Mapped: How climate change affects extreme weather around the world

18 November 2024

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In 2004, a trio of researchers published a study that accomplished something never seen before. They calculated the specific contribution that human-caused climate change made to an individual extreme weather event.

The extreme event in question was the European heatwave in the summer of 2003. Week upon week of extreme heat had a devastating impact, killing more than 70,000 people across the continent.

The scientists worked out that human influence had at least doubled the risk of such an extreme heatwave occurring. The findings made headlines around the world.

The study kick-started the scientific field of "extreme event attribution".

Attribution studies calculate whether, and by how much, climate change affected the intensity, frequency or impact of extremes – from wildfires in the US and drought in South Africa through to record-breaking rainfall in Pakistan and typhoons in Taiwan.

To keep track of this rapidly growing field of research, Carbon Brief has mapped every published study on how climate change has influenced extreme weather.

Further reading:
Q&A: The evolving science of 'extreme weather attribution'

This latest iteration of the interactive map (below) includes more than 600 studies, covering almost 750 extreme weather events and trends.

Across all these cases, 74% were made more likely or severe because of climate change. This includes multiple cases where scientists found that an extreme was virtually impossible without human influence on global temperatures.

Around 9% of the events and trends in the map were made less likely or severe by climate change.

This means that, overall, 83% of the events and trends included in the map were found to have been influenced by human-caused climate change.

In the remaining 17% of cases, the studies either found no human influence (10%) or they were inconclusive (7%), often due to insufficient data.

First published in July 2017, this is the sixth – and most comprehensive – update to Carbon Brief's map.

Studies of almost 750 events and trends reveal the impact of climate change on extreme weather.

Explore the studies either via the map or by the panel of controls below.

Finding   Event type

How did climate change influence
the weather event:

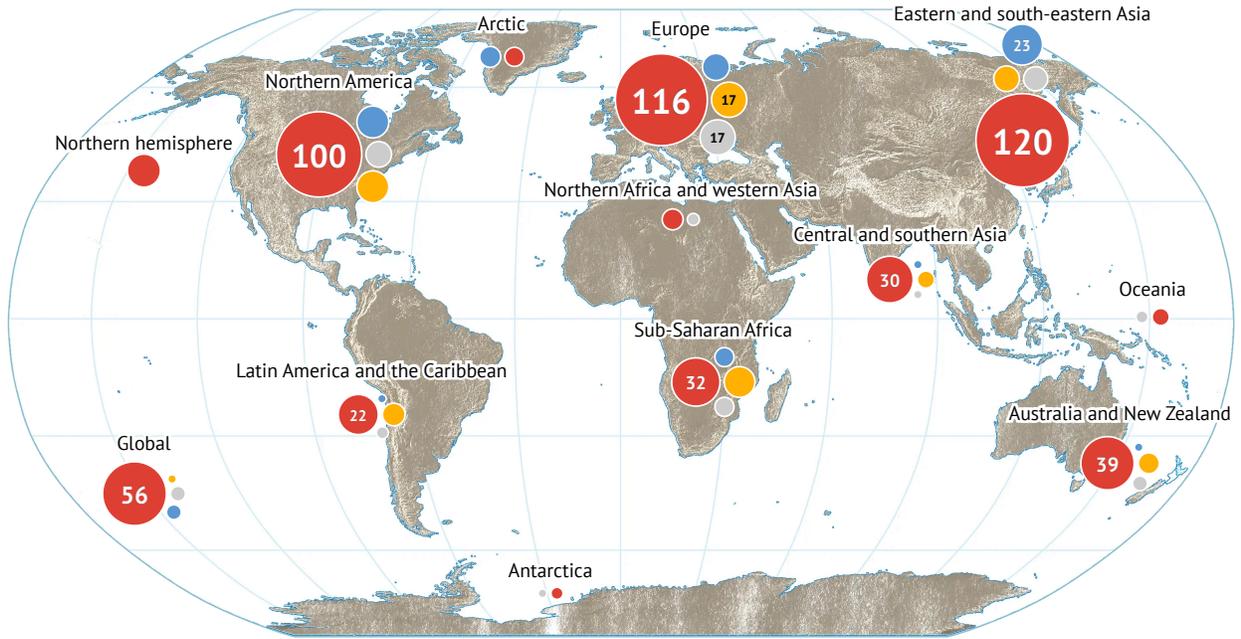|	
More severe or likely	547
Had no influence	71
Less severe or likely	64
Inconclusive	53

