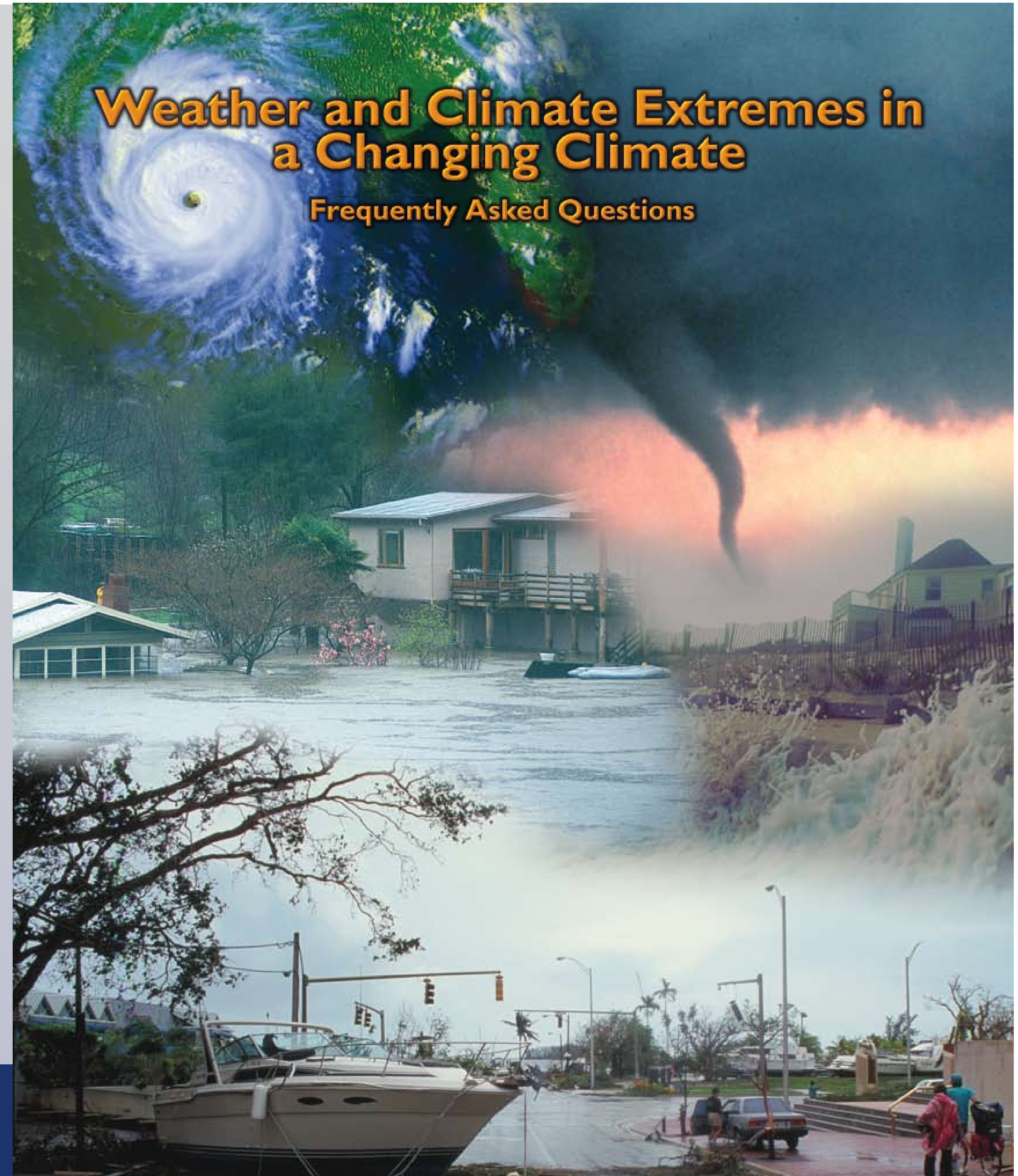
Observed changes in North American extreme events, assessment of human influence for the observed changes, and likelihood that the changes will continue through the 21st century[1].

