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DEPARTMENT OF COMMERCE
UNITED STATES OF AMERICA

SURFACE METEOROLOGICAL FEATURES ASSOCIATED WITH EASTERN COLORADO SEVERE CONVECTIVE STORMS

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ABSTRACT

To better understand the synoptic surface conditions present during severe thunderstorm episodes in eastern Colorado, 300 such days are examined. Four basic surface patterns associated with severe convective weather east of the Continental Divide are identified from this data set. A large majority of severe thunderstorms (i.e., those which produce large hail, and/or damaging wind, and/or tornadoes) are shown to occur in the region north of a stationary surface front in an area of large-scale anticyclonic upslope flow. A severe thunderstorm climatology is developed and a range of values of pre-storm surface parameters (pressure, temperature, dewpoint, and wind) is graphically presented, using spatially interpolated surface observations taken from the surface chart preceding each of the 300 severe storm events. Finally, a surface-based severe storm index, applicable to eastern Colorado, is developed with examples of how it might be used as guidance in severe thunderstorm forecasting.

1. Introduction

The precise prediction of severe convective storms remains a difficult challenge to the forecasting community. The PROFS (Prototype Regional Observing and Forecasting Service) Program, based at ERL Headquarters in Boulder, Colorado, is developing the means and methods to answer that challenge. By applying state-of-the-art technology and developing and testing new methods, the PROFS Program is attacking the broader problem of accurate local short-term forecasting. One of their early objectives is the development of techniques to improve the timeliness and accuracy of severe[1] thunderstorm watches and warnings in Colorado.

While the main concern of PROFS is the local to regional aspect of forecasting, it is important to document and consider the synoptic and meso-α[2] scale meteorological settings that lead to severe convective storms. A forecaster must first be familiar with the large scale conditions favorable for severe thunderstorm development to achieve any improvement in the medium and short-term forecast of these events.

The Office of Weather Research and Modification (OWRM) assists PROFS in developing their objectives by providing meteorological diagnostic studies and tools for implementation into their prototype system. A companion document (Maddox et al., 1981) reports the general meteorological conditions associated with severe thunderstorms in Colorado and presents detailed analyses of a

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[1]"Severe" includes those thunderstorms which produce large hail, and/or damaging winds, and/or tornadoes. Flash flood situations are not included in this study.

[2]Meso-α, as used here, denotes features with a characteristic scale of 250-2500 km.

number of recent significant events. This technical memorandum focuses on the climatology of surface conditions favorable for severe thunderstorms in eastern Colorado (that portion of the state east of the Continental Divide). A number of large-scale surface patterns associated with severe storms are identified, and an index for severe storm forecasting, based on surface observations is developed.

2. Analysis Procedure

Eleven years (1970-1980) of the NOAA publication Storm Data were searched and 300 severe thunderstorm days were selected for examination. Storm Data has acknowledged limitations as a data source, particularly in sparsely populated regions of eastern Colorado where fewer severe storms are reported than probably occur, and those reported are clustered around population centers and major highways. Nevertheless, 300 different severe storm days are a considerable sample and are likely representative of conditions that produce most of eastern Colorado's severe convective weather.

The 3-hrly surface chart (as transmitted by NMC on the facsimile circuit) preceding the first severe storm report on each of the 300 days was reanalyzed. These charts were then categorized as to type of synoptic setting. A surface report was spatially interpolated for the approximate location of each day's first severe storm event. A sequence of charts was examined for reports which were more than 1 1/2 hours after a chart time. Pressure, temperature, dewpoint, and wind were interpolated from the reanalyzed fields. These observations were then used to construct a statistical data base describing prestorm surface conditions.

3. Synoptic Patterns

Upon examination of the synoptic surface features associated with severe convective episodes, four basic patterns emerged. The most frequently recurring pattern is depicted in Fig. 1. Pattern 1 accounted for 186 cases or 62% of the sample. The features shown are consistent with those described in the literature on High Plains severe convection [see, for example, Doswell (1980); Fritsch and Rodgers (1981); Maddox et al. (1981); and Zipser and Golden (1979)]. This pattern develops as a polar air mass advances into the High Plains through the northern tier of states. The front marking its leading edge initially moves fairly rapidly southward and frontal passage may not be accompanied by thunderstorms. The front then slows and becomes stationary in roughly an east-west orientation through Kansas or Oklahoma, turning northward into Colorado following the Front Range of the Rockies. The severe weather conditions develop north and east of the front as the relatively cool anticyclonic flow brings higher dewpoints upslope into Colorado (see Figs. 9, 10 and Table 1). The important features of the pattern are the increasing dewpoints and the local/regional orographic influence. The monthly distribution (see Fig. 1) shows the highest frequency is in July and that this is predominantly a late spring-summer situation. This setting can persist with minor variations (Fig. 2) for several days and is often associated with a sequence of severe thunderstorm days. Careful reanalysis of the surface charts is often needed to detect the presence of the frontal boundaries as they become increasingly weak and diffuse with time.

Pattern 2 (Fig. 3) is similar to Pattern 1. The primary difference is that a pronounced Pacific cold front advances into the eastern Plains intersecting the old quasi-stationary frontal zone. With this pattern, the severe

