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# Lightning Casualties and Damages in China from 1997 to 2009

Wenjuan ZHANG[1], Qing MENG[1], Ming MA[2], Yijun ZHANG[1]

[1]Laboratory of Lightning Physics and Protection Engineering, Chinese Academy of Meteorological Sciences, Beijing, China
[2]University of Science and Technology of China, Anhui, China

## 1. Introduction

Lightning is one of the significant hazards to people and infrastructure in the world. Hundreds of casualties and millions of dollars in damage to buildings, power lines, electrical systems are caused by lightning every year. Lightning is near the top of the list of all types of weather-related deaths in the United States, only fatalities from flash and river floods rank higher (Curran et al. 1999). A complete national description of lightning casualties and damages is essential to improving awareness of this hazard. Such information is critical for understanding the risks of lightning to the general public and sensitive industries, sectors, and activities. It is also essential for evaluating the effectiveness of monitoring and warning information and associated short- and longer-term responses (Mills et al. 2008). Therefore, countless studies on lightning-related casualties and damages have been carried out in many countries (Raul et al. 1998; Coates et al. 1993; Wisdom 2009). Focus of these studies are mainly on quantifying lightning fatality and injure statistics, identifying human injury mechanisms (Lewis 1997; Walsh et al. 2000) and giving suggestions to lightning protection education.

China is located in temperate and subtropical climate regions and has an average Cloud-to-Ground flash density of 1.06 flash/km$^2$ a (Ma et al. 2008). Greater frequency of lightning occurs typically during the warm months from May to September, and at south and east China. Particularly, lightning frequency in the eastern China is greater than the same global latitude regions (Christian et al. 2003). China began setup of the national lightning detection network since 2004, and now forms a network with 237 stations. The network is essential for lightning observation and its data have been applied to understand lightning frequency and climatology. Additionally, the Lightning Nowcasting and Warning System (Meng et al. 2008) was developed by the Laboratory of Lightning Physics and Protection Engineering, Chinese Academy of Meteorological Sciences to estimate potential lightning risk and issues warnings.

The objective of this article is to examine the characteristics of lightning hazards in China from 1997 to 2009, and to improve understanding of the impact of lightning in terms of casualties and property damages. The first section of the article is an overview of lightning hazards studies and its significance. The second section introduces the data sources and lightning reporting methods in China. Then, characteristics of lightning casualties and damages in China are described, in terms of spacial and temporal variations, rural and urban, industries and locations. Finally, the article concludes with a summary of results and recommendations for future work.

## 2. Data sources and reporting methods

This paper summarizes information on fatalities, injuries, casualties (fatalities and injuries combined) and damages due to lightning in China from the National Lightning Hazards Database (NLHD). The advantage of these records is that they are derived from every provincial weather bureau throughout the country and compiled by headquarter in China Meteorological Administration (CMA) with consistent principle and standard. Every month, each provincial weather bureau reports lightning-related fatalities, injuries and damages occurring within the area of responsibility to CMA. The following information are required in each lightning report: a) Year, month, day and time of the event; b) Locality of the event; c) Number and location of fatality/injury; d) Direct/indirect economic loss of the damage. The following information are optional: e) Gender and age of fatality/injury; f) Industry of the damage belongs to; g) Circumstances/activity during incident; h) Degree/type of injury. At the end of each year, provincial weather bureaus make a supplementary report if there is any missing report in each month. After that, all the repots form 31 provinces in this year will be combined by headquarter in CMA and be added to the NLHD. Up to now, the database contains 5033 fatalities, 4670 injuries, and 61614 damage reports and includes damage reports from all provinces in China from 1997 to 2009.