Phenomenon and direction of change	Where and when these changes occurred in past 50 years	Linkage of human activity to observed changes	Likelihood of continued future changes in this century
Warmer and fewer cold days and nights	Over most land areas, the last 10 years had lower numbers of severe cold snaps than any other 10-year period	Likely warmer extreme cold days and nights, and fewer frosts[2]	Very likely[4]
Hotter and more frequent hot days and nights	Over most of North America	Likely for warmer nights[2]	Very likely[4]
More frequent heat waves and warm spells	Over most land areas, most pronounced over northwestern two thirds of North America	Likely for certain aspects, e.g., night-time temperatures; & linkage to record high annual temperature[2]	Very likely[4]
More frequent and intense heavy downpours and higher proportion of total rainfall in heavy precipitation events	Over many areas	Linked indirectly through increased water vapor, a critical factor for heavy precipitation events[3]	Very likely[4]
Increases in area affected by drought	No overall average change for North America, but regional changes are evident	Likely, Southwest USA.[3] Evidence that 1930's & 1950's droughts were linked to natural patterns of sea surface temperature variability	Likely in Southwest U.S.A., parts of Mexico and Carribean[4]
More intense hurricanes	Substantial increase in Atlantic since 1970; Likely increase in Atlantic since 1950s; increasing tendency in W. Pacific and decreasing tendency in E. Pacific (Mexico West Coast) since 1980[5]	Linked indirectly through increasing sea surface temperature, a critical factor for intense hurricanes[5]; a confident assessment requires further study[3]	Likely[4]

[1]Based on frequently used family of IPCC emission scenarios
[2]Based on formal attribution studies and expert judgment
[3]Based on expert judgment
[4]Based on model projections and expert judgment
[5]As measured by the Power Dissipation Index (which combines storm intensity, duration and frequency)

Weather and Climate Extremes in a Changing Climate

Frequently Asked Questions



Findings and Summary of the U.S. Climate Change Science Program
Synthesis and Assessment Report 3.3

Changes in extreme weather and climate events are among the most serious challenges to society in coping with a changing climate.

What Are Extremes and Why do They Matter?

Weather and climate extremes affect all sectors of the economy and the environment, including human health and well-being. During the period 1980-2006, the U.S. experienced 70 weather-related disasters in which overall damages exceeded $1 billion at the time of the event (Figure 1). Clearly, the direct impact of extreme weather and climate events on the U.S. economy is substantial.

There is scientific evidence that a warming world will be accompanied by changes in the intensity, duration, frequency, and geographic extent of weather and climate extremes. Changes in extremes are already observed to be having impacts on social, economic and natural systems, and future changes associated with continued warming will present additional challenges.

The impacts of changes in extremes depend on both changes in climate and ecosystem and societal vulnerability. Vulnerability is shaped by factors such as population dynamics and economic status, as well as developing and utilizing adaptation measures such as appropriate building codes, disaster preparedness, and water use efficiency. Some short-term actions taken to lessen the risk from extreme events can lead to increases in vulnerability to even larger extremes. For example, moderate flood control measures on a river can stimulate development in a now "safe" floodplain, only to see those new structures damaged when a very large flood occurs.

Within a changing climate system, some of what are now considered to be extreme events will occur more frequently (*e.g.*, heat waves), and some less frequently (*e.g.,* cold snaps) (figure 2). More frequent extreme events occurring over a shorter period reduce the time available for recovery and adaptation. In addition, extreme events often occur in clusters. The cumulative effect of compound or back-to-back extremes has far larger impacts than the same events spread out over a longer period of time. For example, heat waves, droughts, air stagnation, and resulting wildfires often occur concurrently and have more severe impacts than any of these alone.

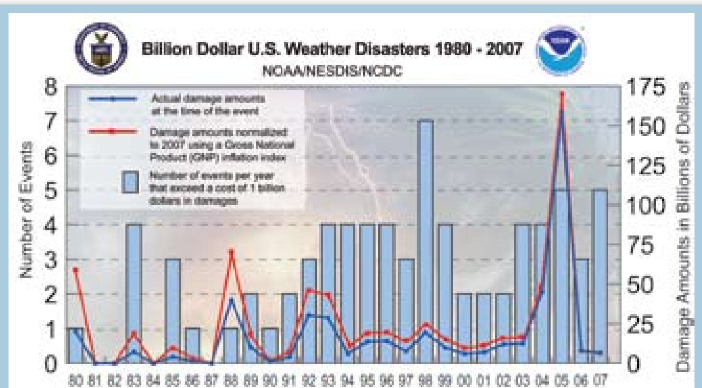


Figure 1 The blue bars show the number of events per year that exceed a cost of 1 billion dollars (these are scaled to the left side of the graph). The blue line (actual costs at the time of the event) and the red line (costs adjusted for wealth/inflation) are scaled to the right side of the graph, and depict the annual damage amounts in billions of dollars.

