



Trends in Extreme Events

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Extremes are the infrequent events at the high and low end of the range of values of a particular variable. Even a relatively small change in the average value of a variable may lead to substantial changes in the frequency of extremes (Karl et al., 1997; Nicholls and Alexander, 2007), and this means that changes in extremes may provide an early indication that climate is changing in a way that can affect humans and the environment substantially.

However, problems with data and analyses of extremes can make it very difficult to determine whether or not these extremes are changing in either frequency or intensity. The Intergovernmental Panel on Climate Change (IPCC), in its first assessment of climate change, did not consider whether extreme weather events had increased in frequency and/or intensity globally (Folland et al., 1992), because data were too sparse to make this a worthwhile exercise. In 1995 the IPCC, in its second assessment, did examine this question, and concluded that “Overall, there is no evidence that extreme weather events, or climate variability, have increased, in a global sense, through the 20th century, although data and analyses are poor and not comprehensive” (Nicholls et al., 1995). The second assessment did, however, note that changes in extremes had been observed for some regions. A major limitation of our ability, at that time, to determine whether extreme weather and climate events were changing was that it is more difficult to maintain the long-term homogeneity of observations required to observe changes in extremes, compared to monitoring changes in averages of variables (Nicholls, 1995), and few countries had undertaken sufficient quality control of the observations to allow an adequate assessment of extremes. Ambiguities in defining extreme events and difficulties in combining different analyses from different sites and countries also complicated attempts to determine, on a global scale, whether extreme events were changing in frequency.

Since the mid-1990s, concerted multi-national efforts have been undertaken to collate, quality control, and analyse data on weather and climate extremes, and to carefully define climate and weather extremes (Karl et al., 1999; Nicholls and Manton, 2005; Nicholls and Alexander, 2007; Peterson and Manton, 2008), although much remains to be done to digitise and analyse data, especially in developing countries (Page et al., 2004). A comprehensive examination of the question of whether extreme events have changed in frequency or intensity is now more feasible than it was 15 years ago (Nicholls and Alexander, 2007), and such an assessment was included in the IPCC Fourth Assessment (IPCC, 2007a). The IPCC AR4 Synthesis Report (IPCC, 2007b) concluded that:

- It is *very likely* that over the past 50 years: cold days, cold nights and frosts have become less frequent over most land areas, and hot days and hot nights have become more frequent.
- It is *likely* that: heat waves have become more frequent over most land areas, the frequency of heavy precipitation events has increased over most areas, and since 1975 the incidence of extreme high sea level has increased worldwide.
- There is observational evidence of an increase in intense tropical cyclone activity in the North Atlantic since about 1970, with limited evidence of increases elsewhere. There is no clear trend in the annual numbers of tropical cyclones. It is difficult to ascertain longer-term trends in cyclone activity, particularly prior to 1970.
- Globally, the area affected by drought has *likely* increased since the 1970s.

The most recent comprehensive assessment of changes in extremes was completed in 2008, as part of the USA Climate Change Science Program (Kunkel et al., 2008). The following summary of observed changes in extremes is drawn from that report, which focuses on North America. In the presentation, the focus will be on changes in extremes in Australia (Alexander et al., 2007; Nicholls, 2008), and where the Australian experience differs from that of North America this is noted below. The focus on these regions (North America, Australia) reflects the ready availability of data and recent analyses of the data for these locales. However, the data and analyses available from other regions tend to reflect the picture gleaned from the North American and Australian trends (Alexander et al., 2007).

Extreme temperatures:

Accompanying a general rise in the average temperature, most of North America is experiencing more unusually hot days and nights. The number of heat waves (extended periods of extremely hot weather) also has been increasing over the past fifty years. There have been fewer unusually cold days during the last few decades. The last 10 years have seen fewer severe cold snaps than for any other 10-year period in the historical record. There has been a decrease in frost days and a lengthening of the frost-free season over the past century. In summary, there has been a shift towards a warmer climate with an increase in extreme high temperatures and a reduction in extreme low temperatures.

Heavy rainfall:

Extreme precipitation episodes (heavy downpours) have become more frequent and more intense in recent decades over most of North America and now account for a larger percentage of total precipitation. For example, intense precipitation (the heaviest 1% of daily precipitation totals) in the continental U.S.A. increased by 20% over the past century while total precipitation increased by only 7%. Over much of Australia, the frequency of heavy rainfall events (and the amount of rainfall received from these events) has decreased where average rainfall has decreased.

Drought:

Averaged over the continental U.S.A. and southern Canada the most severe droughts occurred in the 1930s and there is no indication of an overall trend in the observational record, which dates back to 1895. However, there are recent regional tendencies toward more severe droughts in parts of Canada and Alaska, as well as Mexico and the U.S. Southwest. In Australia, the clearest

indication of a drought trend is that droughts, even if they have not become drier or more frequent, have become warmer over the past five decades. Southern Australia has been affected by more frequent drought, most likely reflecting a polewards shift in storm tracks.

