P2.9 A CLIMATOLOGICAL ANALYSIS OF HEATBURSTS IN OKLAHOMA

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1. Introduction

One of the more rare and fascinating events associated with atmospheric convection are the hot, dry and gusty surface winds that occasionally are produced by decaying nocturnal thunderstorms. These events have been referred to as “warm wakes” by Williams (1963), as “hot blasts” by Froude and Simmonds (1965), and more recently as “heat bursts” by Johnson (1983). Almost all documented events of heatbursts concerned phenomena that occurred across the Great Plains of the United States; all occurred during the warm season, typically between 0000 and 1200 UTC, and were associated with weak or dissipating radar echoes.

Heatbursts are characterized by a sudden and highly localized increase in air temperature, along with a simultaneous decrease in relative humidity and dewpoint temperature, and strong gusty winds. A decrease in air pressure typically accompanies the event. From previously documented events, we learn that heatburst phenomena occur on time scales that range from several minutes to several hours, with sudden temperature increases as high as 13 ^{o}C (Cunningham, 1989), relative humidity decreases as large as 83% (Cunningham, 1989), and wind gusts as strong as 47 m/s (MacKeen et al., 1998).

Although instances of heatbursts have been documented as early as 1909 (Cline), the cause of the phenomena remained a subject of great mystery until Johnson (1983) proposed a hypothesis for the physical process that leads to heatburst development. Based on data collected during an Oklahoma heatburst event on 29-30 May 1976, Johnson theorized that heatbursts were the result of dry microbursts penetrating a surface-based temperature inversion. This mechanism is illustrated by the idealized sounding in Fig. 1.

Subsequent studies, including those of Johnson (1989) and Bernstein and Johnson (1994), verified this hypothesis. However, these studies expanded on the theory, as their data indicated that the descending branch of the rear inflow jet (RIJ) trailing a nocturnal MCS penetrated a surface-based inversion, resulting in heatbursts across central Kansas in June 1985.

The apparent rarity and small spatial extent of heatbursts makes detailed study of these events difficult using the standard federal observation network established in most countries. Thus, a mesonetwork of meteorological stations is essential to detect heatburst phenomena and to observe their meteorological characteristics.

The Oklahoma Mesonet is a network of 115 automated stations deployed at a spatial resolution of 30 kilometers that provide five-minute observations of wind, temperature, relative humidity, and rainfall. Five years of archived data from the Mesonet open the door to a unique opportunity for an extensive, thorough, and first-of-its-kind climatological study of heatbursts.

Between October of 1993 and September of 1998, the Oklahoma Mesonet detected approximately 51 heatburst events across the state. Many were minor in nature, affecting only one Mesonet site, and lasting only several minutes. Some were major in scope, affecting as many as 12 stations, and persisting for several hours. This paper will briefly document one of these 51 events, and present a simplified climatology based upon these events.

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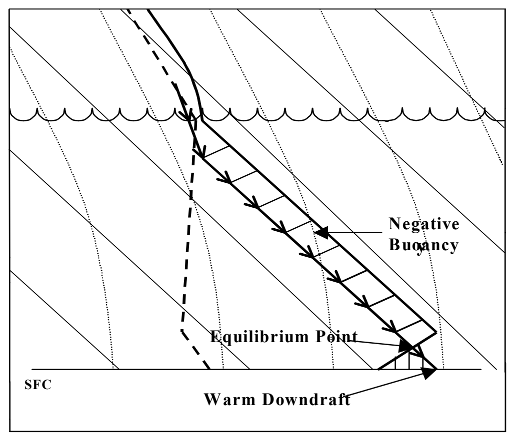

Figure 1. Skew T/log p diagram illustrating an idealized microburst producing a heatburst at the surface. The line of arrows represents the thermodynamic path of the downdraft.

