Testimony of Dr. Michael Wehner
Senate Environment and Public Works Committee
The Science of Extreme Event Attribution: How Climate Change Is Fueling Severe Weather Events

Chairman Carper, Ranking Member Capito and distinguished Members of the Committee, good morning and thank you for the invitation to testify at this important hearing on the science of extreme weather event attribution. I am Dr. Michael Wehner, a senior scientist at the Lawrence Berkeley National Laboratory. My research focuses on the behavior of extreme weather events in a changing climate. My remarks are my own and not intended to represent the positions of the Lawrence Berkeley National Laboratory, the University of California, or the United States Department of Energy.

According to both the US National Climate Assessments and the reports of the Intergovernmental Panel on Climate Change, it is unequivocal that humans have heated the Earth's climate. Indeed, the best estimate is that human activities, principally the use of oil, coal and gas are responsible for all of the observed global warming.

Our understanding about the effects of this human-caused global warming on specific, individual extreme weather events has advanced considerably in the past two decades. Indeed, for many types of weather events, scientists can identify and quantify the ways that the human interference in the climate system has influenced extreme weather. Obviously, we have always experienced extreme weather: heatwaves, droughts, extreme storms, and the like. Extreme weather attribution science attempts to quantify the influence of climate change on specific individual events by answering two related questions. First, has global warming affected the severity of an event of a particular frequency (say, once in a century)? And second, given the observed magnitude or intensity of an event, has global warming affected its rarity.

Because we have only one planet Earth, to answer these questions, scientists must use both climate and statistical models to compare representations of weather events in the actual "world that was" to a counterfactual "world that might have been" without climate change. Confidence in attribution statements is increased when multiple independent author teams use different approaches and arrive at similar conclusions consistent with observed trends. Confidence in quantitative attribution statements is very high about the human influence on heatwaves, agricultural drought and certain classes of severe storms, including hurricanes.

The graph in figure 1 of extreme temperatures in the Pacific Northwest shows how our two attribution questions are two sides of the same coin. Temperatures on the y-axis are plotted as a function of their rarity on the x-axis. The red curve is a simulation of the "world that was" with a realistic as possible representation of the composition of the atmosphere. The blue curve is a simulation of the "world that might have been" without the human changes to the composition of the atmosphere. To answer the first question, we would draw a vertical line down from the observed temperature on the red curve, say for example 106.8^{o}F, finding that it is a once in a century event. We then estimate that without climate change from the blue

curve, that the once in a century event would have been 104.2°F or 2.6°F cooler. Hence, global warming caused such heatwaves to be 2.6°F hotter. To answer the second question, we would draw a horizontal line from the observed temperature on the red curve to the same temperature on the blue curve finding that what is now a 100 year event would have been a once in 1500 year event without climate change. Hence, global warming increased the chances of experiencing such an observed temperature by a factor of 15. This example illustrates that framing of the attribution question is an important consideration when communicating the influence of climate change, if any, on individual extreme weather events.

