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Article *in* Natural Hazards · June 2003

DOI: 10.1023/A:1023674722282

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Natural Hazards **29:** 103–112, 2003.

Compilation and Discussion of Trends in Severe Storms in the United States: Popular Perception v. Climate Reality

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(Received: 30 September 2001; accepted 25 January 2002)

Abstract. The ongoing greenhouse gas buildup and increase in near-surface air temperatures may have an impact on severe weather events in the United States. Output from some numerical modeling simulations suggests that the atmosphere over mid-latitude land areas could become more unstable in the future thereby supporting an increase in convective activity. However, despite the numerical simulation results, empiricists have been unable generally to identify significant increases in overall severe storm activity as measured in the magnitude and/or frequency of thunderstorms, hail events, tornadoes, hurricanes, and winter storm activity across the United States. There is evidence that heavy precipitation events have increased during the period of historical records, but for many other severe weather categories, the trends have been downward over the past half century. Damage from severe weather has increased over this period, but this upward trend disappears when inflation, population growth, population redistribution, and wealth are taken into account.

1. Introduction

Climate change has become arguably the most prominent environmental issue of our time. Hardly a day goes by that we do not see news reports about the many potential threats of ongoing and anticipated global warming. Among other popularized predictions, the public is led to believe that most climate scientists agree that (a) global temperatures are rising due to the continued buildup of greenhouse gases, (b) severe weather will increase as the climate continues to change, (c) severe weather events have increased in both frequency and magnitude over recent decades, and (d) economic damages and fatalities from these storms have been increasing. As documented by Ungar (1999), an American television viewer is three times more likely to see a story on severe weather today than they were only 30 years ago. In contrast, scientists with the United Nations Intergovernmental Panel on Climate Change (IPCC, 2001, p. 5) recently concluded that "No systematic changes in the frequency of tornadoes, thunder days, or hail events are evident in the limited areas analysed” and that “Changes globally in tropical and extra-tropical storm intensity and frequency are dominated by inter-decadal and multi-decadal variations, with no significant trends evident over the 20th century". At first glance, there appears to be a substantial mismatch between public perception and actual trends in severe storm activity.

The purpose of this paper is to examine historical trends in severe storm events in the United States along with predictions for future changes related to the continued greenhouse gas buildup. We will restrict our review to "severe storms" which according to the American Meteorological Society's *Glossary of Meteorology* (Huschke, 1959) are associated with specific events (e.g., tornadoes, hurricanes, thunderstorms) as opposed to longer-term episodes (e.g., heat waves, droughts, floods). In addition to an assessment of historical and anticipated trends in severe storms, we will also examine trends in damages caused by these events in recent decades.

2. Thunderstorm and Hail Events

As greenhouse gas concentrations continue to increase, there is concern that shifts will occur in weather extremes, particularly those related to intense convective activity. In simplest terms, it would seem likely that warming of the atmosphere would enhance the chances for convection, and there is no doubt that warmer regions of the planet and warmer times of the year typically have enhanced convective activity. Furthermore, the observed warming near the surface with little warming in the mid-troposphere over the past few decades (Wallace *et al.*, 2000) should act generally to destabilize the atmosphere and lead to an increase in convective storms. Finally, given the near-surface warming occurring at night in the United States (Easterling *et al.*, 1997), along with the propensity for thunderstorms to occur at night throughout much of the interior of the country (Wallace, 1975), it would seem likely that convection should be enhanced at night over much of the United States.

In a recent comprehensive analysis of long-term fluctuations in thunderstorm activity in the United States, Changnon and Changnon (2001) examined records from 1896 to 1995 for first-order national weather service stations. They evaluated thunderstorm occurrence based on the recorded observation of hearing thunder. A careful analysis of that record for each station (Changnon, 2001) identified only 86 locations with high-quality 100-year thunderstorm records. Changnon and Changnon (2001) evaluated the normality of each time series, used a linear trend analysis, and found that approximately one-third of the stations had an upward trend, one-third had a downward trend, while the other third had no trend whatsoever. They (p. 496) concluded that "The national time distribution of thunder days for 1896–1995 has an upward trend in storm activity from 1896 to a peak occurring during 1936–1955, followed by a moderate decrease in thunderstorm activity." While the national average was on a slight decline (Figure 1), they found that the western part of the country had experienced an increase in thunderstorm activity through the past century, but they did not find any upward trend in the central corridor where thunderstorms occur most frequently at night.

