CORE CONCEPTS

How does climate change influence extreme weather? Impact attribution research seeks answers

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Hurricane Harvey devastated the Houston area when it stalled over southeastern Texas in August 2017. In the weeks that followed, Hurricane Irma traveled up the mainland of Florida, and Hurricane Maria pummeled Puerto Rico. The year 2017 would become the most expensive hurricane season on record.

For decades, climate researchers using computer models have predicted that the warming ocean and atmosphere would likely increase the intensity of such natural disasters. More recently, though, high-resolution datasets and more sophisticated models have allowed researchers to find the fingerprint of climate change in individual weather events. Such analyses are exceedingly tricky, and not all experts the field agree on the best approach. But in recent years, a growing subfield of "attribution" research has produced results that are increasingly compelling—and increasingly concerning. Such work not only investigates the causes of past events but could potentially help improve forecasting for future ones.

One study published in Harvey's aftermath suggests climate change likely boosted the hurricane's rainfall by 20 to 40% (1). To reach that figure, the researchers compared observed precipitation levels with those predicted by a computer model that simulated the hurricane using greenhouse gas levels from more than 60 years ago. Another analysis that pooled results from six different climate models estimated that Harvey-level rainfall was a 1-in-2,000-years event at the end of the 20th century, but by the end of the 21st century that likelihood will be 1 in 100 years (2). In May, a National Science Foundation-funded study estimated that recent named storms would be slower-moving, have faster winds, and be much wetter, on average, if they'd formed in a climate warmed by 5 °C (9 °F)—the change predicted in average temperature over the next century. In other words, the models suggest that even devastating hurricanes such as Harvey will be worse in the future (3).

Attribution work also offers up an outreach opportunity. "Global warming is nebulous," says climate

Hurricanes Irma, Jose, and Katia, seen here moving across the Caribbean Sea and Atlantic Ocean, were three of the many hurricanes that made 2017 a record year. Impact attribution research is attempting to tease out when and to what degree climate change has exacerbated such extreme events. Image courtesy of Shutterstock/lavizzara.

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Hurricane Maria devastated the island of Puerto Rico, including the Ocean Park section of San Juan. Impact attribution work could, in principle, help meteorologists make more informed predictions and thus better protect people and property from future extreme events. Image courtesy of Shutterstock/Alessandro Pietri.

scientist Peter Stott at the Met Office, the government weather service in the United Kingdom. What isn't nebulous, he says, is escaping a hurricane or surviving a drought. "People can't deny those experiences. This research is making the link to personal experience."

Defying Predictions

In the days after wildfires, tornadoes, floods, heat waves, hurricanes, and other severe events, climate scientist Stephanie Herring fields the same question from journalists, researchers, and victims: Was this disaster caused by climate change? Until a few years ago, she says she lacked an appealing response. "We could tell you what we know about trends," says Herring, who's at the National Oceanic and Atmospheric Administration's National Centers for Environmental Information in Boulder, CO. "But we were giving very generic answers."

Experts such as Herring argue that the question of whether an event is due to climate change needs to be reframed. It's more enlightening to ask whether climate change is altering the risk and frequency of types of events. Still other researchers pose the question differently: Given that a particular event happens, how did climate change affect the outcome?

The May NSF study reveals how resource-intensive these kinds of questions can become: The simulations required a full year of calculations on a supercomputer at the NCAR-Wyoming Supercomputing Center, in Cheyenne, WY. Making predictions about risk and intensity for events such as hurricanes requires high-resolution data— to the scale of a few kilometers—and the model has to run long enough to simulate long stretches of time.

