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Weather-Related Pediatric Fatalities in the United States: 2001 to 2021

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abstract

BACKGROUND AND OBJECTIVES: Major weather and climate disasters are increasing in frequency and severity. How often these events result in child deaths is unknown. We assessed temporal and regional trends in pediatric fatalities due to weather events in the United States over the last 21 years.

METHODS: We conducted an ecological study of weather-related pediatric fatalities between 2001 and 2021 using the National Centers for Environmental Information Storm Events Database. Weather-related fatalities were compared with pediatric fatalities included in the Centers for Disease Control and Prevention Wide-ranging ONline Data for Epidemiologic Research database. The change in the proportion of all-cause pediatric fatalities associated with weather events was assessed over time. The frequency of events occurring in regions with Pediatric Disaster Care Centers of Excellence (COE) was examined.

RESULTS: Between 2001 and 2021, weather events were associated with 1423 pediatric fatalities. Sixty percent of fatalities occurred in male children, with a bimodal distribution in age. Flood/currents accounted for the largest proportion of fatalities (37%, $n = 524$), followed by cold/ice/winter weather (13%, $n = 192$), tornadoes (13%, $n = 183$), heat (12%, $n = 168$), and hurricanes/storms (11%, $n = 155$). Although no significant difference was noted in the absolute number of fatalities over time ($P = .18$), the proportion of all-cause pediatric fatalities associated with weather events increased ($P = .006$) over the course of the study. Forty-six percent of pediatric fatalities occurred in areas with an associated COE.

CONCLUSIONS: Pediatric fatalities from weather events make up an increasing proportion of childhood deaths. Expansion of health-system infrastructure for pediatric disaster planning and response may mitigate childhood deaths from weather-related disasters.



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WHAT'S KNOWN ON THIS SUBJECT: Children are known to be more vulnerable than adults to weather-related disasters. Most data focus on the potential medical harm to children from disasters, with few studies having evaluated the associated injuries and fatalities.

WHAT THIS STUDY ADDS: This study characterizes the weather events that most often cause pediatric fatalities and demonstrates that these weather-related pediatric fatalities are increasing. These findings highlight the need for expansion of health-system infrastructure for pediatric disaster management to mitigate weather-related childhood death.

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INTRODUCTION

Weather and climate disasters are increasing in frequency and severity. In the United States, between 1980 and 2022, the average number of climate disasters, also known as “billion-dollar weather events,” was 8.1 events per year. Over the last 5 years (2018–2022), the frequency of events increased to 18.0 events per year and up to 28 events in 2023.^{1,2} Such events strain emergency care systems by disrupting health infrastructure and causing surges in injuries and fatalities.^{3–5} Although it is recognized that major climate events put children at significant risk, recent data suggest that many states are not prepared to care for children during disasters.⁶ Additionally, most data focus on the medical harms that climate change may inflict on child health, such as infection, respiratory disease, and mental health, and not the associated injuries or fatalities that may occur during weather events.^{7,8}

Pediatric response to injury differs from adults due to differences in pediatric physiology and anatomy. These differences make children more vulnerable due to their large surface area to body mass and short stature, increasing their exposure to environmental hazards.³ In one study of 4 disaster events, of the 2196 victims managed by medical teams, 30% were children, with more frequent complaints of wounds, respiratory infection, and musculoskeletal and abdominal pain than adults.⁹ These challenges are compounded by a need for specialty pediatric care that may be inaccessible in many areas. A study of inpatient pediatric admissions to a pediatric trauma center following a major disaster found that one-half of pediatric patients were interfacility transfers, 7 of 10 required a surgical intervention, 8 of 10 required pediatric intensive care unit admission, and 1 patient died.⁵ As evidenced by national pediatric Emergency Department readiness benchmarks, community and adult trauma hospitals are less prepared to accept pediatric patients, which may result in increased mortality for injured children.^{10,11}

To address children’s specific needs during disaster events, the Administration for Strategic Preparedness and Response (ASPR) designated 2 regional COE in 2019 and a third in 2022. These programs cover 19 states and territories and seek to ensure pediatric preparedness for events that may overwhelm health systems. Challenges remain in understanding the hazards that place children at greatest risk. Consequently, any hazard vulnerability analysis may result in insufficient preparedness for rapid triage, transfer, and treatment of pediatric patients by trauma systems.

