BAMS Article

Wind-Related Bounce House Incidents in Meteorological, Regulatory, and Outreach Contexts

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ABSTRACT: Inflatable bounce houses, also known as portable inflatable amusement devices, are safety hazards when they are dragged, blown over, or lofted by winds. We have documented 132 cases of wind-related bounce house incidents worldwide for the years 2000–21 that caused at least 479 injuries and at least 28 deaths. Over three-quarters of these incidents happen in the warm season. A subjective effort to categorize the meteorological conditions leading to these incidents reveals that, of the over 70% of incidents for which a specific meteorological cause could be identified, cold-frontal passages, dust devils, or thunderstorm-related winds are most likely to be occurring at the time of the event. In the United States, regulations regarding bounce house safety vary widely. Seventeen states either have no guidelines or specifically exclude inflatables from regulation. Nineteen U.S. states' laws or regulations explicitly cite American Society for Testing and Materials (ASTM) standards, which set limits on the wind speed in which inflatables should be used and, for commercial bounce houses, require the presence of a meteorologically knowledgeable attendant. For events with nearby wind data available, 22% of all incidents occurred with reported wind speeds lower than any ASTM standards, and 51% below the highest ASTM threshold. Increased vigilance is therefore necessary on the part of bounce house providers and consumers to avoid wind-related incidents. We have created a website for public dissemination of this study's data and safety tips.

KEYWORDS: Small scale processes; Transport; Extreme events; Wind gusts; Health; Societal impacts

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Inflatable bounce houses were first invented by engineer John Spurlock in 1958 (Lipinski 2014) and have since become fixtures at outdoor events involving children, such as birthday parties, family reunions, and carnivals. Bounce houses, also known as bouncy houses, magic castles, jumping balloons, moon bounce/moonwalks, *brinca-brincas*, or more generally portable inflatable amusement devices (PIADs) are constructed of polyvinyl chloride, nylon, and vinyl material that can withstand small punctures. They are inflated with air from a motor-powered blower (CuriousHistory 2014).

Bounce houses come in many shapes and sizes, with castle-like designs being very common (Fig. 1). They are supposed to be anchored to the ground with sandbags and/or stakes. Bounce houses are available for purchase by the public, and hundreds of companies in the United States provide commercial rental options as well. With daily rental costs in the United States as low as $100, bounce houses are an affordable way to organize confined outdoor exercise for relatively large numbers of children (and even adults) who jump up and down inside them.

Fig. 1. A typical castle-type bounce house, with the second author for scale, in El Paso, Texas.

Inflatables, such as bounce houses, are known safety hazards, causing as many injuries as any other type of amusement ride, as noted in previous case studies (e.g., Kok and Chong 2005; McFaull and Keays 2013; Woodcock 2014). The Consumer Product Safety Commission (2015a) found that there “were an estimated 113,272 emergency department-treated injuries associated with inflatable amusements in the years 2003–13” and that 90% were due to bounce houses. Thompson et al. (2012) found a statistically significant fifteenfold increase in pediatric bounce house injuries in the United States between 1995 and 2010, with an average annual rate of 5.28 injuries per 100,000 U.S. children. In Italy, Ferro et al. (2016) estimated more than a seventeenfold increase in pediatric bounce house injuries between 2002 and 2013, amounting to 0.24% of all pediatric emergency department visits.

A much smaller but very high-profile subset of bounce house injuries occurs with weather as a contributing factor. Grundstein et al. (2017) illustrated the potential for the interior of a bounce house to be a heat-health issue on a warm day. In this article we systematically investigate the role of wind in bounce house incidents. Due to the nature of their construction and their high aspect ratios, bounce houses can be tipped over, rolled along the ground, bounced, or even lofted into the air by strong winds or wind gusts, even when occupied. Children can be injured and even killed while inside air-transported bounce houses or by falling out of windblown bounce houses; in addition, bystanders are at risk of being hit or dragged by them. When this happens, such incidents often capture headlines, are lead stories on local and national news programs, and “go viral” on social media internationally [e.g., CNN (2011) and the accompanying national news story at Kindelan (2011)]. The deadly 16 December 2021 Devonport, Tasmania, bounce house incident in Australia, which killed six children, was the subject of international news accounts (e.g., Zhuang 2021).

Moreover, wind-propelled bounce houses can pose a risk to vehicles, traffic, buildings, power lines (Fig. 2), and other infrastructure, and have even caused highway crashes (e.g., Wang 2018), fires, and power outages (e.g., Kauffman 2019). The damage to people and property in the aftermath of these incidents often results in legal actions with high settlement or judgment costs. Additionally, some incidents have even led to criminal liability (Siddique 2018). As we will discuss, these winds do not necessarily have to be associated with “bad weather” or achieve thresholds for high wind or severe conditions. As a result, the public can be at risk unknowingly, especially if the anchoring mechanism is insufficient.

In this paper we provide, for the first time, a long-term, systematic (although inevitably incomplete) compilation of wind-related bounce house incidents across the globe, as well as the number of injuries and fatalities associated with them. We also identify the different types of weather conditions associated with these incidents, based on news accounts and scrutiny of surface weather analyses and remote sensing imagery. We then focus on current

Fig. 2. Sequential still images of a bounce house in flight into high-tension power lines in Niagara County, New York, on 18 Jun 2016. Credit: Storyful/Sarah Laurie.

policies in the United States relating to bounce houses, and discuss education and outreach approaches that could mitigate or prevent injuries from windblown PIADs.

Summary of wind-related bounce house incidents

The authors conducted a thorough, decade-long online search for wind-related bounce house incidents, with the word combinations used in Google searches and daily alerts enumerated in Table 1. In 2011, the second author (Gill) began using online sources to search for bounce house incidents, performing Google searches on combinations of words 1–9 in Table 1, and monitored Google daily alerts for 10 and 11. Beginning in 2015, the third author (Williamsberg) conducted Google searches on word combinations 12–63, and monitored Google daily alerts for word combination 64.

In addition, *Storm Data* (NCEI 2021a) was also searched for bounce house incidents.

Table 1. Search terms used to locate bounce house incidents.

