SOME ASPECTS OF GLOBAL LIGHTNING IMPACTS

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1. UNITED STATES LIGHTNING IMPACTS

1.1 Fatalities and injuries

The number of lightning fatalities in the U.S. has decreased markedly from a maximum of over 400 deaths per year early in the 20th century to less than 30 deaths annually in recent years (Curran et al, 2000; Holle et al. 2005; López and Holle 1998; Roeder 2012). Figure 1 shows that the lightning fatality rate has decreased from as high as 6 fatalities per million people per year early in the 20th century, to 0.1 per million people per year at present (López and Holle 1998). This trend has occurred simultaneously with a decrease from a 60% rural population in 1900 to the current rural population below 20% in the U.S. Note that while the U.S. population has grown significantly during this period, the number of fatalities has greatly decreased. During this period, there has been a significant increase in the quality of homes, workplaces, schools, and other public and private buildings with respect to lightning safety (Holle 2012). Also important is a huge increase since the early 20th century in the availability of fully-enclosed metal-topped vehicles that provide safety from lightning (Holle 2012). Additionally, a significant education and awareness campaign has been sustained across the U.S. for more than a decade (Cooper and Holle 2012; Jensenius and Franklin 2014). It should be noted that in general, there are 10 lightning-related injuries requiring medical treatment per lightning fatality (Cherington et al. 1999).

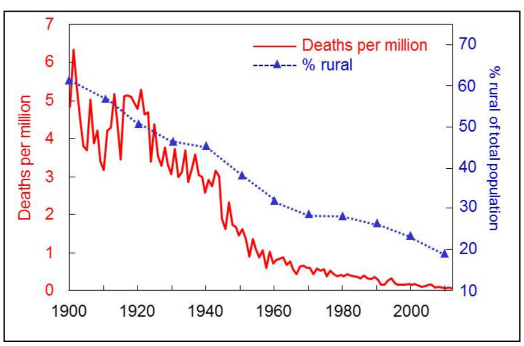

FIGURE 1. Solid red line: U.S. lightning deaths per million people from 1900 to 2013. Dashed blue line: Percent rural population (updated from López and Holle 1998*).*

1.2 Insurance claims

A recent study by the Insurance Information Institute states that over 100,000 homeowner insurance claims for lightning damages were paid for 2013 incidents in the U.S., at a cost of $5869 each (Insurance Information Institute 2014). The result is that paid lightning-caused insurance claims represent about US$3 per person per year. Much of this damage is due to electronic devices that are becoming more vulnerable and expensive than in the past. The cost per claim increased 122% in the last seven years, although the number of claims decreased. In contrast, a study in the late 1990s estimated that the average U.S. claim was $916 (Holle et al. 1996).

1.3 Direct damages

A less certain estimate is available for the substantial direct losses due to lightning to commercial, public and private buildings, factories, and related facilities. The largest category is public utilities, such as electrical transmission and distribution systems, upon which customers are more dependent on uninterrupted power than in the past. The cost of such direct lightning damages is difficult to estimate, but is certain to be in the billions of dollars per year in the U.S. based on various unpublished summaries and anecdotal information. During 2007-2011, 22,600 building fires are estimated to have been started by lightning resulting in $451 million in direct property damage per year (Ahrens 2013). The U.S. National Interagency Fire Center reported 9,000 wildland fires started by lightning from 2008-2012 that burned an average of 420 acres each. An average of four firefighters was killed per year from 2003-2012 fighting lightning-caused fires, mostly in wildland fires (Ahrens 2013).

1.4 Indirect impacts

Less direct is the ongoing costs of protection of a myriad of power, communications, and other utility systems, as well as aircraft and many other components of society. Those costs are mingled with maintenance and replacement expenses, and are also significant, in the billions of dollars per year in the U.S. It is recommended that a systematically-collected objective dataset be published on these impacts that are very difficult to estimate but are certain to be very large. Due to the growing complexity and sensitivity of many parts of modern infrastructure, those costs are likely increasing with time. In addition, forest and range fires increasingly affect communities and infrastructure as they spread to the edge and within regions prone to lightning-caused wildfires.