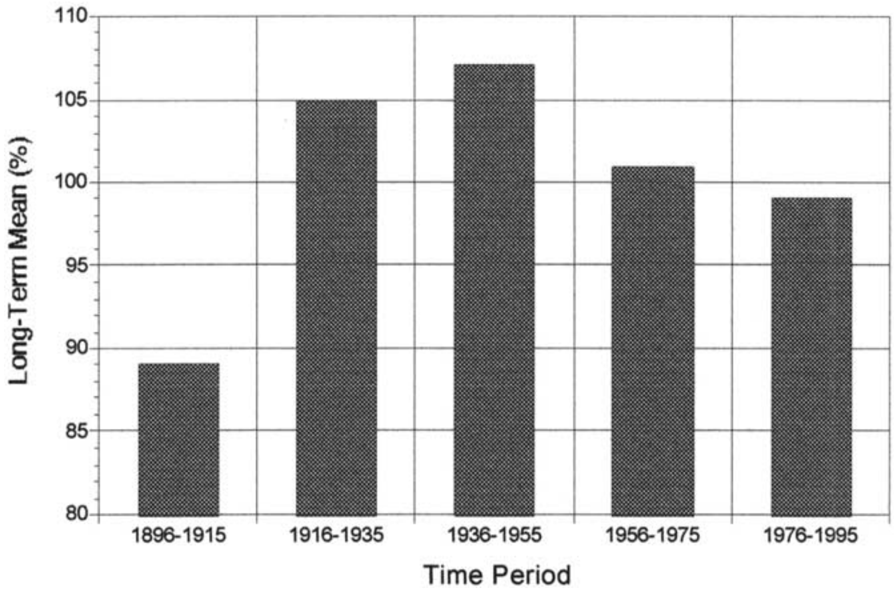

Figure 1. 100-year distribution of United States thunder days, expressed as a percent of the long-term mean, based on data from 86 stations (adapted from Changnon and Changnon, 2001).

Not surprisingly, the situation with hail is generally similar to the spatial and temporal patterns described for thunderstorms. The same Changnon and Changnon (2000) team had a year earlier published an article on long-term fluctuations in hail incidences in the United States over the period 1896 to 1995. They used carefully screened records from 66 first-order stations distributed across the United States and found an overall increase from early in the century (1916) to highest values around 1955. However, from 1955 to 1995, they found a general decline in hail activity for the country as a whole. Changnon and Changnon (2000, p. 658) stated that "The national average based on all station hail values formed a bell-shaped 100-yr distribution with hail occurrences peaking in midcentury".

3. Intense Rain Events

While no evidence can be found of a recent increase in thunderstorm activity over the past half century, Changnon (2001) found that the amount of rainfall from thunderstorms had increased over most of the United States during the past century. Many other scientists (Karl *et al.*, 1995; Karl and Knight, 1998; Groisman *et al.*, 2001) have used a variety of trend-identification statistical techniques and data assemblage procedures and have concluded that precipitation levels are increasing in the country, and much of that increase is reflected in an increase in the occurrence of heavy and extreme daily precipitation events. They have found that over half of the total increase of precipitation is due to positive trends in the upper 10 percentiles of the precipitation distribution. Furthermore, Groisman *et al.* (2001) demonstrated that increases in rainfall intensity have significantly affected streamflow, including the probability of high flow. This increase in precipitation is consistent with many numerical model simulations showing an invigorated hydrological cycle in a world warmed by the greenhouse gas buildup.

