Conceptual Models of Mesoscale Convective Systems

Part 9
Definition

• A mesoscale convective system (MCS) is generally defined as an organized ensemble of convective elements, whose lifecycle is longer than that of the individual convective elements.

• From Houze (1993):
  “A cloud system that occurs in connection with an ensemble of thunderstorms and produces a contiguous precipitation area ~100 km in horizontal scale in at least one direction.”

• Remember that the time scale for mesoscale systems of this extent goes as $f^{-1}$ (~3 hr for midlatitudes) – earth’s rotation and ageostrophic advection important
Definition

- MCSs can occur worldwide and year-round taking different sizes and shapes.
- Largest systems can extend ~500 km in a horizontal direction and persist for ~20 hours.
- In general, these systems are too small to be captured by the routine upper-air sounding network, but too large to be represented by point observations.
- Pose a significant problem to modelers since the systems require models with a domain of several hundred kilometers, yet fine enough resolution to simulate individual thunderstorm elements properly.
Importance

- MCSs are significant rain-producing weather systems.
- In particular, Fritsch et al. (1986) found that MCSs account for 30-70% of the warm season precipitation in the central United States.
- MCSs also produce a broad range of severe convective weather events: strong winds, hail, tornadoes, lightning, and flooding.
- It is not uncommon for MCSs to result in 10s to 100s of severe weather reports.
Types

• Since “MCS” is a general classification, it can be divided into more specific classifications.
• The most commonly cited examples of MCSs include
  – Squall lines
  – Bow echoes
  – Mesoscale convective complexes (MCCs)
• These types of MCSs were independently discovered and named; thus, they are not necessarily mutually exclusive of one another.
• For example, a bow echo is a very specific subset of squall lines. Also, the internal convective structure of a MCC may be arranged as a squall line (or bow echo for that matter).
Types

• It’s important to understand how these systems are defined in order to identify them.
• Squall line – loosely defined as any convective line
  – Easiest to identify by radar, cloud shield can take numerous shapes
• Bow echo – convective line that becomes bowed at some lifecycle stage, convective arc
  – Identifiable by radar
• MCC – large (50,000 km$^2$), quasi-circular (eccentricity >0.7) system with a cold cloud shield (<=-52°C) that persists for more than 6 hrs
  – Solely classifiable by infrared (IR) satellite data
Example

Squall Line
Example

Bow Echo
Example

MCC
Example
Squall Line – MCC system
MCS Classification

• It’s easiest to identify and subsequently classify MCSs by their cold cloud shield characteristics (i.e., size, shape, and duration) – why?

• An objective non-overlapping MCS classification scheme based on IR satellite might be useful (Jirak et al. 2003)
  –MCC [from Maddox 1980]
  –Persistent elongated convective system (PECS) [from Anderson and Arritt 1997]: ecc. <0.7
  –Meso-β circular convective system (MβCCS): cold cloud shield 30,000 km² for >3 hrs
  –Meso-β elongated convective system (MβECS): same except ecc. <0.7
MCS Classification

MCC

PECS

MβCCS

MβECS

Cold cloud shield outline
MCS Classification

• Classification has also been done subjectively based on radar characteristics of MCSs
• Two common approaches of classification: organization and development
• These approaches have focused on squall lines, but only about half of MCSs have organized convective lines (Jirak 2002)
• Organization
  – Houze et al. (1990) identified the leading-line trailing stratiform (TS) structure as the most common organization of mature MCSs
  – Parker and Johnson (2000) also recognized leading stratiform (LS) and parallel stratiform (PS) as common arrangements
MCS Classification

Linear MCS archetypes

Initiation → Development → Maturity

a. **TS**
   Trailing stratiform

b. **LS**
   Leading stratiform

c. **PS**
   Parallel stratiform

[From Parker and Johnson (2000)]
MCS Classification

- Development
  - Bluestein and Jain (1985) identified common patterns of severe squall line formation
MCS Classification

–Jirak et al. (2003) expanded on this scheme to classify all MCSs by their development
MCS Classification

• In summary, when someone discusses a particular type of MCS, be aware of how that system was classified (i.e., what data was used, what lifecycle stage, etc.)

