Climatic Change (2011) 106:129–140
DOI 10.1007/s10584-010-9927-1

Temporal distribution of weather catastrophes in the USA

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Received: 11 February 2009 / Accepted: 22 June 2010 / Published online: 24 August 2010

Abstract The temporal distributions of the nation's four major storm types during 1950–2005 were assessed, including those for thunderstorms, hurricanes, tornadoes, and winter storms. Storms are labeled as catastrophes, defined as events causing $1 million or more in property losses, based on time-adjusted data provided by the insurance industry. Most catastrophic storms occurred in the eastern half of the nation. Analysis of the regional and national storm frequencies revealed there was little time-related relationship between storm types, reflecting how storm types were reported. That is, when tornadoes occurred with thunderstorms, the type producing the greatest losses was the one identified by the insurance industry, not both. Temporal agreement was found in the timing of relatively high incidences of thunderstorms, hurricanes, and winter storms during 2002–2005. This resulted in upward time trends in the national losses of hurricane and thunderstorm catastrophes, The temporal increase in hurricanes is in agreement with upward trends in population density, wealth, and insurance coverage in Gulf and East coastal areas. The upward trends in thunderstorm catastrophes and losses result from increases in heavy rain days, floods, high winds, and hail days, revealing that atmospheric conditions conducive to strong convective activity have been increasing since the 1960s. Tornado catastrophes and their losses peaked in 1966–1973 and had no upward time trend. Temporal variability in tornado catastrophes was large, whereas the variability in hurricane and thunderstorm catastrophes was only moderate, and that for winter storms was low.

1 Introduction

Temporal variations in the various types of damaging storms in the USA are of great concern to the government, financial institutions, the insurance industry,

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and atmospheric scientists. Sudden changes in storm occurrences and their losses have great economic impacts on business and the local, state, and federal agencies (Kunreuther 1998). Changes may also reflect shifts in climate since climate models indicate that global warming will lead to an increase in hurricanes and rain storms in North America (IPCC 2007).

Data on catastrophes, events causing $1 million or more in insured property losses, were used to assess the time differences in their frequency and losses as related to hurricanes, winter storms, tornadoes, and thunderstorms. A recent assessment of catastrophic storm losses reveals that these four storm types account for 98% of all storm-related losses in the USA (State Farm Insurance 2008).

Catastrophe loss data have been collected by the property insurance industry since 1949, and insurance experts have adjusted these data to make past losses comparable to 2005 conditions. These storm data for 1950–2005 were assessed to define the time distributions of storms in each class. During this 56-year period, 78 hurricane catastrophes occurred causing losses of $148.764 billion (Changnon 2008a). There were 218 catastrophic winter storms during 1950–2005 and they caused $35.974 billion in losses (Changnon 2008b). Thunderstorm catastrophes, a result of hail, lightning, high winds, and/or heavy rains, occurred 459 times in the 56-year period and produced losses totaling $104.032 billion (Changnon 2006). Tornadoes produced 79 catastrophes with losses totaling $16.681 billion (Changnon 2009). The insurance industry, in establishing its storm data base, used only the most damaging condition when two or more storm-producing conditions occurred. That is, if thunderstorms caused more losses than did tornadoes (when both occurred), the event was identified as a thunderstorm event and its losses were those reported. The temporal variability in each storm type and relationships between the time distributions of each storm type were assessed, and used to identify possible causes of temporal changes during 1950–2005.

2 Data and analysis

The losses of the catastrophic storms were assessed using adjusted loss data from the property insurance industry. The property insurance industry since 1949 assessed losses of all major storms, labeled as catastrophes, causing $1 million or more in losses. The loss values of each year have been systematically adjusted by insurance experts for temporal changes in insurance coverage, inflation, construction costs, and other property-related changes. This allows them to compare losses in early years with those in recent years.

The property-casualty insurance industry, which collectively supports industry-oriented functions at the American Insurance Services Group, established in 1949 a new division named the Property Claim Services (Insurance Information Institute 1988). It was a group of insurance loss experts organized to identify and make records of major loss events, labeled as catastrophes, and each causing $1 million or more in insured losses. Such property losses could come from weather events, fires, or earthquakes, and included losses to homes, businesses, buildings, vehicles, and other personal effects (Changnon et al. 1997).