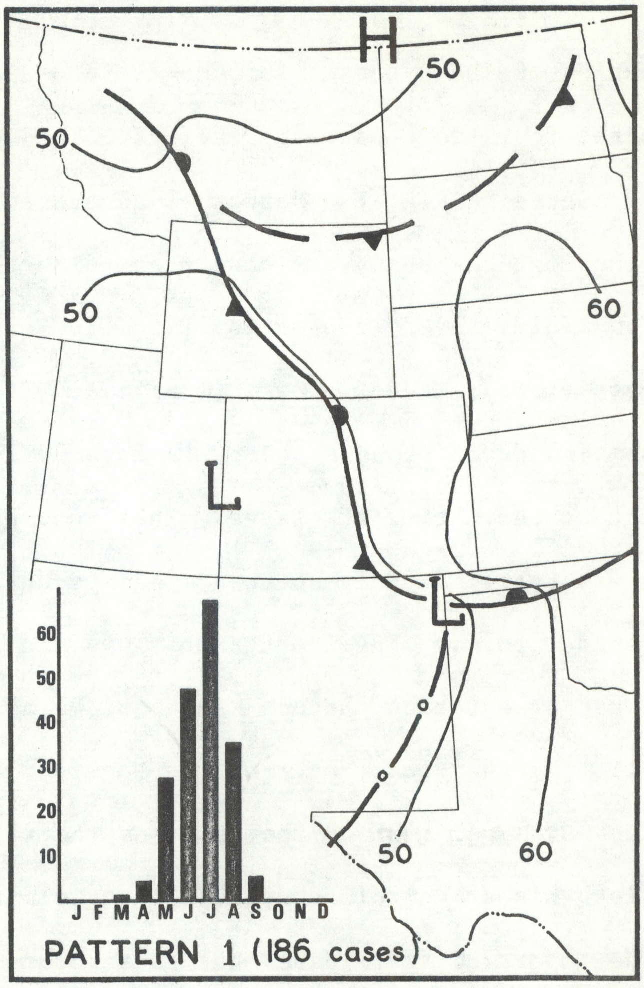

Figure 1. Typical surface features of Pattern 1 storm producing environment; 50° and 60° F isodrosotherms; monthly distribution inset.

weather again occurs in the relatively cool, moist upslope flow north or northeast of the stationary front. Intrusion of 45° - 55° (F) dewpoints coupled with orographic lifting and diurnal heating provide conditions favorable for intense thunderstorm development. This pattern was identified in 39 cases, or 13%, and while it seemed to favor June (see monthly distribution of Fig. 3) it was found to occur from late March through September.

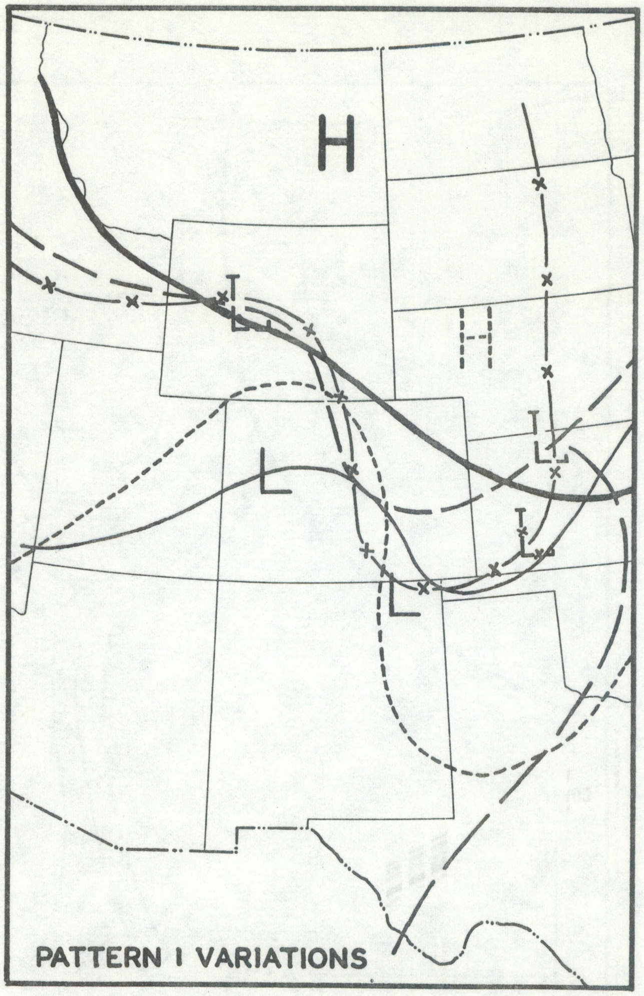

Figure 2. Five examples of variations of Pattern 1 surface front positions.

The third distinct pattern (Fig. 4) reveals a very weak setting characterized by large-scale southeasterly flow that transports high dewpoints into the High Plains and eastern Colorado. A surface dryline or lee-trough usually runs north-south just east of the Rockies with drier air to the west. Isolated severe thunderstorms occasionally occur within this seemingly benign pattern, thus the forecaster must focus on mesoscale features to identify possible areas of severe storm development. The monthly distribution of Pattern 3 (Fig. 4) reveals this to be a summer situation with the peak in July. This pattern accounted for 38, or 13%, of the 300 cases reviewed.

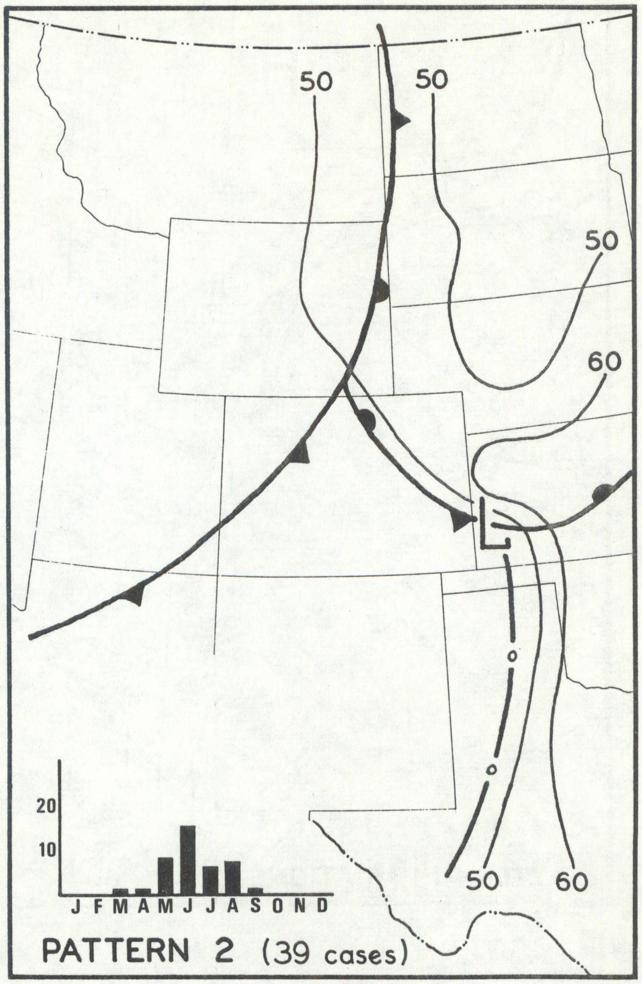

Figure 3. Typical surface features of Pattern 2 storm producing environment; 50° and 60° F isodrosotherms; monthly distribution inset.