Explore further:

Choose a c ⌄

Explore all cases

Last updated 18 November 2024

Get the data (.csv)

Extremes across the world

In total, the map (above) contains 735 extremes from 612 studies. This is a combination of individual events, such as the Australian bushfires of 2019-20, and trends of how extremes are changing, such as a 2020 study into marine heatwaves over the past four decades.

Australian bushfires, 2019-20

Case 395

WILDFIRE — MORE LIKELY · MORE SEVERE · MORE LIKELY · MORE SEVERE

Event type
Wildfire

Finding
More severe or more likely to occur

"[W]e find that climate change has induced a higher weather-induced risk of such an extreme fire season. This trend is mainly driven by the increase of temperature extremes."

Marine heatwaves, 1981-2017

Case 339

OCEANS — MORE LIKELY · MORE SEVERE · MORE LIKELY · MORE SEVERE

Event type
Oceans

Finding
More severe or more likely to occur

"We show that the occurrence probabilities of the duration, intensity, and cumulative intensity of most documented, large, and impactful MHWs have increased more than 20-fold as a result of anthropogenic climate change."

Natural Hazards and Earth System Sciences (2021)
van Oldenborgh, G. J. 2021: Attribution of the
Australian bushfire risk to anthropogenic climate
change, Nat. Hazards Earth Syst. Sci, DOI:
10.5194/nhess-21-941-2021

Science (2020) Laufkötter, C. et al. 2020: High-impact
marine heatwaves attributable to human-induced
global warming, Science,
DOI:10.1126/science.aba0690

Where a single study covers multiple events or locations, these have been separated out into individual entries on the map (where possible).

Such is the sheer quantity of attribution studies, the new map displays them in regional summaries, rather than individual events or trends. (The regions follow those used by the UN, except the UN's "Europe and Northern America" region has been divided into two.)

By default, the map displays the data by attribution result.

The circles in each region indicate how many events and trends have been made more (red) or less (blue) severe or likely by climate change.

Yellow indicates extremes where no human influence was found, while grey shows studies that were inconclusive.

To explore the data for a specific region, click the relevant circles on the map. This reveals a summary page and a link to explore all the studies related to that part of the world.

Across all cases, 74% were found to have been made more likely or severe because of climate change. More than a third of these are heat extremes, which are generally the most straightforward events to link to a warming world.

Around 9% of the events and trends in the map were made less likely or severe by climate change. Unsurprisingly, this category is dominated by blizzards and cold extremes, but there are also cases where climate change has lessened the chances of other extremes – such as the high rainfall event in February 2018 over south-east Africa.

High rainfall in Mozambique, Zimbabwe and Zambia, February 2018

Case 297

RAIN & FLOODING · LESS SEVERE · LESS LIKELY · LESS SEVERE

Event type
Rain & flooding

Finding
Decrease, less severe or less likely to occur

"This multi-method study of high precipitation over parts of Mozambique, Zimbabwe and parts of Zambia in February 2018 indicates decreased likelihood of such events due to climate change, but with substantial uncertainty based on the used observations and models."

Bulletin of the American Meteorological Society (2019) Fučkar, N. S. et al., 2019: On High Precipitation in Mozambique, Zimbabwe and Zambia in February 2018 [in "Explaining Extreme Events of 2018 from a Climate Perspective"]. Bull. Amer. Meteor. Soc., DOI:10.1175/BAMS-D-19-0162.1

The remaining cases are extremes where scientists either identified no human influence (10%) or where the findings were inconclusive (7%).

(It should be noted that these figures are not representative of all extreme weather events as only a small fraction have been subject to an attribution study. In addition, some of the events included in the map have been the subject of more than one study.)

The map can also be viewed by event type, which groups the data into seven categories: heat (red), rain and flooding (navy blue), drought (yellow), storm (purple), cold, snow and ice (blue) and other (grey).

