STATISTICAL ANALYSIS OF HEATBURST EVENTS ACROSS OKLAHOMA FROM 1997 – 2016

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ABSTRACT

Heatbursts are a surface phenomenon characterized by sudden increases in temperatures, winds, and decreases in dew point temperature. While traditionally considered a rare phenomenon, they occur quite commonly over the Midwestern states, and the associated winds have caused millions of dollars of damage in the past. Limited temporal and spatial coverage of weather stations makes studying heatbursts difficult, but the Oklahoma Mesonet offers a solution with 5-minute observations across over 100 locations for 20 years. Archived data from the Oklahoma Mesonet and a set of predetermined metrics identified heatbursts over the entire archive, while drylines and other events were automatically filtered out. This work extended previous work done by (McPherson et al. 2011) and (Lane, 2000) by using dew point depressions and Dew Point Depression Ratios. These updated metrics uncovered 600 heatburst detections, with significant temporal similarities to the results from previous manual inspection studies.

1. Introduction

Heatbursts have been documented since the early 20th Century (Cline, 1909). Since then, classification and names for the events have varied, along with dispute over their cause. Research by Johnson (1983) helped to clarify the now accepted process for heatburst formation.

The process preceding a heatburst begins when rain from a high-based thunderstorm reaches the dry adiabatic layer beneath the evaporating base. The little rain in the parcel evaporates and adds latent heat to the environment. The parcel, now cooler than its surroundings, sinks and compresses at the dry adiabatic lapse rate. It remains cooler than the surroundings due to the adiabatic environmental lapse rate, and therefore gains increasing downward momentum in the presence of this negative buoyancy. Nearing the surface, the parcel encounters an equilibrium point resulting from a nocturnal temperature inversion. If the parcel gained sufficient downward momentum on the descent, then it breaks through the inversion and reaches the surface, where it becomes warmer and drier than its surroundings.

The long-lived adiabatic compression working against an abrupt surface inversion explains the dramatic increases in temperature and decreases in dew point temperature. It also explains why not all thunderstorms create heatbursts at night; sufficient downward momentum to break through the positively buoyant environment below the equilibrium level must exist (McPherson et al., 2011). Thus, the downdrafts strong enough to make it to the surface tend to be accompanied by strong or even damaging winds.

2. Previous Research

A lack of dense weather station networks has limited heatburst research. Most past research focused on case studies of a localized or regional

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event (Trobec, 2008). The thermodynamic changes can be abrupt and dramatic, as Lane (2000) showed. He documented a case where the dry bulb temperature increased by 8.6 °C in 20 minutes (nearly 0.5 °C per minute), while simultaneously, the dew point temperature fell 9.3 °C. He also described another, more impactful heatburst event that devastated areas of southwestern Oklahoma on 23 May 1996. It produced over $18 million dollars in damages, making it the costliest weather-related disaster to occur in Oklahoma in 1996.

Two academic papers on heatbursts, Lane, (2000) and McPherson et al. (2011), have identified heatbursts over the Oklahoma Mesonet using the following criteria:

1. An increase in dry-bulb temperature of 2.7 °C during a 10-minute period,
2. A simultaneous decrease in dew point temperature by 2.7 °C, and
3. A maximum wind gust of at least 10 m/s 5-minutes prior to, after, or during the thermodynamic changes.

This research updated the work by McPherson et al. (2011) by expanding the dataset temporally and adjusting the above criteria in accordance with their proposed suggestions. It also introduced methods to eliminate drylines and other phenomena from the results.

3. Oklahoma Mesonet

The Oklahoma Mesonet consists of 121 automated observation stations across the State of Oklahoma and is jointly operated by University of Oklahoma and Oklahoma State University, with financial support from the state taxpayers. Each station measures meteorological and agricultural variables in five minute intervals, with the majority of stations running since 1994 (Brock et al., 1994).

First conceived in 1984, scientists from both universities saw the need for a surface-based, environmental monitoring system. Following an extensive planning and site implementation period, the network went live on 1 January 1994, with continuous variable measurements though the present. While updated incrementally since its inception, the specific variables that each station measures have remained constant, and the number of stations has remained between 107 and 121 (McPherson et al., 2007). Quality assurance from the Mesonet's headquarters in Norman, Oklahoma, USA results in research quality datasets (Shafer et al., 2000).

Given the previous research from McPherson et al. (2011), which showed the frequent occurrence of heatbursts in Oklahoma, the Mesonet allowed optimal analysis of heatbursts over the state.

