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Nontornadic convective wind fatalities in the United States

Alan W. Black · Walker S. Ashley

Abstract A database was compiled for the period 1977–2007 to assess the threat to life in the conterminous United States from nontornadic convective wind events. This study reveals the number of fatalities from these wind storms, their causes, and their unique spatial distributions. Nontornadic convective wind fatalities occur most frequently outdoors, in vehicles including aircraft, or while boating. Fatalities are most common in the Great Lakes and Northeast, with fewer fatalities observed in the central United States despite the climatological peak in severe thunderstorms in this region. Differences in fatality locations between tornadoes and nontornadic convective wind events highlight the unique combination of physical and social vulnerabilities involved in these deaths. Understanding these vulnerabilities is important to future reduction of nontornadic convective wind fatalities.

Keywords Nontornadic convective wind · Fatalities · Thunderstorm

1 Introduction

While a relatively thorough climatology of tornadoes and tornado casualties exists, information is sparse for other types of nontornadic convective windstorms, especially in terms of their human impacts. Recent research has suggested that nontornadic convective winds are responsible for nearly one out of every four wind-related deaths in the United States. (Ashley and Black 2008). While nontornadic convective wind of any speed can cause fatalities, severe nontornadic convective wind is officially defined in the United

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States as having measured gusts of 25 m s^{-1} or unmeasured gusts that produces damage consistent with gusts of 25 m s^{-1} (Doswell et al. 2005). This study examines both severe and nonsevere nontornadic convective wind fatalities for the period 1977–2007, in order to assess the vulnerability to and mitigate the risks of these storms.

Studies by Kelly et al. (1985) and Doswell et al. (2005) have examined the climatology of nontornadic severe thunderstorms, revealing the temporal and spatial variability in the frequency of these events in the United States. Both studies illustrate that severe convective winds are most common during the warm-season across a broad area from the Great Plains, eastward through Ohio Valley, and extending into the Southeast US and along the Gulf of Mexico. Additional work has examined the climatology of derechos, a type of severe long-lived convective windstorm (Johns and Hirt 1987; Bentley and Mote 1998; Coniglio and Stensrud 2004; Ashley and Mote 2005). Results from these climatological studies conclude that there are two principal derecho activity corridors, one across the Midwest and Great Lakes and the other in the south-central Great Plains. The Great Lakes region experienced the largest number of derecho-related fatalities for the period 1986–2003, and 31.8% of derecho fatalities from 1991 to 2005 occurred in vehicles (Ashley and Mote 2005). However, these storms were responsible for only 38.8% of nontornadic convective wind fatalities, with the remaining fatalities associated with other nonderecho wind modes (Ashley and Mote 2005). Schmidlin (2009) found that nontornadic convective winds were responsible for 165 felled-tree fatalities from 1995 to 2007. Most of these tree-related fatalities occurred during the months of May–August, with 47% of the victims in vehicles and 40% located elsewhere outdoors at the time of death. Ashley (2007) found that tornado fatalities were most common in the Mid South, an area outside of the climatological maximum of tornado occurrence, or so-called "Tornado Alley". In contrast to derecho fatalities, most tornado fatalities occurred in mobile homes and permanent homes, with only 10% occurring in vehicles.

In general, the spatial and temporal characteristics of nontornadic thunderstorm wind hazards, and their human impacts, remain largely unknown. For this reason, a database of fatalities for the period 1977–2007 was constructed to assess the patterns of risk and vulnerability, and ultimately threat to life, in the conterminous US from nontornadic convective wind events. The assessment of fatalities associated with all types of nontornadic convective wind is necessary for a complete understanding of the hazard posed by these storms. In addition, determining the spatial and temporal differences between tornadic and nontornadic convective wind fatalities has implications for mitigation and education efforts, as those applied to tornadoes may not be best suited to address nontornadic convective wind fatalities.

2 Data and methodology

Information on nontornadic convective wind events and fatalities were gathered from *Storm Data* (NCDC 1977–2007). Fatalities were singled out for investigation as they are less subjective than injury information and more reliable than monetary damage estimates. Fatality data acquired from *Storm Data* must be assessed with caution due to the difficulties in the collection of these types of data (Curran et al. 2000; Trapp et al. 2006; Gall et al. 2009). Both Curran et al. (2000) and Ashley and Mote (2005) note that hazards such as derecho and lightning events may receive less media attention than large-impact events such as floods, tornadoes, or hurricanes. Curran et al. (2000) further suggest that one reason for underreporting of lightning fatalities may be that most lighting casualty events involve one person. Additional research by Ashley and Gilson (2009) found that *Storm Data*

underreported US lightning fatalities by nearly 30% during 1977–2004 when compared to fatalities found by searching historical news sources through the online services of *Lex-isNexis Academic* and from the US Centers for Disease Control (CDC) electronic record of death identification. While there may be enhanced awareness of the hazard of nontornadic convective wind compared to lightning, 88% of nontornadic convective wind fatality events involve only one person, and it is hypothesized that these events may be under-reported in *Storm Data* as well. Despite issues with *Storm Data*, the source is the only consistent database for storm-related casualties (Ashley 2007).