The catastrophe assessment group identified potential events shortly after they occurred and created initial estimates of losses. If estimated as approaching $1 million or more, data collection began by surveying all major property-casualty companies (900 in the nation), and using ground and aerial surveys of damaged areas. This continuing endeavor has resulted in records since 1949 of all natural hazards in the USA that caused losses to insured property of $1 million or more. For each qualifying catastrophe, the loss assessors recorded the condition/s causing the losses, the amount of loss, and states where the losses occurred (Property Claim Services 2007). Catastrophe losses represent 90% of all insured property losses that occur nationally (Changnon et al. 1997).

Insurance experts have systematically analyzed in each year since 1949, the historical catastrophe data to update the past catastrophe values to match current year conditions. This resulted in a database allowing a company to perform, at any time, unbiased economic comparisons of current catastrophe losses with those in past years, and to assess the shifting risk of losses in all parts of the nation. The industry provided their adjusted catastrophe data base for this storm research.

This annual loss adjustment effort is a sizable and complex task requiring careful assessment of each past event. Three adjustment calculations are used to modify the original storm loss value for the locations of each catastrophe. One adjustment corrects for time changes in local and regional property values and the cost of repairs/replacements. Hence, this also adjusts for changes in inflation. The second adjustment addresses the relative change in the size of the property market in the areas affected by the storm using census data, property records, and insurance records. This act adjusts losses for shifts in the insured property between the year of a given storm's occurrence and the updated year (2005 in this study). The third adjustment is based on estimates of the relative changes in the share of the total property market that was insured against weather perils in the loss areas, done by using insurance sales records. These estimates could miss the relative changes in the storm's property market if the available sales records were not adequate.

The three adjusted values for a given area of the USA are combined into a single number used to modify a loss value. For example, a storm-related loss in Pennsylvania during 1953 was adjusted upwards to the 2005 level by the insurance experts by a factor of 31.3, whereas loss for a similar type storm in Oregon in 1953, where coverage and other conditions differed from those in Pennsylvania, was adjusted by 37.8. Thus, the losses from a storm, whether in 1949, 1973, or 1989, could be assessed in the terms of 2005 conditions.

The resulting time-adjusted loss data have been assessed by the National Academy of Science along with all other loss data including that from government, and the catastrophe data were evaluated as the best hazard loss data available in the USA (NRC 1999). A study assessed the adjusted loss data for different US regions using demographic and business data and found strong relationships (Changnon and Changnon 1998).

3 Spatial distribution

The temporal analysis was pursued based on findings that defined different major loss areas of the USA. The distribution of catastrophes in the nation's nine climate districts is shown in Fig. 1. If a catastrophe produced losses in two or more regions,

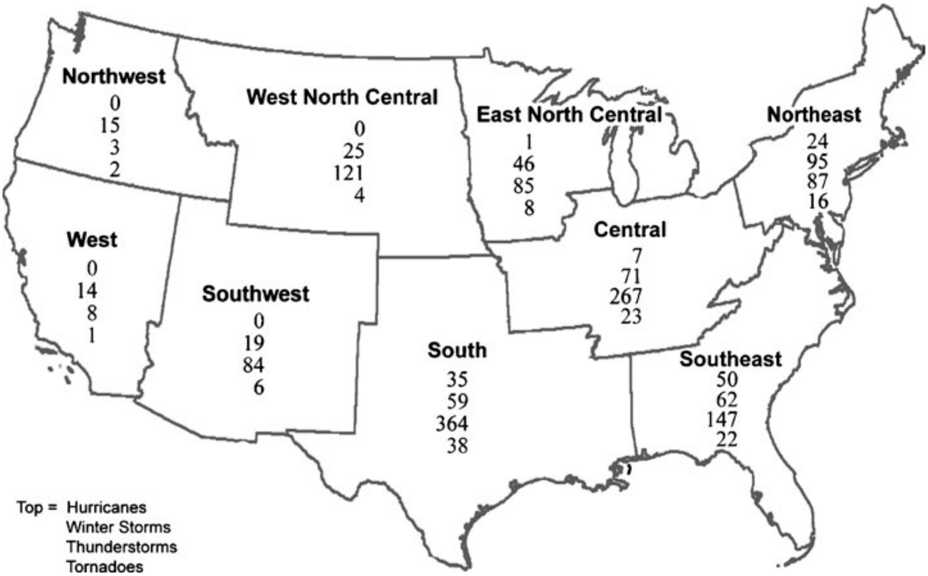

Fig. 1 The frequency of four major storm types in the nine climate regions of the USA

