NOAA TR ERL 336-APCL 35

UNITED STATES OF AMERICA · DEPARTMENT OF COMMERCE

NOAA Technical Report ERL 336-APCL 35

U.S. DEPARTMENT OF COMMERCE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
Environmental Research Laboratories

An Historical Climatology of Damaging Downslope Windstorms at Boulder, Colorado

C. DAVID WHITEMAN
JOHANNA G. WHITEMAN

BOULDER, COLO.
NOVEMBER 1974

U.S. DEPARTMENT OF COMMERCE
Rogers C. B. Morton, Secretary

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
Robert M. White, Administrator
ENVIRONMENTAL RESEARCH LABORATORIES
Wilmot N. Hess, Director

NOAA TECHNICAL REPORT ERL 336-APCL 35

An Historical Climatology of Damaging Downslope Windstorms at Boulder, Colorado

C. DAVID WHITEMAN
JOHANNA G. WHITEMAN

BOULDER, COLO.
November 1974

For sale by the Superintendent of Documents, U. S. Government Printing Office, Washington, D. C. 20402

DISCLAIMER

The Environmental Research Laboratories do not approve, recommend, or endorse any proprietary product or proprietary material mentioned in this publication. No reference shall be made to the Environmental Research Laboratories or to this publication furnished by the Environmental Research Laboratories in any advertising or sales promotion which would indicate or imply that the Environmental Research Laboratories approve, recommend, or endorse any proprietary product or proprietary material mentioned herein, or which has as its purpose an intent to cause directly or indirectly the advertised product to be used or purchased because of this Environmental Research Laboratories publication.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

AN HISTORICAL CLIMATOLOGY OF DAMAGING DOWNSLOPE WINDSTORMS AT BOULDER, COLORADO

C. David Whiteman and Johanna G. Whiteman

A climatology is developed for damaging downslope windstorms at Boulder, Colorado, based on newspaper accounts since 1869. One hundred and fifty-one documented windstorms provide the data on which statistical and climatological calculations are based. The area affected by downslope windstorms is described, information on the temporal distribution of the windstorms is given, including annual, monthly, and diurnal distributions, and windstorm characteristics are discussed. Wind-related damage is classified by severity and areal extent.

1. INTRODUCTION

Heavy Storm in Boulder

Last Wednesday night [17 November] our town was visited with the heaviest wind experienced here for the last five or six years. The storm commenced brewing about 9 o'clock in the evening and lasted till morning. From 12 to 1 o'clock it blew the hardest. At this time different parties were up, bracing their buildings, to prevent their being blown away or broken to pieces. Several new structures on the eve of completion were torn down, or moved off their foundations. The large frame building being put on Pearl Street by Mr. Andrews, was leveled to the ground entirely. It will take some hundreds of dollars to repair its damages. Eggleston's new drug store was writhed [*sic*] and twisted to one side, and had not Mr. G. feared some damage, and commenced bracing it up, his building would have fallen, demolishing another in its fall. A portion of the projecting brick gable on the store occupied by Tourtellot & Squires was blown upon the roof, crushing it in, and doing other damage. Had the weight been much heavier, it would have gone through to the ground, to the great damage of the goods in store. Mr. Sullivan's new frame dwelling, partly enclosed, was slid nearly off its foundation, and sundry other small structures about town were turned over, or otherwise damaged. At Valmont the storm did not rage as furiously, only overturning a few haystacks, etc. We have not heard the amount of damages estimated. Nearly every building the storm reached was more or less shaken, and our citizens may congratulate themselves on escaping as well as they did, and take warning to build more solidly in the future. Were the air as dense here as at sea level, it is probable the town would have been razed to the ground.

Boulder County News

The preceding article, appearing on November 23, 1869, in one of Boulder County, Colorado's earliest newspapers, describes a destructive windstorm that caused damage to the city during the gold rush days. The windstorm of 1869 is a rather typical example of a class of damaging winter windstorms which have struck the Boulder area with surprising frequency over the years. Property damage, injuries, and occasional fatalities have resulted from these strong gusty winds since the Boulder Valley was first settled in the 1850's. Although few weather records are available for the first years of Boulder's history, considerable information on the occurrence and effects of these damaging windstorms is available from early newspapers. This NOAA Technical Report presents a climatology of Boulder's damaging downslope windstorms and is based on information available from local area newspapers from 1869 through 1972. Climatological data include the frequency of damaging windstorms, their annual and monthly distributions, their characteristics, and their effect on Boulder residents and property.

2. DOWNSLOPE WINDSTORMS

Boulder, Colorado (elevation 1632 m), is located on the western edge of the High Plains at the foothills of the Rocky Mountains. The mountains rise abruptly on the west edge of Boulder and culminate 30 to 35 km to the west in a north-south chain of peaks over 3700 m high (fig. 1). These peaks are part of the Colorado Front Range and lie on the Continental Divide. Westerlies are the prevailing winds in the western U.S., and consequently Boulder is in the lee of the mountains.

Occasional brief episodes of strong gusty winds are known to occur in the lee of many of the mountain ranges of the world. Many lee winds are of the foehn variety, a generic classification of winds which were first studied in the Alps. Foehn winds are warm, dry winds in which warming and drying are caused by adiabatic compression as the air descends the mountain slopes on the leeward side of a mountain range. Huschke (1959) presented the following description of foehn conditions attributed to F. Defant:

> The foehn is characteristic of nearly all mountain areas. It is associated with cyclonic scale motions, being produced only when the circulation is sufficiently strong and deep to force air completely across the major mountain range in a short period of time. The exact local nature of foehn winds, however, varies widely and depends on the local topography, the strength of the basic flow across the mountain, the amount of moisture lost through precipitation on the windward side, conditions prior to the onset of the foehn, etc.
>
> The name originated in the Alps where it is best developed, especially as the <u>south foehn</u> on the northern slopes, and where south-north valleys open into plains or large east-west valleys, as at Innsbruck. In other mountain regions the foehn has a variety of local names: <u>chinook</u> of the Rocky Mountains; <u>zonda</u> of the Argentine (for a westerly foehn);

puelche in the Andes (for an easterly foehn); ljuka in Carinthia (northwestern Yugoslavia); halny wiatr in Poland; austru in Romania; favogn in Switzerland. A northeasterly foehn descending the Massif Central of France and extending over the Garonne plain is locally called aspre. A dry wind from the northwest descending the coastal hills in Majorca is named the sky sweeper. In New Zealand a foehn blowing from the New Zealand Alps onto the Canterbury plains is the Canterbury northwester.

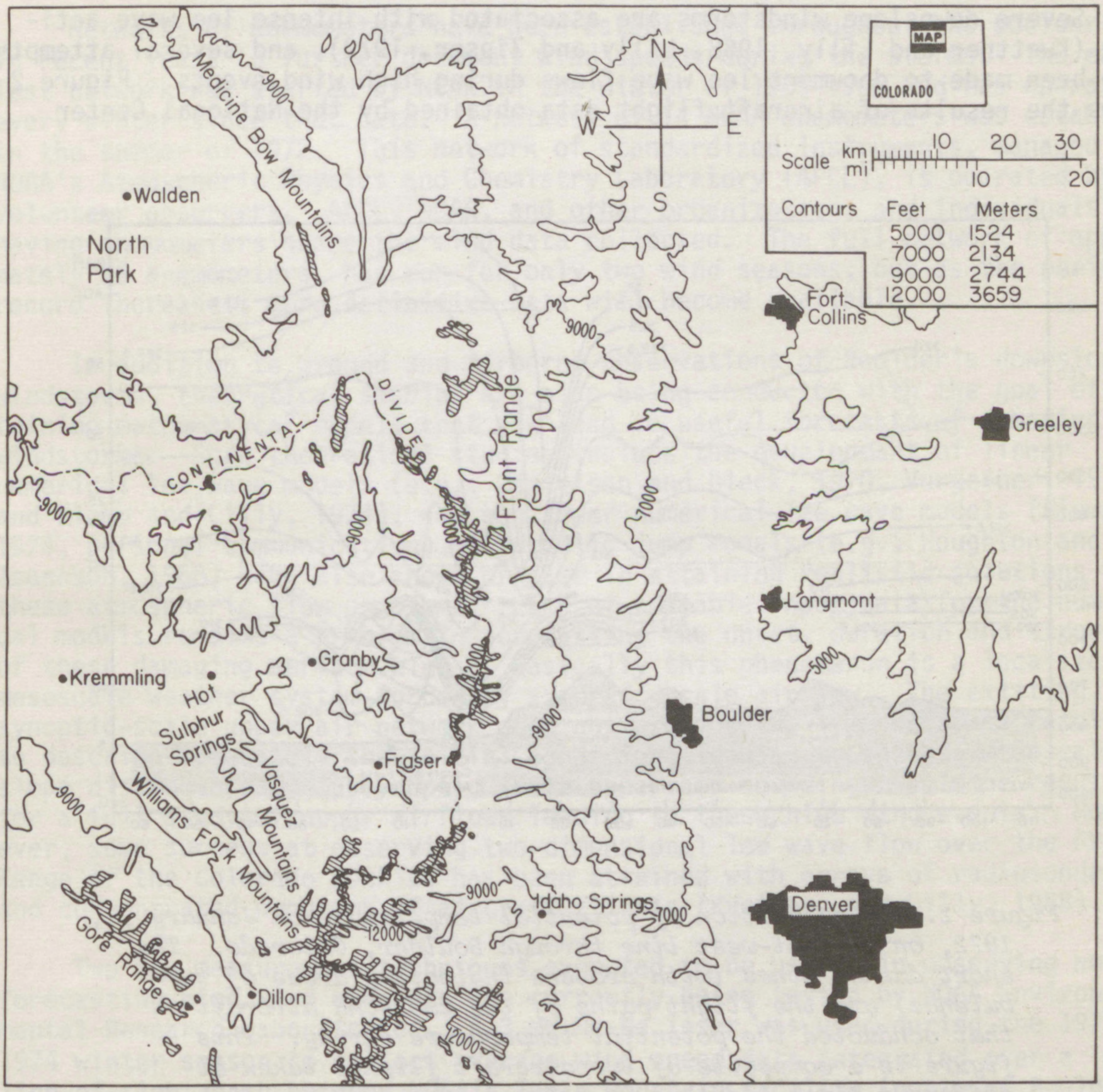

Figure 1. Topography of north central Colorado.

Many of Boulder's damaging winds are foehn, or chinook, winds. Some however, do not satisfy the classical definition of foehn winds since they advect relatively cold air into the region. Brinkmann (1971, 1973) suggests that some of these winds show characteristics of a bora circulation: a downslope wind having a source so cold that the air reaching the foot of the mountain range has received insufficient dynamic warming to raise the air temperature to the normal temperature of the region (Huschke, 1959).

While the temperature and humidity characteristics of these winds have been explained by their adiabatic compression heating and the temperature of the air mass in the source region, the mechanism causing Boulder's winds to reach the surface with such turbulence and force is less well understood.

Severe downslope windstorms are associated with intense lee wave activity (Kuettner and Lilly, 1968; Lilly and Zipser, 1972), and several attempts have been made to document lee wave flows during high wind events. Figure 2 shows the results of aircraft flight data obtained by the National Center

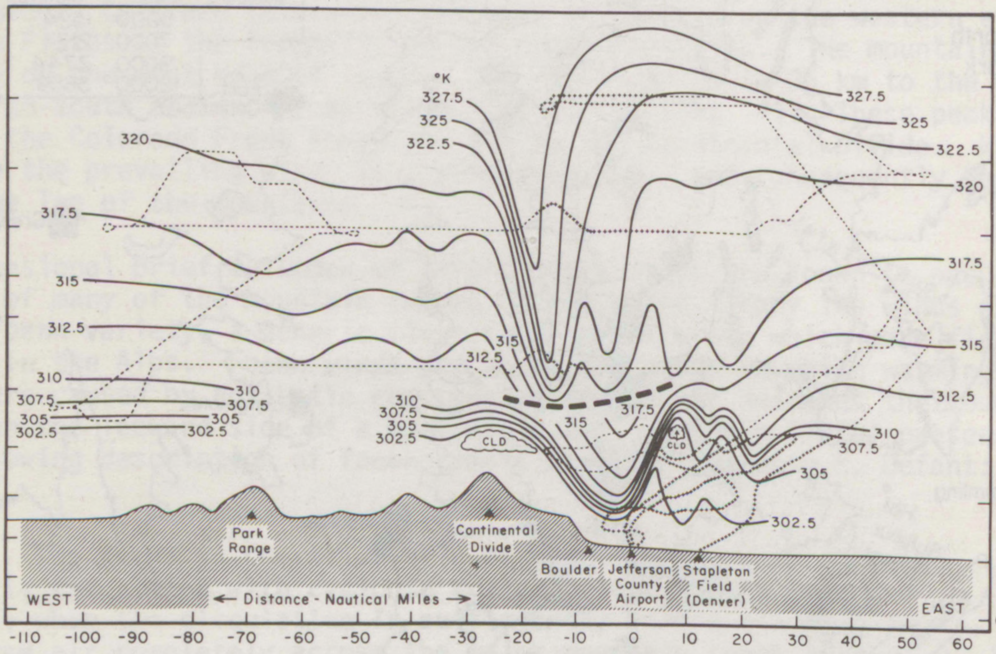

Figure 2. Cross section of potential temperature on January 11, 1972, on an east-west line through Boulder, Colorado. The short dashed lines (with crosses indicating areas of turbulence) are the flight paths of the two NCAR aircraft that conducted the potential temperature survey. This figure is a composite of two aircraft flights taken at different times and thus is not continuous (heavy dashed line marks discontinuity). Lines of constant potential temperature can be considered as streamlines of atmospheric flow (from Lilly and Zipser, 1972).

for Atmospheric Research (NCAR) during the destructive windstorm of January 11, 1972 — a storm that caused over $2.5 million of property damage in the Boulder area. Figure 2 illustrates the unusually intense lee flow disturbance generated during the storm.

Downslope windstorms in the Boulder area have also been observed with ground-based networks of instruments. Studies of the damaging windstorms on January 7, 1969, and January 11, 1972, have been published by Julian and Julian (1969) and Lilly and Zipser (1972). Sangster (1972) studied several years of winter wind data and Brinkmann (1973) conducted a comprehensive study of surface wind characteristics of 20 windstorm episodes. To date, Brinkmann's (1973) study is the most comprehensive analysis of Boulder high wind episodes.

Networks of anemometers have been established throughout the Boulder area in recent years to further document wind speeds during the storms. The earliest network was started by NCAR in the winter of 1965-1966 and has operated every winter since that date. A network of 14 NOAA anemometers was established in the summer of 1972. This network of standardized instruments, managed by NOAA's Atmospheric Physics and Chemistry Laboratory (APCL), is operated by volunteer observers. APCL, NCAR, and other organizations and individuals having anemometers share the wind data collected. The full network of approximately 25 anemometers, has run for only two wind seasons, but as the period of record increases, more definitive data will become available.

In addition to ground and airborne observations of Boulder's downslope windstorms, theoretical studies are also being conducted with the goal of obtaining mathematical models that can lead to useful forecasts of damaging windstorms. Such theoretical studies include the development of linear numerical lee wave models (e.g., Danielsen and Bleck, 1970, Vergeiner, 1971, and Klemp and Lilly, 1974), and nonlinear numerical lee wave models (Klemp, 1974, personal communication). Hydraulic jump models (e.g., Houghton and Isaacson, 1968) have also shown promise in attaining realistic solutions to these atmospheric flow problems. Lack of suitable input data for the numerical models remains a problem in forecasting the onset, duration and strength of these damaging surface winds. Basically this phenomenon is a localized mesoscale weather system forced by synoptic-scale airflow. The existing synoptic-scale upper air network does not provide the time or space resolution to describe adequately the initial conditions leading to intense mesoscale lee slope disturbances. Subsynoptic scale upper air soundings would be required for a full study of upper airflows leading to these high wind events. However, some success at observing two-dimensional lee wave flow over the Front Range of the Colorado Rockies has been attained with arrays of radiosondes and concentrated programs of aircraft flights (Kuettner and Lilly, 1968).

Two new measurement techniques expected to be useful in observing and forecasting high wind episodes are currently being tested by NOAA Environmental Research Laboratories. A 3 mW He-Ne laser was used during the 1973-1974 winter season to collect average wind speed data integrated over a line-of-sight path between NOAA's Table Mountain facility (north of Boulder) and NCAR's Table Mesa site (south of Boulder). The measurement technique used has been described by Lawrence et al. (1972). This technique shows promise for collecting windstorm data in the lower layers of the atmosphere below the safe operating levels of instrumented aircraft. Additionally, a monostatic acoustic echo sounder (Hall, 1972) was stationed at Fraser, Colorado, during the spring of 1973 to monitor the formation of stable layers on the windward side of the Rockies. Refinements of this technique will allow the vertical profile of wind speeds to be determined by acoustic Doppler methods. The physical basis for the stable layer monitoring program was provided by numerical models and by Brinkmann's climatology (1973) which demonstrated a reltionship between the formation of inversions at elevations slightly higher than mountain top level on the windward side of the Rockies and the occurrence of lee wave disturbances farther east.

The synoptic weather patterns leading to high winds in the lee of mountains have long been recognized by meteorologists and can often be forecast, but the biggest unresolved problem is the forecast differentiation between the most severe damaging windstorms with gusts over 100 mph (45m/sec) and the less severe — but more frequent — storms in which gusts reach only 50 to 70 mph (22 to 31 m/sec). Figure 3 shows an example of a synoptic weather pattern leading to a downslope windstorm. Note the high pressure center west of the Continental Divide, a strong pressure gradient across the divide, and a trough along the eastern foothills of the Rocky Mountains. This lee trough or dynamic trough, is often seen during foehn conditions and is attributed to the relatively warm air in the lee of the mountains that is produced by compression heating of descending air. Cyclogenesis is another mechanism causing a lee trough to develop since a cyclonic circulation may form where vertical columns of air are being stretched leading to horizontal convergence.

A strong surface pressure gradient, however, is not in itself a sufficient condition for the development of damaging downslope winds. Strong winds at higher levels of the atmosphere are also necessary. Strong westerly winds aloft — ones that flow directly across the north-south oriented Rocky Mountains — are most conducive to the development of severe downslope windstorms. Figure 4 shows the wind field at 500 mb (ca. 5550 m, or 18,300 ft, above sea level) during the destructive windstorm of January 7, 1969. Note the direction and strength of the winds over northern Colorado.

The availability of routine synoptic-scale upper air data collected by the National Weather Service (NWS) has led to several attempts to develop statistical operational forecasting techniques for these windstorms. The statistical methods generally begin by tabulating and analyzing meteorological data from past high wind episodes. The value of the predictand (surface wind speed) is determined and likely predictors are chosen from available synoptic data. A statistical analysis of the data from a number of high wind episodes results in the selection of the most useful predictors. The statistical model is then run on independent data, and its accuracy is determined.

Wayne E. Sangster (1972) of the National Weather Service Central Region used a screening regression analysis technique to develop an operational objective model for use by the Denver National Weather Service Forecast Office to forecast Boulder's winds. Of the predictors tested statistically in his model, the two showing the greatest utility were (1) the value of a quantity describing the low-level pressure difference across the mountains, and (2) the value of a quantity describing the westerly component of airflow at higher levels.

