NOTES AND CORRESPONDENCE

Fatalities Associated with Nonconvective High-Wind Events in the United States

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ABSTRACT

A database was compiled for the period 1980–2005 to assess the threat to life in the conterminous United States from nonconvective high-wind events. This study reveals the number of fatalities from these wind storms, their cause, and their unique spatial distributions. While tornadoes continue to cause the most wind-related fatalities per year, nonconvective high winds (defined as phenomena such as downslope and gap winds, gradient winds, dust storms, and winds associated with midlatitude cyclones) have the potential to fatally injure more people than thunderstorm or hurricane winds. Nonconvective wind fatalities occur more frequently in vehicles or while boating. Fatalities are most common along the West Coast and Northeast in association with passing extratropical cyclones, with fewer fatalities observed in the central United States despite this region's susceptibility for high-wind gusts. A combination of physical and social vulnerabilities is suggested as the cause for the unique fatality distribution found. More than 83% of all nonconvective wind fatalities are associated with the passage of extratropical cyclones.

1. Introduction

Severe windstorms are responsible for many casualties each year in the United States. While investigations have examined casualties due to tornadoes (e.g., Galway 1975; Brown et al. 2002; Brooks and Doswell 2002; Ashley 2007), severe convective wind events (Ashley and Mote 2005), and hurricanes (Rappaport 2000), no known studies have explored specifically the casualties caused by wind phenomena such as downslope and gap winds, gradient winds, dust storms, and other nonconvective winds associated with extratropical cyclones (hereinafter referred to collectively as "nonconvective" phenomena).

Nonconvective windstorms suffer from a lack of emphasis by the public because of the ambiguity associated with the hazard. Winds associated with tornadoes, hurricanes, and severe thunderstorms have a sense of "essence" or "mass"; that is, they are created by convection that can be witnessed by visual observations or using remotely sensed data. Conversely, nonconvective wind phenomena are not associated necessarily with clouds or precipitation and thus are less likely to be viewed as severe. In addition, nonconvective windstorms tend to occur across much larger spatial and temporal scales in comparison with their convective counterparts, which increases the risk associated with these hazards. In terms of mitigation, a tornado warning has a much greater sense of public urgency than say a high-wind warning. This lack of urgency and awareness may result in people placing themselves in harm's way during nonconvective wind events more so than during convective events.

To illustrate the risk of nonconvective high winds to the U.S. population, this study examines casualties as a result of these events for the 26-yr period 1980–2005. The results herein illustrate the types of storms or phenomena that produce these nonconvective wind casualties using an event-based classification system and highlight the need for more research on these events to improve our understanding of the meteorology, climatology, and hazards of these "low-profile storms." Ultimately, results demonstrate that nonconvective winds are a serious hazard in the United States and are comparable, in terms of fatality numbers, to more recog-

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nized wind hazards, such as hurricanes, severe thunderstorms, and tornadoes. A more thorough analysis of fatalities associated with nonconvective winds is essential to improving education and mitigation efforts concerning these overlooked atmospheric hazards.

2. Methodology

Data for reported casualties produced by nonconvective winds, severe thunderstorm winds, tornadoes, hurricanes, and other wind phenomena were obtained for the period 1980–2005. From 1993 to 2005, casualty data were acquired from the National Climatic Data Center's Storm Events online database (available online at http://www4.ncdc.noaa.gov/cgi-win/wwcgi.dll?wwEvent~Storms), which is derived from the *Storm Data* publication. From 1980 to 1992, data were transcribed from *Storm Data*. Since 1959, *Storm Data* has been the primary source of severe weather event data for climatologists, meteorologists, and hazard scientists examining past severe storm events. *Storm Data* contains the best information available for these hazards since it has been compiled using similar procedures since 1959; however, it is not all inclusive because of variations and problems inherent in the collection of these types of data (e.g., Doswell and Burgess 1988; Curran et al. 2000; Brooks and Doswell 2001; Brooks and Doswell 2002; Trapp et al. 2006). As a whole, casualty data associated with tornado and hurricanes may be the more complete aspect of the historical record because of the high-profile nature of these events. Thus, casualties caused by severe thunderstorm winds and, more so, nonconvective winds may be underreported, although we have no available and competing dataset to support this argument.

