P8.2 THE SIMULATION OF HIGH-PRECIPITATION SUPERCELLS ON PREEXISTING BOUNDARIES IN MULTICELLULAR ENVIRONMENTS

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1. MOTIVATION AND OBJECTIVES

The documented observations of supercells along preexisting boundaries in multicellular environments, characterized by "sub-optimal" deep-layer shear, represent either a fundamental limitation of known diagnostic parameters to discriminate convective mode, irrespective of the presence of localized heterogeneities, or the modulating effect of preexisting boundaries. It is our belief that such observations demonstrate the modulating role of boundaries. The primary objective of this proposed work is to identify the specific mechanisms by which boundaries yield this modulation.

The second objective of this work is to seek an explanation for the observed tendency for supercells to possess a high-precipitation (HP) morphology when interacting with preexisting boundaries in multicellular environments. This tendency has been documented in both case studies (e.g. Moller et al. 1994; Finley et al. 2001) and climatological surveys (e.g. Doswell et al. 1990). This observation is important for assessing the most probable hazards associated with boundary-anchored supercells since the most likely hazards produced by a supercell are dependent on its morphology (Nelson 1987; Doswell et al. 1990; Moller et al. 1990).

2. HYPOTHESES

2.1. Supercells in Multicellular Environments

Supercells have been found to produce a disproportionately high number of casualties and damage (Moller et al. 1994; Doswell 2001) thus the accurate and timely recognition of conditions that yield supercell formation is vital. Much headway has been made toward the identification of conceptual environments that support supercells however, perhaps the most significant contributions have emerged from numerical simulations which assumed horizontally homogeneous initial conditions (e.g. Weisman and Klemp 1982, 1984). Despite the general robustness of the guidelines established by these studies for the recognition of supercellular environments, exceptions like those documented by Finley (2001), Wade and Foote (1982), Moller et al. (1994), and Wakimoto et al. (1998) (see Table 1 for a summary of these studies) indicate that horizontal heterogeneities might play a significant role in modulating convective mode. In each of these cases, supercells were observed on or just behind preexisting boundaries in airmasses that were "sub-optimal" for supercells and therefore more likely to have supported multicells instead.

Considerable attention has been directed toward understanding the role of preexisting boundaries on tornadogenesis (e.g. Maddox et al. 1980; Wakimoto and Wilson 1989; Purdom 1993; Lee and Wilhelmson 1997; Markowski et al. 1998) and low-level mesocyclogenesis (e.g. Atkins et al. 1999; Rasmussen et al. 2000) however a direct examination of the role of preexisting boundaries in the development of supercells in multicellular environments has not been undertaken. Despite their tangential relationship to this work, we believe that we can utilize findings from several of the studies referenced above to explain the development of supercells on boundaries in multicellular environments. Specifically, we propose that the augmentation of the low-level shear within the airmass along and just behind a boundary, associated primarily with the boundary's solenoidal circulation, which was postulated by Klemp (1987), Moller et al. (1990), and Purdom (1993) and shown by Atkins et al. (1999) and Rasmussen et al. (2000) to promote low-level mesocyclone formation or intensification, can also

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foster supercellular updraft maintenance/propagation and rotation in environments that would otherwise be unfavorable for supercells.

The extension of this mechanism to the generation of supercells on boundaries was first proposed by Doswell et al. (1990): "...an externally-created (mesoscale) source of horizontal vorticity, in an environment with (horizontally homogeneous) marginal shear, could be sufficient to produce supercell storms when their large-scale environment suggests they would be unlikely to develop supercell character." Evidence in support of this proposition can be found in previous modeling and observational studies of deep convection in landfalling hurricane environments (e.g. McCaul 1991; McCaul and Weisman 1996) and cool season supercell environments (e.g. Kulie and Lin 1998). Like the environments along and just behind shallow preexisting boundaries, the environments associated with landfalling hurricanes and cool-season supercells are often characterized by strong low-level shear and weak deep-layer shear. Yet, despite their lack of deep-layer shear, these environments have proven capable of supporting supercellular dynamics.

2.2. The HP Tendency on Preexisting Boundaries

Previous examinations of the relationship between supercell morphology and ambient environmental winds have demonstrated that environments with "weak" mid/upper-level storm-relative winds tend to favor an HP morphology (Brooks et al. 1994; Rasmussen and Straka 1998). It has been argued that weak mid/upper-level storm-relative winds yield HP morphologies because they are unable to exhaust precipitation downstream out of the updraft, which induces significant precipitation deposition in the low-levels near the updraft. Following this proposition, we submit that the enhancement of low-level shear along and behind a preexisting boundary in a multicellular environment characterized by "sub-optimal" deep-layer shear will yield a vertical profile of wind with enough shear to support supercells but mid/upper-level winds that tend to favor an HP morphology.

