NOAA TECHNICAL MEMORANDUM NWS CR-114

HAILSTORMS AT CHEYENNE, WYOMING
1892-1996

Jack Daseler
National Weather Service Forecast Office
Cheyenne, Wyoming

October 1998

U.S DEPARTMENT OF Commerce / National Oceanic and Atmospheric Administration / National Weather Service

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Jack Daseler
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Scientific Services Division
Central Region
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TABLE CONTENTS

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I. INTRODUCTION

Hailstorms at Cheyenne, Wyoming, are common from late spring into the middle of summer. On the average, eight to nine hailstorms occur every year, giving the area one of the highest occurrences of hail in the United States (U.S.) (Changnon 1977). However, the majority of the hail that falls is typically small in diameter, with severe hailstorms (those storms that produce hail greater than 3/4 inch, 1.9 cm in diameter) occurring on average every other year. The infrequent occurrence of severe hail in Cheyenne is consistent with findings by Schaefer et al. (1984).

Topography plays a major role in the high occurrence of hail at Cheyenne. Figure 1 shows a map of the region with elevations and major cities noted. Prominent topographic features include the Laramie Range running north-south about 25 miles west of Cheyenne, and the much smaller Cheyenne Ridge extending east-west a few miles south of Cheyenne. Terrain in southeast Wyoming slopes gradually upward from the Nebraska border west to the Laramie Range, while in northeast Colorado the terrain slopes upward from the Ft. Collins and Greeley areas north and west into the Cheyenne Ridge and the Colorado Front Range. Hence, low level flow is upslope at Cheyenne from about 340 degrees clockwise through 210 degrees.

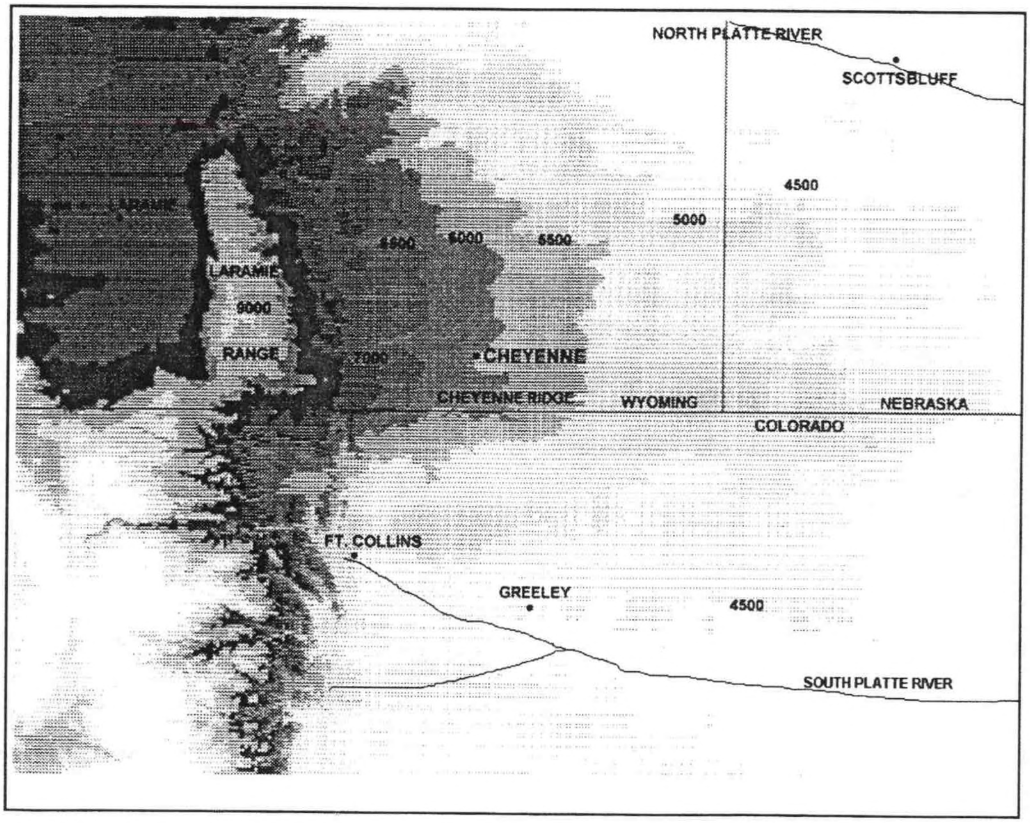


Figure 1. A topography map of the southeast Wyoming region. Major towns and geographic features are shown, with elevation contours in feet.

II. DATA AND ANALYSIS PROCEDURES

Cheyenne has an extensive climatological record. Observations began in 1870, with more complete observations (including hail) starting in 1892. Thus, over a hundred years of hail data has accumulated. Hail occurring at the site of the Cheyenne office was tabulated by date, time of day, hail size and duration. Until about 1930, hail size was generally recorded in non-specific terms, and so it was approximated based on reports available (including newspaper accounts).

Each hailstorm was categorized based on the largest hail size reported. Prior to 1950, this was primarily from the observations at the Cheyenne office. In later years (since about 1950 when *Storm Data* information became available) reports within a three-mile radius of the city were also used. This has resulted in more hailstorm cases in recent times, particularly those with larger hail.

On those days when more than one fall of hail occurred, a difference of at least one hour between the end and start of hail was used to distinguish distinct hailstorms. Occurrence of hail was stratified by hour of day (0000 LST to 2300 LST). For cases where one hailstorm overlapped hours (e.g., 1350 LST to 1410 LST), the occurrence of hail was tallied for both hours.

There was also some question about the reported hail falls in March, early April, late October and November. During these transition seasons, hail reported could actually be ice pellets or snow pellets. However, since the number of these cases was quite small (about 15, or less than 2 percent of the total) and additional data did little to confirm or deny the reports, they were counted and included in the totals.

For the severe hailstorms, local Cheyenne meteorological data such as surface temperature, dew point and wind were collected for each case, as well as regional upper air and surface charts. However, for cases before 1948, upper air and surface charts were not available.

III. CLIMATOLOGY OF ALL HAILSTORMS

Table 1 shows the monthly frequency of both non-severe and severe hail days (hail falling during a calendar day). In 105 years, a total of 904 hail days occurred, giving an average of between eight and nine hail days per year. However, 68 of those days had more than one hailstorm, resulting in a total of 974 hailstorms. A few days even had three separate hailstorms, with one day (June 8, 1909) having four hailstorms. Severe hailstorms have only occurred 86 times (9.5 percent of the total) over the time period of the study.

TABLE 1
Monthly Frequency of Hail at Cheyenne 1892-1996.

	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Total
Total	7	44	214	264	167	122	62	23	1	904
Severe	-	-	19	26	25	12	4	-	-	86

A. Frequency Charts

Figures 2 and 3 show the frequency of all hail days by year and by decade. The years 1923 and 1951 had the most hail days with 19, while no hail days were reported in 1892, 1894 and 1895. A large number of storms occurred in the 1900s, 1920s, late 1940s and 1950s, and to some degree in the 1990s. Fewer storms have occurred in the 1910s, in the 1960s to late 1970s, and to a lesser degree in the 1930s.

The monthly frequency (Figure 4) of all hail days shows a sharp rise in May, a peak in June, and then a gradual decrease into the fall. Examining the data using mid-month periods (Figure 5) shows the highest frequency occurring from the middle of May to the middle of June.

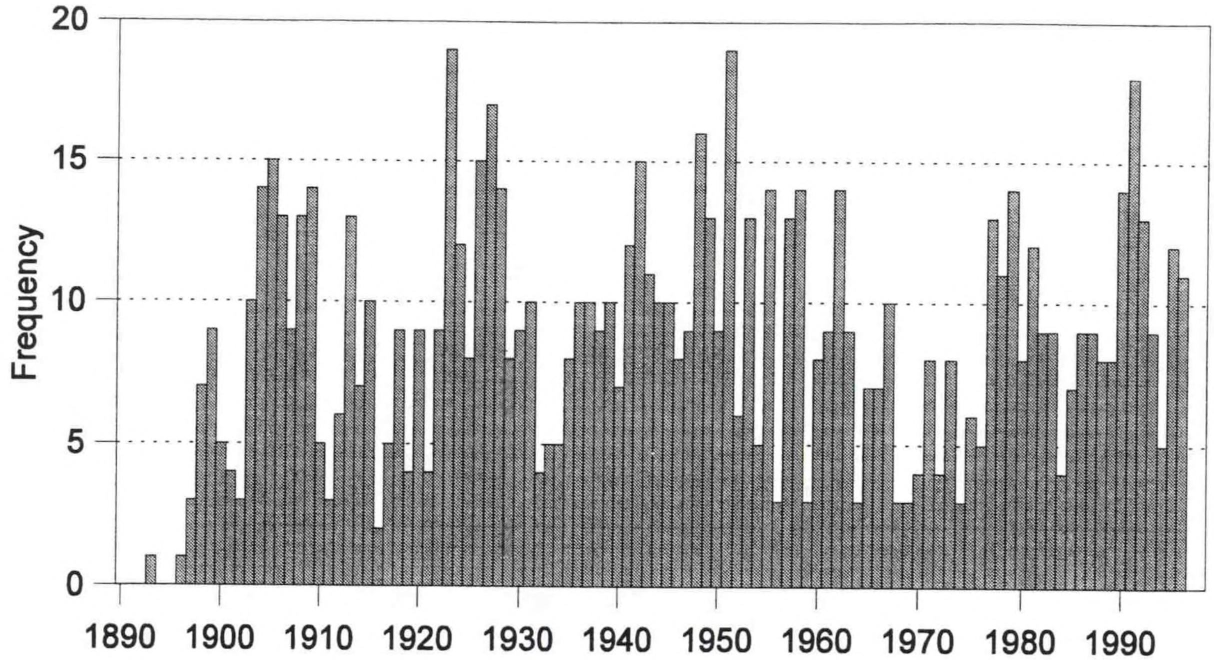


Figure 2. Frequency of all hail days by year.