2. GLOBAL LIGHTNING IMPACTS

2.1 Global lightning fatalities and injuries

There are two recent estimates of global lightning fatalities. One is 6,000 fatalities per year (Cardoso et al 2012), and the other is 24,000 (Holle and López 2003). Underreporting of lightning fatalities, and especially injuries is a major issue due to a number of factors, including the situation that most events involve one person at a time (López et al. 1993). Injuries are assumed to be ten times as frequent as fatalities (Cherington et al. 1999). No complete global information exists regarding fatalities and injuries. Instead there is a limited number of published formal and informal papers in recent years that summarize lightning fatalities on a national scale.

2.2 Global fatality rates by continent

Fatality rates by decade since the 1800s have been published (Holle 2007, 2008) but no summary over recent years has been made. A number of published studies are now summarized that include national lightning fatality rates in the last few decades. Regional, local, short-period (Ab Kadir et al. 2010) and internet-based reports are not included. The most recent published results, applicable for periods ending in 1979 or later, are in Table 1 and Figs. 2 through 7.

These color-coded maps of published national-scale lightning fatalities are the first known to have been compiled. The maps indicate countries with low lightning fatality rates in yellow, medium in orange, and red for highest by country listed in Table 1. White shading indicates no data are available. It is apparent that highest rates are in Africa and South America. Lowest rates are evident in the more developed countries of North America, Western Europe, Japan, and Australia.

2.3 Trends in lightning fatalities

The maps show that the highest population-weighted annual rates of lightning fatalities occur in countries with these features:

- --Fewer lightning-safe homes, workplaces, school, and other facilities than in more developed countries,
- --Fewer easily available fully-enclosed metal-topped vehicles,
- --High rate of labor-intensive manual agriculture,
- --Lack of awareness or data about the lightning threat, its avoidance, and its medical treatment.

The global population living in these situations may be increasing in absolute number, but such statistics are difficult to obtain. Also, the trend toward a reduced percentage of the population in rural areas has not occurred in many areas of the world. For example it has been reported that 97% of lightning fatalities in China occur in rural areas (Ma et al. 2008). As a result, it is likely that the number of lightning fatalities and injuries globally is increasing, and will continue until more people have ready access to safe structures and vehicles, and can spend less time in labor-intensive agriculture and other outdoor occupations. The lightning fatality and injury rate per population is thought to be very high in many of the countries that have no published national fatality data in Table 1 and Figures 2 through 6. For example, India is shown to have an average of 1,755 deaths per year from 1967 to 2012 (Illiyas et al. 2014) which corresponds to a very large total number of 78,975 fatalities during this period.

Table 1. Published annual lightning fatality rates per million people by country ending in 1979 or later.

Continent Country	**References**	**Period**	**Annual fatality rate per million**
Africa			
Malawi	Mulder et al. 2012	2007-2010	84.0
South Africa	Blumenthal 2005	1997-2000	6.3
Swaziland	Dlamini 2008	2000-2007	15.5
Uganda	Ahurra and Gomes 2012	2007-2011	0.9
Zimbabwe	Chitauro 1990; Van Olst 1990	2004-2013	14 to 21
Asia			
China	Zhang et al. 2010	1997-2009	0.3
India	Illiyas et al. 2014	1967-2012	2.0
Japan	Kitagawa, personal communication	1990-1997	>0
Malaysia	Ab Kadir et al. 2012	2008-2011	0.8
Singapore	Pakiam et al. 1981	1970-1979	1.5
Australia			
Australia	Coates et al. 1993	1980-1989	0.1
Europe			
Austria	Kompacher et al. 2012	2001-2010	>0
France	Gourbière 1999	1990-1995	0.2
Greece	Pappas et al. 2012	2000-2010	0.1
Lithuania	Galvonaite 2004	1994-2003	0.1
Poland	Loboda 2008	2001-2006	0.3
Turkey	Tanriover and Kahraman 2013	2012	0.3
U.K.	Elsom and Webb 2014	1988-2012	>0
North America			
Canada	Mills et al. 2010	1990-2004	0.2
Mexico	Raga et. al 2014	1979-2011	2.7
U.S.	Curran et al 2000; López and Holle 1998	2003-2012	0.3
South America			
Brazil	Cardoso et al. 2014	2009-2009	0.8
Colombia	Navarrete-Aldana et al. 2014	2000-2009	1.8

2.4 World lightning safety day

World Lightning Safety Day was first proposed by Ms. Iara Cardoso of Brazil. Such a Day could provide regions around the globe with information and awareness methods to mitigate the large loss of life in many regions due to lightning, and raise the awareness of lightning impacts on property and infrastructure.

