17.3 SENSITIVITY OF MCS DEVELOPMENT TO THE INITIAL CONVECTIVE ARRANGEMENT

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1. INTRODUCTION

Forecasting mesoscale convective systems (MCSs) is very 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 whether the initial convective arrangement can be used as a MCS forecasting aid.

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. Since knowledge of the initial convective arrangement is known prior to MCS development, this information could be useful in making short-term forecasts about the impending impact of MCSs.

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, severity, and precipitation 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 3D simulations of MCS development. These simulations utilize a single grid with 1.5 km horizontal grid spacing over a 750 km by 600 km domain for a 12-h period. Thirty-five vertical levels are used with variable grid spacing, increasing from 100 m spacing at the lowest level to a maximum of 1 km. 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 the 0000 UTC 20 May 1998 sounding from North Platte, NE (LBF) (Fig. 1). This sounding represents a precursor environment capable of supporting a long-lived, eastward-moving, leading-line/trailing stratiform (TS) MCS. Favorable conditions for supporting MCS development are present, including veering winds and convective instability. The winds veer from easterly at the surface to westerly just above 500 mb, contributing to significant vertical shear over this layer. Additionally, the sounding is unstable with over 2000 J kg^{-1} of convective available potential energy (CAPE) and a lifted index (LI) of -7.

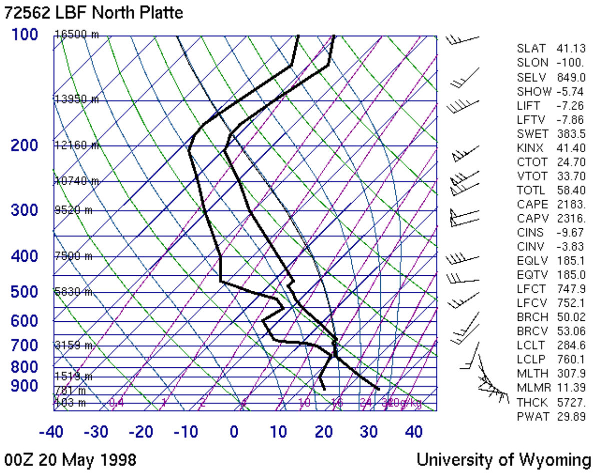

Fig. 1: 0000 UTC sounding from LBF on 20 May 1998.

Convection is initiated using warm (2-K temperature perturbation), moist (20% moisture perturbation) rectangular “bubbles” that extend 10.5 km in each horizontal direction. Each bubble has a minimum spacing of 30 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, severity, and precipitation of the simulated MCSs are analyzed and compared to determine the influence that the initial convective arrangement has on general MCS characteristics.

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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, so a detailed examination is required to highlight the differences. Each MCS reaches a similar maximum size (see Figs. 2 & 3), but the initial N-S linear convective arrangement results in a MCS about 10% larger than the other systems. Additionally, the MCS initiating from the N-S convective line dissipates more slowly than the other systems after it reaches its maximum extent. 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. 3d). Regardless of the change in orientation, this MCS has the fastest growth rate and reaches a maximum size before the other systems (see Fig. 2). The MCSs that develop from areal arrangements (i.e., square and diamond; Figs. 3b & 3c) dissipate more rapidly than MCSs that develop from linear arrangements. This dissipation occurs on the northern end of the areal systems after 9 h, resulting in the MCSs losing contiguity. As a result, the areal MCSs have a shorter duration in these simulations than the linear MCSs. For example, selecting 20 000 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 over 5 h. The system initiating from the N-S convective line does not fall below the size criterion before the simulation ends; thus, it clearly is the longest-lived MCS. Overall, these simulations agree with observations of areal vs. linear MCSs: areal MCSs tend to be smaller and shorter-lived than MCSs that develop from a line of convective cells.

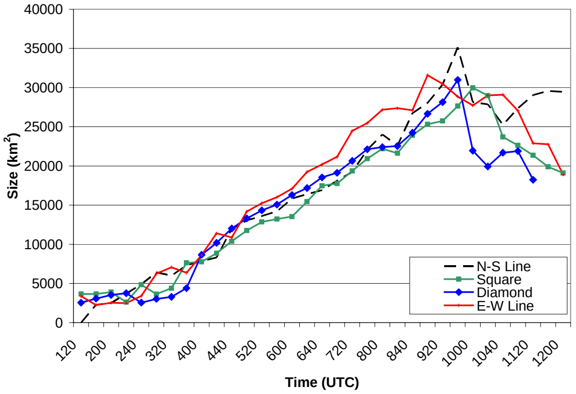

Fig. 2: Time series of MCS size for each of the four initial convective arrangements. The size is given by the area of vertically-integrated condensate >4 mm.

