DOI: 10.1377/hlthaff.2020.01004
HEALTH AFFAIRS 39,
NO. 12 (2020): 2168–2174

By Kristie L. Ebi, Christofer Åström, Christopher J. Boyer, Luke J. Harrington, Jeremy J. Hess, Yasushi Honda, Eileen Kazura, Rupert F. Stuart-Smith, and Friederike E. L. Otto

ANALYSIS

Using Detection And Attribution To Quantify How Climate Change Is Affecting Health

Kristie L. Ebi (krisebi@uw.edu) is a professor in the Department of Global Health, University of Washington, in Seattle, Washington.

Christofer Åström is a research fellow in the Department of Public Health and Clinical Medicine at Umeå University, in Umeå, Sweden.

Christopher J. Boyer is a climate and health researcher and PhD student in the Department of Environmental and Occupational Health Sciences, University of Washington.

Luke J. Harrington is a postdoctoral researcher in climate extremes at the Centre for the Environment, University of Oxford, in Oxford, United Kingdom.

Jeremy J. Hess is a professor in the Department of Environmental and Occupational Sciences, University of Washington.

Yasushi Honda is a professor at the University of Tsukuba, in Tsukuba, Japan.

Eileen Kazura is a master of public health candidate in the Department of Global Health, University of Washington.

Rupert F. Stuart-Smith is a PhD candidate at the Environmental Change Institute, University of Oxford.

Friederike E. L. Otto is acting director of the Environmental Change Institute, University of Oxford.

ABSTRACT **The question of whether, how, and to what extent climate change is affecting health is central to many climate and health studies. We describe a set of formal methods, termed detection and attribution, used by climatologists to determine whether a climate trend or extreme event has changed and to estimate the extent to which climate change influenced that change. We discuss events where changing weather patterns were attributed to climate change and extend these analyses to include health impacts from heat waves in 2018 and 2019 in Europe and Japan, and we show how such impact attribution could be applied to melting ice roads in the Arctic. Documenting the causal chain from emissions of greenhouse gases to observed human health outcomes is important input into risk assessments that prioritize health system preparedness and response interventions and into financial investments and communication about potential risk to policy makers and to the public.**

Most health outcomes have multiple, often interacting drivers. Weather and climate variables interact with multiple other drivers to determine the burden of climate-sensitive health outcomes in a particular region over a particular time period. For example, higher mortality during a heat wave results from the interactions of higher ambient temperatures with characteristics of the built environment, the distribution of factors that increase susceptibility (such as the presence of underlying health conditions), and the extent to which health systems are prepared for managing the health care and public health demands resulting from a severe heat wave.

It is increasingly possible to identify the etiologic factors driving disease burden. The science of detecting changes in the climate system and attributing associated impacts to human-induced (anthropogenic) forcing is termed detection and attribution (D&A).

Evidence-based and cost-effective risk management of the health risks of climate change requires robust evidence of the degree to which climate change is causing adverse health outcomes and negatively affecting well-being.[1] D&A studies can provide important input into policy-making processes by demonstrating the current consequences of recent climate change and calculating the economic burden of these impacts on individuals and communities.[2]

Detection And Attribution Methods

Climatologists have developed formal statistical and process-based methods to answer the question of whether and to what extent the likelihood and intensity of climate trends and extreme events (such as temperature or rainfall above a critical threshold at a particular time and place) are changing above the background of natural climate variability (detection), and how much of that change could be attributed to anthropogenic climate change (attribution).[3] Most D&A studies have been based on observations and on physical and statistical models of the climate system. For decades climate scientists have undertaken D&A studies of large-scale temperature changes, with the results used to inform national and international policies to mitigate greenhouse gas emissions.[4] More recent studies have introduced methods to evaluate the changing likelihood and intensity of extreme meteorological events such as heat waves. To date, such analyses have primarily been applied to events that affected high-income countries.[5]

Application Of Detection And Attribution Studies

Advances in methods appropriate to different contexts have substantially increased the application of D&A studies.[4,6,7] These studies have focused on extreme heat, heavy rainfall, or wind storms and have extended the chain of causality investigated to the loss and damage that arise from these meteorological hazards: the societal impacts of anthropogenic climate change.[8,9] D&A is now a broader interdisciplinary science that applies a range of methods to quantify the impacts of climate change on natural systems, such as biodiversity loss.[10]

Because D&A studies require long-term data sets, understanding of the causal chain between exposure to a climate-related hazard and an adverse outcome, and data on other potential drivers, studies of societal impacts are less common.[3] Attribution studies must contend with challenges in defining counterfactual conditions, limitations in the availability of observational data, and challenges in accounting for nonclimatic factors that mediate societies' vulnerabilities to the physical impacts of climate change.