• We will now discuss the general environmental features that are conducive for the development and sustentation of MCSs

• We will also look in more detail at squall lines, bow echoes, and MCCs, as these systems have received the most attention in the literature
MCS Environments

• Since MCSs are comprised of individual convective elements (i.e., ordinary thunderstorms, multicell thunderstorms, and supercell thunderstorms), we might expect MCSs to form in similar environments:
  – Large CAPE (large lapse rates, significant low-level moisture)
  – Vertical wind shear (amount and depth helps determine structure of system)

• However, there must be additional features that favor the organization of convection into MCSs:
  – Downstream of weak, midlevel trough
  – Low-level jet (LLJ)—provides low-level warm air advection and moisture advection
Low-level Jet

• Most common at night as the boundary layer becomes decoupled due to formation of a surface inversion
• Found just above nighttime inversion – 850 mb maps are often used to assess LLJ
• Low-level southerly flow is enhanced by terrain sloping up toward the west
• Synoptic patterns can also affect the presence and strength of the low-level jet – warm sector is conducive to strong LLJ
Low-level Jet

[From Bonner (1968)]

[From Whiteman et al. (1997)]
U.S. MCS Climatology

- Most MCSs form in the lee of the Rocky Mountains in the late afternoon, evening
- They progress eastward with the prevailing westerly flow toward a favorable environment and reach maximum extent during the night
- Systems weaken and dissipate in the morning hours (~10 hour lifecycle on average)
- Lifecycle is strongly correlated to LLJ
- Upper-level jet also has influence - notice meridional seasonal shift of MCSs
U.S. MCS Climatology

MCCs [From Cunning (1986)]

All MCSs [From Jirak et al. (2003)]
Squall Lines

• Squall line – any line of convective cells

• For a given CAPE, the strength and longevity of a squall line increases with the depth and strength of the vertical wind shear, especially line-perpendicular shear

• In fact, the strength and longevity of squall lines appears to be maximized for a balance between the low-level shear and the strength of the cold pool – RKW theory
Cold Pool/Shear Interactions
Rear Inflow Jet
Squall Line Vertical Cross Section

[From Houze et al. (1989)]
Squall Line Evolution

What would the vertical structure look like for strong shear?
Bow Echoes

- Bow echo – special case when a squall line becomes bowed
- This occurs when the rear inflow jet is very strong, which can be identified on radar as rear inflow notch – weak echo region behind core of the bowed convective line
- Line-end vortices, or bookend vortices, often develop on the ends of the squall line to help intensify the rear inflow jet
- Significance is that a descending intense rear inflow jet can lead to destructive surface winds
Bow Echoes
Formation of Line-end Vortices

Cyclonic vortex to north; anticyclonic vortex to south
Bow Echo Environments

Modified from Weisman
Derechoes

- Derecho – coherent severe wind event that produces damage over a large area (~400 km)
- Strong, long-lasting bow echoes may be called a derecho
- 2 types: progressive and serial
MCCs

- MCC – mesoscale convective complex; large convective system with a quasi-circular cold cloud shield
- Discovered by Maddox (1980). He noticed high frequency of meso-α convective weather systems moving across the central U.S.

<table>
<thead>
<tr>
<th>Physical characteristics</th>
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<tbody>
<tr>
<td><strong>Size:</strong></td>
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<tr>
<td>A-Cloud shield with continuously low IR temperature ≤-32°C must have an area ≥100,000 km²</td>
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<tr>
<td>B-Interior cold cloud region with temperature ≤-52°C must have an area ≥50,000 km²</td>
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<td><strong>Initiate:</strong></td>
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<td><strong>Duration:</strong></td>
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<td><strong>Maximum extent:</strong></td>
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<td><strong>Shape:</strong></td>
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<td><strong>Terminate:</strong></td>
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MCCs

- Large, long-lasting MCCs can become inertially stable and nearly geostrophically balanced (horizontal scales are on the order of the Rossby radius of deformation, $\lambda_R$)
- Divergent flow near the tropopause can result in a weak, short-lived anticyclonic rotation at that level
- Latent heating by the stratiform region can create a cyclonic-rotating vortex (+PV anomaly) in the mid-troposphere – mesoscale convective vortex (MCV)
- An MCV can last for several hours to possibly days after the dissipation of the MCS that generated it
- MCVs are thought to be responsible for initiating subsequent convective outbreaks
Example of a Mesoscale Convective Vortex

Menard and Fritsch (1989, MWR)