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THE INFLOW ENVIRONMENTS OF CELLULAR AND SLABULAR CONVECTIVE LINES

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1. INTRODUCTION

One of the most common modes of mesoscale organization of deep convection is the quasi-linear convective system, or "squall line". Documented features of many squall lines include a surface-based cold pool, a trailing stratiform region, and a mid-level rear inflow jet. The convective region of a squall line, composed of intense updrafts and downdrafts, is located close to the downshear edge of the surface-based cold pool. In radar imagery, the convective region is usually observed as a conglomerate of convective elements and covers an area whose dimensions are significantly greater in the along-line than the cross-line direction.

Great variability from case to case, however, is observed in the organizational mode of the convective elements. In some instances, the convective region resembles a continuous swath of high reflectivity (a "slab") that is roughly two-dimensional in the along-line direction (Fig. 1a). Other squall lines contain discrete high-reflectivity cores ("cells") arranged in a linear manner, with low reflectivity between the cores (Fig. 1b). Many other squall lines do not fall into either the "slab" or the "cell" category, with line segments, arcs, partially-merged cells, or disorganized convection composing the bulk of the convective region. An evolution over time from one mode to another is also commonly observed.

This study sampled representative inflow environments of the two ends of the organizational spectrum described above, i.e. "cellular" and "slabular" convective lines, with the expectation of finding differences in the thermodynamic and/or kinematic environments that may be responsible for the variety of convective-scale organizational modes.

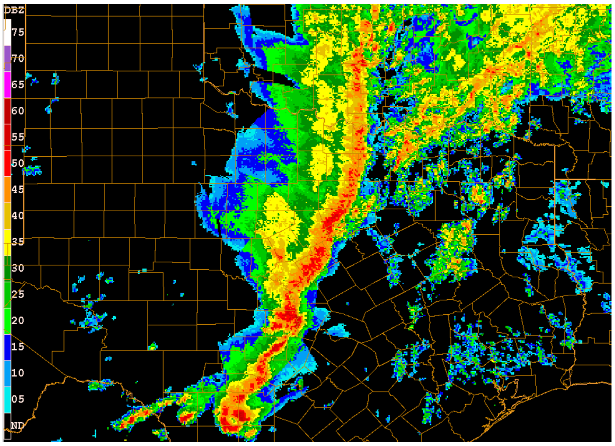

Figure 1(a) A “slabular” convective line.

2. METHOD

Composite radar reflectivity imagery for the contiguous United States was examined on a daily basis from October 2001 through September 2002. Every persistent, coherent convective line that was in existence within two hours of the primary sounding release times of 1200 UTC and 0000 UTC was examined. A number of convective lines that occurred prior to October 2001, for which data were available, were also examined. The mode of convective-scale organization within the convective region was noted, and the event was selected for inclusion in the study if the convective elements were organized in a distinctly cellular or slabular manner. For a system to be classified as slabular, the convective region was required to exhibit an unbroken swath of reflectivity greater than 40 dBZ, whose along-line dimension was at least five times that of the across-line dimension. This criterion must have been satisfied for at least one hour continuously. The cellular cases were characterized by at least three cells with core reflectivity greater than 40 dBZ, organized in a linear manner. The cells were required to be distinct from one another, and to show no tendency to become more slab-like over time. However, no strict constraint was placed on their separation or the level of the reflectivity between cells.

Reports from the synoptic radiosonde network were examined for each of the chosen convective events, in an attempt to obtain a sounding within a representative inflow environment for each case. Any sounding that was released ahead of and within 150 km

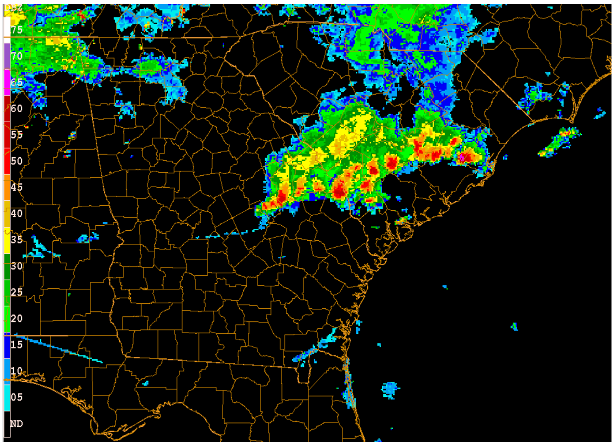

Figure 1(b) A cellular convective line.