Nevertheless, progress has been swift. The first attribution article was published in 2004; since then, says Herring, she has seen hundreds of articles that probe the contribution of climate change to individual weather events. Late this year, the *Bulletin of the American Meteorological Society* (BAMS) will publish its annual collection of studies that measure the impact of climate change on extreme weather events in 2017. The collection has been published since 2012, during which time the journal has featured 131 studies. Events highlighted in the most recent report ranged from flash droughts in southern Africa to extreme rainfall in Australia and China (4). Of all the studies highlighted over the years in BAMS reports, roughly 65% have found that climate change did, indeed, increase the severity or likelihood of an event. The rest did not find a significant contribution from climate change, suggesting either climate change didn't play a role or that the tools used couldn't detect an impact. Not every impact attribution study ends up in a BAMS report, and climate researchers clash over methodology. But the existence of these studies demonstrates a growing push among researchers to develop robust analytical approaches that link climate change to weather.

Climate as Culprit

In August 2003, a heat wave burned across Europe, killing thousands of people. Motivated by the devastating effects, Stott wanted to know the role of climate change in the disaster. He took an approach still used in many studies, comparing observed data with what would have happened, climate-wise, if people hadn't started pumping carbon dioxide into the air.

This method involves two sets of data. One set is created by starting a computer simulation around 1850, assuming preindustrial levels of greenhouse gases in the atmosphere. It runs the clock forward with no infusion of carbon dioxide or other greenhouse gases to generate possible scenarios. The end result is called "counterfactual" data. The other set uses either real-world data or the results from simulations that do account for anthropogenic climate change. Then the researchers analyze how frequently an extreme event occurred in each scenario and compare. If the event shows up at the same intensity in both models, the reasoning goes, then climate change probably didn't play a significant role in its genesis.

Using that approach, Stott and his collaborators reported in 2004 that human-induced changes to the climate ("anthropogenic forcing") had doubled the risk of a severe heat wave as severe as the one that hit Europe in 2003 (5). They used a climate model called HadCM3, which analyzes horizontal slabs of the atmosphere and ocean measuring several hundred miles on each side. "It had a pretty low resolution in space," he says, meaning the model was of little use for making predictions about smaller areas, such as individual regions within a country.

"What we have now are multiple climate models that allow us to cut down on the noise."

—Peter Stott

Now, Stott says, researchers have access to datasets with resolution down to tens of miles, as well as more choices in models. "What we have now are multiple climate models that allow us to cut down on the noise," Stott says. "If we see a common signal across many models, then they're telling us something."

Models have also become more sophisticated, says climate scientist John Walsh at the University of Alaska Fairbanks' International Arctic Research Center. Early ones were almost exclusively atmospheric, but newer models are "more realistic in the way they incorporate the land and the ocean in these simulations," says Walsh. Researchers can tweak simulations to modify linked systems in complex environments, such as vegetation, soil moisture, and snow. Those interactions become particularly important in studying events such as droughts, which arise from interactions between the ground and the air.

One way models quantify the influence of climate change is to calculate an event's fraction of attributable risk, or FAR, which takes a value between zero and one. If an event has a FAR of one, then it wouldn't have occurred without climate change. A FAR near zero indicates climate change likely had no effect. The BAMS report published in January 2018 for the first time included events with a FAR of one, which means the analysis suggests the event wouldn't have happened without climate change.

Those studies include a remarkable Alaskan heat wave with temperatures higher than at any point in the historical record going back hundreds of years. In 2015 and 2016, temperatures soared in the waters off the coast along the entirety of the state. It was associated with a swath of anomalously warm water often referred to as the Blob. To study the event, Walsh and his team used a model called CMIP5 (Coupled Model Intercomparison Project, version 5), which provides scenarios from a suite of models that simulate the last 150 years of climate (6).

"That event required both climate change and natural variability to reach the magnitude that it did," Walsh says. "It's true that it wouldn't have happened without climate change, and it wouldn't have happened without natural variability to kick it in the right direction." He is currently studying sea ice levels in the Bering Strait, which reached record lows in the winter of 2017–2018. Those low ice levels are likely a consequence of the heat wave, Walsh says. "The amount of sea ice this year was half of the lowest ever recorded," he says. "It not only broke the old record, it shattered it."

Challenges and Challengers

Today's models cannot accurately produce data about every type of weather event. They can't, for example, simulate thunderstorms that produce tornadoes. The twisters are just too unpredictable and too dangerous to study up close and in large numbers. "No one does attribution research on tornadoes," says Herring.

