Science of the Total Environment 797 (2021) 149199

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

The individual and synergistic impacts of windstorms and power outages on injury ED visits in New York State

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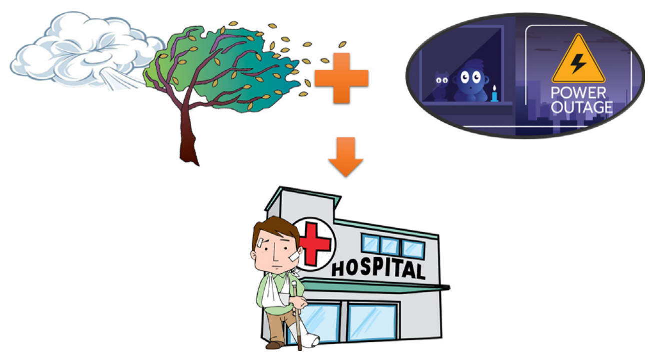
HIGHLIGHTS

- Co-occurrence of PO and wind event is associated with increases in injury ED.
- People who were 65 and older and on Medicaid were more vulnerable.
- Wind events and power outages related ED visits of injuries were more serious.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 5 May 2021
Received in revised form 13 July 2021
Accepted 18 July 2021
Available online 21 July 2021

Editor: Jay Gan

Keywords:
Windstorm
Power outages
Health risk
Injuries

ABSTRACT

Background: There is little work in assessing the impact of storm events combined with power outage (PO). In this study, we evaluated the individual and synergistic impacts of wind events and PO on overall and subtypes of injuries in New York State (NYS) and by demographics.
Methods: The emergency department (ED) visit data were obtained from the NYS Department of Health from November–April 2005–2013 to identify injury cases, length of stay and care costs. Wind event was defined according to high wind, strong wind or thunderstorm wind defined by NOAA. PO occurrence was defined when PO coverage exceeded the 50th percentile of its distribution. By comparing non-event days, we used distributed lag nonlinear models to evaluate the impacts of wind events, PO, and their combined effect on injuries during the cold season over a 0-3-day lag period, while controlling for time-varying confounders. The differences in critical care indicators between event and non-event days were also evaluated.
Results: Overall injuries ED visits (16,628,812) significantly increased during the wind events (highest Risk Ratio (RR): 1.05; 95% CI: 1.02–1.08), and were highest when wind events cooccurred with PO (highest RR: 1.14; 95% CI: 1.10–1.18), but not during PO alone (RR: 1.00; 95%CI: 0.96–1.04). The increase was also observed with all subgroups through Day 2 after the event. Greater risks exist for older adults (≥65 years) and those on Medicaid. After the joint occurrences of wind events and PO, average visits are 0.2 days longer, and cost 13% more, compared to no wind/no PO days.
Conclusion: There is a significant increase in ED visits, length of stay and cost of injuries during wind events, especially when they coupled with PO and especially among older cases and Medicaid holders. Our findings may be used for planning disaster preparedness and recovery efforts.

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https://doi.org/10.1016/j.scitotenv.2021.149199

1. Introduction

One of the most substantial atmospheric hazards is the occurrence of damaging winds (Goldman et al., 2014; Tamura and Cao, 2012; Ashley and Black, 2008; Cugnoni and Whitworth, 1992). Damaging-wind events, or windstorms, can be associated with direct impacts on humans and infrastructure, through the sheer force of the wind creating flying debris and felling trees, which can either directly strike people, damage the built environment, and else lead to an increase in traffic accidents (Goldman et al., 2014). Indirectly, humans can be impacted in the wake of damaging wind events as well, due to the debris that remains, as well as injuries from cleaning up (Saulnier et al., 2017).

Strong winds can arise due to a variety of meteorological situations. Some of the broadest impacts can be observed through tropical cyclone systems and tornadoes, and case studies of such events are common (e.g., Tamura and Cao, 2012). Within the middle latitudes, however, extreme winds can also arise due to severe thunderstorms as well as extratropical cyclones. While the most damaging extratropical cyclones are typically the rapidly deepening cyclones, or "bomb cyclones", across the northeastern US (e.g., Zhang et al., 2020a, 2020b) it has been shown that more ordinary cyclones have a greater overall incidence of high-wind events (Booth et al., 2015); further, there are several different meteorological mechanisms associated with the development of extreme winds within extratropical systems (e.g., Knox et al., 2011).