The National Oceanic and Atmospheric Administration National Centers for Environmental Information maintains the Storm Events Database (SED), which collects data on weather phenomena that have sufficient intensity to cause property damage, loss of life, injuries, or disruption to commerce.¹² We used SED data to understand which types of weather events most often result in pediatric fatalities

and hypothesized that the proportion of pediatric fatalities associated with weather events has increased over time. We secondarily aimed to examine the regional pediatric weather-related fatality trends and understand how these weather-related fatalities overlap with existing regional infrastructure (ie, COEs) for pediatric disaster management.

METHODS

Study Design, Setting, and Participants

Using SED data, we conducted an ecological study of weather-related fatalities in the United States between 2001 and 2021. All pediatric fatalities from weather events included in the SED from January 1, 2001, to December 31, 2021, were included in the study. Pediatric was defined as any person younger than age 18 years. Any fatality without an associated age or individuals who had an age of 18 years or older were excluded from the study. Our institutional review board certified this study as exempt Category 4 research (#22-38532).

SED Variables

The SED obtains data from the National Weather Service (NWS), which receives data from counties, states, federal emergency management officials, law enforcement, NWS damage surveys, newspaper clippings, the insurance industry, and the public.¹³ The SED database consists of a fatalities file, an event details file, and a locations file. All fatalities must be reported by municipalities to be included in the data set. A further description of these files and the SED are included in Supplement 1.

The fatalities file was used to identify individual pediatric fatalities attributed to weather-related events. This file was linked to the event details to characterize the associated weather-related events. The primary geographic units used were state/county. Of the 57 SED event types, 35 were associated with pediatric fatalities and were grouped into the following categories, which were created a priori before analysis: flood/current, cold/ice/winter weather, tornado, heat, hurricane/storm, wind, fires, and other (Supplement 2). Fatality location was categorized into vehicle, outside-water, outside-land, building, and other. Available individual-level data for fatalities were limited to age and sex. No other individual demographic data were available. The fatalities were compared according to the age and sex of the child, the type of event, the event location, and rurality.

Other Data Sources and Definitions

The Centers for Disease Control and Prevention (CDC) Wide-ranging ONline Data for Epidemiologic Research (WONDER) underlying cause of death database was used to examine the change in the proportion of pediatric deaths associated with weather-related events over time.^{14,15} SED data were directly compared against the total number of

pediatric deaths per year in WONDER, described as “all-cause” deaths, which include deaths related to injury, cancer, infections, and other medical ailments. Data were then compared with the number of “unintentional injury”-related pediatric deaths alone. The CDC WONDER external-cause of injury matrix, as defined by the National Center for Health Statistics (NCHS), was used to identify these unintentional injury-related fatalities.¹⁶

To determine rurality, the SED data were linked at the county level to the NCHS Urban-Rural Classification Scheme for Counties to assess the rural vs urban characteristics of communities affected.¹⁷ The NCHS divides counties into 6 classification schemes, 4 of which are defined as metropolitan and 2 as nonmetropolitan; a binary definition of rurality was applied to create a single “urban” cohort and a “rural” cohort.

Regionality was defined according to the ASPR region where the fatality occurred. To assess the overlap of fatalities with existing pediatric disaster infrastructure, data were divided into COE areas, ie, GULF-7, Western Regional Association for Pediatric Emergency Management (WRAP-EM), and Region V for Kids (Region V), as described earlier. The distribution of events was examined according to both ASPR regions and COE designation (ie, a COE area or non-COE area). The COEs include the following states and territories: GULF-7, ie, Alabama, Florida, Georgia, Louisiana, Mississippi, Texas, and Puerto Rico; WRAP-EM, ie, Arizona, California, Nevada, Oregon, Washington, and Utah; and Region V, ie, Illinois, Indiana, Minnesota, Michigan, Ohio, and Wisconsin.

Statistical Methods

Statistical analyses were conducted in STATA 17 (StataCorp LLC). Descriptive statistics were used to assess characteristics of pediatric fatalities and storms causing these fatalities.

