

Forecasting an Unusual Weather Event in Colorado: 15 October 1980

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Abstract

On 15 October 1980, a weather system that had been to the west of Colorado was forecast to move into the state, and to bring with it light to moderate snow in the Rockies, and generally light rain and thundershower activity over the plains to the east. In most regions this forecast was adequate. However, substantially heavier activity (including a small tornado, large hail, heavy rain, and snow) also occurred in some areas. In this paper we show how all relevant real-time data, when properly merged, could have enabled formulation of a useful short-term forecast. In addition we point out how mesonet surface data gathered after the fact could have helped narrow down the forecast area of severe weather and heavy precipitation.

Forecasts by radio and television meteorologists were similar, with only minor variations in location and timing.

It could easily and effectively be argued that the forecasts were, in a general sense, accurate. However, actual events in some localities proved more intense than the outlooks had suggested (Fig. 1 and Table 1). Several occurrences of hail up to 1 in (2.5 cm) in diameter were reported and a small tornado damaged a school building, five houses, and several automobiles in Boulder, Colo. Total damage was estimated at \$50 000. A few local snowfall amounts were more than double expected values. The heavy snow and drifting due to high winds effectively paralyzed ground transport into and out of Laramie, Wyo., for two days.

In recent years there has been an increasing recognition of the need for more accurate short-term forecasts, both to provide more effective public warnings and to help minimize lost economic productivity in weather-sensitive activities such as aviation, construction and transportation. For example, a trucker contemplating travel on Interstate 80 across southern Wyoming on 15 October might have chosen a different route had 14 in of snow been in the forecast instead of a mere 4 in. At the same time, it must be acknowledged that the 350 km space and 12 h time scale of the primary upper-air observation network (especially when combined with standard automated analysis) precludes adequate description, much less accurate quantitative prediction, of many features responsible for rapid weather changes and small-scale hazardous weather events such as severe thunderstorms.

A few useful tools do exist to aid description of the atmosphere on smaller scales. Geostationary satellite observations, hourly surface weather reports, and radar observations all contribute to a real-time understanding of events on the scales important to the short-term forecast. In what follows, we show how data from these disparate sources, when properly merged, could have provided the critical input needed by forecasters to anticipate the rapidly developing weather situation on 15 October. In addition, using more closely spaced surface observations, not available in real time, we suggest how real-time mesonet network data (such as those now available through PROFS³) will greatly aid in narrowing down areas of severe weather threat in future, similar weather situations.

³Acronym for *Prototype Regional Observing and Forecasting Service*—a federally sponsored program having the mandate to develop effective, localized, short-term forecasts and rapid dissemination capability. No PROFS mesonet data were available for this case; however, “after the fact” data available locally (see acknowledgments) were used to simulate the PROFS network.

1. Introduction

On the afternoon of Wednesday, 15 October 1980, a closed 500 mb low was tracking slowly east-northeastward across the state of Utah. Several small perturbations of the main circulation had been identified via numerical analysis of morning rawinsonde data, as well as on real-time satellite photos, as they rotated through the flow toward Colorado and Wyoming.

The various regional forecasting agencies had developed reasonably accurate scenarios of the situation several days in advance. For example, the Colorado state forecast, issued by the Denver National Weather Service (NWS) Forecast Office on Monday, 13 October, called for a threat of showers on the 15th, with snow showers above 7000 ft (2100 m) MSL. On Tuesday, the update for the following day suggested scattered rain and snow showers spreading across the state. Locally heavy snows and blowing snow in the mountains were mentioned with the principal threat being in extreme northern portions of Colorado. Finally, on Wednesday morning the Colorado forecast called for a chance of 6 in (15 cm) or more of snow in the mountains. The NWS outlook for Wyoming was more conservative, calling for snowfall amounts of 4 in (10 cm) or more in western and north-central Wyoming as well as at higher elevations across the state. Furthermore, the Colorado forecast mentioned a chance for scattered thundershowers.

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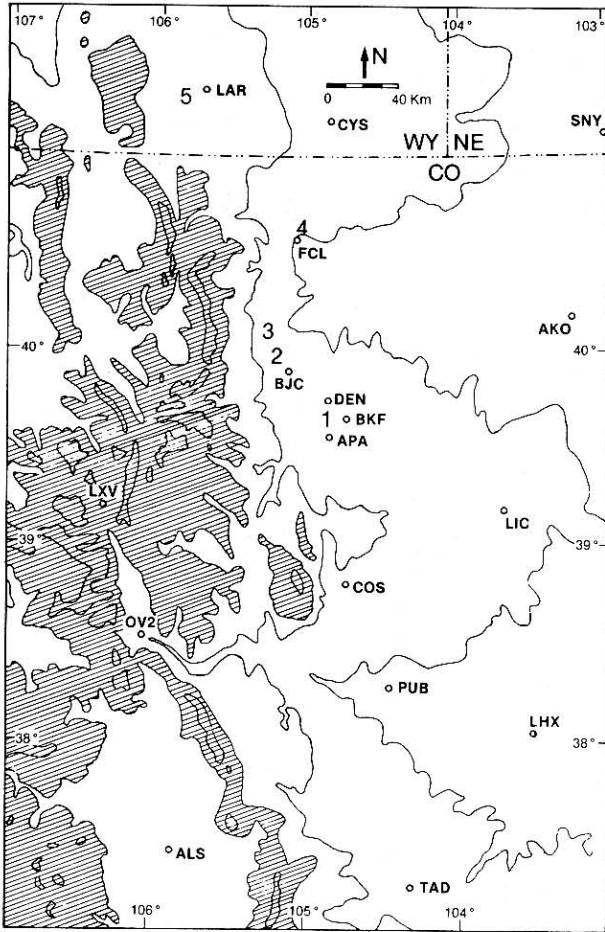


FIG. 1. Map of eastern Colorado and adjacent areas. Contours of elevation are 1500, 2250, 3000, and 3750 m MSL, with terrain elevations above 3000 m hatched. Identifiers locate all stations that typically transmit at least one hourly observation per day through normal channels. Numbers refer to locations referenced in Table 1.

