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NATIONAL LIGHTNING DATA ON THE WESTERN REGION WIDE AREA NETWORK

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Background

For the last 15 years, Western Region (WR) NWS offices have acquired lightning data through a cooperative agreement with the Bureau of Land Management (BLM). The BLM established a lightning network over the western United States to support a multi-agency fire suppression program. WR processed BLM lightning data on an AFOS era processor located at the Boise Forecast Office. The Boise computer generated a series of lightning AFOS graphics and special alerts that were distributed to WR offices via the AFOS communication network. This was an effective system and served WR forecasters well. A combination of two events, the failure of critical non-replaceable components of the Boise computer coupled with BLM decommissioning the lightning network during the spring of 1997, brought an end to access of this data set.

To replace this loss of operational data, WR/SSD developed a solution to acquire lightning data from the National Lightning Detection Network (NLDN). The NLDN is a national system deployed and operated by the Global Atmospherics, Inc. (GAI) company. The NLDN is the only national lightning network data available at this time. Since GAI is owned by the Sankosha Corporation, the NLDN is a private sector data set. As such, the NWS must pay a yearly site license fee to use the data and offices cannot share data with any other government or private sector entity. National Weather Service Headquarters plans to include NLDN data as part of the AWIPS data stream.

GAI has incorporated numerous technical advancements to the lightning detection sensors and network. Many of these advancements should aid WR offices. This Technical Attachment will summarize how this network operates and describes how the data are available to the WR Forecast Offices.

Lightning Basics

A single **Cloud to Ground (CG)** lightning flash is composed of several components. Initially, a weakly charged, normally invisible to the human eye, collection of electrons called Step Leaders begin to move toward the ground from the cloud's base. Each Step Leader advances approximately 50 to 100 meters and last approximately 1 microsecond. A series of Step Leaders is required to move downward through the sub-cloud environment. As the Step Leader approaches the ground, a positively charged Ground Streamer advances from the ground to meet the Step Leader. Once they meet, an ionized channel is formed and electrons can move quickly toward the Earth's surface. As electrons move downward, the electrons recombine with the positively charged ions, first near the surface then moving upward toward the cloud. This recombination produces the brilliant flash, the rapid heating of the air near the ionized channel (thunder) and is called the Return Stroke. Each return stroke exhibits a peak current of 5 to 300 kiloamps and has a nominal duration of 20-50 microseconds. A single flash is normally composed of 2 to 3 return strokes and but can vary from 1 to 20 strokes. A single flash can also contain return strokes that do not follow the same ionized channel. In these cases, the lightning flash can appear as a series of return strokes that are within a few hundred meters of the original channel. In general, most observing systems treat these cases as a single flash. Any good basic meteorology text can provide a more thorough description of the lightning process.

Each cloud-to-ground (CG) return stroke also produces a unique electromagnetic pulse or signature that can travel through the atmosphere for hundreds of miles. It is this electromagnetic signature that most conventional surfaced based lightning detection systems observe. Thunderstorms also produce a variety of other lightning flashes (i.e., cloud-to-cloud, intra-cloud, etc.). Since CG flashes produce the most impact to the public and a consistent electromagnetic signature, conventional lightning data observing systems screen out most of the non-CG lightning flashes. The NLDN provides information about a CG lightning flash which is composed of multiple CG return strokes. The WR system displays CG lightning flashes. The number of return strokes for each flash is part of the NLDN data, if desired.

How the NLDN Operates

For the last 20 years, ground based CG lightning observing systems used one of two basic technologies, Time of Arrival (TOA) or Direction Finding (DF). TOA systems work by listening for the electromagnetic pulse and recording the precise time it was received. This information is then relayed to a central processing site, where the data from a number of sensors are combined and through the use of spherical geometry, a location solution is computed. In order to compute an accurate flash location, three or more sensors are required to observe the lightning flash. Also, maintaining the exact time among a set of widely dispersed sensors was critical to the accuracy computations. TOA systems were also marketed as LPATS systems and were used in the Midwest and southeast United States. The DF class of lightning observing systems used a number of sensors that recorded the time of the pulse and the direction from which the pulse originated. The data was sent to central processing unit, where input from a number of sensors was used to triangulate a solution. Exact timing was not quite so critical with this system, but the accuracy of the angle measurement could cause considerable error. This technology was also known as LLP and was used by SUNYA, BLM, and the NSSL networks.

GAI acquired the patents for both systems, combined the technologies, and added sensor enhancements to improve the system. The new sensors, called Improved Performance from Combined Technology (IMPACT), use the direction finding capability to provide the azimuth (direction) information while the TOA capability is used to accurately assign a time to the electromagnetic pulse. This allows flash solutions to be formed from only two sensors in sensor poor areas. It also allows for additional mathematical optimization to be used to further refine the final flash locations and time. Wave form discrimination was also installed on the sensor to reduce spurious noise and is currently used to filter out non-CG flashes. The result is that the NLDN data should be better than either of its predecessors.

GAI currently uses a mixture of IMPACT and upgraded LPATS sensors that contain much of the IMPACT capabilities. Figure 1 shows the location of the sensor network. Data from each network is uplinked to a central processing unit called the Network Control Center (NCC) located at Tucson, Arizona through a satellite communications system. The NCC computes the location of the lightning flash in real time and uplinks the processed lightning location data through the same satellite system to their customers. Information about a lightning flash is available typically within 40 seconds of its occurrence.

Accuracy and Detection Efficiency

Historically, the observed skill of a lightning network has been measured by the accuracy of locating the lightning flash and how many lightning flashes were observed out of the total produced by a storm (detection efficiency). These measurements are tough to validate and often have been the source of considerable scientific debate. Figure 2 is the estimated accuracy, and Fig. 3 is the estimated detection efficiency for the NLDN network as provided by GAI. In general over WR, detection efficiency is around 80 percent with .5 to 1 km location accuracy. Please note how both detection efficiency and location accuracy fall off rapidly near the coasts and U.S. borders. This is a result of the network configuration. What is of more interest is the improvement made during the last five years by combining the two technologies. Detection efficiency has improved by 10-20 percent and location accuracy has improved by 4-8 km over the old LLP system.