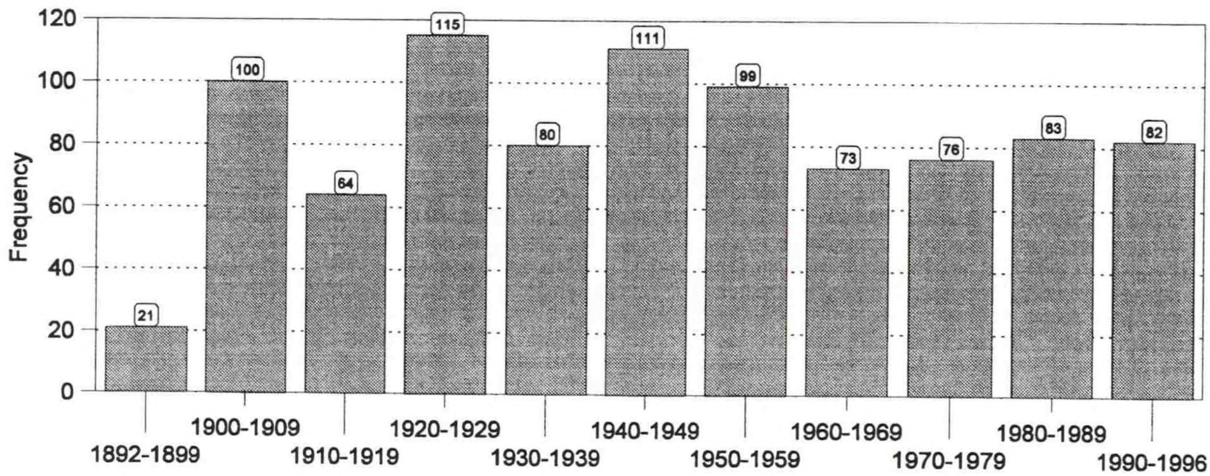


Figure 3. Frequency of all hail days by decade.

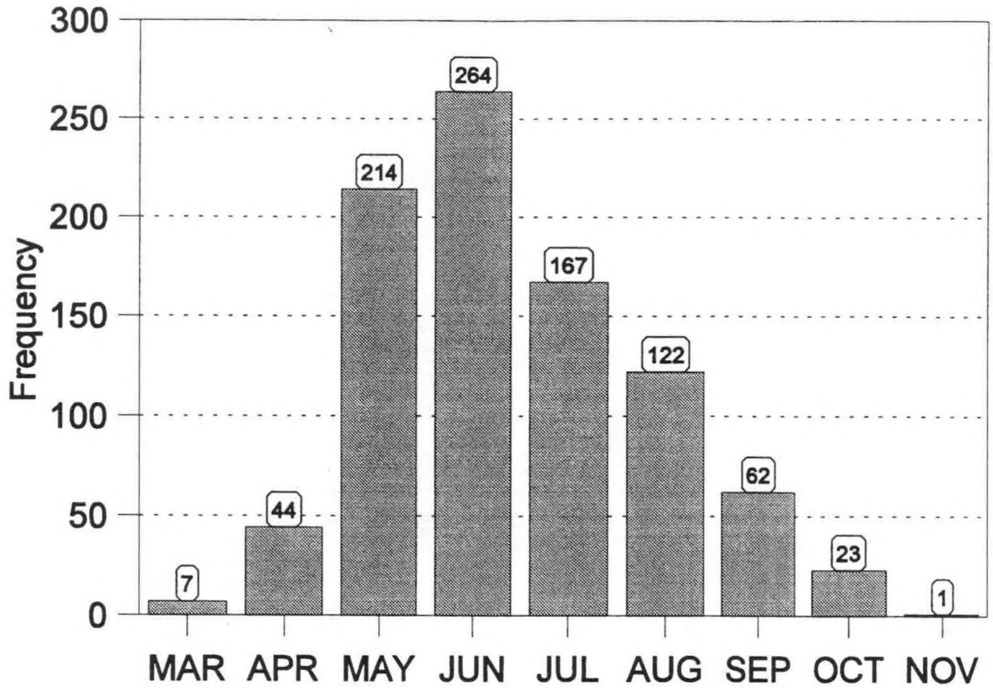


Figure 4. Frequency of all hail days by month.

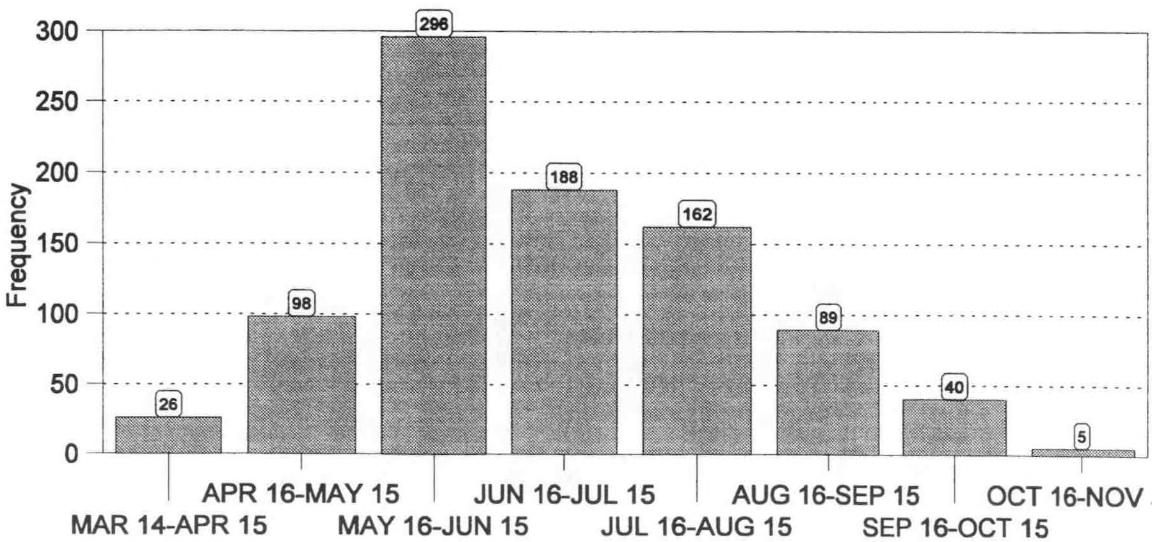


Figure 5. Frequency of all hail days by mid-month periods.

A look at the daily frequency however (Figure 6) reveals more detail. The main hail season in Cheyenne runs from about the middle of May through the third week in June. The dates with the highest frequency of occurrence (15) were May 18, June 9 and June 12. A minimum occurs from the end of June into the first part of July, with July 8 the only summer day on which hail has not been recorded at Cheyenne. A much smaller peak in hailstorms occurs the last two weeks in July into the first week of August, which is likely related to the increase in moisture associated with the monsoon pattern that typically occurs over the Western U.S. in mid-to-late summer.

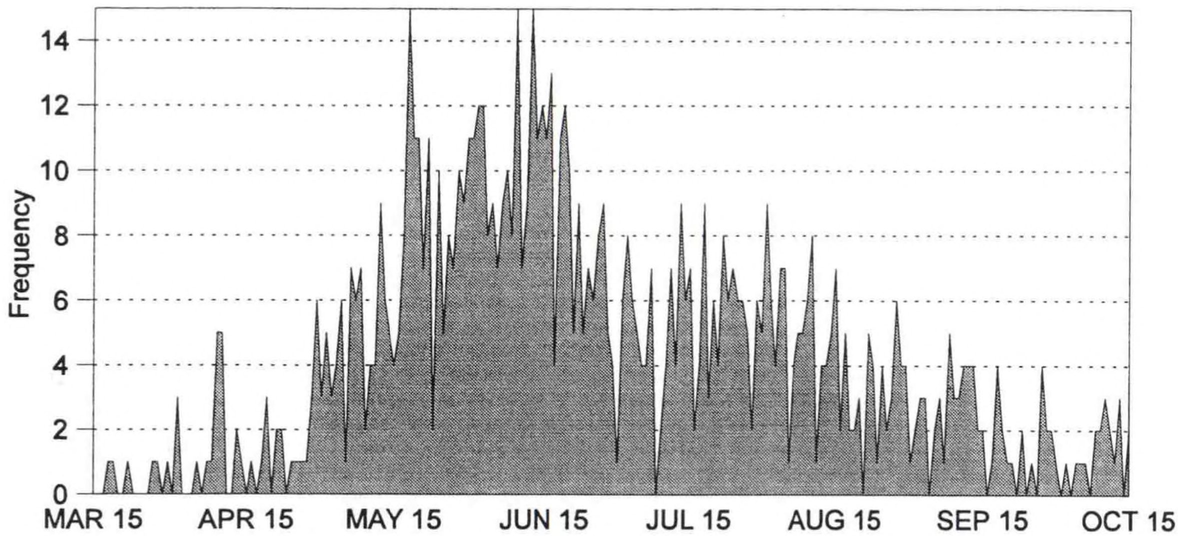


Figure 6. Frequency of all hail days-by-day.

