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

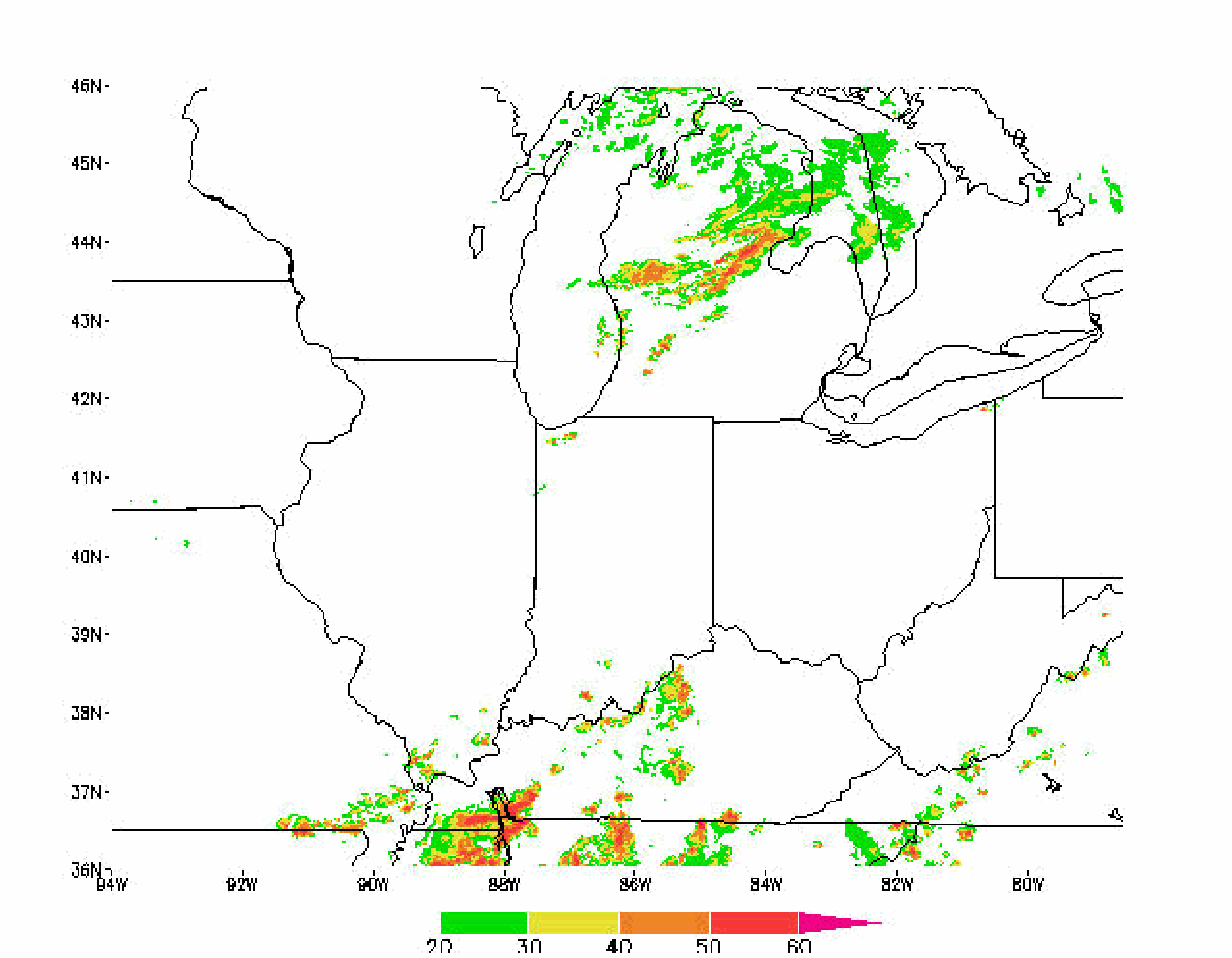
- Since “MCS” is a general classification, it can be divided into more specific classifications.
- The most commonly cited examples of MCSs include
  - –Squall lines
  - –Bow echoes
  - –Meoscale convective complexes (MCCs)
- These types of MCSs were independently discovered and named; thus, they are 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

