Congressional Research Service
Informing the legislative debate since 1914

Is That Climate Change? The Science of Extreme Event Attribution

June 1, 2023

Congressional Research Service
https://crsreports.congress.gov
R47583

CRS REPORT
Prepared for Members and
Committees of Congress

Congressional Research Service
Informing the legislative debate since 1914

SUMMARY

R47583

June 1, 2023

Jonathan D. Haskett
Analyst in Environmental Policy

Is That Climate Change? The Science of Extreme Event Attribution

Climate change attribution is the study of whether, or to what degree, human influence may have contributed to extreme climate or weather events. Scientists can now estimate whether human activities have influenced extreme weather or climate events and changed how likely they are to occur. This is known as the science of climate change attribution.

Attributions of extreme weather to human-induced climate change may affect how policymakers, organizations, and individuals understand and manage associated risks, with the potential benefit of avoiding future costs. The interpretation and evaluation of attribution findings have been part of the discussion of policy on wildfires, heat waves, climate change, and disaster responses, among other issues. Understanding the attribution process and its uncertainties may be helpful in understanding the potential uses and limitations of climate attribution claims.

Before the development of extreme event attribution methods, there was a scientific consensus that, while attribution of global climate trends was possible, attribution of individual events was not possible. This changed with the development of statistical methods to determine the likelihood that human influence had changed the frequency or severity of extreme events, and a better understanding of the connections between components of the Earth's climate system.

Several approaches to extreme event attribution have been developed, including a *risk-based approach*, which seeks to estimate human-influenced changes in the probability of an extreme event, and a *storyline approach*, which seeks to estimate the relative contribution of specific natural and human causes to an extreme event. The two approaches use many of the same analytic tools. Researchers may study different aspects of the same event, or use differing yet valid analytic methods and find results that seem inconsistent.

Numerous attribution studies have been completed on a wide range of extreme events, including heavy rainfall, heat waves, sea ice extent, consecutive dry days, droughts, and others. Results have included instances where changes in event probability were attributed to human influence, instances where evidence of human influence was not found, and instances where the results were inconclusive. For example, a study of record high May 2017 temperatures in South Korea found that the increased probability of such an event was due to human influence, while a study of a 2011 drought/heat wave in Texas did not find evidence of human influence. In recent years, domestic litigation has been brought by states and municipalities seeking compensation for damage caused by adverse climate impacts. Extreme event attribution may become important in this type of litigation in order to establish liability.

Attribution science is subject to uncertainty. Sources of uncertainty include uncertainty in the observational data, uncertainty in the scientific understanding of natural climate variability, and uncertainty in results produced by climate simulation models. Researchers address these uncertainties using model standardization as well as statistical and analytic methods.

The Chips and Science Act (P.L. 117-167) includes provisions for "the development of software and algorithms to enable the productive application of environmental systems and extreme weather in climate and Earth system prediction models." In the 118th Congress, the Earth Act to Stop Climate Pollution by 2030 (H.R. 598) includes the finding that "[t]he United States is already seeing climate change exacerbate extreme weather events." A concurrent resolution (S.Con.Res. 9) includes the finding "that climate change is already increasing the frequency of extreme weather." Other legislative proposals such as the Green New Deal for Health Act (H.R. 2764) and the Food and Farm Act (H.R. 1824) also include findings stating a causal link between climate change and some extreme weather events.

Climate change attribution has been cited in congressional hearings regarding wildfires, disaster preparedness and the role of the Federal Emergency Management Agency, extreme heat, the impacts of climate change, and the Department of Homeland Security, among other issues. In some cases, experts have disagreed as to the attribution of the same set or type of events. Climate attribution science may help Congress understand related policy issues and evaluate testimony and information presented in hearings and from other sources.

Contents

Figures

Contacts

Introduction

Climate change attribution is the study of whether, or to what degree, human influence may have contributed to extreme climate or weather events.

Advances in the science of climate attribution now allow scientists to make estimates of the human contribution to such events.[1] Understanding the attribution process and its uncertainties may be helpful to policymakers, organizations, and individuals in evaluating and weighing these estimates, and in considering how to prioritize and manage associated risks.

A key area of climate research has been the effort to attribute observed changes in the climate to natural and human-related factors.[2] A scientific consensus has emerged that the increase in concentrations of greenhouse gases (GHGs) in the atmosphere is the result of human actions such as the emissions of GHGs from the burning of fossil fuels and land management and that these emissions are influencing the climate.[3] This influence has been confirmed with increasing confidence for many global and regional climate processes.[4]

By the early years of the 21st century there was broad acceptance in the scientific community that some global trends in the climate, such as increases in global average temperature since the mid-20th century, could be attributed to human action with some degree of confidence.[5] However, existing methods could not determine whether a specific weather event, such as a heat wave or a severe storm, could be linked to human-induced climate change.[6] In 2003, a scientist proposed to statistically test whether changes in extreme event probability could be attributed to human influence.[7] Since that time, scientists have developed a variety of methods to investigate human influence on extreme weather or climate events.[8]

---

[1] The U.S. Department of Agriculture on its "Climate Hubs: Extreme Weather" website (https://www.climatehubs.usda.gov/node/1476/) distinguishes weather and climate extreme events:

> Extreme events are occurrences of unusually severe weather or climate conditions that can cause devastating impacts on communities and agricultural and natural ecosystems. Weather-related extreme events are often short-lived and include heat waves, freezes, heavy downpours, tornadoes, tropical cyclones and floods. Climate-related extreme events either persist longer than weather events or emerge from the accumulation of weather or climate events that persist over a longer period of time. Examples include drought resulting from long periods of below-normal precipitation or wildfire outbreaks when a prolonged dry, warm period follows an abnormally wet and productive growing season.