Google searches since 2011	
1	"Wind" AND "bounce house"
2	"Wind" AND "jumping balloon"
3	"Wind" AND "jumping castle"
4	"Wind" AND "bouncy house"
5	"Wind" AND "bouncy castle"
6	"Wind" AND "moon bounce"
7	"Wind" AND "magic castle"
8	"Viento" AND "brinca-brinca"
9	"Rafaga" AND "brinca-brinca"
Google daily alerts since 2011	
10	"Wind" AND "bounce house"
11	"Wind" AND "jumping balloon"
Google searches since 2015	
12	"Wind" + "inflatable"
13	"Wind" + "inflatable" + "accident"
14	"Wind" + "inflatable" + "accident" + "children"
15	"Wind" + "inflatable" + "accident" + "children" + "injured"
The sequence of searches in 12–15 (i.e., starting with two keywords and then adding, one by one, "accident" and "children" and "injured") was repeated for the following sequential combinations of words	
16–19	"Wind" + "jumping balloon"
20–23	"Wind" + "bounce house"
24–27	"Wind" + "house"
28–31	"Wind" + "bouncy castle"
32–35	"Wind" + "castle"
36–39	"Wind" + "jumping castle"
40–43	"Wind" + "inflatable playhouse"
44–47	"Wind" + "inflatable house"
48–51	"Wind" + "inflatable slide"
52–55	"Wind" + "inflatable attraction"
56–59	"Wind" + "inflatable trampoline"
60–63	"Wind" + "brinca"
Google daily alerts since 2015	
64	"Bounce house" + "wind"

As a result of these searches, we compiled a total of 132 documented cases of wind-related bounce house incidents from 1 January 2000 through 31 December 2021. These 132 incidents caused at least 479 injuries and in addition at least 28 fatalities.[1] In the case of conflicting information on injuries and fatalities from media sources, we relied on the media account closest geographically to the incident site, on the assumption that first-hand accounts were more likely to be accurate than republished/edited accounts. We also relied on the latest news account from local sources, in case additional injuries were reported, or if any serious injuries subsequently became fatalities.

This study is inevitably an undercount of both incidents and injuries, and perhaps even of deaths; not all events and their aftermaths will necessarily be reported, especially in English-language media, and even thorough online searches conducted over a decade can overlook reported events. Readers aware of other cases should contact the authors.

A list of each bounce house incident by date, location, and meteorological context is provided in the online supplemental material (https://doi.org/10.1175/BAMS-D-21-0160.2). Figure 3 presents the distribution of incidents by nation in decreasing order of occurrence. Note that these events occur worldwide in all inhabited continents, in both tropical and temperate climates, and in both urban and rural locations, from Australia, Brazil, and South Africa to the United States, Iceland, Hungary, and China. These events generally occur in the warm season (i.e., April–September in the Northern Hemisphere; October–March in the Southern Hemisphere), with 77% of all events occurring in the warm season. In the Northern Hemisphere, where 87% of all incidents occurred, 71% happened in the months of April through July, with May contributing 28% of all Northern Hemisphere events. These results fit with expected behavior patterns related to precollege school schedules, spring and summer holidays, and temperatures conducive for outdoor recreation. Interestingly, there were more

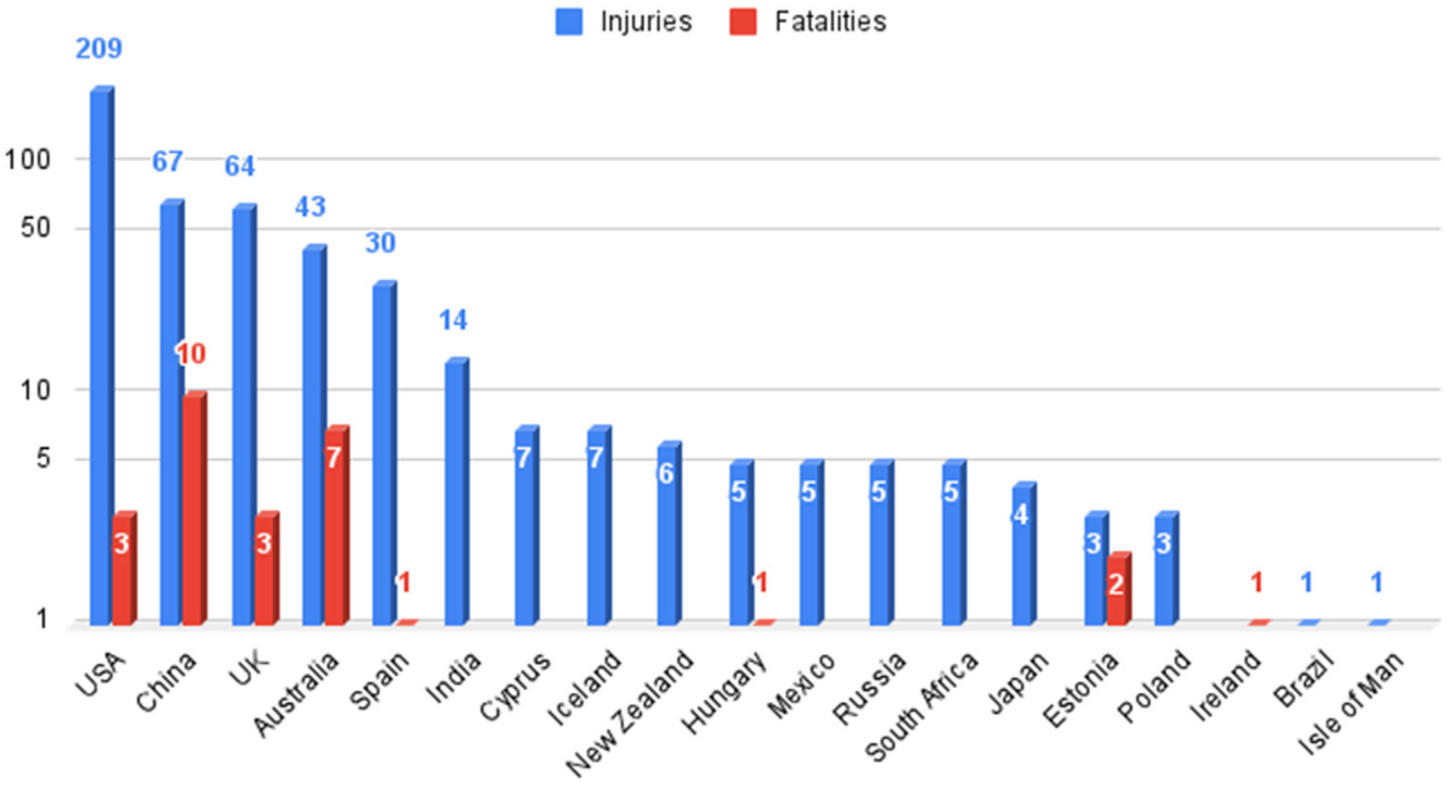

Fig. 3. Injuries (blue) and fatalities (red) due to wind-related bounce house incidents from January 2000 through December 2021 by nation or territory.