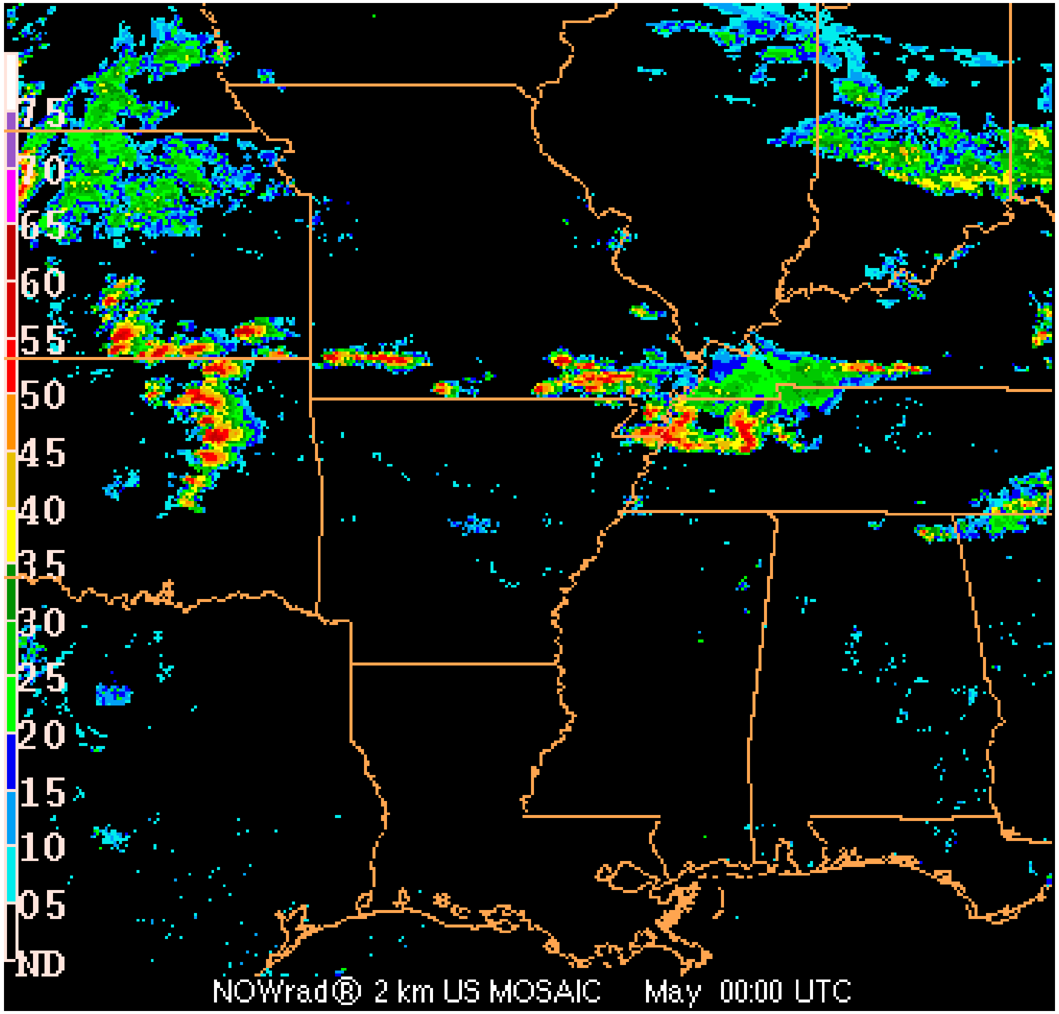
Example

Squall Line



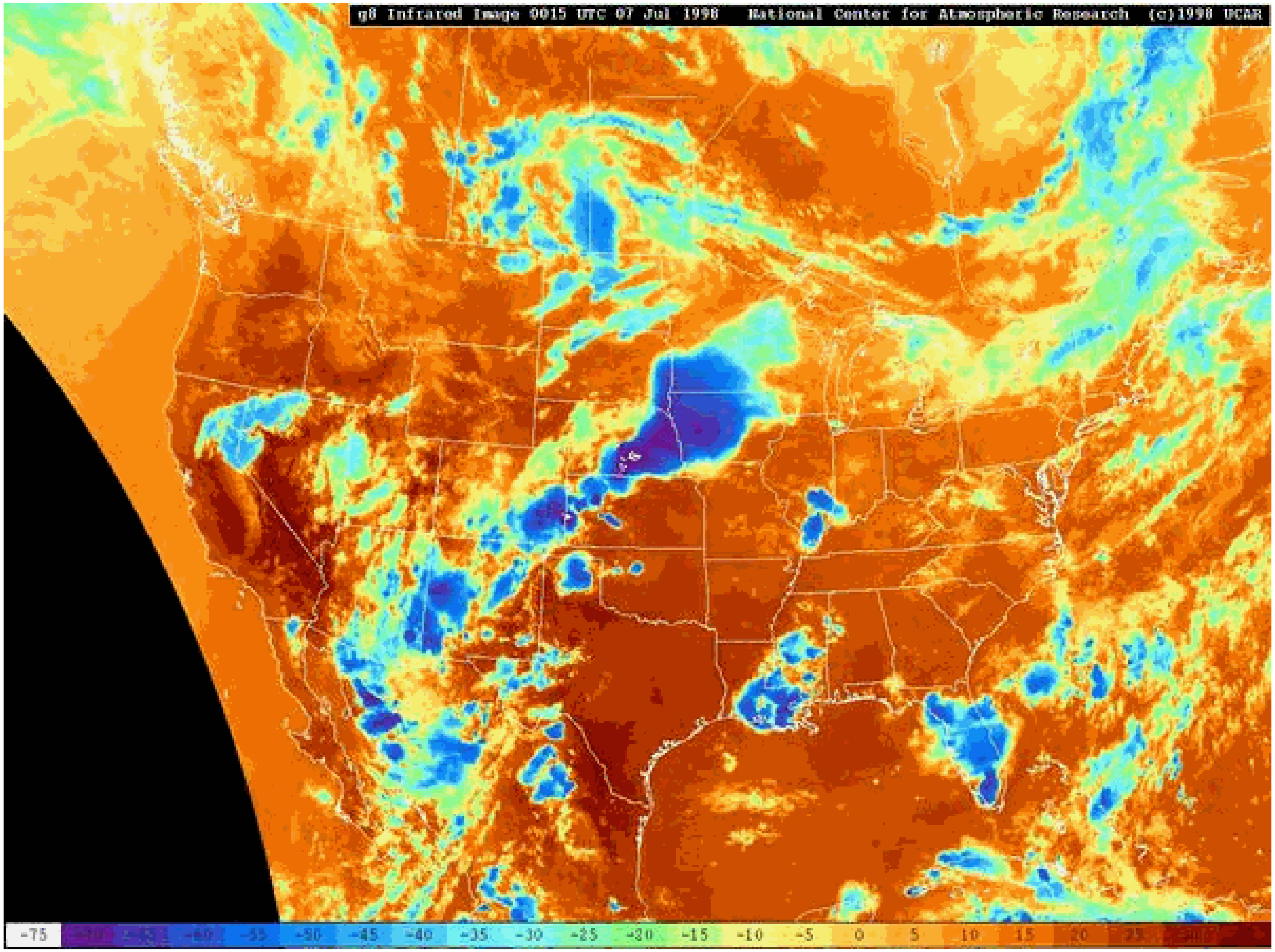
Example

Bow Echo



Example

MCC


g8 Infrared Image 0015 UTC 07 Jul 1998