4. Methods

Data were obtained from the Oklahoma Mesonet from 1 January 1997 to 31 December 2016. Due to issues with sensors, air temperature data before 1 Jan 1997 were not available. A multi-criteria analysis identified potential heatbursts from the archived Mesonet data. Based on previous success with the identification of heatbursts and the aforementioned proposition (McPherson et al., 2011), heatburst detection in this study used the following criteria:

1. An increase in dry-bulb temperature of 2.7 °C or greater over a 10-minute period,
2. A simultaneous increase in dew point depression of 5.4°C or greater, and
3. A maximum wind gust of at least 10 m/s 5-minutes prior to, after, or during the thermodynamic changes.

Test runs with these criteria revealed that dryline passages tended to cause similar thermodynamic changes. In order to factor those out of the detections, a fourth threshold checked the *dew point depression ratio* (DPDR), defined as follows:

$$DPDR = \frac{T_0 - T_{d0}}{T_{\Delta t} - T_{d\Delta t}}, \quad (1)$$

where T_0 is the dry-bulb temperature at the onset of thermodynamic perturbations, T_{d0} is the dew point temperature at the onset of thermodynamic perturbations, $T_{\Delta t}$ is the dry-bulb temperature after some change in time, $T_{d\Delta t}$ is the dew point temperature after a change in time (Δt).

Dryline passages exhibit thermodynamic perturbations that are more prolonged than those observed from heatbursts. The application of this ratio ensured that the dew point depression decreased back to that of pre-event levels after a certain amount of time, and thereby reduced the number of dryline passages from the analysis.

In order to find the best DPDR to run over the Mesonet's archived data, the ratios were compared to a manually analyzed set of flagged events without any DPDR ratio. From 1 January 2014 to 31 December 2016, 169 events were flagged and sorted into one of three categories: heatbursts, drylines, and others (those that do not fit either of the other two categories). Numerous tools were utilized to conduct this manual analysis, including archived WSR-88D radar data, Mesonet data from surrounding stations, and archived surface analysis from the Weather Prediction Center (WPC, 2017).

To reduce subjectivity, two objective users analyzed a random sample of 20 events from the test period. Comparing the categorization of each user yielded an average consensus of 88% (results not shown). Any error was deemed within the realm of interpretation, and thus the categorizations were considered accurate henceforth. These categorizations were used to test the accuracy of each DPDR over the course of the test period.

5. Results

Tables 1, 2, and 3 show the results from the DPDR tests for 2014, 2015, and 2016, respectively. Higher percentages yielded significantly less drylines, while the number of heatbursts remained close to the accepted value. Average absolute accuracy calculations were conducted for each of the ratios over the three years tested:

$$Accuracy = \left(\frac{\alpha-(\beta+\varphi+\lambda)}{\alpha}\right) * 100\%, \quad (2)$$

where α is the number of heatbursts, β is the number of drylines, φ is the number of others, and λ is the number of misses.

Results from the accuracy testing showed that the 1.5 hour, 90% DPDR was the most accurate overall, with an average absolute accuracy of 40.5%. The 1 hour, 90% ratio followed closely at 38.1%, and then by the 2 hour, 80% ratio at 36.7%. It should be noted however, that many 90% DPDR tests removed heatburst events. The high scores by these two examples may be caused by the 2015 test, where few heatburst events occurred and the 90% thresholds did not miss many events. Further, the accuracy equation above gives equal weight to false positive detections (drylines and others) and false negative detections (misses). For these reasons, the 2 hour, 80% DPDR was chosen as the best ratio for representing heatbursts over the archived dataset.

		40%	50%	60%	70%	80%	90%
Time interval from onset	1 hr.	24/28/14	22/23/14	21/11/14	18/8/12	12/2/12	11/1/10
	1.5 hrs.	24/28/14	24/24/14	23/15/13	22/8/13	19/5/11	18/1/10
	2 hrs.	24/28/14	23/23/13	22/16/13	22/11/11	22/7/10	21/4/9
	2.5 hrs.	24/27/15	24/24/14	24/17/12	23/14/10	21/7/10	20/5/8

Table 1. Results from Dew Point Depression Ratio (Onset Dew Point Depression/Dew Point Depression at specified time) tests for 2014. Categories are organized as follows: heatbursts/drylines/others. Accepted number of heatbursts from manual analysis was 24.

		40%	50%	60%	70%	80%	90%
Time interval from onset	1 hr.	9/10/04	9/8/04	9/5/03	9/1/02	9/0/1	9/0/0
	1.5 hrs.	10/9/05	10/7/04	9/5/03	9/2/02	8/1/02	6/0/1
	2 hrs.	10/10/05	9/7/05	9/4/05	9/4/03	9/1/03	7/0/3
	2.5 hrs.	10/11/05	10/8/05	10/4/05	9/3/04	10/3/03	8/1/03

Table 2. Results from Dew Point Depression Ratio (Onset Dew Point Depression/Dew Point Depression at specified time) tests for 2015. Categories are organized as follows: heatbursts/drylines/others. Accepted number of heatbursts from manual analysis was 10.

