8A.7. THE MOTION OF SIMULATED CONVECTIVE STORMS AS A FUNCTION OF BASIC ENVIRONMENTAL PARAMETERS

Cody Kirkpatrick
University of Alabama in Huntsville
Eugene W. McCaul, Jr.*
Universities Space Research Association
Huntsville, Alabama

1. INTRODUCTION

Previous numerical modeling studies that have addressed convective storm evolution have focused on the effects of bulk convective available potential energy (CAPE) and the environmental wind profile (e.g., Weisman and Klemp 1982) and interactions between a storm's updraft and the vertical shear (e.g., Weisman and Rotunno 2000). Later studies have shown that the evolution of simulated storms is affected by other environmental parameters, such as the presence of lower tropospheric dry layers (Gilmore and Wicker 1998).

Observational studies of storm motion have focused mainly on supercell storms, because of their unique properties and propensity to produce severe weather. Maddox (1976) attempted to quantify how right-moving supercells moved relative to atmospheric mean winds, in terms of ground-relative speed and deviation from the direction of the mean wind. This work served as a basis for storm motion research and forecasting for many years. Rasmussen and Blanchard (1998) then developed a method of forecasting supercell motion based on a prescribed deviation from a specified point on the mean shear vector between the lowest 0.5 km and the lowest 4 km of the atmosphere. This method had the advantage of being Galilean invariant, and was subsequently modified and elaborated on by Bunkers *et al.* (2000). All these methods consider supercell motion to be only a function of the properties of the environmental hodograph. None of these investigations, however, managed to parameterize the deviation of storm motion from the mean shear as a function of the strength of the shear, or of any other environmental variable.

McCaul and Weisman (2001, MW01 hereafter) and McCaul and Cohen (2002, MC02 hereafter) presented results from what ultimately developed into a large, eight-dimensional parameter space numerical simulation study of deep convection. Their findings demonstrated that storm morphology and evolution are affected by numerous environmental parameters, and that storm motion is not a function of the wind profile alone. The purpose of this research is to show how storm motions vary within the different parts of the parameter space, and how these sensitivities might be useful in improving our understanding of the variations in supercell deviate motions. Storm motions are being examined in this study for both the dominant right moving and left moving storms in the simulations, but the motion of the mature right-movers is the focus of this paper.

Sensitivity tests involving translation of the starting hodographs confirm that, within the eight-dimensional parameter space, our storm motions are almost entirely Galilean invariant. Thus, it is believed that it is safe and appropriate to try to draw conclusions about how each of the eight basic environmental parameters influence the simulated storm motions. While it is clear that storm motions can be affected by preexisting fronts and boundaries, as well as topography, we view the present work as a preliminary step in documenting storm motion sensitivities to all the vertical environmental profile parameters of idealized storm environments in the absence of topography.

2. METHODOLOGY

The simulations are conducted as in MW01 and MW02 using an updated version of the Regional Atmospheric Modeling System (RAMS; see, e.g., Pielke *et al.* 1992, Walko *et al.* 1995), version 3b, with changes as described in McCaul *et al.* (2004). CAPE takes on the values of 800, 2000, or 3200 J kg^{-1}. The lifting condensation level (LCL) and level of free convection (LFC) have three possible configurations (0.5 and 0.5 km; 0.5 and 1.6 km; 1.6 and 1.6 km, respectively). The shapes of the buoyancy and shear profiles are developed as in MC02, and are permitted to vary within the bounds of reasonable atmospheric regimes and model limitations. Precipitable water (PW) is determined by the temperature at the LCL, and is either roughly 30 mm (T_{LCL} = 15.5°C when LCL = 0.5 km) or 60 mm (T_{LCL} = 23.5°C). In this study, all hodographs are semicircular with a 12 m s^{-1} radius. The shears in these hodographs lie in the range of commonly observed values, but do not span the range of the largest shears found in some supercell environments. Other radii, including larger ones, are currently being simulated and analyzed. Relative humidity everywhere above the LFC is fixed at 90%.

Each simulation is run for two hours of simulated time, with full model history saves at five-minute intervals. The storms are identified by locating the strongest

**Corresponding author address*: Eugene W. McCaul, Jr., Universities Space Research Association, 6700 Odyssey Drive, Suite 203, Huntsville, AL 35806, E-mail: `mccaul@space.hsv.usra.edu`

right- and left-moving updrafts at a model level approximately 1.9 km above the LFC. The updrafts are tracked during the second hour of the simulations, and their movements during that hour are averaged to provide an overall, mean motion along with its standard deviation. The mean standard deviation over all simulations is 1.7 m s^{-1} (this deviation is actually a function of CAPE, discussed below). This sets a first threshold above which variations in storm motion can be deemed "significant" and thereby worthy of further study.

