1.1 RECENT STUDIES OF LIGHTNING SAFETY AND DEMOGRAPHICS

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ABSTRACT

A wide variety of lightning safety-related studies has been made by the author since 2007. The studies involve analyses of large datasets of lightning casualties and flashes, and are oriented toward results that relate to safety topics. Seven topics were presented and published at several conferences and venues that may not be readily available for all of these meetings, so the results will be summarized in the following seven numbered sections:

1. Monthly U.S. cloud-to-ground lightning maps
2. Lightning fatalities by U.S. state
3. Mechanisms of lightning injury.
4. Lightning casualties in and near vehicles.
5. Lightning casualties in dwellings and buildings.
6. Lightning casualties in and near water.
7. Global lightning casualties.

Each section will start with a brief overview of the main results related to lightning safety, including recent references for that section. The rest of each section will summarize the main points from the recent publications with regard to lightning safety issues.

1. MONTHLY U.S. CLOUD-TO-GROUND LIGHTNING MAPS

The monthly distribution of U.S. cloud-to-ground lightning from the National Lightning Detection Network has a rather sharp concentration in June, July, and August in most parts of the country that should affect lightning safety avoidance recommendations (Holle and Cummins 2010; Holle et al. 2011).

Two recent conference papers have described the monthly distribution of U.S. cloud-to-ground lightning from the National Lightning Detection Network (Holle and Cummins 2010; Holle et al. 2011). Monthly maps had not been shown before, although a large number of national and regional climatologies have been developed (see these two references for an extensive list of prior U.S. cloud-to-ground lightning climatologies).

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The new monthly maps have implications for lightning safety recommendations. Lightning is concentrated within a few months in most areas of the country, including Florida that has a strong concentration of its lightning in June, July, and August. In contrast, Arizona and surrounding states have nearly all of their flashes in July and August only.

With these monthly maps, it is possible to define the lightning threat season more clearly for vulnerable activities such as hiking and boating, depending on the area of the country. Since most locations have the lightning threat concentrated in a few months, some outdoor activities can be pursued outside of those months in order to avoid lightning.

1A. Annual

Figure 1 shows measured monthly flash distributions over the contiguous U.S. and adjacent areas. An average of 27 million cloud-to-ground flashes was detected per year by the NLDN over the contiguous U.S. land area. Lightning is most common in summer - two thirds of U.S. cloud-to-ground flashes occur in June, July, and August.

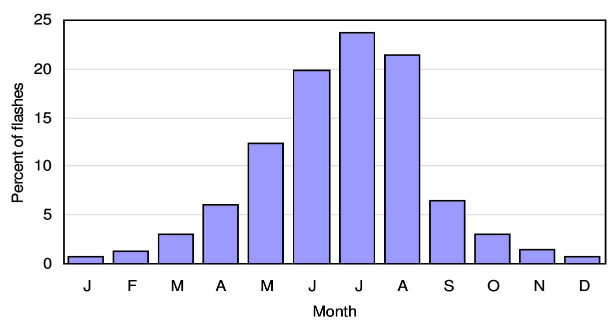

FIGURE 1. Cloud-to-ground flashes per month from 2004 though 2008 for the U.S. and adjacent areas from the National Lightning Detection Network.

1B. Sample monthly flash density maps

In January most 20 by 20 km grid squares in the eastern half of the country had at least some lightning, but many locations in the northwest half had no January flashes in any year. The February and March lightning areas grew in intensity and area until in April, Figure 2 shows extensive areal coverage and flash density in nearly every region of the U.S.

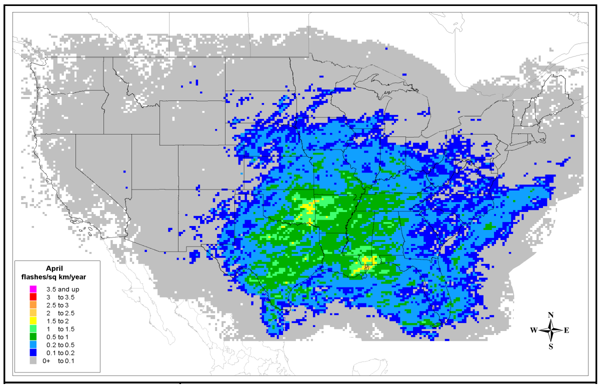

FIGURE 2. Cloud-to-ground lightning flash density per square kilometer in April for the U.S. from 2004 through 2008. Scale is in lower left portion of map.

Lightning continues to intensify and spread until in June, the NLDN in Figure 3 shows the rapid development since May of the Florida lightning maximum exceeding 3.0 flashes/km^2/year across much of the peninsula due to the influence of the two coastal sea breezes. Additional sea breezes are apparent across the Florida Panhandle to Texas. High lightning frequencies are also from Kansas and Oklahoma eastward to Illinois and other states.

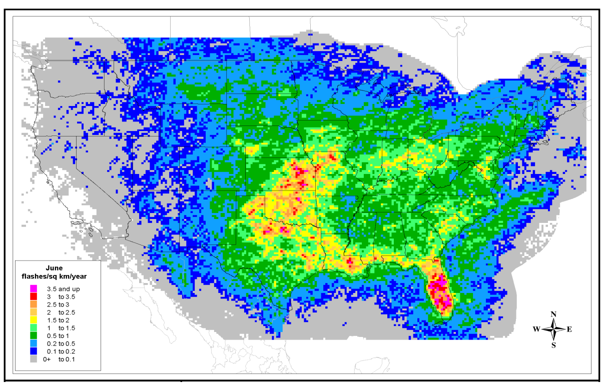

FIGURE 3. Same as Figure 2, except for June.

In July, the NLDN in Figure 4 shows the appearance of two lightning maxima over Arizona compared with June as the Southwest Monsoon begins. Also resulting from monsoonal moisture flow is a large increase in lightning in Colorado and New Mexico compared with June. Over Florida, flash density exceeds 3.5 flashes/km^2/year over many areas of the peninsula.

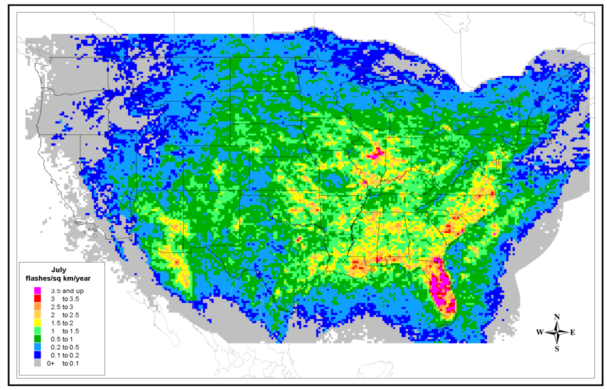

FIGURE 4. Same as Figure 2, except for July.

Vaisala has developed the Global Lightning Dataset GLD360 that detects most cloud-to-ground lightning around the world. Monthly GLD360 summer maps in a region surrounding the NLDN are in Holle et al. (2011). In July GLD360 in Figure 5 shows substantially the same features as the NLDN (Figure 4) over the U.S. GLD360 also shows the extension of the coastal U.S. maximum all along the Gulf of Mexico around Mexico, as well as maxima over Cuba, Hispaniola, and northern South America. The maximum over northwest Mexico has extended into Arizona and New Mexico in July (Figures 4 and 5). The capability of GLD360 to measure global cloud-to-ground flashes has promise for many lightning safety applications.

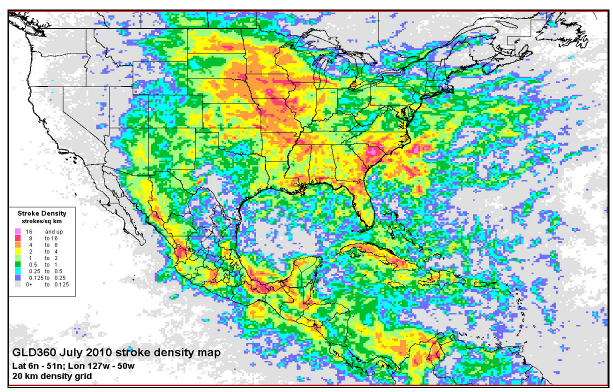

FIGURE 5. Global Lightning Dataset GLD360 cloud-to-ground strokes per square kilometer in July from 2004 though 2008 for the U.S., Mexico, Central America, Gulf of Mexico, Caribbean Sea, and northern South America. Scale is in lower left portion of map.

In August, the NLDN shows a modest lightning decrease over Arizona, Florida, the southeast coast, and offshore Gulf Stream regions from July. In September, a marked decrease in flash density values is across the entire U.S., then a continued broad decrease to the end of the year (Holle and Cummins 2010; Holle et al. 2011).

1C. Sample monthly flash percentage maps

Monthly maps were also shown in Holle and Cummins (2010) and Holle et al. (2011) to show the percentage of flashes compared with the annual totals. Figure 6 shows that January has mostly less than 10% of the annual total. However, along the west coast, there are individual grid squares where up to 100% of the annual flashes occur in this month. Also note the concentration of flashes in the Central Valley of California.

