14.1 **IMPACT OF THE INITIAL CONVECTIVE ARRANGEMENT ON SIMULATED MCS DEVELOPMENT**

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1. INTRODUCTION

Forecasting mesoscale convective systems (MCSs) is challenging because it requires knowledge of areas favorable for convective initiation, organization, and sustenance. Given the difficulty just in forecasting convective initiation, the task of forecasting MCSs seems daunting. Perhaps once convective initiation occurs, however, the arrangement of thunderstorms can provide information about the developing MCS. This study explores how the initial convective arrangement affects the overall development of MCSs.

Previous MCS classification studies (e.g., Bluestein and Jain 1985; Bluestein et al. 1987; Jirak et al. 2003) have observed that MCSs typically develop from either a line of discrete cells or from an areal (i.e., non-linear) arrangement of cells. Jirak et al. (2003) observed that MCSs developing from linearly-arranged convection at initiation tend to evolve toward larger, longer-lived, more severe, and rainier systems than MCSs that develop from areally-arranged convection. This observation agrees with the findings of Bluestein et al. (1987) that broken-areal squall lines are the least likely convective arrangement to be associated with severe weather. If we understand how the initial convective arrangement affects MCS development, then we can apply that knowledge in making short-term forecasts about the impending impact of MCSs given a particular convective arrangement prior to MCS development.

The objective of this study is to examine and better understand the sensitivity of MCS development to the initial convective arrangement by performing several idealized simulations. These simulations differ only in the placement of warm, moist bubbles to determine how the initial convective arrangement affects the size, longevity, and precipitation production of MCSs. The remainder of this paper describes the model setup, methodology, and results in determining the influence of the initial convective arrangement on MCS development.

2. SETUP AND METHODOLOGY

The Regional Atmospheric Modeling System (RAMS Version 4.3; Pielke et al. 1992; Cotton et al. 2003) is used to perform idealized 3-D simulations of MCS development. These simulations utilize a single grid with 1.75 km horizontal grid spacing over a 875-km by 787.5-km domain for a 15-h period. Thirty-seven vertical levels are used with variable grid spacing, increasing from 25-m spacing at the lowest level to a maximum of 900 m. A two-moment bulk microphysics scheme (Saleeby and Cotton 2004) is used with all hydrometeor species activated. Coriolis accelerations and radiative effects are also included in the simulations.

The model is initialized horizontally homogeneously using a modified version of the 0000 UTC 20 May 1998 sounding from North Platte, NE (Fig. 1). The most significant sounding modification is the removal of the meridional component of the wind, leaving only zonal winds (cf. Jirak and Cotton 2006). The sounding is extrapolated down to sea level and slightly dried from just above the surface to 850 mb. This sounding represents a precursor environment capable of supporting a long-lived, eastward-moving, leading-line/trailing stratiform (TS) MCS. The winds are easterly at the surface, weak around 700 mb, and westerly aloft, contributing to unidirectional westerly vertical shear through the troposphere. Additionally, the sounding is unstable with over 3000 J kg^{-1} of surface-based convective available potential energy (CAPE) and a lifted index (LI) of -10.

