Committee on Natural Resources
Minority Staff

Committee on Energy and Commerce
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Going to Extremes:

Climate Change and the Increasing Risk of Weather Disasters

Prepared for:

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"This is what global warming looks like at the regional or personal level. The extra heat increases the odds of worse heat waves, droughts, storms and wildfire. This is certainly what I and many other climate scientists have been warning about."

-Dr. Jonathan Overpeck, The University of Arizona

Introduction

The United States and the world experienced a barrage of extreme weather events over the last several years consistent with what climate scientists have been predicting from global warming pollution. Indeed this summer, U.S. weather was almost apocalyptic: searing heat, ferocious fires, hurricanes, and severe storms left people injured, homeless and in some cases, dead.

This July was the hottest month ever recorded in the lower 48 since recordkeeping began in 1895[1] and the heat claimed at least 100 lives.[2] January through August was the warmest first eight months period for the continental United States, breaking the previous record set in 2006 by 1°F.[3] The year's extreme heat contributed to widespread drought across the majority of the country. In July and again in September, the U.S. Drought Monitor reported that 64% of the continental United States was in drought, putting this year's drought on par with the worst months of the multi-year droughts of the 1930s and 1950s.[4] This extreme summer follows a period of unusual weather that has plagued the country for more than a year, including an unusually warm winter and an early spring drought. In fact, August 2011 to July 2012 is the warmest 12-month period that the continental United States has experienced since the beginning of recordkeeping in 1895.[5] This fire season over 8.6 million[6] acres have burned in the United States, an area about the size of New Jersey and Connecticut combined. With fires still burning in parts of the West in early September, this year may equal or surpass the almost 8.8 million acres burnt in 2006, the worst fire year in the last decade.[7]

Record-breaking was not confined to the land. During the first six months of 2012, sea surface temperatures in the northeastern Atlantic were the highest ever, breaking a record that goes back to 1854.[8] Arctic sea ice coverage shrank to a record low 1.32 million square miles in September, 18% below the previous record set in 2007 and a 49% reduction in the area of the Arctic covered by sea ice as compared to conditions in the 1980s and 1990s.[9]

Beyond the loss of life and impact on communities and livelihoods, severe weather has resulted in large economic costs. The number of natural disasters has increased steadily over the past thirty years[10] with natural disasters in 2011 resulting in the most costly toll in history —$154 billion worth of worldwide losses from floods, tornadoes, hurricanes, wildfires, and other extreme weather events.[11] In the United States alone, 2011 extreme weather events caused almost $60 billion in damages.[12] This total does not include expenses associated with sickness or injuries triggered by the disasters. Given the number and severity of extreme events that have thus far occurred this year, weather-related costs in 2012 could equal or exceed those in 2011. According to Aon Benfield, a global reinsurance company, insured losses associated with natural

disasters have totaled at least $22 billion through August 2012[13] without considering all of the summer's wildfires and the drought which is expected to add billions of dollars more to the total.

Following the record breaking extreme weather of 2011, from the killer tornadoes in Joplin, Missouri to the devastation Hurricane Irene brought to Vermont, many Americans are connecting these events with human-induced global warming. After all, nine of the top ten warmest years globally have occurred since 2000. This August was the 36th consecutive August and 330th consecutive month with a global temperature above the 20th century average.[14] In other words, there has not been a month cooler than the 20th century global average since February 1985.

Scientists have been investigating the link between extreme weather events and man-made global warming for years. They now generally agree that global warming pollution plays a role, along with natural factors such as El Niño or La Niña, in shifting the odds toward extreme events.[15] In fact, NOAA recently concluded, after looking through 50 years of weather data, that droughts like the record 2011 Texas drought was made "roughly 20 times more likely" because of global warming.[16] Indeed, observations have shown that certain extremes—high heat, heavy precipitation and floods, duration and intensity of droughts and extremes related to higher sea levels—have increased over the last half of the century.[17]

Global warming has stacked the deck with extra jokers, making some weather events more frequent and severe and increasing the chances of an event far outside the norm.

Definition of Extreme Events

Extreme weather includes weather phenomena that are at the extremes of the historical distribution of weather events.[18] The most commonly used definition of extreme weather is an event that is expected only 5% of the time, or one time out of twenty.

Global warming has increased average temperatures 1.3°F in the continental United States over the past 100 years.[19] Yet that seemingly small shift increases the likelihood of extreme weather as shown in Figure 1. The two curves illustrate how a modest increase in average temperatures can have a much greater impact at the "extremes" of the curve. In this way, a relatively small shift in the average temperature produces more extreme events like severe heat waves. Scientists at the National Center for Atmospheric Research (NCAR) have predicted that continued increases in global warming pollution in a business-as-usual scenario could lead to record daily high temperatures in the United States outpacing record daily lows by a ratio of 20-to-1 by midcentury.[20]

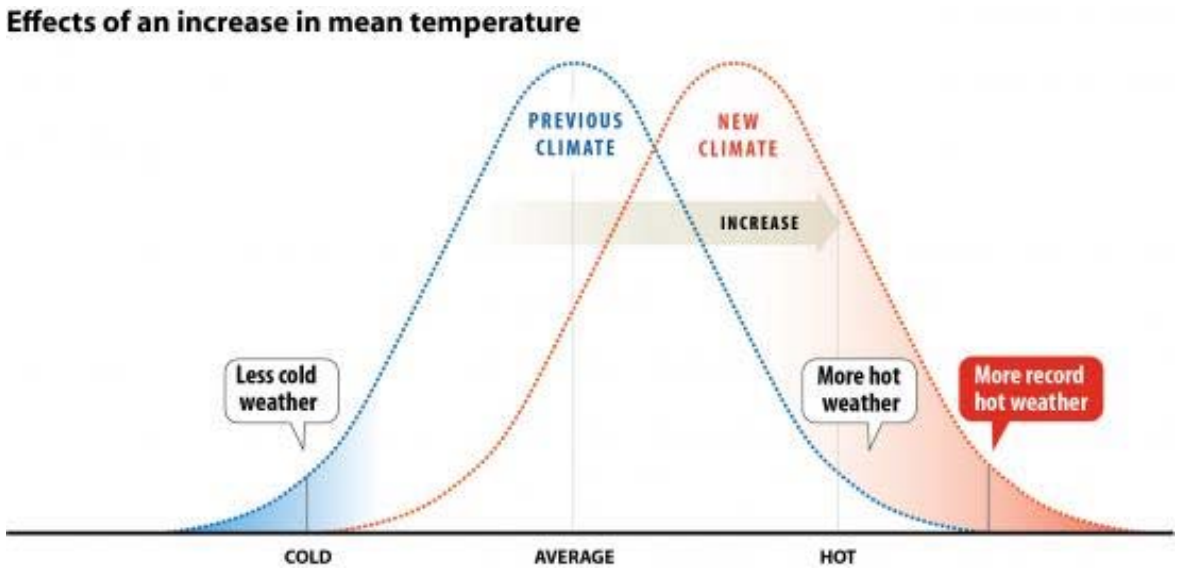

Figure 1: The effect of changes in temperature distribution on extremes. In this example, an increase in average temperature shifts the entire distribution towards more hot weather, increasing the chance of record heat events. Source: IPCC, Summary for Policymakers. In: Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation

U.S. 2012 Record- Breaking Weather and Extreme Events

The multitude of extreme weather events in the United States during 2012 are consistent with scientists' understanding that global warming is increasing the odds of heat waves, heavy precipitation, droughts and wildfires. The following is a discussion of records broken and extreme weather events this year:

Extreme temperatures:

- July was the hottest month ever recorded in the continental United States. The average temperature for the lower 48 states during July was 77.6°F, which is 3.3°F above the 20th-century average.[21] Some areas were up to 8° F warmer than average (Figure 2). The previous warmest July for the nation was July 1936 when the average U.S. temperature was 77.4°F.[22]

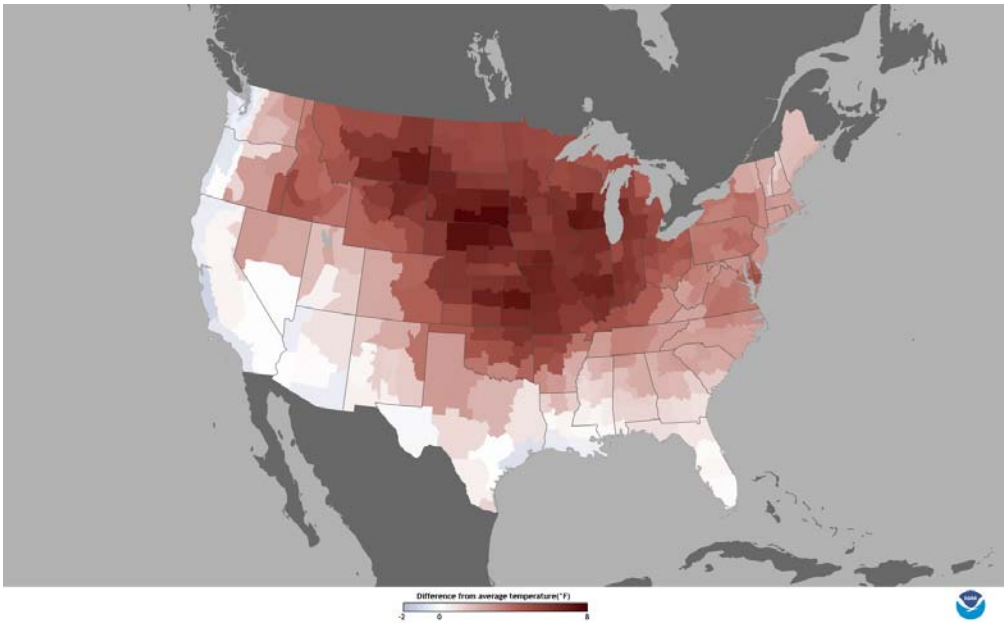

Figure 2: The map above shows average monthly temperature anomaly for the continental United States in July 2012 as compared to the 1981–2010 average. Shades of red indicate temperatures up to 8° F warmer than average and shades of blue indicate temperatures up to 2° F cooler than average—the darker the color, the larger the temperature difference. Source: NOAA/NCDC

