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28 MAY 1991 CASE OF HEAVY RAINFALL AND LARGE HAIL IN SOUTHWEST DENVER: AN APPLICATION OF FLASH FLOOD FORECASTING TOOLS FOR WARM SEASON NOWCASTING

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1. Introduction

For decades, meteorologists along the Colorado Front Range have been frustrated in their task of trying to forecast short term development and propagation of warm season convection. Forecasters have primarily used the standard tools of stability indices, numerical model output, satellite, and radar data to produce general forecasts. Updates were then generally made using an "eyeball assessment" of the most current data. A forecaster could usually tell if a particular day was going to have a major event or not by referencing conceptual models. However, he/she would still have difficulty in predicting the pattern and concentration of the day's convection.

The introduction of prototype AWIPS technology and data at the Denver Weather Service Forecast Office has blasted the forecasting field wide open. Meteorologists now have access to a multitude of new data sets. Out of this, the focus is shifting from synoptic scale models to mesoscale analysis and forecasting to support short-range forecasting in the 0-12 hour time frame.

There has been an increasing awareness that tools used to forecast the larger scale and/or major events can be adopted to develop conceptual models to predict smaller scale but significant events. The case reviewed in this paper should bring to light how this process can evolve.

2. Discussion

On 28 May 1991, the day began with a weak and slow-moving cold front across southeast Colorado (Fig. 1). Surface dew points were not exceptional (40s and 50s (°F) along and behind the front), but sufficient to aid some early morning convection in the southeast part of the state. One eye-catching feature was the 64°F dew point that had wrapped back north of the surface low at North Platte, NE. This air would help fuel convection in northeast Colorado later in the day.

At 1200 UTC, 28 May 1991 the 500 mb chart (Fig. 2) showed Colorado in moderate southwesterly flow between a low over the Pacific Northwest and high pressure over the southeast and south central part of the country. A short wave trough was upstream of Colorado over western Arizona and Utah. This resembles most closely the upper synoptic pattern of a frontal or mesohigh flash flood event (Maddox et al. 1979).

The 6.7 micrometer water vapor imagery (Fig. 3) showed a tropical connection with the Pacific and the Caribbean. There was a well defined wet-dry gradient through eastern Colorado and the Denver area. This was suggestive of a good supply of moisture for heavy rain and a potential for strong instability.

During the afternoon, scattered thunderstorms spread over most of eastern Colorado (Fig. 4) as the front stalled and solar heating acted upon the moisture and released the instability. Some of the storms were severe, producing large hail and funnel clouds. However, no significant convection developed in the Denver area during the afternoon hours.

The reason for this lack of convection can be seen by examining the sounding from 0000 UTC, 29 May 1991 (Fig. 5). Based on a surface parcel, note that the convective temperature is one to two degrees warmer than the observed surface temperature. The shaded area shows that a fair amount of negative area (convective inhibition, CIN) existed on the sounding and afternoon heating was not sufficient to initiate convection.

On the other hand, lifting the surface parcel shows that only a very small amount of CIN existed (Fig. 6). Additionally, an abundant amount of positive area (convective available potential energy, CAPE) was in the sounding and could be released if the parcel reached its level of free convection. If a lifting mechanism were to come along, then it would be quite likely that vigorous convection would result.

A large surface outflow boundary and mesohigh pressure system had developed in northeast Colorado by late afternoon from the thunderstorms east of Denver. This outflow (Fig. 7) progressed westward and moved through Denver around 2300 UTC, 28 May 1991. The Denver Stapleton wind profiler (Fig. 8) showed its passage well, with a deepening and strengthening east to northeast flow. This outflow was just the mechanism needed to force a parcel to its level of free convection, releasing the large amount of CAPE shown in the 0000 UTC Denver sounding.

The surface pattern was now looking very much like that of a mesohigh type flash flood event (Maddox et al. 1979) with Denver located on the southwest side of the mesohigh (Fig. 9). In this case, the abrupt rise of the foothills west of Denver was emulating the quasi-stationary surface boundary depicted in the conceptual model.