2. Synopsis of morning meteorological data

A large area of low pressure was the dominant feature over most of the western United States on the morning of 15 October. The system had progressed as far eastward as northern Colorado at the surface (not shown), but sloped westward with height and was situated along the southwestern border of Utah at 500 mb (Fig. 2). Several small perturbations in the flow were located (by the LFM⁴ initial vorticity analysis, see Fig. 2a) as follows: A wave in west-central California embedded in northwesterly flow, a wave at the southern tip of Nevada in southwesterly flow, and a somewhat larger wave in Wyoming. The flow controlling the Wyoming shortwave was not clear on analysis. However, sequential satellite photos revealed that the head of the “comma cloud” associated with the low and was traveling westward, while the tail of the “comma” was breaking off and moving northeastward, i.e., the wave was in a region of diffluence.

The 0600 MDT⁵ sounding taken at Denver, Colo. (DEN, Fig. 1) revealed only slight potential instability. Furthermore, the overall flow pattern at low levels suggested that no significant increase in low-level moisture should be anticipated. Some destabilization due to differential temperature advection was anticipated as the system aloft approached—thus the inclusion of thundershowers in the forecast.

The LFM prognosis for late afternoon did not indicate much assistance to convection from the Nevada shortwave. The output (Fig. 2b) suggested that this would move rapidly across Colorado during the afternoon as a rather flat, weak

⁴Limited area, Fine-mesh Model; the operational numerical model run at the National Meteorological Center, NWS, used to provide forecast guidance to 48 h.

⁵Mountain Daylight Time = GMT less 6 h. MDT is the local time in effect over the areas of interest and is used throughout this paper.

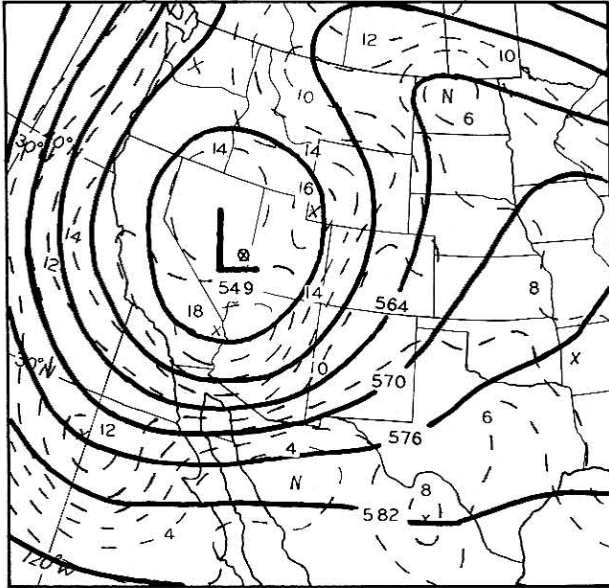
TABLE 1. Significant weather events in northeast Colorado and south-central Wyoming, 15–16 October 1980.

Location on Fig. 1	Time (MDT*)	Event
1	1730–1800	Sudden squall with south to southwest winds of up to 40 kt (20 m s ⁻¹) passed through the central and eastern parts of the Denver metropolitan area.
2	1835–55	Small tornado touched down just east of Boulder. Minor damage to five houses, a school and a storage building. Several automobiles and several camper shells were destroyed. This tornado was rated at F1 intensity (Fujita, 1981) and had a continuous path length of over 2 km.
3	1835–1910	Intense thunderstorm over, north, and east of Boulder. 1 in (2.5 cm) diameter hail, very frequent cloud-ground lightning, local rainfall of over 1.2 in (3 cm) in a 30–60 minute period.
4**	1757–1806	1 in (2.5 cm) diameter hail at Waverly, Colo. (15 km NNE of FCL).
4**	1827–47	1 ¼ in (3.1 cm) diameter hail at Waverly, Colo.
4**	1828	Storm spotter counted individual lightning flashes at a rate of 80 per minute in a storm to the southwest of FCL (30 km).
4	Evening of 15 October	Heavy rain of 2.3 in (5.8 cm) near Waverly, Colo.
5	Evening of 15 October through morning of 16 October.	Heavy snow of 14 in (35 cm) in the Laramie, Wyo., area.

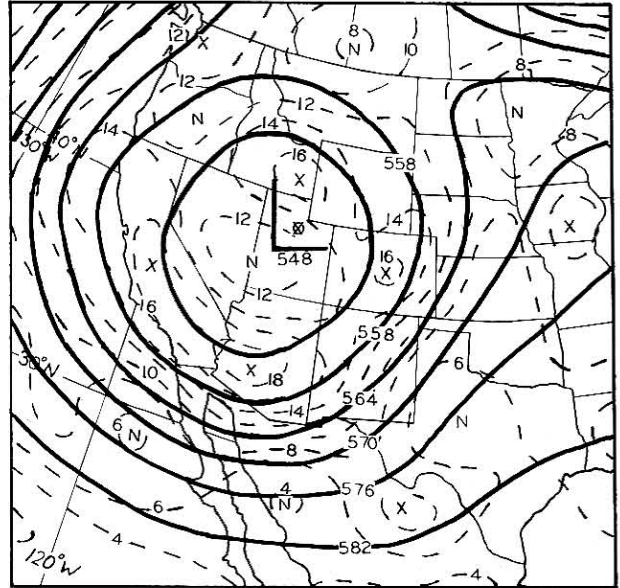
* Mountain Daylight Time = GMT less 6 h.