- Spring 2012 in the continental United States significantly surpassed any historical records for the hottest spring and most extreme season of any kind, according to NOAA's National Climatic Data Center (NCDC).[23] With the warmest March, third warmest April, and second warmest May, the spring season was approximately 5.2°F above average—the largest temperature departure from the average of any season on record for the lower 48 states. In fact, spring 2012 temperatures were a full 1°F above the previous most extreme season, the winter of 1999/2000. According to meteorologist Dr. Jeff Masters, all-time seasonal temperature records are usually broken by only a tenth of a degree[24] making the spring 2012 record heat truly a historic event. (Figure 3)

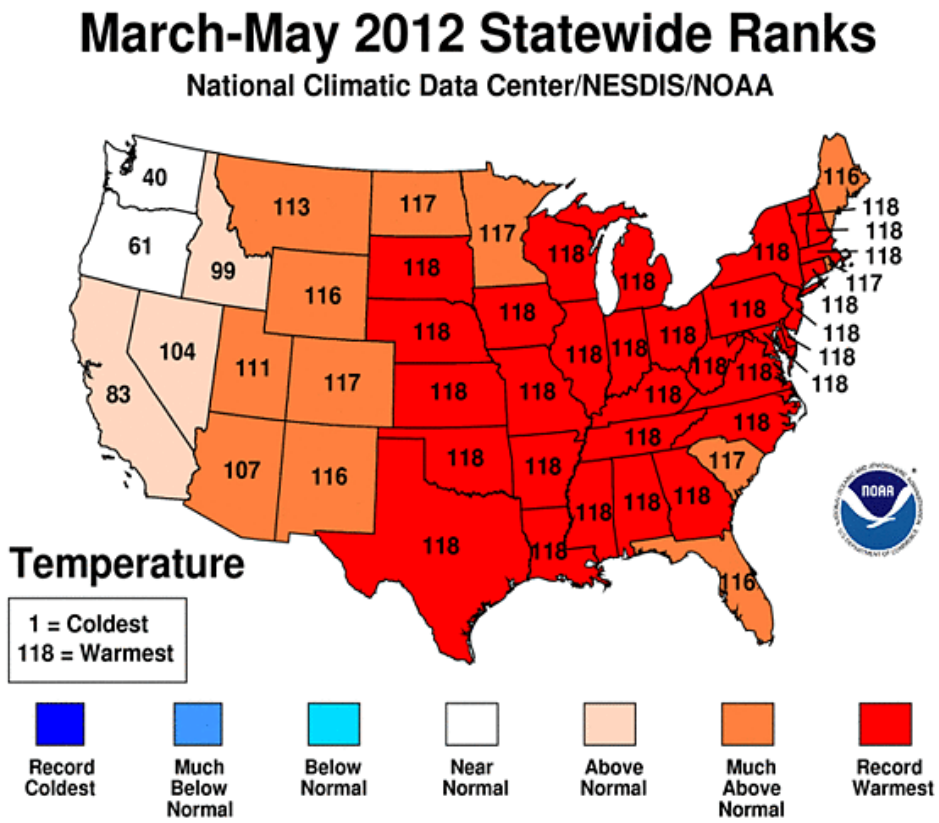

Figure 3: Temperature rankings for spring 2012 in the contiguous United States. Thirty-one states were record warm for the 3-month period and an additional eleven states had top-ten warmth. Spring 2012 beat the previous record for hottest spring on record, set in 1910, by 2°F. Source: NOAA/NCDC

- January through August 2012 was the warmest first eight months period for the lower 48 states, breaking the previous record set in 2006 by 1°F.[25]
- For the continental United States, the August 2011-July 2012 period was the warmest 12-month period since recordkeeping began in 1895. This broke the record set in June 2012 which in turn broke the record set in May 2012 which in turn broke the record set in April 2012. (Figure 4). The past fifteen months have featured the United State's 2nd warmest summer, 4th warmest winter, and warmest spring on record.[26] The 12-month period ending in August 2012 was the 4th warmest on record.[27]

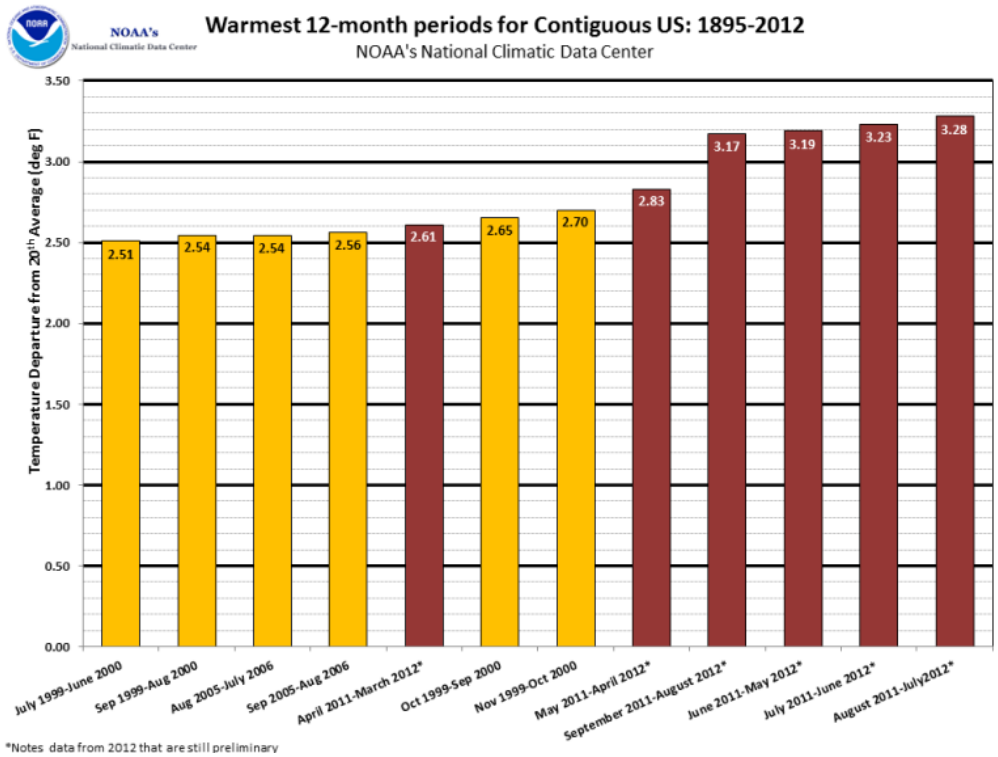

Figure 4: The top five warmest 12- month periods in the lower 48 have occurred since May 2011. Source: NOAA/NCDC

- Temperature observations show that through late June 2012, daily record highs were outnumbering record daily lows by a ratio of 9-to-1.[28] (Figure 5) This skewed ratio suggests the influence of global warming because one would expect record highs to be broken about as often as record lows if random variations were solely dictating temperature records.

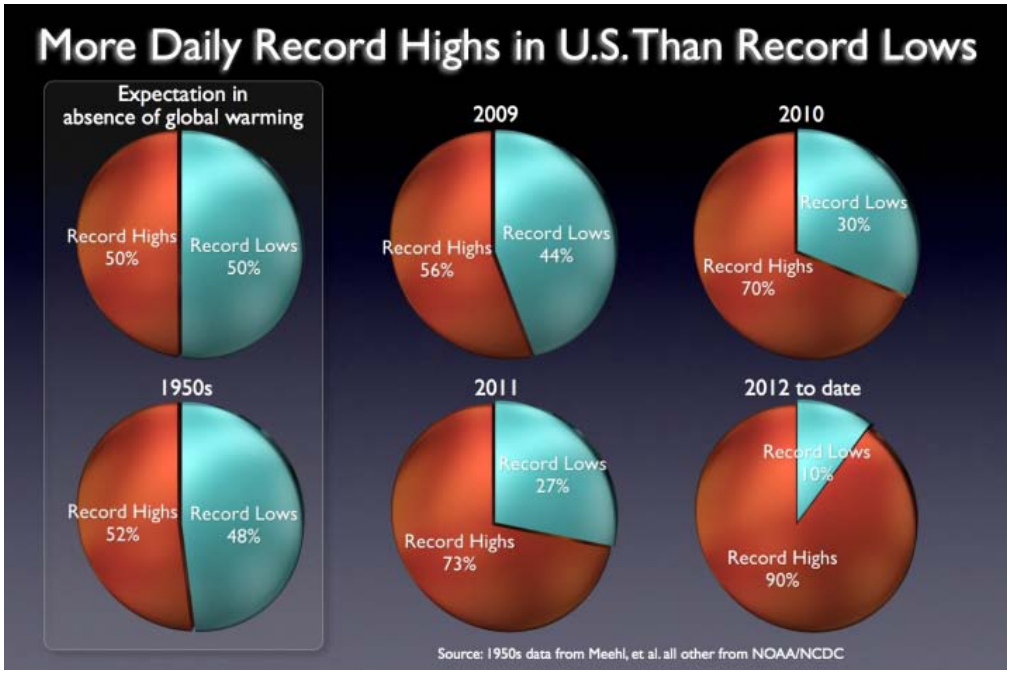

Figure 5: The shifting odds in favor of more daily record high temperatures being set compared to daily record low temperatures. Source: Climate Central (Updated through late June 2012)

