P14.1 "Cooked" boundaries: Preliminary results from numerical experiments

Anthony E. Reinhart* and Adam L. Houston
University of Nebraska, Lincoln, NE

1. INTRODUCTION

Preexisting airmass boundaries initiate, influence, and decay thunderstorms and their processes (Maddox et al. 1980; Markowski et al. 1998; Moncrieff and Changhai 1999). Usually, the air on the dense side of an outflow boundary is assumed to be more stable than the ambient environment. However, there have been cases when the dense airmass was more conditionally unstable than the environmental air that the outflow boundary was moving through. Such boundaries have been termed cooked boundaries. The goal of this work is to identify the mechanisms responsible for the formation of cooked boundaries.

Several cases of cooked boundaries have been identified. The 2 June 1995 severe weather event in west Texas (responsible for the Dimmitt and Friona tornadoes) was characterized by a cooked boundary (Rasmussen and Straka 2007; Rasmussen et al. 2000). Another event influenced by a cooked boundary was the record-breaking hailstone event on 22 June 2003 near Aurora, Nebraska.

2. Case Studies

3.1 2 June 1995

The VORTEX field program sampled this event and because of the high-resolution data this event has been studied extensively (Markowski et al. 1998; Rasmussen and Rasmussen et al. 2000; Straka 2007). During the morning hours of 2 June 1995 several thunderstorms developed in northern Texas. These storms produced strong outflow, which became the cooked boundary later in the day. The outflow boundary propagated southwest through west Texas during the afternoon hours (Fig. 1). Many supercells occurred during this event, however only supercells that traversed the cooked boundary became tornadic.

Transects taken by mobile mesonets at 2058 UTC revealed unusual CAPE values (Rasmussen et al. 2000). South of the boundary the CAPE was 2370 J kg^{-1} but 5 km into the cool airmass CAPE was 2830 J kg^{-1} and 10 km into the cool air the CAPE was 2620 J kg^{-1} (Rasmussen et al. 2000). Mixing ratios were also calculated by the mobile mesonets, and showed that the mixing ratio was as much as 3 g kg^{-1} higher in the cool airmass (Rasmussen et al. 2000). Rasmussen et al. (2000) reasoned that the higher mixing ratios were caused by precipitation occurring on the cool side of the airmass boundary and were responsible for the higher values of CAPE despite the cooler temperatures.

3.2 22 June 2003

Two significant record-breaking events were produced by two separate supercellular thunderstorms on the afternoon of 22 June 2003 near Aurora and Superior, Nebraska. One supercell produced the hailstone that broke the size record, while the other produced a mesocyclone that was the largest and most intense mesocyclone measured by Doppler radar (Wakimoto et al. 2004).

Thunderstorms located over eastern Nebraska and northeast Kansas slowly propagated to the east during the morning hours of 22 June 2003. These storms produced a westward propagating outflow boundary that moved across eastern Nebraska (Fig. 3). High instability was present over Nebraska prior to the passage of the outflow boundaries: CAPE values from RUC20 2200 UTC analysis were over 4000 J kg^{-1} (Guyer and Ewald, 2004). Dewpoint values were several degrees higher on the cooked side of the boundary and helped increase the CAPE to values higher than the airmass on the warm side of the boundary. The supercells initiated before crossing the cooked boundary, but intensified quickly as they crossed into the cooler more unstable air. It is within the cooked boundary that they produced their record-breaking features.

* *Corresponding author address:* Anthony E. Reinhart, Department of Geosciences, University of Nebraska – Lincoln, 214 Bessey Hall, Lincoln, NE 68588. Email: aereinha@huskers.unl.edu

3. Hypotheses

Cooked boundaries are thought to begin with a preexisting boundary created by thunderstorm outflow. The preexisting boundary is more moist due to prior convection affecting the preexisting airmass boundary. Convergence along the preexisting outflow boundary creates pooling of moisture along the dense side of the boundary interface. The increased equivalent potential temperature (θ_e) on the dense side of the boundary interface signals the formation of a cooked boundary.

