P129 ASSESSMENT OF THE BASE-STATE SUBSTITUTION IDEALIZED MODELING TECHNIQUE

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1. INTRODUCTION

A common approach to understanding the fundamental processes of deep, moist convection has been to utilize idealized numerical simulations. These simulations often employ horizontally- and temporally-homogeneous base-state conditions to isolate the key processes at work, even though heterogeneity is inherent in many convective storm environments (e.g., Brooks et al. 1996; Weckwerth et al. 1996; Markowski and Richardson 2007). Accounting for environmental heterogeneity in an idealized setting has largely been avoided because of numerous complicating factors that can prevent a clean separation of cause and effect in experimental results.

Base-state substitution (BSS; Letkewicz et al. 2013) is a new idealized modeling method that approximates the temporal tendencies in temperature, moisture, and wind actually experienced by a storm as it encounters a changing environment; this is done without introducing horizontal gradients and their associated circulations to the simulation. A schematic of the procedure for BSS is shown in Fig. 1 and described in detail in Letkewicz et al. (2013). Briefly, after a certain amount of model run time, BSS separates out the storm-induced perturbations of temperature, moisture, and wind from the original base-state, and then replaces the original horizontally-homogeneous background environment with a new horizontally-homogeneous environment; this is completed at a prescribed temporal interval defined by the model user. This approach permits the user to *independently* modify temperature, moisture, or wind profiles as desired, which provides a significant amount of control over changes to the environment and consequently allows the user to more readily identify cause and effect in their experiments. Furthermore, this approach allows for the study of how the *same storm* would *respond* to different background environments (as opposed to triggering storms in different environments).

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The primary assumption of BSS is that the *integrated* effect of a storm moving across an environmental gradient over time is larger than the *instantaneous* effect of local storm-scale gradients. This assumption is central not only to BSS, but to *all* idealized models with horizontally-homogeneous environments employing a representative proximity sounding to the entire domain. The key question is whether this assumption is valid. Will a BSS simulation, employing only temporal variability, produce a realistic storm evolution? To what extent is employing BSS more realistic than not changing the environment at all? To address these questions, idealized simulations with and without BSS will be qualitatively and quantitatively compared to observations of an isolated supercell thunderstorm.

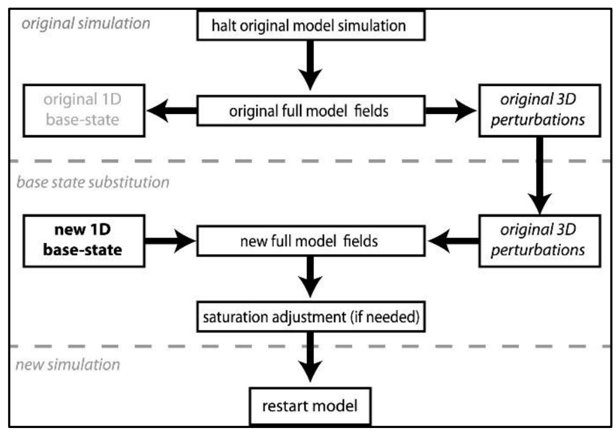

Figure 1: Schematic of the procedure followed for base-state substation. See Letkewicz et al. (2013) for more details.

2. METHODS

The Kingfisher supercell thunderstorm, observed on 29 May 2012 during the Deep Convective Clouds and Chemistry field program (DC3; Barth et al. 2015), was chosen due to the availability of extensive observations of the storm as the near-inflow environment evolved. Three near-inflow soundings were launched over the lifetime of the storm, at 2029, 2255, and 0020 UTC, capturing notable modifications to thermodynamic and kinematic profiles (Fig. 2). Multiple-Doppler data was collected between 2251 and 0000 UTC, providing key observations of storm structure which can then be compared to simulations.

Three mobile radars collected coordinated scans of the Kingfisher storm: the two SMART-Rs (Biggerstaff et al. 2005) and the NOXP radar (Burgess et al. 2010). Time synced radar volumes were collected every three minutes by all three radars, however the storm was never located in the triple-Doppler region. Wind retrieval was achieved using the variational method described in Potvin et al. (2012). A nearby environmental sounding provided the background field for the analysis, which was then blended with the storm using a low-pass filter. Each radar volume was interpolated to a 90 x 60 x 17.5 km Cartesian grid using natural neighbor interpolation (Ledoux and Gold 2005). The horizontal and vertical grid spacing was 500 m.