How the WR System Works

The old WR Boise system transmitted graphics. The new system transmits digital data about each lightning flash directly to each office. National Weather Service Headquarters acquires lightning data from GAI downlink at NWS Telecommunication Gateway. The data are grouped into communication packets and are uplinked over the AWIPS Satellite Broadcast Network (SBN) to any NWS office with a AWIPS satellite antennae. In WR, the

Salt Lake Forecast Office has an early AWIPS system. The data are then re-transmitted through the internal WR Wide Area Network (WAN) to each office that has a site license to use the data. The data can then be displayed on RAMSDIS and the Unix Workstations. On RAMSDIS, the lightning flash data can be animated over the imagery to provide a near real-time depiction on how the lightning activity has been changing during the last 30-45 minutes. Due to limitations in the current WR WAN bandwidth, the lightning data are updated every 7 minutes. A special thanks to Kevin Schrab (WR/SSD) and Dave Tomalak (NWSFO Great Falls) for setting up this system.

Summary

Lightning data are a vital operational data set for Western Region offices. While the impact of lightning data is well known for support of the fire weather program, offices also use lightning data in combination with satellite data to supplement the warning program in areas where the WSR-88D coverage is blocked by terrain or the radar beam is above the convection. In addition, the impact of lightning strikes on the general public is growing. I have attached a paper written by Ron Holle (et al.) on the growing number of damage and insurance claims caused by lightning. Ron collected data for three states and extrapolating for similar damage over all 50 states. Insurance claims, resulting from lightning damage, exceed 300 million dollars a year. While damage statistics vary greatly from year to year, damage from lightning is now approaching damages incurred by hail and straight line thunderstorm winds. Over the next several months, additional Technical attachments will be issued highlighting other lightning issues.

References

Holle, Ron (et al.). 1996: Insured Lightning Caused Property Damage in Three Western States, *J. Appl. Meteor.*, **35**, No. 8, pp 1344-1351. (Attached to this TA)

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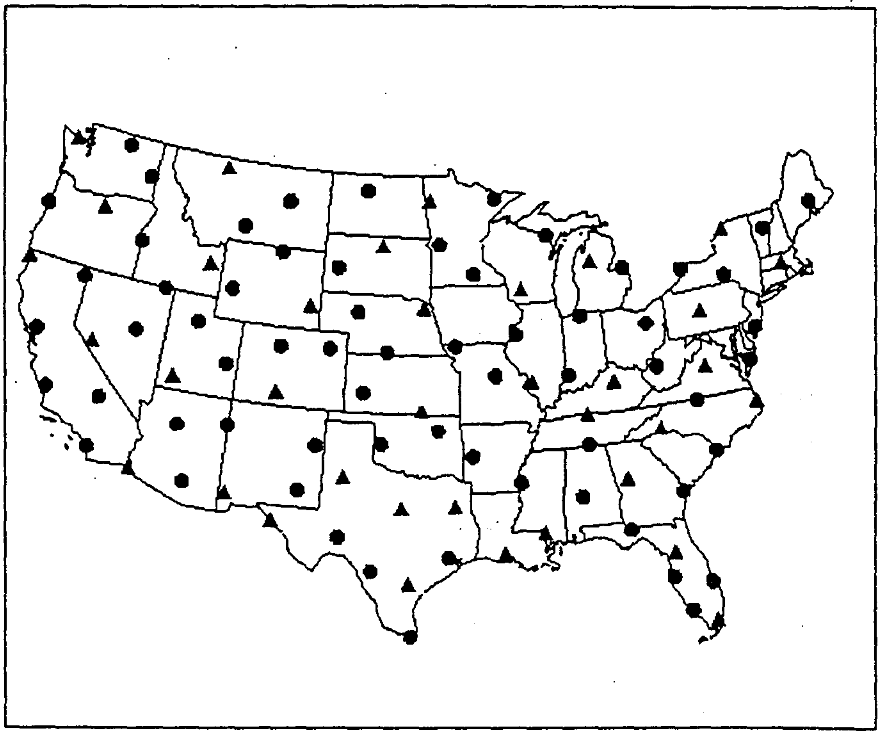

Figure 1 NLDN Sensor Locations. Triangles represent IMPACT sensors; circles represent LPATS sensors.

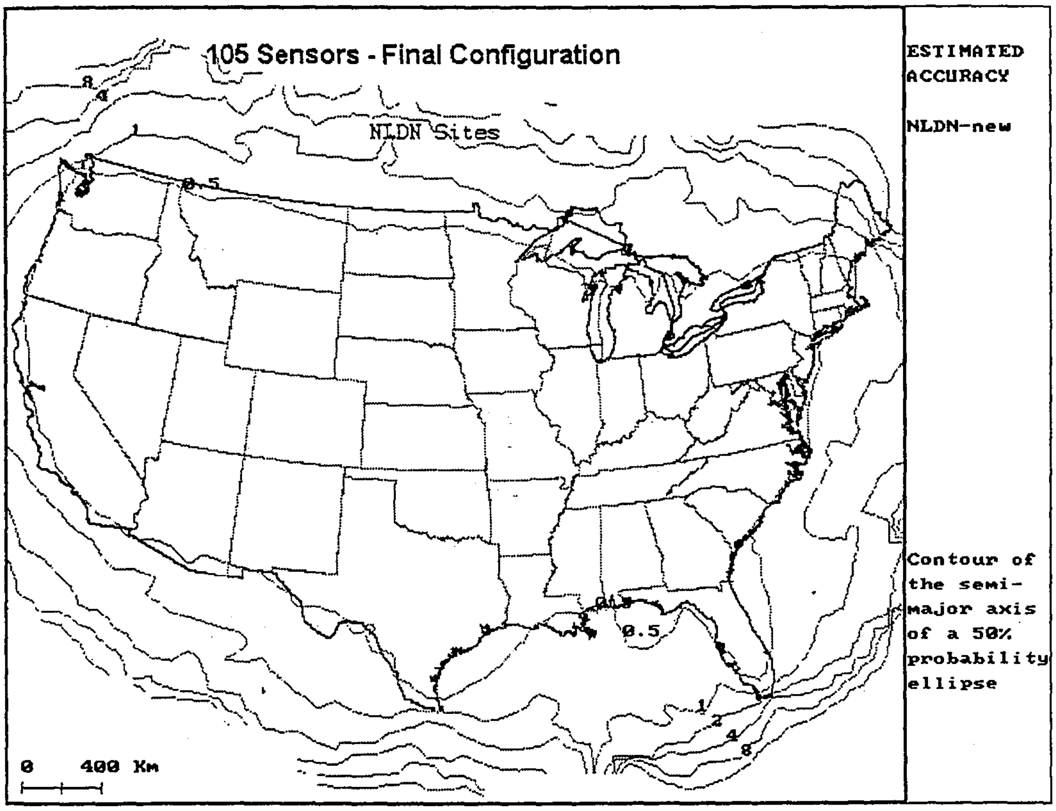

Figure 2 NLDN Location Accuracy Projection (After Upgrade).

