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SOME INTERESTING ASPECTS OF THE SEVERE  
HAILSTORM OUTBREAK OF 2 AUGUST 1986 IN COLORADO

John F. Weaver  
NOAA/NESDIS/RAMM Branch

James J. Toth  
Department of Atmospheric Science

Colorado State University  
Fort Collins, Colorado 80523

1. INTRODUCTION.

On August 2, 1986, a major outbreak of severe weather occurred along the front range of the Rocky Mountains in northeast Colorado (Fig. 1). There were numerous reports of 2.0-7.5 cm (3/4"-3") hail with extensive damage in many front range cities (Storm Data, 1986). Total damage estimates range as high as \$200 million. In rural areas, thousands of birds and hundreds of small animals were killed or injured, and crop damage totaled well over \$100 million.

The weather pattern on August 2nd was a fairly common one for severe thunderstorms on the high plains (Doswell, 1980). A cool front had swept through Colorado on the previous day, leaving the state in low-level easterly (upslope) flow. Such a pattern tends to advect moist, low-level air westward to the front range of the Rockies. The 500 mb analysis revealed moderately strong flow (northwest at 35 knots over Denver-DEN in Fig. 1), with a minor shortwave approaching the region. The afternoon temperature/dewpoint values, for the front range region of northern Colorado, were forecast to be 74F and 54F, respectively. When these values are used to define the afternoon boundary layer, and substituted into the morning sounding taken at Denver, the Lifted Index (Galway, 1956) has a value of -5, and the total positive buoyant energy is 2,850 Joules/Kg. On a scale where 1,500 Joules/Kg marks the approximate lower boundary for severe thunderstorms, this day was particularly ominous.

As the day evolved, the temperature and dewpoint forecasts were met and exceeded in most locations throughout the state. However, the severe weather was confined to a short, narrow corridor in north central Colorado. Post analysis of the day's data revealed two possible clues to help unravel the mesoscale nature of this event. First, the pre-cursor, cloudiness in the mesoscale airmass in northeastern Colorado LOOKED dramatically different from other areas in satellite imagery (both visible and IR wavelengths). Second, a mesoscale analysis of surface pressure data found a meso-a ridge jutting into northeast Colorado from the northeast. It appears now that a mesoscale convective system (MCS) (e.g., McAnelly and Cotton, 1986) that crossed Nebraska nearly 24 hours earlier, played a key role in setting up the boundary layer for severe activity. Finer scale analysis was possible, because the event occurred in the area where the PROFS (Program for Regional Observation and Forecast Systems) surface mesonet is located.

This paper discusses the development of the mesoscale airmass associated with the August 2nd hailstorms. The following synopsis of events provides a brief outline of the evidence for this contention.

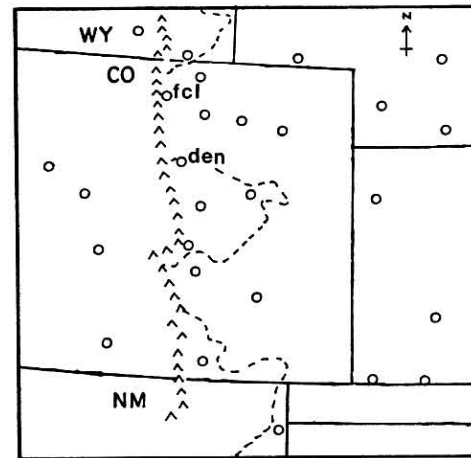


Figure 1. Colorado (CO) and vicinity. North-South line of carets represents the front range of the Rocky Mountains. The East-West ridges (dashed lines) are, from top to bottom, the Cheyenne Ridge, the Palmer Lake Divide, and the Raton Mesa, respectively.

2. DEVELOPMENT OF ACTIVITY ON 1 AUGUST 1986.

The thunderstorm activity in the northern plains on August 1st represented an extremely complex series of interactions between thunderstorm outflows on many different scales. To fully understand this evolution, a detailed analysis of satellite data was performed which cannot be presented in proper detail here, because of space limitations. Thus, only the highlights are discussed.

Similarly, though dozens of different analyses of surface data were performed, only 'adjusted station pressure' analyses are presented. These are the most illustrative data for the features discussed. As noted by Sangster (1987), altimeter settings over sloping terrain poorly indicate the 'actual' surface horizontal pressure gradient when temperatures are significantly warmer or colder than standard atmosphere values. Our 'adjusted station pressure' values are station pressures adjusted to 1600m using a layer mean virtual temperature equal to the average of 25C (representative of the temperature at 1600m) and the station temperature. This choice provides a more accurate and detailed analysis of pressure at elevations close to that of the area of interest in Colorado (CO). In general, over the lower terrain of eastern Nebraska (NE) and Kansas (KS), the adjusted pressure field is a poor approximation to reality. However, in this case, the mesoscale features were found to be nearly identical to (though not as

strong as) those found by analysis of unadjusted altimeter setting.

