17.4 THE OKLAHOMA TORNADO OUTBREAK AND FLASH FLOOD EVENT OF 4-5 OCTOBER 1998

Jonathan Racy *
NOAA/NWS/Storm Prediction Center, Norman, Oklahoma

Joseph A. Rogash
NOAA/NWS/ Weather Forecast Office, El Paso, Texas

1. INTRODUCTION

Deep convection and associated severe weather phenomena remain a forecasting challenge for operational meteorologists due to both the complexity of the atmospheric processes involved and the hazards posed to the public. Flash flooding, lightning, tornadoes and damaging thunderstorm winds account for nearly all fatalities and a major proportion of property damage associated with thunderstorms across the United States. Statistics show that for the period 1990 to 2000, a yearly average of 88 fatalities were attributable to heavy rain events, 56 fatalities from tornadoes and 28 deaths from severe thunderstorm wind gusts (National Climatic Data Center 1990-2000). Therefore, thunderstorm complexes which produce significant tornadoes and flash floods within a limited time and area represent an extremely dangerous situation (Corfidi et al. 1990; Schwartz et al. 1990; Rogash and Smith 2000; Rogash and Racy 2002). Furthermore, emphasis on the correct recognition of pre-convective environments that lead to severe thunderstorms and flash flood events is paramount in improving the National Weather Service response to multi-hazard situations (Schwartz et al. 1990).

To better understand environments associated with these simultaneous phenomena, this paper will investigate an occurrence of deep convection which produced both numerous tornadoes and flash flooding. The major tornado and flash flood event occurred over central and eastern Oklahoma from the afternoon of 4 October to the early morning of 5 October 1998. Widespread destruction or damage to homes and businesses occurred when thunderstorms produced at least 26 tornadoes, including one of F3 intensity and at least eight rated F2 (Fig. 1). In addition to the tornadoes, very heavy rainfall occurred over central and eastern Oklahoma with some areas receiving between 5 and 7 inches (125-175mm) of rain. The resultant flooding washed out bridges, damaged homes and businesses, and made numerous roads impassable due to the high water.

2. METHODOLOGY AND DATA ANAYLYSIS

Data used for the 4-5 October 1998 case include subjective analyses of surface observations along with upper air data obtained from the standard and specially launched rawinsondes. Soundings were analyzed using an advanced version of the SHARP workstation (Hart and Korotky 1991), with several parameters related to instability and wind shear closely examined. Numerical model output from both the Eta and Rapid Update Cycle (RUC II) were used to assess certain kinematic and dynamic parameters. Storm evolution was also evaluated using the WSR-88D Doppler radar in order to examine the convection responsible for both strong tornadoes and flash flooding.

**Corresponding author address:* Jonathan Racy, NOAA/NWS/Storm Prediction Center, Norman, OK 73072; e-mail: jonathan.racy@noaa.gov

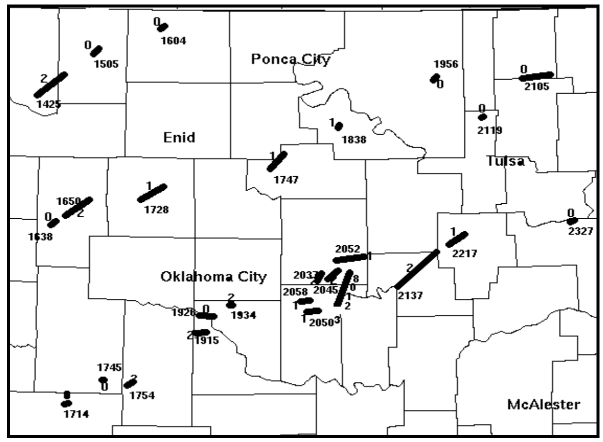

Fig. 1. Map of eastern and central Oklahoma showing tornado tracks for 4-5 October 1998. Line segments indicate the tracks, single numbers represent Fujita intensity scale and remaining numbers indicating time of occurrence (CST).

