Lightning Casualties and Damages in the United States from 1959 to 1994

E. BRIAN CURRAN*

National Weather Service Forecast Office, Fort Worth, Texas

RONALD L. HOLLE AND RAÚL E. LÓPEZ

National Severe Storms Laboratory, NOAA, Norman, Oklahoma

(Manuscript received 12 November 1998, in final form 29 June 1999)

ABSTRACT

Lightning-caused fatalities, injuries, and damage reports for the United States are listed in the National Oceanic and Atmospheric Administration publication *Storm Data.* Previously published studies of lightning casualties and damages in the United States covered only portions of the period since *Storm Data* began publication in 1959, did not weight by population, or did not present complete information with respect to time of year and day. Therefore, an analysis was made of all 3239 deaths, 9818 injuries, and 19 814 property damage reports in *Storm Data* due to lightning from 1959 to 1994. This paper depicts lightning casualties (deaths and injuries combined) and damage reports stratified by state and region of the United States, decade, population, time of year and day, and all other information in *Storm Data.*

Florida had the most deaths (345) and injuries (1178) from lightning, and Pennsylvania had the most damage reports (1441). A rate of one fatality per 86 000 cloud-to-ground flashes is estimated from recent lightning detection network information. After population was taken into account, Wyoming and New Mexico had the highest death, injury, and casualty rates. The U.S. rate is 0.42 lightning deaths per million people per year from 1959 to 1994. Highest population-weighted damage rates were on the plains, but the pattern was variable from decade to decade. July had more lightning entries of all types than any other month; damage reports were spread more evenly through the year. Casualties and damages in the northern half of the United States had narrower distributions centered on summer than did the southern half. Two-thirds of the casualties were between noon and 6 P.M.; damage reports were relatively frequent at night in the plains and Midwest. Most lightning incidents involved one person, and males were five times as likely as females to be killed or injured. *Storm Data* excludes most small losses but includes more expensive and widely known lightning-related losses.

1. Introduction

This paper summarizes information on casualties (deaths and injuries combined) and damages due to lightning in the United States from the National Oceanic and Atmospheric Administration (NOAA) publication *Storm Data*. This resource was used in a similar study by Dittmann (1994) of state-by-state per capita rates of flood deaths from 1959 to 1991.

Annual summaries of weather impacts based on *Storm Data* have been published since 1990 by NOAA's National Weather Service. Table 1 shows that lightning is reported to have caused 44% of the fatalities, 19% of injuries, and 3% of damages from convective weather during three recent years. Absolute values must be considered with caution, however, for reasons given in the next section. Lightning is also near the top of the list of all types of weather-related deaths; only fatalities from flash and river floods rank higher (Table 2).

Several studies have been published on U.S. lightning-caused casualties and damages, and a number of publications describe lightning impacts in other countries; their results will be compared with findings of this paper. Curran et al. (1997) has expanded versions of many figures and tables of the present paper.

A more complete national climatic description of lightning casualties and damages is essential to improving awareness and education concerning this hazard. The understanding of medical issues concerning lightning victims has also improved during the 1990s (Andrews et al. 1992; Cooper 1995; Cooper and Andrews 1995; Primeau et al. 1995; Cherington et al. 1997). Better demographic distributions and medical

* Current affiliation: National Weather Service, Midland, Texas.

Corresponding author address: Ronald L. Holle, National Severe Storms Laboratory, NOAA, 1313 Halley Circle, Norman, OK 73069.
E-mail: holle@nssl.noaa.gov

TABLE 1. Annual convective weather deaths, injuries, and property damage reports, 1992–94 (from National Weather Service, Office of Meteorology). Order is by deaths per year.

Convective weather type	Fatalities	Injuries	Damage ($ million)
Lightning	51	345	32
Tornadoes	47	1,114	551
Thunderstorm wind	18	352	295
Hail	0	43	345

TABLE 2. Weather-related deaths per year in last 30 years, and 1994 deaths and casualties (from National Weather Service, Office of Meteorology). Order is by 30-yr death rate, then 1994 deaths.

Weather type	30-yr deaths per year	1994 deaths	1994 injuries
Flash flood		59	33
	139		
River flood		32	14
Lightning	87	69	484
Tornado	82	69	1067
Hurricane	27	9	45
Extreme temperature		81	298
Winter weather		31	2690
Thunderstorm wind		17	315
Other high wind		12	61
Fog		3	99
Other		6	59
Total		388	5165

profiles of lightning victims have resulted in a multidisciplinary effort concerning lightning safety and education (Holle et al. 1999). At the present time, a significant emphasis is being placed on recreation and sports (Bennett 1997; Walsh et al. 1997).

2. Lightning casualty and damage reports

Every month, each National Weather Service office compiles a list of damaging or notable weather phenomena occurring within the office's area of responsibility. This list is sent to NOAA headquarters, then to NOAA's National Climatic Data Center (NCDC) in Asheville, North Carolina. These lists are combined at NCDC and *Storm Data* is published. For this study, an electronic database of lightning events contained in *Storm Data* from 1959 through 1990 was obtained from NCDC. Events from 1991 through 1994 were extracted from monthly *Storm Data* publications and manually added to the database. Each report consists of the following:

- Year, month, and day of the event;
- Time in local standard time (LST);
- State and county;
- Number, gender, and location of fatalities;
- Number, gender, and location of injuries; and
- Categorical amount of damage.

If an element of the lightning event is unknown, then that element is coded as missing. The number of events where the time or date of occurrence was missing decreased from over 60% of the total events during the 1960s to less than 10% after 1987. In total, *Storm Data* contained 3239 fatalities, 9818 injuries, and 19 814 occurrences of property damage due to lightning during the period of study.

Absolute values in Tables 1 and 2 must be considered with caution. Lightning casualties and damages often are less spectacular and more dispersed in time than other weather phenomena such as tornadoes and hurricanes. Consequently, lightning-related casualties and damages receive less attention than these large-impact events and are underreported with respect to other weather hazards. For example, Mogil et al. (1977) found 33% more lightning deaths in Texas than reported in *Storm Data*. In Colorado, López et al. (1993) found 28% more fatalities and 42% more injuries requiring hospitalization than reported in *Storm Data*. Cherington et al. (1999) also found from Colorado medical records that the ratio of lightning injuries to deaths is about 10:1 rather than the commonly reported value of 3:1 or 4:1. Concerning damages, Holle et al. (1996) found an underreporting in *Storm Data* damage events in three western states by a ratio of 367:1 from a comparison to insurance claims. The latter paper suggests that lightning-caused costs are similar to, or exceed damages from, other phenomena in Table 1. When other unquantified losses are considered, lightning may consistently cause more damage than any other weather phenomenon.

Factors contributing to the underreporting of casualties and damages in *Storm Data* include the following.

- The National Weather Service relies on newspaper clipping services for many lightning events in *Storm Data* (López et al. 1993). Some offices do not have, or do not use, these clipping services.
- Most lightning casualty events involve one person.
- Lightning is sometimes listed as a secondary rather than primary cause of death or injury by the medical system (Mogil et al. 1977; López and Holle 1998).

Nevertheless, *Storm Data* is the only consistent data source on lightning casualties and damages for several decades, since it has been compiled with similar procedures since 1959. With the exception of changing 106 incorrectly coded monetary damage amounts in 1989 to the unknown category (see section 8), the NCDC dataset was used without modification.

3. Variations by state in reported numbers

Section 3 discusses actual frequencies and ranks of lightning reports in the 48 contiguous states. Table 3 shows the number and rank of fatalities, injuries, casualties, and damage reports for each state.

TABLE 3. Number of lightning fatalities, injuries, casualties, and damage reports, and their ranks, for states, the District of Columbia, and Puerto Rico from 1959 to 1994.

State	Fatalities No.	Fatalities Rank	Injuries No.	Injuries Rank	Casualties No.	Casualties Rank	Damage reports No.	Damage reports Rank
Alabama	84	16	211	17	295	18	287	28
Alaska	0	51	0	52	0	52	3	52
Arizona	59	24	105	29	164	30	84	43
Arkansas	110	9	245	13	355	12	576	14
California	21	35	58	40	79	38	60	45
Colorado	95	11	299	11	394	10	312	26
Connecticut	13	42	75	35	88	36	269	29
Delaware	15	41	27	44	42	43	83	44
District of Columbia	5	48	18	48	23	49	14	48
Florida	345	1	1178	1	1523	1	450	19
Georgia	81	18	329	10	410	9	656	10
Hawaii	0	52	4	51	4	51	14	49
Idaho	20	37	67	38	87	37	305	27
Illinois	85	15	275	12	360	11	412	21
Indiana	74	22	164	24	238	23	350	24
Iowa	65	23	162	25	227	26	579	13
Kansas	56	25	178	22	234	25	1182	2
Kentucky	82	17	196	19	278	19	566	15
Louisiana	116	6	231	15	347	14	315	25
Maine	22	34	104	30	126	31	253	30
Maryland	116	7	134	26	250	20	455	18
Massachusetts	24	33	331	9	355	13	603	12
Michigan	89	12	643	2	732	2	814	6
Minnesota	53	27	116	28	169	29	406	23
Mississippi	89	13	207	18	296	17	205	33
Missouri	79	20	97	31	176	28	253	31
Montana	20	38	44	42	64	41	88	42
Nebraska	41	30	70	36	111	33	618	11
Nevada	6	47	12	49	18	50	11	50
New Hampshire	8	45	68	37	76	40	206	32
New Jersey	55	26	130	27	185	27	98	41
New Mexico	81	19	168	23	249	21	54	47
New York	128	4	449	5	577	5	1005	3
North Carolina	165	2	464	4	629	4	960	4
North Dakota	11	44	24	45	35	46	145	37
Ohio	115	8	430	6	545	6	412	22
Oklahoma	88	14	243	14	331	15	826	5
Oregon	7	46	19	46	26	48	150	35
Pennsylvania	109	10	535	3	644	3	1441	1
Puerto Rico	30	32	6	50	36	45	4	51
Rhode Island	4	49	45	41	49	42	122	38
South Carolina	77	21	229	16	306	16	717	8
South Dakota	20	39	59	39	79	39	437	20
Tennessee	124	5	349	7	473	8	764	7
Texas	164	3	334	8	498	7	689	9
Utah	34	31	82	34	116	32	107	39
Vermont	12	43	18	47	30	47	151	34
Virginia	51	28	184	21	235	24	487	17
Washington	3	50	37	43	40	44	56	46
West Virginia	20	40	88	32	108	34	146	35
Wisconsin	47	29	194	20	241	22	509	16
Wyoming	21	36	83	33	104	35	105	40
United States	3239		9818		13 057		19 814	