Similar to other recent atmospheric hazard fatality research (e.g., Ashley and Black 2008; Ashley 2007), data were gathered from the description of the fatality provided in *Storm Data* for casualties associated with nontornadic convective winds, tornadoes, non-convective winds and hurricane-associated winds. Beyond basic information, such as the date and time of the fatality, most nontornadic convective wind events in *Storm Data* include a narrative text description of damage and how casualties occurred. This supple-mental information was recorded, along with information on the county, parish, and/or town of the death, as well as details on the circumstance of death or building structure type where the fatality took place (e.g., permanent home, mobile home, outdoors, and vehicle.).

An initial investigation of *Storm Data* showed only 29 aircraft-related fatalities and failed to capture several high-profile nontornadic convective wind-induced (i.e., micro-burst; see Fujita (1985) for descriptions) aircraft crashes (e.g., July 9, 1982 crash of Pan Am Flight 759 upon take off from New Orleans, LA and the crash of Delta Flight 191 during landing in Dallas, TX on August 2, 1985). Due to concerns about undercounting of these aviation events, the National Transportation Safety Board's (NTSB) Aviation Accident Database (http://www.ntsb.gov/ntsb/query.asp) was assessed to locate and record additional aircraft fatalities caused by nontornadic convective wind that were undocu-mented in *Storm Data*. Aircraft fatalities due to nontornadic convective wind were iden-tified by reading the accompanying description and using the narrative of the crash to determine if the accident was nontornadic convective wind related. In many cases, thun-derstorms were mentioned as a primary cause, along with microbursts and macrobursts. Cases where it was not clear that the accident was related to nontornadic convective winds were excluded from this analysis.

A geographic information system (GIS) was used to reveal the spatial patterns of these fatality data. Latitude and longitude information for the location of each fatality was collected, and in cases where only the county (or parish) name was provided, the latitude and longitude of the county seat was used as a surrogate for the unspecified fatality location. Fatalities were mapped on an 80 km × 80 km grid; a grid cell of this size encloses the same area as a circle with radius 45.6 km (24.6 n mi), which is similar to the area under consideration by NOAA Storm Prediction Center's thunderstorm outlooks (Doswell et al. 2005). The climatology of nontornadic convective wind was compared to fatalities from nonconvective high winds and tornadoes to assess any regional similarities or differences that may exist in the spatial distribution of fatalities.

3 Results

3.1 Characteristics of nontornadic convective wind fatalities

There were 1,195 direct fatalities *recorded* due to nontornadic convective wind for the 31-year period of record (Fig. 1), 465 or 38.9% of which were aircraft related. Including
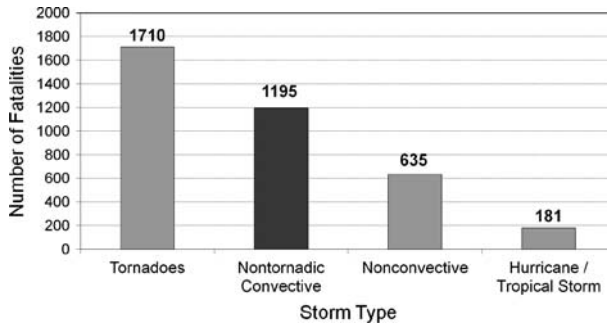
**Fig. 1** Wind-related fatalities by storm type, 1977–2007

aircraft fatalities, nontornadic convective winds account for 32.1% of all fatalities caused by wind phenomena during the period. For the same period, 1,710 tornado fatalities and 635 nonconvective wind fatalities were recorded, with an additional 181 fatalities due to hurricane or tropical storm winds. Ashley and Black (2008) suggested that even though nonconvective and nontornadic convective winds collectively present a comparable threat as tornadoes, they receive much less attention in terms of research, media coverage, and public hazard perception. From 1977 to 2007, nonconvective and nontornadic convective winds, including aircraft fatalities, were responsible for 49.2% of all recorded wind-related fatalities, while tornadoes were responsible for 45.9% of recorded wind fatalities. These results support the hypothesis of Ashley and Black (2008) and highlight the need for further research into *all* types of windstorm casualties. Recently, research has begun to uncover the factors—climatological, meteorological, and societal—that lead to potentially deadly nontornadic windstorms (e.g., Ashley and Mote 2005; Lacke et al. 2007); however, a sustained and enhanced focus on these windstorms in the meteorological and hazard communities is necessary for future mitigation success.