3. RESULTS AND DISCUSSION

As expected, the shape of the shear profile has the most pronounced effect on mean storm motion of the parameters studied herein (circles vs. squares, Fig. 1). This influence is observed at all values of CAPE and PW. It is most pronounced at low (800 J kg^{-1}) and moderate (2000 J kg^{-1}) CAPE values, where the magnitude of vector mean motion differences between "distributed" and "concentrated" low-level shear profiles ranges from 3-6 m s^{-1}. The effect of the shear profile is also more noticeable when low-level lapse rates are maximized. The storms in concentrated shear environments also exhibit larger pressure perturbations and surface vertical vorticity (not shown) compared to their distributed shear counterparts, corroborating the findings of Droegemeier *et al.* (1993). In the large CAPE regime, storms tended toward multicellular behavior, and outflow boundaries and storm interactions may have affected the storm motion estimates.

Increasing the low-level lapse rate (i.e., concentrating more CAPE closer to the LFC) has somewhat weaker but still significant effects, increasing the off-hodograph motion generally by 1.5-2.5 m s^{-1}. The effect is steady across most of the parameter space, with the exception of the extremely low CAPE, high PW and high CAPE, low PW cases. In the former, excessive water loading cannot overcome the weak updraft velocities allowed by the small CAPE, regardless of where buoyancy is concentrated; these storms remain weak (maximum updraft velocities at or below 20 m s^{-1}). Generally, storms in the high CAPE, low PW case are already strong enough (maximum updraft velocities in excess of 60 m s^{-1}) to overcome hydrometer loading in the updraft and the LCL-LFC configuration becomes more important than PW (discussed below).

Storm movement sensitivity to changes in mixed layer depth (i.e., LCL height; Fig. 2) increases as CAPE increases. At low and intermediate CAPE, storm speeds are somewhat more affected (but by no more than 2 m s^{-1}) by changes in LFC height, but the direction of motion is altered by as much as 20-30 degrees. Both the LCL and LFC heights affect storm motion, at high CAPE, but the changes are smaller than at other CAPE values. An increase in LFC height from 0.5 to 1.6 km causes the simulated storms to veer in a clockwise direction; these results suggest that the LFC height regulates the "steering level" of the storms.

Decreasing the atmospheric precipitable water content increases the amount of off-hodograph deviate motion in 90% of the simulation "pairs" that produced storms (i.e., both the high-PW and low-PW simulations, all other parameters being held constant). The effect was most pronounced at intermediate CAPE. A low-PW environment corresponds to a colder cloud base and a generally cooler environment; the contribution to buoyant energy from the latent heat of fusion over a deeper layer of the atmosphere, as well as a reduction of condensate loading aloft, leads to stronger updraft speeds in the low-PW cases (McCaul *et al.* 2004) and thus an increase in the updraft-environment interactions that promote off-hodograph motion.

The mean storm motions in the low CAPE regime exhibit the greatest inter-simulation variability across the different parts of the parameter space. Those storms, however, are better behaved than their higher CAPE counterparts, when it comes to intra-simulation variability of storm motion. The mean standard deviation of storm motion increases from 1 m s^{-1} when CAPE = 800 J kg^{-1} to 2.5 m s^{-1} when CAPE = 3200 J kg^{-1} (Figs. 3 and 4). As CAPE decreases, the motion of the simulated storms becomes more consistent and predictable, but also becomes more dependent on other environmental parameters. The sensitivity of storm motion standard deviation to CAPE is evidently related to variations in the environmental bulk Richardson Number (BRN), and the associated tendencies for storms to display supercell characteristics in certain BRN regimes.

The temporal variability of storm motion is also a function of environmental parameters other than CAPE. For instance, when CAPE is large, decreasing the level of maximum buoyancy (i.e., using a large value of the m parameter to concentrate the buoyancy at low levels) results in an average 1.4 m s^{-1} increase in the standard deviation of motion (Fig. 3); the standard deviations change by less than 1 m s^{-1} at low and intermediate CAPE. Variations in the shear profile shape and in PW content have negligible effect. Changes to the LCL-LFC configuration (Fig. 4) affect the deviations only at high CAPE and high PW, but storm intensity is also greatly affected, making that finding difficult to interpret.