a. Casualties

Figure 1 uses shading to separate the top 30 states in lightning-caused casualties (Fig. 1a) and damages (Fig. 1b) by steps of 10 in rank. Florida has more than twice as many casualties as any other state (Table 3). In order, the other top 10 are Michigan, Pennsylvania, North Carolina, New York, Ohio, Texas, Tennessee, Georgia, and Colorado. Other high-ranking states are in southern and eastern regions of the country, and the populous northeastern states. Relatively frequent casualties are apparent in Colorado, New Mexico, and Arizona. The only similar maps that were previously published showed

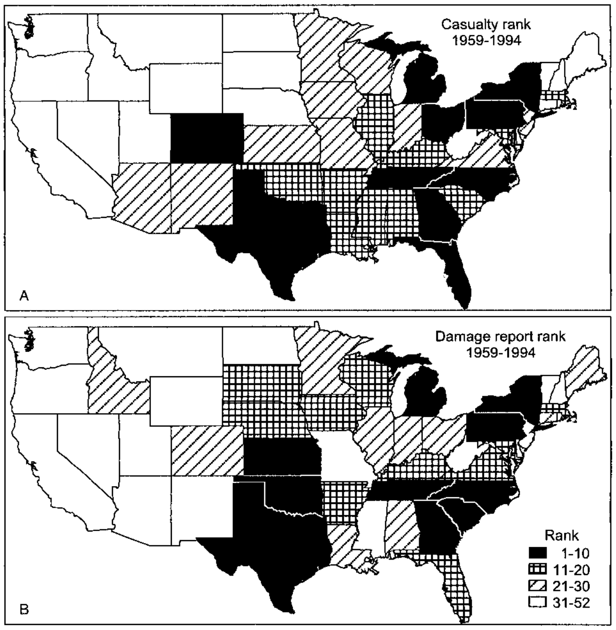

Fig. 1. Map of the rank of each state in number of lightning casualties (a) and damage reports (b) from 1959 to 1994.

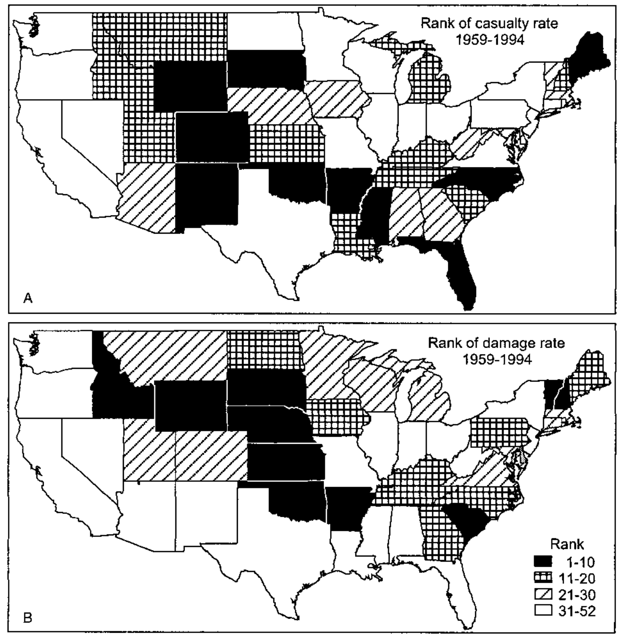

Fig. 2. Map of the rank of each state in the rate of lightning casualties (a) and damage reports (b) from 1959 to 1994.

deaths, injuries, and damages by county in Michigan (Ferrett and Ojala 1992) and casualties by county in Colorado (López et al. 1995).

There was an average of 363 casualties per year (Table 3) from 1959 to 1994. The National Lightning Detection Network (Cummins et al. 1998) identified an average of 21 746 000 cloud-to-ground flashes per year from 1992 to 1995 (Orville and Silver 1997). Assuming this 4-yr average to be representative, the result is one casualty for every 60 000 flashes. Since approximately 70% of the flashes were detected, about 86 000 flashes occurred for each casualty.

b. *Fatalities*

Fatalities are distributed similarly to casualties (Curran et al. 1997). Florida had more than twice as many lightning deaths as any other state. The other top 10 states are the same as for casualties except Louisiana, Maryland, and Arkansas replace Michigan, Georgia, and Colorado (Table 3). Lightning caused an aircraft crash that killed 81 people in Maryland in 1963; that state became seventh in fatalities over the period. Michigan was in the top 10 casualty list, but not that of fatalities, because of two injury cases: 90 people were injured at a campground in one case and 45 at a National Guard camp in another (Ferrett and Ojala 1992).

Previous studies of lightning impacts on people often described fatalities. Thresholds of the number of deaths rather than state ranks were shown by Duclos and Sanderson (1990) using data from the National Center for Health Statistics from 1968 to 1985. Deaths from *Storm Data* were plotted by state (Mogil et al. 1977) from 1968 to 1976 or at specific locations (Zegel 1967) from 1959 to 1965; results were similar to Fig. 2. Single-state maps of deaths by county have been compiled for Florida (Duclos et al. 1990), North Carolina (Langley et al. 1991), Michigan (Ferrett and Ojala 1992), and Colorado (López et al. 1995). Outside the United States, a table of fatalities by Canadian province from 1939 to 1958 was developed by Hornstein (1962). Pakiam et al. (1981) plotted each fatality on a map of Singapore. Maps of lightning deaths divided by political boundaries were shown by Coates et al. (1993) for Australia and Gourbière et al. (1997) for France.

c. *Injuries*

The distribution of injuries by state is not shown here but is in Curran et al. (1997). The distribution is nearly identical to casualties in Fig. 1a, since 75% of the casualties are injuries. Florida had nearly twice as many injuries as Michigan. Michigan was second in injuries but 12th in deaths due to large numbers of injuries in the two cases mentioned earlier. Georgia and Massachusetts on the injury list replace Arkansas and Maryland on the fatality list.

The U.S. average is 2.54 injuries per death. However, Missouri had only slightly more injuries (93) than deaths (78), while Puerto Rico had six injuries but 30 deaths; a few other locations approach a 1:1 ratio. The geographical distribution of the injury to death ratio has no coherent pattern (not shown). A low ratio may indicate an underreporting of injuries and that deaths are the better statistic for a state.

d. Damage reports

The distribution of damages by state (Fig. 1b) is very different from that of casualties. Damage reports are relatively frequent over the plains from South Dakota to Texas. The largest number is from Pennsylvania, where less than half as many casualties were reported as in Florida. While Florida is first on all casualty lists, it is not high on the damage list. Six of the 10 states with the highest damage counts are on the top 10 lists for casualties, deaths, or injuries. But Kansas, Oklahoma, Nebraska, and South Carolina do not have a high casualty rank. There are few damage reports in New Mexico, where there is a rather large number of deaths.

The damage to casualty report ratio tends to be near 1 or less in the southwestern and southeastern states, and Florida (not shown). Northwestern states have nearly two damage reports for every casualty. It is unknown whether this ratio is influenced by better reporting of casualties, a greater underreporting of damages in some states, or other factors.

e. Summary

Florida led the nation in casualties, deaths, and injuries by a wide margin. The largest number of damage reports came from Pennsylvania, but it had less than half as many casualties as Florida. North Carolina had uniformly high frequencies in all categories: second in deaths, fourth in injuries, and third in damages. Kansas ranks were less consistent; it was fourth in damages, but 25th in deaths and 22d in injuries. Alaska, Hawaii, Puerto Rico, the District of Columbia, and Nevada had very few casualties and damage reports over the 36-yr period.