Drought:

- As of early September, 64% of the continental United States was experiencing drought (Figure 6), slightly surpassing the levels experienced in July.[29] The extent of drought in July, August and September 2012 is on par with the worst months of the multi-year droughts of the 1930s Dust Bowl and the mid-1950s.[30] September, July and August 2012 have the second, third and fourth greatest monthly percentage area of the continental United States in moderate or greater drought. Only July 1934—when 80% of the lower 48 states were experiencing drought—had a higher percentage of the United States impacted in a single month. By the beginning of August, over half the counties in the United States had been designated disaster zones because of the drought.[31]
- The combination of heat and dryness has severely reduced the quality and quantity of the corn and soybean crop, with 51% of the corn and 38% of the soybeans rated as poor or very poor as of August by the U.S. Department of Agriculture.[32] Some states, such as Missouri (84%), Kentucky (79%), Illinois (73%), Kansas (73%), and Indiana (70%) had much more of their corn adversely rated.[33]

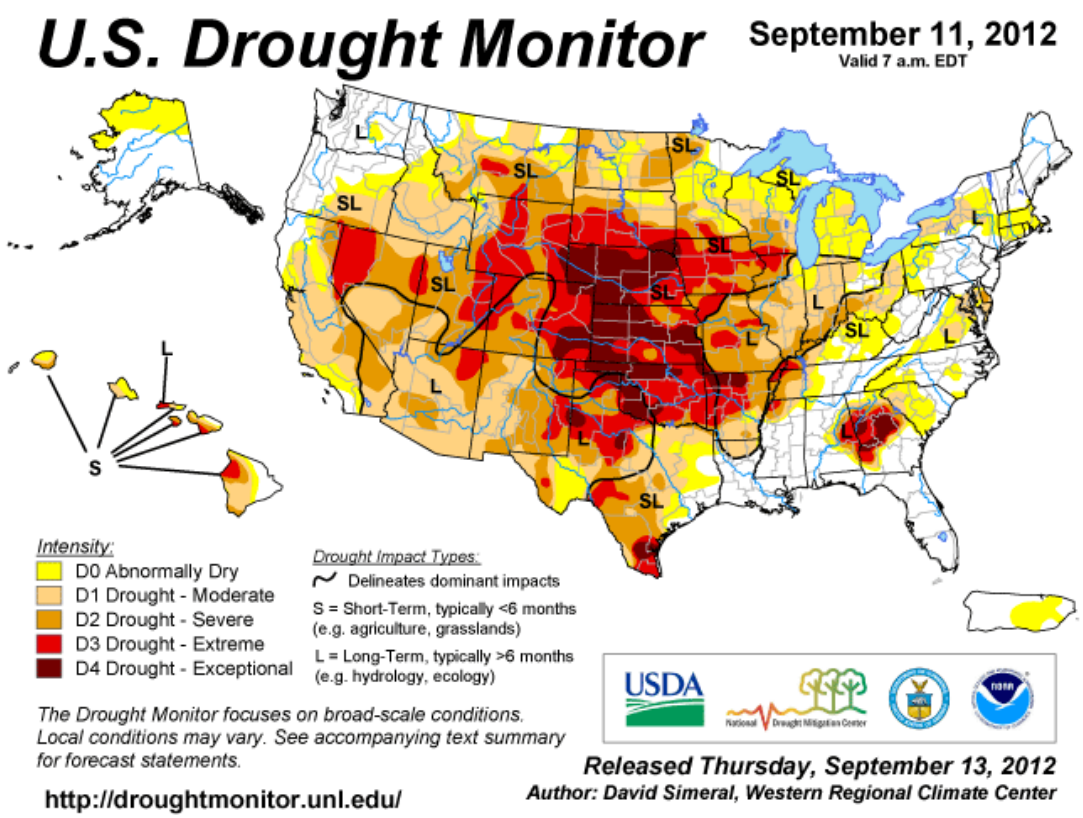

Figure 6: - Dryness and drought, exacerbated by above-normal temperatures, has covered much of the central and northern United States. Source: NOAA/NCDC

Wildfires:

- This fire season over 8.6 million[34] acres have burned in the United States, an area about the size of New Jersey and Connecticut combined. This is well above the 10-year average of 6.5 million acres burned. With fires still burning in parts of the West, this year may equal or surpass the almost 8.8 million acres burnt in 2006, the worst fire year in the last decade.[35]
- In particular, Colorado suffered the worst fires in the state's history in July. Overall, the wildfires in Colorado destroyed 600 homes, killed 6 people, and caused approximately $500 million in property damage.[36] The Waldo Canyon fire in Colorado Springs was the most destructive fire in Colorado's history while the High Park fire was the state's largest fire.[37] In New Mexico, the Whitewater Baldy fire burned more than 297,000 acres and caused $22.6 million in damages.[38] It became the largest fire in state history, breaking the record set last year by the Las Conchas fire near Los Alamos. In July, the Long Draw Fire in Oregon burned half a million acres and was the largest fire in the state since the 1840s.[39]

- Wildfires in the United States are already increasing due to warming. In the West, there has been a nearly four-fold increase in large wildfires in recent decades, with greater fire frequency, longer fire durations, and longer wildfire seasons.[40] This increase is strongly associated with increased spring and summer temperatures and earlier spring snowmelt, which have caused drying of soils and vegetation.[41]

> *"Throughout the country, we're seeing longer fire seasons, and we're seeing snowpacks that, on average, are disappearing a little earlier every spring …Our scientists believe this is due to a change in climate."* Tom Tidwell, Chief of the U.S. Forest Service

Storms:

- The powerful "derecho" storm system in early July left a trail of death, destruction and downed power lines from Illinois to Virginia, killing at least 23 people, leaving over 3.7 million people without power during extreme heat, and causing hundreds of millions of dollars in damages.[42]
- In late June, Tropical Storm Debby slowly traversed Florida, dropping over a foot of rain, causing the state to have its wettest June on record.[43] At least 7 people died, and over 7,500 homes and businesses across the state were either flooded or had significant infrastructure damage.[44]
- At the end of August, Hurricane Isaac became the first hurricane to make landfall along the Gulf Coast since 2008. The Category 1 storm caused multiple days of torrential rainfall and a storm surge up to 15 feet in places. Louisiana was the hardest hit, but Mississippi, Alabama and Florida all suffered impacts. The storm caused at least seven deaths and total economic losses are expected to be in the billions of dollars.[45] Rainfall from Hurricane Isaac contributed to Louisiana and Mississippi experiencing their second wettest August on record and to Florida experiencing its wettest summer ever.[46]

Extreme Water Levels and Temperatures:

- Drought in the Mississippi watershed has caused near-record low river levels in places, reducing vital barge transportation and harming aquatic life.[47] Water levels barely reach 5 feet in some parts of the river, making it difficult for some barges to reach their destinations.[48] Some barge companies have reduced their loads by 25% due to the low water levels, making it far more expensive to ship products along the river.[49] Near Memphis, the river level was more than 12 feet lower than normal for this time of the year.[50] The low water levels have forced five harbor closures in Tennessee, Missouri, Arkansas and Mississippi, and the low water levels are expected to continue into October.[51,52] Some stretches are close to record-low water levels experienced in 1988, when river traffic was suspended in several spots and the barge industry suffered losses of about $1 billion.[53]

- Heat and low water are also causing tens of thousands of fish to die in Midwestern rivers and lakes. So many fish died in one Illinois lake that the carcasses clogged an intake screen near a power plant, lowering water levels to the point that the station had to shut down one of its generators.[54]
- In July, water temperatures in the Great Lakes reached temperatures typically seen in late August or early September with three buoys recording temperatures of 60 and 65°F, more than 10-degrees warmer than the same time last year.[55] In fact, Lake Superior which is the northernmost, coldest, and deepest of the five Great Lakes, was the warmest it has been in July in at least a century.[56]

Figure 7: Lake Superior at the end of the winter of 2008 – 2009 (top), compared to the end of the winter of 2011 – 2012 (bottom) Source: NASA/weatherunderground.com

- Satellite photos show that only about 5% of the Great Lakes surface froze this winter, compared to the average 40% that is covered by ice in a typical winter.[57] (Figure 7) Ice cover on the Great Lakes has declined 71% since 1973.[58] Lake Ontario has experienced the greatest ice loss between 1973 and 2010 with an 88% decline in ice cover. Lake Superior lost 79% of its ice; Lake Michigan lost 77%; Lake Huron lost 62%; and Lake

Erie lost 50%. The declines in ice cover follow increases in temperatures. Winter air temperatures over the lower Great Lake increased by about 2.7°F (1.5°C) from 1973 – 2010, and by 4 – 5°F (2.3 – 2.7°C) over the northern Lakes, including Lake Superior.