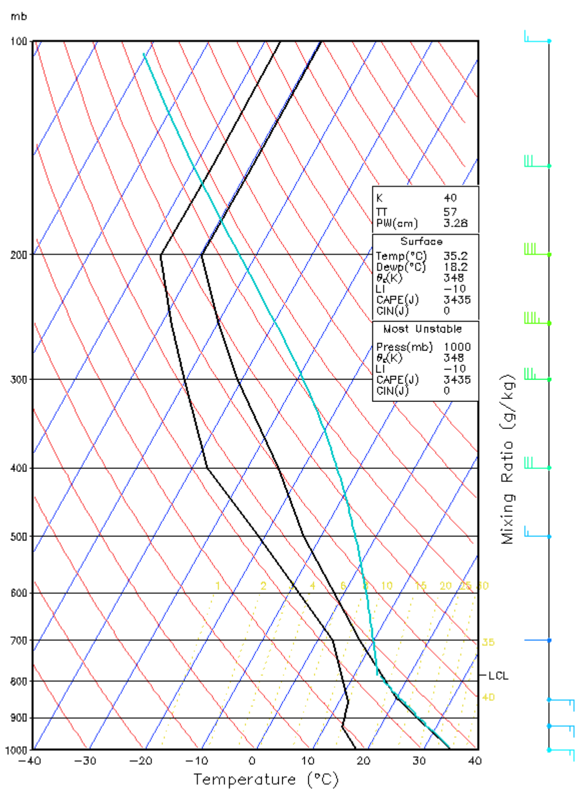

Fig. 1: Sounding used to initialize the MCS simulations.

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Convection is initiated using warm (2-K temperature perturbation), moist (20% moisture perturbation) rectangular “bubbles” that extend 12.25 km in each horizontal direction. Each bubble has a minimum spacing of 35 km between the other bubbles. Four bubble arrangements (each consisting of four bubbles) are examined in this study to test the sensitivity of MCS development to different configurations: north-south (N-S) line, east-west (E-W) line, square, and diamond patterns. The size, duration, and precipitation of the simulated MCSs are analyzed and compared to determine the influence that the initial convective arrangement has on general MCS characteristics.

3. COMPARISON OF MCS CHARACTERISTICS

3.1 Size and Duration

Even though each simulation is initialized with a different arrangement of warm, moist bubbles, an eastward-propagating elongated MCS develops in each case. In fact, the MCSs that develop look qualitatively similar to one another (see Fig. 2), so a detailed examination is required to highlight the differences. The MCSs developing from linear convective arrangements (i.e., N-S line and E-W line) have faster growth rates than the MCSs developing from areal convective arrangements (i.e., square and diamond) (Fig. 3). Each MCS reaches a similar maximum size (see Figs. 2 & 3), but the linear convective arrangements result in MCSs about 10% larger than the areal systems. The dissipation rate is similar for all of the systems (Fig. 3), and the systems look very similar in structure and location during the dissipation stage around 11 hours into the simulations. In general, the faster growth rate of linear systems and similar dissipation rates of all systems lead to a longer duration for the linear systems. For example, selecting 15 000 km^2 as the MCS size criterion at the 4 mm threshold of vertically integrated condensate results in approximately 4-h durations for the areal MCSs while the linear MCSs have durations around 5 h. The E-W linear arrangement stands out from the others since it transitions from an E-W orientation to a N-S orientation in just a few hours (see Fig. 2) and still maintains a fast growth rate. Overall, these simulations agree with observations of areal vs. linear MCSs: MCSs that develop from non-linearly arranged convection tend to be smaller and shorter-lived than MCSs that develop from a line of convective cells.

3.2 Precipitation

The accumulated surface precipitation generated by the MCSs is strongly influenced by the size and longevity of the systems (Fig. 4). The precipitation produced by these simulated systems is less than the radar-estimated accumulated precipitation of 3.8 million acre-feet for an average MCS (Jirak et al. 2003), so these systems fall on the smaller end of MCS classification. Through the first five hours, the accumulated precipitation is similar for all of the systems. After that point, the disparity in size and