Nonconvective winds were often referred to as "high wind" in *Storm Data*; however, other terms, such as "strong wind" or "gusty wind," were also found. Other common categories of wind found in *Storm Data* were "blowing dust," "dust storm," "heavy surf," and "heavy seas." For all categories, the event description that accompanies most reports within *Storm Data* was employed to determine if the event occurred in a convective or nonconvective environment. Events occurring in a nonconvective environment were included in these data, and those occurring in a convective environment (e.g., "tornado" or "severe thunderstorm wind") *or* with unknown circumstances were excluded.

The decision on inclusion or exclusion of casualties due to nonconvective wind in this study was made as judiciously as possible. In most cases in the dataset, the casualties were induced undoubtedly by nonconvective wind events. In other instances, identifying and classifying nonconvective wind casualties were not as obvious. For example, dust storm and blowing dust casualties were included in our dataset because the hazard (the blowing dust) was created when nonconvective winds picked up the dust and the fact that the hazard would not have been present without the wind. Casualties caused by outflow winds and associated haboobs from high-based thunderstorms were excluded in our tallies. For the "heavy surf" and "heavy seas" categories, only events in a nonconvective environment where the circumstance of the casualty involved a boat (e.g., a boat was capsized by the high winds) were included; circumstances in which a boat was not involved (e.g., a fisherman was swept from a pier by waves or a swimmer drowned in heavy seas or in a rip current) were not included. Casualties associated with blowing snow were also included for the same reason as the blowing-dust casualties, but only if it was obvious from the description in *Storm Data* that snow had fallen and then been blown by the wind, reducing visibilities. Casualties occurring when snow was falling at the time of the casualty or with unknown circumstances were not included. We understand that there may be some debate about what should or should not be included in the nonconvective wind casualty dataset; however, we feel after examining each individual case in detail that we have made the most logical decisions regarding the classifications.

To assess spatially the risk associated with nonconvective winds, the geographic location for each casualty event was recorded. When specified in *Storm Data*, the city where the casualty occurred or the city nearest to the casualty location was utilized to find the latitude and longitude. For events for which only a county (or parish) was specified, the latitude and longitude of the county seat were used. Casualties were classified further by the place or "setting" (e.g., mobile home, permanent home, outdoors, etc.) where the death or injury occurred. Within each category, these data were separated further into deaths that were related to falling trees and those that were not. Unless a tree was mentioned specifically in the description, the death was assumed to be unrelated to a tree. Indirect or "secondary" nonconvective casualties due to, for example, heart attacks and debris cleanup are not included in this analysis.

Last, nonconvective windstorm morphologies were analyzed to assess the meteorological phenomenon associated with each fatality. The analysis included examination of 1200 UTC synoptic-scale surface features and 500-hPa height patterns from National Oceanic and Atmospheric Administration's *Daily Weather Map Se-*

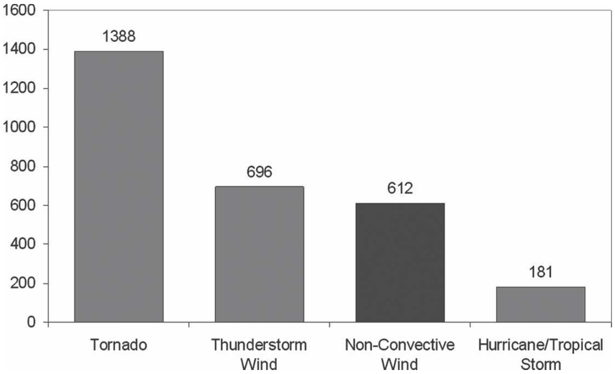

FIG. 1. Fatalities due to various wind-related hazards, 1980–2005. Tropical system fatalities only include those deaths due to wind.