Collectively, these less-studied extratropical situations can be as deadly as tropical systems or broad scale severe weather outbreaks. Of all wind-related fatalities, Ashley and Black (2008) found that non-convective (not associated with thunderstorms) winds were associated with 616 deaths across the US from 1980 to 2005, over 20% of the total associated with the wind. Looking specifically at the 407 known fatalities due to fallen trees within the US between 1995 and 2007, Schmidlin (2009) shows that thunderstorms (41%) and non-convective winds (35%) together are associated with far more fatalities than tropical cyclones (14%) and tornadoes (7%). Due to the complex nature of high-wind origins and their difficulty in forecasting, over 23% of wind fatalities due to tornadoes and 53% of non-tornadic wind-related fatalities did not have associated warnings by the National Weather Service between 1986 and 2007 (Black and Ashley, 2011). Moreover, between 1996 and 2013 more than 74% of all fatalities and injuries in the US associated with wind were associated with peak gusts below the high-wind warning criteria as defined by the NWS, with 28% below the lower wind-advisory threshold (Miller et al., 2016).

Within the modern world, one of the most concerning impacts of high-wind events are power outages (PO), as electricity infrastructure is damaged through fallen trees and debris as well (Panteli et al., 2017). The loss of power has been shown to compound the impacts of extreme heat on human health (e.g., Conlon et al., 2011; Dominianni et al., 2018; Gasparrini et al., 2015), winter storms (Zhang et al., 2020a, 2020b; Degelia et al., 2016; Call, 2009), and extreme cold (Dominianni et al., 2018; Phung et al., 2016), generally through increased cardiovascular and respiratory ailments. Power outages associated with wind events can increase vulnerability to injuries as well, along with carbon monoxide poisonings, electrocutions, and the worsening of chronic medical conditions (Goldman et al., 2014).

High-wind events based on wind gust criteria have increased in the US in recent decades (Gilliland et al., 2020) and wind is likely to become increasingly hazardous in terms of intensity and frequency in the future (Tamura and Cao, 2012). Nearly all of the research cited in Goldman et al. (2014) that examine the collective detrimental impacts of power outages and wind on health have used tropical cyclones or tornadic outbreaks as case studies. Given the broad health impacts of wind that have been identified outside of such events, using hospital admissions data we analyze the individual and joint effect of wind and power outages (PO) on emergency department (ED) visits for injuries for New York State, one of the most vulnerable areas in the US for non-convective fatal winds (Ashley and Black, 2008), for the period 2005–2013. We focus on the colder time of year (November to April) as impacts of wind events during this time of year is less well studied than wind impacts during the summer, which are dominated by convective systems.

2. Methods

2.1. Health data

Hospital admissions data were obtained from the New York State (NYS) Department of Health Statewide Planning and Research Cooperative System (SPARCS), which we have used in our previous research (Fitzgerald et al., 2014; Garcia et al., 2010). The SPARCS database covers 95% of hospitals in NYS and each record includes personal information for each patient, such as sex, age, race, and ethnicity; as well as medical data such as dates of admission and discharge, health insurance, and the ICD code for the principal diagnosis and up to 24 comorbidities.

We initially obtained all emergency department (ED) visits, both inpatient and outpatient, related to accidents (ICD9 code E) within the SPARCS data set for the period 2005–2013. Within this broad category, we also created subsets related to the most plausible wind-related injury ICD9 codes:

- Motor vehicle accidents (E810-E825)
- Accidental falls (E880-E888)
- Accidents due to natural and environmental factors, including heat, cold, lack of food, lightning, animal bite, or direct storm impact (E900-E909)
- Accidents caused by submersion and other accidents, including being struck by an object, overexertion, and trauma from repetitive motion (E910,916,917,918,926,927)

The residential address of each case was assigned to one of the 1742 operating divisions of the electricity network across NYS, as defined by NYS Department of Public Service (Fig. S1). The outcome variable of interest is the sum of the daily number of ED visits for each category of analysis for each operating division. The methods for processing these data are fully discussed in Zhang et al. (2020a, 2020b).