A cooked boundary can also occur when vertical mixing occurs slower on the cool side of the boundary than on the warm side. Thermals located within the cool-side airmass are a smaller scale, due to the shallowness of the capping inversion, than thermals operating within the warm-side airmass. A larger thermal is more effective at entraining low-θ_e into the PBL. After a time, the warm-side airmass will have a lower θ_e than the cool-side airmass.

4. Methodology

Idealized 2D numerical simulations will be preformed using the Advanced Research core of the Weather Research and Forecasting (WRF) version 3.0 model (Skamarock et al. 2005). The seabreeze module was modified to include a cold block to initiate the density current. The main initialization sounding used was taken from 2 June 1995, near Dimmitt, Texas. During preliminary testing a neutral sounding and a stable sounding were also used.

The simulations domain spans 100km with a horizontal gridpoint spacing of 100 meters and is 2 km tall with a vertical gridpoint spacing of 50 meters (40 vertical levels). This resolution is able to resolve large eddies so no planetary boundary layer parameterization is used. The Noah Land Surface Model (LSM) is used to parameterize surface characteristics (Chen and Dudhia 2001). The Noah LSM was chosen due to its wide use among WRF users and the ability of customizing important LSM values. The soil and other basic parameters needed by the Noah LSM are set to western Texas values.

Idealized simulations will test a range of environmental conditions determining the necessary factor(s) for creating a cooked boundary. Tests will include different moisture gradients, different soil moisture values, radiative features, and the outflow boundary. Vegetation will be consistently set to West Texas values.

Varying the moisture content across the boundary will simulate the effect of precipitation from a previous convective event. This tests the moisture pooling via convergence hypothesis. The moisture gradient will range from no moisture gradient across the domain to a highly positive gradient. A positive gradient means that the soil is more moist behind or in the boundary than outside the boundary. Changing soil moisture levels inside the boundary allows for more evapotranspiration and other surface fluxes that would occur after a precipitation event.

Modifying the amount of solar radiation present in the model simulation tests the vertical mixing hypothesis. Lessening the radiation incident on the boundary or the environmental airmass can also approximate clouds. Cloudiness effects the evolution of boundaries, and cannot be neglected.

The outflow boundary will change for different simulations in both depth and potential temperature difference between the environmental airmass and cool-side airmass. Many of the simulated outflow boundaries may be to shallow (deep) or not dense enough to yield a cooked boundary.

4. Preliminary Results

WRF numerical simulations have successfully replicated a density current in a neutral environment with full parameterizations discussed above. This is a reality that was not easily attainable with the previous generation of WRF. Numerical simulations run so far have just been preliminary tests on integrating certain parameterizations into the idealized core.

5. Conclusions and future work

Cooked boundaries have not been extensively studied in literature even though they have likely played a role in several important severe weather events. A cooked boundary enhanced supercells that occurred on 2 June 1995: only those supercells that crossed the boundary became tornadic. On 22 June 2003 a cooked boundary allowed for two records to be broken: the largest recorded mesocyclone and largest hailstone were both produced by storms on the cool side of a cooked boundary.

Future work will include extensive simulations of cooked boundaries. Experiments will test the effect of moisture gradients at the surface and in the air, wind speed, and boundary strength and depth. These future simulations will aim to expose the mechanisms responsible for the formation of cooked boundaries.

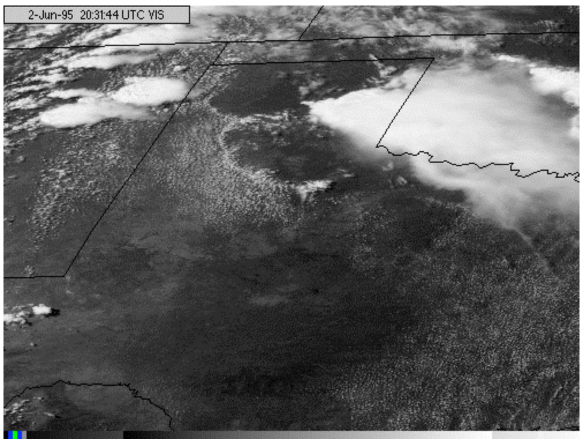

Figure 1: Visible satellite image from 2 June 1995 at 2030 UTC. The boundary is shown by the area of cumulus clouds in the center of the image.