A time loop of the Mesoscale Analysis and Prediction System (MAPS, Miller and Benjamin 1992) surface equivalent potential temperature (theta-e) analysis, indicated that a ridge of warm moist air had developed across the Front Range and southeast Colorado during the early evening. By 0300 UTC, 29 May 1991 this region was marked by a maximum of theta-e just east of Denver (Fig. 10). Thunderstorms had developed rapidly southwestward over Denver by this time. The infrared satellite picture (Fig. 11) showed rapid development of a single-clustered heavy convective rainfall system (Scofield 1991).

Thunderstorms with large hail and heavy rain were widespread over Denver and its suburbs between 0200 UTC and 0500 UTC. Mile High Doppler Radar reflectivity at the 1.2 degree elevation for 0439 UTC (Fig. 12) showed the strongest activity to be over the southwest suburbs, a pattern which had persisted through the entire event.

By 0430 UTC, 29 May 1991, the Storm Total Precipitation product based on Doppler reflectivity (Fig. 13) showed that parts of southwest Denver had received rainfall amounts between 1 and 2 inches (marked by the lightest shading). Although hail contamination of the precipitation algorithm was likely in some areas, these amounts were reasonable when compared to spotter reports.

During the period from 0200 UTC to 0500 UTC, rainfall totals up to 1.25 inches and hail up to   inch in diameter were reported in the west and southwest Denver metropolitan area. Minor flooding occurred.

3. Conclusions

Several good points have come out of reviewing this case:

a. The back edge of the tropical connection was just to the east of the theta-e ridge present over Denver. Heavier rainfall and major flooding might have occurred if the tropical connection and theta-e ridge had been in phase;

b. Severe weather was focused along the tightest theta-e gradient, rather than in the middle of the theta-e ridge;

c. Rapid/prolonged increase of theta-e over a small area is a flag to watch for rapid thunderstorm development if a lifting mechanism is present;

d. Using the forecasting tools of conceptual models for major events, such as flash floods, can be helpful in making nowcasts for other small but significant events during the warm season.

5. References

Maddox, R.A., C.F. Chappell, and L.R. Hoxit, 1979: Synoptic and meso-alpha scale aspects of flash flood events. *Bull. Amer. Met. Soc.*, **60**, 115-123.

Miller, P.A. and S.G. Benjamin, 1992: A system for the hourly assimilation of surface observations in mountainous and flat terrain. Submitted to *Mon. Wea. Rev.*

Scofield, R., 1991: Flash flood forecaster's course: satellite applications. NOAA/NESDIS, Presented at NWS Training Center, Kansas City, Missouri.

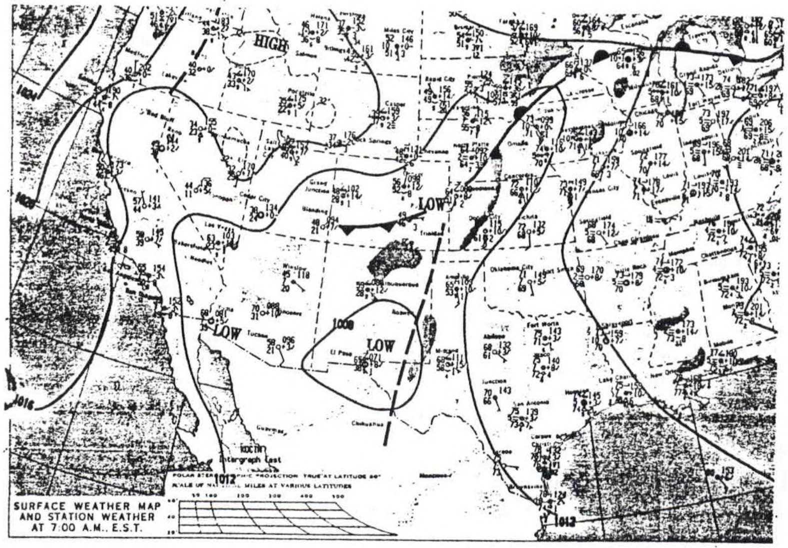

Fig. 1. 1200 UTC 28 May 1991 surface map showing station plots, fronts and isobars.