4. Variations by state weighted by population

a. Casualty rate per population

Figure 2a shows major differences between the rates of lightning-caused casualties and reported numbers in Fig. 1a. The main effect of taking population into account is to shift maxima from populous eastern states to the Rocky Mountain and plains states. The top two rates are from Wyoming and New Mexico (Table 4); these states were 35th and 21st in number of casualties (Table 3). Wyoming had most of its casualties in the 1960s and 1970s (section 4) and almost none since then. Southeastern states often have high rankings in both Figs. 1 and 2. The only states in the top 10 for both casualties and casualty rate are Florida, Colorado, and North Carolina. Similar maps to those of casualty rate per state population were in Ferrett and Ojala (1992) and López and Holle (1995). López et al. (1995) showed casualty rates for Colorado counties.

b. Death rate per population

The map of lightning-caused death rate for the United States (not shown) is very similar to the casualty map in Fig. 2a. New Mexico and Wyoming have the highest lightning-caused death rates, as for casualty rate, except they exchange first and second places. The national average is 0.42 deaths per million people per year. This rate is one-fourth the rate of 1.7 deaths per million in Singapore for 1961–79 (Pakiam et al. 1981). In contrast, the U.S. rate is more than two orders of magnitude greater than the 0.001 rate in Australia from 1980 to 1989 (Coates et al. 1993). Similar maps of death rates per population were shown by Ferrett and Ojala (1992), Zegel (1967), and Duclos and Sanderson (1992).

c. Injury rate per population

Locations with highest injury rates are almost identical with high casualty rates (Curran et al. 1997). Florida and North Carolina are the only states that rank in the top 10 for both injuries and injury rate. Otherwise, states with high injury rates have smaller than average to average populations. The only previous injury rate map was by Ferrett and Ojala (1992) over a similar period.

d. Damage report rate per population

A swath of high rates of damage reports is located from Idaho into the Dakotas to Oklahoma and Arkansas (Fig. 2b). However, except for the plains maximum, there is not much of a pattern. The plains also had high numbers of damage reports with two exceptions. North Dakota did not have many reports, but this less populous state becomes sixth in damage rate. Although Texas had numerous reports, its damage rate was small due to it being so populous. Recall that Holle et al. (1996) showed *Storm Data* damage reports to be underreported by a ratio of 367:1 based on insurance claims, so a highly organized pattern for damages should not be expected. New Mexico had few damage reports (41st in country) but a high casualty rate (second). No previous publication has shown a damage rate map.

e. Summary

Wyoming and New Mexico led the nation in lightning-caused death, injury, and casualty rates. The highest rates of damage reports were from Idaho to the plains. New Mexico had a low damage rate while it was second in casualty rates. Alaska, Hawaii, California, Washington, Puerto Rico, and Oregon always had low rates of casualties, deaths, and injuries.

5. Year-to-year variations

a. Nation by year

The number of lightning deaths decreased from 1959 to 1994, while injuries and casualties increased (Fig.

TABLE 4. Average population, and rate per million people per year of lightning fatalities, injuries, casualties, and damage reports, and their ranks, for all states, the District of Columbia, and Puerto Rico from 1959 to 1994. Population is average of decennial census values from 1960 to 1990.

	Avg population	Fatality rate		Injury rate		Casualty rate		Damage rate	
State	[1000s]	Rate	Rank	Rate	Rank	Rate	Rank	Rate	Rank
Alabama	3660	0.64	24	1.60	23	2.23	22	2.18	34
Alaska	369	0	52	0	52	0	52	0.23	50
Arizona	2364	0.69	19	1.23	30	1.93	26	0.99	44
Arkansas	2086	1.46	3	3.26	4	4.73	4	7.67	7
California	22 275	0.03	49	0.07	51	0.10	50	0.07	51
Colorado	2536	1.04	6	3.24	5	4.28	5	3.42	21
Connecticut	2990	0.12	45	0.70	42	0.82	44	2.50	29
Delaware	564	0.74	17	1.33	27	2.07	24	4.09	17
District of Columbia	691	0.20	44	0.89	37	0.92	41	0.56	45
Florida	8605	1.10	4	3.80	3	4.91	3	1.45	40
Georgia	5119	0.44	28	1.79	17	2.23	23	3.56	19
Hawaii	869	0	51	0.10	49	0.10	51	0.45	46
Idaho	833	0.67	22	2.23	13	2.90	13	10.17	4
Illinois	11 011	0.21	42	0.69	43	0.91	43	1.04	43
Indiana	5223	0.39	29	0.87	38	1.26	37	1.86	35
Iowa	2818	0.64	23	1.60	24	2.24	21	5.71	13
Kansas	2317	0.67	20	2.13	15	2.80	14	14.17	2
Kentucky	3401	0.67	21	1.63	21	2.30	20	4.62	16
Louisiana	3830	0.83	9	1.65	19	2.48	17	2.28	32
Maine	1078	0.57	25	2.68	6	3.25	8	6.52	11
Maryland	4005	0.80	12	0.94	36	1.74	29	3.16	23
Massachusetts	5648	0.12	47	1.63	22	1.75	28	2.97	25
Michigan	8813	0.28	37	2.03	16	2.31	19	2.57	28
Minnesota	3918	0.38	30	0.84	39	1.21	38	2.88	26
Mississippi	2372	1.04	5	2.42	7	3.47	6	2.40	30
Missouri	4758	0.46	27	0.54	44	1.00	40	1.48	38
Montana	739	0.75	15	1.65	20	2.41	18	3.31	22
Nebraska	1511	0.75	16	1.27	28	2.02	25	11.36	3
Nevada	694	0.24	40	0.52	45	0.76	45	0.44	47
New Hampshire	844	0.26	38	2.24	12	2.50	16	6.78	10
New Jersey	7082	0.22	41	0.49	46	0.71	46	0.38	49
New Mexico	1200	1.88	1	3.89	2	5.76	2	1.25	41
New York	17 642	0.20	43	0.71	41	0.91	42	1.58	37
North Carolina	5535	0.84	8	2.32	10	3.16	10	4.82	15
North Dakota	635	0.48	26	1.05	34	1.53	31	6.34	12
Ohio	10 501	0.30	34	1.13	32	1.44	35	1.09	42
Oklahoma	2764	0.88	7	2.42	8	3.31	7	8.30	6
Oregon	2334	0.08	48	0.23	48	0.31	48	1.79	36
Pennsylvania	11 715	0.26	39	1.26	29	1.52	32	3.42	20
Puerto Rico	2296	0.36	31	0.07	50	0.44	47	0.05	52
Rhode Island	939	0.12	46	1.33	25	1.45	34	3.61	18
South Carolina	2895	0.78	13	2.22	14	2.99	12	6.88	9
South Dakota	683	0.81	10	2.40	9	3.21	9	17.77	1
Tennessee	4240	0.81	11	2.29	11	3.09	11	5.01	14
Texas	12 998	0.35	32	0.71	40	1.06	39	1.47	39
Utah	1283	0.74	18	1.78	18	2.51	15	2.32	31
Vermont	477	0.76	14	1.05	35	1.80	27	8.79	5
Virginia	5037	0.28	36	1.06	33	1.35	36	2.69	27
Washington	3815	0.02	50	0.27	47	0.29	49	0.41	48
West Virginia	1837	0.30	33	1.33	26	1.63	30	2.21	33
Wisconsin	4492	0.28	35	1.21	31	1.49	33	3.15	24
Wyoming	397	1.47	2	5.74	1	7.21	1	7.35	8
United States	216 738	0.42		1.26		1.67		2.54	

3a). The resulting ratio of injuries to deaths increased substantially over the period (Fig. 3b). After population growth was taken into account (normalization), several major trends were identified by López and Holle (1996, 1998).

- A 30% decrease in normalized casualties was attributed to improved forecasts and warnings, better awareness of the lightning threat, more substantial buildings available for safe refuge, and other socio-economic changes.

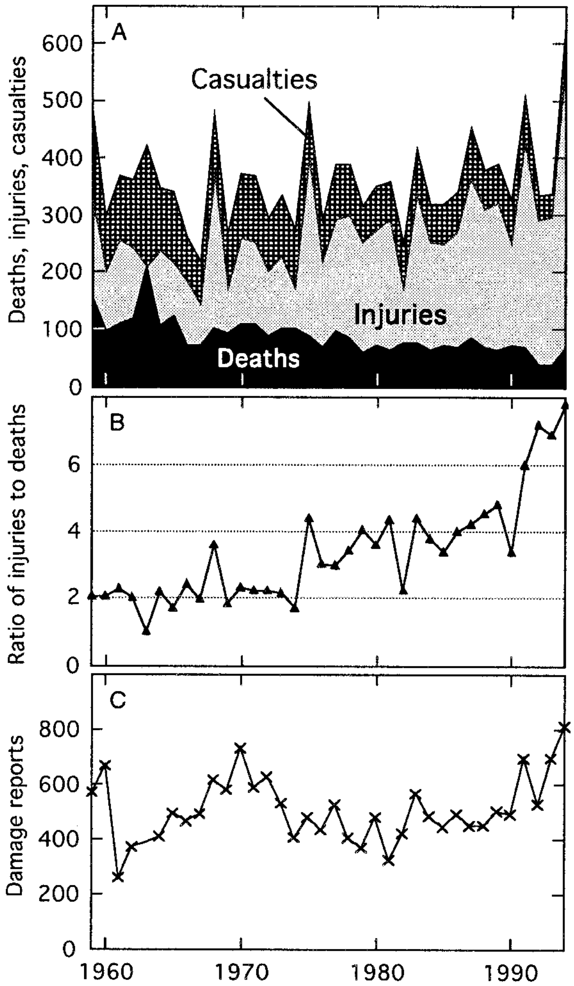

FIG. 3. Annual number of casualties, deaths, and injuries (a); ratio of injuries to deaths (b); and number of damage reports (c).

- An additional 40% reduction in normalized deaths may be due to improved medical care, and emergency communications and transportation.
- Normalized injuries decreased only 8% due to the transfer of potential deaths into injuries.
- Additional fluctuations on the scale of one or two decades broadly parallel national-scale changes in frequencies of thunder days, cyclones, and surface temperature.

The number of damage reports (Fig. 3c) shows a gradual increase from 1959 to 1994 that could be due to population growth. While Holle et al. (1996) showed that *Storm Data* lightning damages are vastly underreported, Fig. 3c appears to have no systematic bias through time.

Notable decreases in lightning deaths over long periods have been documented in England and Wales from 1852 to 1990 (Elsom 1993), in England and Wales compared to Australia from 1920 to 1969 (Golde and Lee 1976), and in Singapore from 1922 to 1979 (Pakiam et al. 1981). Coates et al. (1993) showed an increase in the number of lightning deaths in Australia from 1825 to a maximum in 1918, then a decrease through 1991.