To delve into the individual extremes, click "explore all cases" in the map legend or choose a specific country from the dropdown list. A searchable table is also included at the end of this article.

Profile 01

The United States

There are more than 103 attribution studies focusing on events in The United States. 72 studies found that climate change increased the severity or likelihood of the event. Explore the studies for The United States

72 More severe or likely   13 Less severe or likely   11 Had no influence
7 Inconclusive

Latest: Pacific north-west heatwave shows climate is heading into 'uncharted territory'

Evolving methods

Following the first extreme event attribution study in 2004, the research field has rapidly gained momentum – with many more scientists and institutions carrying out studies and new methods being developed.
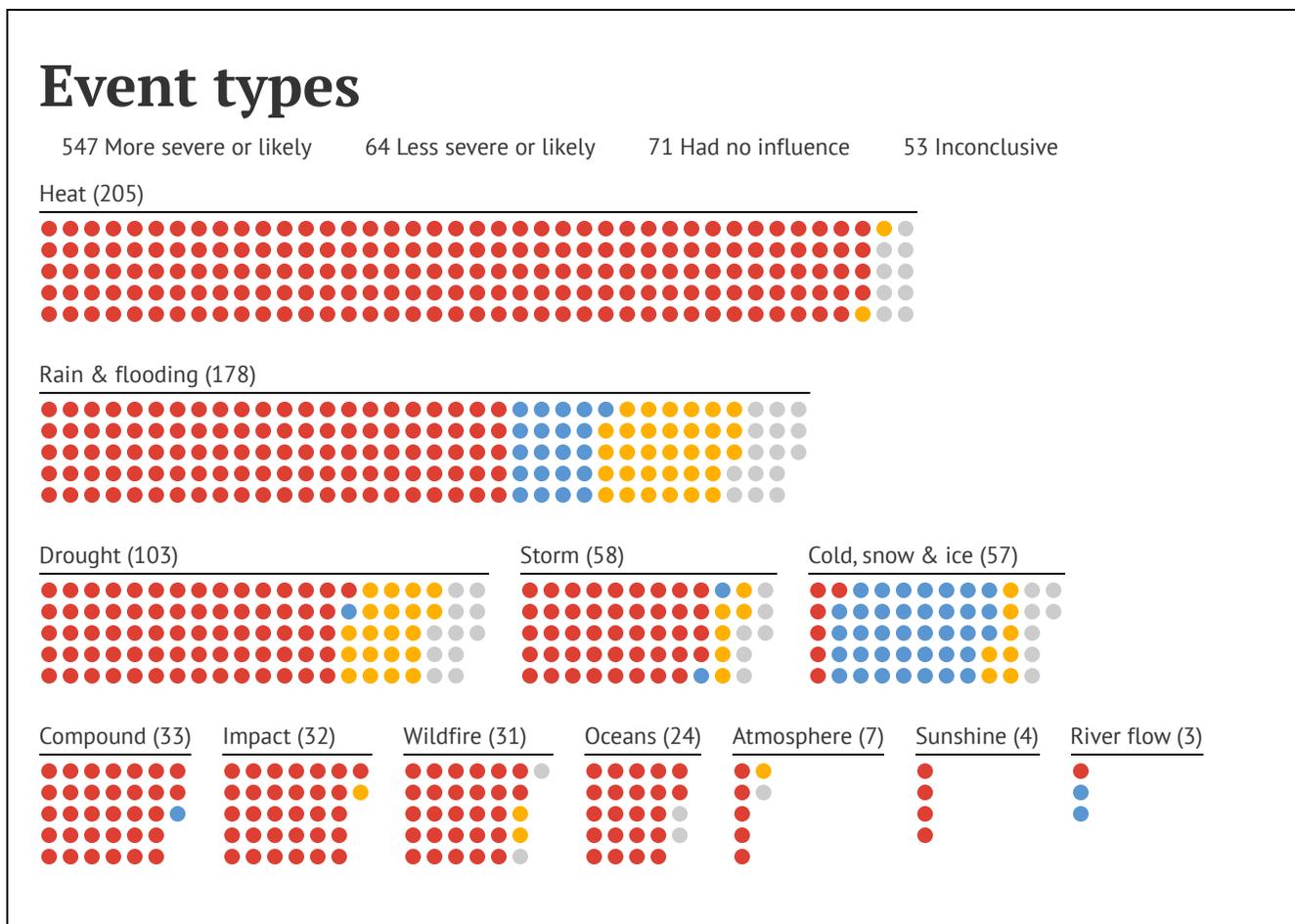
And what started as a trickle of studies has turned into a flood. In the 10 years following that first scientific paper, around 50 more were published. In the 10 years after that, the number has risen tenfold by more than 500.