Mass casualty events due to aviation accidents may skew overall results toward these specific, nonterrestrial events; thus, these fatality events are excluded from the subsequent analysis and are discussed in Sect. 3.2. Excluding these aircraft-related fatalities, the number of nontornadic convective wind fatalities varied from 9 in 1978 to 46 in 1998, with an average of 25.5 per year (Fig. 2). The year-to-year variability in the number of non-tornadic convective wind fatalities is large and there is no discernable trend in the number of deaths per year. Analysis of the 2001 through 2007 period of record suggests a slight decreasing trend in the number of fatalities, but a more extensive period of analysis is required to see if this is a definitive trend or simply a deviation from the long-term mean.

Nontornadic convective wind fatalities are most frequent in the late spring and summer months (Fig. 3). July had the most fatalities during the period of record, followed by June, May, and August, in contrast to tornado fatalities that peak in April and May. Fatalities were then compared to the number of severe nontornadic convective wind events reported each month by the Storm Prediction Center (SPC) during the years 1977–2007 to contrast the monthly fatality distribution to climatology. The temporal frequency of fatalities coincides well with the warm-season climatological maximum of nontornadic convective wind occurrence found in previous research (Kelly et al. 1985; Doswell et al. 2005). The four months with the largest number of fatalities were also the months with the most nontornadic convective wind events.
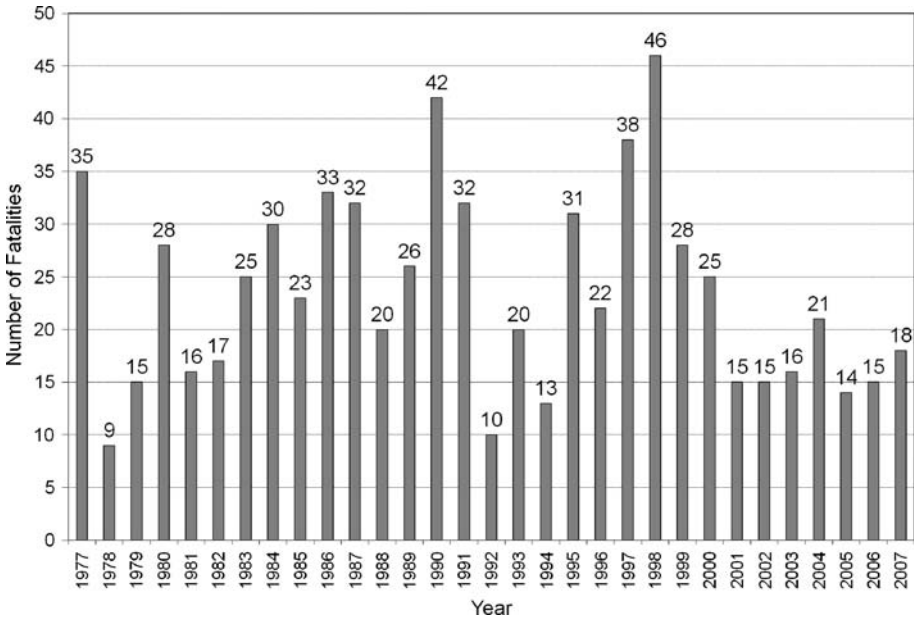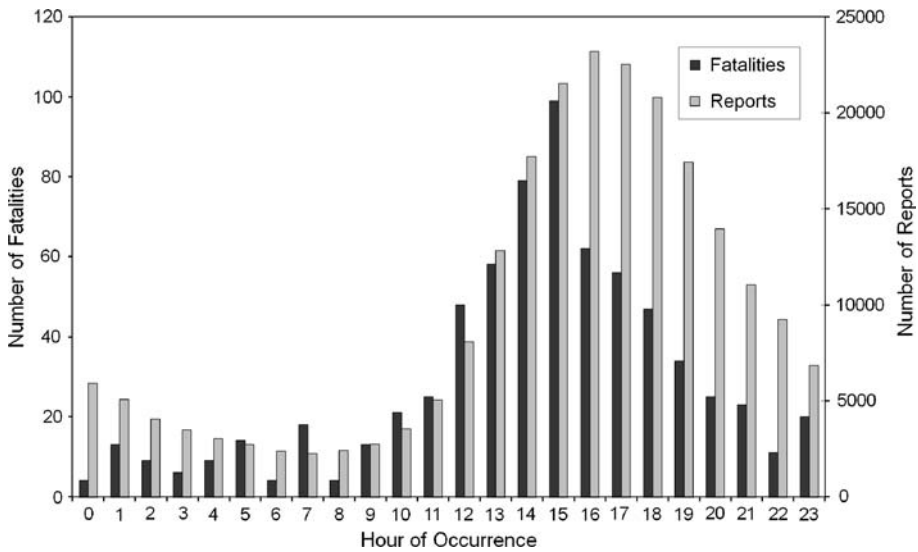
Fig. 2 Nontornadic convective wind fatalities, excluding aviation fatalities, by year, 1977–2007
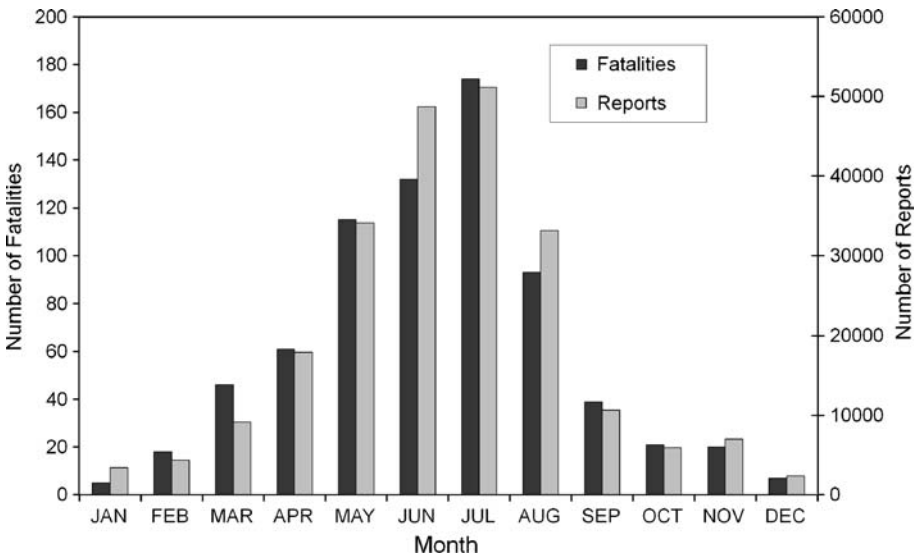
Fig. 3 Nontornadic convective wind fatalities (*dark gray*), which exclude aviation-related fatalities, and number of severe wind reports (*light gray*) by month of occurrence, 1977–2007. Left y-axis scale indicates number of fatalities, while right y-axis scale indicates number of severe wind reports

