# P6.4 NUMERICAL SIMULATION OF STORM BOUNDARY ANCHORING IN A HIGH-CAPE, LOW-SHEAR ENVIRONMENT: IMPLICATIONS FOR THE MODULATION OF CONVECTIVE MODE

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## 1. MOTIVATION

Independent of any other features (e.g. preexisting boundaries), does the extreme CAPE, low-shear environment represent an inflection in the convective mode continuum, wherein the resultant large vertical motions can make up for the lack of vertical shear and produce long-lived, *rotating* storms? Modeling studies that effectively cemented the relationship between convective mode archetypes and potential buoyancy and shear (Weisman and Klemp 1982; 1984) never considered such extreme conditions. Extrapolation of these early findings to the extreme-CAPE, low-shear environments was traditionally done using the bulk Richardson number which, by these standards, dictates that the extreme-CAPE, low-shear, and therefore high BRi environment, would support air mass thunderstorms. The potential failing here is that the concept of the BRi was originally formulated in two dimensions using a crude representation of convection. (Moncrieff and Green 1972). Its application to three-dimensional convection by Weisman and Klemp (1982, 1984) was made because the transition from multicell to supercell in 3D coincided with the transition from multicell to long-lived single cell in 2D. *It is therefore conceivable that the extreme-CAPE, low-shear environment is an aberration to this model.*

An alternative hypothesis, and the one that we propose, is that in the stratified world of horizontally homogeneous simulations, the extreme-CAPE, low-shear environment will indeed support short-lived, single cell (air mass) convection and that it is only when environmental heterogeneities are included, namely preexisting air mass boundaries, that an inflection in the convective mode continuum is observed. With one notable exception (the 28 August 1990 Plainfield, IL tornado; Korotky et al. 1993) previous (primarily anecdotal) observations of extreme-CAPE, low-shear convection support this hypothesis: *air mass boundaries played an integral role in the morphology of these storms.*

## 2. OBJECTIVES

The primary objective of this work is to understand the role of preexisting boundaries on storms in high-CAPE, low-shear environments. The modeling work detailed here will serve as a complement to an in-depth study of the 27 May 1997 central Texas tornadic thunderstorms using radar data, described in paper 12.4 elsewhere in these proceedings.

Our first objective in this portion of the work is to demonstrate that, in a “typical” extreme-CAPE, low-shear environment, the absence of a preexisting air mass boundary precludes the development of intense, long-lived, rotating convection. The second objective is to identify the role of the preexisting boundary in the modulation of convective mode in this environment, viz. the development of long-lived (relative to the extreme-CAPE, low-shear archetype), rotating updrafts. Our final objective is to diagnose the primary source(s) of vertical vorticity in the development of low-level rotation. This last objective is designed to address the role of the preexisting boundary in low-level vorticity generation (please see paper 12.4 elsewhere in these proceedings for a full discussion) beyond its role in the modulation of convective mode.

## 3. MODELING ENVIRONMENT

Preliminary simulations for this work were conducted using the Collaborative Model for Multiscale Atmospheric Simulations (COMMAS; Wicker and Wilhelmson 1995). Ongoing and future simulations conducted for the work utilize ICOMMAS (Illinois COMMAS). ICOMMAS is a successor to COMMAS and utilizes the 3rd-order Runge-Kutta time-split implementation of the numerics described by Wicker and Skamarock (2001). Terms responsible for

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vertically propagating sound waves are treated implicitly. Advection is computed using a polynomial approximation to the grid fluxes that is 5th-order in the horizontal and 3rd-order in the vertical and includes the 1D flux limiter described by Thuburn (1996) to mimic monotonicity. Subgrid scale mixing is parameterized using the Klemp and Wilhelmson (1978) implementation of prognostic turbulent kinetic energy. Ongoing simulations also include Tao three-phase ice microphysics in place of warm-rain microphysics, a higher resolution grid (250m grid spacing in the horizontal and 50m vertical grid spacing in the boundary layer) to improve the resolution of convective cells as well as the preexisting boundary structure, and a more sophisticated thermal initialization procedure to more accurately represent the initial development of convection.

## 4. RESULTS TO DATE AND WORK IN PROGRESS

### *4.1. Control run vs. boundary run*

Preliminary simulations using COMMAS have shown promise. Using an idealized representation of the environment associated with the 27 May 1997 Central, Texas tornadic storms, a storm modeled without a preexisting air mass boundary storm evolved in agreement with the low-shear, high-CAPE archetype; namely, an intense updraft formed in response to the initial thermal perturbation but rapidly decayed as outflow undercut the updraft and failed to regenerate deep convection (Fig 1).