There are various ways of carrying out an attribution study, but scientists commonly use climate models to simulate an extreme event in the current climate and compare them with idealised model runs of that event in a

world without human-caused warming. The difference between the two sets of simulations indicates how the likelihood or severity of that extreme event has changed.

The evolution of attribution methods over the past two decades is explored in detail in an accompanying Carbon Brief article.

The chart below reveals that the most-studied extremes are related to heat (28%) and rainfall and flooding (24%), which together account for more than half of the events and trends in the map. The next-largest group is for drought (14%), followed by storms and cold, snow and ice (both 8%).

Event types

547 More severe or likely   64 Less severe or likely   71 Had no influence   53 Inconclusive

Heat (205)

Rain & flooding (178)

Drought (103)   Storm (58)   Cold, snow & ice (57)

Compound (33)   Impact (32)   Wildfire (31)   Oceans (24)   Atmosphere (7)   Sunshine (4)   River flow (3)

One of the most significant developments seen in attribution science is the advent of "rapid" studies.

In 2015, the World Weather Attribution (WWA) initiative was founded, which streamlined the attribution process in order to produce results within days of an extreme event occurring.

The team uses a standard, peer-reviewed methodology for their analysis, but does not routinely publish the results in formal journals – instead publishing them directly on the WWA website as soon as the analysis is complete.

This has allowed scientists to answer the question of how climate change contributed to an extreme event in the immediate aftermath, rather than months later.

For example, on 30 July, heavy rainfall in Kerala, India, triggered massive landslides that killed hundreds of people. Within two weeks, WWA was able to show that human-caused climate change had made the extreme rains 10% heavier.

The Carbon Brief map includes WWA studies as well as those from selected other groups, including the Grantham Institute at Imperial College London and the UK Met Office. (See methodology at the end

Heavy rainfall behind Kerala landslide, July 2024

Rapid study. Case 582

Event type
Rain & flooding

Finding
More severe or more likely to occur

"The available climate models indicate a 10% increase in intensity."

World Weather Attribution (rapid study) (2024) Zachariah, M. et al, 2024: Landslide-triggering rainfall made more intense by

human-induced climate change, devastating highly vulnerable communities in northern Kerala, World Weather Attribution

Another recent advance is "impact attribution", which quantifies the social, economic and/or ecological impacts arising from the influence of climate change on extreme weather.

In this latest iteration of the map, Carbon Brief has created a specific category for all of these studies. These include, for example, <u>research</u> showing how climate change increased the risk of people being displaced by Tropical Cyclone Idai when it hit Mozambique in 2019, and a <u>study</u> showing that 370 deaths during Switzerland summer of 2022 "could have been avoided in absence of human-induced climate change".

Human displacements from Tropical Cyclone Idai, 2019

Case 538

IMPACT

Event type
Impact

Finding
More severe or more likely to occur

"Our main estimates indicate that climate change has increased displacement risk from this event by approximately 12,600-14,900 additional displaced persons."