- During the first six months of 2012, sea surface temperatures in the northeastern Atlantic were the highest ever, breaking a record that goes back to 1854. The average sea surface temperature exceeded 51°F during the first half of 2012, breaking the previous record high in 1951. Above-average temperatures were found from the ocean bottom to the sea surface and across the region, extending even beyond the continental shelf to the Gulf Stream. In some nearshore locations like the Delaware and Chesapeake Bays, temperatures were more than 11°F above the historical average at the surface and more than 9°F above average at the bottom. In deeper offshore waters to the north, bottom waters were 2°F warmer in the eastern Gulf of Maine and greater than 3.6°F warmer in the western Gulf of Maine.[59]

2012 U.S. Weather Disasters Costs

Although the total costs of 2012 extreme events are not yet known, they are expected to be significant and may rival the record-breaking $55 billion from 2011. According to Aon Benfield, a global reinsurance company, insured losses associated with natural disasters have preliminarily totaled over $22 billion through August 2012 with more than 220 deaths.[60] These losses do not include all of the summer's wildfires and the drought, which are expected to add billions of dollars more to the total.

As the drought of 2012 continues, farmers and ranchers are feeling the heat while the drought's impacts begin to ripple through the economy as crop prices rise. An agricultural economist at Wells Fargo, the largest commercial agriculture lender in the country, has suggested that the drought could cost the economy $50 billion over the next year.[61] The drought is also exacerbating the damage from wildfires in the Southwest, West, and Southeast. For example, the Waldo Canyon Fire in the Colorado Springs vicinity became the most damaging blaze in Colorado state history, destroying 347 homes that had with a combined housing market value of $110 million and damaging an additional 50.[62]

Extreme weather, specifically extreme heat and flooding, is also taxing the nation's aging infrastructure. Record heat events are changing the pattern of electricity use, raising peak demand higher than ever while violent storms and forest fires affect water quality and water use. Concrete and steel that support much of the U.S. transportation infrastructure has been stressed to the point of failure and in many cases requiring expenses repairs.[63] Low water levels and warm water temperatures are also impacting the production of electricity from hydroelectric dams and coal and nuclear power plants that use river or coastal water to cool critical equipment.[64]

U.S. Weather Disasters in 2011

The 2012 extreme weather events follow the record-breaking events of 2011. Last year the United States experienced 14 weather and climate disasters that each caused at least $1 billion or more in damages—breaking the previous record of 9 such disasters set in 2008. The 14 disasters caused almost $60 billion in damages and were responsible for 646 fatalities in total.[65] As shown in Figure 8, the damages sustained in 2011 were far more than any other year since 1980.[66]

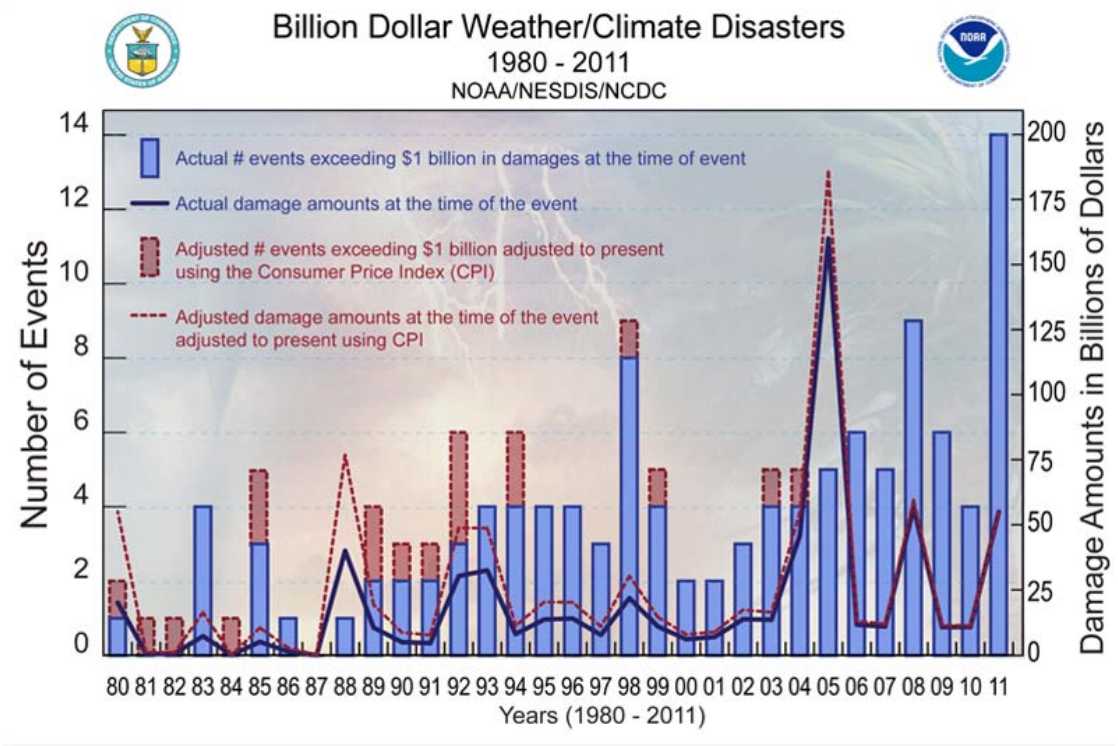

Figure 8: Historical number and damage estimates of U.S. weather and climate disasters from 1980 – 2011. Source: NOAA

The complete 2011 list of $1 billion disasters include:

- Groundhog Day blizzard - $1.8 billion, 36 deaths *(January 29-February 3, 2011)*
- Midwest/Southeast tornadoes – $2.8 billion, 9 deaths *(April 4-5, 2011)*
- Southeast/Midwest tornadoes – $2.2 billion *(April 8-11, 2011)*
- Midwest/Southeast tornadoes – $2.1 billion, 38 deaths *(April 14-16, 2011)*
- Southeast/Ohio Valley/Midwest tornadoes – $16.2 billion, 321 deaths *(April 25-28, 2011)*
- Midwest/Southeast tornadoes – $9.1 billion, 177 deaths *(May 22-27, 2011)*
- Midwest/Southeast tornadoes and severe weather – $1.3 billion, 3 deaths *(June 18-22, 2011)*
- Southern Plains/Southwest drought and heatwave – $10 billion *(Spring-Fall, 2011)*
- Mississippi River flooding – $3-4 billion *(Spring-Summer, 2011)*
- Rockies and Midwest severe weather – $1 billion, 2 deaths *(July 10-14, 2011)*

- Upper Midwest flooding – $1 billion, 5 deaths *(Summer 2011)*
- Hurricane Irene – $7.3 billion, 45 deaths *(August 20-29, 2011)*
- Texas, New Mexico, Arizona wildfires – $1 billion, 5 deaths *(Spring-Fall 2011)*
- Tropical Storm Lee – $1 billion, 5 deaths *(Early September, 2011)*

Global Extreme Events

Worldwide weather has also been extreme over the last several years. This August was the fourth warmest August globally — marking the 330th consecutive month that global average temperatures were above the 20th century average.[67] Additionally, 2011 witnessed severe drought in the Horn of Africa, Australia's third wettest year in its 112-year period of recordkeeping, massive floods in Thailand and Pakistan, and record or near-record warmth in parts of Western Europe during the spring, including temperatures in Germany almost 7.9°F (4.4°C) above average.[68] (Figure 9)

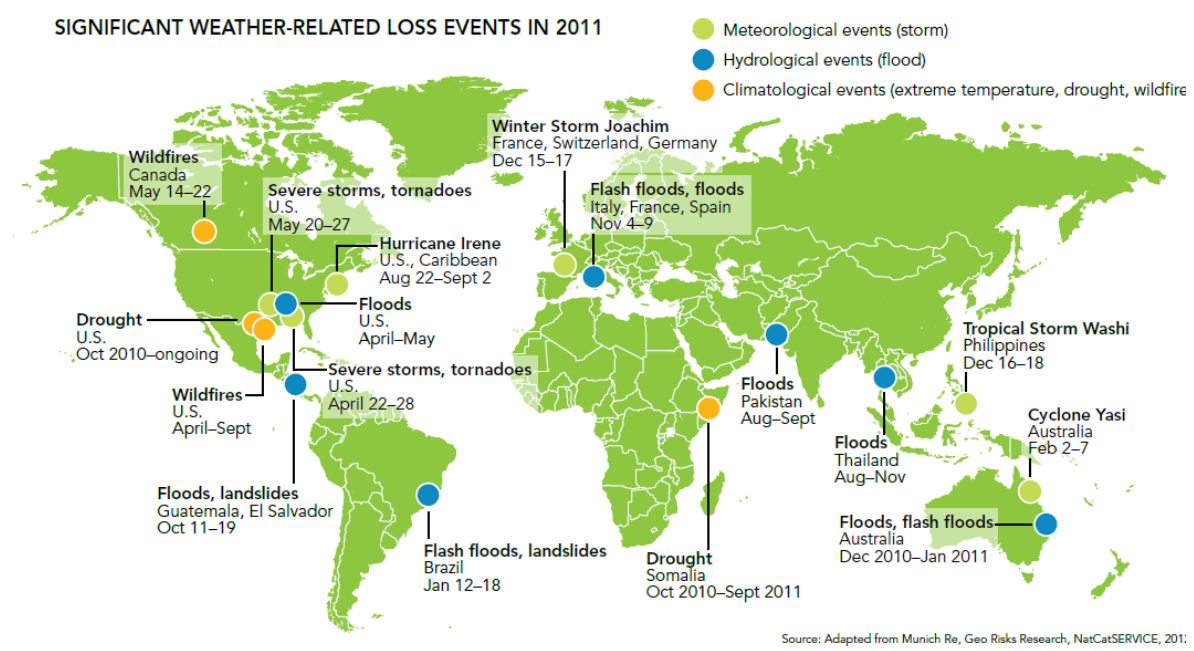

Figure 9: 2011 Worldwide significant weather-related losses as compiled by Munich Re, a global reinsurance company. Source: Munich Re