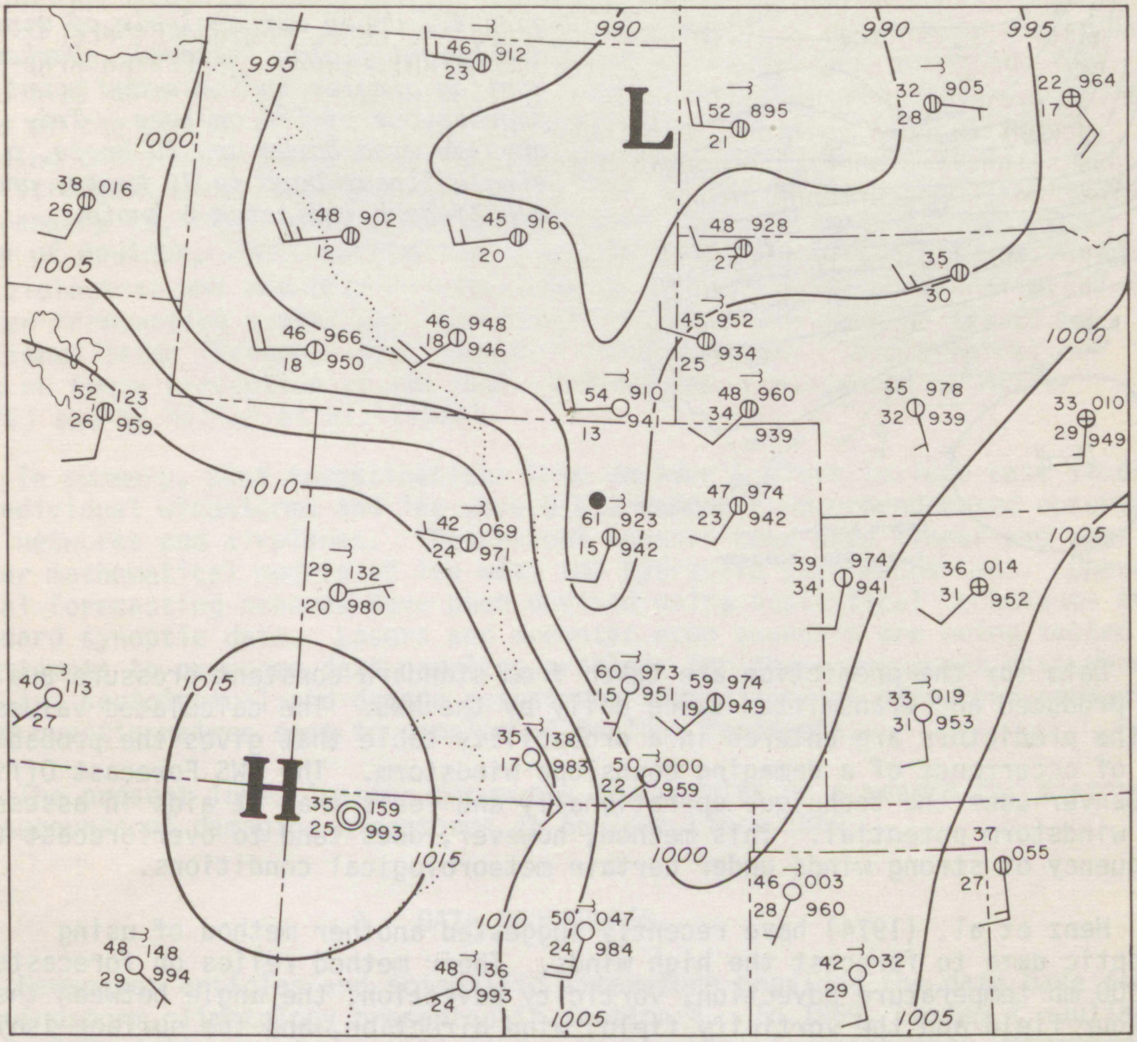

Figure 3. Surface weather map and pressure pattern - January 7, 1969, 1800 MST. Altimeter settings are at the lower right of the station model. Other parts of the station model are conventional. The dotted line shows the Continental Divide (from Julian and Julian, 1969).

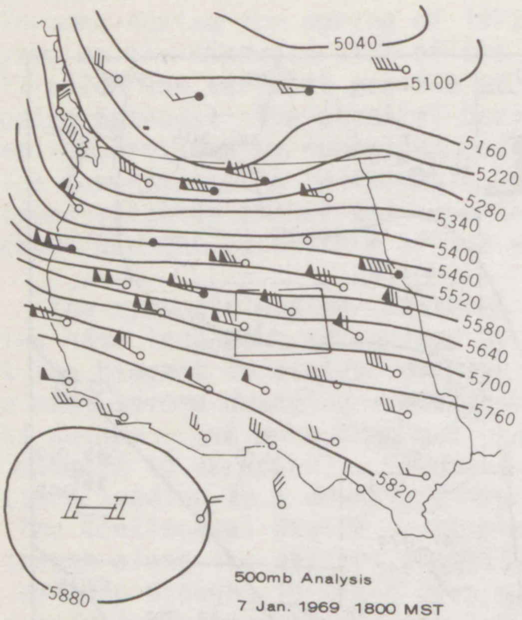

Figure 4. Upper air analysis of wind and height fields (meters). Darkened station circles indicate dew point depressions of 5°C or less. Triangular wind barbs are 50 knots, a single linear barb is 10 knots, and a half-barb indicates 5 knots.

Data for the prediction are taken from standard constant pressure analyses produced and transmitted twice daily by the NWS. The calculated values of the predictors are entered in a probability table that gives the probability of occurrence of a damaging downslope windstorm. The NWS Forecast Office in Denver uses the technique operationally and feels that it aids in assessing windstorm potential. This method, however, does tend to overforecast the frequency of strong winds under certain meteorological conditions.

Henz et al. (1974) have recently suggested another method of using synoptic data to forecast the high winds. Their method relies on forecasts of 500 mb temperature advection, vorticity advection, the angle between the contour field and the vorticity field, wind direction, and the surface isallobaric field. The success of their model in predicting high wind episodes has not yet been fully verified. This synoptic model is built around Brinkmann's (1973) work in which certain characteristics of synoptic-scale flow were found to be associated with strong winds in Boulder. Of special interest is the occurrence of an inversion slightly above the mountaintops on the windward side of the range and below the mountaintops on the lee side. Henz et al. interpreted the inversion noted under foehn conditions as being caused by a strong subsidence field, and their forecast method relies on synoptic means of forecasting this field.

The statistical approach used in most of the operational forecast schemes suffers from a lack of accurate data on the most severe and damaging storms. Anemometers have collected wind data in Boulder County only since the late 1920's, with the earliest anemometer apparently having been installed at Valmont, east of Boulder. Many wind records have been lost over the years, and the comparison of wind velocities at different locations has been difficult because of the wide variety of exposures and heights of instruments.

An accurate short-term forecast of downslope wind velocities could be expected to yield great dividends for Boulder's residents, since various precautions could be taken before the onset of the storm. A survey of wind-related property damage after the January windstorms of 1969 (City of Boulder, 1970) produced much information on the types of damage that occurred, the means available to individuals and governments to reduce the damage, and the costs of the storms to Boulder's residents. As a result of this survey, building codes were changed to require more rigorous roofing standards and more stringent wind-loading requirements for fences (City of Boulder, 1971). The January 11, 1972, windstorm prompted more changes in the building code (City of Boulder, 1972) calling for blocking and tying down of mobile homes. A sociological and economic impact study to assess the potential value of a better forecasting system was recently circulated; the results are to be published later (Bergen, 1974, personal communication). Sociological work on human perception of the high wind hazard is discussed by Miller (1972) and by Miller et al. (1974).

In summary, past investigations into Boulder's winds include case studies of individual windstorms and lee wave disturbances from ground-based observation networks and airplanes. Theoretical studies have used linear and non-linear mathematical models of lee wave and hydraulic jump mechanisms. Operational forecasting schemes have been devised using statistical techniques and standard synoptic data. Lasers and acoustic echo sounders are being tested in attempts to overcome data sampling problems for these mesoscale disturbances. Finally, sociological and damage assessment investigations have been conducted using questionnaires sent to samples of Boulder residents.

The present investigation documents the results of a search for historical accounts of damaging windstorms in Boulder since 1869.

3. DATA PROCEDURES

Newspaper articles and scientific literature provided the data base for the windstorm climatology presented in section 4. In 1969, Lesley T. Julian and Paul R. Julian wrote an article for Weatherwise in which they described the January 7, 1969, windstorm and presented a preliminary climatology of Boulder's windstorms based on newspaper accounts and the U. S. Environmental Data Services Publication, Storm Data. Seventy-six windstorms that had occurred since 1906 were included in their climatology. Their preliminary data, consisting mostly of windstorm dates, were loaned to the authors and became the basis for a more exhaustive search for newspaper accounts of windstorms.

Dates of newspaper articles on Boulder windstorms were obtained from WPA topical indices for the Rocky Mountain News from 1865 to 1885, the Boulder County News from 1869 to 1880, and the Boulder Daily Camera from 1891 to 1900. In a few instances, newspaper accounts referred to new storm dates, which led to a page-by-page search for articles describing those storms. Page-by-page searches were also conducted to locate reports of the storms included in the Julian climatology. Finally, clippings in the Boulder Daily Camera's topical files were reviewed.

Most of the storms included in the climatology occurred since 1946. The incompleteness of the data before the end of World War II and the consequent bias of the climatology toward the more recent years are due to two main factors:

1. Not all windstorms were reported by newspapers. Because most of the early Boulder County newspapers were weeklies (Oehlerts, 1964), windstorms causing little or no damage might not have been newsworthy enough to be reported unless they occurred just before the publishing deadline. Probably only the most damaging Boulder windstorms were reported to Denver newspapers, since Denver was often unaffected by the winds. The poor communications networks of the early years may also have reduced the amount of coverage by the Denver papers.

2. Information on early windstorms was difficult to find. Indices are available for only two of Boulder County's 19th Century newspapers and none are available after 1900. Collections of most Boulder County newspapers are incomplete or nonexistent. The file of newspaper clippings at the Boulder Daily Camera was irregularly maintained until after World War II.

The search for windstorm dates produced 187 windstorms. Accounts of the windstorms were then carefully and repeatedly studied to extract the climatological and statistical information, which is presented in Appendix A. Forty-nine storms were eliminated from the original list of 187 windstorms because they produced no damage in Boulder, or were judged not to be true downslope windstorms. No attempt was made to check weather maps to verify whether individual storms were true downslope windstorms. It is felt, however, that sufficient information is provided by newspaper accounts to make this determination since windstorm types are generally quite different in several important respects (table 1). Thirteen of these windstorms having no reports of property damage but having published wind velocities above calculated damage thresholds (as determined by correlating the occurrence of damage with peak windspeeds for individual anemometers) were included in the statistical sample to provide a total of 151 damaging downslope windstorms at Boulder, Colorado. Appendix B presents the damage threshold analysis for individual anemometers in the Boulder area.

Some general comments are in order relating to the quality of these data and the applicability of the statistical results. First, as stated above, the data sample is biased towards inclusion of the most recent storms. Second, the amount of newspaper coverage of individual storms has increased markedly in the past 10 to 20 years. Third, the classification of data into quasi-objective categories required subjective assessment of newspaper windstorm accounts, the quality and consistency of which are affected by reporter-related factors and by external factors, such as copy deadlines and availability of communication and transportation facilities. Also, storms vary in newsworthiness, as shown by the good coverage given minor storms that follow a major damaging storm.

Table 1. Typical Characteristics of Windstorm Types

Characteristic	Thunderstorms	Cold Frontal Passage	Downslope Windstorm
Duration of Winds	Isolated gusts, short storm duration	1/2 to several hours	Several hours to several days
Precipitation	Thundershowers-possible hail	Showers - possible associated thunderstorms	Generally no precipitation during the windstorm
Clouds	Cumulonimbus	Cumulus types	Clear or partly cloudy with high and middle level clouds - possible isolated rotors
Wind direction	Variable	Generally northerly - wind shift with frontal passage	Westerly
Season	Generally warm season	All seasons	Generally cold season

Statistical computations are, in general, based on data from all 151 windstorms. The sample is considered to be large enough and sufficiently representative of damaging windstorms in Boulder to provide useful information on this natural hazard that affects the Boulder Valley.

4. WINDSTORM CLIMATOLOGY

4.1 Areal Extent of Downslope Windstorms

Strong downslope windstorms in the lee of the Central Rocky Mountains generally occur in a narrow band extending along the foothills from Colorado Springs to Cheyenne, Wyoming, and in some of the mountain communities on the eastern slopes. Damaging windstorms apparently occur most frequently in the Boulder area, midway between Colorado Springs and Cheyenne. The total area affected by the damaging windstorms varies greatly from storm to storm. Section 1 of Appendix C presents accounts of two windstorms limited in areal extent. Accounts of the November 23, 1869 windstorm which affected several eastern slope communities, are also included in section 1 of Appendix C. A more current windstorm causing damage in many communities occurred on January 11, 12, 1972 (App. A).

4.2 Temporal Distribution of Damaging Windstorms

Annual. Table 2 lists the number of windstorms included in the data sample for each year since 1869. Nearly one-half of the windstorms in the data sample occurred since 1961, and three-quarters have occurred since 1936.

Table 3 shows the distribution of the same data by "wind year," defined as the period from July 1 of one year through June 30 of the next year. The number of storm days as well as the number of storms is listed for each wind year. The number of storm days will be equal to or greater than the number of windstorms since some windstorms may occur over portions of 2 or more days. If newspaper articles showed that two wind episodes were separated by more than 12 hrs, they were classified as two separate wind storms; if separated by less than 12 hrs, they were classified as a single storm having a lull in wind speeds. Most storms, as seen in table 3, consisted of a single storm day.

Tables 2 and 3 show the high variability in the annual number of windstorms. This feature of the distribution is most easily seen in the last few years for which the data sample is assumed to be complete. The coefficient of variation of the annual number of storms from 1961-1962 through 1971-1972 is 0.68, indicating that the standard deviation of the number of storms is two-thirds of the mean annual number of storms in the period.

Monthly. The monthly distribution of storm days is shown in figure 5. January has the highest frequency of storm days (65), nearly twice the number of storm days as November (36), the second windiest month. November and

Table 2. Yearly Distribution of Windstorms, 1869-1972.

YEAR	NUMBER OF STORMS	YEAR	NUMBER OF STORMS	YEAR	NUMBER OF STORMS	YEAR	NUMBER OF STORMS
1869	1	1910	1	1943	3	1962	1
1871	1	1911	2	1946	2	1963	4
1872	1	1912	1	1947	1	1964	8
1873	1	1916	1	1948	5	1965	6
1874	2	1920	1	1949	2	1966	2
1876	1	1925	1	1950	3	1967	8
1880	2	1927	3	1951	1	1968	4
1883	1	1928	1	1953	5	1969	8
1893	1	1929	1	1955	4	1970	9
1899	1	1930	2	1956	1	1971	11
1906	1	1932	1	1958	3	1972	14
1907	1	1934	1	1959	6		
1908	2	1935	1	1960	2	Total	151
1909	1	1936	2	1961	2		

Table 3. Distribution of Windstorms by Wind Year, 1869-1972.

WINDSTORM SEASON	NUMBER OF STORMS	NUMBER OF STORM DAYS	WINDSTORM SEASON	NUMBER OF STORMS	NUMBER OF STORM-DAYS
1869-70	1	2	1931-32	1	2
1870-71	1	1	1932-33		
1871-72			1933-34	1	2
1872-73	1	2	1934-35	1	1
1873-74	1	1	1935-36	2	3
1874-75	2	3	1936-42		
1875-76	1	1	1942-43	2	2
1876-79			1943-44	1	1
1879-80	1	1	1944-45		
1880-81	1	1	1945-46	2	4
1881-83			1946-47	1	2
1883-84	1	1	1947-48	2	5
1884-92			1948-49	4	6
1892-93	1	1	1949-50	3	4
1893-98			1950-51	2	2
1898-99	1	1	1951-52		
1899-06			1952-53	1	2
1906-07	1	1	1953-54	4	6
1907-08	3	4	1954-55	2	5
1908-09			1955-56	3	3
1909-10	2	3	1956-58		
1910-11	1	2	1958-59	5	6
1911-12	1	1	1959-60	4	4
1912-13	1	2	1960-61	3	3
1913-16			1961-62	2	2
1916-17	1	2	1962-63	4	4
1917-19			1963-64	3	5
1919-20	1	1	1964-65	10	15
1920-24			1965-66	2	2
1924-25	1	1	1966-67	7	11
1925-26			1967-68	4	5
1926-27	1	1	1968-69	7	8
1927-28	2	2	1969-70	6	12
1928-29	2	3	1970-71	16	25
1929-30			1971-72	13	20
1930-31	2	3	1972	2	3
			TOTAL	151	216

December have nearly the same number of storm days, as do February and March; April and October; and May, June, and September. Only one storm day was discovered for August and none was found for July.

The sharp increase in the number of storm days from October to November, the continued high frequency of storm days for the 3-month period November through January, and the sharp decrease in the number of storm days from January to February are significant features of the histogram. Sixty-four percent of the windstorm days occurred during the November through January period.

Table 4 compares the monthly distributions of wind occurrences determined in the present climatology with those of the Julian climatology, and the Brinkmann and the Sangster data samples. No significant differences are

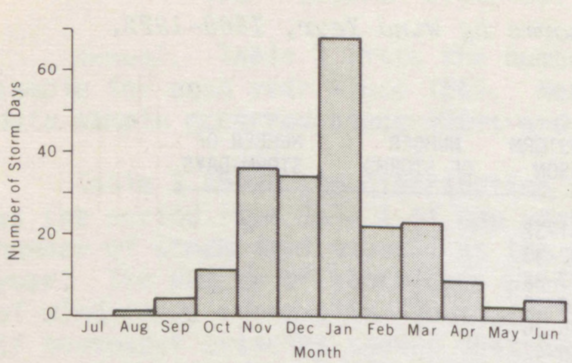

Figure 5. Monthly distribution of windstorm days at Boulder, Colorado.

Table 4. Comparison of Windstorm Data Samples.

MONTH	PRESENT[1] CLIMATOLOGY	JULIAN & JULIAN[2] CLIMATOLOGY	BRINKMANN[3] SAMPLE	SANGSTER[4] SAMPLE
JULY	0	0	-	-
AGUST	0	0	-	-
SEPTEMBER	2	4	-	4
OCTOBER	5	5	-	5
NOVEMBER	17	21	15	10
DECEMBER	16	13	10	18
JANUARY	32	29	40	35
FEBRUARY	10	7	15	13
MARCH	11	15	15	6
APRIL	4	5	5	8
MAY	1	1	-	1
JUNE	2	0	-	-
TOTAL	100 %	100 %	100 %	100 %

[1]Whiteman and Whiteman (1974), 216 windstorm days, 1869-1972. Based on newspaper articles. [2]Julian and Julian (1969), 76 winter windstorms, 1906-1969. Speeds > 60 to 70 mph and/or causing damage. Based on newspaper articles and other accounts. [3]Brinkmann (1973) 20 windstorms over three winters. Based on anemographs from several sites. [4]Sangster (1972), 6-hr peak gusts $\geq$ 60 mph for 34 months (3 years of September and May data, 4 years of October through April). Based on anemographs from several sites.

apparent between the Julian's distribution and the present climatological distribution of monthly windstorm occurrences. The larger data sample used in the present study does, however, result in a somewhat smoother distribution.