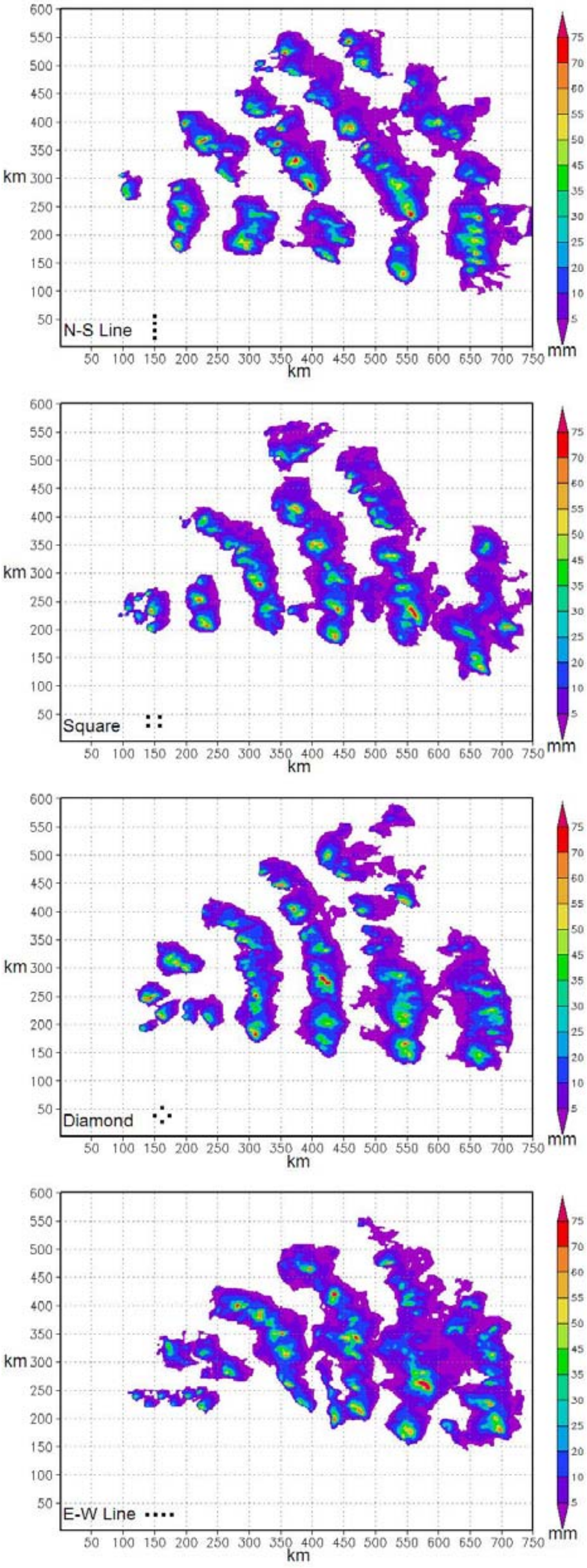

Fig. 3: MCS lifecycle displayed as vertically-integrated condensate every 2 h (0120-1120 UTC) for the different initial convective arrangements.

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 eight hours, the accumulated precipitation is similar for all of the systems. After that point, the disparity in size and longevity results in significant differences in accumulated precipitation by the end of the simulations. The N-S line produces the most precipitation averaged over the entire domain followed by the E-W convective line. The areal convective arrangements generate the least amount of precipitation. A difference of 300 000 acre-feet (~15%) in accumulated precipitation may not seem like a significant amount, but it is equivalent to about 10 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.

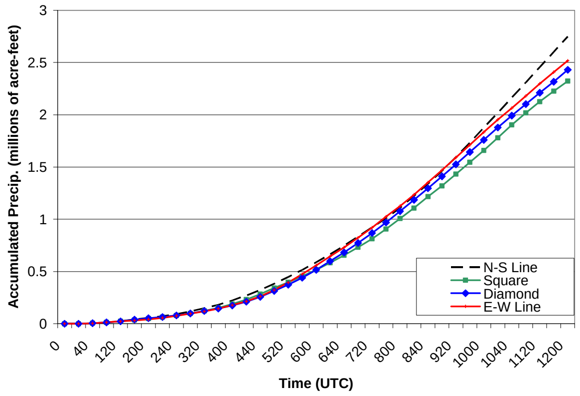

Fig. 4: Surface accumulated precipitation for the four initial convective arrangements.