Comparing the number of hail days with the number of thunderstorm days at Cheyenne (Table 2), it can be seen that overall about 18 percent of all thunderstorm days were also hail days. The highest percentage occurred in May with over a quarter of the thunderstorms containing hail (28 percent).

B. Hail Size

Figure 7 shows the breakdown of the diameter of the stones in the 974 Cheyenne hailstorms. Just over three-fourths of the hailstorms (751 storms) produced hail of only a quarter inch or less (< 0.6 cm). Another 137 storms produced hail from three-eighths to five-eighths of an inch (1.0 to 1.6 cm).

TABLE 2
Occurrence of Hail vs. Occurrence of Thunderstorms.

	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Total
Number of days with thunderstorms	22	211	766	1131	1346	1133	465	87	5161
Number of days with hail	7	44	214	264	167	122	62	23	904
Percentage of thunderstorm days with hail	32%	21%	28%	23%	12%	11%	13%	26%	18%

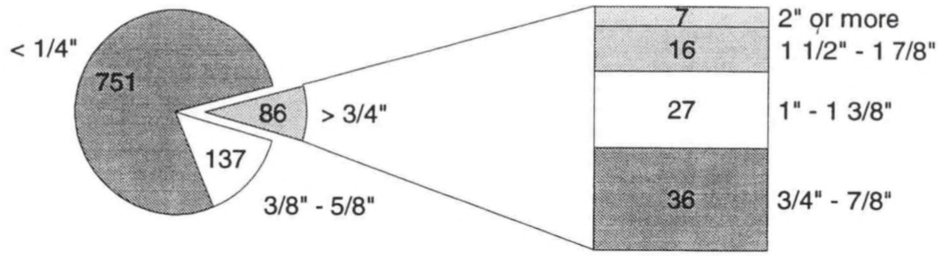


Figure 7. Number of hailstorms in each size category, based on the largest hailstone reported (total of 974 hailstorms).

The monthly frequency of hail size is shown in Table 3. May and June show the highest incidence of occurrence for smaller hail. Interestingly, the month of July has the highest percentage of hailstorms that were severe (14 percent), which is likely linked to the monsoon weather pattern that typically occurs in that month.

TABLE 3
Occurrence of Hail Size by Month, Using Individual Hailstorms.

	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Total	Percent of All storms
≤¼"	7	48	186	227	122	89	49	22	1	751	77%
⅜"-⅝"	-	1	31	40	31	24	9	1	-	137	14%
¾"-⅞"	-	-	11	7	12	3	3	-	-	36	4%
1"-1⅜"	-	-	5	9	7	6	-	-	-	27	3%
1½"-1⅞"	-	-	3	7	4	1	1	-	-	16	2%
2"-2⅜"	-	-	-	2	2	1	-	-	-	5	-
2½"-2⅞"	-	-	-	1	-	-	-	-	-	1	-
≥3"	-	-	-	-	-	1	-	-	-	1	-
Total	7	49	236	293	178	125	62	23	1	974	
Severe	-	-	19	26	25	12	4	-	-	86	
Percent of Storms Severe	-	-	8%	9%	14%	10%	6%	-	-	9%	

C. Duration

Most of the hailstorms last less than 10 minutes, according to Figure 8. The average for all hailstorms is about 12.5 minutes. The longest duration occurred during a storm on August 1, 1985 when hail fell a total of 97 minutes over a two and one-half hour period. Over six inches of rain and melted hail fell, resulting in a deadly flash flood (Glancy and Daseler 1986).

Peaks of occurrence for durations of 5, 10, 15, 20 and 25 minutes are evident in Figure 8. These peaks have been noted by other researchers (Changnon 1977). They reflect human tendencies to round off to the nearest five minutes, especially when starting and stopping weather phenomena during hectic weather situations.

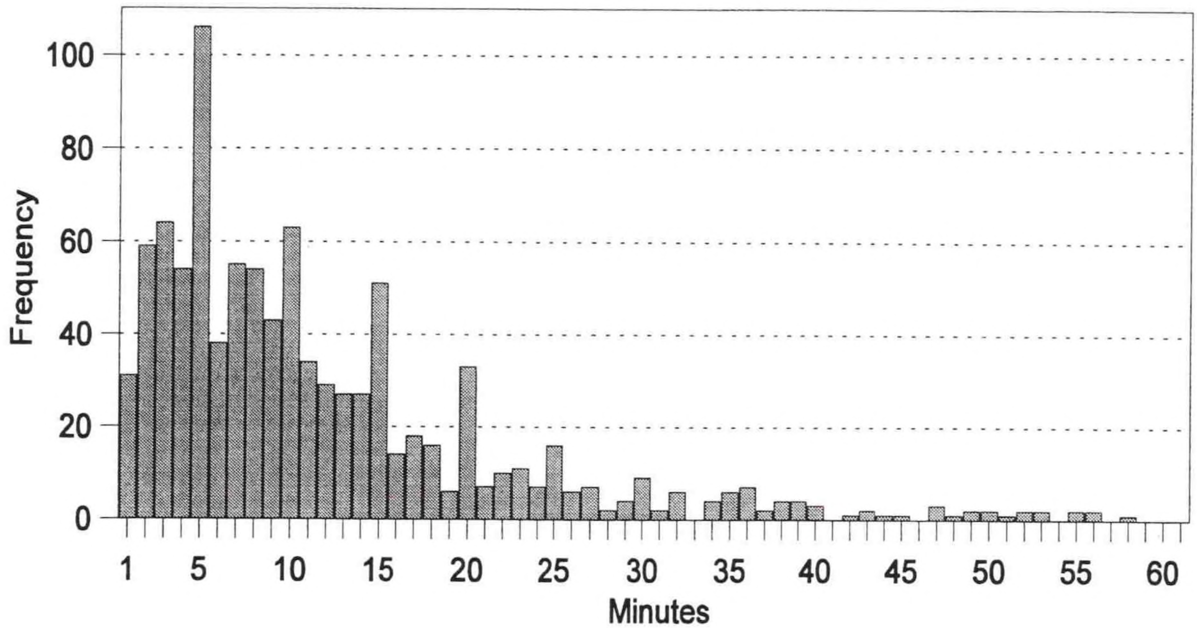


Figure 8. Frequency of the duration of all hailstorms.

D. Time of Day

The occurrence of all hailstorms by time of day is shown in Figure 9. The majority of the storms (75 percent) occur in the afternoon hours, with a broad peak between noon and 6:00 p.m. MST. This is followed by a sharp decrease through the evening hours, with a few storms lingering past midnight. A minimum of hailstorms occurs in the early morning hours between 3:00 a.m. and 6:00 a.m..

E. Consecutive Hail Days

Table 4 shows the monthly frequency of consecutive hail days. The vast majority occur as two day events, although a few three, four and even five day episodes of successive hail days have occurred. More than half of these events occur in the months of May and June, which is similar to the frequency observed for all hailstorms. Other researchers have noted this tendency for successive days of severe weather in the central High Plains region (Rodgers and Maddox 1981).

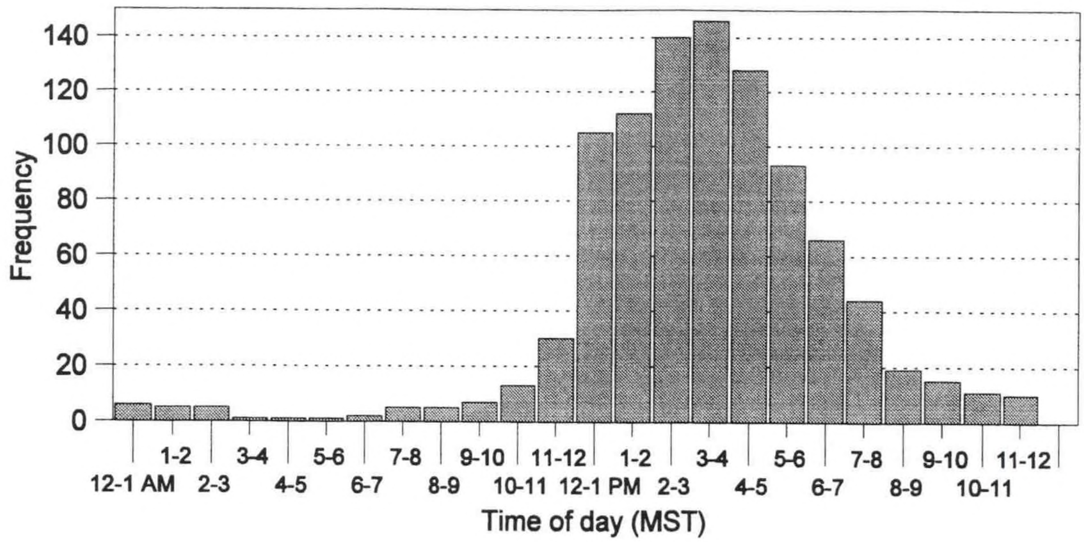


Figure 9. Frequency of the time of occurrence of all hailstorms.