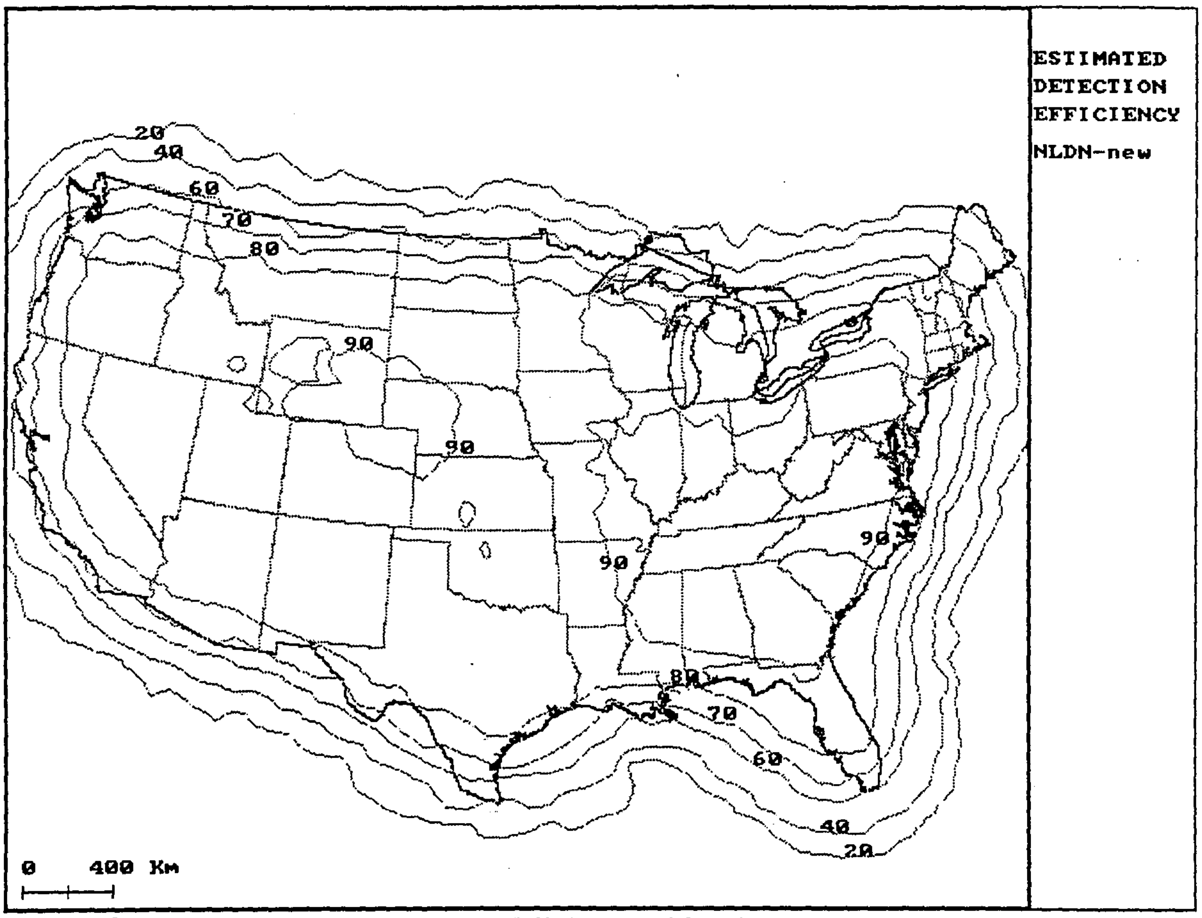

Figure 3 Projected NLDN Detection Efficiency (After Upgrade).

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Insured Lightning-Caused Property Damage in Three Western States

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ABSTRACT

Insurance claims resulting from lightning damage in Colorado, Utah, and Wyoming were analyzed during the period from 1987 to 1993. Most claims were from personal accounts, while some were commercial.

Lightning damage in the three states resulted in an annual average of 6755 claims being filed. Most claims were from Colorado, and more than half were from the Denver metropolitan area. Over $7 million a year in lightning losses occurred in the three states for these types of insurance policies when a $150 deductible was included; most losses were in Colorado. The average value paid per claim was $916 for all three states and types of claims; commercial claims averaged $1369, and personal claims averaged $873. One lightning insurance claim was estimated to occur in the three-state region for every 55 cloud-to-ground lightning flashes recorded by detection networks. Nearly all lightning claims were from May through September. The largest number of claims were from counties with the largest populations. However, the claim rate per population and the dollar loss per claim were not well related to county population. A rate of 4.7 claims per 10 000 people applied for Colorado, 1.4 for Utah, and 3.9 for Wyoming.

Annual U.S. totals of 307 000 claims and $332 million in losses were extrapolated on the basis of population in the three states. The dataset for Colorado, Utah, and Wyoming had 367 times as many claims as similarly insurable damage reports in the National Oceanic and Atmospheric Administration's *Storm Data* during the same years. This publication is widely used as the basis for lightning and other storm-related casualty and damage information. The results suggest that *Storm Data* greatly underestimates lightning damage.

1. Introduction

Cloud-to-ground (CG) lightning flashes cause a large amount of material damage, as well as many deaths and injuries. Statistics that are commonly quoted are taken from the National Oceanic and Atmospheric Administration (NOAA) publication *Storm Data,* which lists lightning as a relatively small cause of property damage across the entire United States (Table 1). To assess the impact of lightning more completely, an insurance claim database was made available covering significant damage done by lightning to dwellings, small businesses, and their contents.