χ^2 tests were used to compare categorical data, and Wilcoxon rank-sum tests were used for comparisons of continuous data, given nonnormal distributions. Unadjusted linear regression was used to assess whether there was a statistically significant change in the proportions over time. Statistical significance was set as $P < .05$.

RESULTS

All Pediatric Fatalities

From 2001 to 2021, weather events were associated with 1423 pediatric fatalities, accounting for 9% of all weather-event-related fatalities ($N = 18\,841$). The mean (SD) number of pediatric fatalities per year was 68 (17). Most pediatric fatalities (61%) occurred in male individuals, and a bimodal distribution was noted in age, with peaks from ages 1 to 2 years and ages 14 to 17 years (Figure 1). Most children were in a vehicle (32%) at the time of the event. Flood/currents accounted for the largest proportion of fatalities (37%, $n = 524$), followed by cold/ice/winter weather (13%, $n = 192$), tornadoes (13%, $n = 183$), heat (12%, $n = 168$), and hurricanes/storms (11%, $n = 155$). Forty-two percent of these fatalities occurred in rural communities (Table 1).

Variation was noted in the types of weather events associated with pediatric fatalities each year between 2001 and 2021 (Figure 2). Over this period, the annual proportion of fatalities caused by hurricanes/storms significantly decreased ($P = .04$). There were no discernable trends found for the proportion of deaths associated with flood/currents ($P = .87$), cold/ice/winter weather ($P = .38$), tornadoes ($P = .77$), heat ($P = .16$), wind ($P = .39$), or fires ($P = .49$).

There was no significant difference in the absolute number of weather-associated fatalities over time ($P = .18$). However, there was a significant increase in the annual

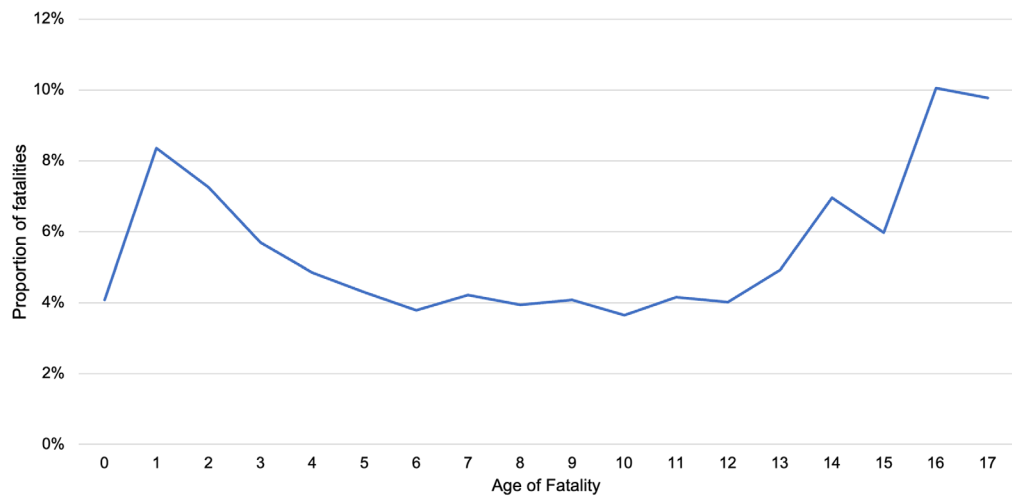


FIGURE 1. Distribution of pediatric fatalities by age.

TABLE 1. Pediatric fatality demographics and event characteristics associated with climate events between 2001 and 2021.