2.5 Global lightning damages

As reliable electric power and communications become increasingly essential to the activities of more people in developing countries, lightning-caused disruption to utilities and other infrastructure will become more critical. Modern communications and computer systems require reliable power, and poorly-protected utility systems need to have improved lightning protection, as well as better response to outages caused by lightning. Knowledge of where and when lightning occurs in real time, as well as over long periods, can aid in minimizing these disruptions. In Canada, annual damage and disruption costs from lightning range from CA$600 million to CA$1 billion; forestry and electricity damages account for most of the total (Mills et al. 2010). These values are consistent with unpublished U.S. information. Additional rates and comparisons of lightning damages need to be compiled and published.

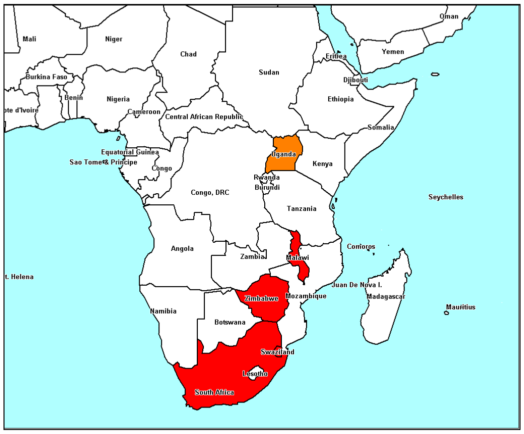

FIGURE 2. Lightning fatality rate per million people per year in Africa. Red shading indicates rate > 5.0 fatalities per million per year, orange is 0.6 to 5.0, and yellow is < 0.5. White indicates no national summaries have been published for datasets ending in 1979 or later.

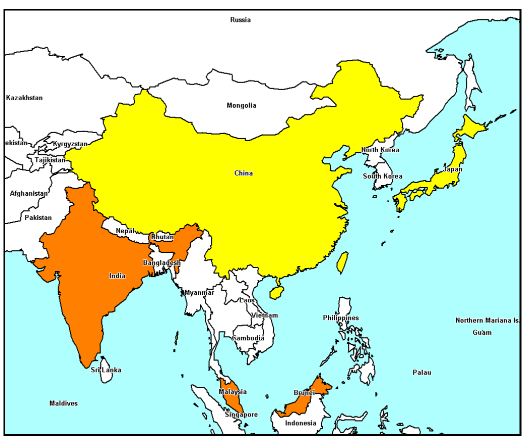

FIGURE 3. Same as Fig. 2 for Asia.

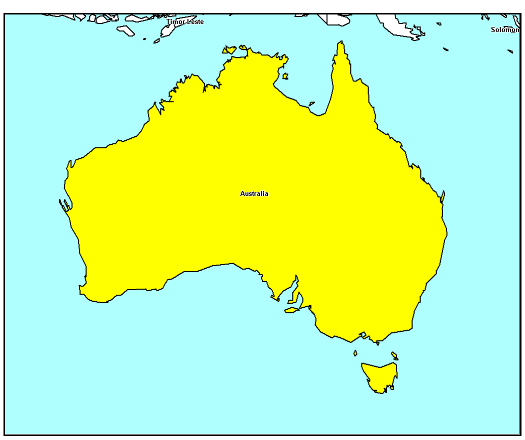

FIGURE 4. Same as Fig. 2 for Australia.