Pattern 4 (Fig. 5) depicts a strong synoptic situation that is quite typical of favored settings for severe storms farther to the east over the Great Plains. A significant surface cyclone produces strong southerly flow from the Gulf of Mexico north-northwestward into the plains of Colorado. Because of the significant large-scale weather system, the lowest pressures, strongest pressure gradient, and highest winds of the four patterns are associated with this setting. It is not surprising that Pattern 4 produced the

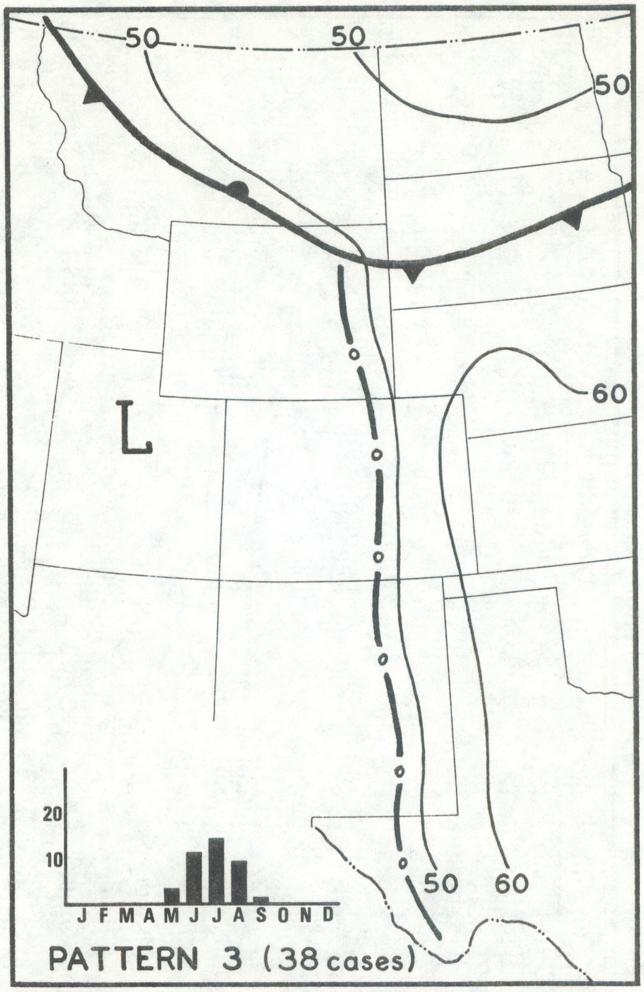

Figure 4. Typical surface features of Pattern 3 storm producing environment; 50° and 60° F isodrosotherms; monthly distribution inset.

strongest tornado yet documented in Colorado (Baca County, 18 May 1977). The monthly distribution (Fig. 5) shows that this pattern occurs in the spring with a significant peak in May. With 27 cases, this pattern represents only 9% of the sample.

The remaining 10 cases did not fit any of the above patterns. Six of these involved damaging thunderstorm wind gusts. The settings that produced these events could be described as weak and disorganized with very low

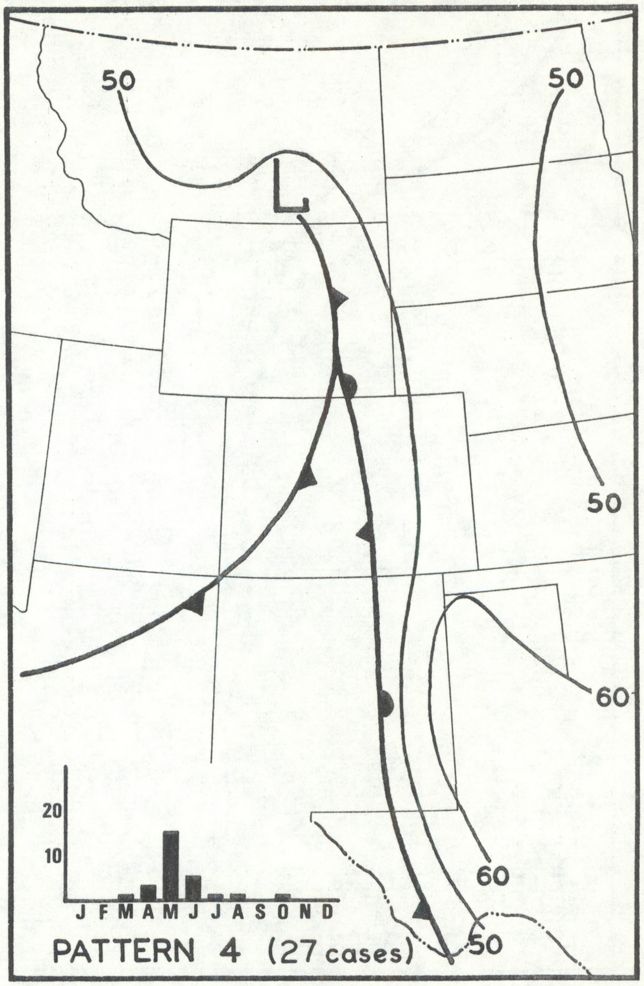

Figure 5. Typical surface features of Pattern 4 storm producing environment; 50° and 60° F isodrosotherms; monthly distribution inset.

dewpoints (low 30's °F) being a common factor. These situations are probably quite similar to those described by Brown et al. (1982). The last four cases are quite undistinguished. Apparently on these days, the surface meteorological features responsible for the severe storms are are too subtle to be classified.

