The Facts of the Weather Extreme Events in the United States: Is there a Trend?

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Received: March 10, 2011 Accepted: April 5, 2011 doi:10.5539/jsd.v4n4p14

Abstract

Numerous weather and climate extremes impact human society, the societal infrastructure, and the natural environment. The main purposes of this study were to review the historical record of weather extremes in the United States, identify the frequency and intensity of severe storms in the historical record, and examine the extent of economic damage resulting from those extreme events which occurred over the most recent decades. Potential changes in climate are forecast to result in possible frequency and/or intensity changes in extreme events, increases in precipitation, decreases in extreme low temperatures, increases in extreme high temperature, and changes in ecological systems such as climate-induced phonological shifts and possible biological extinctions. However, the impacts of tropical storms, hurricanes, and rainfalls on society and the nature systems need to be further investigated due to the difficulties of evaluations on variations of storms' activities (intensity and frequency). Climatologists, biologists, and social scientists need to work together to bridge the gaps among the disciplines. Future research may consider focusing on future trends and changes in frequency of extreme events based on the outcomes of the most integrated climate models to evaluate the relationships between the severe weather extremes and the continued greenhouse gas scenarios of the coming decades.

Keywords: Weather extreme events, Economic damage, Greenhouse gas

1. Introduction

Human and natural systems experienced the stressors induced by extreme events. Many economists, sociologists, political scientists, agriculturalists, hydrologists, environmental engineers, and atmospheric scientist-geographers have been working separately and have recently become involved in interdisciplinary collaborations to investigate routine weather effects (conditions that occur annually) and abrupt weather extremes (floods, droughts, and severe storms).

Numerous weather and climate extremes impact human society, the societal infrastructure, and the natural environment. Property losses, losses of life, displaced populations, economic damages, and environmental hazards induced by extreme events have been heavily documented in various regions globally. According to Easterling et al. (2000), the definition of climate extremes may be grouped as (1) simple statistics (extreme low / high daily temperatures, or daily / monthly heavy rainfall) that occur every year, and (2) extreme events (floods, drought, or hurricanes) that occur sporadically.

A limited number of studies in the literature have focused on the changes in frequency of temperature extremes (e.g., cold and heat waves that occurred exceeding days / nights temperature) in order to examine the gaps between the historical observed trends and predicted future trends by running various climate scenarios coupled with comprehensive climate forces. These climate studies and model simulations (Trenberth, 1999; Zwiers and Kharin, 1998; Kothavala, 1999; Easterling et al., 2000) have found an increase in mean temperatures, an increase in extreme warm days, a decrease in extreme cold days, a decrease in diurnal temperature range (Zwiers and Kharin, 1998), an increase in intensity of rainfall / precipitation events (Durman et al., 2001), and an increased change of drought events associated with seasonality (e.g., an increase in low summer precipitation due to enhanced evaporation and warmer temperature). Zwiers and Kharin (1998) indicated that the West Coast of the North American region has been experiencing more increases in extreme temperature and moister soil due to the increase in precipitation. However, the majority of research findings have been unable to overcome the inherent level of uncertainty due to the infrequent occurrences of such extreme events.

Since 1987, over 360 weather-related events in the US alone have caused damage in excess of one billion US dollars (over $5 million per event). For example, the 1988-1989 Midwest droughts caused losses of $39 billion, the 1992 Hurricane Andrew produced $30 billion in losses in South Florida and adjacent regions, and the 1993 Midwest floods caused losses in excess of $19 billion (Changnon et al., 2000). Hurricanes Ivan in 2004 and

Katrina, Rita and Wilma in 2005 had an enormous impact on infrastructure and produced billion economic damages resulting in devastating years. Floods and storms were the major natural disasters (77%) in the United States in 2009. During the previous 10 years (2000-2009), storms (90%), floods (5%), and wildfires (3%) caused most of the major economic damage. Over the past decade, approximately 95% of the affected population was impacted by floods, storms, droughts, and extreme temperatures, while floods (7%), storms (78%), and extreme temperatures (8%) caused more than ninety three percent of human loss (Chen, 2011).

One very important question has arisen from these events, are these extreme events influenced by the impacts of climate change or are they mainly a reflection of ordinary fluctuations in natural systems? Being able to identify climate forcing factors and detecting climate-induced changes (e.g., anthropogenic shifts) has been a challenge with respect to distinguishing the impact factors of basic climate statistics vs. extreme weather events driven by climate change.