Weekly. The distribution of storms within the 52 weeks of the year is presented in figure 6.

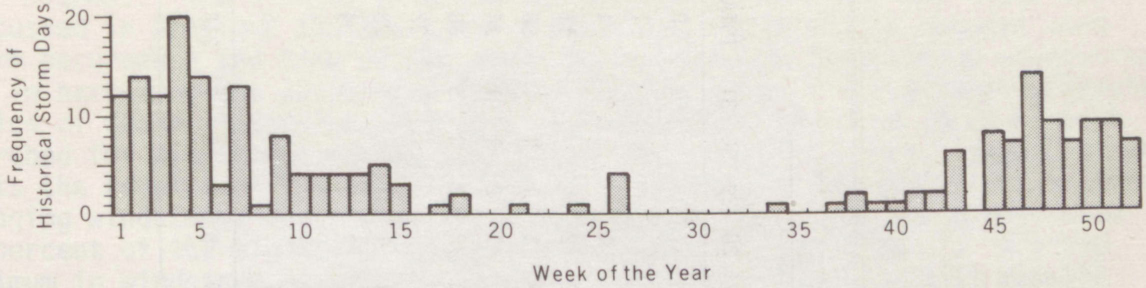

Figure 6. Number of downslope windstorm days at Boulder, Colorado, for each of the 52 weeks of the year.

Daily. Table 5 presents the distribution of storm days by the days of the year. Nine dates in November, January, February, and March have had four or more windstorms since 1869.

Seasonal. Figure 7 is a synthesis of climatological information into a mean annual distribution curve for the occurrence of damaging windstorms in Boulder. The figure can be used to determine historically the percentage of storm days that have occurred after a given date. For example, the percentage corresponding to January 1st is 60 percent indicating that 60 percent of stormdays occurred after January 1. The percentage of historical windstorm days occurring within a given period can also be determined. For example, 91 percent (i.e., 96 percent minus 5 percent) of all damaging windstorm days occurred in the 6 months from October 15 (96 percent) through April 15 (5 percent). Sixtyfour percent of storm days occurred in the 3 months from November 1 (93 percent) through February 1 (29 percent).

The distribution curve can be used to indicate the probability of future windstorm occurrences within a given period. Taking the November 1 through February 1 example, 64 percent is the probability of a given windstorm occurring within that time interval.

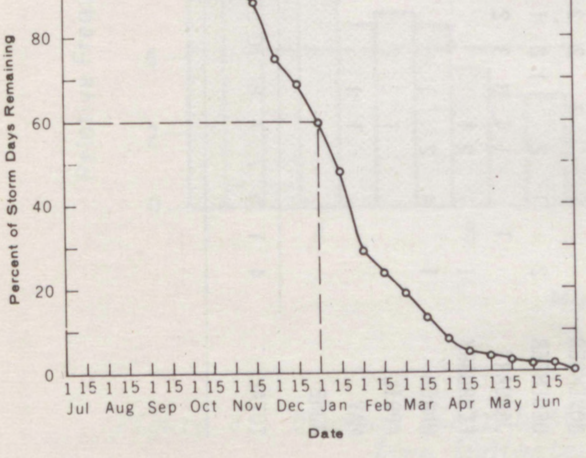

Figure 7. Distribution curve for climatological mean wind season.

Table 5. Distribution of Storm Days with Days of the Year.

MONTH	DAY OF MONTH																															TOTAL
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	
JULY																																0
AUGUST																							1									1
SEPTEMBER																1	1	1										1				4
OCTOBER							1			1	1				1						1	1				1	2	2				11
NOVEMBER							2	2	1	1	2	1		1	2	1	1	1		2	1	1	1	4	5	2	2	1	1	1		36
DECEMBER	2		1	2		1	2	1		2	2		1	1	2	1				2	3	3	1	1	1			1	2	1	1	34
JANUARY		1		1	4	3	3	2	1	3	2	2	3	1	3	2	1	1		1	4	3		4	6	2	3	2	2	3	5	68
FEBRUARY	1		1	2	1					1	1		2	2	1	4	3	1							1	1						22
MARCH	1		4	2		1			1	1	1		1		1	1		1	1		1	2					1	1	1		1	23
APRIL					1	2	2						1	1	1									1								9
MAY					1	1															1											3
JUNE													1												1	2	1					5
TOTAL	4	1	6	7	7	8	10	5	3	9	9	3	9	6	11	10	6	5	1	5	11	10	3	10	14	8	9	8	6	5	7	216

Diurnal. The diurnal distribution of wind occurrences has often been discussed in previous studies since a clear-cut relationship between windstorm occurrence and time of day would be valuable in forecasting windstorms and in narrowing the search for factors causing some of the dynamic characteristics of these windstorms. For this investigation, the data (App. A) were searched for windstorms having both onset and cessation times. Figure 8 presents the results of the analysis for 32 windstorms. The data indicate that damaging windstorms occur most frequently during the nighttime hours, with 66 percent of the windstorms occurring between 1900 and 0700 LT. A broad maximum in windstorm occurrence appears in late evening and early morning and a distinct minimum occurs in early afternoon.

Peak wind speeds were also studied. Sixty-four storms were found for which the time of peak winds was either given explicitly in newspaper accounts or could be determined from the time of maximum damage or when fire calls were most frequent. The data appeared in one of two forms: a single time (e.g., 1300) or a short period (e.g., 1300 to 1400). Figure 8 presents the distribution of peak winds by hour. The two maxima in the histogram, one between midnight and 0100 and the other in the early afternoon, are nearly 12 hrs apart. There are fewest occurrences of peak winds in the late afternoon and early evening and from 0600 to 1000 LT.

The frequencies of peak wind speeds in early afternoon are higher than the corresponding windstorm frequencies; whereas, frequencies are comparable for the remaining hours of the day. Damaging winds may thus occur at any time of the day at Boulder, Colorado, but with a preference for the nighttime hours and for maximum gust occurrence during the night and in the early afternoon.

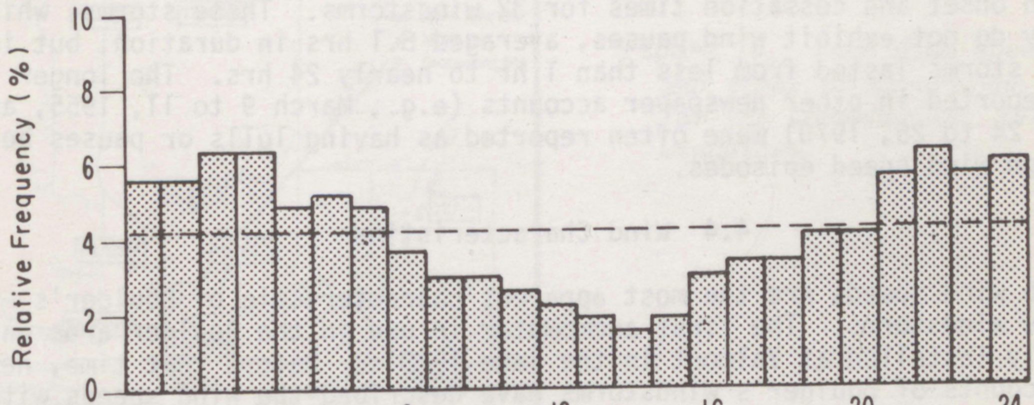

Figure 8. Diurnal distribution of windstorms. The dashed line indicates the average.

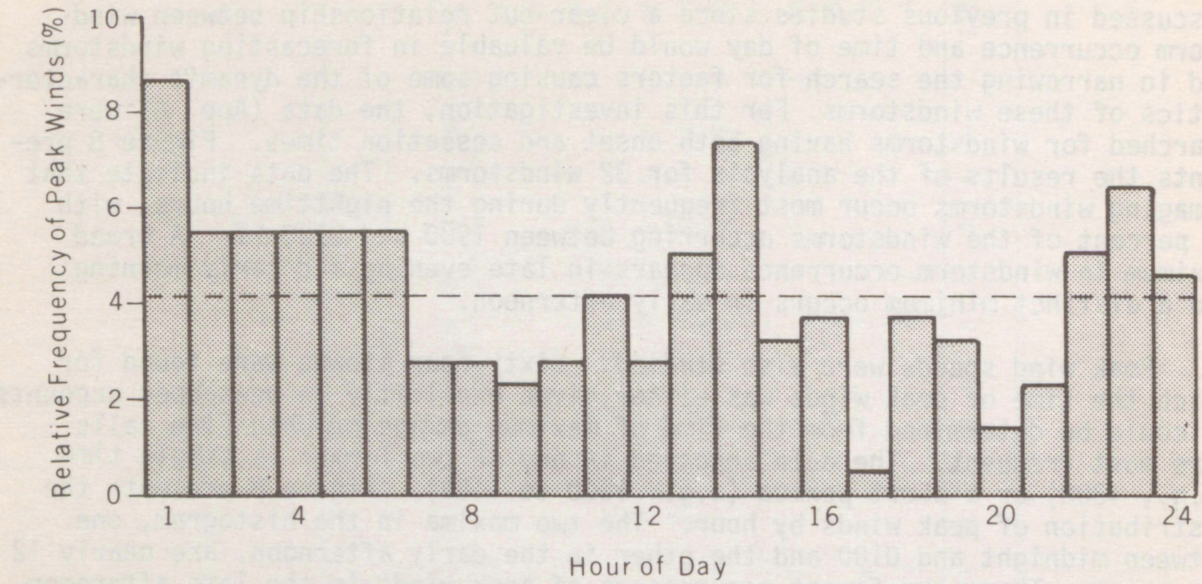

Figure 9. Relative frequency of occurrence of peak winds within 1-hr intervals. The dashed line indicates the average.

4.3 Windstorm Duration

It is difficult to determine from newspaper accounts the average duration of the storms. Storm onset and cessation times are occasionally given in the reports, but the estimates are necessarily subjective. The perception of what wind speeds constitute the beginning and end of a strong windstorm varies widely from individual to individual. Newspaper accounts provide both onset and cessation times for 32 windstorms. These storms, which generally do not exhibit wind pauses, averaged 8.1 hrs in duration, but individual storms lasted from less than 1 hr to nearly 24 hrs. The longer storms reported in other newspaper accounts (e.g., March 9 to 11, 1955, and January 24 to 26, 1970) were often reported as having lulls or pauses between high wind speed episodes.

4.4 Wind Characteristics

High wind speeds are the most apparent characteristic of Boulder's downslope windstorms. The first anemometer in use in the Boulder area was apparently installed at Valmont in the late 1920's. Before that time, newspaper accounts of Boulder's windstorms have described the wind speeds with phrases such as "heavy gale," "terrible wind," "blew great guns," "west wind blast," "tornado," "almost cyclonic velocity." Since the late 1920's, most newspaper accounts have included anemometer information, particularly peak gust data. Peak wind speeds recorded by the Valmont, National Bureau of Standards, and Boulder Daily Camera anemometers generally range from 40 to almost 100 mph (18 to 45 m/sec). Anemometers located on the southern end of Davidson Mesa, on Rocky Flats, and at NCAR on Table Mesa occasionally record peak gusts above 100 mph. The locations of anemometers have changed frequently over the years and comparisons are difficult because of differences in exposure and instrumentation. A network of anemometers installed at locations with similar exposures within the city was established during the summer of 1972 and spatial analyses of observations of high wind events are now becoming available. Peak wind speed data for the November 26, 1972, windstorm, including data from 12 of the anemometers in the 1972 network, are given in figure 10. Appendix A includes wind speed information for most of the damaging windstorms included in this climatology.

In addition to high wind speeds, extreme gustiness is another characteristic of Boulder's damaging windstorms. Brinkmann (1973) concluded that Boulder's downslope winds are much gustier than other types of winds but that the gustiness is comparable with that of downslope windstorms in other locations around the world. The high gustiness of the November 26, 1972, windstorm is illustrated by the anemograph presented in figure 11. The data are from a propeller-type vane anemometer on top of a 45 ft (14 m) tower on Rocky Flats, 7.5 mi (12 km) south of Boulder. Gusts occurred every few minutes with an average variation in wind speed of about 40 mph (18 m/sec). Figure 11 also shows the steady westerly wind direction during this storm. Although newspaper accounts seldom mention wind direction, Boulder's damaging winds are generally out of the west or west-northwest.

Occasional lulls or pauses in wind activity have been noted in downslope windstorms at Boulder and at other locations around the world and are characteristic of both bora and foehn winds. Wind pauses are generally thought to be caused by changes in critical upstream airflow characteristics. A wind pause may allow a different air mass to move into the area causing sudden changes in temperature, relative humidity, atmospheric pressure, wind speed,

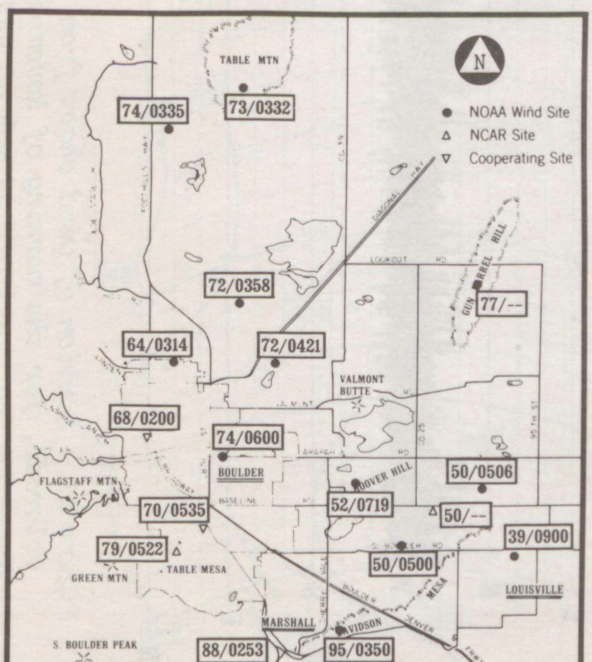

Figure 10. Peak wind speeds (mph) and times of occurrence (MST) for the November 26, 1972, windstorm.

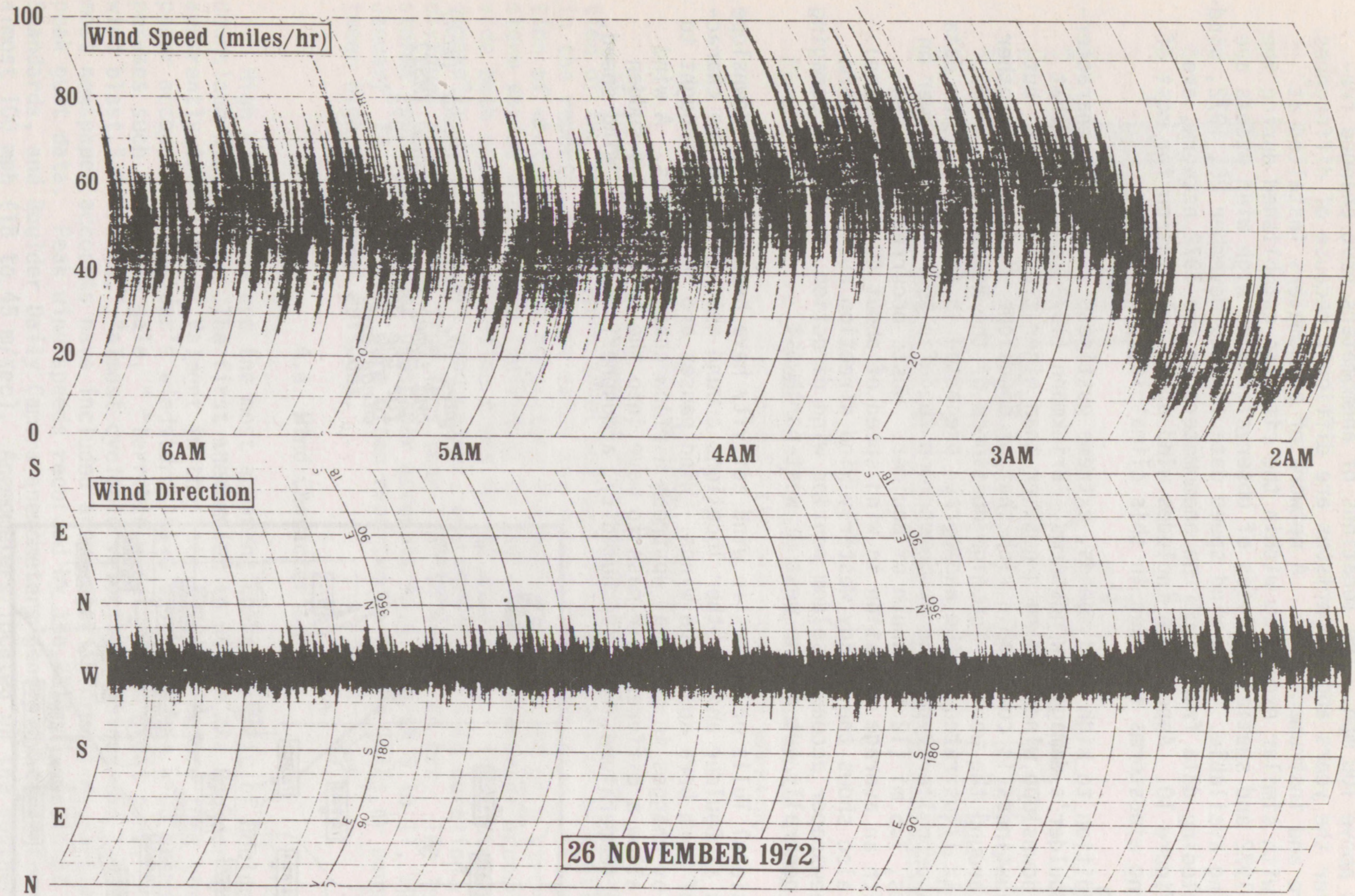

Figure 11. Portion of wind chart from the Dow Chemical Company anemometer at Rocky Flats, Colorado, for the morning of November 26, 1972. Times are in Mountain Standard Time. Note the peak gust of 104 mph at 0333 MST.

and wind direction. Since the disturbed air in a foehn is warm and dry, the change of air masses during a foehn pause generally leads to a significant decrease in temperature and an increase in relative humidity. Changes in temperature and relative humidity are generally less apparent during a lull in a bora wind.

Newspaper accounts indicate that small rotational eddies sometimes occur during windstorms and may be a factor in causing damage. In newspaper accounts, these eddies are often referred to as dust devils, tornadoes, or twisters (see accounts in App. C, Part II).