National Center for Atmospheric Research (c)1998 UCAR
-75
-60
-55
-50
-45
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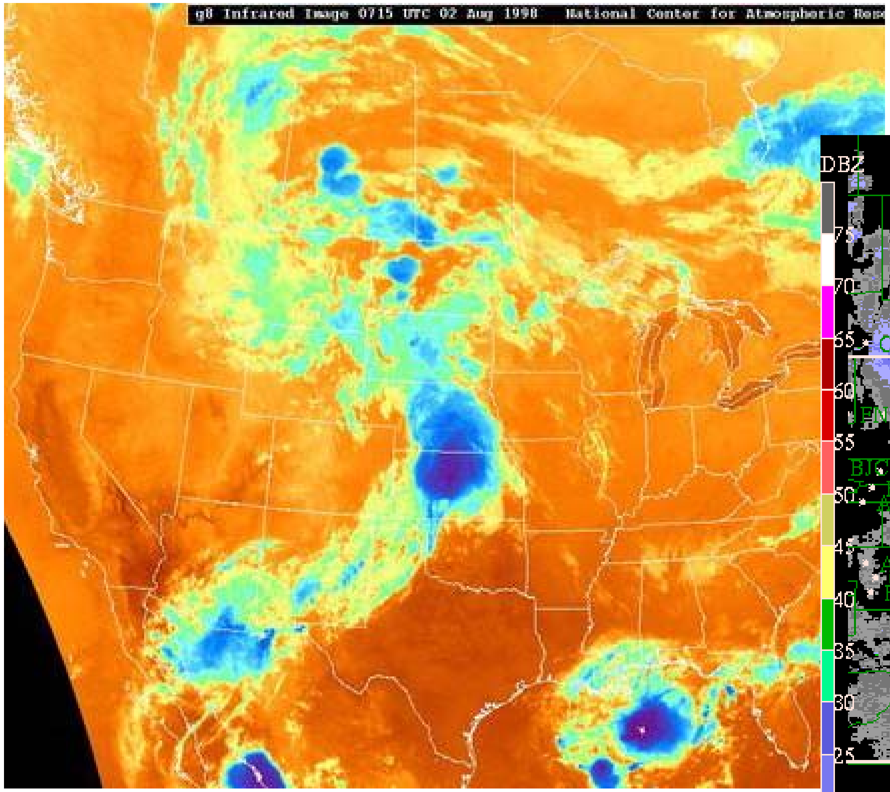
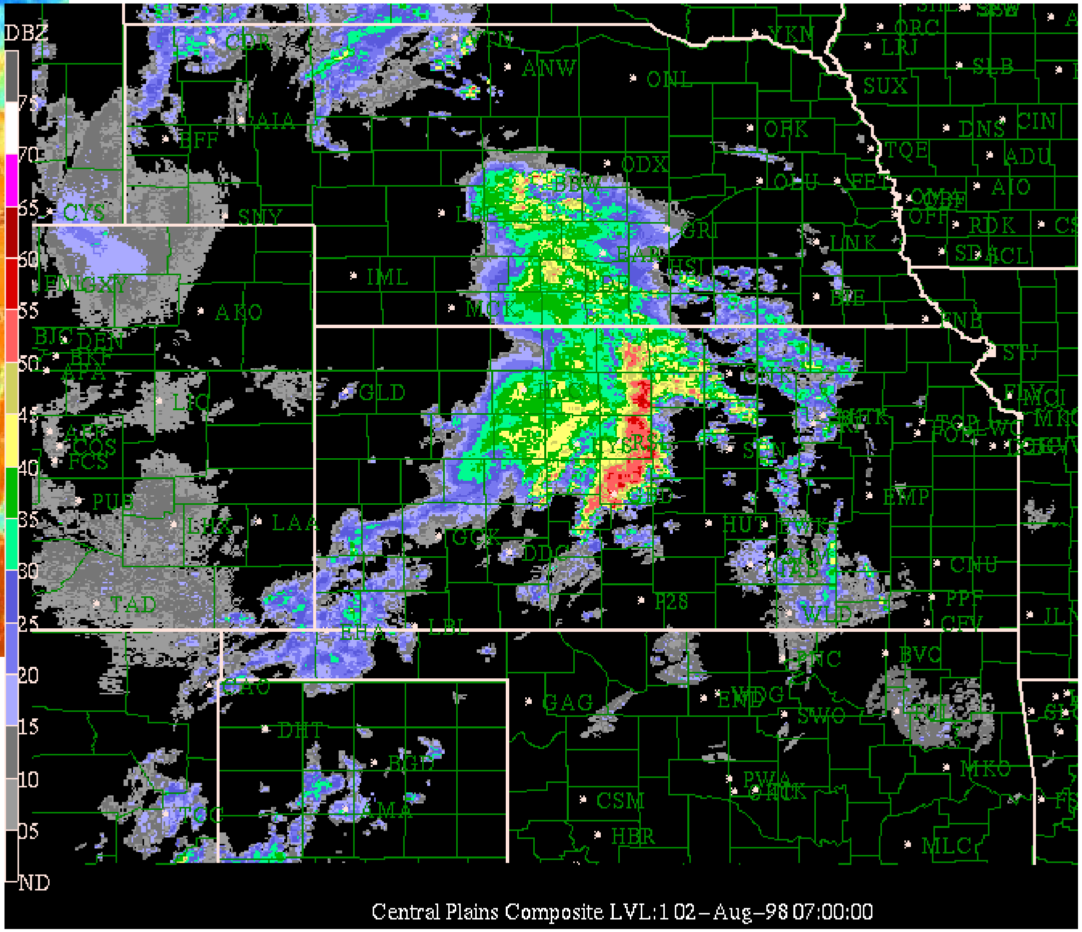
15
20
25