Storm Data includes deaths, injuries, and material damage reports from the weather phenomena in Table 1, and is available from NOAA in Asheville, North Carolina. Reports in *Storm Data* usually contain the date, time, location, and type of casualty or damage; the age and gender of victims; a verbal description of the event; and the type of property or object that was impacted. For lightning, entries in *Storm Data* are compiled primarily from newspaper reports provided to the National Weather Service (NWS) by contracted clipping services (López et al. 1993). Information from each NWS office is sent to the National Climatic Data Center in Asheville where *Storm Data* is compiled and published. *Storm Data* was shown by López et al. (1993) to underestimate lightning-caused deaths by 22% and hospitalized injuries by 42%; Mogil et al. (1977) found similar rates. The reporting of lightning casualties has some unique features compared to other weather phenomena.

- Most cases affect one person.
- Events may not be part of widespread storms such as floods or tornadoes.
- The event may be considered minor, and few people may be aware of the event.

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TABLE 1. Summary of 1990, 1991, and 1992 property damage costs in the United States from *Storm Data.*

	Damage in millions of dollars			
Weather type	1990	1991	1992	Average
Hurricane	0	1164	33,611	11,592
Winter weather	621	514	28	775
Tornado	668	798	765	744
Extreme temperatures	1317	224	480	674
Drought	2	157	1780	646
River flood	1125	418	263	602
Other high wind	163	1564	44	590
Hail	716	412	533	554
Flash flood	625	429	428	494
Thunderstorm wind	425	294	266	328
Lightning	41	25	16	27
Other	319	204	140	221
Total	6022	6203	38,354	16,860

• When the event is brought to the attention of the media, the news may not survive the assembly of the daily or weekly paper.

The problem is greatly amplified for property damage. The media usually do not report a house or other object damaged by lightning unless there is a casualty, a large dollar loss, or multiple buildings or objects struck in the same storm. It must be emphasized that there is no effective way for NWS staff assembling *Storm Data* to reconstruct a database of all lightning cases when they are rarely reported to emergency agencies or covered by the media and involved no casualties.

Damage due to lightning during three recent years in the United States is reported in Table 1 by *Storm Data* to average $27 million a year; these years include the period of the following study. However, previous estimates of lightning damage, not documented in the formal meteorological or climatological literature, showed that *Storm Data* greatly underestimated losses by a large and highly variable amount. For example, Krider and Uman (1995, p. 230) estimated the frequency of lightning strikes to a house in a region with moderate thunderstorm frequency to be ''about once every 200 years. Another way to think of this hazard is that, in this region, 1 of 200 houses will be struck each year, on average.''

Concerning other weather phenomena, note in Table 1 the very large loss caused by hurricanes, which is in the billions of dollars. Changnon (1972) used detailed crop-insurance claim information from several sources to find that hail sometimes caused large losses that were not reported well in *Storm Data.*

Recent studies of the lightning threat to people and property in Colorado using *Storm Data* have been made by López et al. (1993, 1995) and Holle et al. (1995). Intercomparison of the present study with those results will allow better characterization of the lightning claim record.

2. Insurance database

Lightning-caused damages that led to insurance claims being paid by a large insurer were obtained through the Colorado Chapter of Chartered Property and Casualty Underwriters. Data were divided into Colorado, Utah, Wyoming, and the Denver metropolitan area (Fig. 1). Policies were divided into two categories.

• Personal policies were issued to occupants of homes, farms, apartments, and condominiums. These policies included the contents of the house.

• Commercial policies were issued for offices, mercantile stores, contractors, hotels, motels, churches, apartments, and condominiums. Not included were schools, warehouses, refineries, and manufacturing, agricultural, and similar facilities.

Lightning damage for a claim was determined by several methods summarized by W. Dye (1994, personal communication). It was difficult to separate a claim resulting from lightning or electrical disturbance from maintenance-related claims. Dye categorized the effects into two groups.

• Direct effects of lightning striking an object were generally obvious and accompanied by the burning of materials and evidence of damage. Such effects may be found on a building, television antenna, or an outdoor air conditioning unit.

• Indirect effects occurred where the flash hit elsewhere and its effects were transmitted to another location, typically through power or telephone lines. Most insurance claims were of this type. The flash may directly strike the lines or something connected to

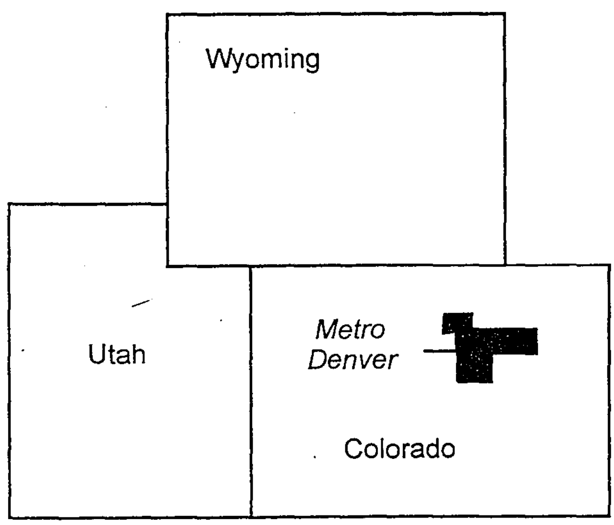

FIG. 1. Region of lightning claim study.

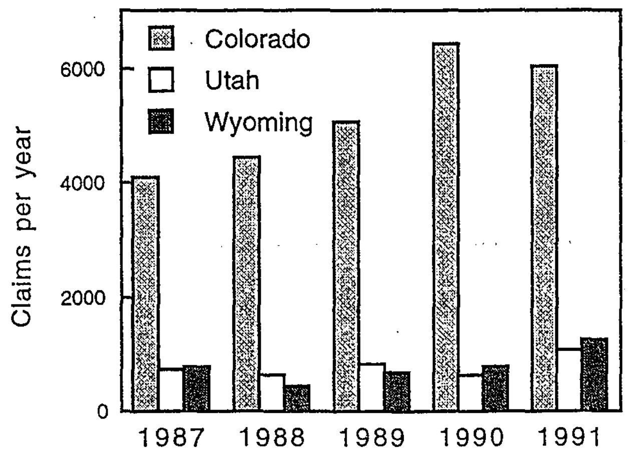

FIG. 2. Annual number of personal and commercial lightning claims in Colorado, Utah, and Wyoming from 1987 to 1991, extrapolated to all insurers.

them, or effects may result from a power surge induced by lightning striking close to the lines. Such effects include damage to television sets, well pumps and sprinkler systems, and air conditioning units, or a sudden failure of other appliances.