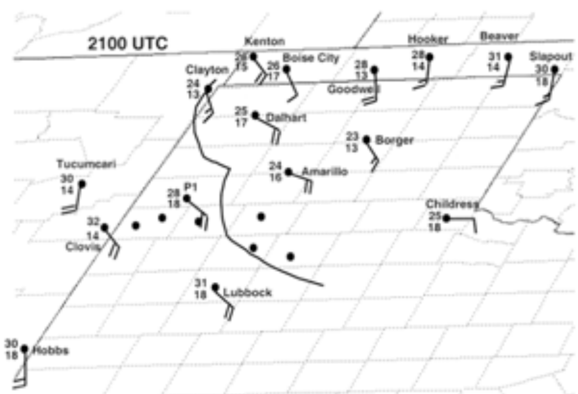

Figure 2: Figure 7 from Rasmussen et al. (2000); Shows the location of the boundary at 2100 UTC with surface observations.

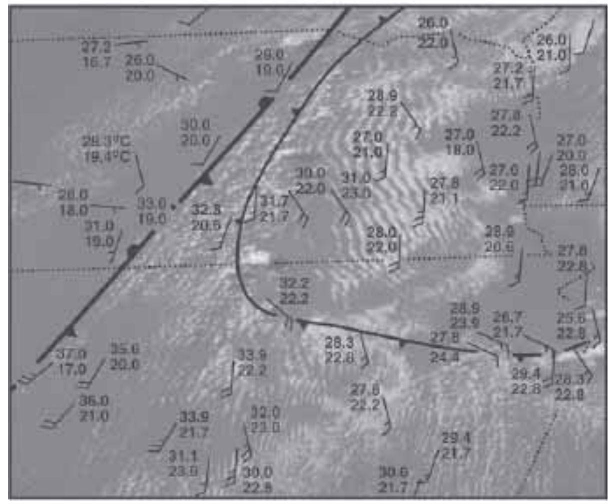

Figure 3: Figure 3b from Wakimoto et al. 2004; Frontal positions and surface observations from 22 June 2003 at 2200 UTC. Visible satellite shows the westward propagating cooked boundary.

6. **References**

Chen, F., and J. Dudhia, 2001: Coupling an Advanced Land Surface–Hydrology Model with the Penn State–NCAR MM5 Modeling System. Part I: Model Implementation and Sensitivity. *Monthly Weather Review*, **129,** 569-585.

Maddox, R. A., L. R. Hoxit, and C. F. Chappell, 1980: A Study of Tornadic Thunderstorm Interactions with Thermal Boundaries. *Monthly Weather Review*, **108,** 322-336.

Markowski, P. M., E. N. Rasmussen, and J. M. Straka, 1998: The Occurrence of Tornadoes in Supercells Interacting with Boundaries during VORTEX-95. *Weather and Forecasting*, **13,** 852-859.

Moncrieff, M., W., and L. Changhai, 1999: Convection Initiation by Density Currents: Role of Convergence, Shear, and Dynamical Organization. *Monthly Weather Review*, 2455-2464.

Rasmussen, E. N., and J. M. Straka, 2007: Evolution of Low-Level Angular Momentum in the 2 June 1995 Dimmitt, Texas, Tornado Cyclone. *Journal of the Atmospheric Sciences*, **64,** 1365-1378.

Rasmussen, E. N., S. Richardson, J. M. Straka, P. M. Markowski, and D. O. Blanchard, 2000: The Association of Significant Tornadoes with a Baroclinic Boundary on 2 June 1995. *Monthly Weather Review*, **128,** 174-191.

Skamarock, W. C., J. B. Klemp, J. Dudhia, D. O. Gill, D. M. Barker, W. Wang, and J. G. Powers, 2005:

A Description of the Advanced Research WRF Version 2. *NCAR Technical Note***,** 100.
Wakimoto, R. M., H. Cai, and H. V. Murphey, 2004: The Superior, Nebraska, Supercell During BAMEX. *Bulletin of the American Meteorological Society*, **85,** 1095-1106.