Globally, 2012 weather has also been anomalous. More than 17 million people are facing possible starvation, in part due to drought caused by poor rainfall in 2011 in West Africa's Sahel region, the zone skirting the southern portion of the Sahara Desert.[69] In addition, the six-year severe drought in the Horn of Africa continues to persist, with more than 9 million people facing starvation.[70] In other areas, China experienced extreme flooding in nearly 20 provinces in June that caused numerous fatalities, damaged or destroyed 175,000 homes and caused at least $3

billion in economic losses.[71] Russia and Indonesia also experienced extensive flooding in July that caused many deaths and property damage.

The Arctic, one of the areas of the world hit hardest by global warming, experienced its 5th smallest winter sea ice extent in February. On August 26th, the summer sea ice extent fell below the previous smallest extent (1.67 million square miles) set in mid-September 2007. On September 16th, the sea ice coverage shrank to a new record low of 1.32 million square miles, 18% below the previous record set in 2007 and a 49% reduction in the area of the Arctic covered by sea ice as compared to conditions in the 1980s and 1990s.[72] (Figure 10)

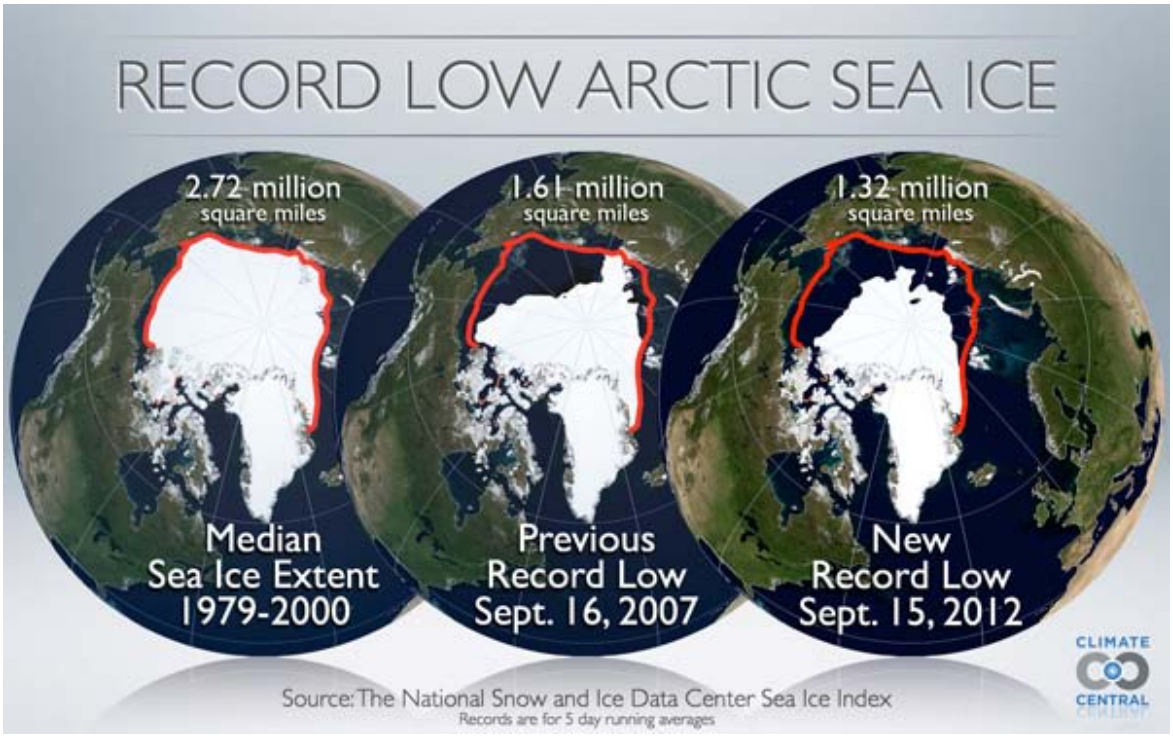

Figure 10: Comparison of 2012 Arctic Sea ice extent with the 2007extent and the median extent from 1979 to 2000. Source: NSIDC Sea Ice Index and Climate Central

In addition, sea surface temperatures are significantly higher than average along the western coast of Greenland, which likely contributed to the loss of a massive chunk of ice twice the size of Manhattan from the Petermann Glacier in mid-July.[73]

Climate Predictions

For years, scientists have warned that global warming will increase the risk of extreme weather. The UN Intergovernmental Panel on Climate Change (IPCC) has warned that continued emissions of heat-trapping pollution at or above current rates will cause further warming, droughts, floods, storms, as well as increased the probability of other extreme events. The unprecedented extreme weather events in the United States during 2011 and 2012 are consistent

with these scientific predictions. There have been several notable scientific reports in recent years that have begun to highlight the link between extreme weather and global warming, including:

1. A report published by scientists at NOAA and other institutions determined that climate change has made some extreme weather events – like the 2011 Texas drought – 20 times more likely to occur now than 50 years ago. [74]
2. Recent assessment reports by the U.S. National Academy of Sciences[75] and the U.S. Global Change Research Program[76] concluded that man-made climate change is likely responsible for the rise in several types of extreme weather events and that these trends are expected to continue.
3. A study published this summer based on observational datasets concluded that the droughts experienced by Texas and Oklahoma in 2011 were a consequence of climate change. [77] The opening lines of the paper encapsulate what the build-up of global warming pollution in the atmosphere is doing to our climate system: "'Climate dice,' describing the chance of unusually warm or cool seasons, have become more and more 'loaded' in the past 30 years, coincident with rapid global warming."

Extreme Heat

Scientists predict that global warming will bring more record-breaking heat (Figure 11). Hotter temperatures will likely affect food and agriculture production, human health, and tourism.[78]

As average temperatures continue to rise, the number of days with a heat index (i.e. how temperature "feels") above 100°F is projected to increase. The United States, especially in the Midwest, is also expected to experience an increase of 60 to 90 days per year in which the heat index is more than 100°F by the end of the century.[79] Heat waves also are expected to last longer. In addition, the ratio of record high temperatures to record low temperatures is projected to increase to 20-to-1 by midcentury and 50-to-1 by the end of the century.[80]

Precipitation Changes

Beyond higher temperatures, scientists predict global warming will significantly alter regional rainfall patterns with dry areas getting even drier and wet areas wetter (Figure 12). This is partly due to the fact that warmer temperatures tend to increase evaporation from oceans, lakes, plants, and soil, which will boost the amount of water vapor in the atmosphere by about 7% per 1°C (1.8°F) of warming.[81] Although enhanced evaporation provides more atmospheric moisture for rain and snow in some downwind areas, it also dries out the land surface, which exacerbates the impacts of drought in some regions like the southwestern United States.[82]