The following questions were listed by W. Dye (1994, personal communication) for the insurance adjuster to ask when investigating a claim reported as due to lightning.

- Was there visible lightning damage?
- Were fuses blown or circuit breakers tripped?
- Were other appliances also damaged?
- Was there evidence of lightning damage to the building?
- Was lightning in the immediate area?
- Do National Weather Service records confirm that lightning strikes were observed or recorded in the area?

3. Extrapolation to all insurers

Information for this study was provided by one insurer for Colorado, Utah, and Wyoming. The share of this insurer in the total market was known on a state-by-state basis to average about one-fourth of the total, so the data were extrapolated to the total claims and losses for each state by assuming that the entire market was represented by the data provider. Since the market share was available only for homeowner claims, the commercial claim share was assumed to be the same as the personal share for each state, although no information was available to verify this assumption. Information in subsequent sections will refer to the claims and losses after extrapolation is made to the total insurance market from the data source.

4. Claims and losses in Colorado, Utah, and Wyoming

The annual frequencies of personal and commercial claims attributed to lightning from 1987 to 1991 (Fig. 2), extrapolated to all insurers, show that Colorado had much higher numbers than Wyoming or Utah. The annual rate was 6755 lightning claims for the three states. In Colorado, there were more claims from the six Denver Metropolitan counties (Fig. 1) than from the rest of Colorado; these counties have more than half of the state's population. The ratio of personal to commercial claims was 11:1 in Colorado, 16:1 in Utah, and 7:1 in Wyoming. Lightning accounted for 2.1% of all insurance claims in these states from 1989 to 1993. Details for these and most other subsequent statistics are in Holle et al. (1995).

Annual dollar losses from these claims due to lightning from 1987 to 1991 over the three states, extrapolated to all insurers, totaled over \$6 million (Fig. 3); \$5 million was from personal and commercial accounts in Colorado. Commercial losses were 14% of personal losses. Lightning accounted for 1.4% of all insured dollar losses in the three states from 1989 to 1993.

5. National extrapolation

The insurance claim dataset was from three western states whose combined population of 5 470 832 was

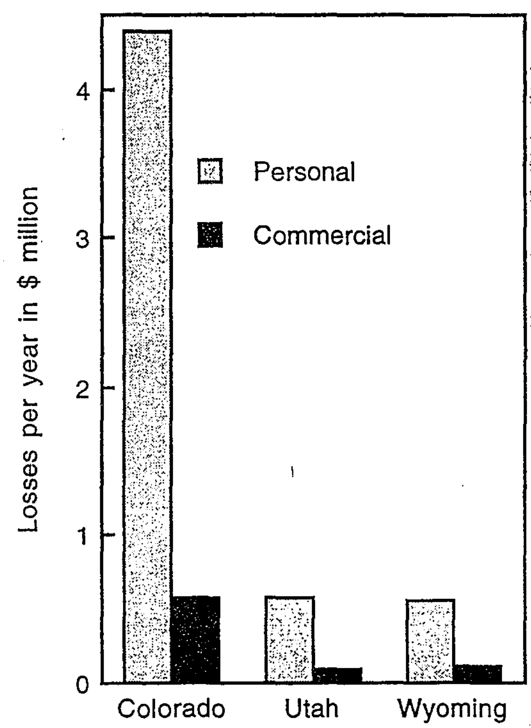

FIG. 3. Average losses from lightning insurance claims per year in Colorado, Utah, and Wyoming from 1987 to 1991, extrapolated to all insurers. Additional costs of deductibles paid by policyholders are not included.

2.2% of the U.S. total in 1990. National estimates of claims and losses were found by extrapolation on the basis of population, with the assumption that claim experiences in the three states were representative of the entire country. When total claims and annual dollar losses for Colorado, Utah, and Wyoming were applied on a national basis (Table 2), the result is 307 000 lightning-related claims for a total of $286 million annually in paid insurance for the 50 U.S. states.

This method did not include lightning-caused losses of objects and facilities in the following categories, and there are no doubt many others such as the following:

- insured losses in addition to the homeowners and smaller commercial facilities in the database;
- situations where no insurance coverage was purchased;
- federal, state, and other governmental losses that were self-insured;
- forest and range fire losses to timber and other related infrastructures; and
- utility and communication losses.

The preceding results did not take into account the deductible amount of the loss paid directly by the policyholder before insurance took effect. Most policyholders had deductibles on the order of $100–$250 during the time covered by the database. An amount of $150 was assumed to adjust the claim total. For the entire United States then, the total of $286 million (Table 2) for the insurance industry increases to $332 million when the $46 million first paid by policyholders is included.

Only population was included in the national extrapolation for these results, although it is recognized that the number of flashes may be equally important. Population is a very important factor in impacting insurance claims, perhaps the most important single factor, since this study shows (section 9) that the most populous state and most populous counties have the largest numbers of claims. The number of flashes per state and perhaps per county is becoming reliably known throughout the entire United States for an adequate sample size (since 1988) from the national lightning network. The number of claims according to the number of flashes could be found, but this has not yet been done due to a lack of lightning data until recently for this period and the need to devise an approach to match flashes over oddly shaped counties and states.

6. Flashes per claim

Comparisons can be made between insurance claims and previously published lightning frequencies by two methods. The first used results from a Denver-area lightning climatology that shows 123 663 flashes during June, July, and August of 1983 (López and Holle 1986). There were 2401 claims per year made to all insurance providers from 1987 to 1991 in the Denver metropolitan area when extrapolated to the total market share. Assuming that the number of lightning flashes during each year was comparable, the conclusion is a rate of one lightning-caused insurance claim for every 52 CG flashes in the Denver area.