	Total	Non-COE	COE	P value
	n = 1423	n = 652	n = 771	
Age, median (Q1–Q3)	9 (3–15)	9 (3–15)	10 (4–15)	.84
Sex, n (%)				.71
Female	553 (39)	252 (39)	301 (40)	
Male	851 (61)	393 (61)	458 (60)	
Missing	19	7	12	
Fatality location, n (%)				.2
Vehicle	459 (32)	225 (35)	234 (30)	
Outside-Water	155 (11)	77 (12)	78 (10)	
Outside-Land	269 (19)	114 (17)	155 (20)	
Building	380 (27)	161 (25)	219 (28)	
Other	160 (11)	75 (12)	85 (11)	
Event type, n (%)				<.001
Flood/current	524 (37)	239 (37)	285 (37)	
Cold/ice/winter weather	192 (13)	118 (18)	74 (9.6)	
Tornado	183 (13)	102 (16)	81 (11)	
Heat	168 (12)	65 (10)	103 (13)	
Hurricane/storm	155 (11)	45 (6.9)	110 (14)	
Wind	153 (11)	76 (12)	77 (10)	
Fires	8 (0.6)	0 (0.0)	8 (1.0)	
Other	40 (2.8)	7 (1.1)	33 (4.3)	
Rurality, n (%)				<.001
Urban	802 (58)	329 (53)	473 (63)	
Rural	572 (42)	289 (47)	283 (37)	
Missing	49	34	15	

Event characteristics described for all fatalities and according to whether fatalities occurred in COE areas. Fatality location refers to the location of the child at the time of the fatality. Abbreviations: COE, Pediatric Disaster Care Centers of Excellence; Q, quartile.

proportion of pediatric fatalities associated with weather events compared with “all-cause” nationwide pediatric fatalities ($P = .006$). The annual proportion of weather-event-associated fatalities compared with all pediatric “unintentional injury” fatalities also increased significantly ($P = .003$, Figure 3).

ASPR Region, COE, and non-COE Area Fatalities

When ASPR regions were examined, more than one-quarter of pediatric weather-related fatalities occurred in ASPR Region 4, followed by 20% in ASPR Region 6, and approximately 13% in ASPR Region 5 (Figure 4). When COEs were examined, 46% of all weather-related pediatric fatalities occurred in areas with an associated COE. The majority occurring in a COE area were in the GULF-7 (30%), followed by WRAP-EM (14%) and Region V for Kids (11%). Twenty percent of weather-related fatalities occurred in the non-COE-associated states of North Carolina, Tennessee, Missouri, Arkansas, Kentucky, and Oklahoma. Significant differences were noted in types of weather events that occurred in COE areas ($P < .001$, Table 1), with heat and storm events occurring more often in COE areas, whereas tornadoes and cold/ice/winter weather events occurred more often in non-COE areas. COE area weather-related fatalities were more likely to occur in urban communities when compared with non-COE fatalities ($P < .001$).

DISCUSSION

We found that the proportion of pediatric fatalities caused by weather events in the United States between 2001 and 2021 was increasing compared with both “all-cause” and

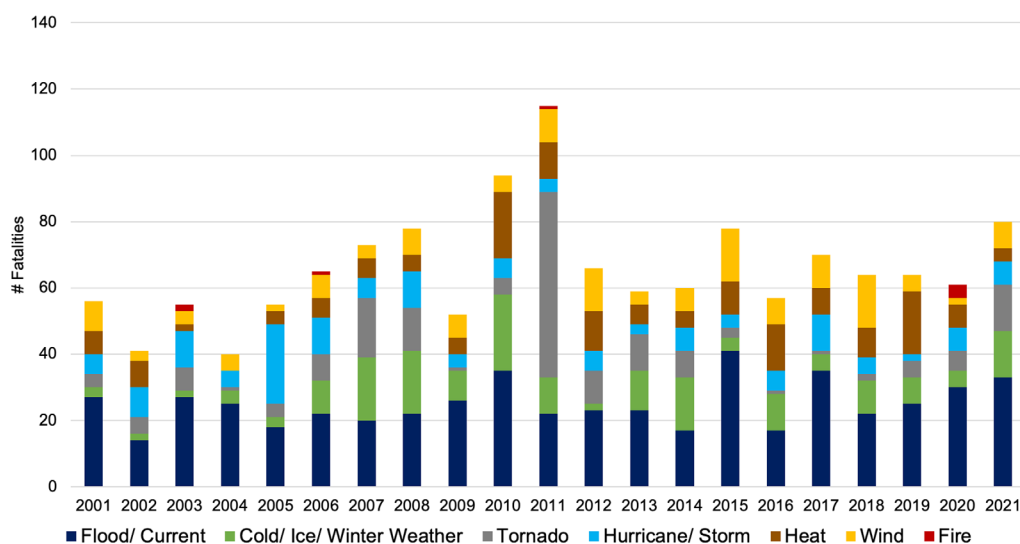


FIGURE 2.