4. Climatology

The following severe thunderstorm climatology for the eastern half of Colorado was developed as a forecasting aid. Based on the 300 interpolated surface observations, these distributions of the standard surface parameters delineate conditions present during the majority of severe weather periods.

The monthly distribution (Fig. 6) of the 300 severe thunderstorm reports in Colorado follows a somewhat atypical distribution. July is the month of peak activity for severe convective weather. The period May through August is obviously the severe storm season for Colorado, with 93% of the reports falling within those four months. This distribution can be contrasted with that of the central and eastern states where, for example, tornado activity peaks from April to June then drops sharply in July and August (McNulty *et al.*, 1979).

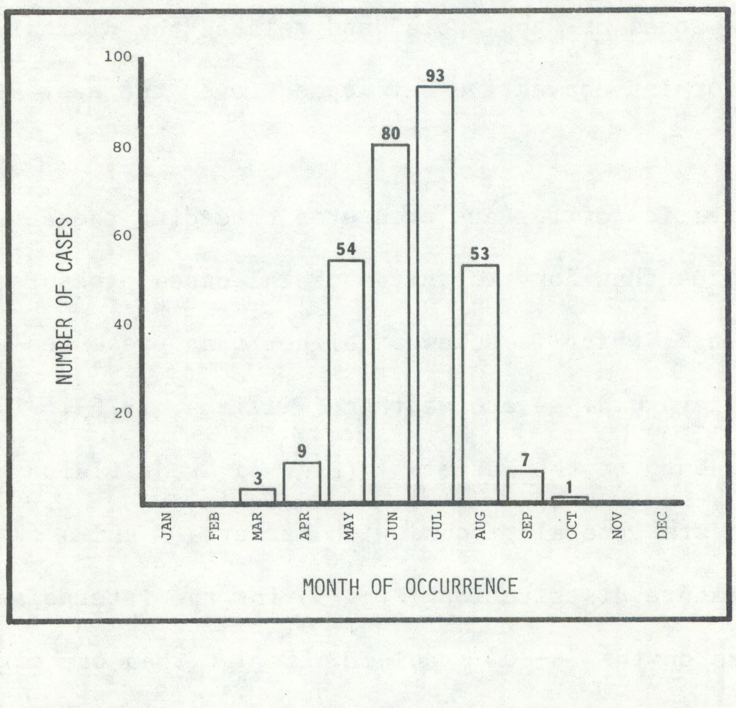

Figure 6. Monthly distribution of severe thunderstorm reports.

The diurnal frequency of severe weather events (Fig. 7) is very similar to the diurnal frequency of summer (June-August) radar echoes detected by the NWS Limon, Colorado, WSR-57 [see Karr and Wooten (1976) Fig. 1]. The cross-hatched portions of Fig. 7 constitute vague reports (as described in Storm Data) that specified only "afternoon" or "evening". Although these reports are probably distributed across several adjacent hours, they were arbitrarily assigned to either the 1501-1600 or 1901-2000 periods, respectively. This graph is a summary of reports from all of eastern Colorado and does not account for the diurnal tendencies at individual stations. The data of Karr and Wooten (1976) indicates that locations closer to the east slopes and foothills would tend to peak earlier in the afternoon than those farther east. In their study of Colorado summer radar echoes, Karr and Wooten determined that convection frequently initiates in the late morning over the foothills and Front Range in several preferred areas. Then, typically, the echo maximum moves eastward during the afternoon hours. Henz (1973) also documented these convective genesis zones or "hot spots" and related the diurnal foothills wind cycle to late morning convective development over the east slopes of the Front Range.

The distribution of surface pressures preceding the severe weather events (Fig. 8) indicates that for two-thirds of the cases pressures fall within the 1006-1015 mb range, which is somewhat higher than pressures associated with central and eastern U.S. severe weather (Williams, 1976). This reflects the dominating frequency of the Pattern 1 (Fig. 1) Great Plains high circulation. Lower pressures are generally found with Patterns 3 and 4 (Figs. 4 and 5).

The temperature distribution (Fig. 9) for the interpolated prestorm observations peaks on the 76-80° F column. Cooler than one might expect, these temperatures again reflect the influence of the Pattern 1 surface high. Few

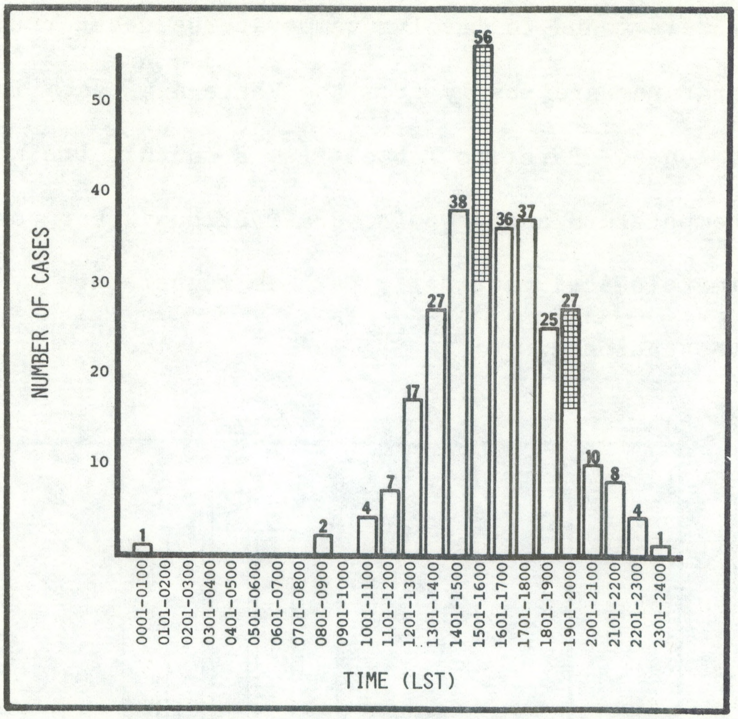

Figure 7. Diurnal distribution of severe thunderstorm reports.