The other method used the average of 17 600 000 CG flashes (a range of 14 300 000 to 24 200 000 flashes per year) detected by the National Lightning Detection Network across the United States from 1989 to 1993 (GeoMet Data Services 1994). The extrapolated annual total of national lightning claims was 307 000 (Table 2). The conclusion is that there is one lightning-caused insurance claim for every 57 CG flashes in the United States.

Considering the disparity in data sources, these methods give close values. More reliable results can be expected if insurance claims and flash datasets were better matched in time and space.

A similar calculation for dollar amounts can be made. The total loss was $332 million a year for the United States, including deductibles, based on the three states. Given the average of 17 600 000 flashes per year in the United States, the result is an insured loss of $18.86 for each flash that strikes the country.

TABLE 2. Annual national extrapolation based on population of the number of lightning claims and costs from 1987 to 1991 frequencies in three western states. Deductibles are not included.

	Colorado, Utah, and Wyoming	United States
Claims	6755	307 000
Losses	$6,292,000	$286,000,000

7. Losses per claim

The average loss for personal and commercial claims combined was $916 per claim. Distributions of lightning costs per claim in Figs. 4 and 5 are from 1987 through June 1992. Results are as follows.

- There was no payment for 12% of the claims. A claim for lightning damage was filed by the policyholder, but the deductible exceeded the costs. The insurer paid nothing to the insured for this incident, although the deductible was partially met if some type of loss occurred later in the policy's yearly cycle.
- Another 10% of the losses is in the $1–$100 range.
- The next four categories have similar frequencies of 16%–19%. The categories span increasing ranges of losses.
- 4% of the losses are from $2501 to $5000.
- A few claims are over $5000, and seven personal and two commercial claims exceed $25,000. The largest was a personal claim for over $300,000 in the Denver area.

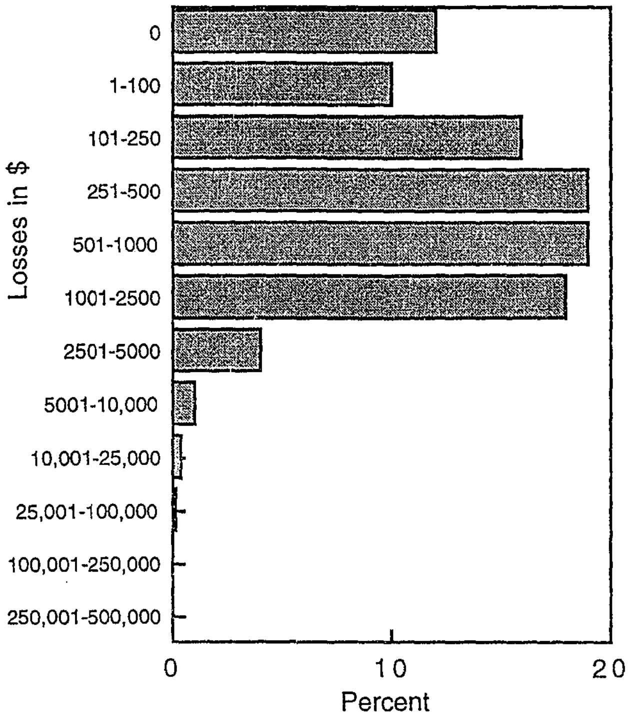

FIG. 4. Distribution by amount of losses from lightning claims in Colorado, Utah, and Wyoming from 1987 to June 1992. Deductibles are not included.

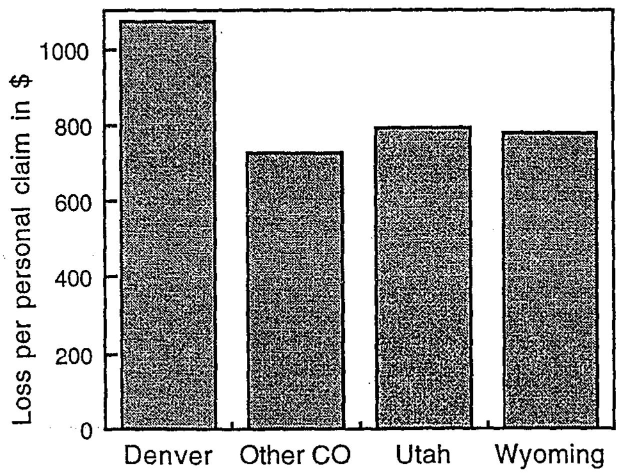

FIG. 5. Average loss per personal lightning insurance claim from 1987 to June 1992 in Denver, the rest of Colorado, Utah, and Wyoming. Deductibles are not included.

- In terms of cumulative losses, almost half of all claims are under $500, and more than three-quarters are under $1000.

With regard to location, Fig. 5 shows that for personal claims, the highest average loss is $1071 in Denver. Other locations have smaller losses of around $750. The larger amount for the Denver metropolitan area could reflect higher values of homes in that region.

Commercial claims averaged $1369 and personal claims averaged $873 (Holle et al. 1995). Personal claims were more frequent in the $0–$250 range (38%) than were commercial claims (30%). However, commercial claims were more frequent from $2501 to $25,000 (13%) than were personal claims (5%).

8. Monthly distribution

Monthly distributions of claims for Colorado (Fig. 6) show that lightning losses occur primarily in summer. There is a dramatic increase in lightning claims from April to May, then values are high during summer months until September when claims are half of the August number.

Figure 6 also compares the claim results to *Storm Data* lightning damage reports from 1950 to 1991 in Colorado (López et al. 1995); monthly percentages are very similar. Lightning victims in *Storm Data,* however, were more sharply clustered from June through August than the damage reports from either source show. The difference may be due to more people being involved in outdoor recreation during the summer months, while reports of damage to inanimate objects are more representative of actual lightning activity.