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[1] Fatalities are not also counted as injuries. Some incidents also occurred prior to 2000, but the rise of the internet and then social media in the late 1990s and 2000s has made it easier to create a representative global database from 2000 forward.

incidents in the Northern Hemisphere in March (eight incidents) and October (seven incidents) than in August (five incidents) and September (four incidents).

Figure 4 depicts the occurrence of incidents in the United States, with larger (gray) circles for greater numbers of injuries and fatality locations denoted by red squares. There is no obvious geographical clustering of the U.S. events, demonstrating that this is a widespread hazard without any noticeable regional biases.

Meteorological contexts

Upon further investigation of these 132 events, we determined the most probable meteorological phenomenon contributing to each incident via two independent rounds of analyses by different authors.

The meteorological data sources used in the analyses were as follows:

1) Surface weather maps for the United States (NCEP 2021), Asia except for India (Kitamoto 2021), Australia (Bureau of Meteorology 2021a), Europe (Wetter3 2021; Met Office 2021; ESWD 2021), and South Africa (South African Weather Service 2021);
2) Surface wind and weather observations through the Weather Underground (2021) and the Australian Bureau of Meteorology Climate Services (Bureau of Meteorology 2021b);

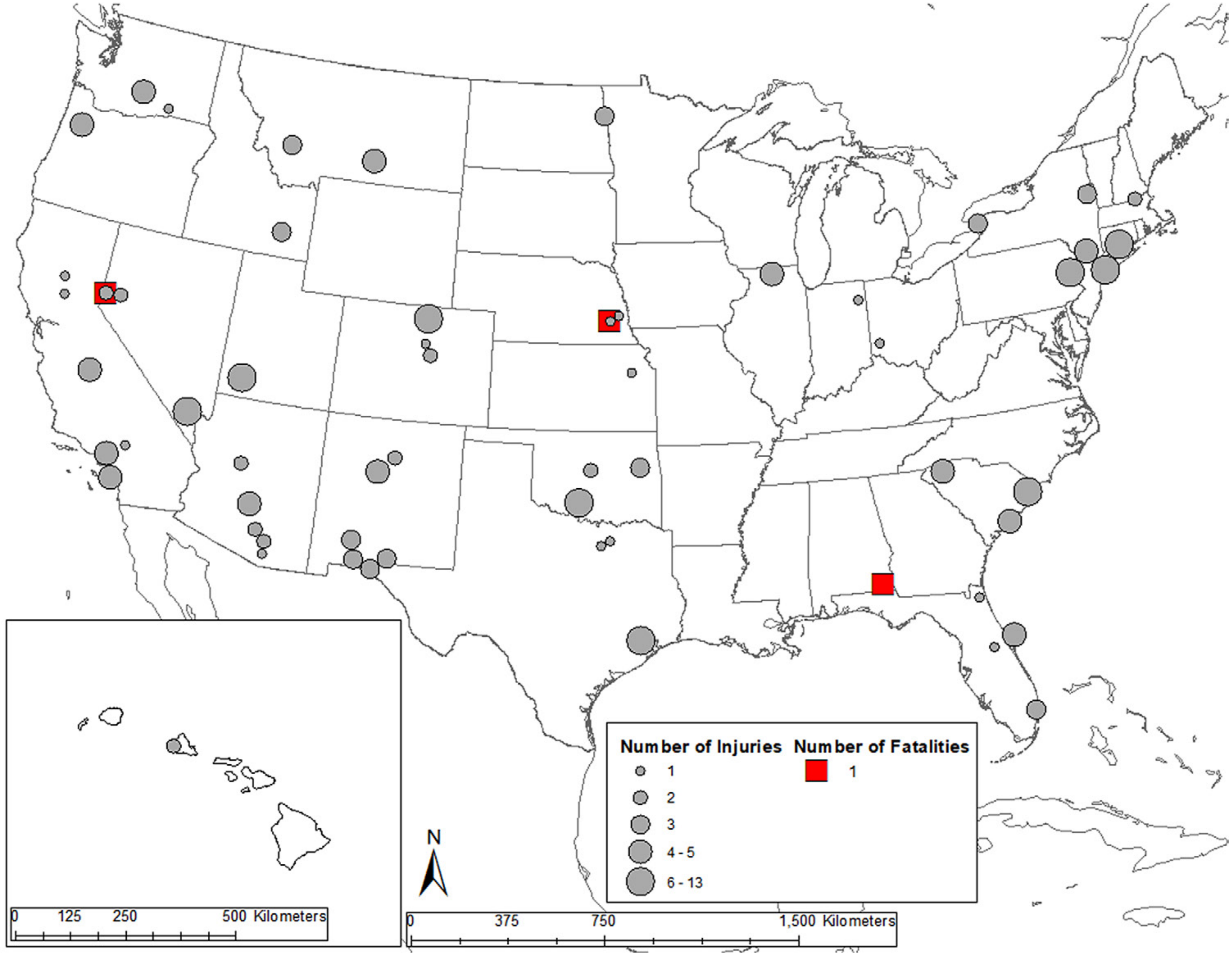


Fig. 4. Injuries (gray graduated circles) and fatalities (red squares) due to wind-related bounce house incidents in the United States from January 2000 through December 2021.

Table 2. Meteorological causes of bounce house incidents and their identifying characteristics, as determined and employed by the authors.

Meteorological phenomenon (in approximate descending order of scale)	Identifying characteristics: Incident occurred
Cold front	Within 12 h or fewer of cold-frontal passage on synoptic maps, with evidence of gusty winds from observations
Post–cold front	Within 12 h to 2 days after cold-frontal passage on synoptic maps, with evidence of gusty winds from observations, in cold air and especially during daytime, with no other phenomena present
Other synoptic scale	With strong surface pressure gradients on the synoptic scale not located near or behind cold fronts (e.g., warm sector of frontal cyclone)
Tropical cyclone	In proximity to a tropical cyclone on synoptic maps
Santa Ana	In proximity to warm downsloping winds in California with high pressure to the east or northeast
Thunderstorm	With surface reports, radar evidence, and/or eyewitness accounts of thunderstorm in the immediate vicinity of the incident
Gust front/outflow	With surface reports of sudden wind gusts within approximately 50 km (~30 miles) of thunderstorm activity, especially if accompanied by radar echoes or NWS statements indicating outflow, but without thunderstorm activity near the incident
Waterspout	With eyewitness reports or video of a waterspout, plus favorable conditions (e.g., nearby showers along or near coastline)
Dust devil	With eyewitness reports or video of dust devil, plus favorable conditions (e.g., daytime, clear skies, and strong surface heating)
Nonconvective mesoscale	With eyewitness reports and/or wind data indicating a mesoscale phenomenon not otherwise on the list (e.g., sea breeze)

3) Satellite imagery (SSEC 2021); and, for the United States,
4) *Storm Data* (NCEI 2021a);
5) Radar imagery (NCEI 2021b);
6) National Weather Service (NWS) forecast discussions (Iowa Environmental Mesonet 2021); and
7) NWS hourly wind observations (University of Utah 2021).