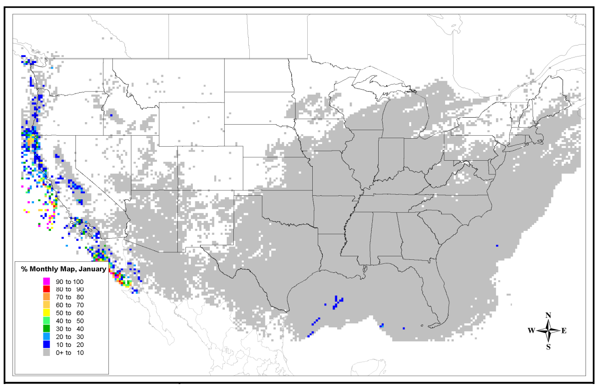

FIGURE 6. Percentage of annual cloud-to-ground lightning flashes that occur in January for the U.S. from 2004 through 2008. Scale is in lower left portion of map.

In April, eastern Oklahoma southeastward to the Gulf and southern Texas has up to 20% of the annual lightning. The western Sierra Nevada range of California and Cascades of Oregon and Washington have much of their annual lightning in April.

During May, percentages are very low in Florida, while west Texas, Kansas, and Nebraska have up to 40%. Some areas in central Washington exceed 40 to 50% in May, and a few Oregon coastal areas exceed 80%.

During June, Figure 7 shows an area exceeding 40% over much of Montana. The high May percentage area in west Texas has moved to the Panhandle. Scattered areas above 40% are apparent across the northeast in June. Florida has 20 to 30% of its annual lightning in June. Nearly all of Arizona and surrounding adjacent states, and the Central Valley of California have a very low incidence of June lightning.

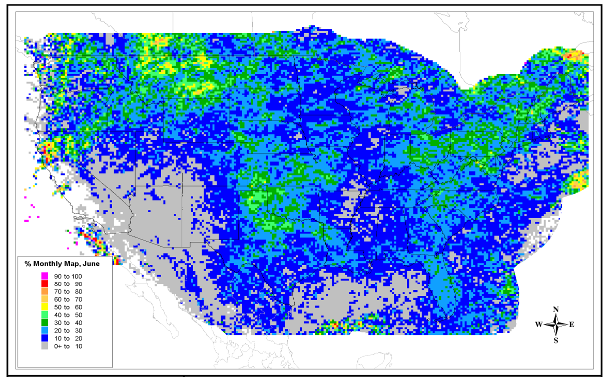

FIGURE 7. Same as Figure 6, except for June.

In July, Figure 8 indicates a sharp increase in the flash percentage in Arizona and nearby states. In southern Nevada, over half of the year's lightning occurs in July. Also notable are high percentages across New England and the Atlantic coast from Maryland northward, where July is the dominant month for lightning in many large northeastern cities. Much of north Florida has over 30% of its lightning in July. July lightning is absent in much of Texas and Oklahoma, and adjacent northeast regions.

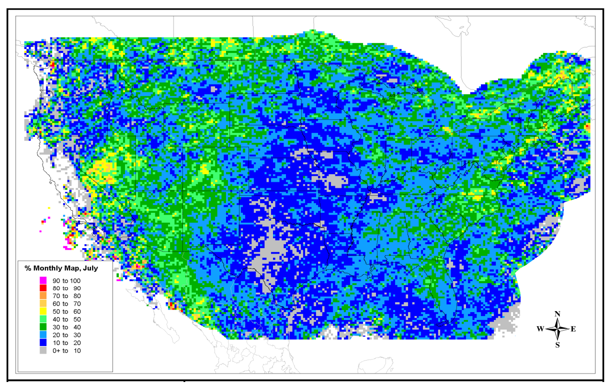

FIGURE 8. Same as Figure 6, except for July.

In August, Arizona and associated monsoon regions have up to 50% or more of the year's lightning. Lower deserts of southern California into northern Baja California have most of their year's flashes in August, as well as central Oregon. Across most of the Florida peninsula, at least 20% of the year's lightning is during August.

1D. Summary

Monthly maps of lightning frequency and their monthly percentages show that most states and regions have a concentration of cloud-to-ground lightning in a few months (Holle and Cummins 2010; Holle et al. 2011). Such information is important for planning to avoid the lightning threat, as well as the timing and messages for lightning safety programs.

2. LIGHTNING FATALITIES BY U.S. STATE

U.S. states with the most lightning fatalities, when weighted by population, are in the southeast and the Northern Rocky Mountains (Holle 2009c).

Holle (2009c) shows state by state rankings in maps and tables of lightning fatalities and population-weighted lightning fatalities that were prepared by the author for the latest 10 years. These datasets are completed annually during May after the previous year's *Storm Data* reports are finalized. Fatalities have been the focus of these maps and tables since U.S. fatalities are reported better than injuries (Mogil et al. 1977; López et al. 1993; Richey et al. 2007; Shearman and Ojala 1999; Ashley and Gilson 2009). It is estimated that there are 10 injuries for every lightning fatality (Cherington et al. 1999).

John Jensenius of the National Weather Service (NWS) in Gray, Maine updates the lightning fatality list for the current year on a daily basis. He has also been very helpful in checking the author's compilation of these maps and tables each year. They are placed onto the NWS Lightning Awareness Week website www.lightningsafety.noaa.gov before the annual lightning emphasis by the NWS and others during the last full week of June each year.

For 2000 through 2009, Figures 9 and 10 show that the states with the most lightning fatalities are in southeast, populous northeast and Midwest states, and Texas and Colorado. However, when weighted by population, the highest ranks are in two main groups, the southeast states and the Northern Rocky Mountain states. The population-weighted data are considered to be more representative of the lightning fatality situation because it reduces the emphasis on highly populated states. First attempts to relate these state-by-state differences to numerous other meteorological parameters are explored in Holle (2009a).

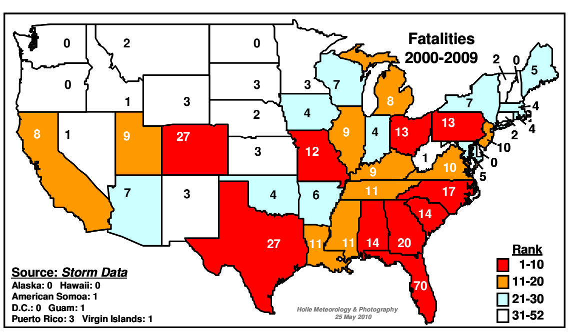

FIGURE 9. *Map of the number and rank of U.S. lightning fatalities by state from 2000 to 2009 from* Storm Data.

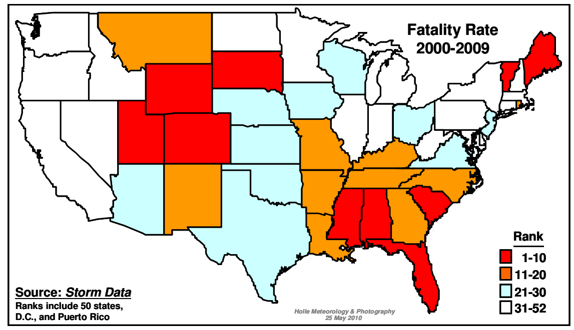

FIGURE 10. *Map of the rank of U.S. lightning fatalities weighted by population by state from 2000 to 2009 from* Storm Data.

Further historical context has been provided by extending the data back in time. Curran et al. (2000) showed maps and tables of state-by-state fatalities and injuries, both with and without population weighting from 1959 to 1994 (*Storm Data* began in 1959). Figures 11 and 12 show lightning fatalities and population-weighted fatality rates for the entire period of data from 1959 to 2009 from *Storm Data*. Shifts in recent years are shown by comparison with Figures 9 and 10 for 2000-2009. It is recommended that the latest decade of record is much more appropriate to show for educational purposes.

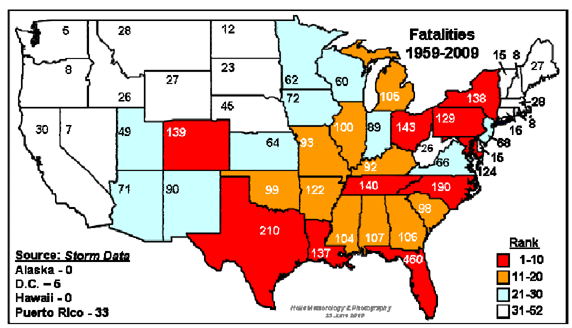

FIGURE 11. *Map of the number and rank of U.S. lightning fatalities by state from 1959 to 2009 from* Storm Data.

