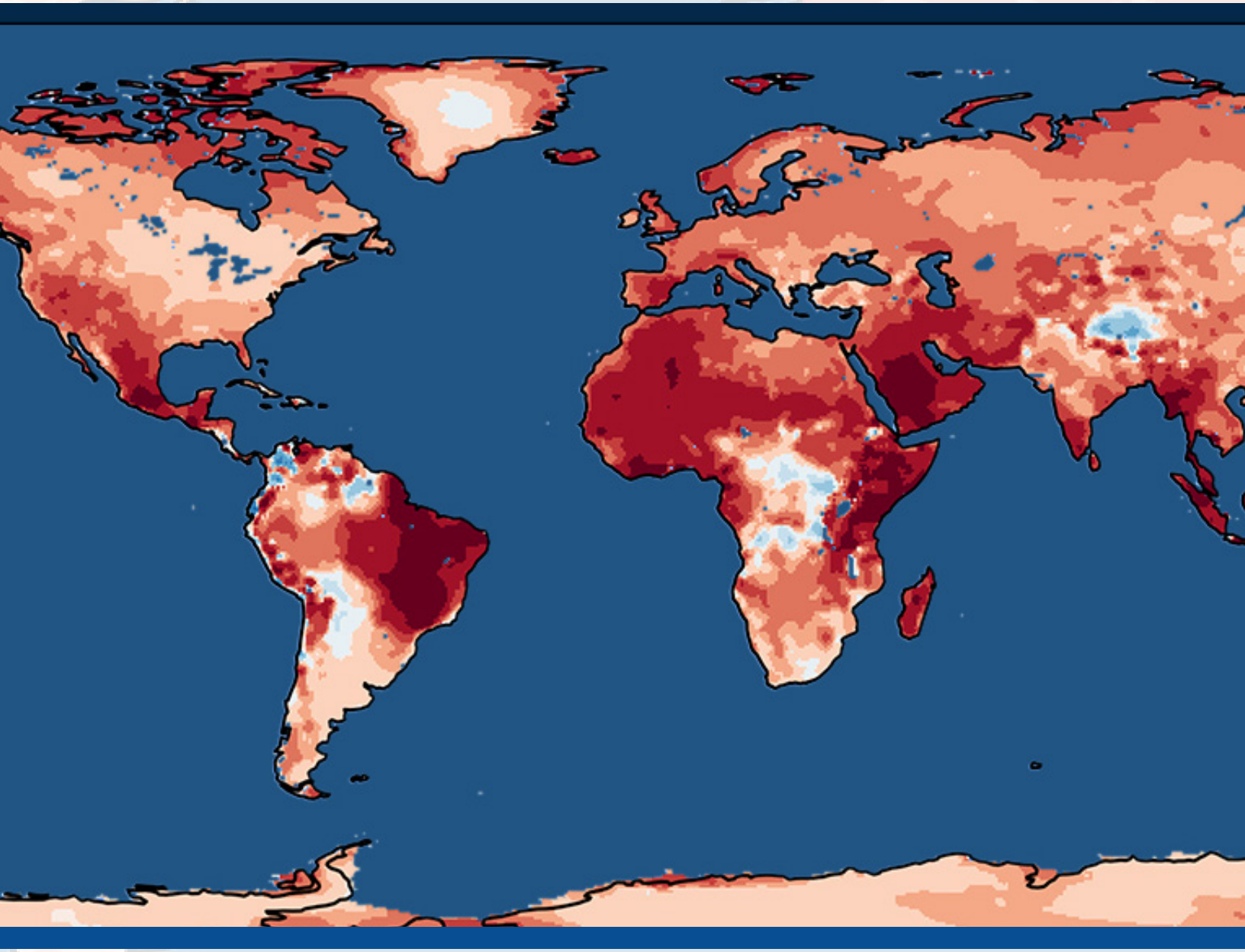
365 Days on a Warming Planet

Revealing the fingerprints of human-caused climate change on daily temperatures around the world—using the Climate Shift Index