Natural Hazards and Earth System Sciences (2023)
Mester B. et al., 2023: Human displacements from Tropical Cyclone Idai attributable to climate change, Natural Hazards and Earth System Sciences, doi:10.5194/nhess-23-3467-2023

Deaths during Switzerland summer heatwave, 2022

Case 537

IMPACT

Event type
Impact

Finding
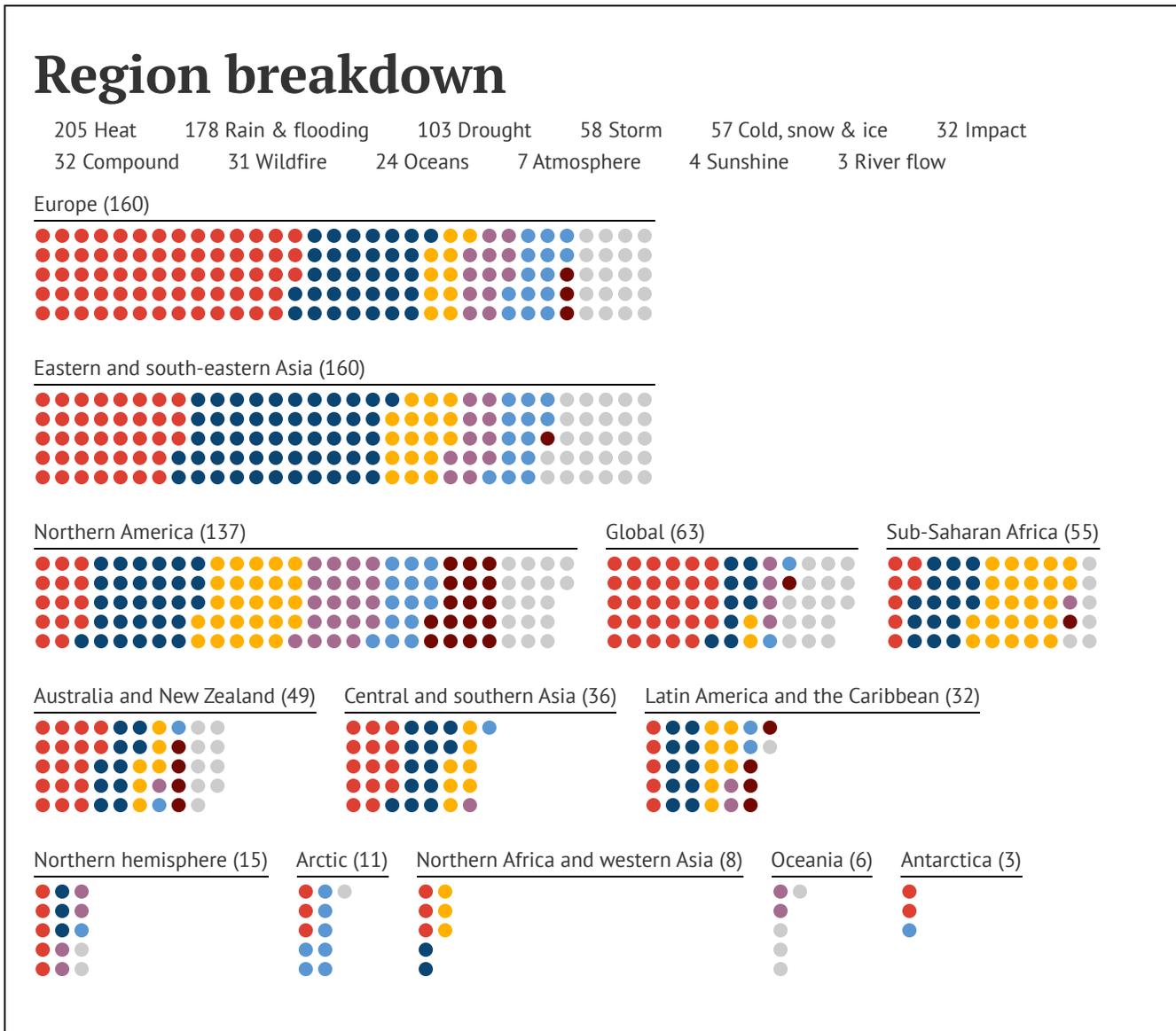More severe or more likely to occur

"We estimate 623 deaths due to heat between June and August 2022...we find that 60% of this burden could have been avoided in absence of human-induced climate change"

Environmental Research Letters (2023) Vicedo-Cabrera. A. et al., 2023: The footprint of human-induced climate change on heat-related deaths in the summer of 2022 in Switzerland, Environmental Research Letters, DOI: 10.1088/1748-9326/ace0d0

Uneven spread

Even a cursory look at the Carbon Brief map reveals the uneven spread of studied extremes across the world, with the vast majority in the global north.