TABLE 4
Number of Consecutive Hail Day Episodes by Month.

	Apr	May	Jun	Jul	Aug	Sep	Oct	Total
2 Day	4	19	27	12	7	5	1	75
3 Day	-	2	1	3	-	1	-	7
4 Day	-	-	1	-	-	-	-	1
5 Day	-	1	1	-	1	-	-	3
Total	4	21	30	15	8	6	1	86

IV. CLIMATOLOGY OF SEVERE HAILSTORMS

A. Frequency Charts

Severe hailstorms have pelted Cheyenne 86 times since 1892. Figure 10 shows their annual frequency, with severe storms occurring in 49 of the 105 years. Note that not many severe hailstorms were recorded prior to the mid 1930's, yet an increase in occurrence was recorded thereafter. This may be attributed to not only more stringent observational procedures, but also the initiation of *Storm Data* that incorporates reports of hail not only in Cheyenne but also those in the Cheyenne vicinity. This trend was not evident on the yearly chart for all hailstorms (Figure 2).

Figure 11 shows the monthly occurrence of severe hailstorms. The month of June exhibits the highest frequency. July has the second highest total, which is different from that for all hailstorms which had May with the second largest total. However, using the mid-month approach (Figure 12), the period from May 16 to June 15 has the highest frequency, which is consistent with that for all hailstorms.

The daily frequency is shown in Figure 13. There is a peak period of occurrence from the middle of May into the middle of June, similar to the daily frequency of all storms. However, another peak period of severe hailstorms exists from the middle of July into the first week of August. This differs from the frequency of all storms. This second peak is likely linked to the availability of deeper moisture associated with the monsoon from the southwest U.S. (Rodgers and Maddox 1981). Hence, even though there are somewhat fewer hailstorms during the monsoon season, a higher percentage of them tend to be severe.

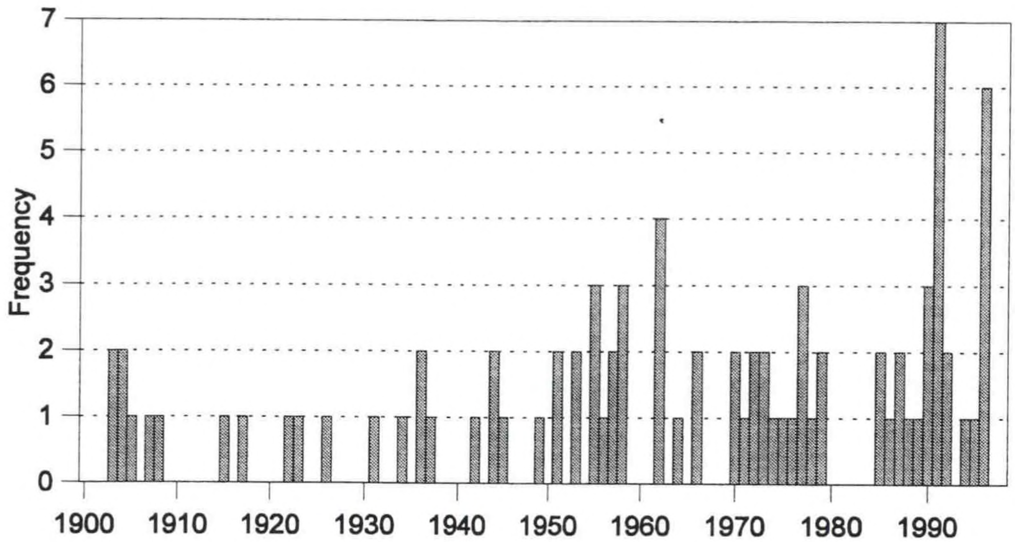


Figure 10. Frequency of severe hailstorms by year.

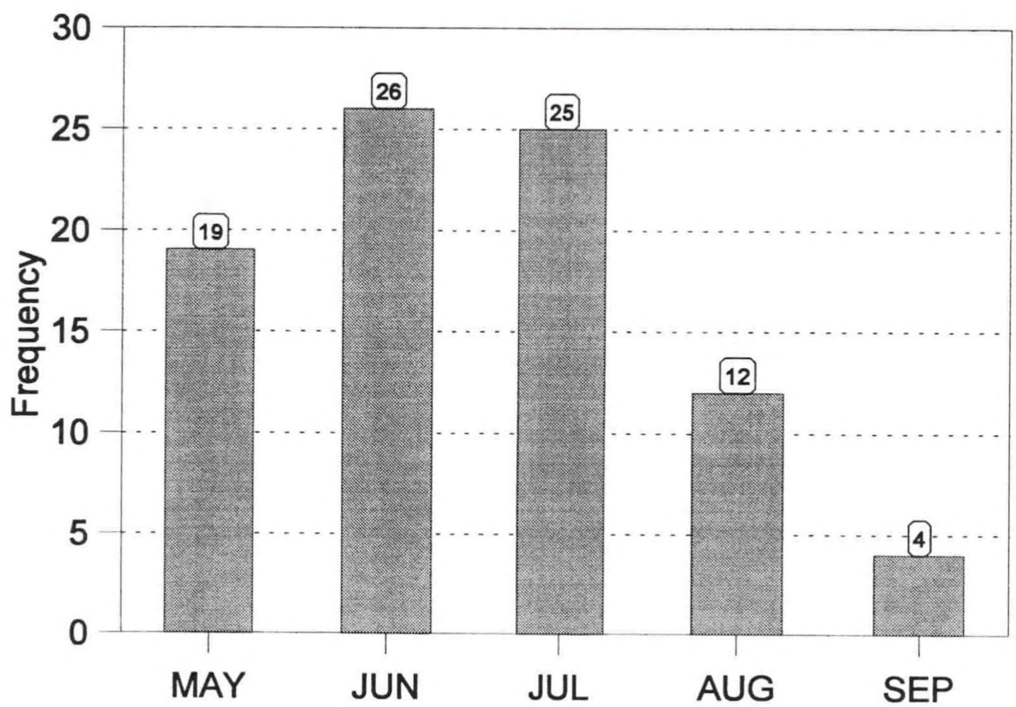


Figure 11. Frequency of severe hailstorms by month.

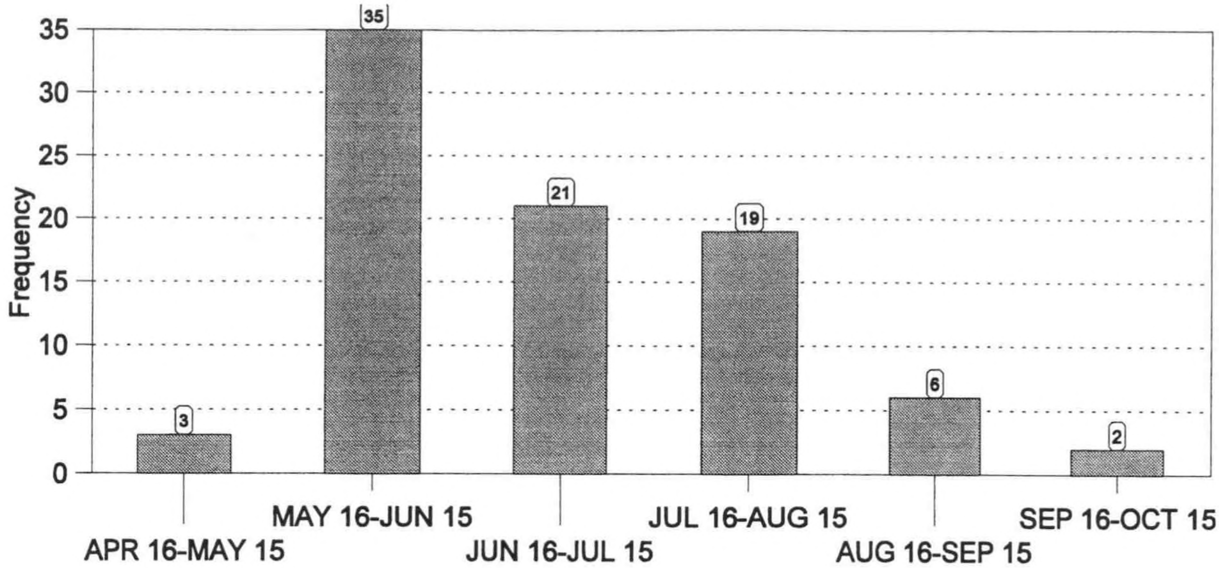


Figure 12. Frequency of severe hailstorms by mid-month periods.