The categories of causes, as defined by the authors, and their identifying characteristics are described in Table 2.

The first, second, and fourth authors (Knox, Gill, and Smith) examined news accounts of the incidents as well as meteorological data sources and reached a consensus opinion as to the meteorological contributing cause for each of the events.

Separately, the sixth author (Black) conducted an independent analysis of these events and classified them according to the causes listed in Table 2. The consistency between the two groups of coders was then evaluated using Krippendorff's alpha (α) statistic (Hayes and Krippendorff 2007) on a scale from 0 to 1, with higher values indicating more consistency among the coders' categorization of the weather phenomenon. The Krippendorff's α for the coding of the incidents is 0.936, indicating a high degree of intercoder reliability, a measurement commonly used in qualitative research to determine the agreement between two or more independent coders (Lombard et al. 2002).

The determinations of the meteorological contributing causes are inevitably somewhat subjective. The causes of some events are definite, e.g., in the case of a dust devil caught on video. Other contributing causes are inferred from synoptic weather maps or satellite loops. Some incidents have unclear causes and were left in an "undetermined" category.

Based on our subjective analysis, we found the following distribution of meteorological causes of bounce house incidents:

- Undetermined (default category; 36 events)
- Cold front (25)
- Post–cold front (21)

- Dust devil (20)
- Other synoptic-scale (10)
- Thunderstorm (10)
- Gust front/outflow (6)
- Santa Ana (1)
- Tropical cyclone (1)
- Waterspout (1)
- Nonconvective mesoscale (1)

Figure 5 summarizes this information in terms of percentages.

The distinctions made between these categories are subtle in some cases. “Undetermined” is the default category in the absence of persuasive evidence of a particular meteorological phenomenon as a cause of the incident, and represents 27.3% of all incidents examined. Events occurring in temporal and spatial proximity to a cold front were labeled “cold front,” while those occurring independent of other phenomena many hours to a day or two after cold-frontal passage were categorized separately as “post–cold front.” Together, these represent another 34.8% of incidents. Similarly, events occurring during an active thunderstorm are categorized as “thunderstorm”; however, those near, but not in, thunderstorm activity or linked definitely to thunderstorm outflow signatures on radar or NWS statements were labeled “gust front/outflow.” These two categories account for 12.1% of all incidents. The 7.6% of all incidents that occurred due to strong synoptic-scale (e.g., the size of midlatitude low pressure system) pressure gradients that were not associated with other categorized phenomena were classified as “other synoptic-scale.” While this manuscript was in revision, the Devonport bounce house incident occurred. The authors determined that this incident was associated with a sea-breeze front, which we have classified as “nonconvective mesoscale,” denoting an event not associated with thunderstorms whose triggering phenomenon is larger than a few kilometers but smaller than a midlatitude low pressure system.

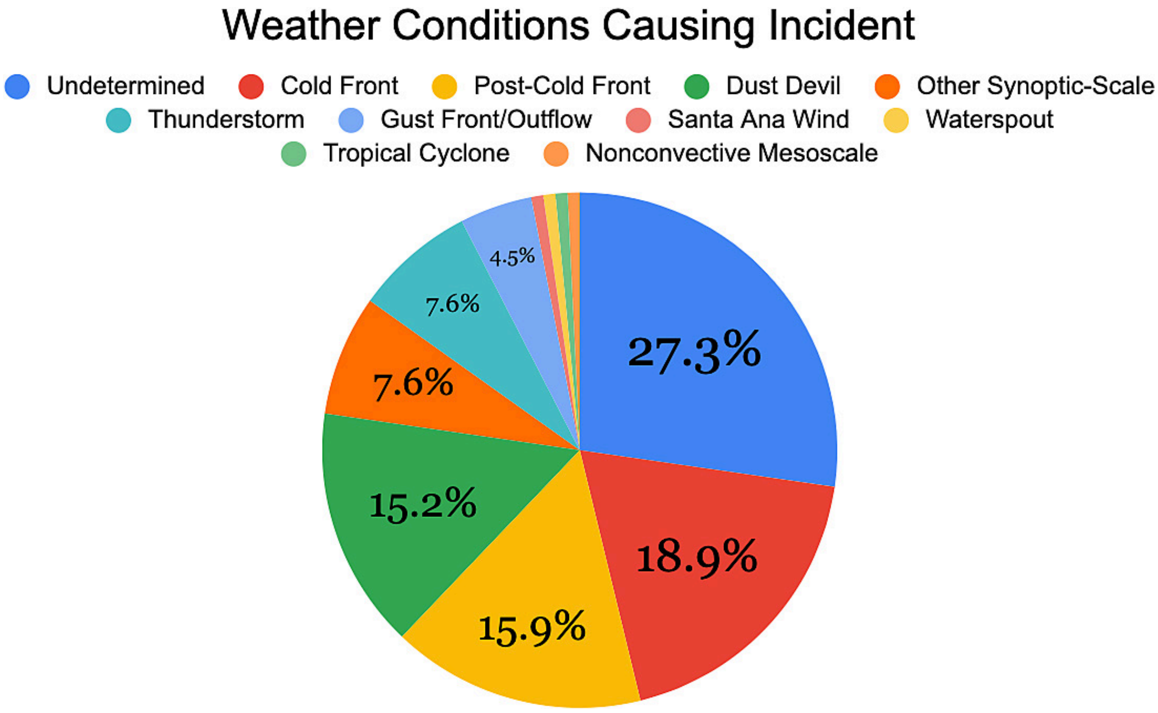


Fig. 5. **Pie chart depicting the inferred meteorological contributing cause of all documented wind-related bounce house incidents globally from January 2000 through December 2021. See text for more information on how causes were determined.**

Some of the “undetermined” incidents described as sudden gusts may have been the result of “plumes” or “bursts” of dry convection contacting the ground. These ephemeral phenomena are well-known but poorly observed due to their short lifetime and small scale, although they have been implicated in aircraft accidents (Spillane and Hess 1988) and documented to raise dust clouds in bare desert areas (Knippertz 2014).