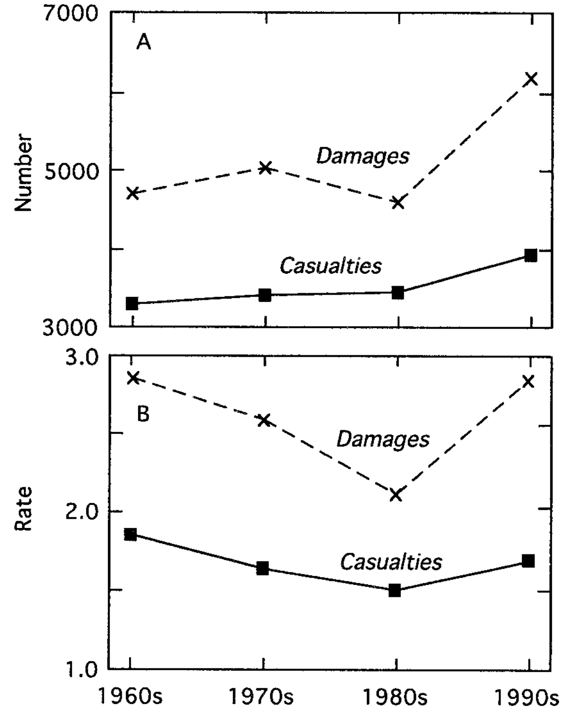

FIG. 4. Casualties and damage reports by decade. Number is shown in (a); rate per million people in (b).

b. Nation by decade

Yearly data in Fig. 3 are divided into decades in Fig. 4. Casualties are somewhat more frequent in the 1990s compared to earlier decades, and damages are much more frequent in the 1990s (Fig. 4a). Population-weighted casualties (Fig. 4b) show a decrease until the 1990s, as well as damages. Values for the 1990s were obtained by doubling 1990–1994 values.

c. Region by decade

Decadal trends in the rates of casualties and damages are graphed for eight regions in Fig. 5. The casualty rate has increased during the last one or two decades in the West Coast, southern Rockies, southern plains, and southeast regions but stayed the same elsewhere. Damage report rates have increased during the last decade or two in all but the West Coast and Midwest regions. Time series for unweighted decadal data (Curran et al. 1997) are nearly identical to those in Fig. 5, since a region's population changes are less variable from decade to decade than the lightning reports.

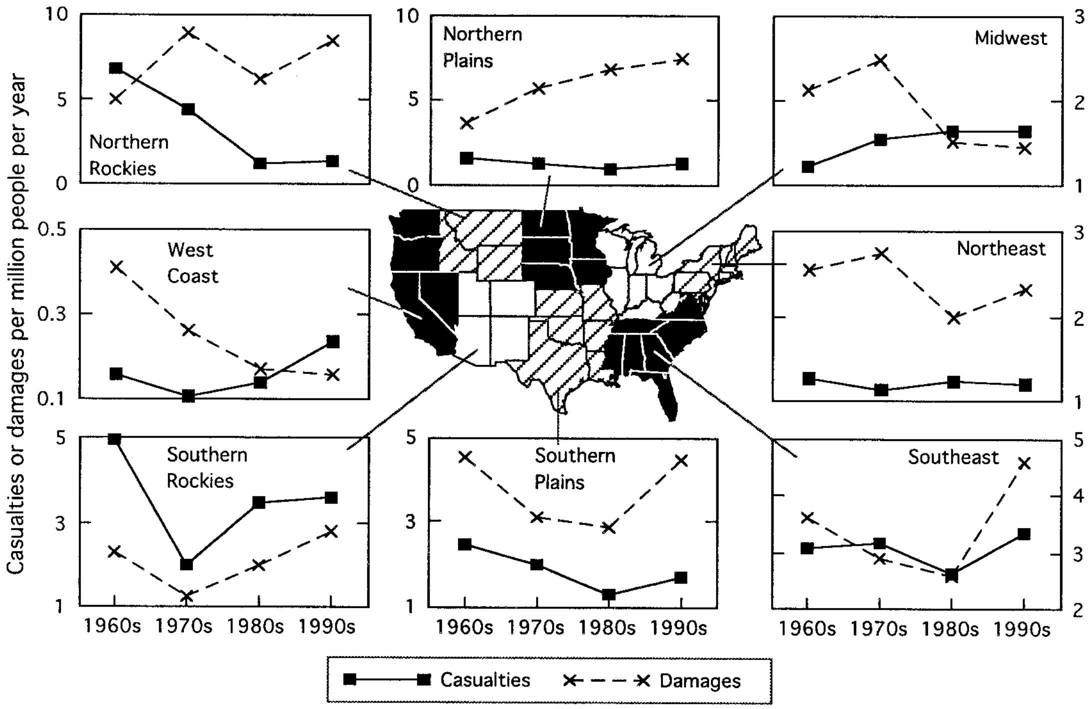

FIG. 5. Decadal variations of casualties per million people per year (solid line and square) and damages per million people per year (dashed line and ×) by region.

d. States by decade

New Mexico and Arkansas are always among the top 10 states for casualty rate (Fig. 6, left column). Highest casualty rates are consistently in the Rocky Mountain and southeastern states; there is a shift toward the southwest with time. Most states stay within one group of 10 from the previous decade. Wyoming has a high rate in the 1960s but drops to a low rate by the 1990s.

Nebraska and Oklahoma are among the top 10 states for damage rates in every decade. Highest rates are in the northern plains, southeastern, and northeastern states. As noted earlier, damage reports are not especially reliable; for example, Georgia increased from 83 reports in the 1960s to 321 from 1990 to 1994, while Mississippi decreased from 58 to 6 over the same two periods.

6. Monthly and seasonal variations

a. Nation by month

Lightning casualties and damages peak during summer, and July has the maximum percentage frequencies for all categories (Fig. 7). Monthly percentages increase gradually before, then decline more quickly after, July. Cloud-to-ground flashes from 1992 to 1995 also show these features (Orville and Silver 1997). A higher percentage of deaths occurs in spring than injuries. The 1963 Maryland aircraft crash that killed 81 people accounts for the December anomaly.

Casualties reach a stronger July maximum than damage reports (Fig. 7b). Differing distributions may result from a greater exposure of people to lightning during summer than spring or fall. In contrast, immovable objects are shown to be impacted more often than people before and after the summer maximum; the shape of the damage report distribution may represent better the actual flash distribution.

Most prior *Storm Data* studies found a July maximum, a slower increase before and a faster decrease after July (Zegel 1967; Mogil et al. 1977; Duclos and Sanderson 1990; Ferrett and Ojala 1992; López and Holle 1995; López et al. 1995). In Florida, however, August maxima were found in fatalities (Duclos et al. 1990), and fatalities and property damages (Holle et al. 1993); injuries in the latter study peaked in July. Slightly more lightning insurance claims were made during August than July in Colorado, Utah, and Wyoming (Holle et al. 1996). Singapore at 1°N had fatality maxima in November and April in an annual cycle similar to that of local thunderstorms (Pakiam et al. 1981). In Australia, the largest number of fatalities were in midsummer (January), but the buildup to the maximum was somewhat faster than the dropoff (Coates et al. 1993).

b. Region by month

By region, Fig. 8 shows that damage reports are usually spread more widely through the year than ca-

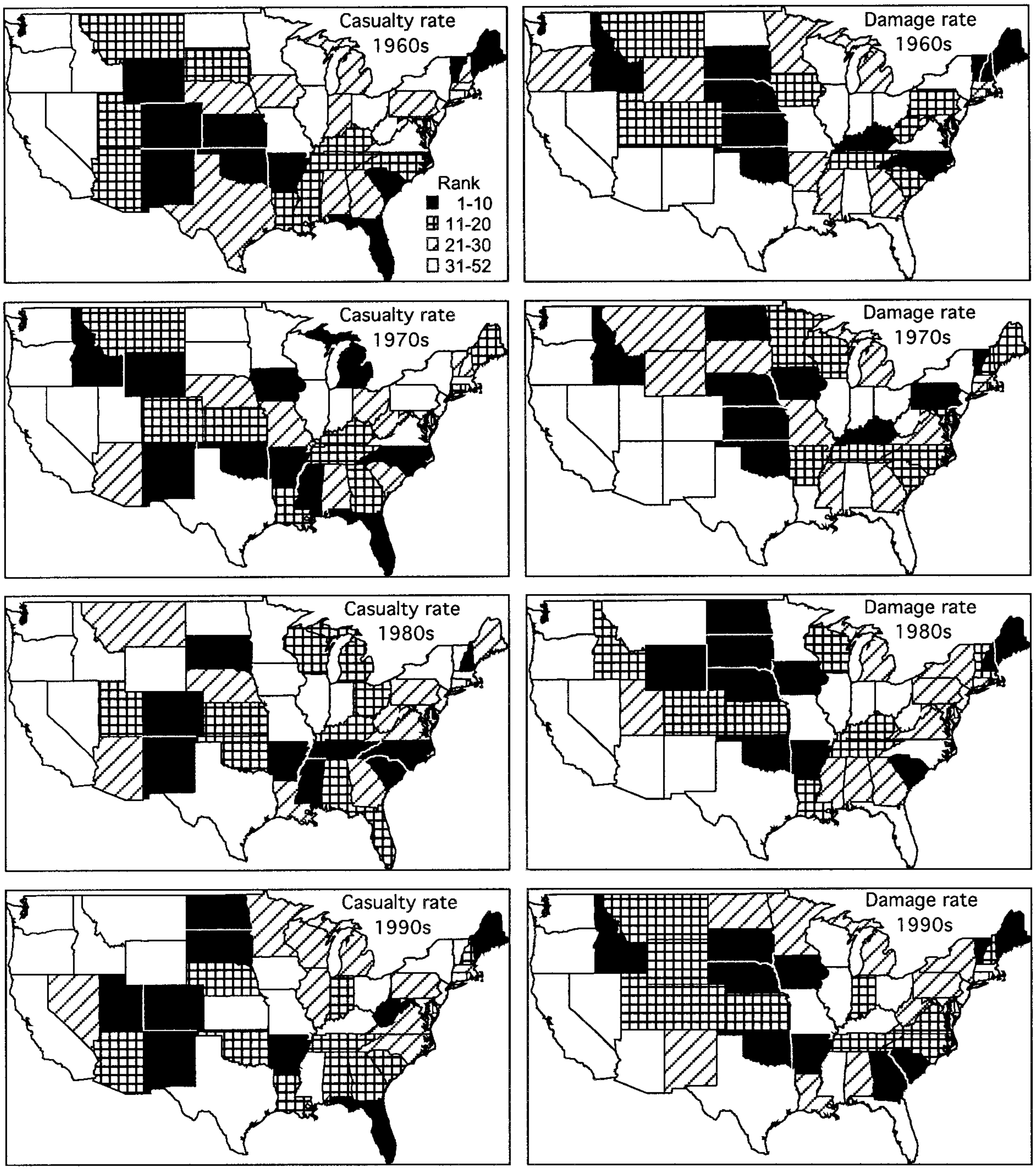

FIG. 6. Maps of the rank of each state in casualties (left column) and damages (right) per million people per year for different decades.