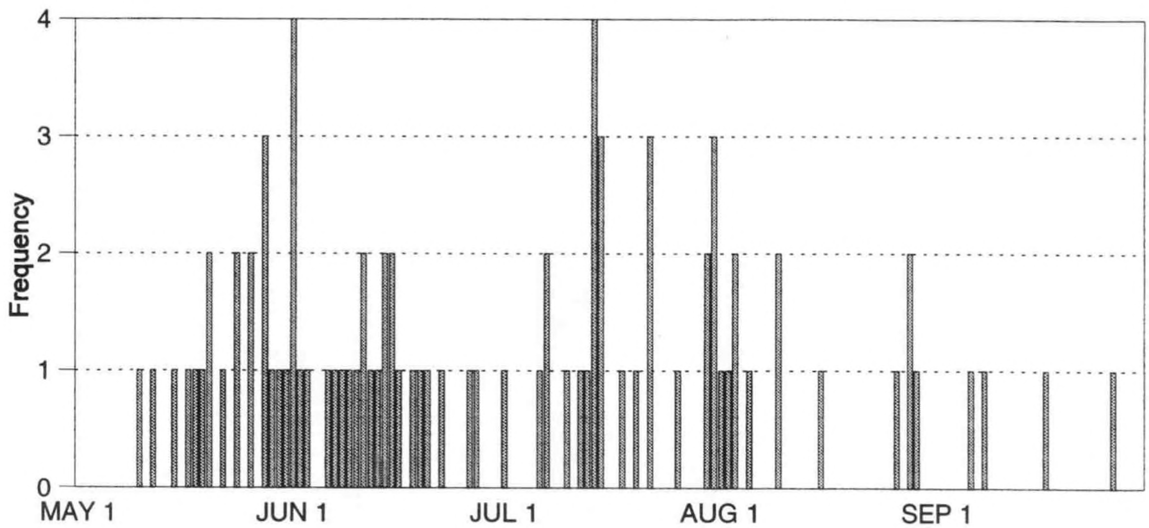


Figure 13. Frequency of severe hailstorms by day.

B. Hail Size

Figure 7 showed the breakdown of hail by size. Of the 86 severe hailstorms, about 40 percent of them produced hail under an inch in diameter (1.9 to 2.4 cm). Another 50 percent dropped hail ranging from an inch to just under 2 inches (2.5 to 4.9 cm). Only seven storms produced hail of two inches or more in diameter (over 5 cm). The largest hailstones, measuring 3 inches in diameter (7.6 cm), fell on August 2, 1957.

C. Duration

The duration of severe hailstorms is shown in Figure 14. The mean duration is around 20 minutes, which is longer than the average for all hailstorms. Even though severe hailstorms tend to last longer on average, they commonly contain a major period of small hail accompanied by a minor period of large hail. Figure 14 also does not exhibit the tendency for rounding to the nearest 5 minutes that was noted in Figure 7.

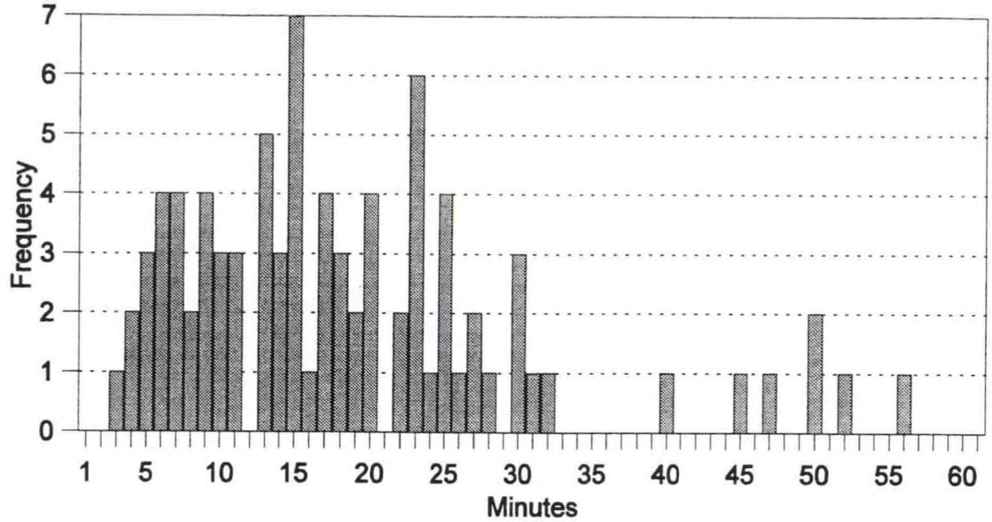


Figure 14. Frequency of the duration of severe hailstorms.

D. Time of Day

Severe hailstorms occur mainly in the mid afternoon to early evening hours (Figure 15). This is somewhat similar to that for all hailstorms, although the peak is broader for severe storms and it extends later into the 5:00-7:00 p.m. periods. After 7:00 p.m., even though there are fewer total hailstorms, a higher percentage of them (18 percent) tend to be severe than between 2:00 p.m. and 7:00 p.m. (10 percent).

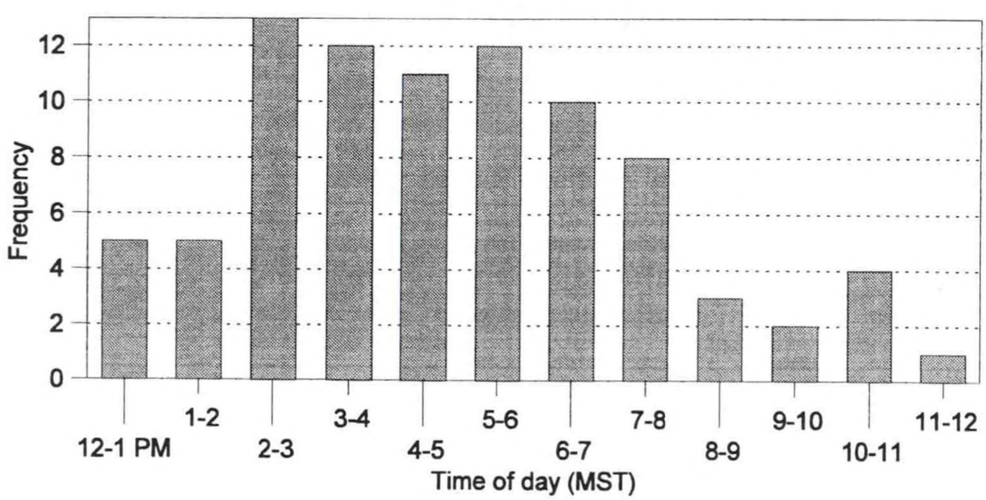


Figure 15. Frequency of the time of occurrence of severe hailstorms.

V. PRE-STORM CLIMATOLOGY AND SYNOPTIC PATTERNS OF SEVERE HAILSTORMS

Storms with large hail pose a greater danger and cause much more property damage that storms with small hail, therefore an in-depth investigation was conducted on the severe hailstorm cases. Pre-storm surface parameters such as dew point temperatures and wind directions were evaluated and categorized for these cases, using hourly observations recorded at the Cheyenne airport. For temperatures and dew points, the highest value in the two hours prior to the storm was used. For winds, the average of the values in the two hours before the storm was used. Surface and upper air patterns for severe hailstorms were also collected and analyzed. However, charts were not available for cases before 1948.

A. Pre-storm Climatology of Severe Hailstorms

1. Temperatures

Figure 16 shows the pre-storm temperatures for severe hailstorms, broken down into five degree increments. Surprisingly, nearly half of the cases were associated with surface temperatures less than 70°F, with the most cases associated with temperatures between 65°F and 69°F. However, as Table 4 illustrates, there is a gradual increase in the average temperature for severe hailstorms from May into June and July.

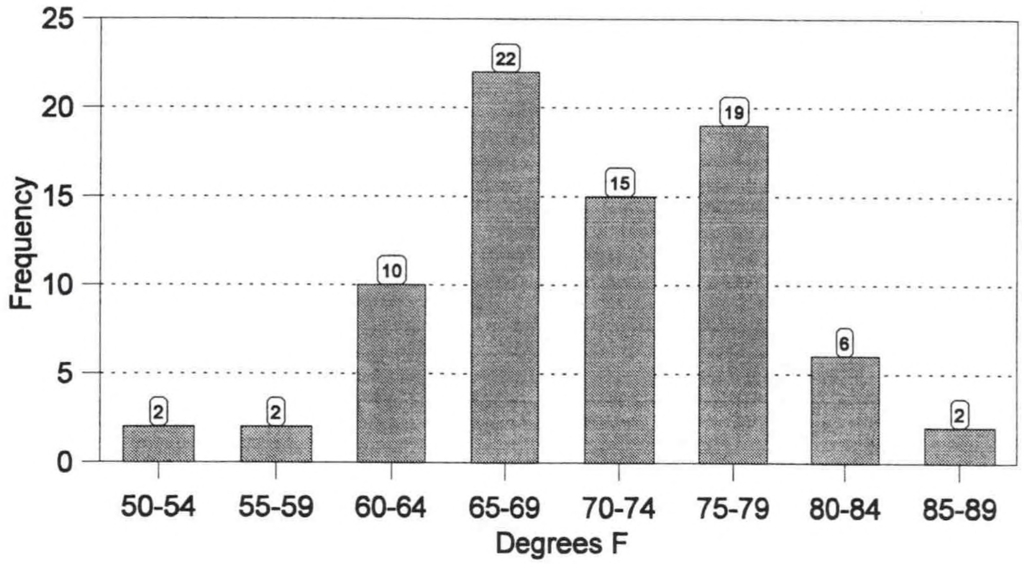


Figure 16. Frequency of pre-storm temperatures (°F) for severe hailstorms.

2. Dew point temperatures

Figure 17 displays the frequency of pre-storm dew points. By far the highest number of cases were associated with dew points in the 50°F to 54°F range. Nearly two-thirds of the storms occurred with dew points in the 50s. Figure 17 also shows that the threat of large hail generally starts with dew points in the middle 40s, which is similar to northeast Colorado (Rodgers and Maddox 1981).