Further analysis of fatalities by hour reveals that the number of fatalities remains relatively low overnight, with a dramatic increase in counts during the late-morning hours (Fig. 4). Fatality tallies peak between 1400 and 1559 CST, with 27.8% of fatalities

Fig. 4 Nontornadic convective wind fatalities (*dark gray bar*), excluding aviation fatalities, and number of severe wind reports (*light gray bar*) by hour of occurrence (in CST), 1977–2007. Left *y*-axis scale indicates number of fatalities, while right *y*-axis scale indicates number of severe wind reports

occurring during this 2-h time span. Comparison of fatalities and nontornadic convective wind reports by hour shows that the afternoon maximum in fatalities coincides with the afternoon peak of nontornadic convective wind events. Kelly et al. (1985) note that roughly 20% of nontornadic convective wind events occur between midnight and noon, nearly identical to the percentage of fatalities occurring during the same hours in this study. While 10.6% of nontornadic convective wind events take place in the overnight period (0000 to 0559 CST), only 7.7% of nontornadic convective wind fatalities occurred during the same period. A clear contrast exists in the hourly distribution of tornadic and nontornadic convective wind fatalities. Ashley et al. (2008) found that while only 27.3% of tornadoes occurred at night, those nocturnal events were responsible for 39.3% of fatalities. In addition, overnight (local midnight to sunrise) tornadoes were 2.5 times as likely to cause a fatality when compared to those during the day. Much of this nocturnal difference is attributed to difficulty in spotting these tornadoes at night, an increased likelihood that vulnerable housing would be the primary shelter type during the overnight hours, and a breakdown in warning dissemination due to normal sleeping patterns (Simmons and Sutter 2008; Ashley et al. 2008). While the difficulty in spotting and break in warning dissemination would also apply to nontornadic convective wind fatalities, the low percentage of overnight fatalities indicate that occupying even a weak structure may provide considerably better shelter against nontornadic convective wind compared to tornadoes.