each region got a count. Thus, the totals for each storm class, based on the values in Fig. 1, are greater than the actual number of storms during 1950–2005. For example, the sum of the thunderstorm catastrophes shown on Fig. 1 is 1,166, whereas the actual number of thunderstorm catastrophes was 459, revealing that many of the thunderstorm events affected multiple regions. Storm sizes were calculated using the insurance data which lists the number of states with losses. Thunderstorm catastrophes had an average loss area of 7.9 states, whereas the averages for winter storms was 7.1 states. The average loss area for hurricanes was 2.9 states, and that for tornadoes was 1.2 states.

Ranks based on the top four regional totals are listed in Table 1. Comparison reveals that the same four regions rank highest for all four storm types. Thus, storm-caused catastrophes in the USA peak in the eastern half of the nation which has had 85% of all catastrophes. Thus, atmospheric conditions causing storms and societal vulnerability to storm damages are greatest in this part of the USA.

Table 2 presents the 56-year totals of the number of catastrophes and their losses for the five climate regions that experienced the most catastrophes during 1950–2005. The South with 496 catastrophes during 1950–2005, ranked first, followed by the Central region with 366, the Southeast with 281, and the Northeast with 222 catastrophes. The Northwest and West regions (Fig. 1) had the fewest catastrophes.

Table 1 The top four highest ranked regions based on the frequencies of four storm types

Storm types	Rank 1	Rank 2	Rank 3	Rank 4
Thunderstorms	South	Central	Southeast	Northeast
Winter storms	Northeast	Central	Southeast	South
Tornadoes	South	Southeast	Central	Northeast
Hurricanes	Southeast	South	Northeast	Central

Table 2 The ranks of the five climate regions with the largest number of catastrophes and losses during 1950–2005

Rank	Frequency of catastrophes		Rank	Amount of loss, $ billion	
1	South	496	1	Southeast	103.746
2	Central	366	2	South	83.152
3	Southeast	281	3	Northeast	44.179
4	Northeast	222	4	Central	32.661
5	East North Central	140	5	East North Central	15.353

The regional losses (Table 2) had different ranks than the number of events. The losses in the Southeast totaled $103.746 billion and ranked highest largely because hurricane losses were so large in that area. Large hurricane losses helped make the South's total losses second ranked.

4 Temporal distributions regionally

The temporal distributions of catastrophes in the four regions with the greatest numbers of catastrophes appear in Figs. 2, 3, 4, 5. The time series analysis was based on the 4-year total values for each catastrophe. These values were also used to calculate the time trends of each storm type. In the South region (Fig. 2) the thunderstorm catastrophes had a upward time trend, but the other three storm types had flat time trends. The highest values of thunderstorms came during 1982–1997, and those for winter storms came in 1982–1993. Hurricane events peaked during 1998–2005, and tornadoes during 1966–1973. The coefficients of variation, measures