Example

Squall Line – MCC system

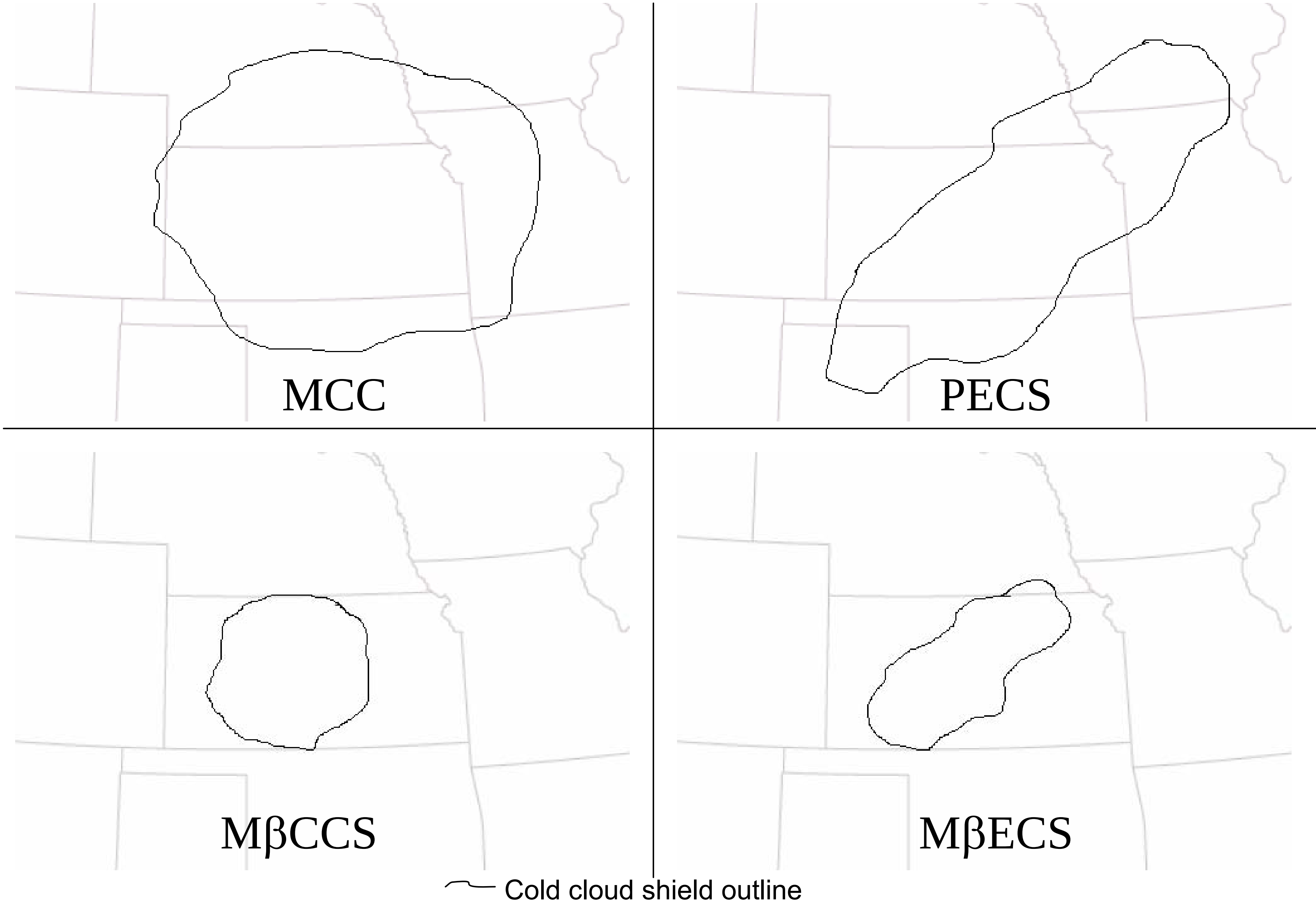




MCS Classification

- 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 km^2 for >3 hrs
    - Meso-β elongated convective system (MβECS): same except ecc. <0.7