The results of these studies are probabilistic causal estimates similar to the epidemiological causality frameworks that, for example, demonstrated that smoking causes cancer. Given the wide range of inputs and associated uncertainties, confidence intervals around estimates can be large. For example, Sarah Kew and colleagues estimated that human-induced climate change increased the likelihood of extreme temperatures of the same magnitude as or higher than those observed in southern Europe during summer 2017 by at least a factor of 5 but with a best guess of 140.[11] Kew and colleagues also estimated that an event with the same return time (the expected time between occurrences) as the 2017 summer heat wave would have been 0.9–3.7°C cooler had it instead occurred in the climate of 1950.[11] This example also shows that the same study can address the attribution question using different parameters, focusing on the intensity of an event or the likelihood that it will occur. Depending on the needs of decision makers, estimating the extent to which climate change affected the intensity of an event may be more informative than estimating the average time between events.[12] Most health impact assessments focus on the intensity of events.

Despite these challenges, D&A studies of the extent to which climate change is causing adverse health outcomes are beginning to be conducted.[1,13] These analyses fill an important gap between the rich literature describing relationships between weather variables and a wide variety of health outcomes and the growing literature using those relationships to project the magnitude and pattern of risks under different climate and development pathways.[14]

Formal impact attribution assessments for health outcomes first require a D&A analysis concluding that climate change contributed to the climatic shift, shock, or stress that resulted in the health impact. For example, the risk of contracting illnesses from *Vibrio parahaemolyticus* in harvested oysters occurs only when water temperatures exceed 15°C.[15] An impact attribution analysis would therefore start by assessing whether and to what extent climate change affected the occurrence of this water temperature.

Conducting health D&A studies is complex because of the many drivers of these health outcomes and because long health data series are often needed to detect trends.[1] To date, research in this area has focused on heat waves and on the emergence of infectious diseases in new areas (Lyme disease in Canada and *Vibrio* in the Baltic).[1,13]

In this article, case studies provide examples of how D&A studies conducted for meteorological events could be extended to include health impacts.

Study Data And Methods

The authors selected the case studies to illustrate the potential to conduct detection and attribution studies of human-induced climate change impacts on human health. Very limited health data were available, illustrating a key constraint to these analyses.

The case studies required a D&A study of the climatic event. Sources included the World Weather Attribution analyses,[16] which use peer-reviewed methods, and peer-reviewed publications. Publications were identified from PubMed and the Web of Science that detailed the background to the case study; summarized the causal pathway between known climate-sensitive exposures of relevance to health; summarized D&A analyses of the hazard of interest; provided estimates of how anthropogenic climate change affected at least one exposure parameter (for example, severity, frequency, duration); and documented impacts or estimates risks to human health. These impacts and risks are quantified, where data are available, or expressed qualitatively.

Study Results

Three case studies provide examples of incorporating health impacts into D&A studies of meteorological events.

CASE STUDY 1: NORTHERN EUROPE HEAT WAVES, 2018

▶ **BACKGROUND:** Heat waves, or multiday periods of extreme heat, are becoming more frequent, more intense, and longer as the world warms. In higher latitudes where population exposure to heat has historically been limited, protective measures such as heat wave early warning systems and widespread air conditioning use are less prevalent. Dramatic, significant departures from historical temperature regimes, such as the European heat waves of 2006, 2008, and 2018, among others, have had significant impacts on all-cause mortality.

▶ **CAUSAL PATHWAY:** Ambient temperature has well-known associations with health. Populations generally exhibit a minimum mortality temperature above and below which health impacts rise, with a steeper rise in risk associated with temperatures above the minimum mortality temperature. Heat puts strain on bodily systems and is strongly associated with increased risk of direct harms (such as heat stroke) and less strongly with exacerbations of chronic diseases in people with pre-existing conditions, leading to excess morbidity and mortality that contribute more than heat stroke does to overall excess disease burden.

▶ **DETECTION AND ATTRIBUTION OF EXPOSURE CHANGE:** In 2018, northern Europe experienced high temperature anomalies from May to August.[17] Parts of northern Scandinavia experienced record-breaking daily temperatures, with three-day average maximum temperatures more than 5ºC warmer than in 1981–2010. In July 2018, a rapid assessment of whether and to what extent human-induced climate changed altered the likelihood and intensity of the heat wave in seven different northern European locations was conducted;[17] a heat wave was defined as an event with at least three days reaching the annual maximum temperature. The study found that the event had a return time of around seven years in Denmark but at least ninety years in northern Finland in the present climate and that the same event would have been approximately five times less likely to occur if not for human-induced climate change.