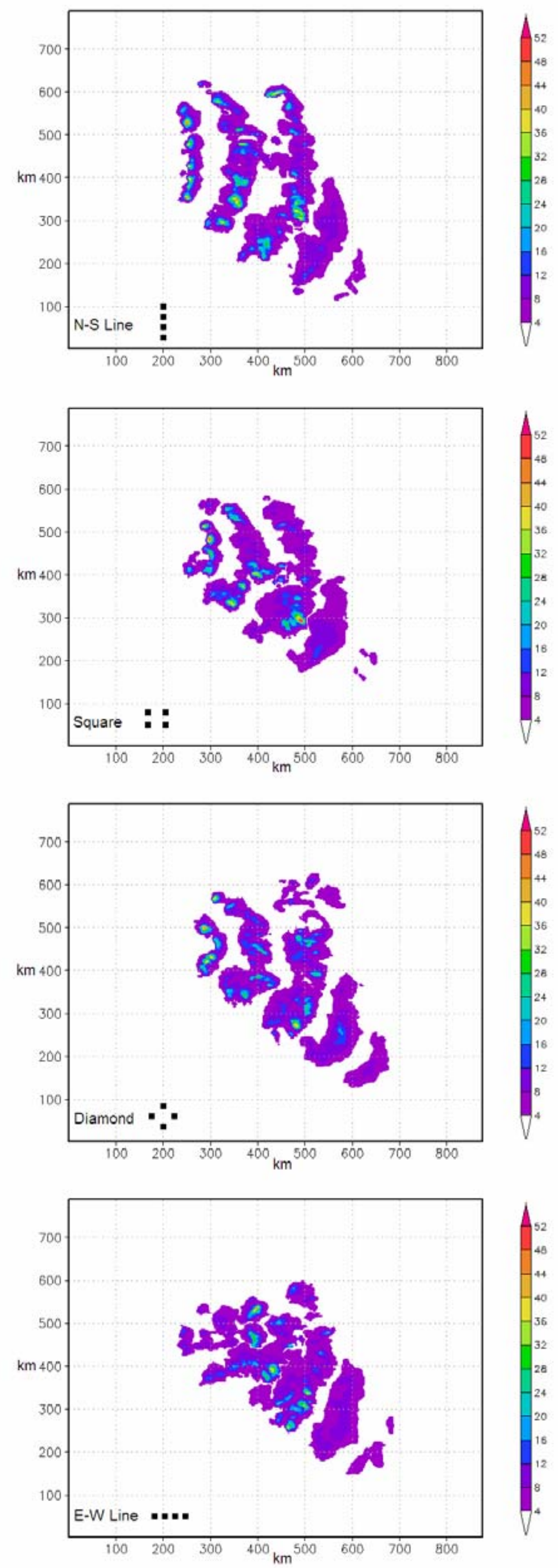

Fig. 2: MCS lifecycle displayed as vertically integrated condensate (mm) every 160 minutes for each of the different initial convective arrangements.

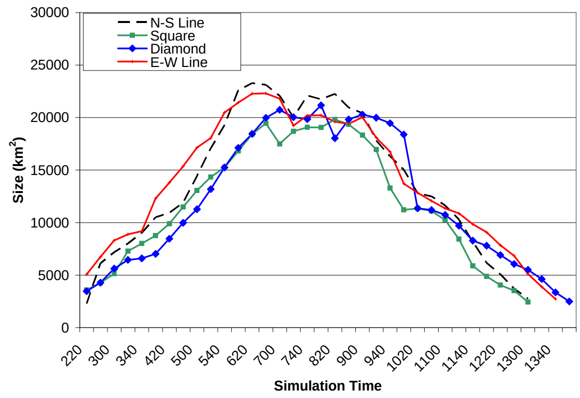

Fig. 3: Time series of MCS size for each of the four initial convective arrangements. The size is given by the area of vertically integrated condensate >4 mm.

longevity results in significant differences in accumulated precipitation by the end of the simulations. The N-S line produces the most precipitation over the entire domain followed by the E-W convective line. The areal convective arrangements generate less accumulated precipitation. A difference of 150 000 acre-feet (~15%) in accumulated precipitation between the N-S line and square arrangements may not seem like a significant amount, but it is equivalent to about 5 times the annual water usage of the city of Fort Collins (pop. 125 000). In general, these simulations agree with observations that areal systems produce less precipitation than MCSs that originate from a line of storms.