Table 5 shows a breakdown of average dew points by certain periods. Dew point temperatures also gradually increase from May into June, but then drop off a little into early July. During the last two weeks in July into the first part of August, i.e., the "monsoon" season, average dew points increase again as temperatures decrease.

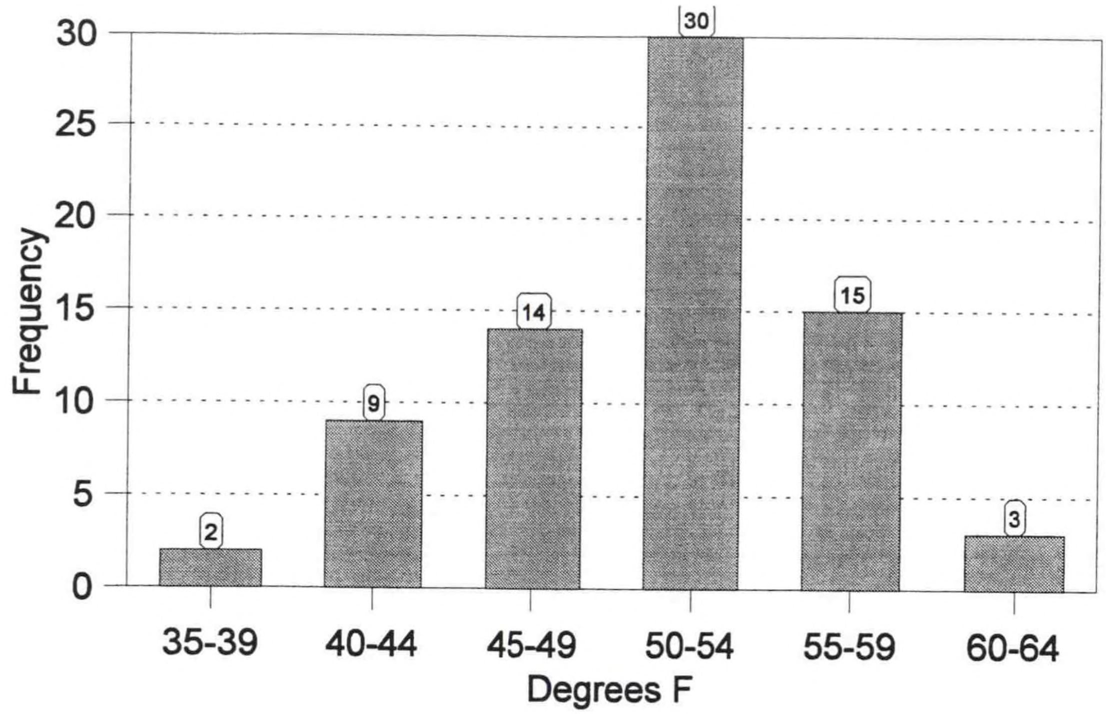


Figure 17. Frequency of pre-storm temperatures for severe hailstorms.

TABLE 5
Pre-storm Averages of Temperatures and Dew Point Temperatures (°F) for certain periods.

Period	Number of Cases	Average Temperature	Average Dew Point
May 10-Jun 7	23	64.8	48.2
Jun 8-Jun 30	16	69.3	52.3
Jul 1-Jul 14	9	78.2	49.2
Jul 15-Aug 9	16	75.6	53.4
Aug 10-Aug 31	3	74.7	46.0

3. *Wind speeds*

Figure 18 shows the occurrence of pre-storm wind speeds for severe storms. The highest frequency occurs with speeds between 10-to-14 knots, with the next highest from 5-to-9 knots. Only 17 percent of the cases had winds of 15 knots or more.

4. *Wind directions*

Pre-storm wind direction dramatically plays a major role in the development of hailstorms in the Cheyenne area. Figure 19 shows the breakdown of these storms by wind direction. The vast majority (80 percent) of the cases occurred with directions from northeast to east and southeast (the shaded region). The figure also shows that the most frequent directions were east and east-southeast, occurring in nearly half of the cases (47 percent). This is somewhat different from an earlier study in northeast Colorado which showed more of a preference for south or southeast winds (Rodgers and Maddox 1981).

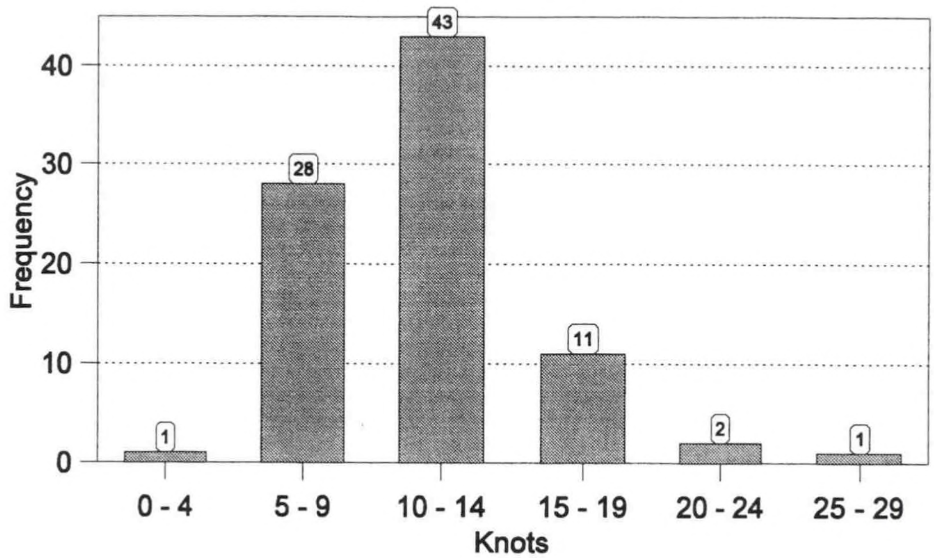


Figure 18. Frequency of pre-storm wind speeds for severe hailstorms.

B. Synoptic Patterns of Severe Hailstorms

Surface and 500 hPa charts for 63 severe hailstorm cases were analyzed, using mainly Daily Weather Maps after about 1965 and plotting of raw data when available before 1965. Initially, the storms were categorized mainly by the 500 hPa flow, but after more research (Rodgers and Maddox 1981) and analysis, a breakdown by surface pattern was also done because of the dependence on surface wind direction (Figure 19). All of the surface and upper air patterns are for 1200 UTC (5:00 a.m. MST) on the day of the event.

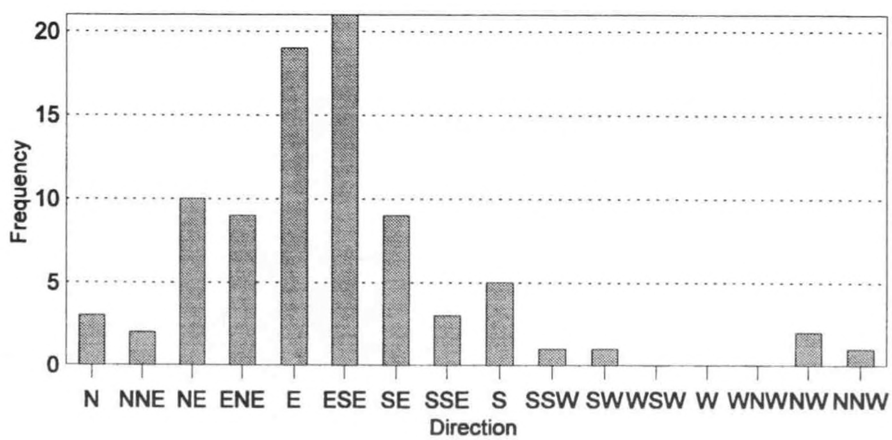


Figure 19. Frequency of pre-storm wind directions.

1. 500 hPa patterns

All of the examined storms occurred with southwest, west or northwest flow aloft at 500 hPa. Figure 20 shows a breakdown of the upper air patterns, with two examples and a frequency diagram for each type. More detailed analyses resulted in five types of southwest flow aloft, two types of west flow aloft, and three types of northwest flow aloft.

Southwest flow occurred with 25 of the cases in the study (Figure 20a). The majority of these occurred in the months of May and June when rather strong synoptic scale systems (most with a closed upper low over Nevada/Utah/Idaho and upper jet over Wyoming) move into the region from the western U.S. (Figure 20a, right). Other storms with southwest flow aloft were mainly caused by weak short wave troughs (mainly detectable in the thermal analysis at 500 hPa) moving northeast on the back side of an upper level ridge over the central U.S. (Figure 20a, left).

Westerly flow aloft occurred with 18 of the severe storms. Most of these storms occurred in June and July (Figure 20b). These cases were characterized by either a flat west-east upper ridge over the Four Corners with a weak short wave trough moving across the top of the ridge (Figure 20b, left), or by an upper ridge right over the region with no apparent short wave trough (Figure 20b, right).

Northwest flow aloft was associated with a total of 20 cases. The majority of these occurred in the month of July (Figure 20c). A number of them took place with a weak short wave trough moving through the region with an upper ridge along the West Coast (Figure 20c, left). The rest occurred with the upper ridge over eastern Idaho or western Wyoming with no readily apparent short wave trough (Figure 20c, right).