[2] H. Le Treut et al., "Historical Overview of Climate Change" in Intergovernmental Panel on Climate Change (IPCC), *Climate Change 2007: The Physical Science Basis—Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, 2007.

[3] The glossary in IPCC, *Climate Change 2014: Mitigation of Climate Change—Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, 2014, defines *greenhouse gases* as "those gaseous constituents of the atmosphere, both natural and anthropogenic, that absorb and emit radiation at specific wavelengths within the spectrum of terrestrial radiation emitted by the earth's surface, the atmosphere itself, and by clouds. This property causes the greenhouse effect."

[4] IPCC, *Climate Change 2021: The Physical Science Basis—Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, 2021 (hereinafter IPCC AR6 WGI 2021).

[5] CRS Report R45086, *Evolving Assessments of Human and Natural Contributions to Climate Change*, by Jane A. Leggett; and CRS Report R43229, *Climate Change Science: Key Points*, by Jane A. Leggett.

[6] Friederike E. L. Otto, "Attribution of Weather and Climate Events," *Annual Review of Environment and Resources* vol. 42, no. 1 (2017), p. 627 (hereinafter Otto 2017). See also CRS Report R45086, *Evolving Assessments of Human and Natural Contributions to Climate Change*, by Jane A. Leggett.

[7] Myles Allen, "Liability for Climate Change," *Nature*, vol. 421, no. 6926 (2003), p. 891. See also Otto 2017.

[8] D. Swain et al., "Attributing Extreme Events to Climate Change: A New Frontier in a Warming World," *One Earth*, vol. 2, no. 6 (2020), p. 522 (hereinafter Swain 2020).

When an extreme weather or climate event occurs, there is often discussion in the media about whether the event was influenced by climate change. Journalists, in their reporting, will sometimes cite extreme event attribution studies that have been carried out rapidly and have not yet been peer reviewed.[9] Longer-term, peer-reviewed studies that are published later in scientific journals may produce findings that support or do not support the earlier study, but they are typically not covered as prominently in the media.[10]

Congressional hearings on a range of topics including climate policy, disaster preparedness, and wildfire management have included sometimes conflicting witness testimony citing climate attribution studies that might be seen as being in support of or in opposition to particular policy positions.[11] Legislation introduced in the 117th Congress included, for example, provisions regarding extreme event attribution, such as the addition of the risk of climate-related extreme events to be part of financial risk disclosure (S. 1217; Climate Risk Disclosure Act of 2021).[12] Another bill would have required the Administrator of the Federal Emergency Management Agency (FEMA) to address the threat of climate change in part because of an increase in climate-related extreme events (S. 280; FEMA Climate Change Preparedness Act).[13] Understanding the process of attribution, including the ways in which historical and simulation datasets are used, may be useful in evaluating claims about human influence that are presented in public discussion and in congressional deliberations. Moreover, climate attribution studies could become relevant in domestic climate litigation. Some observers have suggested that attribution may be part of international climate loss and damage discussions in the future.[14]

This report provides a primer on the science of climate change attribution and its application, including a description of techniques and an outline of the steps that are common to many attribution studies. This overview of climate change attribution is not a comprehensive review and analysis of all published studies.

[9] See, for example, Reuters, "Pacific Northwest Heat Wave 'Virtually Impossible' Without Climate Change—Research," July 8, 2021, at https://www.reuters.com/business/environment/heat-wave-pacific-northwest-could-soon-repeat-due-climate-change-research-2021-07-07/.

[10] K. A. Reed et al., "Forecasted Attribution of the Human Influence on Hurricane Florence," *Science Advances*, vol. 6, no. 1 (2020). See also Roger Pielke, "Three Rules For Accepting Climate 'Event Attribution' Studies," *Forbes*, January 6, 2020, at https://www.forbes.com/sites/rogerpielke/2020/01/06/three-rules-for-accepting-climate-event-attribution-studies/.

[11] U.S. Congress, House Committee on Oversight and Reform Subcommittee on Environment, *Recovery, Resiliency and Readiness: Contending with Natural Disasters in the Wake of Climate Change (Climate Change Part III)*, hearings, 116th Cong., 1st sess., June 25, 2019.

[12] S. 1217.

[13] S. 280.

[14] Sophie Marjanac and Lindene Patton, "Extreme Weather Event Attribution Science and Climate Change Litigation: An Essential Step in the Causal Chain?" *Journal of Energy & Natural Resources Law*, vol. 36, no. 3 (2018), p. 265 (hereinafter Marjanac and Lindene 2018). See also Karen Sokol, "What Comes After the Loss and Damage Fund for Responsibility and Repair in a Climate-Disrupted World?" *Lawfare*, December 14, 2022, at https://www.lawfareblog.com/what-comes-after-loss-and-damage-fund-responsibility-and-repair-climate-disrupted-world.

