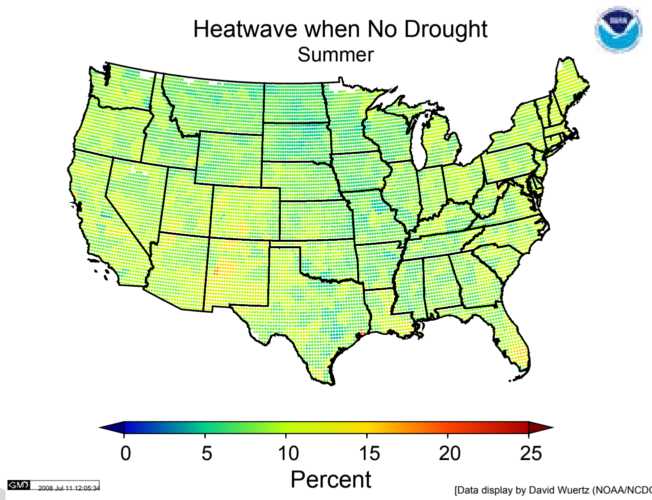
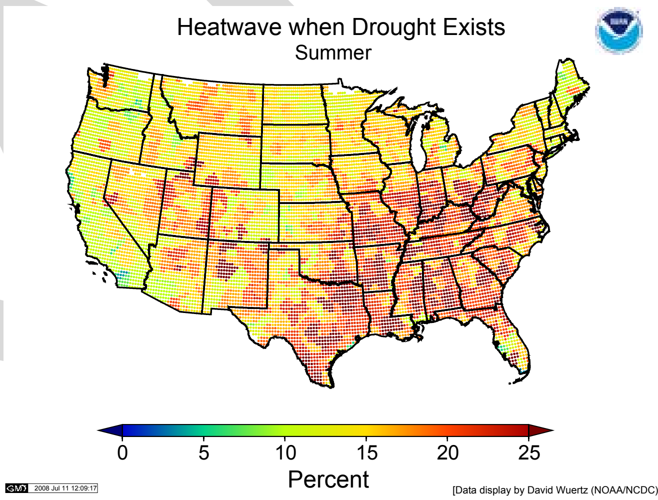
Complex Interactions

Climate change and its impacts do not occur in isolation. Rather, they interact with each other and with many other factors, resulting in impacts that can be much greater than those due to any of these factors individually. In some cases, key thresholds can be crossed, causing very large-scale and/or irreversible impacts, such as the extinction of species or elimination of entire ecosystems. In some cases, the results of complex interactions can be entirely unexpected. Some examples of such complex interactions are already being observed and the resulting impacts are expected to increase as warming proceeds.

Droughts, heatwaves, and stagnant air

Research has shown that heatwaves and poor air quality often occur simultaneously and in combination with other extreme events such as drought. One of the most costly and prolonged periods of drought, excessive heat, and poor air quality occurred during the summer of 1988. More than 7,000 deaths and economic losses of more than $70 billion were estimated to have occurred in the U.S. due to extreme drought and excessive heat that year. Half of the nation was affected by drought, and 5,994 all-time high temperature records were set around the country in June, July, and August. Poor air quality contributed to the many deaths that occurred, as lack of rainfall, high temperatures, and stagnant conditions led to an unprecedented number of unhealthy air quality days throughout large parts of the country. Although the Environmental Protection Agency (EPA) air quality standard for tropospheric ozone (smog) was less stringent in 1988 than it is today, the poor air quality in many of the nation's city was reflected in hundreds of incidents in which areas exceeded the EPA standard designed to protect the public health.





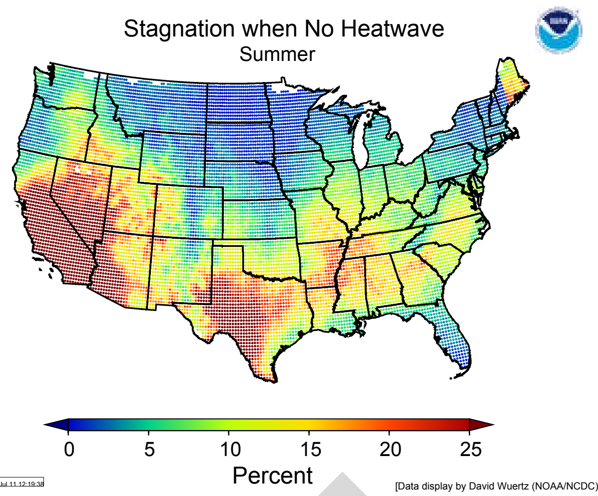
Long-lasting and extreme events such as these occurring simultaneously can lead to tremendous economic losses and loss of life. The likelihood that such episodes will occur in the future increases as the climate continues to warm. Although heatwaves, drought, and poor air quality can occur independently, experience and research have shown that these events are interrelated. Atmospheric conditions that lead to the presence of one of these often produce another, and the presence of one can contribute to the occurrence of another.