3.3 *Severity*

Lastly, the systems are examined for their potential to generate severe weather. The model does not produce a significant amount of hail that reaches the surface, so a meaningful investigation of hail production by these MCSs is not possible. A couple of parameters are investigated with regard to the severity of systems: surface wind speed (Fig. 5) and vertical velocity (Fig. 6). All of the systems produce comparable maximum surface wind speeds on the order of 25-30 m s^{-1} throughout their lifecycles (see Fig. 5). The N-S line produces the strongest gusts early on while the areal systems produce their strongest winds later in the simulations. All of the systems appear to be capable of generating severe surface winds. The maximum vertical velocities of the MCSs are also comparable, typically around 15-20 m s^{-1} at 700 hPa (see Fig. 6). After the convection organizes into a MCS (i.e., after 0500 UTC), the MCSs that develop from a line of convection generally show larger vertical velocities than the areal systems. The E-W line in particular shows strong upward motion through the later stages of the simulation. These results do not confirm that line systems are more severe than the areal systems, but it does demonstrate the potential for these systems to be more severe.

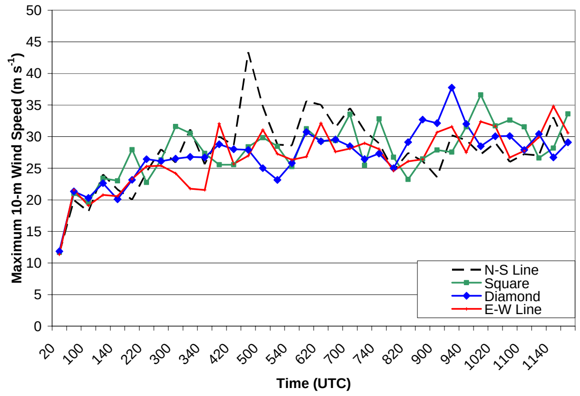

Fig. 5: Time series of the maximum 10-m wind speed for the four initial convective arrangements.

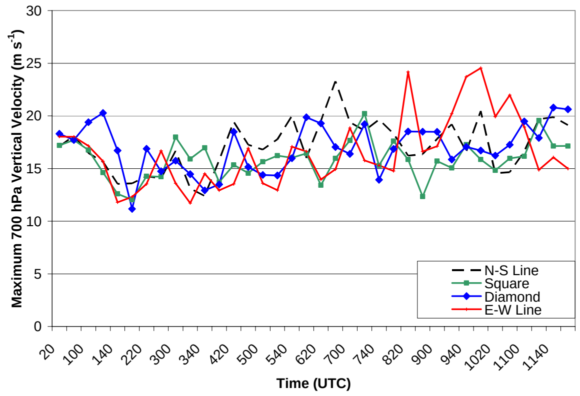

Fig. 6: Time series of the maximum 700 hPa vertical velocity for the four initial convective arrangements.

4. ANALYSIS OF 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 examining 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 (15.5 m s^{-1}; 210°) is used in the analysis. This low-level south-southwesterly shear influences storm evolution and differences among the systems.

The horizontal extent of the gust front normal to the ambient shear provides some information pertinent to MCS development (Fig. 7). The E-W line initially has the longest gust front normal to the ambient shear, which may explain its faster growth rate (c.f. Figs. 2 & 7). Another significant feature of all of the systems is that the horizontal extent of the cold pool normal to the ambient shear maximizes and levels out about 2 h before the MCS reaches its largest size (c.f. Figs. 2 & 7). Perhaps this information could be useful in forecasting when a MCS will likely reach its maximum size. Additionally, the N-S line produces a cold pool with a similar horizontal extent as the other systems until 0720 UTC when it starts to generate a much longer gust front perpendicular to the low-level shear. Accordingly, it becomes the largest MCS about 2 h later and remains relatively large through the end of the simulation (see Fig. 2).

Examination of the precipitation and cold pool evolution for each system provides additional information about MCS development (Fig. 8). The arrangement of convection in a N-S line results in the development of non-contiguous precipitation (see Fig. 8a). Consequently, a larger cold pool develops by 0720 UTC with a greater extent normal to the ambient shear. In fact, a large portion of the leading edge of the cold pool is arranged as a line nearly perpendicular to the ambient shear. The areal systems (Figs. 8b & 8c), on the other hand, produce a more contiguous area of precipitation initially which leads to a stronger cold pool, resulting in an acceleration of the gust front (e.g., compare location of gust front at 0720 UTC in Figs. 8a & 8b). Additionally, the gust front becomes more curved for the areal systems, resulting in a smaller extent normal to the ambient shear. The E-W line of convection (Fig. 8d) undergoes more rapid growth early on due to the favorable orientation of the cold pool to the south-southwesterly shear. As the contiguous area of precipitation strengthens the cold pool, the leading edge becomes oriented in a less favorable N-S direction, ultimately resulting in the dissipation of the system. Throughout the lifecycle of these MCSs, the extent of the leading edge of the cold pool normal to the ambient shear appears to have a strong influence on the system development.