When examining nontornadic convective wind fatalities by location and/or circumstance of occurrence (Fig. 5), most fatalities were aircraft related (37.0%), took place outdoors (18.6%), in a vehicle (17.4%), or while boating (14.3%). These four categories, collectively, account for 88.3% of all nontornadic convective wind fatalities. A clear difference can be seen when comparing the circumstance of fatalities caused by nontornadic convective, nonconvective, and tornadic winds. Nontornadic convective and nonconvective wind fatalities share similar circumstances, with most fatalities in vehicles,
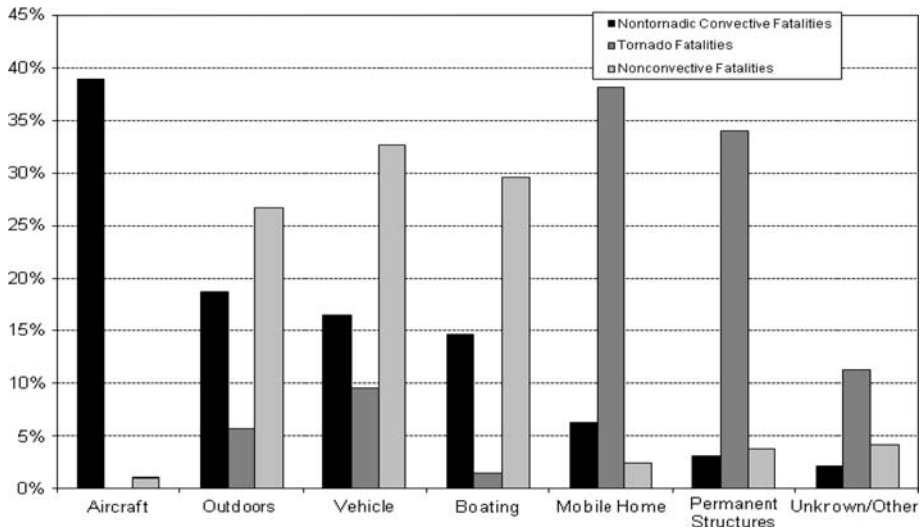
Fig. 5 Percentage of nontornadic convective wind (*black bar*), tornado (*dark gray bar*), and nonconvective wind (*light gray bar*) fatalities by circumstance of occurrence, 1977–2007

outdoors, or while boating. In contrast, over 70% of tornado fatalities occur within mobile home or permanent structures, and less than 10% of tornado fatalities occur in vehicles or boats. These results support the hypothesis of Ashley and Black (2008) that people are more likely to take shelter from a tornado than in nontornadic convective or nonconvective wind situations. This may, in part, explain the low percentage of overnight nontornadic convective wind fatalities as the public is more likely to be in a shelter when compared to the daylight hours.

Overall, 43% of nontornadic convective wind fatalities involved a felled tree; although, this may be a conservative estimate as each fatality was only classified as tree related if enough information was available from *Storm Data* to make that distinction. Previous research by Schmidlin (2009) found that 53% of nontornadic convective wind fatalities were tree related, and of those fatalities, 47% occurred in vehicles and 40% in other outdoor locations. Results of this study were similar, finding that of tree-related fatalities, 51% occurred in vehicles and 36% occurred outdoors. Additional outdoor fatalities were attributed to the collapse of buildings under construction or construction equipment, the victim being struck by flying debris, or the victim being blown down by or off a structure by the wind. Most boating fatalities were due to boats being capsized by the waves generated by the nontornadic convective wind. These boats ranged in size from small pleasure craft to commercial vessels, with the largest boat mentioned in *Storm Data* being ninety feet in length. These fatalities were found in both offshore waters and inland lakes and rivers.

Only fatalities classified as direct were included in this analysis. Direct fatalities are those that are directly attributable to the hydrometeorological event. Descriptions of each fatality provided in *Storm Data* were compared to National Weather Service (NWS) criteria, as specified in NWS Instruction 10-1605 (NOAA 2007), to determine if the fatality was direct or indirect. As a result, 26 fatalities initially identified as storm related were excluded from our dataset and classified as indirect. Most of these fatalities occurred in vehicles when nontornadic convective winds raised dust that reduced visibilities and caused accidents. Additional indirect fatalities were the results of vehicles colliding with

previously felled power poles or trees, or leaving the roadway while swerving to avoid debris. Cases lacking a description of the event or where the circumstances of the event were unclear were also excluded from this analysis.