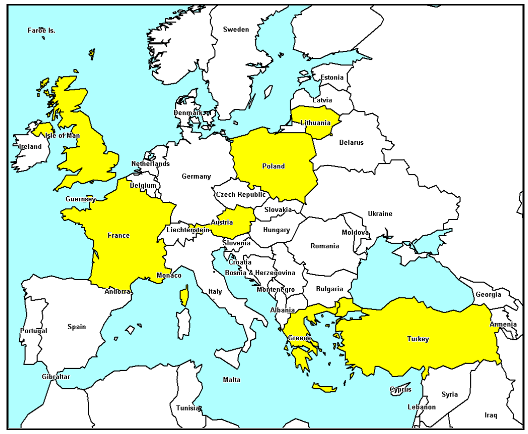

FIGURE 5. Same as Fig. 2 for Europe.

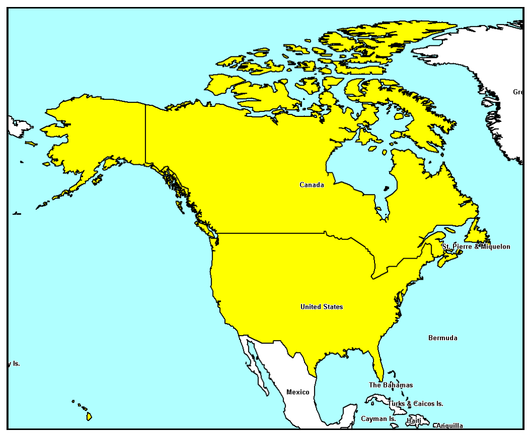

FIGURE 6. Same as Fig. 2 for North America.

Fig. 7. Same as Fig. 2 for South America.

3. GLOBAL LIGHTNING DETECTION

Over the U.S., a large number of maps of cloud-to-ground lightning flashes have been prepared for many years using data from the National Lightning Detection Network (NLDN). A series of NLDN studies has explored the monthly and diurnal distributions of lightning so that these aspects of the lightning threat are quite well known across the continental U.S. (Holle et al. 2011; Holle and Cummins 2010; Holle 2014).

The network providing data to the Global Lightning Dataset GLD360 has been in operation since 2011; three full years of strokes are shown in Fig. 8 (Poelman et al. 2013; Pohjola and Mäkelä 2013; Said et al. 2013). In real time, GLD360 seamlessly covers the continents as well as the oceans to show lightning on a minute-by-minute and daily basis, as well as on monthly, regional, and annual scales. Since 80% of the lightning events detected by GLD360 are cloud-to-ground strokes, the actual lightning threat is now much better known around the globe than had been the case.

Land areas clearly have most of the lightning, and that represents a threat to people as well as to infrastructure. But lightning is not uniformly distributed. Some areas have much more lightning at certain times of day and year than others, and this knowledge can be useful in many situations to improve the understanding of the lightning threat. Studies have been made of the variability of lightning in time and space in a number of countries. There also exists a new opportunity for global studies using datasets such as GLD360 with substantially uniform areal detection.

First steps to combining lightning data with population were made by noting that U.S. lightning fatalities tend to be concentrated in urban areas {Ashley and Gilson 2009). Extending this approach in a new study of lightning fatality risk combines lightning frequency from a detection network with population data in the U.S. (Roeder et al. 2014). Such an approach could be considered in other countries.

4. DISCUSSION

Education and awareness are needed to take full advantage of such global lightning data in reducing human casualties and material damages due to lightning. To be effective, there needs to be an end-to-end process that initiates with an acceptance that lightning is a threat, and that there are solutions to reduce lightning's human and material impacts. For example, there is a 1 in 1250 probability that a person in the U.S. will be killed or injured by lightning, or be a close relative or friend of a victim at today's casualty rate, over an 80-year life span. In many developing countries, that probability is higher.