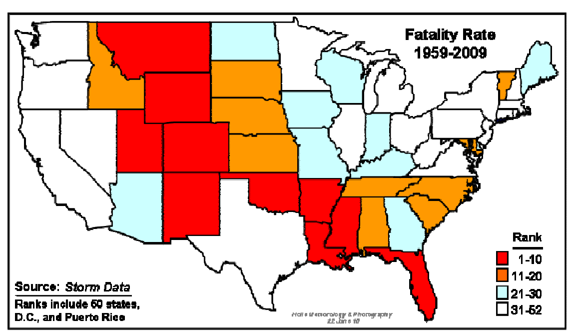

FIGURE 12. *Map of the rank of U.S. lightning fatalities weighted by population by state from 1959 to 2009 from* Storm Data.

3. MECHANISMS OF LIGHTNING INJURY

Lightning injury is due to five distinct mechanisms, but while the direct strike is the most discussed, it is actually the least common (~5%) so it should not be a significant factor in lightning education (Cooper and Holle 2010).

3A. Introduction

Section 1 described the distribution of cloud-to-ground lightning, then section 2 described locations of lightning fatalities. Section 3 lists the mechanisms of lightning injuries to people, which vary in subsequent sections on casualties related to vehicles (section 4), buildings (section 5), and water (section 6).

Cooper and Holle (2010) is the most recent presentation on the methods of lightning injury (Figure 13). The distribution of injuries between the different mechanisms is based on reviews of hundreds of cases over several decades by researchers primarily from more developed countries. Although web, newspaper, and other media reports and personal accounts most often recount 'direct strike' as the mechanism of lightning injury, examination of hundreds of injuries reveals that direct strike is a very small proportion of the injuries.

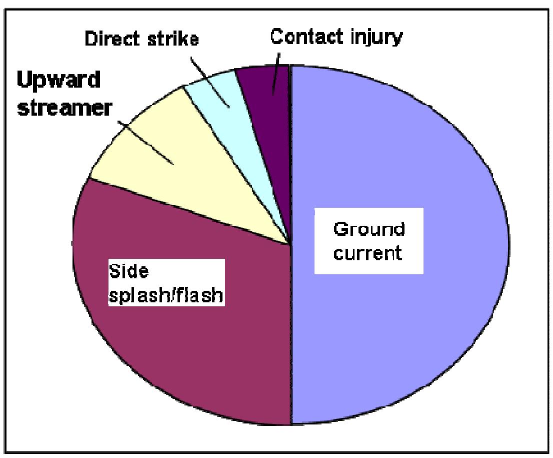

FIGURE 13. Distribution of lightning injury mechanisms.

Reasons for misreporting include lack of knowledge of other mechanisms by the witness, victim or reporter; errors in observation; assumptions by eyewitnesses untrained in lightning observation; amnesia of the victims; and over-dramatization of the event. In addition, the misreporting of lightning injury mechanisms is partially due to the retrospective nature of the reports that are usually gathered from witnesses and survivors of the lightning strike. Further, the expectation of direct strike is so prevalent that it is considered as the only mechanism despite evidence to the contrary.

3B. Direct strike - 3 to 5%

A direct strike occurs when the lightning stroke attaches directly to the victim. This is most likely in the open when a person has not taken the time to reach the safety of a large substantial building or fully-enclosed metal-topped vehicle. While it is intuitive that the direct strike might be the most likely to cause fatalities, this has not been shown in any studies or reviews of large number of lightning casualties.

3C. Contact injury - 3 to 5%

Contact, or touch potential, injury occurs when the person is touching or holding onto an object to which lightning attaches such as indoor hard wired telephones or plumbing, or outside wire fencing that transmits the current to the person. A voltage gradient is set up on that object from strike point to ground, and the person in contact with the object is subject to the voltage between their contact point and the earth, and a current flows through the person.

3D. Side flash - 30 to 35%

A more frequent cause of injury is a side flash, also termed splash. Side flashes occur when lightning hits an object such as a tree or building, and travels partly down that object before a portion "jumps" to a nearby victim. Standing under or close to trees and other tall objects is a very common way in which people are splashed. Current divides itself between the two or more paths in inverse proportion to their resistances.

3E. Ground current - 50 to 55%

Ground current, also known as Earth Potential Rise (EPR), arises because the earth, modeled ideally as a perfect conductor, is not so in reality. When lightning current is injected into the earth, it travels through the earth just like it would in any other conductor. Earth has a finite resistance so that voltages are set up in the ground, decreasing in size with distance from the strike point. The voltage (or potential) of the earth is raised, hence the term EPR.

Ground current effects may be more likely to be temporary, slight and less likely to produce fatalities. However, multiple victims and injuries are frequent. Kitigawa et al. (2001) have identified further subdivisions of the EPR phenomenon. He notes that not only can EPR occur as above, but it can also occur in a manner similar to the surface flashes over a body, with arcs developing over a ground surface.

The grounding earth is not homogeneous and provides arc generation points. If the terrain is very irregular, the spreading lightning current may reach the surface and a surface arc discharge develop together with the flow of the conduction current in the ground. This mechanism of injury makes it particularly dangerous on a mountainside to shelter inside a shallow cave or under a small cliff or outcropping of terrain where surface arcing is much more likely to occur, despite an impression that some degree of safety had been reached.

3F. Upward leader - 10 to 15%

Injury may occur when a victim serves as the conduit for one of the usually multiple upward leaders induced by a downward stepped leader and its field. Leaders also occur when there is no attachment between them and the stepped leader. While one might think that these are weak in energy compared to the full lightning strike, they may carry several hundreds of amperes of current which can be transmitted through or around the victim. This mechanism has been mentioned by many engineering and physicist lightning experts in their writings and a case report has been published in the medical literature. Upward streamer injury is probably a much underestimated mechanism of injury.

3G. Blunt injury - unknown

Persons may suffer from (non-electrical) blunt injury, either by 1) being close to the concussive force of the shock wave produced by a nearby lightning strike, or 2) ground current or some other mechanism induces intense muscle contractions which can throw the victim up to tens of yards. In addition, a person struck by lightning may suffer from explosive and implosive forces created by thunder, resulting in contusions and pressure injuries, including tympanic membrane rupture. Another mechanism of blunt injury is blast injury resulting from vaporization of water on the body surface from a surface flashover spark.

3H. Discussion

The vast majority of lightning injuries and deaths are caused by mechanisms other than direct strike. Any public education efforts should take into account all of these mechanisms.

There have been many reports of multiple injuries. It is likely that these may involve groups who are exposed to a combination of mechanisms, with the majority of the people injured by EPR and upward streamers, sometimes complicated by side flashes if people are standing too close together. In summary, information on the exact mechanisms of lightning injury remains poorly documented and understood, however the direct strike is not a frequent mechanism of lightning injury.

4. LIGHTNING CASUALTIES IN AND NEAR VEHICLES

Fully-enclosed metal-topped vehicles are very safe places from lightning that should be reached when they are nearby, although they are often damaged and the experience frightening; motorcycles are very unsafe from lightning (Holle 2007b, 2008b).

4A. Introduction

Holle (2007b and 2008b) have the first summaries of a large number of people impacted by lightning in and near vehicles. A separate study by Cooper and Holle (2007) showed that motorcycles and similar small exposed vehicles are very unsafe from lightning. Lightning safety recommendations identify two reliable safe places (Holle et al. 1999 and others). One is inside a fully-enclosed metal-topped vehicle. The other safe location is inside a large enclosed building (section 5).

Fully-enclosed metal-topped vehicles are very safe places from lightning that should be reached when they are nearby, although they can be damaged and the experience can be frightening. The category of “Near vehicles” accounted for 4.1% of deaths and 5.0% of injuries in Holle et al. (2001, 2005).

The cases in the following sections were randomly collected through newspapers, web reports, broadcast media, published papers, the NOAA publication *Storm Data,* and other sources. The reports in this study are mainly from the last 20 years. Situations under which people have become lightning victims in the vicinity of vehicles are in Table 1.

TABLE 1. Type and number of vehicle-related events, deaths, and injuries.

Type of vehicle event	Events	Deaths-	Injuries
Inside fully enclosed metal-topped vehicles	76	4	77
Direct contact	36	9	37
On or near non-enclosed vehicles	29	7	67
Parking lots	24	8	30
Other casualties related to vehicles	47	14	77
Total	212	42	288

4B. People inside fully-enclosed metal-topped vehicles struck by lightning

During the 76 events in Table 1 in this category, people inside the vehicles described themselves as *uninjured* in more than half of the events (40). Since more than half of the direct strike events involved no injuries, and the rest were typically minor impacts, recommended lightning safety precaution (Holle et al. 1999) to seek safety inside a fully-enclosed metal-topped vehicle appears well supported.

Of the four events in Table 1 involving deaths inside a vehicle, two were ambiguous (Holle 2007b, 2008b). Most reliable involved a 74-year-old woman starting a crash when lightning struck near her vehicle. She and another driver were killed; there were two injuries. Otherwise, there are no fatalities to people inside fully-enclosed metal-topped vehicles in 212 cases.