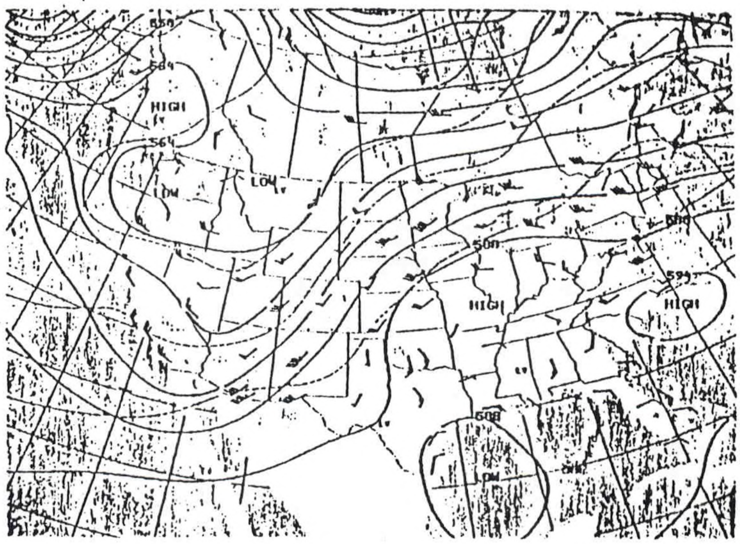

Fig. 2. 1200 UTC 28 May 1991 500 mb heights, temperatures and winds.

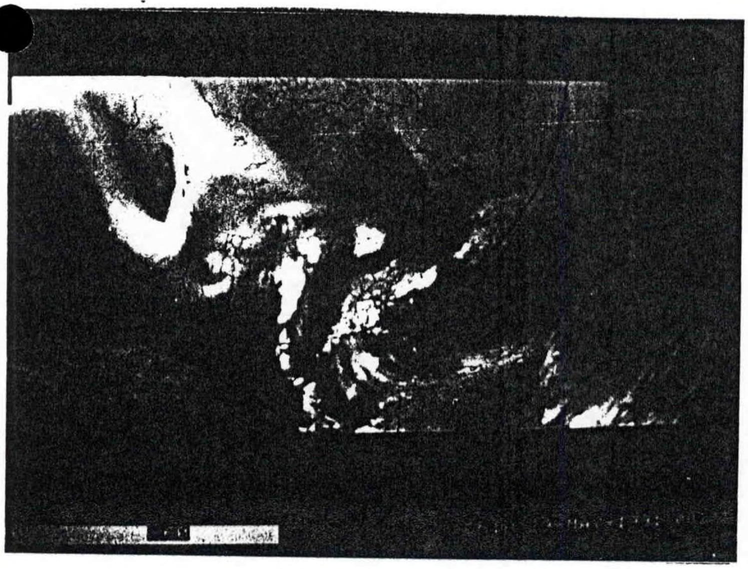

Fig. 3. 1200 UTC 28 May 1991 GOES 6.7 micron water vapor imagery.

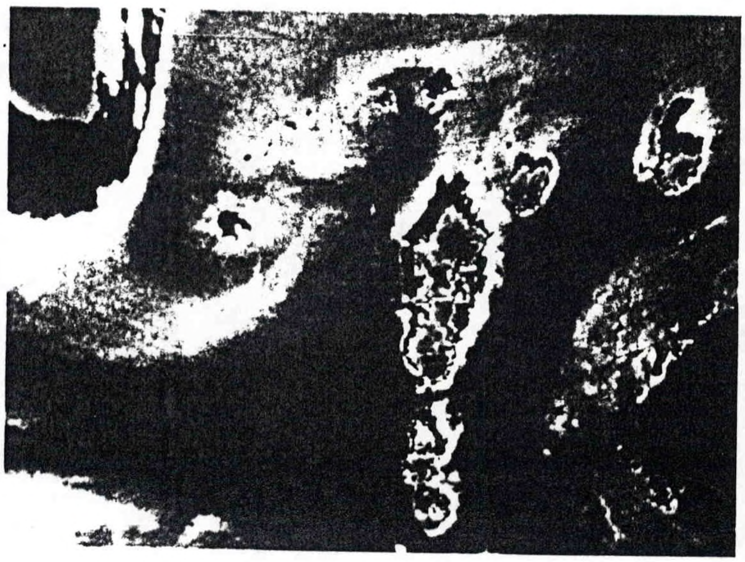

Fig. 4. 2100 UTC 28 May 1991 GOES IR satellite imagery.