Dust devils are a notable cause of bounce house incidents, composing 15.2% of all incidents. In some of these instances, bounce houses were not rolled over but were physically lofted high enough in the air to sail over buildings. This increases the risk of injuries from being physically thrown or falling from a height, as has been concluded from studies of tornado casualties (Millie et al. 2000). We infer that this suspension of the bounce houses is related to the significant vertical as well as horizontal motions associated with dust devils (Sinclair 1973). We intend to explore this phenomenon in a separate article. Dust devils are an underrecognized weather hazard in the United States, causing approximately three documented injuries per year *not* related to bounce houses in the United States, and with field-documented pressure drops estimated to be sufficient to suspend a bounce house (Lorenz and Lanagan 2014; Lorenz et al. 2016).

Aside from thunderstorms, tropical cyclones, and waterspouts, typical severe weather phenomena are largely missing from the categories. The reason appears to be simple: children are highly unlikely to be playing in bounce houses, and bounce houses are unlikely to be used, during approaching severe weather. Instead, many of the phenomena are associated with what would usually be perceived as “fair-weather” conditions: a cool and sunny day after a cold front, with clearing skies inspiring outdoor play; a hot, calm day that happens to trigger dust devils; or a fair-weather summer day with a thunderstorm in the distance. In these circumstances, bounce houses are far more likely to be in use, and the seemingly good weather may disguise the inherent risks. Ashley and Black (2007) found similar fair-weather scenarios for many nonconvective wind fatalities in the United States.

Being primarily “fair-weather” or small-scale phenomena that are too brief and small to forecast, many of these incident-causing conditions do not currently trigger warnings from government meteorological agencies and are not discussed or considered in public weather forecasts. As Miller et al. (2016a) have shown, however, the vast majority of nonconvective wind damage reports, injuries, and deaths in the United States are associated with subsevere wind speeds, and greater than one-quarter of reports, injuries, and deaths are associated with winds below wind advisory thresholds. Our results are similar. This circumstance places responsibility on the regulation of bounce house use, which we explore in the next section.

Mitigation and prevention of bounce house incidents via regulation

When examining weather-related incidents involving inflatables, it would be a mistake to ignore the policies that currently exist regarding their use. We focus on the state-by-state regulatory situation in the United States, which consist of *statutes*, which are laws introduced by a state or federal legislature that have been enacted, and *regulations*, which are rules, regulations, or orders issued by an executive authority or regulatory agency of government and have the force of law. (Local municipalities may also have their own bounce house policies; however, an examination of the safety codes for the approximately 20,000 incorporated municipalities in the United States was beyond the scope of this initial study.) We encourage interested readers to investigate the regulatory situation in other nations.

The standards of the American Society for Testing and Materials (ASTM), an international standards organization, play a central role with regard to regulation of inflatables in the United States. In particular, ASTM standard F2374 “Standard Practice for Design, Manufacture, Operation, and Maintenance of Inflatable Amusement Devices” (ASTM 2021) governs commercial bounce houses, and standard F2729 (ASTM 2018) governs inflatable play devices for home use.

To obtain information on existing legislation and regulations, the third, fifth, and seventh authors (Williamsberg, Boggs, and Skypek) initially conducted research on the topic. The first stage of investigation included exploring rental company websites, and additional state regulations that were identified on these websites (e.g., Bounce Houses Now 2021). This provided some insight into the policies and regulations that exist across the country. For example, we learned that many, but not all, bounce house–related statutes and regulations across the nation were found under "amusement."

Then the first, second, and third authors (Knox, Gill, and Williamsberg) conducted an iterative search and classification process: for each state, the three authors independently searched each state's statutes and regulations using state government sites provided by the fifth author (Boggs) that were updated through 2021. The search terms used in the searches were as follows:

1) "Wind"
2) "Inflatable"
3) "Bounce"
4) "Bouncy"
5) "Castle"
6) "Moon walk" (or "moonwalk")
7) "Air-supported" (or "air supported")
8) "Air structures"

In cases where none of the search terms succeeded in locating regulations, searches were performed on "amusement." From these searches, the authors devised a five-category classification system, as described below and illustrated in Fig. 6:

Category 0:	No guidelines for amusements or inflatables
Category 1:	Amusement guidelines that explicitly exclude inflatables in their definition of amusement ride/device, *or* a state's amusement ride definition obviously does not include bounce houses
Category 2:	Amusement guidelines that *may* include inflatables given their generic definition, but do not specifically call out "inflatables" in their definition
Category 3:	Amusement guidelines that specifically include inflatables in their definitions, but have no other specific guidelines for inflatables
Category 4:	Amusement guidelines that call out ASTM standards that govern inflatables *and/or* provide specific inflatable criteria with regard to anchoring, use in extreme weather, and/or use in strong winds

The first three authors then came to consensus on the category classification for each of the 50 states. To test the reliability of this consensus, the fourth author (Smith) independently classified all states using a coding book and links to statutes and regulations provided by the third author (Williamsberg). The intercoder reliability statistics indicate strong agreement, with a Krippendorff's α value for the coding of the states of 0.829. The authors then conferred to resolve remaining classification differences, resulting in the state-by-state classifications discussed below.

Which states regulate bounce house use, and how? The regulatory situation for PIAD use in the United States is a mixed bag (Fig. 6). As of 31 December 2021, there were three U.S. states with no regulations at all for amusement parks/rides: Alabama, Idaho, and Wyoming. Another 14 states either explicitly excluded inflatables from regulation, or had regulations