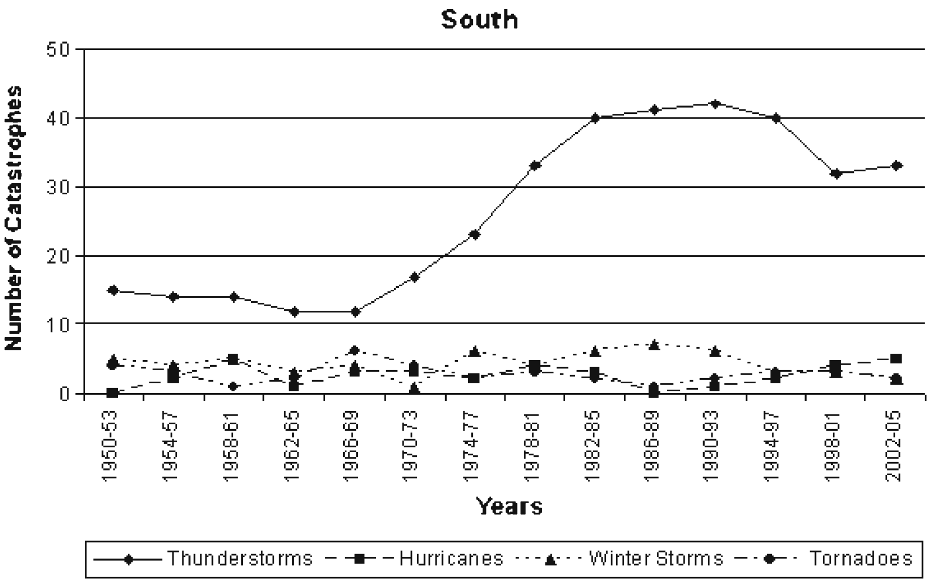

Fig. 2 The frequency of four types of storm catastrophes in the South region during 1950–2005

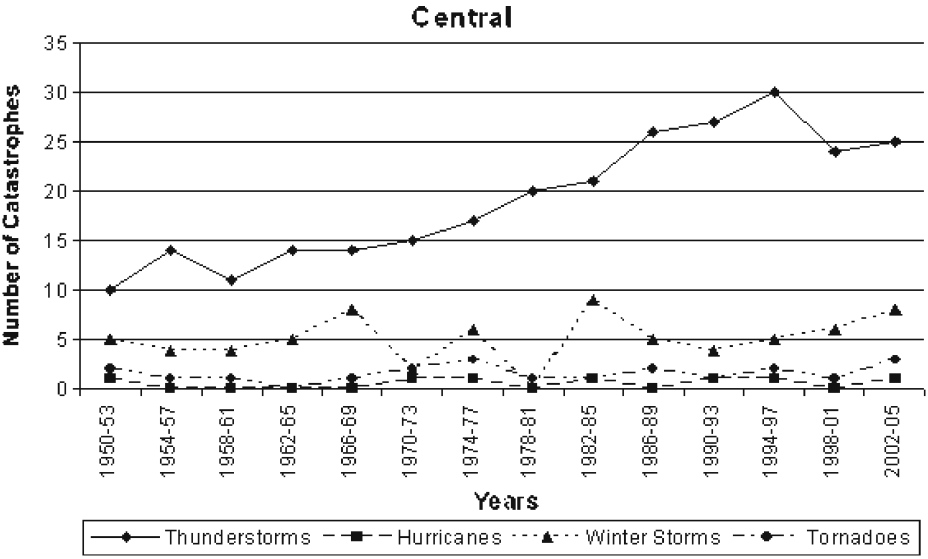

Fig. 3 The frequency of four types of storm catastrophes in the Central region during 1950–2005

of the temporal variability of the 56 values of each storm type, appear in Table 3. Tornado incidences exhibited great temporal variability in all regions, whereas thunderstorm and hurricane events were moderately variable in most regions, and winter storms had a lesser variability over time.