Overview of Climate Change Attribution

The Intergovernmental Panel on Climate Change (IPCC) has stated, "It is unequivocal that human influence has warmed the atmosphere, ocean and land."[15] The IPCC has also commented that human-induced climate change has affected extremes of weather and climate globally.[16]

The Fourth National Climate Assessment has made attribution statements about regional warming in the United States; for example: "In summary, there is medium confidence for detectable anthropogenic [human influenced] warming over the western and northern regions of the contiguous United States."[17]

Such global and regional climate statements differ from attributing specific extreme weather events to specific human influences, which scientists once considered infeasible with then-existing data and methods.[18] This changed with the publication of an article in 2003 proposing a method of establishing legal liability for climate change by determining how much human influence had changed the probability of an undesirable event, such as flooding.[19] The first application of the proposed attribution method was a study of the European heat wave of 2003.[20] Researchers estimated a change in the probability of an event of that magnitude, stating that "human influence has at least

Definition of *Risk*

The term *risk* is used in different ways with regard to natural hazards and in specific climate attribution studies. Some use *risk* to mean the probability of occurrence of an extreme climate or weather hazard event, such as a heat wave. Others use *risk* to mean the combination of the probability that a natural hazard event will occur plus the consequences of its occurrence on humans and human systems.

The use of *probability* and *risk* interchangeably can cause confusion. For example, two common methods to estimate the probability of occurrence of a natural hazard event include the term *risk* in their names: the Risk Ratio (RR) and the Fraction of Attributable Risk (FAR). In this report, when referring to RR and FAR, the term *risk* refers to the climatic or meteorological probability of an event of a specific magnitude, not to the potential impact of the event on human systems. Apart from discussing these specific terms that use *risk* in their definitions, this report uses the term *hazard* as the probability of a particular event occurring, such as a hurricane, and *risk* as the hazard combined with the vulnerability of humans and human systems to that hazard. In this sense, the *risk* is the likelihood of adverse outcomes from the hazard. For example, the hazard of a major hurricane striking the Florida coast today and 100 years ago may be the same, but the risk is much higher today because of the growth in the amount of exposed infrastructure.

[15] IPCC AR6 WGI 2021.

[16] IPCC AR6 WGI 2021. Note in the quotation "AR5" refers to IPCC, *Climate Change 2014: Synthesis Report—Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, 2014.

[17] U.S. Global Change Research Program, *Climate Science Special Report: Fourth National Climate Assessment, Volume I*, 2017. See also the methodology described in T. R. Knutson et al., "Multimodel Assessment of Regional Surface Temperature Trends: CMIP3 and CMIP5 Twentieth-Century Simulations," *Journal of Climate*, vol. 26, no. 22 (2013), p. 8709.

[18] Otto 2017; IPCC, *Climate Change 2013: The Physical Science Basis—Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, 2013, p. 928, states, "In the present climate, individual extreme weather events cannot be unambiguously ascribed to climate change, since such events could have happened in an unchanged climate."

[19] Myles Allen, "Liability for Climate Change," *Nature*, vol. 421, no. 6926 (2003), p. 891.

[20] P. Stott et al., "Human Contribution to the European Heatwave of 2003," *Nature*, vol. 432, no. 7017 (2004), p. 610 (hereinafter Stott 2004).

doubled the risk of a heatwave exceeding this threshold magnitude."[21] A subsequent attribution study has confirmed the attribution of human influence for this event.[22]

Many attribution studies share common features:

- the selection of an event for study,
- the detection of a trend in the observed historical climate record,
- the simulation of that trend by appropriate climate models,
- the comparison of simulations using (a) all natural and human climate drivers with simulations using (b) only natural drivers,[23] and
- an attribution statement sometimes including a statistical confidence estimate.

An example of this type of analysis is the attribution study of the record global average surface temperature in 2015.[24] In this study, trends in observational data (**Figure 1**) showed that 2015 set a record for global average surface temperature from the start of modern temperature documentation in 1880, and also showed a warming trend starting after 1955 that continued through 2015.[25] In the study, climate model simulations with both human and natural climate drivers were in close agreement with the observed global temperature trends. However, simulations without human drivers (natural drivers only) did not reproduce the observed increase in global average surface temperatures.[26] Researchers estimated the probability for this record temperature with and without human influence. A statistical analysis indicated that the chance of the record global temperature of 2015 occurring naturally, without the influence of human GHGs, was 10%.[27]

[21] Stott 2004.

[22] D. Mitchell et al., "Attributing Human Mortality during Extreme Heat Waves to Anthropogenic Climate Change," *Environmental Research Letters*, vol. 11, no. 7 (2016), p. 074006.

[23] Climate drivers are explained as follows: "The difference between incoming and outgoing radiation is known as a planet's radiative forcing (RF). In the same way as applying a pushing force to a physical object will cause it to become unbalanced and move, a climate forcing factor will change the climate system. When forcings result in incoming energy being greater than outgoing energy, the planet will warm (positive RF). Conversely, if outgoing energy is greater than incoming energy, the planet will cool.... Another way to refer to climate forcings is to call them climate drivers. Natural climate drivers include changes in the sun's energy output, regular changes in Earth's orbital cycle, and large volcanic eruptions that put light-reflecting particles into the upper atmosphere. Human-related, or anthropogenic climate drivers include emissions of heat-trapping gases (also known as greenhouse gases) and changes in land use that make land reflect more or less sunlight energy." See National Oceanographic and Atmospheric Administration (NOAA), "Climate Forcing," at https://www.climate.gov/maps-data/climate-data-primer/predicting-climate/climate-forcing#:~:text=Another%20way%20to%20refer%20to,particles%20into%20the%20upper%20atmosphere.provides.