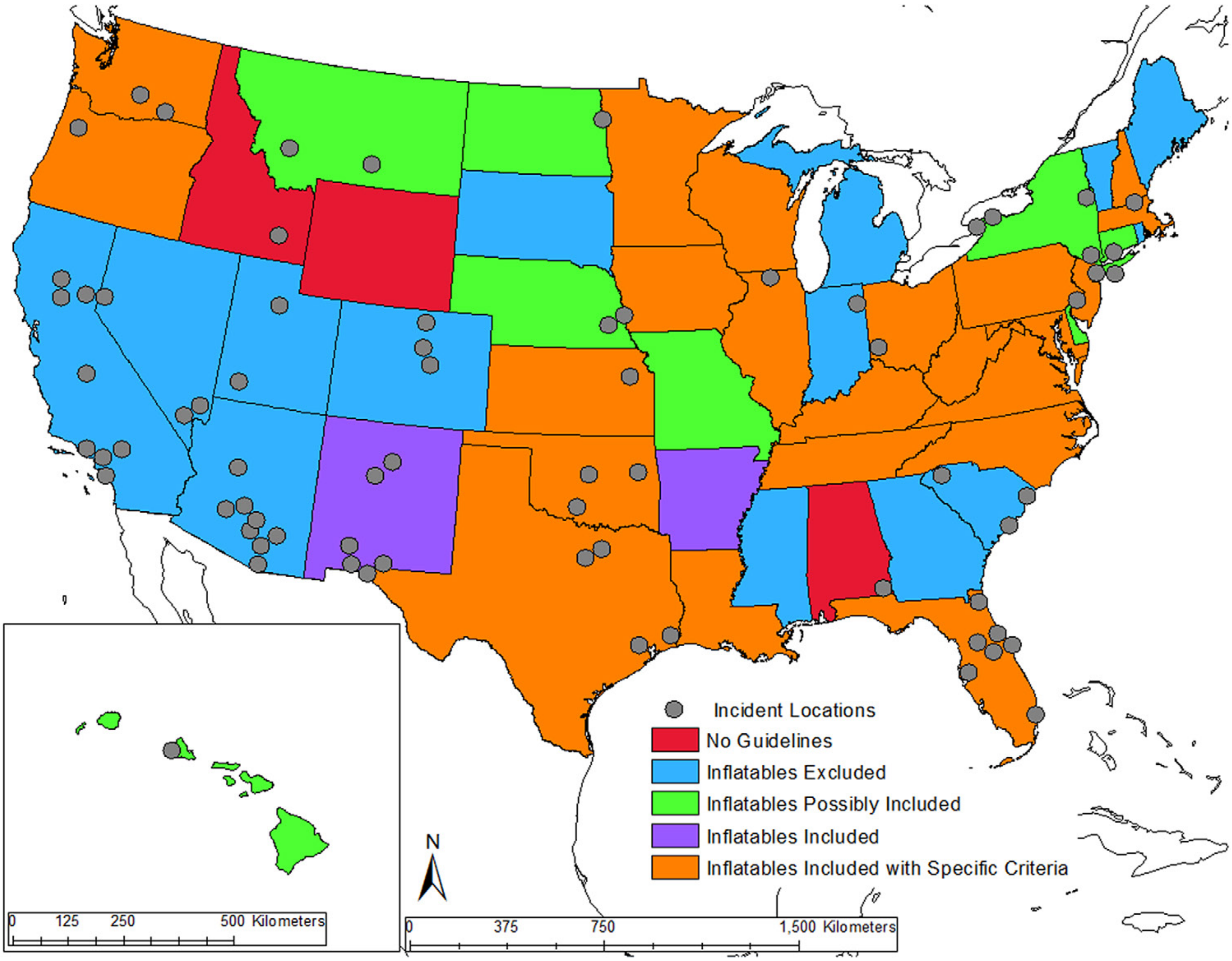


Fig. 6. U.S. map classifying each state by one of three categories for amusement ride/park state statutes and regulations: none (red), inflatables explicitly or implicitly excluded (blue), inflatables possibly included (green), inflatables explicitly included without additional criteria (purple), and inflatables explicitly included with additional criteria (orange). Incident locations are indicated with a round gray symbol. Regulations in Alaska (not shown due to lack of events) are in the "possibly included" category.

that are clearly interpretable as excluding inflatables. Of the remaining 33 states, 9 had statutes or regulations that can be read to include inflatables; 2 states explicitly included inflatables, but without any standards or criteria referenced; and 22 states explicitly included inflatables with specific criteria related to wind safety. Of these 22 states, 19 explicitly require adherence to ASTM standards. (It should be noted that Florida includes ASTM standards in its regulation while excluding inflatables in its statute; legally this means that the ASTM standards are required, but are confusing to nonlawyers.) Maryland, one of the few states to include numerical wind speed guidance for bounce house use within its regulations, requires that "inflatable amusement attractions may not be operated when the wind speed is 25 mph [$11.2\ \mathrm{m\ s^{-1}}$] or greater" (Maryland Code of Regulations 09.12.66.09; www.law.cornell.edu/regulations/maryland/title-09/subtitle-12/chapter-09.12.66).

In summary, fewer than half of U.S. states have explicit statutes and regulations for bounce house use; of those that do, most do not explicitly state weather and wind conditions required for bounce house use. Instead, most of these states' regulations reference the ASTM standards, which contain extensive calculations of the wind forces impacting such devices, forming the basis of specified wind speed limits of operation and detailed requirements for anchoring bounce houses to the ground. We now delve into the ASTM standards in some detail, to illustrate the confusing nature of even the best-available safety standards.

Challenges and overlap in existing policies. ASTM standard F2374 states, "The design [of a bounce house] shall assume a maximum allowed operational wind speed of at least 25 mph (11.1 m s^{-1}) with highest sustained gusts over a 3-s period. A higher operational wind speed shall not be used unless the anchorage has been verified as sufficient by a professional engineer" (ASTM 2021, 5.6.4.1). Furthermore, the maximum operating wind speed for the device shall be at least 5 mph (2.2 m s^{-1}) lower than the wind speed for which anchoring was designed (ASTM 2021, 5.6.4.2). Last, in the absence of a manufacturer-determined maximum allowable wind speed for operation, a maximum sustained wind speed of 15 mph (6.7 m s^{-1}) is to be used unless an engineer determines otherwise [ASTM 2021, 7.5.5.3 (2)(a)].

Thus, depending on the situation, commercial bounce house operators in the United States have up to three different ASTM wind thresholds to keep in mind: 15 mph (sustained), 20 mph (in the event that anchorage is designed for 25 mph), and 25 mph (gust). In addition, ASTM F2374 mandates that the wind speed limit (and other restrictions) must be included in an information plate permanently affixed to the device.

Also included in ASTM standard F2374 is the requirement that commercial devices must be supervised by trained operator/attendant(s) while inflated, who, among numerous other duties, are required to "monitor weather and sustained wind speed, if operating outdoors." The ASTM standard for commercial inflatable amusement devices also mandates that both installers and operator/attendants "shall be trained on how to monitor and assess wind speed using an anemometer, Beaufort Scale, or other reliable method" and that "the owner/operator should provide operator/attendants with wind speed assessment guidance that will work reliably in their specific situation" (i.e., application of the Beaufort scale to an area without trees). Portable inflatable amusement devices must be immediately evacuated and deflated when winds exceed the criteria. ASTM F2374 includes a detailed table (ASTM 2021, Table X8.1) discussing the Beaufort scale and relating it to safety practices with bounce houses. It is worth noting that the wind conditions during which bounce houses should not be used as per ASTM standards are characterized somewhat benignly as "moderate/fresh/strong breeze" in the Beaufort scale description, with an example used of small tree branches in motion. Furthermore, the Beaufort scale was not originally derived for use on land (Miller et al. 2016b).