		40%	50%	60%	70%	80%	90%
Time interval from onset	1 hr.	27/17/9	26/15/7	25/7/6	17/6/6	13/3/3	11/1/02
	1.5 hrs.	29/17/9	27/16/9	24/12/7	22/7/6	21/2/5	18/1/3
	2 hrs.	32/17/9	31/16/9	29/14/7	27/8/6	21/3/5	16/3/4
	2.5 hrs.	32/20/8	31/17/8	29/15/7	24/8/8	21/5/6	18/3/5

Table 3. Results from Dew Point Depression Ratio (Onset Dew Point Depression/Dew Point Depression at specified time) tests for 2016. Categories are organized as follows: heatbursts/drylines/others. Accepted number of heatbursts from manual analysis was 33.

Figures 1 and 2 show the monthly and hourly results from the 2 hour, 80% DPDR. There was a total of 600 detections across the state, with the majority of those occurring in late spring and early summer (May and June) and in the overnight hours. May had the most detections overall, with 143 (23.8% of all detections). May and June combined produced 46.8% of all heatburst detections. Hourly, 04z – 05z recorded 67 detections, the most out of any hour. Further, 90.7% of detections were recorded between 23z and 12z.

Thermodynamic changes varied from relatively minor to extreme. Hobart, OK, USA, recorded the greatest 10-minute temperature change on 23 May 2005. At the onset of the event, 13:35 UTC, the temperature was 23.4 °C (74.1°F). Ten minutes later at 13:45 UTC, the temperature was measured at 34.1 °C (93.4 °F), an increase of 10.8 °C. (10.7 °C of this change was actually observed in five minutes, between 13:40 UTC and 13:45 UTC). Figure 3 shows a plot of this event. Other extremes include a 10-minute dew point depression increase of 21.7 °C at Hollis, OK, USA, on 13 May 2009, and a wind gust of 34.6 m/s at Cherokee, OK, USA, on 26 August 2006.

6. Discussion

While the DPDR threshold eliminated significant amounts of dryline passages from the data, there are a couple of things to consider:

- There was always an inherent subjectivity when labeling detections as heatbursts, drylines or others. This impacted the results despite attempts at mitigation.
- Three years does not contain enough data to test the ratios. It may provide a decent understanding of their accuracy, but for a comprehensive overview, it would be best to compare ratios to labelled events across the entire data set. This is possible in future research.
- Due to their anomalous nature, applying a rigid threshold to detect heatbursts can never capture every event. For example, DPDR ratios eliminated a heatburst on 19 August 2014 from its results because it occurred shortly before sunrise, and thermodynamic thresholds were not met after strong adiabatic forcing.

7. Summary

Heatbursts have been shown to be quite common across Oklahoma, especially in the late spring and early summer. Studying them using traditional federal weather networks brings inherent difficulties due to their small spatial scale. Data from the Oklahoma Mesonet provided the necessary spatial and temporal resolution to detect heatbursts using a series of pre-determined metrics.

Previous research required manual inspection to distinguish each detection between heatbursts, drylines, and other, typically diabatically forced events. DPDR thresholds automatically eliminated drylines and others from the study with relative accuracy. This leaves a dataset full of heatbursts with no manual inspection required. Results from this automation agree strongly with results from hand-analysis done by (McPherson et al., 2011) and (Lane, 2000). Further research could better determine the ideal ratio.

