HAIL, HAIL, HAIL !
THE SUMMERTIME HAZARD OF EASTERN COLORADO

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INTRODUCTION

Hail ! the word itself sends feelings of frustration through Colorado farmers. Each year, millions of dollars of agricultural losses occur when hailstorms sweep across the Eastern Plains. Hundreds of Colorado wheat farmers can tell tales of disappointment about years when their crop had survived drought, windstorms, winter cold, and insects only to be wiped out by hail the day before harvest. If it wasn't last year or the year before, then it might be this year or the next.

Hail is a pain, but it's also an unavoidable part of life east of the Rockies. All the way from Alberta, Canada, south to eastern New Mexico, hundreds (maybe thousands) of hailstorms develop each year. There is no other place in North America with more numerous or more severe hailstorms, and Colorado is right in the middle of it. There are areas in Wyoming, Montana, South Dakota, Nebraska and New Mexico that may challenge Colorado as the hail capital of the U.S., but more often than not, Colorado takes that honor.

Hail used to be viewed as primarily an agricultural problem. The past 20 years, however, has brought one catastrophic hailstorm after another to Front Range population centers. The culmination came July 11, 1990 when Denver took a direct hit by a prolific hail-making thunderstorm. When it was all over, damage totals close to $600 million were reported ! the greatest property losses from hail ever reported from one storm up to that time. Property damage in Colorado has exceeded $50 million in 5 of the last 7 years. Front Range car dealers tremble every time the summer skies turn dark. Insurance agents have nightmares about being buried alive beneath piles of claim forms.

Colorado hail can also be life threatening. A child was killed in Fort Collins in 1979 when struck in the head by a large hailstone. There have been many instances of lesser injuries. Livestock fatalities from hail are fairly common.

HAIL INFORMATION

We receive literally hundreds of questions each year about hail in Colorado. Questions like, "Where can I set up greenhouses where the risk of hail won't be too great?" or "How often will stones larger than one inch fall at such-and-such location?" are common. We also find ourselves on both sides of insurance claims. Individuals who are filing claims but can't remember when the hail fell will call us. Likewise, insurance investigators routinely call or write to verify if hail did indeed occur at a particular time and place.

As I have attempted to answer these many questions, I have always been frustrated by the lack of information about hail. Systematic observations of hail are taken at only a handful of stations in Colorado. The National Weather Service offices at

Denver, Colorado Springs, Pueblo, Grand Junction and Alamosa have gathered hail information for many years ! but only right at their offices. Some of the 200+ cooperative weather stations in Colorado also report their hailstorms. The Fort Collins weather station, for example, has more than 100 years of local hail reports.

The data from these few locations are very useful. Unfortunely, if you ask for information from Boulder, Lamar, Breckenridge or most any other location in Colorado, we probably won't have much data to refer to. Since hail occurs only briefly (typically, just a few minutes per year even at the most hail prone locations) and tends to be very localized (Colorado hailstorms are at most a few miles wide), many storms go undetected by the "official" weather stations. For example, Denver Stapleton Airport, the source of Denver's hail data since 1950, only had a few hail stones on 11 July 1990 ! the day that much of the city was pulverized.

The National Weather Service (NWS), as a part of their duty to warn citizens of the threat of severe weather, obtains reports of severe weather from pilots, law enforcement officers, news media, local civil defense organizations, volunteer storm "spotters," private citizens and any other credible source. These data are used in real time to help issue and verify severe thunderstorm and tornado warnings. At the end of each month, severe weather reports are assembled, checked and then transmitted to the National Climatic Data Center. Several months later, the publication "Storm Data" is published for the country providing historical documentation of significant storms.

Another source of information is the insurance industry. In densely or uniformly populated regions of the country, property and crop insurance claims give a detailed picture of the locations and frequency of hail that greatly compliments weather station data. Here in Colorado, population is far from uniformly distributed, and farmland is not uniformly distributed. Thus, insurance data are not much help in improving hail information. Also, many farmers choose not to insure their crops against hail since the cost of insurance is so high. Some farmers try to self insure their crops by spreading their fields several miles apart so the likelihood is small that all their crops will be hit at the same time.

Weather radar can be used to detect hail. It is difficult, time consuming and expensive to go through years of past radar data to try to reconstruct storm locations, frequencies and intensities, so few such radar climatologies have been completed. New NWS radars now being deployed may make this task easier.

