

## United States of America | United States of America

### 1.0 Climate Overview

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The vast area of the United States and its varied topography gives rise to very diverse climatic regions; humid, subtropical and tropical areas of the south-east and Hawaii; arid, desert climate dominating the south-west; mild, maritime climates of the north-east and north-west seaboard; alpine conditions of the mountain areas; polar regions in Alaska and arid plains of the central belt.

With such a varied climate, much of the United States is susceptible to a range of extreme events. The northeast experiences cold winter extremes and blizzards, whilst the western and central states often have very hot, dry years which can lead to water shortages and wildfires. The states bordering the Gulf of Mexico are particularly prone to hurricanes or tropical cyclones, and tornadoes occur regularly in the areas of the Midwest referred to as Tornado Alley. Table 1 outlines some of the notable extreme events recorded across the United States in the last 20 years.

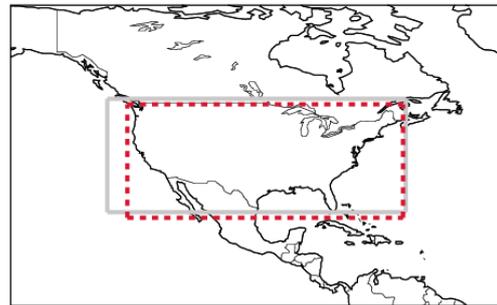


Figure 1. Location of boxes for the regional average time series (red dashed box) in Figures 3, 6 and 7 and the attribution region (grey box) in Figures 4 and 5.

### 2.0 Temperature Extremes (Heat waves/extreme cold)

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#### 2.1 Temperature extremes overview

Northern Alaska experiences the coldest conditions in the US, as tundra and arctic conditions predominate, and the observed temperature has fallen as low as  $-62^{\circ}\text{C}$ <sup>4</sup>. On the other end of the spectrum, Death Valley, California has recorded temperatures of  $56.7^{\circ}\text{C}$ , the second-highest temperature ever recorded on Earth.<sup>5</sup> Studies have found that temperature extremes may be changing, with increases in the frequency of warm events (e.g. warm nights and warm summer days) and decreases in the frequency of cold events (e.g. ice days, cold spell duration) observed between 1893-2005<sup>6</sup>. An increase in heat wave intensity averaged over the U.S. has also been observed.<sup>7</sup>

On average, the mountains of the western states receive the highest levels of snowfall on Earth. The greatest annual average snowfall level is found at Mount Rainier in Washington, at 1,758 cm; the record there was 2,850 cm in the winter of 1971-72. This record was broken by the Mt. Baker Ski Area in north-western Washington which reported 2,896 cm of snowfall for the 1998-99 snowfall season. However, significant extreme cold events bringing large amounts of snowfall have a particularly high impact when hitting large urban centres where infrastructure is severely affected, as shown in the example below from 2011.

#### 2.2 Blizzard, January 2011

The 2011 North American Blizzard on January 8–13 was a major winter storm affecting portions of the South-eastern United States. The blizzard left a 2,000-mile-long trail of snow and ice and two thirds of the nation facing downed power lines, blocked highways and thousands of flight cancellations. This followed a similar event that severely affected region in December 2010, and was followed by severe winter weather later that January. Blizzards were estimated to have led to a loss of 150,000 jobs in the United States for January <sup>15</sup>. Several deaths were also blamed on the storm labelled a "winter storm of historic proportions" by the National Weather Service, and emergency rooms saw a massive increase in injuries associated with falls and traffic accidents. <sup>16</sup>

The storm dropped large amounts of snow and ice from eastern Texas, and eastward across portions of Arkansas, Louisiana, Mississippi, Alabama, Tennessee, Georgia, and the Carolinas, causing significant travel emergencies and accidents. Hartsfield-Jackson Atlanta International Airport, the busiest in the world had many flights cancelled however the airport did not close.

A second storm system also moved south-eastward from Alberta, Canada, delivering light amounts of snow to the Dakotas, the Upper Midwest and the Great Lakes regions. The two systems then combined to form the storm that delivered over 2 feet of snow to New England. The storm affected portions of New Jersey, New York, much of Connecticut, Rhode Island, and Massachusetts. Central Park received 9.1 inches of snow; however, a lot of the areas in central and eastern Long Island saw 15 to 20 inches of snow <sup>17</sup>.

Connecticut bore the brunt of the storm, with many locations reporting snowfall totals of 20 to 30 inches <sup>17</sup>. Heavy snow caused the roof of an apartment building in Norwich to collapse, forcing the evacuation of 10 residents <sup>18</sup>. A 50-mile stretch of Interstate 95 in southwest Connecticut was closed due to numerous trucks becoming stuck on the highway in the snow <sup>19</sup>. The highest amount of snowfall was reported at Savoy, Massachusetts, with 40.5 inches. The storm also caused widespread flight delays and school closures in the region.

### **2.3 Heat wave, July 2006**

The 2006 North American heat wave spread throughout most of the United States and Canada beginning on July 15, 2006, killing at least 225 people. Temperatures regularly exceeded 49 °C. The California heat wave in particular broke local records. According to some reports it was "hotter for longer than ever before, and the weather patterns that caused the scorching temperatures were positively freakish." <sup>8,9</sup> Fresno, in the central California valley, had six consecutive days with temperatures exceeding 43 °C. <sup>10</sup>

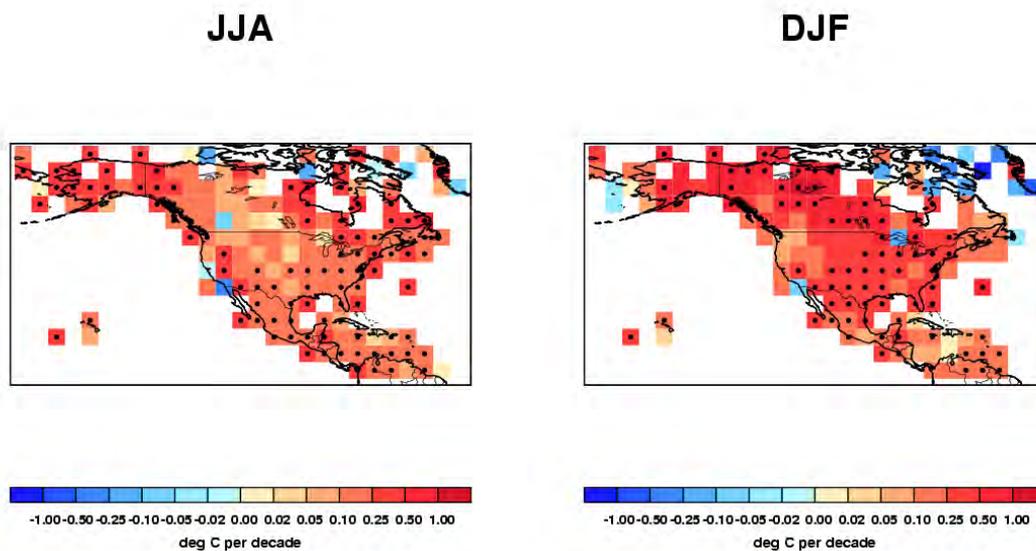
The most severe death toll was in California, principally in the interior region. By the end of July, when the sweltering heat in California subsided, the number of confirmed or suspected heat-related deaths reached 163 <sup>11</sup>, the largest number of heat-related deaths since 1989, when records began <sup>12</sup>. The impact on farm animals and agriculture was also apparent, with the death of more than 25,000 cattle and 700,000 fowl, prompting emergency measures by the state. <sup>13,14</sup>