4. FUTURE WORK

The present results point to the importance of environmental factors that enhance storm intensity and rotation, which play a key role in determining storm deviate motion. Traditional methods of forecasting storm motion based solely on hodograph characteristics (e.g., Bunkers *et al.* 2000) thus need to be revised to account for the influence of these other thermodynamic aspects of the storm environment. The findings also suggest that storm motion estimates based on "proximity soundings" must be used with caution and the uncertainties in those soundings must be taken into account.

The sensitivity of storm motion temporal variability, most pronounced with respect to CAPE in the data discussed here, suggests reduced predictability in higher CAPE environments. Work continues to clarify the character of the temporal variability, which could be caused either by quasi-cyclic dynamical changes in the storms, or by gradual accelerations or decelerations in storm speed. In the case of the former, the present findings could have implications for understanding what regulates phenomena such as cyclic mesocyclogenesis (Adlerman *et al.* 1999; Adlerman and Droegemeier 2002).

Expansion of the current parameter space study is ongoing. A change in hodograph radius will have an obvious effect on storm motion; a variety of hodograph radii and shear profiles are being examined. Sensitivity tests have demonstrated that storm motions are also responsive to variations in model microphysical parameters such as the mean diameters of hail and graupel particles (e.g., Cohen and McCaul 2004). Work continues on exploring the effect of variations in free tropospheric relative humidity and its impact on storm morphology and motion; these sensitivities will be addressed in a future paper.

5. ACKNOWLEDGMENTS

This research is a part of the COnvection Morphology PArameter Space Study (COMPASS), which is supported by grant ATM-0126408 from the National Science Foundation under the supervision of Dr. Stephan Nelson. For additional information, see http://space.hsv.usra.edu/COMPASS.

6. REFERENCES

Adlerman, E. J., K. K. Droegemeier, and R. Davies-Jones, 1999: A numerical simulation of cyclic mesocyclogenesis. *J. Atmos. Sci.*, **56**, 2045–2069.

Adlerman, E. J., and K. K. Droegemeier, 2002: The sensitivity of numerically simulated cyclic mesocyclogenesis to variations in model physical and computational parameters. *Mon. Wea. Rev.*, **130**, 2671–2691.

Bunkers, M. J., B. A. Klimowski, J. W. Zeitler, R. L. Thompson, and M. L. Weisman, 2000: Predicting supercell motion using a new hodograph technique. *Wea. Forecasting*, **15**, 61–79.

Cohen, C., and E. W. McCaul, Jr., 2004: The sensitivity of simulated convective storms to variations in prescribed microphysics parameters. *Preprints*, 22nd Conf. Severe Local Storms, Hyannis, MA, Amer. Meteor. Soc., paper 8A.4.

Droegemeier, K. K., S. M. Lazarus, and R. Davies-Jones, 1993: The influence of helicity on numerically simulated convective storms. *Mon. Wea. Rev.*, **121**, 2005–2029.

Gilmore, M. S. and L. J. Wicker, 1998: The influence of midtropospheric dryness on supercell morphology and evolution. *Mon. Wea. Rev.*, **126**, 943–958.

McCaul, E. W., Jr., and M. L. Weisman, 2001: The sensitivity of simulated supercell structure and intensity to variations in the shapes of environmental buoyancy and shear profiles. *Mon. Wea. Rev.*, **129**, 664–687.

—, and C. Cohen, 2002: The impact on simulated storm structure and intensity of variations in the mixed layer and moist layer depths. *Mon. Wea. Rev.*, **130**, 1722–1748.

—, —, and C. Kirkpatrick, 2004: The sensitivity of simulated storm structure and intensity to the temperature at the lifted condensation level. submitted to *Mon. Wea. Rev.*

Maddox, R. A., 1976: An evaluation of tornado proximity wind and stability data. *Mon. Wea. Rev.*, **104**, 133–142.

Pielke, R. A., W. R. Cotton, R. L. Walko, C. J. Tremback, W. A. Lyons, L. D. Grasso, M. E. Nicholls, M. D. Moran, D. A. Wesley, T. J. Lee, and J. H. Copeland, 1992: A comprehensive meteorological modeling system - RAMS. *Meteor. Atmos. Phys.*, **49**, 69–91.

Rasmussen, E. N., and D. O. Blanchard, 1998: A baseline climatology of sounding-derived supercell and tornado forecast parameters. *Wea. Forecasting*, **13**, 1148–1164.

Walko, R. L., W. R. Cotton, M. P. Meyers, and J. Y. Harrington, 1995: New RAMS cloud microphysics parameterization. Part I: the single-moment scheme. *Atmos. Res.*, **38**, 29–62.