2. Data Analysis Procedures

Each observation from every Mesonet station was examined over a 5-year period from October of 1994 through September of 1998. This required examination of approximately 60 million observations. Criteria were chosen to search the archived data for potential heatbursts. The screening criteria were (1) an increase in air temperature of 2.7 ^{o}C during a 10 minute period, simultaneous with (2) a decrease in dewpoint temperature of 2.7 ^{o}C, and (3) a maximum wind gust of at least 10 m/s five minutes prior to, during, or five minutes after the thermodynamic perturbations. These criteria were chosen due to their consistency with past observations of heatbursts, including those that were known to have occurred within the Mesonetwork prior to the start of this research.

This screening process resulted in the flagging of 108 observations as potential heatburst occurrences. Closer analysis of these observations indicated that approximately half of the potential events were the result of processes not related to heatbursts, particularly the passage of the dryline, and other instances of boundary layer mixing. Once these nil cases were removed from consideration, 51 heatburst cases were identified to have occurred within the network during this 5-year period.

3. 15 May 1995 Event

During the late evening of 14 May 1995, a strong-to-severe MCS developed along a stalled frontal boundary across western north Texas and southwest Oklahoma. During the early morning hours, the MCS weakened as it moved into south central Oklahoma. By this time, the MCS had developed many radar characteristics typical of a mature MCS. A well-defined reflectivity notch had developed along the upshear side of the leading line of convection, indicative of the presence of a rear inflow jet (RIJ; Smull and Houze 1985). In addition, a small area of stratiform precipitation had developed behind the main convective line. Meanwhile, surface analysis indicated the presence of a mesoscale area of low pressure, or “wake depression” along the back edge of the stratiform precipitation area. This wake depression was likely the result of a hydrostatic response to subsidence-induced warming within a descending branch of the rear inflow jet (Johnson and Hamilton 1988).

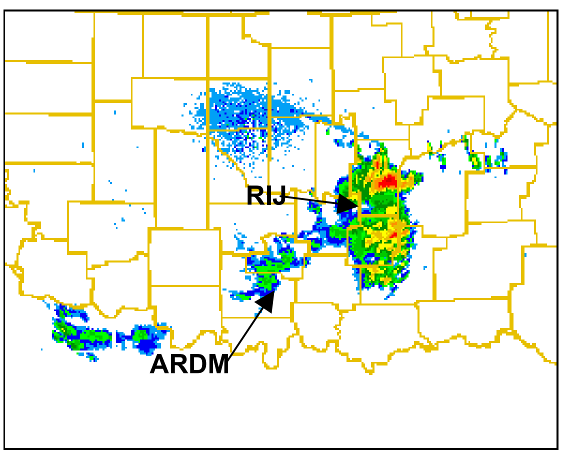

Figure 2. Base reflectivity image at the 0.5 degree elevation slice from the Twin Lakes (KTLX) WSR-88D at 0826 UTC, on 15 May 1995.

By 0826 UTC, the leading convective cells had moved into southeast Oklahoma (Fig. 2), while the small area of lighter precipitation beneath the trailing anvil extended southwest into south central Oklahoma. Meanwhile, analysis of Mesonet data (Fig. 3) revealed the presence of the wake depression near the Oklahoma/Texas border.

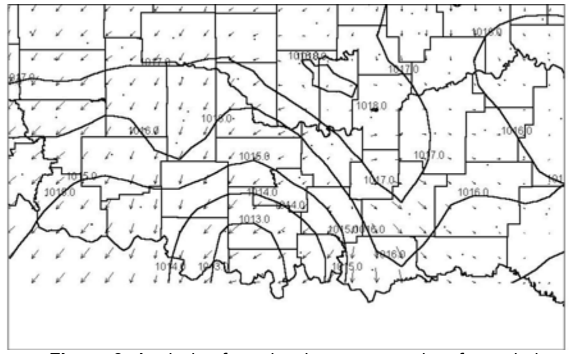

Figure 3. Analysis of sea level pressure and surface wind vectors from the Oklahoma Mesonet at 0825 UTC on 15 May 1995. Pressure is analyzed every 1 mb.