3. PRE-STORM ENVIRONMENT

At 1200 UTC the 500 mb analysis reveals a broad middle-tropospheric trough covering most of the western United States with an axis of maximum vorticity aligned from central Colorado into northwestern New Mexico (Fig. 2). A core of 50 to 70 kt (25 to 35 m s^{-1}) winds stretches across the base of the trough through Arizona into central New Mexico, with considerably weaker flow across Oklahoma. The 1200 UTC 850 mb analysis (not shown) indicates a low center over eastern Colorado with an associated trough axis extending southwestward into northwestern New Mexico, and a dry line from southeastern New Mexico into extreme western Texas. The resultant height gradient supports strong 850 mb flow with 40-45 kt (20 m s^{-1}) southerly to southwesterly winds from west-central Texas through western Oklahoma. This pattern contributed to a significant transport of moisture from the Gulf of Mexico northward with precipitable water values of around 1.50 inches (38 mm) (around 200% of normal for October) through central Texas into Oklahoma and south-central Kansas.

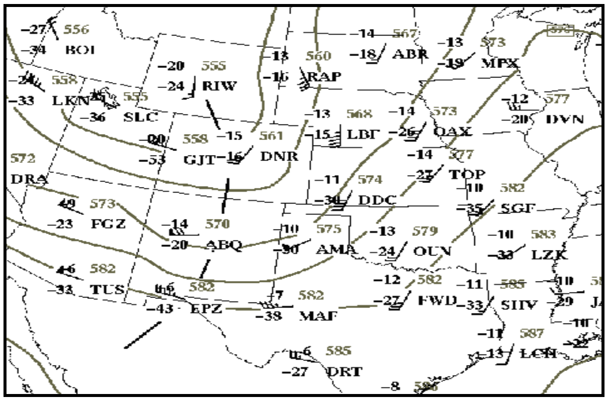

Fig. 2. 500 mb analysis valid 12 UTC 4 October 1998 showing height contours (solid line in decameters). Full wind barb is 10 kt with pendant indicating 50 kt. Heavy dashed line indicates axis of shortwave trough.

Surface data at 1200 UTC (Fig. 3) indicate a rather complex pattern. Low pressure centers are over eastern Colorado, with a warm front extending southeastward across south-central Kansas. Surface data are consistent with the 850 mb analysis showing a strong north-south moisture gradient across the southern high plains. Dewpoints range from the lower 40s to lower 50s (deg F) over eastern New Mexico but increase substantially to greater than 70^{o} F over western Oklahoma and west central Texas. Accordingly, a dry line is analyzed through southeast Colorado into eastern New Mexico.

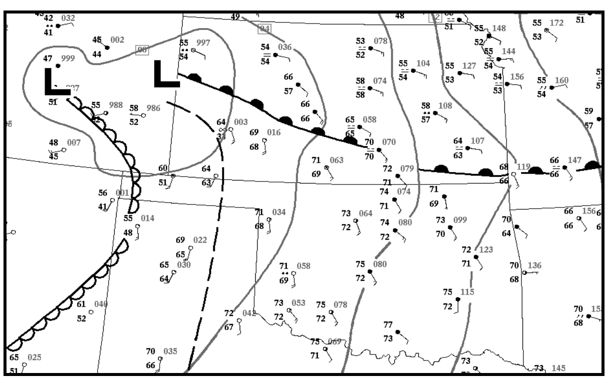

Fig. 3. Surface analysis for 12 UTC 4 October 1998. Standard plotting model and abbreviations are used with pressure in mb, and temperature/dew point in degrees F.

The 1200 UTC Eta model predicted the 500 mb trough would advance farther eastward through the morning hours with the midlevel shortwave trough extending from eastern Colorado into western Oklahoma by 1800 UTC (not shown). Forecasted vertical motion fields show upward motion in the middle troposphere through south central Kansas and across most of Oklahoma (excluding the panhandle) at 1800 UTC. The environment at 850 mb, as derived from the six hour Eta forecast , includes a low-level southerly jet axis of 40-50 kt (20 to 25 m s^{-1}) through central Texas, Oklahoma and central Kansas. Dew points at 850 mb are forecast to be around 14 C, with precipitable water values of 1.50-1.75 inches, (38-44 mm) enhancing the potential for heavy rain assuming deep moist convection develops.