Weisman, M. L., and J. B. Klemp, 1982: The dependence of numerically simulated convective storms on vertical wind shear and buoyancy. *Mon. Wea. Rev.*, **110**, 504–520.

—, and R. Rotunno, 2000: The use of vertical wind shear versus helicity in interpreting supercell dynamics. *J. Atmos. Sci.*, **57**, 1452–1472.

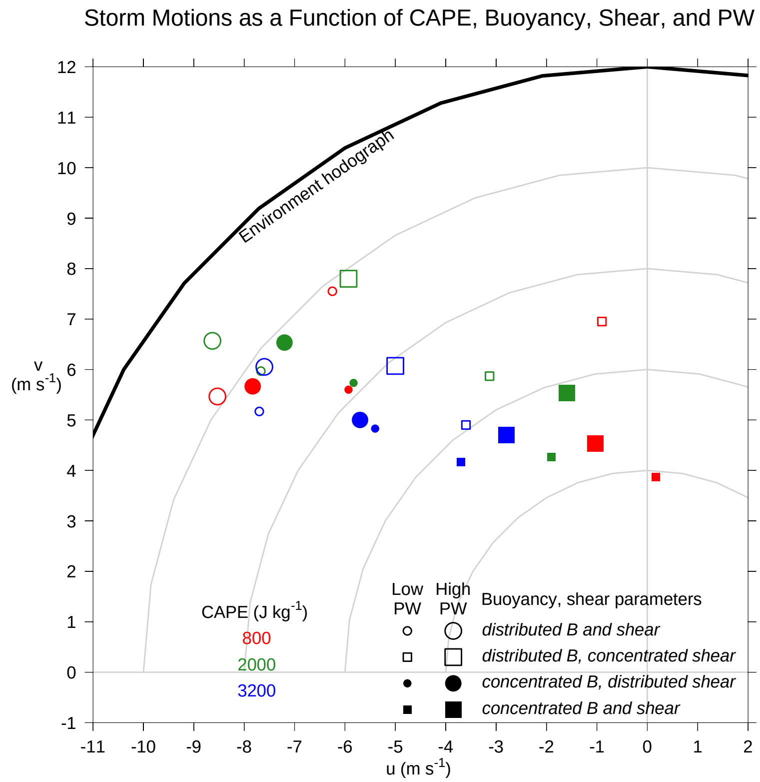

Fig. 1. Mean storm motions during the second hour of simulations. Each point is the average over the three LCL-LFC configurations, all other parameters held constant.

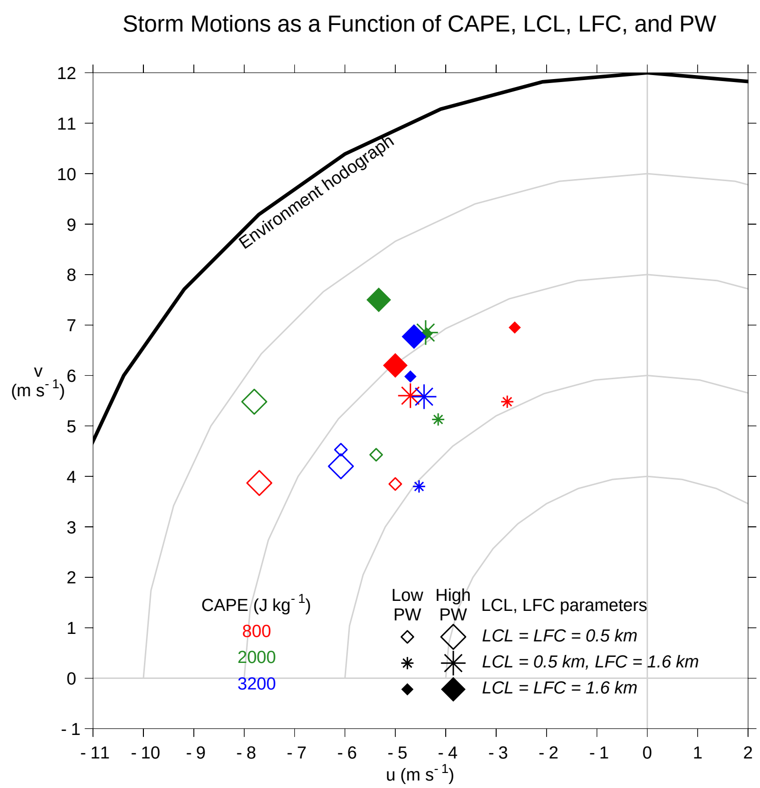

Fig. 2. Mean storm motions during the second hour of simulations. Each point is the average over the four buoyancy- shear profile configurations, all other parameters held constant.