2.2. Wind and power outage data

We obtained all wind events from 2005 to 2013 from all the storm data or local storm reports in New York State compiled in the National Oceanic and Atmospheric Administration (NOAA) Severe Weather Data Inventory (https://www.ncdc.noaa.gov/stormevents/). This storm data documents the occurrence of storms and other significant weather events having sufficient intensity to cause loss of life, injuries, significant property damage, and/or disruption to commerce. The definition of wind events defined by NOAA was also used in this study, i.e., inclusive of the categories of the more extreme *High Wind or Strong Wind*, both associated with non-convective wind events, or *Thunderstorm Wind* related to convection. Specifically, ***High Wind*** was defined as sustained non-convective winds of 35 knots (40 mph) or greater lasting for 1 h or longer, or gusts of 50 knots (58 mph) or greater for any duration (or otherwise locally/regionally defined). ***Strong Wind*** was defined as non-convective winds gusting less than 50 knots (58 mph), or sustained winds less than 35 knots (40 mph). ***Thunderstorm Wind*** was defined as winds, arising from convection (occurring within 30 min of lightning being observed or detected), with speeds of at least 50 knots (58 mph), or winds of any speed (non-severe thunderstorm winds below 50 knots). Commensurate with the climate of the region, as our study focuses on November to April, the wind events included in this study are nearly all non-convective in nature. These specific definitions can be found at https://www.ncdc.noaa.gov/stormevents/details.jsp. We geocoded each event record to the operating division.

We acquired power outage (PO) data from the NYS Department of Public Service (https://www.dps.ny.gov/). These data include the total number of customers in each of the r power operating divisions (with an average population of 11,061 per division, Fig. A1), along with the date of a PO and the number of customers affected by the PO within each division. For each division on each day, we computed the PO coverage as the percent of customers affected. Then among all the records (i.e. division*day) with PO coverage >0, we chose the 50th percentile of PO coverage as the threshold. We defined PO occurrence for each record (i.e. division*day) based on whether the PO coverage exceeded the threshold. Since there is no established criterion regarding the cutoff value of PO coverage, the 50th percentile was used as the threshold in this study. This criteria has been used in multiple published studies (Zhang et al., 2020a, 2020b; Lin et al., 2021) and is stricter than a previous PO study in New York City led by Dominianni et al. (2018).

2.3. Study design and statistical analysis

To analyze the temporal impacts of PO and wind events on injuries, we used the distributed-lag nonlinear models (DLNM) framework developed by Gasparrini et al. (2010). As there is little previous research in the area, we employ the DLNM because it can identify not only the immediate impacts of PO and wind events on injuries, but also readily identify temporally lagged impacts as well. As we are primarily concerned with cold-season hazards, since summertime convective activity can lead to very irregular patterns of wind damage, we only examine November to April herein.

For each operating division in NYS, we ran different DLNM models for each of the different outcome variables (injury ED visits) described above. Each model includes a categorical predictor indicating the type of days (e.g. days with PO only, days with wind events only, days with both, days with neither). We thus were able to test the relative risk of injury ED visits for three different occurrences: wind events without power outages, power outages without wind events, and winds event combined with power outages. In all three cases, the reference condition was days with neither a power outage nor a wind event.

In previous studies, we fitted curves to model up to 6 days of lag between event and impacts, when such impacts included different medical conditions (Zhang et al., 2020a, 2020b). In this study, due to the nature of injuries that would lead to an ED visit being more likely to occur in the immediate wake of the event, we used the same model as in our previous study (Lin et al., 2021) but only considered lag days up to 3 days. Included in each model are confounders, which include splines to fit daily mean temperature (3 df), mean humidity (3 df), both from the integrated surface database (ISD) of NOAA, and time to control the long-term trend (4 df for the dates and 4df for the variable indicating day of the year as described in Gasparrini, 2020); alongside indicator variables for day of the week and holidays to remove potential temporal patterns. While we initially explored the role of PM2.5 as a potential confounder, this was found to have no impact and thus was excluded from the final model. For each power operating division, atmospheric conditions were assigned based on the station nearest to the centroid of the division. Division-level estimates were then pooled to an overall risk ratio (RR) for New York State with fixed effect meta-analyses which was commonly used in environmental health studies (e.g., Rich et al., 2019; Zhang et al., 2018).