Spatial examination of nontornadic convective wind, tornado, and nonconvective wind fatalities and occurrence on an 80 km × 80 km grid reveal several patterns (Fig. 6). A primary fatality axis stretches from the Great Lakes to the Northeast and Mid-Atlantic states with a secondary axis across the South and Southeast, including Texas, Louisiana, Alabama, and Georgia (Fig. 6a). Each of the top five states in terms of fatalities falls into one of these fatality corridors with the Great Lakes states of Ohio (59 fatalities), Michigan
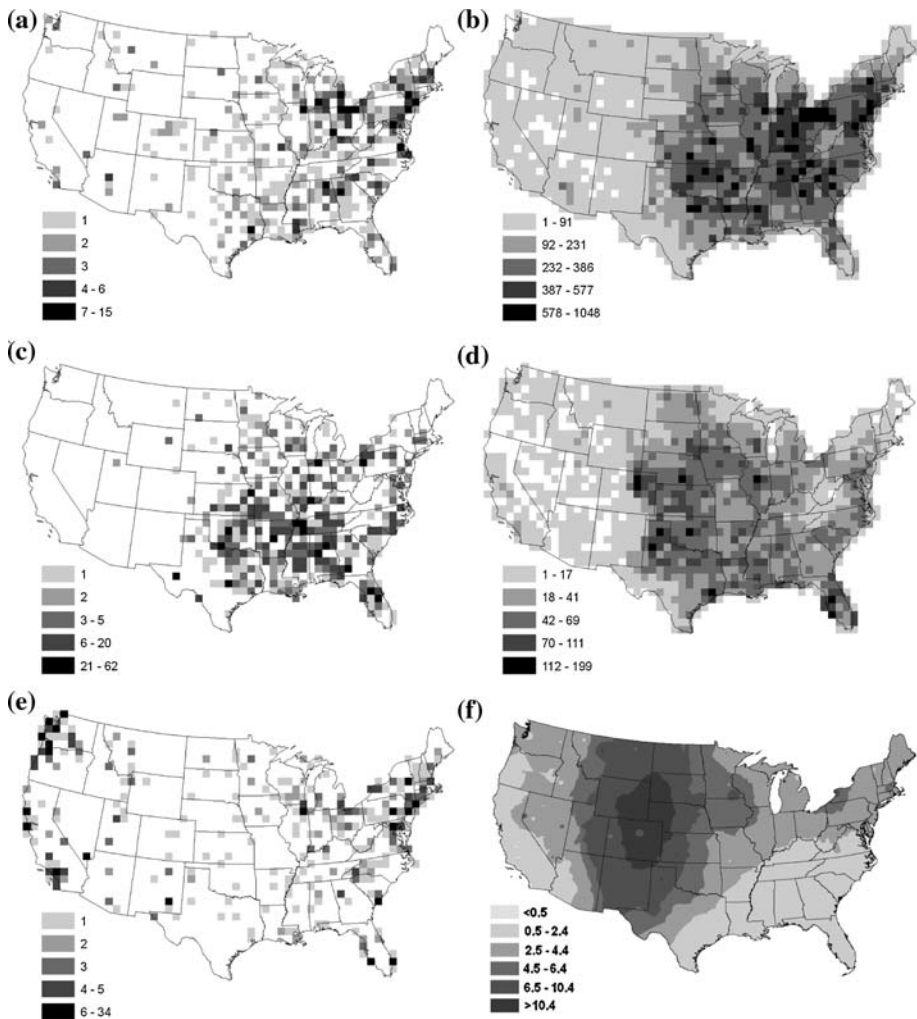
Fig. 6 Number of **a** nontornadic convective wind fatalities (excludes aviation-related fatalities), **b** nontornadic severe convective wind reports, **c** tornado fatalities, **d** tornado touchdowns, and **e** nonconvective wind fatalities in an 80 km × 80 km grid, 1977–2007 Panel **f** illustrates the mean annual occurrences of peak wind gust greater than or equal to 22.35 m s^{-1} (panel derived from data obtained from NCDC's *Climate Atlas of the United States, 2nd ed.* (NOAA 2002))

(58), and New York (42) accounting for 21% of fatalities in the dataset. The other two states in the top five, Texas (48) and Alabama (33), lie within the secondary fatality axis and experience 11% of all nontornadic convective wind fatalities.