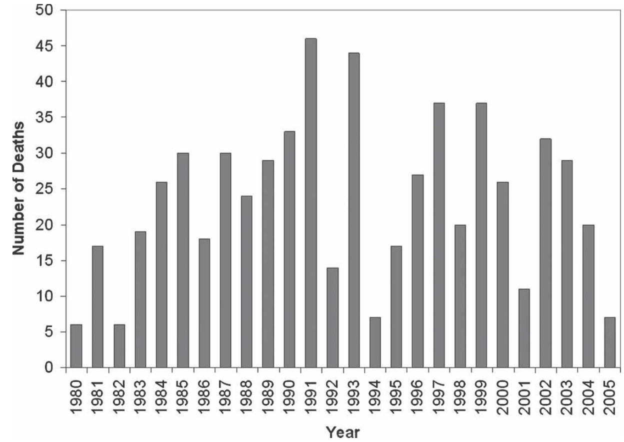

FIG. 2. Number of nonconvective wind fatalities by year, 1980–2005.

ries (available online at http://docs.lib.noaa.gov/rescue/dwm/data_rescue_daily_weather_maps.html). Placement and movement of midlatitude systems, frontal boundaries, tropical systems, and upper-level troughs and ridges from the *Daily Weather Map Series* were examined to classify each deadly-wind-producing phenomenon. The classification of each event is a subjective procedure, so a decision tree was created to ensure the process was as objective as possible. Conditions on the day of the fatality, as well as the day previous and following, were examined to determine if the event was caused by a midlatitude cyclone, downslope or gap winds, extreme gradient wind, or a postfrontal wind event.

3. Results

a. Fatality tallies and distributions

There were 616 fatalities and 2865 injuries *recorded* as due to nonconvective high winds for the 26-yr period of record. These 616 fatalities account for 21.4% of all fatalities caused by wind phenomena during this time. For the same period, 1388 deaths were recorded as due to tornadoes and 696 as due to other nontornadic convective high-wind events (Fig. 1). Thus, at least in terms of fatalities, nonconvective high winds are a comparable hazard to convective straight-line wind events that are associated with derechos (Ashley and Mote 2005) and other thunderstorm wind phenomena (see Fujita and Wakimoto 1981 for examples). In fact, during 1990–2005, the number of fatalities associated with nonconvective winds was greater than that associated with straight-line thunderstorm winds.

Convective and nonconvective straight-line wind fatalities represent a combined 45.5% of all wind-related fatalities, illustrating that these events are as comparable a threat to humans as the more prominent (in terms of research, media, and the public's perception of a hazard) tornado phenomenon. The low tally associated with hurricanes is somewhat surprising, but Rappaport (2000) has illustrated in an analysis of 30 yr of hurricane fatality data that only 12% of tropical cyclone fatalities are due solely to tropical cyclone winds. Inland freshwater flooding is responsible more than one-half of U.S. deaths directly associated with tropical cyclones (Rappaport 2000).

The number of nonconvective wind fatalities per year varied from 6 in 1980 and 1982 to 50 in 1991, with an average of 23.7 per year (Fig. 2). There is a large amount of variability in the number of fatalities and there is no discernable trend in the number of deaths per year like that observed with tornadoes (see Brooks and Doswell 2002; Ashley 2007). Temporally, nonconvective wind deaths are most frequent in March, with a secondary maximum in November (Fig. 3). These maxi-

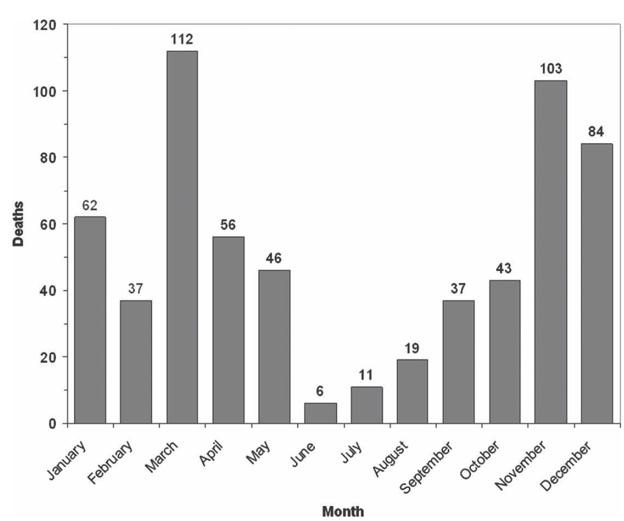

FIG. 3. As in Fig. 2, but by month.