Lightning-related casualties and damages are usually underreported and receive less attention than large-impact event. A few researchers have attempted to estimate the underreporting by evaluating data from multiple sources. Mogil et al. (1977) found 33% more lightning deaths in Texas than reported in *Storm Data*. Mills et al. (2008) indicated the mortality underestimation in the United States ranges from 17% to 33%. Lightning may consistently cause more damage than any other weather phenomenon when other unquantified losses are considered (Curran et al. 1999). In China, underreporting of lightning-related fatalities and injuries are mainly result from the traditional beliefs and superstition on lightning casualty, particularly in rural and smaller urban areas. Nevertheless, the NLHD is the only consistent data source on lightning incidents in meteorological department in China, for its standardized reporting protocol and coding for all variables.

## 3. Spacial variations

### 3.1 Variations by province in reported numbers

Table 1 shows the number and rank of lightning-related fatalities, injuries, casualties and damage reports from all provinces in China. Guangdong has the highest fatalities, casualties and damage reports. Yunnan has the most lightning injures. For lightning causalities, the top 10 provinces are Guangdong, Yunnan, Jiangxi, Guizhou, Guangxi, Hunan, Sichuan, Hubei, Fujian and Shandong. Nine provinces are located in south and east China, except the last one Shandong. Guangdong has the highest number of lightning damage reports and has more than three times as many as the second rank (Hunan).

Table 1. Number of lightning fatalities, injuries, casualties and damage reports, and their ranks for all provinces in China from 1997 to 2009.

| Province | Fatalities | | Injuries | | Casualties | | Damage reports | |
|---|---|---|---|---|---|---|---|---|
| | No. | Rank | No. | Rank | No. | Rank | No. | Rank |
| Anhui | 159 | 12 | 140 | 13 | 299 | 13 | 1728 | 12 |
| Beijing | 17 | 29 | 46 | 23 | 63 | 26 | 1007 | 16 |
| Chongqing | 55 | 23 | 95 | 16 | 150 | 20 | 425 | 22 |
| Fujian | 255 | 6 | 175 | 10 | 430 | 9 | 4585 | 4 |
| Gansu | 33 | 27 | 27 | 27 | 60 | 27 | 130 | 29 |
| Guangdong | 595 | 1 | 518 | 2 | 1113 | 1 | 17098 | 1 |
| Guangxi | 248 | 7 | 273 | 6 | 521 | 5 | 1735 | 11 |
| Guizhou | 301 | 4 | 345 | 3 | 646 | 4 | 937 | 17 |
| Hainan | 143 | 14 | 199 | 9 | 342 | 11 | 639 | 19 |
| Hebei | 125 | 16 | 85 | 18 | 210 | 16 | 3045 | 7 |
| Heilongjiang | 61 | 21 | 44 | 24 | 105 | 23 | 443 | 21 |
| Henan | 136 | 15 | 152 | 12 | 288 | 15 | 1456 | 14 |
| Hubei | 244 | 8 | 251 | 7 | 495 | 8 | 1800 | 10 |
| Hunan | 221 | 10 | 300 | 4 | 521 | 6 | 4968 | 2 |
| Inner Mongolia | 92 | 18 | 66 | 20 | 158 | 19 | 482 | 20 |
| Jiangsu | 238 | 9 | 104 | 15 | 342 | 12 | 3263 | 5 |
| Jiangxi | 494 | 2 | 293 | 5 | 787 | 3 | 2448 | 8 |
| Jilin | 63 | 20 | 36 | 25 | 99 | 24 | 758 | 18 |
| Liaoning | 115 | 17 | 47 | 22 | 162 | 18 | 1384 | 15 |
| Ningxia | 14 | 31 | 23 | 28 | 37 | 30 | 59 | 31 |
| Qinghai | 42 | 24 | 84 | 19 | 126 | 21 | 244 | 26 |
| Shaanxi | 56 | 22 | 66 | 21 | 122 | 22 | 357 | 23 |
| Shandong | 219 | 11 | 175 | 11 | 394 | 10 | 3188 | 6 |
| Shanghai | 36 | 25 | 31 | 26 | 67 | 25 | 247 | 25 |
| Shanxi | 36 | 26 | 16 | 30 | 52 | 28 | 306 | 24 |
| Sichuan | 261 | 5 | 239 | 8 | 500 | 7 | 1596 | 13 |
| Tianjin | 17 | 30 | 2 | 31 | 19 | 31 | 236 | 27 |
| Tibet | 75 | 19 | 90 | 17 | 165 | 17 | 190 | 28 |
| Xinjiang | 33 | 28 | 18 | 29 | 51 | 29 | 95 | 30 |
| Yunnan | 491 | 3 | 590 | 1 | 1081 | 2 | 1950 | 9 |
| Zhejiang | 158 | 13 | 140 | 14 | 298 | 14 | 4815 | 3 |
| Total | 5033 | | 4670 | | 9703 | | 61614 | |