** Observation courtesy of Mountain States Weather Services, Ft. Collins, Colo.

a) 0600 15 OCT 80 ANAL



c) 1800 15 OCT 80 ANAL



b) 1800 15 OCT 80 12 h LFM

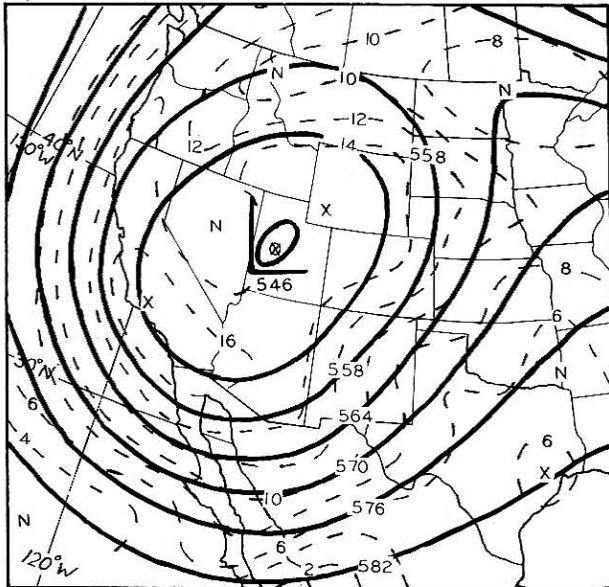


FIG. 2. LFM output of 500 mb heights (solid) and vorticity (dashed). a) Analysis for 0600 MDT 15 October 1980. b) 12 h forecast for 1800 MDT 15 October 1980. c) Analysis for 1800 MDT 15 October 1980.

to moderate strength feature. Winds aloft forecast for DEN at 1800 MDT from this same LFM run (see Fig. 3) indicated a significant downslope (see Fig. 1) component in the low and middle troposphere, further arguing against heavy precipitation or intense thunderstorms in the densely populated "front-range metroplex" running north and south from DEN.

3. The short-term forecast update period

A narrow, somewhat diffuse band of middle or high clouds in eastern Arizona on the 0545 MDT satellite photo (Fig. 4) was

coincident with the leading edge of the Nevada wave. As the morning progressed, both visual and IR satellite photos showed the cloud band becoming more organized and taking on the "comma" shape often associated with positive vorticity advection (e.g., Oliver, 1968). At 1200 MDT, the cloud band extended southeast from Utah into southwest Colorado and northwest New Mexico and thence south and southwestward. It was moving northeastward at 20 m s^{-1} . Meanwhile the large cloud mass over southeastern Wyoming drifted slowly (3 m s^{-1}) toward the northeast. The slower movement in this region may have been due to weaker winds in the relaxed pressure gradient of the diffluent zone, or have occurred via propagation resulting from vertical motion in the zone, or (most probably) a combination of both. The important issue from the forecast viewpoint, however, was that the zone existed, was persistent, and that a shortwave trough was approaching from the southwest.

During late morning and early afternoon, hourly reporting stations in southwest Colorado and northwest New Mexico, beneath the northeastward moving cloud band, reported snow showers and steady or falling temperatures. Figure 5 is the National Meteorological Center (NMC) surface chart (minus isobars) for 1200 MDT (1800 GMT). In addition to the broad, slowly moving low center near Denver, with its warm front extending to the east, there is indicated a dissipating stationary front of Pacific origin over eastern Colorado, and a prominent dry line extending from western Kansas into west Texas. Of greater interest for eastern Colorado, however, are signs of an active, mobile trough in the surface data over southwest Colorado and northwest New Mexico, corresponding roughly to the leading edge of the aforementioned cloud band. This trough is indicated by a dashed line in Fig. 5, and separates an area of generally south to south-

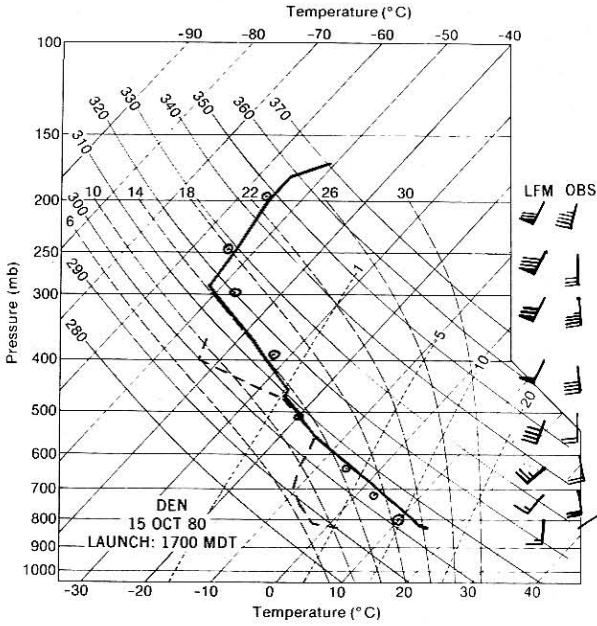


FIG. 3. Denver sounding launched at 1700 MDT 15 October 1980 plotted on a skew-*T*, log-*p* diagram. The circled dots are LFM-predicted temperatures for 1800 MDT. To the right are plotted observed (OBS) and LFM-predicted winds.

west winds and 1–2 mb per 3 h pressure falls over north-central New Mexico and south-central Colorado from southwest to west winds, lower temperatures, and nearly steady or rising barometers over Arizona. Shortly afterward, Alamosa (ALS, Fig. 1), in south-central Colorado, reported thunder, a windshift from south to southwest, an 8°F (5°C) drop in temperature, and a rise in pressure between 1300 and 1400 MDT. Although thunder was brief, low temperatures, rising pressure, and a southwest wind persisted.