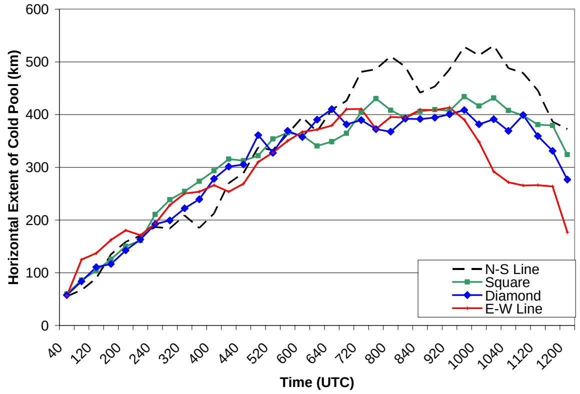

Fig. 7: Approximate horizontal extent of the gust front where the magnitude of the 0-3 km ambient wind shear normal to the leading edge of the cold pool is ≥5 m s^{-1} for the four initial convective arrangements.

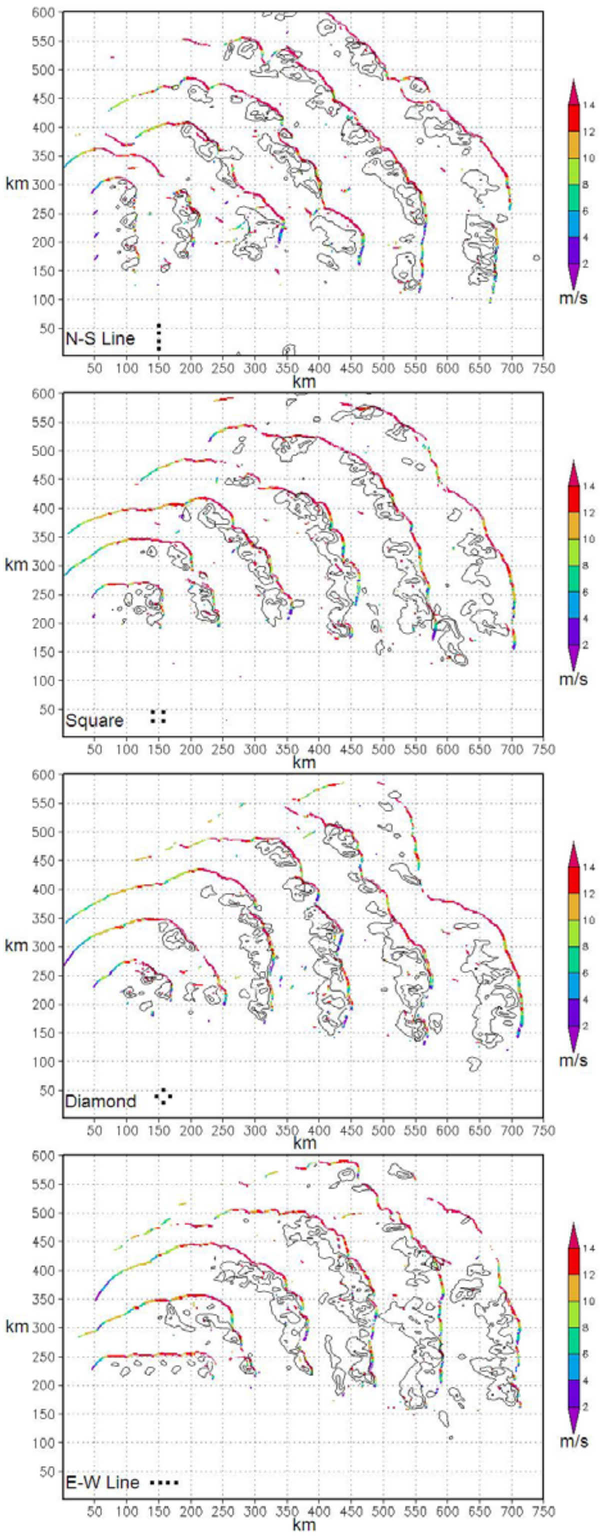

Fig. 8: MCS lifecycle displayed as surface precipitation rate (contoured at 5, 20, & 80 mm h^{-1}) and the magnitude of the 0-3 km shear normal to the gust front (shaded) along the leading edge of the cold pool every 2 h (0120-1120 UTC) for the different initial convective arrangements.

5. SUMMARY AND CONCLUSIONS

In order to test the sensitivity of MCS development to the initial convective arrangement, several simulations 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 in these simulations. Though the systems appeared qualitatively similar, a closer inspection revealed important differences among the systems. The simulated linear systems, especially the N-S line, were larger, longer-lived, and rainier than the simulated areal MCSs. Further analysis showed that the horizontal extent of the leading edge of the cold pool normal to the ambient shear influenced MCS development and overall system characteristics. In fact, the maximum horizontal extent of the cold pool normal to the ambient shear occurred a couple of hours *before* each system reached a maximum size. Thus, the initial arrangement of convection may have some MCS forecasting value to the extent that the given arrangement produces a cold pool having a favorable orientation with respect to the ambient shear.

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