4. Tornadoes

Tornadoes represent the most violent phenomenon associated with severe weather. The occurrence of a massive tornado that struck Oklahoma City in 1999 may fuel speculation that severe tornadoes may have become more common through the 20th century. As with thunderstorm activity and hail occurrences, scientists have examined available tornado data, and they have been unable to identify any realistic upward trend in tornado activity. One commonly used measure of the severity of a tornado is Fujita's F-scale of tornado damage (Grazulis, 2001). Although this scale, based on observed physical damage, may be inappropriate in certain trend analyses (particularly for areas of sparse population or with poorly constructed structures), it does provide a means of comparing tornado intensities over time. Using databases of reported tornado occurrences, it is evident that total tornado reports have increased by a factor of ten in the last fifty years (e.g., Grazulis, 1993; Brooks and Doswell, 2001). But Brooks and Doswell (2001) attribute that increase to better observation and reporting procedures, particularly of weaker tornadoes, as well as a greater observing population. When only the most severe tornadoes (F3 tornadoes and greater, consequently less likely to be influenced by observational changes) are identified and plotted by 5-year periods, no observable trend in tornado occurrence is seen over the last fifty years (Figure 2). This plot is based on a tornadic database taken between January, 1950 to December, 2000 and derived from data from the National Severe Storms Forecast Center (now the Storm Prediction Center) and the NOAA publication *Storm Data*. Indeed Grazulis (2001, p. 287) specifically notes that "any link of tornado activity with climatic change of any kind should be treated with the greatest skepticism. The ingredients that go into the creation of a tornado are so varied and complex that they could never be an accurate indicator of climate change".

5. Hurricanes

Virtually every popularized presentation of the potential hazards associated with global warming suggests that climate scientists believe that hurricanes striking the United States will increase in frequency and intensity as the planet warms in response to elevated concentrations of greenhouse gases. The foundation for this assertion can be traced to a series of articles published in the mid-to-late 1980s by Emanuel (1986, 1987, 1988) showing that elevated sea-surface temperatures could increase the potential destructive power of tropical storms by 40 to 50 percent. In

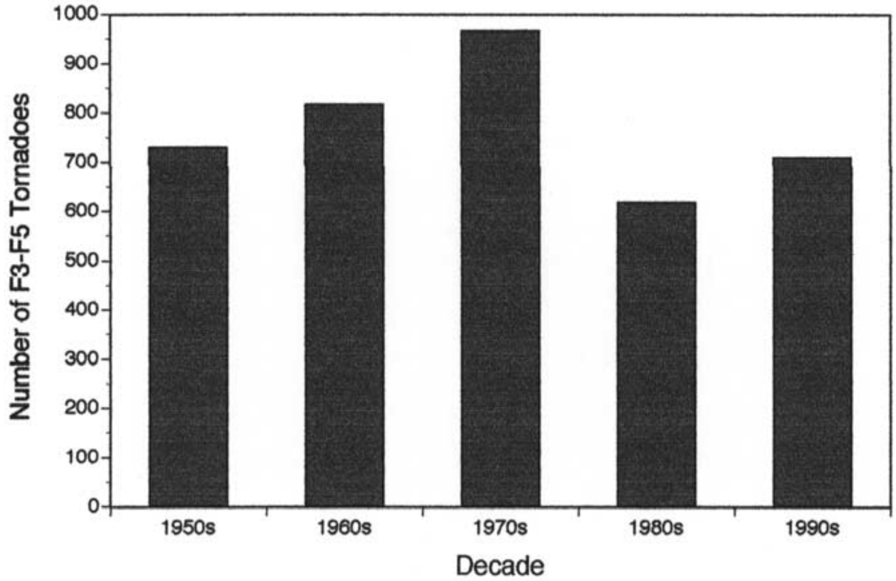

Figure 2. Number of F3 to F5 tornadoes reported in the United States over the past half century.

the past few years, others have conducted numerical experiments suggesting that hurricane activity in the United States could increase due to global warming. For example, Druyan *et al*. (1999) used the popular GISS general circulation model to compare potential hurricane activity for ambient and twice-ambient atmospheric CO_2 concentrations. Although cautious in their interpretation, they did find a 50% increase in the genesis frequency of tropical cyclones over the western North Atlantic/Gulf of Mexico basin. More recently, Knutson *et al*. (2001) ran a series of numerical simulations and found that elevated CO_2 could increase maximum hurricane wind speeds by up to 10%. Furthermore, they found significant increases of near-storm precipitation under high-CO_2 climate, relative to control (present day) conditions. Although not all numerical experiments lead to the "prediction" for increased hurricane activity given the continued buildup of greenhouse gases (e.g., Shen *et al*., 2000), it is noteworthy that a solid theoretical basis for this prediction can be identified in the literature.