At mid-morning (Fig. 2, 1600 UTC = 0900 Mountain Standard Time), a rather broad low pressure area dominated most of eastern CO. A large MCS was propagating across central NE, leaving in its wake a fairly complex, mesoscale pressure field at low levels. Satellite imagery shows a broad region of stable, wave clouds over KS and northeast CO. A second, dissipating convective system over the NE panhandle had generated an outflow over southeastern Wyoming (WY). This feature, though not resolved by surface observations, could easily be identified in the satellite imagery. The tracks of the convective systems and locations of the outflow boundaries were oriented mainly along the synoptic scale, low-level isotherms, and the resulting northwesterly flow aloft. In addition, the mesoscale detail of the temperature and pressure gradients over extreme northeast CO may have been influenced by the outflow from yet another convective system which had propagated through the region the previous evening (31 July).

Development over the next couple of hours found the large WY/NE outflow trapped by the pre-existing temperature inversion to produce a cold surge along the northern half of the CO front range during the remainder of the morning. The cold surge, and associated high pressure ridge, nosed rapidly southward (Fig. 3, 1800 UTC), and eventually worked eastward some 200 km. The progression of the leading edge of this surge is

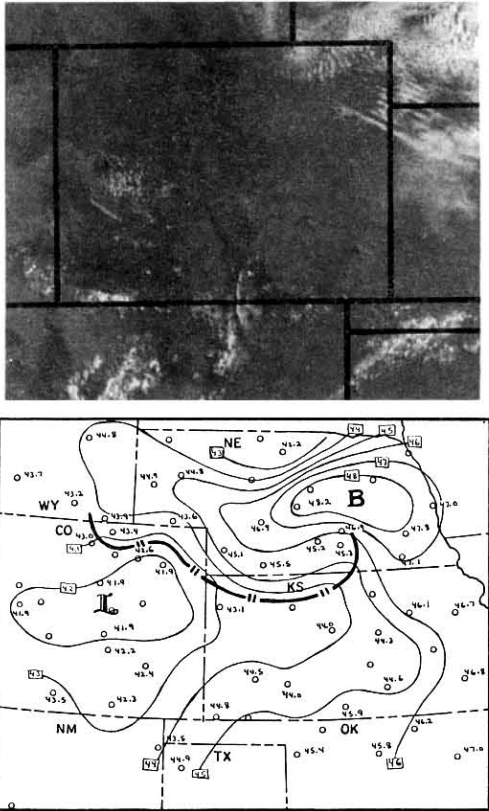


Figure 2. a) Visual wavelength satellite photo from 1 Aug 86 over the region shown in Fig. 1, at 1600 UTC. b) Analysis of 'adjusted station pressure' for 1600 UTC. Pressure values have been adjusted by the method described in text. 800 mb has been subtracted from each plotted observation for clarity. NOTE that scale of part b is different than part a.

easily followed using surface analyses and satellite imagery (cloud development on the boundary/lack of clouds behind it).

The southward direction to the push of the cold surge was aided, in part, by the damming effect of the high terrain of the Rocky Mountains. A highly idealized numerical simulation of this

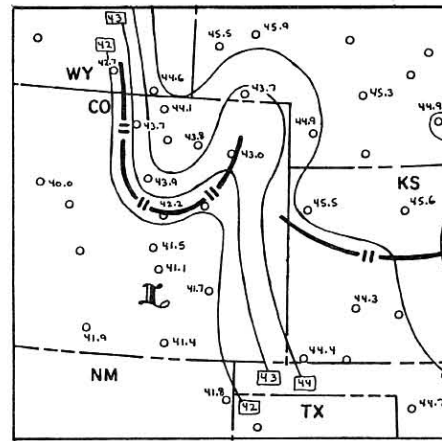
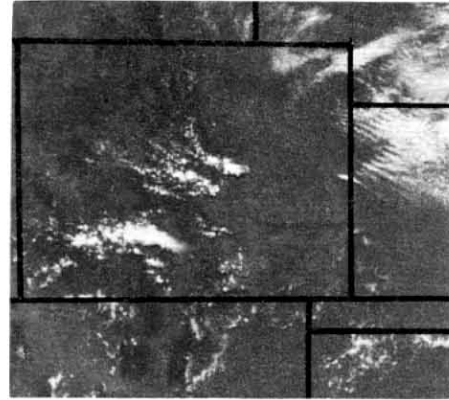


Figure 3. Same as Fig. 2, except that the scale in part b more closely matches that in part a. Also, the time is 1800 UTC, 1 Aug 86.