2. Purpose of the Study

The main purposes of this study were to (1) review the historical record of weather extremes in the United States and (2) report the extent of economic damage resulting from those extreme events which occurred over the most recent decades.

3. Precipitation and Temperature

Many countries, including the US, have reported an increase in days with heavy precipitation during the 20th century (Zhai et al., 1999). Specifically, an increase in annual numbers of days exceeding two to four inches of precipitation has been noted in the US since the early 20th century (Karl et al., 1996; Knutson, et al., 1998), while the largest increase in total annual precipitation was recorded in the Midwest, Southwest, southern Mississippi River valley, and the Great Lakes areas.

Land surface precipitation has shown an increase in the mid to high latitudes, with nearly 0.6 °Celsius (C) increases in the global mean temperature in the early period of the 20th century (Nicholls, 1995). Recorded observations also demonstrated a decrease of land surface precipitation in the sub- and tropics regions (Nicholls, 1995). Due to an increase in annual precipitation and frequency in heavy precipitation events, an increase in greater wetness has been notable since the 1970s (Karl et al. 1996), while there is no obvious increase in long-term drought events and trends in the US.

Studies reported that a decreased frequency of both warm maximum temperatures, extreme cold days (DeGaetano, 1996), and an 11-day earlier arrival of frost-free season have been noted in the northeastern US (Cooter and LeDuc, 1995). According to Karl et al. (1996), the mean temperature shows an overall warming, while the number of temperature extremes decreased over the whole US despite the southeastern region exhibiting a cooling condition.

Trends indicated that an increase of surface maximum temperature, to over 32.2 °C, was impacted by the droughts during the 1930s and 1950s. Historically, the 1930s experienced a high frequency of heat waves compared to the rest of the 20th century (Karl and Knight, 1998). Interestingly, there was a significant increase in frequency and numbers of droughts in the 1930s and 1950s in the US. Since the 1700s, the intensity of droughts peaked in the 1930s according to the historical record; over the past two-thousand years of recorded weather events, although, droughts occurred in the Great Plains regions before the 1600s that were greater than the ones in the 1930s in terms of length and breadth (Easterling et al., 2000**;** Woodhouse and Overpeck, 1998). Meanwhile, a decrease in the number of days below 0 °C coupled with regional variations during the years of 1910-1998 in the US has been reported (Easterling et al., 2000).

According to (Easterling, 2000), every studied country has revealed a decrease in the number of frost days while consistently warming in average minimum temperature. For example, in the US (Karl et al., 1991) there was an increase in the minimum temperature during the years of 1951-1989, while an increase in water vapor was documented for the period of 1973-1993 (Ross and Elliot, 1996). Because temperature and humidity affect human health, an abrupt heat wave that occurred in the Chicago area resulted in hundreds of deaths in 1995 (Changnon et al., 1996). In addition to human beings, many other species have been impacted by climate events; there is a substantial amount of documentation detailing how non-human creatures experienced altered physical characteristics and breeding traits (Hoffman and Parsons, 1997) concomitant with climate changes (including changes in precipitation, temperature, drought, and frequency of weather extremes).

4. Effects of Climate Change in the Natural Systems

Several previous studies reported the effects of climate change on species' allocations and shifts in biotic trends using unsophisticated linkage evidence and analyses (Hughes, 2000; Wuethrich, 2000; Pielke, et al., 2008). Although there are gaps among the relationships between climate change, weather extremes, and the natural systems, ecological and physiological studies provided evidence of how climate affects species' distribution (Parmesan et al., 1999), behavior (Rubenstein, 1992), morphology (Hadiy, 1997), population density (Singer, 1972), and local community (Walker and Willig, 1999).

Studied species included frog, birds, insects, small – large size mammals, and plants. Additionally, marine biotic and land ecosystems appear to be affected by tropical storms, floods, tornadoes, and various other extreme events (Walker and Willig, 1999). More specifically, several species experienced various behavioral and physical changes while many other species had significant distribution impacts (Parmesan et al., 2000). Population upward and northward shifts (e.g., butterfly) due to variations of temperature and precipitation have also been observed (Parmesan, 1996; Singer, 1972; Boughton, 1999). Abrupt weather extremes have at some points caused species' extinction in affected areas (Singer and Ehrlich, 1979**;** Ehrlich, 1980). However, the main limitations of these climate-induced species studies were lack of sufficient historical observed data, clear linkages between the extreme events and species' distribution changes; additionally, the unclear mechanistic criteria (gradual long-term biotic change vs. abrupt climate change, or gradual climate change vs. abrupt ecosystem disturbances) limit the studies' findings.