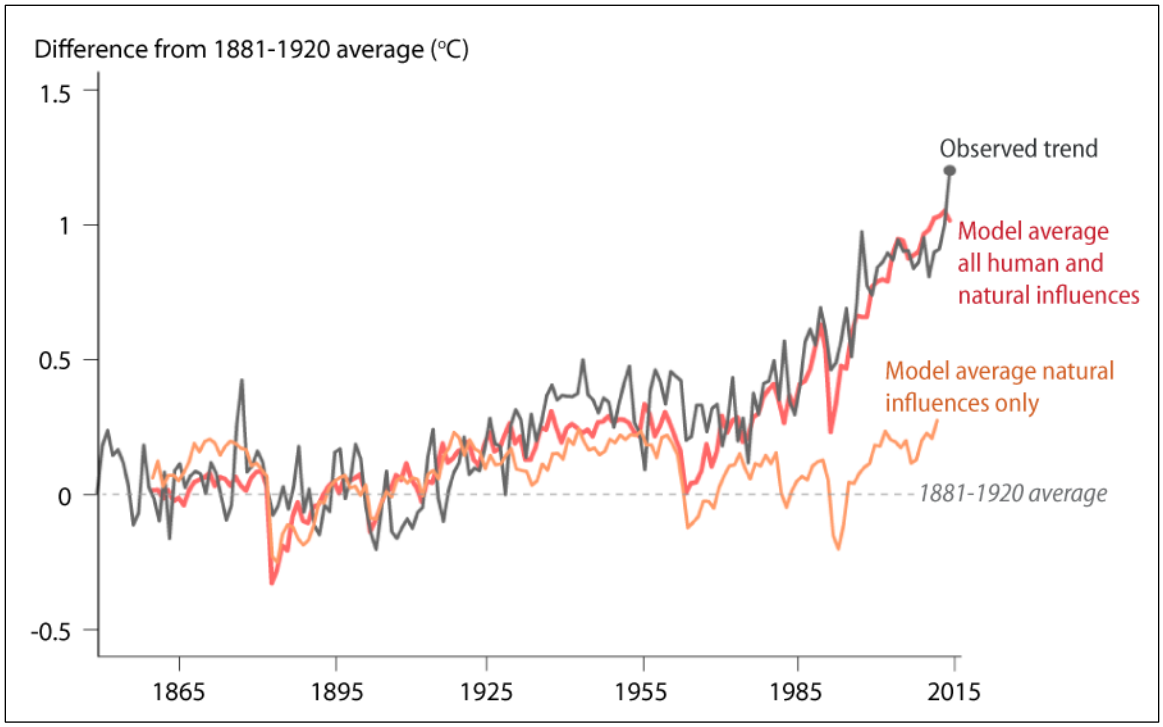
[24] J. Kam et al., "Multimodel Assessment of Anthropogenic Influence on Record Global and Regional Warmth During 2015," *Bulletin of the American Meteorological Society*, vol. 97, no. 12 (2016), p. S4 (hereinafter Kam 2016).

[25] National Aeronautics and Space Administration (NASA), "Analyses Reveal Record-Shattering Global Warm Temperatures in 2015," January 19, 2016, at https://climate.nasa.gov/news/2391/analyses-reveal-record-shattering-global-warm-temperatures-in-2015/. See also Kam 2016.

[26] Kam 2016.

[27] Kam 2016. Note that in this study, uncertainty in model estimates of human influence was explored by comparing the results of the eight simulation models used. It was found that seven of the eight models were in agreement regarding the estimate of the level of human influence.

Figure 1. Global Average Surface Temperature Differences from 1881-1920 Average Baseline



Source: CRS, adapted from National Oceanographic and Atmospheric Administration, at https://www.climate.gov/media/7832 (adapted from J. Kam et al., "Multimodel Assessment of Anthropogenic Influence on Record Global and Regional Warmth During 2015," *Bulletin of the American Meteorological Society*, vol. 97, no. 12 [2016]).

Notes: The black line is the global average surface temperatures from an observational dataset of global surface temperature anomalies. The red line is the Coupled Model Intercomparison Project Phase 5 (CMIP5) group average of ensemble simulations of global average surface temperature with all (human and natural) climate change drivers. The yellow line is the CMIP5 ensemble simulations of global average surface temperature using only natural drivers of climate change.

Extreme Event Attribution

Extreme event attribution is a specific type of climate change attribution. Multiple approaches to extreme event attribution have been developed. A recent review of the field identified two principal types of extreme event attribution analysis, the (1) risk-based approach and (2) the storyline approach.[28] The authors also stated that these approaches could be combined as a third approach to provide complementary types of information on the attribution of an extreme event.[29] Information on risk-based and storyline approaches is presented here, but it is beyond the scope of this report to present and compare all approaches.