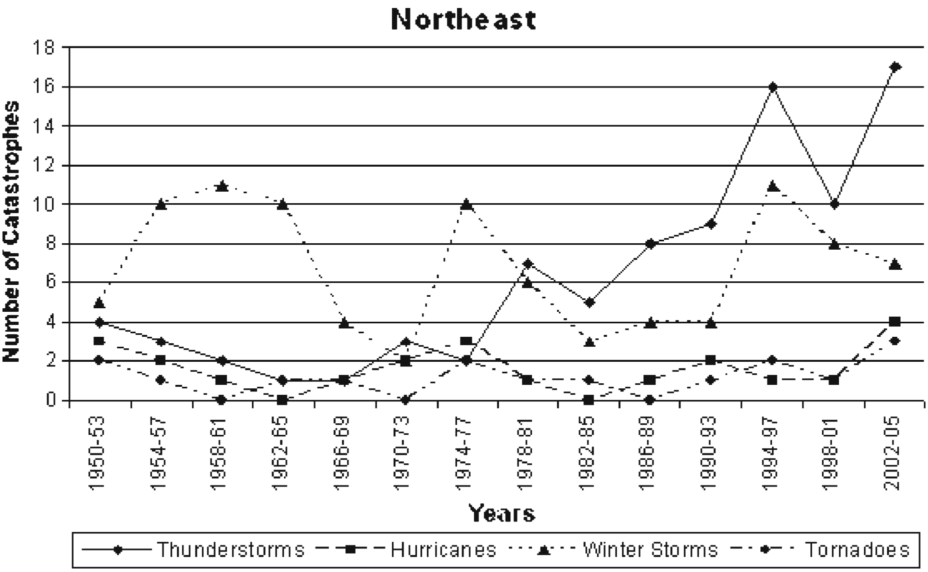

Fig. 4 The frequency of four types of storm catastrophes in the Northeast region during 1950–2005

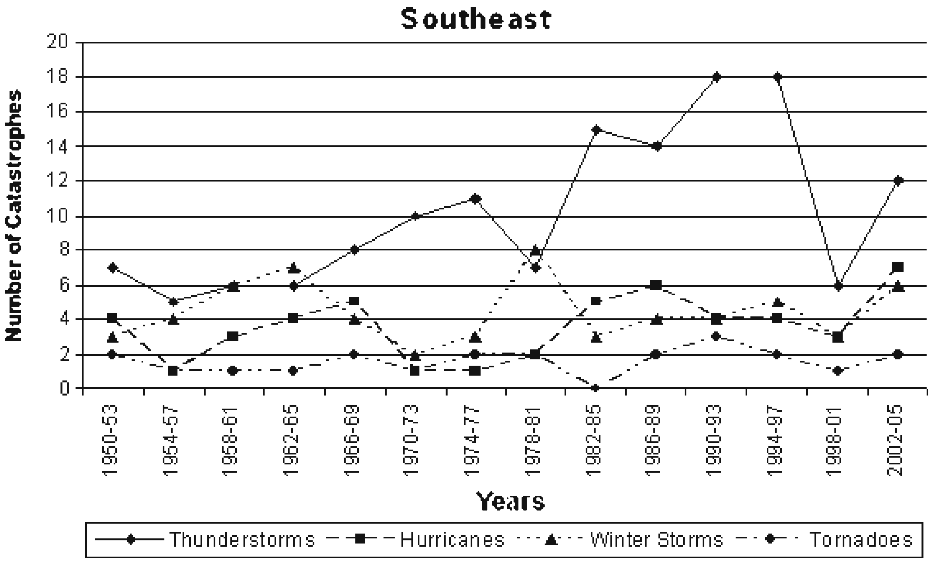

Fig. 5 The frequency of four types of storm catastrophes in the Southeast region during 1950–2005

In the Central region (Fig. 3) the thunderstorm events had an upward time trend during 1950–2005, but the other three storms types had flat time trends. The hurricane, winter storm, and tornado distributions each had three minor peaks during the 56-year period. Hurricane incidences had great temporal variability (Table 3) with moderate variability in tornado occurrences and less temporal variability in thunderstorm and winter storm occurrences.

In the Northeast region (Fig. 4) thunderstorm catastrophes had a statistically significant linear upward time trend, whereas the other three storm types had flat time trends during 1950–2005. Winter storm incidences had three minor peaks; tornadoes peaked early and late in 1950–2005; and hurricane events had three peaks with the largest in 2002–2005. Temporal variations in the incidences of thunderstorms and tornadoes were large (Table 3), but winter storm frequencies had a low variability with time.

Table 3 Coefficient of variation for incidences of storm types during 1950–2005 in four major storm regions and nationally

Regions	Values are percentages (standard deviation/average × 100%)			
	Thunderstorms	Hurricanes	Winter storms	Tornadoes
South	54	64	39	61
Central	36	86	44	55
Northeast	80	66	45	74
Southeast	42	51	38	47
National	55	52	31	80

The catastrophes in the Southeast (Fig. 5) revealed upward trends in thunderstorm and in hurricane catastrophes. Winter storms and tornadoes had three peaks during the 56-year period and both had flat time trends. All four storm types exhibited moderate to low temporal variability in the Southeast (Table 3).