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October, 2022

365 Days on a Warming Planet

Key Facts

- Climate Central is launching the Global Climate Shift Index (CSI-Global)—a new tool that quantifies the local influence of climate change on daily temperatures around the world.
- Climate Central's first-ever global CSI analysis reveals the influence of human-caused climate change on **daily average temperatures** for each of the **365 days** from October 1, 2021 to September 30, 2022 **across the globe**—including **1,000+ global cities**.
- **Human-driven warming affected everyone, everywhere.** Over the last 12 months, human-caused climate change affected temperatures experienced by 7.6 billion people. That's nearly every person on the planet (96% of the global population).
- **Those living near the equator and on small islands were especially impacted**. Mexico, Brazil, western and eastern Africa, the Arabian Peninsula, and the Malay Archipelago experienced the strongest influence of human-caused climate change on temperatures over the 365 days analyzed.
- **On each of the 365 days analyzed, at least 200 million people felt the fingerprint of climate change.** The number of people exceeded 1 billion on 75 of those days. Global exposure peaked on October 9, 2021, when more than 1.7 billion people worldwide experienced warm conditions that were made at least three times more likely due to human-caused climate change.
- **Hotspots of human exposure**: When accounting for urban population size, the total human exposure to daily temperatures altered by climate change was highest in Lagos, Nigeria; Mexico City, Mexico; and Singapore.

INTRODUCTION

Humans have caused global average temperatures to increase by 1.1°C (2°F) since 1850. But people don't experience global average temperatures. Instead, we mainly experience climate change through shifts in the daily temperatures and weather patterns where we live.

Recent scientific advances now make it possible to measure the influence of climate change on daily weather. In 2022, Climate Central developed the Climate Shift Index tool to do this daily. The Climate Shift Index (CSI) quantifies how much climate change has changed the odds of daily temperatures that people experience in their own backyards or city blocks. The CSI is grounded in peer-reviewed climate change attribution science, continuing Climate Central's contributions to this groundbreaking area of research.

Here, we report results from the first-ever global CSI analysis carried out by Climate Central. The analysis puts a CSI value on the daily average local temperatures experienced across every continent for each of the 365 days from October 1, 2021 to September 30, 2022. We also include population data to quantify how many people worldwide have experienced temperatures altered by climate change over these 12 months.

This report has two main components:

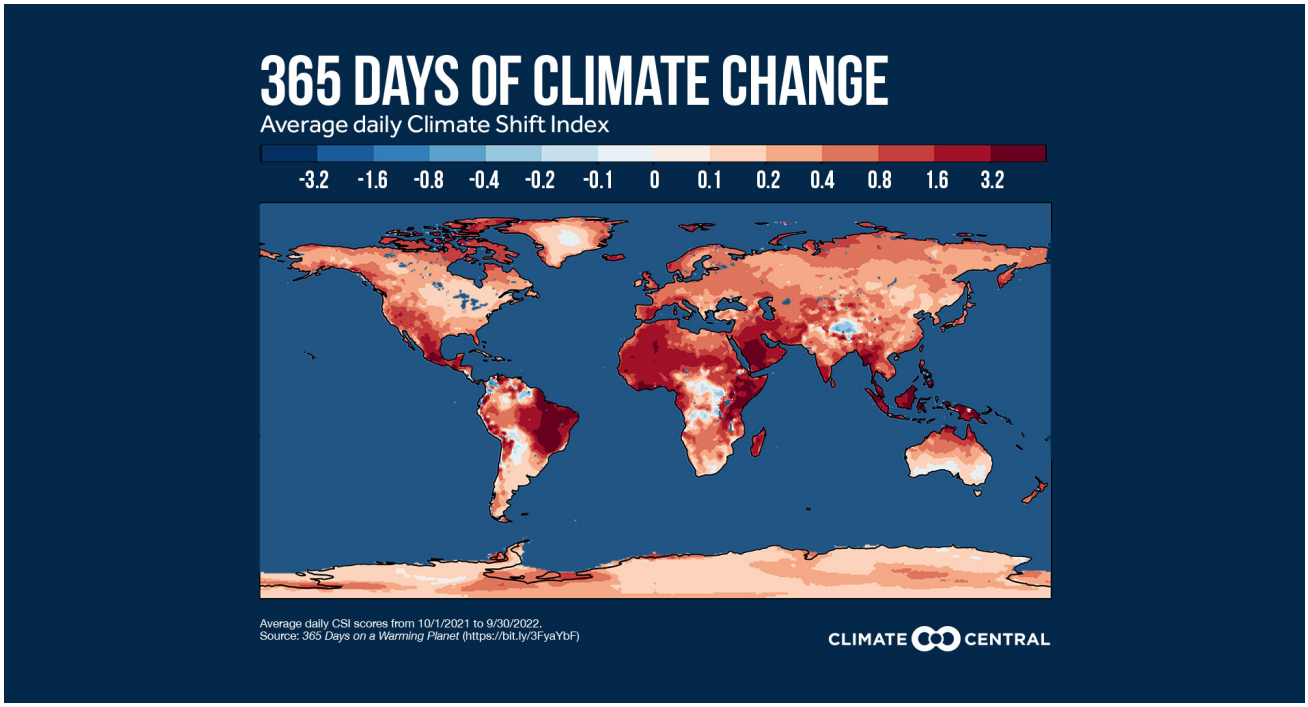
Fingerprints of climate change on heat events. First, we use the Climate Shift Index to pinpoint the day when each continent had the largest signal of human-caused climate change. This shows how the CSI can identify heat events around the world that may receive less attention but nonetheless may have significant impacts on the people who experience them.

