How do climate scientists study the causes of climate change?

Much has been written about extreme events in the strange summer of 2021. There's been much to write about. I won't repeat the lists of record-breaking heat, drought, floods and wildfires. Lists of extreme events in North America, Europe and Asia. Lists documenting human suffering and death. Property destruction. Ecosystem devastation.

Instead, I'd like to tell you about causation. How do climate scientists study the causes of climate change? And how do they investigate whether human-caused planetary warming is affecting extreme events?

I've done such attribution science for over 30 years. Back in 1995, I took part in an assessment of climate science conducted by the Intergovernmental Panel on Climate Change — the IPCC. I was in charge of the chapter that dealt with attribution science. After several years of work, our chapter concluded that "the balance of evidence suggests a discernible human influence on global climate."

In retrospect, this was a cautious, even wimpy statement. Nevertheless, it marked a turning point. The international scientific community, in a major assessment report, had for the first time claimed detection of a human-caused global warming signal. Signal detection was not some future hypothetical. It had happened in our lifetimes. After 1995, humans could no longer plead ignorance of the climate disruption they were causing.

Attribution science was still a young science in 1995. It focused mostly on the 20th-century warming of Earth's land and ocean surfaces. What caused this warming?

To answer this question, attribution scientists looked at patterns of climate change. Geographical patterns. Slices through the atmosphere and ocean. Seasonal patterns. Patterns were powerful; different influences on climate had different "fingerprints."

Computer models helped to reveal these differences. In model world, you could do the thought experiment we can't do in the real world — you could change all the major human and natural influences on climate, one by one, to isolate the fingerprint of each influence. This pattern information helped scientists to separate natural changes in volcanic activity and the sun’s energy output from the fingerprints of human-caused fossil fuel burning, stratospheric ozone depletion, and deforestation.

Attribution science was not just about fancy pattern recognition techniques or complex computer models of the climate system. Attribution relied on evidence from studying climate fluctuations over “deep time,” before humans began industrial scale burning of fossil fuels. Attribution was informed by lab research revealing how greenhouse gases trap heat. Venusian and Martian atmospheres were another kind of laboratory, useful for studying the climates of planets with greenhouse gas levels very different from those of Earth. And observations of our home planet — from space, in the oceans, and on land — provided the hard data on global-scale climate change that scientists needed for attribution studies.

All these independent lines of evidence — from basic theory, “deep time,” planetary atmospheres, computer models, observations and pattern recognition techniques — pointed toward a dominant human role in recent climate change.

The consistency of different lines of evidence was scientifically compelling. But at a personal level, the evidence was also deeply concerning. You know your species is changing the climate in a way that’s likely to impact present and future inhabitants. That disquieting knowledge is always there, a constant unwelcome companion.

The 1995 IPCC report didn’t devote much attention to figuring out whether human activities contributed to changes in extreme events. There were few relevant studies to assess.

Things changed dramatically after the European summer heatwave in 2003. This catastrophic event led to significant excess mortality — to tens of thousands of additional deaths that would not have happened without the heatwave. For many climate scientists, “climate change and extreme events” suddenly transitioned from the category of “academically interesting” to “critically important for us to understand.”

The 2003 European summer heatwave jump-started a field now called “event attribution.” Scientists in the U.K. were pioneers in this field. They asked a simple question: Had human-caused warming increased the likelihood of a heatwave of the size and scale of the 2003 event?

They found that it had. Global warming increased the risk of an event like the 2003 European heatwave by at least a factor of two.

This type of calculation involved comparing two different worlds — a world with human-caused global warming, and a world without it. Climate modelers routinely perform such pairs of calculations. In each simulated world, one can determine the risk of some bad outcome, and then compare how the addition of human influence altered the risk. A similar type of “risk ratio” is often used in evaluating the effectiveness of a particular drug or medical treatment.

Today, event attribution has dozens of practitioners around the world. Increasingly, such “climate CSI” teams use a sophisticated array of computer modeling, statistical approaches and observations to calculate changes in risk after a specific extreme event.

A good example is the evaluation of the human contribution to the extraordinary, record-shattering heat wave that affected much of the Pacific Northwest in July 2021. From analysis of temperature observations, it’s estimated that this was a once in a millennium event. Analysis of many different model simulations showed that the Pacific Northwest heatwave was virtually impossible without human-caused warming.

At the frontier of event attribution science, there is now greater emphasis on trying to understand the specific meteorological situation that accompanied an extreme event.

Is large warming over the Arctic systematically changing atmospheric circulation patterns, the location and waviness of the jet stream, and the likelihood of unusual heat domes? While the jury is still out on these more nuanced questions, they are critically important questions to answer — and answer fast. But it’s pretty clear that human-caused warming of Earth’s climate is already affecting our weather patterns.

What’s the outlook for all of us? More extreme extremes. The once in a millennium heat wave becomes something we experience many times in our lives. More severe impacts of extreme events on health, lives, every aspect of our economy and global ecosystems. Daily demonstration of human vulnerability to a rapidly changing climate.

But it does not have to be this way.

When confronted by a global pandemic, scientists worked at unprecedented speed to develop multiple vaccines. The vaccines are remarkably effective. They save lives. Overwhelmingly, those who now die from COVID-19 are unvaccinated. In the United States, where the Moderna, Pfizer and Johnson & Johnson vaccines are widely available, vaccination is now a life-or-death personal choice.

We face similarly grave choices in addressing human-caused climate change. There are multiple clean energy "vaccines." They work. They reduce our dependence on fossil fuels. They lower emissions of greenhouse gases. We can choose to deploy low-carbon energy production systems rapidly and at scale. Or we can choose to ignore climate science, follow a "business as usual" strategy of fossil fuel use — and remain unvaccinated against the ever-increasing risks of serious climate disruption. It's a choice.

One lesson learned from COVID-19 is that receiving a vaccination isn't helpful at the point when you're already in the ICU, being intubated because you're struggling to breathe. Nor will it be helpful if real action on climate change is deferred for decades — when we are all struggling to breathe air that isn't tainted with wildfire smoke.