Meanwhile a tongue of cool, northerly surface flow developed southward along the lee of the Rockies in eastern Wyoming and northeastern Colorado. (The southern boundary of this is shown as a dashed line in Fig. 5.) It is believed that this important feature came about as a result of two factors: 1) A general tendency toward northeasterly flow north of the surface low which was just east of DEN, reinforced by 2) heavy precipitation, which had occurred beneath the eastern Wyoming cloud system north of the low (amounts averaging 10–15 mm over several hours at most locations) during the previous 12 h. The consequent cooling (and later inhibition of heating due to cloud cover) allowed penetration of cold air as far south as DEN from north of the warm front. Notice the strong convergence of surface air along this boundary in north-central Colorado at 1500 MDT (Fig. 6). The radar echoes from the WSR-57 radar at Limon, Colo. (LIC),

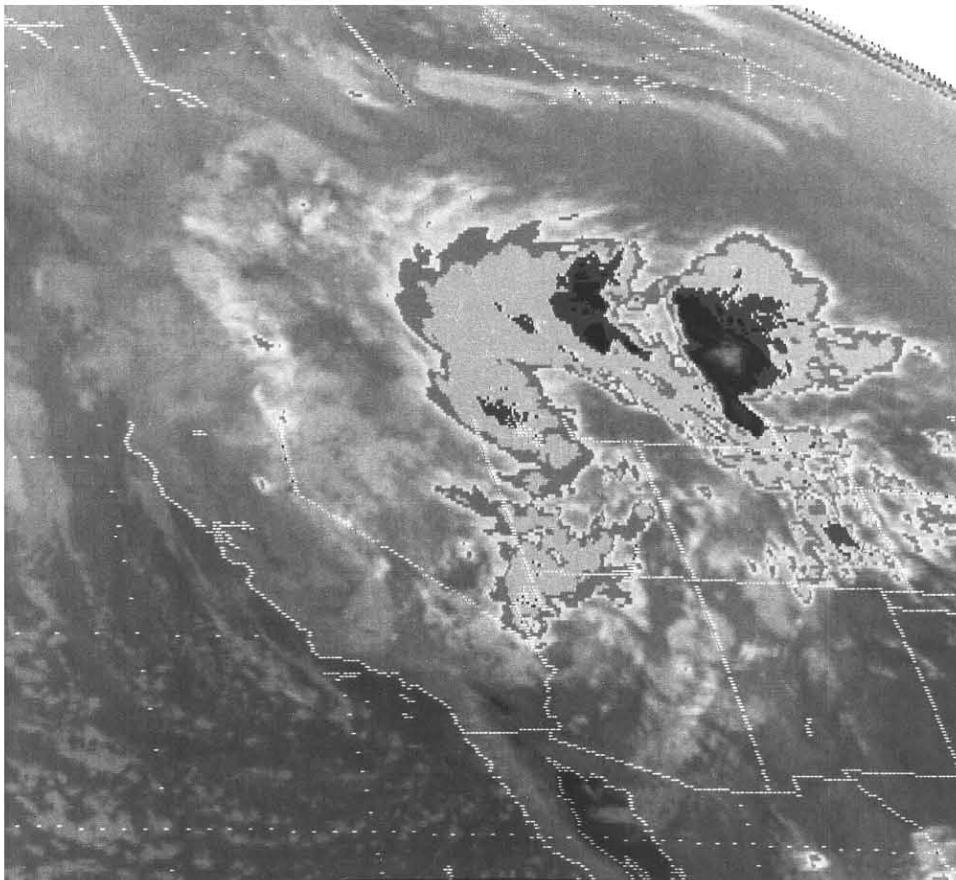


FIG. 4. Infrared photograph of the United States taken from GOES-West satellite at 0545 MDT 15 October 1980.

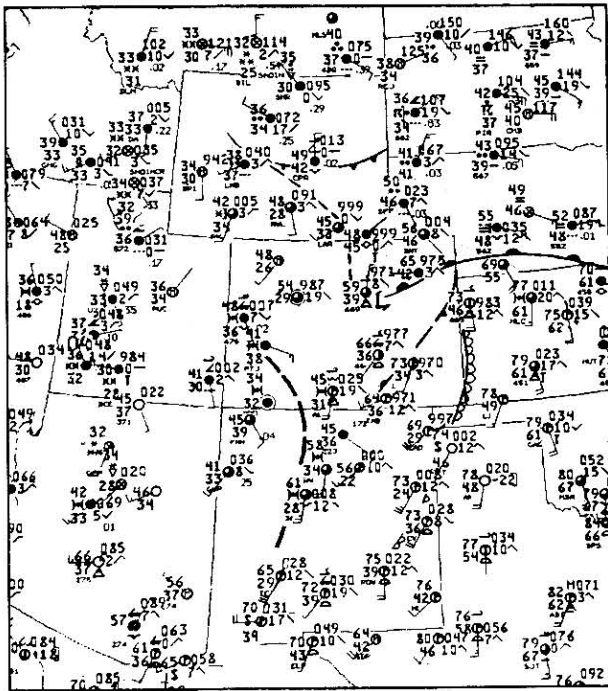


FIG. 5. NMC surface chart for 1200 MDT 15 October 1980. Isobars not shown.

at 1430 MDT are superimposed on the surface data. Plotted on Fig. 6 are supplementary surface observations, not available in real time, that help to reveal the strength of the convergence along this boundary and to define its location more precisely. From northwest of DEN northward into Wyoming the boundary is constrained by the terrain from further advance westward.

A third complication was a surge of continental polar air advancing southward across Wyoming at about 10 m s^{-1} . The leading edge of this, indicated by a cold front symbol on Fig. 5, had time continuity back to before 0600 MDT over northern Wyoming and southern Montana. All three features are shown in Fig. 7 superimposed on the 1445 MDT visual satellite picture.

It was during the early afternoon that the first indications appeared suggesting that events were veering somewhat from expected. At 1400 MDT La Junta, Colo., (LHX, Fig. 1) reported pea-sized hail, and at 1518 MDT Pueblo, Colo. (PUB, Fig. 1), reported 40 kt (20 m s^{-1}) wind gusts accompanying a thunderstorm. The 1530 MDT LIC radar summary described two cells as TRWXXA (extremely strong thunderstorms with hail) within an area of TRWX/+ (strong thunderstorms increasing in strength). Intense convective activity of this nature is unusual in Colorado during October (particularly in light of the morning data on this day).