The idealized numerical model CM1 (Bryan and Fritsch 2002), release 17, was utilized for the modeling component of this study. The domain was 300 x 500 x 20 km; to provide as straightforward of a comparison as possible to the radar analysis, a horizontal and vertical grid spacing of 500 m was used. Convection was initiated using moist convergence (relative humidity initially set at 95% within the zone of convergence; Loftus et al. 2008) over the first 30 min of the simulation. Microphysics were governed by the National Severe Storm Laboratory's double moment variable graupel and hail density scheme (Mansell et al. 2010).

The observed soundings were utilized to describe the horizontally-homogeneous base-state environment in the model. The 2029 UTC profile represented the original base-state environment; the control simulation

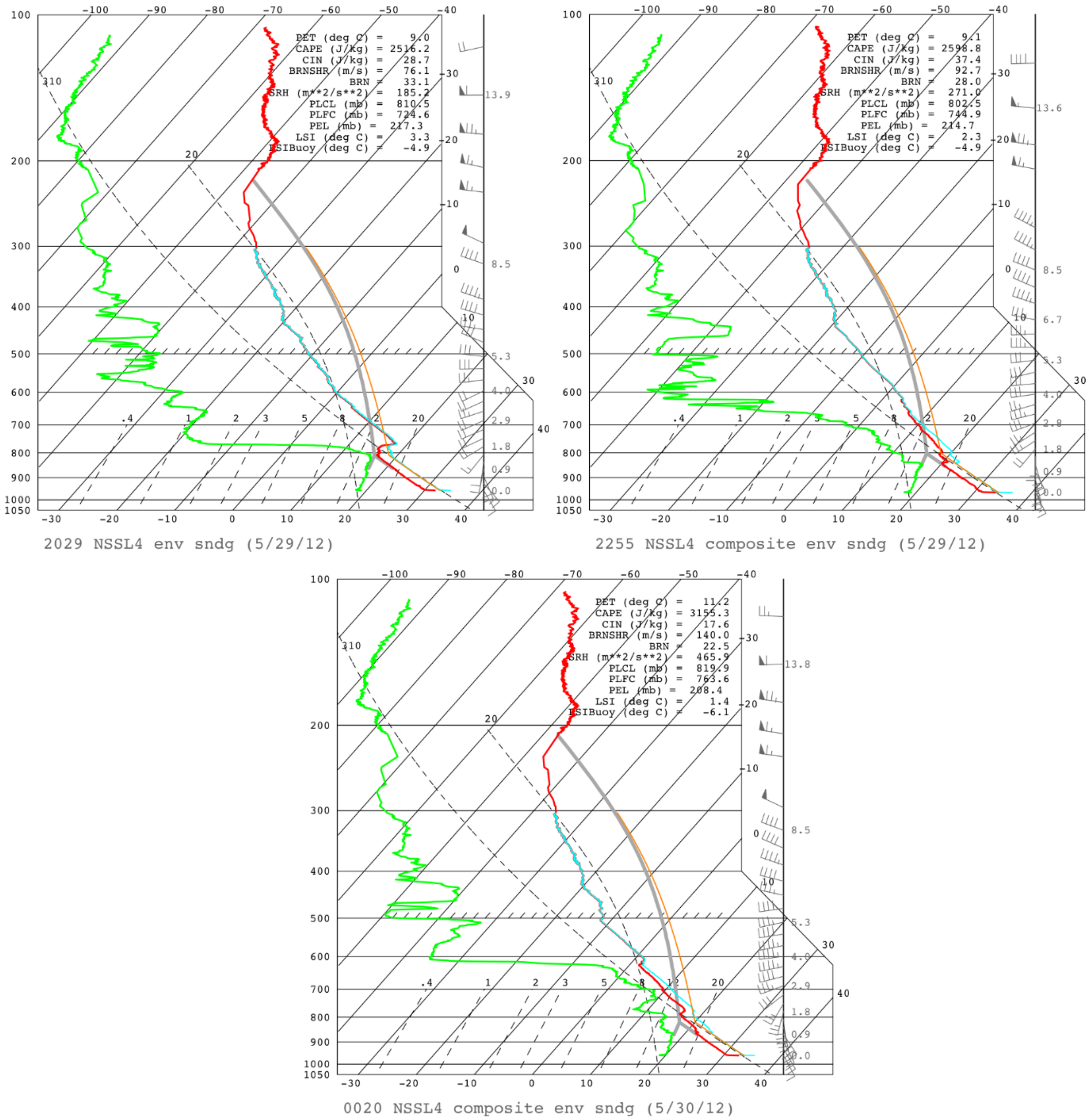

Figure 2: Skew-T log-p diagrams of observed inflow soundings from DC3 experiment on 29-30 May 2012.