We compared the critical care indicators between the exposure and non-exposure periods using the mean comparison based on bootstrap resampling methods and multivariate regression models as described in Zhang et al. (2020a, 2020b). We ran these time-series analyses for each of the five different injury subtypes, for PO, wind, and combined PO/wind, for lags of 0-3 days, and for each SES group. We also compared the length of hospital stay and total cost between the event and non-event days to further understand the health impact of PO/wind events. Sensitivity analyses were also performed to ensure the robustness of the results. These analyses changed the df for splines of temperature, humidity, and time trend, with minimal impact on overall significance of results. All analyses were performed in R 3.5.1 (https://www.r-project.org/) using the *dlnm* and *metafor* packages.

3. Results

A total of 2111 wind events occurred in New York State during the cold seasons (November–April) of 2005–2013, with an increase observed over the course of the period of study. Nearly all of these are non-convective in nature, and wind is the second largest cold-season hazard in NOAA's database after winter storms. Fig. 1 shows the percentage of wind events, power outages, and their joint occurrence in New York for the study period, 2005–2013. Overall there were 7514 division days with wind events but without power outages, 27,168 division days with power outages but without wind events, and 4387 division days with co-occurrences of wind events and power outages. It should be noted that when an event spans multiple power divisions (Fig. A1) it is counted as a separate event for each division, hence the large sums. On average there were 5059 injury-related ED visits per day; including 1397 accidental falls, 1045 related to submersion and other accidents, 465 related to motor vehicle accidents, and 192 due to natural and environmental factors. Supplemental Figs. 2–7 depict the time series of PO and all ED visits.

The associations between wind events, power outages, and their joint occurrences; and overall injuries are shown in Fig. 2, with the subdivisions of injuries shown in Table 1. For power outages alone, there is no statistically significant increase in ED visits for overall accidents or any of the accident types analyzed, with only a weak positive (and not significant) correlation with overall accidents observed. Interestingly, power outages alone without wind events are associated with a protective effect of motor vehicle injury on Day 0, which could be due to less driving during the PO days. In contrast, wind events are associated with increases in most accident types analyzed, particularly during the shorter lags. On the day of a wind event (Lag 0), all accident types become statistically significantly more frequent, most notably motor vehicle accidents (RR = 1.39; CI = 1.29, 1.50), and natural and environmental accidents (1.43; 1.22–1.68). This positive association tends to decrease after Day 0, though is still statistically significant. A similar drop is observed in natural and environmental factors although this increases on Day 3 again.

Once analyzing the combined subset of power outages and wind events, there once again is a very substantive increase in ED visits, much greater than when wind events occur alone, with a pronounced significant impact out through Day 3 for overall accidents, and most subsets. While in all cases the point value of the relative risk is greater for joint impacts, in some cases the confidence intervals between joint events and wind only events do not overlap, such as accidental falls, suggesting a much higher risk when power outages and wind events co-occur.

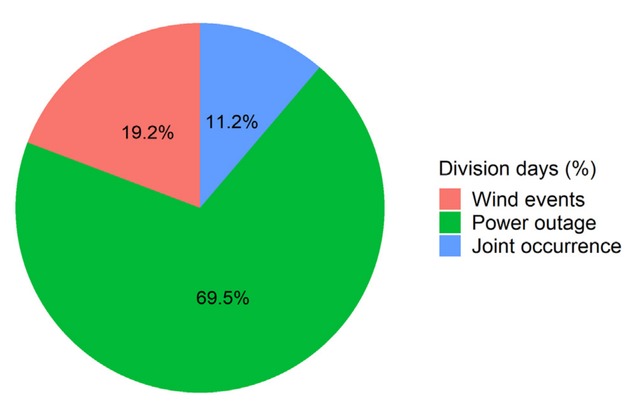

Fig. 1. Breakdown of ED visits used in this study, based on occurrence of wind events, power outages, or both, for New York State for the period 2005–2013.