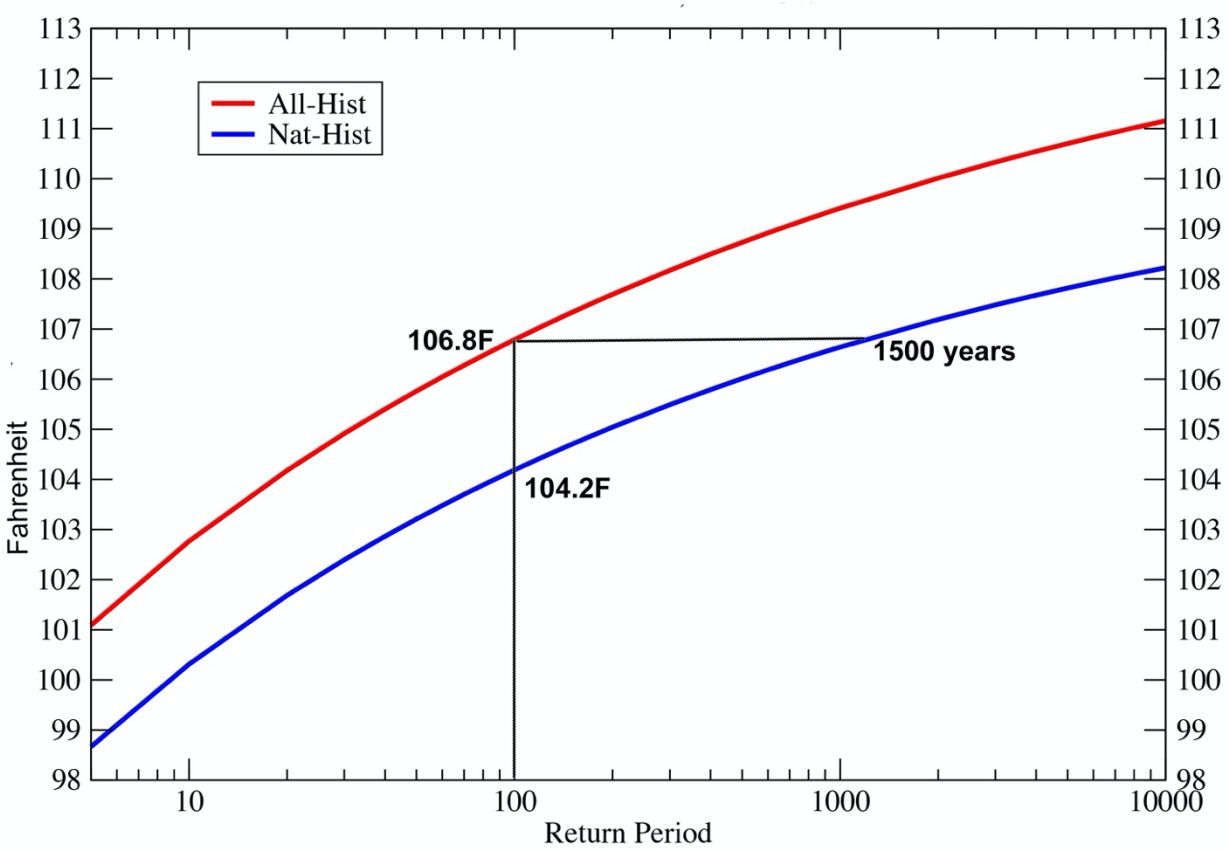


Figure 1: Analysis of the human influence on Pacific Northwest heatwaves using the Community Atmospheric Model (CAM5)[1,2]. What was a once in 1500 years event is now a once in a century event because of global warming.

It is also important to note that in a high quality attribution study, multiple climate models and observational datasets should be used if possible and a full analysis of the statistical confidence disclosed. Oftentimes, the calibrated language[3] of the Intergovernmental Panel on Climate Change (IPCC) is used to convey statistical analysis in plain language. For instance, the phrase "global warming *very likely* increased the chances of an event by *at least* a factor of X" is a very conservative statement. The key words in this sentence are "*very likely*" and "*at least*" as they are meant to convey that X is the lower bound of a 90% confidence interval on the estimated change in rarity. Any "best estimate" of such a change would generally be considerably larger.

Indeed, as the Earth warms, every one that we now experience is hotter than it would have been without climate change, including those this past summer in the United States and throughout the Northern Hemisphere. In the lower 48 states, I estimate that any heatwave of reasonable rarity is now 2.5 to 5 degrees Fahrenheit hotter than it would have been without the human interference in the climate system[2] as shown in figure 2. This increase has adverse health effects, including possible death, on all Americans but particularly the very young, the very old and the very poor. For instance, extreme heatwaves in California often lead to excess hospitalization and morbidity rates of outside laborers especially agricultural workers, many of whom are in the Latino/Latina community[4].