### 3.2 Variations by province weighted by population

The rate and rank of lightning-related fatalities, injuries, casualties and damage reports from each province weighted by population are shown in table 2. When taking population into account, the maxima shift from southern and eastern provinces to low population provinces such as Tibet, Hainan and Qinghai. For lightning casualty rate, the top two are Tibet and Hainan, which were 17$^{th}$ and 11$^{th}$ in number of casualties (Table 1). The other eight provinces in top 10 are Yunnan, Qinghai, Jiangxi, Guizhou, Guangdong, Fujian, Guangxi and Hubei. The ranks of populous provinces such as Henan, Shandong and Sichuan degrade, with casualty rank of 15$^{th}$, 10$^{th}$, and 7th (Table 1), to 26$^{th}$, 20$^{th}$ and 15$^{th}$ (Table 2). Except for Tibetan Plateau area, provinces with high casualty rate are located in south China. Casualty rate ranks of the northwest provinces are still low.

Table 2. Rate per million people of lightning fatalities, injuries, casualties and damage reports, and their ranks for all provinces in China from 1997 to 2009. Population values are from the fifth national census in China in 2000.

| Province | Population (million) | Fatalities rate | | Injuries rate | | Casualties rate | | Damage rate | |
|---|---|---|---|---|---|---|---|---|---|
| | | Rate | Rank | Rate | Rank | Rate | Rank | Rate | Rank |
| Anhui | 59.86 | 2.66 | 17 | 2.34 | 18 | 4.99 | 16 | 28.87 | 17 |
| Beijing | 13.82 | 1.23 | 30 | 3.33 | 13 | 4.56 | 19 | 72.87 | 6 |
| Chongqing | 30.9 | 1.78 | 23 | 3.07 | 14 | 4.85 | 17 | 13.75 | 25 |
| Fujian | 34.71 | 7.35 | 7 | 5.04 | 9 | 12.39 | 8 | 132.09 | 2 |
| Gansu | 25.62 | 1.29 | 29 | 1.05 | 28 | 2.34 | 29 | 5.07 | 30 |
| Guangdong | 86.42 | 6.88 | 8 | 5.99 | 8 | 12.88 | 7 | 197.85 | 1 |
| Guangxi | 44.89 | 5.52 | 9 | 6.08 | 7 | 11.61 | 9 | 38.65 | 13 |
| Guizhou | 35.25 | 8.54 | 5 | 9.79 | 5 | 18.33 | 6 | 26.58 | 19 |
| Hainan | 7.87 | 18.17 | 2 | 25.29 | 2 | 43.46 | 2 | 81.19 | 4 |
| Hebei | 67.44 | 1.85 | 22 | 1.26 | 25 | 3.11 | 25 | 45.15 | 11 |
| Heilongjiang | 36.89 | 1.65 | 26 | 1.19 | 26 | 2.85 | 27 | 12.01 | 26 |
| Henan | 92.56 | 1.47 | 28 | 1.64 | 22 | 3.11 | 26 | 15.73 | 23 |
| Hubei | 60.28 | 4.05 | 10 | 4.16 | 11 | 8.21 | 10 | 29.86 | 16 |
| Hunan | 64.4 | 3.43 | 12 | 4.66 | 10 | 8.09 | 11 | 77.14 | 5 |
| Inner Mongolia | 23.76 | 3.87 | 11 | 2.78 | 17 | 6.65 | 12 | 20.29 | 21 |