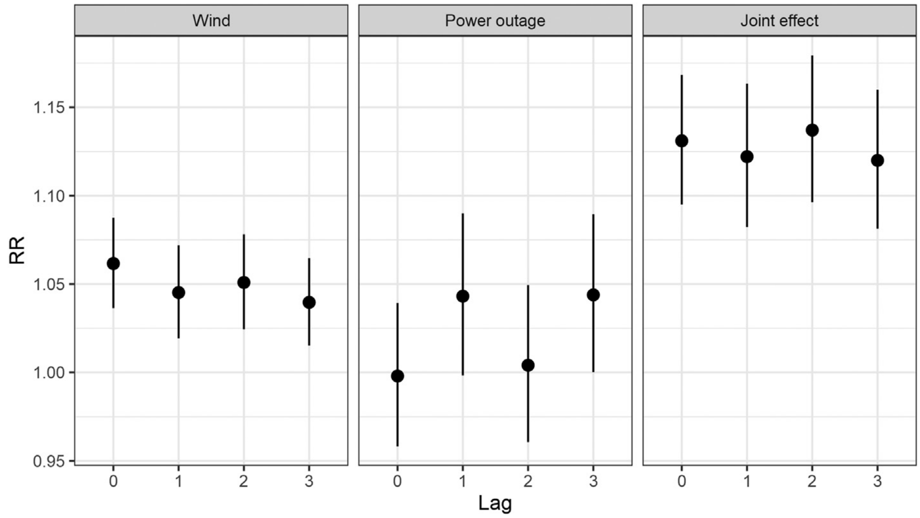

Fig. 2. Relative risks of ED visit likelihood for all injury types, subdivided by occurrence of wind events, power outages, or both, for New York State for the period 2005–2013.

Table 2 shows the comparison across socio-economic subgroups in terms of relative risk on Day 0 of a joint PO/wind event. Because of smaller sample sizes in different power districts once subdivisions were made, the relative risks are somewhat more variable. Some divisions were excluded because models could not be run due to reduced sample size in the stratified analysis; hence the precise number of cases varies slightly. Nevertheless, the risk of ED visits on combined PO/wind events is most substantive for those 65 and older, and for those on Medicaid (the US program that provides insurance coverage for those over 65 and those of limited financial resources). Interestingly, there is no difference between men and women, and risk among Black and Latino populations is not statistically significantly increased.

In Table 3, aspects of the ED visits are statistically different between joint PO/wind events and non-events. Overall costs are \$1091, or 13% higher, with a mean length of stay that is 0.2 days longer. Statistically significant increases also appear for accidental falls and submersion, with non-significant increases observed for the subsets with the smallest sample sizes, motor vehicle accidents, and natural and environmental factors.

4. Discussion and conclusions

Our results show that emergency department visits for injuries overall, as well as for multiple subsets, are statistically greater during the wind events, especially the strongest synergistic effects were found when power outage and wind event co-occur. Aside from the number of visits, these visits are also associated with costlier and slightly longer stays. These conclusions support previous research on the hazards of

Table 1
The relative risk of emergency department visits related to injury (overall and subtypes) between wind events and power outages (PO) combined, wind events alone and PO alone, compared to non-event and non-PO periods, by lag days, for New York State for the period 2005–2013.