The relentless heat also brought with it wildfires and blackouts for millions, with the state's electricity grid coming close to meltdown as reserves dropped below 5 per cent. Energy officials blamed the crisis in part on the intensive use of air conditioning in homes and offices <sup>12</sup>. This period of heat also saw a wind storm in St. Louis that caused widespread power outages, including for cooling centres designed to provide relief for those suffering from the heat. In addition, places on the West Coast, like California's Central Valley and Southern California experienced humid heat, which is unusual for the area. <sup>8</sup>

### **2.4 Analyses of Observed Temperature from 1960**

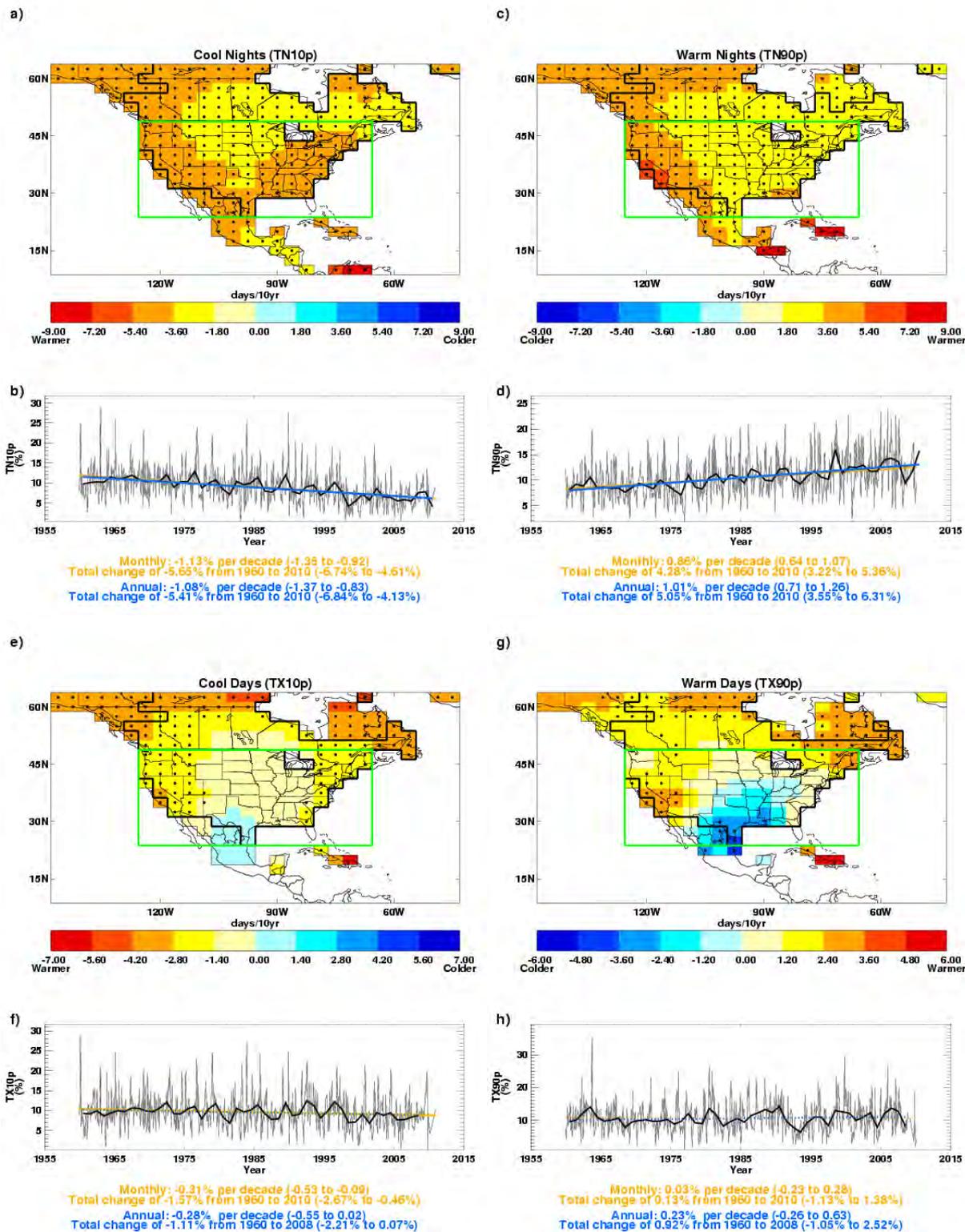
### 2.4.1 Long-term Features in the Mean Temperature

Over the period 1960 to 2010 there is a spatially consistent signal of warming over the contiguous US (Figure 2), as shown in previous research (Field et al. 2007). Grid-boxes showing high confidence in this signal are not ubiquitous but widespread for both summer (June to August) and winter (December to February). Regionally averaged trends (over grid boxes included in the red dashed box in Figure 1) calculated by the median of pairwise slopes show warming signals with high confidence. This trend is greater over winter at  $0.27\text{ }^{\circ}\text{C decade}^{-1}$  (5<sup>th</sup> to 95<sup>th</sup> percentile of slopes:  $0.13\text{ to }0.43\text{ }^{\circ}\text{C decade}^{-1}$ ) than summer at  $0.16\text{ }^{\circ}\text{C decade}^{-1}$  (5<sup>th</sup> to 95<sup>th</sup> percentile of slopes:  $0.10\text{ to }0.22\text{ }^{\circ}\text{C decade}^{-1}$ ).



**Figure 2.** Decadal trends in seasonally averaged temperatures for the US over the period 1960 to 2010. Monthly mean anomalies from CRUTEM3 (Brohan et al. 2006) are averaged over each 3 month season (June-July-August – JJA and December-January-February – DJF). Trends are fitted using the median of pairwise slopes method (Sen 1968, Lanzante 1996). There is high confidence in the trends shown if the 5<sup>th</sup> to 95<sup>th</sup> percentiles of the pairwise slopes do not encompass zero because here the trend is considered to be significantly different from a zero trend (no change). This is shown by a black dot in the centre of the grid-box.