Types of climate events associated with pediatric fatalities from 2001 to 2021.

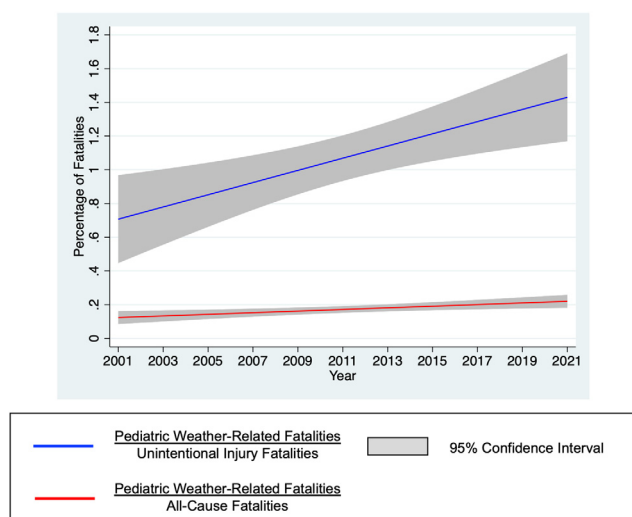


FIGURE 3.

Percentage of all-cause pediatric fatalities and unintentional injury pediatric fatalities that were associated with climate events between 2001 and 2021. Annual data for all-cause pediatric fatalities and unintentional injury fatalities were obtained from the CDC WONDER database. All-cause fatalities include deaths from injury, cancer, infections, and other medical ailments. CDC WONDER external-cause of injury matrix was used to identify fatalities from unintentional injuries. Abbreviations: CDC, Centers for Disease Control and Prevention; WONDER, Wide-ranging ONline Data for Epidemiologic Research.

“unintentional injury” pediatric fatalities. These fatalities were most often associated with flood/rip current events, which accounted for more than 1 in 3 weather-related

pediatric fatalities. Winter weather, tornadoes, and extreme heat together accounted for another third of all weather-related fatalities. Over one-quarter of these fatalities occurred in ASPR Region 4, and 1 in 5 occurred in ASPR Region 6. Less than one-half of these fatalities occurred in areas associated with a Pediatric Disaster Care COE, and non-COE area pediatric fatalities were more often associated with tornadoes and winter weather. Together, these data raise concerns that weather events may have an increasing impact on child fatalities and that many regions across the United States are ill-prepared.

The high proportion of fatalities among young children and children in rural areas is particularly concerning. One-fourth of children whose deaths were associated with weather events were age 3 years or younger. Young children often have no control over their built environment and depend on their caregivers to flee disaster situations.³ Children who may be at risk for injuries and fatalities from weather may also live in vulnerable communities. For instance, 42% of pediatric weather-related fatalities occurred in rural communities, whereas only 22% of American children live in these areas,¹⁸ suggesting that severe weather events disproportionately affect rural children.¹⁹ Rural communities are more likely to be impoverished and have existing nonenvironmental vulnerability, as demonstrated by the Climate Vulnerability Index.²⁰ The COEs are currently concentrated in urban states. Of the 20 states with the largest rural populations, only 3 states are included in COEs.²¹ Attention must be paid to ensuring that