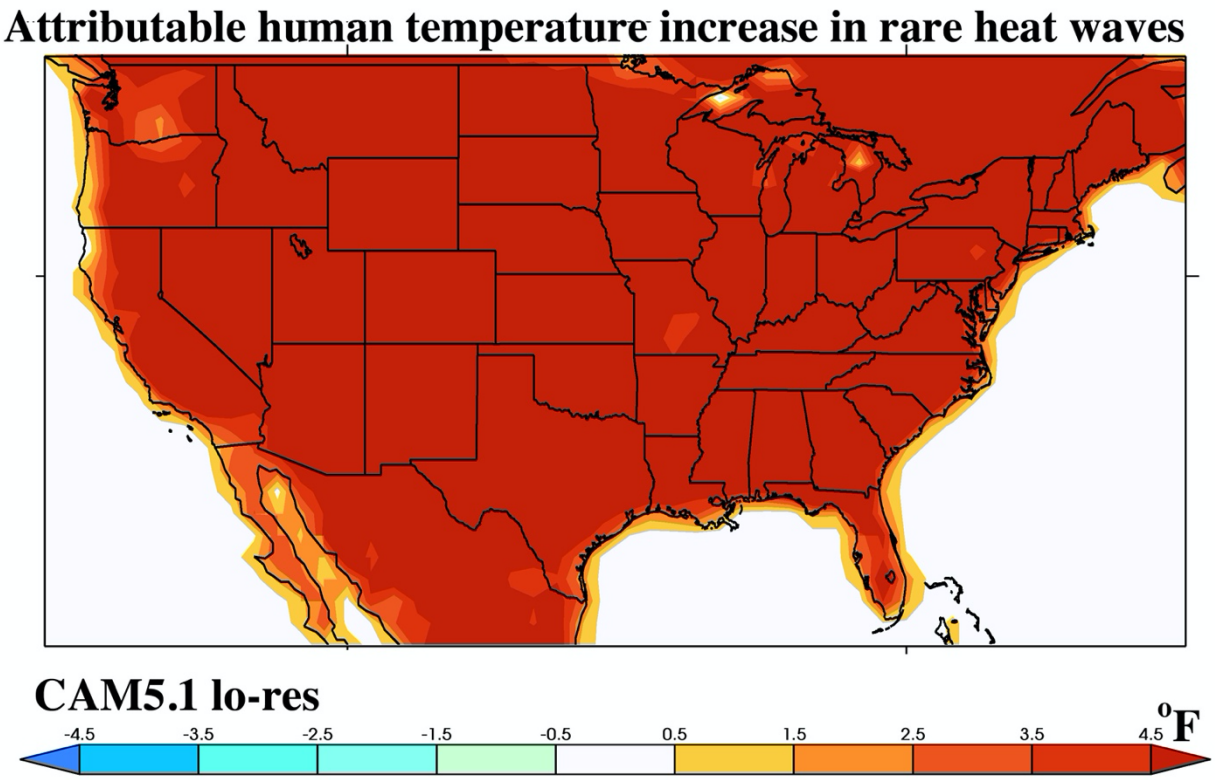


Figure 2: Attributable change in once in 20 year single day heatwaves as simulated by the Community Atmospheric Model (CAM5)[1,2]. Results are essentially the same for heatwaves of greater rarity.

Extreme storms have been made wetter by climate change as well. For instance, of the more than 30 different hurricanes that have been studied in an attribution context, all of the analyses reveal a significant human fingerprint on the total rainfall amounts[5–8]. Generally, these human induced increases in hurricane rainfall amount exceed that expected from the human induced thermodynamic increases in available moisture. Figure 3 and supporting literature reveal that the parts of hurricanes that rain the most experience the largest increase and become more efficient at raining out the increased moisture from the warmer saturated air due to climate change[9,10]. Shown is a “storyline” analysis of Hurricane Maria, a storm that devastated much of Puerto Rico in September 2017[6].