PAST STUDIES

Our hail problem here in Colorado shouldn't be a surprise to us. Long before the 20th Century, Native Americans living on the High Plains were familiar with hail. Native American folklore referred to "Ice balls from the sky when summer winds blow from the east." Early European settlers knew about hail, but surprisingly little was written about it. Climate summaries written prior to the late 1930s contained almost nothing about hail. A very small number of scientists embarked on descriptive hail climatologies around 1940. After World War II, Air Force and commercial airline studies of hail began. A special network of volunteer weather observers was established in the Denver area in 1949 and operated for at least 10 years. Several fascinating papers were written in the 1950s and 1960s by W. Boynton Beckwith of United Airlines using this data set.

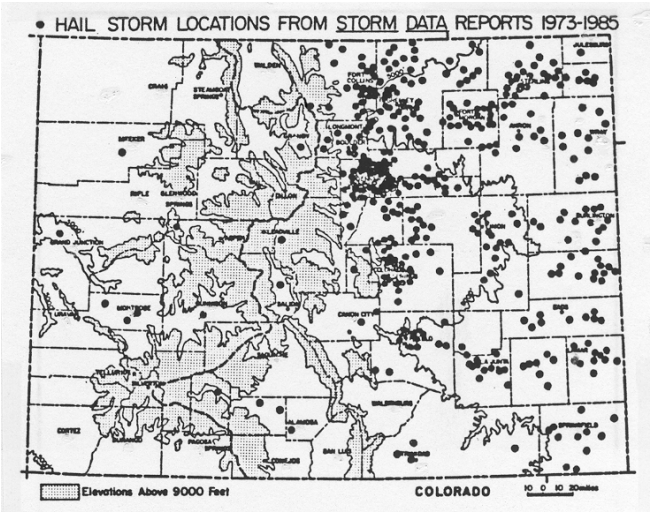
Interest in hail research in Colorado expanded rapidly in the 1960s, and a number of published references can be found. Much of the interest centered around the

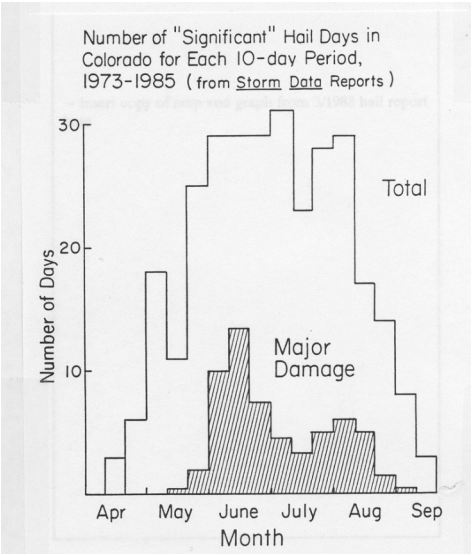
possibility of reducing hail damage by seeding clouds with silver iodide. This interest culminated in a large scientific experiment, the National Hail Research Experiment (NHRE), to learn more about hailstorms. This early 1970s project attracted scientists from around the world to places like Grover and Keota, Colorado. Cloud seeding aspects of this project attracted much controversy. The project came to a premature end, and much climatological information gathered on eastern Colorado hail was never analyzed.

Since the 1970s, most research has turned toward modelling and predicting severe storms. Studies of Colorado severe weather and tornadoes have brought noticeable improvements in forecasting severe storms, but little information to better define the risks of hail has been assembled. In the past few years, new meteorological radars in Colorado are paving the way for expanded studies of storm characteristics.

CCC HAIL PROJECT

The Colorado Climate Center has been working to improve climatological information about hail for Colorado decision makers. Back in the March 1988 issue of Colorado Climate we compiled some information about hail in Colorado. All significant hail reports for Colorado for a 13 year period, 1973-1985 were reviewed. The following map and graph show some of the features of Colorado hail patterns derived from those data.