Fingerprints of climate change on global cities. Second, we determine 365 daily CSI levels for over 1,000 major cities around the globe. For each of these cities, we determine the number of days that had temperatures that were made more likely by human-caused climate change. We use population data to determine total human exposure to days with significant climate fingerprints over the last year.

RESULTS

According to our analysis, 96% of the world's population—7.6 billion people—experienced daily temperatures that were made warmer by human-caused climate change over the study period (October 1, 2021 through September 30, 2022). Most places on Earth had a positive Climate Shift Index (Figure 1) indicating not only that many places have warmed, but also that they are warmer due to human-caused climate change.

Figure 1



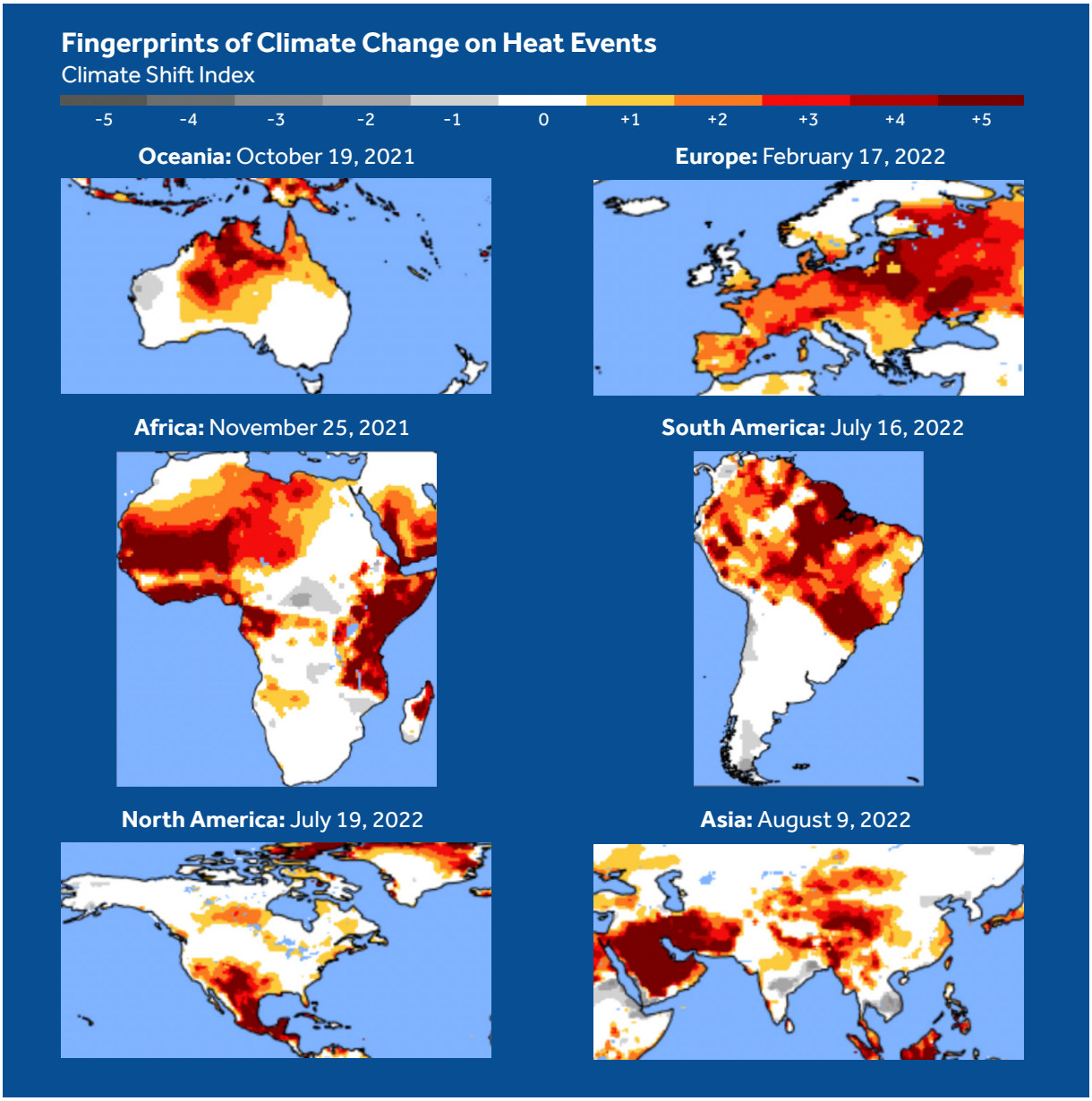
Annual average Climate Shift Index (CSI) levels were especially high in the Malay Archipelago (which includes Indonesia, the Philippines, Singapore, and Papua New Guinea), northern and central-west Brazil, the Arabian Peninsula, the Horn of Africa, and Mexico. These regions tend to have relatively small day-to-day changes in temperature, so even a small absolute increase in their local temperatures due to global warming results in a relatively large increase in the CSI level. Several of these locations are also surrounded by the ocean. Ocean warming is one of the strongest signals of climate change, and the heat stored in the ocean boosts the temperatures at these locations, especially at night.