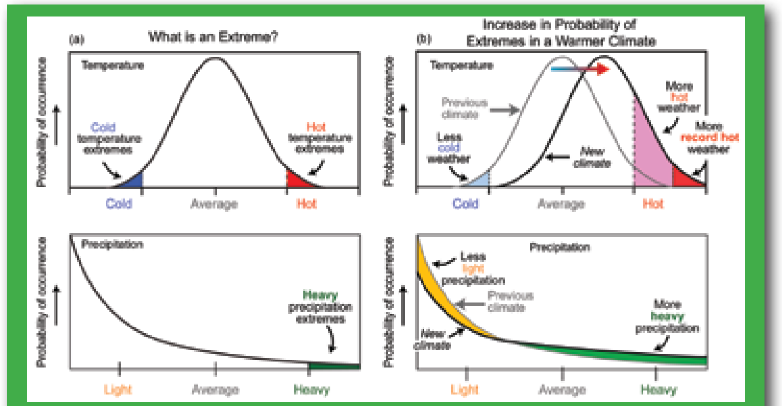


Figure 2 Most measurements of temperature (top) will tend to fall within a range close to average, so their probability of occurrence is high. A very few measurements will be considered extreme and these occur very infrequently. Similarly, for rainfall (bottom), there tend to be more days with relatively light precipitation and only very infrequently are there extremely heavy precipitation events, meaning their probability of occurrence is low. The exact threshold for what is classified as an extreme varies from one analysis to another, but would normally be as rare as, or rarer than, the top or bottom 10% of all occurrences.

What Changes Have Already Occurred?

Many extremes and their associated impacts are now changing. For example:

- Most of North America is experiencing more unusually hot days and nights and fewer unusually cold days. The last 10 years have seen fewer severe cold waves than any other 10-year period in the historical record, which dates back to 1895. The number of heat waves has also been increasing since 1950.
- There has been a decrease in frost days and a lengthening of the frost-free season over the past century.
- Extreme precipitation episodes (heavy downpours) have become more frequent and intense and now account for a larger percentage of total precipitation.
- Droughts are becoming more severe in some regions.
- Atlantic tropical storm and hurricane destructive potential has increased substantially since about 1970.
- Storm tracks have shifted northward in both the North Atlantic and North Pacific over the past fifty years. The strongest cold season storms are becoming even stronger in the North Pacific.

The data used to examine changes in the frequency and severity of tornadoes and severe thunderstorms are inadequate to make definitive statements about actual changes.

Why Have These Changes Occurred?

As the climate has warmed, primarily due to human activities, we have also seen a variety of changes in extremes. Some examples of extremes that have an identifiable cause:

- Human-induced warming has likely caused much of the average temperature increase in North America over the past fifty years and, consequently, changes in temperature extremes. For example, the effect of human-induced emissions of greenhouse gases has been associated with the very hot year of 2006 in the U.S.
- Heavy precipitation events averaged over North America have increased over the past 50 years, consistent with the observed increases in atmospheric water vapor, which have been linked to human-induced increases in greenhouse gases.
- It is likely that the human-induced increase in air temperatures, and the associated increase in evaporation potential over land, are already contributing to droughts that are longer and more intense.
- It is very likely that the human-induced increase in greenhouse gases has contributed to the increase in sea surface temperatures in the hurricane formation regions. Because there is a strong statistical connection between Atlantic tropical sea surface temperatures and Atlantic hurricane activity (Figure 3), this suggests a human contribution to recent hurricane activity (a confident assessment will require further study).
- Human influences on changes in sea-level pressure patterns have been detected over the Northern Hemisphere and this affects the location and intensity of cold season storms.

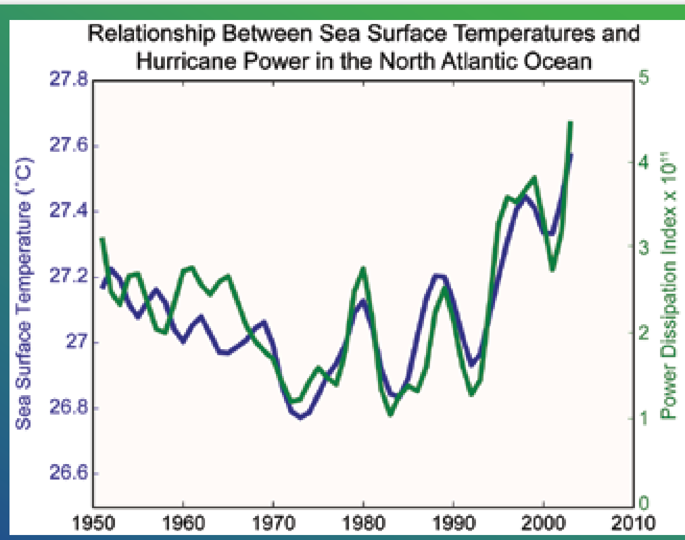


Figure 3 Sea surface temperatures (blue) are correlated with the Power Dissipation Index (a measure that integrates frequency, intensity, and duration) for North Atlantic hurricanes (Emanuel, 2007).