### 2.4.2 Long-term Features in the Daily Maximum and Minimum Temperature



**Figure 3.** Percentage change in cool nights (a,b), warm nights (c,d), cool days (e,f) and warm days (g,h) for the US over the period 1960 to 2010 relative to 1961-1990 from the GHCND dataset (Durre et al. 2010). a,c,e,g) Grid-box decadal trends. Grid-boxes outlined in solid black contain at least 3 stations and so are likely to be more representative of the wider grid-box. Trends are fitted using the median of pairwise slopes method (Sen 1968, Lanzante 1996). High confidence in a long-term trend is shown by a black dot if the 5th to 95th percentile slopes are of the same sign. Differences in spatial coverage occur because each index has its own decorrelation length scale (see Methods section). b,d,f,h) Area averaged annual time series for 125.625° to 65.625° W and 23.75° to 48.75° N as shown by the green box on the map and Figure 1. Monthly (orange) and annual (blue) trends are fitted as described above. The decadal trend and its 5th to 95th percentile confidence intervals are shown as well

as the change over the period for which there are data. High confidence, as denoted above, is shown by a solid black line as opposed to a dotted one.

The trend in the number of cool nights shows a uniform decrease across the whole of the contiguous US (Figure 2), with high confidence throughout. A stronger decrease is observed towards the coasts. This is also seen, but to a lesser extent, in the trend for the number of warm nights, which shows an increase with high confidence throughout. Recent studies have also found that average night-time temperatures have seen a larger rise than daytime. Spring and autumn have experienced a greater warming than summer and winter (Field et al. 2007).

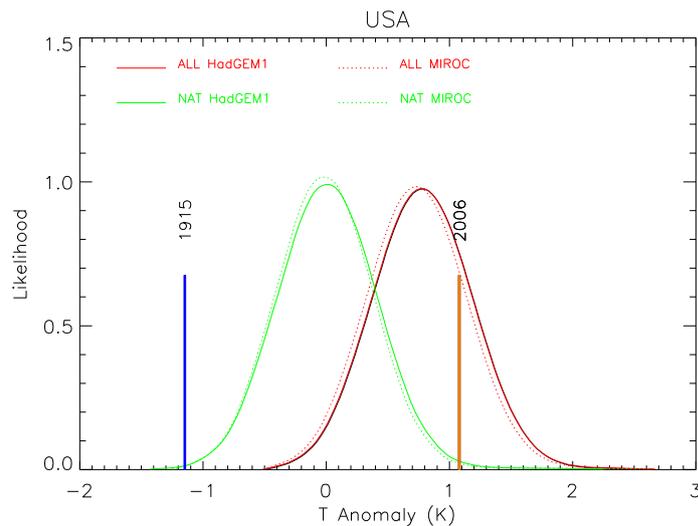
There is lower confidence generally in the trends for the frequency of cool and warm days. Although the central parts of the US appear to show an increase in cool days, there is low confidence in this signal. However the decrease in the number of cool days and the increase in the number of warm days are prominent on the west coast and in the Rocky Mountains. In the far south of Texas there is high confidence in a decrease in the number of warm days

The time-series in Figure 2 shows the large annual variability in occurrence of warm nights and days and cool nights and days. The underlying trend in the minimum temperature (cool and warm nights) is also clearly visible and there is high confidence that the trend is different to zero. However for the cool and warm days, no clear trend is observed, which matches what is shown in the maps.

## **2.5 Attribution of changes in seasonal mean temperatures**

### **2.5.1 Summer 2006 and the heat wave event**

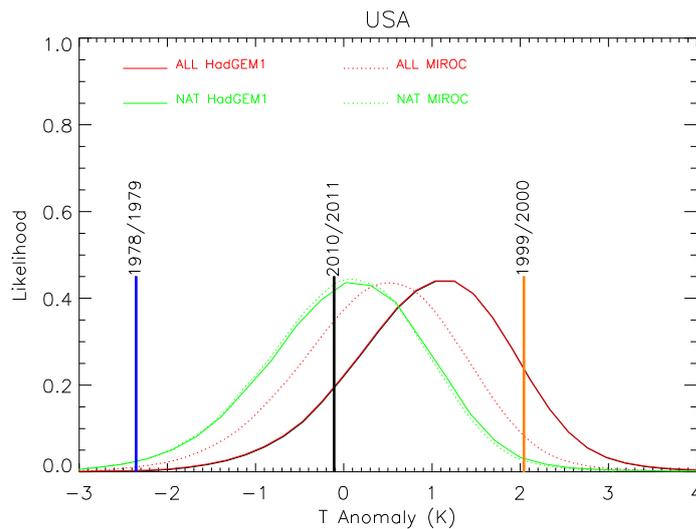
The PDFs of the summer mean regional temperature in recent years in the presence and absence of anthropogenic forcings are shown in Figure 4. Analyses with both models suggest that human influences on the climate have shifted the distribution to higher temperatures. Considering the average over the entire region, the 2006 summer is average/warm, as it lies in the central sector and towards the warm tail of the temperature distributions for the climate influenced by anthropogenic forcings (red PDFs), and it is also the hottest since 1900 in the CRUTEM3 dataset. The warmest season would be expected to lie further into the warm tails of the distributions plotted in red. Possible reasons why this is not the case could be that the limited number of observations in recent years does not adequately sample the distribution, or that the models have a warm bias in the region. In the absence of human influences on the climate (green PDFs), the season would be exceptionally warm, as it lies further into the tail of the distributions plotted in green. It should be noted that the attribution results shown here refer to temperature anomalies over the entire region and over an entire season, whereas the actual extreme event had a shorter duration and affected a smaller region. As the summers become warmer and the temperature distribution shifts to higher temperatures, it is expected that the occurrence of extreme events like the heatwave in July 2006 will become more frequent.



**Figure 4.** PDFs of the June-July-August mean temperature anomalies (relative to 1961-1990) averaged over the US region (130-65W, 25-50N – shown in Figure 1) including (red lines) and excluding (green lines) the influence of anthropogenic forcings. The distributions describe the seasonal mean temperatures expected in recent years (2000-2009) and are based on analyses with the HadGEM1 (solid lines) and MIROC (dotted lines) models. The vertical orange and blue lines correspond to the maximum and minimum anomaly in the CRUTEM3 dataset since 1900 respectively.