	Power outage & wind		Wind only		Power outage only	
Lag	Cases	RR (95% CI)	Cases	RR (95% CI)	Cases	RR (95% CI)
Overall						
0	3,684,004	1.13 (1.09, 1.17)	3,956,662	1.06 (1.04, 1.09)	3,650,642	1.00 (0.96, 1.04)
1	3,524,923	1.12 (1.08, 1.16)	3,896,708	1.05 (1.02, 1.07)	3,445,225	1.04 (1.00, 1.09)
2	3,620,865	1.14 (1.10, 1.18)	3,917,388	1.05 (1.02, 1.08)	3,562,053	1.00 (0.96, 1.05)
3	3,638,085	1.12 (1.08, 1.16)	3,926,528	1.04 (1.02, 1.06)	3,615,973	1.04 (1.00, 1.09)
Motor vehicle accidents						
0	267,933	1.52 (1.35, 1.72)	317,016	1.39 (1.29, 1.50)	258,294	0.85 (0.74, 0.98)
1	247,411	1.40 (1.21, 1.61)	312,391	1.25 (1.15, 1.35)	233,253	1.01 (0.85, 1.21)
2	253,688	1.53 (1.33, 1.76)	303,863	1.24 (1.13, 1.35)	240,484	1.04 (0.88, 1.23)
3	251,882	1.54 (1.35, 1.76)	311,139	1.26 (1.17, 1.37)	246,400	1.13 (0.96, 1.33)
Accidental falls						
0	975,831	1.26 (1.19, 1.34)	1,075,695	1.11 (1.06, 1.16)	960,864	1.03 (0.96, 1.11)
1	956,783	1.25 (1.17, 1.33)	1,063,947	1.11 (1.07, 1.16)	926,435	0.99 (0.92, 1.08)
2	958,504	1.29 (1.21, 1.38)	1,068,688	1.13 (1.08, 1.18)	920,349	1.00 (0.93, 1.09)
3	974,847	1.29 (1.21, 1.37)	1,071,361	1.11 (1.06, 1.15)	940,858	1.06 (0.98, 1.15)
Natural and environmental factors						
0	28,708	2.39 (1.81, 3.16)	44,047	1.43 (1.22, 1.68)	25,088	1.09 (0.75, 1.57)
1	27,615	1.90 (1.36, 2.66)	40,928	1.41 (1.18, 1.68)	26,074	1.16 (0.79, 1.69)
2	20,139	2.01 (1.39, 2.90)	40,880	1.26 (1.05, 1.50)	19,261	1.25 (0.79, 1.98)
3	27,301	1.95 (1.40, 2.73)	40,024	1.53 (1.31, 1.79)	26,143	1.03 (0.72, 1.47)
Submersion and other accidents						
0	626,022	1.38 (1.29, 1.48)	704,013	1.23 (1.17, 1.29)	593,748	0.97 (0.88, 1.06)
1	596,918	1.38 (1.27, 1.49)	692,729	1.15 (1.09, 1.22)	580,281	1.08 (0.98, 1.19)
2	627,644	1.38 (1.28, 1.50)	699,515	1.21 (1.15, 1.28)	594,912	0.97 (0.88, 1.06)
3	593,201	1.32 (1.22, 1.42)	706,930	1.18 (1.12, 1.23)	574,758	0.94 (0.86, 1.03)

Table 2
The relative risk of emergency department visits related to injury (overall) between wind events and power outages (PO) combined, for lag 0, separated by demographic indicators, for New York State for the period 2005–2013.

	Cases	RR (95% CI)	p
Male	1,808,437	1.20 (1.15, 1.26)	<0.001
Female	1,699,216	1.21 (1.16, 1.27)	<0.001
Hispanic	337,520	1.10 (0.99, 1.23)	0.081
non-Hispanic	3,024,150	1.14 (1.10, 1.18)	<0.001
Black	586,561	1.06 (0.98, 1.16)	0.164
non-Black	3,072,194	1.15 (1.11, 1.19)	<0.001
65 and older	517,539	1.44 (1.34, 1.55)	<0.001
45-64	668,149	1.39 (1.30, 1.49)	<0.001
Under 45	2,178,748	1.16 (1.11, 1.21)	<0.001
Self-paying	218,273	1.31 (1.14, 1.51)	<0.001
Medicaid	191,144	1.46 (1.28, 1.66)	<0.001
Other insurance	3,031,817	1.15 (1.11, 1.19)	<0.001

wind, and non-convective wind in particular. Non-convective wind events, which mostly involve the passage of extratropical cyclones (Booth et al., 2015; Ashley and Black, 2008), have been shown to be nearly as deadly in absolute numbers as mortality from thunderstorm winds (Ashley and Black, 2008).