FINGERPRINTS OF CLIMATE CHANGE ON HEAT EVENTS

For each continent, we determined the day with the highest CSI level averaged over the land area (Figure 2). Peak continental CSI days were spread throughout the 12 months of the study period.

- Oceania (including Australia and New Zealand) had a peak in mid-October 2021 that was driven by high CSI values in northern and central Australia.
- Africa's peak CSI day in late November, 2021 was driven by high CSI values stretching from western Africa to northern Africa, as well as the eastern coast. The Sahel in particular stands out as a region of high CSI.
- Europe's peak CSI day in mid-February, 2022 was driven by high CSI levels across the continent, especially in Poland and Ukraine.
- Peak CSI days in North and South America were within days of each other in mid-July, 2022, with large areas of the southern U.S., Mexico, and Central America and the northern half of South America experiencing high CSI levels.
- Asia's peak CSI day was in mid-August, 2022 driven by large swaths of high CSI levels in the Arabian Peninsula, Central Asia, the Malay Archipelago, and western China.

Figure 2



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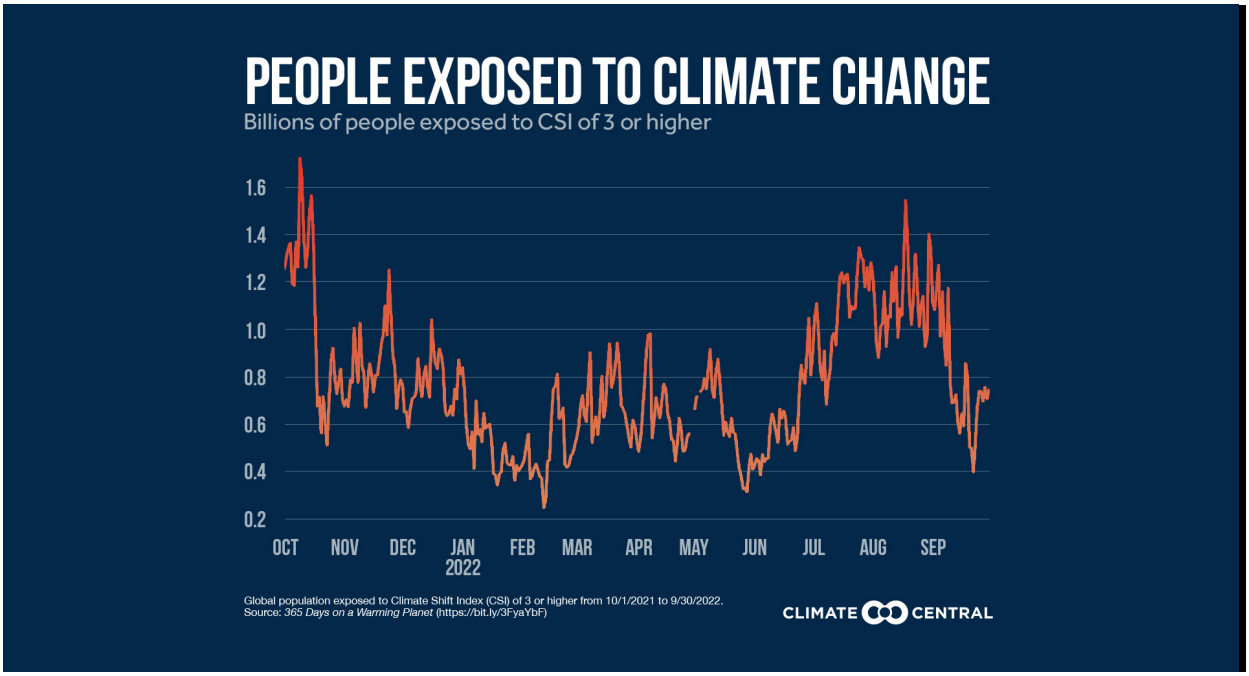
Peak continental CSI days did not necessarily coincide with major heat waves. For example, although Spain, France, and the United Kingdom all had high CSI levels during a July 18-19, 2022 heat wave (consistent with independent analysis finding that climate change made the extreme summer temperatures more likely), the CSI analysis for all of Europe indicates that climate change had a more widespread influence on temperatures in February.

Figure 3



The total number of people experiencing CSI levels of 3 or higher fluctuated across the study period (Figure 3). On each of the 365 days analyzed, at least 200 million people around the world experienced temperatures that were three times more likely due to climate change. The total number of people affected increased dramatically during the Northern Hemisphere summer. During most days in July and August, at least 1 billion people experienced temperatures that were significantly altered by human-caused climate change. In total, there were 75 days where more than 1 billion people experienced CSI level 3 or higher.

The Climate Shift Index (CSI)

Climate Central launched the first operational daily attribution service based on the CSI in June 2022. The debut service, CSI-USA, focuses on the continental United States. The CSI-Global tools use the same CSI scale.