Over the next two hours the thunderstorm activity remained strong, although reports of conditions approaching "severe" ceased. Surface data continued to reveal the sharp convergence zone (Fig. 6) which separated (generally) southerly from northeasterly wind flow. Furthermore, the cloud pattern (tracked via satellite) associated with the upper disturbance approaching from the southwest moved into the Denver-Boulder region. Because strong storms were already

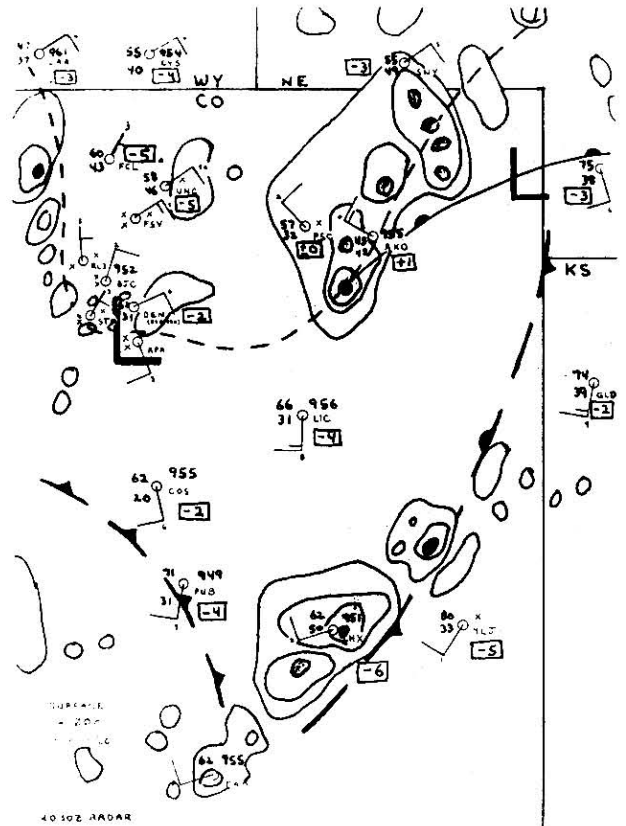


FIG. 6. Surface chart for 1500 MDT 15 October 1980. Temperature and dewpoint are plotted in degrees Fahrenheit. Altimeter settings are in inches. Irregular shaped areas are tracings of radar echoes from LIC weather surveillance radar. Standard NWS VIP levels are presented. Boxed numbers adjacent to stations reporting dewpoint are surface-based lifted index (see text).

in progress while the upper support was still to the southwest, a forecast update at this point should have included the possibility of very heavy thunderstorms for central and north-central Colorado.

Another feature of extreme importance to the rapidly changing weather situation made its appearance during this period. This was a tongue of very strong and gusty southerly winds, which developed somewhere south or southwest of DEN and moved northward. Unfortunately, the only regularly reporting station that experienced the phenomenon was DEN (Fig. 8). However, the event is seen quite clearly in surface mesonet data (Fig. 9). (Stations APA and BJC are county airports where hourly observations are made during daylight hours. However, their reports usually do not appear on Service A teletypewriter. Observations taken at Buckley Air National Guard base (BKF) sometimes appear in the Service A military collection. Data from other sites except DEN are not available in real time.) The authors suggest without proof that the origin of this feature was downward turbulent momentum transport accompanying the passage of the small but intense upper wave advancing from the southwest, as cold advection aloft destabilized the lapse rate sufficiently to allow vertical overturning. The occurrence of vertical mixing is supported by the sounding at DEN (Fig. 3),

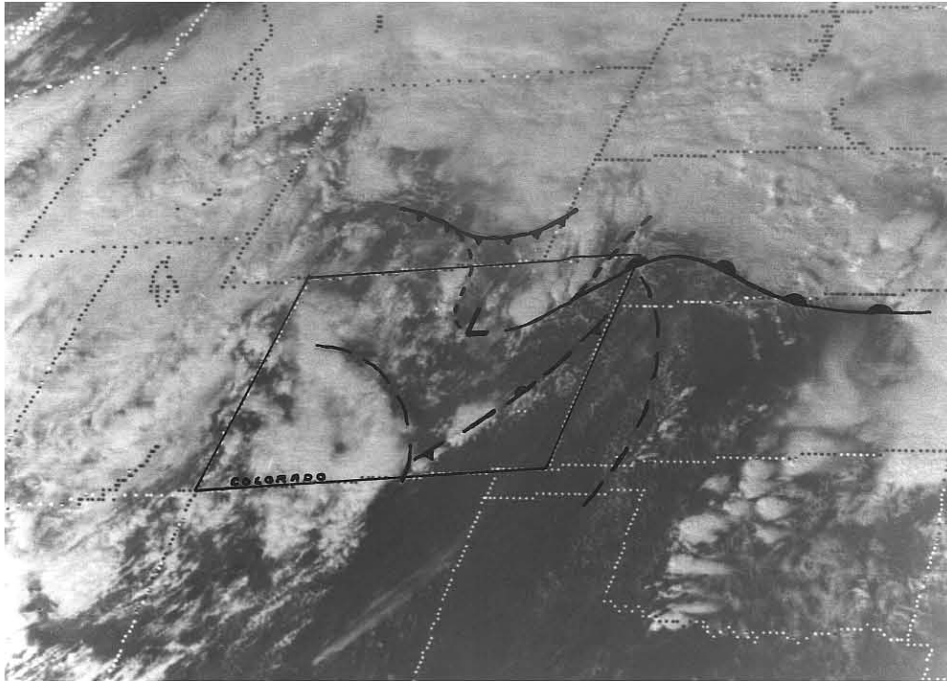


FIG. 7. Visible GOES-West satellite image at 1445 MDT 15 October 1980. Superimposed are fronts and boundaries discussed in text.

launched 30 min prior to the surface wind shift at DEN, which shows a nearly dry-adiabatic lapse rate from a little above the surface to above 500 mb. That vertical wind shear through much of this layer is very small further argues for vertical mixing. The radar film record from LIC shows a band of weak radar echoes, mostly less than 30 dB(Z), moving rapidly from the southwest after 1530 and reaching the vicinity of APA about the time the strong southerly blast struck. This band may have been a manifestation of mid-level remnants of earlier convection, associated with the upper wave, over the mountains of southern Colorado. Cooling aloft by evaporation and melting of precipitation may therefore have significantly enhanced the vertical mixing. McCarthy and Koch (1982) proposed that vertical mixing of momentum was important in developing localized strong surface convergence, leading subsequently to formation of severe thunderstorms, along a dry line in Oklahoma.

