State of the Science FACT SHEET
How Changing Climate Affects Extreme Events

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION • UNITED STATES DEPARTMENT OF COMMERCE

This summary of extreme weather and climate events was developed by NOAA scientists and economists and approved by NOAA's Science Council.

Extreme weather events have significant impacts on society and ecosystems.

From 2010 through 2020, there were 141 weather and climate events in the U.S. with losses exceeding $1 billion each. These events resulted in a total of more than $800 billion in direct losses and included tropical cyclones, severe local storms, winter storms, inland floods, a crop freeze, droughts, and wildfires. This is a notable increase over the previous decade, which saw 62 billion-dollar events totaling more than $500 billion in direct losses. As impacts from extreme events continue to increase, people are asking whether and how human-caused climate change affects extreme events. We already know that human-caused changes in Earth's climate system are contributing to changes in the frequency and intensity of some types of extreme events. NOAA is helping communities and businesses further understand extreme events by advancing our understanding of their causes and impacts.

Have extreme events changed over the last 50 to 100 years?

The observational record that is sufficient for determining long-term changes in temperature and precipitation extremes in the United States is now more than 120 years long. This record documents changes in extremes of temperature, precipitation, and in some instances in storms including hurricanes. Cold extremes in the United States have become less frequent over the past century, while long-term changes in warm extremes, such as heatwaves, are more nuanced owing to the lingering influence of the Dust Bowl of the 1930s on long-term trends. However, since the 1930s there have been many more record high temperatures as compared to record low temperatures in the United States. Globally, there is a clear increase in heatwaves and extreme high temperatures over much of the globe, over land, and in the form of marine heatwaves. Average temperatures and atmospheric moisture have increased in the United States and globally. Consistent with the increased atmospheric moisture, extreme precipitation events have also increased in the United States and over much of global land regions where there are sufficient data to support analysis. Figure 2 shows trends in heavy precipitation events over the United States. Almost all areas show increases, with the largest increases occurring in the Northeast and Midwest.

Century-scale changes in destructive storms, such as hurricanes, tornadoes, or even severe winter storms are more difficult to determine owing to uncertainties in the long-term observations of these events. However, since 1980, satellite date show evidence of increases in hurricanes intensity and in the fraction of hurricanes reaching Category 3 or higher, both globally and in the Atlantic basin. As of yet, these increases have not been confidently attributed to human-caused climate change. U.S. landfalling hurricane frequency has remained stable over the longer period since 1900.

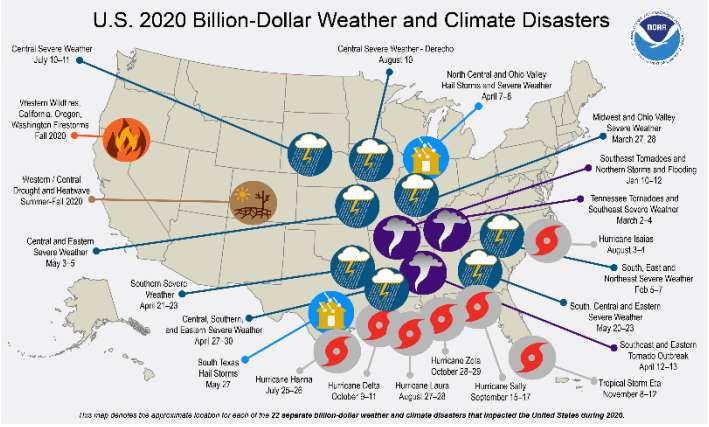

Figure 1: Approximate location for each of the twenty-two $1billion weather and climate disasters that impacted the United States during 2020. Source: NOAA National Centers for Environmental Information

The influence of human-caused climate change on drought is also difficult to determine owing to challenges in process understanding and in distinguishing human-caused trends from natural variability. However, droughts remain a recurring and destructive extreme on many time scales.

How do scientists determine the influence of human-caused climate change on extreme events, and what have they found?