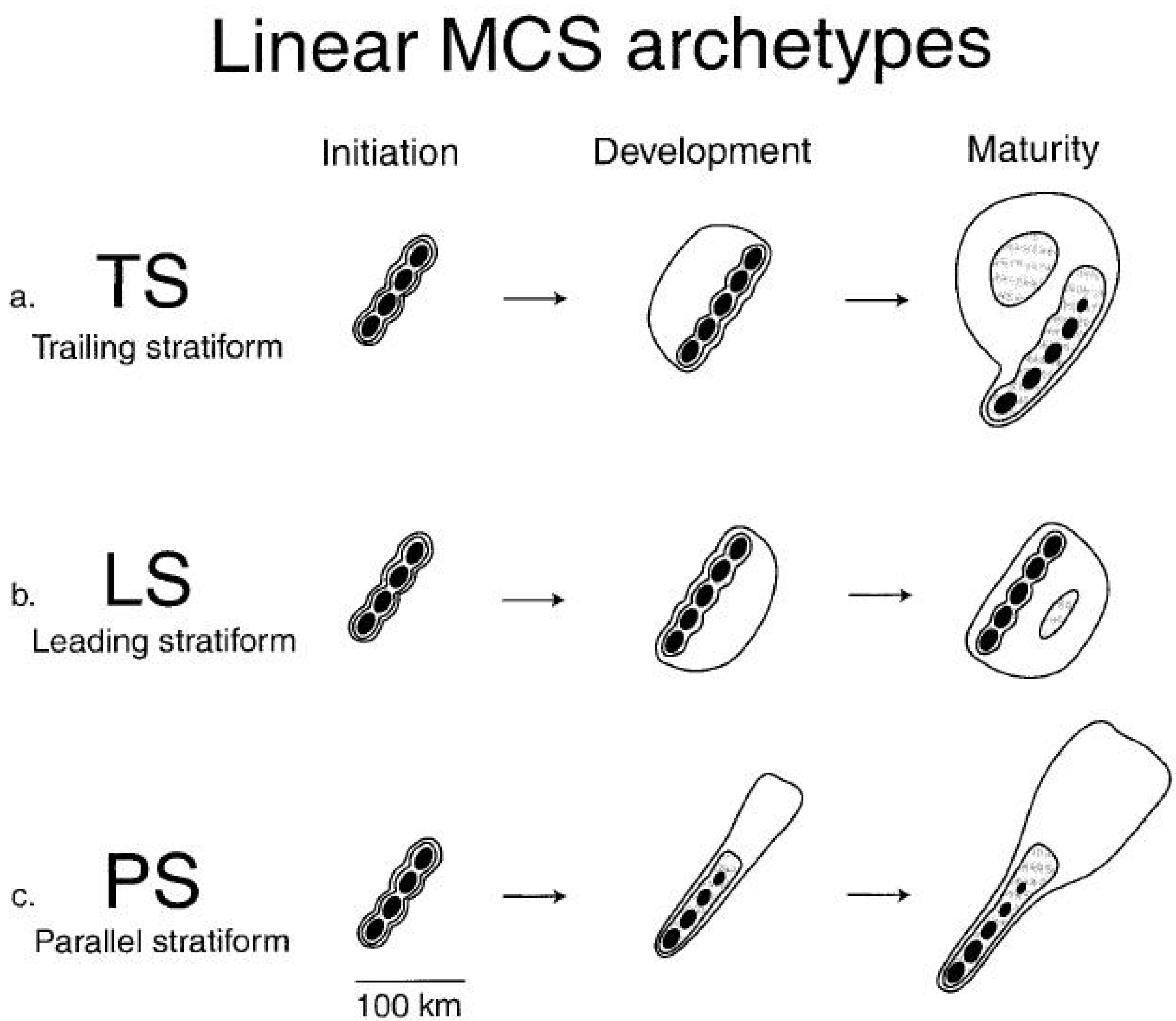
MCS Classification



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

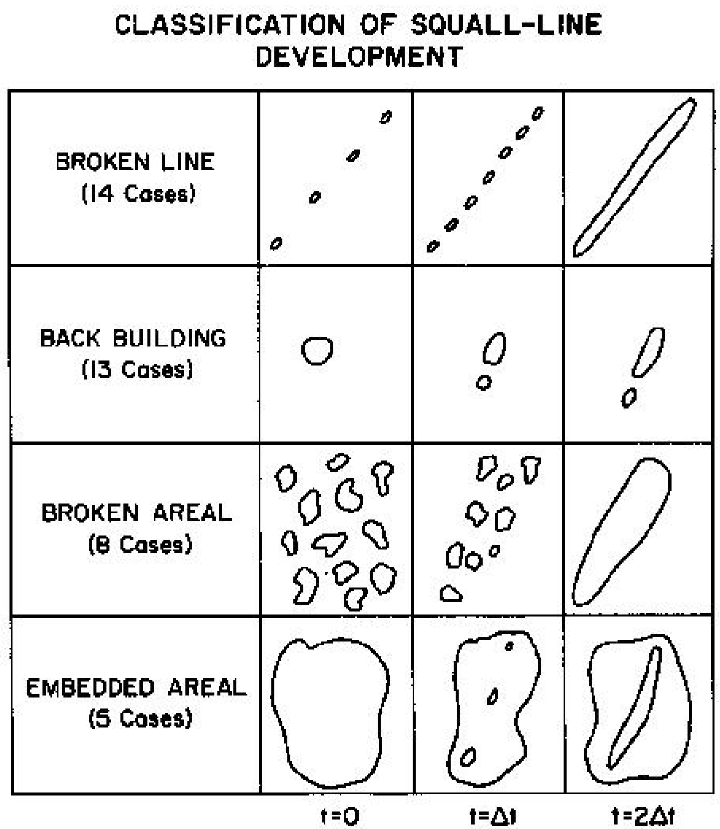
MCS Classification



[From Parker and Johnson (2000)]

MCS Classification

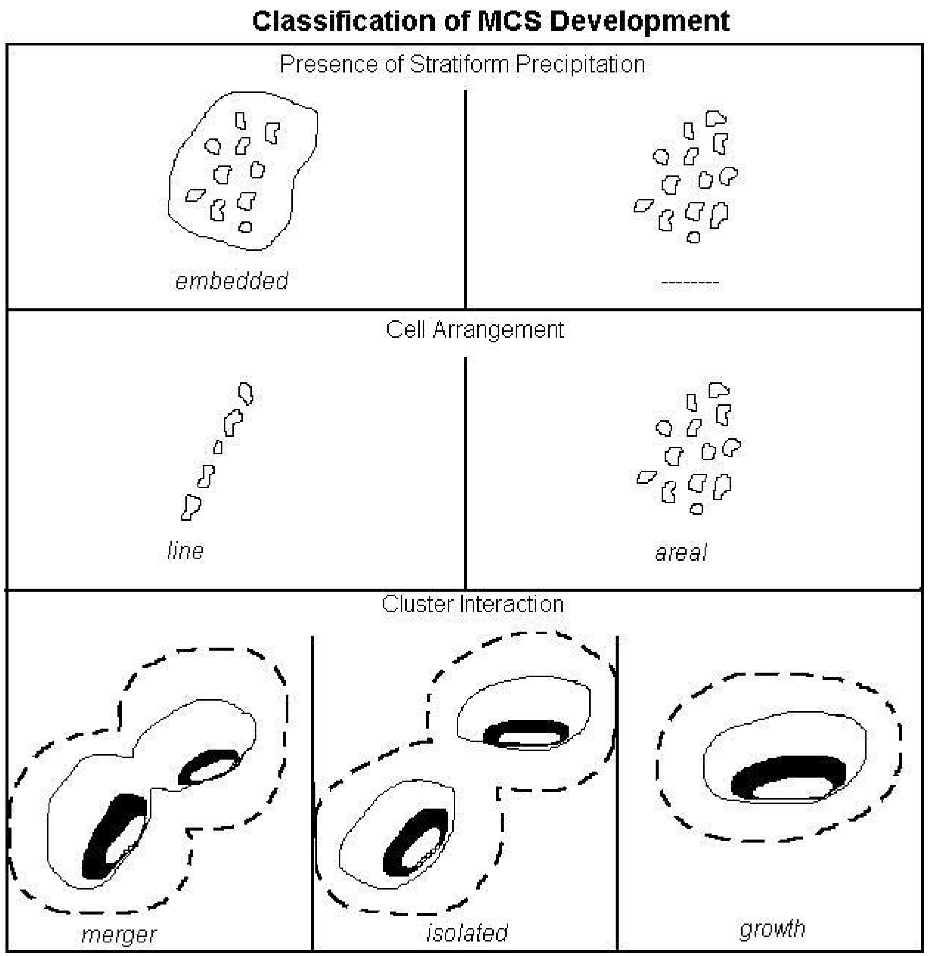
- Development
  - –Bluestein and Jain (1985) identified common patterns of severe squall line formation



[From Bluestein and Jain (1985)]