As this wind shift occluded the pre-existing boundary separating warm southerly flow from cooler, more moist northeasterly flow (see Fig. 9), a marked increase in convergence occurred, and a north-northwest/south-southeast line of rapidly growing cumulus congestus with rain-free cloud bases developed. This was observed to the south by meteorologists in Boulder before 1800 MDT. At the same time, pre-existing, moderately heavy thunderstorms to the northwest of Boulder began regenerating southward. Details are a bit sketchy, but it seems from eyewitness reports that the tornado (location indicated by a "T" on 1845 MDT panel of Fig. 9) was spawned where a north-south oriented flanking line (associated with the pre-existing storms; position at 1720 and 1745 MDT sketched on Fig. 9) intersected the northward advancing wind surge (Fig. 9).

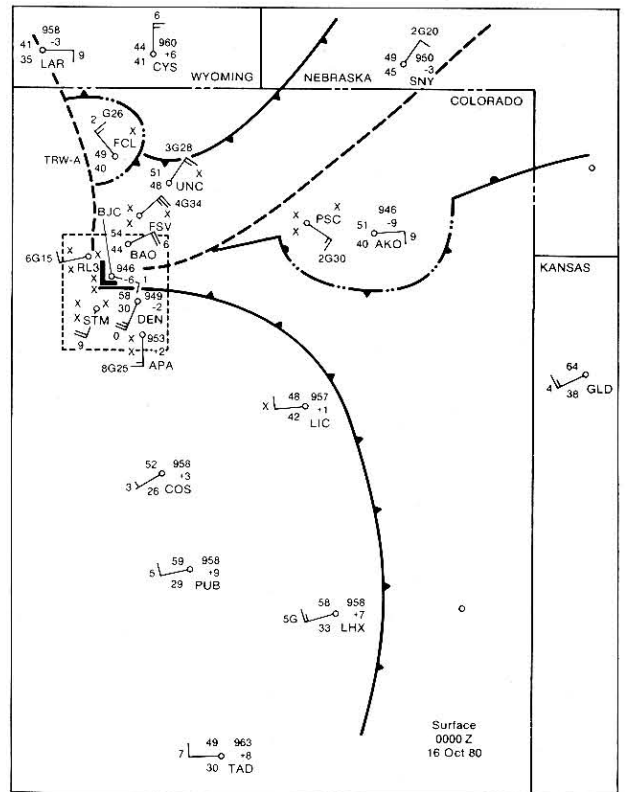


FIG. 8. As Fig. 6 for 1800 MDT, 15 October 1980, minus lifted index and radar. Dashed lines enclose area enlarged in Fig. 9. Signed numbers below altimeter reading show 1500-1800 MDT altimeter change.

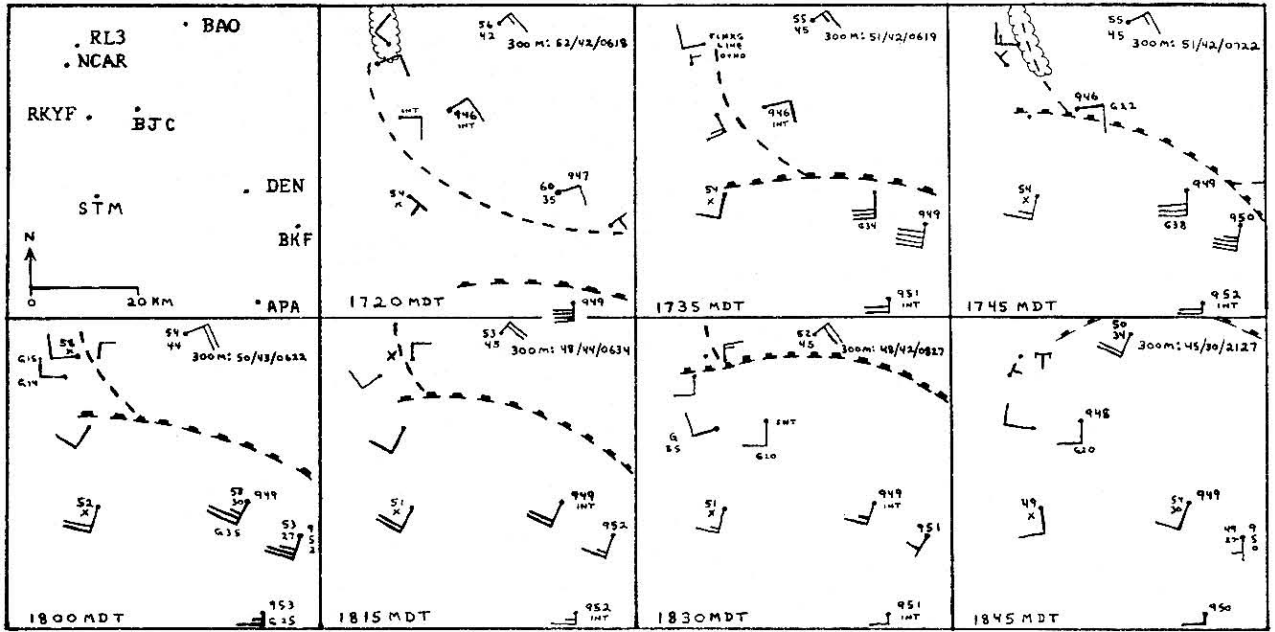


FIG. 9. Sequence of events in the Denver area just before and during the period of severe weather. Map in upper left identifies stations; temperature and dewpoint are plotted in degrees Fahrenheit, altimeter settings in inches. The letters "INT" adjacent to a station indicate time interpolation when no observation was available within 10 min of indicated time.