The 1800 UTC surface analysis (not shown) reveals that the low had consolidated and deepened since 1200 UTC with the center moving northeastward into southwestern Nebraska. The trailing dry line concurrently moved eastward, being positioned nearly along the western Oklahoma-Texas border, with the cold front situated from northwestern Kansas into east-central Colorado. East of the dry line the air mass is rather moist and warm with dew points mainly in the lower 70s (deg F) and temperatures ranging from the upper 70s in southern Kansas to the lower 90s in central Texas. The six hour forecast from the 1200 UTC Eta model indicates boundary layer moisture convergence is being focused along the dry line suggesting the concurrence of upward vertical motion and moisture transport or advection along this boundary (Carr and Bosart 1978).

Due to the severe weather and heavy rainfall potential, a special sounding was released over Norman, Oklahoma at 1800 UTC. As shown in Figure 4, the air mass over central Oklahoma is extremely unstable by this time with the warm moist air mass in the lower troposphere contributing to a 100 mb layer mean mixed CAPE value of 2511 J kg $^{-1}$. The high moisture content is also reflected by the sounding's precipitable water value of 1.55 inches (41 mm), which is more than 200 percent of normal. The collocation of the 40 kt (20 m s^{-1}) low level southerly wind near 850 mb with the increasing southwesterly flow in the middle troposphere results in a surface to 3 km storm relative helicity (SRH) of 300 m ^{2} sec $^{-2}$ around Oklahoma City, Thus, critical factors are in place which favors flash flooding and the potential for supercells over much of Oklahoma.

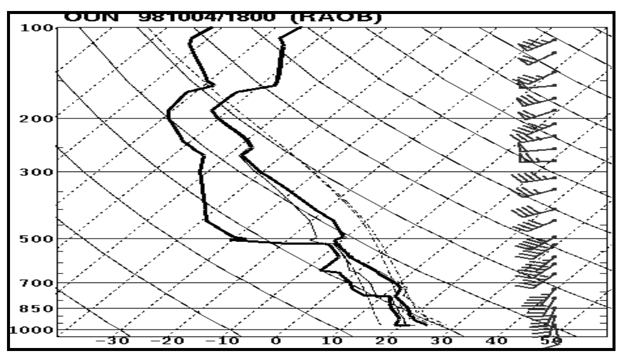

Fig. 4. The 18 UTC 4 October 1998 Norman sounding showing temperaure and dew point on a skew T log P diagram. Moist adiabat of a lifted parcel from level of free convection is shown as long dashed line.

4. STORM SCALE EVOLUTION

Just after 1830 UTC thunderstorms organized in vicinity of the dry line across northwest Oklahoma, northward into central Kansas. By 2100 UTC (Fig. 5) one thunderstorm in northwestern Oklahoma (Supercell A in Fig. 5) evolved into a supercell with regional Doppler radars detecting strong rotation. This storm eventually produced several tornadoes as it moved into north-central Oklahoma during the late afternoon hours.

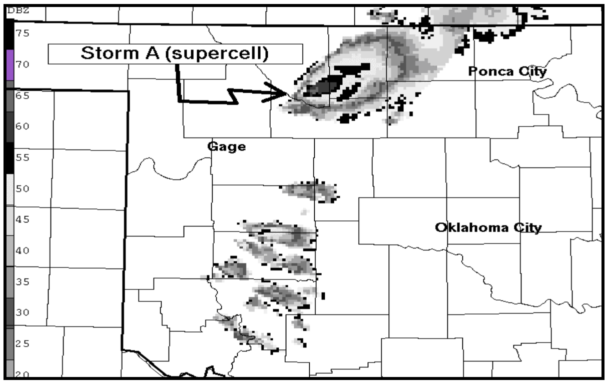

Fig. 5. WSR-88D base reflectivity image (0.5 degree tilt) at 21 UTC 4 October 1998. Data is based on mosaic of local area radars. Data is filtered for 20 dbz or greater.

Between 2200 and 0000 UTC the thunderstorms which initiated near the dry line moved eastward with deep convection also developing southwestward into southwest and south-central Oklahoma. As illustrated in Fig. 6, by 0000 UTC a broken line of discrete cells is noted, with the most intense storm, supercell B, at the southern portion of the line. Supercell B produced numerous tornadoes as it advanced into northeastern Oklahoma during the next three hours. One tornado produced F2 damage over southern portions of the Oklahoma City metro area at about 0130 UTC with a stronger F3 tornado causing damage to homes and buildings over Pottawatomie County between 0317 and 0325 UTC (Fig. 1). As the supercells matured, several small mesoscale convective complexes evolved, generating a substantial cold pool. Thus, several outflow boundaries became evident in the 03 UTC surface mesoanalysis (Fig 7). These outflow boundaries were important features in the development of heavy rainfall.