Utah had fewer insurance claims in June than during May and July; June is after the winter and spring disturbances in the westerlies and before the summer monsoon for Utah (Holle et al. 1995). Wyoming lightning claims started later and ended earlier than in Colorado since the state is at a higher latitude and altitude, and

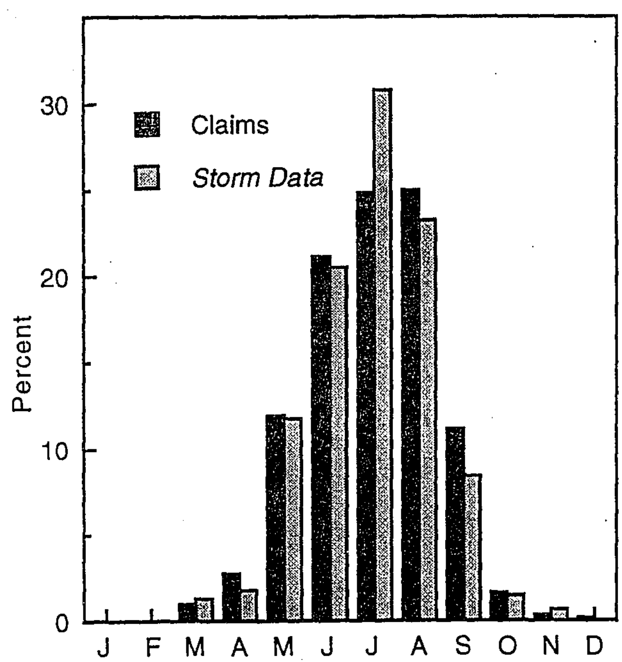

FIG. 6. Claims: monthly Colorado insurance claims due to lightning from 1987 to 1991. *Storm Data:* monthly Colorado property damage reports from 1950 to 1991 (from López et al. 1995).

has a cooler spring and fall than most of Colorado and Utah.

9. Claims by county

The geographical distribution of lightning claims by county in Colorado, Utah, and Wyoming is shown in Fig. 7. Information was not available in the insurance database by city. The highest numbers of claims are from counties with large populations in and near cities shown in Fig. 7. In Utah, most people live in Salt Lake City and surrounding cities, towns, and populous unincorporated portions of counties. In Wyoming, the southeast county includes the state capital of Cheyenne. Most people in Colorado live along the eastern slope of the Rocky Mountains in a north–south region that includes Denver, Colorado Springs, and other cities and counties with large populations.

Claims are graphed in Fig. 8 according to county population in the three states. In general, the most populous counties have more claims, and the least populous counties have fewer claims. The same result applies for each state separately. Some other results by county include the following.

- When the claim rate per 10 000 people is calculated, most counties had a rate of less than 7 (Holle et al. 1995). High rates usually occurred for small claim samples in less populous counties, and the natural variability of a few claims easily changed rates. However, a concentration of high rates extended north to south through central Colorado high-mountain counties where there was more lightning than on the plains in López and Holle (1986). López et al. (1995) also found a higher rate of lightning deaths and injuries in these counties.
- When loss per claim is plotted against county population, nearly all populations had a rate of \$500–\$750 (Holle et al. 1995). Highest losses were in some of the less populous counties in no obvious organization across the three states. Since one large loss raised the average in a county with few claims, little meaning should be attributed to a high average loss in a small county. Factors that can affect the average loss include differences in housing costs, amount of buried utility lines, proportion of multifamily housing, vulnerability of structures to lightning, extent and type of agricultural facilities, ratio of insured properties to the total number of properties, and others not identifiable with the present dataset.

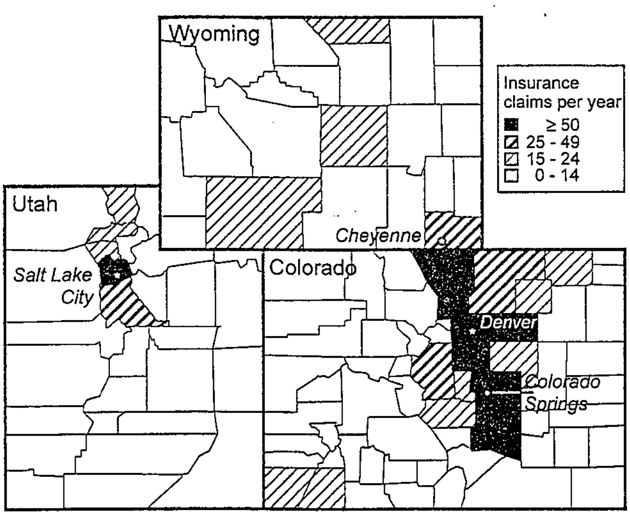

FIG. 7. Number of insurance claims per year due to lightning by county in Colorado, Utah, and Wyoming from 1989 to 1993.

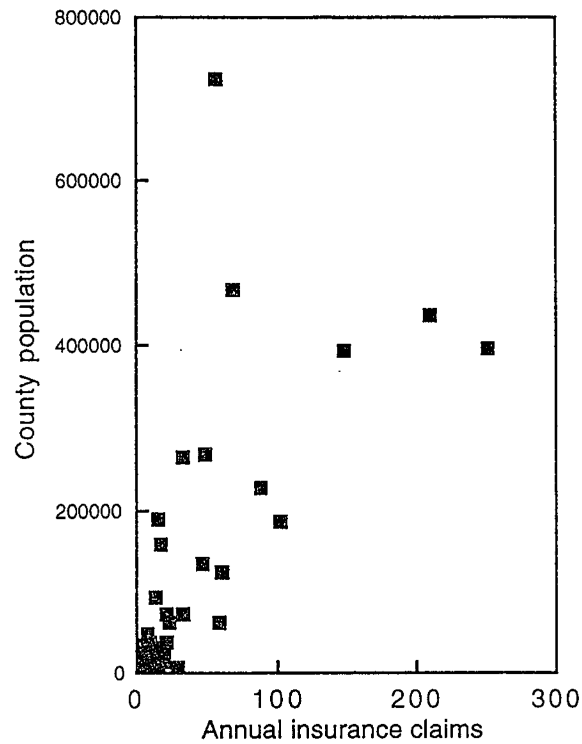

FIG. 8. Population of each county in Colorado, Utah, and Wyoming plotted against annual number of lightning claims in the database from 1989 to 1993.

The rate of claims per 10 000 people in Utah was 1.4 compared to 4.7 for Colorado. The lower Utah rate was not due to less lightning compared to Colorado since Reap (1986) and Orville (1994) showed no significant differences between flash densities for these states. The rate in Wyoming was 3.9, almost the same as Colorado. However, Reap (1986) and Orville (1994) showed a lower lightning frequency for Wyoming compared to Colorado. Better understanding could result if flashes on state and county bases were directly compared to claims.