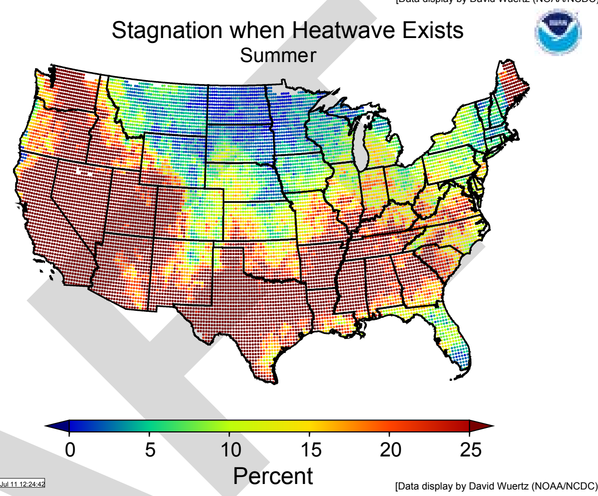
Climate observations bear this out. The maps show the percentage of time since 1950 that summer heatwaves have occurred without drought present and when drought was present[1]. The occurrence of heatwaves was

[1]Heatwave conditions were defined as any day when the maximum temperature exceeded that of the 90th percentile of all days. Drought was defined by a monthly Palmer Drought Severity Index of less than -2.

clearly higher in all regions of the contiguous U.S. in the presence of drought, exceeding 20% in large parts of the Midwest, Southeast, southern Plains, and parts of the Southwest, and greater than 10% in most other areas.

Atmospheric conditions that produce heatwaves also often lead to stagnant air masses and poor air quality. While heatwaves and poor air quality threaten the lives of thousands of people each year, the simultaneous occurrence of these hazards compounds the threat to vulnerable populations such as the elderly, children, and people with asthma. The maps show the frequency of occurrence of stagnant air conditions without heatwaves and when heatwave conditions were also present. Although stagnant air occurs more than 25 percent of the time in parts of the South and West, even in the absence of excessive heat, a far larger part of the United States is affected by stagnant air when heatwaves are present. Since 1950, air stagnation and heatwaves have simultaneously occurred more than 25 percent of the time from the mid-Atlantic to the Deep South, southern Plains and across most of the West.





As planning for adaptation to climate change proceeds, it is important to consider all of these factors. For example, in assessing air conditioning demand, projections of heat waves will be important in shaping peak electricity demand. When considering power plants[2], cooling water needs, the potential for drought should be taken into consideration. But we also must realize that during drought when cooling water is at its lowest is often the time when electricity demand for cooling due to a heat wave will be at its highest.

California wildfires that degrade air quality are exacerbated by heat-waves and drought.

[2]The frequency of occurrence of stagnant conditions was defined as any day that was part of a 4-day air stagnation event. Heatwave conditions were defined as any day when the maximum temperature exceeded that of the 90th percentile of all days.

Bark Beetle Infestations

Another example of complex interactions between changes in climate and other factors is that of insect infestations that are reaching levels that seriously damage the health of forests and cause significant economic losses. The combination of insects and disease in forests has been estimated to cost approximately $1 billion per year, on average, in the U.S. alone.

While large, periodic outbreaks of insects are a natural part of many U.S. forests, these phenomena are taking on new dimensions, and have grown substantially in both extent and severity due to several interacting causes, including long-term changes in climate. Perhaps the best-studied example is the current infestation of pine bark beetles in both the Canadian province of British Columbia and in the Colorado Rocky Mountains.

The mountain pine bark beetle is a native species in mid-elevation lodgepole pine forests throughout the West. Its periodic outbreaks are important features of the overall life cycle of these ecosystems, providing periodic disturbances that open up the canopy for regeneration of seedlings. But throughout the West, there are now three concurrent trends that have affected the way in which the bark beetle interacts with the forest.

Many stands of trees are composed of relatively even-aged trees, most of which are large, mature, and already past their period of rapid growth. This is a consequence of land-use history, specifically the history of logging throughout the region in the late 1800s and 1900s. Trees of this age and size are highly favored by the beetles as hosts, rather than young, rapidly growing trees.

Summers have warmed throughout the region, and there have been increasing periods of drought. The water stress experienced by the trees, both from the direct effects of higher temperatures, and indirectly through earlier snowmelt and reduced availability of water later in the year, are known to increase the susceptibility of the trees to insect attack.

Winter temperatures have also increased, permitting a much higher fraction of the insect larvae to survive the winter. Larvae of the beetle over-winter under the bark of the lodgepole pine, and temperatures of -40˚F for several days are required to kill them off and reduce the numbers of emerging insects the following spring. However, such extremely cold temperatures have become much less frequent in recent decades throughout the mountain West, with the result that many more insect larvae live through the winter.

The net result of these interacting factors is that mountain pine bark beetles have infested and killed lodgepole pines in historically unprecedented numbers and in overall area affected. Over 33 million acres of forest in Canada have been affected, and at least another 620,000 acres in Colorado in the U.S. Mortality of affected lodgepole pine stands has approached 90% of the trees. There is now evidence that the spread of the beetles has crossed the continental divide, which was previously thought to be a natural barrier to their dispersal, but appears now to have been overwhelmed by the insects' sheer numbers. There is even evidence in Canada that the beetles have begun attacking another host species, jack pine, which is one of the characteristic conifers of the southern boreal forest, the range of which extends to the Atlantic Ocean.

Just as the causes of these massive pine bark beetle infestations have multiple dimensions, so do the consequences. There are obvious physical consequences to the ecosystems. The massive, nearly synchronous death of trees raises fire risk while the dried needles are still on the trees. Even if fire does not immediately result, once the needles drop, there are significant changes in the amount of solar energy that reaches the surface and heats the soil, and there are also large changes in the amount of water intercepted and held in the forest ecosystem. In addition, large areas of forest that were once suitable habitat for wildlife are no longer suitable, potentially leading to significant changes in local species.

In addition to these ecological consequences are social and economic consequences for many communities in the West. Especially in British Columbia, these forests are economically valuable for timber and pulp, and the damage from the beetle infestation has had serious negative economic consequences for both forest product companies and the local communities that depend on forest resources for employment and income.

Additional discussions of insect infestations appear in the *Alaska* region and the *Natural Environment and Biodiversity* sector.