Our results also show that during cold-season power outages that are not associated with a wind event, there is no statistically significant change in ED visits across all subsets analyzed. This result stands in contrast with a wind-only event (absent of a power outage), in which there still is a statistically significant increase in injuries that lead to ER visits. Thus, it could be argued that the occurrence of a power outage augments the dangers already present from wind damage. This augmentation is largest on Day 0, and for accidental falls, natural and environmental factors, and submersion; for each of these three subsets on Day 0 the confidence intervals of joint PO/wind are fully above those of wind alone.

These increases in ED visits for injuries across multiple subtypes highlight the need for greater awareness, especially since many fatal non-convective events are unwarned (Black and Ashley, 2011; Miller et al., 2016). During wind events, wind gusts of 20 m/s could not only lead to some pedestrians and cyclists being blown over, but also can make high-profile vehicles unstable (Baker and Lee, 2008). Goldman et al. (2014) identify fallen trees and flying debris as two of the main direct impacts of high wind events as they are happening, which corresponds well with our results on overall injuries, as well as the

Table 3
Comparison of critical care indicators between injuries related to ED visits during joint wind/power outage events injuries related to ED visits when there was neither a wind event nor a power outage, for New York State for the period 2005–2013.

	No wind/no PO	Joint wind/PO	Difference
Length of stay (d)			
Overall	1.2 (1.2, 1.2)	1.4 (1.3, 1.5)	0.2 (0.1, 0.3)
Motor vehicle accidents	0.5 (0.5, 0.5)	0.6 (0.4, 0.8)	0.1 (−0.1, 0.2)
Accidental falls	1.0 (1.0, 1.0)	1.2 (1.1, 1.3)	0.1 (0.0, 0.2)
Natural and environmental factors	0.4 (0.4, 0.4)	0.8 (0.4, 1.0)	0.3 (−0.0, 0.6)
Submersion and other accidents	0.1 (0.1, 0.1)	0.2 (0.2, 0.2)	0.1 (0.0, 0.1)
Cost of visit (USD)			
Overall	8074 (8054, 8094)	9164 (8598, 9620)	1091 (520, 1546)
Motor vehicle accidents	5219 (5179, 5260)	5471 (4312, 6306)	252 (−926, 1088)
Accidental falls	6440 (6417, 6459)	7300 (6717, 7840)	860 (268, 1400)
Natural and environmental factors	2402 (2338, 2454)	3933 (2109, 4883)	1531 (−315, 2485)
Submersion and other accidents	1417 (1410, 1424)	1555 (1426, 1667)	138 (11, 251)

categories of accidental falls, vehicle accidents, and natural and environmental factors.

A further key result from our study is that the impacts of wind events on various injuries can be observed from the same day to two days after their occurrences. This is biologically plausible and suggests that it is not just the event itself that is hazardous, but also cleanup activities during the short period after the disaster. Other published studies also found similar short-term effects of winter, power outage, and wind disaster on injuries (Lin et al., 2021). In a tropical cyclone situation, increases in laceration hospital visits were observed up to two weeks after landfall (Hendrickson et al., 1997). For wind events overall, our results corroborate the conclusions of the Goldman et al. (2014) review, who further identify that wounds from cleanup activity are among the greatest post-impact sources of injuries. Interestingly, they note a lesser impact of submersion as a factor more recently during wind events, which conflicts with our results; however, as much of the work in their review is related to tropical cyclones which are very different hazards, the results may not be comparable.

While not much research has explicitly tested the impacts of power outages on the hazards of wind, our results are similar to other research showing an augmentation of detrimental human impacts when a power outage co-occurs with other phenomena, such as a heat wave (Lin et al., 2011) or winter storm (Lin et al., 2021). Much of the literature on wind hazards covered in Goldman et al. (2014) and Saulnier et al. (2017) that mention power outages discusses those outages in the context of post-impact hazards such as electrocutions, carbon monoxide poisonings and house fires; these impacts, in addition to a greater difficulty in clearing debris during a power outage can make many types of injury more likely when power outages and wind events co-occur.