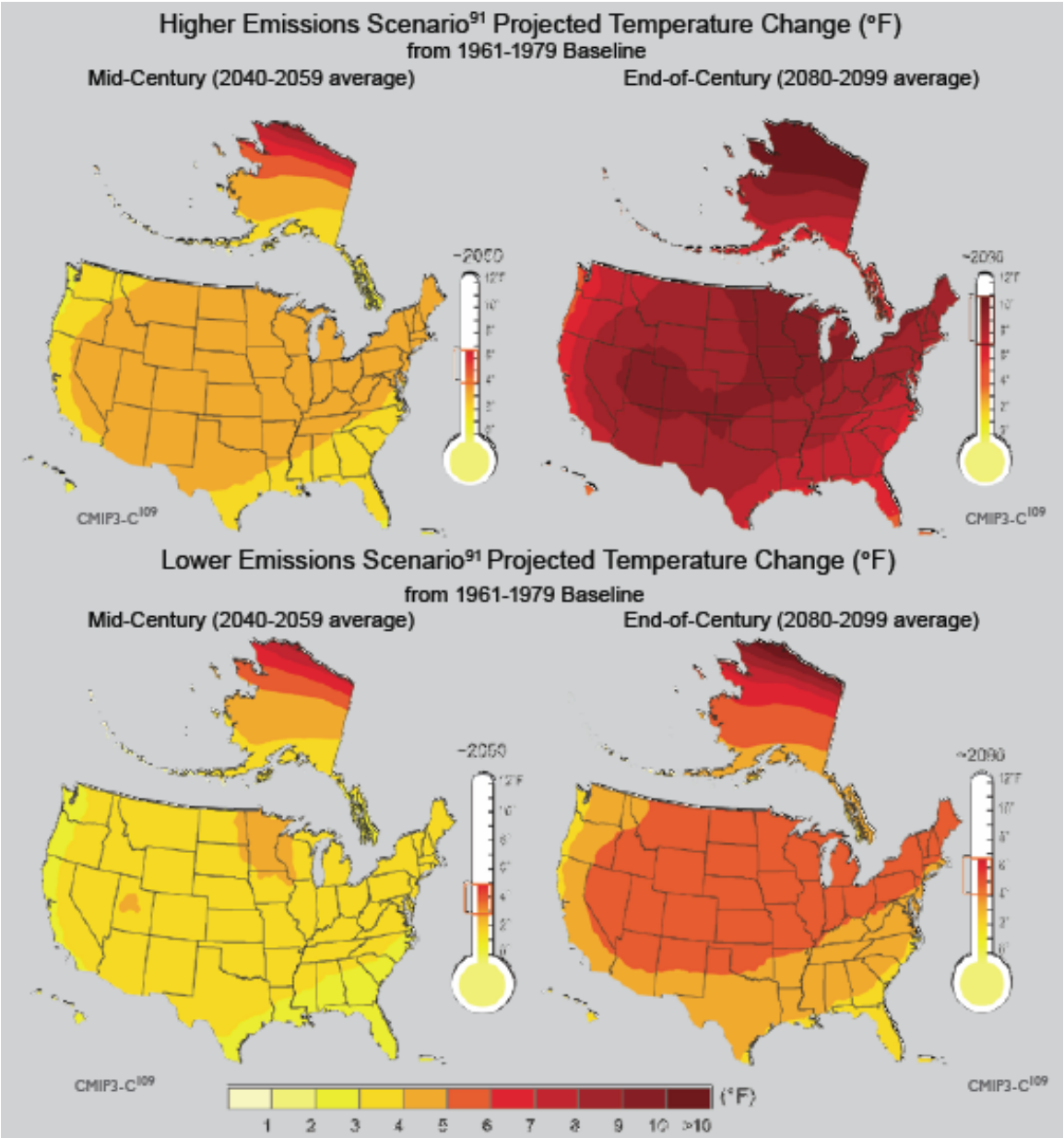

Figure 11: The maps on this page are based on projections of future temperature by 16 of the Coupled Model Intercomparison Project Three (CMIP3) climate models using two emissions scenarios from the Intergovernmental Panel on Climate Change (IPCC), Special Report on Emission Scenarios (SRES). The brackets on the thermometers represent the likely range of model projections, though lower or higher outcomes are possible. The difference between the two scenarios demonstrates that the higher the heat-trapping emissions the higher temperatures will rise. Source: USGCRP, Global Climate Change Impacts in the United States, 2009

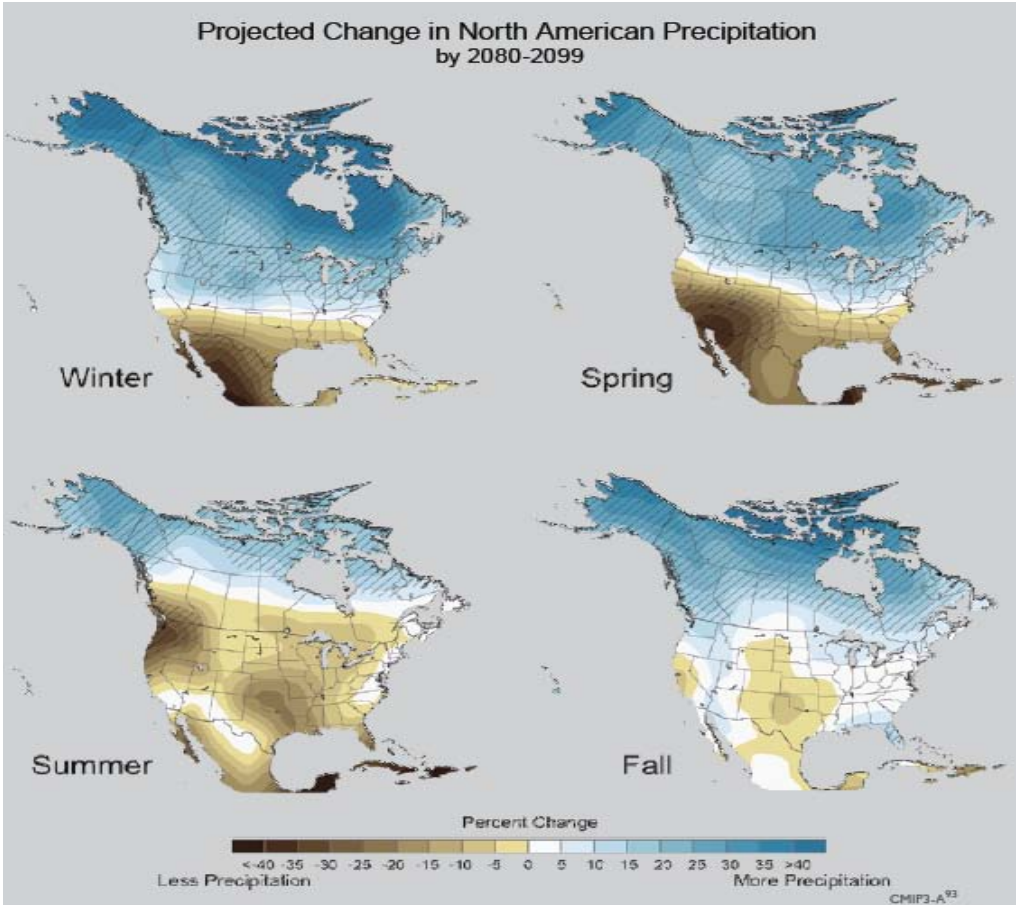

Figure 12: The maps show projected future changes in precipitation relative to the recent past as simulated by 15 climate models. The simulations are for late this century, under a higher emissions scenario. For example, in the spring, climate models agree that northern areas are likely to get wetter and southern areas drier. There is less confidence in exactly where the transition between wetter and drier areas will occur. Confidence in the projected changes is highest in the hatched areas. Source: USGCRP, Global Climate Change Impacts in the United States, 2009

Wildfires

In the next 100 years, global warming is projected to lead to larger, longer lasting, and more damaging wildfires (Figure 13). In fact, large wildfires already have increased worldwide over the past 40 years, particularly in the western United States.[83] Global warming pollution directly increases the risk of fire through rising temperatures, increased evaporation and drought. The average area burned by wildfire per year in parts of the western United States is expected to increase annually by two to four times per degree of warming.[84]

The IPCC concluded that disturbances from fires are projected to have increasing impacts on forests, with longer fire seasons and large increases in burned area due to climate change. This is because a warming climate causes more favorable fire conditions via a longer summer period

that dries fuels, which promotes easier ignition and faster spread of fires. Researchers have found that in the last three decades the wildfire season in the western United States has increased by 78 days and burn durations of fires greater than 2,400 acres have increased from 7.5 to 37.1 days.[85] Furthermore, between 1970 and 2003, spring and summer moisture availability declined in many forest in the West; most major wildfires occurred in these same drought stricken areas.[86] Finally, snowpacks are now melting 2 to 4 weeks earlier throughout much of the West,[87] which extends the summer dry period and puts more forest area at risk of fire.

The climate models evaluated by the IPCC indicate that precipitation is projected to decrease further in the southwestern United States while the frequency and intensity of drought will increase. Drought leads to increased flammability of live and dead fuels and increased susceptibility to a number of insects (in particular the bark beetle). Insect epidemics kill trees across large regions, providing additional dead and desiccated fuels for future fires. Warm conditions have also led some beetle species to have additional mating cycles, leading to prolific increases in destructive populations. It is important to recognize that the ecosystems that emerge after fires will be altered and likely more arid. Thus, dry climates will get drier in the future, a pattern that is already emerging in current data.[88]

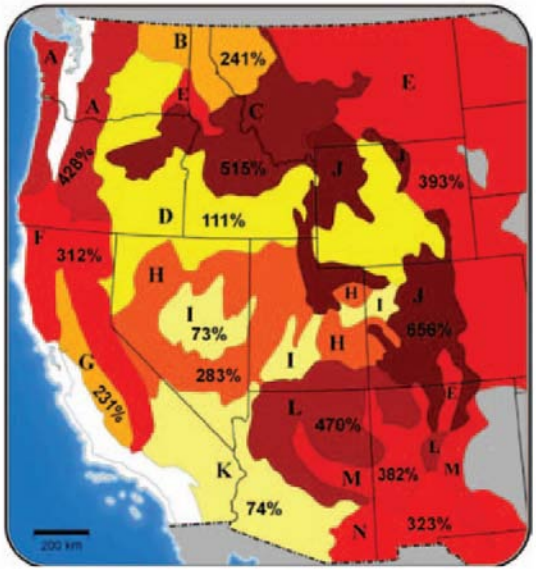

Figure 13: Rising temperatures and increased evaporation are expected to increase the risk of fire in many regions of the West. This figure shows the percent increase in burned areas in the West for a 1.8°F increase in global average temperatures relative to the median area burned during 1950-2003. For example, fire damage in the northern Rocky Mountain forests, marked by region B, is expected to more than double annually for each 1.8°F increase in global average temperatures. Source: National Research Council, 2011a