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of the line was used, with one exception: all soundings that exhibited a stable layer near the ground were discarded. Such a stable layer may have resulted from cold outflow due to pre-existing convection or the presence of cold marine air at low levels; these soundings were regarded as representing the environment of elevated convection, which was not of interest in this study. In one instance, a sounding was included whose distance from the convective line was undetermined, because the line formed a short time after the sounding release time, but it was considered that the environment sampled was representative. No constraint was placed on how close to the line the sounding was permitted to be; the closest instance was a sounding released 34 km from the center of the radar-observed convective region.

Of the cases that occurred in combination with a representative sounding, ten cellular and ten slabular events were selected to construct two composite soundings. The ten most cellular and the ten most slabular cases were subjectively chosen, based solely on their appearance in radar imagery, in order to sample the two ends of the organizational spectrum described in Section 1. The soundings corresponding to these events were then composited; care was taken to preserve significant features, following the methodology of Brown (1993). Kinematic features that were identified in every sounding and preserved in the compositing process were low-level maxima in both the line-parallel and line-perpendicular components of the wind. In the thermodynamic profiles, the top of the surface-based mixed layer was the only feature identified as present in almost all cases. No mixed layer was evident in two slab cases, and in these instances the top of the mixed layer was taken to be at the ground for the purpose of compositing

High-resolution simulations using the cloud-resolving numerical model of Bryan and Fritsch (2002) were initialized with the two composite soundings. A line of warm, moist bubbles was introduced to the initially horizontally homogeneous base state, in a domain with dimensions 300 x 60 km. The horizontal and vertical grid spacings were 1000 m and 500 m respectively. It was found that both of the composites were able to maintain, but not to initiate, a strong, long-lived convective system. Therefore both the slab and cell composites were modified by deepening the mixed layer to 2.25 km, in order to initiate convection. Beginning at three hours into each simulation, once the squall line had developed a strong surface-based cold pool and mesoscale pressure perturbations, the unmodified thermodynamic profiles were gradually advected into the domain from ahead of the convective line. In both cases, by six hours into the integration, the squall line had adjusted to the new environment and continued to persist as a mature, long-lived system.

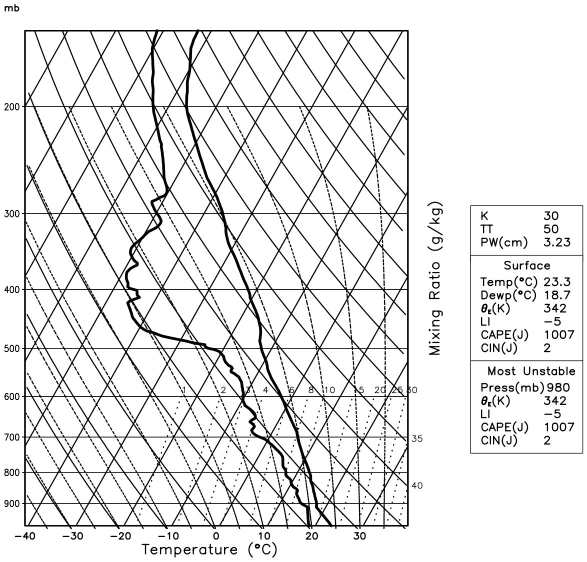

Figure 2 (a) Slab composite skewT-logP diagram.