There is compelling scientific evidence that the nature of some extreme events is altered by climate variations and change (see USGCRP 2017). Improved understanding of these relationships is of profound importance to decision makers, who are demanding better information on how changes in climate may influence future extremes and what impacts these changes may have on our lives, livelihoods, businesses, and the ecological systems that support us. While extreme events, such as hurricanes and droughts, have always happened and will continue to occur, increasingly, evidence is indicating that climate change is playing a role in various types of extreme events. Additionally, human-caused changes to the climate have been found to be a primary driver of many events, particularly heat-related events.

Determining how human-caused climate change affects extreme events requires scientific observations, climate models, and a fundamental understanding of how various natural and human factors influence weather and climate. Observations, especially from previous extreme events, are essential for advancing this understanding. Climate models are the main tools used to examine how different factors contribute to extreme events. They provide a firm scientific basis for examining the impacts of human activities on the climate system, despite some inherent uncertainties. The main influences humans have had on Earth's climate include increasing concentrations of greenhouse gases in the atmosphere, changes in aerosol forcing, and land-use change. In order to assess

human influences on extreme events, scientists use computer models to simulate Earth's climate first with only natural forcings such as volcanoes and solar variability, and then with both natural and human-caused forcings, including increasing concentrations of greenhouse gases. Data produced by the model simulations are then analyzed to see how often extreme events occur under each set of conditions. If the number of extreme events is similar for each type of simulation, we tentatively assume there is no human influence. But if extreme events occur more often or are more severe in the simulations with human-caused factors, we tentatively conclude that there is a human influence. It is also important to evaluate whether model simulations are consistent with observed trends or other changes in the climate system. In attributing changes in extreme events to human influence, confidence is typically greater when past observations show significant long-term trends in the occurrence of that type of extreme event.

The extent of human influence on extremes varies with the type of weather event. At a global scale, human-induced climate change has very likely (>90% chance) led to an increase in the number of extreme warm days and nights, and likely (>66% chance) lengthened the duration of heat waves. Impacts vary regionally and depend on the type of extreme event considered. A warmer climate has led to increases in the amount of water vapor in the atmosphere and has very likely resulted in more extreme rainfall (amount and intensity) in many regions. For other types of extreme events, like hurricanes and tornadoes, there is no clearly detectable human influence to date, apart from sea level rise exacerbating hurricane surge-related coastal flooding. However, based on models and scientific theory, scientists anticipate that there will be future attributable human influences on the most extreme hurricanes and associated precipitation.

A new focus for climate science is event *attribution*: determining whether *individual* extreme events have been affected by human-induced climate change. Climate scientists use event attribution methods to assess the influence of human-caused climate change on both the intensity and probability of occurrence of an extreme event. For example, in August, 2017 Hurricane Harvey dropped more than 50 inches of rain over a five-day period on parts of the Houston area. A recent event attribution study estimated that the rainfall total from Harvey was about 15% more due to human-induced warming of the climate, including ocean temperatures.

In the future, climate change is expected to exert a stronger influence on extreme events.

Some types of extreme events are expected to increase in intensity and frequency during the 21st century due to climate change (see USGCRP 2017 for details). Changes in the near term may be small compared to natural variability, but cumulative change over time are expected to be transformative in some areas. Further, how natural cycles— such as the El Niño–Southern Oscillation (the cycle responsible for El Niño and La Niña events)—change in the future will also impact extremes. It is virtually certain (99–100%