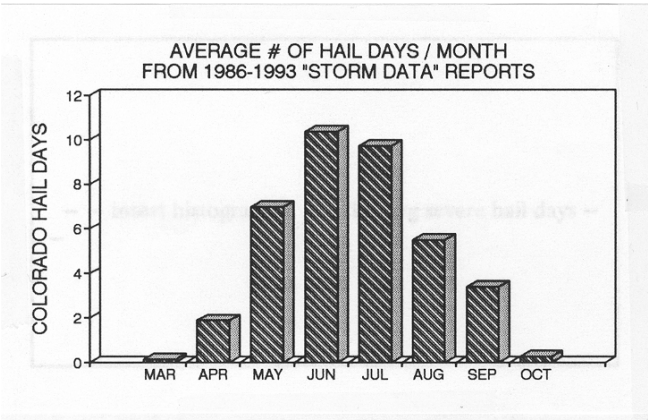


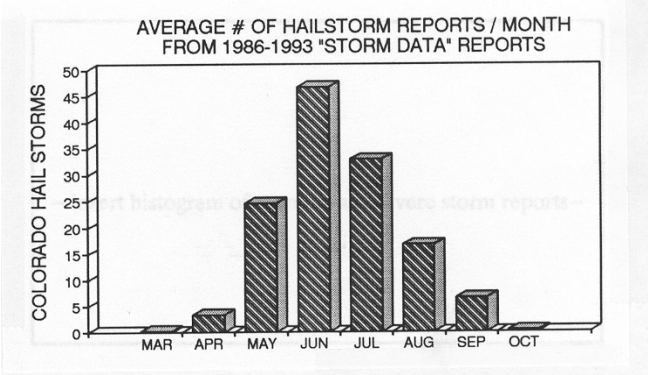
In recent months, with the help of part time assistance from Natalie Tourville (High School intern) and Jim Harrington, we have now updated our Colorado hail statistics. Based on more than 1,200 hailstorm reports, 1986-1993, more detail can now be offered to better describe the characteristics of hail in Colorado.

The data used for this study included point weather station data from a small number of sites in and near Colorado along with statewide data on severe hailstorms obtained from the national publication, "Storm Data." It is important to note that to be reported as a severe storm, maximum hailstone diameter must be at least 3/4 inch. Therefore, the numerous storms that produce smaller stones were usually not included in the statewide data unless they caused significant crop damage or accumulated to significant depths. Some of the larger hailstorms reported during this 8-year period included several storm data reports. In some of the analyses that follow, multiple reports were combined to define a single storm.

MONTHLY HAIL FREQUENCIES

The hail season in Colorado begins in March and ends in October. Average monthly distributions of hail (all sizes included) for selected locations show that overall, June has the highest frequency of days with hail. However, some individual sites, such as Fort Collins and Grand Junction, have more frequent hail in May. MayBAugust accounts for the vast majority of Colorado hail events. It would be very interesting to have mountain stations to add to this comparison. July-August thunderstorms are common throughout the Colorado high country, and many of these storms are accompanied by small and usually soft hail or graupel. This type of hail rarely does damage and is sometimes even reported as snow.

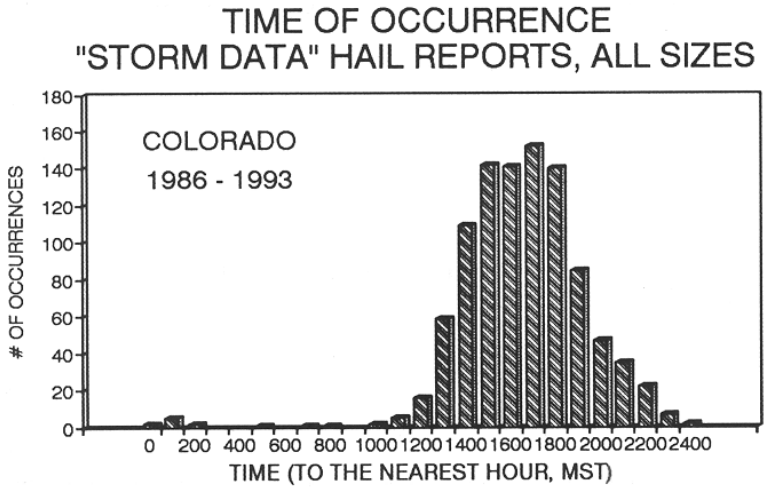




Statewide severe hail day statistics show a similar monthly distribution. Out of an average of 37 days per year with large hail, June is the peak month with slightly more than 10 days. July has almost as many hail days. However, if you look at the actual number of hailstorm reports, June is clearly the leader with an average of 46 storms. This means that the number of severe hailstorms per hail day is larger in June than any other month. There have been an average of more than 130 reported severe hailstorms each year since 1986.