### 2.5.2 Winter 2011 and the blizzard in January

The PDFs of the winter mean regional temperature in recent years in the presence and absence of anthropogenic forcings are shown in Figure 5. Analyses with both models suggest that human influences on the climate have shifted the distribution to higher temperatures. Considering the average over the entire region, the 2010/11 winter is cold, as it lies near the cold tail of the temperature distributions for the climate influenced by anthropogenic forcings (PDFs plotted in red). It is, however, considerably warmer than the winter of 1978/79, the coldest in the CRUTEM3 dataset. In the absence of human influences on the climate (green PDFs) the season lies in the central sector of the temperature distribution and would therefore be more common. It should be noted that the attribution results shown here refer to temperature anomalies over the entire region and over an entire season whereas the cold extreme event had a shorter duration and affected a smaller region. As the winters become warmer and the temperature distribution shifts to higher temperatures, it is expected that the occurrence of cold events like the blizzard in January 2011 will become less frequent.



**Figure 5.** PDFs of the December-January-February mean temperature anomalies (relative to 1961-1990) averaged over the US region (130-65W, 25-50N – shown in Figure 1) including (red lines) and excluding (green lines) the influence of anthropogenic forcings. The distributions describe the seasonal mean temperatures expected in recent years (2000-2009) and are based on analyses with the HadGEM1 (solid lines) and MIROC (dotted lines) models. The vertical black line marks the observed anomaly in 2010/11 and the vertical orange and blue lines correspond to the maximum and minimum anomaly in the CRUTEM3 dataset since 1900 respectively.

### 3.0 Rainfall Extremes

#### 3.1 Rainfall extremes overview

Rainfall patterns vary widely across the United States. Late summer and autumn (fall) extra-tropical cyclones bring the majority of the precipitation received by western, southern, and southeast Alaska annually. During the fall, winter, and spring, Pacific storm systems bring most of the precipitation to Hawaii and the western United States, and north-easterly winds tracking up the East coast bring winter precipitation to the Mid-Atlantic states. The El Niño-Southern Oscillation affects the precipitation distribution by altering rainfall patterns across the West, Midwest, the Southeast, and throughout the tropics.<sup>20,21,22,23</sup>

During summer, the Southwest monsoon combined with moisture from the Gulf of California and Gulf of Mexico brings afternoon and evening thunderstorms to the southern part of the country as well as the Great Plains<sup>24</sup>. Tropical cyclones enhance precipitation across southern and eastern sections of the country, as well as Puerto Rico, the United States Virgin Islands, the Northern Mariana Islands, Guam, and American Samoa.<sup>25</sup>

Flooding is most common in the Appalachian region and the Midwest, although widespread severe flooding is rare. Some exceptions include the Great Mississippi Flood of 1927, the Great Flood of 1993, and widespread flooding and mudslides caused by the 1982-1983 El Niño in the western United States. Localized flooding can, however, occur anywhere. Mudslides from heavy rain cause problems in many mountainous areas, as does heavy rainfall in regions with narrow canyons, often leading to flash flooding.

The Southwest is particularly prone to droughts. Although severe drought is rare, it has occasionally caused major problems, such as during the Dust Bowl (1931–1942), which coincided with the Great Depression. Farmland failed throughout the Plains, entire regions were virtually depopulated, and dust storms affected large areas of land. More recently, the western U.S. experienced widespread drought from 1999-2004, and again in 2007.

Snowmelt is occurring 1 to 4 weeks earlier across the mountainous areas of the continent, and ice break-up across North America has become earlier by 0.2 to 12.9 days over the last century <sup>2</sup>. Across much of North America, precipitation has increased during the 20<sup>th</sup> century, particularly in Alaska. This is not the case in the south-western US, which has seen a decrease in precipitation rates of 1 to 2% per decade as droughts conditions prevail <sup>3</sup>. Snowfall and snow cover has decreased across much of North America despite the increased precipitation, largely as a result of increasing temperatures.

### **3.2 Drought, September 2007**

Extreme drought conditions affected approximately 43 percent of the United States during September 2007, with many areas experiencing record drought conditions.

One of the major impacts of the drought was on the energy industry. Drought in the southeast lowered rivers in Alabama to the point where there was insufficient stream flow to meet the demand of industry, agriculture, municipalities, and natural evaporation. Alabama Power, the state's largest utility, was forced to operate some of its coal plants at significantly reduced levels to avoid raising water temperatures in the Coosa, Black Warrior and Mobile rivers and the Tennessee Valley Authority shut down a nuclear power plant due to inadequate stream flow. <sup>26</sup>

This drought also coincided with heat wave conditions across much of western, southern and eastern North America that lasted from June to October 2007. Nearly two dozen states were in either Heat Advisories, or Excessive Heat Warnings or Watches. 13 new all time maximum high temperatures were set, along with several hundred new daily high maximum temperature records <sup>27</sup>. August 2007 turned out to be one of the 20 warmest Augusts for the United States since 1895 when records began. More than 50 deaths were reported as well as cases of heat exhaustion and heat Stroke. Most occurred in the very elderly and people who could not afford air conditioning due to high energy costs. <sup>27</sup>

Combined, the heat wave and drought had major impacts on the agricultural harvest, particularly in the southeast. 81 percent of the Alabama corn crop was in poor or very poor condition and the corn crop in many parts of Tennessee was forecast to be a total loss. Between 40% and 52% of pasture and rangeland in Alabama, North Carolina, and Tennessee was listed as being in "very poor" condition. Many herd owners were forced to sell some of their livestock due to a lack of water and vegetation and the escalating costs of food due to the effects of the heat wave and drought <sup>27</sup>. The drought and heat also created conditions ideal for wildfires and caused significant water shortages.

### **3.3 Flooding events Flooding, June 2008**

The June 2008 floods were flooding events which affected portions of the Midwest United States. After months of heavy precipitation, a number of rivers overflowed their banks for several weeks at a time and broke through levees at numerous locations. Flooding continued into July. States affected by the flooding included Illinois, Indiana, Iowa, Michigan, Minnesota, Missouri, and Wisconsin. The American Red Cross assisted the victims of flooding and tornadoes across seven states and the National Guard was mobilized to assist in disaster relief and evacuation.

Flooding continued as long as two weeks with central Iowa and Cedar Rapids being hardest hit. The upper Mississippi Valley experienced flooding in Missouri and Illinois as the region's estuaries drained floodwater into the river. The flood left thirteen dead and damage region-wide was estimated to be tens of billions of dollars. <sup>28</sup>

## Flooding, May 2011

During May 2011, thousands of U.S. residents were evacuated from their homes along the Mississippi River as flooding in some communities reached levels not seen in more than 80 years. The natural disaster occurred along North America's largest river system that extends more than 3,700 kilometres from the northern part of the United States to the Gulf of Mexico on the southern perimeter of the country.

