Assessing Planetary Boundary Layer Parameterizations During the 17 July 2023 Cherokee, Oklahoma, Heat Burst Event

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Motivation

Heat bursts are a convectively driven process where the temperature at the surface increases and relative humidity decreases significantly in a short period of time and is often associated with high winds (e.g. Johnson 1983; Johnson et al. 1989; Bernstein and Johnson 1994; Pettet and Johnson 2003; McPherson et al. 2011). Thus, forecasting heat bursts are crucial in protecting the public and preventing damage.

Numerical weather prediction (NWP) is one method that can be used to forecast heat bursts while also providing NWP experience for the author. Thus, the Weather Research and Forecasting (WRF) Advanced Research WRF (WRF-ARW) model was used to model the 17 July 2023 Cherokee, Oklahoma heat burst.

Goal:

Use WRF-ARW to model a heat burst by comparing two planetary boundary layer parameterizations to observed conditions and qualitatively determine which performs better.

Conceptual Model: Heat Bursts

Heat Burst Process:

1. Shallow surface inversion underneath dissipating convection.
2. Warm, dry air parcel/inflow jet underneath stratiform precipitation but above inversion.
3. Precipitation evaporates, cooling air parcel/inflow jet.
4. Cooled air sinks from becoming more dense in conjunction with downdraft.
5. The air penetrates the surface inversion with enough momentum.
6. Air compresses and warms up as it approaches the surface.

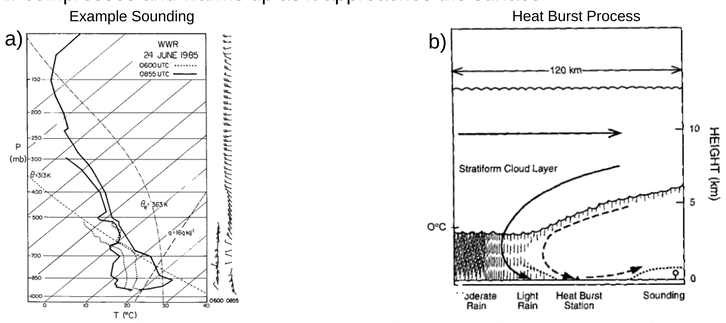


Fig. 1: Conceptual models for creating a heat burst. (a) example of a sounding before a heat burst taken from Fig. 14 in Johnson et al. (1989). (b) conceptual model for creating a heat burst, taken from Fig. 16 in Bernstein and Johnson (1994).

Observed Conditions

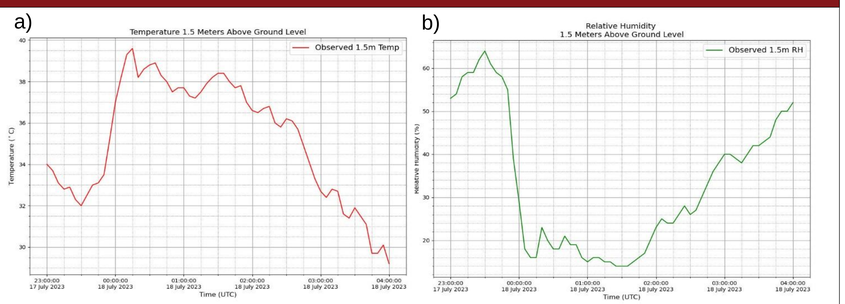


Fig. 2: Observed surface conditions at Cherokee, Oklahoma Mesonet location (location shown in Fig. 5) from 2300Z 17 July 2023 – 0400Z 18 July during the heat burst. (a) shows the 1.5-m AGL temperature, (b) shows the 1.5-m AGL relative humidity. The observation were recorded every five minutes.

The storm formed along the Kansas-Oklahoma border traveling SSE arriving near Cherokee by 2229Z 17 July. At 2330Z 17 July, while the storm was dissipating, the temperature rose 7.5°C, relative humidity decreased by 37% at 1.5-m AGL, and the 10-m AGL wind increased by 15 m s^{-1} in 45 minutes. This event lasted for 3.5 hours.