| Jiangsu | 74.38 | 3.20 | 14 | 1.40 | 23 | 4.60 | 18 | 43.87 | 12 |
| Jiangxi | 41.4 | 11.93 | 3 | 7.08 | 6 | 19.01 | 5 | 59.13 | 8 |
| Jilin | 27.28 | 2.31 | 20 | 1.32 | 24 | 3.63 | 23 | 27.79 | 18 |
| Liaoning | 42.38 | 2.71 | 16 | 1.11 | 27 | 3.82 | 22 | 32.66 | 15 |
| Ningxia | 5.62 | 2.49 | 18 | 4.09 | 12 | 6.58 | 13 | 10.50 | 27 |
| Qinghai | 5.18 | 8.11 | 6 | 16.22 | 3 | 24.32 | 4 | 47.10 | 9 |
| Shaanxi | 36.05 | 1.55 | 27 | 1.83 | 21 | 3.38 | 24 | 9.90 | 28 |
| Shandong | 90.79 | 2.41 | 19 | 1.93 | 19 | 4.34 | 20 | 35.11 | 14 |
| Shanghai | 16.74 | 2.15 | 21 | 1.85 | 20 | 4.00 | 21 | 14.76 | 24 |
| Shanxi | 32.97 | 1.09 | 31 | 0.49 | 30 | 1.58 | 31 | 9.28 | 29 |
| Sichuan | 83.29 | 3.13 | 15 | 2.87 | 16 | 6.00 | 15 | 19.16 | 22 |
| Tianjin | 10.01 | 1.70 | 25 | 0.20 | 31 | 1.90 | 30 | 23.58 | 20 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Tibet | 2.62 | 28.63 | 1 | 34.35 | 1 | 62.98 | 1 | 72.52 | 7 |
| Xinjiang | 19.25 | 1.71 | 24 | 0.94 | 29 | 2.65 | 28 | 4.94 | 31 |
| Yunnan | 42.88 | 11.45 | 4 | 13.76 | 4 | 25.21 | 3 | 45.48 | 10 |
| Zhejiang | 46.77 | 3.38 | 13 | 2.99 | 15 | 6.37 | 14 | 102.95 | 3 |
| China | 1262.28 | 5.09 | | 5.49 | | 10.57 | | 43.74 | |

# 4. Temporal variations

## 4.1 Year-to-year variations

A total of 5033 fatalities, 4670 injuries and 61614 damages were reported from 1997 to 2009 and the year-to-year variations are shown in Fig. 1. The number of lightning fatalities and injuries increased from 1997 to 2007 and began to decrease since 2008. With widely use of electric equipments in modern days, damage reports showed an increase all along the period, only with a low value in 2008 (Fig. 1). Lightning casualties and damages were very low from 1997 to 2001 and then present a sharp increase in 2002. The sharp increase could be attributed in part to the improved reporting procedure, especially in rural areas. Although lightning damage reports increased all along this period, fatalities and injuries began to drop since 2008. The drop of casualties in the last two years of the record was owe to improved warning and nowcasting, better public education, better lightning protection technology, and improved medical care.

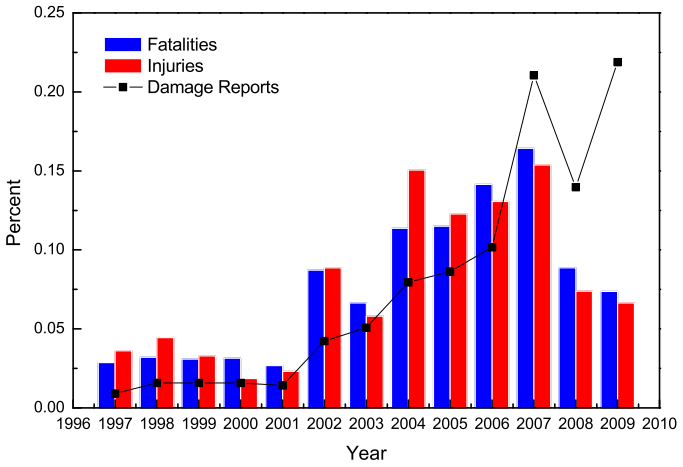


Fig 1 Inter-annual variation of lightning-related fatalities, injuries and damage reports in China from 1997 to 2009.