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

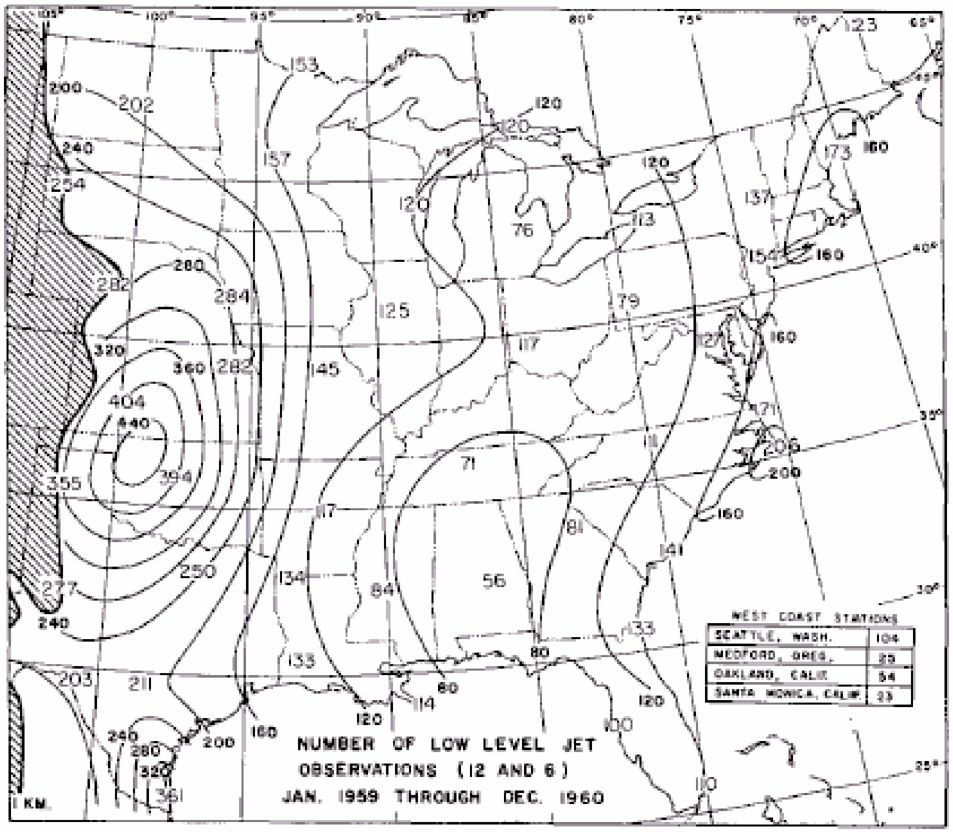
MCS Environments

- 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

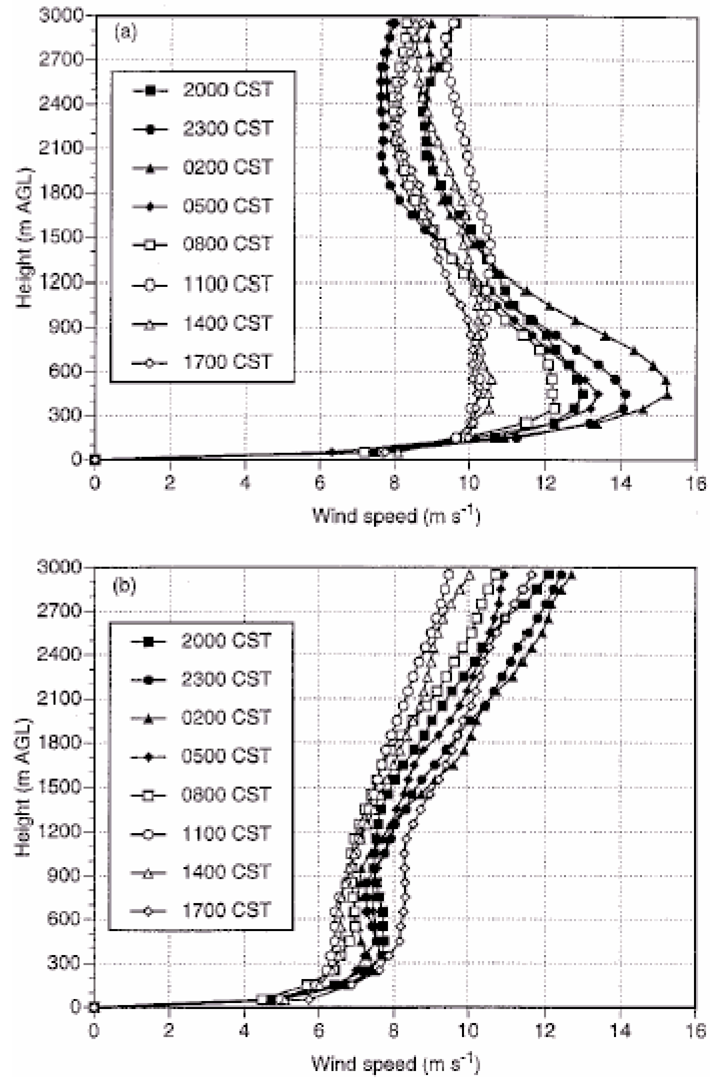
Low-level Jet

- 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)]

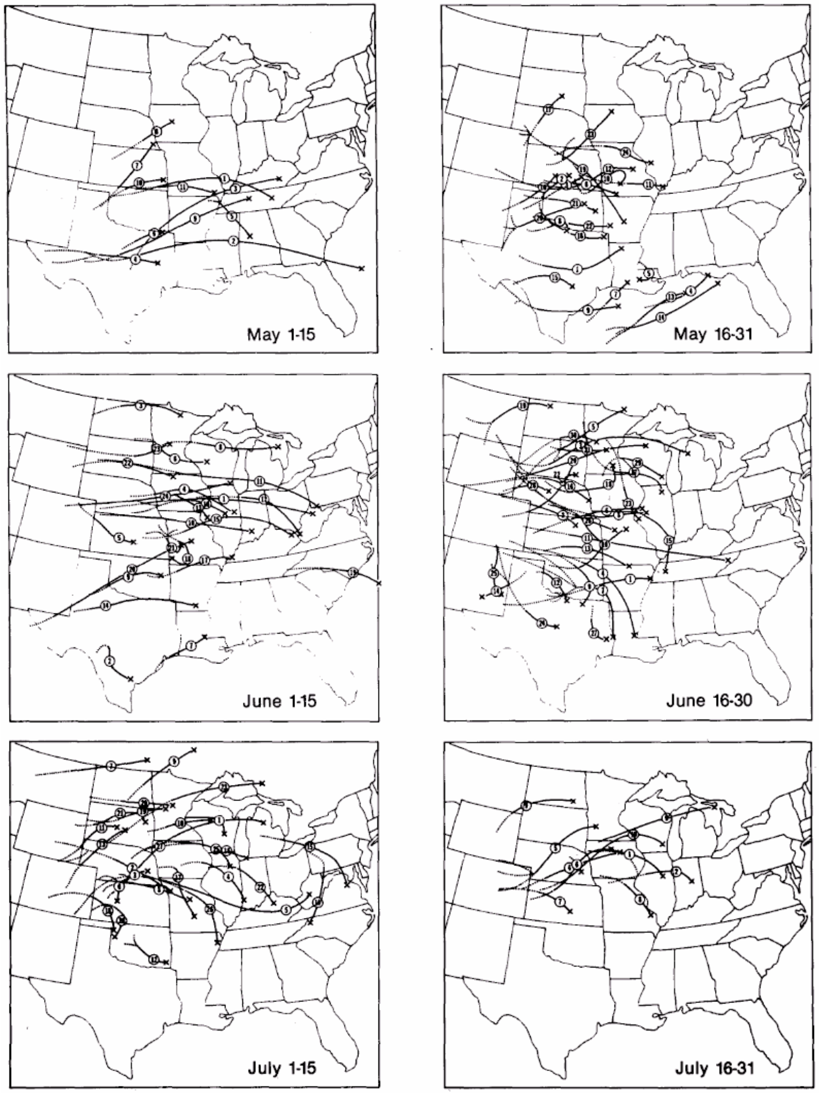


[From Whiteman et al. (1997)]