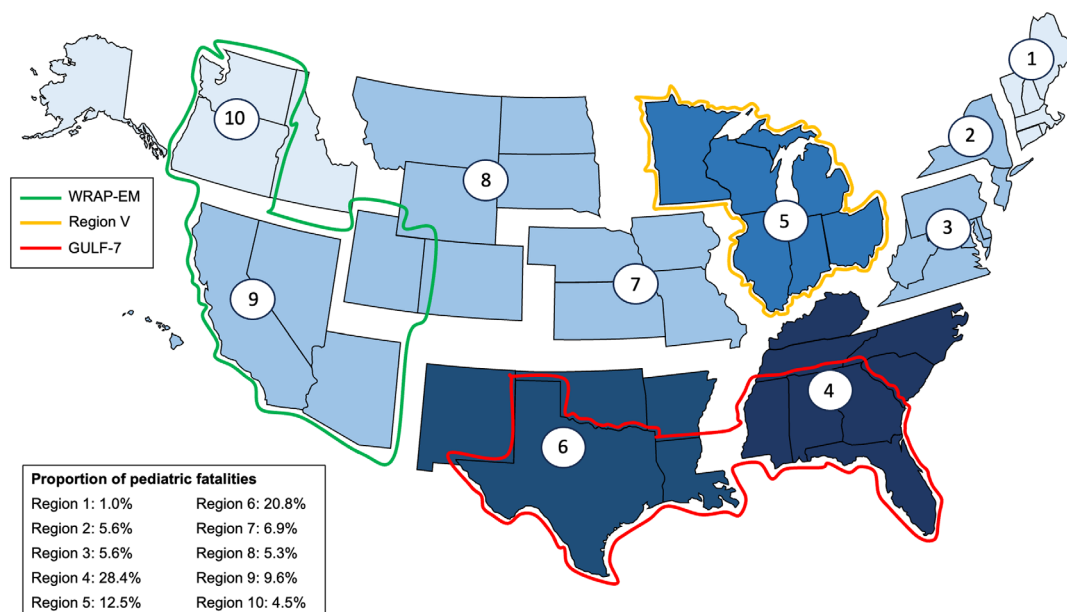


FIGURE 4.

Regional trend in pediatric fatalities associated with climate events. ASPR designations are used to define regions. Each region has a regional emergency coordinator tasked with developing regional preparedness and response. Abbreviation: ASPR, Administration for Strategic Preparedness and Response; WRAP-EM, Western Regional Association for Pediatric Emergency Management.

emergency health and trauma systems are equitably distributed, prepared for disasters, and inclusive of pediatric needs to mitigate the impacts of these events on vulnerable children in every community.

To improve hazard vulnerability analyses and preparedness, consideration must be given to the association between certain types of weather events and pediatric fatalities. Flood/rip current events accounted for the greatest proportion of pediatric fatalities. The risk is expected to grow as estimates of flood trends predict increases in the Northwest, Southwest, and Northern Great Plains, placing an additional 11.3 million children at risk for floods.²² Other weather events, although less often associated with fatalities, are expected to change in severity and nature. Extreme heat events have been increasing, most pronounced in the New England, Middle Atlantic, Mountain, and Pacific regions.²³ There has been an increase in atmospheric rivers in the Western coastal areas, an anticipated increase in the intensity of tropical storms, and increased severity of winter storms in the Northeast.⁸ Finally, tornadoes are shifting into the Southeast, which may lack the community infrastructure to mitigate these disasters.^{20,24} These potential changes, in conjunction with the known risks to child health, highlight the great need for hospitals, health systems, states, and regions to evaluate and prepare for potential surges in pediatric injury and fatality in the setting of severe weather events.

State trauma systems are one of the primary entities in charge of ensuring preparedness for the management of injured children during disasters. State preparedness for injured pediatric patients is variable: 30% do not include children in their disaster plans, 40% do not include the transfer of children in mass casualty drills, and 50% do not have destination-determination protocols for children.⁵ The establishment of pediatric disaster COEs should support the integration of children's needs into state plans. However, 46% of child fatalities occurred in states not associated with a COE, with 20% of all fatalities occurring in North Carolina, Tennessee, Missouri, Arkansas, Kentucky, and Oklahoma. The Pediatric Pandemic Network, which is a national program that seeks to support the preparedness for all hazards leveraging children's hospitals and their associated networks of care, may help mitigate some of these risks, as this network also extends support into non-COE areas. By combining and expanding the unique efforts and strengths of both programs, these networks can help to ensure the continued growth of critical pediatric disaster management infrastructure across the United States.