The movement of wind features across the city is also characteristic of Boulder's downslope windstorms. Data collected during the November 26, 1972, windstorm indicate that the storm moved slowly from west to east. Figure 12 presents an isochrone analysis for the time of onset of the storm. The gust front traveled at an average speed of 3 mph or 1.4 m/sec (i.e., at about walking speed) with average wind speeds in central Boulder just behind the gust front around 40 to 45 mph (18 to 20 m/sec) and peak gusts of 70 to 75 mph (31 to 33 m/sec). Brinkmann (1973) provides additional examples of this phenomenon. One possible cause for the movement is a change in the wavelength of the lee waves or a change in their position relative to the mountain barrier. Such changes apparently could also result in an east to west movement of wind features across the city.

4.5 Precipitation: Relationship to Windstorms

Efforts were made to determine if there is a climatologically significant relationship between the occurrence of damaging windstorms and the time of precipitation episodes at Boulder.

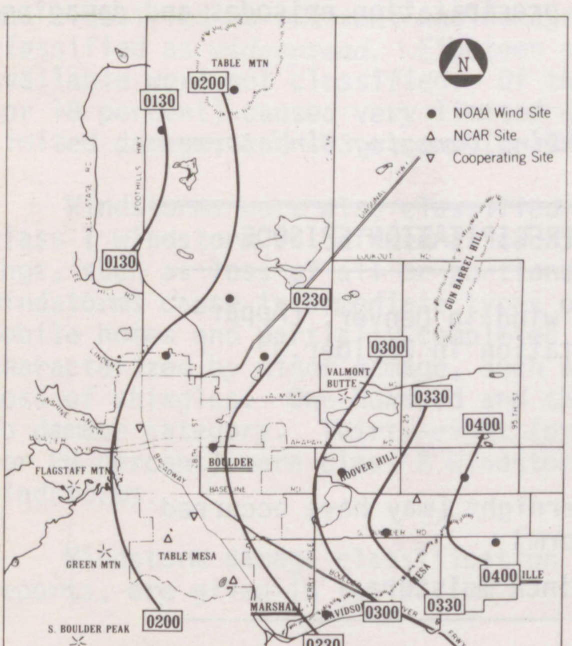

Figure 12. Isochrone analysis (MST) for the time of onset of the windstorm of November 26, 1972.

Precipitation information on individual windstorms in newspaper accounts was recorded (see App. A). Recorded information includes the actual time of the precipitation episode, the time of precipitation relative to the windstorm (before, during, or after), the source of information (observation or forecast), and the type and quantity of precipitation. Because the present climatology is based on newspaper accounts of windstorms, there is a sampling bias toward the precipitation episodes occurring before or during a damaging windstorm. Information on precipitation occurring after windstorms was not systematically sought.

Accounts of 54 of the windstorms provided enough precipitation information to be included in this analysis. Of these windstorms, 13 were preceded by precipitation, five occurred along with precipitation, and 36 were followed by precipitation. A further and more thorough search of local newspapers and of other types of data including synoptic climatological records would result in a more definitive precipitation — windstorm relationship. However, the above figures appear to be consistent with the physical basis of the windstorms. During intense downslope windstorms, the air descending in the lee of the Colorado Rockies warms and dries by compression heating, which results in suppression of cloudiness and precipitation. In fact, only traces of precipitation were noted in Boulder during the five windstorms that occurred along with precipitation (table 6).

Similarly, post-windstorm precipitation has a strong meteorological basis since windstorms frequently occur ahead of eastward-moving Pacific cold fronts and are often followed by cyclogenesis in eastern Colorado. Both cold frontal passages and the development of low pressure centers in eastern Colorado may lead to precipitation after a windstorm.

Pre-windstorm precipitation apparently does not occur frequently, and a clear meteorological relationship between precipitation episodes and damaging windstorms has not been demonstrated.

Table 6. Precipitation Occurrences During Damaging Windstorms.

DATE	DESCRIPTION OF PRECIPITATION EPISODE
May 21, 1925	Rain, along with wind in Denver. [Apparently no precipitation in Boulder.]
Jan 14-15, 1950	Skiff of snow
April 7, 1971	Light drizzle
Jan 28-29, 1972	Trace of snow overnight [may have occurred after the windstorm]
March 3, 1972	Light rain 0.01 inch moisture

4.6 Fires, Injuries, and Fatalities

Fires occur frequently during Boulder's windstorms and are often difficult to control under the high wind conditions. Fires have been reported in 57 of the 151 windstorms. Only one windstorm account indicated that no fire occurred. Common causes of fires include broken power lines, spark-ignited fuel, and windblown ashes. Fires early in Boulder's history were often caused by inadequately covered ashpits, or sparks from heating and cooking stoves. Some fires in the greenbelt west of Boulder have been caused by failure to extinguish campfires.

Similarly, wind-related injuries and even deaths are not uncommon during Boulder's windstorms. Brinkmann (1973) reports that over 50 individuals were injured during the three most severe storms in recent years.

Of the 151 storms studied, injuries were reported in 28 accounts and seven fatalities occurred in the Boulder area alone. The accounts of these fatalities as reported by Boulder newspapers are in Appendix C, Part III.

4.7 Damage Classification and Damage Trends

4.7.1 *Damage Classification*

Damage resulting from individual Boulder windstorms was classified into one of three categories of areal extent. Damage to an isolated part of town (e.g., a single city block or group of houses) was classified as *very limited* in areal extent; damage in only certain geographical sections of the valley was classified as *limited*; and damage throughout the Boulder Valley was classified as *widespread*. Eighteen storms for which no information was available were not classified. Of the 133 windstorms classified, 24 storms (or 18 percent) caused very limited damage, six storms (or 5 percent) caused limited damage, and 103 storms (or 77 percent) caused widespread damage.

Windstorms were also classified as to the types of damage produced. A class 1 windstorm is defined as causing structural damage to completed buildings, such as loss of all or portions of roofs, or collapse of walls. Class 2 windstorms cause intermediate types of damage, such as structural damage to mobile homes and partially completed buildings. Class 3 windstorms are characterized by minor damage, such as broken glass, falling tree limbs, and loss of shingles. One-hundred and thirty-eight windstorms were classified as to damage category. Thirty-eight (or 28 percent) were class 1 windstorms, 40 (or 29 percent) were class 2 windstorms, and 60 (or 43 percent) were class 3 windstorms.

Windstorm damage classification figures, based solely on newspaper reports, are given in table 7.

Table 7. *Windstorm Damage Classifications*

		Damage Type 1	2	3	No Report	TOTAL STORMS	%
Areal Extent	WIDESPREAD	35	31	37	0	103	68
	LIMITED	0	2	4	0	6	4
	VERY LIMITED	3	7	14	0	24	16
	NO REPORT	0	0	5	13	18	12
	TOTAL STORMS	38	40	60	13	151	100
	PERCENTAGE	25	26	40	9	100	

4.7.2 *Damage Trends*

The population of Boulder has increased from 343 residents in 1870 to almost 70,000 residents in 1970 (fig. 13). As the population has increased, more man-made structures have been built, resulting in an increase in damage potential. If new buildings are located on sites with high wind exposure, the damage potential may increase faster than the growth in population.

Figure 14 indicates that the frequency of damaging windstorms in the Boulder area has increased over the years. If we assume that the mean number of windstorms (i.e., damaging and non-damaging) has not changed significantly over the years, then the data indicate that the proportion of damaging to non-damaging windstorms has increased. A comparison of figures 13 and 14 suggests that the increase in damaging windstorm frequency results from population growth and increasing damage potential. Although data before 1946 are incomplete, after that date data are assumed to be relatively complete and demonstrate the relationship between population growth and damaging windstorms.

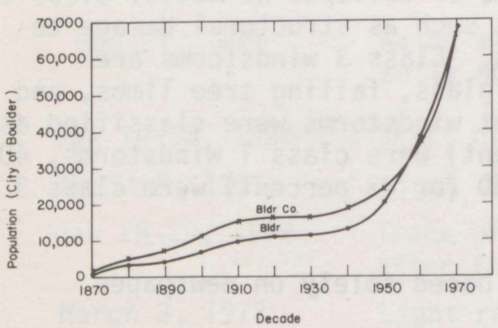

Figure 13. Population of Boulder County and the City of Boulder, 1870 - 1970.

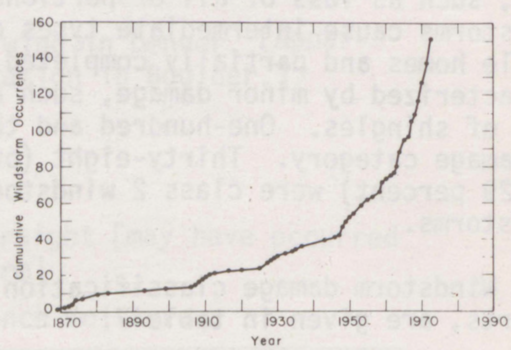

Figure 14. Cumulative number of damaging windstorms, 1869 - 1970.

Figure 15 presents the cumulative number of windstorms from 1869 through 1972 in each of the three damage classes. The graph shows that the distribution within the three classes has been changing. Since 1946, the number of class 3 storms has increased at about the same rate as the population. The average number of class 2 storms per year has changed little, as indicated by the fairly flat curve. The number of class 1 storms shows a marked increase in the early 1960's. Calculations based on the slopes of the three curves in figure 15 show that since 1958 an average year has 1.3 class 1 storms, 1.6 class 2 storms, and 2.5 class 3 storms.

Similar information on the areal extent of windstorm damage in the Boulder area is given in figure 16. The number of widespread storms increases, paralleling growth in the Boulder Valley. An abrupt increase in the number of storms causing damage to only small sections of the city is apparent in the late 1950's. This sudden increase, as well as the increase in class 1 storms in the early 1960's, appears to be caused by housing developments being located in the high wind hazard areas. Variations in the quality of new construction may also be a factor.

The costs of wind damage have varied widely over the years as the potential for damage has increased and as the value of the dollar has changed. In recent years, multi-million dollar damage has been caused by individual storms. The January 11, 1972, storm, for example, caused an estimated $2.5 million of property damage in Boulder (Lilly and Zipser, 1972). In the early days of the community, damage was measured in hundreds or thousands of dollars. Estimates of damage costs resulting from the December 25, 1883, windstorm are given in Appendix C, Part IV.

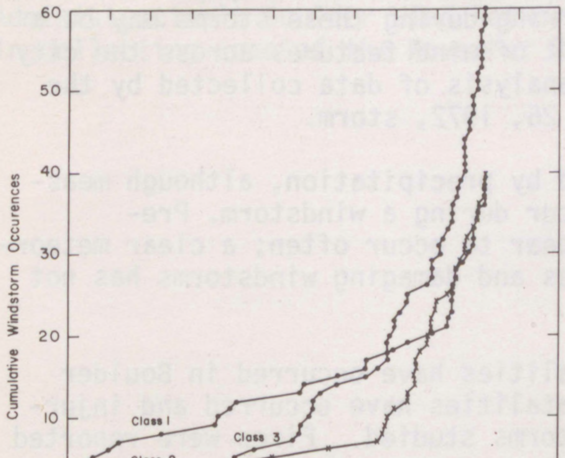

Figure 15. Cumulative number of windstorms in three damage classes, 1869 - 1972.

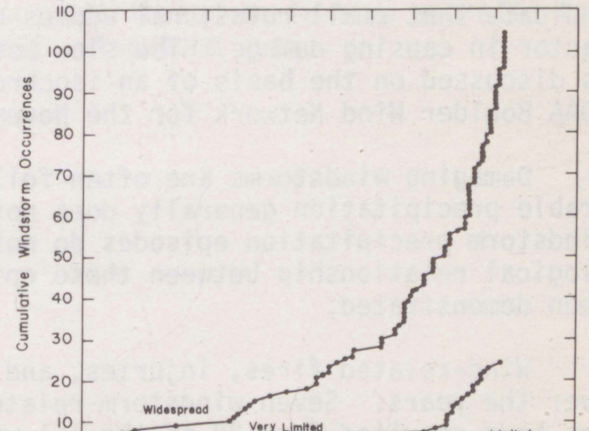

Figure 16. Cumulative number of windstorms having different areal extents of damage, 1869 - 1972.

An analysis of costs has not been attempted because of the changing value of the dollar and the sparseness of the data. Appendix A presents estimated damage costs when available.

5. SUMMARY AND CONCLUSIONS

Boulder, Colorado, located on the eastern edge of the central Rocky Mountains, is often affected by strong and sometimes damaging downslope windstorms. A study of newspaper accounts from 1869 through 1972 resulted in the compilation of statistical and climatological information about 151 damaging downslope windstorms.

An analysis of the temporal distribution of the windstorm sample shows that the number of windstorms per year is highly variable. Damaging windstorms occur most often in January, November, and December, with nearly twice as many occurring during January than during any other month. Windstorms may occur at any time of the day but occur most frequently during the nighttime. Peak winds are most likely to occur during the night (2200-0600 LT) or during a brief period in the early afternoon. The average duration of reported windstorms is estimated to be about 8 hours although damaging windstorms may persist, at least intermittently, up to 48 hours.

General characteristics of Boulder's downslope windstorms are discussed on the basis of newspaper accounts. High wind speeds are the most apparent characteristic with peak gusts at most locations of 40 to 100 mph (18 to 45 m/sec). Anemometers located on exposed sites have recorded wind speeds over 100 mph. Extreme gustiness as well as pauses in wind activity are frequently noted characteristics of these windstorms. While Boulder's damaging winds are generally out of the west or northwest, some newspaper accounts indicate that small rotational eddies occurring during these storms may be a factor in causing damage. The slow movement of wind features across the city is discussed on the basis of an isochrone analysis of data collected by the NOAA Boulder Wind Network for the November 26, 1972, storm.

Damaging windstorms are often followed by precipitation, although measurable precipitation generally does not occur during a windstorm. Pre-windstorm precipitation episodes do not appear to occur often; a clear meteorological relationship between these episodes and damaging windstorms has not been demonstrated.

Wind-related fires, injuries, and fatalities have occurred in Boulder over the years. Seven windstorm-related fatalities have occurred and injuries have resulted from 28 of the 151 windstorms studied. Fires were reported in 57 of the 151 windstorm accounts.

In addition to studying Boulder's windstorms for their general characteristics, the storms were also classified by the areal extent and severity of the resulting damage. One hundred thirty-three windstorms were classified by areal extent (very limited, limited, and widespread damage); 77 percent of these storms caused widespread damage.

Of the 138 windstorms classified by damage severity, 28 percent were class 1 windstorms, those that caused structural damage to completed buildings; 29 percent were class 2, those that caused intermediate damage, and 43 percent were class 3, those that caused minor damage.

If one assumes that the mean number of windstorms (i.e., damaging and non-damaging) has not changed over the years, then the data indicate that the proportion of damaging to non-damaging windstorms has increased. Comparing population figures for the City and the County of Boulder for 1870 to 1970 with the cumulative number of damaging windstorms from 1869 to 1972 suggests that the increased frequency of damaging windstorms result from population growth and increased damage potential.

Data for 1958 through 1972 indicate that the average wind year has 1.3 class 1 storms, 1.6 class 2 storms, and 2.5 class 3 storms. In the early 1960's, the frequency of class 1 windstorms increased markedly. This increase, as well as the marked increase in the late 1950's in the frequency of storms that were very limited in areal extent, appears to be due to the location of housing developments in high-wind hazard areas.

6. ACKNOWLEDGMENTS

Credits are due to Dr. Paul R. Julian and Lesley T. Julian, who made their raw data available to the authors. The staffs at the Denver Public Library's Western History Collection, at the University of Colorado's Norlin Library, and at the Boulder Daily Camera's newspaper library aided the authors in their search for historical information.

The volunteer wind observers of the National Oceanic and Atmospheric Administration's Boulder Wind Network also contributed their time and efforts in collecting some of the November 26, 1972, windstorm data.

7. REFERENCES

Boulder County News, Weather Files and Microfilm (1869-1880). Located at the Western History and Archives Section, Norlin Library, University of Colorado, Boulder, Colo.

Boulder Daily Camera, Weather Files and Microfilm (1892-1972). Located at the Western History and Archives Section, Norlin Library, University of Colorado, Boulder, Colo.

Brinkmann, W.A.R. (1971), What is a Foehn? *Weather* 26(6), 230-239.

Brinkmann, W.A.R. (1973), A climatological study of strong downslope winds in the Boulder area, NCAR Cooperative Thesis No. 27/INSTAAR Occasional Paper No. 7, University of Colorado, Boulder, Colo., 229 pp.

City of Boulder (1970), Analysis of damage to residential properties from high winds occurring on January 7 and January 31, 1969, in Boulder, Colorado, Office of City Manager, Boulder, Colo., 22 pp.

City of Boulder (1971), Uniform Building Code Ordinance No. 3749, Boulder, Colo., 13 pp.

City of Boulder (1972), Mobile Home Tie-Down Ordinance No. 3781, Boulder, Colo., 6 pp.

Danielsen, E.F., and R. Bleck (1970), Tropospheric and stratospheric ducting of stationary mountain lee waves, *J. Atmos. Sci.* 27(5), 758-772.

Hall, F.F., Jr. (1972), Temperature and wind structure studies by acoustic echo-sounding, in *Remote Sensing of the Troposphere*, V.E. Derr, ed., U.S. Government Printing Office, Washington, D.C., pp. 18.1-18.25.

Henz, J.F., V.R. Scheetz, and J.M. Fritsch (1974), Use of NMC numerical guidance in the prediction of severe downslope windstorms, Preprint volume, Fifth Conf. on Weather Forecasting and Analysis, March 4-7, 1974, St. Louis, Mo., *Amer. Meteorol. Soc.*, Boston, Mass.

Houghton, D.D., and E. Isaacson (1968), Mountain winds, *Studies in Numerical Analysis* 2, 21-52.

Huschke, Ralph E. (ed.)(1959), *Glossary of Meteorology*, Am. Meteorol. Soc., Boston, Mass., 638 pp.

Julian, Lesley T., and Paul R. Julian (1969), Boulder's winds, *Weatherwise* 22(3), pp. 108-112, 126.

Klemp, J.B., and D.K. Lilly (1974), The mechanisms of wave-induced downslope winds, submitted to *J. Atmos. Sci.*

Kuettner, J.P., and D.K. Lilly (1968), Lee waves in the Colorado Rockies, *Weatherwise* 21(5), pp. 180-185, 193.

Lawrence, R.S., G.R. Ochs, and S.F. Clifford (1972), Use of scintillations to measure average wind across a light beam, *Allied Optics* 11(2), 239-243.

Lilly, D.K., and E.J. Zipser (1972), The front range windstorm of 11 January 1972 - A meteorological narrative, *Weatherwise* 25(2), 56-63.

Miller, D.J. (1972), Human perception of and adjustment to the high wind hazard in Boulder, Colorado, M.A. thesis, Dept. of Geography, University of Colorado, Boulder, Colo., 40 pp.

Miller, D.J., W.A.R. Brinkmann, and R.G. Barry (1974), Windstorms: A case study of wind hazards for Boulder, Colorado, in *Natural Hazards: Local, National, and Global*, G.F. White, ed., Oxford University Press, New York, N.Y., 288 pp.

Oehlerts, Donald E. (1964), *Guide to Colorado Newspapers, 1859-1963*, Biographical Center for Research, Denver, Colo., 184 pp.