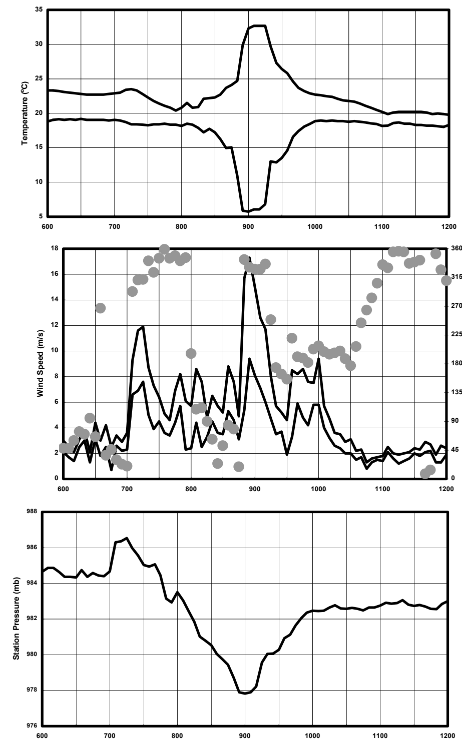

Figure 4. Time series plot of air and dewpoint temperature in °C (top), wind speed, peak gust (m/s), and wind direction (middle) and station pressure in mb (bottom). Data is in 5-minute increments.

As the wake depression moved northeast toward Ardmore (ARDM) between 0830 and 0900 UTC, the Mesonet site there sampled a heatburst. Figure 4 is a time series plot of 5-minute data from ARDM spanning a 6-hour period centered on the time of peak heatburst intensity. The data plot indicated a period of increasing wind speeds and weak cooling between 0715 and 0800 UTC, which was likely associated with the passage of the leading outflow boundary. By 0800 UTC, weak warming and drying were indicated, possibly due to boundary layer mixing, as the wind remained gusty in response to the wake depression located to the southwest. A sharp drop in station pressure that began at 0740 UTC indicated the approach of the wake depression.

The magnitude of warming and drying increased steadily between 0800 and 0850 UTC, as boundary layer mixing continued. These thermodynamic perturbations were likely aided by subsidence in the vicinity of the approaching wake depression. Between 0850 and 0855 UTC, the warming and drying were dramatic, as the air temperature increased to 29.9 ^{o}C, an increase of 5.2 ^{o}C. Concurrently, the dewpoint decreased to 6.2 ^{o}C, a decrease of 5.0 ^{o}C. Meanwhile, the station pressure continued to decrease, and reached a minimum of 978.2 mb at 0900 UTC, as the wake depression passed over the station. This represented a decrease in pressure of 6.8 mb since 0740 UTC. Additionally, a peak gust of 17.3 m/s (at 0855 UTC) accompanied this period of intense heating.

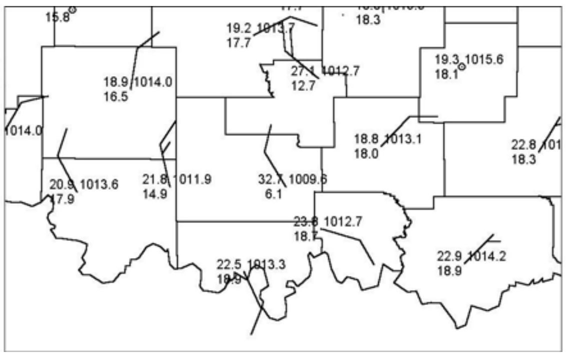

Figure 5. Station plot of air temperature (top left in ^{o}C), dewpoint (bottom left in ^{o}C), and sea level pressure (top right in mb). A full wind barb is 5 m/s, with 2.5 m/s represented by a half-barb.

