Conceptual Models for Origins and Evolutions of Convective Storms

Advanced Warning Operations Course

IC Severe 1

Lesson 4: Organized Multicell Storms

Warning Decision Training Branch

The title for the instructional component is "**Conceptual Models for Origins and Evolutions of Convective Storms"** . This is the first instructional component in the AWOC Severe Track. Lesson 4 will be on conceptual models for organized multicell storms.

Lesson 4 Learning Objectives

1. Identify 3 distinct modes of linear Mesoscale Convective Systems.
2. Identify the primary factors influencing the evolution of organized multicell storms.
3. Identify the role of storm-relative winds on multicell storm propagation.
4. Identify the effects of cold pool strength in squall line evolution.
5. Determine the role of the rear-inflow jet on squall line longevity.

These are the learning objectives in this lesson.

Lesson 4 Learning Objectives

6. Distinguish between the effects of positive shear and cold pool lifting based on RKW theory.
7. Identify the effects of instability on multicell propagation.

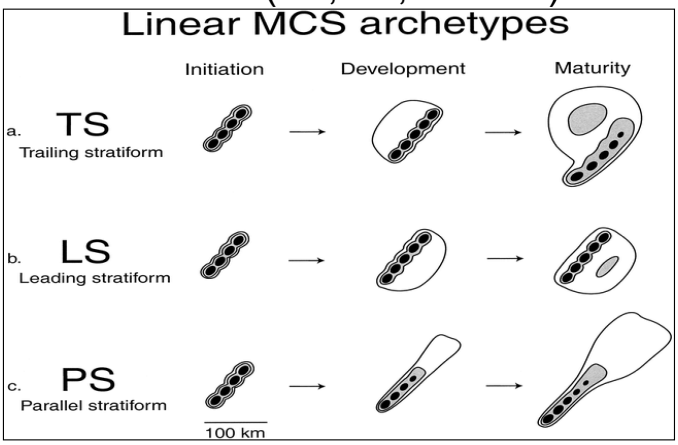
Multicell Storms

- Morphology and evolution of organized wind storms in multicells
- Environment of organized multicell wind storms
- References

Damaging wind storms can occur from supercells and even pulse (or ordinary) storms, but the majority of damaging events occur from organized multicell systems. We will discuss some of the factors influencing the morphology and evolution of organized wind storms in multicells.

Morphology and Evolution

- Role of air flows in complex multicell system
  - 3 distinct modes (TS, LS, and PS)



Parker and Johnson (2000)

This is Parker and Johnson's (2000) schematic reflectivity drawing of idealized life cycles for three linear MCS archetypes: (a) TS, (b) LS, and (c) PS. Approximate time intervals between phases: for TS 3–4 h; for LS 2–3 h; for PS 2–3 h. Levels of shading roughly correspond to 20, 40, and 50 dBZ. Their study found that there exists three distinct modes of linear MCSs: trailing stratiform (TS, 60% of the cases), leading stratiform (LS, 20% of the cases), and parallel stratiform (PS, 20% of the cases).

The TS MCSs experienced front-to-rear storm-relative winds throughout their depth, moved rapidly, and were the longest lived of the three classes. The LS MCSs experienced weak middle- and upper-tropospheric rear-to-front storm-relative winds, moved slowly, and persisted for approximately half as long as TS MCSs. The PS MCSs experienced significant middle- and upper-tropospheric line-parallel storm-relative winds, moved more rapidly than LS MCSs but less rapidly than TS MCSs, and persisted for approximately half as long as TS MCSs. At some point in their life cycle, a majority of MCSs evolve toward TS structure. The synoptic conditions associated with linear MCSs in this study largely resembled those discovered by previous authors (e.g., Maddox, 1983, Bluestein and Jain, 1985, Kane et al. 1987). In addition to a nocturnal maximum in linear MCS frequency, a secondary near-sunrise mode existed similar to that documented by Geerts (1998).

One case study suggests that for PS MCSs, the orientation of a linear trigger to the tropospheric wind profile may be of first-order importance, while another suggests that LS MCSs may be sustained in a variety of ways, including inflow from the rear.