And it's difficult for researchers to evaluate the quality of computer models because the counterfactual scenarios, by definition, didn't actually happen. Some events may be better represented than others, and studies have only recently begun to account for the natural variability that occurs during El Niño and La Niña systems.

Some climate researchers argue that the conventional approach can lead to an incomplete—and potentially misleading—picture of the impact of climate change. Kevin Trenberth, at the National Center for Atmospheric Research in Boulder advocates for a more direct methodology. Instead of looking at a fictional world without anthropogenic forcing and comparing it with actual events, his method involves taking the weather event as a given and then figuring out how climate change did or did not made it worse. "What's the role of climate change," he asks, "given that we already have these weather events?"

This question still leads to a comparison. But instead of starting the clock in the past, researchers look at the present by comparing counterfactual data to real-world scenarios. They run simulations of the same specific weather event with and without the known thermodynamic changes brought about by climate change. By comparing those data, they can draw conclusions not on the likelihood of a type of event occurring, but rather on how much climate change influenced a real event.

This conditional method is often referred to as a "storyline" approach. And where the conventional approach emphasizes natural variability, the conditional approach focuses on the role of climate change, says Trenberth. The different methodologies produce disparate reports. For example, studies in the 2017 BAMS report suggested climate change did not increase the likelihood of the 2013 floods in Boulder. But a study published in 2017 that uses Trenberth's conditional approach found that climate change did increase rainfall by 30% and worsen the flood. Not using the storyline tools, say its advocates, can lead to an underestimation of the impact of climate change (7).

Still other approaches emphasize the study of atmospheric dynamics over the focus on thermodynamics and statistics approaches that are part and parcel of most attribution work. Such dynamics can start to explain how hot air from Africa gets funneled over western Europe or how a rerouted polar vortex carries cold air away from the North Pole and onto North America, resulting in unseasonable temperatures at both places. For example, Stefan Rahmstorf, at the Potsdam Institute for Climate Impact Research in Germany, has been researching planetary (or Rossby) waves, oscillations that form naturally in the atmosphere because of the rotation of the planet. His work has linked the behavior of these waves with extreme weather events. A 2013 study led by Rahmstorf found that during heat waves in Europe (2003), Russia (2010), and North America (2011), components of planetary waves became exceptionally large.

Rahmstorf, working with Michael Mann, at Pennsylvania State University, showed that the last 120 years or so have brought an uptick in favorable conditions for large-scale planetary waves (8). "That strengthens the conclusion that climate change is making … these conditions more likely," says Rahmstorf, who suspects that atmospheric dynamics are not well-represented in current climate models used for attribution studies.

Attribution Outreach

In 2016, climate scientist Daniel Mitchell at the University of Oxford's Environmental Change Institute in the United Kingdom revisited that 2003 European heat wave. Instead of investigating whether climate change made the event more likely, as Stott did, Mitchell estimated how it increased the death toll from an actual event. In other words, he looked at how anthropogenic forcing is threatening survival (9).

Studies such as one show the immediacy of risk, says climate scientist Jesse Bell at the University of Nebraska Medical Center, in Omaha, NE. "A lot of times when we talk about climate change we talk about how things are changing the future," he says. But Mitchell's study emphasizes the here and now. "This isn't something that's going to just have an impact in 25 or 50 years. Climate change is now."

Bell integrates climate data with potentially related trends on death and disease, working on ways to present data at the county or regional level. For example, the incidence of coccidioidomycosis, a fungal infection, is on the rise, in part because of how climate change affects spore dissemination. In 2017, Bell and his colleagues reported on the population's vulnerability to this fungus at the county level, data that could be used by county health officials to prepare for an uptick in infections.

"They can use that data to understand the impacts on their particular region," Bell says, noting that data on increased risk can help officials prepare. That sort of information will become invaluable as average temperatures continue to climb. "The extremes will get more extreme. And because of that," Bell adds, "populations can become more exposed."

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