Risk-based extreme event attribution uses statistics to test whether, or to what extent, changes in the likelihood of an extreme weather or climate event may be influenced by human factors. The term *risk* in this approach is used to refer to the hazard that an event of this type will occur and

[28] C. Qian et al., "An Updated Review of Event Attribution Approaches," *Journal of Meteorological Research*, vol. 36, no. 2 (2022), p. 227 (hereinafter Qian 2022).

[29] Qian 2022.

does not refer to the potential consequences of the event for human systems (see earlier text box). *Storyline attribution* is an attempt to estimate the contribution of anthropogenic climate change to a specific event by determining the climatic and meteorological causes of the event and estimating human influence on those specific causes.

Each of these general approaches has advantages and disadvantages.[30] An advantage of the risk-based approach is that it provides an estimate of the change in the probability that an extreme event of a particular magnitude would occur due to human influence, but has the disadvantage of not providing information on the specific underlying causes of the event. The storyline approach does not provide estimates of the change in the event probability due to human influence, but it has the advantage of estimating the relative importance of the underlying causes of the specific event, including ocean and atmospheric processes, anthropogenic climate change, and natural climate variability. An additional disadvantage of the storyline approach is that some of the underlying causes, such as atmospheric circulation patterns, may themselves be influenced by anthropogenic climate change, something the analysis may not account for.

Storyline Attribution Analysis

Research using storyline attribution is an analysis of causes:

> It [the Storyline Approach] is a framing based on analysis of physical processes and is similar to an accident investigation.... The causal chain of factors leading to the event is first identified, and the role of each factor is assessed.[31]

Researchers analyze atmospheric circulation and meteorological patterns using models and observational data to try to establish the factors that contributed to the event.[32] This analysis includes determining linkages among factors. For example, a circulation pattern may contribute to extreme precipitation in a study area, and the increased water vapor in the air carried by the circulation may be linked to an area of increased sea surface temperature.[33]

The next step is to estimate anthropogenic climate influence on the causes linked to the event[34]—for example, the extent to which human influence may have affected sea surface temperatures, temperatures that, in turn, contributed to increased precipitation in an extreme event.[35] An attribution statement can then be made about the degree of human influence on the causes of the event.[36]

Researchers studying the record-setting 2011 drought/heat wave in Texas used a combination of observational data and climate model simulations to examine specific factors that may have influenced the magnitude of the event. The researchers found that the "principal physical process" contributing to the drought/heat wave was the extreme and continuing lack of rainfall in the

[30] Qian 2017. See also Laura García-Portela and Douglas Maraun, "Overstating the Effects of Anthropogenic Climate Change? A Critical Assessment of Attribution Methods in Climate Science," *European Journal for Philosophy of Science*, vol. 13, no. 1 (March 11, 2023), p. 17.

[31] Qian 2022.

[32] K. Trenberth et al., "Attribution of Climate Extreme Events," *Nature Climate Change*, vol. 5, no. 8 (2015), p. 725 (hereinafter Trenberth 2015).

[33] Trenberth 2015.

[34] M. Hoerling et al., "Anatomy of an Extreme Event," *Journal of Climate*, vol. 26, no. 9 (2013), p. 2811 (hereinafter Hoerling 2013).

[35] Trenberth 2015.

[36] Hoerling 2013.

previous winter and spring.[37] This rainfall deficit was in turn linked to changes in sea surface temperatures. As the associated sea surface temperatures were within the range of natural variability, the researchers did not find evidence of human influence in their analysis of this extreme event.[38]

Analysis using the storyline approach is specific to the event under study and cannot be generalized to other similar events of a similar magnitude. The storyline approach does not provide information on the probability that an event of this magnitude will recur.[39]

As the specific causes of each extreme event are unique, the procedures of a storyline approach can be variable; however, some analytic tools such as extreme event definition, observational trend analysis, and model selection are used by both the risk-based and storyline approaches and are described in more detail in the following section on the risk-based approach.[40]

Risk-Based Attribution Analysis

Risk-based attribution uses statistics to test whether, or to what extent, changes in the likelihood of an extreme weather or climate event may be influenced by human factors. To make this determination, risk-based analysis estimates the likelihood of an extreme event with possible human influence and compares it to the likelihood of the event as part of the natural variability of the climate in the absence of human influence. If the odds that the event would have occurred are greater with human influence than without, then human activities may have influenced the extreme weather or climate event.

To do risk-based attribution, researchers calculate the probability of the event from the observational record. Values in the observational record include both the influence of natural climate variability and the influence, if any, of human activities. To estimate the probability of the event without human influence, researchers simulate the probability of the extreme weather or climate event using models of the Earth's climate from which the increase in GHGs due to anthropogenic emissions has been excluded. This provides an estimate of the probability that the extreme weather event would have occurred within the range of natural variability if human influence was absent. The probability of the event calculated from observations is mathematically compared with the probability calculated from a hypothetical climate that does not have an increase in anthropogenic GHGs. If the probabilities are the same, the event is just as likely with or without human influence and, being within the range of natural variability, is not attributed to human influence. If human influence has increased the probability of the extreme weather event, this probability can be calculated. Two measures that are sometimes used to quantify human influence are the fraction of attributable risk (FAR) and risk ratio (RR) statistical measures (see text box below).