Rocky Mountain News Weather Files and Microfilm (1865-1885), Located at Denver Public Library's Western History Collection, Denver, Colo.

Sangster, Wayne E. (1972), An objective forecast technique for Colorado downslope winds, Tech. Memo. NWS CR-50, Natl. Weather Service, NOAA, Kansas City, Mo., 26 pp.

Vergeiner, I. (1971), An operational linear lee wave model for arbitrary basic flow and two dimensional topography, *Quart. J. Roy. Meteorol. Soc.* 97, pp. 30-60.

Miller, D.C., W.A.R. Brinkmann, and R.G. Barry (1974). Windstorms: A case study of wind hazards for Boulder, Colorado. In Natural Hazards: Local, National and Global. G.F. White, ed., Oxford University Press, New York, N.Y., 288 pp.
Oehlerts, Donald E. (1964). Guide to Colorado Newspapers, 1859-1963, Bibliographical Center for Research, Denver, Colo., 332 pp.
Rocky Mountain News Weather Files and Microfilm (1859-1963). Located at Denver Public Library's Western History Collection, Denver, Colo.
Sangster, Wayne E. (1972). An objective forecast technique for Colorado downslope winds. Tech. Memo. NWS CR-56, Natl. Weather Service, NOAA, Kansas City, Mo., 26 pp.
Vergeiner, I. (1971). An operational linear lee wave model for arbitrary basic flow and two-dimensional topography. Quart. J. Roy. Meteorol. Soc., 97, pp. 30-60.

APPENDIX A. DATA TABLE: FRONT RANGE WINDSTORMS, 1869-1970

KEY TO DATA TABLE

Column 1: Dates of storm; year, month, day(s) of month, day(s) of week.

A blank before the date indicates that the storm described is used in the climatology of Boulder's downslope winds.

A * before the date indicates the storm described is used in the climatology, although some aspect of the storm description indicated that the storm might not be a true Boulder downslope wind.

A ** before the date indicates that the storm described is not used in the climatology. The reason for the omission is indicated in a later column by the same symbol. Two reasons for excluding these storms follow:

(1) No information could be found to indicate that the storm occurred in Boulder (** in col. 6).

(2) No information could be found to indicate that storm damage occurred in Boulder (** in col. 11) and recorded wind velocities for the storm were below the damage threshold (** in col. 12).

Column 2: Period during which the storm blew in Boulder.

Column 3: Occurrence (x) or non-occurrence of high winds within 6-hr intervals of the day. Two x's mean the storm blew during that time period on 2 days.

0000 to 0600	0600 to 1200
1200 to 1800	1800 to 2400

Occurrences are marked by x's in the appropriate squares.

Column 4: Time of peak winds.

Column 5: Time of precipitation relative to the time of the windstorm. For example, before indicates that precipitation fell before the windstorm began.

Column 6: Area affected by the windstorm. A blank in this column means that Boulder was the only community mentioned in the newspaper articles.

Column 7: Occurrence (x) or non-occurrence (-) of fires in Boulder and vicinity during the windstorm.

Column 8: Number of fatalities recorded in Boulder and vicinity during the windstorm.

Column 9: Occurrence (x) or non-occurrence (-) of wind-related injuries.

Column 10: Dollar amount of property damage caused by windstorms in Boulder and vicinity. Other communities are not included.

Column 11: Damage classification in Boulder and vicinity:

(1) Area affected

(a) Widespread - covered most or all of Boulder and vicinity.
(b) Limited - covered only a portion of Boulder and vicinity.
(c) Very limited - Damage occurred in one or two isolated spots.
(d) Other - Damages occurred in other communities.

(2) Type of Damage

(a) 1 - Major structural damage to completed buildings (roofs blown off, walls collapsed, etc.)
(b) 2 - Structural damage to buildings under construction and out buildings
(c) 3 - Minor damage (shingles blown off, tree limbs broken, windows broken, fences damaged, etc.)

Column 12: Velocity of winds. Descriptive phrases are used for the early storms and wind velocities in miles per hour are given when anemometer data are available. Special abbreviations are used for some anemometer sites:

Abbreviation	Place	Location
AFA	Air Force Academy	No. of Colorado Springs
BDC	Boulder Daily Camera Office	11th & Pearl Sts.
COLO BLDG	Colorado Building	1919-14th Street
JEFFCO	Jefferson County Airport	2 mi SW of Broomfield
LILLY	Dr. Doug Lilly's home	417 Wewoka Drive

Abbreviation	Place	Location
NBS	Natl. Bureau of Standards	325 Broadway, Boulder.
NBS(Table Mtn)	NBS Table Mountain Field Site	8½ mi N of Boulder
NCAR	Natl. Center for Atmospheric Research	Table Mesa (Boulder)
NCAR (30th St.)	Natl. Center for Atmospheric Research	30th & Marine Sts., Boulder
NOAA	Natl. Oceanic & Atmospheric Admin.	30th & Marine Sts., Boulder

Wind gusts are indicated by the letter G. The time of occurrence of the wind gust is indicated in local time when available.

Column 13: Comments. Many of the comments describe the intensity of the storm in surrounding communities, or damage estimates for the storm statewide.

DATA TABLE: FRONT RANGE WINDSTORMS, 1869-1970

DATE (1)	TIME (2)	TIME (3)		TIME OF PEAK (4)	PRECIPITATION (5)	AREA (6)	Fires (7)	Fatalities (8)	Injuries (9)	DAMAGE (BOULDER ONLY) IN $ (10)	CLASS (11)	VELOCITY (12)	COMMENTS
1869													
Nov 17-18 Wed-Thurs	Began 9 PM Lasted until morning	x	x	12-01 AM	Before- snow in mountains day or two previous	Boulder, Denver, Georgetown Golden, mountains				Some hundreds of dollars	Widespread 1	Heaviest wind in 5 or 6 years	NW wind
1870													
**Sep 21-22 Wed-Thurs	Began Wed. morning. Lasted 2 days.	x xx	xx x		After- snow on Thursday	Boulder, Central City, Denver, Georgetown					**	**	
1871													
Jan 5 Thurs	Morning		x							$500 partial	Widespread 1	Heavy gale	
**Oct 15 Sun	Night		x		During- snow	**Caribou						Terrible wind	Widespread 1
1872													
Dec 21-22 Sat-Sun	Night	x	x								Widespread 1	Blew big guns	
1873													
**Apr 14 Mon						**Evans						Severe gale	Very limited 2, $3000 partial
Nov 26 Wed	Evening		x							$300 partial	Widespread 1	Blew great guns	
1874													
*Sep 16 Wed	During working hours	x	x						x		Very limited 2	West wind blast	Possibly a thunderstorm
Oct 27-28 Tue-Wed	11 PM-04 AM	x	x		Before- light rain Tue during day.					$150 partial	Widespread 2	Tornado	West wind; tornado; cloud band over the mountains
**Dec 22 Tue	Afternoon	x				**Sunshine							Very limited 1
1876													
Jan 31 Mon						Boulder, Central City (Mon night)					Very limited 1	Hurricane	

DATE (1)	TIME (2)	TIME (3)		TIME OF PEAK (4)	PRECIPITATION (5)	AREA (6)	Fires (7)	Fatalities (8)	Injuries (9)	DAMAGE (BOULDER ONLY) IN $ (10)	CLASS (11)	VELOCITY (12)	COMMENTS
1880													
Jan 13 Tue	Now, today	x	x			Boulder and a few miles south			x		Widespread 1	Most terrific windstorm ever known in this section	
Dec 8 Wed	Night	x				Boulder, Ft. Collins (Dec 4-5)			x		Widespread 2	Severe	
1883													
Dec 25 Tue	Early morning before daylight	x								$1100 partial	Widespread 1	Terrific	Gusty
1892													
**Dec 22 Thur	Began about noon	x				**Copper Rock, Sunset, Ward calm in Boulder			x			Terrible wind	Young tornado
1893													
Jan 10 Tue	Afternoon	x		5 PM		Boulder, Lyons, Sunshine Hill			x		Widespread 1		West wind
1899													
Jan 5 Tue	Today		x								Very limited 3	Strong Wind	
1906													
Nov 15 Thur	Began 3 PM into the night	x	x			Boulder, mountains Calm a few miles north, south and east		1	x	Several thousand dollars	Widespread 1	Howled and roared	
1907													
Dec 23-24 Mon-Tue	Mon night, all day Tue (recurred Wed night)	x x	x x			Boulder, north of Denver, Marshall	x	1	x		Widespread 1 (Other)	Almost a hurricane	
1908													
Jan 6 Mon	A while Mon						x				Widespread 3	Furious wind	
Jan 7 Tue	1 PM	x							x		Very limited 3	High wind	Gusty
1909													
Nov 20 Sat	1 PM	x		1 PM						$3000	Very limited 2		Steady blow

DATE (1)	TIME (2)	TIME (3)		TIME OF PEAK (4)	PRECIPITATION (5)	AREA (6)	Fires (7)	Fatalities (8)	Injuries (9)	DAMAGE (BOULDER ONLY) IN $ (10)	CLASS (11)	VELOCITY (12)	COMMENTS
1910													
Jan 25-26 Tue-Wed	Night	x	x			Boulder, Marshall, White Rock	x				Widespread 1 (Other)	Gale of great velocity	West wind
1911													
Jan 7-8 Sat-Sun						Boulder, north of Boulder			x		Limited 3	Gale	
Nov 7 Tue	Today	x	x								Widespread 3	High winds	Gusty
1912													
Dec 29-30 Sun-Mon	Night-morning fire 3:15 AM. Lights off early evening, around midnight.	x	x				x			Hundreds of dollars	Widespread 1	One of the most terrific in the history of the city	
1916													
Dec 14-15 Thur-Fri	Thur afternoon Fri afternoon	x xx	x x		Before- snow on the ground	Boulder, north of Boulder, south of Longmont to Lafayette, mountains					Widespread 3		West wind
1920													
Mar 18 Thur	Morning Damage 8:15 AM		x			Boulder, Denver, Ft. Collins to Cheyenne	x	2	x		Widespread 2	Terrific windstorm	
1925													
May 21 Thur	Afternoon 3:30 PM lasted ½ hour		x	3:30 PM	During- rain along with wind in Denver	Boulder, Ault, Berthoud, Broomfield, Denver, Eaton, Ft. Collins, Greeley, Platteville, Windsor		1	x		Widespread 3 (Other)	Almost cyclonic velocity	Fatality in Berthoud, another in Platteville. SE gust destroyed hen house, but workers blown to the east (?)
1927													
Jan 27 Thur	Night Fire calls 7:15 - 10:00 PM		x			Boulder, mountains	x				Widespread 3	Silver Lake 50 (estimated)	
Nov 27 Sun	5 PM to Midnight	x	x				x				Very limited 3		West wind

DATE (1)	TIME (2)	TIME (3)		TIME OF PEAK (4)	PRECIPITATION (5)	AREA (6)	Fires (7)	Fatalities (8)	Injuries (9)	DAMAGE (BOULDER ONLY) IN $ (10)	CLASS	VELOCITY (11)			COMMENTS (12)
1927															
Nov 28 Mon	10 AM Climax mid-afternoon	x	x	Noon-2:30 PM	After- snow 7:44 AM on 29th, preceded by light rain	Boulder, northeast of Erie	x		x		Widespread 1	Valmont	65 30 60	noon-1 PM 1-4 PM 4 PM	West winds cyclonic twist
1928															
Nov 14 Wed	Night, 2-4 AM Subsided morning	x								$300-500 partial	Widespread 1	Valmont	70, estimated 85		
1929															
Feb 16-17 Sat-Sun		x x	x x	Midnight Sat, 11 AM and 1:30 PM Sun	Before- snow at night, Feb 15	Boulder, 2 miles south of Lafayette			x		Limited 3	Boulder	84	Sat midnight, 11 AM Sun 1:30 PM Sun	West wind
1930															
Nov 16 Sun	Began early morning, power out 4 AM, lasted most of day	x x	x		After- snow on Nov 17		x				Widespread 3	Valmont	52		
Nov 24-25 Mon-Tue	Early Mon night - early Tue	x	x x		Before- recent blizzard	Boulder, Colorado Springs, Pueblo, Kit Carson, Walsenburg, mountains					Widespread 3	Valmont	40 peak 35 or less rest of night Calm at sunrise Picked up at 8 AM		
1932															
Feb 4-5 Thur-Fri	Thur night, early Fri 7 PM-7 AM. Damage 6:15 AM	x	x x	Midnight-4 AM	Before- 9" snow Feb 3; snow Feb 4	Boulder, light wind elsewhere in county, little or no wind in Denver					Widespread 3	Boulder Valmont	70 (estimated) 60 peak		
1934															
Mar 3-4 Sat-Sun	Sat night. Sun morning	x	x	Midnight-3 AM		Boulder, vicinity	x			hundreds of dollars	Widespread 2	Valmont	62 peak 38	Sat night Sun night	
1935															
Mar 15 Fri	Afternoon Night	x	x			Boulder, south of Lafayette, Valmont, Grand Island, Hasting, Lincoln, Sidney						Lincoln, Neb Sidney, Neb Valmont	60 63 60	night	
**Mar 23 Sat	Afternoon	x				**Around Boulder, but not downtown. Southeast Colo.									
**Mar 26 Tue	3:30 PM 2 PM Denver - lasted 20 min	x				Boulder, Denver									**East wind

DATE (1)	TIME (2)	TIME (3)		TIME OF PEAK (4)	PRECIPITATION (5)	AREA (6)	Fires (7)	Fatalities (8)	Injuries (9)	DAMAGE (BOULDER ONLY) IN $ (10)	CLASS	VELOCITY (11)			COMMENTS (12)
1936															
Jan 2 Thur	Late afternoon Fires 5:30-6:30 PM	x	x			Boulder, Marshall	x				Widespread 3	High wind			
Jan 12-13 Sun-Mon	8 PM-11 AM	x	x x	9 PM-3 AM (9-10 PM)		Boulder, Eldorado Springs, Pleasant View	x				Widespread 1	Valmont University	55 49 avg. 40-50 avg 60+ peak	9:30 PM 9-10 PM until 11 AM	One roof blown SSE, another NNW
1943															
Jan 15 Fri	Began during night, subsided at noon, recurred late afternoon fires 5:30 AM-2:22 PM	x x	x x	9-10 AM 5:15 PM	After- snow Jan 16	Boulder, Berthoud, Colorado Springs, Denver, Ft. Collins, Ft. Morgan, Loveland, Weld County	x				Widespread 1 (Other)	Valmont University Airport	84-96 45 avg 84-90	9-10 AM (1 hour)	West wind Chinook
Jan 21 Thur	4:30 AM-noon	x	x	6-7 AM		Boulder, Colorado Springs, Golden, Lafayette	x		—		Widespread 1 (Other)	Colo. Springs University Airport	75 37 avg 92	6-7 AM	West wind
Sep 18 Sat	Afternoon, evening	x	x		After- rain at night on the 18th	Boulder, Coal Creek Canyon, Rollinsville	x				Widespread 3	Airport	30+ gust		
1946															
Jan 24-25 Thur-Fri	Late Thur after-noon, Early Fri morning	x x	x		After- light snow forecast for night of 25th	Boulder, Longmont, mountains, Cheyenne	x		x		Widespread 2	Cheyenne (Thur) Valmont	60 avg 80-102 gusts 76 gust peak 60 gust 72 gust 50 25-35	 Before noon Mid-afternoon 4-6 PM 7:30-10:30 PM After 11 PM Early morning	
Jan 30-31 Wed-Thur	Late Wed - Early Thur morning	x	x			Boulder, Louisville					Widespread 3	Strong wind			
1947															
Jan 24-25 Fri-Sat	Fri night	x	x	2-3 AM			x				Widespread 2	Valmont	72 peak avg	2-3 AM	
**Mar 3 Mon	Today	x	x		Before- 7 days previous week	Most of Colorado					**No reports	** Strong			Chinook early Sat morning 0° Later Sat - 24°, Sun - 38°, Mon noon - 40's
**April 15 Tue	Early morning	x			After- snow morn-ing and afternoon	Boulder, Denver, Lafayette					**No reports	**			**Cold air mass moving in from Canada, strong northerly winds

DATE (1)	TIME (2)	TIME (3)		TIME OF PEAK (4)	PRECIPITATION (5)	AREA (6)	Fires (7)	Fatalities (8)	Injuries (9)	DAMAGE (BOULDER ONLY) IN $ (10)	CLASS	VELOCITY (11)			COMMENTS (12)
1948															
Jan 10-11 Sat-Sun	9 PM - early Sun, After-noon (1 PM)	x x	x x	11 PM - Midnight	After- light snow at noon on 12th, more for night of 12th	Boulder, Lakewood, mountains, north of Nederland	x				Widespread 3	Valmont University	50-60 27 peak avg	9 PM-Sun after-noon 11 PM-Midnight	
Mar 27-29 Sat-Mon	4:30 - 11:03 PM Sat 3 - 10:05 PM Sun, 1:55 AM-3:35 AM Mon (Fire calls)	x xx	 xx	2-3 AM Mon			x				Widespread 3	Boulder Valmont	35+ (estimated 75 50-60	 3 AM Mon Before midnight Sun	
Oct 15 Fri	Morning (Police call 9:35 AM)		x	10 AM		Boulder and vicinity	x				Widespread 3	Valmont Airport	50 (max. steady vel.) 60+ G	10 AM	
Dec 10-11 Thur-Fri	Late afternoon night 4 PM-midnight (power outages)	x x	x x			Boulder, east of Boulder, south of Louisville	x			$1750 partial	Widespread 2	Valmont Airport	70+ 70+ 40	Afternoon and evening Afternoon and evening Fri morning	
Dec 20 Mon	1:15 - 10 AM (fire calls) "less furious blow" con-tinued into after-noon	x x	x	2-3 AM		Boulder, Central City (Sun), Ft. Collins, Marshall Valmont, Wyoming	x		x		Widespread 2 (Other)	Casper Cheyenne Laramie Rock Springs Ft. Collins Valmont Airport	64 avg 84 G 50 avg 70 avg 75 G 60 avg 96 G 41 avg 45 peak 30	 11 AM Noon 8 AM	
1949															
Apr 5-6 Tue-Wed	Night	x	x								Limited 3				
Oct 10 Mon	Early Mon. Fire calls 1 - 5:12 AM	x		3:30 AM		Boulder, Longmont	x		–	$107,000 partial	Widespread 1 (Other)	Valmont	85 peak (estimated)		"believed to be worst in Boulder's history"
1950															
Jan 14-15 Sat-Sun	3 PM Sat - 2 PM Sun	x xx	x x	5-6 AM 10 AM-2 PM Sun	During- skiff of snow Sat night	Boulder, Louisville	x				Widespread 3	Valmont	60 sustained peak 60+ G 10-12 50-60	5-6 AM 5-6 AM 8 AM 10 AM-2 PM	
Jan 21 Sat	Afternoon	x			After- light wet snow on 24th		x				Limited 2				
Oct 7 Sat	Morning. Power out 5:30 AM	x	x								Widespread 3	Heaviest windstorm since January			