The leading states in terms of fatalities share similar characteristics. First, these states are adjoined to large bodies of water and numerous smaller bodies of water, which increases the probability of a boating-related fatality. In addition, the two fatality axes correspond to highly forested areas (cf. Ashley's (2007) Fig. 8c), which enhance the likelihood of a felled-tree fatality. Further, population centers are subject to a greater human vulnerability as larger numbers of people are exposed to the hazard of nontornadic convective wind compared to rural locations. Finally, each of these high-fatality regions (the Northeast, Great Lakes, and the Southeast) coincide with areas associated with an enhanced climatological risk of severe convective winds as shown in Fig. 6b and in prior research (Johns and Hirt 1987; Bentley and Mote 1998; Coniglio and Stensrud 2004; Ashley and Mote 2005; Doswell et al. 2005).

The relative high frequency of nontornadic convective winds in these regions may increase public awareness of the hazard, but it also may cause residents to ignore warnings and not seek shelter (due to complacency) and increase, ultimately, their vulnerability to the hazard. In addition, not all areas of high frequency of nontornadic convective winds correspond to high-fatality regions. For example, the southern Great Plains are frequently subject to these winds but have few recorded fatalities during the period of record. The relatively low frequency of fatalities may be due to lack of large forested areas or bodies of water, or may be due to socio-economic factors present in this region that cause residents to respond to warnings differently than in the other high-frequency areas. Future surveys of residents within these high-frequency and high-fatality areas may help identify socioeconomic factors and attitudes that contribute to the unique vulnerabilities found in these regions.

Similarly, both tornado fatalities and nonconvective wind fatalities are most common outside their areas of highest frequency. Ashley (2007) found that tornado fatalities are most common in the interior South, especially the lower Arkansas, Tennessee, and lower Mississippi River Valleys, while tornado frequency is highest in the Great Plains (Fig. 6c, d). Nonconvective wind fatalities are most common along the West Coast, and in the Northeast and Great Lakes, while the highest frequency of these events is along the Front Range of the Rockies (Fig. 6e, f; also, see Ashley and Black (2008)). The interior South—a region with a high frequency of tornado fatalities—has relatively few nontornadic convective wind fatalities, indicating that the factors that increase vulnerability to tornadoes may have little effect on nontornadic convective wind vulnerability. Nonconvective wind fatalities and nontornadic convective wind fatalities are concentrated in similar geographic regions, such as the Great Lakes and Northeast. This suggests that similar physical and social vulnerabilities may contribute to both nonconvective and nontornadic convective wind fatalities. The lack of nontornadic convective wind fatalities along the West Coast is likely due to the relatively infrequent occurrence of these events in this region (Fig. 6b).

3.2 Aircraft-related fatalities

As previously mentioned, 465 aircraft-related, nontornadic convective wind fatalities were recorded from 1977 to 2007, over twice as many as the next closest fatality "location of occurrence" category of outdoors. An initial examination of *Storm Data* revealed only 29 aircraft fatalities during the period of record; the remaining fatalities were acquired from the NTSB database (Table 1). Several high-fatality events such as the July 9, 1982 crash of Pan Am Flight 759 upon take off from New Orleans, LA and the crash of Delta Flight 191

Table 1 Date, location, and number of fatalities due to aircraft-related nontornadic convective wind, 1977–2007