TIME OF DAY

Hail is primarily an afternoon or evening phenomenon here in Colorado. 90% of all severe hailstorms reported 1986-1993 occurred between 1:00 p.m. and 9:00 p.m. MST. Previous studies of hail at Fort Collins and in the Denver area, including both large and small hail, showed about 80% of all hail fell during those same hours. The least likely hours for hail in Colorado are between 2:00 a.m. and 10:00 a.m. Less than 2% of the reported severe hailstorms occurred between



11:00 p.m. and 10:00 a.m. with most of those occurring before 2:00 a.m.

There are some variations in the preferred times for hail at different times of the year and in different parts of the State. Nearly all reports of morning (5:00 a.m.-10:00 a.m.) hailstorms have been in April and May with a few in September. Some of these storms, including one in the Denver area on April 25, 1994, have dropped large quantities of hail, but stones are typically small. There is a detectable shift in preferred times of day for hail as you move eastward across Colorado. Most hail (including small stones) in and near the mountains occurs between 11:00 a.m. and 6:00 p.m. Out near the eastern border of Colorado, storms are most likely from 3:00 p.m. to midnight. The large majority of severe hailstorms reported after 9:00 p.m. in Colorado have occurred over the eastern quarter of the State.

Average Number of Days with Hail

Station	Month													
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total	Period-of-record
Alamosa	0	0	0.1	0.1	0.6	0.8	0.4	0.4	0.3	0.3	0	0	3.0	1984-1993
Cheyenne, WY	0	0	0.1	0.4	2.0	2.5	1.6	1.2	0.6	0.2	--	0	8.6	1892-1993
Colorado Springs	0	0	0.2	0.5	1.2	1.9	0.9	0.9	0.4	0	0	0	5.8	1974-1993
Denver	0	0	0.1	0.2	1.2	1.2	1.0	0.8	0.1	0.1	0.1	0	4.8	1974-1993
Fort Collins	0	0	0.1	0.5	1.4	1.2	0.7	0.5	0.3	0.1	0	0	4.8	1979-1993
Goodland, KS	0	0	0.1	0.3	1.5	1.4	0.8	0.3	0.1	0.1	0	0	4.6	1982-1993
Grand Junction	0	0	0.1	0.1	0.4	0.1	0.1	0.2	0.2	0.1	0.1	0	1.2	1974-1993
Limon	0	--	0.2	0.4	1.6	1.8	1.3	1.3	0.4	0.1	0	0	7.1	1989-1993 Est.
Pueblo	0	0	0.1	0.1	1.1	1.0	0.7	0.7	0.3	0.1	0	0	4.1	1974-1993 (except 1979-83)

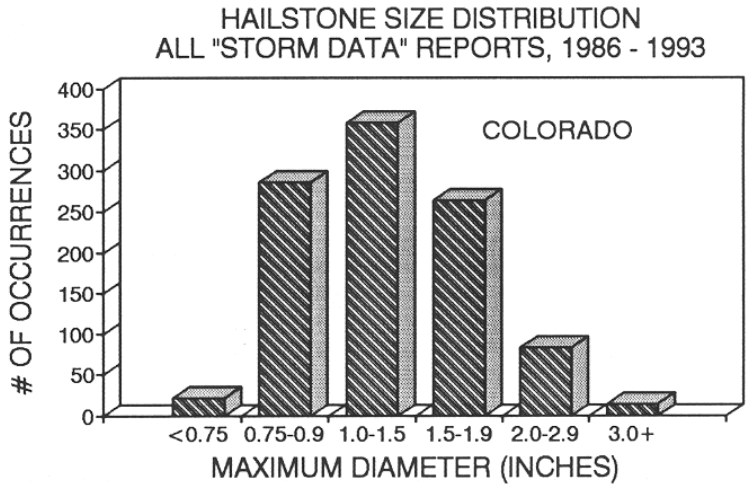
HAILSTORM DURATIONS

At any given point, hail usually only falls for a few minutes. Hail that continues for more than 15 minutes is unusual. A study of 60 Fort Collins hail events showed the median duration to be 6 minutes. Just over 10% of the storms lasted for more than 20 minutes, but these included most of the severe storms that included large stones. An awesome hailstorm that hit parts of the Denver area on 13 June 1984 dropped stones as large as baseballs for up to 40 minutes straight.

While hail at a given point is usually short-lived, the storm complexes that produce hail may last for for several hours. The 11 July 1990 storm that crossed the Denver area began near Estes Park and continued southward to El Paso County. This system lasted for more than 3 hours and dropped hail for most of that time. Severe thunderstorm systems out on the Eastern Plains have produced severe weather for 6 hours or longer.