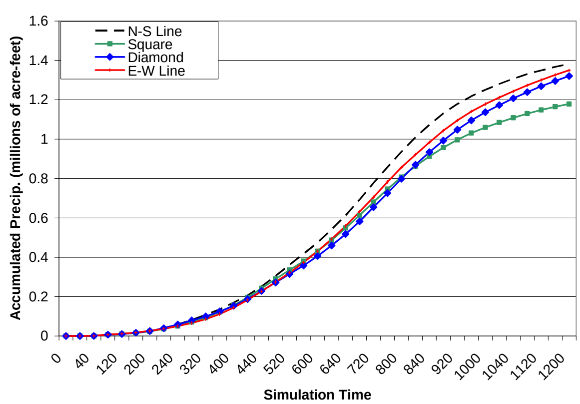

Fig. 4: Surface accumulated precipitation for the four initial convective arrangements.

4. ANALYSIS OF MCS DIFFERERNCES

4.1 Cold Pool-Shear Interaction

MCSs that develop from different initial convective arrangements have been shown to possess different characteristics in observations (Jirak et al. 2003) and in these simulations. In order to better understand why these differences exist, an analysis is performed that examines the interaction between the leading edge of the cold pool and the ambient low-level vertical wind shear, which is theorized to play an important role in the longevity of convective systems (see Rotunno et al. 1988; Weisman and Rotunno 2004). In this study, the 0-3 km ambient vertical wind shear (8.8 m s^{-1}; 270°) is used in the analysis. This low-level westerly shear appears to have some influence on storm evolution, leading to differences among the systems.

The horizontal extent of the gust front normal to the ambient shear provides some information pertinent to MCS development (Fig. 5). The N-S oriented line forms the longest gust front normal to the ambient westerly shear and becomes the largest MCS. For three of the systems, the horizontal extent of the cold pool normal to the ambient shear levels out about one hour before the MCS reaches its largest size (c.f. Figs. 3 & 5). For the E-W line, the extent of the gust front normal to the ambient shear doesn't appear to have as significant of an influence on MCS growth. The E-W oriented line has the shortest gust front normal to the ambient shear initially, but still undergoes rapid growth while the extent of the gust front normal to shear slowly increases (Fig. 5). Even though these results are not as conclusive as found by Jirak and Cotton (2006) for a veering wind profile, the extent of the gust front normal to the ambient wind shear ahead of the storm still might be useful in forecasting when a MCS will likely reach its maximum size.

Examination of the precipitation and cold pool evolution for each system provides additional information about MCS development (Fig. 6). The arrangement of convection in a N-S line results in a more linear MCS than the other systems, which have more curvature due to their initial convective arrangement. As the low levels stabilize through the night, the systems weaken and the gust front advances well ahead of the precipitation leading to the complete dissipation of the MCSs. In general, the interaction of the storm-generated cold pool with the ambient westerly shear appears to have an impact on MCS development.

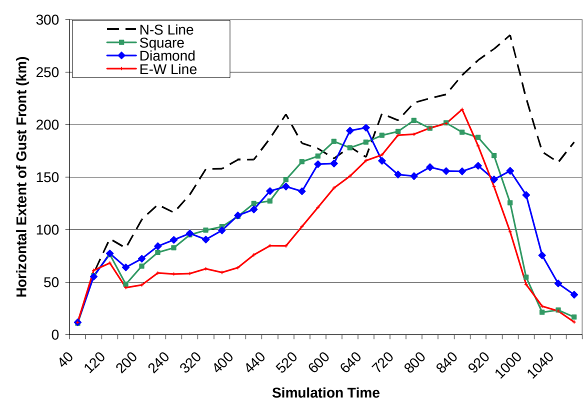

Fig. 5: Approximate horizontal extent of the gust front where the magnitude of the 0-3 km ambient wind shear normal to the leading edge of the cold pool is ≥5 m s^{-1} for the four initial convective arrangements.