Date	Location		Deaths	Source
	City	State		
6/12/1980	Valley	NE	13	SD
3/16/1982	San Diego	CA	1	SD
7/9/1982	New Orleans	LA	153	NTSB
8/29/1982	Mediapolis	IA	4	NTSB
1/27/1983	Scottsdale	AZ	6	SD
8/11/1984	Reed	OK	3	NTSB
10/31/1984	Carbondale	KS	3	SD
8/2/1985	Dallas	TX	135	NTSB
10/23/1985	Hamilton	AL	1	NTSB
12/31/1986	Jasper	FL	6	NTSB
7/21/1987	Avery	ID	2	SD
4/1/1988	Henrietta	TX	2	NTSB
11/27/1988	Molino	FL	4	NTSB
6/25/1989	Fort Worth	TX	2	NTSB
7/4/1989	Springfield	TN	1	NTSB
7/8/1989	Louisville	CO	2	NTSB
7/16/1989	Libertytown	MD	3	NTSB
1/16/1990	Appleton	WI	1	NTSB
5/31/1990	Longmont	CO	1	NTSB
8/18/1990	Watertown	WI	7	NTSB
2/18/1991	Thornton	TX	1	NTSB
6/17/1992	Troy	MI	1	SD
7/8/1992	Lolo Pass	ID	2	SD
7/15/1992	Greenville	GA	2	NTSB
6/10/1994	Asheville	NC	1	NTSB
7/2/1994	Charlotte	NC	37	NTSB
8/3/1995	Rehoboth	MA	1	NTSB
8/18/1995	Ardoch	ND	2	NTSB
3/15/1995	Winder	GA	1	NTSB
4/11/1996	Cheyenne	WY	3	NTSB
4/16/1996	Rocky Mount	VA	2	NTSB
4/29/1996	Powelton	GA	2	NTSB
8/2/1996	Grand Canyon Village	AZ	1	NTSB
5/24/1997	Bend	OR	2	NTSB
9/19/1997	Sebring	FL	2	NTSB
8/9/1998	New Hampton	IA	3	NTSB
9/26/1998	Hawthorne	NV	1	NTSB
6/1/1999	Little Rock	AR	11	NTSB
6/25/1999	Mandan	ND	1	SD
8/14/1999	Worcester	VT	3	NTSB
4/3/2000	Lake Charles	LA	1	NTSB
6/5/2000	Howard	CO	2	NTSB
8/14/2000	Ironwood	MI	2	NTSB

Table 1 continued

Date	Location		Deaths	Source
	City	State		
12/2/2001	El Dorado	CA	4	NTSB
5/30/2002	Pleasant Mount	PA	2	NTSB
7/18/2002	Grindstone	PA	2	NTSB
8/28/2003	Grand Marais	MN	2	NTSB
3/21/2004	Pyote	TX	4	NTSB
10/20/2004	Santa Rosa Beach	FL	3	NTSB
6/20/2005	Naples	FL	1	NTSB
6/20/2005	Ft. Pierce	FL	3	NTSB
7/24/2005	West Jordan	UT	3	NTSB
4/19/2006	Ludville	GA	1	NTSB
7/5/2006	Block Island	RI	3	NTSB
9/1/2006	Argyle	FL	1	NTSB
7/9/2007	Tyringham	MA	2	NTSB

Source column indicates where data were obtained, either SD for *Storm Data* or NTSB for the National Transportation Safety Board's Aviation Accident Database

during landing in Dallas, TX on August 2, 1985 were missing from *Storm Data*. Both of these accidents were the result of the aircraft encountering a convective microburst (Fujita 1983, 1986) and were responsible for 288 fatalities or 62% of aircraft-related nontornadic convective wind fatalities. At best, only 6% of aircraft-related nontornadic convective wind fatalities were recorded in *Storm Data*. This further illustrates the need for improvement in the methods used to gather damage and casualty information from weather-related hazards as suggested in several other studies (Curran et al. 2000; Trapp et al. 2006; Ashley 2007; Ashley and Black 2008; Gall et al. 2009).

4 Conclusions

Assessment of the human impact of nontornadic convective winds is essential to improving mitigation of this hazard and has received relatively little attention compared to tornadoes. Analysis of 31 years of US fatality data associated with nontornadic convective wind events illustrates that they are responsible for approximately one in three wind-related deaths. The highest vulnerability to nontornadic convective winds exists from the Great Lakes eastward through the Northeast and Mid-Atlantic States, as well as across areas of the Mid and Deep South. Climatologically, these regions see a high frequency (i.e., risk) of nontornadic convective wind events. Vulnerability is further enhanced in these regions by large forested areas, proximity to bodies of water, and relatively high population densities. Excluding aircraft fatalities, the most common fatality locations are outdoors, in vehicles, and boating, which combined for 81.2% of all nontornadic convective wind fatalities.

This study supports the recommendations of Ashley (2007) and Ashley and Black (2008); namely, that a concerted effort to collect information on all weather-related casualties, both direct and indirect, and damage is needed to improve the watch-warning process, mitigation activities, and reduce casualties. Nontornadic convective wind fatalities are likely underreported as they receive less attention than more prominent windstorms such as tornadoes and hurricanes and because 88% of events result in only one fatality, reducing the likelihood that the fatality will be reported.

This analysis provided a view into the complex human–environment interplay of risk and vulnerability that culminates in human impacts in these nontornadic convective wind events. In addition to increasing our meteorological knowledge of these wind events in the future, gathering a more robust understanding of public perception and response to these hazards will offer the best approach to reducing potential human impacts of these events.

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