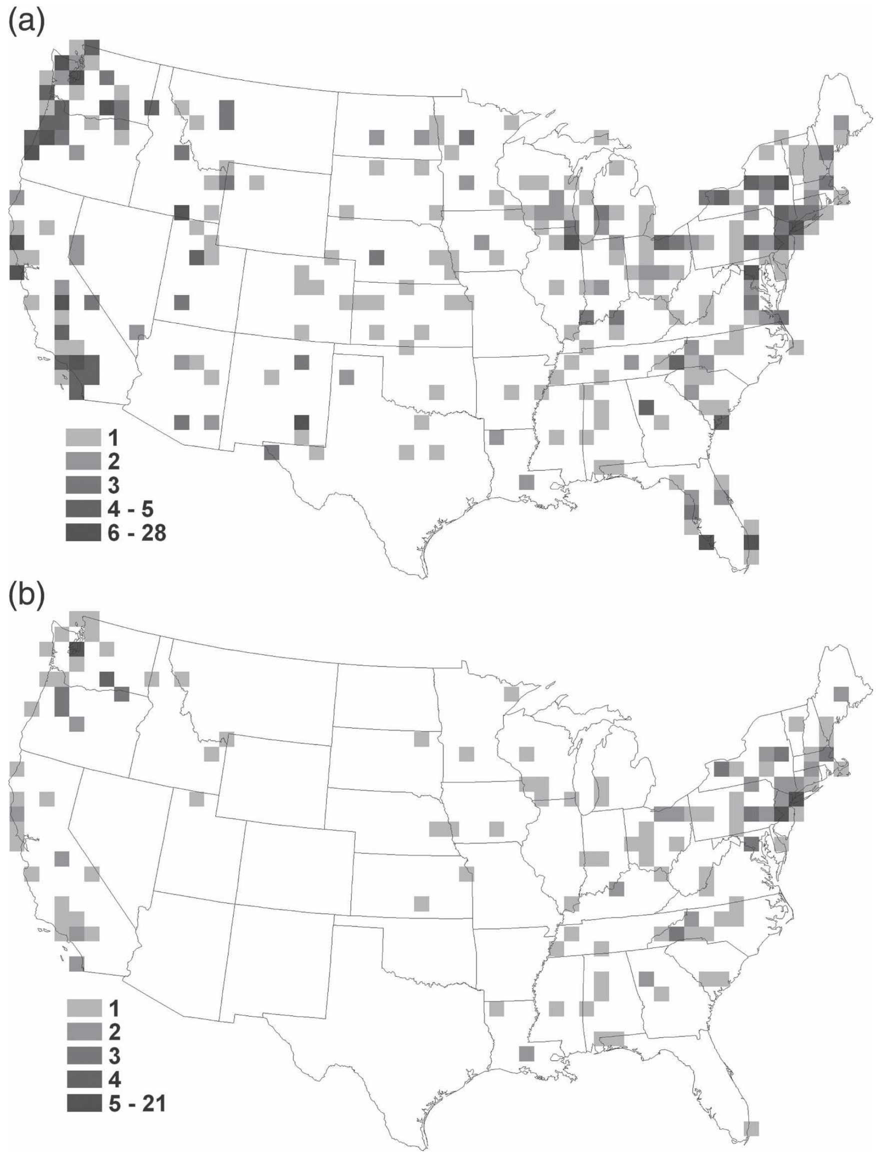

FIG. 4. Number of (a) nonconvective wind fatalities and (b) tree-related nonconvective wind fatalities in an 80 km × 80 km grid, 1980–2005.

mums are likely due to the enhanced frequency and strength of midlatitude cyclones during the transition seasons (Sanders and Gyakum 1980; Carlson 1998).

Several unique trends and region-specific vulnerabilities are revealed in these data when they are examined spatially (Fig. 4a; Table 1). Three western states, California (96 fatalities), Oregon (46), and Washington (66), account for 33% of all fatalities in the dataset. The Northeast has a relatively high number of fatalities with New York (57 fatalities), Pennsylvania (23), Connecticut (8), New Jersey (11), Maryland and Washington, D.C. (12), and Delaware (1) accounting for 18% of all fatalities during this period. Standardizing the state tallies by area illustrates the states with the highest vulnerability to nonconvective wind fatalities (Table 1). Three Northeast states, Connecticut, New Jersey, and New York, lead in terms of normalized fatalities. Climatologically, the Northeast is a favored region for powerful midlatitude cyclones that can produce intense pressure gradients and, in turn, strong nonconvective wind gusts in all quadrants of the storm system.