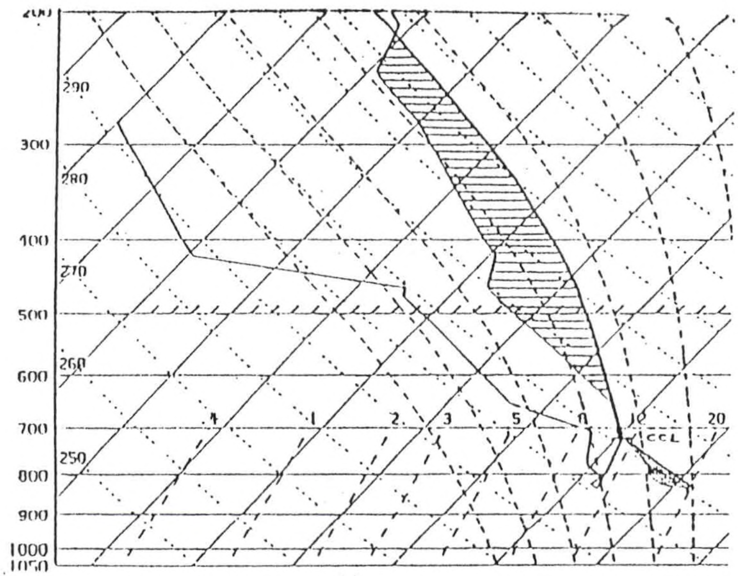

Fig. 5. 0000 UTC 29 May 1991 Denver sounding. Shaded area denotes CIN (negative energy) that would have to be overcome to initiate convection from surface heating.

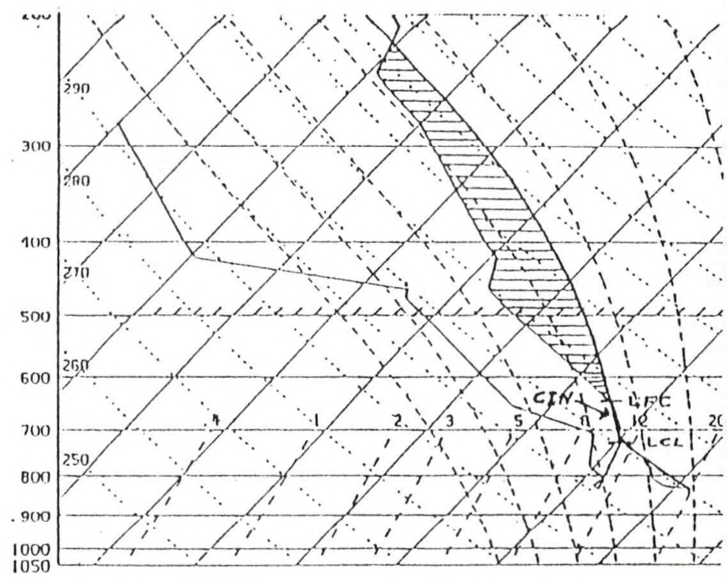

Fig. 6. 0000 UTC 29 May 1991 Denver sounding. Shaded area denotes CIN (negative energy) that would have to be overcome to initiate convection through lifting. Hatched area shows positive area (CAPE).

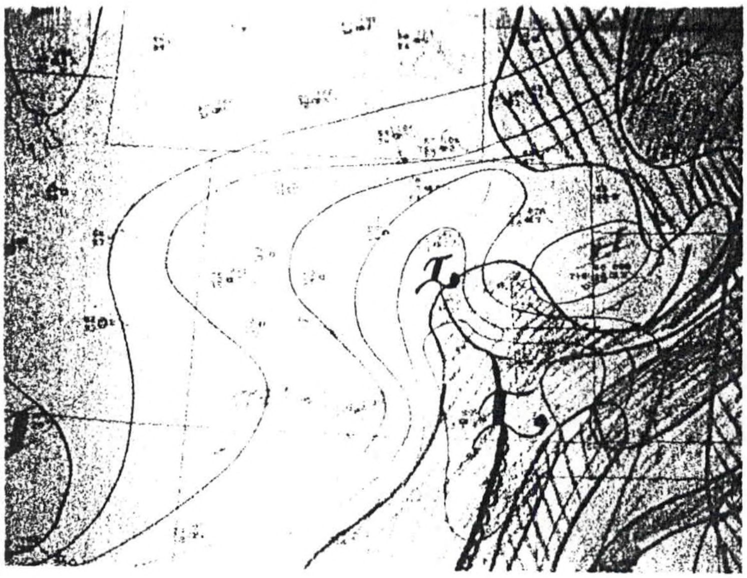

Fig. 7. 0000 UTC 29 May 1991 regional mesoscale surface analysis.