Table 2 has injuries inside fully-enclosed metal-topped vehicles. The most common injury involved the arm or elbow. No significant injuries appear to have resulted from direct contact with metal in the vehicle, except for a case with an earplug attached by a power cord to the dashboard. As a result, less emphasis may be made in vehicle safety recommendations about avoiding metal contact while inside a safe vehicle.

TABLE 2. Injuries reported to people inside fully-enclosed metal-topped vehicles, summarized from Table 1.

Symptom	Events
Arms/elbows tingling, burned, struck, or numb	7
Ears ringing, hearing loss, or earphone damage	4
Shaken, jolted, or dizzy	4
Other single-event symptoms	10

With respect to vehicle damage with people inside, the most common impact was for the antenna to be hit. Next most common was destroyed or damaged electrical systems. Flat tires were reported, as well as glass damage, a stopped engine, burn marks, and smoke. Pavement beneath the vehicles was damaged in some cases. It is appropriate to relate these results to the myth about rubber tires saving people inside vehicles. Some direct strikes to vehicles involve lightning current flowing around the outside metal body. Sometimes current will find its way to an axle and arc to the ground, resulting in blown tires or observed pavement marks.

It should be noted that most vehicles were in motion when struck by lightning. The rest were waiting at a stop sign, intersection, parking lot, football game, or for the thunderstorm to end.

4C. People in direct contact with vehicles struck by lightning

Table 3 summarizes major categories that involved people in contact with the outside of vehicles at the time of a strike. The most common category is entering/exiting vehicles. This category in section 3E is ground current or Earth Potential Rise, also described as step voltage. This is very dangerous; five of the nine direct-contact deaths were in this posture. A formerly unknown category had eight events when people were working on vehicles when current from a nearby flash traveled to them in contact with the ground. Details are in Holle (2007b, 2008b).

TABLE 3. Situations of people in direct contact with vehicles when struck by lightning.

Activity	Events	Deaths-	Injuries
Entering/exiting vehicles	11	5	7
Working under or on vehicles	8	0	14
Leaning on vehicles	4	2	4
Rolling up windows	3	2	2
Other	10	0	10

4D. People on or near non-enclosed vehicles

Table 1 has 29 events with lightning casualties while on or near non-enclosed vehicles. In these cases, there was no protection provided by any structure surrounding the people, in contrast to cases with people inside fully-enclosed metal-topped vehicles. The most common location was standing or working near a crane, followed by being under a trailer awning or porch (Holle 2008b, 2009b).

4E. Parking lots

Table 1 has 24 events of people who were lightning casualties, often fatalities, while in parking lots. These casualties were not inside vehicles, or in direct contact with vehicles. People in these cases were usually in the process of crossing a parking lot to or from a vehicle, or under a tree at the lot.

4F. Other casualties related to vehicles

Other cases when people were near vehicles when killed or injured by lightning are listed in Table 1. The most common event occurred when people were outside waiting for a bus or other type of transportation. All other cases included people outside a vehicle. Details are in Holle (2008b, 2009b).

4G. Summary of vehicle casualties

The most common type of vehicle impact was a strike to a fully-enclosed metal-topped vehicle with people inside. People described themselves as *uninjured* in more than half of these events. One case had two fatalities resulting from a driver apparently reacting to a nearby flash and driving into oncoming traffic. With the exception of that case, few events involved major injuries.

Only one injury resulted from direct contact with metal in the vehicle. As a result, less emphasis may be made in safety recommendations about the posture or position inside the vehicle such as avoiding metal contact. It is concluded that being inside a fully-enclosed metal-topped vehicle is a safe place to be from the danger of lightning compared to remaining outside at the same time and place.

5. LIGHTNING CASUALTIES IN DWELLINGS AND BUILDINGS

Large well-constructed buildings are very safe from lightning if people inside are not in contact with conducting paths of wiring and plumbing. Unfortunately many buildings in lesser-developed areas of the world are not safe, including dwellings, schools, and other small straw-roofed structures (Holle 2009a, 2009b, 2010).

5A. Introduction

Lightning safety recommendations identify two reliable safe places (Holle et al. 1999 and others). One is inside a fully-enclosed metal-topped vehicle (section 4). The other is inside a large substantial building (Holle 2009a, 2009b, 2010). "Indoors" accounted for 4% of lightning deaths and 12% of injuries from 1991-1994 (Holle et al. 2001, 2005). These are much lower than 100 years ago, when 29% of deaths and 61% of injuries were indoors.

Large enclosed buildings are those where people often live or work. Beginning in the 20th century in more developed countries, they surround occupants with an effect similar to that of a Faraday cage such that a direct strike is conducted around people inside the structure. When such buildings are grounded according to code, people inside are usually safe from lightning if not in direct contact with the conducting paths. In addition, structures in more developed countries tend to have a metal reinforcing infrastructure that can help dissipate lightning.

The following cases were randomly collected through the same methods as in the previous vehicle section 4. U.S. cases were separated to be representative of situations in more developed areas of the world, although similar structures are also located in all other areas of the world.

5B. U.S. dwellings

Table 1 shows 355 events related to U.S. dwellings. These cases accounted for 106 deaths and 295 injuries. The ratio of 3 injuries for each death is low compared with the ratio of 10 injuries per death found from a review of all available medical records in Colorado by Cherington et al. (1999).

TABLE 4. Type and number of lightning-related events, deaths, and injuries involving U.S. dwellings.

Activity	Events	Deaths-	Injuries
Deaths inside	21	31	4
Injuries inside	169	0	173
During construction	27	15	16
On property	138	60	102
Total	**355**	**106**	**295**

5B.1. Deaths inside U.S. dwellings

Table 4 has 21 U.S. dwelling events with 31 deaths and four injuries. All but three occurred from a home catching fire, and most occurred between 11 pm and 8 am. Note that lightning-caused home fire cases may not be reported as a cause of lightning deaths. In these events, 14 of the 31 deaths occurred to people aged 70 or older; the oldest was 101. The remaining cases mostly affected children under 18; two involved mentally and/or physically challenged people.

5B.2. Injuries inside U.S. dwellings

Table 1 lists 169 events that involved people who were injured while inside U.S. dwellings, which is a much larger category than the number of fatalities inside dwellings. Most injuries were minor, although they can result in significant long-term impacts (Cooper et al. 2007). There are several major groupings:

- **Wiring**: 42 events involved wiring connected to an electrical device inside a U.S. dwelling,
- **Telephone**: 26 involved telephones being used inside a U.S. dwelling (Andrews 1992; 2007),
- **Plumbing**: 19 involved plumbing inside a U.S. dwelling.

Lightning safety recommendations often add to stay away from windows inside a dwelling; however, only 10 of the 168 injury entries involved a window. Besides wiring, telephones, and plumbing, the categories of doorways (20) and garages (19) are actually larger than windows (10).

5B.3. Construction of U.S. dwellings

A previously unrecognized category in Table 1 involves 27 cases of dwellings under construction. The roof is very unsafe, as well as other locations inside. It appears that a complete Faraday cage effect is not provided inside an unfinished dwelling, although the perception may be that the enclosure is safe from lightning, since it provides shelter from rain. In this case, the safety recommendation is to go inside fully-enclosed metal-topped vehicles that are typically located at a construction site, rather then waiting out the storm within such a structure (Holle 2007b, 2008b).

5B.4. On property of U.S. dwellings

Lightning safety recommendations emphasize going inside a substantial building that provides safety from the effects of lightning. Being on the property near a dwelling is the largest dwelling fatality category - outside a dwelling, as anywhere else outside is very unsafe from lightning. Table 2 lists 138 cases with 60 deaths and 102 injuries; 80% were male. The major categories are:

- **Yard**: 45 events involved people in the yard, not necessarily in the garden, resulting in 15 deaths and 32 injuries.

- **Tree in yard**: 16 events involved a person under or near a tree.
- **Mowing lawn:** 13 events involved a person mowing the lawn; more than half were killed.
- **Garden**: 12 events involved people working in the yard or garden. Six cases involved a resident or neighbor working in a yard or garden, and another six involved hired yard workers.
- **Playing in yard:** Nine events involved six children who were killed, and 10 children were injured while playing in the yard of a dwelling.
- **Driveway**: Seven events involved people in a driveway.

TABLE 5. Casualties from lightning to people on property of U.S. dwellings

Activity	Events	Deaths-	Injuries
Yard	45	15	32
Tree in yard	16	7	9
Mowing lawn	13	7	6
Playing in yard	9	6	10
Driveway	9	3	7
Working in yard/garden	6	6	0
Gardener	6	3	3
Clothesline	4	4	2
Caring for animals	2	1	1
Working on vehicle	2	1	1
Fleeing house on fire	1	2	0
Securing property	1	1	2
Burying pet in yard	1	1	1
Other single-fatality events	3	3	0
Birthday party	1	0	9
Events with 1 or 2 injuries	19	0	20
Total	**138**	**60**	**102**

5B.5. Summary of U.S. dwellings

Being inside a U.S. dwelling is safe from lightning unless it catches fire and an elderly, young, or disabled person is unable to leave, especially at night. Most injuries occur while in contact with wiring, a telephone, or plumbing; frequent cases also occur in doorways and garages. Dwellings under construction are very unsafe; safety should be sought in a vehicle. Frequent deaths and injuries occur in the yards of U.S. dwellings, as well as in the vicinity of trees in the yard, while mowing the lawn, and during other everyday activities and locations outside the home.