Collectively, the Northeast and West Coast regions are responsible for more than half of all nonconvective wind fatalities in the conterminous United States. Both of these regions have large forested areas (Fig. 5a) and large bodies of water nearby that may combine to in-

TABLE 1. Number of nonconvective wind fatalities and standardized fatalities (deaths per square kilometer × 10 000) by state, 1980–2005. Cells with numbers in boldface indicate top five for their respective categories.

State	Deaths	Standardized deaths by state area
AL	6	0.441 94
AR	2	0.145 21
AZ	9	0.304 822
CA	**96**	2.264 311
CO	5	0.185 459
CT	8	**5.572 195**
DE	1	1.551 109
FL	**28**	1.644 119
GA	6	0.389 841
IA	3	0.205 842
ID	16	0.739 214
IL	17	1.133 348
IN	8	0.848 167
KS	6	0.281 563
KY	8	0.764 387
LA	4	0.297 921
MA	3	1.097 454
MD/DC	12	**3.714 02**
ME	7	0.763 809
MI	11	0.438 708
MN	9	0.399 696
MO	1	0.055 392
MS	1	0.079 723
MT	8	0.210 065
NC	14	1.004 383
ND	6	0.327 668
NE	8	0.399 311
NH	4	1.6518
NJ	11	**4.869 842**
NM	12	0.381 055
NV	6	0.209 533
NY	**57**	**4.033 999**
OH	16	1.378 17
OK	1	0.055 238
OR	**46**	1.805 302
PA	23	1.928 188
SC	11	1.326 388
SD	4	0.334 082
TN	4	0.366 465
TX	9	0.129 195
UT	9	0.409 301
VA	15	1.353 974
VT	3	1.204 771
WA	**66**	**3.574 039**
WI	13	0.766 333
WV	1	0.159 35
WY	2	0.078 932

crease the probability of a felled tree, vehicular, and/or boating-related fatality. In addition, these regions have high population densities, which increase the likelihood that fatalities will occur because of these windstorms. These regions generally have a low likelihood of severe weather as compared to areas such as the Great Plains (including traditional "Tornado Alley"), the Midwest, and the South (Brooks et al. 2003; Doswell et al. 2005). In addition, the Northeast and West Coast are regions that tend to be frequented rarely by strong winds (Fig. 5b). Though high-wind events tend to be rare in these locations, they can be particularly intense when they do occur because of their association with strong extratropical cyclones. As a result, there may be a decreased awareness that may lead ultimately to an enhanced vulnerability to these high-wind events in these areas. Thus, these regions appear to have a unique combination of physical and social vulnerabilities that explain partially the relatively high distribution of fatalities. Conversely, regions such as the Intermountain West and high plains are routinely buffeted by high winds, which may lead to a greater awareness of these hazards. In addition, these regions contain large areas with either no forest cover or trees with high-wind resistance, which may tend to reduce the probability of felled trees in these "windy" regions. In the end, this reduced vulnerability is revealed in the lack of fatalities in these areas despite the regions' climatological wind gust maximums.

One of the more important aspects of hazard analysis is illustrating risk, or probability, of a particular hazard. Unfortunately, it is difficult, if not impossible, to compare the frequency or climatology of tornadoes and other convective winds to that of nonconvective winds because there are no formal datasets of nonconvective wind reports beyond that reported in *Storm Data* (e.g., see http://www.spc.noaa.gov/climo/historical.html for comparable tornado and severe thunderstorm datasets). In addition, nonconvective winds occur over much larger spatial and temporal scales compared to thunderstorm phenomena, making it difficult to identify specific "storm reports" required to generate a climatology. A few studies are beginning to emerge examining nonconvective wind phenomena (e.g., Niziol and Paone 2000; Browning 2004; Knox 2004; Martin and Konrad 2006), but these investigations tend to focus exclusively on midlatitude cyclone winds and/or specific locales. Hence, there is a need for future research to continue to evaluate the climatology and risk of nonconvective wind phenomena.