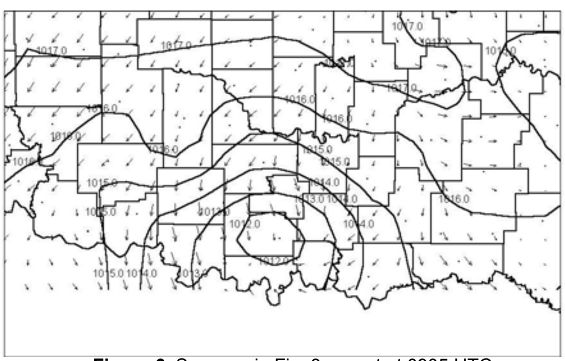

Figure 6. Same as in Fig. 3 except at 0905 UTC.

The surface continued to warm after 0855 UTC, as the air temperature increased to a maximum of 32.7 ^{o}C at 0905 UTC. The dewpoint temperature reached a minimum of 5.9 ^{o}C at 0900 UTC. The plan view Mesonet data plot from 0905 UTC (Fig. 5) provided another perspective of the heatburst. Inspection of this data indicated that ARDM was as much as 14 ^{o}C warmer than surrounding stations. The event concluded at ARDM at 0920 UTC, as thermodynamic parameters began to recover, exhibiting a temperature decrease of 3.0 ^{o}C, and a dewpoint increase of 5.9 ^{o}C from the previous observation.

Due to the limitations of the available data, the mechanism that induced subsidence that led to the heatburst of 15 May 1995 is debatable. However, considering radar data indications of a RIJ, as well as passage of an apparent wake depression over the ARDM Mesonet site, it would appear that the most likely source of subsidence was descent of a RIJ.

4. Climatology

Analysis of the 51 heatburst events detected by the Oklahoma Mesonet from October of 1993 through September of 1998 indicates that the average Oklahoma heatburst induces a local temperature increase of 5.7 ^{o}C, along with a dewpoint decrease of 8.0 ^{o}C. These perturbations are typically accompanied by a peak wind gust of 18.3 m/s. The average duration of a heatburst is approximately 30 minutes.

The number of detections of heatbursts at each Mesonet site during the 5-year period is shown in Figure 7. The frequency of heatbursts increases dramatically as one moves northwest across the state. Heatbursts are practically non-existent in southeast Oklahoma; yet, they are relatively frequent in the northwest quarter and Panhandle sections. Of the 51 heatburst events documented in this study, 36 affected Mesonet sites within the northwest quarter of the state. The Panhandle of Oklahoma experiences a high incidence, as 12 events (of the 51 documented in this study) affected at least 1 of the 6 sites in that area. Meanwhile, only 4 events affected the southeast quarter of Oklahoma.

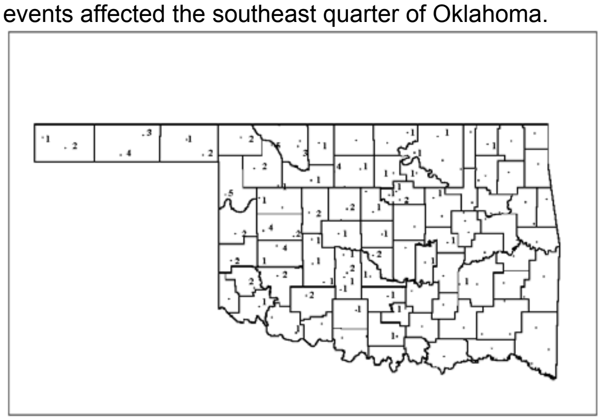

Figure 7. Number of heatburst occurrences per station. Dots represent location of all 115 Mesonet stations, while the number beside each dot represents the number of detections at each station during the 5-year study period.

This geographical distribution of heatburst episodes seems related to the dramatic difference in atmospheric moisture between southeast and northwest Oklahoma. Normally, the planetary boundary layer is dry across northwest Oklahoma versus that in the southeast. Therefore, the environment depicted by the sounding in Fig. 1 is much more likely to occur in northwest Oklahoma than in the southeast.