The relationships of the 4-year values in the 56-year time distributions of the four storm types in each region were assessed using simple correlation analyses. The temporal relationships of the four storm types in all four regions were not strong. For example, the only moderately good relationship in the South was between thunderstorms and winter storms, which had a correlation coefficient of +0.51. In the Central region the only moderately good correlation was between hurricanes and tornadoes with a coefficient of +0.61. The same was true for the Northeast which had a coefficient of +0.60 for the hurricane and tornado distributions. In the Southeast, the highest correlation was +0.50 found for the distributions of thunderstorms and hurricane catastrophes. The correlations suggest that the atmospheric conditions causing each storm type differed from those causing the other types, but part of this difference is due to how events were classified when two or more conditions occurred together.

The thunderstorm catastrophe distributions in all four regions showed upward time trends. This is in agreement with a study of the frequency of thunderstorm days across the nation during 1901–1995, which revealed increases had occurred during the 1945–1995 period in the eastern half of the nation (Changnon 2006). Assessment of the periods with high loss values for each type of catastrophe in the four regions reveals certain similarities. Thunderstorm catastrophes peaked in all four regions in the 1990–2001 period. All four regions experienced low thunderstorm frequencies during the 1958–1965 period. The overall 56-year distributions of thunderstorm catastrophes in the four regions (Figs. 2–5) exhibit varying levels of temporal variability (low to high), and all have an upward trend. Tornadoes peaked in 1950–1953 in the South, Southeast, and Central regions and in 2002–2005 in the Central region. Their incidences exhibited moderately high levels of temporal variability in all four regions (Table 3).

Winter storms peaked during1958–1965 in the Northeast and Southeast regions, and peaked during 1982–1989 in the South and Central regions. Winter storms were low in all four regions during 1970–1973, and were low again in 1982–1985 in the Northeast and Southeast. Regional frequencies exhibited low variations over time. The 56-year distributions of winter storm catastrophes in the four regions and nationwide have flat time trends with three minor peaks in early, middle, and later segments of the 56-year period.

The incidences of hurricanes during 1950–2005 revealed that all four regions had high values in 2002–2005. The Southeast and Northeast also had peaks during 1982–1989. Low incidences came in all four regions during 1959–1965. The long-term distribution of hurricane catastrophes, in three regions and nationally (Fig. 6), had flat time trends but with a late 4-year peak in 2002–2005. The temporal variability of hurricanes was large in all regions except the Southeast where they are most frequent (Fig. 1). Climate change is reported to begin causing an increase in hurricanes and their intensity, and other forms of severe weather are predicted to increase in the future (IPCC 2007).

Tornado catastrophe distributions in all four regions had flat trends for the 1950–2005 period and exhibited two or three minor peaks in the 56-year period. Tornado frequencies had moderate to large temporal variability in all four regions (Table 3).

5 Temporal distributions nationally

Figure 6 presents the temporal distributions of catastrophes based on national frequencies during 1950–2005. All storms except tornadoes show peaks in frequencies during the 1994–2005 period. Low frequencies occurred in 1970–1973 for winter storms and thunderstorms. Hurricanes and winter storms were not frequent during 1990–1993, and both had flat time trends for 1950–2005, as did tornadoes. The thunderstorm and hurricane incidences exhibited moderate time-related variations, but temporal variability of tornadoes was large and that for winter storms was lowest.