maintained this background environment for the entirety of the simulation (7 hours). In the BSS simulation, the base-state temperature, moisture, and wind was gradually nudged (see Letkewicz et al. 2013 for a description of the gradual BSS technique) to the 2255 and 0020 UTC profiles. The background environment was replaced every 3 min starting 3 hours into the simulation, once a mature, quasi-steady isolated supercell was produced. Once BSS was complete, the base-state environment remained unchanged for the duration of the simulation.

3. RESULTS

An overview of the simulation results is shown in Fig. 3. It is evident in both the control and BSS simulations that long-lived supercells are produced, though their appearances are quite different. One clear difference is that the BSS supercell is larger overall, likely due to the increase in moisture over time (Fig. 2). Additionally, the edge of the forward flank precipitation in the BSS supercell changes from a predominately east-west orientation at 2300 UTC to a northwest-southeast orientation by 0000 UTC, more in line with the observed supercell. Another qualitative feature of note is that the BSS supercell exhibits a weak low reflectivity ribbon (LRR; e.g., Griffin et al. 2014), an echo of the much clearer LRR present in the observed supercell at 0000 UTC (Fig. 3). While such similarities are not present throughout the BSS simulation, qualitatively speaking, it is clear that BSS better reflects the observed storm evolution than the control.

Qualitative comparisons of reflectivity provide a useful first-glance at how the simulations compare to the observations, but to fully assess the ability of BSS to produce realistic results, we wish to probe deeper with quantitative, statistical comparisons. This is achieved by first computing distributions of reflectivity and vertical velocity at every vertical level in the observations and both simulations, limited to a 40 x 40 km box surrounding the storm of interest. Next, the non-parametric two-way Kolmogorov-Smirov (KS) test is used to determine the similarity of the distributions at each vertical level. Comparisons are made between the observations and the control simulation, as well as the observations and the BSS simulation. The KS test quantifies the distance between the empirical distribution functions of the two sample distributions; the null hypothesis is that the two samples are drawn from the same distribution. Thus, a small p-value (close to zero) indicates that the two samples are likely drawn from *different* distributions, while a large p-value (close to one) indicates that the two samples are likely drawn from the *same* distribution. Vertical profiles of p-values will illustrate the similarity of the distributions to the observed distribution throughout the depth of the storm. Given the desire of this study to evaluate the ability of BSS to produce a realistic storm evolution, we will focus on the extent to which BSS distributions of reflectivity and vertical velocity are similar to the observations, and