The CSI scale is centered on zero. A CSI level of zero means that there is no detectable influence of human-caused climate change on the temperature on that day–the temperature is equally likely in both the modern climate and one without global warming. Positive CSI levels 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. Events above this level are unusual and likely require special statistical techniques.

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

There were several other notable spikes in global population exposure:

- On April 8, 2022, during a heat wave in India and Pakistan, over 900 million people experienced CSI levels of 3 or higher.
- The maximum population exposure occurred on October 9, 2021, when much of Southeast Asia and the Malay Archipelago, as well as parts of India, western Africa, and the Arabian Peninsula experienced high CSI levels. On that single day, more than 1.7 billion people worldwide—more than 20% of the human population—experienced warm conditions that were made much more likely due to human-caused climate change.

CSI-Global: Tools, Data, and Custom Alerts

Here are three ways to use Climate Central's global CSI analysis:

- **Sign up for alerts.** Beginning today (October 27, 2022) and running through the scheduled end of COP27 (November 18, 2022), Climate Central will distribute daily emails summarizing conditions on that day for the 1,000+ cities featured in this report. Sign up here to receive these summaries and to be notified when we begin permanent ongoing services in 2023.
- **Use the tools.** Climate Central is also creating an online map tool to allow you to see which parts of the world are experiencing high CSI levels. This tool will be available going forward and updated daily.
- **Explore the data.** The city-level summary data from this report are available to download. Dive into the data to see in more detail how climate change affected people in over 1,000 global cities over the last year.

FINGERPRINTS OF CLIMATE CHANGE ON GLOBAL CITIES

People experience climate change where they live, and more than half of the global population now lives in urban areas. To understand this perspective, we identified 1,021 cities from around the world and computed their daily CSI scores. The cities include major population centers (see Methods for criteria), national capitals, and Climate Central's standard set of 246 U.S. cities. We averaged the daily CSI levels over the study period and computed the number of days with a CSI level of 3 or higher.