The thunderstorms diminished in severity somewhat as they moved north, but continued to produce very heavy rain and hailfall from Boulder to north of Ft. Collins (FCL, Fig. 1). On satellite, the explosive growth of the storms near Boulder could be seen as the sudden appearance of very cold storm tops. These tops were colder than any others within several hundred kilometers and became so as the northwest-

southeast cloud band (seen in Figs. 4 and 7 and associated with the small shortwave trough evident in the 500 mb vorticity field of Fig. 2c) reached the Boulder area. After 1800 MDT, this band slowed down and moved northward eventually to disappear as a clearly identifiable entity. The cold front in Wyoming on Fig. 5 is shown in Fig. 8 as just having advanced into Colorado at 1800 MDT. The air behind this

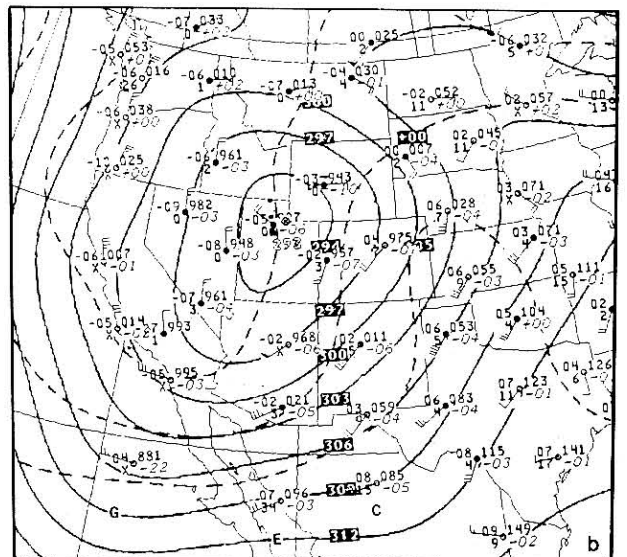
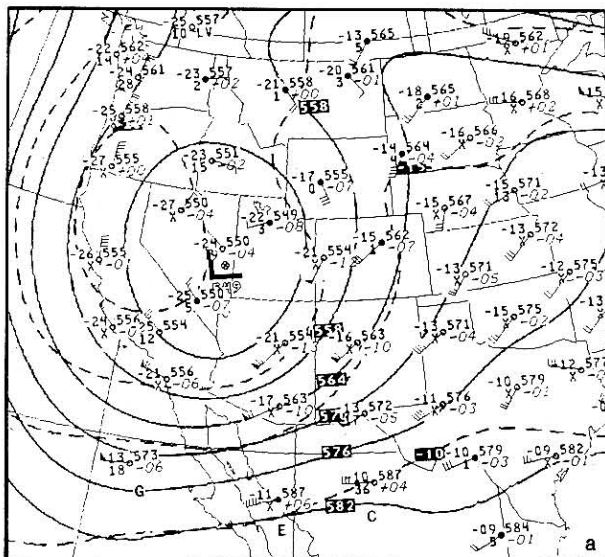


FIG. 10. NMC plot and LFM two-dot analysis for 0600 MDT 15 October 1980. Temperatures and dewpoint depressions are in degrees Celsius. Contours of geopotential height are in decameters. a) 500 mb, plotted heights in decameters. b) 700 mb, plotted heights in meters.

front was too cold to support convection. However, the interaction between the southward moving front and the northward moving shortwave trough contributed to strong warm advection at 700 mb (not shown) at 1800 MDT over southern Wyoming. It is not surprising, then, that significant snowfall was widespread across southern Wyoming during the next several hours. The particularly heavy snow, accompanied by thunder at Laramie, Wyo. (LAR, Fig. 1) later in the evening, may have been partly due to residual convection in the dying mesoscale convective system that had formed earlier near Boulder and then moved northward. As the surface low near DEN (Fig. 8) moved eastward, low-level flow over southeastern Wyoming became northwest to north during the evening and persisted through the night. At LAR this flow direction has an upslope component.

4. Discussion

As was noted at the beginning of this paper, National Weather Service forecasts for this case were accurate, in a general sense, on the synoptic space/time scale. But, as often happens, the most significant, destructive, and life-threatening events occurred in conjunction with features of subsynoptic time and space scale.

The following discussion addresses the question of how an alert forecaster, with adequate time to examine the available data, might have provided a more precise short-term forecast of these events. Also, we shall look at where and how mesoscale surface data might have been utilized at critical points in the rapidly evolving scenario.

a. Remarks on the LFM 12 h forecast for 1800 MDT

Figure 2 illustrates the 12 h LFM forecast of 500 mb heights and vorticity along with the evening "initial" panel for comparison. In the broadest sense, the two are very similar, and, for the large scale, the prediction seems reasonably accurate. As was pointed out in Section 2, however, the LFM predicted that the middle and lower tropospheric winds would have a significant downslope component at DEN. Moreover, the 12 h forecast height contours at 500 mb (Fig. 2) and 700 mb indicated that the downslope component at these levels would extend as far north as the Colorado–Wyoming border. In fact, the observed winds showed little or no downslope component below 500 mb with the downslope extending no farther north than central Colorado.