The cases included in the map are dominated by extremes in Europe (22%), eastern and south-east Asia (22%) and northern America (19%). In contrast, relatively few of the studied extremes are in central and southern Asia (5%), Oceania (1%) and northern Africa and western Asia (1%).

Region breakdown

205 Heat   178 Rain & flooding   103 Drought   58 Storm   57 Cold, snow & ice   32 Impact
32 Compound   31 Wildfire   24 Oceans   7 Atmosphere   4 Sunshine   3 River flow

Europe (160)

Eastern and south-eastern Asia (160)

Northern America (137)   Global (63)   Sub-Saharan Africa (55)

Australia and New Zealand (49)   Central and southern Asia (36)   Latin America and the Caribbean (32)

Northern hemisphere (15)   Arctic (11)   Northern Africa and western Asia (8)   Oceania (6)   Antarctica (3)
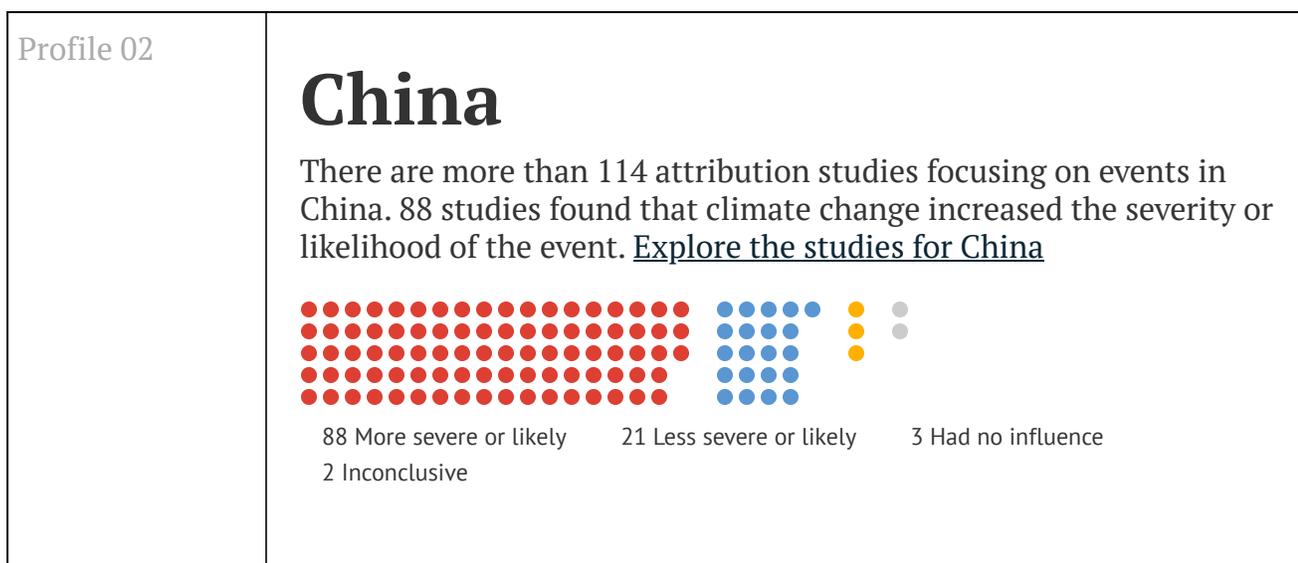
There are a number of reasons for this, including a lack of weather data and monitoring of extremes in many developing countries. Another factor is that scientists and their institutions that conduct attribution research are often themselves based in global-north countries.

This imbalance is something that many attribution scientists are trying to address, putting a greater focus on extremes in countries that are often overlooked.

What is also noticeable in this latest iteration of the map is the large number of studies examining extremes in China, following record-breaking heatwaves, severe drought and deadly rainfall events in recent years.

In total, 114 extremes and trends in China have been the subject of an attribution study – making up 16% of all the cases included in the map. More than 70% of them have been published in the past four years.