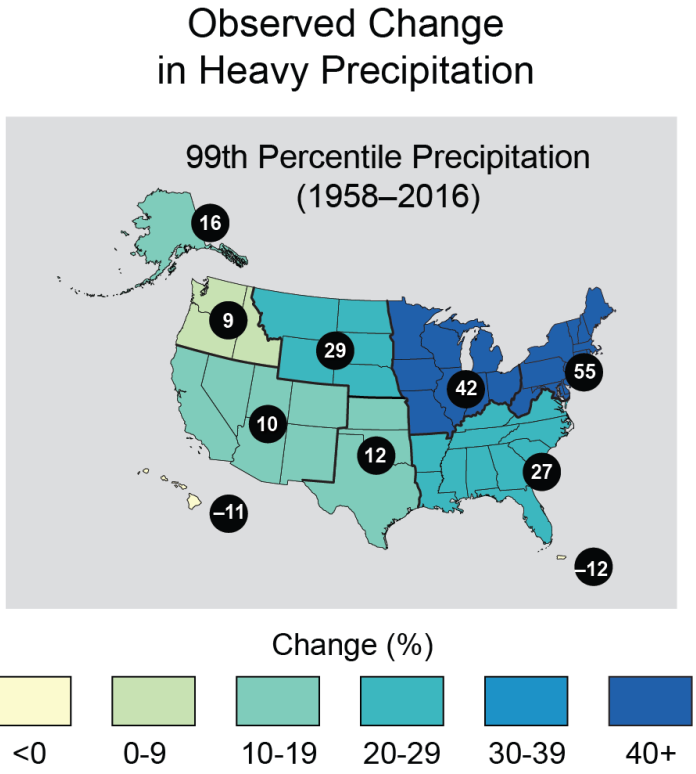

Figure 2: Observed changes in the number of heavy one-day precipitation events, from USGCRP, 2017.

chance) that the frequency and intensity of daily heat extremes will increase and that there will be fewer cold extremes. It is very likely that the frequency of heavy precipitation events will increase over many regions, but there is uncertainty around effects on flooding in specific areas. A recent assessment concludes that tropical cyclone wind intensities and precipitation rates are projected to increase (with medium to high confidence) by roughly 5% and 14%, respectively, for a 2°C global warming scenario (Knutson et al. 2020). In contrast, global tropical cyclone frequency is projected to stay the same or decrease, although with somewhat less confidence. For other extreme events, like tornadoes, the influence of human-caused climate change remains very uncertain, and further observations and research are needed.

It is important that we continue to advance our understanding of extreme events and how human activities may be affecting their occurrence. In addition to individual extreme events, scientists study compound extremes, like the simultaneous occurrence of drought and heat, because they often result in larger impacts than individual events alone. NOAA is a leader in sustaining observations of extreme events, as well as conducting research to understand how extremes may change in the future. In particular, NOAA is currently developing a capability to respond quickly to questions about the origins of individual extreme events and the role of climate change in their occurrence and/or severity.

NOAA's work helps decision makers manage risks from extreme events to people's lives, livelihoods, and the ecosystems on which we all depend.

Additional Resources

USGCRP, 2017: Climate Science Special Report: Fourth National Climate Assessment, Volume I [Wuebbles, D.J., D.W. Fahey, K.A. Hibbard, D.J. Dokken, B.C. Stewart, and T.K. Maycock (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, 470 pp.

Herring, S. C., N. Christidis, A. Hoell, M. P. Hoerling, and P. A. Stott, Eds., 2020: Explaining Extreme Events of 2018 from a Climate Perspective. *Bull. Amer. Meteor. Soc*., **101 (1)**, S1–S128, doi:10.1175/BAMS-ExplainingExtremeEvents2018.1.

Knutson, T. R., S. J. Camargo, J. C. L. Chan, K. Emanuel, C.-H. Ho, J. Kossin, M. Mohapatra, M. Satoh, M. Sugi, K.Walsh, and L. Wu, 2020: Tropical Cyclones and Climate Change Assessment: Part II. Projected Response to Anthropogenic Warming. *Bull. Amer. Meteor. Soc*., **101**(3), DOI:10.1175/BAMS-D-18-0194.1.

NOAA/NWS/Climate Prediction Center: https://cpc.ncep.noaa.gov

NOAA/Climate.gov: https://climate.gov