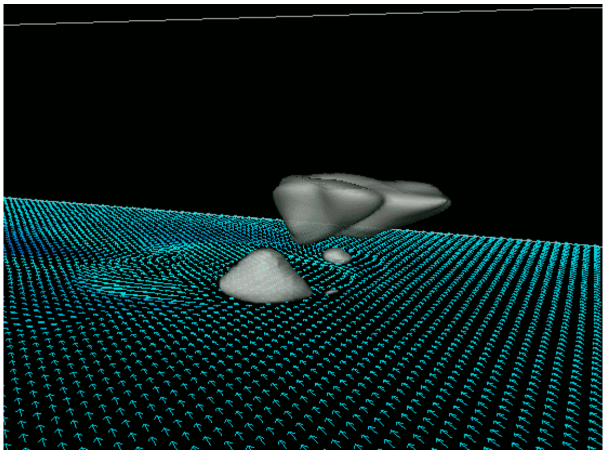

**Figure 1**: Simulated cloud for the control run at 4800s. The shading is the $1x10^{-3}$ g/kg isosurface of rainwater mixing ratio and the vector field is the wind velocity at 50 m.

On the contrary, in the presence of a preexisting boundary, an anchored storm developed, back-built against the mean-flow, and possessed strong updraft rotation (Fig 2). We are currently reproducing this experiment with the new modeling environment.

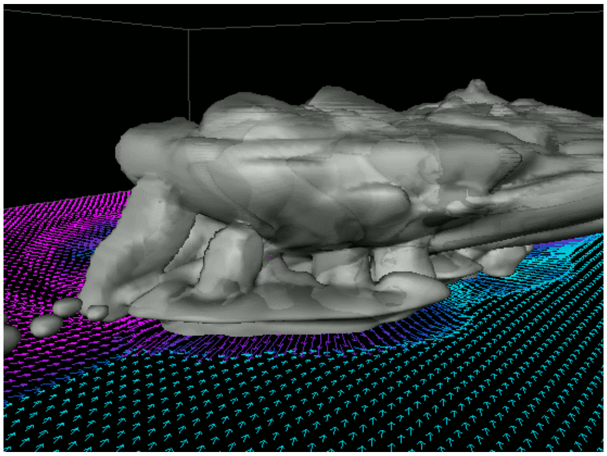

**Figure 2**: Same as in Figure 1 but for the run with the preexisting boundary at 6000s

### *4.2. Modulation of convective mode*

The air-mass thunderstorm that would ordinarily be expected in the extreme-CAPE, low-shear environment is typically characterized by a strong initial updraft that rapidly dissipates as precipitation falls through the updraft and the surging gust front cuts-off the supply of buoyant, boundary layer air. Additionally, any subsequent updrafts that might develop on the gust front of the spreading cold pool should be weak, short-lived, and absent of substantial, persistent rotation. Therefore, the aim of our analysis must be to explain the method by which the preexisting boundary modifies updraft sustenance, initiates cell redevelopment, and promotes updraft rotation. Specifically we will address (1) the role of meso-γ (Orlanski 1975) gyres along the preexisting boundary on cell redevelopment, (2) the source(s) of vertical vorticity in the mid-level mesocyclones, (3) the role of the mesocyclone in updraft maintenance, and (4) the effect of cell mergers on mesocyclone and updraft intensities.

#### *4.2.1. <u>Cell development</u>*

Radar analysis of the Jarrell case revealed that cell initiation occurred along the preexisting boundary on the south end of meso-γ cyclonic gyres that appeared to develop in response to the interaction of the preexisting boundary and the southernmost extent of the expanding storm-induced outflow. Analysis of the numerical results will focus on isolating the mechanism responsible for this behavior.

### 4.2.2. Mid-level vertical vorticity tendency

One of the more intriguing aspects of the Jarrell case was the presence of persistent, occasionally strong, mid-level mesocyclones. This observation is intriguing because the traditional source of mid-level vertical vorticity is the horizontal vorticity of the ambient shear yet the weak shear that characterized the Jarrell case would seem to be prohibit such a mechanism. However, we propose that, consistent with the supposition by Rasmussen and Blanchard (1998), the large available buoyancy can, in part, make up for the weak shear since the tilting mechanism is a function of both the horizontal vorticity and the vertical velocity ($\omega \bullet \nabla w$; where $\omega$ is the horizontal vorticity vector and $w$ is the vertical velocity). Therefore, we believe that the dominant source of mid-level vertical vorticity is the horizontal vorticity of the ambient vertical shear. We also believe that further augmentation of mesocyclone strength comes from the vertical vorticity along the preexisting boundary.