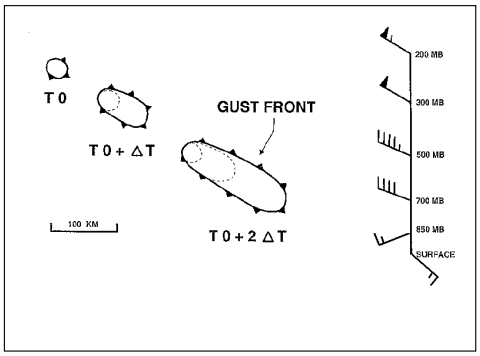
Factors Influencing Evolution of Organized Multicells

- Environmental winds (all levels)
- Storm-relative wind distribution
- Cold pool strength
- Orientation of gust front relative to storm low-level inflow
- Instability gradients
- Boundary interactions

As you can see, there are multiple mechanisms governing movement and subsequent evolution of multicells.

Effects of Cloud Bearing Wind

- Affects gust front speed and resulting system movement

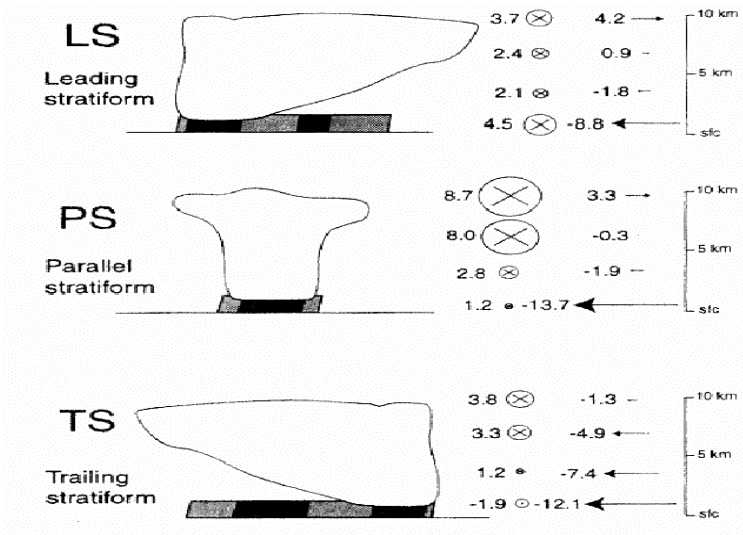


From Corfidi (2003)

The strength of the mean wind helps determine motion and stratiform precipitation distribution. The mean cloud layer winds help to advect systems downstream. Propagation effects are a result of many factors which we will discuss later.The strength of the environmental winds and resulting cold pool speed determines to a large degree the intensity and longevity of the multicell system.

Evans and Doswell (2000) also showed a relationship between mean winds in the 0-6 km layer and the 0-2 km system-relative inflow when trying to distinguish between derechoes and non-derecho multicell systems. Observations have shown that new cell development most often occurs where the ambient low-level inflow relative to the boundary is greatest. This is where low-level convergence is maximized. Often, this is the region that is governed by the position of the low-level jet. Even when the low-level jet is not favorably positioned away from the boundary, if sufficient relative motion exists between a gust front and the low-level environmental wind, convergence maxima may develop. Propagation in the downwind direction may result if surface based instability is present as well. Momentum transfer also contributes to gust-front motion and speed.

Effects of Storm-Relative Flow



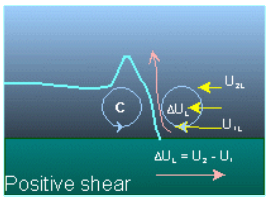
From Parker and Johnson (2000)

From Parker and Johnson's study, vertical profiles of layer-mean storm-relative pre-MCS winds for linear MCS classes. Wind vectors depicted as line-parallel (X) and line-perpendicular (arrows) components in m s^{-1}. Layers depicted are 0–1, 2–4, 5–8, and 9–10 km. Typical base scan radar reflectivity patterns (shading) and hypothetical cloud outlines are drawn schematically for reference. MCSs' leading edges are to the right.