The entire list of cities and their statistics for the study period are available here. As a high-level summary, we ranked the cities in each continent by their average CSI, and the total number of days over the study period that had CSI levels of 3 or higher.

Cities in small island developing states had the highest average CSI scores. Apia, Samoa and Ngerulmud, Palau are the top two cities in terms of average daily CSI scores. Both cities also experienced the most total days with CSI scores of 3 or higher: 331 and 328 days, respectively, or over 90% of the last 365 days.

Urban residents felt the fingerprints of climate change. In 26 cities, at least 250 (69%) of the 365 days analyzed had temperatures that were at least three times more likely due to climate change. These 26 cities were in east Africa, the Malay Archipelago, Mexico, Brazil, and small island developing states in the Caribbean and Oceania. A total of 143 cities with 174 million inhabitants had more than 100 days at CSI level 3 or higher.

More than 100 cities were hotspots of human exposure. Global cities range vastly in population size. According to the UN, while 33 megacities have populations larger than 10 million, nearly half of the global urban population lives in settlements with populations smaller than 500,000. When accounting for the number of people in each of the 1,000+ cities analyzed (i.e., multiplying the population of each city by the total number of days with CSI levels of 3 or higher in that city), CSI-Global reveals that the total number of "people-days" over the study period exceeded 1 billion in:

- Lagos, Nigeria (2.8 billion people-days)
- Mexico City, Mexico (2.0 billion people-days)
- Singapore (1.2 billion people-days)

There were 121 cities with more than 100 million people-days over the study period, including major cities such as Shanghai, China; Beijing, China; Tokyo, Japan; Mumbai, India; São Paulo, Brazil; Jakarta, Indonesia; and Cairo, Egypt. It is notable that no cities in the United States and only one city in Europe (Madrid, Spain) appear on this list.

African cities feeling the heat. Moroni, Comoros and Mogadishu, Somalia were the top two cities in Africa in terms of average CSI (4.1 and 3.4, respectively) and number of days with CSI levels of 3 or higher (296 and 254, respectively). When accounting for urban population, Lagos, Nigeria experienced the highest total human exposure (2.8 billion people-days) globally over the study period. Four other African cities experienced total human exposure greater than 500 million people-days: Abidjan, Côte d'Ivoire (886 million people-days); Nairobi, Kenya (765 million people-days); Dar es Salaam, Tanzania (650 million people-days); and Mogadishu, Somalia (538 million people-days).

CONCLUSIONS

The human causes of global climate change have been known for decades. However, people do not experience the global average temperature; they experience the day-to-day changes in temperature and weather patterns where they live. The Climate Shift Index was designed to bridge the gap between global climate change and people's everyday experience.

Climate Central's analysis of 365 days through the lens of the CSI reveals that the fingerprint of climate change is already detectable in the daily lives of nearly everyone on the planet. However, this experience is not evenly distributed in space or time. People living near the equator or on islands surrounded by heat-storing ocean water are already experiencing more days with strong climate fingerprints. People living in these places have contributed less to the global carbon problem, yet the CSI reveals that, over the last 12 months, they've experienced more days altered by climate change than anywhere else on Earth. As the climate continues to warm, those impacts will almost certainly intensify.

Top 10: Africa

Average CSI		High-CSI days: Days with CSI = 3 or higher		Human Exposure: High-CSI days X population	
Moroni, Comoros	4.1	Moroni, Comoros	296	Lagos, Nigeria	2,800,000,000
Mogadishu, Somalia	3.4	Mogadishu, Somalia	254	Abidjan, Côte d'Ivoire	886,000,000
Mamoudzou, Mayotte	2.8	Lomé, Togo	215	Nairobi, Kenya	765,000,000
Lomé, Togo	2.8	Mamoudzou, Mayotte	211	Dar es Salaam, Tanzania	650,000,000
Victoria, Seychelles	2.7	Victoria, Seychelles	203	Mogadishu, Somalia	538,000,000
Douala, Cameroon	2.5	Asmara, Eritrea	181	Addis Ababa, Ethiopia	447,000,000
Abidjan, Côte d'Ivoire	2.4	Lagos, Nigeria	181	Douala, Cameroon	436,000,000
Lagos, Nigeria	2.4	Douala, Cameroon	178	Antananarivo, Madagascar	287,000,000
Asmara, Eritrea	2.4	Abidjan, Côte d'Ivoire	178	Kumasi, Ghana	281,000,000
Porto Novo, Benin	2.3	Porto Novo, Benin	172	Accra, Ghana	254,000,000