The national distribution of thunderstorm catastrophes has a distinct upward trend with time (Fig. 6). This increase in catastrophes partially results from increases in several storm-related conditions. The incidence of heavy rain days has been increasing across the USA since the 1930s (Karl and Knight 1998). This is reflected in an increase in flood events that began in the 1960s (Kunkel et al. 1999). Occurrences of hail days nationally began increasing in the 1970s and has continued (Changnon 2000). High wind events, defined by speeds >86 km/h in the central USA where most such events are created by thunderstorms, show an increase since 1950 (Changnon 1990). These various increases in convective storm activity are the likely causes of the increases over time in thunderstorm catastrophes, suggesting that this increase is due to changes in convective storm-related atmospheric conditions. The incidence of thunderstorm days also increased since 1945 and this was found to be related to more unstable atmospheric conditions over the Midwest and East Coast (Changnon 2001). Recent studies have shown that increases in societal vulnerability (growth in population and wealth) have led to increases in damages from storms (Changnon et al. 2000). However, societal factors did not lead to increases in catastrophic losses from tornadoes or winter storms, suggesting that atmospheric shifts were the major cause of the increase in thunderstorm catastrophes.

Figure 7 shows the temporal distribution of national losses during 1950–2005. Three types of catastrophes (thunderstorm, hurricane, and winter storms) reached

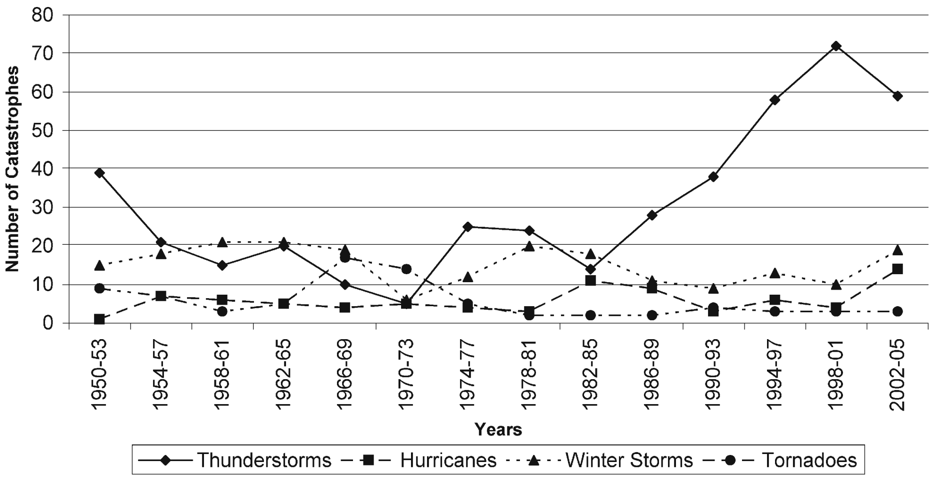

Fig. 6 The national frequency of four types of storm catastrophes during 1950–2005