Updraft motion provides some support for this hypothesis. Detailed analysis of cell evolution and motion in the Jarrell case described in paper 12.4 illustrated that the most persistent updrafts propagated to the right of the mean environmental wind yet, despite their deviant motion, these updrafts were also observed to remain very near the preexisting boundary for much of their lives. While rightward deviance suggests that the tilting of environmental horizontal vorticity may be the primary source of vertical vorticity the extended residence time near the preexisting boundary indicates that the vertical advection of vertical vorticity may also be important. We will test our hypothesis through analysis of the terms in the vertical vorticity tendency equation.

### 4.2.3. Importance of mid-level mesocyclone rotation to updraft maintenance

As a corollary to the supposition that the tilting of horizontal vorticity is the dominant source in the mid-level mesocyclone, updraft maintenance must also be driven by the same mechanism. We intend to investigate this possibility through diagnosis of the three components of the pressure field: buoyancy, fluid shear, and fluid extension (Klemp and Rotunno 1983). We believe that updraft maintenance is driven by the fluid shear term associated with the tilted environmental vorticity with a significant contribution from the fluid extension term associated with the forced ascent along low-level boundaries.

### 4.2.4. Cell Mergers

Analysis of cell evolution and motion in the Jarrell case revealed that numerous cell mergers occurred between discrete cells moving generally with the mean wind and the long-lived, rightward moving primary updrafts. The importance of these mergers to mesocyclone intensity, updraft maintenance, and/or tornado development was not directly addressed in the preliminary analysis of the radar data, although intensification of the Jarrell tornado was observed to coincide with a cell merger. Previous work on mergers (Lemon 1976; Westcott 1984; Finley 2001) has shown that mergers can enhance both vertical velocities and vertical vorticities. It is our belief that mergers play the same role in this case. Examination of the vertical velocity and vertical vorticity trends associated with mergers may illuminate this.

It should be noted that although the proposed primary source of mid-level vertical vorticity (the horizontal vorticity of the ambient shear) is independent of the preexisting boundary, the resulting deviate motion promotes cell mergers and therefore enhances the contribution made by the preexisting boundary to the modulation of convective mode.

## *4.3. Low-level vorticity tendency*

Previous work by Magsig et al. (1998a,b) found that several of the tornadoes, including the strongest in the sequence (the Jarrell tornado), developed on storm induced gust fronts well east of the preexisting boundary. Their finding effectively dismissed the notion that vertical vorticity on the preexisting boundary directly contributed to tornadogenesis. They proposed that both the tilting of solenoidally generated horizontal vorticity along with the stretching of vertical vorticity along the gust fronts might have contributed to tornadogenesis. Although the resolution of our simulations is inadequate to fully resolve tornado-scale rotation, it is more than sufficient to capture the parent low-level circulation. Our analysis will attempt to quantify the contributions from these two processes through inspection of the terms in the vertical vorticity tendency equation.

## 5. SUMMARY

This work is designed to explore the role of preexisting boundaries in the modulation of convective mode in extreme-CAPE, low-shear environments. Preliminary simulations have demonstrated the importance of the preexisting boundary to the development and rotation of modeled convection.

Current and future numerical experiments, motivated by preliminary analysis in the observational branch of this work, are designed to test the following hypotheses:

1. Enhanced convergence associated with cusps in the preexisting boundary coincident with the intersection of the southernmost storm-induced gust front and the preexisting boundary initiate new updrafts.
2. Vertical vorticity in the mid-level mesocyclone emerges primarily from the horizontal vorticity of the ambient vertical shear but has a significant contribution from the vertical vorticity along the preexisting boundary.
3. Updraft maintenance in the strongest updrafts is controlled by pressure gradients induced by the interaction of the updraft with the horizontal vorticity of the vertical shear with an additional contribution from forced ascent along gust fronts.
4. Cell mergers contribute to the intensity of both updrafts and mesocyclones.
5. Low-level rotation is driven by the stretching of vertical vorticity along gust fronts as well as the tilting of solenoidally generated horizontal vorticity.

For the latest results please refer to the following URL: http://redrock.ncsa.uiuc.edu/~ahous/Supercell-DC/

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