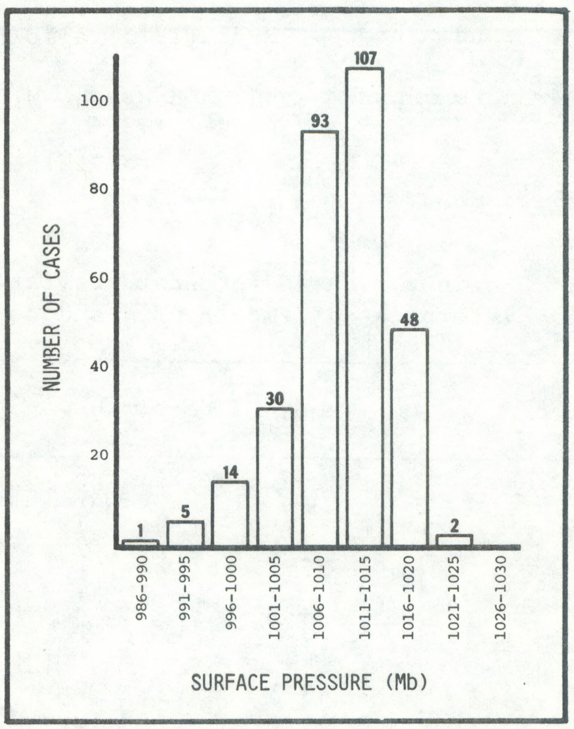

Figure 8. Distribution of surface pressures for interpolated prestorm observations.

severe storms were found to involve temperatures greater than 90° F. The coldest temperatures are mostly from the Pattern 4 cases involving deep springtime cyclones. Refer to Table 1 for a monthly breakdown of mean values of prestorm temperature and dewpoint observations. For comparison, Table 2 shows the climatological mean daily maximum temperature by month for four representative stations.

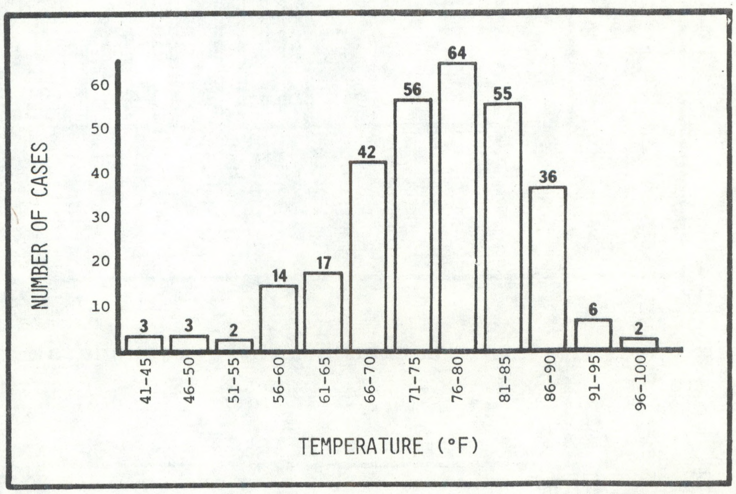

Figure 9. Distribution of temperatures for interpolated prestorm observations.

Table 1. Monthly mean and standard deviation of prestorm interpolated temperatures and dewpoints.

	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
No. of cases	3	9	54	80	93	53	7	1
Mean Temp. (°F)	46	62.9	67.9	76.2	82.4	78.9	73.1	64
Std. Deviation	1.7	10.3	7.2	8.3	6.3	6.5	7.3	--
Mean Dewpoint (°F)	34	43.3	49.2	54.0	55.4	53.9	49.7	55
Std. Deviation	1	6.3	5.7	5.1	5.5	5.2	3.9	--

Table 2. Climatological mean daily maximum temperature (°F) for selected stations.

	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
Denver	50.8	60.5	69.9	81.2	87.9	86.5	78.1	66.9
Akron	49.9	59.8	70.1	81.4	88.9	87.3	78.9	66.4
Lamar	59.9	69.8	77.5	89.3	94.3	93.2	86.0	73.8
Trinidad	56.7	65.1	73.9	84.4	88.8	87.7	81.2	70.4

The corresponding dewpoint distribution (Fig. 10) indicates 82% of the cases occurred with dewpoint temperatures between 46° and 60° F. Doswell (1980) notes that the return of 45° F or greater dewpoints to the immediate lee of the Front Range signals the beginning of severe weather potential, based on a composite of 30 High Plains severe thunderstorm days in June and July, 1979. It is rare to see a dewpoint higher than the low 60's in eastern Colorado. The lowest dewpoints frequently were associated with wind damage likely produced by high-based thunderstorms (see again Brown et al., 1982).

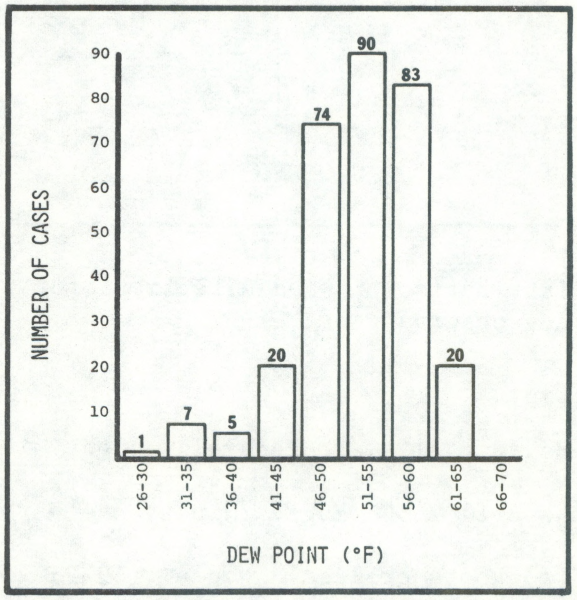

Figure 10. Distribution of dewpoint temperatures for interpolated prestorm surface observations.