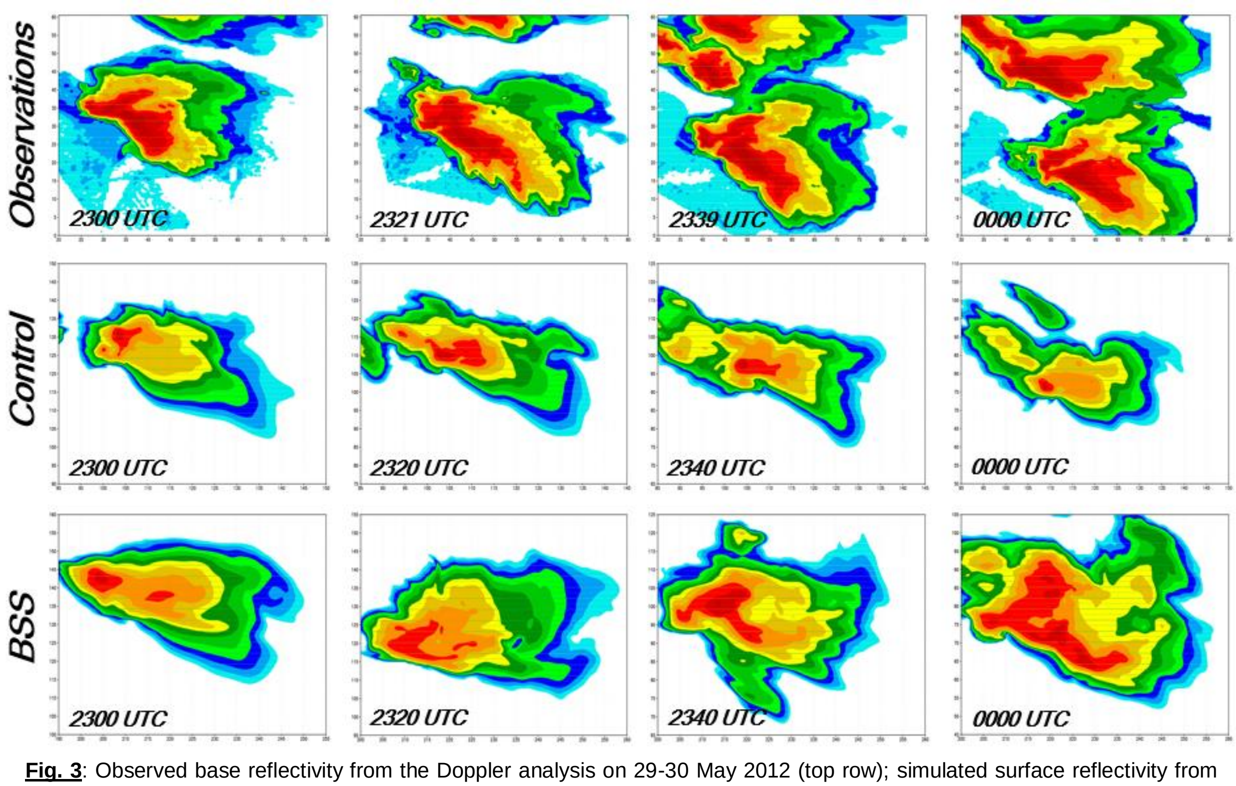

Fig. 3: Observed base reflectivity from the Doppler analysis on 29-30 May 2012 (top row); simulated surface reflectivity from the control (middle row) and base-state substitution (bottom row) simulations.

how much of an improvement BSS provides over the control.

The vertical profile of p-values for comparisons of reflectivity is shown in Fig. 4. At 2300 UTC, near the beginning of the multiple-Doppler window, the control and BSS distributions of reflectivity were generally equally similar to the observations. Over time, both the control and BSS simulations became more similar to the observations, though the control generally exhibited higher p-values than BSS. This is somewhat surprising given the clear trend of BSS qualitatively looking more similar to the observations in Fig. 3. However, this statistical approach focuses on *distributions*, rather than similarities to any particular feature. Additionally, the qualitative comparison was only at the lowest model level, rather than throughout the depth of the storm. Even so, further investigation is needed to determine in what ways the distributions are similar or different (i.e., at the tails, skewness, etc.).

Comparisons of vertical velocity distributions show a much sharper contrast between the control and BSS simulations in relation to the observations. As evident in Fig. 5, over time, the control simulation becomes much *less* similar to the observations, while the BSS simulation becomes much *more* similar to the observations. The primary exception to this trend is in the low-levels, below 2 km, where the control simulation tends to be closer to the observations. Even so, it is encouraging that, overall, the BSS supercell is becoming more like the observed Kingfisher supercell as the background environment changes while the control storm becomes less similar as the background environment remains unchanged.

4. SUMMARY AND FUTURE WORK

Base-state substitution is a new approach to accounting for the effects of environmental variability in an idealized setting while still maintaining a large degree of control over the simulations. However, it is unknown the extent to which a realistic storm is produced or a realistic evolution results. Given the idealized context, how much more realistic is a storm produced via BSS than one produced in a simulation without any environmental changes?

To address these questions, comparisons were made between multiple-Doppler observations of the Kingfisher supercell storm and two idealized simulations of it, one with shifts in the background environment and one without. Qualitatively, the BSS supercell better