sualties. Both casualties and damages tend to have narrower distributions to the north centered on summer than to the south. Broadest monthly distributions are in the southern plains. Northern areas have up to 4% more casualties and damages in midsummer, while southern regions have more cases in spring and, to a lesser extent, in autumn.

c. Nation by season

The spring map of 1840 casualties during March, April, and May (Fig. 9) is similar to the annual pattern (Fig. 1a), except northeastern states have less casualties in spring than other regions. The 3590 spring damage reports show a similar distribution to the year

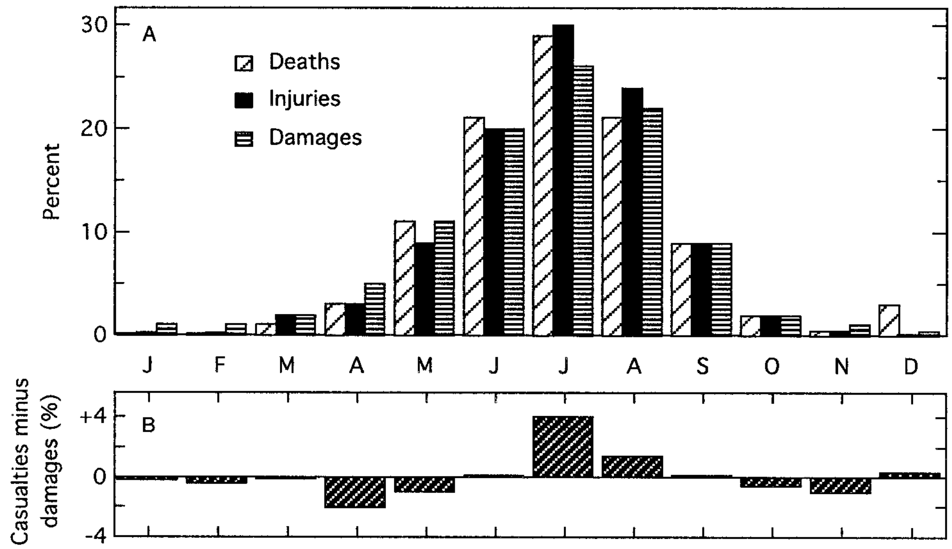

FIG. 7. (a) Monthly variations of fatalities, injuries, and damage reports. (b) Percent of casualties minus percent of damage reports by month.

in Fig. 1b, except for the same reduction in the northeast. Summer maps of 9586 casualties and 13 369 damage reports are almost identical to the annual map, since summer has 73% of the year's casualties and 67% of the damages. The 1464 autumn casualties return to high rankings in the southern plains. West Coast states rank relatively high in casualties during autumn and winter, but very low over the entire year. The 2511 autumn damage reports are distributed similarly to the spring pattern. Only 167 casualties oc-

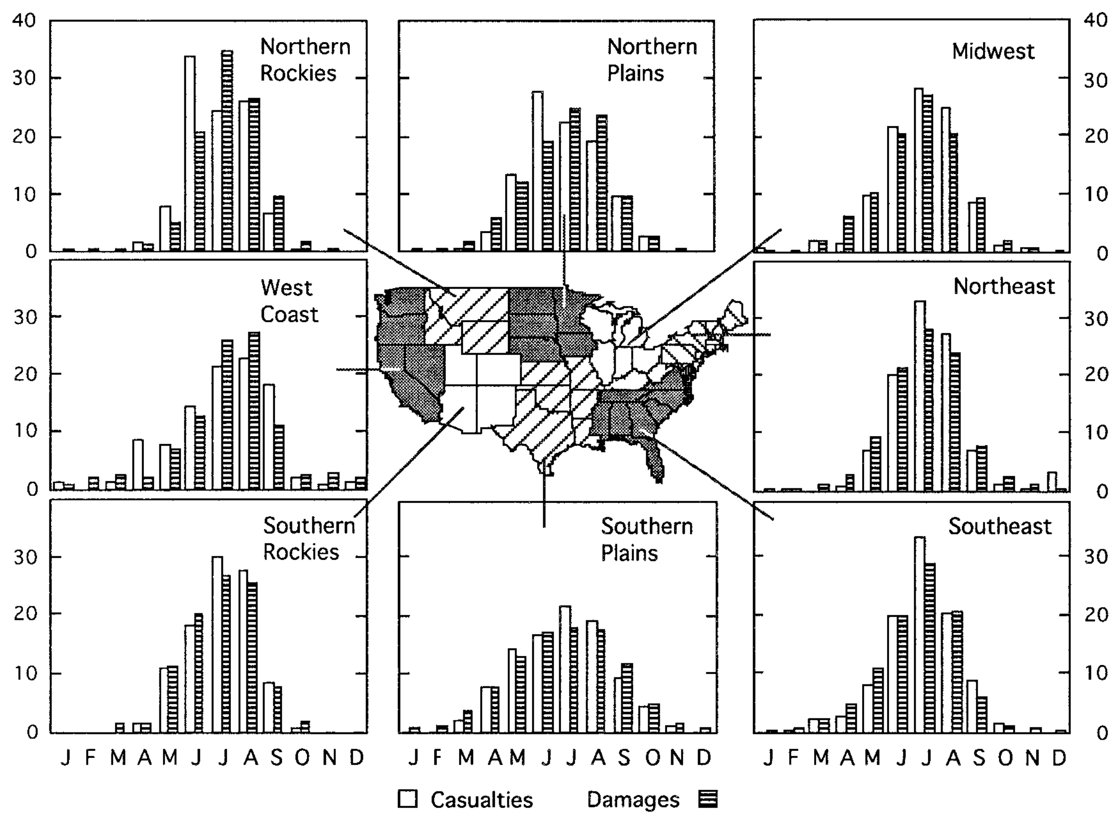

FIG. 8. Monthly variations in the percentage of casualties and damage reports by region.

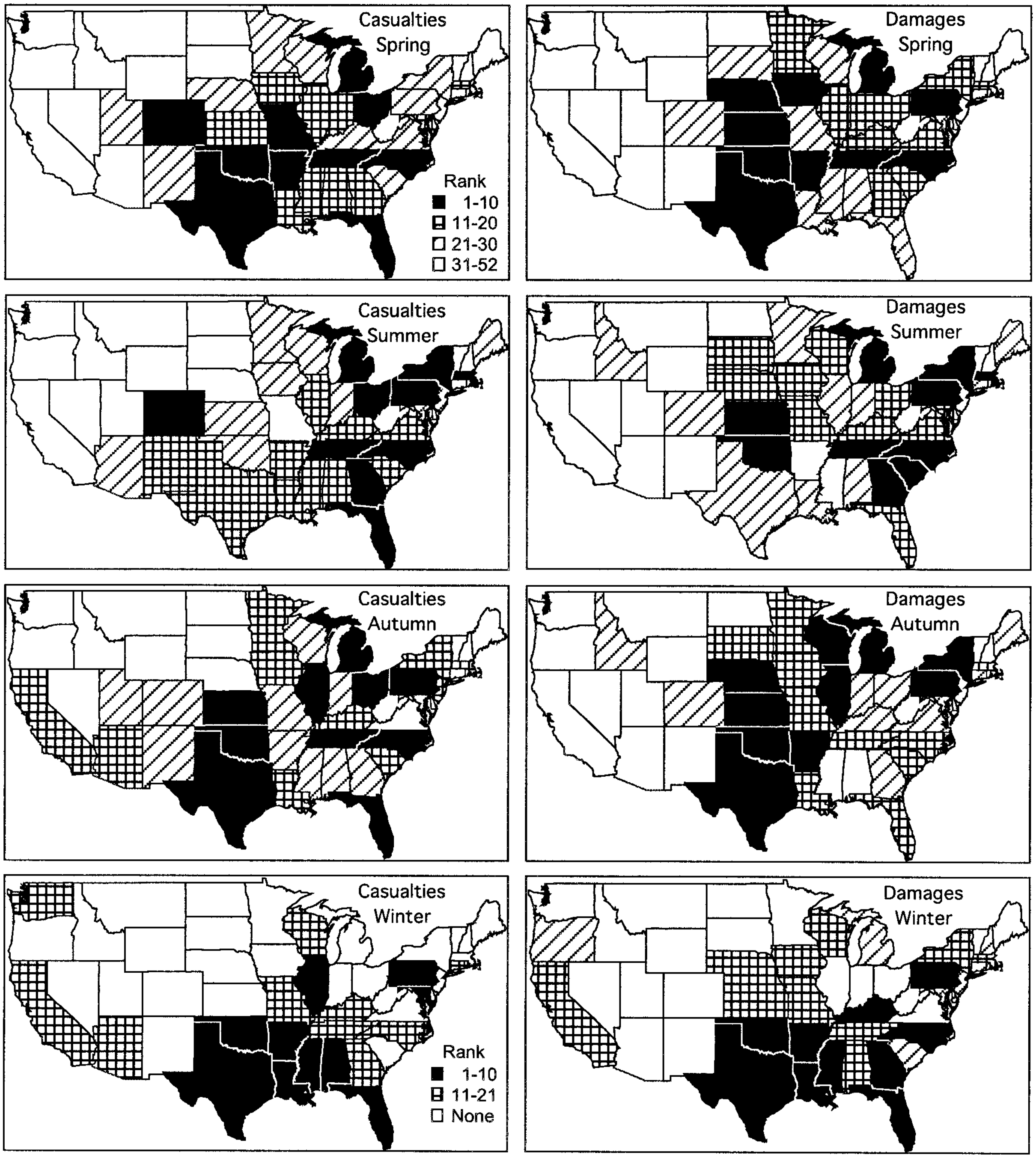

FIG. 9. Maps of state rankings in number of lightning casualties and damage reports for each season.

