Signature of a Precipitation Event: A Comparison of Three Spatial Perspectives

Stephen J. Walsh
University of North Carolina

and
Mark S. Gregory
Oklahoma State University

INTRODUCTION

On April 03, 1981, a precipitation event in the form of a series of thunderstorm cells affected the central portion of Oklahoma. The event was recorded by the WSR-57 radar positioned at the National Severe Storms Laboratory in Norman, Oklahoma. In addition, the rainfall from the series of thunderstorms was recorded at rainfall gauges located at the Oklahoma Cooperative Weather Stations distributed throughout the state. The ground pattern of the corresponding rainfall event also was detected by the NOAA-6 (National Oceanic and Atmospheric Administration) satellite over-pass on April 04, 1986, one day after the precipitation event.

This paper presents three techniques—radar traces, rainfall gauges, and meteorological satellite data—for characterizing the spatial pattern of thunderstorm development and migration. Each technique, which provides a unique perspective regarding the signature or character of the event, will be evaluated as to the type of information retrieved and its applicability for characterizing the spatial component of precipitation events.

STUDY AREA

The state of Oklahoma covers over 180,000 square kilometers, straddles the forest/grassland ecotone, and is prone to substantial climatic inter-seasonal and intra-seasonal variations. Precipitation varies from a mean of 130 cm annually in the southeast to less than 40 cm in the northwest portion of the state. A period of maximum precipitation occurs in the spring with a second, lesser maximum occurring in the early fall. Precipitation in Oklahoma is strongly tied to the advection of moisture from the Gulf of Mexico. Summertime, afternoon thunderstorms are a common event throughout the southern Great Plains: on the average 40 to 50 days per year within this region are affected by thunderstorms.

Temperatures vary less across the state than does precipitation. Mean annual temperatures range from 17.5°C at Idabel, in the extreme southeast corner
of the state, to 12°C at Biose City, in the western part of the Oklahoma Panhandle. Average July temperatures range from 25°C in the Panhandle to 27.5°C in the southeastern quadrant of the state. January average temperatures range from 0°C in the Panhandle to 6.5°C in the southeast. Maximum temperatures of 37.8°C or higher may be expected in Oklahoma from June to September.

METHODOLOGY

On April 03, 1981 at 1159 LST, the National Severe Storms Laboratory (NSSL) in Norman, Oklahoma began monitoring the location and intensity of a thunderstorm developing in central Oklahoma. Surveillance of the thunderstorm was terminated at 1625 LST. The NSSL employs a WSR-57 radar which operates at a wavelength of 10 cm. The radar system has a resolution beamwidth of 2 degrees and an approximate range of 240 km.

The Oklahoma Cooperative Weather Stations, which collect precipitation and temperature data, are distributed throughout the state in a relatively uniform fashion (Figure 1). There are 174 stations which measure meteorologic data as part of the Oklahoma network. Meteorologic/climatic information for Oklahoma are gathered and distributed by the Oklahoma Climatological Survey in Norman, Oklahoma. Rainfall data for April 1–4, 1981 were acquired for all Oklahoma weather stations.

The NOAA-6 AVHRR satellite operates in four parts of the electromagnetic spectrum, 0.58–0.68, 0.725–1.10, 3.55–3.93, and 10.50–11.50 micrometers, and provides daily radiometric coverage of the earth at a spatial resolution of 1.1 km. Initially, the acquired April 04, 1981 NOAA AVHRR digital data set was processed to reformat the satellite digital data for more efficient use by the resident software. The data were also prepared for display on the image processing system. An initial color table and function were developed in order to assign a color and intensity to each pixel of the four AVHRR spectral channels. The assignment of color was based upon the level of spectral radiance of each pixel. The second processing step involved the geographical referencing of the reformatted and displayed AVHRR data to the Universal Transverse Mercator (UTM) coordinate system. The process involves the selection of control points which can be located on USGS topographic quadrangles and on the AVHRR digital data. Selected control point pairs, UTM northing and easting coordinates from the topographic maps, and AVHRR scan line and element co-

![Figure 1: Oklahoma Cooperative Weather Stations](image_url)
ordinates read by the image processing system, were used in a georeference algorithm to resample the satellite data and to produce a spatially and geometrically accurate map.