5C. Non-U.S. dwellings

Table 6 summarizes lightning casualties related to dwellings that are not in the United States. Note that many more people in less developed areas spend much more of their time outside of dwellings and buildings than in more developed regions.

TABLE 6. Type and number of lightning-related events, deaths, and injuries involving dwellings not in the U.S.

Type of event	Events	Deaths-	Injuries
Deaths inside	26	106	33
Injuries inside	27	0	30
Hut	25	76	68
On property	13	17	4
Total	**91**	**199**	**135**

5C.1. Deaths inside non-U.S. dwellings

Only six of the 26 events in Table 6 are known to involve people sleeping, presumably at night, and three events mention burns or fires. Compared with the U.S. dwelling events in Table 4, the ratio of fires and late-night events is much lower. No cases from outside the U.S. mention physical or mental disability, or a tendency toward elderly people, as in the U.S. Cases involving a rondavel (thatch-roofed dwelling in South Africa) are described later.

The number of casualties per event is much higher than in the U.S. cases. More than half (15 of 26) of the events involved two or more fatalities; 16 people were killed in one case in a home. The most frequent U.S. case was one person per incident.

The current scenario in non-U.S. dwellings, mainly in developing countries, is similar to that of U.S. events in the late 1800s (Holle et al. 2001, 2005). At that time, people were killed inside U.S. dwellings before there was widespread grounding by coded electrical and plumbing systems.

5C.2. Huts

A separate category was identified for non-U.S. dwellings described as a hut used as a dwelling. In most cases, the term hut was explicitly used in the English-language news reports that originated within the country where the event occurred. These reports are not included in other groups in Table 6.

All hut events involved at least one fatality. Most involved multiple casualties - one case involved 13 deaths and another had 21 injuries. More than half of the hut reports came from South Africa, where the typical dwelling was a rondavel (thatch-roofed dwelling). More than half (13 of 25) of the events involved a hut or rondavel catching fire.

5C.3. Casualties on property of non-U.S. dwellings

Table 6 lists 13 incidents resulting in 17 deaths and four injuries on the property of non-U.S dwellings. Many of the situations are the same as found in Table 4 for the U.S. property cases. However, there is only one tenth as many reports from outside the U.S. compared with the U.S. In addition, all incidents include fatalities, and few have injuries, which reinforces the tendency for reports of lightning casualties outside the U.S. to consist primarily of fatalities.

5C.4. Summary of non-U.S. dwellings

Non-U.S. dwellings are often not safe inside from lightning. Large numbers of people are killed inside dwellings in developing countries, especially inside thatch-roofed houses, huts, and rondavels in Africa and other developing countries.

Table 6 has a ratio of less than one injury to each death is extremely low compared with the ratio of 10 injuries per death requiring medical treatment in Colorado (Cherington et al. 1999). One factor for the low ratio is that non-U.S. dwellings in developing countries are often not safe from lightning due to a lack of safe grounding, structural metal components, and other construction factors. A second factor is that few reports from outside the U.S. refer to lightning events involving injuries only.

5D. U.S. buildings, except dwellings

Table 7 shows 146 events related to U.S. buildings that are not dwellings; the cases had 25 deaths and 319 injuries. The ratio of 13 injuries per death is similar to the ratio of 10 injuries per death requiring medical treatment in Colorado (Cherington et al. 1999).

TABLE 7. Summary of type and number of lightning-related events, deaths, and injuries involving U.S. buildings other than dwellings.

Type of event	Events	Deaths-	Injuries
Inside	24	0	42
On property	25	6	55
Schools	44	9	88
Small structures	34	10	110
Communications	19	0	24
Total	**146**	**25**	**319**

5D.1. Casualties inside U.S. buildings

Table 7 lists 24 events that involved people who were casualties inside U.S. buildings. When the very large number of buildings are considered, and the large amount of time that people spend in such structures, it is notable that no fatalities and very few injuries occur inside them. It can be concluded that the vast majority of such buildings are quite safe from lightning while inside.

5D.2. Casualties related to U.S. schools

Tables 7 and 8 list 44 school events. Most events were outside of schools; only a few injuries occurred inside. Many cases involved transportation, including those around buses and in parking lots. The largest activity category was walking near buildings of schools. Seven universities, eight high schools, three middle schools, and 16 grade schools were involved. Two events occurred outside administration buildings. Issues involved in school lightning safety are addressed in Allsopp et al. (2001), and some cases were also in the vehicle study in Section 4.

TABLE 8. Lightning-related events, deaths, and injuries to people at U.S. schools.

Location	Events	Deaths-	Injuries
Inside	**4**	**0**	**5**
Grade school office	2	0	3
Other single-event injuries	2	0	2
On property	**40**	**9**	**83**
Walking	8	0	10
Parking lot	5	0	5
Soccer	2	2	3
Football	2	0	4
Others on property			
Waiting for/leaving grade school bus	2	2	10
Under trees by university bldg.	2	1	3
Waiting outside school	2	0	4
Crossing guard, grade school	2	0	2
Jogging on middle school track	1	1	1
At high school	1	1	0
Outside dining hall at university	1	1	0
Track meet, high school	1	1	0
Fence at grade school	1	0	12
School playground by tree	1	0	9
Outside middle school; boiler exploded	1	0	8
Waiting for class at high school	1	0	3
Playing in tree, grade school	1	0	2
Roofing grade school	1	0	2
Other single-injury events	5	0	5
Total	**44**	**9**	**88**

5D.3. Casualties related to U.S. small structures

Tables 7 and 9 lists 34 events within small U.S structures. The category of small structures was identified in Holle et al. (2001, 2005) as the source of 3% of U.S. deaths and 2% of U.S. injuries from 1991 to 1994.

Nine cases involved people seeking safety under small structures on golf shelters. These structures are often far from the clubhouse, so that enough time was not taken to reach a safe place, or people returned to the course too soon (Holle 2005). Other locations were also being sought for shelter from rain, including pavilions, gazebos, and sheds that have mostly open sides and minimal or no grounded wiring, plumbing, or other features that provide a reasonably complete Faraday cage effect around people. Any small structure where people do not often live or work can be assumed to be unsafe from lightning because of the inadequacy of the Faraday cage-like effect. Such facilities can be made safe from lightning with specific knowledgeable advance planning (Kithil and Rakov 2001; Tobias 2002).

TABLE 9. Lightning-related events, deaths, and injuries to people at small U.S. structures not used as a dwelling.

Location	Events	Deaths	Injuries
Shelter on golf course	9	3	33
Beach pavilion/pavilion	5	3	20
Fishing shed	2	1	2
Hut on coastal vacation island	1	1	1
Mailbox kiosk	1	1	0
Phone booth hit by falling object	1	1	0
Shed in back yard	3	0	3
Baseball dugout	2	0	7
Soldiers by rifle range pavilion	1	0	21
Gazebo at zoo	1	0	10
Lean-to attached to garage	1	0	2
Other-single-injury events	7	0	7
Total	**34**	**10**	**110**

5D.4. Casualties related to U.S. communications

Table 7 also lists 19 events that injured 24 people in the U.S. who were casualties of lightning while using communications, except in dwellings. The largest group consists of people working inside buildings using corded telephones. Nearly as large was 911 operators at emergency operations centers. Many resulted in serious injuries, and some incidents involved a person on a headset at the base of a tall communications tower that was struck by lightning.

5D.5. Summary of U.S. buildings other than dwellings

Inside a U.S. building other than dwellings is quite a safe location from lightning. Outside of any building, however, lightning vulnerability is as high as any other outdoor location. Quite a few cases involved people on the property of schools, while there were few incidents inside U.S. schools. Most notable were deaths and some injuries within small structures such as golf shelters and pavilions that provided protection from rain but were unsafe from lightning. Telephone users inside buildings were sometimes injured by lightning, as well as operators at emergency communications centers.

5E. Non-U.S. buildings, except dwellings

Table 10 shows 79 events related to non-U.S. buildings. Note that the number of cases in Table 10 outside the U.S. is half that within the U.S. in Table 7. However, the number of deaths is nearly ten times as large and injuries are twice as frequent.

TABLE 10. Summary of type and number of lightning-related events, deaths, and injuries involving non-U.S. buildings other than dwellings.

Location	Events	Deaths	Injuries
Inside	11	26	189
On property	10	18	77
Schools	30	79	378
Small structures	28	111	179
Total	**79**	**234**	**823**

5E.1. Casualties inside non-U.S. buildings, except dwellings and schools

Table 10 has 11 events involving people who were casualties of lightning while inside non-U.S. buildings that were not dwellings or schools. The largest was a Philippine prison camp explosion near midnight resulting from lightning striking a concrete ammunition bunker that blasted through nearby buildings housing 107 inmates that were injured.