curred in 21 states during winter; the highest concentration is in the southern plains. The West Coast region ranks relatively high in winter, as in autumn. Winter damage reports (344) are most common in the southern plains. California and Hawaii rank among the top 30 states in winter but rank low in summer.

In summary, summer maps of casualties and damage reports closely follow the annual maps. During other seasons, lightning cases are more frequent in the southern states. Frequencies in northeastern states are low except during summer and are relatively high in the West Coast region during autumn and winter.

7. Time of day variations

a. Nation

Most lightning casualty and damage reports occur in the afternoon in the United States (Fig. 10a). Two-thirds

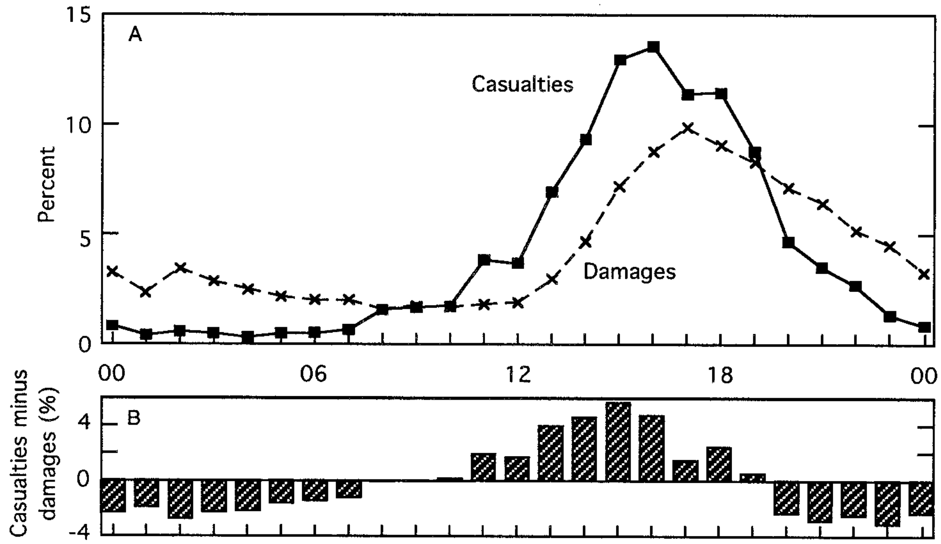

Fig. 10. (a) Percent of casualties and damage reports by hour. (b) Percent of casualties minus percent of damage reports by hour. Time label is for end of hour.

of all casualties occur between 1200 and 1800 LST; they show a steady increase toward a maximum at 1600 LST, followed by a slightly slower decrease after the maximum. Damage reports are more broadly distributed through the day; they have a steeper increase until the 1700 LST maximum, then a steady decrease until midnight. *Storm Data* has times associated with 66% of the casualties and 61% of the damage reports.

During the afternoon, there are up to 6% more casualties than damage reports, while some nighttime hours have nearly 4% more damage reports than casualties (Fig. 10b). People may be less likely to be involved in lightning-sensitive activities at night than during the day and tend to avoid activities during a brightly-illuminated nighttime storm. An additional reason for the difference is that damages may not be identified until people arrive home in late afternoon at the end of the work day. Nocturnal mesoscale convective systems (MCSs) over the plains in summer can produce over 3000 ground strikes an hour (Goodman and MacGorman 1986).

By region, highest frequencies of casualties are typically within one hour of 1500 LST (Curran et al. 1997). Damage reports usually peak an hour or two later than casualties. Relatively narrow distributions are apparent in the northern Rockies, the southeast, and the northeast.

Maximum lightning impacts from 1400 to 1600 LST were documented for Florida deaths (Duclos et al. 1990), Michigan deaths, injuries, and damage reports (Ferrett and Ojala 1992), and U.S. casualties (López and Holle 1995). Duclos and Sanderson (1990) found an 1800 LST peak in North Carolina deaths.

b. 6-h periods

During the night (0000–0559 LST), casualties and damage reports are most frequent in the plains, northern Midwest, and a few populous eastern states (Fig. 11). Compared to Fig. 1a for the year, highest-ranking states shift to the north and east. Only the first 27 ranks of casualties are shown; states lower than 27th have one or zero casualties. There were 62 deaths (3% of fatalities with known times), 135 injuries (2%), and 1753 damage reports (15%) in *Storm Data* during these nighttime hours. *Storm Data* indicated that 59% of the deaths at night from 1980 to 1994 occurred when people were in a house set on fire by lightning, and 21% were campers in tents.

Casualties in the morning (0600–1159 LST) are spread widely across the country (Fig. 11). Damage reports are most common on the plains in a pattern similar to nighttime. The morning had 11% of the deaths, 13% of the injuries, and 10% of the damage reports.

Casualties during the afternoon resemble the distribution in Fig. 1a for the entire day, since these are the most frequent hours for deaths (67%) and injuries (63%). But afternoon damage reports (41%) are not as closely related to the whole day map in Fig. 1b. Afternoon maxima were also found for deaths, injuries, and damage reports in central Florida (Holle et al. 1993), fatalities in Australia (Coates et al. 1993), and casualties and damage reports in Colorado (López et al. 1995).

Evening deaths (18%) and injuries (22%) are distributed similarly to nighttime. Evening damage reports are more similar to the whole-day map in Fig. 1a.

c. Seasons

Casualties in spring (Fig. 12) occur during nearly the same afternoon hours as for the entire year and country in Fig. 10, except for a secondary peak before noon. Spring damage reports show a weaker diurnal cycle than spring casualties, or damages for the year, and occur

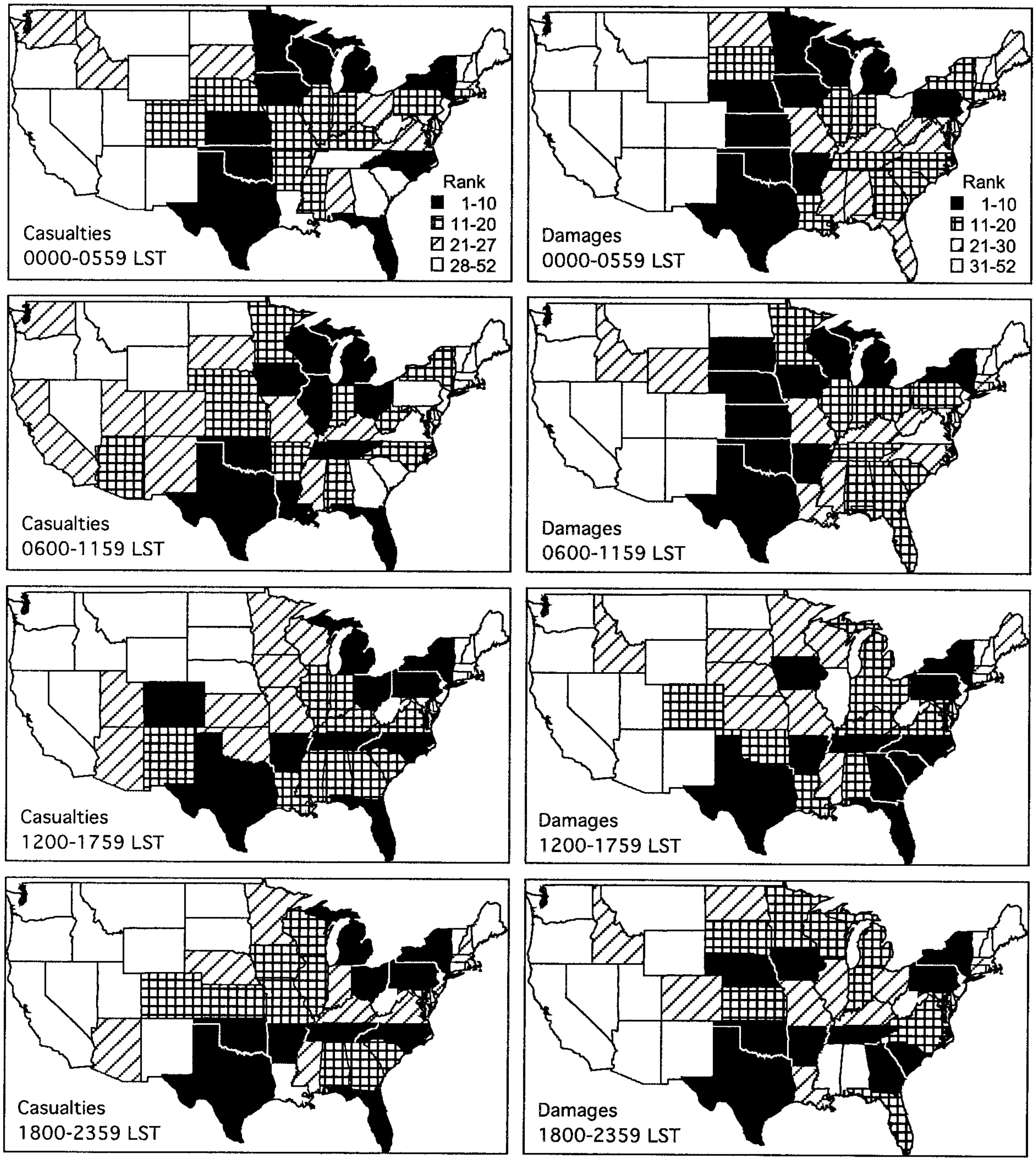

FIG. 11. Maps of state rankings in lightning casualties and damage reports for 6-h periods.