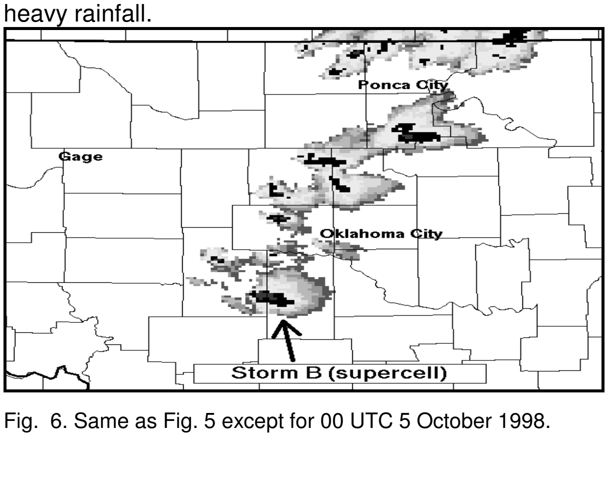

Fig. 6. Same as Fig. 5 except for 00 UTC 5 October 1998.

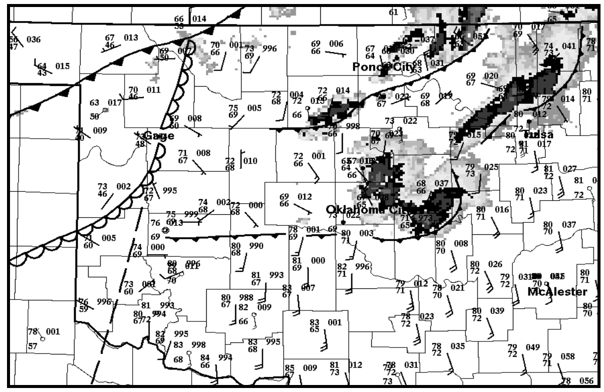

Fig. 7. Same as Figs. 5 and 6 except for 03 UTC 5 October 1998. Surface data from Oklahoma Mesonet and regular surface stations included with format the same as in Fig. 3. Surface fronts are denoted in standard format.

The 0000 UTC Norman sounding (Fig. 8) indicates the combination of instability and wind shear remained favorable for supercells with a 100 mb layer mean mixed CAPE of 1924 J kg $^{-1}$ and the surface to 3 km SRH increasing to around 500 m ^{2} s $^{-2}$. Supercells and tornadoes continued until around 0530 UTC across northeastern Oklahoma. However, another critical aspect of the environment includes the wind and moisture profiles between 1500 to 3000 m AGL; within this layer winds are southerly and southwesterly between 40-50 kt (20 to 23 m s $^{-1}$) and mixing ratios average near 12 g kg^{-1} , evidence of the pronounced moisture flux in the lower troposphere.

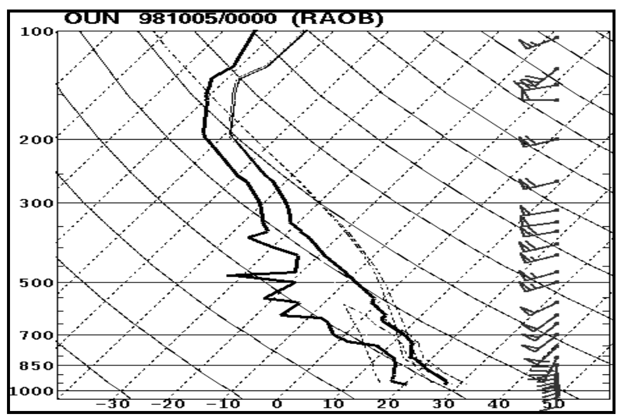

Fig. 8. Same as in Fig. 4, except for 00 UTC 5 Oct 1998.

