State of the Science FACT SHEET

How Human-Caused Climate Change Affects Extreme Events

Extreme weather and climate events have significant impacts on society and ecosystems. Climate records show that several types of extreme events have changed over the past 50 to 100 years. Climate science strives to detect changes in weather and climate extremes, and to assess the extent to which human-caused climate change has influenced extreme events, including their frequency and intensity. Climate models are used to project future human-caused changes in extreme events.

The intensity and frequency of some extreme events have increased

NOAA's observational records of temperature and precipitation extremes in the U.S. span about 130 years. These data indicate that cold extremes in the U.S. have become less frequent over the past century. In contrast, time series of the warmest temperature of each year do not show increasing trends since 1900 over most regions east of the Rockies owing to the influence of events like the Dust Bowl of the 1930s. However, since the 1930s, there have been many more record-high temperatures compared to record-low temperatures in the U.S. Sea surface temperatures averaged globally or in the tropical Atlantic reached record high levels in 2023 and 2024. Across much of the globe, there is a clear increase in heatwaves and extreme high temperatures over land, and marine heatwaves within oceans, with impacts such as heat stress-related human health problems, exacerbated air pollution, extreme coral bleaching events, and declines in fish abundance. Average temperatures and atmospheric moisture have increased in the U.S. and globally. Consistent with the increased atmospheric moisture, extreme precipitation events have also increased over much of global land regions where there is sufficient data to support such an analysis. Figure 1 summarizes changes in heavy precipitation events over the U.S. over 1958-2016. 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, and severe winter storms, are more difficult to determine owing to uncertainties in long-term observations of these events. However, observations since 1980 show evidence of increases in hurricane intensity and the fraction of hurricanes reaching Category 3 or higher in the Atlantic basin. Decreases in sulfate aerosols or dust, increases in greenhouse gases, and natural variability all may have contributed to the intensity increases since 1980; thus, the quantitative impact of human-caused greenhouse gas increases on hurricane intensities remains uncertain. U.S. landfalling hurricane frequency and major hurricane frequency have remained stable over the longer period since 1900 (e.g., Figure 2).

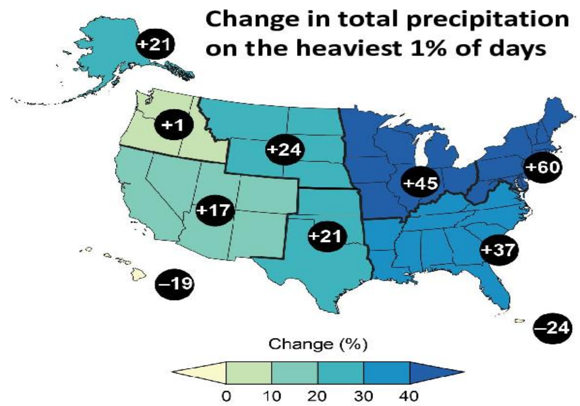

Figure 1. Observed percentage changes in extreme precipitation, 1958-2016. From NCA5, USGCRP 2023. Numbers in black circles represent percent changes at the regional level.

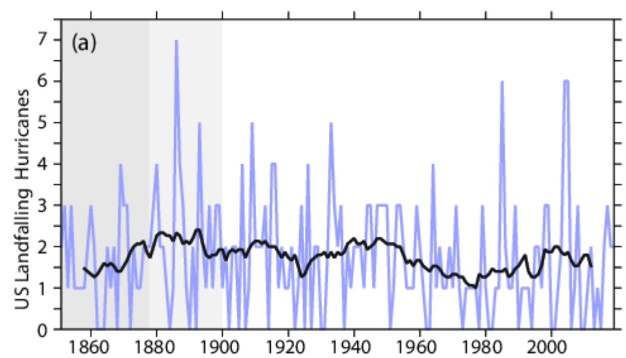

Figure 2. U.S. landfalling hurricane counts since 1851. Darker gray shading in earlier decades denotes lower confidence due to limited observing capabilities. Source: Vecchi et al., Nat. Comm. 2021

Assessing the human-caused climate change contribution to extremes

There is compelling scientific evidence that some extreme events are altered by climate variability and change (U.S. Fifth National Climate Assessment, NCA5). Improved understanding of these relationships is profoundly important to decision makers, who require better information on how climate change may influence future extremes and what impacts these changes may have on health, habitat, businesses, and ecosystems.

Assessing how human-caused climate change in particular affects extreme events requires observations, climate models, and a fundamental understanding of how various natural and human factors influence weather and climate. Observations, especially the historical record of extreme events, are essential for advancing this understanding. Computer models are the main tool providing a scientific basis to examine how different natural and human-caused physical factors contribute to extreme events. The main human influences on Earth's climate have been the result of changes in atmospheric greenhouse gas concentrations, aerosols, and land-use. Climate model simulations–with and without changes in these influencing factors–can be used to explore how the intensity and frequency of certain extreme events has been influenced by human-caused climate change.