HAILSTONE SIZES

The distribution of hailstone size is of critical importance for evaluating hail damage potential. Crops can be damaged by almost any size of hail. Even pea-sized stones can damage tender crops, especially if propelled by strong winds. Windblown marble-sized hail has been known to effectively strip paint from buildings. To damage vehicles and roofs requires larger stones. The NWS hail criteria for severe thunderstorms equalling or exceeding 3/4" diameter is consistent with the size of stones that begin to be capable of more extensive property damage. Since this study was primarily limited to severe storm reports, most reports are at least 3/4".



If we somehow could count, measure and weigh all the hailstones that fall from the sky, we would surely find that the vast majority of stones that fall here on Colorado are 1/2" diameter or smaller. Local studies elsewhere in North America have suggested that at least 95% of all hailstones are less than 1/2" diameter. But just east of the Rockies, the percentage of larger stones appears to increase. Each year, Colorado gets more than its fair share of larger stones as well. The high frequency of larger stone sizes here contributes directly to the excessive property damage that occurs.

The most common size range for damaging hail in Colorado is 1 to 1.5" in diameter. This size range, which includes the classic "golfball" size, accounts for more than 1/3 of the severe hailstorm reports during this study. Slightly more than 1/3 of the storm reports included maximum stone diameters greater than 1.5 inches. These are truly large stones by any definition. Six percent of the reported severe hailstorms had maximum stone diameters of 2.5" of greater. Huge hailstones 3 inches in diameter or greater are not common, but they have been reported in 7 of the last 8 years and probably occur briefly and over limited areas every summer somewhere in eastern Colorado. These stones are commonly classified as "baseball-sized" or larger.

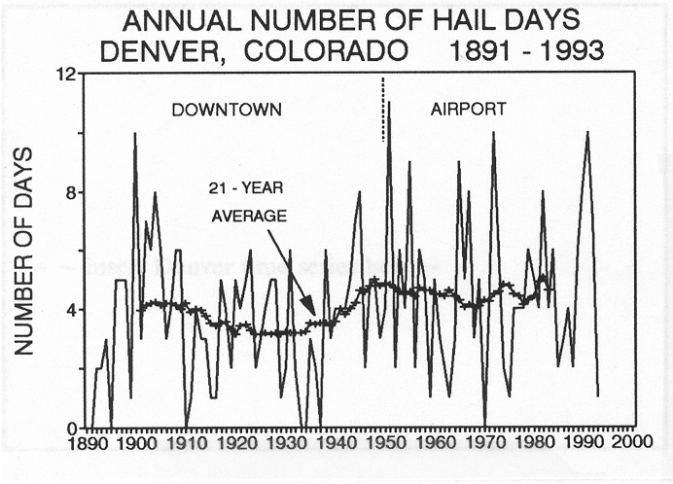
The maximum stone size reported in this study was 4.5 inches. Such stones may fall at speeds of close to 90 miles per hour and can do incredible damage. Not only do these stones dent cars and break windshields, they can penetrate corrogated metal as well as asphalt shingle/plywood roofs. Very few stones ever exceed this size, but the largest documented hailstone anywhere in the U.S. was found in Kansas. It was 5.5 inches in diameter and weighed nearly 2 pounds. (Note to all readers: If you ever become aware of a Colorado hailstone of a comparable size, please contact us immediately. Be ready to provide witnesses and photographic documentation.)

The largest hailstones reported in Colorado have a different monthly distribution than storms in general. Their season is limited to the period from late June through August, and they are most likely in July.

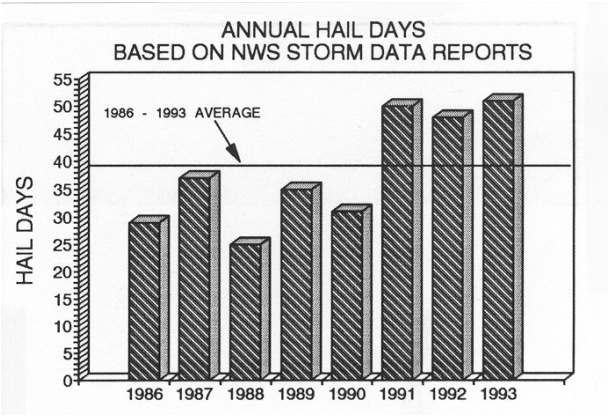
We have also performed a single-station analysis of hail size distribution using all reported hail of any size (see below). Based on hail data collected 1962-1993 at the Colorado State University campus weather station, we found that only 11% of the reported hail events included stones sizes of 3/4 inch or greater. Hail in excess of 1 inch diameter has occurred only twice in the past 32 years. While large hail may be common somewhere within a large area, this suggests that at a point the risk of severely damaging hail may not be quite as great as we think. It may be possible for some of our roofs to grow old naturally.