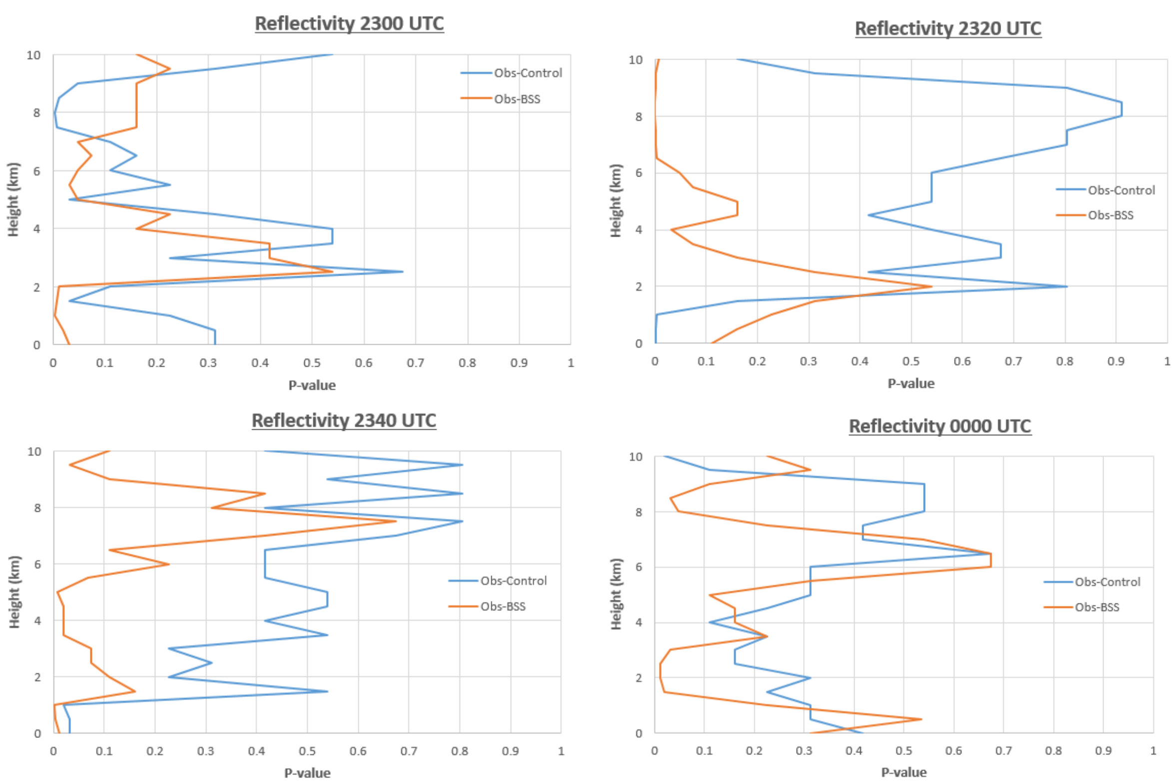

Fig. 4: Vertical profiles of p-values resulting from the two-way Kolmogorov-Smirov test comparing distributions of reflectivity between the observations and the control simulation (blue line) and the observations and the BSS simulation (orange line).