Event Definition

An attribution study starts with the definition of an extreme weather or climate event. An event may be identified for study for a variety of reasons, including resulting economic damage, setting

[37] Hoerling 2013.

[38] Hoerling 2013.

[39] Theodore G. Shepherd, "A Common Framework for Approaches to Extreme Event Attribution," *Current Climate Change Reports*, vol. 2, no. 1 (2016), p. 28.

[40] Otto 2017.

a record, or by a statistical measure.[41] Event definition is a critical first step because how an event is defined can affect the results of an attribution study.[42]

Observational Trend Analysis

Researchers use observational trend analysis to estimate the probability that the type of event under study would occur and whether that probability has changed over time. Some researchers state that a 50-year observational data record is a minimum for such an analysis.[45]

The historical data are analyzed using statistical methods to calculate the likelihood that an event of this magnitude would occur, the *event probability*.[46]

Climate Model Application

Some climate models can simulate the probability and magnitude of an extreme event in a hypothetical global climate in which the increases in anthropogenic GHGs are removed. This estimate of the probability and magnitude of the event occurring in a global climate uninfluenced by increases in GHGs allows for comparison with the probability and magnitude of the event estimated from actual observations (i.e., the event probability described above).

Fraction of Attributable Risk and Risk Ratio

One statistical measure that is used to determine human climate-related influence is the fraction of attributable risk (FAR). The risk of an event is expressed as the probability (P) that it will occur. The probability of an extreme event is estimated under current conditions with all human and natural climate drivers (P_I). Then, using simulation, the probability of the event is estimated using only natural drivers in the absence of human climate drivers (P_0). The FAR or fraction of the risk that can be attributed to human influence can then be calculated as follows:

$$FAR = 1 - (P_0 / P_I)$$

An attribution study of the European heat wave of 2003 found an overall best estimate of FAR near 0.75, meaning, "On this basis, human influence is to blame for 75% of the increased risk of such a heatwave."[43]

The same variables P_0 and P_I can be used to express the change in risk as a risk ratio (RR):

$$RR = P_I / P_0$$

An attribution study of heavy precipitation in China in 2017 estimated RR for this event to be 2.1, indicating that the probability of the event had about doubled and that "anthropogenic influence may have increased the chance for such an event happening."[44]

---

[41] NOAA, "Extreme Event Attribution: The Climate Versus Weather Blame Game," December 15, 2016, at https://www.climate.gov/news-features/understanding-climate/extreme-event-attribution-climate-versus-weather-blame-game. This source describes *sigma* as follows:

> Scientists may also describe the severity of an extreme event in terms of "sigmas," which is a term from statistics that describes how far an individual observation is from the average of all the values in a data set. Sigma is shorthand for "standard deviation;" it comes from the fact that statisticians use the Greek letter sigma to represent standard deviation in equations.
>
> Sigmas are used to describe the range of natural variability in a given climate or weather characteristic. For most types of climate data, there are many more observations close to the average (within 1 or 2 sigmas) than there are far away. So, if a climate expert describes a heavy rain event as a "5-sigma" event, she is talking about rainfall so extreme that it was 5 standard deviations away from the average rainfall for that location for a given period of time—way out at the tail end of the range of all values that have been observed.

[42] Stott 2016.

[43] Stott 2004.

[44] Y. Sun et al., "Anthropogenic Influence on the Heaviest June Precipitation in Southeastern China Since 1961," *Bulletin of the American Meteorological Society*, vol. 100, no. 1 (2019), p. S79.

[45] G.J. van Oldenborgh et al., "Pathways and Pitfalls in Extreme Event Attribution," *Climatic Change*, vol. 166, no. 1 (May 10, 2021), p. 13, at https://doi.org/10.1007/s10584-021-03071-7.

[46] P. Naveau et al., "Statistical Methods for Extreme Event Attribution in Climate Science," *Annual Review of Statistics and Its Application*, vol. 7, no. 1 (2020), p. 89 (hereinafter Naveau 2020).

Probability Analysis and Attribution

If researchers judge that the risk-based approach finds that the probability of the extreme event is significantly higher when human climate drivers are included than when they are absent, they may attribute the difference in probability to human influence. Measures such as FAR and RR (see text box) allow the researchers to quantify the estimated contribution of human influence to the probability of the event.

Examples of Attribution Studies

Extreme event attribution studies have found both events with evidence of human influence, and events where attribution to human influence was not found or where the potential influence was not clear. Examples include the following:

- Evidence of human influence was found when researchers initiated an extreme heat attribution study of record-high May 2017 temperatures in South Korea.[47] The researchers found values for FAR and RR of 0.72 and 3.53, respectively, for extreme heat in early summer and stated that these results indicated "that the extreme risk increases about 3 to 4 times due to the anthropogenic forcing."[48]
- A study of the 2016 drought event in northeastern Brazil failed to find a contribution of human influence. Researchers found with 95% certainty that the range of RR values included 1, a value indicating that the risk was unchanged. The researchers stated that "no change in drought risk can be detected or attributed. Our multimethod analysis suggests that there is not enough evidence that anthropogenic climate change increased drought risk."[49]
- In three separate global and regional attribution studies, researchers calculated a FAR of 1, or 100%. Researchers interpreted these findings to indicate that although there was a contribution from natural climate variability, the events under study could not have happened without human influence.[50]

[47] S. Min et al., "Anthropogenic Contribution to the 2017 Earliest Summer Onset in South Korea," *Bulletin of the American Meteorological Society*, vol. 100, no. 1 (2019), p. S73 (hereinafter Min 2019).