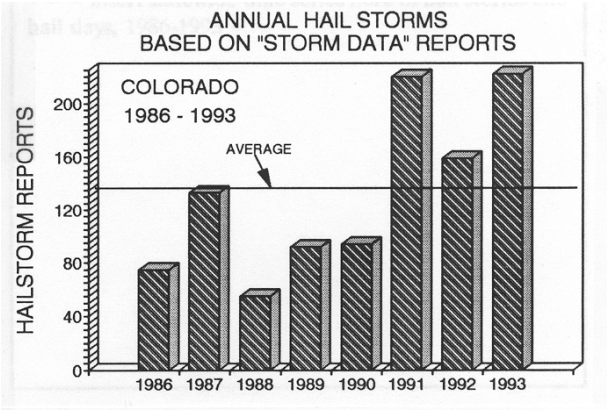
MONTHLY AND INTERANNUAL VARIABILITY

One of the big challenges of trying to deal with hail is its variability. An area can go decades without a severe hailstorm and then be hit three years in a row. The graph below gives an indication of year-to-year variations in hail frequencies at a point. More than 100 years of hail observations have been gathered by the National Weather Service in Denver. The annual number of hail days (including stones of any size) has ranged from 0 to 11.



Even over the entire area of Colorado, the number of hailstorms and hail days varies considerably. For example, there were only 25 severe hail days in 1988 compared to 51 in 1993. The number of storms varies even more. There were 55 reported severe hailstorms in 1988 compared to 222 in 1993. Within a given month, the magnitude of variation is greater yet. The number of severe hailstorm reports in June has ranged from 12 to 96 during the past 8 years. If we had more years of data to study, I'm sure the observed variations would be even greater.