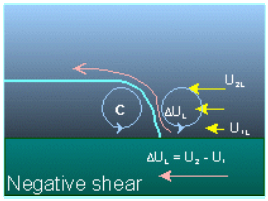
For each linear MCS, they selected nearby NPN wind profiles from three times at which the reflectivity structure best resembled the case's predominant organizational archetype. These profiles were then composited to produce mean wind fields for each linear MCS mode. The TS cases' mean line-perpendicular storm-relative wind components, as constructed from the profiler data, were significantly different from those of the LS and PS classes. The TS class mean exhibited negative line-perpendicular storm-relative winds at every level. Above 2 km, TS cases exhibited significantly larger rearward storm-relative winds than those observed for the LS and PS classes. This result is consistent with rearward advection of hydrometeors by the mean flow, which has been argued to explain trailing stratiform precipitation regions (Houze et al., 1990). In contrast, the LS and PS classes were nearly indistinguishable from one another in most of the line-perpendicular fields, exhibiting weak middle-tropospheric storm-relative winds and modest rear-to-front storm-relative winds at upper levels. The notable exception was the 0–1-km layer, in which the magnitude of line-perpendicular flow for the PS cases was, on average, greater than that of the TS cases. The lower-tropospheric line-perpendicular winds near PS cases were quite strong within a shallow layer. Above 2 km, PS MCSs exhibited deep line-parallel storm-relative flow, such that the middle-tropospheric advection of hydrometeors was largely along the line. In the 5–8-km layer, in which Rutledge and Houze (1987) found bulk transport of MCS hydrometeors to be focused, PS cases exhibited almost purely line-parallel storm-relative winds. The line-perpendicular storm-relative winds attending LS cases were not remarkably distinct from those in PS cases, although the line-parallel winds were much weaker. Thus, in LS cases there was a greater average rear-to-front component of the storm-relative flow aloft, which may help to explain the forward advection of hydrometeors. The 5–8- and 3–10-km mean line-perpendicular storm-relative winds were by far the most statistically significant differentiators among the three classes in this study, suggesting that the middle- and upper-tropospheric storm-relative flow field is of primary importance in determining the organizational mode of linear mesoscale convection.

Cold Pool Effects
RKW Theory

- Positive shear case
  - Promotes deeper lifting along downshear side



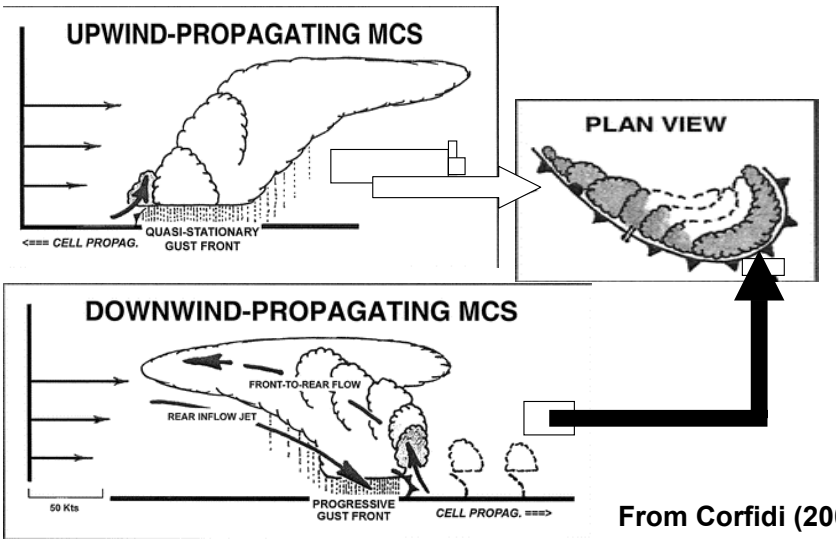
- Negative shear case
  - Decreases net lifting



Adapted from COMET (1996)

In the framework of RKW theory (Rotunno, Klemp and Weisman), new cell growth is favored on the downshear side of a multicell cold pool. The depth of the shear layer needs to be calculated when considering this theory in operations.