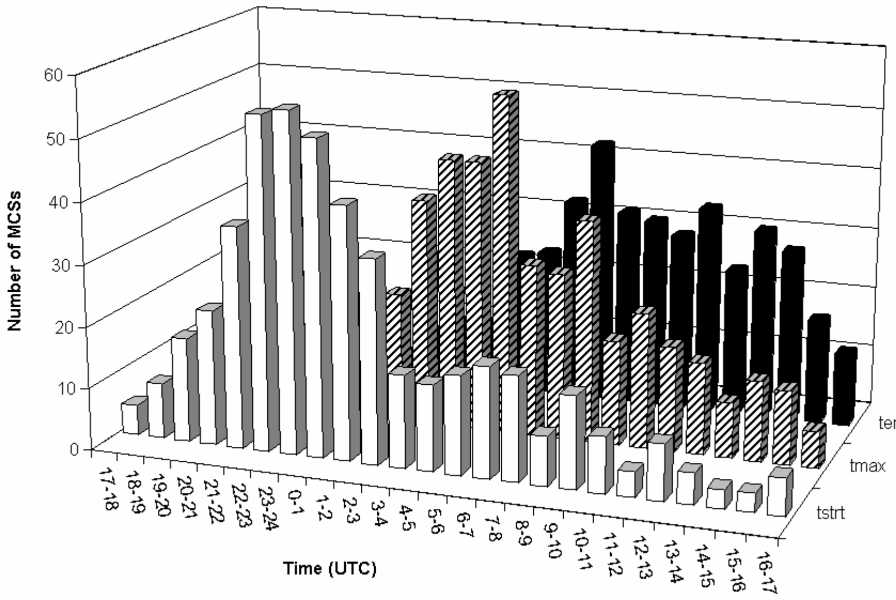
U.S. MCS Climatology

- 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)]

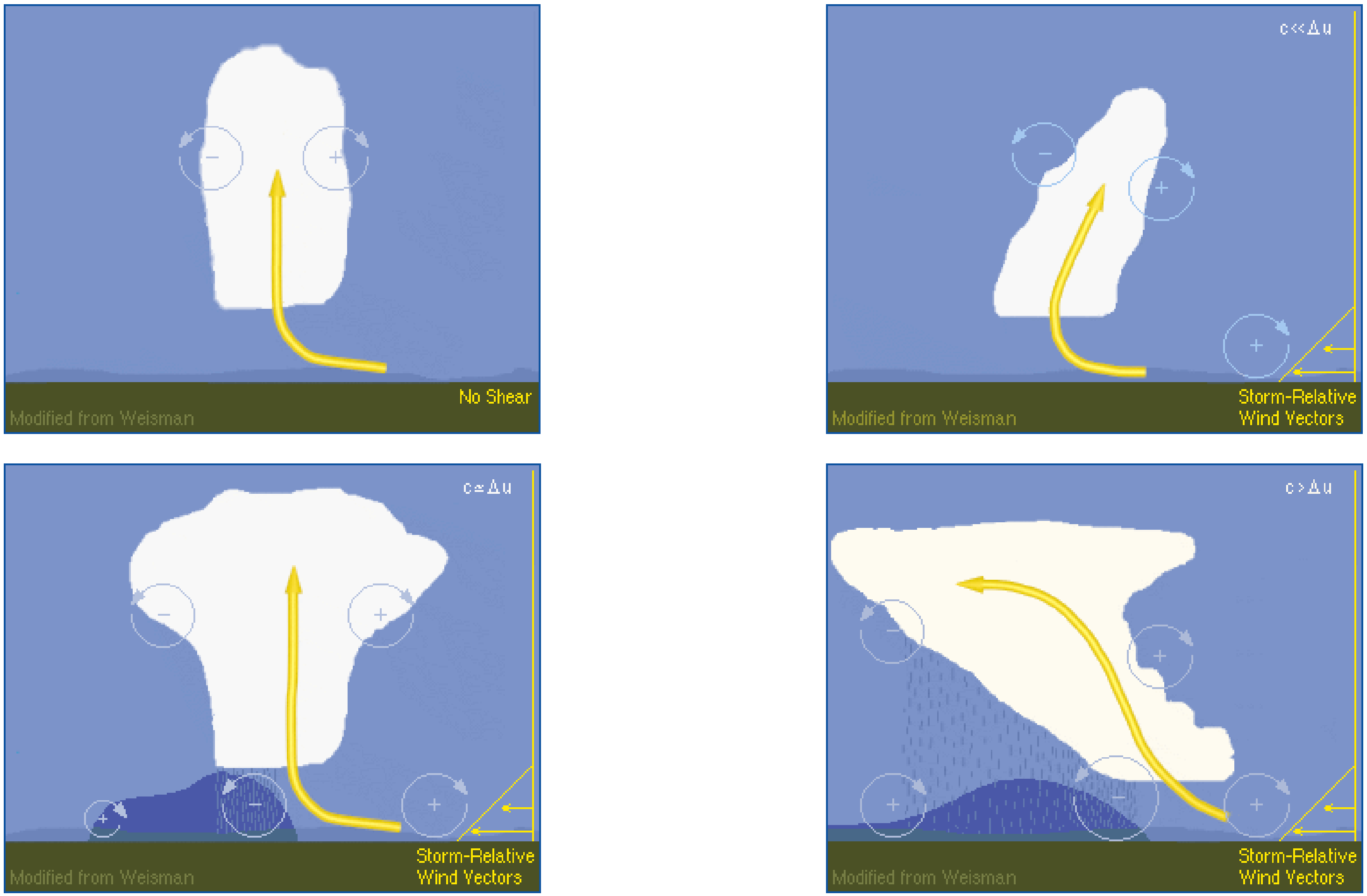


All MCSs [From Jirak et al. (2003)]