Profile 02

China

There are more than 114 attribution studies focusing on events in China. 88 studies found that climate change increased the severity or likelihood of the event. Explore the studies for China

88 More severe or likely   21 Less severe or likely   3 Had no influence
2 Inconclusive

Use the searchable table below to see all extremes and trends for a specific country, and/or use the dropdown lists to select specific regions or types of extremes.

Explore the studies

Filter by region and by event type

| All regions ▼ | All events ▼ | Reset |

Search cases [   ]

Showing 1 to 12 of 735 results

| « Prev | - | Next » |

European summer heatwave, 2003

Case 000

Event type
Heat

Finding
   More severe or more likely to occur

"We estimate it is very likely (confidence level >90%) that human influence has at least doubled the risk of a heatwave exceeding this threshold magnitude."

Nature (2004) Stott, P. et al., 2004: Human contribution to the European heatwave of 2003. Nature, 432, 610-614

Global temperature extremes, since 1950

Case 001

Event type
Heat

Finding
   More severe or more likely to occur

"Comparing these observations with climate model simulations in an optimal detection analysis shows a significant human influence on patterns of change in extremely warm nights."

Geophysical Research Letters (2005) Christidis, N. et al., 2005: Detection of changes in temperature extremes during the second half of the 20th century, GRL, 32 (20), DOI:10.1029/2005GL023885

Record warm autumn in Europe, 2006

Case 002

Event type
Heat

Finding
   More severe or more likely to occur

Increasing frequency of 'very warm' northern hemisphere summers, 1860-2009

Case 003

Event type
Heat

Finding

"Global warming has made a warm autumn like the one observed in 2006 much more likely by shifting the temperature distribution to higher values."

Climate of the Past (2007) Van Oldenborgh, G-J. et al., 2007: How unusual was autumn 2006 in Europe? Climate of the Past, 3, 659-668

More severe or more likely to occur

"We detect the dominant influence of anthropogenic factors on observed warming in almost every region, which has led to a rapidly increasing risk of hot summers."

Journal of Geophysical Research: Atmospheres (2007) Jones, G. et al., 2007: Human contribution to rapidly increasing frequency of very warm Northern Hemisphere summers, J. Geophys. Res., 113, D02109, DOI:10.1029/2007JD008914

Moscow summer heatwave, 2010

Case 004

Event type
Heat

Finding
　More severe or more likely to occur

"For July temperature in Moscow, we estimate...an approximate 80% probability that the 2010 July heat record would not have occurred without climate warming."

Proceedings of the National Academy of Sciences (2011) Rahmstorf, S. & Coumou, D. 2011: Increase of extreme events in a warming world. PNAS, 108 (44), 17905.

Global warm nights, 1950-2003

Case 005

Event type
Heat

Finding
　More severe or more likely to occur

"A large part of the observed global-scale trend in TN90 results from the trend in mean temperature, which has been attributed largely to anthropogenic greenhouse gas increase. This suggests that the detected global-scale trends in the number of warm nights are at least partly anthropogenic."

Geophysical Research Letters (2011) Morak, S. et al., 2011: Detectable regional changes in the number of warm nights. GRL, 38 (17)

Global 'extremely warm' daytime temperatures, 1950-99

Case 006

Event type
Heat

Finding
　More severe or more likely to occur

Africa 'anomalously warm' seasonal temperatures, 1961-2008

Case 007

Event type
Heat

Finding
　More severe or more likely to occur

"Anthropogenic forcings alter the regional distributions, indicating that extremely warm days have become hotter."

Journal of Climate (2011) Christidis, N. et al., 2011: The Role of Human Activity in the Recent Warming of Extremely Warm Daytime Temperatures. J. Climate, DOI:10.1175/2011JCLI4150.1

"In the June-August and September-November seasons, many of the sub-continental regions of Africa and Asia show robust attributable increase in the frequencies of anomalously warm seasonal temperatures."