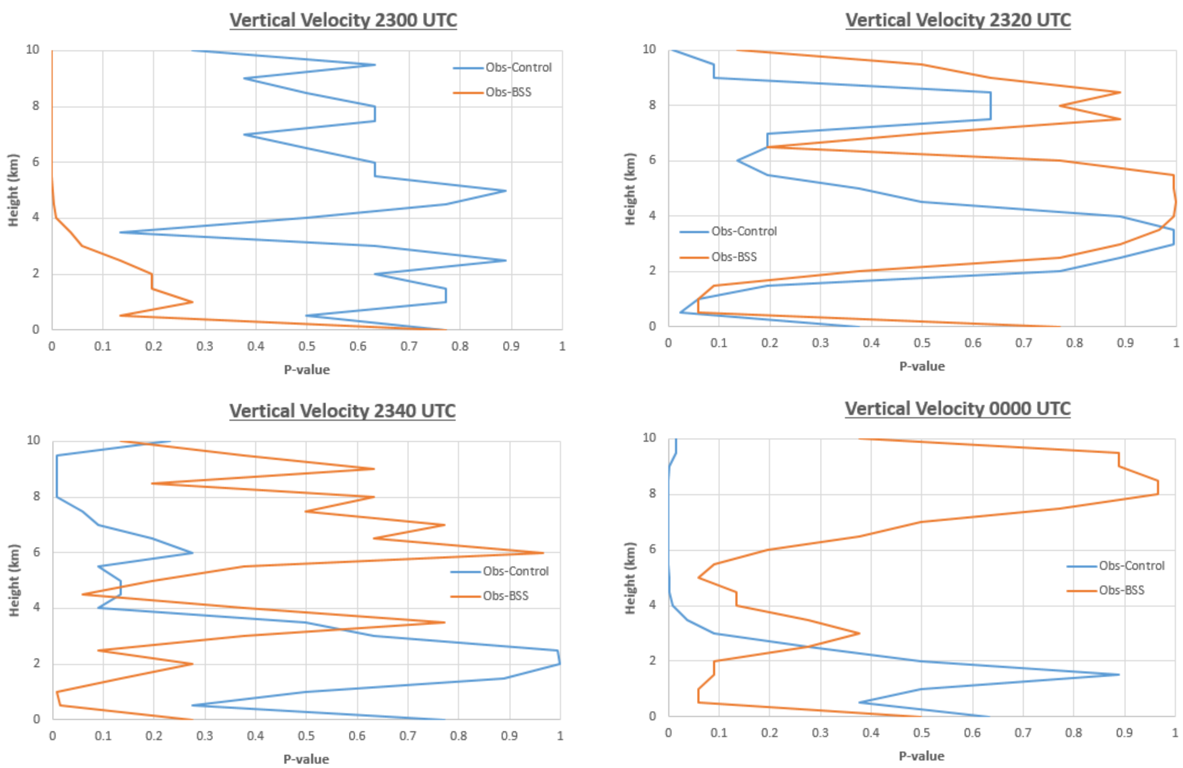

Fig. 5: As in Fig. 4, but for distributions of vertical velocity.

replicated certain features of the observed storm, including the orientation of the forward flank region, as well as the presence of an LRR (Fig. 3). Statistical comparisons of distributions of reflectivity and vertical velocity using the two-way KS test demonstrated that, over time, the BSS storm generally became more similar to the observations than the control simulation, particularly when comparing distributions of vertical velocity. Indeed, this does represent an improvement over the control simulation, where the background environment remained unchanged.

The results presented here represent preliminary work, and a significant amount of additional work will be completed. For example, other storm properties will be compared between the observations and the simulations (e.g., vertical vorticity distributions). To confirm the present results, other non-parametric statistical tests (e.g., Wilcoxon rank sum test) will be run. Additional simulations will also be conducted to determine the sensitivity of the results to model settings, such as the choice of microphysical parameterization.

5. REFERENCES

Barth, M.C., and Coauthors, 2015: The Deep Convective Clouds and Chemistry (DC3) Field Campaign. *Bull. Amer. Meteor. Soc.*, **96**, 1281—1309.

Biggerstaff, M.I., and Coauthors, 2005: The Shared Mobile Atmospheric Research and Teaching Radar: A Collaboration to Enhance Research and Teaching. *Bull. Amer. Meteor. Soc.*, **86**, 1283—1274.

Brooks, H.E., C.A. Doswell III, M.T. Carr, and J.E. Ruthford, 1996: Preliminary analysis of VORTEX-95 soundings. NOAA/NSSL, 133 pp.

Bryan, G.H., and J M. Fritsch, 2002: A benchmark simulation for moist nonhydrostatic numerical models. *Mon. Wea. Rev*., **130**, 2917—2928.

Griffin, C.B., Weiss, C.C., Reinhart, A.E., Snyder, J.C., Bluestein, H.B. Wurman, J.M., Kosiba, K.A., and P. Robinson, 2014: In situ and radar observations of the low reflectivity ribbon. Preprints, *27th Conf. on Severe Local Storms*, AMS, Madison, WI.

Letkewicz, C.E., A.J. French, and M.D. Parker, 2013: Base-state substitution: An idealized modeling technique for approximating environmental variability. *Mon. Wea. Rev.*, **141**, 3062—3086.

Loftus, A. M., D. B. Weber, and C. A. Doswell III, 2008: Parameterized mesoscale forcing mechanisms for initiating numerically simulated isolated multicellular convection. *Mon. Wea. Rev*., **136**, 2408–2421.

Mansell, E. R., C. L. Ziegler, and E. C. Bruning, 2010: Simulated electrification of a small thunderstorm with two-moment bulk microphysics. *J. Atmos. Sci*., **67**, 171–194.

Markowski, P., and Y. Richardson, 2007: Observations of vertical wind shear heterogeneity in convective boundary layers. *Mon. Wea. Rev*., **135**, 843—861.

Potvin, C.K., Shapiro, A., and M Xue, 2012: Impact of a Vertical Vorticity Constraint in Variational Dual-Doppler Wind Analysis: Tests with Real and Simulated Supercell Data. *J. Atmos. Oceanic Techol.*, **29**, 32—49.

Weckwerth, T.M., J.W. Wilson, and R.M. Wakimoto, 1996: Thermodynamic variability within the convective boundary layer due to horizontal convective rolls. *Mon. Wea. Rev.*, **124**, 769—784.