ASTM standard F2729 for inflatable play devices for home use states that "anchoring for inflatable devices for outdoor use shall be designed to withstand a minimum Beaufort scale 6 wind speed (11.1 m s^{-1} [i.e., 25 mph])." The manufacturer is required to convey information on the method used for the anchoring system, the number of anchor points, appropriate anchor methods for different soil types, how to drive the anchors, and the maximum safe wind speed while inflated (among other requirements) in instructional literature. In addition, "any restrictions related to operating in windy conditions" shall be "permanently marked in a conspicuous location" on the inflatable device.

In summary, inflatables used by private citizens have an ASTM-mandated threshold of a 25-mph wind, whereas in contrast the threshold for commercially used inflatables is, depending on the situation, somewhere between 15 and 25 mph. This is confusing enough. Furthermore, the distinction between sustained wind and wind gust is blurred in the ASTM standards. In contrast, a Consumer Product Safety Commission (2015b) safety bulletin states clearly that bounce houses should not be used when wind speeds, *including gusts*, exceed 20 mph.

Which of these thresholds is "correct"? Wind engineers Yoshida and Tamura (2009) studied one of the incidents in our database, in Tokyo in February 2008, and determined via theoretical calculations and wind tunnel experiments that winds of about 10 m s^{-1} (22.4 mph) were needed to move an inflated, anchored, occupied bounce house. Therefore, the various thresholds found in the ASTM standards bracket the values determined experimentally.

Evaluating current policies: Do they work? Next we compare these regulatory thresholds with the available wind information from our database of bounce house incidents. For the 85 incidents worldwide for which we were able to obtain local wind information of some type, 22% of incidents occurred when the wind speeds (both sustained and any gusts) were between 0 and 15 mph, the lowest threshold set by ASTM F2374. Moreover, 33% of incidents occurred with reported wind speeds between 0 and 20 mph, and 51% of incidents happened when the reported wind speeds were 0–25 mph. The corresponding statistics for the United States (61 events) are as follows: 20% of incidents with wind data occurred when the wind speeds (both sustained and any gusts) were 0–15 mph, 31% of incidents occurred when reported wind speeds were between 0 and 20 mph, and 48% of incidents happened when the reported wind speeds were 0–25 mph.

Obviously, the winds in microscale phenomena, for example, a dust devil, are unlikely to be measured by an official weather reporting station, so these percentages may be an overestimate of the number of incidents that actually occurred with subthreshold wind speeds at the bounce house site. Inadequate grounding is referred to in multiple media accounts of incidents, and could also be to blame. Nevertheless, these percentages raise concerns that even the most stringent available guidelines for bounce house use, even if interpreted conservatively, are necessary but not sufficient to prevent incidents.

Mitigation and prevention through education and outreach

While regulation is an important aspect of increasing operator and user safety regarding bounce houses and other PIADs, the previous section illustrates why regulation is not enough. Even the best and most rigorous regulations are, at present, ambiguous and are unlikely to be followed to the letter in everyday practice. Therefore, education and public awareness should be components of any strategy to increase safety.

Furthermore, supervision of portable inflatables must be close and consistent. Research on non-wind-related bounce house incidents indicates that close supervision is often absent when children are injured in PIADs. Avoian et al. (2008) reported there was no adult supervision 43% of the times that skeletal injuries were experienced by children utilizing bounce houses; Corominas (2018), in a similar study in the United Kingdom, found that 47% of the injured child's parents said they were not supervising the child, nor in the vicinity of the bounce house, and were subsequently notified of the fall of the child. Based on our research, this lack of close supervision seems to be the case for some wind-related incidents as well.

In the case of wind-related bounce house incidents, the problem is compounded by both the nature of the wind phenomena and the ambiguities of the thresholds. Because of the small-scale nature of some of the phenomena that lead to incidents, the wind may reach or exceed thresholds in a very localized area instantaneously. In other situations, wind thresholds may not be interpreted correctly by vendors or users. It is possible that winds with speeds below the thresholds may still lead to incidents.

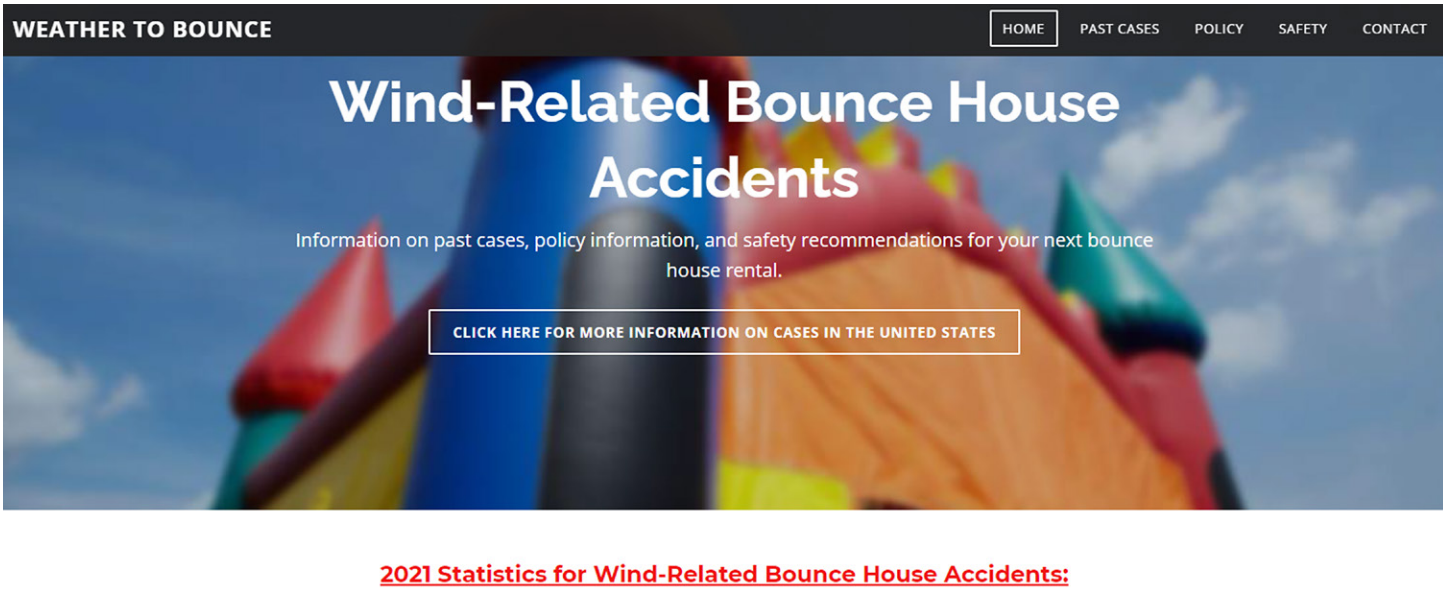
In the absence of public health messaging or a specific educational outlet for this topic, the media and parents/caregivers are forced to obtain relevant information from websites whose primary goal is to sell inflatables. While these sites do provide some information about policies and previous incidents, it is our perception that there is a lack of weather-related prevention information. Therefore, with our research study documenting known previous wind-related bounce house incidents, the authors agreed that it would be beneficial to take the first steps ourselves toward educating the public by providing our findings and safety recommendations on a website.