Many other scientists have examined selected hurricane records over the past century and, despite the results from numerical models, have found no upward trend or even declining levels of tropical storm frequency and intensity in the specific types of tropical cyclones they examined. Wilson (1999) examined intense hurricanes in the Atlantic basin from 1950 to 1998 and found a decreasing trend and fewer intense hurricanes during the warmer periods. Easterling *et al*. (2000) reported a general decline in landfalling Atlantic hurricanes in the latter part of the twentieth century. However, in the case of the United States, Elsner *et al*. (2000) warn that the Arctic warming and the relaxation of the North Atlantic Oscillation may reverse these downward trends and bring an increase in North American hurricane activity in the near future.

6. Extra-Tropical Cyclones and Nor'easters

Of great importance to residents of the eastern seacoast of the United States is the question of long-term variability in the occurrence of severe extratropical winter storms. Past severe coastal winter storms, termed 'nor-easters' because of prevailing storm wind direction, have caused great property damage and loss of life. For example, the great blizzard of 1888 (Huschke, 1959) and the "March Superstorm" of 1993 (Kocin *et al*., 1995) have often been cited as two of the greatest weather disasters to occur in the United States.

Several recent schemes of classifying such storms exist and, while they differ in the type of data used to identify the event, basically all agree that no discernible trends exist in the occurrence of such storms over the last fifty years. For example, study of tropical and winter storms using storm surge data obtained from hourly tide gauge records shows considerable interdecadal variability but no discernible long-term trend in the number and intensity of moderate or severe coastal storms during this century (Zhang *et al.*, 2000). Hirsch *et al*. (2001) limited their recent investigation to only east coast winter storms defined using the criteria of (a) location along the east coast of the United States, (b) movement from the south-southwest to the north- northeast, and (c) winds greater than 10.3 m s^{-1} for at least six hours. Their study reported no significant trends in winter storm frequency over a 46-yr period beginning in 1951. Indeed, the one marginally statistically significant winter storm trend was an increase in average minimum pressure of winter storms, indicating the possibility of reduced severity.

7. Blizzards

Although nor'-easters are severe winter storms, their impact is generally limited to the coastal areas of the North American Atlantic seaboard. Other adverse winter-type weather events have a larger geographical influence across the continent. In particular, severe winter weather, including blowing snow, blizzards, and high-wind-chill events, can occur across wide expanses of the continental regions of the United States. Dery and Yau (1999) used the European Centre for Medium-Range Weather Forecasts Re-Analysis gridded data for 1979 to 1993 and identified significant interannual and monthly variabilities in the number of blowing snow, blizzard, and high-wind-chill events but did not examine trend. Such interannual and monthly variability is also demonstrated by a slightly earlier study (Branick, 1997) based on a 13-year database of reported damaging or injurious winter events including seasonal fluctuations, relative frequencies of different hazards (e.g., heavy snow versus freezing precipitation), duration variations, and size (areal coverage) distributions. Branick (1997) concluded that "significant winter weather" occurs within the contiguous United States "almost daily" from mid-November through March. The high temporal and spatial variability of these events compounds various statistical problems associated with confirming or denying the existence of trends in the data.

8. Severe Storm Losses

There is little doubt that economic losses from severe storms across the United States have been on the rise in absolute terms, but the increase is probably not due to any significant change in the climate. A comprehensive article by Kunkel *et al.* (1999) specifically addressed trends in economic and human health impacts from weather and climate extremes. In terms of severe weather, Kunkel *et al.* (1999, p. 1077) report that "increasing losses are primarily due to increasing vulnerability arising from a variety of societal changes, including a growing population in higher risk coastal areas and large cities, more property subject to damage, and life-style and demographic changes subjecting lives and property to greater exposure." Kunkel *et al.* (1999, p. 1077) also noted that while fatalities and economic damages have increased due to severe storms, "when changes in population, inflation, and wealth are considered, there is instead a downward trend." Similarly, Changnon *et al.* (2001) developed national indices for weather-related losses that were all adjusted to 1997 dollars. Changnon *et al.* (2001, p. 1) concluded that "Trends were upward for certain key variables between 1950 and 1997, including the incidence and losses associated with winter storms, flood losses, crop losses, and incidence of heavy rains. Trends were downward for other weather-driven loss variables, including hurricane losses, energy costs, thunderstorm losses, wind storm losses, and hail losses".