Atmospheric Science Letters (2011) Stott, P. et al., 2011: Single-step attribution of increasing frequencies of very warm regional temperatures to human influence. Atmos. Sci. Lett, 12 (2), 220-227, DOI:10.1002/asl.315

Asia 'anomalously warm' seasonal temperatures, 1961-2008

Case 007

HEAT · MORE SEVERE · MORE LIKELY

Event type
Heat

Finding
More severe or more likely to occur

"In the June-August and September-November seasons, many of the sub-continental regions of Africa and Asia show robust attributable increase in the frequencies of anomalously warm seasonal temperatures."

Atmospheric Science Letters (2011) Stott, P. et al., 2011: Single-step attribution of increasing frequencies of very warm regional temperatures to human influence. Atmos. Sci. Lett, 12 (2), 220-227, DOI:10.1002/asl.315

Global daily temperature extremes, 1961-2000

Case 008

HEAT · MORE SEVERE · MORE LIKELY

Event type
Heat

Finding
More severe or more likely to occur

"Therefore, it is concluded that the influence of anthropogenic forcing has had a detectable influence on extreme temperatures that have impacts on human society and natural systems at global and regional scales."

Journal of Climate (2011) Zwiers, F. et al., 2011: Anthropogenic Influence on Long Return Period Daily Temperature Extremes at Regional Scales, J. Climate, 10.1175/2010JCLI3908.1

Russia summer heatwave, 2010

Case 009

HEAT · NO HUMAN INFLUENCE

Event type
Heat

Finding
No discernible human influence

"Analysis of forced model simulations indicates that neither human influences

Hurricanes Ivan & Katrina, 2004-05

Case 010

RAIN & FLOODING · MORE SEVERE · MORE LIKELY

Event type
Rain & flooding

Finding
More severe or more likely to occur

"The environmental changes related to human influences on climate since 1970

nor other slowly evolving ocean boundary conditions contributed substantially to the magnitude of this heat wave."

Geophysical Research Letters (2011) *Dole, R. et al., 2011: Was there a basis for anticipating the 2010 Russian heat wave? Geophysical Research Letters, 38, L06702*

have increased SSTs and water vapor, and the results suggest how this may have altered hurricanes and increased associated storm rainfalls, with the latter quantified to date to be of order 6 to 8%"

Journal of Geophysical Research: Atmospheres (2007) *Trenberth, K. et al., 2007: Water and energy budgets of hurricanes: Case studies of Ivan and Katrina. JGR Atmosphere, 112 (D3)*

Methodology

Carbon Brief draws on a number of sources to identify attribution studies for this map.

A broad search on the Scopus database of scientific papers produced a large dataset of potentially relevant studies. A first assessment of these search results to identify attribution papers focusing on extremes was carried out using an AI tool. The shortlisted papers were then evaluated manually to create a final list.

Studies are also identified through Carbon Brief's contacts, reporting and monitoring of new research.

The final list was cross-referenced with other databases to identify any gaps. These included Climate Signals, the Health Attribution Library and the database maintained by the Sabin Center for Climate Change Law.

Rapid studies have been included from the World Weather Attribution, the Grantham Institute at Imperial College London and the UK Met Office.

There has been a recent proliferation of groups undertaking rapid attribution analysis. To keep the map manageable, it is limited to dedicated studies rather than rolling or brief assessments, such as those produced by ClimaMeter, the Canadian government and Climate Central's Climate Shift Index.

Using the complete list of papers, the database that underlies the Carbon Brief map was populated manually. Where a single study covers multiple events or locations, these have been separated out into individual entries (where possible).

It should also be noted that the map only includes attribution studies related to extremes. While attribution research has also identified the human influence in other indicators of climate change, such as increasing average temperature or sea level rise, these types of studies have not been included.

The map also currently only includes studies published in English.

Carbon Brief's original attribution map, published in July 2017, was created by Roz Pidcock and Rosamund Pearce. It was subsequently revised and updated on four occasions by Robert McSweeney, Tom Prater and Joe Goodman. These updates were published in March 2019, April 2020, February 2021 and August 2022, which are still available at the archived links included here.

Please note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Carbon Brief concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries.

Update 21/11/2024: The underlying database has been amended to correct the event types of a few cases and also remove several duplicated entries.

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