## 4.2 Monthly variations

Lightning casualties and damages occurs all through the year but most events are during the summer months between June to August (Fig. 2). Lightning fatalities, injuries and damages in these three months account for 72%, 67% and 63% of the whole year. The greatest number of casualties and damages occurs in July (26% and 21%) with the second most in June (23%) for casualties and August (21%) for damages. The peak months are between June to August, which is also the period of intense thunderstorm activity in China. During the winter months from November to February of the following year, the number of lightning fatalities, injuries and damage reports are lowest in the year.

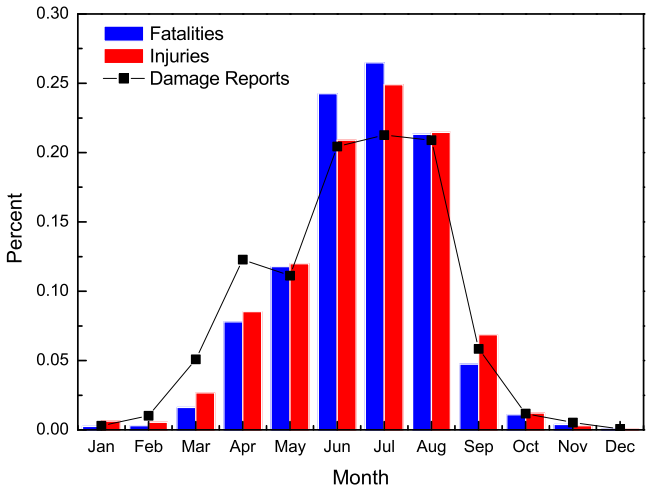


Fig 2 Monthly variations of lightning-related fatalities, injuries and damage reports in China from 1997 to 2009.

# 5. Additional information

## 5.1 Rural and urban casualties

Lightning fatalities and injuries mostly occur in rural regions in China (Fig. 3). Rural regions account for 51% and 29% of all lightning fatalities and injuries reported from 1997 to 2009. Lighting casualties in urban areas only account for 6%. If take no account of unknown factors (13.5%), rural regions account for 93% of all lightning casualties. The large proportion of casualties in rural regions is attributed to the life style and living environment. A majority of fatalities and injuries occurred when rural people were doing field work. Furthermore, the rural structures are often poorly grounded and built in exposed areas, which increase the chance of direct lightning strikes.

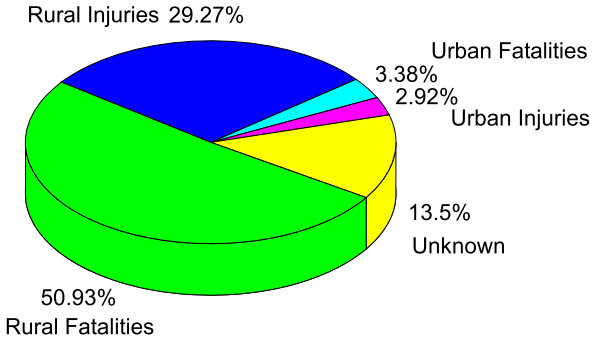


Fig.3 Frequency distribution of lightning casualties in rural and urban regions

## 5.2 Economic losses

Lightning causes millions of dollars property losses in China every year. Fig. 4 shows the year-to-year variation of direct economic losses caused by lightning. Direct economic losses increased from 50 million RMB in 1997 to 450 million RMB in 2007, and began to decrease in 2008. Direct economic loss per damage decreased during this period that indicated increase of lightning damage reports. The result was same with Fig. 1. Economic losses are divided into nine fields (Fig. 5) to see which industry has the most severe damages by lightning. Civil field has the largest economic loss and accounts for 40% of total losses.