Observed Conditions Continued

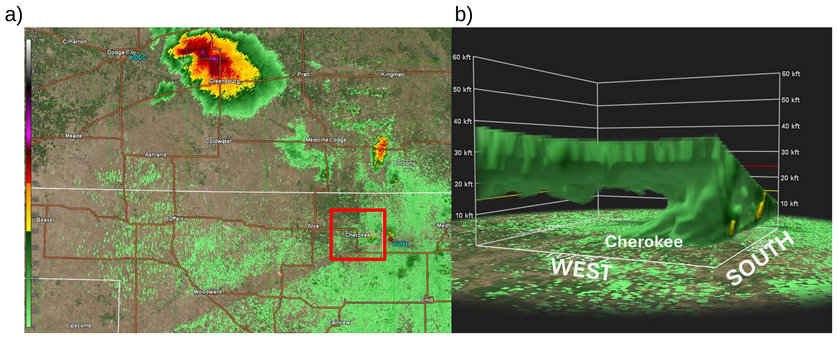


Fig. 3: Base-reflectivity from Vance Air Force Base at 2229Z 17 July 2023. (a) is the plan view at the lowest elevation angle of the base-reflectivity. The red box indicates the area of interest and location of the 3D volume scan shown in (b). (b) is the 3D volume scan facing northeast as the storm travels SSE. Images grabbed using GR2 Analyst.

WRF-ARW Coverage

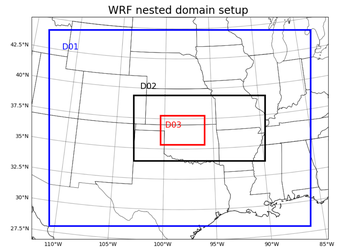


Fig. 4: Map of the continental United States of America showing the WRF-ARW domain coverage. The blue outer box represents domain 1, black middle box-domain 2, and red inner box-domain 3. Spatial-resolution of 2/3-km in domain 3.

The initial conditions for WRF-ARW model used HRRR data gathered from Blaylock et al. (2017). The WRF-ARW model conditions were based on Dawn and Satyanarayana (2018).

Results

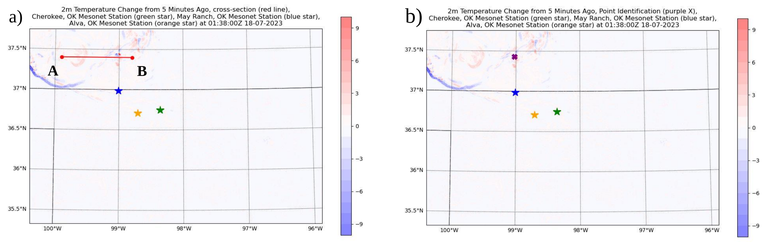


Fig. 5: Simulated 2-m temperature change for 0138Z 18 July from five minutes ago with Mesonet stations of interest located on the map represented by stars. The blue star represents the locations for May Ranch, yellow star Alva, and green star Cherokee. (a) is the output from BouLac WRF-ARW run with cross-section identified. Capital letters "A" (37.4°N, 99.9°W) and "B" (37.4°N, 98.8°W) are overlaid to provide an orientation for cross-section images shown later. (b) is the BouLac WRF-ARW run with a point location of interest identified by purple "x".