b. *Location of fatality occurrence*

When examining nonconvective wind fatalities by location of occurrence, vehicle-related deaths account for 43% of all fatalities (Fig. 6). This is similar to the findings of Ashley and Mote (2005), who noted that over 50% of fatalities from derechos occurred in vehicles or boats. Conversely, over 70% of tornado fatalities occur *within* housing structures and less than 10% of tornado

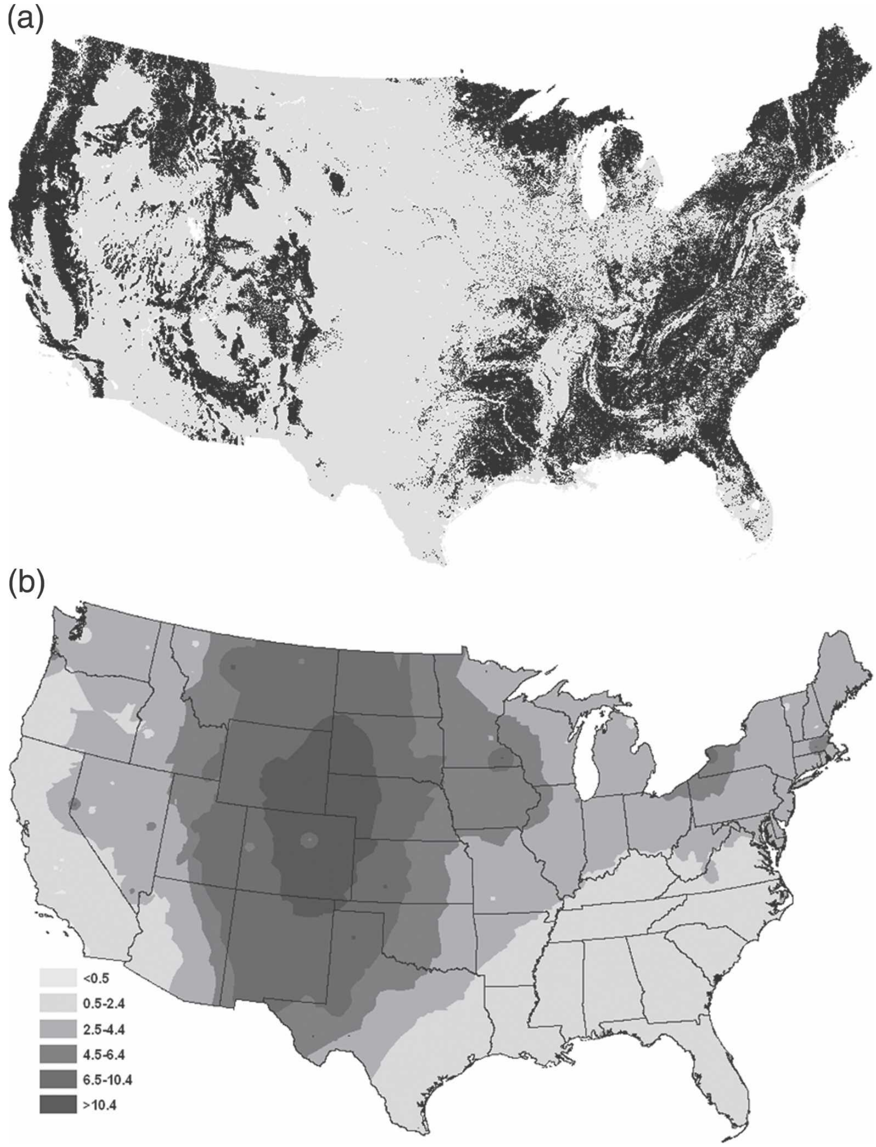

FIG. 5. (a) Forest cover (solid black) for the United States as determined by Advanced Very High Resolution Radiometer (AVHRR) data (http://nationalatlas.gov/articles/biology/a_forest.html) and (b) mean annual occurrences of peak wind gust greater than or equal to 22.35 m s^{-1} [map derived from data obtained from National Oceanic and Atmospheric Administration (2002)].

fatalities occur in vehicles or boats (Ashley 2007). These comparisons illustrate that people are more likely to take shelter in a tornadic situation in contrast with convective or nonconvective straight-line wind scenarios. In addition, a tornado is generally a visible, relatively "small" wind event, which can be recognized and avoided by those in vehicles.