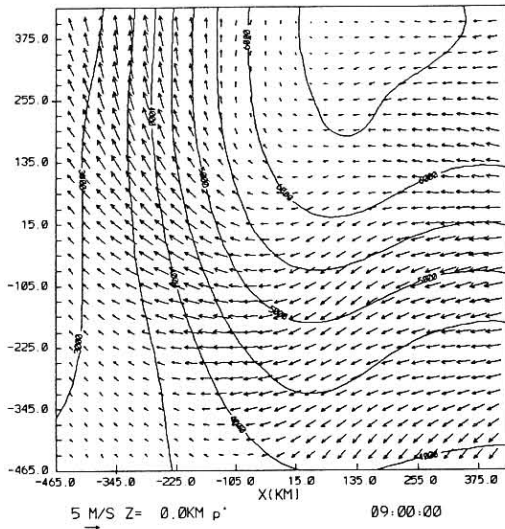


Figure 4. Numerical simulation of a southwest propagating cold surge in a region where the terrain height is increasing from east to west (rt. to lt. in figure). Contour interval is 0.5 mb. Note the development of a pressure ridge as the cold air is blocked and diverted south by the terrain.

event (Toth, 1987) reproduces the southward nose of high pressure (Fig. 4). In our analysis of the adjusted station pressure, the tight spacing of the isobars along the mountains results from the cold air packing against them. It reflects, a pressure gradient 'through' the mountain, rather than at the surface.

By late afternoon (Fig. 5, 2300 UTC), the southern edge of this meso-ridge had finally pushed over the Palmer Lake Divide (Fig. 1). The surge had slowed as the cold air tried to move over this high ridge line, partly due to friction, and partly due to gravity as the air tried to move uphill (although the cold pool was still quite deep at this time -- 1.9km above ground level as revealed by the evening radiosonde at Denver). Heating of higher terrain at the southern and, especially, the western edges of the cold air also contributed to the slowing. That is, the heating of the slopes to the west probably encouraged a strong upslope component which acted to impede the diversion of air to the south. Late in the afternoon, in fact, the cold air did spill over to the mountain stations of the PROFS mesonet, evidenced by windshifts, temperature falls, and minor pressure rises.

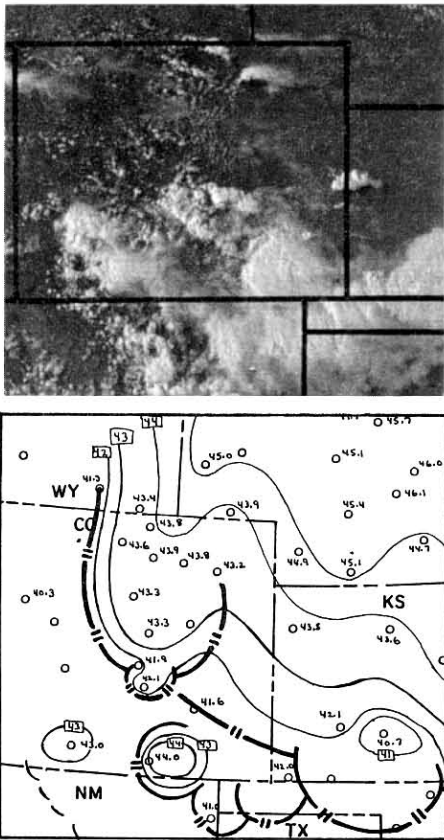


Figure 5. Same as Fig. 3, except at 2300 UTC.

### 3. AUGUST 2, 1986.

Analysis of the adjusted pressure field throughout the night continued to show the effects of the MCS-induced pressure ridge. In fact, even when a sub-synoptic, east-west pressure trough began to push its way into the state around dawn (e.g., 1200 UTC, Fig. 6), the meso-ridge remained basically intact.

Figure 7 illustrates the persistence of this feature quite clearly by showing a 24 average of the adjusted station pressure. While the averaged data manages to "wash out" the transient features over most of the analysis area, the meso-ridge in northeast CO shows up quite clearly. The small dots plotted on the analysis constitute the 37 reports of excessively large hail later that day. It is interesting to note that 35 out of the 37 events occurred on the "high terrain" side of the 1-2 August meso-ridge.