Damages in civil field include destruction of houses and household appliances. Lightning damage of power lines has the second largest (19%) economic loss. Education field is the next largest group. The economics losses in education field refers to destruction of buildings and appliances in schools.

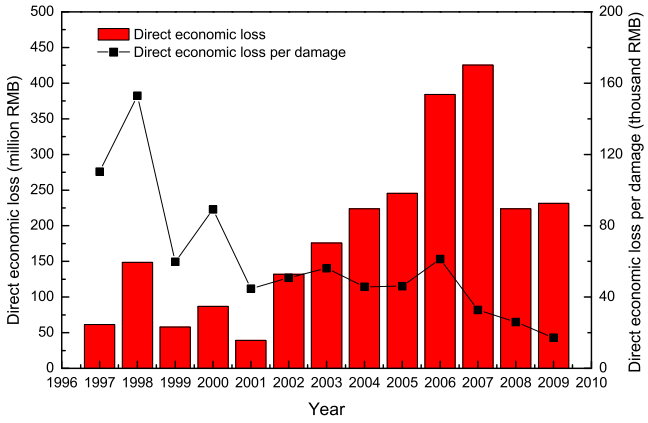


Fig. 4 Annual variation of direct economic loss caused by lightning in China from 1997 to 2009.

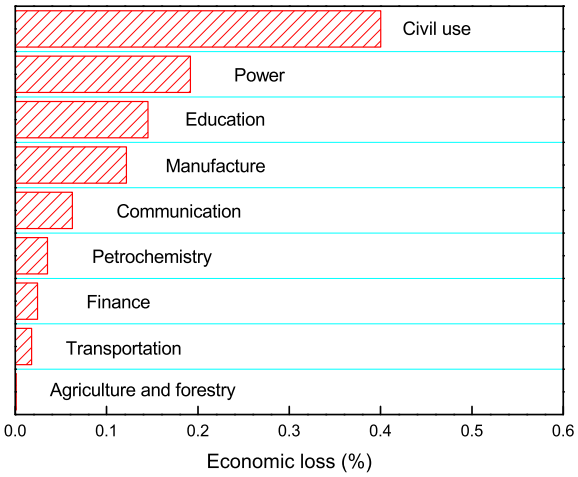


Fig. 5 Frequency distribution of economic loss in different fields

## 5.3 Location

Lightning casualties are mainly determined by the activity and location of the individuals during the thunderstorm. In this study, locations of lightning casualties are divided into nine groups- farm, open fields, water fields, in buildings, factories and building sites, mountains, trees, telephones and radios, bikes and motorcycles (Fig. 6). “Farm” is the largest category for 37% were struck whilst working on farm. “Open fields” is the next largest category and accounts for 14% casualties. “Water fields” is the third largest group and accounts for 9% casualties. Fig. 6 points to the fact that the majority (79%, sum of farm, open fields, water fields, mountains, trees, bikes and motorcycles) of lightning casualties occurs outdoors in open areas, that is similar with the results of Mills et al. (2008).

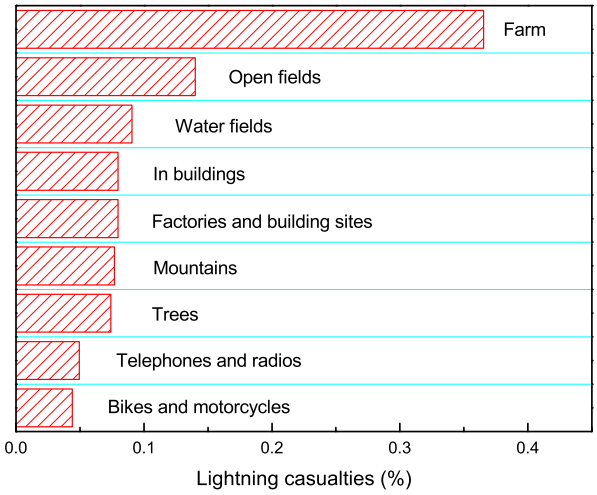


Fig. 6 Frequency distribution of the locations of lightning casualties

## 6. Conclusions

Lightning is a common meteorological hazard in China that leads to fatalities, injures and large amount of economic losses. Based on the National Lightning Hazards Database, lightning-related fatalities, injures, casualties and damage reports were summarized from 1997 to 2009. Large casualties and damage reports were located in south and east China. When population was taken into account, the maxima shift from southern and eastern provinces to low population provinces such as Tibet, Hainan and Qinghai and the ranks of populous provinces such as Henan, Shandong and Sichuan degraded.