5E.2. Casualties related to non-U.S. schools

Tables 10 and 11 list 30 events involving casualties of lightning at non-U.S. schools. There were many more deaths and injuries in fewer cases than at U.S. schools (Tables 7 and 8). Most incidents had multiple casualties in Africa and Southeast Asia.

TABLE 11. Lightning-related events, deaths, and injuries to people at non-U.S. schools.

Location	Events	Deaths	Injuries
Inside school	15	31	208
On property	11	29	82
Unidentified location	4	19	88
Total	**30**	**79**	**378**

5E.3. Casualties related to non-U.S. small structures

Table 10 lists 28 events of lightning casualties within non-U.S. small shelters not used as dwellings. A notable number of cases involved people seeking safety in huts in agricultural fields when heavy rain arrived. Not included here are beach shelter incidents (Holle 2007). The largest loss of life was 17 deaths at a Honduras soccer game. Another 35 were injured when the crowd stood under a shelter, type unspecified, next to the soccer field during heavy rain.

5E.4. Summary of non-U.S. buildings other than dwellings

Non-U.S. buildings are often unsafe from lightning and the source of multiple fatalities. A large number of deaths occurred inside churches in Africa, schools in Africa and Southeast Asia, as well as in small structures where people sought safety from rain, especially in agricultural situations.

5F. Fatalities per event inside buildings

Curran et al. (2000) found that 91% of U.S. *Storm Data* lightning fatalities involved one person per incident. Another 8% involved two people, and 1% involved more than two. For the present study, Figure 14 shows that the number of U.S. single events is 77% compared with 23% outside the U.S. The number of U.S. incidents with two fatalities is 17% and 33% for non-U.S. locations. No U.S. case had more than five fatalities inside buildings, while 23% had more than five outside the U.S.

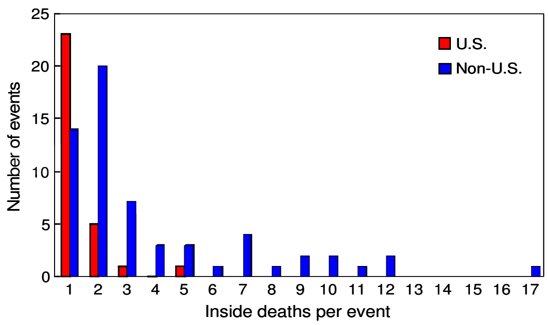

FIGURE 14. Number of fatalities per event inside buildings within and outside the U.S.

5G. Comparisons

Figures 15 and 16 summarize results from 687 incidents involving dwelling and building events resulting in 565 deaths and 1614 injuries. Figure 15 shows seven times as many dwelling deaths per non-U.S event than within the U.S., and 18 times as many building deaths. Figure 16 shows a high relative frequency of reported lightning deaths inside non-U.S. buildings compared with the U.S., and a similar number of deaths on the property of buildings in both places.

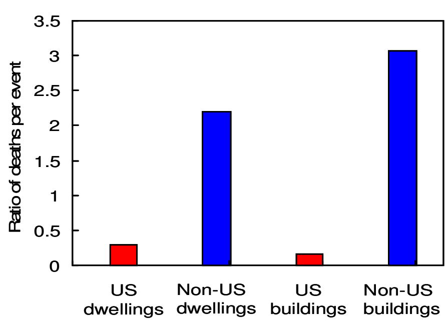

FIGURE 15. Ratio of building-related lightning deaths per event separated by dwellings and other buildings, within and outside the U.S.

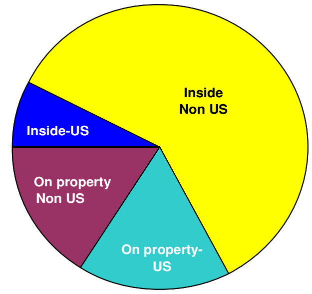

FIGURE 16. Building-related lightning deaths separated by whether people were inside or on property of buildings, within and outside the U.S.

5H. Safety in buildings and dwellings

For the U.S., large substantial buildings where people live and work are very safe from lightning. While such structures are often hit directly by lightning, fatalities inside them are extremely rare. Inside U.S. dwellings and buildings, the only lightning-caused fatalities were to elderly, very young, or mentally or physically challenged people who were unable to leave the dwelling in a nighttime fire. There were no fatalities inside offices, schools, or other large buildings. As a result, adequate safety is attained by directing people to go inside a large substantial building, including a dwelling.

Outside the U.S. in less developed countries, large substantial buildings are often not available. Small non-enclosed structures and huts often have fatalities inside. Adequate safety can only be attained by directing people to fully-enclosed metal-topped vehicles (section 4). If they are not available, lightning protection needs to be added to dwellings, schools, and agricultural rain shelters.

The general recommendations with respect to lightning safety in and around buildings are:

U.S.

- Inside large substantial buildings - no deaths
- Dwellings - need advanced planning for physically and mentally vulnerable people from fires at night
- Many casualties in small non-enclosed structures that are used for rain protection
- Many fatalities on property of dwellings
- Emphasize going indoors for all buildings.

Non-U.S.

- Many deaths in schools
- Many deaths inside small structures
- Many deaths inside huts
- Go into fully-enclosed metal-topped vehicles, if they are available
- Need to have, or install lightning protection systems on unsafe dwellings and buildings.

6. LIGHTNING CASUALTIES IN AND NEAR WATER

Anywhere on the water places a person at risk from lightning; the largest casualty categories are fishing, beach, and boat events (Holle 2007b).

6A. Introduction

The category of "Beach/water" accounted for 18.0% of U.S. lightning deaths and 7.2% of injuries (Holle et al. 2005) using the NOAA publication *Storm Data*. There is a wide variety of situations under which people have become lightning victims in the vicinity of water. Table 12 shows 202 events related to water; these cases involved 147 deaths and 254 injuries.

The most frequent type of water event in Table 12 is related to fishing, followed by beaches and boats. Table 12 shows a ratio of one death per 1.7 injuries for the entire water-related dataset. In particular, two of the largest types of water events, fishing and boating, have nearly the same number of deaths as injuries. This is a very large ratio compared to the 10 lightning-caused injuries requiring medical treatment for every lightning-caused death in Colorado (Cherington et al. 1999). This large ratio appears to indicate that people in water situations are especially exposed to the lightning danger by being taller than the surrounding water.

TABLE 12. Summary of type and number of lightning events, deaths, and injuries related to bodies of water.

Type of water event	Events	Deaths-	Injuries
Fishing	66	55	53
Beach	37	24	85
Boats	23	17	18
Boat ramp	9	3	13
Lake, pond	9	3	9
Small island	7	14	9
Swimming – not in pool	7	12	9
Personal watercraft (jetski)	7	2	5
River	6	5	14
Swimming pool	6	4	5
Lifeguard	6	1	7
Other casualties related to water	19	7	27
Total	202	147	254

6B. Multiple casualty events

There are 14 events with five or more lightning casualties in Table 12. One multiple-injury case apparently involved people swimming in the ocean in 1987 in Japan (Kitagawa 2002). Others involved boaters, surfers, and rafters (5 injuries each), as well as Malaysian soldiers crossing a river (6 injuries). More than half of these events were in two situations:

- Five cases occurred on crowded beaches, and accounted for 2 deaths and 51 injuries. In three cases, the reports describe 100 or more people on the beach at the time of the flash that caused the casualties.
- The small island category in Table 12 has three events that account for 13 deaths and 5 injuries, a high ratio of deaths to injuries. A small island is especially vulnerable to lightning, since it is taller than the surrounding water surface.

6C. Swimming pools

Swimming pools are often considered to be a source of danger from lightning. Table 12 includes six pool events that involve being in the pool, leaving the pool, on the deck, holding onto a metal ladder, and working inside a pool building. The range of situations indicates that anywhere in a pool complex is vulnerable to lightning. Detailed accounts are in Holle (2007b).

6D. Location

Oceans and lakes account for about half of all locations of events, deaths, and injuries (Table 13). The other half involves rivers, as well as nearly every type of water entity, ranging from the ocean to a stock tank. Note that eight events involved people near some type of water when they sought safety under a tree when a storm was approaching or overhead. Another four events occurred when people sought safety under a building overhang or river bluff close to the water. There were three cases involving lifeguards on observation towers.

TABLE 13. Summary of locations of lightning events, deaths, and injuries near and on water.