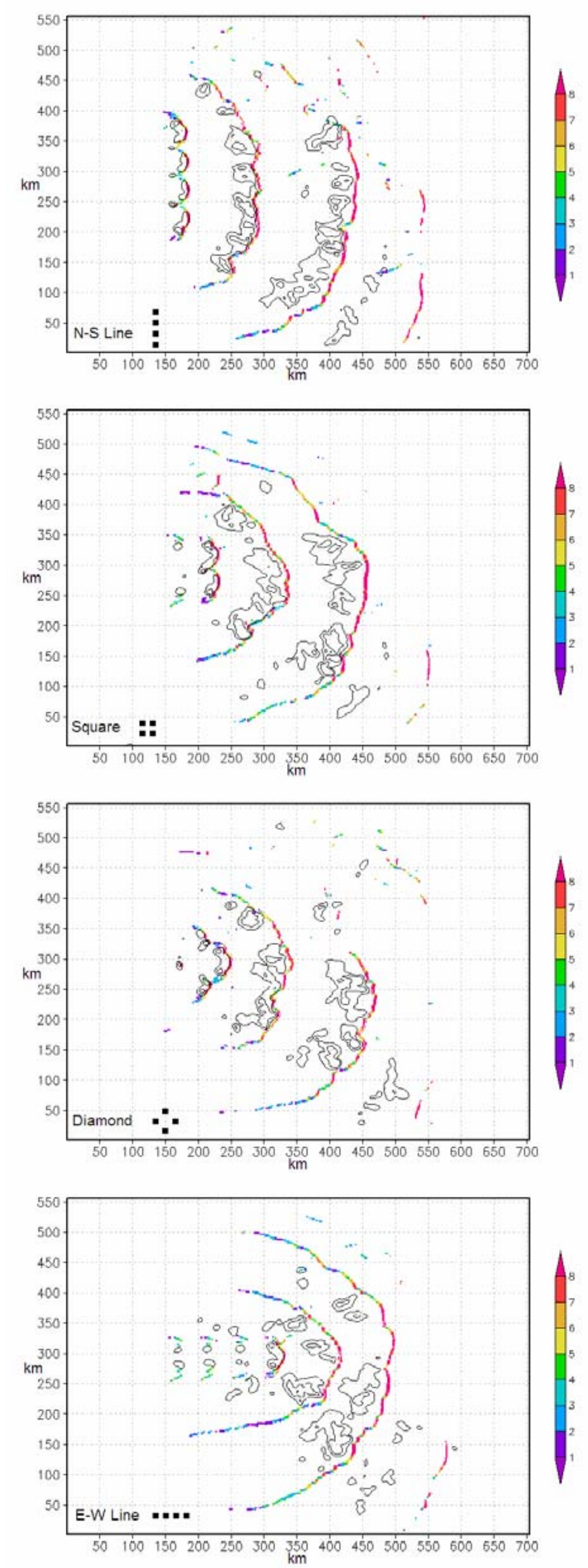

Fig. 6: MCS lifecycle displayed as surface precipitation rate (contoured at 2, 8, & 32 mm h^{-1}) and the magnitude of the 0-3 km shear normal to the gust front (shaded; m s^{-1}) along the leading edge of the cold pool every 160 minutes for each of the different initial convective arrangements.

4.2 MCS Dissipation

Even though the cold pool-shear interaction seems to have an influence on MCS *growth*, it appears to have less influence on MCS *dissipation*, also found by Gale et al. (2002). One might think that the increasing stability through the night leads to MCS dissipation. However, MCSs often persist well into the nighttime hours after surface-based instability has disappeared, so the issue of the influence of the diurnal cycle of stability on MCS dissipation needs further investigation.

In attempting to capture the entire lifecycle of MCSs in these simulations, it became obvious that modeling the complete dissipation of MCSs in a homogeneous environment is a complicated issue. Using high vertical resolution (i.e., 25-m grid spacing) at the lowest levels to generate a nocturnal inversion did not automatically lead to MCS dissipation, as elevated instability continued through the night. Hence, MCSs would form, but would not dissipate during the simulations. After some careful modifications to the initial sounding to reduce elevated instability, the complete dissipation of MCSs was captured in the simulations.