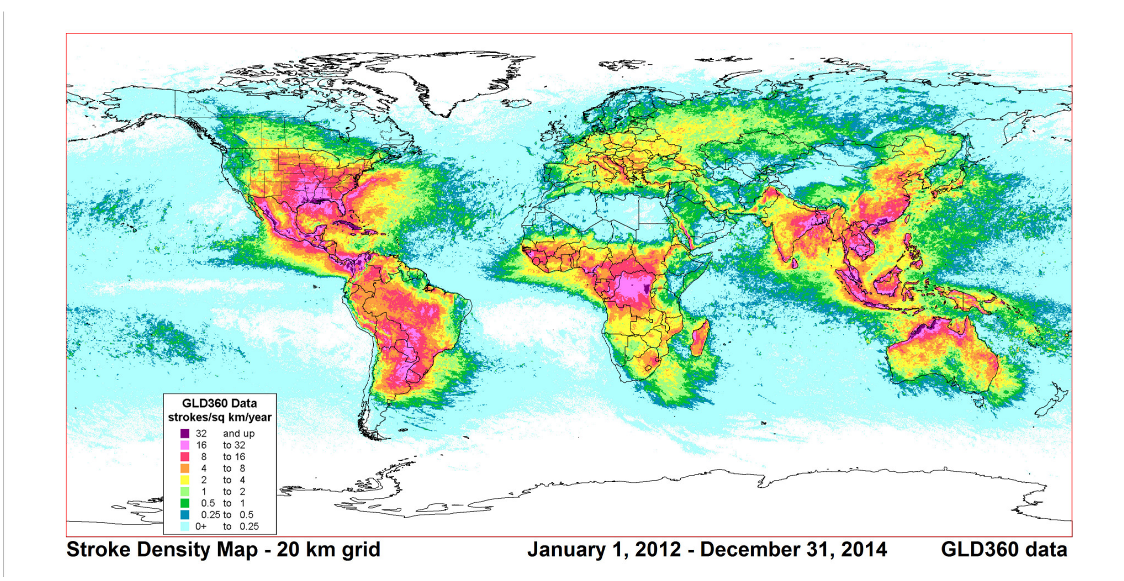

FIGURE 8. Lightning stroke density per square kilometer per year from GLD360 for the globe from January 2012 through December 2014. A total of 2,358,685,762 strokes is plotted during these three years. Scale is at lower left. The grid size is 20 by 20 km.

Education and awareness are the next steps to be taken - in advance of lightning occurrence. These are followed by the availability of real-time and climatological lightning information, then actions are taken in response to the lightning threat. Initial activities have been taken with regard to education and awareness of the threat to people in several Asian countries through the Centre of Excellence on Lightning Protection (CELP) (Cooper and Ab Kadir 2010; Gomes et al 2006, 2012; Jayaratne and Gomes 2012) and the newly-formed African Centre for Lightning Electromagnetics (ACLE).

With regard to property damage and interruptions of lightning-sensitive infrastructure, knowledge of the number, temporal and spatial distribution of lightning is very effective in developing mitigation strategies on a regional or local level. Value-added products that highlight vulnerable areas and industries can be developed that apply to specific needs through a variety of approaches.

5. CONCLUSIONS

The impacts of lightning are shown to vary greatly between more developed countries, and lesser-developed areas. In the U.S., the population-weighted rate of lightning fatalities and injuries has greatly reduced from a maximum about a century ago. In contrast, the vulnerability of ever-increasing sophisticated infrastructure is growing. Direct and indirect costs are extremely difficult to obtain and are rarely in the published literature, but are reasonably estimated to be in the billions of dollars per year.

In many lesser-developed countries, the population-weighted rate of lightning fatalities and injuries may be steady or slowly decreasing due to urbanization and many other factors. However, the absolute number of lightning-vulnerable people may be increasing so that the actual number of lightning casualties may also be growing due to these socio-economic factors.

There are two target groups of people in many of these countries that need attention in order to achieve a decrease in lightning deaths and injuries. One is the significant number of people working in labor-intensive agriculture. The other is the lack of lightning-safe buildings and vehicles that are widely available in more developed countries. The most immediate solution appears to be providing protection to dwellings and public buildings during both day and night, as well as providing safe places for agricultural workers during daytime thunderstorms. Data from the GLD360 global lightning detection network can help identify those areas of most need. Through a combination of sound science, education, and uniform global lightning data availability, significant advances can be made in reducing the impacts of lightning on people and assets.

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