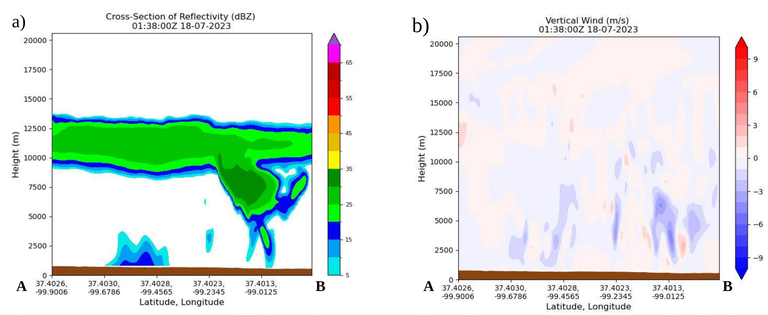


Fig. 6: Model cross-section at 0138Z 18 July. Capital letters "A" and "B" correspond to the "A" and "B" in Fig. 5a. (a) is the simulated reflectivity. (b) is the simulated vertical wind.

The stratiform precipitation in Fig. 6a aligns with the conceptual model in Fig. 1b, cooling the air and causing a downdraft as shown in Fig. 6b, which also aligns with the conceptual model.

Results Continued

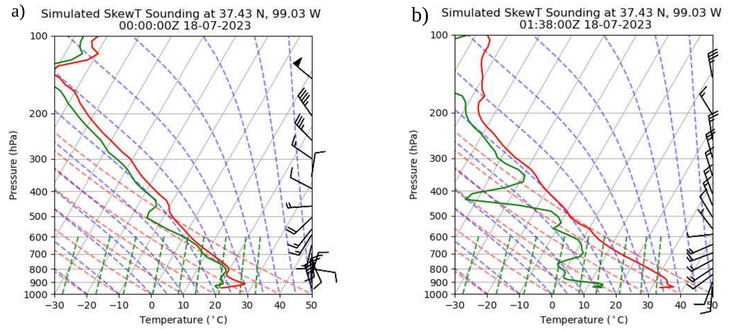


Fig. 7: Simulated soundings at the point designated in Fig. 5b. (a) is the sounding before the event at 0000Z 18 July 2023. (b) is during the event at 0138Z 18 July.

As needed, a surface inversion is shown in Fig. 7a similar to Fig. 1a. The simulated sounding in Fig. 7b shows a temperature increase and dry air at the surface.

Comparisons

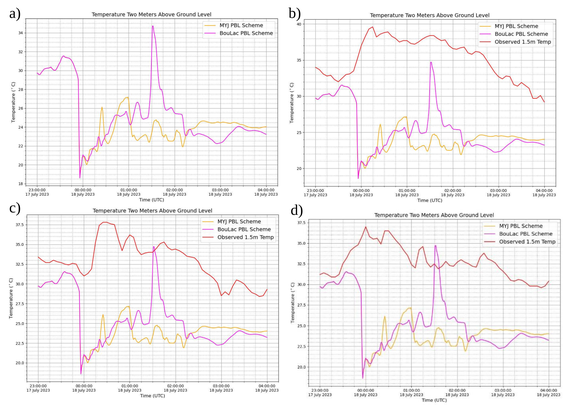


Fig. 8: Temperature time series at the point of interest. The yellow line represents 2-m temperature for MYJ planetary boundary layer WRF-ARW run scheme while the purple line represents BouLac WRF-ARW run. The red line represents the observed 1.5-m temperature at various stations. The observed temperature is at Cherokee, Alva, and May Ranch in (b), (c), and (d), respectively.

An intense warming occurred at 0138Z 18 July (10°C), more than the observed temperature increase at Cherokee. The temperature at Alva reached the observed temperature, but at May Ranch, the simulated surface temperature surpassed the observed conditions. However, a temperature and duration difference is present.

Conclusions/Future Work

WRF-ARW can simulate a heat burst, but failed to accurately reproduce the observed conditions by magnitude, duration, and location. Despite the differences, the BouLac planetary boundary layer parameterization scheme performed the best qualitatively in creating a heat burst.

However, the observed storm did not provide ideal conditions for modeling based on the convection's size. Future work in analyzing other events that involve larger convection may aid in more accurately recreating a heat burst event. Two potential cases are:

- Spicewood, Texas – 20 June 2023
- Randolph Air Force Base, Texas – 10 September 2023

References/Acknowledgments

Scan QR Code for references:

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