Monthly heatburst occurrence is depicted in Fig. 8. Each station affected during each event is included in the graphs. The graph indicates that 92% of the detections of heatbursts occurred during May, June, and July. At the other extreme, events did not occur during December through February. Obviously, this frequency distribution can be directly connected to the annual frequency of occurrence of convection across Oklahoma. Although heatbursts are rarely observed during winter months, they are possible during this time of year. Since convection is possible during the winter months, so must heatbursts be a possibility.

The frequency of heatbursts in Oklahoma according to time of day is indicated by the graph in Fig. 9. The time of onset of heatburst activity was used in creating these graphs. The charts reveal a peak time of heatburst activity between 0000 and 0200 UTC. It is during this time that convection is most likely to coexist with a “penetrable” surface-based temperature inversion. A gradual decrease in the phenomena is observed after 0200, with a more dramatic decrease in activity observed after 0800 UTC. Eighty percent of the detections occur between 0000 and 0800 UTC. This decrease in heatburst activity can be attributed to the strengthening of the surface-based inversion that typically occurs as the night progresses. As the inversion continues to strengthen, the likelihood of subsiding air penetrating the inversion decreases.

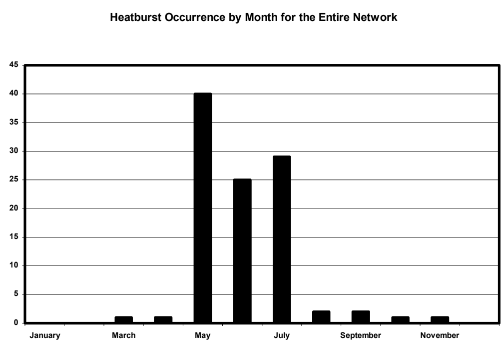

Figure 8. Monthly frequency of heatburst occurrence at each Mesonet site (a total of 102 detections.)

Nevertheless, heatbursts are still quite possible during the early morning hours. During the late spring, when synoptic forcing is still relatively strong, convective activity in Oklahoma is largely nocturnally driven, and is typically organized as an MCS. As discussed earlier, heatbursts can develop as the result of the descent of the RIJ in the vicinity of a wake depression.

5. Summary

Prior to the commissioning of the Oklahoma Mesonet in 1994, observations of heatbursts were largely confined to the rare occurrence of an event affecting a *temporar*y mesoscale observing network. This resulted in documentation of only a handful of events. However, the permanence of the Oklahoma Mesonet has allowed for the identification of 51 heatburst events during a 5-year period. A climatology was developed based upon these 51 events. This climatology verified that heatbursts are largely nocturnal, warm season events. Heatbursts are more common in northwest Oklahoma than in the eastern portion of the state. It has been suggested in previous studies that heatbursts are the result of dry microbursts penetrating a surface-based inversion. The more arid nature of the northwestern Oklahoma climate, as opposed to that of eastern Oklahoma, is much more likely to provide an environment favorable for the development of dry microbursts.

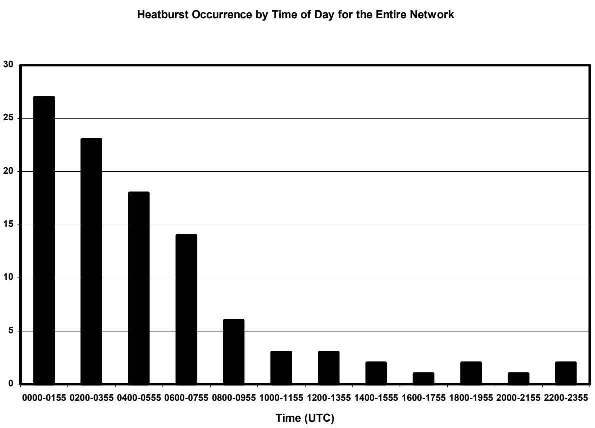

Figure 9. Same as in Fig. 8, except for frequency of heatburst occurrence by time of day.

5. Acknowledgements

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