DATE (1)	TIME (2)	TIME (3)		TIME OF PEAK (4)	PRECIPITATION (5)	AREA (6)	Fires (7)	Fatalities (8)	Injuries (9)	DAMAGE (BOULDER ONLY) IN $ (10)	CLASS	VELOCITY (11)		COMMENTS (12)
1951														
**Jan 3 Wed						Boulder, Berthoud Pass Fairplay, South Park					**	**		
Jan 22 Mon	Early morning Fire calls - Mid- night -3:40, 5:23	x			After- snow flurries forecast for 23rd		x				Widespread 3	Heavy windstorm		
1953														
*Feb 15-16 Sun-Mon	Sun night, early Mon morning, Fire calls 8:06 PM- 2:26 AM	x	x		After- snow fore- cast for mountains on 16th	*Boulder, Colorado mountains, Kansas, Nebraska, Oklahoma					Widespread 3 (Other)	Okla. City Sidney, Neb Western Kans Denver Yuma, Colo Boulder	72 G 80 G 40-60 54 G 70 near gale	North, northwest winds (Kansas, Oklahoma)
Sep 17 Thur	Most of day Twister 2 PM Not severe after 2 PM	x	x							Thousands of dollars	Very limited 1			Gusts, no sus- tained blow, freak twister
Sep 28 Mon	Afternoon	x			Before- sprinkle of rain, snow in high mountains						Widespread 3			
Nov 22-23 Sun-Mon	Sun night, Mon morning (recurred Mon night, but no damage)	x	x x				x			$18,000	Widespread 2	Valmont Airport	80 G 80 G (estimated)	
Dec 6-7 Sun-Mon	3 PM Sun after 2 AM Mon	x x	x		Before- snow Sat in Colo and Wyo. After- snow Tue	Boulder, Colorado Springs to Cheyenne			x	$1500 partial	Limited 2 (Other)	Lookout Mtn Denver	80 G 65 G	
1955														
Mar 9-11 Wed-Fri	Wed afternoon - Thur morning (minor damage). Thur afternoon-Fri	xx xx	xx xx	2-4 PM Thur		Boulder, south of Longmont, Colorado and Wyoming	x		x	$10,000	Widespread 2 (Other)	Rock Springs Valmont Rocky Flats	76 G 60 G 95 G	
Mar 21-22 Mon-Tue	Midnight - early Tue. Damage 2 AM	x	x		Before- "recent snow"				x		Widespread 2	Rocky Flats	98 G	
Nov 10 Thur	Morning	x	x			Boulder and vicinity					Widespread 2	Rocky Flats	80 G	
Dec 13 Tue	Morning, damage 1:09 AM. Fire 6:25 AM	x	x				x				Widespread 2	Rocky Flats	72 peak	
1956														
Jan 5 Wed	Night		x								Very limited 2			

DATE (1)	TIME (2)	TIME (3)		TIME OF PEAK (4)	PRECIPITATION (5)	AREA (6)	Fires (7)	Fatalities (8)	Injuries (9)	DAMAGE (BOULDER ONLY) IN $ (10)	CLASS	VELOCITY (11)	COMMENTS (12)
1957													
**Jan 20-21 Sun-Mon	Sun afternoon Mon morning				During- snow	**South central eastern slope, Colorado Springs, Walsenburg							
1958													
Nov 8-9 Sat-Sun	Night	x	x								Widespread 2	Hard winds	
Nov 25 Tue	Early Tue 2-3 AM	x				Boulder, Fairview, twister hits 1 sq. mi. in Adams County					Widespread 3 (Other)	NW of Denver 100 G Rocky Flats 88	Arctic air moving in from the north. $50,000 to $500,000
Dec 7 Sun	Afternoon	x		3-4 PM		Boulder, 2 miles east of Boulder				$10,000	Widespread 2	? 75 estimated	Worst storm in several years $5,000 - $50,000
1959													
Jan 18 Sun	8 AM - early PM	x	x	9 AM		Boulder, Broomfield, Denver, Longmont	x				Widespread 2 (Other)	Longmont 70	$5,000 - $50,000
**April 2 Thur	Afternoon, evening	x	x			**Greeley, Eastern Colorado						? 50-60	$5,000 - $50,000
Apr 24 Fri	Morning Damage before 7 AM, 9 AM		x								Very limited 3	Downtown Boulder 60 G	
**Nov 4-5 Wed-Thur	All day				During- snow	**Eastern Colorado, Wyoming						NE Colo. E. Wyo. 70 Denver 70 G Pueblo 61	
Nov 11 Wed	Night Damage 10 PM		x		After- forecast for Thur night with northeast winds	Boulder, South Park					Widespread 2	South Park 40	NW wind, cold wave, $500 - $5,000
Nov 24 Tue											Very limited 3		
Nov 25 Wed	Early morning. Fire calls 1-5 AM Damage 1:30 AM	x				Boulder, Eldorado Springs, Matterhorn Restaurant	x			$3000 partial	Widespread 1	Matterhorn Restaurant 100 (estimated)	
Nov 29 Sun	Morning		x								Very limited 3		

DATE (1)	TIME (2)	TIME (3)		TIME OF PEAK (4)	PRECIPITATION (5)	AREA (6)	Fires (7)	Fatalities (8)	Injuries (9)	DAMAGE (BOULDER ONLY) IN $ (10)	CLASS	VELOCITY (11)		COMMENTS (12)
1960														
**Apr 16 Sat	Afternoon			Noon	During- snow flurry for 5 minutes	**Denver, eastern Colorado					**	?	80 G	$50,000-500,000
Nov 15 Tue	Night Damage 11:45 PM		x			Boulder, Denver, Pueblo				$2000 partial	Very limited 2 (Other)	Denver Pueblo ?	40 40 70	$5,000-50,000
Nov 24 Thur	Early morning Damage 4:30 PM	x									Very limited 2	violent wind gusts		
**Dec 27 Tue	Early morning	x			During- wind driven snow	**Monument Hill, mountains, eastern Colorado								
1961														
Mar 1 Wed	Night Fire calls 8-9 PM		x	10 PM			x				Widespread 3	Colo. Bldg.	65 peak 10 PM	
**Jun 3 Sat	Afternoon	x			During- heavy rain above Lyons						Widespread 3			**Small tornado ? Black skies, one gust from east.
Oct 11 Wed	Damage early Wed	x									Very limited 3			
**Dec 21 Thur	Mid-afternoon - night				Before and during snow, sleet, rain	**Denver, Loveland Pass, Montana, Wyoming						Livingston, Mont Denver	97 G 62	Cold front $5,000 - $50,000
1962														
Jan 6 Sat	Damage 5:45 AM	x			After- trace snow Sat, forecast snow for Sat night	Damage 2 miles north of Boulder				$1350	Very limited 3			
**Jan 20 Sat						**						Colo. Springs	70	
**Feb 12 Mon						**El Paso County						Colo. Springs	70	$5,000 - 50,000

DATE (1)	TIME (2)	TIME (3a)	(3b)	TIME OF PEAK (4)	PRECIPITATION (5)	AREA (6)	Fires (7)	Fatalities (8)	Injuries (9)	DAMAGE (BOULDER ONLY) IN $	CLASS (10)	VELOCITY (11)	COMMENTS (12)
1963													
Jan 31 Thur	Morning 5:30-7 AM	x	x								Very limited 2	Boulder 70	
Jan 31-Feb 1 Thur-Fri	Night, early morning. Died down 4 AM Power out 9:30 - 10:30 PM	x	x		After- rain Fri morning, heavy snow and rain in mountains	Boulder (especially south and southeast Boulder), Air Force Academy, Colorado Springs to Estes Park	x			$100,000	Widespread 1 (Other)	Colo. Springs 59 Denver 80 Littleton 100 Rocky Flats 90	Chinook, $500,000 - $5,000,000
Mar 16 Sat	Early Sat Midnight-6 AM	x		4-6 AM		Boulder, north of Boulder, Broomfield, Colorado Springs, Denver, Jeffco, Lakewood, Littleton, Westminster				$4500 partial	Widespread 1 (Other)	Colo. Springs 69 Jeffco 98 Littleton 87 Pueblo 78 Boulder 90-100 BDC 32-38 avg 3-6 AM 30 after 6 AM 67 G	$50,000 - $500,000
Apr 15 Mon	Afternoon	x		2-4 PM	After- snow and rain forecast by the 17th	Boulder, Denver, Lamar, Loveland, Cheyenne, Goodland	x				Widespread 3 (Other)	Cheyenne 85 Denver 63 G BDC 35 pk avg 2-4 PM 70 G	
**Dec 6 Fri						**Ft. Collins, Greeley, Sterling						? 80 G	$5,000-50,000
1964													
Jan 16-17 Thur-Fri	Thur night Fri morning, night	x	x xx			Boulder (especially Vassar Drive), Jeffco, Longmont					Widespread 1	AFA 74 Pueblo 72 Boulder Gale velocity Rocky Flats 83	High velocity winds with strong twisters; $500,000 - $5,000,000
Jan 25 Sat	Morning Wires down 9:45 AM		x			Boulder, Golden					Widespread 2 (Other)	Jeffco 80	$5,000 - 50,000
**Apr 26-27 Sun-Mon					After- snow in mountains on 28th	**eastern Colorado						Denver Airport 37 Mon 50-60 gusts	$50,000 - 500,000
May 5-6 Tue-Wed	Night Subsided 4 AM Fire call 9:17 PM	x	x	Midnight - 2 AM		Boulder (especially south Boulder					Widespread 3	Jeffco 80 Boulder 54 G BDC 32-38 Most of night	$50,000 - 500,000
Nov 11-12 Wed-Thur	Night Power out 10:40-11:10 PM, 5:29-6:15 AM	x	x		After- snow forecast for night of 12th						Widespread 3	BDC 25 avg 10 PM - 3 AM 42 G Calm 3:30 - 9 AM 15 avg 9-11 AM	

DATE (1)	TIME (2)	TIME (3)		TIME OF PEAK (4)	PRECIPITATION (5)	AREA (6)	Fires (7)	Fatalities (8)	Injuries (9)	DAMAGE (BOULDER ONLY) IN $ (10)	CLASS	VELOCITY (11)			COMMENTS (12)
1964 (con't)															
**Dec 12 Sat	5 AM - 10 PM Brief calm mid-afternoon	x x	x x								**	**BDC	20-25 avg 40 G		
Dec 15-16 Tue-Wed	12:45 AM - noon (15th), continued intermittently and moderately until 6 AM on the 16th	xx x	x x	12:45 AM 10-10:30 AM Tue	After- light snow Wed morning, more forecast for Wed night	Colorado, Idaho, Kansas Montana, New Mexico, North and South Dakota, Washington, Wyoming			x	Tens of thousands of dollars	Widespread 1 (Other)	Livingston, Mont Cheyenne Denver Jeffco Rocky Flats BDC (Tue)	70 G 80+ 67 94 81 57 pk Calm 48 G 30 avg	 12:45 AM 3:30-8:30 AM 10 AM night, morning	West wind "forerunner of a severe blizzard" $500,000 - $5,000,000
Dec 20-21 Sun-Mon	2 - 10 PM 10 PM - 6:15 AM - "spotty"	x x	 x	5-7 PM			x				Widespread 3	BDC	32 G		
Dec 21-22 Mon-Tue	Damage 7 PM - 1 AM Mon night, early Tue	x	 x	11 AM - 1 AM		Boulder, Marshall	x		x	Many thousands of dollars	Widespread 1	Jeffco BDC	100 pk 45 45+ (estimated) later	 12:30 AM	
Dec 22 Tue	2 PM - 7 PM	x	x	6 PM	After- rain on 23rd and 24th	Boulder, Berthoud, east of Lafayette, Longmont	x		x		Widespread 1	NCAR (30th St)	82 G	Afternoon and evening	High temperature 67°, low temperature 59°
1965															
Jan 27-28 Wed-Thur	Late morning Wed - early Thur Damage 12:05 PM, 4 PM, 5:15 PM, 6 AM	x x	xx x		After- snow mid-morning Thur	Boulder, Denver, Ft. Collins, Longmont	x		x		Widespread 1 (Other)	Denver Ft. Collins Rocky Flats BDC NCAR (30th St) NBS (Table Mtn)	54 73 87 53 55 72.5 89	 12:30 PM 7 PM	$5,000 - 50,000
Jan 29 Fri	Damage morning, subsided late afternoon. Calm 7 PM	 x	x		After- 5" snow Fri evening, Sat morning						Very limited 2				
Jan 30-31 Sat-Sun	Began about 8:30 PM. Damage 3-5 AM	x	x x	3-5 AM	After- 5" snow Sun afternoon and night (preceded by rain)	Boulder, Eldora, widespread over Colorado	x		—		Widespread 1	BDC NBS (Table Mtn)	53 G Calm 97 G	3-5:30 AM Noon Early Sun	Chinook Temp rose 25°, 8:30 PM - 10 PM Sat
Mar 22 Mon	Late morning Power out 11:50 AM		x								Very limited 3	BDC			

DATE (1)	TIME (2)	TIME (3)		TIME OF PEAK (4)	PRECIPITATION (5)	AREA (6)	Fires (7)	Fatalities (8)	Injuries (9)	DAMAGE (BOULDER ONLY) IN $ (10)	CLASS	VELOCITY (11)			COMMENTS (12)
1965 (con't)															
Jun 26-27 Sat-Sun	Sat night, early Sun, 9 PM 6:30 AM	x	x x							$600 partial	Widespread 3	BDC	38 pk		
Nov 27 Sat	Early Sat	x	x							$11,000 partial	Widespread 2	BDC Colo Bldg	25 avg 30 pk 75	2-7:30 AM 3 AM	
1966															
**Feb 12-13 Sat-Sun	Late Sat night				During- snow began 4 PM Sat, forecast to continue through Sun afternoon						**	**High winds			
Mar 3 Thur	Night		x		Before- 1.3" snow night of 2nd. After- snow forecast	Boulder, Byers County, Weld County					Very limited 3	Cheyenne Wells Denver NCAR (30th)	63 90 (unofficial) 55 pk	 9 PM	Cold, NW wind $5,000 - 50,000
**Mar 16-17 Wed-Thur	Wed night, Thur	x	x x	8:06 AM	During- snow in mountains, in Boulder early Thur morning	Boulder, Denver, Pueblo					** (Other)	**Denver Pueblo Table Mesa	55 65 56 pk	 8:06 AM	$5,000 - 50,000
**Jul 20 Wed	5:45 PM - 6:15 PM (Lyons) Early evening				During- wind-driven rain	**Lyons, Niwot, Northglenn					No reports				**Funnel cloud sighted
Oct 21-22 Fri-Sat	Afternoon and night Fire 7:50 PM Calm by early Sat afternoon	x x	x x				x				Widespread 2	Lilly	46 G	11 AM Fri	Frigid gale
1967															
**Jan 3 Tue	Morning		x								**	**BDC NCAR	35 pk 90		Chinook - 12° - 7 AM 40° - Noon
Jan 13 Fri	Nearly all day 7:30 AM - 4:30 PM Damage 9:25 PM	 x	x x	1-2 PM	After- snow on the 14th, forecast for the 15th		x				Widespread 2	BDC	35 avg 50 G 70 G	1-2 PM 1-2 PM 1-2 PM	
Jan 15-16 Sun-Mon	Sun night, early Mon Began 8 PM Began to subside 4 AM Calm 8 AM	x	 x	9 PM - 2 AM (9:30 - 11:30 PM)	Before- 7.7" snow Sat. After- 2" snow Mon morning	Boulder, Denver, Golden Lyons	x		x	$500,000	Widespread 1	Airport BDC NCAR Lilly	125 (estimated) 40 avg 70+ G 84 G 50-60 avg 124 G 125 G 124 G 70	 3 hr peak 11:15 PM 9:30 PM 9:42 PM 11:06 PM Midnight	Sharp warming trend Sun night & evening. "The worst single wind-storm in Boulder's history" $50,000 - $500,000

DATE (1)	TIME (2)	TIME (3)		TIME OF PEAK (4)	PRECIPITATION (5)	AREA (6)	Fires (7)	Fatalities (8)	Injuries (9)	DAMAGE (BOULDER ONLY) IN $ (10)	CLASS	VELOCITY (11)	COMMENTS (12)
1967 (con't)													
Jan 27 Fri	Early morning Power out 1:03 AM	x									Very limited 3		
Feb 13-14 Mon-Tue	6:30 PM - 5 AM	x	x			Boulder, Colorado Springs, Ft. Collins, Loveland	x			$3000 partial	Widespread 2	? 60-90 BDC 25 avg 70 G NCAR 50-55 avg 108 G	$5,000 - 50,000
Feb 17-18 Fri-Sat	Fri night, early Sat. Power out early Sat	x	x								Widespread 3		
Mar 13 Mon	2:30 PM	x									Very limited 3		"A gust of wind"
**Oct 23 Mon	Morning	x	x		After- showers. Snow forecast Mon night, early Tue						**	**BDC 20 avg 40+ G	
Oct 28 Sat	Subsided at dark	x	x		After- possible showers forecast for the 29th		x				Widespread 3	Downtown Boulder 65	Cold front expected Sun morning
**Dec 6 Wed	8 AM - Noon		x		Before- snow in mountains and in several cities in Colorado Tue night After- 5.2" snow Dec 8	Boulder, Denver to Ft. Collins, northern Colorado, southern Wyoming					**	**Cheyenne 58 Denver 55 75 (unofficial) Ft. Collins 66 Sterling 40 G Boulder Gale, heavy windstorm	Westerly winds, $5,000 - 50,000
Dec 11 Mon	Morning, early after-noon	x	x	Noon - 1 PM	After- snow late on Mon and on Tue						3	BDC 50 G noon-1 PM 57 G noon-1 PM 58 G noon-1 PM	
1968													
Apr 13-14 Sat-Sun	Fires 8:30 PM, 9:12 PM. Calm period during the night, came up again before sun-rise; 14th calm by mid-morning	x	x x	8 - 9:30 PM			x		x	$3500 partial	Widespread 2	BDC 60+ G 8-9 PM 73 G 8-9 PM NCAR 102 8:30 PM 50 steady 8:30-9:30 PM	$5,000 - 50,000
*Jun 13 Thur	Early afternoon Gust 12:29 PM	x		12:29 PM						$7500	Very limited 1	"A violent gust of wind"	Possible thunderstorm