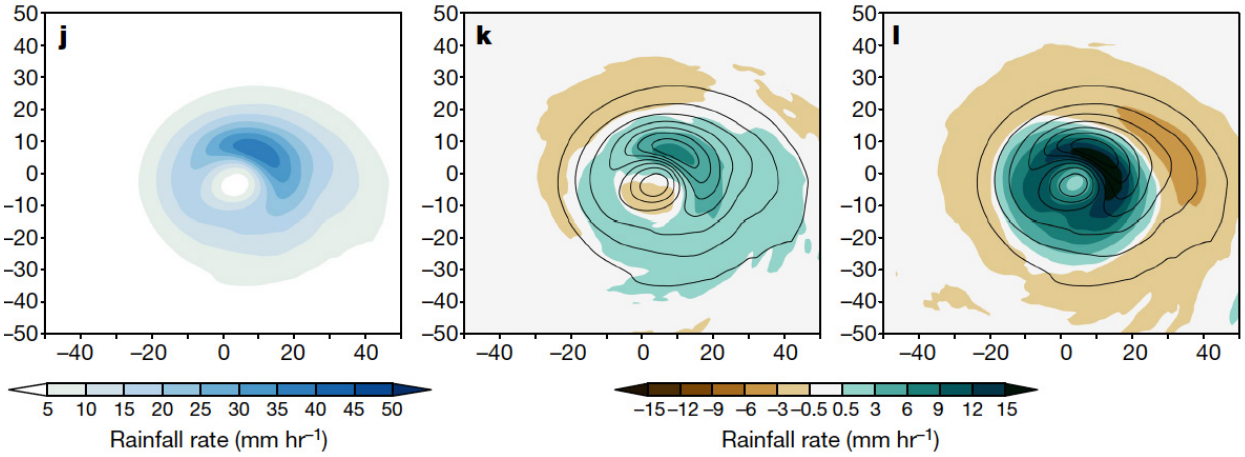


Figure 3: Left: A composite hindcast simulation of Hurricane Maria's rainfall. Center: The pattern of attributable rainfall changes under the current amount of climate change. Right: The pattern of projected rainfall changes at the end of the century under a "no-policy" high emissions scenario (RCP8.5).

I, along with many of my colleagues, feel that the state of the science has matured to the point that for certain extreme weather events, attribution statements could be made operational[9,11,12]. By that I mean that this responsibility could be transferred from the academic research community to an appropriate Federal agency capable of producing extreme weather event attribution statements on a regular basis. Indeed, several nations are considering doing this both to satisfy the public demand for this sort of information as well as increasing our scientific understanding.

Recent advances in attribution science have gone beyond just studying the human influence on the meteorology of extreme weather events to examine the human influence on the impacts that these events have on real people. Take Hurricane Harvey and the record flooding it caused in the greater Houston area. Global warming caused the surface waters of the Gulf of Mexico to be about 2 degrees Fahrenheit warmer than before the widespread use of coal, oil, and gas. These warmer waters caused the rainfall during Hurricane Harvey to be about 20% greater[13–15]. This increased rainfall caused the flooded area to increase by about 14%[16]. Because much of the flooding was in densely populated areas, using this estimate of the attributable increase in flooded area, the number of flooded homes in Harris County was increased by even more – by about 32%[17]. NOAA estimates about 155 billion dollars in damages occurred due to Hurricane Harvey flooding (https://www.ncei.noaa.gov/access/billions/dcmi.pdf) , so a crude estimate is that global warming is responsible for about one third of this amount, or 50 billion dollars.

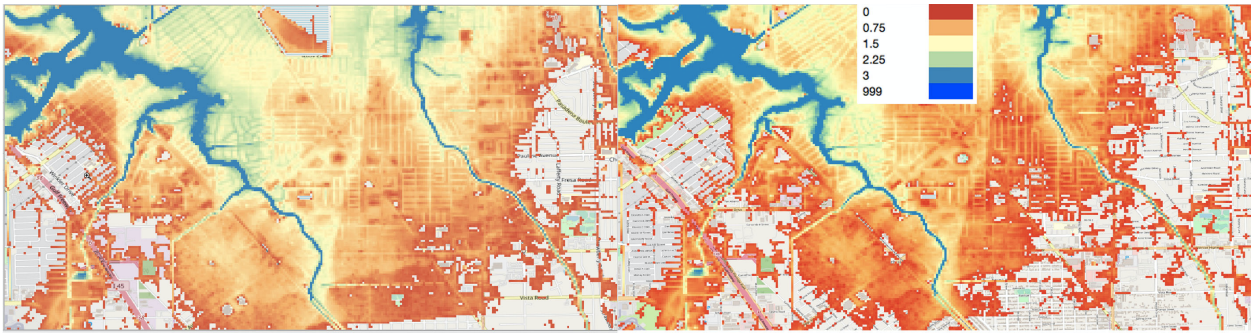


Figure 4: Left: Simulated flood depth (meters) in the South Houston, Texas neighborhood using observed Hurricane Harvey rainfall amounts. Right: Simulated flood depth in the South Houston, Texas neighborhood without climate change if global warming caused a 19% increase in Harvey's rainfall. If there was less rain, the flood would cover less area and be about 4 feet shallower in this neighborhood[16,18].