Agriculture

Scientists warn that global warming may threaten global food security as the changing climate could fundamentally affect humanity's collective ability to feed itself. Although an increase in the amount of carbon dioxide in the atmosphere may initially promote plant growth, it does not necessarily translate into more food. Crops tend to grow more quickly in higher temperatures, leading to shorter growing periods and less time to produce grains. However, a changing climate will bring other, more significant hazards for agriculture, including greater water stress and the risk of higher temperature extremes that can quickly damage crops.[89] Agricultural impacts will vary across regions and by crop. Moderate warming and changes in precipitation are expected to decrease yield in seasonally dry and low-latitude areas. In California, where half the nation's fruit and vegetable crops are grown, climate change is projected to decrease yields of almonds, walnuts, avocados, and table grapes by up to 40% by 2050.[90]

Scientists have determined that any benefits increased carbon dioxide for some crops will be largely outweighed by negative factors if global temperature rises more than 1.8°F (1.0°C) from late 20th century values. It is expected that for each degree of warming, yields of corn in the United States and Africa, and wheat in India, will drop by 5-15%. In addition, if temperatures rise 9°F (5°C), most regions of the world would experience yield losses and global grain prices would potentially double.[91]

Conclusions

The links between climate change and extreme weather are abundant, robust and well-documented in peer-reviewed scientific studies. The authoritative science organizations active in the relevant disciplines, including NASA, NOAA and the U.S. National Academy of Sciences, have consistently confirmed the connections between climate change and extreme weather.

Many types of extreme weather, like heavy downpours and heat waves, have increased in severity and frequency across the globe in recent years. This increase is directly linked to the changes in the Earth's climate system driven by heat-trapping gases from burning fossil fuels.

All weather events are now impacted by climate change to some degree because the underlying conditions that give rise to weather have been changed. Climate change has contributed to shattered records and unprecedented weather catastrophes, like those the United States has experienced this summer. It's as if global warming has stacked the deck with extra jokers, making some weather events more frequent and severe and increasing the chances of an event far outside the norm.

Endnotes

[1] NOAA, State of the Climate, National Overview (July 2012) http://www.ncdc.noaa.gov/sotc/national/2012/7
[2] Aon Benfield, July 2012 Global Catastrophe Recap http://thoughtleadership.aonbenfield.com/Documents/201207_if_monthly_cat_recap_july.pdf
[3] NOAA, State of the Climate, National Overview (August 2012) http://www.ncdc.noaa.gov/sotc/national/2012/8/
[4] U.S. Drought Monitor, Tabular Statistics Archive for the contiguous United States (September 11, 2012) http://droughtmonitor.unl.edu/dmtabs_archive.htm
[5] NOAA, State of the Climate, National Overview (July 2012) http://www.ncdc.noaa.gov/sotc/national/2012/7
[6] National Interagency Fire Center, Year-to-date statistics (September 19, 2012) http://www.nifc.gov/fireInfo/nfn.htm
[7] National Interagency Fire Center, Year-to-date statistics (September 19, 2012) http://www.nifc.gov/fireInfo/nfn.htm
[8] NOAA, Ecosystem Advisory for the Northeast Shelf Large Marine Ecosystem, (September 18, 2012) http://www.nefsc.noaa.gov/press_release/2012/SciSpot/SS1209/
[9] National Snow and Ice Data Center, "Arctic sea ice extent settles at record seasonal minimum" (September 19, 2012) http://nsidc.org/arcticseaicenews/2012/09/arctic-sea-ice-extent-settles-at-record-seasonal-minimum/
[10] Schuster, Sandra. "Managing the Unavoidable: Natural Catastrophes – data, trends, and analysis," Presented at Greenhouse 2011 Conference, Cairns, Australia (April 2011)
[11]Janet Raloff, ScienceNews, "Insurance payouts point to climate change" (January 4, 2012) http://www.sciencenews.org/view/generic/id/337368/title/Science_%2B_the_Public__Insurance_payouts_point_to_climate_change
[12] NOAA, Extreme Weather 2011 (January 19, 2012) http://www.noaa.gov/extreme2011/
[13] Aon Benfield, August 2012 Global Catastrophe Recap http://thoughtleadership.aonbenfield.com/Documents/201209_if_monthly_cat_recap_august.pdf
[14] NOAA, State of the Climate, Global Analysis (August 2012) http://www.ncdc.noaa.gov/sotc/global/2012/8
[15] Current Extreme Weather & Climate Change, Climate Communication Press Conference (September 2011) with K. Trenberth (National Center for Atmospheric Research (NCAR)), J. Meehl (NCAR), J. Masters (Weatherunderground), R. Somerville (Scripps).
[16] Blunden, J., and D. S. Arndt, Eds., 2012: State of the Climate in 2011. *Bull. Amer. Meteor. Soc*., 93 (7), S1–S264.
[17] IPCC, 2012: Summary for Policymakers. In: Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation [Field, C.B., V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L. Ebi, M.D. Mastrandrea,, K.J. Mach, G.-K. Plattner, S.K. Allen, M. Tignor, and P.M. Midgley (eds.)]. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK, and New York, NY, USA, pp. 1-19. http://www.ipcc-wg2.gov/SREX/images/uploads/SREX-SPMbrochure_FINAL.pdf
[18] IPCC, 2001: Working Group 1: The Scientific Basis, Section 2.7 "Has Climate Variability, or have Climate Extremes, Changed?" http://www.grida.no/publications/other/ipcc_tar/?src=/climate/ipcc_tar/wg1/088.htm
[19] C. Tebaldi, D. Adams-Smith and N. Heller, "The Heat is On: U.S. Temperature Trends" (June 2012) http://www.climatecentral.org/wgts/heat-is-on/HeatIsOnReport.pdf
[20] UCAR, "Record high temperatures far outpace record lows across U.S." (November 12, 2009) https://www2.ucar.edu/atmosnews/news/1036/record-high-temperatures-far-outpace-record-lows-across-us
[21] NOAA, State of the Climate, National Overview (July 2012) http://www.ncdc.noaa.gov/sotc/national/2012/7
[22] NOAA, State of the Climate, National Overview (July 2012) http://www.ncdc.noaa.gov/sotc/national/2012/7
[23] NOAA, State of the Climate, National Overview (May 2012) http://www.ncdc.noaa.gov/sotc/national/2012/5
[24] J. Masters, "Spring 2012: most extreme season in U.S. history" (June 8, 2012) http://www.wunderground.com/blog/JeffMasters/comment.html?entrynum=2115
[25] NOAA, State of the Climate, National Overview (August 2012) http://www.ncdc.noaa.gov/sotc/national/2012/8/
[26] NOAA, State of the Climate, National Overview (July 2012) http://www.ncdc.noaa.gov/sotc/national/2012/7
[27] NOAA, State of the Climate, National Overview (August 2012) http://www.ncdc.noaa.gov/sotc/national/2012/8/supplemental/page-6/
[28] A. Freedman, "Explaining explosion of daily record highs easy as pie" (July 16, 2012) http://www.climatecentral.org/blogs/more-heat-records-compared-to-cold-records/