Although this was not a large error when the LFM grid spacing is considered, it was significant for the local forecast. Because of the strong orographic control on low-level vertical motion in the vicinity of the Rockies, the forecast cross-mountain component of the flow below 500 mb is of special importance. The prevailing view amongst forecasters in this area is that the LFM forecasts of the 700 mb height and sea-level pressure fields do provide usable guidance for prediction of the strength and depth of upslope and downslope components of the flow. In this case, then, the morning fore-

caster, having the fresh 12 h LFM forecast for 1800 MDT would have had reason to downplay the threat of heavy precipitation and severe weather, at least in the Front-Range Metroplex.

Careful examination of data plotted on the LFM two-dot analyses of 700 and 500 mb (Fig. 10) and comparison with the analyses themselves might, however, have impressed an alert forecaster that the morning LFM run should be treated with more than ordinary caution. (These analyses, along with analyses at other mandatory levels, were used to define the LFM initial fields.) However, it is not possible to prove, without rerunning the LFM with a corrected initial analysis, that these errors (discussed in the Appendix) were responsible for the deficient LFM forecast.

b. Remarks concerning midday data

There were several clues available to the forecaster by early afternoon that the early outlook was going astray. One such clue is the northeastward moving cloud band seen in Figs. 4 and 7. This feature had good continuity during the morning. It could readily be associated with a discernible isallobaric field (Fig. 5 and Section 3), indicating that it likely represented a significant shortwave trough in the upper flow.

A second clue was the isallobaric field (Fig. 5) to the east of the Rockies in Colorado and Wyoming. Whereas the 12 h LFM surface forecast (not shown) had indicated that sea-level pressure would decrease more in Wyoming than Colorado (thus weakening, or even reversing the geostrophic upslope component), no such change had occurred up to 1200 MDT. In fact, one could have concluded from northeastward extrapolation of the pressure falls in New Mexico and southern Colorado that just the opposite would occur, i.e., stronger upslope would develop.

A third unexpected development was the narrow tongue of cool, moist air along the east slopes of the Rockies in north-central Colorado. The result was a line of surface convergence as indicated in Figs. 5 through 9. Perhaps this feature would not have been considered particularly ominous, since indications were that the cool air was quite shallow near its southern edge (e.g., at DEN the temperature was rising and the dewpoint decreasing). However, the feature persisted as the afternoon wore on.

Finally, the development of strong thunderstorms in central Colorado was an obvious indication that the approaching shortwave was not as disorganized as implied.

c. Remarks on the mesoscale surface data

The mesoscale surface data permitted precise positioning and analysis of the boundary that separated the cool, moist air in north-central Colorado from the warmer, drier air to the south. The additional data indicated the boundary was situated across the southern portion of the DEN metropolitan area (Fig. 6). Furthermore, a surface-based, Lifted Index (LI) computation was made for each available station by lifting the surface air to 5486 m (18 000 ft) adiabatically and subtracting the parcel's temperature from a time interpolated

environment temperature⁶ at this level (boxed numbers, Fig. 6)⁷. The computations show significant instability over most of eastern Colorado. Note especially that the surface air north of the boundary across the DEN area is fully as unstable as that to the south.

Given the presence of this boundary, the potential buoyant energy of the air converging into it, the continued cooling aloft predicted by the LFM, and the obviously intense short-wave trough approaching the region, the threat of very heavy thunderstorms in north-central and central Colorado was certainly apparent by mid-afternoon. The trigger for this potentially explosive situation, i.e., the sudden surge of strong, southerly winds, made its appearance shortly before 1720 MDT. Thereafter, its traverse of the DEN Metroplex was well described by the supplementary stations (Fig. 9). The data also showed the subsequent development of concentrated convergence and a hint of cyclonic circulation in the area from BJC-BAO-RL3-BJC. The BAO (Boulder Atmospheric Observatory) tower data further indicated that the unstable air (LI of -6, based on 1800 MDT DEN sounding data) was at least 300 m deep.

The value of a dense surface network in pinpointing the area of greatest severe weather threat seems obvious for this case. Of particular import was definition by these data of the surge of strong, southerly winds. We have also pointed out that a number of clues were available in the more conventional data (particularly surface, satellite, and radar observations) to have allowed real-time tracking of the evolving situation had sufficient time (or automation?) been available to allow a full analysis.

Appendix

The erroneous data referred to in Section 4a are as follows (data for these stations plotted at 850, 300, and 200 mb are acceptable):

- 1) Guadalupe Island (Station number 76151 and location G on Fig. 10) reports an erroneously low height at

⁶ Interpolation was made between the 0600 MDT observed values and the LFM 12 h forecast values. The 12 h LFM temperature forecast was sufficiently accurate to be of use in this application (see Fig. 3). The 12 h LFM upper-wind forecast, transmitted over NAFAX, provided the necessary forecast data.

⁷ Had mesonet data been available, this computation could have easily been machine generated (with meso-analysis software, such as that being developed by PROFS) or even done by hand. It required 15 min to do so in this case.

700 mb (500 mb height appears correct). Curiously, the 700 mb "Hough" analysis for this same time (transmitted over NAFAX-National Facsimile Circuit), shows a more reasonable height report of 3082 m and a wind from 290° at 15 kt (8 m s⁻¹). A copy of the original station record, obtained from the National Climatic Center, indicates a 700 mb height of 3081 m. Otherwise all 700-500 mb data agrees with that plotted in Fig. 10.

- 2) Empalme (station 76256 and location E on Fig. 10) and Chihuahua (76225/location C) report 500-700 mb thicknesses (in Fig. 10) equivalent to layer mean temperature of 8°C and 9°C, respectively. These values are clearly inconsistent with the plotted 700 and 500 mb temperatures. The original records from Empalme and Chihuahua show the 500 mb heights to be 577 and 578 dam, respectively. Otherwise all is in agreement with Fig. 10.

Fig. 10 suggests that the LFM analysis did treat these observations with skepticism. Nevertheless, heights at 700 mb are analyzed 30 m too low in the vicinity of Guadalupe Island, and 500 mb heights are analyzed too high (again by 20-30 m) in northern Mexico.

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