Cold Pool Effects Movement of Systems



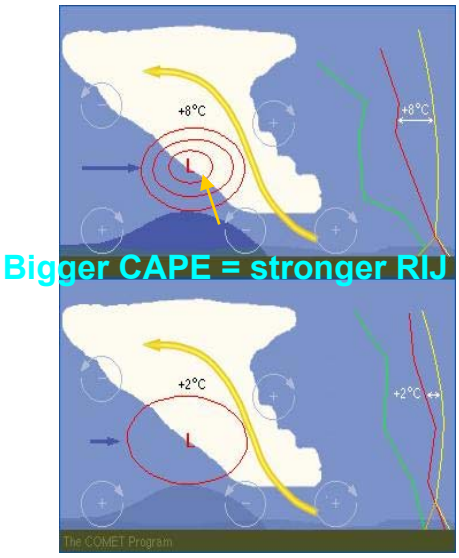
From Corfidi (2003)

Main points from Corfidi (2003) were:

- A cold pool will elongate in the direction of the mean cloud-layer wind as a result of momentum transfer.
- The degree of elongation increases as the wind profile becomes more unidirectional, and this effect occurs on all time- and space scales.
- Propagation, or new cell development relative to existing storms, occurs most readily on the periphery of the cold pool (i.e., along those portions of the gust front), where the relative inflow is strongest and where surface-based convective instability is present.
- Upwind-developing MCSs are most favored along quasi-stationary (mean flow parallel) portions of the gust front, and
- Downwind-developing MCSs are favored on the more progressive (mean flow perpendicular) parts of the boundary.
- Thermodynamic factors modulate the role played by gust-front orientation and motion: a) upwind-developing environments are characterized by comparatively moist conditions through the low to midtroposphere and, therefore, relatively weak convective-scale downdrafts, and (b) downwind-developing environments are characterized by comparatively dry conditions at midlevels and/or in the subcloud layer and, therefore, a tendency to produce strong convective-scale downdrafts.

Role of Rear-Inflow Jet (RIJ)

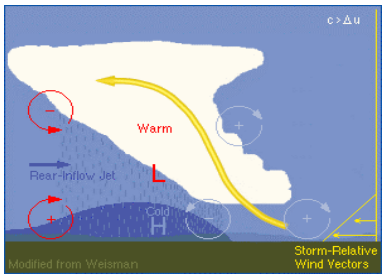
- Produced by perturbation hydrostatic pressure gradients from buoyancy differences across the updraft, esp. in anvil
- Rear to front flow orientation
- Modulated by strength of cold pool and shear

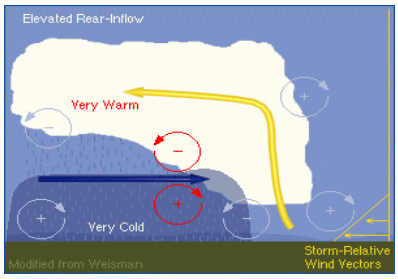


Stronger RIJ is due to larger CAPE, steeper lapse rates, larger theta-E differences from surface to midlevels. Given the same buoyancy for updrafts and cold pools, shear can help to modulate the intensity of the RIJ. Thus, according to Weisman's numerical simulations, the longevity of a squall line depends on the rear-to-front slope of the RIJ. This has not been verified operationally.

RIJ Schematic

- Results in upshear tilted structure
- If RIJ remains elevated, it can help to restore balance of cold pool with environmental shear and allow squall line updraft to remain vertically erect for longer periods (Weisman, 1993).