3. EXPERIMENTAL DESIGN

Proposed experiments designed to meet our two objectives, will be conducted using the Illinois Collaborative Model for Multiscale Atmospheric Simulations (ICOMMAS) (Houston and Wilhelmson 2002, 2004), a non-hydrostatic, finite difference model designed for medium to high-resolution cloud-scale simulations. Two sets of experiments will be conducted: (1) a basic suite, which will be directed at addressing the hypotheses introduced above, and (2) sensitivity studies that intend to add robustness to the conclusions made based on the basic suite. The basic suite will include an initially horizontally homogeneous (control) simulation with a multicellular reference state environment but no preexisting boundary, an initially horizontally *heterogeneous* simulation with the multicellular reference state environment and a preexisting boundary (initialized as a perturbation in the potential temperature, mixing ratio, and wind fields), and an initially horizontally homogeneous simulation with a reference state environment that characterizes the airmass a few kilometers into the cool air behind the preexisting boundary.

The second set of experiments will address the sensitivity of convective mode and morphology to (1) the orientation between the preexisting boundary and the mean flow, (2) the temperature deficit behind the preexisting boundary, and (3) the magnitude of the reference state deep layer shear. Each of these experiments is motivated by the following premise: the presence of enhanced vertical wind shear along and/or behind the preexisting boundary does not guarantee supercell formation. Instead, supercell formation on boundaries in multicellular environments is dependent on each of the following conditions:

1. The magnitude of the reference state deep layer shear (i.e. the "marginality" of the reference state)
2. The magnitude of the solenoidally driven horizontal vorticity along/behind the boundary
3. The stability of the airmass behind the boundary
4. The length of time that a storm resides over the "favorable" portion of the airmass along/behind the boundary.

Furthermore, the ability of a given storm-boundary interaction to favor an HP morphology will depend on how the interaction modifies the storm motion and therefore the storm-relative mid/upper-level flow.

4. SIGNIFICANCE AND APPLICATION OF EXPECTED RESULTS

While the basic suite of simulations is expected to answer the two primary questions of this proposal (what causes supercell formation on preexisting boundaries in multicellular environments and why do these supercells tend to be HP) the most practical results will emerge from the proposed sensitivity studies. Since the specific hazards associated with a given deep convective storm are dependent on its convective mode (e.g. multicell vs. supercell) and morphology (e.g. HP) it is imperative that the operational forecaster is equipped to recognize which types of boundaries will foster HP supercells in multicellular environments. The proposed sensitivity studies have been designed to provide some basic guidelines for assessing (1) the likelihood that a given boundary (defined in this work based on the temperature deficit behind the boundary and the orientation of the boundary relative to the mean flow) in a multicellular environment will support supercells and (2) the likelihood that these supercells will be HP.

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Table 1. Summary of cases involving supercells on boundaries in multicellular environments. Four diagnostic parameters are included to broadly characterize each environment. The definitions of each follow:

$$\overline{\mathrm{S}}\ \text{[mean shear (Rasmussen and Wilhelmson 1983)]} \equiv \frac{1}{h}\int_0^h \frac{\partial \mathbf{v}}{\partial z}\,dz$$

$$\text{BRiS [bulk Richardson shear]} \equiv \left|\overline{\mathbf{v}}_{6km} - \overline{\mathbf{v}}_{BL}\right|$$

$$\text{BRi [bulk Richardson number (Weisman and Klemp 1982; 1984)]} \equiv 2\cdot CAPE\Big/\left(BRiS\right)^2$$

$$\text{VGP [vorticity generation parameter (Rasmussen and Blanchard 1998)]} \equiv \overline{S}\sqrt{CAPE}\ ,$$

where $h \equiv \text{depth} = 4000\text{m}$, $\mathbf{v}$ is the wind velocity, $\overline{\mathbf{v}}_{6km}$ is the density-weighted mean wind velocity in the lowest 6km, $\overline{\mathbf{v}}_{BL}$ is the mean wind velocity in the boundary layer, and $CAPE$ is the convective available potential energy.

Reference	Event Date	$\overline{\mathrm{S}}$ ($\times 10^{-3}$ s^{-1})	BRiS (m s^{-1})	BRi	VGP
Median Values for Supercells		*6.92* [a]	*19.1* [a]	*29* [b]	*0.21* [a]
Finley et al. (2001)	30 June 1993	7.4	3.6	138	0.45
Foote and Wade (1982) Wade and Foote (1982)	22 July 1976	2.5	6.2	55	0.10
Moller et al. (1994)	4 May 1989	4.0	12.9	79	0.27
Wakimoto et al. (1998) [c]	16 May 1995	3.5	16.2	75	0.21

[a] *Values for proximity soundings "associated with storms that produce large hail but not significant tornadoes" from Rasmussen and Blanchard (1998)*

[b] *Values for RUC-2 analysis gridpoint soundings associated with non tornadic supercells from Thompson et al. (2003)*

[c] *The supercell simulated without a boundary by Atkins et al. (1999) was in an environment with stronger shear.*