Our website, weathertobounce.com (Fig. 7), contains a regularly updated table of incidents, injury prevention information, and current policies/guidelines surrounding bounce house incidents. After examining other preventative messaging associated with bounce house and inflatable incidents, we noticed that weather-related phenomena were absent from the current messaging, or the dangers of wind were not emphasized. To combat this lack of weather-related messaging, we developed our own safety tips in pdf format to ensure that parents, caregivers, and inflatable business owners could have it available for their bounce house event. While we have not yet tested the effectiveness of our recommendations, we hope that by using this safety-tip document and other information from our website, individuals should be able to become more educated about the risks and properly evacuate the inflatable in the event of danger.

Conclusions and future work

We have compiled for the first time and then analyzed a global database of bounce house incidents involving wind from 2000 through 2021. Key results include the sizable number of events (132) and the number of injuries (479). These bounce house incidents often occur on days with "fair-weather" synoptic-scale meteorological patterns, e.g., dust devils on sunny days, or post-cold-frontal weather. We have also analyzed this topic from the regulatory perspective for the United States, highlighting the state-by-state differences in policies governing inflatables and the meteorological ambiguities in even the best available standards for bounce house use. We have also taken the initiative in education and outreach by developing a website for dissemination of both data and safety information. We hope that through this work the public will be better informed and more vigilant with regard to the use of bounce houses on windy, or even merely moderately breezy, days.

Future work on bounce house incidents from a meteorological perspective could include expanding the search to include reports of incidents in languages other than English and investigating the ability of dust devils and other small vortices to loft bounce houses high into the air. In addition, the contributory roles of the shape of PIADs, the angle of incidence of



Wind-Related Bounce House Accidents

Information on past cases, policy information, and safety recommendations for your next bounce house rental.

2021 Statistics for Wind-Related Bounce House Accidents:

Fig. 7. Front page of weathertobounce.com website.

the wind, the anchorage of bounce houses, and soil conditions to incidents could be studied more intensively.

While more research is undeniably required to fully explore the potential for weather-related incidents regarding inflatables, it is clear that the statutes and regulations that currently exist in the most safety-conscious states (e.g., Maryland) could be implemented federally or on a state-by-state basis in the meantime. These regulations would be an excellent first step in combating the increased number of not only weather-related PIAD incidents, but also non-weather-related incidents—the latter of which lead to more than 99% of all injuries associated with PIADs. Distinctions between commercial and privately used bounce houses should be eliminated or streamlined. As further research is conducted, some of these measures may be deemed inadequate or otherwise modified; however, all users of inflatables would benefit from these necessary safety measures. In this way, the high-profile nature of a relatively few wind-related bounce house incidents can be leveraged to spread the word about safety that can then reduce the thousands of non-weather-related bounce house injuries that happen without media attention every year.

Another potential avenue to explore, beyond currently existing measures, involves the opportunity to require vendors to regularly obtain or provide access to wind information to inform customers of potentially dangerous wind conditions in the forecast. This addition to the regulation would 1) provide additional information and warning to parents/caregivers renting a bounce house and 2) require the customer to complete additional paperwork releasing the vendors' responsibility in the event of a weather-related inflatable incident. Perhaps these additional steps in the renting process and the added warnings of increased wind speeds would make customers more vigilant in assessing the wind conditions throughout the entirety of the bounce house rental. Future research should explore the thoughts and opinions of PIAD business owners, in an attempt to better understand their concerns about wind, including additional policies/regulations, and their willingness to provide additional safety information regarding weather-related hazards. Also, how often the ASTM standards are followed to not only evacuate, but also to *deflate*, bounce houses in adverse wind conditions should be determined by surveying PIAD business owners. We have noted in our research some incidents where empty, but not deflated, bounce houses caused wind-related injuries and damage.

Future research in education and outreach should investigate how the dangers associated with wind and other weather-related phenomena are currently communicated to parents/caregivers/event organizers renting inflatables. Are they required to read the fine print on the PIAD rental contract, or should it be the business's responsibility to verbally state all the risks? Perhaps including a handout, like the one provided on our website, could clearly communicate the risks associated with bounce houses without a renter/purchaser having to search for safety information on their own. Furthermore, with the growing popularity of residential bounce houses and inflatables, will we see an increase in incidents in the future? Future work should attempt to address how to reach and educate parents/caregivers on the risks associated with wind-related bounce house incidents when a third party does not regulate or inform them of the risks. Perhaps an interdisciplinary approach, using other residential injury prevention scenarios as a guide, could be applicable. Providers and users of bounce houses should also be made aware in particular of the number of bounce house incidents caused by dust devils as found in our study, and to be on the lookout for such phenomena.

To alert the public to the danger of airborne bounce houses and other PIADs, we recommend that the National Weather Service include, in its wind-related products, statements, and advisories recommending "precautionary/preparedness actions," a reminder to leave, deflate, and secure bounce houses. This advice should also appear in NWS safety literature and on its website. These changes would be fully in keeping with the NWS's emphasis on impact-based warnings (NWS 2021). Current NWS wind advisories often mention the need to secure items such as lawn furniture or holiday decorations in the event of strong winds; we believe that adding bounce houses to the list is appropriate and important, based on the results of our study.

At a more basic level of communication, a memorable phrase to encourage safety, akin to the famous NWS phrase “Turn Around, Don’t Drown” for flood safety, might help convey the most basic information. As this article demonstrates, “Even in Clear Skies, Bounce Houses Can Fly.”

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Data availability statement. Data used in this study were obtained from various news and meteorological sources, and from state government sites for statutes and regulations, and then collected, reformatted, and analyzed for this article. These data, or links to these data, are provided at our website weathertobounce.com.

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