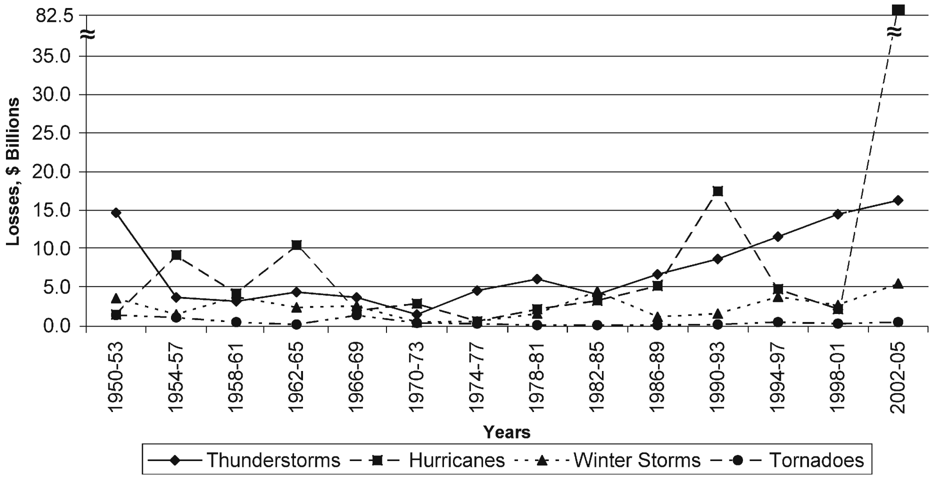

Fig. 7 The national losses of four types of storm catastrophes during 1950–2005

maximums in losses during 2002–2005. Lesser peaks occurred during 1990–1998 in hurricane and thunderstorm losses. Winter storm losses and those from hurricanes had a minor peak in 1958–1965. These three types of catastrophes had low losses during 1970–1977. Tornado losses had minor fluctuations over time and were highest during 1966–1969. An upward time trend for 1950–2005 existed for losses from thunderstorm and hurricane catastrophes, and they both had large temporal variations in their annual losses, as did tornadoes. The temporal up trend in hurricane losses without a up trend in hurricane frequencies reflects shifts in storm intensities and/or in changes in societal vulnerability. Pielke and Pielke (1997) have shown how increases in population and wealth along the hurricane-prone Gulf and East Coasts have led to greater hurricane losses. Landsea et al. (1996) found no temporal increase in intense Atlantic hurricanes. However, an increase in the intensity of hurricanes is expected to result from a climate change due to global warming (IPCC 2007).

Comparisons of storm types on the national scale revealed that the frequency of catastrophes for the four storm types were poorly related. All correlation coefficients between storm types were +0.2 or less. However, the correlation based on the time distributions of storm losses revealed coefficients of +0.54 (thunderstorms and winter storms), +0.52 (hurricanes and winter storms), and +0.50 for thunderstorms and hurricanes. The correlation between time distributions of all catastrophes during 1950–2005 and their total losses, revealed a correlation coefficient of +0.72. Thus, the number of catastrophes explained 51% of the variations in losses created. A few recent hurricanes had exceptionally large losses and kept this relationship from being stronger.

6 Summary and conclusions

A valuable national data set containing the occurrences of all storm catastrophes, events causing $1 million or more in losses, was utilized to assess the temporal distributions of the nation's four major storm types including thunderstorms, hurricanes, tornadoes, and winter storms. Most (85%) catastrophes during 1950–2005 occurred in four climate regions located in the eastern half of the nation. Regional analysis of the time distributions of the four storm types showed they had little relationship, revealing that atmospheric conditions responsible for each storm type were quite different over time. Upward time trends were found for thunderstorm events, and except for the Southeast region, all the other three storm types had flat time trends for 1950–2005. Hurricane catastrophes in the Southeast an upward time trend and peaked during 2002–2005.

Assessment of the national number of catastrophes revealed three types had a peak during 1994–2005: hurricanes, thunderstorms, and winter storms. Thunderstorm catastrophes had a statistically significant upward linear time trend for 1950–2005, but the other three storm types did not. The upward trend in thunderstorm catastrophes is a result of upward trends in several thunderstorm-related conditions including the frequency of heavy rain days, floods, high wind events, and hail days. This indicates that atmospheric conditions conducive to strong convective activity have been increasing nationally since the 1960s. The national temporal variability of tornadoes was large, those for thunderstorms and hurricanes were moderate, and winter storm incidences exhibited much less time-related variations.

Assessment of the national losses created by the catastrophes revealed that the amount of loss created by hurricanes and by thunderstorms were the largest, $148.7 billion and $104 billion, respectively. Losses due to hurricanes and thunderstorms each had upward time trends for 1950–2005, whereas losses from winter storms and tornadoes had flat time trends. The number of catastrophes explained 51% of the variations in losses, not a strong relationship and a result of a few recent very large hurricane losses. All forms of storms had large temporal variations in their annual loss amounts.

Studies of hurricane frequencies and intensities in the USA reveal no increases over time, and these studies concluded that increases in hurricane losses in the southeastern USA were due to a growth in population, structures, and wealth in the storm-prone coastal regions. Climate change due to global warming is also expected to increase hurricane intensities. The upward trend over time in the frequency of thunderstorm catastrophes is also in agreement with trends in population density, wealth, insurance coverage, and inflation. However, the temporal increases in heavy rain days, hail days, high winds, and floods indicate temporal shifts in atmospheric conditions that create convective activity were responsible.

Acknowledgements The services of Eileen Deremiah were very helpful. She provided the illustrations and made many mathematical calculations. Kevin Merrifield helped with various computer-related tasks. Kenneth Kunkel provided a good review.

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