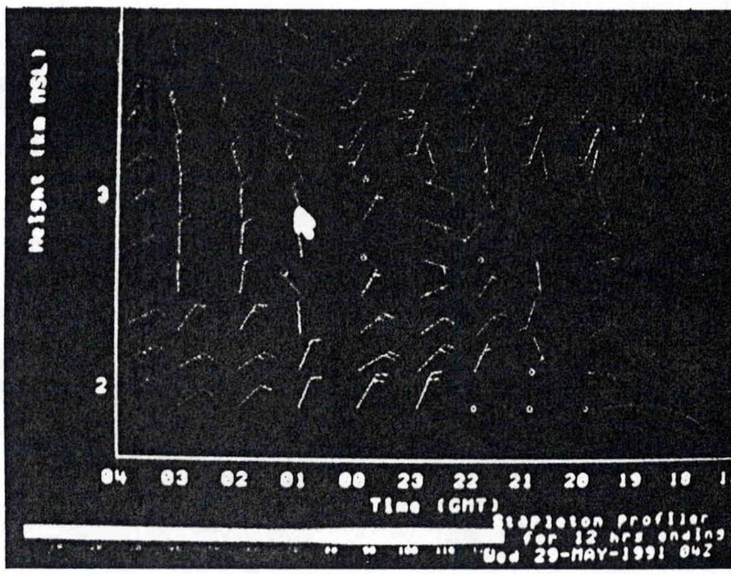

Fig. 8. Winds aloft as measured by Stapleton wind profiler. Time runs from right (1700 UTC 28 May 1991) to left (0400 UTC 29 May 1991). Heights (km msl) shown on left.

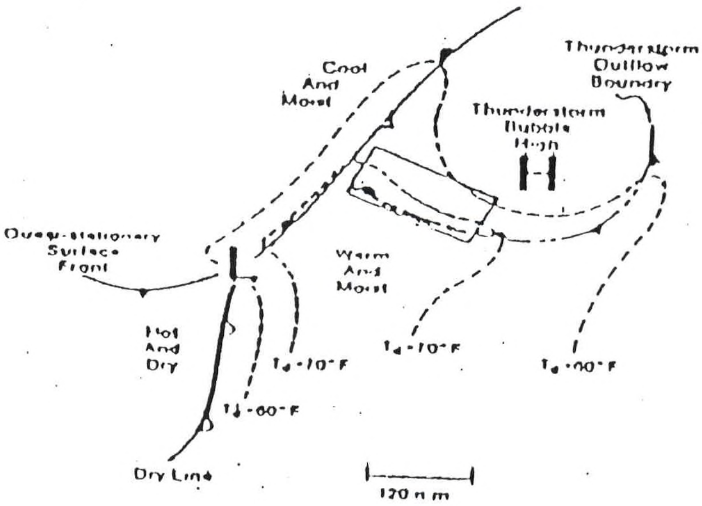

Fig. 9. Surface pattern for typical mesohigh type flash flood event, from Maddox et al. 1979.

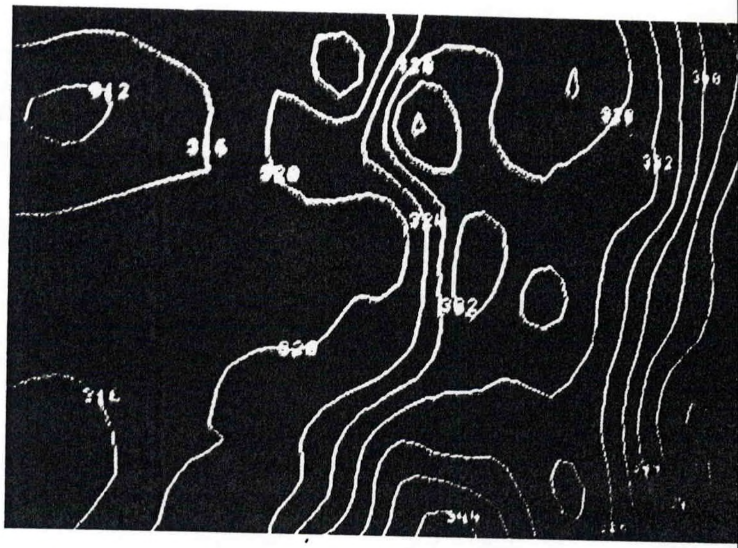

Fig. 10. 0300 UTC 29 May 1991 MAPS analysis of surface equivalent potential temperature (theta-e, K).