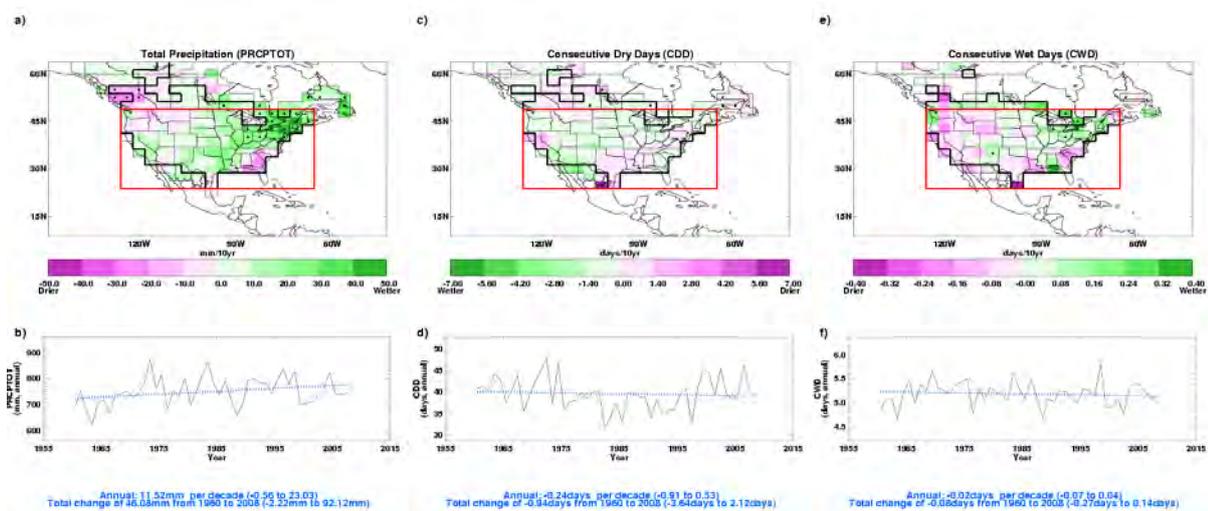
The flooding along the Mississippi, and the Ohio River that feeds into it, forced residents to evacuate as the waters made their way from the Midwest to the Gulf of Mexico. Thousands of acres of crops, timber and catfish farms were flooded, mostly by tributaries that flooded as the Mississippi River was so high. Hundreds were displaced from flooded homes.

Despite the flooding being not as bad as originally predicted, it still remained treacherous for those affected. Some 5,600 people have now applied for government assistance in Mississippi and Tennessee, though the damage is still being assessed because high waters are still causing problems for officials. Meanwhile, early estimates indicate flooding swamped 450,000 acres of cropland and caused more than \$250 million in damages to agriculture in Mississippi alone. However, an exact measure of the damage is not yet available because thousands of acres are still flooded.<sup>29</sup>

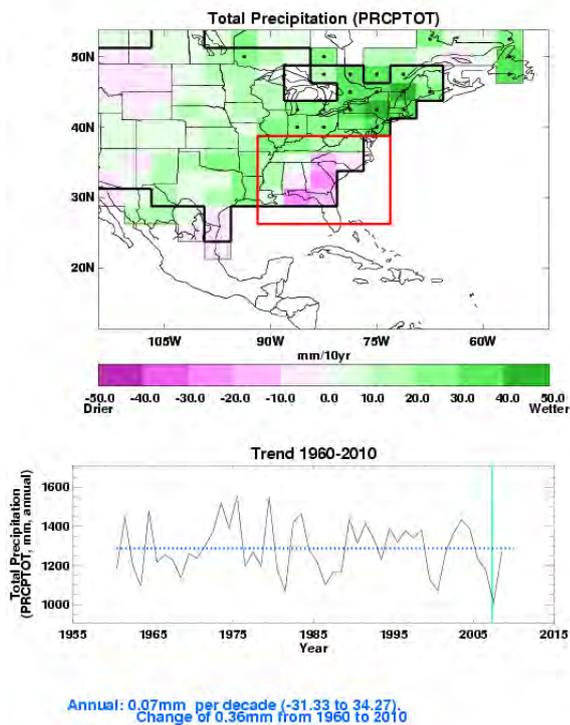
## 3.4 Analyses of Observed Precipitation from 1960

The trends for the total precipitation (Figure 6) show an increase on the north eastern seaboard which has high confidence. For the remainder of the country, there is no significant trend, but on average there appears to be an increase in precipitation. For the numbers of continuous wet and dry days, there is no clear coherent distribution of the trends, of which very few are significant.

The time series for the total precipitation, (also plotted in Figure 5), shows a large amount of annual variability and although a linear best fit shows an increase but with low confidence. In Figure 7 we focus on the south east of the US to highlight the drought which occurred there in 2007. The drop in the total precipitation can clearly be seen and was the lowest value since 1960 for this region.



**Figure 6.** The change in the the total rainfall (a,b), the number of continuous dry days (c,d) and continuous wet days (e,f) over the period 1960-2010. The maps and timeseries have been created in exactly the same way as Figure 3.



**Figure 7.** Change in the total rainfall over the period 1960-2009. The map and time-series have been created in exactly the same way as Figure 3. The green vertical line shows the drought of 2007.

## 4.0 Storms

### 4.1 Storms overview

Deadly and destructive hurricanes occur almost every year along the Atlantic coast and the Gulf of Mexico<sup>30</sup>, and can also affect Hawaii in the Pacific Ocean<sup>31</sup>. Particularly at risk are coastal Texas, Louisiana, the east coast of Florida, and North Carolina. Hurricane season runs from June to November, with a peak from mid-August through early October<sup>32</sup>. Some of the more devastating hurricanes have included the Galveston Hurricane of 1900<sup>33</sup>, Hurricane Andrew in 1992<sup>34</sup>, and Hurricane Katrina in 2005<sup>35</sup>. The remnants of tropical cyclones from the Eastern Pacific also occasionally impact the south-western United States, bringing heavy rainfall.<sup>36</sup>

The Great Plains and Midwest, because of the contrasting air masses that meet here, have frequent severe thunderstorms and tornado outbreaks during spring and summer. In central portions of the U.S., tornadoes are more common than anywhere else in the world.<sup>37</sup>

### 4.2 Hurricane Katrina, August 2005 and Hurricane Ike, September 2008

Hurricane Katrina was the costliest natural disaster, as well as one of the five deadliest hurricanes, in the history of the United States<sup>38</sup>. It was also the sixth strongest Atlantic hurricane ever recorded. At least 1,836 people died in the actual hurricane and in the subsequent floods, making it the deadliest U.S. hurricane since the Okeechobee hurricane in 1928; and total property damage was estimated at US\$81 billion.<sup>38</sup>

Hurricane Katrina formed over the Bahamas on August 23, 2005 and crossed southern Florida as a moderate Category 1 hurricane, causing some deaths and flooding there before strengthening rapidly in the Gulf of Mexico. The storm weakened before making its second

landfall as a Category 3 storm in southeast Louisiana. It caused severe destruction along the Gulf coast from central Florida to Texas, much of it due to the storm surge. The most significant amount of deaths occurred in New Orleans, Louisiana, which flooded as the levee system catastrophically failed, in many places hours after the storm had moved inland<sup>39</sup>. Eventually 80% of the city and large tracts of neighbouring parishes became flooded, and the floodwaters lingered for weeks<sup>39</sup>. However, the worst property damage occurred in coastal areas, such as all Mississippi beachfront towns, which were flooded over 90% in hours from when Katrina made landfall, as boats and casino barges rammed buildings, pushing cars and houses inland, with waters reaching 6–12 miles (10–19 km) from the beach. Years later, thousands of displaced residents in Mississippi and Louisiana are still living in temporary accommodation.