It is interesting to note from the monthly frequencies in Figure 20 that the majority of the storms transition from southwest flow aloft to west and then to northwest flow aloft as the hail season progresses. This is likely related to the gradual change from spring-like patterns with strong synoptic scale dynamics to summer-like situations dominated by the development and persistence of an upper level ridge in the western U.S. with weak or no synoptic scale dynamics.

In the presence of the west or southwest flow aloft, the storms that develop along the Cheyenne Ridge move into the Cheyenne area, and depending on surface and upper air temperatures and moisture, can become severe and produce large hail. Storms can also develop west of Cheyenne along and east of the Laramie Range where upslope easterlies initiated convection. The hypothesis of initial thunderstorm genesis areas to the west and southwest of Cheyenne is further reinforced by the fact that nearly two-thirds of the severe hailstorms were identified (primarily via surface observations) as being the first storms to move into the area.

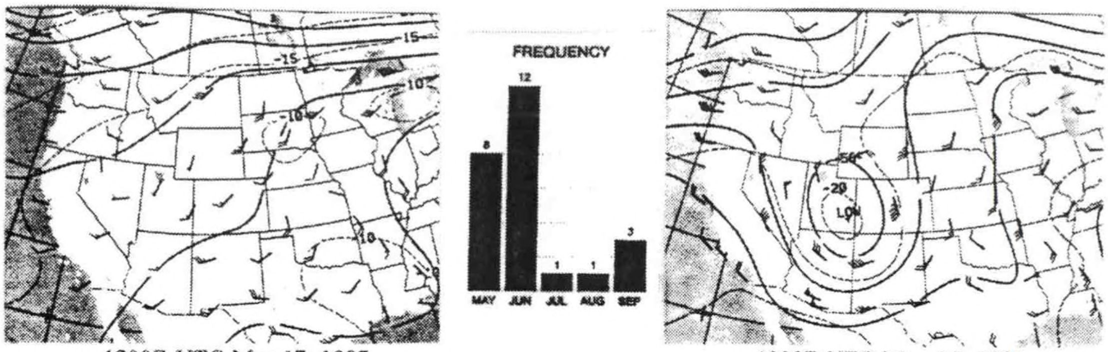
Northwest flow aloft however appears to be associated with different storm initiation zones. A number of the severe hail cases involving northwest flow aloft clearly indicated that they were caused by supercell storms moving south or southeast from the plains north of Cheyenne.

2. Surface patterns

Because of the rather large variety of 500 hPa patterns and the rather strong dependence of the severe hailstorms on surface flow, it was decided to concentrate more on the surface patterns. An analysis of the surface patterns revealed three general types, which were similar to those in Rodgers and Maddox (1981). The first two types contained storms that occurred about a day or two after a cold frontal passage, while the third type contained storms that occurred just prior to a vigorous Pacific frontal system.

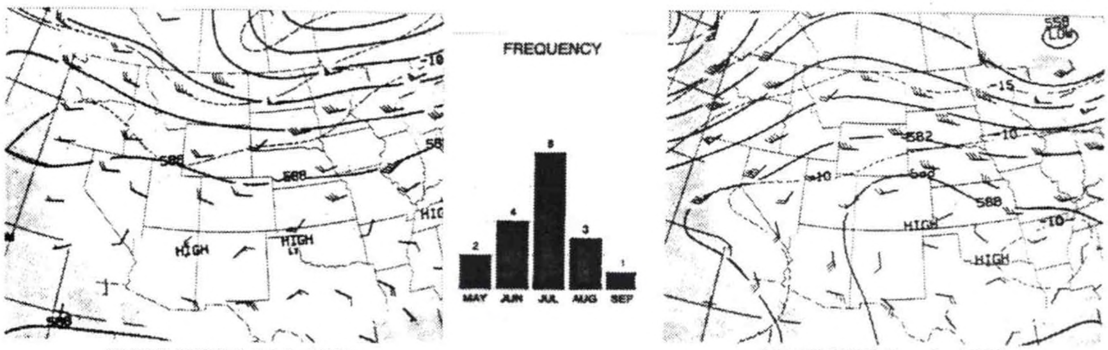
The first two types were differentiated by the time of the cold frontal or cool outflow passage. Type 1 contained cases where the passage occurred from 1 to 18 hours before the storm. Type 2 consisted of storms with frontal passage 18 hours or more prior to the hailstorm.

(A) SOUTHWEST FLOW ALOFT



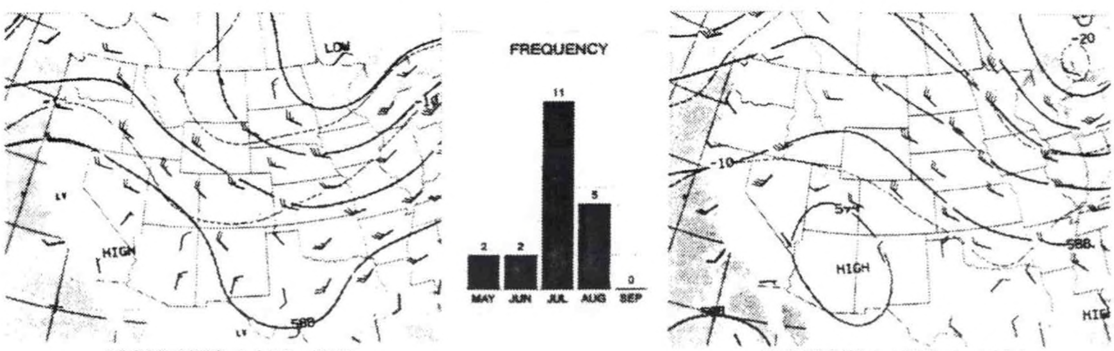
1200Z UTC May 17, 1987   1200Z UTC May 15, 1991

(B) WEST FLOW ALOFT



1200Z UTC Jul 14, 1985   1200Z UTC Jun 9, 1990

(C) NORTHWEST FLOW ALOFT



1200Z UTC Jul 22, 1990   1200Z UTC AUG 3, 1986

Figure 20. Examples of upper air (500 hPa) charts associated with different flow patterns for severe hailstorms, with frequency graphs by month for each type.

Figure 21 shows the breakdown of the surface pattern types, along with two examples of each one (valid at 1200 UTC the day of the event). The Type 1 pattern produced the most hailstorms with a total of 35 severe storms. Type 1 events (Figure 21a) were characterized by a cold front or outflow boundary in far southern Wyoming or far northern Colorado, having passed through Cheyenne at about 1 to 18 hours earlier. A surface ridge axis typically extended southeast from a high pressure area in southern Alberta or northern Montana. Higher dew points streamed into the region on north or northeast surface winds, which then become more easterly prior to the severe storm.

Type 1 storms occurred mainly during the May through August period, and more often in July than any other month. There was also a tendency for the storms to progress from southwest flow aloft during May and June, to west and northwest flow aloft in the months of July and August.

Figure 22 shows the time of occurrence of the frontal or outflow passage for Type 1 storms. The majority of the cases (25 out of 35) had wind shifts between 2:00 a.m. and 9:00 a.m. on the day of the event. Cases where the passage occurred between 4:00 p.m. and 10:00 p.m. on the day of the event when all the cases were associated with outflow boundaries from nearby thunderstorms.

The Type 2 surface pattern accounted for 14 of the cases in the study, most of them occurring in the months of May, June and July (Figure 21b). In this type, a cold front passed through Cheyenne, nearly a day or more before the event. The front had typically become stationary from across southern Kansas or northern Oklahoma then northwest along the Front Range of Colorado into central Wyoming. A surface high pressure area was located over the Northern Plains, with a surface ridge south into the Southern Plains. Moist air with high dew points was advected into the region on southeast low level flow.

In comparing the pre-storm wind directions for Type 1 and 2 surface patterns (Figure 23), there was a tendency for more of the Type 1 storms to occur with wind directions from the north through east-southeast, while the Type 2 storms were mainly associated with directions from east through south. This was likely because the Type 1 pattern had frontal passages from 1 to 18 hours before the event, while the Type 2 pattern had passages 18 hours or more before the event. Hence, winds that started out more north through east on the first day of the frontal passage tended to become more east through south on the second day. A general overall synoptic sequence becomes evident then, with the Type 1 pattern transitioning into the Type 2 pattern as the surface high pressure area drifts further east, with surface winds changing from north through east around to the southeast and south.

This tendency to have episodes of severe weather has been noted before (Rodgers and Maddox 1981). Table 4 showed the occurrence of consecutive hail days for all sizes of hail. In addition to the 86 cases shown in Table 4, there were 70 other cases that were almost consecutive hail days (hail occurred on one day, skipped a day, and then fell on the next day). Using both consecutive and nearly consecutive criteria, there were nearly 330 hail days that occurred in episodes, which is more than a third of all occurrences (38 percent). For severe hailstorms, 30 of them occurred during an episode period, about a third (35 percent) of all the severe storms.

The last type of surface pattern, Type 3, was characterized by an approaching Pacific frontal system over western Wyoming, or by a strong surface low developing in eastern Colorado (Figure 21c). In some of the cases, a weak warm front extended northwest-southeast across southeast Wyoming. The hailstorms typically occurred either just before or just after the Pacific frontal passage, with rather strong dynamics in southwest flow aloft. Only 12 of these cases occurred, with most of them in the late spring or early summer, and again in the fall.