Figure 11 shows that the surface wind strongly favors northeasterly to southeasterly directions for severe weather. This, too, is supported by Patterns 1 and 2. Almost all cases had an easterly component in the surface wind. This results in orographic lifting as the terrain rises two to three thousand feet from the Kansas border to the foothills.

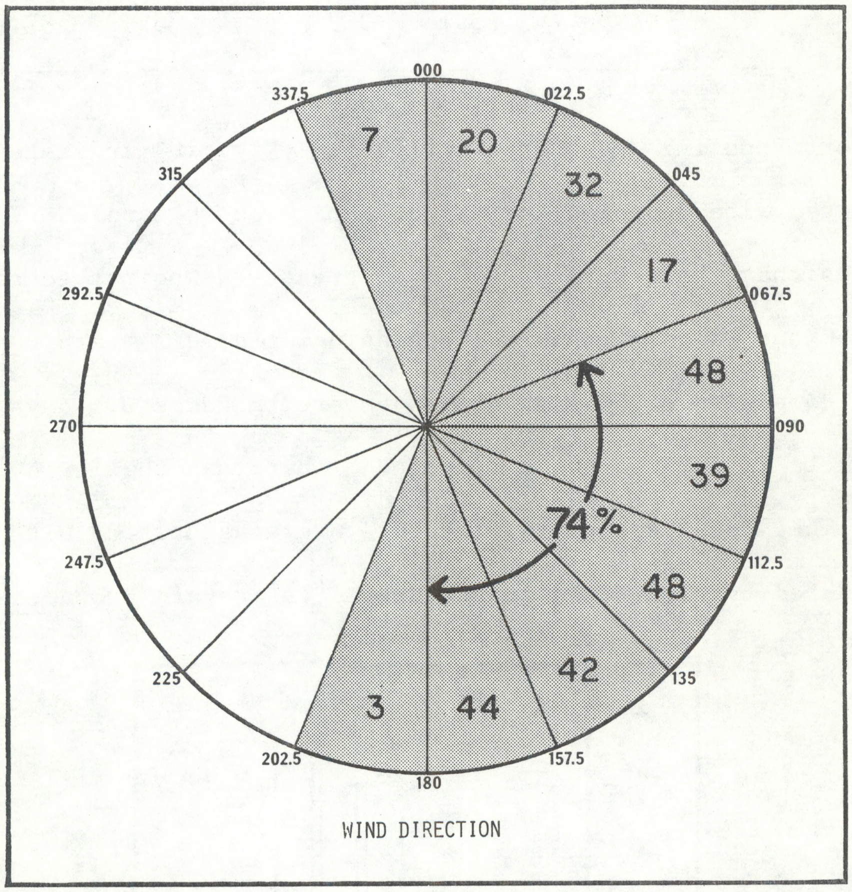

Figure 11. Distribution of wind directions for interpolated prestorm surface observations.

The wind speeds (Fig. 12) are generally light with almost half of the cases falling in the 6-10 knot range. Ninety-one percent of the total 300 cases had winds of 15 knots or less. Modahl (1979) found a tendency for the mean wind speed to increase during the day on thunderstorm and hail days in northeast Colorado, presumably due to reinforcement of the synoptic-scale upslope circulation by the well-recognized diurnal upslope flow.

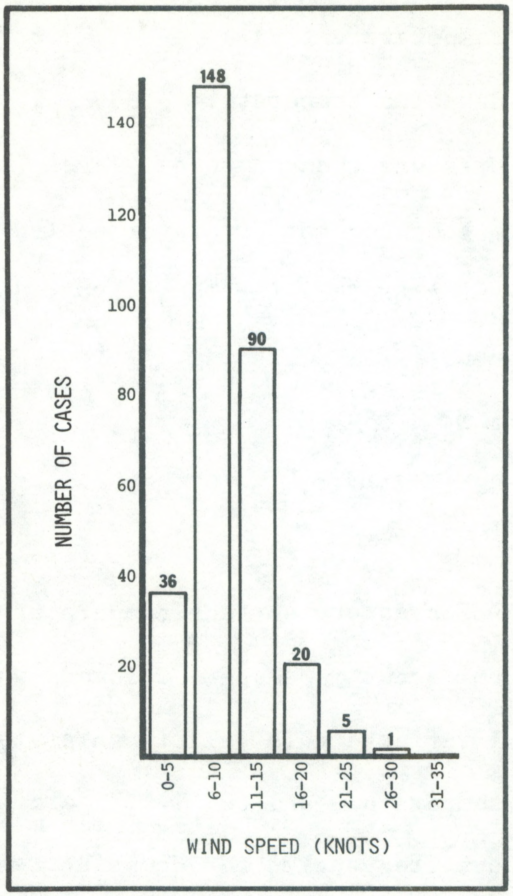

Figure 12. Distribution of wind speeds for interpolated prestorm surface observations.

5. A Surface-Based Storm Index

The climatology of surface conditions described in Section 4 has been used to modify a severe thunderstorm forecast index [the SPOT index described by Maddox (1973)] that is based on surface observations. This new index is designed for application in Colorado east of the Continental Divide. The Colorado Severe Storm Index (CSSI) is computed as follows:

$$\text{CSSI} = \underset{1}{(t-60)} + \underset{2}{2 * (t_d-45)} - \underset{3}{|1010.0 - \text{SLP}|} + \underset{4}{W}, \quad (1)$$

where: t = surface temperature (°F)

t_d = surface dewpoint temperature (°F)

SLP = surface pressure reduced to sea level (mb)

W = wind term computed for DD/SS (direction/speed)

with $W = -2 * SS$ (kt) for $180° < DD < 360°$

all other DD

$W = SS$ if $T_d < 45$

$W = 2 * SS$ if $T_d \geq 45$.