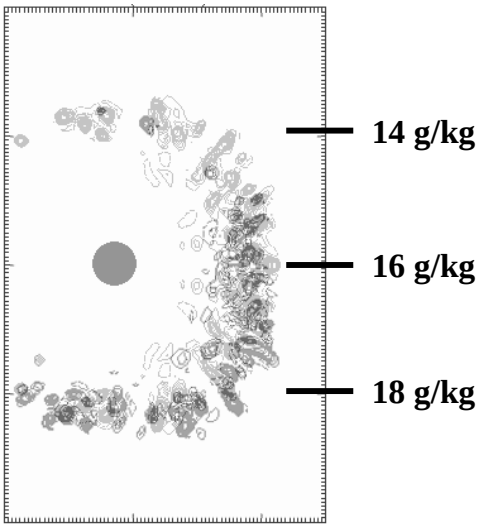




More on the MCS web site at http://meted.ucar.edu/convectn/mcs/

Instability Effects

- Instability effects
  - Can modulate propagation of multicells toward areas of higher instability

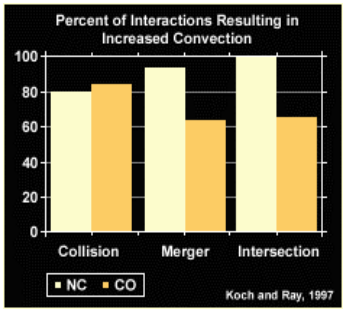


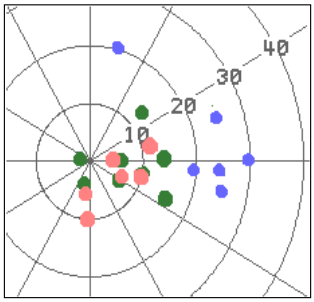
From Richardson (1999)

Simulated storms moved toward higher areas of low-level moisture and I suspect, greater instability. Surface based instability has been shown to influence MCS movement.

Boundary Interactions

- Modulates/enhances development of new convection



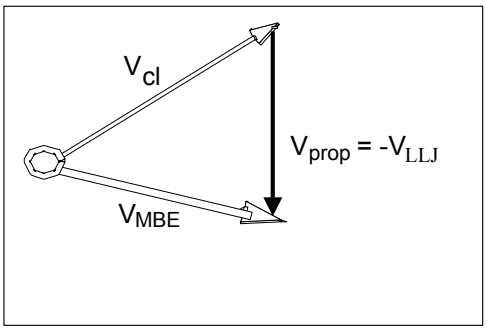


Blue = steering layer flow
Green=triple pt motion
Red = multicell motion
(Weaver, 1979)

Boundary location can override the other factors by modulating the convergence.

Quantifying Effects of Propagation

Quantifying propagation of multicells (after Corfidi, 1996 and 2003)

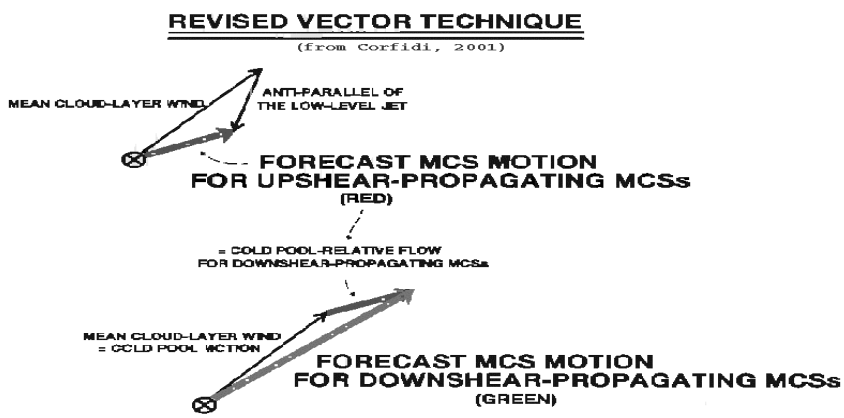


This technique works well for backbuilding events

The V_{prop} is the anti- parallel vector of the low-level jet. V_{mbe} is the resulting movement of the mesoscale beta element – centroid of the MCS.

Quantifying Effects of Propagation

- For Forward Propagation (Corfidi, 2003)



For forward–propagating MCSs, you need to take into account the cold pool relative flow. This makes the resulting forecast Vmbe motion much larger.