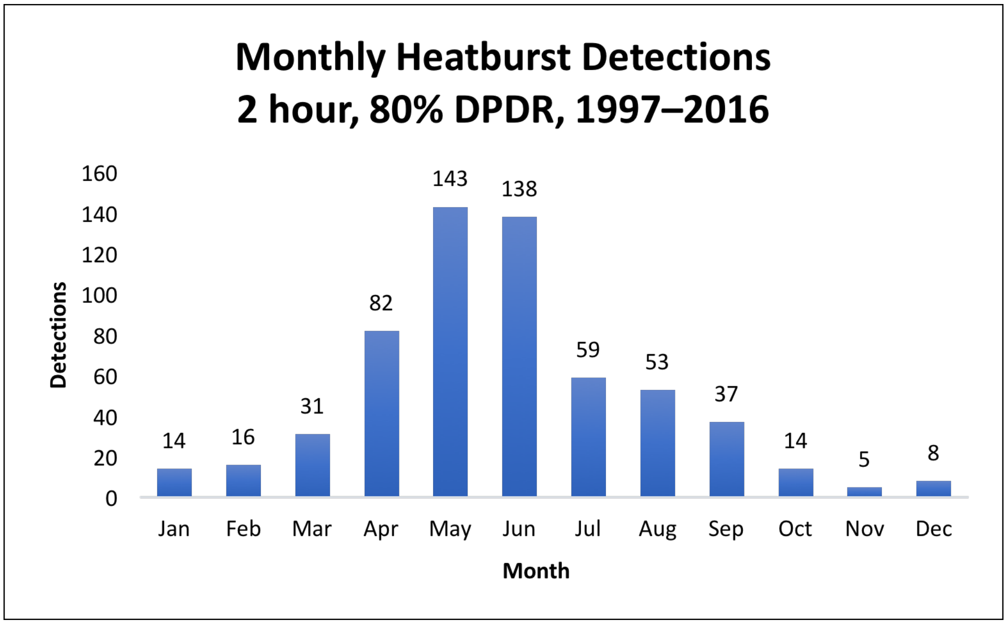

Figure 1: Monthly distribution of heatburst detections using a 2 hour, 80% Dew Point Depression Ratio from 1 January 1997 to 31 December 2016.

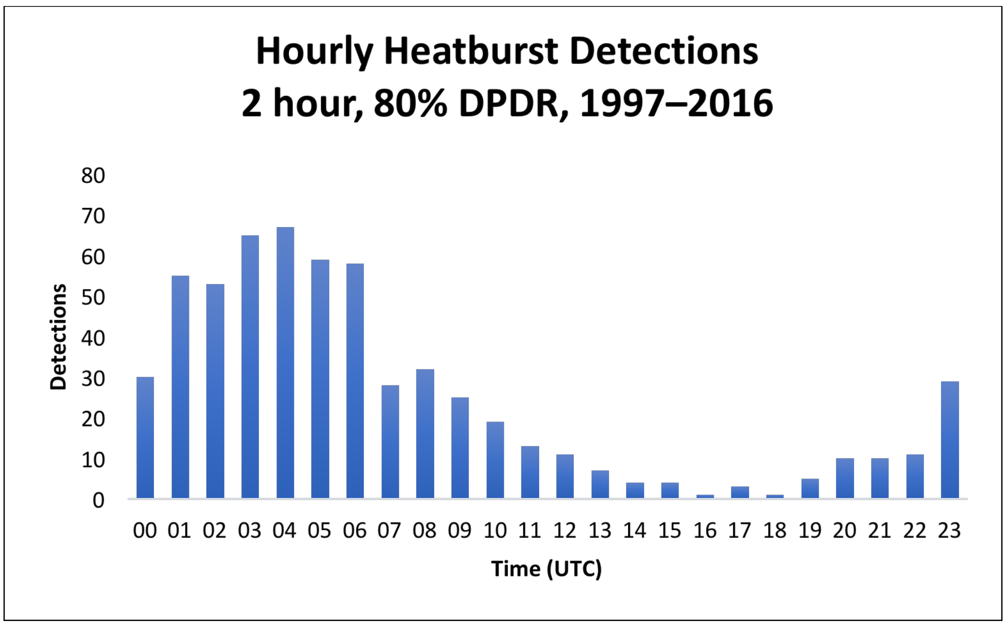

Figure 2: Hourly distribution of heatburst detections using a 2 hour, 80% Dew Point Depression Ratio from 1 January 1997 to 31 December 2016.

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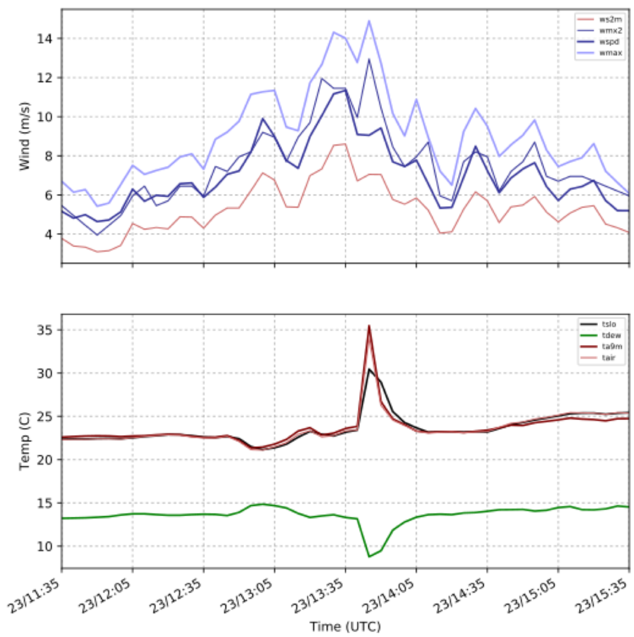

Figure 3: Mesonet data for Hobart, Oklahoma, USA, on 23 May 2005. Data shown includes max wind gusts at 10 meters, surface temperature, and surface dew point temperature (both of which are measured/calculated at 1.5 meters).

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