Previous work examining the effects of climate on children has primarily focused on the medical implications of climate change, such as respiratory disease, exposure to infections, and mental health.⁷ Although the frequency of weather-related fatalities is low, with approximately 68 deaths per year, the significant increase in the proportion of pediatric deaths associated with weather events is

notable, as it highlights an increasing risk to children. Moreover, pediatric mortality from injury is a rare event, with epidemiologic data suggesting that a fatality occurs in only 0.1% of all unintentional injuries.²⁵ Given the lack of information on weather-related pediatric injuries without mortality, one can extrapolate these data to the present study, suggesting that an estimated 68 000 weather-related pediatric injuries may occur every year. The potential burden these injuries place on trauma systems with limited pediatric capacity highlights the need to ensure adequate preparedness of such systems.

This study has several limitations. First, as an ecological study, all conclusions can only be extrapolated to the population level. Additionally, the SED is a weather database and not specifically intended for the examination of health outcomes. The SED is not subjected to the validation metrics used in the National Vital Statistics data. This may introduce both selection and information bias into the data. There is also a risk of missing data, which may be both due to the inability to classify by age the fatalities within the data set, the lack of attribution of a fatality to a storm, and improper exclusion from the data set. All fatalities included in the SED must be reported by municipalities to the NWS, as described in the storm data preparation instructions.²⁶ Prior studies have suggested that these counts may differ from other sources, with the SED underestimating deaths compared with the Federal Emergency Management Agency (FEMA)/Red Cross reports, whereas the SED estimates may be higher than Vital Statistics data.²⁷ However, these other data sources are limited in their consistent collection of weather data to allow for the regular attribution of fatalities to weather events. FEMA/Red Cross data are limited to declared disasters requiring organizational response. Vital Statistics data require that clinicians consistently attribute fatalities to weather events when completing death certificates. The CDC has created a toolkit to improve the attribution of deaths to natural disasters when the death occurs at the scene.²⁸ However, limits remain for the attribution of deaths from storms if the patient comes to a health care facility and subsequently dies of their injuries. Given that SED data report fatalities between FEMA and Vital Statistics, the authors felt that it could provide an appropriate population-level estimate of pediatric fatalities over time. Regarding missingness within the data set, consideration was given to estimating the potential proportion of pediatric fatalities among those fatalities without listed age within the database, as would be done with a sensitivity analysis. However, the addition of these deaths might alternatively give the impression of inflating the data. The decision was made to simply exclude these fatalities from the study cohort and maintain a conservative estimate of confirmed pediatric fatalities.

An important consideration in the interpretation of these data are whether the increasing proportion of pediatric fatalities from weather-related events is related to a relative

decline in unintentional injury fatalities among children. Over the past 20 years, significant injury prevention efforts, including state statutes regulating seat belt use and child safety seat use, have resulted in decreased pediatric fatality from injury.^{29,30} It is possible that these decreases may explain the change in proportions. Even so, these injury prevention efforts would be expected to mitigate injuries/fatalities during disasters, which suggests that there still remains a great need to attend to and prepare for disaster-associated injuries and fatalities among children.

The lack of linkage to disaster data in trauma or health data sets is a major gap that must be addressed to ensure that the implications of climate on trauma, injury, and health can be fully understood. Future emergency and trauma system preparedness will remain insufficient without these data. Such linkages would allow for the geo-mapping of disaster-associated injuries, evaluation of response times, evaluation of triage/transfer processes, and linkage of these metrics with trauma outcomes. Such quality metrics are critical to ensure appropriate response and mitigate future climate disaster effects.

CONCLUSIONS

Pediatric fatalities from weather events make up an increasing proportion of childhood deaths, placing the most vulnerable children at risk. Extrapolating the expected death-to-injury ratio from epidemiologic data for pediatric unintentional injuries, an estimated 68 000 weather-associated pediatric injuries may occur every year. Expansion of the current health-system infrastructure for pediatric disaster management is greatly needed to mitigate the potential child deaths due to weather-related events.

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ABBREVIATIONS

ASPR: Administration for Strategic Preparedness and Response
COE: Pediatric Disaster Care Centers of Excellence
CDC: Centers for Disease Control and Prevention
FEMA: Federal Emergency Management Agency
NCHS: National Center for Health Statistics
NOAA: National Oceanic and Atmospheric Administration
NWS: National Weather Service
SED: Storm Events Database
WRAP-EM: Western Regional Alliance for Pediatric Emergency Management
WONDER: Wide-ranging Online Data for Epidemiologic Research

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