ANALYSIS

Figure 2 shows the location of the thunderstorms at 1159 LST as detected by the WSR-57 radar in Norman, Oklahoma. Figure 3 shows the storms at 1255 LST; Figure 4 at 1356 LST; Figure 5 at 1446 LST; Figure 6 at 1528 LST; and Figure 7 shows the precipitation event at 1625 LST. Figures 3 through 7 depict the movement of the storms through central Oklahoma over a 3.5 hour period. The Figures show the intensity levels of the storms with each radar storm trace. According to Figure 3 through Figure 7, the storm increased its areal coverage by 248 km in a southwest to northeast orientation and by 16 km in a northwest to southeast orientation. The series of thunderstorm cells affected a region of 185 km in a west to east direction during the radar detection period. Figure 8 shows a composite of the six radar storm traces presented in Figures 3 through 7. The change in the relative geographic position and the increase in size in the storm cells during the analysis period are readily apparent in the presented figures.

The pattern of development and decay of thunderstorm cells is one of the most important factors governing the movement of the storm as a whole (1). As is the typical situation, the storm cells on April 03, 1981 moved toward the northeast. New cells form to the right of existing cells, and old cells dissipate on the left. Thus propagation of the thunderstorm results in a movement of the system as a whole toward the right of the path of movement of its individual cells (2).

The rainfall distribution as determined through the analysis of the weather station data indicates a southwest to northeast orientation of the rainfall concentration (Figure 9).
Figure 3: Radar Storm Trace, Time: 1255 LST

Figure 4: Radar Storm Trace, Time: 1356 LST
Figure 5: Radar Storm Trace, Time: 1446 LST

Figure 6: Radar Storm Trace, Time: 1528 LST
WSR-57: RADAR
STORM TRACE

DATE: APRIL 03, 1981
TIME: 1625

Figure 7: Radar Storm Trace, Time: 1625 LST

WSR-57: RADAR
STORM TRACE

DATE: APRIL 03, 1981

Figure 8: Radar Storm Trace Composite, Time: 1159–1625 LST
The west-to-northeast orientation of the storm pattern is maintained as the precipitation event progresses towards the southeastern portion of the state. The zone of maximum precipitation is located in central Oklahoma. Rainfall amounts range to a maximum value of nearly 3.0 cm. Precipitation levels in excess of nearly 2.0 cm are limited to the central Oklahoma region. The location, shape, and pattern of the rainfall event as a consequence of the passage of the thunderstorm cells show a very similar pattern as compared to the radar traces.

Figure 10 shows "streaks or stains" located over central Oklahoma as detected by the NOAA AVHRR satellite digital data acquired on April 04, 1981. This...
pattern was apparent only on the thermal channels and not on the visible and near-infrared channels. The data were acquired one day after the passage of the precipitation event. The thermal infrared data indicate a cooling of temperature associated with measured rainfall. Latent energy of evaporation, soil thermal properties, and transpiration contribute to the observed cooling. After surface drying following a rainfall event, thermal inertia and evapotranspiration remain sufficiently affected so that the increased soil moisture is detected through decreases in temperature, independent of land cover and soil type (3). Evaporative cooling through latent heat produced a thermal gradient of approximately 2°C which effectively outlined the "streaks or stains." Idso et al. (4) demonstrated that degrees of soil moisture in the upper soil layer were related to radiances in the reflected spectral regions. Significant correlations have been obtained between soil moisture in the surface layer and the diurnal range of surface temperature. The thermal response maintains its sensitivity to soil moisture variations in the presence of a plant canopy (5).