[48] Min 2019.

[49] E. Martins et al., "A Multimethod Attribution Analysis of the Prolonged Northeast Brazil Hydrometeorological Drought (2012–16)," *Bulletin of the American Meteorological Society*, vol. 99, no. 1 (2018), p. S65.

[50] S. Herring et al., "Explaining Extreme Events of 2020 from a Climate Perspective," *Bulletin of the American Meteorological Society*, vol. 103, no. 3 (2022), p. S1. See also T. Knutson et al., "CMIP5 Model-Based Assessment of Anthropogenic Influence on Record Global Warmth During 2016" in "Explaining Extreme Events of 2016 from a Climate Perspective," *Bulletin of the American Meteorological Society*, vol. 99, no. 1 (2018), p. S11 (hereinafter Knutson 2018); Y. Imada et al., "Climate Change Increased the Likelihood of the 2016 Heat Extremes in Asia," in "Explaining Extreme Events of 2016 from a Climate Perspective," *Bulletin of the American Meteorological Society*, vol. 99, no. 1 (2018), p. S97; J. Walsh et al., "The High Latitude Marine Heat Wave of 2016 and Its Impacts on Alaska," in "Explaining Extreme Events of 2016 from a Climate Perspective," *Bulletin of the American Meteorological Society*, vol. 99, no. 1 (2018), p. S39; and the additional study by C. Funk et al. that also calculated a FAR of 1 but rather than characterizing the event as impossible without human influence, characterized it as "extremely unlikely without human-influenced climate change." See C. Funk et al., "Examining the Potential Contributions of Extreme 'Western V' Sea Surface Temperatures to the 2017 March–June East African Drought," *Bulletin of the American Meteorological Society*, vol. 100, no. 1 (2019).

One journal, the *Bulletin of the American Meteorological Society*, publishes an annual special supplement that highlights extreme event attribution studies that could be a source for examining trends in extreme weather and climate event attribution.[51]

Sources of Uncertainty in Attribution Studies

Three sources of uncertainty in extreme event attribution studies are

1. uncertainty in the observational data and ways to interpret it,
2. uncertainty in the understanding of natural climate variability, and
3. uncertainty in the bias and performance of the climate models.

Uncertainty in the observational data includes differences in sampling and measurement methods, which have changed over time. For example, sea surface temperature measurements date back to the 18th century. Sampling methods over that time span include buckets, engine-room seawater inlets, buoys, and satellites, making direct comparison of measurements difficult,[52] although uncertainties can be addressed by statistical methods, among other approaches.[53]

The natural variability of the Earth's climate system and its components, such as circulation and oscillation patterns, is not well understood. This may lead to uncertainty in discerning how natural variability versus human influences can affect extreme weather and climate events.[54] The uncertainties inherent within climate models themselves have been recognized as a challenge in climate change studies.[55] Efforts to reduce the uncertainty in climate models include greater standardization of internal model parameters.[56] Researchers also attempt to increase confidence in attribution studies by using multiple different groups of models and by combining different analytic techniques.[57]

Considerations for Congress

Climate change attribution has been cited in congressional hearings regarding wildfires, disaster preparedness and the role of FEMA, extreme heat, the impacts of climate change, and the

[51] For an example of this publication, see S. Herring et al., "Explaining Extreme Events of 2020 from a Climate Perspective," *Bulletin of the American Meteorological Society*, vol. 103, no. 3 (2022), p. S1.

[52] John J. Kennedy, "A Review of Uncertainty in in Situ Measurements and Data Sets of Sea Surface Temperature," *Reviews of Geophysics*, vol. 52, no. 1 (2014), p. 1 (hereinafter Kennedy 2014).

[53] Kennedy 2014. See also E. Lundstad et al., "The Global Historical Climate Database HCLIM," *Scientific Data*, vol. 10, no. 1 (2023), p. 44.

[54] Theodore G. Shepherd, "Atmospheric Circulation as a Source of Uncertainty in Climate Change Projections," *Nature Geoscience*, vol. 7, no. 10 (2014), p. 703.

[55] K. S. Carslaw et al., "Climate Models Are Uncertain, but We Can Do Something About It," *EOS*, February 26, 2018, at https://eos.org/opinions/climate-models-are-uncertain-but-we-can-do-something-about-it.

[56] B. Soden et al., "Reducing Uncertainties in Climate Models," *Science*, July 27, 2018.

[57] Knutson 2018. See also J. Eden et al., "Multi-Method Attribution Analysis of Extreme Precipitation in Boulder, Colorado," *Environmental Research Letters*, vol. 11, no. 12 (2016), p. 124009.