How Will Extremes Change in the Future?

Projected continued warming of North America has direct implications for the occurrence of extreme weather and climate events. For example, climate models indicate that many currently rare extreme events will become more commonplace. For a mid-range scenario of future greenhouse gas emissions, a day so hot that it is currently experienced only once every 20 years would occur every three years by the middle of the century over much of the continental U.S. and every five years over most of Canada. By the end of the century, it would occur every other year or more.

- Future changes in extreme temperatures will generally follow changes in average temperature. Abnormally hot days and nights and heat waves are very likely to become more frequent (Figure 4). Cold days and cold nights are very likely to become much less frequent. The number of days with frost is very likely to decrease.
- Sea ice extent is expected to continue to decrease and may even disappear entirely in the Arctic Ocean in summer in the coming decades. This increases extreme coastal erosion in Arctic Alaska and Canada due to the increased exposure of the coastline to strong wave action.
- On average, precipitation is likely to be less frequent but more intense, and precipitation extremes are very likely to increase.
- In the future, droughts are likely to become more frequent and severe in some regions, leading to an increased need to respond to reduced water supplies, increased wildfires, and various ecological impacts. These regions include the U.S. Southwest and parts of Mexico.
- For North Atlantic and North Pacific hurricanes, it is likely that rainfall and wind speeds will increase in response to human-caused warming. Analyses of model simulations suggest that, for each 1°C (1.8°F) increase in tropical sea surface temperatures, core rainfall rates will increase by 6 to 18% and the surface wind speeds of the strongest hurricanes will increase by about 1 to 8%.
- In the future, there are likely to be more frequent strong cold-season storms in both the Atlantic and Pacific basins, with stronger winds and more extreme wave heights.

> Current and future impacts resulting from changes in weather and climate extremes depend not only on the changes themselves, but also on responses by human and natural systems.

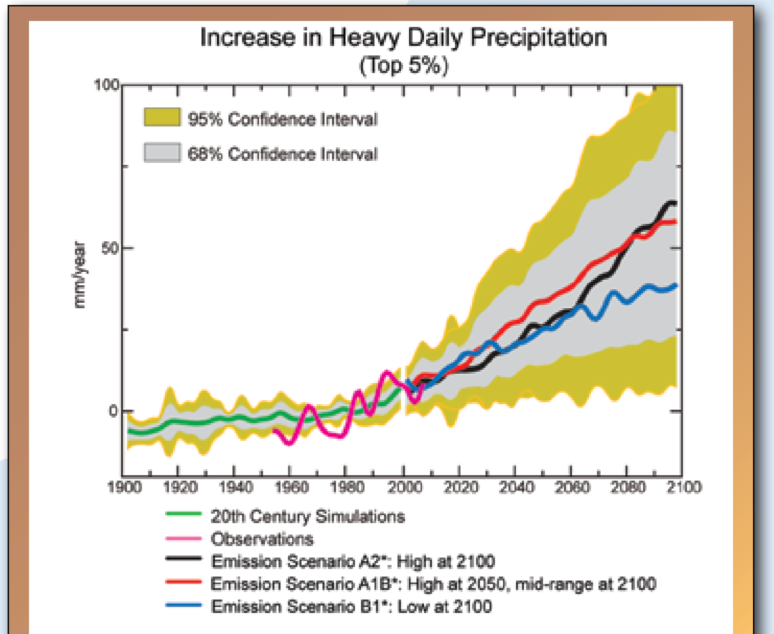


Figure 4 Increase in the amount of daily precipitation over North America that falls in heavy events (the top 5% of all precipitation events in a year) compared to the 1961-1990 average. Various emission scenarios are used for future projections*. Data for this index at the continental scale are available only since 1950.

*Three future emission scenarios from the IPCC Special Report on Emissions Scenarios:
A2 black line: emissions continue to increase rapidly and steadily throughout this century.
A1B red line: emissions increase rapidly until 2050 and then decline.
B1 blue line: emissions increase very slowly for a few more decades, then level off and decline.