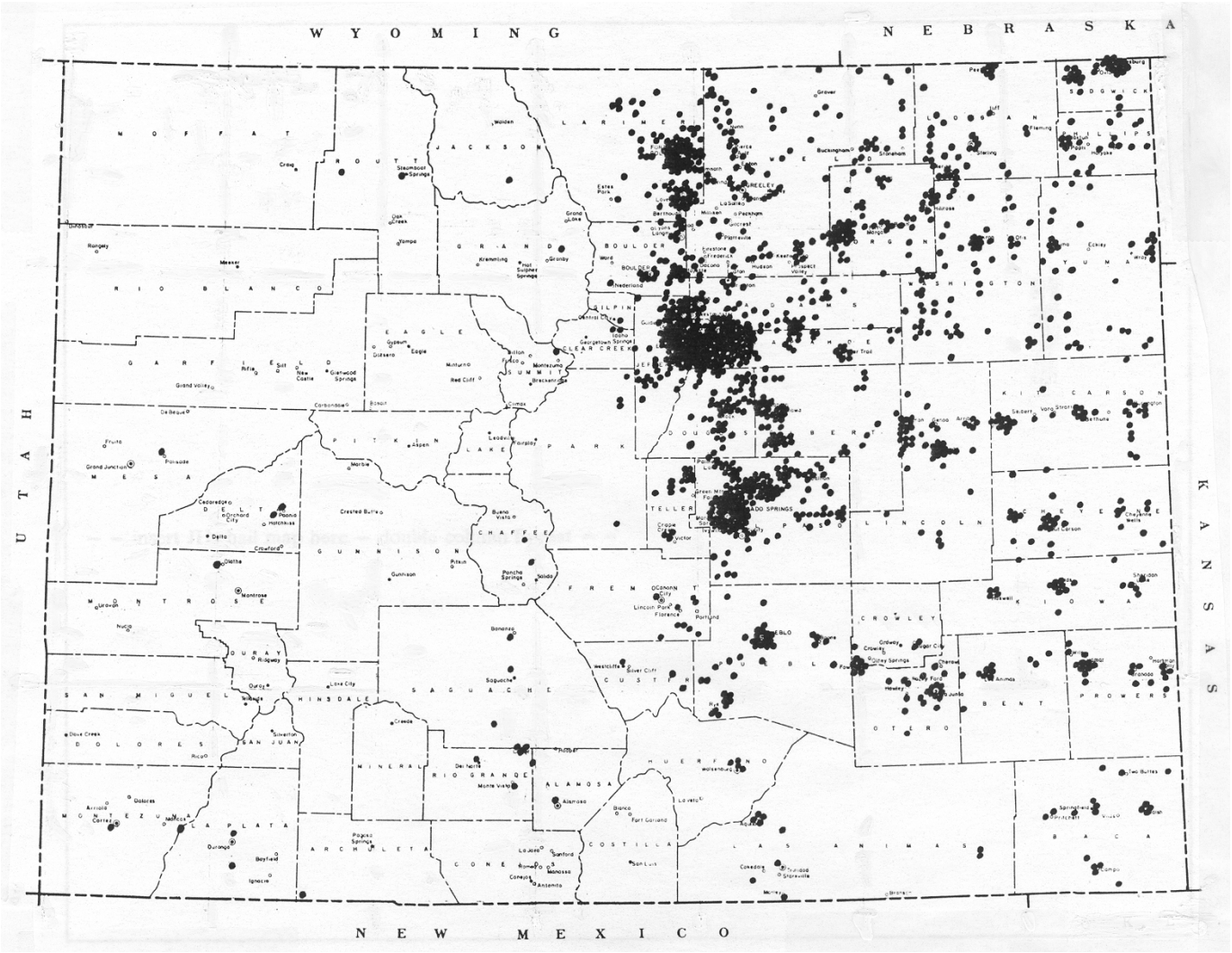




The numbers seem to suggest an upward trend in Colorado hailstorms. We predict this trend will continue, but not because hail is actually increasing. Rather, we believe that growing population, more cellular phones and greater aware-ness will mean that more storms will be reported in the years ahead.

SPATIAL DISTRIBUTION

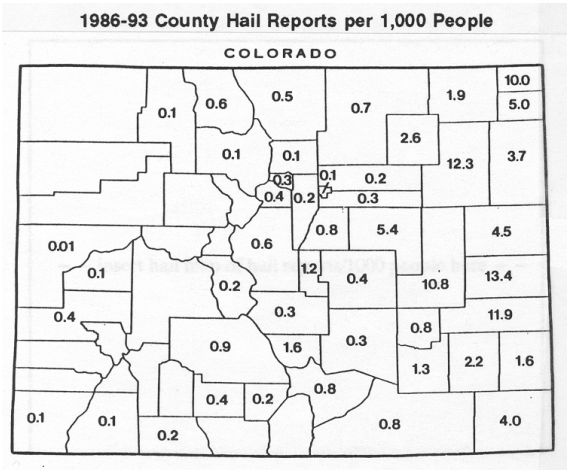
Each of the approximately 1,200 reported severe hailstorms was plotted as a single dot on the map below. This is not a totally appropriate method for displaying hail occurrences. Some storms were only severe in a very small area, but some storms produced long hail swaths. The point method is clearly inadequate for presenting spatial characteristics of hail, but we have no better data sources at this time.

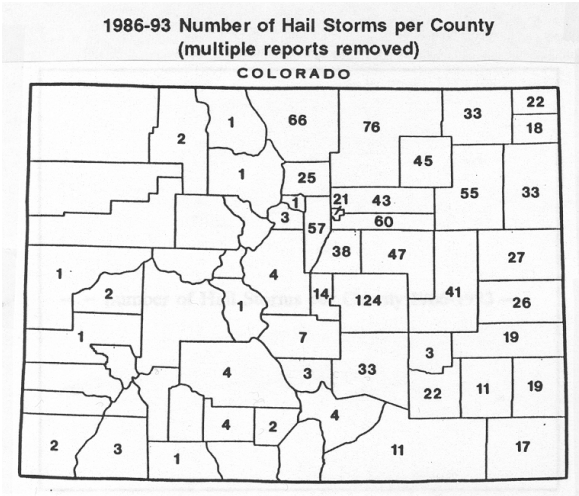


Two features of Colorado hail are evident here. 1) Severe hail is not a problem statewide. Rather it is clearly limited to eastern Colorado beginning in the eastern foothills and extending across all the the Eastern Plains. Out of the more than 1,200 severe hail reports statewide in the past 8 years, only about 50 were in the mountains or on the Western Slope. Of these western Colorado hailstorms, few produced significant property damage and only a handful included stone diameters in excess of 1 inch. 2) Local details of storm concentrations east of the mountains are probably (and unfortunately) not realistic. Using the type of data available to us, hail patterns are strongly influenced by population density. The more people and personal property there are, the more severe hail reports we receive. Not only do towns and cities show up clearly on the map, so do highways. U.S. Highway 24 from Colorado Springs to Limon shows up clearly on the map even though few people live along that road.