Location	Events	Deaths-	Injuries
Ocean, ocean dune	48	36	74
Lake	45	30	71
River, by river	25	15	32
Bay, dune, inlet of ocean	11	3	13
Dock, pier, jetty	11	3	8
Pond, reservoir	10	6	10
Bridge, canal, creek, dam, marsh, sound, stream, stock tank	10	6	8
Under tree near water	8	6	7
Small island	7	14	9
Swimming pool, by pool	7	4	8
Under overhang-building/ bluff	4	3	4
Lifeguard tower	3	0	3
Other water-related locations	8	12	6
Total	197	138	253

6E. Activity

The combination of fishing and boating activities in Table 14 accounts for a third of all water events and deaths, and somewhat less of the injuries. Walking and standing also occur often around water when lightning occurred. Seeking safety under trees (11 events) accounted for multiple casualties. The activity of swimming (9) and standing (3) directly in the water is a very dangerous category. In addition to boating, there were eight cases in the process of surfing and sailing, as well as seven events on personal watercraft (jetski).

The activities during the many other 50 cases at the end of Table 14 include people killed or injured by lightning while, among other activities, canoeing, casting nets, clamming, crabbing, fighting a fire, kayaking, paddle boating, picnicking, playing, pontoon boating, rafting, shaking out a beach towel, and working.

TABLE 14. Summary of activities during time of lightning events, deaths, and injuries related to nearby water.

Activity	Events	Deaths-	Injuries
Fishing	24	15	20
Fishing from boat	20	21	12
Boating	16	12	15
Sought safety under tree	11	12	15
Walking	11	4	14
Standing	9	7	10
Swimming	8	12	10
Riding personal watercraft	7	2	5
Hurrying to cover	5	4	11
Pulling boat off water	5	2	7
Surfing, windsurfing	5	0	9
Lifeguard duty	4	2	8
Leaving water	3	2	4
Wading	3	2	1
Sailing	3	0	6
Other water-related activities	50	37	74
Total	184	134	221

6F. Summary

The most common type of lightning impact on a water event relates to fishing, whether from a boat or elsewhere. The next most frequent cases occur on beaches and boats. A dangerous location is being on a small island where there are trees. Locations of lightning casualties most often were on or near an ocean or lake. Other large categories included rivers, and people seeking safety from lightning under trees and buildings next to the water. Activities of lightning casualties were most often related to fishing and boating.

7. GLOBAL LIGHTNING CASUALTIES

A very general extrapolation of six deaths per million people applying to four billion people results in an estimate of 24,000 lightning deaths and 240,000 lightning injuries per year worldwide, but data to verify these numbers are very sparse (Holle 2007a, 2008a).

7A. Background

The annual number of lightning deaths has been compiled in the U.S. since 1900, and in other developed countries. However, there has been little systematic collection of information on lightning deaths in many regions of the world. Holle and López (2003) first made an assessment of the worldwide impact of lightning, and concluded that 24,000 deaths and 240,000 injuries occur per year. Holle (2007a, 2008a) builds on Holle and López (2003).

The underlying basis is that a rate of less than 0.3 deaths per million people applies to more developed countries with substantial housing and a decreasing amount of labor-intensive agricultural labor. Other regions were assumed to have an annual lightning fatality rate of 6 deaths per million per year, and this rate was applied to a large portion of the world's population.

These assumptions were made in the absence of much in the way of fatality rate data. The best data source is for entire countries for long periods. There are also more variable-quality data from regions within countries for short periods that have been extrapolated to a national rate for some countries, since fatality data are often not available for a country for long periods. Only fatalities are considered in this paper.

As mentioned earlier, fatality and injury data are underreported in the best datasets, but death totals are more accurate than injuries (López et al. 1993). Although exact death totals continue to be somewhat inconsistent where data are well documented (Richey et al. 2007), the extent of underreporting in other countries is unknown and appears to be very large. Also as described earlier, the ratio of injuries to deaths appears to be 10 to 1 (Cherington et al. 1999).

All known published lightning fatality data around the world are described in detail by country and decade in Holle (2007a, 2008a). Details of the information source, assumptions, and some indication of their reliability are in those publications. Figures 17 to 19 summarize all of these results by decade and region for three centuries; Holle (2007a, 2008a) include the details.

7B. 19th century

Figure 17 combines 19th century fatality rates for eight countries in Europe and Australia. While there is a wide range, the median decadal value in these countries was in the range of 3 deaths per million people per year. Rates over 4 deaths per million per year for a decade in a country were not unusual. Note that most of these reporting countries are in Europe, which has less lightning than many tropical regions. In general, 19th-century populations in these countries lived in rural areas and had agricultural occupations. In addition, homes and workplaces had little to no protection provided by wiring, plumbing, and structural metal components that presently serve to provide safe places for people inside them when lightning strikes buildings.

7C. 20th century

Fatality rates are combined for the 20th century in Figures 18 and 19. Data were available in this century for eight countries in Europe and eight more in the rest of the world.

Figure 18 summarize decadal rates during the 20th century for eight countries in Europe. Most rates are low, especially in the latter half of the century. The median annual rate in Europe is in the range of 0.3 deaths per million. This value represents a ten-fold reduction since the typical range of 3 fatalities per million per year during the 19th century in Europe (Figure 17).

Figure 19 summarizes decadal rates from eight countries outside Europe during the 20th century. During the first half of the 20th century in the more developed countries of Australia, Canada, Japan, Singapore, and the U.S., the typical annual rate was around 2 deaths per million. During the last half of the 20th century, the developed countries have had a median annual value of around 0.4 deaths per million. This value is similar to the rate of 0.3 late in the 20th century in European countries. However, recent rates in South Africa and Zimbabwe are quite high, and may be representative of lesser developed regions of the world.

7D. 21st century

Table 15 combines results for 15 countries in several previous tables into one 21st-century list beginning in 2000. National data are provided first, when available, followed by regional results. The same rates are repeated in both columns of Table 15 when only one year of data, or one number for several years was provided by several sources.

Some countries and regions have annual rates as low as 0.1 to 0.2 fatalities per million people, or lower. Many of these lower rates are in Europe and North America and other more developed countries, and their rates have been decreasing for over a century.

However some low rates are also included for more rural agricultural areas such as Bangladesh and China, which appear to represent incomplete data collection. At present, high rates of lightning deaths are found from very limited data in Africa and some portions of Asia. Lightning frequencies are also high in these regions, and the population is often rural, oriented toward agriculture, and living or working in structures that often are not safe from lightning. The lack of current reliable data for these populous regions is a significant gap for this study.

TABLE 15. Annual lightning deaths per million people during the first decade of the 21st century. National rates are followed by regional rates when available.

Country	Decadal fatality rate	Maximum annual rate
Bangladesh	0.9	0.9
Brazil (Sao Paulo)	0.8	0.8
Canada	0.1	0.3
China	0.5	0.7
Guangdong	0.9	0.9
Guizhou	1.2	1.2
Hainan	10.6	10.6
Hong Kong	0.04	0.04
Greece	0.2	0.4
India (Orissa)	2.5	2.5
Lithuania	0.1	0.1
Malaysia	3.4	3.4
Nepal	2.7	2.7
South Africa	8.8 rural 1.5 urban	8.8 rural 1.5 urban
Sri Lanka	2.4	2.4
Vietnam	1.2	1.2
Bac Lieu	8.8	8.8
United States	0.2	0.2
Yemen (Saada)	71.4	71.4
Zimbabwe	14.2	14.2

7E. Discussion

At this point, it is appropriate to include Table 16 (Holle and López 2003) that lists assumptions relating to the estimate of 24,000 worldwide annual lightning deaths. As mentioned, the annual rate of 6 deaths per million was assumed to apply to four billion people, which gives an annual worldwide result of 24,000 fatalities.

The present study attempted to address factor number 2 in Table 16, that of the 6 per million rate per year. Unfortunately, the present study does not provide a definitive answer. Quite a few more developed regions support a lower rate, while others show 6.0 to be a candidate to consider. The lightning fatality rate information continues to be missing for the most heavily-populated areas of the world with high lightning frequencies in Africa, Southeast Asia, and the Indian subcontinent.

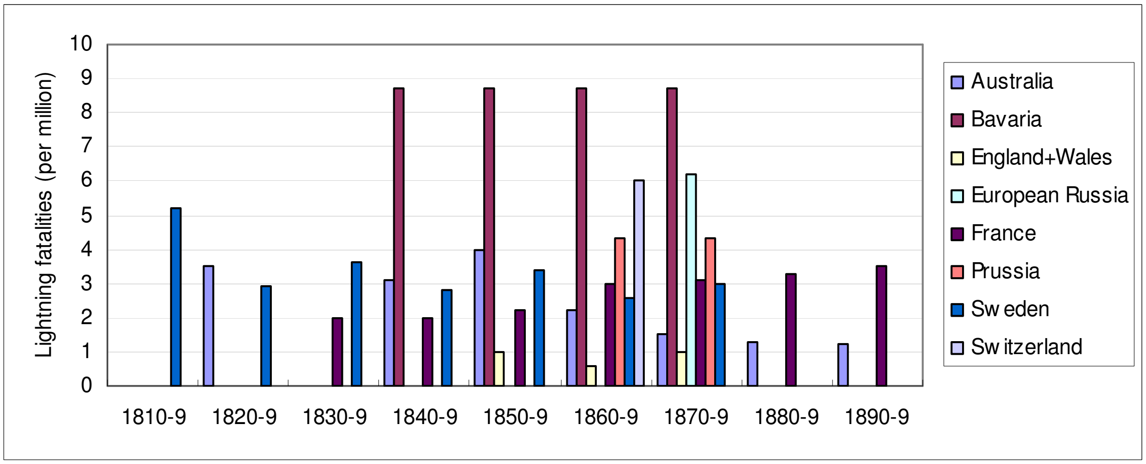

FIGURE 17. Lightning deaths per million people per year for eight countries in Europe and Australia by decade during 19th century.