several hours later than casualties. Summer casualties and damage reports follow the annual curves, since they compose more than half of the year's sample. Autumn casualties occur in a broad afternoon maximum and have a secondary morning peak. Autumn damage reports are spread through the day in a manner similar to spring, are most common in late afternoon, and lag casualties by several hours. Winter casualties are distributed erratically, as shown by a maximum at 0900 LST and a secondary peak during midafternoon; the sample is only 63 cases. Winter damage reports are spread evenly across both day and night.

8. Additional *Storm Data* information

a. Gender

Males account for 84% of the lightning fatalities, 82% of injuries, and 83% of casualties for the country. By

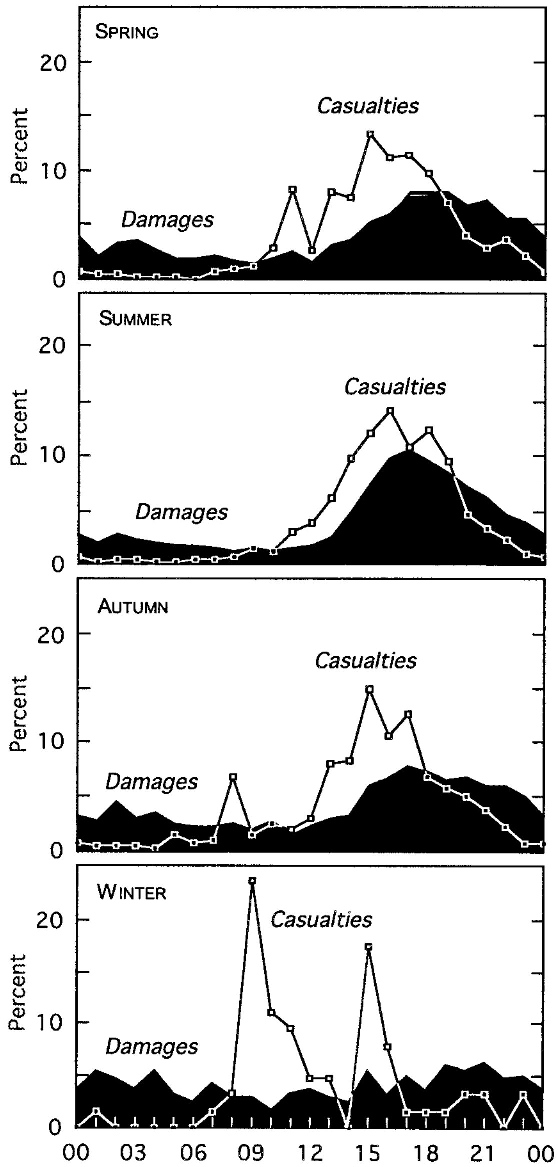

FIG. 12. Percent of casualties and damages by hour for each season.

region, between 76% and 94% of the deaths and injuries are to males (Curran et al. 1997). Corresponding ratios indicate that males are killed 4.6 times as often as females and injured 5.3 times more often than females. *Storm Data* does not specify gender for 18% of the deaths and 34% of injuries, and has ''both'' for deaths when one male and one female were killed in the same event. A similar definition for both applies to injuries.

Males were found to be 79%–89% of the victims in the United States (Duclos and Sanderson 1990), Florida (Duclos et al. 1990; Holle et al. 1993), North Carolina (Langley et al. 1991), Singapore (Pakiam et al. 1981), and England and Wales (Elsom 1993). Numerous studies have suggested that males in their twenties are the most frequent victims of lightning. The digital *Storm Data* record does not include age, although the descriptive paragraph often provides this information.

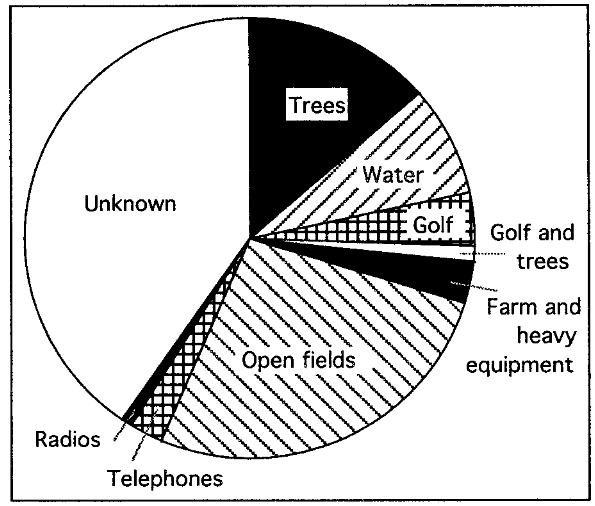

FIG. 13. Frequency distribution of the locations of lightning casualties.

b. Location

Storm Data divides the locations of lightning victims into eight groups and two unknown categories (Fig. 13). Starting with the most frequent, the categories are as follows.

- ''Not reported'' and ''at various other and unknown locations'' account for 40% of *Storm Data* entries.
- ''Open fields, ballparks, playgrounds, etc.'' is the next largest category in every region, the United States, and Michigan (Ferrett and Ojala 1992).
- ''Under trees'' is the third largest group in the United States, most regions, and Michigan (Ferrett and Ojala 1992).
- ''Water related, fishing, boating, swimming, etc.'' is next in the United States and most regions.
- ''Golfing'' and ''golfing under trees'' account for 8% of known lightning casualties in the United States. While there is a widespread impression that golfers are the most frequent victims of lightning, this is not the case.
- ''Driving tractors, farm equipment, heavy road equipment, etc.'' is a small segment in *Storm Data* since 1959. But agricultural activities in rural areas were common situations for lightning victims earlier in the century (López et al. 1995).
- ''Telephone-related'' is an infrequent but persistent source of lightning casualties in all regions (Andrews et al. 1992).
- ''Radios, transmitters, antennas, etc.'' occur at a low rate in all regions.

These location categories are of limited value; more

TABLE 5. Percent deaths, injuries, and casualties in each *Storm Data* incident.

Victims	Deaths (%)	Injuries (%)	Casualties (%)
1	90.9	68.2	68.4
2	7.8	17.4	17.4
>2	1.4	14.4	14.1
Incidents	2834	5212	7181

can be learned about locations from other datasets or the descriptive paragraphs in *Storm Data.* This time-consuming task has not been performed for the entire country. But North Carolina medical examiner data have been used to develop two systems of victim locations. Casualties in North Carolina were most often at their home or in the home's surroundings from 1972 to 1984 (Duclos and Sanderson 1990), while Langley et al. (1991) found that fatalities were most often in a farm, field, or garden. In Florida, a significant number of lightning victims were in the vicinity of water (Duclos et al. 1990; Holle et al. 1993). Colorado lightning casualties increased during outdoor recreation since 1950, while agricultural casualties decreased (López et al. 1995). Not only is location important, but a person's activity can tell a great deal about a lightning victim's situation.

c. Victims per event

The most common situation is for one victim to be involved in an incident when someone was killed or injured by lightning. Table 5 shows that for incidents with deaths only, 91% of the cases had one fatality and 8% had two people killed. The largest fatality event was the Maryland airliner crash that killed 81 people. For incidents with injuries only, 68% of the cases had one injury. The largest injury event involved 90 people at a campground in Michigan (Ferrett and Ojala 1992). The distribution of casualty events closely resembles the injury distribution.

The same tendency for single victims was noted in fatalities in the United States (70%) by Zegel (1967), Singapore (85%) by Pakiam et al. (1981), and Australia (92%) by Coates et al. (1993). In Colorado, one person was involved in 89% of the deaths, 70% of the injuries, and 66% of the casualties (López et al. 1995).

d. Day of week

Sunday has 24% more lightning deaths than other days; a tendency for more fatalities is evident on Wednesday (Curran et al. 1997). The largest numbers of injuries are on Wednesday and weekend days, and the fewest on Tuesday and Friday. The casualty distribution follows the injury curve. Damage reports are greatest on Monday, then decrease until reaching the lowest number on Saturday. The existence of more casualties on the weekend suggests that recreation is a factor. It is difficult to understand why there are more damage reports on weekdays, but this trend could result from reports in newspapers that do not publish every day.

e. Damage report costs

According to *Storm Data*, nearly half of all lightning damages were between \$5000 and \$50 000 (Curran et al. 1997). The categories of \$500–5000 and \$50 000–\$500 000 are also frequent; these three categories account for 93% of the reports. All regions of the United States have the interval of \$5000–\$50 000 as most frequent, and \$500–\$5000 is next. There is a tendency for somewhat higher costs from the southern plains eastward, compared to the northern plains westward. Decadal changes show smaller losses increasing while larger amounts are decreasing.