Figure 8 is shown to illustrate the mesoscale character of the northeastern CO airmass as it appeared on satellite, and surface pressure analysis on the morning of August 2, 1986.

### 4. CONCLUDING REMARKS AND SPECULATIONS.

Because they are often fed cool, moist air by stratiform rain for hours after the convective line has passed, the effects of outflows from mesoscale convective systems can be quite persistent (e.g., Weaver and Nelson, 1982 or McAnnelly and Cotton, 1986). In this case, the effects were even more evident as the natural

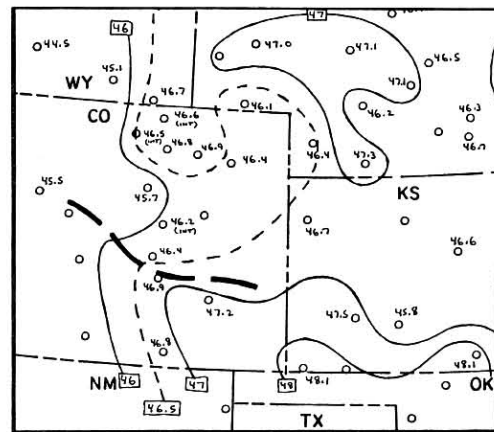


Figure 6. Same as Fig. 3b, except at 1200 UTC on August 2, 1986.

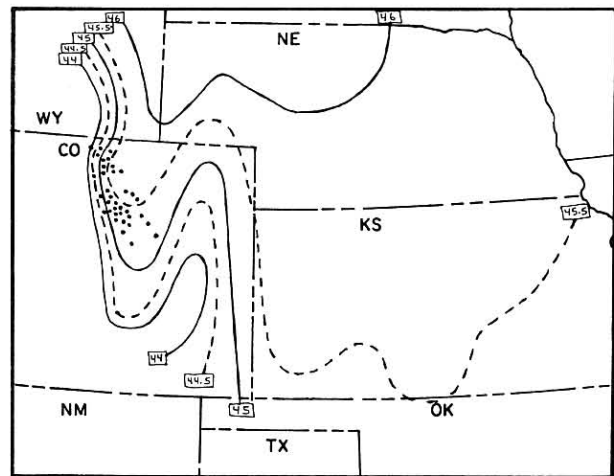


Figure 7. 24-hour average of 'adjusted station pressure' (see text) for the period 1700 UTC, 1 Aug 86 through 1600 UTC, 2 Aug 86. Dots are plotted locations of large hail reports from the afternoon of 2 Aug 86.

terrain barrier in central CO kept the 'cold dome' compact and concentrated.

A recurrent feature of summertime weather in eastern CO is the development of the daily upslope cycle (Toth and Johnson, 1985). This upslope on August 2nd was somewhat reinforced by the synoptic, post-frontal gradients, but more importantly (in northeastern CO) by flow responding to the pressure gradients associated with the meso-ridge. We speculate that the result of the meso-ridge was a deep layer of higher moisture along the foothills in northern CO. The source of this moisture was, at least in part, the MCS activity which occurred on the previous day. That activity produced a meso-b region of particularly potentially unstable air. The area also remained capped throughout most of the day as evidenced by both visual observations by the first author, as well as by VIS satellite imagery which showed suppressed cloudiness throughout the favored region until mid to late afternoon. It was in this region where 95% of the severe weather occurred.

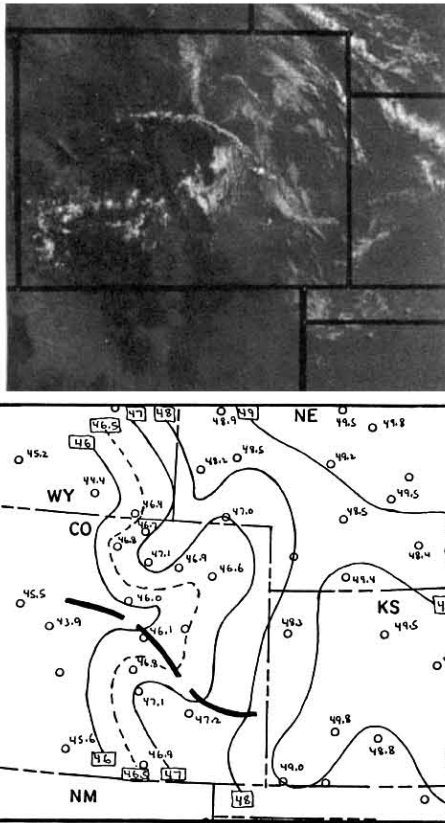


Figure 8. Same as Fig. 3, except at 1600 UTC on August 2, 1986.

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