To try to more accurately define the distribution of damaging hail in Colorado, the number of severe hailstorms per county were mapped. These values were then divided by the population (1990 Census) and expressed as hailstorms per 1,000 people. This paints quite a different picture of the spatial distribution of Colorado hail. While El Paso and Weld Counties were the leaders in reported storms, the greatest frequency of per

capita severe hail occurs in eastern Colorado near the Kansas and Nebraska borders. But this, too, may be misleading.





Meteorological evidence (radar, satellite, historic weather observations) points to the Palmer Ridge (high ground between Denver and Colorado Springs that extends eastward beyond Limon) and the Cheyenne Ridge (high ground that extends eastward along the Colorado-Wyoming-Nebraska borders) as the most hail-prone regions of Colorado. Our study does not show these areas to be unusually stormy with respect to adjacent areas. However, except for U.S. Highway 24, these areas have little population, little transportation, and not much agriculture. Our experience with hail reporting also suggests that where people are most accustomed to hail, they are likely to only report extremely severe storms, so it remains very possible that these areas are indeed more hail prone.

Results of mapping hail, although somewhat dissappointing, still contain helpful information. For example, there appears to be a distinctly lower hail risk in Boulder and Longmont than in other Front Range cities. Also, despite relatively dense population and intense agricultural activities along the South Platte River from Denver north to Greeley, the number of hail reports there are relatively low. By comparison, the Lafayette area east of Boulder has had many hail reports. A relatively large number of severe hailstorms have also been reported north of Greeley along U.S. Highway 85. The Wiggins area along with Sedgwick-Julesburg have been especially active during the 1986-93 period.

There is considerable anecdotal evidence of preferred "hail paths" in eastern Colorado and along the Front Range. This might very well be true. At this point, we do not have the enough information to prove it one way or the other. Even when the results of the 1973-1985 study are combined, consistent patterns do not emerge.

MEMORABLE HAILSTORMS

The storms we remember most are the storms that get the most attention in the media. Many of Colorado's largest hailstorms plaster the Eastern Plains, flatten wheat fields, bruise cattle but pass unnoticed by most of us. I will list a few dates, locations

and impacts of some relatively recent storms below, but there are many other storms that could just as easily be mentioned.

Memorable Colorado Hailstorms		
Date	Location	Remarks
7/30/1979	Fort Collins	3-4" diameter stones, baby killed.
6/4/1983	Greeley	Millions in damage.
6/13/1984	NW-W Denver	1-3" inch stones, long duration, $200 M damage.
8/2/1986	Front Range	Widespread damage, Fort Collins to Denver.
6/23/1987	Pueblo/La Junta	1-4" hail, $70 M damage.
7/11/1990	Denver area	$625 M property damage.

WHY COLORADO?

There are some very good reasons why Colorado and similar locations just east of the tall Rocky Mountain barrier are so prone to hail. Contrasting dry continental air masses and humid subtropical air from the Gulf of Mexico often clash just east of the Rockies in late spring and summer. This is a key ingredient for severe thunderstorm development. The nearby mountains serve as preferred initiation points for thunderstorm formation.

The high elevations of the western Great Plains also enhances hail potential in two ways. First, the high ground warms quickly under the intense western sunshine and provides an elevated heat source that intensifies convective updrafts. The greater the vertical speed of air within a cloud, the greater the hail potential. The cumulonimbus clouds (thunderheads) associated with Colorado's severe hailstorms frequently climb to heights of 45,000 feet or more above ground. Secondly, the high elevation means that hail does not have as far to travel to reach the ground. Thus, the chances of it melting are reduced. This is further supported by the dry air that typically lies just west of the Great Plains storms. Precipitation evaporating into the nearby dry air cools the air further, increases downdrafts and increases the likelihood that the hail will hit the ground before it melts. Many spring and summer thunderstorms across the eastern and southern U.S. also contain hail, but that hail usually melts before it reaches the ground.

Many other graphs and data summaries were developed during the course of this research which cannot be shown in the compresses report. If you have more detailed questions or additional information about Colorado hail, please contact the Colorado Climate Center.