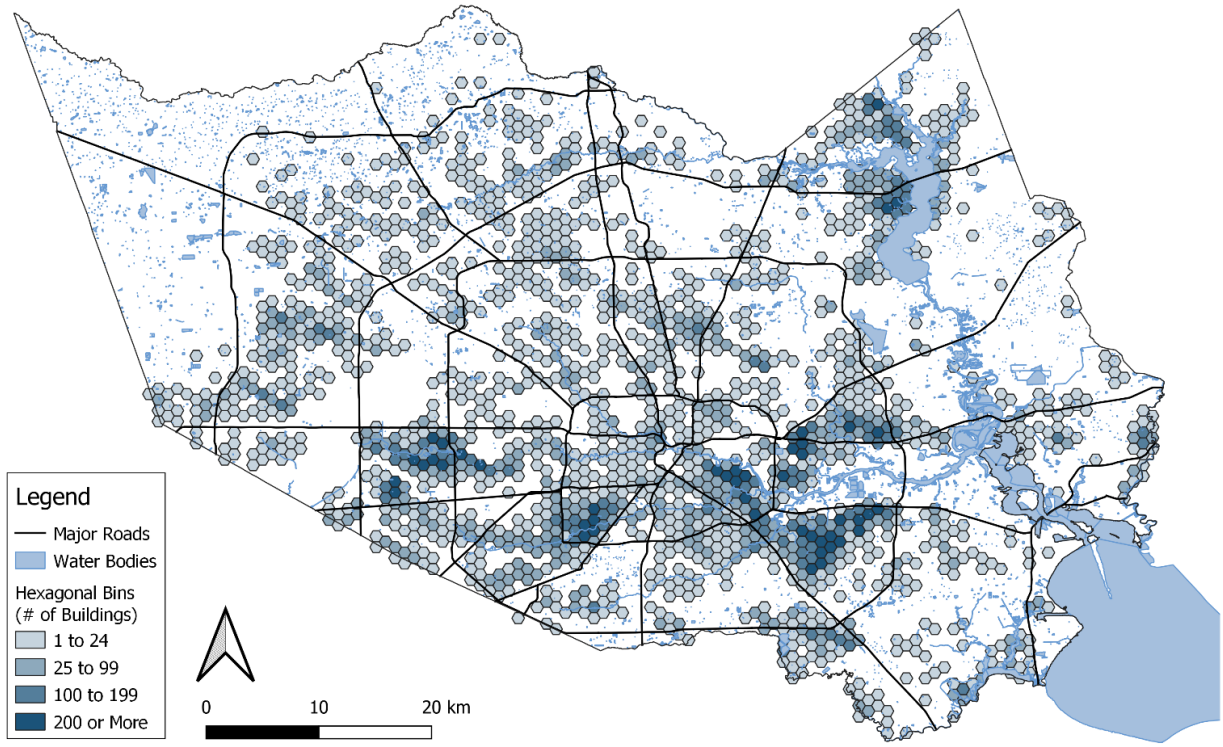


Figure 5: Climate Change-Attributed Flooding of buildings (Worst case:38% Scenario) in Harris County, Texas during Hurricane Harvey[17].

These damages were not equally distributed across socioeconomic groups. Half of these flooded homes were in low-income Hispanic neighborhoods[17]. As about third of Harris County is characterized as low-income Hispanic, this disproportionate impact represents an environmental injustice. We are finding similar injustice to the most vulnerable of our society in

an analysis of flooding in New York, New Jersey, and Pennsylvania from the remnants of Hurricane Ida: the most vulnerable portion of the local population was disproportionately affected, and climate change exacerbated this injustice[19].

This recent extension of attribution science from weather to impacts could be informative in the negotiations for the Loss and Damages fund to aid nations "particularly vulnerable" to climate change. This fund was established, but not financed, at last year's meeting of the Conference of Parties (COP27), part of the United Nations Framework Convention on Climate Change, and will certainly be one of the topics discussed later this month at COP28 in Dubai (https://unfccc.int/event/cma-4).

As my examples show, confidence in quantitative attribution statements is very high for heatwaves and certain classes of severe storms. As a member of the lead author team for the IPCC 6th Assessment chapter on extreme weather[20], we developed a protocol[21] for assessing confidence in attribution statements published in the scientific literature as shown in the flowchart of figure 6. As you can see, in order to assess "high confidence" as defined in the IPCC calibrated language[3], multiple and consistent lines of evidence from different author teams using different methods and datasets were required. Any single credible study, if assessed, was deemed "low confidence". However, it is important to note that "low confidence" in the IPCC calibrated language is not to be interpreted as no confidence.