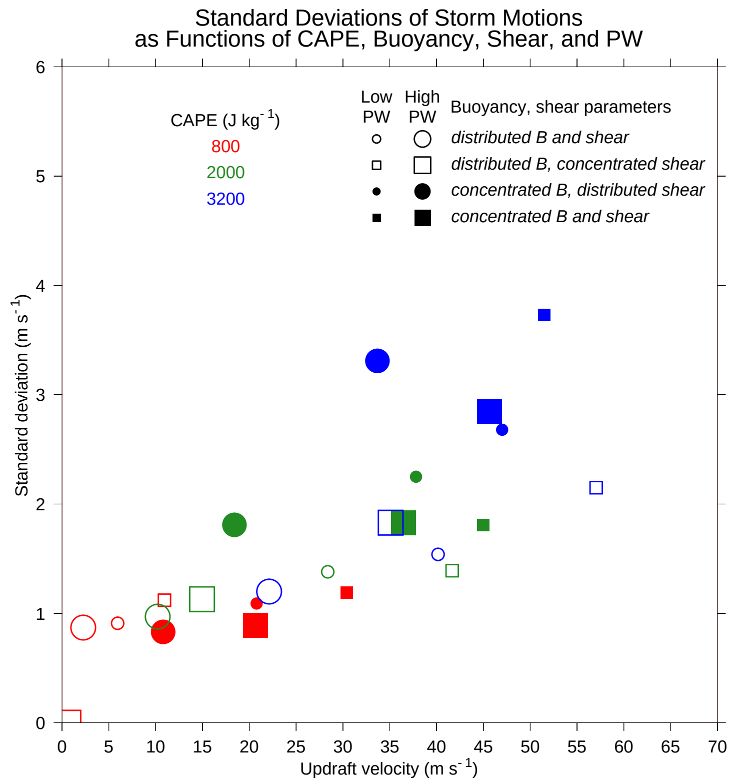

Fig. 3. Standard deviations of storm motions as a function of mean updraft velocity during the second hour. Each point is averaged over the three LCL- LFC configurations, all other parameters held constant.

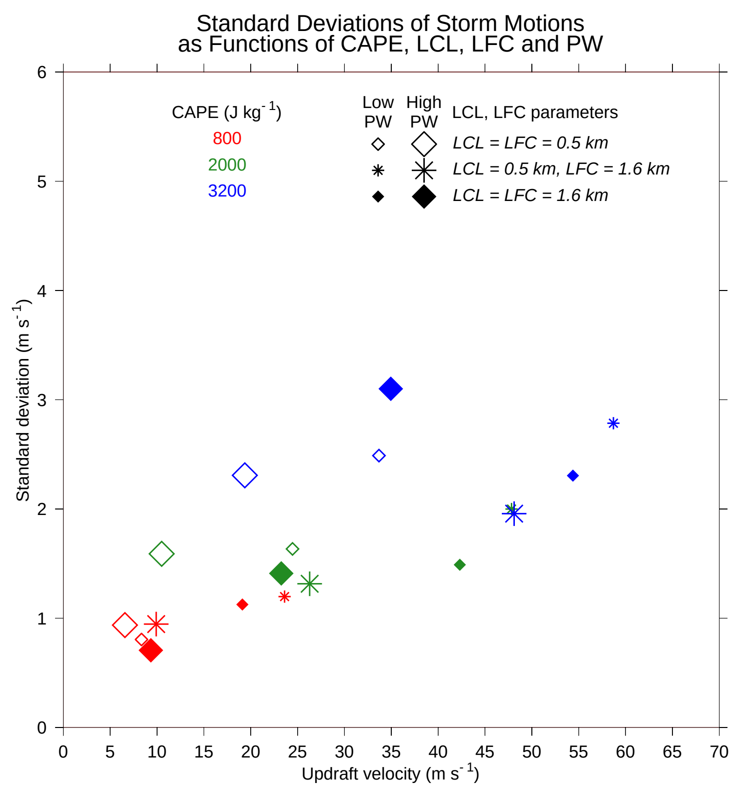

Fig. 4. Standard deviations of storm motions as a function of mean updraft velocity during the second hour. Each point is averaged over the four buoyancy- shear profile configurations, all other parameters held constant.