[29] U.S. Drought Monitor, Tabular Statistics Archive for the contiguous United States (September 11, 2012) http://droughtmonitor.unl.edu/DM_tables.htm?archive
[30] J. Masters, "Major severe thunderstorm outbreak expected; U.S. drought intensifies" (July 26, 2012) http://www.wunderground.com/blog/JeffMasters/comment.html?entrynum=2161#commenttop
[31] CNN, "Historic drought puts over half of U.S. counties in disaster zones, USDA says" (August 1, 2012) http://articles.cnn.com/2012-08-01/us/us_us-usda-disaster-zones_1_crop-food-prices-massive-drought
[32]USDA, Weekly Weather and Crop Bulletin. http://www.usda.gov/oce/weather/pubs/Weekly/Wwcb/wwcb.pdf
[33]USDA, Weekly Weather and Crop Bulletin. http://www.usda.gov/oce/weather/pubs/Weekly/Wwcb/wwcb.pdf
[34] National Interagency Fire Center, Year-to-date statistics (September 19, 2012) http://www.nifc.gov/fireInfo/nfn.htm
[35] National Interagency Fire Center, Year-to-date statistics (September 19, 2012) http://www.nifc.gov/fireInfo/nfn.htm
[36] Kirk Siegler, NPR, "In Colorado wildfires' wake, survivors live in limbo" (August 13, 2012) http://www.npr.org/2012/08/13/158707569/in-colorado-wildfires-wake-survivors-live-in-limbo
[37] Laura Nelson, Los Angles Times, " Colorado's most destructive fire ever, Waldo Canyon, is contained" (July 11, 2012) http://articles.latimes.com/2012/jul/11/nation/la-na-nn-waldo-canyon-fire-contained-20120711
[38] Aon Benfield, June 2012 Global Catastrophe Recap http://thoughtleadership.aonbenfield.com/Documents/201207_if_monthly_cat_recap_june.pdf
[39] NOAA, State of the Climate, National Overview (July 2012) http://www1.ncdc.noaa.gov/pub/data/cmb/images/us/2012/jul/monthlysigeventmap-072012.gif
[40] National Research Council (2010), "Advancing the Science of Climate Change." http://www.nap.edu/catalog.php?record_id=12782
[41] Global Climate Change Impacts in the United States, Thomas R. Karl, Jerry M. Melillo, and Thomas C. Peterson, (eds.). Cambridge University Press, 2009.
[42] Jeff Masters, "Severe thunderstorms erupt along a swath 1,500 miles long, killing 2" (July 27, 2012) http://www.wunderground.com/blog/JeffMasters/comment.html?entrynum=2162
[43] NOAA, State of the Climate, National Overview (June 2012) http://www.ncdc.noaa.gov/sotc/national/2012/6
[44] Aon Benfield, June 2012 Global Catastrophe Recap http://thoughtleadership.aonbenfield.com/Documents/201207_if_monthly_cat_recap_june.pdf
[45] Aon Benfield, August 2012 Global Catastrophe Recap http://thoughtleadership.aonbenfield.com/Documents/201209_if_monthly_cat_recap_august.pdf
[46] NOAA, State of the Climate, National Overview (August 2012) http://www.ncdc.noaa.gov/sotc/national/2012/8/
[47] NOAA, State of the Climate, National Overview (July 2012) http://www1.ncdc.noaa.gov/pub/data/cmb/images/us/2012/jul/monthlysigeventmap-072012.gif
[48] Stephen Lacey, "Mississippi River reaches historic lows" (Augus 16, 2012) http://thinkprogress.org/climate/2012/08/16/698461/mississippi-river-reaches-historic-lows-we-have-50-year-guys-whove-never-seen-anything-like-this-before/
[49]John Yang, "Drought sends Mississippi into uncharted territory" (August 15, 2012) http://usnews.nbcnews.com/_news/2012/08/15/13295072-drought-sends-mississippi-into-uncharted-territory
[50] Associated Press, "Corps: Lower Mississippi River levels to persist into fall" (August 21, 2012) http://www.foxnews.com/us/2012/08/21/corps-low-miss-river-levels-to-persist-into-fall/
[51] U.S. Army Corp of Engineers (August 7, 2012) http://www.mvd.usace.army.mil/offices/pa/releases/2012/Rel1214.pdf
[52] Associated Press, "Corps: Lower Mississippi River levels to persist into fall" (August 21, 2012) http://www.foxnews.com/us/2012/08/21/corps-low-miss-river-levels-to-persist-into-fall/
[53] Associated Press, "Corps: Lower Mississippi River levels to persist into fall" (August 21, 2012) http://www.foxnews.com/us/2012/08/21/corps-low-miss-river-levels-to-persist-into-fall/
[54] Chris Hoenig, "Drought killing fish, hurting economy" (August 6, 2012) http://radio.foxnews.com/2012/08/06/drought-killing-fish-hurting-economy/#.UFsZ9KD1kjE
[55] Jonathan Oosting, "State of the Great Lakes" (July 12, 2012) http://www.mlive.com/news/index.ssf/2012/07/state_of_the_great_lakes_michi.html

[56] Andrew Freedman, "Great Lakes water temperatures at record levels" (July 25, 2012) http://www.climatecentral.org/news/great-lakes-water-temperatures-at-record-levels/

[57] Associated Press, "Report: Great Lakes ice down 71 percent since 1973" (March 10, 2012) http://minnesota.publicradio.org/display/web/2012/03/10/great-lakes-ice/

[58] Wang, Jia, Xuezhi Bai, Haoguo Hu, Anne Clites, Marie Colton, Brent Lofgren, 2012: Temporal and Spatial Variability of Great Lakes Ice Cover, 1973–2010. *J. Climate*, 25, 1318–1329.

[59] NOAA, Ecosystem Advisory for the Northeast Shelf Large Marine Ecosystem, (September 18, 2012) http://www.nefsc.noaa.gov/press_release/2012/SciSpot/SS1209/

[60] Aon Benfield, August 2012 Global Catastrophe Recap http://thoughtleadership.aonbenfield.com/Documents/201209_if_monthly_cat_recap_august.pdf

[61] Joshua Zumbrun and Mark Drajem, "Worst in generation drought dims U.S. farm economy hopes" (July 16, 2012) http://www.bloomberg.com/news/2012-07-16/worst-in-generation-drought-dims-u-s-farm-economy-hopes.html

[62] Aon Benfield, June 2012 Global Catastrophe Recap http://thoughtleadership.aonbenfield.com/Documents/201206_if_monthly_cat_recap_june.pdf

[63] Matthew Wald and John Schwartz, "Weather extremes leave parts of U.S. grid buckling" (July 25, 2012) http://www.nytimes.com/2012/07/26/us/rise-in-weather-extremes-threatens-infrastructure.html

[64] Juliet Eilperin, "Climate change challenges power plant operations" (September 9, 2012) http://www.washingtonpost.com/national/health-science/climate-change-challenges-power-plant-operations/2012/09/09/42b26b8e-f6a5-11e1-8b93-c4f4ab1c8d13_story.html

[65] NOAA, Extreme Weather 2011 (January 19, 2012) http://www.noaa.gov/extreme2011/

[66] NOAA, Extreme Weather 2011 (January 19, 2012) http://www.noaa.gov/extreme2011/compare.html

[67] NOAA, State of the Climate, Global Analysis (August 2012) http://www.ncdc.noaa.gov/sotc/global/2012/8

[68] NOAA, State of the Climate, Global Analysis (2011 Annual) http://www.ncdc.noaa.gov/sotc/service/global/significant-extremes/201113.gif

[69] World Bank, (May 8, 2012) http://web.worldbank.org/WBSITE/EXTERNAL/NEWS/0,,contentMDK:23191363~pagePK:64257043~piPK:437376~theSitePK:4607,00.html

[70] "New Horn of Africa drought warning" (March 5, 2012) http://www.rtcc.org/nature/new-horn-of-africa-drought-warning/

[71] Aon Benfield, January 2012 Global Catastrophe Recap http://thoughtleadership.aonbenfield.com/Documents/201201_if_monthly_cat_recap_january.pdf

[72] National Snow and Ice Data Center, "Arctic sea ice extent settles at record seasonal minimum" (September 19, 2012) http://nsidc.org/arcticseaicenews/2012/09/arctic-sea-ice-extent-settles-at-record-seasonal-minimum/

[73] Jeff Masters, "Record warmth at the top of the Greenland ice sheet" (July 18, 2012) http://www.wunderground.com/blog/JeffMasters/comment.html?entrynum=2156

[74] Blunden, J., and D. S. Arndt, Eds., 2012: State of the Climate in 2011. *Bull. Amer. Meteor. Soc*., 93 (7), S1–S264.

[75] National Research Council (2010), "Advancing the Science of Climate Change." http://www.nap.edu/catalog.php?record_id=12782

[76] T. Karl, et al., Weather and Climate Extremes in a Changing Climate (June 2008) http://downloads.climatescience.gov/sap/sap3-3/sap3-3-final-all.pdf

[77] J. Hansen, et al., "Perception of Climate Change" Proceedings of the National Academy of Sciences (August 6, 2012) http://www.pnas.org/content/early/2012/07/30/1205276109.full.pdf

[78] National Research Council (2012), "Climate Change: Evidence, Impacts and Choices – Answers to Common Questions about the Science of Climate Change."

[79] National Research Council (2012), "Climate Change: Evidence, Impacts and Choices – Answers to Common Questions about the Science of Climate Change."

[80] National Research Council (2012), "Climate Change: Evidence, Impacts and Choices – Answers to Common Questions about the Science of Climate Change."

[81]National Research Council (2012), "Climate Change: Evidence, Impacts and Choices – Answers to Common Questions about the Science of Climate Change."
[82] National Research Council (2012), "Climate Change: Evidence, Impacts and Choices – Answers to Common Questions about the Science of Climate Change."
[83] O. Pechony and D. T. Shindell, "Driving forces of global wildfires over the past millennium and the forthcoming century," Proceedings of the National Academy of Sciences (October 25, 2010) http://www.pnas.org/content/early/2010/10/20/1003669107
[84] National Research Council (2012), "Climate Change: Evidence, Impacts and Choices – Answers to Common Questions about the Science of Climate Change."
[85] Westerling, A.L., H.G. Hidalgo, D.R. Cayan, T.W. Swetnam, 2006: Warming and earlier spring increase western U.S. forest wildfire activity. *Science*, 313, 940-943.
[86] Westerling, A.L., H.G. Hidalgo, D.R. Cayan, T.W. Swetnam, 2006: Warming and earlier spring increase western U.S. forest wildfire activity. *Science*, 313, 940-943.
[87] Mote, P., A. F. Hamlet, M. P. Clark, and D. P. Lettenmaier, 2005: Declining mountain snowpack in western North America. *Bull. Amer. Meteor. Soc.*, 86, doi: 10.1175/BAMS-1186-1171-1139.
[88] Wentz, F.J. L. Ricciardulli, K. Hiburn, C. Mears. 2007. How much more rain will global warming bring? *Science*, 317, 233-235.

[89] Rosamond Naylor, Climate Impacts on Global Food Security Under Increasing Demand Pressures, Presentation at American Association for the Advancement of Science, Vancouver Canada, February 2012
[90] National Research Council (2012), "Climate Change: Evidence, Impacts and Choices – Answers to Common Questions about the Science of Climate Change."
[91] National Research Council (2012), "Climate Change: Evidence, Impacts and Choices – Answers to Common Questions about the Science of Climate Change."