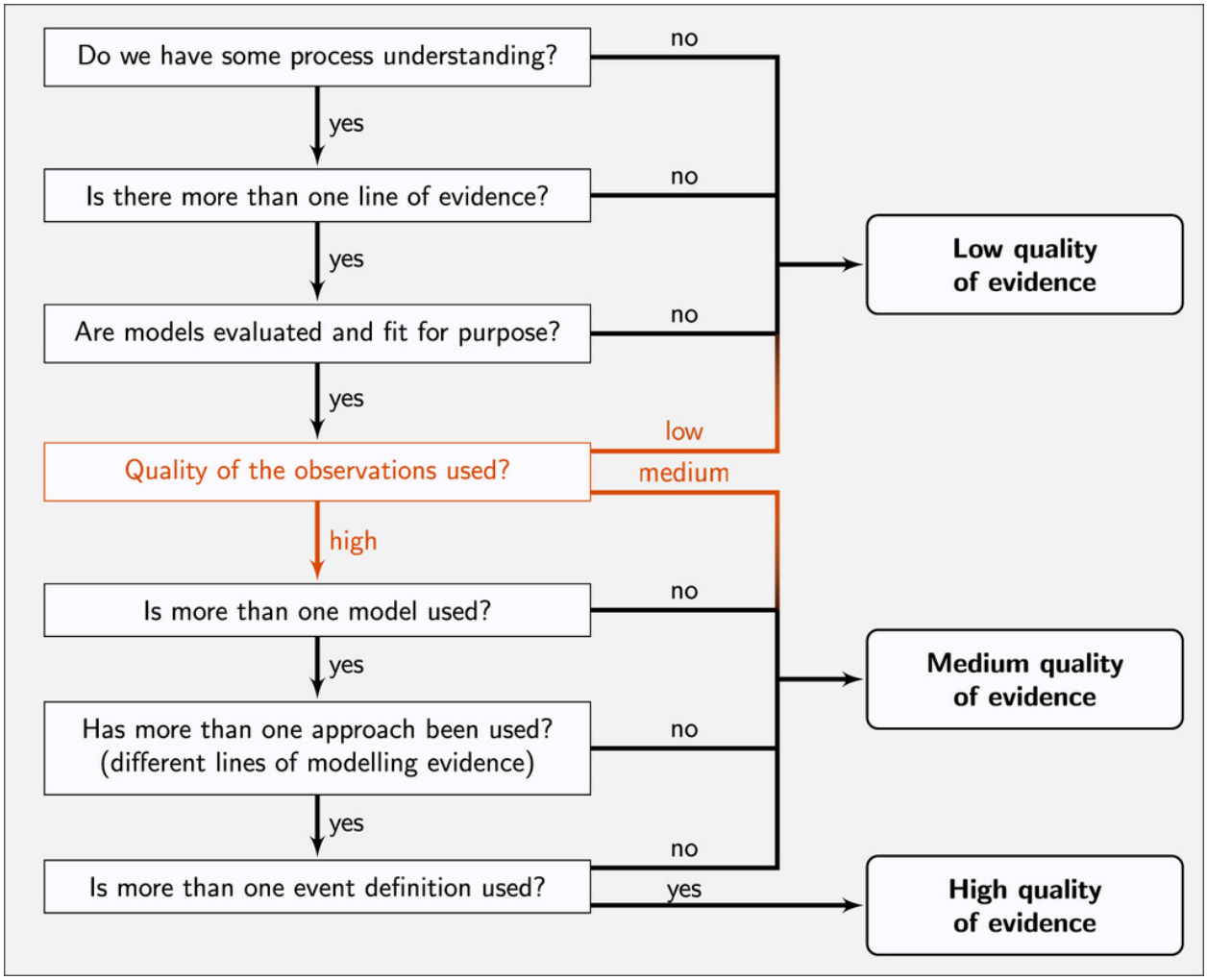


Figure 6: Flowchart describing the protocol used in Chapter 11 of the IPCC Working Group 1 6th Assessment Report to assess confidence in extreme event attribution statements.

The human influence on extreme weather and its impacts on people is quite clear. I am often asked why do we do these attribution studies. There are three answers to this question. First, the public demand for information of how climate change affects them personally is very high. Second, increasing the number and variety of individual extreme weather events studied increases our understanding of the extent of the human influence on them. Third, such quantitative understanding can aid decisionmakers in increasing the resilience of our society to a future yet warmer world.

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