DATE (1)	TIME (2)	TIME (3)		TIME OF PEAK (4)	PRECIPITATION (5)	AREA (6)	Fires (7)	Fatalities (8)	Injuries (9)	DAMAGE (BOULDER ONLY) IN $ (10)	CLASS	VELOCITY (11)			COMMENTS (12)
1968 (con't)															
Aug 23 Fri	Morning	x	x	4:30 - 5:30 AM							Widespread 3	NCAR	55 avg 85 G	4:30-5:30 AM	
Dec 4 Wed	Morning	x	x						—	$7000 partial	Limited 3	BDC	52		
1969															
Jan 7 Tue	6-11:30 PM		x	6-8 PM	After- light snow on 8th	Boulder, (especially Devil's Thumb and Table Mesa), IBM, Nederland, Peaceful Vally, Ward	x	1	x	Over one million dollars	Widespread 1	BDC NCAR	96 G 60 100G 130 G	6 PM Until 10 PM 6-8 PM	"Twister" extreme gustiness $500,000 - $5,000,000
Jan 31 Fri	Morning Intense 3:45 - 9:45 AM	x	x	7-8 AM			x		x		Widespread 1	BDC NCAR	83 G 50-70 55 avg 115	7:15 AM 6-7:30 AM Just after 7 AM	
Mar 19 Wed	Began just after midnight	x	x			Boulder, Lafayette, eastern slope of the Rockies	x				Widespread 3	Airport BDC NCAR	80-90 G 62 G 25-30 avg 105 G	 8:30 AM Morning	
Apr 7 Mon	Came up at 3 AM	x	x	6:30 - 7:30 AM	After- snow at noon							BDC	53 G 25 avg	 Morning	
Jun 25-26 Wed-Thur	Wed and Thur morning Fatality 4:45 PM Wed	xx x	xx x	10:30 AM Wed 11:22 AM Thur	Before- rain on Tue	Boulder (especially Table Mesa and tree damage in older section)	x	1	x		Widespread 1	BDC NCAR	70 G 35-40 avg 59 G 30-40 avg 123 G 88 G 55-60 avg	Wed Wed Thur Thur 10:30 AM Wed Thur Thur	
Nov 7-8 Fri-Sat	8 PM - midnight 5 AM - 7:30 AM	x	x x								Widespread 3	BDC	48 G 45 G	 5:30 AM	
Dec 10 Wed	Came up 7 AM Intense 10 AM - noon. Fire 10:20 AM		x				x				Very limited 3	BDC	30 avg 55 G	10 AM-noon 10 AM-noon	
Dec 21-22 Sun-Mon	Sun night, Mon morning.Power out 9:22 PM	x	 x	8:30 - 10:30 PM		Boulder, Jefferson, Larimer Counties	—				Widespread 2	BDC NCAR	75 G 50 115 G 100 G's	9:15 PM 8:30-10:30 PM 9:30 PM	$5,000 - 50,000
**Dec 23 Tue	Afternoon	 x				**West of Broomfield			x	$4000	Very limited 3				Gust of wind

DATE (1)	TIME (2)	TIME (3) a	TIME (3) b	TIME OF PEAK (4)	PRECIPITATION (5)	AREA (6)	Fires (7)	Fatalities (8)	Injuries (9)	DAMAGE (BOULDER ONLY) IN $ (10)	DAMAGE CLASS (10)	VELOCITY (11) station	VELOCITY (11) value	VELOCITY (11) time	COMMENTS (12)
1970															
Jan 24-26 Sat-Mon	Sat afternoon Sun, Mon morning to 9:30 AM	xx xx	xx xx	11 PM Sat, 3:30-4 AM Sun 7 AM, 8:30 AM Mon		Eastern Boulder county, northeastern Colorado				$2500 partial	Widespread 1	BDC NCAR	40+ G's 54 G 61 G 70 G (estimated) 122 G 109 G 90 G's	 3:30-5:30 PM Sat 3:45 AM Sun Sat night 7:06 AM Mon 8:30 AM Mon	Steady blow, not too gusty $5,000 - 50,000
**Jan 27 Tue	Afternoon	x				**South of Boulder, halfway between Marshall and Superior						High winds			
Feb 3-4 Tue-Wed	Subsided 5:15 AM on the 4th	x x	x x		After- light snow	Northern foothills					Widespread 2	BDC NCAR	62 G 35 avg 60 G 59 G 115 G 45 avg 102 G 35 avg	1:30 PM 1:30 PM 4 PM 9:15 PM 3:30 PM 3:30 PM 9 PM 9 PM	$5,000 - 50,000
Feb 16-17 Mon-Tue	Began 11:35 PM Mon Firecalls 1:14 AM, 4:30 AM, 8:45 AM Tue	x	x x				x				Widespread 3	BDC NCAR	30-40 avg 53 G 52 G 45 avg 90 G's	11:35 PM - 6:30 AM 3 AM 3:30 AM 1 AM	
**Feb 17-18 Tue-Wed	Tue night Wed morning	x	x x								**	**BDC NCAR	30+ G's 20-25 avg 42 G 30+ G's 70 G 45 avg 70 G 45 avg	4-8:30 PM 4-8:30 PM 9:10 PM Wed morning 11:15 PM 11:15 PM 7:30 AM 7:30 AM	
Nov 20-21 Fri-Sat	Fri night, Sat morning & afternoon	x x	x x		After- snow forecast for Sun						Widespread 3	BDC NBS Wea. Bur.	45 59 G 55 78 G	 11:30 AM 2:50 PM	Cold front Sat night
Nov 24-25 Tue-Wed	Began 10:30 PM, continued Wed morning Damage 7 AM Power out 2 AM Fire 5 AM	x	x x		After- snow forecast for Wed night, Thur		x				Widespread 2	BDC NCAR NOAA	61 G 69 (59?) G 54 G 48 G 95-97 G 81 G 30 avg	12:30 AM 1:45 AM 3 AM 8:55 AM after midnight 2 AM 9:30 AM	Warm, gusty winds in advance of cold front
**Nov 28 Sat	Increased as day went on			9-10 AM							**	BDC	47 G 77(?) G	8, 9:20 and 9:45 PM	Chinook

DATE (1)	TIME (2)	TIME (3)		TIME OF PEAK (4)	PRECIPITATION (5)	AREA (6)	Fires (7)	Fatalities (8)	Injuries (9)	DAMAGE (BOULDER ONLY) IN $	CLASS (10)		VELOCITY (11)		COMMENTS (12)
1970 (con't)															
Nov 30-Dec 1 Mon-Tue	9:40 AM Mon - Tue morning Car accident 1:45 AM Lull 12:30 - 4:30 AM Fires 9 PM, 9:45 PM	x x	xx x	8 PM 10:45 PM 12:30 PM		Boulder, Ft. Collins, Littleton Monarch Pass, Rye, Walsenburg, Cheyenne, Colorado, Kansas, Wyoming	x		—		Widespread 1 (Other)	Jeffco Airport BDC NCAR NBS	74 50-60 76 69 74 75 55 50 53 112 G 107 G 90-100 G's 50-60 avg 96	10 PM Tue morning 4 PM 7:45 PM 8:30 PM 12:30 AM 3 AM 6:30 AM 9:15 AM 10:45 PM 12:30 AM 4:30-6 AM 8 AM 8 PM	$50,000 - $500,000
Dec 3-4 Thur-Fri	Thur evening - Fri morning started 8 PM	x x	x x								No reports	BDC NBS	50 G's 25 avg 50 G 40 avg 70 G	2:30, 4:15, 8:30 PM Night Noon Fri morning 8:12 AM	
Dec 28-29 Mon-Tue	Started 6:30 PM continued thru night into Tue morning	x	x x								3	BDC NCAR	45 G's 46 G 87 G	8:15, 9 PM 12:45 AM 9 PM	
Dec 31 Thur	Afternoon	x		2 PM	After, snow fore- cast for Thur night, Fri						No reports	NCAR NBS	92 G 70 G	2 PM 2 PM	Warm, dry winds
1971															
Jan 8 Fri	Morning and afternoon	x	x	12:30 PM	Before- snow Jan 2-3 After- snow pos- sible Jan 10							BDC	52	12:30 PM	Rising temperature
Jan 20-21 Wed-Thur	Began 3 PM Wed	x x	x x	5:30 PM			x		x	$15000 partial	Widespread 2	BDC NCAR NBS	49 G 53 G 42 G 70-75 G's 72 G 30-45 G's 55 G's	4:30 PM 5:30 PM 8:15 AM Early morning 5:30 PM	Dust devil
Jan 21-22 Thur-Fri	Picked up 9 PM Thur Died down before noon Fri	x	x x								3	BDC NBS	68 G 20-40 57 G 65 G 77 G 35 avg 20 avg	1 AM Night 12:30 AM 5 AM 7:10 AM 11:30 AM	

DATE (1)	TIME (2)	TIME (3)		TIME OF PEAK (4)	PRECIPITATION (5)	AREA (6)	Fires (7)	Fatalities (8)	Injuries (9)	DAMAGE (BOULDER ONLY) IN $ (10)	CLASS	VELOCITY (11)			COMMENTS (12)
1971 (con't)															
Jan 25 Mon	Began 4-5 AM	x	x	6-7 AM		Boulder, Jeffco, Longmont, Nederland					Widespread 3	Jeffco	75 G	Early AM	
												Nederland	40 G	Early AM	
												BDC	87G	6:20 AM	
													65 G	9:45 AM	
												NCAR	147 G	6:15 AM	
													120 G	6:30 AM	
													100+ G's	6:30-7 AM	
													90+ G's	8:30 AM	
												NBS	23 avg	4-5 AM	
													30 avg	5-6 AM	
													51 avg	6-7 AM	
													42 avg	7-8 AM	
													42 avg	8-9 AM	
													40 avg	9-10 AM	
													56 G	4:06 AM	
													61 G	5:32 AM	
													91 G	6:33 AM	
													84 G	7:13 AM	
													70 G	8:10 AM	
Jan 30 Sat	Early morning Died down after 2 AM	x		1:30 - 2 AM	After- possible light snow forecast for Sat night						3	NCAR	102 G		
													99 G	Before 2 AM	
													85 G	1:50 AM	
												NBS	76 G	1:26 AM	
													74 G	1:57 AM	
Feb 10-11 Wed-Thur	Began 7:30 PM early Thur morn-ing	x		1-1:30 AM							No reports	BDC	Steady 35		
			x	3-3:15 AM									43 G	1 AM	
													40 G	3:10 AM	
												NCAR	80 G	1:30 AM	
													65-70 G's	1-4 AM	
												NBS	46 G	11:25 PM	
													58 G	1:30 AM	
													69 G	3:15 AM	
Feb 25-26 Thur-Fri	Gusty Thur after-noon, strong at 5 PM	x	x								No reports	BDC	40+	5 PM	
													53 G's	6:45 PM, 4 & 6 AM	
													50 G	9:45 AM	
	Slower 1:30 - 4:30 AM	x	x										48 G	10:15 AM	Temperatures dropped Thur afternoon
												NCAR	85 G	11:30 PM	
													100 G	Morning	
Mar 3-4 Wed-Thur	Began 11:45 PM Declined rapidly after 4 AM	x		12:30 - 1 AM							No reports	BDC	57 G's	12:40 & 2:20 AM	
													35 avg	12:30 - 2:30 AM	
			x									NCAR	90 G's	Midnight-1 AM	
													102 G	1 AM	
												NBS	44 avg	11:45 PM-4 AM	
													83 G	12:38 AM	

DATE (1)	TIME (2)	TIME (3)		TIME OF PEAK (4)	PRECIPITATION (5)	AREA (6)	Fires (7)	Fatalities (8)	Injuries (9)	DAMAGE (BOULDER ONLY) IN $ (10)	CLASS	VELOCITY (11)			COMMENTS (12)
1971 (con't)															
**Mar 14 Sun	Sun, Sunday night	x	x x								**	**NBS	51G	10:55 PM	Gusty
Mar 31 Wed	Lasted until 6 PM Car accident 2:15 PM	x	x			Boulder, Denver to Ft. Collins LaPorte	x				Widespread 3 (Other)	Ft. Collins NBS	40-50 72 G 83 G 46 avg	 4:45 PM Afternoon	One fatality, several injuries in Ft. Collins. $50,000 - $500,000
Apr 7 Wed	10 - 11 PM		x	10:35 PM	During- light drizzle						Widespread 3	BDC NBS	54 G 69 G	10-10:30 PM 10:35 PM	
**Oct 18 Mon	Morning	x	x		Before- trace of rain on Sunday						**	**BDC	45 G 46 G 48 G	3 AM 9:15 AM 10:16 AM	
Oct 26-27 Tue-Wed	Tapered off around 8 AM Overnight	x	x x	4:30 - 5:30 AM	During- snow at Lake Eldora After- light drizzle Wed night; snow on Thur						No reports	BDC NBS	50 G 48 G 35 G 62 G	4:45 AM 5:25 AM 7:45 AM 4:55 AM	
1972															
Jan 4-5 Tue-Wed	Started 7:30 PM Calm 10:30 PM - 3:30 AM Nearly calm by late morning	x	x x	8:30 - 9:30 AM	Before- snow Jan 2-3	Boulder, Broomfield, Denver, calm in Longmont					Widespread 2	Denver Jeffco. Nederland BDC NBS	16-33 G's 60 G 15-25 10 42 G 50-60 G 74 G 85 G	 Early morning 10 AM 10:30 PM 3:30 AM 8:45 AM 9:20 AM	Warm wind
Jan 6 Thur	Died down 4 AM Early morning	x		1 AM							3	BDC NBS	52 G 45 G's 69 G	1 AM Until 4 AM 1 AM	
Jan 9-10 Sun-Mon	Sun evening Damage Sun 9:50 AM	x x	x x		After- snow Mon afternoon and evening	Boulder, Lake Eldora					Widespread 1	BDC NBS	43 G 53 G 86 G 60-70 G's	7 AM Sun 1:45 AM Mon 9:52 AM Sun Through Sun	Cold front 10-11 AM Monday
Jan 11-12 Tue-Wed	Began late Tue morning Lull mid-after-noon - 5 PM Over by noon on Wed Car accidents: 11:50 AM on 11th 12:50 PM on 11th 1:10 PM on 11th Fire calls 12:47 - 2:50 PM on 11th	x x	xx x	1-1:30 PM 9-10 PM	Before- snow Mon afternoon and evening After- snow Wed afternoon and evening	Boulder, Broomfield, Colorado Springs, Denver, Ft. Collins, Georgetown, Lafayette, Longmont, Louisville, Loveland, Lyons, Jefferson County, Weld County	x		x	Two million dollars	Widespread 1 (Other)	Jeffco Mines Pk (Berthoud Pass) Rocky Flats BDC NBS	85 G 116 G 105 G 100 G 87 G 90 G 72 G 87 G 91 G 78 G 97 G 64 G 62 G 78 G 54 G	15 min Tue PM 1:28 PM Tue 10:15 PM Tue Late Tue AM 1:30 PM Tue Before 6 PM Tue 9:25 PM Tue 1:12 PM Tue 5:27 PM Tue 9:14 PM Tue 12:19 AM Wed 1:08 AM Wed 2 AM Wed 5 AM Wed	Cold wave warning for Wed night

DATE (1)	TIME (2)	TIME (3)		TIME OF PEAK (4)	PRECIPITATION (5)	AREA (6)	Fires (7)	Fatalities (8)	Injuries (9)	DAMAGE (BOULDER ONLY) IN $ (10)	CLASS		VELOCITY (11)		COMMENTS (12)
1972 (con't)															
**Jan 13 Thur			x		Before- 7.6" snow Wed afternoon and evening After- snow flurries forecast for Thur night						**	**BDC	37 G	11:30 AM	
**Jan 18 Tue	Picked up 10 AM		x								**	**BDC	35 G		
Jan 21-22 Fri-Sat	Started 4 PM Fri Lull 10 PM - midnight Died down 9:30 PM Sat	x xx	x xx	1-2 PM	After- forecast for occasional snow Jan 24-26						Very limited 3	BDC NBS	50 G's 52 G 56 G 74 G 71 G	3:30-4 AM Sat 10:45 AM 1:40 PM 7:21 PM Fri 1:10 PM Sat	
Jan 24 Mon	Mon morning Strong gusts started at 10:10 AM	x	x	11 AM	After- chance of snow forecast for 26th						Widespread 2	BDC NBS	66 G 83 G 92 G 69 G 40 G's 25 G's	11 AM 10:58 AM 11:01 AM 1:15 PM 4 PM 7 PM	West wind
Jan 28-29 Fri-Sat	Started Fri evening Subsided 2:30 AM Sat	x	x	10:45 PM	During or after- trace of snow overnight				–		Widespread 2	BDC NBS	30 G 64 G 76 G 43 G 34 G 46 G 90 G 87 G 50 G	7:30 PM 10:25 PM 11:20 PM 1:15 AM 3:15 AM 9:45 PM 10:47 PM 11:35 PM 2:30 AM	Temperature remained cold
Feb 13-14 Sun-Mon	Picked up Sun evening	x	x	1 AM								BDC NBS	49 G 67 G	Before 1 AM Evening	Preceded cold front
Feb 16 Wed	Fire 7 PM	x	x	6-7 PM			x				No reports	BDC NBS	51 G 30 G's 58 G	6 PM Thur morning 6:30 PM	
Mar 3 Fri	Morning	x	x		During- light rain (0.01" moisture)							Boulder BDC	55 G 52 G's	 2-3 AM and shortly before noon	
Mar 6 Mon	Afternoon and evening Damage 3 PM, 9:15 PM Began morning	x	x x	10 - 11:30 PM	After- trace of snow early on Tue				–		Widespread 1	Airport BDC NBS	100 G 56 G 64 G 60 G 46 G 51 G 60 G 64 G	3 PM 4 PM 10 PM 11:30 PM Morning 3:08 PM 4:57 PM 11:10 PM	Tornado-like gust at airport; "dust devils" preceded cold front

DATE (1)	TIME (2)	TIME (3)		TIME OF PEAK (4)	PRECIPITATION (5)	AREA (6)	Fires (7)	Fatalities (8)	Injuries (9)	DAMAGE (BOULDER ONLY) IN $ (10)	CLASS	VELOCITY (11)	COMMENTS (12)
1972 (con't)													
Apr 6 Thur	Began 2 AM Morning	x	x	4:30 - 6 AM							Widespread 3	BDC 54 G 4:30 AM 54 G 5-5:30 AM 30 G's Noon 10-15 avg Noon NBS 68 G 5:53 AM	
Nov 25-26 Sat-Sun	Sat night - Sun morning 8 PM - 8 AM	x	x x	2-6 AM	After- 10.4" snow Mon morning (0.70" moisture)	Boulder, Denver, Ft. Collins					Widespread 2	Rocky Flats 104 G 4:05 AM BDC 68 G 2 AM NBS 51 G 10:45 PM 70 G 5:35 AM	
Dec 1 Fri	Began 9:30 AM	x	x	1:10 PM							No reports	BDC 53 G 11:35 AM 65+ G 1:10 PM	Chinook winds

APPENDIX B

WIND SPEED DAMAGE THRESHOLDS

Figure B.1 shows the peak gusts experienced at four anemometer sites during windstorms in which damage actually occurred. The abscissa of each graph is divided into the three storm damage classes. Class 3 storms, in which only minor damage occurs, are of special interest. The lower wind speed in this category can be interpreted as a damage threshold. Peak wind speeds below this threshold are generally associated with no damage; wind speeds above this are generally associated with some kind of property damage. The damage threshold concept is important where wind speeds vary markedly throughout the city and where reports of damage may not reach local newspapers. Accordingly, a wind damage threshold was estimated conservatively for each of these four anemometers located in the city. Storms having peak wind speeds above these thresholds were included in the climatology even if no damage was reported in newspaper accounts. We found 138 Boulder downslope windstorms in which property damage occurred. An additional 13 storms were included in climatological calculations on the basis of the damage threshold concept (table B.1). Thus, 151 windstorms affecting Boulder, Colorado, provide the climatological base from which the statistics are derived.