While winds strongly veered with height between 850 and 500 mb, there is only modest speed shear [10 kt (5 m s $^{-1}$)] between these levels with nearly constant winds between 500 and 300 mb. As discussed by Corfidi et al. (1996), a wind profile exhibiting these characteristics suggests the low level storm-inflow is of comparable strength to the cloud layer mean wind, thus indicating a propensity for new convective cells to develop (or propagate) upstream in a direction opposite to the mean cell motion. Consistent with this paradigm is the behavior of deep convection over northern and central Oklahoma between 0300 and 0600 UTC; during this period individual thunderstorms generally moved to the east-northeast at 30-40 kt (15 to 20 ms^{-1}) but new convection redeveloped or "backbuilt" to the west. Another critical factor affecting the evolution of the convective system was the location of surface outflow boundaries associated with the evening thunderstorms. As illustrated in Fig. 7, the boundaries extended from northeastern into central Oklahoma while to the south, 10-20 kt (10 m s^{-1}) southeasterly winds at the surface continued transporting warm moist air northward. The resultant moisture convergence along the boundaries supported the redevelopment of new convection over north-central Oklahoma, which subsequently moved east-northeastward. Thus, by 0600 UTC thunderstorms with heavy rainfall still covered a large portion of north-central and northeastern Oklahoma (Fig. 9), illustrating the backward propagation of individual meso-beta elements within the larger mesoscale convective system. This process was responsible for thunderstorms repeatedly moving or "training" over this region with excessive rainfall and flash flooding occurring in numerous counties.

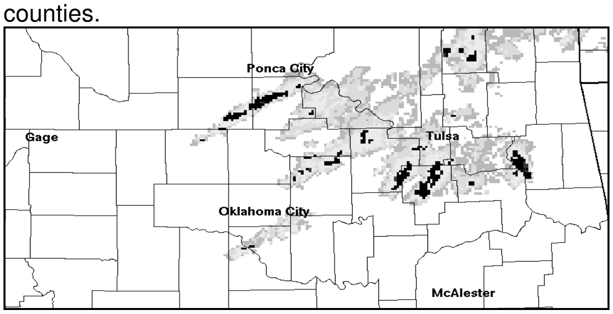

Fig. 9. Same as in Fig. 5 and 6, except at 0600 UTC and reflectivity of 35 dbz or greater.

5. SUMMARY AND CONCLUSIONS

This study demonstrates how meteorological conditions can exist which are favorable for both the occurrence of numerous tornadoes and heavy rainfall. Important ingredients necessary for the near temporal and spatial concurrence of tornadoes and flash floods may include a very unstable air mass with relatively high moisture content, especially in the lower troposphere. Environmental wind and moisture characteristics should also indicate vertical wind shears favorable for tornadic supercells, and lower- tropospheric moisture flux of sufficient magnitudes to support heavy rainfall. A strong low-level jet may be especially critical since such a feature may enhance the storm relative helicity while also supporting the backward propagation or "backbuilding" of convective cells, thus enhancing the heavy rain potential.

6. REFERENCES

Carr, F.H., and L.F. Bosart, 1978: A diagnostic evaluation of rainfall predictability for Tropical Storm Agnes, June 1972. *Mon. Wea. Rev.* , 106, 363-374.

Corfidi, S.F., N.W. Junker and F.H. Glass, 1990: The Louisiana/Mississippi flash flood and severe weather outbreak of 15-16 November 1987. Preprints, *16th Conference on Severe Local Storms,* Kananaskis Park, AB, Canada, Amer. Meteor. Soc., 627-633.

Corfidi, S.F., J.H. Merritt and J.M. Fritsch, 1996: Predicting the movement of mesoscale convective complexes. *Wea. Forecasting,* **11**, 41-46.

Hart, J.A., and W.D. Korotky, 1991: The SHARP Workstation v1.50 users guide. National Weather Service, NOAA, 30 pp. [Available from NWS Eastern Region Headquarters, Scientific Services Division, 630 Johnson Ave., Bohemia, NY 11716.]

National Climatic Data Center, 1990-2000: *Storm Data.* National Climatic Data Center, Asheville, NC.

Rogash, J.A., and R.D. Smith, 2000: Multiscale overview of a violent tornado outbreak with attendant flash flooding. *Wea. Forecasting,* **15,** 416-431.

Rogash, J.A., and J.P. Racy, 2002: Some meteorological characteristics of significant tornado events occurring in proximity to flash flooding. *Wea. Forecasting,* **17,** 155-159.

Schwartz, B.E., C.F. Chappell, W.E. Togstad, X. Zhong, 1990: The Minneapolis flash flood: meteorological analysis and operational response. *Wea. Forecasting,* **5,** 3-21.