Several later studies conducted D&A analyses of the same heat wave. For example, Pascal Yiou and colleagues defined the heat wave across a larger spatial area and a longer temporal extent (July 15–August 2, 2018); this approach increased the climate signal and concluded that the likelihood of occurrence of the heat wave was about 100 times more likely, compared with four times more likely as found in an earlier study.[18]

▶ **HEALTH IMPACTS:** The Public Health Agency of Sweden estimated an excess mortality of 750 deaths in Sweden during July 2–August 5, 2018, with more than 600 attributed to higher temperatures when compared with the same weeks in 2017.[19] A Public Health England study attributed 409 excess deaths above baseline in the subgroup of people age sixty-five and older to the heat wave in that country during July 21–29, 2018.[20] The Finnish Institute for Health and Welfare attributed 380 deaths in Finland to the 2018 heat wave,[21] and the Danish Statens Serum Institut attributed 250 deaths in Denmark to it.[22] It is not possible to aggregate the mortality data to regional estimates because the heat waves occurred over different time periods. The numbers of deaths underestimate the total health impact of the heat waves because they do not include hospitalizations, impacts on maternal and child health, consequences for well-being, and other possible impacts.

CASE STUDY 2: JAPAN HEAT WAVE, 2018

▶ **BACKGROUND:** As noted above, climate change is associated with the increased frequency and severity of extreme heat events.

▶ **CAUSAL PATHWAY:** Extreme heat also affects use of the health care system. Excess morbidity associated with heat waves leads to increased use of emergency medical services, outpatient care, and inpatient hospitalizations.

▶ **DETECTION AND ATTRIBUTION OF EXPOSURE CHANGE:** The summer of 2018 saw record-breaking temperatures in Japan preceded by an extreme precipitation event that resulted in a national emergency. Contributing factors included climate change and warmer-than-average high-pressure systems in the upper troposphere (North Pacific Subtropical High and Tibetan High). One preliminary analysis using simulations from one climate model[23] concluded that the event had an estimated 20 percent probability of occurring in today's world but a near-zero probability in simulations that excluded anthropogenic climate change.[24] A separate study compared modest and extreme heat-wave

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days, defined as when daily maximum temperatures exceeded the 75th and 90th percentiles for at least seven consecutive days over 1980–2018. Compared with 1941–79, the probability of the defined heat-wave event over a thirty-year period was one and a half times higher for 1980–2018 and seven to eight times higher for 2019–50.[25]

▶ HEALTH IMPACTS: In Tokyo, based on a common risk function performed by Yasushi Honda and colleagues, annual emergency vehicle (such as ambulance) visits increased from an estimated 3,000 in the ten years prior to 4,500 in 2018.

CASE STUDY 3: LOSS OF ICE ROADS IN WESTERN ALASKA

▶ BACKGROUND: The Arctic region is warming at a rate two to three times faster than the global annual average,[26] resulting in observable impacts for Arctic communities.[27] However, there are almost no data on the consequences for health. Extreme weather events, shifting migration patterns, and warmer and shorter winters[28] have led to concerns about food security and impacts on infrastructure,[29] with potential impacts on rates of food- and waterborne illness and injuries. The rate of change in the Arctic Region and the number of observations of extreme events,[30] shifted seasonal patterns, and temperature increases suggest a shift in relevant exposures that, ceteris paribus, would likely lead to adverse health impacts. Although the populations in the region are small from the global perspective, these impacts are significant for the affected communities.

▶ CAUSAL PATHWAY: Communities in western Alaska generally depend on sea ice and ice roads for intercommunity transportation, hunting and fishing, coastal buffering from storms, and ecosystem services. Ice roads are often the only means of ground travel between communities. Ice road stability is compromised during periods of extreme warming, which can lead to morbidity and mortality from injuries and drowning related to unstable ice, more open water, and other conditions.

▶ DETECTION AND ATTRIBUTION OF EXPOSURE CHANGE: The winter of 2017–18 was unusually warm, resulting in extremely low sea ice cover in the Bering Sea.[31] Sea ice extent was the lowest in recorded and reconstructed history; this would have been an estimated 2-in-1,800-year event in a preindustrial climate.[32] Communities such as Shishmaref and Unalakleet experienced late freeze-up, delaying the use of sea and river ice for travel and making such travel more dangerous. A December 2017 flyover of the travel corridor by the local search and rescue operation suggested that the number of open water holes was "uncountable."[33] While a formal D&A analysis has not been conducted of the impacts of climate change on ice roads themselves, this case study illustrates how causal relationships could be established.

▶ HEALTH IMPACTS: In Bethel one person died and five were rescued after they encountered open water on the Kuskokwim River when traveling by snow machine.[34] These numbers would presumably be much larger if more health data were collected across northern communities.

Discussion

D&A studies substantiate the causal chain from emissions of greenhouse gases to observed human health outcomes. This attribution has important potential in several applications, including loss and damage calculations, risk assessment, and health system preparedness and response. Attributing health impacts to climate change also has important rhetorical implications for prioritizing climate action. By estimating the magnitude and burden of the impacts resulting from climate change to date, communications concerning and public understanding of the risks posed by climate change to individuals, communities, and countries shift from an emphasis on a future threat to one that is occurring and needs to be addressed today.