5. Overviews: Types of Extreme Events

Previous studies documented that hurricanes produce extreme rainfall events that amplify monthly rainfall anomalies, mostly in the mid-Atlantic, New England, eastern Massachusetts and the Appalachian regions of the US (Evans and Hart, 1999). Several studies (Karl *et al*., 1995; Karl and Knight, 1998**;** Changnon, 2009; Groisman *et al*., 2001) utilized various statistical approaches and data sets, and have concluded that there has been an increase in precipitation due to an increase in the occurrences of severe storms and heavy daily precipitation events over the past century. Furthermore, Groisman *et al*. (2001) reported that an increase in the stream's high flow was caused by an increase in intensity of rainfall.

Many studies (Emanuel, 1986, 1987, 1988) forecast an increase in frequency and intensity of hurricanes due to the sea-surface temperature increase. Indeed, Druyan *et al*., (1999) and Knutson *et al*. (2001) demonstrated a positive relationship between an increase in frequency of tropical cyclones and the elevated concentrations of greenhouse gases resulting in warming temperature, while Zhang *et al.* (2000) used hourly tide gauge records and reported that there was no discernible long-term trend in the frequency and intensity of severe coastal storms over the past century.

Changnon and Changnon (2000) used 66 first-order stations' data sets to examine the historical trends in hail activities and concluded that 1916–1955 had the most frequent occurrences of hail, while there was a decline in hail events during 1955-1995. Changnon (2001) examined observed data sets from 86 stations and reported that there was an increase in thunder days during the years of 1936-1955 and a moderate decrease in thunderstorm activities from 1956 to 1995. The two studies yielded consistent conclusions and indicated a bell-shaped 100-year (1896-1995) distribution for the hail and thunderstorm occurrences.

With respect to windstorms*,* when strong winds reach more than 72 kph, the occurrences of property damages begin to accumulate and the strong winds are categorized as *damaging*. According to FEMA (2009), damaging winds were established by downbursts (descending winds from thunderstorms), strong low pressure systems cyclonic conditions (mostly occurring in the Midwest US), and downward sloping winds (mostly occurring along the mountain ranges in the western US). Wind damages directly affected power lines, home, trees, and poles (Changnon 1980). Regarding the winter extremes, Branick (1997) concluded that adverse winter weather extremes culminated in larger geographical impacts and reported economic damages over the past decade in the US caused by winter weather extremes including heavy snow, blizzard, high-wind-chill, and freezing precipitation. Regardless of the types of weather extremes, in the past decade (2000-2009) weather disasters' damages cost $50 billion in insured property losses and $15 billion in federal disaster relief funds.

6. Economic Damages Caused by Extreme Events

Many studies have reported various weather extremes cause economic damages. For instance, Changnon (2001) reported that annual insured losses increased from $100 million in the 1950s to $6 billion in the 1990s, and the frequency of storms increased 3 fold over those five decades. These previous studies focused on the following events: 1987-1989 drought which caused $39 billion in economic damages (Riebsame et al., 1991); 1995 Hurricane Andrew which produced losses of $30 billion (Pielke, 1995); 1993 floods in the Midwest US which caused $21 billion worth of damages (Changnon, 1996); and 1997-1998 El Nino event which induced $19 billion gains and $4 billion in economic damages (Changnon, 1999).

Maunder (1986) reported that economic losses in agricultural sectors caused by adverse weather accounted for 15.5% of agricultural revenues and highlighted that weather losses contributed only 2% of the total gross revenue. According to Subcommittee on Natural Disaster Reduction (1999), there was a weekly average of $1 billion in economic damages caused by natural disasters which accounted for 0.7% of the US gross domestic product (GDP). Riebsam et al. (1991) reported that the 1987-1989 droughts caused a 0.4% decrease in GDP in 1988, and Changnon (1996) assessed that corporate profits were down 0.01% in 1993 due to flood disasters. During the years of 1950-1997, there was a 7-9% decrease in the US agricultural sector annual net income caused by weather extremes (Changnon and Hewings, 2001).