The distribution of prestorm surface temperatures (Fig. 9) indicates that few severe thunderstorms occur in eastern Colorado when it is cooler than 60° F. Term 1 in the CSSI reflects this relationship via a simple difference between the observed temperature and 60° F. Figure 10 shows a pronounced increase in severe storm frequencies for dewpoint temperatures in excess of 45° F. Since the dewpoint temperature is closely related to available moisture and conditional instability, its input to the final index is increased by a simple multiplication in Term 2. The distribution of surface pressures observed in the eastern Colorado prestorm environment (Fig. 8) is peaked about 1010 mb and Term 3 reflects this by reducing the final value of the CSSI as pressures deviate, in either direction, from 1010 mb. Figure 11 clearly illustrates the importance of an easterly component in the surface winds. Term 4 is designed to both decrease the final CSSI when surface winds are westerly and to markedly increase the CSSI if winds are easterly in conjunction with dewpoints above 45° F.

The CSSI should provide an estimate of the potential for severe thunderstorms in the vicinity of a given surface observation relative to surrounding observations. The wind term acts to emphasize wind shift lines and thereby reflects surface convergence in a simple way. Considering these characteristics of the CSSI, one would expect that severe thunderstorms might be most likely in regions of strong CSSI gradient. Suggestions on how such a surface-based index might be used in real-time forecasting are discussed in Maddox (1973) and Miller and Maddox (1975).

The CSSI would be most valuable when used in conjunction with a lifted index. Surface LI (again see Maddox, 1973) is best expressed as the temperature (°C) excess or deficit of a parcel lifted adiabatically from the surface to 500 mb. The 500 mb temperatures used could be merely the observed 12 Z (morning) field or they could be taken from the LFM forecast. The surface LI could be added to the CSSI as a fifth term; however, the authors feel that it would be most useful to forecasters if it were computed and displayed separately, as in the following example.

Figure 13 shows contours of the CSSI and a surface LI, computed using the morning 500 mb temperature, for 2100 Z on the 22nd of June 1979. The surface LI has been modified by multiplication by 5 so that its values are roughly the magnitude of the CSSI. An intense, very damaging hailstorm tracked southeastward along the western edge of a region characterized by high values of both the CSSI and surface LI. Figure 14 shows a satellite photograph of the storm activity at 2300 Z. Another case is illustrated in Figs. 15 and 16. The 2100 Z surface index analysis shows fairly significant conditional instability over much of Colorado and indeed the corresponding satellite image indicates considerable thunderstorm activity underway. However, the CSSI values are much lower for this particular case and no severe thunderstorms were reported.

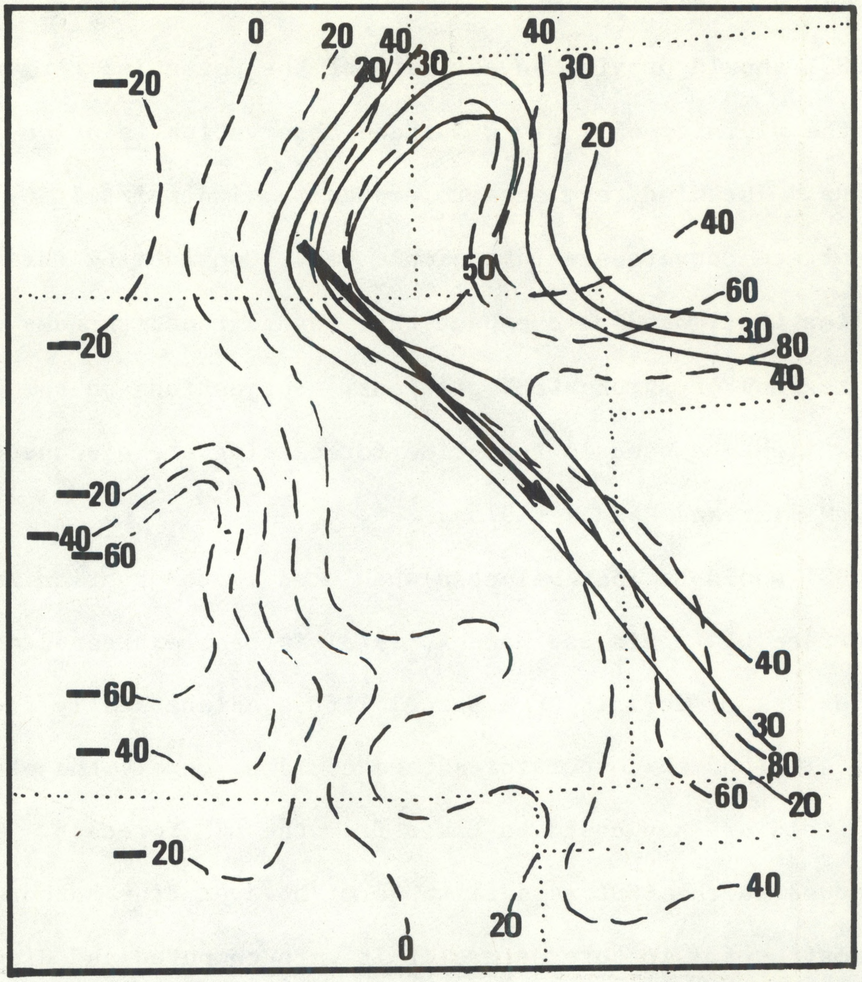

Figure 13. Analysis of the CSSI (dashed) and the modified surface LI (solid) for 2100 GMT on 22 June 1979. Heavy arrow shows the track of a damaging hailstorm.