Federal disaster declarations covered 90,000 square miles (233,000 km<sup>2</sup>) of the United States, an area almost as large as the United Kingdom. The hurricane left an estimated three million people without electricity, and also caused substantial damage to many roads and much of the infrastructure in the affected states. Even in 2010, debris remained in some coastal communities.<sup>40</sup>

More recently, in 2008, Hurricane Ike caused at least 195 deaths. Of these, 74 were in Haiti, which was already trying to recover from the impact of three storms earlier that year. In the United States, 112 people were killed<sup>41</sup>. Due to its immense size, Ike caused devastation from the Louisiana coastline all the way to Texas. In addition, Ike caused flooding and significant damage along the Mississippi coastline and the Florida Panhandle. Damages from Ike in U.S. coastal and inland areas are estimated at \$29.6 billion (2008 USD)<sup>41</sup>, with additional damage of \$7.3 billion in Cuba (the costliest storm ever in that country), \$200 million in the Bahamas, and \$500 million in the Turks and Caicos, amounting to a total of at least \$37.6 billion in damage. Ike was the third costliest Atlantic hurricane of all time, only surpassed by Hurricane Andrew of 1992 and Hurricane Katrina of 2005<sup>41</sup>. The hurricane also resulted in the largest evacuation of Texans in that state's history. It became the largest search-and-rescue operation in U.S. history.<sup>42</sup>

#### **4.3 Tornadoes, Spring 2011**

As of June 8th, there were 1,458 tornadoes reported in the US in 2011, making it an exceptionally destructive and deadly year for tornadoes. It is the deadliest year in the United States since 1936, causing an estimated 536 fatalities in the United States (compared to 564 US total deaths in the 10 years prior)<sup>43</sup> due mostly to the 322 deaths from tornadoes that occurred during the April 27th outbreak across the South-eastern United States and the 151 deaths in the 2011 Joplin Tornado.<sup>44</sup>

Between April 25th and 28th, a historic tornado outbreak now known as the 2011 Super Outbreak took place across much of the Southern United States as well as parts of the Midwest and Northeast. With over 300 confirmed tornadoes and 317 fatalities, the outbreak ranks as the worst in United States history. More than three dozen tornadoes were confirmed each day of the event, with 39 on April 25th, 55 on April 26th, a record 188 in 24 hours on April 27th and 45 on April 28th. On April 25<sup>th</sup> a tornado emergency was declared for Vilonia, Arkansas as a tornado caused extensive damage, killing at least four people with many more injured. On April 27th, a large tornado struck Tuscaloosa, Alabama, killing at least 41 people. The Tuscaloosa mayor called the damage “catastrophic.” A large tornado hit the northern suburbs of Birmingham, Alabama, shortly thereafter. Over 180 tornadoes were reported during April 27<sup>th</sup> and 28<sup>th</sup>. Over 305 deaths have been reported as a result of the outbreak, with as many as 204 in Alabama alone.<sup>45</sup>

A moderate risk of severe weather was issued for much of the Midwest south to Oklahoma for May 22nd. The first tornado supercell that day developed in the mid-afternoon hours over the western Twin Cities damaging in and around Minneapolis, Minnesota<sup>46</sup>. An intense

tornado also tracked towards Harmony, Minnesota that afternoon and a tornado emergency was issued. The same day, a very large and intense tornado resulted in catastrophic damage in Joplin, Missouri. Many houses and businesses were flattened and some even were blown away in Joplin. The main hospital was heavily damaged and many people were reported to have been trapped in destroyed houses. Reports suggest there were at least 151 fatalities, and another 1,000+ injured.<sup>47</sup>

## 5.0 Conclusions

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### The main features seen in observed climate over USA are :

- The USA has a varied climate, and much of the country is susceptible to a range of extreme events.
- Recent extreme events include the Blizzard on January 8–13, 2011 which left a 2,000-mile-long trail of snow and ice and two thirds of the nation facing downed power lines, blocked highways and thousands of flight cancellations and the heatwave of July 2006 which killed at least 225 people.
- There has been a widespread warming trend over the country since 1960.
- There has been a widespread reduction in the number of cool nights across the whole of the contiguous US (Figure 2), with stronger decreases observed towards the coasts.
- There has been a general increase in summer and winter temperatures averaged over the country as a result of human influence on climate, making the occurrence of warm summer and winter temperatures more frequent and cold summer and winter temperatures less frequent.
- Since 1960 there has been a positive trend in precipitation on the north eastern seaboard but for the remainder of the country, there is no significant trend.
- Extreme drought conditions affected approximately 43 percent of the United States during September 2007, with many areas experiencing record drought conditions.
- Hurricane Katrina was the costliest natural disaster, as well as one of the five deadliest hurricanes, in the history of the United States and the sixth strongest Atlantic hurricane ever recorded.

## 6.0 References

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Brohan, P., Kennedy, J.J., Harris, I., Tett, S.F.B. and Jones, P.D. (2006): Uncertainty estimates in regional and global observed temperature changes: a new dataset from 1850. *J. Geophys. Res.*, 111, D12106. doi:10.1029/2005JD006548.

Durre, I, Menne, MJ, Gleason, BE, Houston, TG, Vose, RS, 2010, Comprehensive Automated Quality Assurance of Daily Surface Observations, *Journal of Applied Meteorology and Climatology*, 49, 8, 1615-1633

Field, C.B., Mortsch, L.D., Brklacich, M., Forbes, D.L., Kovacs, P., Patz, J.A., Running, S.W. and Scott, M.J. (2007): North America. *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds., Cambridge University Press, Cambridge, UK, 617-652.

Lanzante, J. R. (1996): Resistant, robust and non-parametric techniques for the analysis of climate data: theory and examples, including applications to historical radiosonde station data. *Int. J. Clim.*, 16, 1197–226.

Sen, P. K. (1968): Estimates of the regression coefficient based on Kendall's tau. J. Am. Stat. Assoc., 63, 1379-89.