Tropical storms:

Atlantic tropical storm and hurricane destructive potential has increased. This increase is substantial since about 1970, and is likely substantial since the 1950s and 60s. There have been fluctuations in the number of tropical storms and hurricanes from decade to decade and data uncertainty is larger in the early part of the record compared to the satellite era beginning in 1965. Even taking these factors into account, it is likely that the annual numbers of tropical storms, hurricanes and major hurricanes in the North Atlantic have increased over the past 100 years. There is no observational evidence for an increase in North American mainland land-falling hurricanes since the late 1800s. There is evidence for an increase in extreme wave height characteristics over the past couple of decades, associated with more frequent and more intense hurricanes. Hurricane intensity shows some increasing tendency in the western north Pacific since 1980. It has decreased since 1980 in the eastern Pacific. There is no evidence of an increase in tropical cyclone numbers around northern Australia, and tropical cyclone activity may have actually decreased since about 1970, despite strong warming of tropical sea surface temperatures.

Other storms:

There has been a northward shift in the tracks of strong low-pressure systems (storms) in both the North Atlantic and North Pacific over the past fifty years. The number of mid-latitude storms affecting southern Australia appears to have decreased, most likely due to a polewards shift in storm tracks. In the North Pacific, the strongest storms are becoming even stronger. Evidence in the Atlantic is insufficient to draw a conclusion about changes in storm strength. Increases in extreme wave heights have been observed along the Pacific Northwest coast of North America based on three decades of buoy data, and are likely a reflection of changes in cold season storm tracks. The pattern of changes in ice storms varies by region. The data used to examine changes in the frequency and severity of tornadoes and severe thunderstorms are inadequate to make definitive statements about trends. Over the 20th century, there has been considerable decade-to-decade variability in the frequency of snowstorms. Regional analyses suggest that there has been a northward shift in snowstorm occurrence over the U.S. In northern Canada, an increase in heavy snow events has been observed.

Despite the recent assessments of changes in extremes, and recent improvements in data quality and availability for such assessments, many important questions remain regarding how extremes may or may not be changing. Some of the following questions will be addressed, using Australian data and analyses, in the presentation:

Hot and cold days/nights: Are extremes changing faster than average temperatures? Is there evidence that temperature variability is increasing, or are the changes in extremes simply reflecting overall warming?

Heavy rainfall events: Are these increasing in frequency and/or severity even where total rainfall is declining?

Drought: What is the influence of warming on drought frequency/severity, even if rainfall totals are not declining?

Tropical cyclones: Why are there such strong spatial variations in trends and links to ocean temperature? Are we seeing a shift to more intense cyclones, even where total numbers of tropical storms are not increasing?

Extratropical storms: Are the spatial variations in trends simply reflecting shifts in the atmospheric circulation, or are storms changing in intensity?

El Niño - Southern Oscillation: Has there been a trend to more or stronger Niño events?

Small scale extremes (tornadoes, hail, strong winds...): Are there ways to circumvent the problems caused by lack of consistent data regarding these small-scale events??

Summary

Many of the trends in extremes discussed above remain inconclusive because of concerns about the quality, comprehensiveness, and comparability of data over decades. The major exception to this is with regard to extreme temperatures, where extensive work and international cooperation over the past 15 years has led to a clear depiction of increasing warm extremes and decreasing frequencies of cold extremes (Nicholls and Alexander, 2007). So, the 15 years of progress regarding monitoring extremes has resulted in a substantial improvement in our understanding of how extreme temperatures are changing (essentially a shift in the frequency distributions towards warmer values, with fewer cold extremes), but for the other extremes (droughts, heavy rainfalls, cyclones, tornadoes...) data concerns, and variations of trends from region to region, overwhelm us, still. For some regions and variables there is little or no evidence of trends, even where the data are good. It remains impossible to say whether the global climate and weather is becoming more extreme or variable. Even in the case of extreme temperatures, it is still a moot point as to whether the increase in extreme warm events and decrease in cool extremes simply reflects the overall warming of the global climate, or whether increased variability of the climate is contributing to this change.

Despite the advances of the past 15 years (Nicholls and Alexander, 2007), some of the questions posed above may never be answered, using data available up to now, because of the many data problems that need to be overcome if we are to produce credible historical time-series of weather and climate extremes. This is especially the case for the small-scale extremes. Our inability to determine how some climate and weather extremes have changed in the past should provide a lesson for what we must do with weather and climate data in the future. The highest priority, if we are to determine at some point in the future if weather events have become more extreme, is to “establish and protect high-quality stations capable of monitoring the most important extreme events...and ensure that changes affecting the recording of extreme events (e.g., changes in exposure) are meticulously documented” (Nicholls, 1995).

Unfortunately, the “continued degradation of conventional surface-based observing systems in many countries” (Karl et al, 1995) that threatens the availability of data to monitor changes in extremes, has continued in recent decades.

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