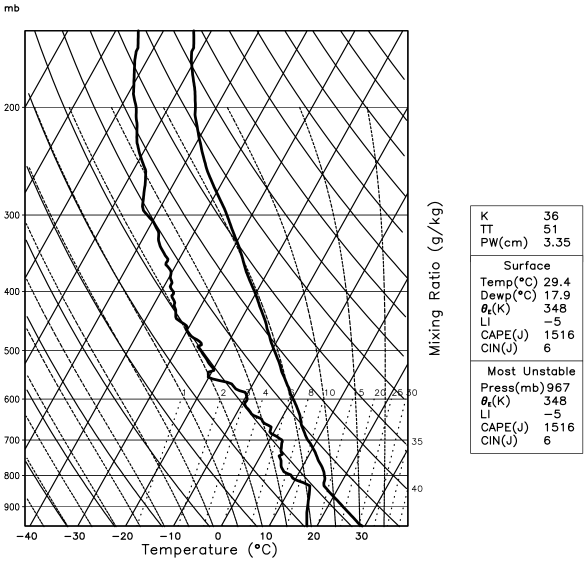

Figure 2 (b) Cell composite skewT-logP diagram.

3. RESULTS AND DISCUSSION

The composite soundings representative of the inflow environments of the slab-like and cell-like systems are shown in Figures 2 and 3. The most striking difference between the thermodynamic profiles is that the surface-based mixed layer is much deeper, and the lifting condensation level (LCL) is almost 100 hPa higher, in the cell composite. The surface relative humidity for the cell cases is 50 %, compared to 75 % for the slab environment. Despite the drier low levels, however, the CAPE is about 50 percent higher in the cell composite than in the slab composite. Each of these differences may be explained partially by the tendency for some slab cases to be observed in the morning hours (1200 UTC), whereas every one of the cell cases was observed in the early evening (around 0000 UTC).

Another noticeable difference between the thermodynamic profiles is the vertical distribution of moisture. The slab environment exhibits very moist low

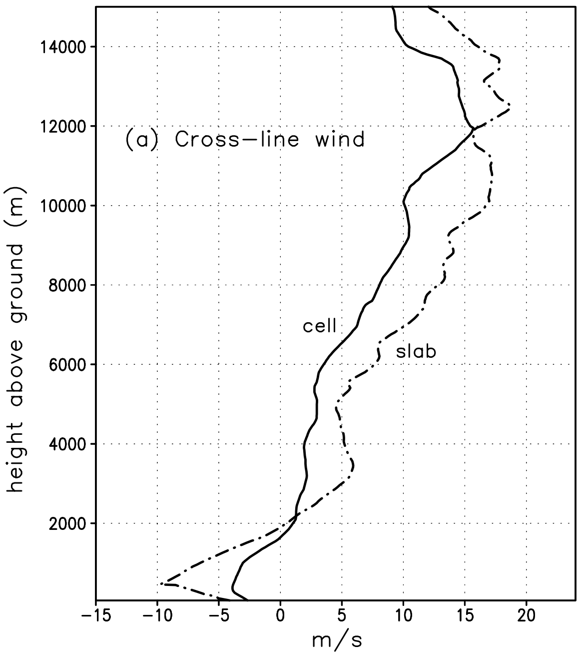

Figure 3 (a) Line-perpendicular wind components (m s^{-1}) in the slab and cell composites, plotted against height above ground level (m).