Fig. 11. 0300 UTC 29 May 1991 GOES infrared satellite imagery. X marks location of Denver.

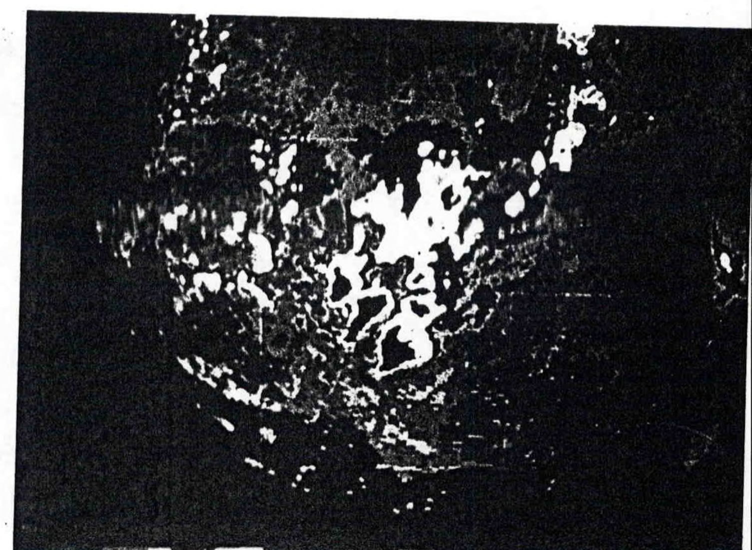

Fig. 12. 0439 UTC 29 May 1991 Mile High Radar reflectivity at 1.2 degrees elevation angle. Bright areas just southwest of center of figure indicate stronger reflectivities detected south of Denver.

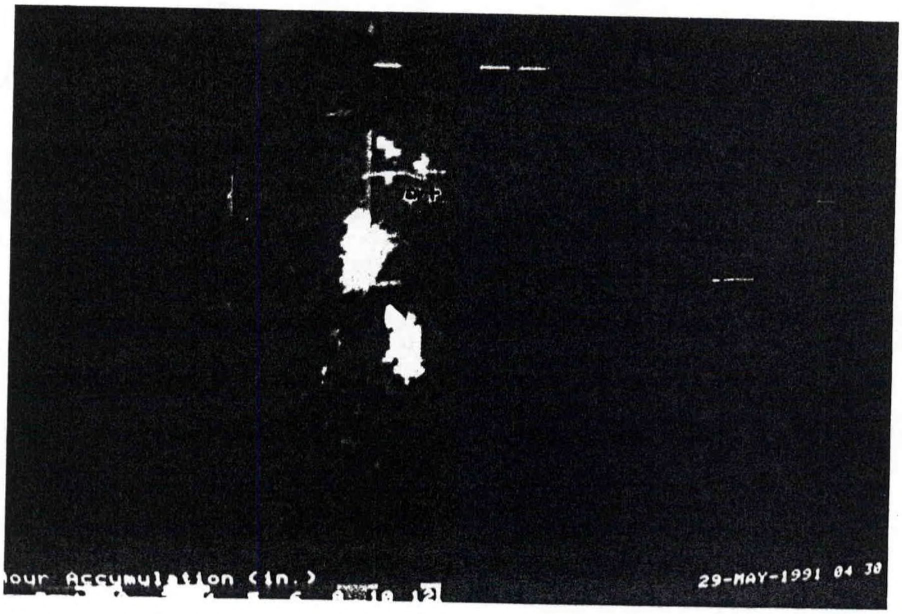

Fig. 13. 0430 UTC 29 May 1991 Storm Total Precipitation image based on Mile High Doppler reflectivity data.