Summary

- Organized multicell storms
- Review objectives
  - Morphology and evolution of organized multicells
  - Environment
  - Multiple factors influencing organization and evolution

The objectives for this lesson are:

1) Identify 3 distinct modes of linear Mesoscale Convective Systems.
2) Identify the primary factors influencing the evolution of organized multicell storms.
3) Identify the role of storm-relative winds on multicell storm propagation.
4) Identify the effects of cold pool strength in squall line evolution.
5) Determine the role of the rear-inflow jet on squall line longevity.
6) Distinguish between the effects of positive shear and cold pool lifting based on RKW theory.
7) Identify the effects of instability on multicell propagation.

References

- See handout reference list or refer to AWOC Severe Track web site

Severe Track IC 1
Lesson 4 References

Bluestein, H. B., and M.H. Jain, 1985: Formation of mesoscale lines of precipitation: Severe squall lines in Oklahoma during the spring. *J. Atmos. Sci*., 42, 1711-1732.

COMET , 1996: Anticipating convective storm structure and evolution. CD-ROM.

COMET, 1999: Mesoscale Convective Systems: Squall Lines and Bow Echoes. Online training module, http://www.meted.ucar.edu/convectn/mcs/index.htm.

Coniglio, M. C., and D. J. Stensrud, 2001: Simulation of a Progressive derecho using composite initial conditions. *Monthly Weather Review*, 129, 1593BB1616.

Corfidi, S.F., 2003: Cold Pools and MCS Propagation: Forecasting the Motion of Downwind-Developing MCSs. *Wea. Forecasting.*

____, J.H. Merritt, and J.M. Fritsch, 1996: Predicting the movement of mesoscale convective complexes. *Wea. Forecasting*, 11, 41-46.

Evans, J.S. and C. A. Doswell III, 2001: Examination of Derecho Environments Using Proximity Soundings**.** *Weather and Forecasting*: Vol. 16, No. 3, pp. 329–342.

Geerts, B,, 1998: Mesoscale convective systems in the Southeast United States during 1994-1995: A survey. *Wea. Forecasting*, **13**, 860-869.

Houze, R. A., B. F. Smull and P. Dodge, 1990: Mesoscale Organization of springtime rainstorms in Oklahoma. *Mon. Wea. Rev*., **118**, 613-654.

Junker, N. W. , R. S. Schneider and S. L. Fauver, 1999: Study of heavy rainfall events during the Great Midwest Flood of 1993. *Wea. Forecasting*, **14**, 701-712.

____, N. W. and R. S. Schneider, 1997: Two case studies of quasi-stationary convective during the 1993 Great Midwest Flood. *Natl. Wea. Dig.*, **21**, 5-17.

Kane, R. J., C. R. Chelius and J. M. Fritsch, 1987: Precipitation characteristics of mesoscale convective weather systems. *J. Climate Appl. Meteor*., **26**, 1345-1357.

Klimowski, B. A., M. J. Bunkers, M. R. Hjelmfelt, and J. N. Covert, 2003: Severe convective windstorms over the northern High Plains of the United States. *Wea. Forecasting,* 18, 502-519.

Maddox, R. A. 1983: Large-scale meteorological conditions associated with midlatitude mesoscale convective complexes. *Mon. Wea. Rev*., **111**, 1475-1493.

Parker, M. D. and R. H. Johnson, 2000: Organizational modes of midlatitude mesoscale convective systems. *Mon. Wea. Rev*., **128**, 3413-3436.

Przybylinski, R.W., 1995: The bow echo: observations, numerical simulations, and severe weather detection methods. Wea. Forecasting, 10, 203-218.

Richardson, Y.P., 1999: The Influence of horizontal variations in vertical shear and low-level moisture on numerically simulated convective storms. Ph.D. Dissertation, School of Meteorology, University of Oklahoma - Norman, 236 pp.

Rutledge, S. A., and R.A. Houze, 1987: A Diagnostic Modelling Study of the Trailing Stratiform Region of a Midlatitude Squall Line. *Journal of the Atmospheric Sciences*: Vol. 44, No. 18, pp. 2640–2656.

Weaver , J. F., 1979: Storm Motion as related to boundary-layer convergence. *Mon. Wea. Rev.,* **107,** 612-619.

Weisman, M. L., 1993: The genesis of severe, long-lived bow echoes. *J. Atmos. Sci.,* **50**, 645–670.