Department of Homeland Security, among other issues.[58] In some cases, experts have disagreed as to the attribution of the same set or type of events.[59]

Climate change attribution may have a role in domestic litigation in determining compensation for adverse impacts of climate change.[60] Lawsuits have been filed by cities and states in the United States seeking compensation for damages allegedly due to human-induced climate change, including specific events such as Hurricane Sandy.[61] The possibility that extreme event attribution might be used as evidence in U.S. litigation in damage claims against GHG emitters is the subject of legal analysis.[62] Litigation could have implications for the insurance industry,[63] and for the energy[64] and transportation sectors.[65]

Language on the attribution of extreme climate events was included in legislation introduced in the 117th Congress. The Chips and Science Act (P.L. 117-167), signed into law in August 2022, includes provisions for "the development of software and algorithms to enable the productive application of environmental systems and extreme weather in climate and Earth system prediction models."[66] The Climate Risk Disclosure Act of 2021 (S. 1217) would have added the risk of climate-related extreme events to be part of financial risk disclosure. The FEMA Climate Preparedness Act (S. 280) would have directed the Administrator of FEMA to "address threats of climate change," and included the following language attributing some extreme events to climate change, as part of "Section 4. Statement of Intent and Policy":

> "(2) as a direct result of climate change, the United States faces the increased threat of—

[58] U.S. Congress, House Oversight and Reform Subcommittee on the Environment, *Fighting Fire With Fire: Evaluating The Role Of Forest Management In Reducing Catastrophic Wildfires*, hearings, 117th Cong., 2nd sess., March 16, 2022; U.S. Congress, House Oversight and Reform Subcommittee on the Environment, *Recovery, Resiliency and Readiness: Contending With Natural Disasters In the Wake of Climate Change (Climate Change Part III)*, hearings, 116th Cong., 1st sess., June 25, 2019; U.S. Congress, House Committee on Science, Space, and Technology Subcommittee on Environment, *Silent Killer: The Rising Problem of Extreme Heat in the U.S.*, hearings, 117th Cong., 1st sess., July 21, 2021; and U.S. Congress, House Committee on Natural Resources, *Climate Change: The Impacts and the Need to Act*, hearings, 116th Cong., 1st sess., February 6, 2019. See also U.S. Congress, House Committee on Homeland Security Subcommittee on Emergency Preparedness, Response and Recovery, *Examining Climate Change: A Threat to the Homeland*, hearings, 117th Cong., 1st sess., June 8, 2021.

[59] U.S. Congress, House Oversight and Reform Subcommittee on the Environment, *Recovery, Resiliency and Readiness: Contending With Natural Disasters In the Wake of Climate Change (Climate Change Part III)*, hearings, 116th Cong., 1st sess., June 25, 2019.

[60] Sophie Marjanac and Lindene Patton, "Extreme Weather Event Attribution Science and Climate Change Litigation: An Essential Step in the Causal Chain?" *Journal of Energy & Natural Resources Law*, vol. 36, no. 3 (2018), p. 265, at https://doi.org/10.1080/02646811.2018.1451020.

[61] David Hasemyer, "Five States Have Filed Climate Change Lawsuits, Seeking Damages From Big Oil and Gas," *Inside Climate News*, September 15, 2020, at https://insideclimatenews.org/news/15092020/climate-change-lawsuit-connecticut-deleware/. See also Bruce Gil, "U.S. Cities and States Are Suing Big Oil Over Climate Change. Here's What the Claims Say and Where They Stand," PBS *Frontline*, August 1, 2022, at https://www.pbs.org/wgbh/frontline/article/us-cities-states-sue-big-oil-climate-change-lawsuits/.

[62] Marjanac and Lindene 2018.

[63] Don Jergler, "Attribution Science, Extreme Weather and Why They Matter," *Insurance Journal*, October 2, 2014, at https://www.insurancejournal.com/news/national/2014/10/02/342559.htm.

[64] CRS Legal Sidebar LSB10805, *Climate Liability Suits: Is There a Path to Federal Court?*, by Benjamin M. Barczewski.

[65] Maria Antonia Tigre, "The Contribution of Automakers to Climate Change: Broadening the Reach of Private Sector Defendants in Climate Litigation," *Climate Law* (Columbia Law School blog), October 14, 2021, at https://blogs.law.columbia.edu/climatechange/2021/10/14/the-contribution-of-automakers-to-climate-change-broadening-the-reach-of-private-sector-defendants-in-climate-litigation/.

[66] P.L. 117-167.

"(A) changing, more frequent, and more severe extreme weather events.[67]

Language on attribution of extreme weather and climate events also is included in legislation introduced in the 118th Congress. The Earth Act to Stop Climate Pollution by 2030 (H.R. 598), a bill to provide climate change mitigation by ensuring 100% renewable electricity, zero-emission vehicles, and regenerative agriculture, includes the finding that "[t]he United States is already seeing climate change exacerbate extreme weather events."[68] A concurrent resolution entitled "A concurrent resolution expressing the sense of Congress that there is a climate emergency which demands a massive-scale mobilization to halt, reverse, and address its consequences and causes" (S.Con.Res. 9) includes the finding "that climate change is already increasing the frequency of extreme weather."[69] Other legislation, such as the Green New Deal for Health Act (H.R. 2764) and the Food and Farm Act (H.R. 1824), also include findings stating a causal link between climate change and some extreme weather events.

Author Information

Jonathan D. Haskett
Analyst in Environmental Policy

Disclaimer

[67] S. 280.

[68] H.R. 598.

[69] S.Con.Res. 9.