Because of the increase in awareness of economic damages caused by weather extremes promoted by literature campaigns, the US National Weather Service began pursuing efforts to improve data collection approaches and moderate quality control and perform storm data adjustment (Pielke, 1999). Additionally, crop and property insurance records have been recognized as valuable resources by which to compile more reliable weather extreme databases. Studies have been carried on to investigate changes in affected regions' population density, structure codes, and ranges of insurance coverage; findings have helped in the establishment of more comprehensive adjusted data analyses integrated with weather extreme losses and gains (e.g., crop yields) (Changnon and Hewings, 2001; Changnon et al., 2001). Good weather conditions produced gains in crop yields in 1950-1997 and resulted in an annual average $1.9 billion, while the El Nino extremes (1997-1998) and warm winter (2001-2002) induced an increase in economic benefits by nearly $20 billion (Winstanley and Changnon, 2004).

In the 1900s, studies estimated the national economic impacts of climate change. By using assumptions of warming from 2.5–3.0 °C with the losses of $50 billion (Nordhaus, 1993), $53 billion (Cline, 1992), and $69 billion (Hewing, 1994), they concluded a small impact on monetary values in the US economy. Smith (1996) extended the economic impact assessment by using similar assumptions, but extended the prediction to the year 2060; this estimation yielded an amount of $42-53 climate-change-induced damages which would account for less than 1% of GDP in the US.

Several previous studies reported various weather-sensitive components and their losses in the GDP due to weather extremes, with the amount of economic damages ranging from $36 billion to $3.8 trillion and accounting for 2% to 20% of GDP (Dutton, 2002; National Research Council, 2003). Meanwhile, Changnon (2003, 2009) cautioned that the calculated values were limited in accuracy due to inconsistent definitions of 'weather-sensitive' and 'weather extremes' and insufficient explanations regarding the economic impact estimations.

National Assessment Synthesis Team (2001) utilized the Hadley model and the Canadian climate model to investigate the effects of climate change in the US and identify types of effects without providing monetary value. Reilly (2002) reported that the range of losses for crop yields accounted for $0.5 billion to gains of $3.5 billion (Canadian model) and $6-12 billion (Hadley climate model) annually. Mendelsohn and Smith (2002) estimated economic impacts of climate change by utilizing three climate scenarios resulting in nearly 0.1% of GDP by the year 2060. Specifically, when there is a 1.5 °C temperature increase and a 15% increase in precipitation, an increase in net national economic impact will account for $36 billion (1998 dollars) by 2060. A $19.9 billion decrease in net national annual impact was predicted to occur when there was a 5 °C increase in temperature without precipitation (Table 1).

[Insert Table 1 about here]

In summary, the main limitations were lack of sufficiency of including possible future factors (technology development) and uncertainties in the economic structures and systems of the future. Changnon et al. (2001) indicated that the variations of weather extremes showed an upward trend in losses with cautious adjustments involving insurance and societal variables. Changnon et al. (2000) concluded that the majority of economic impacts of climate change were in societal variables while calculating the monetary losses. Those societal variables included expensive property in the affected area, extensive urbanized population shifts toward the coastal areas, inadequate building codes, and weak infrastructure.

7. Conclusions

Potential changes in climate are forecast to result in possible frequency and/or intensity changes in extreme events, increases in precipitation, decreases in extreme low temperatures, increases in extreme high temperature, and changes in ecological systems such as climate-induced phonological shifts and possible biological extinctions. However, the impacts of tropical storms, hurricanes, and rainfalls on society and the nature systems need to be further investigated due to the difficulties of evaluations on variations of storms' activities (intensity and frequency) (Chen, 2011).

Many studies have reported and forecast the economic damages caused by climate change. Public, private, and voluntary sectors are willing to explore and assess existing loss values (property, economic damages, and human life) and predict possible future impacts of climate-induced natural disasters on the business sector and the local community. Weather extremes during the 1990s produced billion dollar losses in affected communities. Winstanley and Changnon (2004) used the estimates provided by the National Weather Service and reported that during the years of 1950-1999 there were nearly $174 million losses in property and crops in the US annually. Many property insurance companies have started keeping records of weather-related disasters in detail and have categorized events that lost >$1 million as catastrophes (Changnon, 2009). Studies that are related to impacts of climate extremes have pointed out the limitations including lack of long-term systematical data collection and agreeable definitions of losses / costs and financial / economic specific terms within the previous analyses.