Studies in the annual special issue on extremes in the *Bulletin of the American Meteorological Society*, have quantitatively assessed the contribution of human-caused climate change to observed extreme events. For such studies, confidence is greater when past observations show detectable (unusual compared to natural variability) long-term trends in the occurrence of that type of extreme event. Ideally, detectable long-term trends based on observed extremes can be compared to the modeled attributable human-caused contribution to the extreme event to assess whether the modeled and observed changes are consistent.

The extent of human influence on extremes varies by region, the type of weather or climate event, and period of examination. According to the IPCC Sixth Assessment Report (AR6), there is high confidence that human-caused climate change has been the main contributor to more frequent and intense heat extremes globally and was likely the main driver of increased frequency and intensity of heavy precipitation events for most land regions since the 1950s. For other types of extreme events, like hurricanes and tornadoes, there is no clearly detectable human influence to date on frequency and intensity trends at the global scale, apart from sea level rise, which exacerbates hurricane and non-tropical surge-related coastal flood risk.

The influence of human-caused climate change on drought is difficult to determine owing to challenges in process understanding, regional characteristics, and in distinguishing human-caused trends from natural variability. There is no significant trend since 1900 in the percent of the U.S. in moderate to extreme drought, although by some measures the Southwest U.S. during 2000-2021 experienced one of the two driest 22-year periods of the last 1200 years. Below-normal precipitation periods are a critical driver of drought conditions. However, many droughts and their effects are more extreme due to human-caused increases in temperatures that reduce water availability through increased evaporation. For example, in the Colorado River basin, warming-induced snow cover reductions have energized evaporation. Exacerbated drought conditions affect agricultural yields, water quantity and quality, and ecosystems. NCA5 concludes that climate change has contributed to very large and severe fires in the western U.S. in recent years. These worsening wildfires and their impacts, including smoke, have been due to several factors, such as historical fire suppression, land-use practices, and climate change. Factors related to human-caused climate change include increased near-surface air temperature, which leads to increased dryness in fire-prone areas resulting in fuels that promote wildfire spread.

Human-caused climate change is expected to exert a stronger influence on some extreme events in the future

Some types of extreme events are expected to increase in intensity and frequency during the 21st century due to climate change (see NCA5). It is virtually certain (99–100% chance) that the frequency and intensity of daily heat extremes will increase and that there will be fewer cold extremes (AR6). It is very likely that the frequency of heavy precipitation events will increase over many regions, but there is uncertainty around effects on river flooding in specific areas (AR6). A NOAA modeling study projects unprecedented future extreme rainfall events over the Northeast regions; these are expected to be distinguishable from natural variability by the mid-21st century. Sea-level rise is expected to cause major (destructive) and moderate (damaging) high tide floods in the U.S. to occur as often by 2050 as moderate and minor (disruptive) floods occur in 2020. Future changes in El Niño–Southern Oscillation are also expected to impact some regional weather and climate extremes.

A World Meteorological Organization Task Team on Tropical Cyclones and Climate Change concluded in 2020 that tropical cyclone wind intensities and precipitation rates are projected to increase (with medium to high confidence) by roughly 5% and 14%, respectively, under a 2°C global warming scenario. In contrast, global tropical cyclone frequency is projected to stay the same or decrease, although with lower confidence. NCA5 concludes it is likely that the total soil moisture in the Southwest U.S. and parts of the Southern Great Plains will decrease with climate warming; drying of surface soils is projected to occur nearly everywhere in the U.S. Confidence in future regional projections of drought is limited by remaining uncertainties in important processes, including precipitation processes, changes in atmospheric circulation, and land-atmosphere interactions. A 2022 NOAA modeling study projects a large increase in wildfires and up to a tripling of associated particulate matter (PM) pollution in the Pacific Northwest over the 21st century during August through September under a high greenhouse gas emission scenario. For other extreme events, like tornadoes, the influence of projected human-caused climate change remains very uncertain, and further research is needed.

Science can help advance our understanding of extreme events and how human activities may be affecting their occurrence. NOAA is a leader in sustaining observations of extreme events, as well as conducting modeling and research to understand why extremes changed in the past and how they may change in the future. NOAA is a key source for multiple climate-relevant datasets, including observations from oceans, the atmosphere, ecosystems, and satellites, and for data from weather and climate models. NOAA's work helps decision makers manage risks from extreme events to people's lives, livelihoods, and the ecosystems on which we all depend.