Top 10: Asia

Average CSI		High-CSI days: Days with CSI = 3 or higher		Human Exposure: High-CSI days X population	
Zamboanga City, Philippines	3.9	General Santos, Philippines	285	Singapore	1,230,000,000
Makassar, Indonesia	3.8	Zamboanga City, Philippines	283	Riyadh, Saudi Arabia	957,000,000
General Santos, Philippines	3.8	Male, Maldives	280	Tehran, Iran	939,000,000
Male, Maldives	3.7	Makassar, Indonesia	279	Chennai, India	875,000,000
Banjarmasin, Indonesia	3.5	Bagam, Indonesia	259	Bangalore, India	574,000,000
Batam, Indonesia	3.5	Banjarmasin, Indonesia	254	Baghdad, Iraq	544,000,000
Davao, Philippines	3.2	Davao, Philippines	230	Jakarta, Indonesia	538,000,000
Tasikmalaya, Indonesia	3.1	Tasikmalaya, Indonesia	223	Quanzhou, China	486,000,000
Mecca, Saudi Arabia	3.0	Singapore	219	Mumbai, India	449,000,000
Singapore	3.0	Mecca, Saudi Arabia	218	Guangzhou, China	435,000,000

Top 10: Europe

Average CSI		High-CSI days: Days with CSI = 3 or higher		Human Exposure: High-CSI days X population	
Longyearbyen, Svalbard	1.1	Valletta, Malta	77	Madrid, Spain	216,000,000
Madrid, Spain	1.1	Longyearbyen, Svalbard	72	Moscow, Russia	92,400,000
Valletta, Malta	1.1	Madrid, Spain	66	London, United Kingdom	88,300,000
Valencia, Spain	1.0	Valencia, Spain	59	Barcelona, Spain	85,900,000
Zaragoza, Spain	0.9	Zaragoza, Spain	58	Saint Petersburg, Russia	70,000,000
Douglas, Isle Of Man	0.9	Barcelona, Spain	53	Rome, Italy	57,500,000
Barcelona, Spain	0.9	Douglas, Isle Of Man	36	Valencia, Spain	46,600,000
Tórshavn, Faroe Islands	0.8	Gibraltar	34	Zaragoza, Spain	39,200,000
Genoa, Italy	0.7	Naples, Italy	34	Berlin, Germany	33,000,000
Naples, Italy	0.7	Genoa, Italy	33	Naples, Italy	32,800,000

Top 10: North America

Average CSI		High-CSI days: Days with CSI = 3 or higher		Human Exposure: High-CSI days X population	
Saint George's, Grenada	4.2	Saint George's, Grenada	309	Mexico City, Mexico	1,970,000,000
Road Town, British Virgin Islands	4.0	Road Town, British Virgin Islands	302	Puebla, Mexico	397,000,000
Charlotte Amalie, U.S. Virgin Islands	3.9	Charlotte Amalie, U.S. Virgin Islands	294	Guatemala City, Guatemala	349,000,000
Kingstown, Saint Vincent And The Grenadines	3.9	Kingstown, Saint Vincent And The Grenadines	285	León de los Aldama, Mexico	226,000,000
Fort-de-France, Martinique	3.7	Fort-de-France, Martinique	272	Morelia, Mexico	216,000,000
Roseau, Dominica	3.7	Roseau, Dominica	268	Querétaro, Mexico	139,000,000
Basse-Terre, Guadeloupe	3.5	Basse-Terre, Guadeloupe	257	Irapuato, Mexico	105,000,000
San Juan, Puerto Rico	3.5	San Juan, Puerto Rico	256	Havana, Cuba	98,500,000
Puebla, Mexico	3.5	Puebla, Mexico	252	San Luis Potosí, Mexico	83,500,000
Philipsburg, Sint Maarten	3.4	Saint John's, Antigua and Barbuda	246	San Juan, Puerto Rico	82,800,000