In more specific studies, Pielke and Landsea (1998) addressed damage from hurricanes and found that the upward trend in losses in recent decades disappeared when they controlled for inflation and population growth in coastal areas. In the case of hail, Changnon and Changnon (2000, p. 658) noted "across the country as a whole, national hail insurance loss values have declined since the 1950s, also agreeing with the hail-day decrease since midcentury". While Grazulis (2001) found deaths by tornadoes in the United States have markedly declined in recent decades, he associated the downward trend in tornado deaths to greater public awareness of the danger of tornadoes and dissemination of warnings and not to any long-term climatic change.

9. Conclusions

There is considerable concern about future climate change and potential impacts on severe storms in the United States. There are certainly general circulation model simulations suggesting that an increase in greenhouse gas concentration could significantly warm the planet and create an environment more favorable for severe storms over mid-latitude continental areas. Most scientists would agree, however, that the present-day numerical climate models (because of their spatial resolution and quality of input data) have substantial limitations with regard to predicting future changes in severe weather events in any specific region of the planet, and their results should be only used with caution.

Many scientists have examined historical records of severe weather events in the United States including thunderstorms, hail events, intense precipitation, tornadoes, hurricanes, and winter storm activity. Overall, there appears to be no overall upward trend in severe weather over the past half century, although many scientists have identified an increase in heavy precipitation. In other severe storm categories, the trends are downward, although well within the natural variability of the climate system. While the public at large may perceive some increase in the frequency and magnitude of severe weather events, many analyses of severe storm records fail to confirm the public perception.

Damage from severe weather appears to be on the increase in an absolute sense, but generally speaking, these upward trends disappear when inflation, population growth, population redistribution, and wealth are taken into account. Consequently, any public perception of increased severe storm activity likely relates to the observation documented by Ungar (1999) that a current American television viewer is substantially more likely to see coverage of disasters than a viewer of thirty years ago. That increased coverage thereby leads the viewer to perceive an overall increase in severe storm activity irrespective of the actual trends, or lack thereof, in the climate system.

But any severe weather "disaster" consists of two parts: (1) the actual phenomenon causing the destruction, and (2) a human population that is influenced by the phenomenon. As Grazulis (2001) notes, an F5 tornado that strikes an uninhabited area would be difficult to classify as would other severe storm phenomenon occurring in some uninhabited area. As a greater number of people develop in areas prone to severe storm activity, it is likely that absolute damage from severe weather will continue to be on the increase while the actual severe storm phenomena may show no significant trends whatsoever.

References

Branick, M. L.: 1997, A climatology of significant winter-type weather events in the contiguous United States, 1982–1994, *Weather and Forecasting* **12**, 193–207.

Brooks, H. E. and Doswell, C. A.: 2001, Normalized damage from major tornadoes in the United States: 1890–1999, *Weather and Forecasting* **16**, 168–176.

Changnon, S. A.: 2001a, Assessment of the quality of thunderstorm data at first-order stations. *J. Appl. Meteorol.* **40**, 783–794.

Changnon, S. A.: 2001b, Thunderstorm rainfall in the conterminous United States, *Bulletin of the American Meteorological Society* **82**, 1925–1940.

Changnon, S. A. and Changnon, D.: 2000, Long-term fluctuations in hail incidences in the United States, *J. Climate* **13**, 658–664.

Changnon, S. A. and Changnon, D.: 2001, Long-term fluctuations in thunderstorm activity in the United States, *Climatic Change* **50**, 489–503.

Changnon, S. A., Changnon, J. M., and Hewings, G. J. D.: 2001, Losses caused by weather and climate extremes: A national index for the United States, *Phys. Geogr.* **22**, 1–27.

Dery, S. J. and Yau, M. K.: 1999, A climatology of adverse winter-type weather events. *J. Geophys. Res.* **104**, 16657–16672.

Druyan, L. M., Lonergan, P., and Eichler, T.: 1999, A GCM investigation of global warming impacts relevant to tropical cyclone genesis, *Int. J. Climatol.* **19**, 607–617.

Easterling, D. R., Evans, J. L., Groisman, P. Y., Karl, T. R., Kunkel, K. E., and Ambenje, P.: 2000, Observed variability and trends in extreme climate events: A brief review, *Bulletin of the American Meteorological Society* **81**, 417–425.

Easterling, D. R., Horton, B., Jones, P. D., Peterson, T. C., Karl, T. R., Parker, D. E., Salinger, M. J., Razuvayev, V., Plummer, N., Jamason, P., and Folland, C. K.: 1997, Maximum and minimum temperature trends for the globe, *Science* **277**, 364–367.