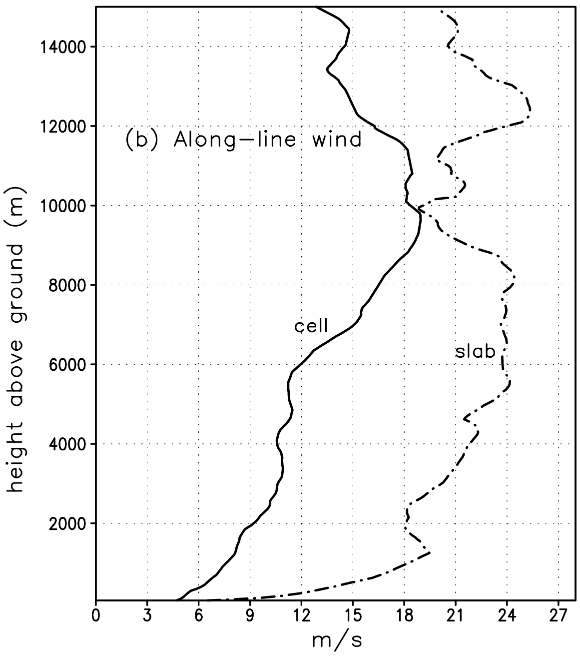

Figure 3 (b) As in Figure 3 (a), but for the line-parallel wind components.

levels (up to 500 hPa) and a pronounced dry layer between 500 hPa and 300 hPa. In contrast, the cell composite shows a gradual drying trend with increasing altitude, up to about 400 hPa.

The composite kinematic profiles also show distinct differences in both the line-parallel and line-perpendicular components of the wind (Fig. 3). For the slab cases, the line-perpendicular component exhibits strong low-level shear of about 15 m s^{-1} over 2.5 km. This is close to the value considered optimal for the existence of strong, long-lived squall lines in the simulations of Weisman, Klemp and Rotunno (1988). There is also very strong low-level shear, almost 10 m s^{-1} over 1.0 km, in the line-parallel wind component. The low-level shear is much weaker, about 5-6 m s^{-1} over 2.5 km in both wind components, in the cell composite. The absolute magnitude of the along-line wind is also much weaker through most of the troposphere in the cell environment.

The relatively weak shear in the cell environment extends throughout the troposphere in both the line-parallel and line-perpendicular components of the wind. In contrast, the slab environment contains little shear in the along-line wind above 1 km. The cross-line wind for the slab cases contains a 2 km deep layer of slight reverse shear between 3 and 5 km above ground level, and about 12 m s^{-1} of shear from 5 to 10 km.

Figure 4 demonstrates that the contrast between the composite kinematic profiles is accentuated when the line-perpendicular wind component is calculated in a line-relative sense. The mean ground-relative propagation speed of the slab cases (14.2 m s^{-1}) was much higher than for the cellular lines (6.0 m s^{-1}). On average, line-relative inflow was observed up to about 9 km above ground level in the instances of slab-like convection.

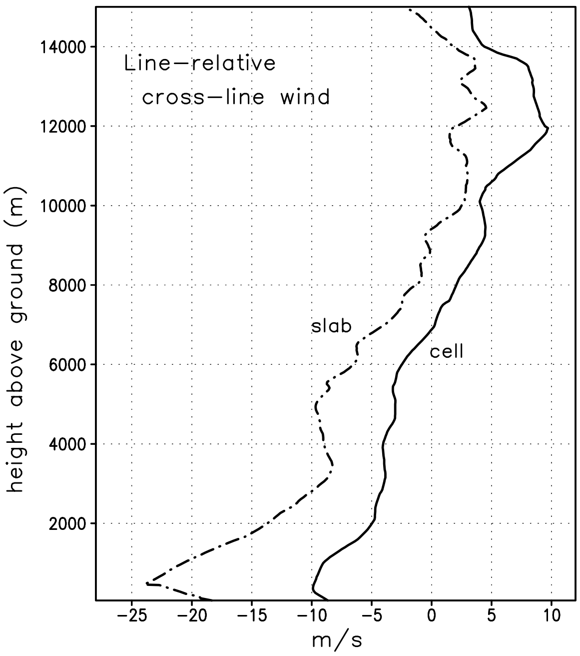

Figure 4 Line-perpendicular wind components (m s^{-1}) in a line-relative reference frame, for the slab and cell composites.