Table B.1. Thirteen Windstorms Exceeding Wind Speed Damage Thresholds

DATE OF WINDSTORM	PEAK WIND SPEED REPORTS (mph)
March 15, 1935	Valmont 60
April 7, 1969	BDC 53
December 3-4, 1970	BDC 50, NBS 70
December 31, 1970	NCAR 92, NBS 70
January 8, 1971	BDC 52
February 10-11, 1971	BDC 43, NCAR 80, NBS 69
February 25-26, 1971	BDC 53, NCAR 100
March 3-4, 1971	BDC 57, NCAR 102, NBS 83
October 26-27, 1971	BDC 50, NBS 62
February 13-14, 1972	BDC 49, NBS 67
February 16, 1972	BDC 51, NBS 58
March 3, 1972	BDL 52
December 1, 1972	BDC 65

BDC - Boulder Daily Camera, 11th & Pearl Sts.
NCAR - Natl. Center for Atmospheric Research, Table Mesa Site.
NBS - Natl. Bureau of Standards, 325 Broadway.

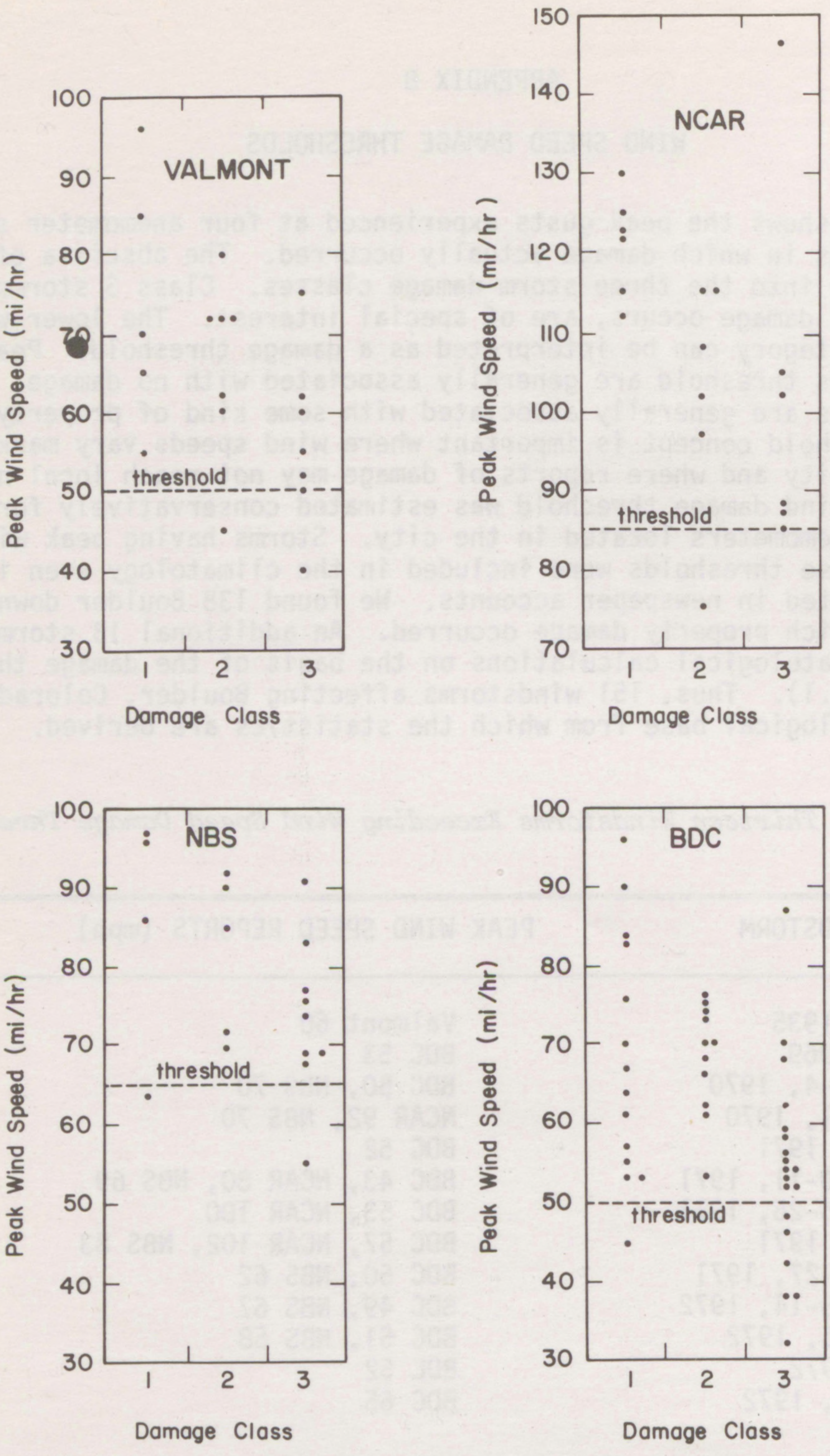

Figure B.1. Peak wind speeds as a function of damage class for four individual anemometer sites (Valmont power plant, National Center for Atmospheric Research at Table Mesa, National Bureau of Standards, and the Boulder Daily Camera office). Estimated wind speed damage thresholds are indicated.

APPENDIX C

NEWSPAPER ACCOUNTS

C.I. AREAL EXTENT OF DOWNSLOPE WINDSTORMS

C.II. ROTATIONAL EDDIES

C.III. WIND-RELATED FATALITIES

C.IV. COST OF WIND DAMAGE

C.I. AREAL EXTENT OF DOWNSLOPE WINDSTORMS

Boulder County News
November 23, 1869, 2:2-3
[Tuesday evening]

The Storm . . . . Damages, Etc.

We give below accounts of the terrific storm that raged over different localities in this Territory, clipped from our exchanges:

The most destructive gale that has visited Denver since Christmas, 1864, occurred yesterday morning [November 22]. It came from the northwest and was the breath of the snowstorm that had been raging in the mountains for a day or two previous. The storm began about three o'clock, but was most severe between five and six. The damage occasioned in town will probably aggregate fifteen or twenty thousand dollars, and is mainly in the tearing off of tin roofs. [A list of buildings damaged followed].

– Rocky Mountain News

During the storm in Golden [several roofs were blown off, the Episcopal University and two houses destroyed, and hay blown away].

– Tribune

This has been a sad Thanksgiving day for the citizens of Georgetown. An awful and destructive windstorm, with savage violence came plunging down the mountains about four o'clock this morning, and continued to rage with unabated violence during most of the day. One little girl, a daughter of A. M. Brocket, was killed instantly by the timbers of a falling house, and Mr. B. was seriously injured, so that doubts are entertained of his recovery. Several persons have legs and arms broken and dislocated. The Episcopal Church is in ruins, the large stable of the Reynolds Brothers is a total wreck, the old Georgetown mill building smashed, and a great many valuable private residences injured and some entirely destroyed. The total amount of damages done to property is estimated at $25,000. The telegraph line is down for a long distance.

– Georgetown Miner

The Daily Camera
December 23, 1892 1:4-5
[Friday]

Storm in the Hills

Dan Lynch of Ward Blown Down the Mountain With His Team

In Boulder yesterday, a more beautiful day could hardly be asked for. Cold and crisp, to be sure, but calm and pleasant. Up in the hills only a few miles away, however, it was different. The wind commenced blowing around noon, and it made matters pretty interesting in the country around Ward and Copper Rock.

In the afternoon Dan Lynch, the well known freighter of Ward, was pulling up the Sunset Hill with a load of freight when a young tornado struck him and over went the wagon, team and Dan down the hill. Dan landed against a stump with a portion of his freight on top of him and sustained serious injuries. He was taken to Ward. The team was also badly mashed up and the wagon wrecked.

The terrible wind drifted snow badly in the canon, and the afternoon train did not reach Sunset until after 6 o'clock and then only after a hard struggle with the snow drifts. Two stages were over from Ward but refused to attempt the trip back after dark, and the half dozen Ward passengers were compelled to remain at Sunset over night.

Conductor McGaffey reports that it was one of the severest storms he ever saw in the hills.

The Boulder News
November 22, 1906 1:4
[Thursday]

. . . . But the strangest feature of the storm was the small area it covered. In the mountains to the west the wind was strong, but a few miles north, south and east there was none at all. Five or six miles down the valley they could see a great cloud of dust around Boulder, but there was no wind at all there.

C.II. ROTATIONAL EDDIES

Boulder Daily Camera
September 17, 1953 1:4-8
[Thursday]

A freak twister of tornadic power ripped almost the entire roof off the new residence of Fred N. Gardner at 865 Circle Drive this afternoon . . .

Gusts of wind had been occurring most of the day but there was no sustained blow of damaging velocity. After the sudden twister hit about 2 pm, the wind was not severe.

Boulder Daily Camera
January 18, 1964 1:1-5
[Saturday]

The pattern of the destruction was such that it lead observers to believe the high-velocity winds were accompanied by extremely strong twisters.

Boulder Daily Camera
January 9, 1969 3:1-2
[Thursday]

Shingle-Ripping Gusts Remind Man of "Twisters"

"Being an old flat-lander from Kansas and Nebraska, I'd swear that wind was a 'twister'."

These were the words of Joe Rothmeier, 2420 Briarwood, who said with the first gust of Tuesday night's gale, all the shingles on his house were torn off and went swirling in all directions . . .

Mrs. Rothmeier said they were standing in the kitchen when the first wind hit and the shingles began to fly.

"The oddity of it was that the shingles were all lying around the house, not on one side or down the block, like they would have been if the wind was blowing in one direction," Rothmeier said.

Boulder Daily Camera
January 21, 1971 1:1-5
[Thursday]

Wind tore apart a nearly-completed house at 4396 Eldorado Springs Drive Wednesday afternoon.

According to an eyewitness account, the roof was lifted some 50 feet in the air before plunging to earth. When it was over, two men working on the house were bruised and scratched, and debris was scattered over a half-mile area.

Bill Van Dunkler, an Eldorado Springs contractor who was working on a house next door, described the wind that struck the home owned by Gerald Grand as a circular motion "dust devil".

C.III. WIND-RELATED FATALITIES

The Boulder News
November 22, 1906
[Thursday]

Wind Storm

One of the Liveliest Days Boulder Ever Witnessed.

One Death and Numerous Injuries to Persons and Property

Thursday afternoon of last week was the liveliest time that Boulder has had in many a day. About three o'clock a wind storm come up suddenly that put everything in motion that was loose and loosened a good many things that were supposed to be tight. Almost before the people were aware of it, the atmosphere was dark with dust, leaves, shingles, and debris of every kind. The wind howled and roared, swept the streets, rushed around the corners, upset vehicles, started boxes and barrels careening along the streets, toppled over chimneys, upset outhouses, blew off a number of roofs, blew down telegraph and telephone poles, ripped awnings, broke windows and so on. People who were caught out found it difficult to gain home or shelter, and there was great danger from the missiles that filled the air.

As usual, the damage did not begin to correspond with the noise and apparent fury of the storm, which continued into the night, but there were hundreds of cases of small damage and the total will amount to severeal thousand dollars. It caused one death and probably more, and a great many lesser injuries.

John Shuemaker, whose home was on Portland Avenue, was working on the new Sunshine road about two miles up the canyon, went into an old barn out of the storm, and it blew down, killing him instantly, also two horses and a burro that were in it. Several other hands who were outside, escaped.

The Boulder News
December 26, 1907
[Thursday]

Fierce Storm

Train Blown from Track – One Man Killed
Many Injured – Numerous Accidents

One of the worst windstorms that has visited this section for a long time, began Monday night and continued all day Tuesday. At times, it blew almost a hurricane, making it not only disagreeable but dangerous to be out and there were numerous small accidents and some more serious.

The worst was the blowing of a passenger train from the track a mile this side of Marshall. It was the train due here at 11:35, and when at that point where the wind sweeps down with terrific force through the gap in the mountains, the express, smoker and first coach toppled over. There was a scene of intense excitement for a time and it looked as if many must be killed. The engine ran to Boulder as quickly as possible and returned with a relief train and physicians. A train was also hurried up from Denver but the injured had been taken to University Hospital. The injured are . . . . [list of names and specific injuries -- one fatality] .

Where the accident happened is known as the windiest point on the road, and accidents have happened there before, and the train crews are always fearful during a wind storm.

Boulder Daily Camera
March 18, 1920
[Thursday]

[Two men were killed and four injured in a collision between a police car and a fire truck at 19th and Pearl.] Indications are that a misunderstanding between Frank Urie, driver of the fire truck, and Chief Johnson, occasioned by the wind, was responsible for the accident. . . . The story told by Frank Urie, driver of the fire truck, shows that a misunderstanding due to the wind was responsible for the accident.

"Ordinarily in answering a call on lower Pine Street", said Urie, "we would go up 11th to Pine and down Pine to avoid the congestion of the business section of Pearl Street. I knew though that Chief Johnson was at the corner of Thirteenth and Pearl streets and drove that way to let him know where we were going."

"As the truck neared the corner I slowed up somewhat and yelled at Emil: Thirty-eighth and Pine."

"Undoubtedly he heard me indistictly because of the high wind and thought I had said Twenty-eighth and Pearl."

[A collision between the two vehicles occurred at 19th and Pearl as the fire truck started to turn up 19th towards Pine, and the close-following car was unable to slow down quickly enough for the unexpected turn.]

Boulder Daily Camera
May 21, 1925
[Thursday]

**Boulder Carpenter Killed in Storm
Two Others Injured**

L. S. Bennett, 1838 Pine Street, died this afternoon of injuries received at 3:30 when a roof on which he was working near Eighteenth and Baseline was blown off during the storm. S. B. Turner and Walter Blanchard were injured in the same accident. All three were taken to the hospital. Shock and internal hemorrhage caused Bennett's death. Blanchard and Turner were not badly hurt, and have left the hospital.

Boulder Daily Camera
January 8, 1969
[Wednesday]

Fires Widespread; Local Man Killed

Boulder and rural firemen summed up Tuesday night's firefighting activities in two words -- miraculous and tragic.

The miracle, they said, was getting through the night with no more fire damage than resulted. Tragic was the death of one of their own, Raymond E. Dovala, 34, a Cherryvale volunteer fireman who died this morning of head injuries suffered in a fall from a pumper truck. . . . [The truck was] traveling about 20 miles per hour, but the wind was fierce and may have blown Dovala from the vehicle, the chief said.

Boulder Daily Camera
June 26, 1969
[Thursday]

Thomas W. Hafer, Jr., 24, of Andover, Mass., was killed on the University campus Wednesday about 4:45 pm while attempting to sail under a parachute in the strong wind.

Two companions were holding a rope guideline attached to the parachute which also had a rope attached to a car as a ground anchor.

A strong gust of wind, according to one witness, whipped the parachute, with Hafer dangling beneath it, 30 to 40 feet high. The chute circled and went into the ground. . . . Hafer was dead on arrival at the hospital.

C.IV. COST OF WIND DAMAGE

Rocky Mountain News
December 27, 1883, 2:1
[Thursday]

Boulder visited by a Destructive Conflagration
Destroying several large businesses and private houses
Heavy winds play sad havoc in many places

Boulder's Blow. Boulder received quite a benefit from Colorado zephyrs Christmas Eve, or rather Christmas morning before daylight. It was one of those terrific windstorms which comes in gusts and carries all loose material with it. It did considerable damage to property in the way of blowing over chimneys, fences, outhouses, etc. and damaging roofs and buildings. The tower of the central fire station proved to be too weak for the blast and went over, dropping the bell on top of the station house. The roof of the building was considerably damaged and also the council chamber, which entertained with pleasure a competitor to the city fathers in furnishing wind. The damage to the city will be in the neighborhood of 300 dollars. The portable photograph gallery of J. R. King was blown to pieces entailing a loss of 400 dollars. A part of the roof of the American house was blown off, damaging it to the amount of 100 dollars. A number of window lights were blown out of the courthouse. A large part of the roof of the Homer block, occupied by Rittmaster's dry goods store, was blown off and carried over the Dietz store, knocking 2 holes in the roof there, and thence against the Odd Fellows block, knocking the corner off it. The damage here was about $300. The gable end of John Slater's residence was blown off and the top of Major Whiteley's barn blown off and the Pomeroy barn blown to pieces, and various other smaller damages created.

ENVIRONMENTAL RESEARCH LABORATORIES

The mission of the Environmental Reasearch Laboratories is to study the oceans, inland waters, the lower and upper atmosphere, the space environment, and the earth, in search of the understanding needed to provide more useful services in improving man's prospects for survival as influenced by the physical environment. Laboratories contributing to these studies are:

Atlantic Oceanographic and Meteorological Laboratories (AOML): Geology and geophysics of ocean basins and borders, oceanic processes, sea-air interactions and remote sensing of ocean processes and characteristics (Miami, Florida).

Pacific Marine Environmental Laboratory (PMEL): Environmental processes with emphasis on monitoring and predicting the effects of man's activities on estuarine, coastal, and near-shore marine processes (Seattle, Washington).

Great Lakes Environmental Research Laboratory (GLERL): Physical, chemical, and biological, limnology, lake-air interactions, lake hydrology, lake level forecasting, and lake ice studies (Ann Arbor, Michigan).

Atmospheric Physics and Chemistry Laboratory (APCL): Processes of cloud and preciptation physics; chemical composition and nucleating substances in the lower atmosphere; and laboratory and field experiments toward developing feasible methods of weather modification.

Air Resources Laboratories (ARL): Diffusion, transport, and dissipation of atmospheric contaminants; development of methods for prediction and control of atmospheric pollution; geophysical monitoring for climatic change (Silver Spring, Maryland).

Geophysical Fluid Dynamics Laboratory (GFDL): Dynamics and physics of geophysical fluid systems; development of a theoretical basis, through mathematical modeling and computer simulation, for the behavior and properties of the atmosphere and the oceans (Princeton, New Jersey).

National Severe Storms Laboratory (NSSL): Tornadoes, squall lines, thunderstorms, and other severe local convective phenomena directed toward improved methods of prediction and detection (Norman, Oklahoma).

Space Environment Laboratory (SEL): Solar-terrestrial physics, service and technique development in the areas of environmental monitoring and forecasting.

Aeronomy Laboratory (AL): Theoretical, laboratory, rocket, and satellite studies of the physical and chemical processes controlling the ionosphere and exosphere of the earth and other planets, and of the dynamics of their interactions with high-altitude meteorology.

Wave Propagation Laboratory (WPL): Development of new methods for remote sensing of the geophysical environment with special emphasis on optical, microwave and acoustic sensing systems.

Marine EcoSystem Analysis Program Office (MESA): Plans and directs interdisciplinary analyses of the physical, chemical, geological, and biological characteristics of selected coastal regions to assess the potential effects of ocean dumping, municipal and industrial waste discharges, oil pollution, or other activity which may have environmental impact.

Weather Modification Program Office (WMPO): Plans and directs ERL weather modification research activities in precipitation enhancement and severe storms mitigation and operates ERL's research aircraft.

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
BOULDER, COLORADO 80302

☆U.S. GOVERNMENT PRINTING OFFICE: 1975—677-347/1208 REGION NO. 8