1. Field, C.B. et al., (2007) North America. Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, M.L. Parry et al., Cambridge University Press, Cambs, UK, 617-652.
2. Magnuson, J.J. et al., (2000) Historical trends in lake and river ice cover in the Northern Hemisphere. Science, 289, 1743-1746.
3. Trenberth, K.E. et al., (2007) Observations: Surface and Atmospheric Climate Change. Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, S. Solomon et al. Eds. Cambridge University Press, Cambs, UK, 235-336.
4. Williams, Jack: Each state's low temperature record, USA today. <http://www.usatoday.com/weather/wcstates.htm>
5. National Park Service (2002), "Weather and Climate". Official website for Death Valley National Park. U. S. Department of the Interior. January 2002. pp. 1-2. <http://www.nps.gov/deva/planyourvisit/upload/Weather.pdf>.
6. Brown, P.J., R.S. Bradley and F.T. Keimig (2010) Changes in Extreme Climate Indices for the Northeastern United States, 1870-2005. Journal of Climate, AMS Vol 23, No. 24. Doi: 10.1175/2010JCLI3363.1
7. Mass, C. A. Skalenakis and M. Warner (2010) Extreme Precipitation over the West Coast of North America: Is There a Trend? Journal of Hydrometeorology, Vol 12, 310-318. Doi: 10.1175/2010JHM1341.1
8. S.F. Chronicle, ( 2006) The heat wave that was, <http://sfgate.com/cgi-bin/article.cgi?f=/c/a/2006/07/27/WEATHERPAST.TMP>
9. Bay Area Record Breaking Heat, National Oceanic and Atmospheric Administration
10. <http://www.suntimes.com/output/news/cst-nws-heat29.html>
11. Midwest suffers as heat bears down Carla Johnson, Associated Press, appearing in Houston Chronicle, July 31, 2006
12. Times Online (2006) [http://www.timesonline.co.uk/tol/news/world/us\\_and\\_americas/article694184.ece](http://www.timesonline.co.uk/tol/news/world/us_and_americas/article694184.ece)
13. Heat Wave Proving Deadly for Pets, KCBS, San Leandro, Calif., posted July 24
14. California's Cattle Death Toll Surpasses 25,000 USAgNet, July 31, 2006.
15. Lahart, Justin (2011) "Job Report Muddies Outlook". Wall Street Journal. <http://online.wsj.com/article/SB10001424052748704709304576123862334939594.html>.
16. ABC News (2011) <http://abcnews.go.com/US/blizzard-2011-mega-snowstorm-pounds-midwest-snow-ice/story?id=12818948>
17. National Weather Service Forecast Office: Snowfall Reports for the Current Storm <http://forecast.weather.gov/product.php?site=NWS&issuedby=OKX&product=PNS>
18. WTNH-TV (2011) Roof Collapses at Norwich Apartment Building
19. WTNH-TV (2011) Stuck trucks clog I-95 for Hours
20. Romm, J. (ed) (2007) Climate Progress Website <http://thinkprogress.org/romm/2007/10/16/201979/record-us-drought-global-warming/>
21. John Monteverdi and Jan Null (1997), Western Region Technical Attachment NO. 97-37 NOVEMBER 21, 1997: El Niño and California Precipitation. <http://tornado.sfsu.edu/geosciences/elnino/elnino.html>
22. Nathan Mantua. UCAR Report: La Niña Impacts in the Pacific Northwest. <http://www.ccb.ucar.edu/lanina/report/mantua.html>
23. Southeast Climate Consortium. SECC Winter Climate Outlook. <http://www.agclimate.org/Development/apps/agClimate/controller/perl/agClimate.pl/agClimate.pl?function=climforecast/outlook.html&location=local&type>
24. Reuters. (2008), "La Nina could mean dry summer in Midwest and Plains." <http://www.reuters.com/article/domesticNews/idUSN1619766420070216>
25. National Weather Service Forecast Office Flagstaff, Arizona. The Monsoon. <http://www.wrh.noaa.gov/fgz/science/monsoon.php?wfo=fgz>
26. David M. Roth. Tropical Cyclone Maxima per U. S. State. <http://www.hpc.ncep.noaa.gov/tropical/rain/tcstatemaxima.gif>

27. NOAA (National Oceanic and Atmospheric Administration) (2007) August 2007 Heat wave Special Report <http://www.ncdc.noaa.gov/special-reports/2007-aug-heat-event.html>
28. Summary of impacts on different states, for further references: [http://en.wikipedia.org/wiki/June\\_2008\\_Midwest\\_floods#Deaths](http://en.wikipedia.org/wiki/June_2008_Midwest_floods#Deaths)
29. Holbrooke, M., M. Kunzelman and A. Sainz (2011) Associated Press, [http://news.yahoo.com/s/ap/us\\_mississippi\\_river\\_flooding](http://news.yahoo.com/s/ap/us_mississippi_river_flooding)
30. Hurricane Research Division (2006), Chronological List of All Hurricanes which Affected the Continental United States: 1851-2005. <http://www.aoml.noaa.gov/hrd/hurdat/ushurrlist.htm>
31. Central Pacific Hurricane Center. Previous Tropical Systems in the Central Pacific.
32. National Hurricane Center. Peak of Season Graphic. <http://www.prh.noaa.gov/cphc/summaries/>
33. National Oceanic and Atmospheric Administration. (NOAA) The Galveston storm of 1900—The deadliest disaster in American history. <http://web.archive.org/web/20070213214146/http://www.noaa.gov/galveston1900/>
34. Ed Rappaport (1993). "Hurricane Andrew Preliminary Report". National Hurricane Center. <http://www.nhc.noaa.gov/1992andrew.html>.
35. Knabb, Richard D; Rhome, Jamie R.; Brown, Daniel P (2005; updated, 2006). "Tropical Cyclone Report: Hurricane Katrina: 23–30 August 2005" (PDF). National Hurricane Center. [http://www.nhc.noaa.gov/pdf/TCR-AL122005\\_Katrina.pdf](http://www.nhc.noaa.gov/pdf/TCR-AL122005_Katrina.pdf).
36. David M. Roth. Tropical Cyclones in the West. <http://www.hpc.ncep.noaa.gov/tropical/rain/tcwest.html>
37. NOVA (2004), Tornado Heaven, Hunt for the Super twister, <http://www.pbs.org/wgbh/nova/tornado/country.html>
38. Knabb, R.D., Rhome, J.R. and Brown, D.P (2006) Tropical Cyclone Report: Hurricane Katrina: 23-30 August 2005. National Hurricane Centre.
39. Swenson, D.D., Marshall, B. (2005) Flash Flood: Hurricane Katrina's Inundation of New Orleans, August 29, 2005. Times-Picayune.
40. Clark, L. (2010) 'Spill colors fabric of Gulf coastal life.' The Sun News.
41. Berg, R. (2008) 'Hurricane Ike Tropical Cyclone Report'. National Hurricane Centre.
42. Hurricane Recovery Network (2008) 'Hurricane Ike Fast Facts' <http://www.houstonhurricanerecovery.org/node/163>
43. NOAA Tornado Statistics (2011) <http://www.spc.noaa.gov/climo/torn/fataltorn.html>
44. NOAA Annual Tornado Death Tolls (2011) <http://www.norman.noaa.gov/2009/03/us-annual-tornado-death-tolls-1875-present/>
45. NOAA (2011) Storm Report April 27<sup>th</sup> 2011 [http://www.spc.noaa.gov/climo/reports/110427\\_rpts.html](http://www.spc.noaa.gov/climo/reports/110427_rpts.html)
46. NOAA (2011) Storm Report May 22<sup>nd</sup> 2011 [http://www.spc.noaa.gov/climo/reports/110522\\_rpts.html](http://www.spc.noaa.gov/climo/reports/110522_rpts.html)
47. St Louis Post (2011) [http://www.stltoday.com/news/state-and-regional/missouri/article\\_87e452c5-860d-5588-8e6f-ad7a323ae1de.html](http://www.stltoday.com/news/state-and-regional/missouri/article_87e452c5-860d-5588-8e6f-ad7a323ae1de.html)