These *Storm Data* amounts are in strong contrast to insured losses in Colorado, Utah, and Wyoming (Holle et al. 1996). Over a third of those insurance losses were between \$251 and \$1000, and only a few were over \$5000. *Storm Data* apparently includes more widely known large events and fewer small losses. It is not possible for National Weather Service staff preparing *Storm Data* to be aware of these numerous small losses when they did not result in a call to an emergency agency or were not reported in a newspaper.

The types of expensive events that reached *Storm Data* can be indicated by the 17 lightning losses over \$5 000 000. Some were due to forest fires in western states, some involved one or more homes destroyed, some were crop loss cases, and some were other single events. Note that the digital database contains 106 entries in 1989 in the damage category of over \$500 million. A review of these events in *Storm Data* indicated they were not capable of producing so large an amount of damage. These erroneously coded events were changed to the ''unknown'' category.

9. Summary and conclusions

Lightning-related fatality, injury, and damage reports for the United States were summarized for 36 years from the NOAA publication *Storm Data.* Florida led the nation in the actual number of deaths and injuries. The largest number of damage reports came from Pennsylvania. There were large variations among decades in both casualties and damages.

When population was taken into account, Wyoming and New Mexico led the nation in death, injury, and casualty rates. High casualty rates were also found in Florida and the Rocky Mountains, plains, southeast, and northeast regions. The highest damage report rate was on the plains. Decadal population-weighted casualties and damages decreased until the 1990s, then increased again.

July maxima were reached by all types of lightning reports. Casualties had a strong July maximum, while damage reports were spread more evenly through the year. Casualties and damages in northern states had narrower distributions centered on summer than southern states.

Two-thirds of the casualties occurred between 1200 and 1600 LST. Casualties showed a steady increase toward a maximum at 1600 LST, followed by a somewhat faster decrease. Damage reports lagged casualties and declined more gradually than casualties. There were relatively frequent damage reports at night in the plains and Midwest regions. In spring and autumn, casualty maxima were less distinct than for summer, and damages were spread more uniformly through day and night. In winter, the afternoon peak disappeared for damage reports and was weak for casualties.

For incidents involving deaths only, 91% of the cases had one fatality; 68% of the injury cases had one injury. The dominance of single-person events shows the need for lightning safety education so that people take personal responsibility for the threat from lightning.

Forty percent of the *Storm Data* entries had unknown locations for victims. Outdoor recreation was the next most frequent location in every region, followed by under trees, proximity to bodies of water, golf courses, then agricultural situations. Much more complete studies are needed of locations and activities of victims than is provided by the digital dataset.

Half of all lightning-caused damages were between $5000 and $50 000, according to *Storm Data*. Comparison with an insurance dataset shows these entries to include more widely known events and fewer small losses. Together with an unusual day-of-week damage pattern, damage reports appear to be poorly represented in *Storm Data*.

Possible future work includes comparisons of casualty and damage results with ground-strike data collected over the United States since the late 1980s on annual, seasonal, monthly, and diurnal scales. It would also be helpful to identify trends in the activities of casualties over a century. The latter two studies are under way by the authors. There is also a need to compare the exposure to lightning of people versus objects, because the patterns of these two categories in time and space were very different.

Acknowledgments. We appreciate the careful assistance of Brian Mast of the University of Oklahoma in checking the last few years of data and compiling many of the data lists used in this paper. We thank the Scientific Services Division of the National Weather Service's Southern Region for obtaining the *Storm Data* digital record of lightning casualties and damages.

REFERENCES

Andrews, C. J., M. A. Cooper, M. Darveniza, and D. Mackerras, 1992: *Lightning Injuries: Electrical, Medical, and Legal Aspects.* CRC Press, 195 pp.

Bennett, B. L., 1997: A model lightning safety policy for athletics. *J. Athletic Training,* **32,** 251–253.

Cherington, M., E. P. Krider, P. R. Yarnell, and D. W. Breed, 1997: A bolt from the blue: Lightning strike to the head. *Neurology,* **48,** 683–686.

——, J. Walker, M. Boyson, R. Glancy, H. Hedegaard, and S. Clark, 1999: Closing the gap on the actual numbers of lightning casualties and deaths. Preprints, *11th Conf. on Applied Climatology,* Dallas, TX, Amer. Meteor. Soc., 379–380.

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

Cooper, M. A., 1995: Myths, miracles, and mirages. *Sem. Neurol.,* **15,** 358–361.

——, and C. J. Andrews, 1995: Lightning injuries. *Wilderness Medicine,* P. Auerbach, Ed., 3d ed., C. V. Mosby, 261–289.

Cummins, K. L., M. J. Murphy, E. A. Bardo, W. L. Hiscox, R. B. Pyle, and A. E. Pifer, 1998: A combined TOA/MDF technology upgrade of the U.S. National Lightning Detection Network. *J. Geophys. Res.,* **103,** 9035–9044.

Curran, E. B., R. L. Holle, and R. E. López, 1997: Lightning fatalities, injuries, and damage reports in the United States from 1959–1994. NOAA Tech. Memo. NWS SR-193, 64 pp. [Available from National Weather Service, 819 Taylor St., Ft. Worth, TX 76102.]

Dittmann, R. H., 1994: Annual flood death statistics per state per capita for the United States and Puerto Rico during the period 1959–1991. NOAA Tech. Memo. NWS SR-153, 11 pp. [Available from National Weather Service, 819 Taylor St., Ft. Worth, TX 76102.]

Duclos, P. J., and L. M. Sanderson, 1990: An epidemiological description of lightning-related deaths in the United States. *Int. J. Epidemiology,* **19,** 673–679.

——, ——, and K. C. Klontz, 1990: Lightning-related mortality and morbidity in Florida. *Public Health Rep.,* **105,** 276–282.

Elsom, D. M., 1993: Deaths caused by lightning in England and Wales, 1852–1990. *Weather,* **48,** 83–90.

Ferrett, R. L., and C. F. Ojala, 1992: The lightning hazard in Michigan. *Michigan Acad.,* **24,** 427–441.

Golde, R. H., and W. R. Lee, 1976: Death by lightning. *Proc. Inst. Elect. Eng.,* **123,** 1163–1180.

Goodman, S. J., and D. R. MacGorman, 1986: Cloud-to-ground lightning activity in mesoscale convective complexes. *Mon. Wea Rev.,* **114,** 2320–2328.

Gourbière, E., J. Lambrozo, C. Virenque, P. Menthonnex, and J. Cabane, 1997: ''Lightning injured people in France'': The first French national inquiry with regard to the striking of people—objectives, methods, first results. *Proc. Conf. on Lightning and Mountains '97,* Chamonix Mont Blanc, France, Société des Electriciens & des Electroniciens and Fédération des Clubs Alpins Français, M71–M83.

Holle, R. L., R. E. López, R. Ortiz, C. H. Paxton, D. M. Decker, and D. L. Smith, 1993: The local meteorological environment of lightning casualties in central Florida. Preprints, *17th Conf. on Severe Local Storms and Conf. on Atmospheric Electricity,* St. Louis, MO, Amer. Meteor. Soc., 779–784.

——, ——, L. J. Arnold, and J. Endres, 1996: Insured lightning-caused property damage in three western states. *J. Appl. Meteor.,* **35,** 1344–1351.

——, ——, and C. Zimmermann, 1999: Updated recommendations for lightning safety–1998. *Bull. Amer. Meteor. Soc.,* **80,** 2035–2041.

Hornstein, R. A., 1962: Canadian lightning deaths and damage. Meteorological Branch, Dept. of Transport, Canada, CIR-3719, TEC-423, 5 pp. [Available from Meteorological Service of Canada, 4905 Dufferin St., Downsview, ON O3H 5T4, Canada.]

Langley, R. L., K. A. Dunn, and J. D. Esinhart, 1991: Lightning fatalities in North Carolina 1972–1988. *N. Carolina Med. J.,* **52,** 281–284.

López, R. E., and R. L. Holle, 1995: Demographics of lightning casualties. *Sem. Neurology,* **15,** 286–295.

——, and ——, 1996: Fluctuations of lightning casualties in the United States: 1959–1990. *J. Climate,* **9,** 608–615.

——, and ——, 1998: Changes in the number of lightning deaths in the United States during the twentieth century. *J. Climate,* **11,** 2070–2077.

——, ——, T. A. Heitkamp, M. Boyson, M. Cherington, and K. Langford, 1993: The underreporting of lightning injuries and deaths in Colorado. *Bull. Amer. Meteor. Soc.,* **74,** 2171–2178.

——, ——, and T. A. Heitkamp, 1995: Lightning casualties and property damage in Colorado from 1950 to 1991 based on *Storm Data. Wea. Forecasting,* **10,** 114–126.

Mogil, H. M., M. Rush, and M. Kutka, 1977: Lightning—An update. Preprints, *10th Conf. on Severe Local Storms,* Omaha, NE, Amer. Meteor. Soc., 226–230.

Orville, R. E., and A. C. Silver, 1997: Lightning ground flash density in the contiguous United States: 1992–95. *Mon. Wea. Rev.,* **125,** 631–638.

Pakiam, J. E., T. C. Chao, and J. Chia, 1981: Lightning fatalities in Singapore. *Meteor. Mag.,* **110,** 175–187.

Primeau, M., G. H. Engelstatter, and K. K. Bares, 1995: Behavioral consequences of lightning and electrical injury. *Sem. Neurology,* **15,** 279–285.

Walsh, K. M., M. J. Hanley, S. J. Graner, D. Beam, and J. Bazluki, 1997: A survey of lightning policy in selected Division I colleges. *J. Athletic Training,* **32,** 206–210.

Zegel, F. H., 1967: Lightning deaths in the United States: A seven-year survey from 1959 to 1965. *Weatherwise,* **20,** 169–173, 179.