Toth and Johnson (1985) examined the summer surface flow characteristics over northeast Colorado, and documented a diurnal pattern in the surface winds. Southeast winds were found to occur at midday across northeast Colorado in an upslope "pocket" formed by the intersection of the north-south Front Range and the east-west Cheyenne Ridge. In the Cheyenne area westward to another upslope "pocket" formed by the intersection of the north-south Laramie Range and the east-west Cheyenne Ridge, winds can become more east or northeast due to circulation around a surface high pressure. This scenario induces a well-defined convergence zone along the Cheyenne Ridge, and indeed radar studies (Karr and Wooten 1976) show that the ridge is a preferred area of initial thunderstorm development.

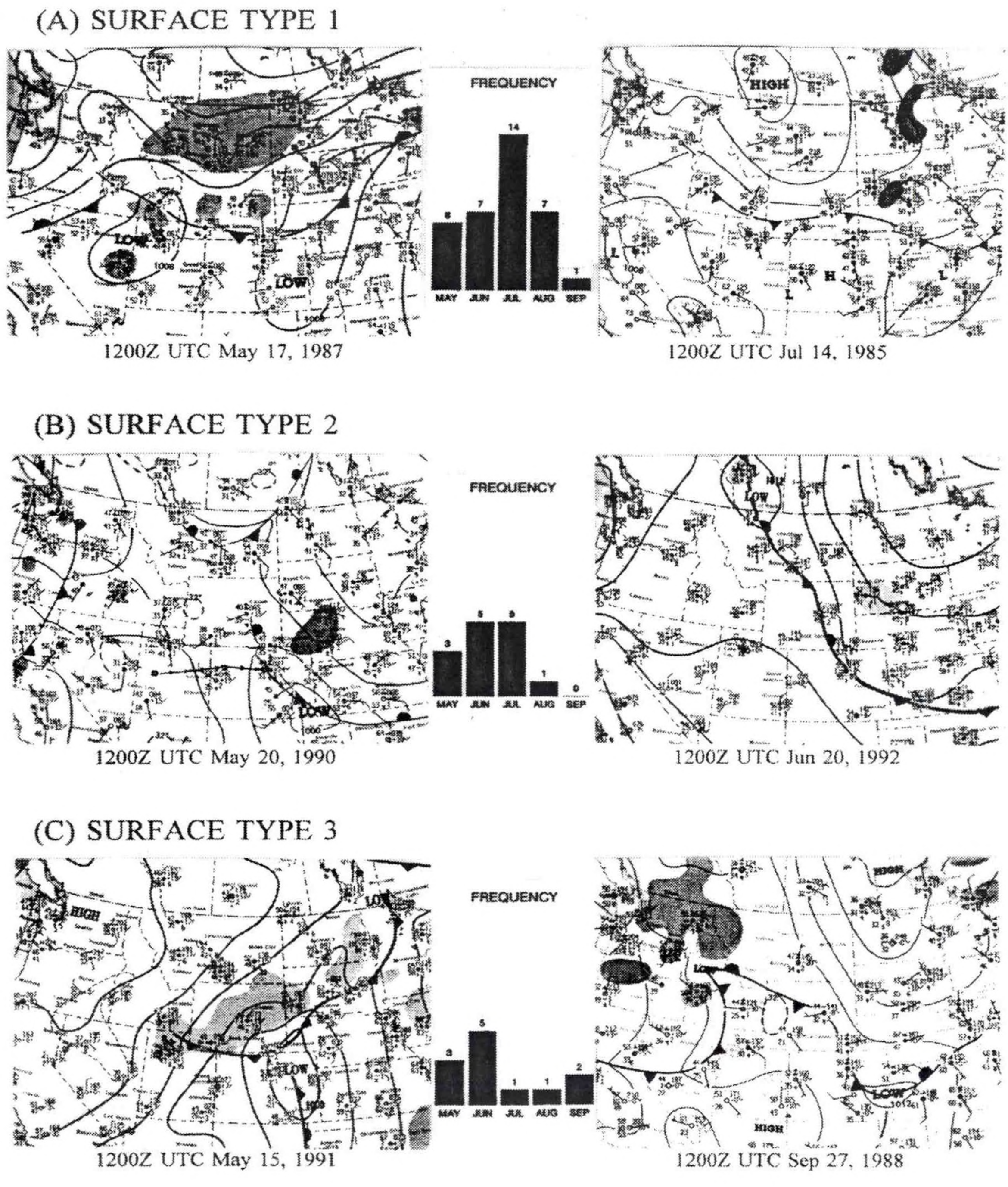


Figure 21. Examples of surface weather patterns associated with severe hailstorms, with frequency graphs by month for each type.

3. Surface flow vs. flow aloft

Figure 24 shows a comparison of the pre-storm surface flow to the flow aloft for the severe hailstorm cases. With southwest flow aloft, a wide range of surface wind directions occurred, with some from the north and northwest. For west flow aloft, the most prevalent directions are east and east-southeast, with no cases of north or northwest winds. In the case of northwest flow aloft, even more cases occurred with an easterly or southerly wind. Hence, as the flow aloft veers from southwest to west and then to northwest, there is a tendency for the pre-storm surface winds to go from more northerly and easterly around to more easterly and southerly

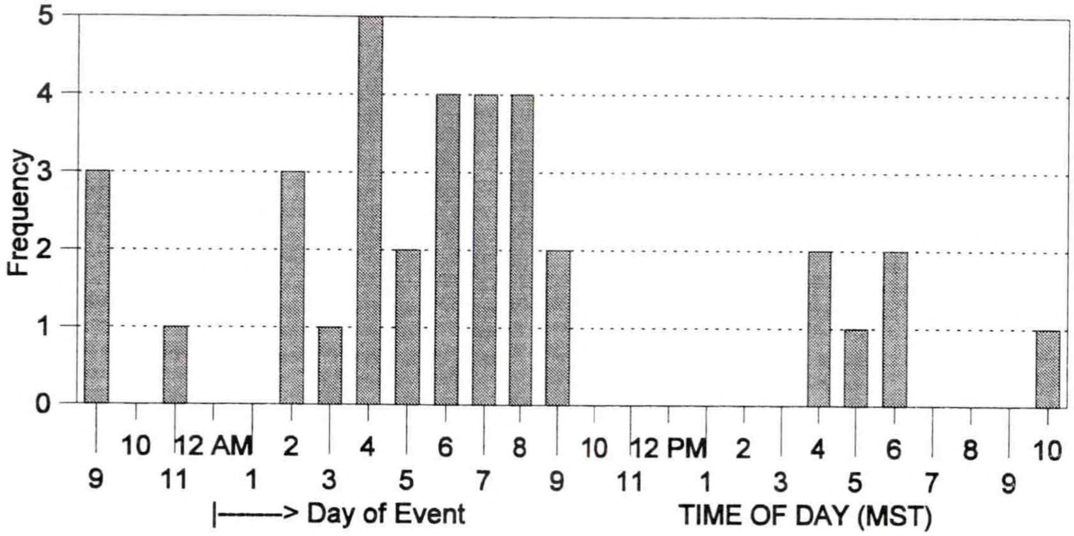


Figure 22. Frequency of the time of frontal passage prior to severe hailstorms associated with Type 1 surface patterns.

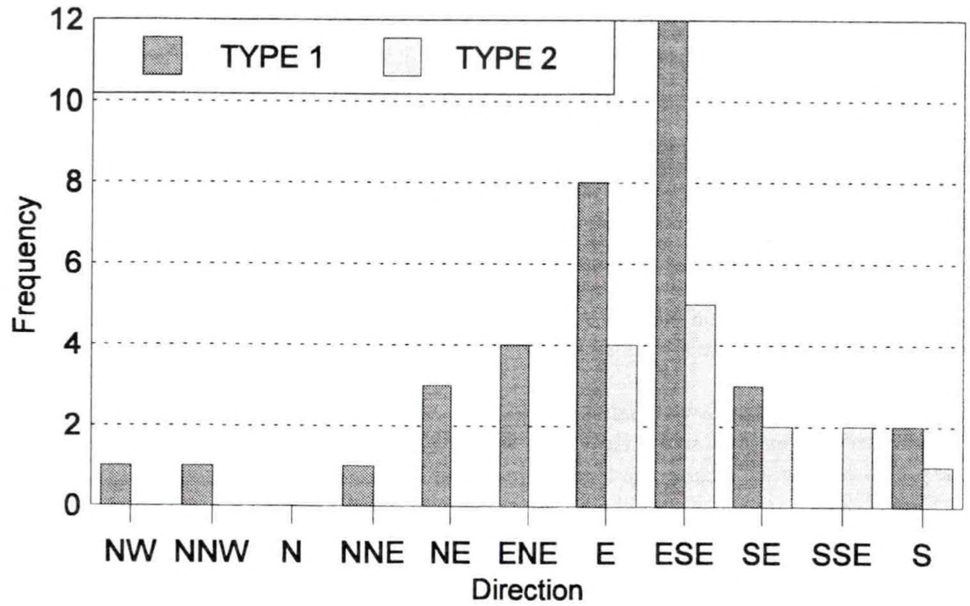


Figure 23. Frequency of pre-storm wind directions for severe hailstorms associated with Type 1 and Type 2 surface patterns.

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