The number of lightning fatalities and injuries increased from 1997 to 2007 and began to decrease since 2008, while the damage reports showed an increase all along the period, only with a low value in 2008. The peak months of lightning fatalities, injuries and damages were between June to August, which was also the period of intense thunderstorm activity in China. July maxima were reached by all types of lightning reports. The number of lightning fatalities, injuries and damage reports were lowest between November to February of the following year.

Rural regions accounted for 51% and 29% of all lightning fatalities and injuries. A majority of fatalities and injuries occurred when rural people were doing field work. Direct economic losses by lightning increased from 50 million RMB in 1997 to 450 million RMB in 2007 and began to decrease in 2008. Direct economic loss per damage decreased during this period which indicated increase of lightning damage reports. Civil field had the largest economic losses and power industry was the second category. A significant number (79%) of lightning casualties occurred outdoors in open areas, with 37% working on farm, 14% in open fields and 9% on water fields.

Future work will focus on comparisons of casualties and damages with ground lightning flash density data detected by the National Lightning Detection Network and improvement of a better lightning reporting protocol which will include all the variables discussed above. This can help reduce the underestimation of lightning casualties and damages and develop a more concise national lightning hazard database.

## Acknowledgment

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## References

Curran E. Brian, Ronald L. Holle and Raul E. Lopez. 1999. Lightning casualties and damages in the United States from 1959 to 1994. *Journal of Climate*, 13: 3448-3464.

Mills Brian, Dan Unrau, Carla Parkinson, Brenda Jones, Jennifer Yessis, Kelsey Spring, Laurel Pentelow. 2008. Assessment of lightning-related fatality and injury risk in Canada. *Nat Harzards*, 47: 157-183.

Raul E Lopez, Ronald L Holle. 1998. Changes in the number of lightning deaths in the United States during the twentieth century. *Journal of Climate*, 11: 2070-2077.

Coates L, Blong R, Siciliano F. 1993. Lightning fatalities in Australia, 1824-1991. *Nat Hazards*, 8: 217-233.

Wisdom M. Dlamini. 2009. Lightning fatalities in Swaziland: 2000-2007. *Nat Hazards*, 50: 179-191.

Lewis AME. 1997. Understanding the principles of lightning injuries. *J Emerg Nurs*, 23(6): 535-541.

Walsh KM, Bennett B, Cooper MA, Holle RL, Kithil R, Lopez RE. 2000. National Athletic Trainers' Association position statement: lightning safety for athletics and recreation. *J Athl Train*, 35(4): 471-477.

Ma Ming, Lu Weitao, Zhang Yijun, Meng Qing. 2008. Analysis of lightning disasters in China and their correlative factors. *Advances in Earth Science*, 23: 856-865. (In Chinese)

Christian H J, Blakeslee R J, Boccippio D J, et al. 2003. Global frequency and distribution of lightning as observed from space by the optical transient detector. *J Geophys Res*, 108(D1): 4005-4019.

Meng Qing, Zhang Wenjuan et al. 2008. Research on Lightning Nowcasting and Warning System and its evaluation experiment. *WMO Technical Conference on Meteorological and Environmental Instruments and Observation.* St.Petersburg, Report No. 96, WMO/TD-No.1462.

Mogil H M, M Rush, M Kutka. 1977. Lightning-An updata. *10th Conf. on Severe Local Storms*, Omaha, NE, Amer. Meteor. Soc., 226-230.