Elsner, J. B., Jagger, T., and Niu, X.-F.: 2000, Changes in the rates of North Atlantic major hurricane activity during the 20th century, Geophysical *Res. Lett.* **27**, 1743–1746.

Emanuel, K.: 1988, The maximum intensity of hurricanes, *J. Atmos. Sci.* **45**, 1143–1155.

Emanuel, K. A.: 1986, An air-sea interaction theory for tropical cyclones. Part I: Steady-state maintenance, *J. Atmos. Sci.* **43**, 585–604.

Emanuel, K. A.: 1987, The dependence of hurricane intensity on climate, *Nature* **326**, 483–485.

Grazulis, T. P.: 1993, Significant tornadoes: 1680–1991, *Environ. Films* 1326 pp.

Grazulis, T. P.: 2001, *The Tornado: Nature's Ultimate Windstorm*, University of Oklahoma Press, 324 pp.

Groisman, P. Y., Knight, R. W., and Karl, T. R. 2001, Heavy precipitation and high streamflow in the contiguous United States: Trends in the twentieth century, *Bulletin of the American Meteorological Society* **82**, 219–246.

Hirsch, M. E., DeGaetano, A. T., and Colucci, S. J.: 2001, An East Coast winter storm climatology, *J. Climate* **14**, 882–899.

Huschke, R. W.: 1959, *Glossary of Meteorology*, American Meteorological Society, 638 pp.

IPCC: 2001, Climate change 2001, The Scientific Basis: Summary for Policymakers and Technical Summary of the Working Group I Report. Cambridge, Cambridge University Press.

Karl, T.R., and Knight, R. W.: 1998, Secular trends of precipitation amount, frequency, and intensity in the United States, *Bulletin of the American Meteorological Society* **79**, 231–241.

Karl, T. R., Knight, R. W., Easterling, D. R., and Quayle, R. G.: 1995, Trends in U.S. climate during the twentieth century, *Consequences* **1**, 3–12.

Knutson, T. R., Tuleya, R. E., Shen, W., and Ginis, I.: 2001, Impact of CO_2-induced warming on hurricane intensities as simulated in a hurricane model with ocean coupling, *J. Climate* **14**, 2458–2468.

Kocin, P. J., Schumacher, P. N., Morales, R. F., and Uccelini, L. W.: 1995, Overview of the 12–14 March 1993 superstorm, *Bulletin of the American Meteorological Society* **76**, 165–182.

Kunkel, K. E., Pielke Jr., R. A., and Changnon, S. A.: 1999, Temporal fluctuations in weather and climate extremes that cause economic and human health impacts: A review, *Bulletin of the American Meteorological Society* **80**, 1077–1098.

Pielke, R. A. and Landsea, C. W.: 1998, Normalized hurricane damages in the United States: 1925–1995, *Weather and Forecasting* **13**, 621–631.

Shen, W., Ginis, I., and Tuleya, R. E.: 2000, A sensitivity study of the thermodynamic environment on GFDL model hurricane intensity: Implications for global warming, *J. Climate* **13**, 109–121.

Ungar, S.: 1999, Is strange weather in the air? A study of U.S. national network news coverage of extreme weather events, *Climatic Change* **41**, 133–150.

Wallace, J. M.: 1975, Diurnal variations in precipitation and thunderstorm frequency over the conterminous United States. *Mon. Wea. Rev.* **103**, 406–419.

Wallace, J. M., Christy, J. R., Gaffen, D. J., Grody, N. C., Hansen, J. E., Parker, D. E., Peterson, T. C., Santer, B. D., Spencer, R. W., Trenberth, K. E., and Wentz, F. J.: 2000, *Reconciling Observations of Global Temperature Change*, National Academy Press, Washington, D.C.

Wilson, R. M.: 1999, Statistical aspects of major (intense) hurricanes in the Atlantic basin during the past 49 hurricane seasons (1950—1998): Implications for the current season, *Geophys. Res. Lett.* **26**, 2957–2960.

Zhang, K. Q., Douglas, B. C., and Leatherman, S. P.: 2000, Twentieth-century storm activity along the US east coast, *J. Climate* **13**, 1748–1761.