Over 82% of all nonconvective wind vehicle fatalities were in passenger cars or pickup trucks, with only 6% occurring in tractor trailers and the remaining 12% taking place in other vehicle types (e.g., recreation vehicles, buses, motorcycles). Felled trees onto vehicles and vehicles striking felled trees represent 44% of fatalities associated with vehicular-related fatalities. These vehicular tree-related fatalities are primarily found near the Pacific coast, and generally along and east of the Mississippi River (not shown), illustrating the enhanced vulnerability of forested regions. Blowing dust and snow compose 28% of vehicle fatalities. Of 73 vehicle deaths involving blowing dust or snow, only 11 were a result of blowing snow, while 62 were a result of blowing dust. Most of these fatalities were in the west-

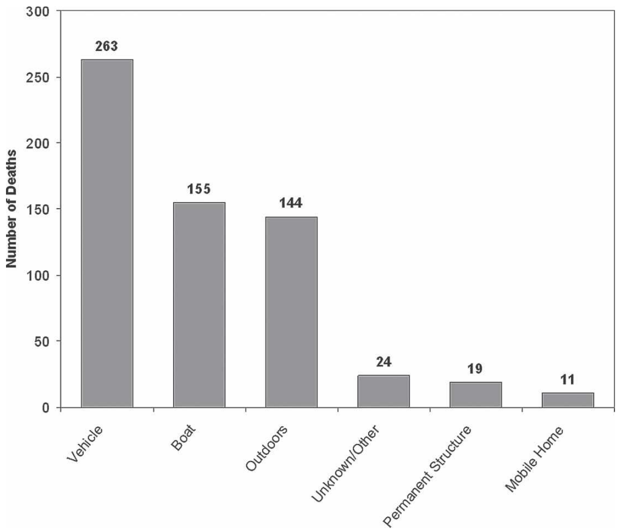

FIG. 6. Number of nonconvective wind fatalities by location of occurrence.

ern United States, with a few blowing snow–related fatalities in New York, the only blowing dust or snow fatalities recorded in the eastern United States.

Boating fatalities represent 25% of all nonconvective fatalities. California and Florida had the greatest number of nonconvective wind deaths in boats, with 25 (16% of boating fatalities) and 23 (15%), respectively. A large number of boating fatalities were noted along the West Coast and Northeast (not shown). Although more fatalities occurred in vehicles, boating fatalities caused the most deaths per event. Of 110 boating events causing at least one fatality, 38 of these cases caused two or more fatalities (35%). Of 192 events in vehicles with at least one fatality, only 29 events caused two or more fatalities (15%).

Fatalities occurring outdoors make up 23% of nonconvective fatalities. Felled trees caused 40% of the reported deaths outdoors, with 31% of outdoor fatalities produced by flying debris, and 19% occurred at construction sites where equipment or buildings under construction were felled by winds.

Deaths due to nonconvective high winds for which felled trees were involved were examined in greater detail because of their association with an enhanced vulnerability. Deaths for which felled trees were involved accounted for 33% of the total. Additional fatalities, and thus a greater percentage of deaths, may have been produced by trees, but only those cases that had descriptions with enough information to deduce that a fatality was in some way caused by a tree are included in this analysis. Forested areas of the United States (Fig. 5b) correspond closely to the areas with the highest numbers of tree-related deaths (Fig. 4b), illustrating the enhanced vulnerability of these forested regions.

c. *Deadly nonconvective windstorm morphologies*

Nonconvective severe winds are produced by extreme pressure gradients. These pressure gradients may be caused by terrain effects, temperature gradients, or the passage of a mesoscale or synoptic-scale systems. In this section, we utilize archived daily surface and 500-hPa charts for the period surrounding deadly nonconvective windstorms to determine what "storm" types were the primary genitors of fatalities. Five different windstorm classifications were used, including extratropical cyclone winds, post–cold frontal winds, extreme pressure gradient winds (occurring external to surface features, i.e., fronts, surface lows, etc., associated with midlatitude cyclones), downslope and/or gap winds, and unknown (three fatalities).