Several studies concluded the difficulties of providing current and future economic impacts of climate change and cost allocations associated with mitigations since there are too many unpredictable factors in the social, environmental, and political systems (Yohe, 2003; Azar and Lindgren, 2003; Hovarth, 2003; Tol, 2003). Previous climate models have indicated the difficulties to present conclusive simulations that can well predict the track changes, intensity, or frequency of storms. Ideally, up-to-date climate models have the advantage of higher resolution associated with nested regional models and reported an increase in intensity of possible tropical cyclones in the future due to an increase in surface wind speed and precipitation. However, the various simulation outcomes are subject to the availability of homogeneous data, lack of consensus on the definition of extreme events, and agreeable environmental forces (increasing greenhouse gases).

8. Recommendations

According to some simulation results of climate models, increased greenhouse gases (GHGs) are expected to induce a warmer outcome of surface temperatures, cause an increase in atmospheric moisture, and produce more evaporation. The main limitations of current climate models include calculations of uncertainty, various characteristics of systematic errors, and restricted regional-scale climate scenarios. On the other hand, there is an obvious interest in evaluating how human activities impact the climate change, weather extremes, and the natural systems.

Several researchers (Parry, 2001; Travis, 2010) have indicated the importance of implementing a climate change warning system as one of the strategies to evoke an appropriate action on adaptations that are associated with abrupt change severity scales. A feasible strategic plan needs to be established and integrated with effective communication amongst stakeholders, policy makers, public perceptions, and scientists. Many public, private, and voluntary research centers have explicitly addressed the importance of making responsive efforts on providing strategies that are associated with climate adaptation and mitigation, promoting the holistic and technical use of collaborative systematic evaluation processes.

While numerous controversial issues occurred recently during the 2009 Copenhagen summit, it remains worthy to learn how the various sectors can rely on one another and accountably provide knowledge that can give a clear picture and offer linkages amongst impacts, mitigation, and adaptation. Some questions have been asked and may be answered in the coming decades: Can 3% per-year reductions in greenhouse gas emissions reduce the global average surface temperature by the predicted dates and years? How can combined emission reductions and timely adaptations reach an optimal level that can minimize the negative impacts of climate change? How will the abrupt events be impacted by the international agreement if signed at the summit in the future? Overall, the challenges that the scientists are facing are focused on how they can utilize the most updated and modified models and approaches to accommodate uncertainty and future variability related to the fluctuations in the nature systems, abrupt extremes caused by climate change, possible relocations of the species, geo-changes, and interventions of renovated technologies on human beings' daily life.

In summary, it seems that limited climate models can quantify the precise changes of greenhouse gases (GHGs), extreme temperatures, precipitation, frequency of cyclones, and other climate-related forces while facing the challenges of the constraints of available observed data sets and ranges of uncertainty. Bio-geographic and physiological studies have indicated that forces that involve climatic changes, extreme events, land conversion, water diversion, pollution, and urbanization impact wildlife directly and indirectly. Climatologists, biologists, and social scientists need to work together to bridge the gaps among the disciplines. Future research may consider focusing on future trends and changes in frequency of extreme events based on the outcomes of the most integrated climate models to evaluate the relationships between the severe weather extremes and the continued greenhouse gas scenarios of the coming decades.

Acknowledgements

The author would like to thank Dr. Joshua Fu and Dr. Don Worster for contributing their valuable insights to this study. The author also would like to thank the Office of Research at the University of Tennessee for the SARIF fund.

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Table 1. Regional Economic Damages Caused by the Extreme Events

Authors/Year	**Case/Amount**
Riebsame et al. (1991)	1987-1989 drought which caused $39 billion in economic damages
Pielke (1995)	1995 Hurricane Andrew which produced losses of $30 billion
Changnon (1996)	1993 floods in the Midwest US which caused $21 billion worth of damages
Changnon (1999)	1997-1998 El Nino event which induced $19 billion gains and $4 billion in economic damages
Reduction (1999)	a weekly average of $1 billion in economic damages caused by natural disasters
Changnon (2001)	annual insured losses increased from $100 million in the 1950s to $6 billion in the 1990s