DISCUSSION AND CONCLUSIONS

Reynolds and Smith (6) indicate that the combined use of ground-based digital weather radar and meteorological satellite data is important in interactive systems for meteorological case studies and forecasting. Negri (7) and Heymsfield et al. (8) successfully related the internal thunderstorm structure and flow determined from ground-based radar with cloud top information from meteorological satellite data. Lovejoy and Austin (9) report that the utility of meteorological satellites lie in the detection and measurement of areas affected by a precipitation event, and Walsh (3) identified a relationship between rainfall amounts and the spectral signature of surface soil moisture conditions detected by the NOAA-6 meteorological satellite.

Collectively, these researchers indicate the value of integrating ground-based radar, meteorological satellite data, and rainfall data collected at weather stations for monitoring the spatial character of precipitation events. Integration of such data collection techniques are warranted because each technique assesses slightly different properties or attributes of the spatial signature of the precipitation event. A study of the spatial character of the precipitation event afforded through each of the three data collection techniques renders a more complete description of the location, severity, and progression of the event.

The ground-based radar provides a spatial, as well as, temporal perspective of precipitation events. The active radar pulses transmitted to and backscattered from the thunderstorm indicates the location and severity of the event. Multiple radar traces over time show the spatial variation of the event on a user-defined temporal basis. It is difficult, however, to accurately measure actual rainfall amounts for specific geographic locations from the radar storm intensity levels. The radar system utilized in this study had a maximum operational range of approximately 240 km. Regions outside of that range could not be assessed.

The distribution and number of weather stations directly affects the level of precision in characterizing the location, severity, and progression of precipitation events. Since 24 hours is the typical time period for monitoring precipitation accumulations at state cooperative weather stations, only daily cumulative effects can be assessed. Temporal analyses of rainfall magnitude, therefore, are limited to daily scenarios. Within Oklahoma a relatively dense network of 174, rather uniformly spaced, weather stations are employed to provide a description of rainfall distribution. Large variations, however, can be expected between adjacent stations. Significant variation in rainfall amounts occurring within the region may escape analysis because of the relatively large geographic area represented by an individual weather station. Therefore, rainfall data collected at state cooperative weather stations provide a general overview of spatial variations in precipi-
itation events. Even with the coarse network of weather stations, variation is observed in the collected rainfall data. The variation which may occur in localized areas of limited geographic extent, such as, precipitation events related to a single thunderstorm cell, may be excluded from the ground-based, fixed point method of data collection utilized at the weather stations. Once the weather station data are collected for analysis, the data must be converted from point measures to geographically referenced area measures and portrayed as either continuous statistical surfaces, such as, isoline maps, or as discontinuous surfaces, such as, choropleth maps.

AVHRR thermal infrared satellite data can detect a cooling of earth-surface temperature associated with measured rainfall following a precipitation event. The pattern of surface cooling measured by the AVHRR sensors does not seem to be associated with rainfall amounts beyond some threshold value which accounts for adequate surface wetting. The signature of the "streaks or stains" was more pattern oriented than temperature derived (3).

Thermal infrared sensors on-board meteorological satellites can be applied to rainfall monitoring through the identification of the areal extent of antecedent precipitation events, and general, near-surface soil moisture conditions. The satellite data provide a description of the landscape limited by the spatial, temporal, spectral, and radiometric resolution of the system. Like the weather stations, the satellite data provide a general description of the precipitation event on a daily basis. Unlike the weather station data, however, the satellite data sense the entire study area and assign spectral values to each resolution unit. The satellite data are area oriented and provide a detailed spatial perspective. At the weather station locations where rainfall data are collected, satellite data can not as accurately determine the magnitude of the precipitation event. An integration of ground-based radar, rainfall data collected at weather stations, and satellite spectral information can best achieve a satisfactory description of the spatial character of a precipitation event.

REFERENCES