Any fatalities occurring at a location and during the same day as the passage of a midlatitude cyclone or affiliated fronts were classified as midlatitude cyclone-induced fatalities. These extratropical systems were responsible for 76.3% of nonconvective wind fatalities during the 26-yr period. An additional 6.7% of nonconvective fatalities were considered "post–cold frontal" and were associated with the winds occurring at least *one day after* the passage of a midlatitude cyclone's cold front. Therefore, including this subgroup, extratropical cyclone phenomena were responsible for nearly 83% of all fatalities in the dataset. "Gradient" winds account for an additional 10.9% of nonconvective wind fatalities. Events were classified as gradient wind when it was clear that a strong pressure gradient existed on the surface chart that was not related directly to features associated with a midlatitude cyclone.

Downslope or gap (venturi) winds, or winds generated by terrain effects, were responsible for only 5.7% of nonconvective wind fatalities during this period. For this classification, events were categorized as being terrain-induced if the event was categorized as generated orographically by its description in *Storm Data* (e.g., Santa Ana winds) or if the event was in close proximity to terrain and if the event did not fall into the extratropical cyclone or gradient wind categories. While terrain-induced winds are not unique to California, all of the fatalities caused by these winds during this study's period of record occurred in this state.

4. Conclusions

The assessment of the human impact of nonconvective high-wind events has attracted far less attention than effects caused by tornadoes or other convectively generated high-wind phenomena. Analysis of 26 yr of casualty data associated with these events illustrates that nonconvective windstorms cause as many fatalities as straight-line winds associated with severe thunderstorms and far more than winds associated with tropical cyclones. Spatial examination of the fatality distribution suggests that the greatest vulnerability to nonconvective high-wind events exists along the Northeast and West Coasts. These areas have a unique combination of factors, including large forested areas, large bodies of water, relatively high population densities, and infrequent but strong extratropical cyclones that contribute to the increased vulnerability. Most fatalities (68%) associated with nonconvective winds occur in vehicles or boats. Further analysis of vehicle fatalities illustrated that the majority of vehicle fatalities associated with high winds occurred when trees were felled onto vehicles and when blowing dust reduced visibilities, causing accidents. Winds associated with extratropical cyclones cause more than four-fifths of all nonconvective wind fatalities.

While many procedures and educational programs are already in place in an attempt to mitigate the hazards associated with convective high winds, few organized programs exist to cope with the hazards presented by nonconvective high winds. The efficiency of the current high-wind warning system is hampered because these advisories last much longer and cover much greater areas than typical convective warnings, which, in addition to the perception of the events as a nonhazard, may lead to inaction and complacency by the public. Nevertheless, there are still cases where simply improving the "call to action" statements by highlighting specific vulnerable activities and areas within high-wind advisories and warnings could be utilized to reduce future casualties. For example, specific wording in advisories and warnings targeting boaters and those who are outdoors in areas with trees may aid these groups in taking appropriate safety precautions, or convince these groups to avoid outdoor activities, minimizing their risk. In areas prone to blowing dust, specific wording could be added to advisories or road signs to make motorists aware of this hazard. Educating specific groups, such as boaters, campers, hikers, and others who regularly use outdoor areas or forested regions, about the hazards of convective *and* nonconvective high winds may reduce casualties by making people more aware of the risk posed by these events. While many of these suggested practices do exist (in varying degrees of effectiveness), on the whole, there should be a much greater focus on education and mitigation activities for these often unperceived hazardous events.

In summary, the results of this analysis indicate that nonconvective high winds have the potential to be as deadly as more prominent convective hazards, such as tornadoes, derechos, and hurricanes. Again, it is likely that the nonconvective wind casualties within this study are conservative tallies because these events and their impacts are less likely to be recorded than more notable windstorms, such as tornadoes and hurricanes. Meteorologists should make a concerted effort to report and document fully *all* future weather-related casualties and damages because such information is critical to improving future watch-warning activities and saving lives. Ultimately, an increased awareness of the hazard of nonconvective high winds will allow forecasters, policy makers, and the public to make informed decisions to mitigate this hazard.

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