10. Claims compared to *Storm Data*

On the county level for Colorado, López et al. (1995) listed the number of lightning-caused deaths,

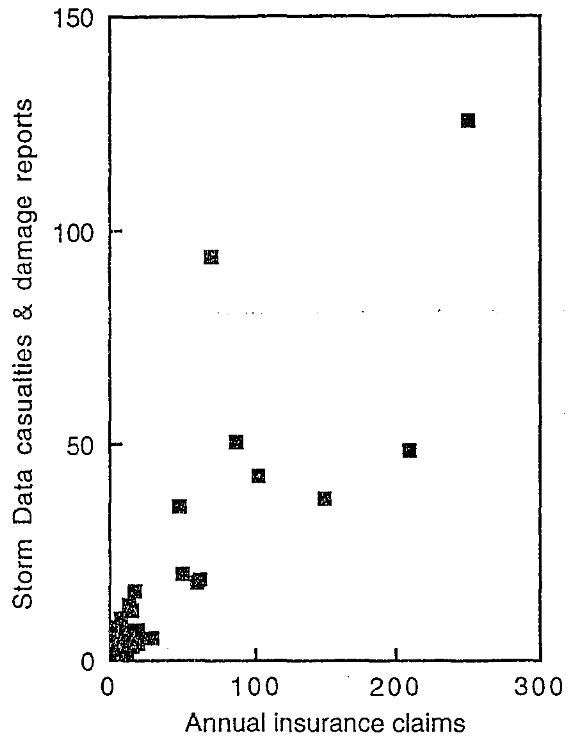

FIG. 9. Annual lightning insurance claims (1989–93) plotted against combined *Storm Data* lightning casualty and damage reports (1950–91) by county in Colorado.

injuries, and damage reports from 1950 to 1991 in *Storm Data.* Figure 9 shows a general trend that large numbers of claims in a county from 1989 to 1993 are related to many casualties and damage reports; however, this applies only to counties with highest frequencies.

On the state level, the number of claims was compared to numbers of lightning victims in *Storm Data.* There was no close relationship for a single state or year for Colorado and Utah (Holle et al. 1995) since the number of claims was a larger, more constant number than casualties. There were no Wyoming lightning victims during the period.

Storm Data was searched to find property-related lightning damage reports that could have resulted in personal or commercial insurance claims. Table 3 compares five years of lightning damage reports in *Storm Data* to lightning insurance claims. Ratios range from 341 insurance claims to 1 *Storm Data* report in Colorado to 610:1 in Wyoming. The overall ratio is 367 claims per *Storm Data* report.

11. Summary and conclusions

A total of 6755 insurance claims per year was found from 1987 to 1991 in Colorado, Utah, and Wyoming when the database from one large insurer was extrapolated to all companies. Annual losses were $5,000,000 per year in Colorado and $650,000 per year each in

TABLE 3. Annual lightning insurance claims compared to damage reports in *Storm Data* from 1987 to 1991.

State	Insurance claims	*Storm Data* reports	Ratio
Colorado	5188	15.2	341:1
Utah	774	2.2	352:1
Wyoming	793	1.8	610:1
All	6755	18.4	367:1

Utah and Wyoming. The database did not include the type of damage to buildings or their contents. All but one year between 1987 and 1991 had more claims than during the previous year for the three states together, but population also increased during these years, and lightning frequency varies.

A national estimate of the insurance risk from lightning was based on the three-state database by assuming that population and lightning risk in the region are representative of the whole country. A separate study of lightning claims compared to the actual lightning frequency would help separate the influences of population and flashes on claim reports. The extrapolated totals for the United States were 307 000 lightning claims and a total cost of $332,000,000 when a $150 deductible was taken into account. When this amount is plotted (Fig. 10) rather than the three-year average of $27 million from *Storm Data* in Table 1, lightning becomes as significant a source of loss as most other weather phenomena. Losses from hail were also found by Changnon (1972) to be underreported, and the same is true to some extent for other weather phenomena. But

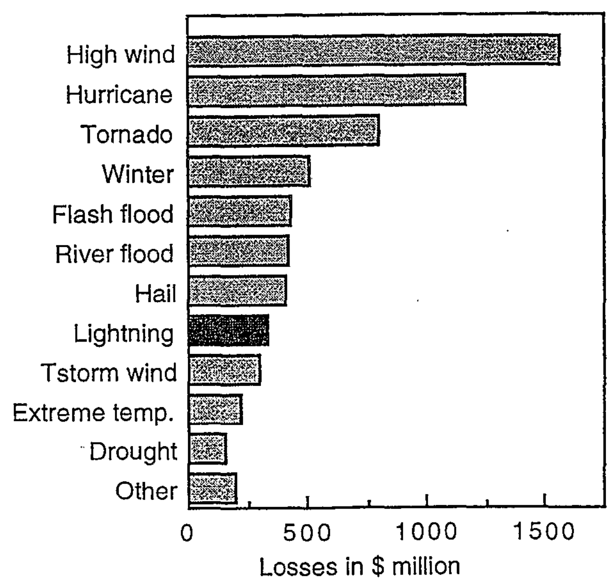

FIG. 10. Weather-related property damage in 1991 in the United States from Table 1 except showing $332 million for lightning insurance claims found in the current study.

lightning probably has the lowest ratio of *Storm Data* losses to the actual number because the ratio is dominated by a large number of small losses.

Maps of claims showed that largest numbers were always in counties with the largest populations. The dollar loss per claim was not well related to the population and tended toward large amounts in some counties with less population. Both claim rate and loss per claim varied widely in less populous counties due to variability caused by a few claims. A rate of 4.7 claims per 10 000 people applied for Colorado, 1.4 for Utah, and 3.9 for Wyoming. These differences were not attributable to known differences in state lightning frequencies. Other factors are important, such as type and cost of housing and agricultural facilities, the portion of dwellings that are apartments or have buried utility lines, the ratio of insured properties to the total number of properties, and other influences that could not be resolved with the data.

There were 367 times as many claims as insurable damage reports in *Storm Data* during the same years in Colorado, Utah, and Wyoming. Losses in the United States from 1990 to 1992 averaged $27 million according to *Storm Data,* but personal and commercial losses alone ($332 million) from this study of insurance claims were more than 10 times that amount.

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