An examination of the time series of MCS properties and environmental stability provides some insight into MCS dissipation (Fig. 7). Initially, the most unstable parcel ahead of the system is surface based without any convective inhibition (CIN). As the surface cools, some CIN develops and the most unstable parcel becomes elevated above the nocturnal boundary layer by 5 h into the simulation. Notice, however, in Fig. 7 that the cold pool is still deeper than the level of free convection (LFC) of the most unstable parcel until around 7 h into the simulation. Thus, lifting of that parcel to its LFC by the cold pool allows convection to be sustained, as shown by growth of the MCS. After that time, the depth of the cold pool remains fairly constant, but the LFC of the most unstable parcel increases in height to a level above the top of the cold pool. Consequently, the MCS begins to dissipate as deep convection can no longer be sustained without the necessary lifting to the LFC. Therefore, comparing the depth of the cold pool to the LFC of the most unstable parcel ahead of the system appears to provide an indication of when MCS dissipation is likely to occur.

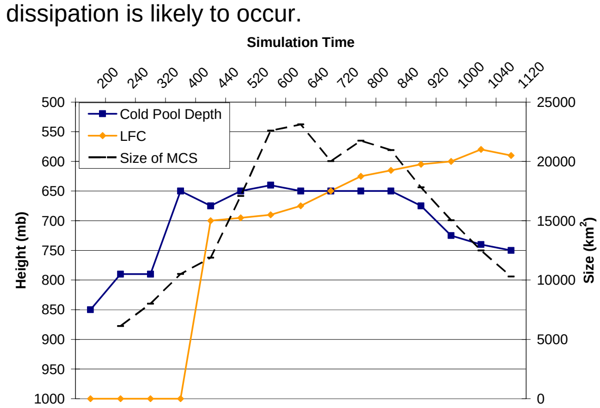

Figure 7: Time series of cold pool depth (given as pressure (mb) at the top of the cold pool, LFC height (mb) of the most unstable parcel ahead of the MCS, and MCS size (km^2) for the N-S line arrangement.

All systems in this study develop cold pools of similar depth regardless of the initial convective arrangement. Similarly, the environment out ahead of the systems is nearly identical given that they were initialized with the same sounding. These similarities help explain why the systems might have similar dissipation rates, assuming the cold pool depth and the LFC ahead of system are important factors in MCS dissipation. Many other MCS simulations (not shown here) have been performed with a slightly different sounding that did not capture MCS dissipation. In these simulations, the LFC of the most unstable parcel (elevated above the nocturnal boundary layer) never reached above 650 mb, which was below or near the top of the cold pool. Consequently, deep convection continued, and the systems never dissipated through the simulations.

5. SUMMARY AND CONCLUSIONS

In order to test the sensitivity of MCS development to the initial convective arrangement, several simulations initialized with unidirectional shear were performed using RAMS that differed only in the placement of warm, moist bubbles. The characteristics of the simulated MCSs were compared with one another to see if they supported the observation that MCSs developing from linearly-arranged convection at initiation tend to evolve toward larger, longer-lived, more severe, and rainier systems than those that develop from areally-arranged convection at initiation. Regardless of the convective arrangement at initiation, eastward-propagating elongated MCSs developed and dissipated in these simulations. Though the systems appeared qualitatively similar, a closer inspection revealed important differences among the systems: the simulated linear systems were larger, longer-lived, and rainier than the simulated areal MCSs.

Further analysis helped to understand the MCS lifecycle and explain the differences among the systems:

– The *arrangement of convective cells* at initiation primarily affects the *growth* rate of MCSs.
    - A linear arrangement (i.e., greater maximum horizontal scale) of convective cells generally leads to faster growing, larger MCSs, regardless of the orientation to low-level shear.
    - The horizontal extent of the cold pool normal to the low-level ambient shear typically levels off *before* the MCS reaches a maximum size.
– The *environment* tends to push the systems toward similarity, primarily affecting the *dissipation* rate of MCSs.
    - All systems develop cold pools of similar depth.
    - The MCSs dissipate after the LFC of the most unstable parcel ahead of the systems increases in height through the night to a level above the top of the cold pool.

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