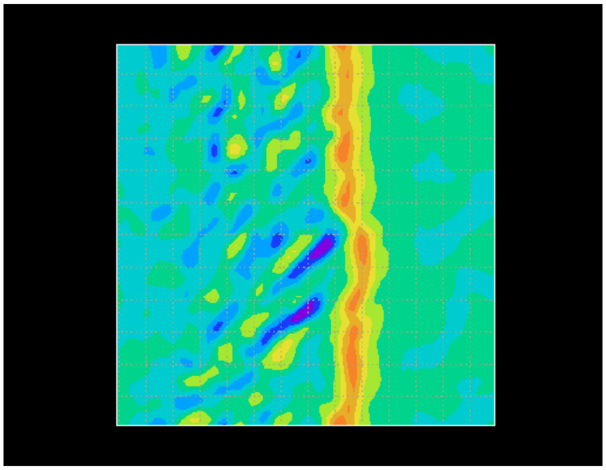

Figure 5 (a) Vertical velocity at 1.75 km above ground level for the slab simulation, 9 hours after initiation. Shading interval is 1 m s^{-1}; darkest orange corresponds to 4 m s^{-1}. Dotted grid shows 5 km intervals.

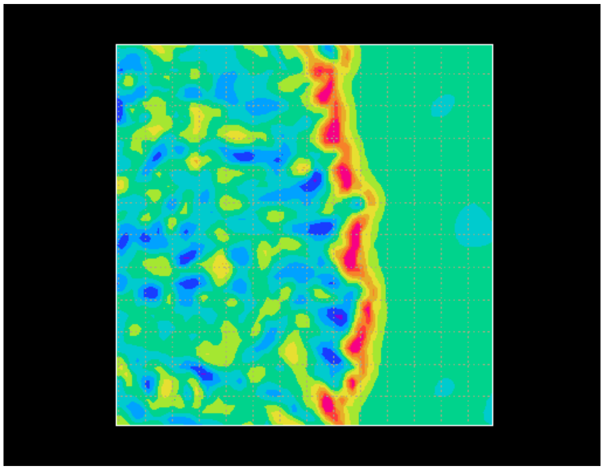

Figure 5 (b) As in Figure 4 (a) but for the cell simulation. Bright pink corresponds to vertical velocity greater than 6 m s^{-1}.

The existence of a distinct low-level jet in the slab composite is consistent with the well-known concurrence of mesoscale convective systems with low level jets (Maddox 1983, Laing and Fritsch 2000). The jet provides a large transport of moist, unstable air into the convective system and often allows strong convective overturning to persist into and sometimes throughout the night, even as the surface-based mixed layer cools. It is notable that not a single cellular line was observed near the morning sounding release time (1200 UTC), while four of the ten slab cases were observed in the morning hours. We suspect that this result is related to the forced mesoscale ascent caused by the interaction of the jet with the convectively-generated cold pool (Bryan and Fritsch 2000).

The characteristics of the convective systems produced by our preliminary simulations with the numerical model are briefly illustrated in Figure 5. In both cases, the leading edge of the advancing cold pool generated strong ascent. In the squall line produced by the slab composite, the lifting exhibited little along-line variability and appeared almost two-dimensional; the cellular composite gave rise to low-level ascent with more along-line variability and larger peak magnitudes.

4. CONCLUSIONS

A compositing approach has been used to demonstrate that significant differences exist between the inflow environments of cell-like and slab-like convective lines. The thermodynamic profile ahead of a two-dimensional (“slabular”) line typically has a shallow (or non-existent) surface-based mixed layer with a low LCL. The slab environment is also characterized by strong low-level shear in both the line-parallel and line-perpendicular components of the wind. In contrast, long-lived lines of discrete cells usually form in environments with a deep mixed layer, a higher LCL, and winds that are relatively weak in absolute magnitude and in shear.

Preliminary high-resolution numerical simulations suggest that it may be possible to reproduce the contrasting convective modes observed with the slab and cell environments. Further experimentation with higher resolution simulations will be performed in order to investigate the mechanisms responsible for these diverse modes of convective-scale organization.

5. ACKNOWLEDGMENTS

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