We believe this study is the first study to systematically examine the interrelationship between wind events, power outages, and injuries over a long-term period, capitalizing upon the availability of an extensive hospitalization dataset from New York State, with over 2.6 million hospitalization cases annually. Between the large sample, and the diversity of the state, both in terms of the rural and urban aspects, and the diversity of socio-economic status, suggest that these results may be broadly applicable to society at large. This said, there are a number of limitations to what can be concluded. The impact on injuries overall is likely understated in our work, as many of those injured may not go to the ER. Although this study focused on cold-season wind events, which tend to be broader in spatial scale than summertime convective impacts, there is still substantive spatial variability in the resultant damage from wind, and how it impacts humans. With the ED visit database we used, we cannot specifically identify injuries that can be attributed to the wind and/or power outage event, as details on the causal mechanisms are not present. The use of the power divisions, the smallest available subset of data for which outage data are systematically available, helps to home in on specific areas impacted by a power outage, but it results in small sample sizes of ER visits within each district. This sample size limitation manifests itself in the discrepancies seen in some of the subsets when compared to the overall impact. Further, wind events during the cold season in the middle latitudes often do not occur independently of other impactful weather. Strong winter mid-latitude cyclones in New York typically bring not just strong winds, but snow and ice as well. While some research suggests that injury is less dependent on precipitation (e.g., Mirchandani et al., 2005), there was no effective way to stratify wind events by occurrence of snow or ice, and thus there is potential for confounding. Last, the data set on high-wind events only includes events that caused substantial damage and/or fatalities (without systematic assessment) injuries, and thus there is an inherent exclusion of the occurrence of high winds that did not have any discernible impact. Unfortunately, this is the only relatively complete data set of high-wind events. Wind is not systematically chronicled by NOAA unless it cause substantial building damage or human fatality or injuries events. There is no systematic assessment of such “non-impact” events and so the occurrence of wind is certainly greater than can be assessed.

There is substantial interest in mitigating the hazard of wind, such as in the UN's International Group for Wind-Related Disaster Risk Reduction (Tamura and Cao, 2012). To help further understand this hazard, we encourage further research to partition out potential impacts by specific weather events, beyond just extreme events such as tornadoes and hurricanes. Other research of ours (Zhang et al., 2020a, 2020b) has shown vulnerability to extreme weather to be highly dependent on community factors, such as income and housing density. This said, our results in this current paper showing no difference in risk between men and women is different from other literature that highlights men as disproportionately impacted (Goldman et al., 2014). We do show that there is increased vulnerability for those older, or of limited income, similar to general assumptions on variability in vulnerability to hazards. However, we also show racial/ethnic minorities are less impacted, something that runs counter to general discourse (Cutter and Finch, 2008). We encourage further assessment of socioeconomic variability in the impacts of wind as well.

Trends suggest that high-wind events based on wind gust speeds have increased across the eastern US (Gilliland et al., 2020), and this is echoed in our sample. Moving forward, a changing climate may yield yet greater incidence of strong wind events (Tamura and Cao, 2012), and the lack of resilience of the power network to extreme weather events has been noted (e.g. Gao et al., 2018). Many wind-related fatalities are associated with events that fall below National Weather Service warning criteria (Miller et al., 2016; Black and Ashley, 2011), making overall awareness of the hazard critical. While the energy grid of the future may be more resilient to extreme events (Hussain et al., 2019), it is nevertheless critical to understand the current impact of power outages for better preparedness in the health infrastructure.

CRediT authorship contribution statement

Scott C. Sheridan: Conceptualization, Data curation, Writing – original draft, Writing – review & editing. **Wangjian Zhang:** Formal analysis, Software, Writing – review & editing. **Xinlei Deng:** Writing – review & editing, Visualization. **Shao Lin:** Conceptualization, Validation, Resources, Writing – review & editing, Supervision, Project administration.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgement

This work was supported by Grant # 1R15ES02800001A1 from the National Institute of Environmental Health Sciences of United States. We thank the New York State Department of Health for providing the comprehensive health data (data sharing protocol number: 1509-01 A), and thank the New York Department of Public Service for providing the statewide power outage data.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.scitotenv.2021.149199.

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