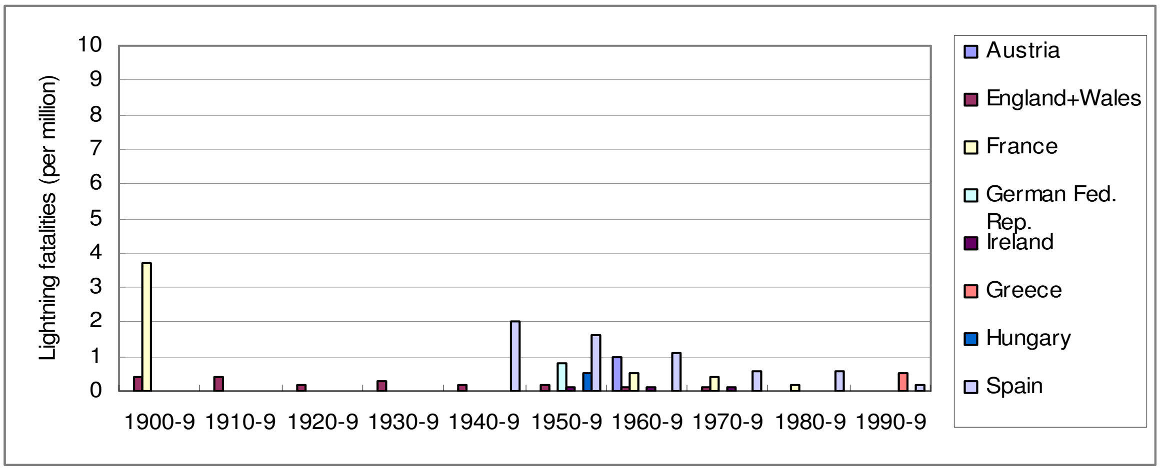

FIGURE 18. Lightning deaths per million people per year for eight countries in Europe by decade during 20th century.

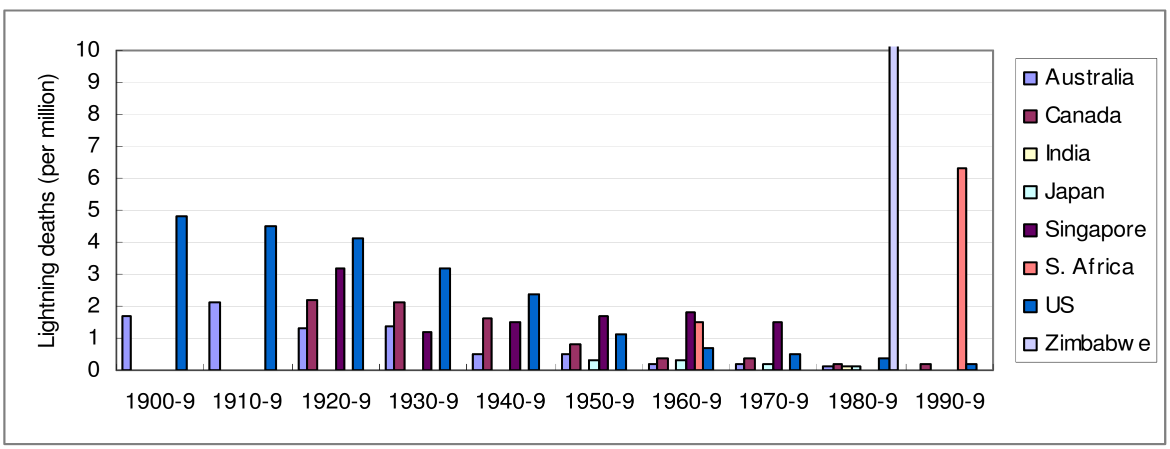

FIGURE 19. Lightning deaths per million people per year for eight countries outside Europe by decade during 20th century. Note that 1990s Zimbabwe value is 17.8.

TABLE 16. Factors that can change the estimate of 24,000 worldwide lightning fatalities per year (Holle and López 2003, Table 3).

Factor	Change	Impact on number of deaths
1. Area of high lightning frequency	Too small Too large	Increase Decrease
2. Fatality rate of 6 deaths per million people	Too low Too high	Increase Decrease
3. Rural-agricultural setting of people in high lightning areas compared to US and western Europe in 1900	More rural Less rural	Increase Decrease
4. Buildings occupied by people in high lightning areas compared to US and western Europe in 1900	Less substantial More substantial	Increase Decrease
5. Fatalities in areas outside Table 1 regions	Add areas	Increase
6. Organized recreational sports compared to US and western Europe in 1900	More	Increase
7. Meteorological forecasts and warnings	Improved	Decrease
8. Awareness of the lightning threat through education, planning and detection	Enhanced	Decrease
9. Medical care and emergency communications	Enhanced	Decrease
10. Other socioeconomic changes	Unknown	Unknown

7F. Conclusions

The lightning fatality rate in Australia, Canada, Europe, Japan, and the US has dropped by an order of magnitude, or more, from the 1800s to the present. Death rates were typically 3 per year per million people in the 1800s in these more developed countries, while it is now on the order of 0.3 deaths per million per year. This order-of-magnitude reduction coincides with a major population shift from rural to urban areas and away from labor-intensive agriculture, as well as the occupancy of substantial buildings, better forecasts and awareness of weather and lightning, improved medical care and emergency communications, the widespread availability of fully enclosed metal-topped vehicles, and other unknown factors. Since most of these middle-latitude regions do not have especially high lightning frequencies, a higher rate applies to many other areas.

The suggestion was made in Holle and López (2003) that an annual rate of 6 deaths per million was appropriate for rural agriculturally-dominated areas with little protection inside unsubstantial buildings that may be common in those regions. The recent data for lesser developed countries are incomplete in time and space. Some high rates have been reported in Africa, Asia, and India where such rates might be expected due to frequent lightning occurrence. However, there are also some very low rates that show indications of being due to data collection inadequacies.

An original question was to examine whether it was possible to attribute an annual rate of 6 lightning-caused deaths per million people to a large population of the world. While a lower lightning death rate of 0.3 can be applied to more developed regions, the higher rate is less clear. While no single rate for lesser developed countries is evident in the available data, an annual rate of 6 deaths per million people in Africa and Asia continues to be a number to consider as a starting point. The other issue is to how many people this rate should be applied. As shown for China and South Africa (Table 15) there are high rates in more rural regions, while the rate is very low in urban areas.

For the lack of better information, the estimate of 6 deaths per million per year continues to be a candidate for the appropriate rate in less developed countries. If this rate applies to 4 billion people (Holle and López 2003), the resulting worldwide estimate continues to be 24,000 deaths and 240,000 injuries from lightning every year. The collection of lightning fatality information over long periods is encouraged on a national basis in order to investigate the validity of these estimates.

8. CONCLUSIONS

A multidisciplinary group of lightning safety experts met in 1998 to develop guidelines that had not been adjusted in any meaningful way for several decades (Holle et al. 1999). Development of national lightning detection networks and availability of other meteorological datasets had caused major rethinking of existing guidelines. Most of the 1998 guidelines have been supported, others have been evaluated, and some have been adjusted further or placed into a more limited context. Most pre-1998 recommendations are recognized as based on false assumptions and have become obsolete. It is now apparent that there are no reliable places outside to be safe from lightning, and the present paper shows how the lightning safety recommendations can be clarified with this recent information collected and summarized by the author.

The first sections of this summary paper identify better the actual lightning threat (section 1), and the lighting fatalities by state (section 2). Some recommendations continue to insist that the direct strike is the most common type of injury, which is not the case (section 3). Earlier recommendations had not sufficiently emphasized the nearly complete safety of being inside a large substantial building or fully-enclosed metal-topped vehicle, as described in sections 4 and 5. Instead, lightning recommendations should be pointing out the reliable safety that is usually present in more developed countries in nearby substantial buildings and fully-enclosed metal-topped vehicles. The lack of these safe places in lesser developed countries results in a high lightning casualty rate at the present time that is difficult to estimate (section 7).

A comparison can be made between vehicle-related casualties in section 4 and water-related casualties in section 6. Despite the similar sample size, there were 147 deaths related to water and 38 related to vehicles. The number of injuries was nearly the same. It can be concluded that people are highly vulnerable to lightning in the vicinity of water since they are taller than the surrounding horizontal water surface.

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