Limited understanding of the present impacts of climate change on public health restricts investment in building climate-resilient health systems. Just 0.5 percent of multilateral international adaptation funding has explicitly supported projects to reduce current impacts and prepare health systems for additional climate change (Elena Villalobos Prats, World Health Organization, personal communication, 20 June 2019). Robust attribution estimates of the consequences of climate change for human health could demonstrate that certain health care needs are the direct result of climate change and therefore within the mandate of climate finance institutions, thereby releasing funding to address pressing population health challenges.

The case studies we have presented demonstrate that many opportunities are available for estimating the current health impacts of climate change. The number of exposure events that can be partially or entirely attributed to climate change is increasing steadily as methods improve and climate change accelerates. Limited health data are collected for climate-related events, complicating D&A studies, but these studies need not be limited to mortality. For example, the role of climate change in the burden of mental health after a tropical cyclone devasted a city would be best estimated based on an event attribution study focusing on the intensity of the hurricane in question and estimations of morbidity associated with mental health impacts.

When D&A analyses are being conducted, several considerations are important. First, there is the causal pathway and the linkage between the exposure and health outcomes. Consideration of how to specify the health impacts associated with an extreme event, or those associated with longer-term trends in mean climate, is crucial. Second, there are exposure parameters to consider. Analyses can focus on attributable changes to either the intensity or the frequency of an exposure (or both). Third, there is the consideration of geographic and temporal scope for the analysis. These factors affect the attribution estimations related to the exposure, as highlighted in the discussion of the northern Europe heat wave. Fourth, climate change is worsening the magnitude and frequency of many extreme events but, so far, is rarely the sole cause (that is, attribution is partial), which complicates accounting.

There are also methodological choices to make. Many D&A studies are ecological. Stronger causal inferences can be made if quasi-experimental methods such as difference-in-differences analyses are used. Methods could also include estimation based on known exposure-outcome associations derived from the literature. Different methods may be needed for D&A analyses of slow-onset, persistent impacts such as long-term climate trends and glacial retreat. For example, ambient temperature is a key driver of the geographic range, seasonality, and intensity of transmission of the *Aedes* mosquito species that can transmit the dengue virus.[35] A D&A study examining whether climate change contributed to the anomalous outbreaks of dengue fever in 2019 might use traditional trend-attribution methods, in concert with probabilistic methods that suit the analysis of specific extreme events, to assess the potential shift in upstream drivers affecting vector ecology.

Attribution of health impacts may provide new avenues for climate change communication.

Attribution of health impacts may also provide new avenues for climate change communication. Climate change impacts can be seen as distant to members of the public—in time, geography, or social cohort. This reduces engagement with, and support for, actions to address climate change.[36] D&A studies reveal the immediacy and concreteness of climate impacts.[37] Extending attribution to human health increases understanding of climate change impacts and may lead to new opportunities to communicate with policy makers and the public.

D&A studies also inform climate change litigation, intergovernmental negotiations on "loss and damage,"[38] and multilateral adaptation financing. Globally, more than 1,400 climate-related cases have now been brought before the courts.[39] In litigation relating to climate change impacts, attribution science can provide a firm evidentiary basis for the alleged causal relationship between the greenhouse gas emissions of defendants and damages sought by plaintiffs.[40] Some past climate-related lawsuits alleged that because of the health impacts of climate change, courts should compel defendants to reduce their greenhouse gas emissions or pay compensation to affected parties,[41] without using attribution evidence. *Juliana vs. United States*, for instance, cites asthma attacks resulting from an increased frequency of forest fires in Oregon as an impact on the health of plaintiffs for which climate change is responsible.[42] Numerous jurisdictions explicitly grant citizens the right to health or a healthy environment.[43] However, challenges to using D&A in a legal context include selecting which greenhouse gas and aerosol contributions to warming should be included,[44] modeling uncertainties (the magnitude of which varies between climatic phenomena), and uncertainties that arise because of multiple drivers in the relationship between emissions and impacts.[45]

Conclusion

Detection and attribution methods are powerful tools that can be used to protect and promote population health in a changing climate. As climate change progresses, further opportunities for the application of D&A methods will accompany increases in the mean climate and associated weather extremes. Partnering with climatologists with expertise in statistical and process-based methods will increase the robustness of conclusions concerning the extent to which climate change is affecting health now, providing critical information for evidence-based and effective actions to reduce greenhouse gas emissions and increase resilience to the impacts of climate change on population health and health care infrastructure. ■

Kristie Ebi reports having received occasional support from the World Health Organization (travel), Green Climate Fund, and Global Commission on Adaptation. The authors thank Marci Burden, University of Washington, for her valuable support in manuscript production.

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