Top 10: South America

Average CSI		High-CSI days: Days with CSI = 3 or higher		Human Exposure: High-CSI days X population	
Fortaleza, Brazil	4.1	Fortaleza, Brazil	295	Fortaleza, Brazil	723,000,000
Natal, Brazil	3.6	Natal, Brazil	265	São Paulo, Brazil	674,000,000
Goiânia, Brazil	3.1	Goiânia, Brazil	221	Brasília, Brazil	561,000,000
Uberlândia, Brazil	3.0	Uberlândia, Brazil	210	Belo Horizonte, Brazil	368,000,000
Cayenne, French Guiana	2.8	Belém, Brazil	202	Goiânia, Brazil	308,000,000
Belém, Brazil	2.8	Valledupar, Colombia	202	Belém, Brazil	303,000,000
Valledupar, Colombia	2.8	Cayenne, French Guiana	196	Recife, Brazil	276,000,000
Brasília, Brazil	2.7	Ribeirão Preto, Brazil	188	Medellín, Colombia	273,000,000
Ribeirão Preto, Brazil	2.6	Brasília, Brazil	186	Salvador, Brazil	266,000,000
Abaeté, Brazil	2.6	Abaeté, Brazil	177	Natal, Brazil	233,000,000

Top 10: Oceania

Average CSI		High-CSI days: Days with CSI = 3 or higher		Human Exposure: High-CSI days X population	
Apia, Samoa	4.5	Apia, Samoa	331	Port Moresby, Papua New Guinea	29,200,000
Ngerulmud, Palau	4.5	Ngerulmud, Palau	328	Auckland, New Zealand	22,900,000
Port-Vila, Vanuatu	3.9	Palikir, Federated States of Micronesia	293	Port-Vila, Vanuatu	14,800,000
Palikir, Federated States of Micronesia	3.9	Port-Vila, Vanuatu	287	Apia, Samoa	12,500,000
Hagåtña, Guam	3.7	Capitol Hill, Northern Mariana Islands	273	Nouméa, New Caledonia	8,650,000
Capitol Hill, Northern Mariana Islands	3.7	Hagåtña, Guam	265	Papeete, French Polynesia	6,450,000
Flying Fish Cove, Christmas Island	3.4	Flying Fish Cove, Christmas Island	250	Majuro, Marshall Islands	6,240,000
Majuro, Marshall Islands	2.9	Majuro, Marshall Islands	208	Suva, Fiji	5,470,000
Mata-Utu, Wallis And Futuna	2.3	Funafuti, Tuvalu	180	Gold Coast, Australia	4,470,000
Funafuti, Tuvalu	2.2	Mata-Utu, Wallis And Futuna	162	Nuku□alofa, Tonga	3,160,000

METHODS

Calculating the Climate Shift Index

Calculating the CSI begins with high-resolution daily temperatures (high, low, and daily average). For this report, we use data from NOAA's Climate Forecast System. For our operational services, we use NOAA's Global Forecast System. We estimate how often the temperature at a particular location is likely to occur in the current climate. We also estimate the likelihood in a climate without human-caused climate change. The CSI is built from the ratio of these two likelihoods. For this report, we focus on daily average temperatures.

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.

Event Analysis

For our event analysis, we developed an objective way of identifying events with a strong climate fingerprint. First, we calculated the amount of land coverage for each continent that had a CSI level of 3 or higher. We then identified when and where the peak CSI level occurred during the study period. Data were smoothed using a 3x3 median smoother prior to mapping.

We also explored how many people experienced climate change throughout the year. For each day, we found the total number of people (data from NASA's Socioeconomic Data and Applications Center) exposed to CSI levels of 3 or higher.

City Analysis

We first compiled a list of representative cities. This list includes

- National capitals (244)
- Cities in the U.S. included in Climate Central's Climate Matters Program (246)
- Cities in China with more than 5,000,000 people (80)
- Cities in India with more than 1,000,000 people (47)
- Cities in other countries with more than 500,000 people (692)

These criteria result in a set of 1,021 cities that cover the continents at a reasonable density without being overly-biased toward particular countries. We also included Sharm El-Sheikh, the location of the upcoming 2022 United Nations Climate Change Conference, more commonly referred to as COP27.

For each city, we extracted the time series of 365 daily average CSI levels from the nearest location in the gridded data. We then averaged the daily CSI levels over the study period and computed the total number of days with CSI levels of 3 or higher. We also developed a metric of human exposure to climate change by multiplying each city's total number of days with CSI levels of 3 or higher by the number of people in that city. This population-weighting approach produces the "people-days" units reported in the Results section of this report.

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