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Year	Month	Event	Details	Impacts
1994	July	Flooding	Record floods in Georgia	
1994	July	Storm	Tropical cyclone ALBERTO	
1994	Aug	Storm	Tropical cyclone BERYL	
1994	Summer	Drought	Drought and associated fires	Wildfire
1994	April	Flooding	Episodes of extreme localised floods in Florida	
1994	Oct	Flooding	Record floods in Texas	
1995	August	Heatwave	Brief but deadly heat wave in Chicago (IL) Maximum temperature recorded was 41C	
1995	Sept	Storms	Tropical cyclone OPAL and ROXANNE, within 10 days of each other	
1995	Apr - May	Flooding	Heavy rains and flooding	
1995	Jun - Sep	Drought	Drought followed by heavy precipitation - East coast	
1995	Nov - Dec	Flooding	Heavy rains flooding	
1996		Flooding	15 month surpluses 660 - 975mm at some sites - East coast	
1996	Jan - Jun	Dry	Very dry and warm - West coast	Record US area consumed by wildfires
1996	Feb	Cold	Record cold US	
1996	Feb & Dec	Flooding	Very wet early & late	
1997	Aug	Heatwave	Near record heat wave northeast coast US	
1997	Jan-Feb	Flooding	Rain & snowmelt floods northwest coast US	
1997	July	Storm	Tropical cyclone DANNY (Florida)	
1997	September	Storm	Tropical cyclone NORA (New Mexico)	
1997	October	Snow	Heavy snow (Texas)	
1997	Apr-Oct	Drought	Drought, northeast US, 55%-70% of normal precipitation	
1998	January	Ice storm	A massive ice storm hits northeast US	Widespread destruction
1998	August	Storm	Tropical cyclone BONNIE, up to 250mm rain, NE coast US	
1998	Apr-Jun	Wet	Wet/severe weather - Northern US	
1998	Jan-May & Dec	Wet	Wet/cool - Western US	Crop losses
1998	Jun-Dec	Dry	Very dry - Northeast US	
1998	June	Hot/dry	Severe fires - Southeast US	
1998	September	Storm	Tropical cyclone GEORGES - Central US	Heavy rain + damages
1998	August	Storm	Tropical cyclone CHARLEY - Southwest US	
1998-2000	Jan 1998 - May 2000	Drought	Severe drought (Hawaii) - 930-2400mm below normal rainfall.	

1998-2000	May 1998-Dec 2000	Drought	Drought - 500-1675mm below normal	
1999	January	Storms	Severe weather - tornadoes 3x old Jan record	
1999	January	Snowstorm	Severe blizzard Midwestern and ne states, up to 19 inches of snow (Chicago) and temperatures of -25°C	68 deaths reported
1999	Apr-Jan	Storm	wet, severe weather in western states	
1999	Aug/Sept	Flooding	Heavy rain/floods, up to 915mm - ne USA	
2000	winter 1999-2000	Warm	Warmest winter on record	
2000	July-Sept	Hot/dry	Very hot and dry	Crop stress, wildfires - largest area burnt since 1988
2000	November	Flooding	Floods (Hawaii) - daily totals up to 700mm	
2000	Nov-Dec	Cold	Coldest Nov-Dec on record	
2002	Feb-May	Drought		Wildfires
2003		Drought	Continuation of drought (western USA)	Wildfires - over 300,000 hectares burnt in California
2003	February	Snowstorm	Numerous new snowfall and storm records	
2005		Heatwave	Third warmest summer in Alaska	Wildfires - record area burnt across USA
2005		Drought	Severe winter drought (NW USA)	
2005	July	Heatwave	Heat wave - many new records (western US)	
2005	summer	Drought	Severe drought expands (central US)	
2005	August	Storm	Hurricane Katrina	1,322 deaths
2005	October	Flooding	Record wet October (Northeast USA) - more flooding in April	
2005	Jan	Storm	Major winter storm - snowiest month on record for Boston	
2006	December	Storms		Power cuts, 16 killed in US and Canada, most by fumes from home power-generation
2006	July	Heatwave	Heat wave -California and Central	Over 140 deaths in California, record wildfire season
2006	November	Flooding	Heavy rain and flooding (NW)	
2006	summer	Wet	Wettest summer on record	
2006	Feb	Snow	Record snowfall in New York	
2007	August-October	Heatwave	Heatwave - numerous records, folding spring severe to exceptional drought - driest spring on record (SE USA)	Over 50 deaths, 2nd worst fire season, US\$2.5 billion in damages in October fires alone
2007	Feb/March	Storm	Winter storm	300,000 affected
2008	February	Storm	Tornado outbreak in the southern US	58 dead
2008	September	Storms	Hurricane Ike	US\$30 billion in damages
2008	June	Flooding	Flooding across Midwest - worst floods since 1993	11 million affected, US\$10 billion in damages
2008		Drought	Persistent drought across western and south-eastern US	3rd worst fire season, US\$2.2 billion in damages from fires in November

2009	March/October	Flooding	Record Floods on Red River in the northern plains region, wettest October since records began	
2011	February	Snowstorm	Blizzard	375,000 households without power, and at least 12 deaths in US and Canada
2011	Spring	Storms	Deadliest tornado season since 1936 in the US, with over 1,458 tornadoes reported	536 fatalities in the United States

Table 1: Notable extreme events recorded in United States 1994-2011. Highlighted events are discussed in more detail within this chapter.