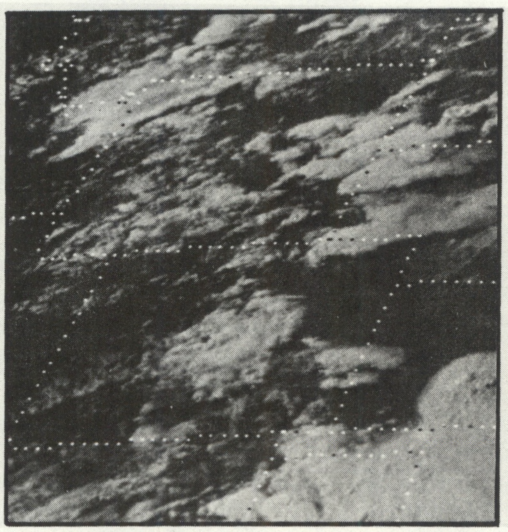

Figure 14. Satellite image for 2300 GMT, 22 June 1979. Severe hailstorm is in northeastern Colorado just south of Wyoming and Nebraska borders.

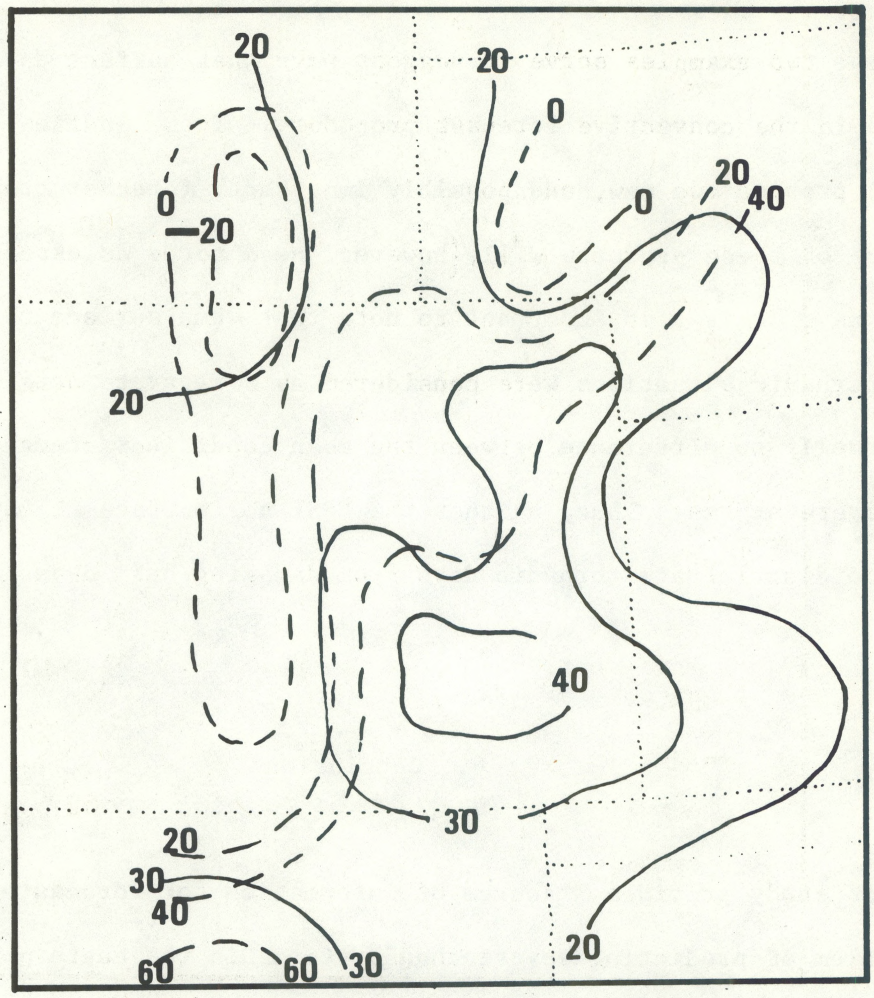

Figure 15. Analysis of the CSSI (dashed) and the modified surface LI (solid) for 2100 GMT on 31 July 1979.

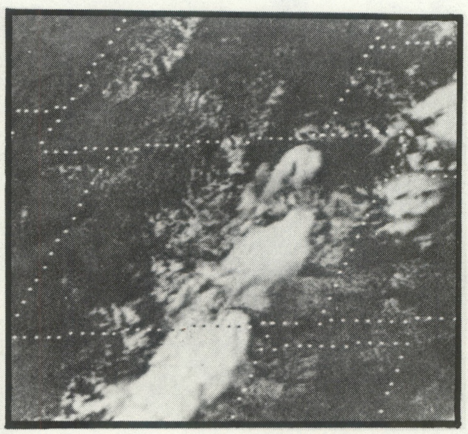

Figure 16. Satellite image for 2300 GMT on 31 July 1979.

These two examples serve to suggest ways that surface data might be utilized in the convective forecast procedure. These indices (CSSI and surface LI) provide two new, and possibly important, forecast tools for Colorado. The value of these products will, however, need to be assessed during PROFS' operations. It is also important to note that when surface observations preceding tornadic situations were considered as a separate data sample, there was virtually no difference between the mean conditions preceding tornadic and other severe storms. Thus, neither the CSSI nor surface LI may be used directly to discriminate tornadic days from damaging hail days.

6. Conclusions

This study provides a source of information for forecasters faced with the problem of predicting severe thunderstorms in the eastern half of Colorado. Familiarization with the synoptic surface patterns and the ranges of possible values of prestorm surface parameters, coupled with the application of the Colorado Severe Storm Index, offer important forecast tools. Using these guidelines to identify the onset of periods of strong convective activity, the forecaster can then apply his/her knowledge of local terrain and diurnal tendencies to narrow the area of concern for the issuance of watches and warnings.

7. Acknowledgments

This being my first professional publication as lead author, I want to use this opportunity to thank my wife, Suzanne, for the years of love, support, and encouragement she provided which helped me get to this point in my career. Thanks also to my beautiful daughter, Jennifer, who can bring a smile to my face even when I'm deeply engrossed in severe storm data. I wish to express appreciation to my co-author and technical supervisor, Dr. Robert Maddox, and Drs. John Brown and Stan Barnes, also of OWRM, for their guidance and suggestions in the preparation of this report.

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