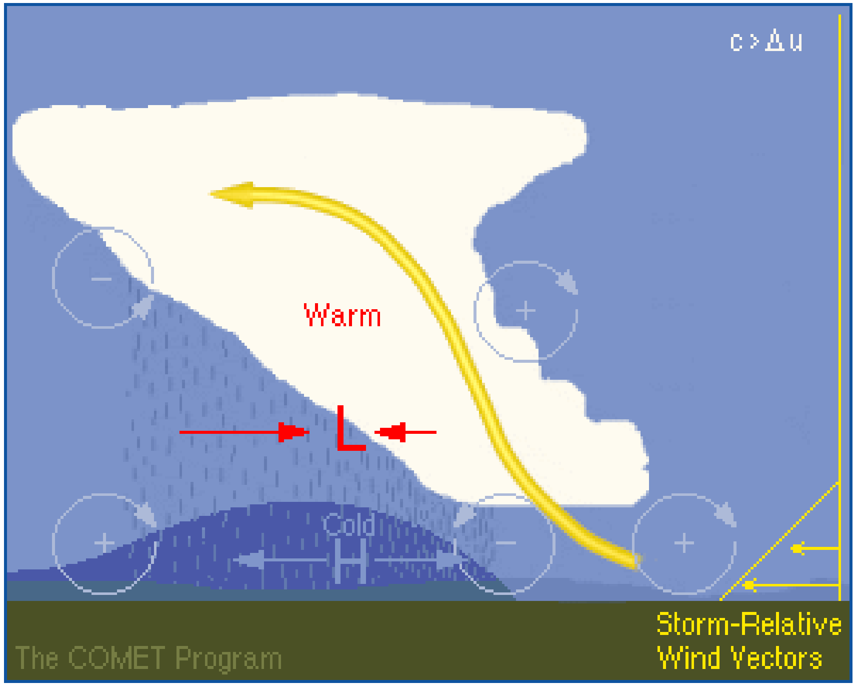
Squall Lines

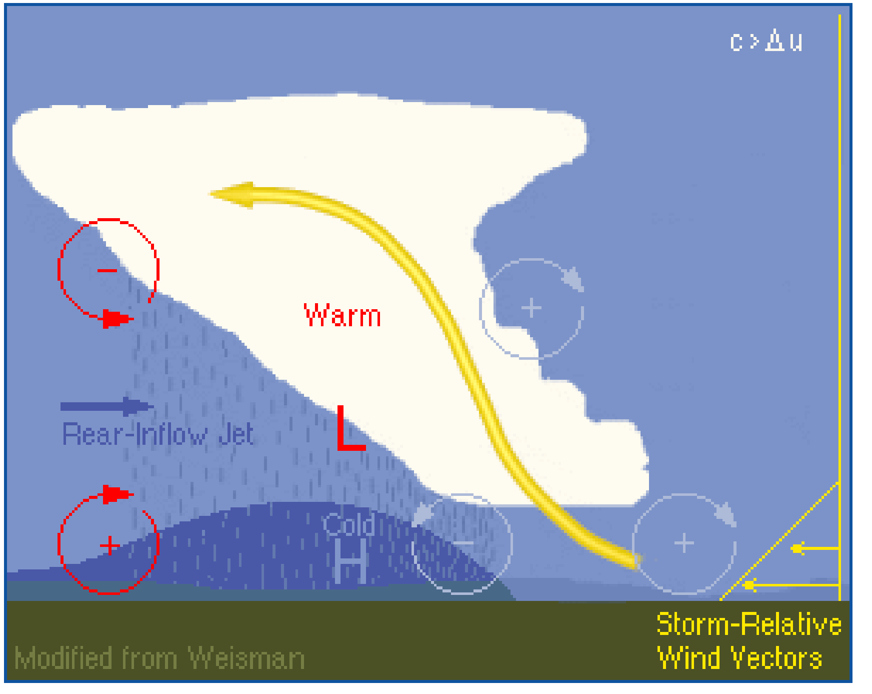
- Squall line – any line of convective cells
- For a given CAPE, the strength and longevity of a squall line increases with the depth and strength of the vertical wind shear, especially line-perpendicular shear
- In fact, the strength and longevity of squall lines appears to be maximized for a balance between the low-level shear and the strength of the cold pool – RKW theory

Cold Pool/Shear Interactions

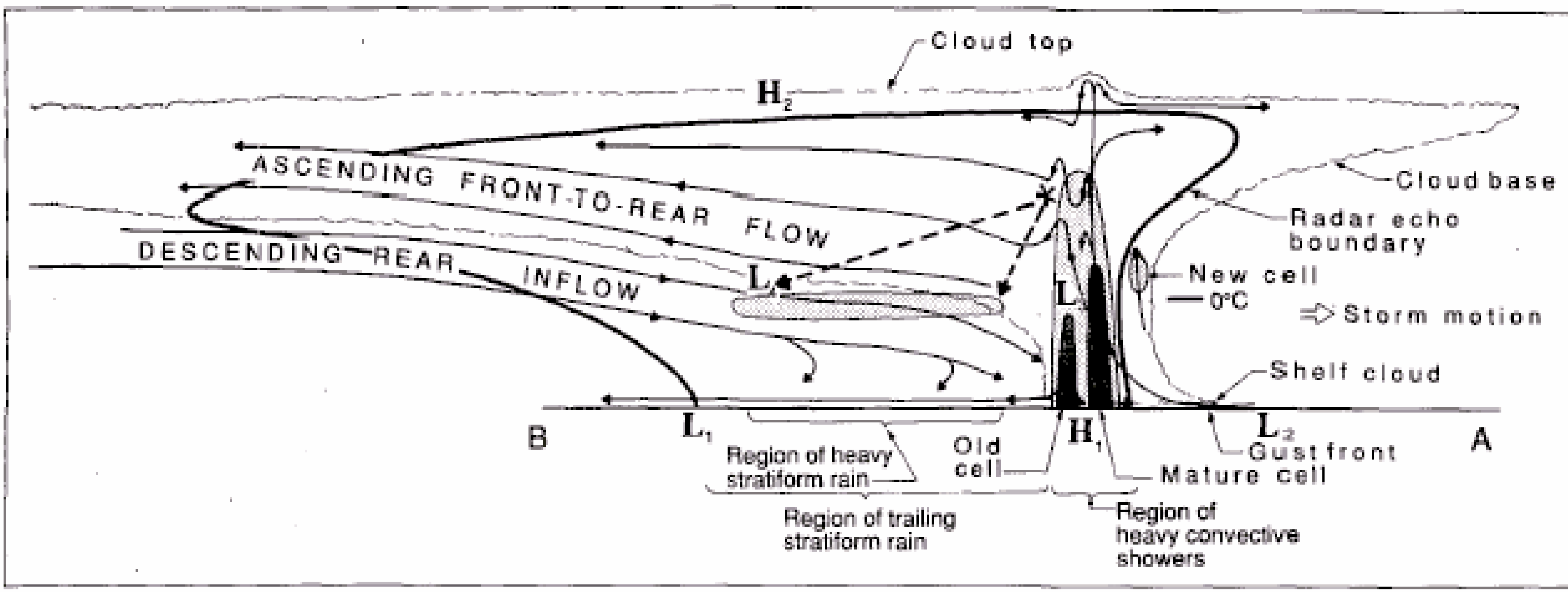


Rear Inflow Jet



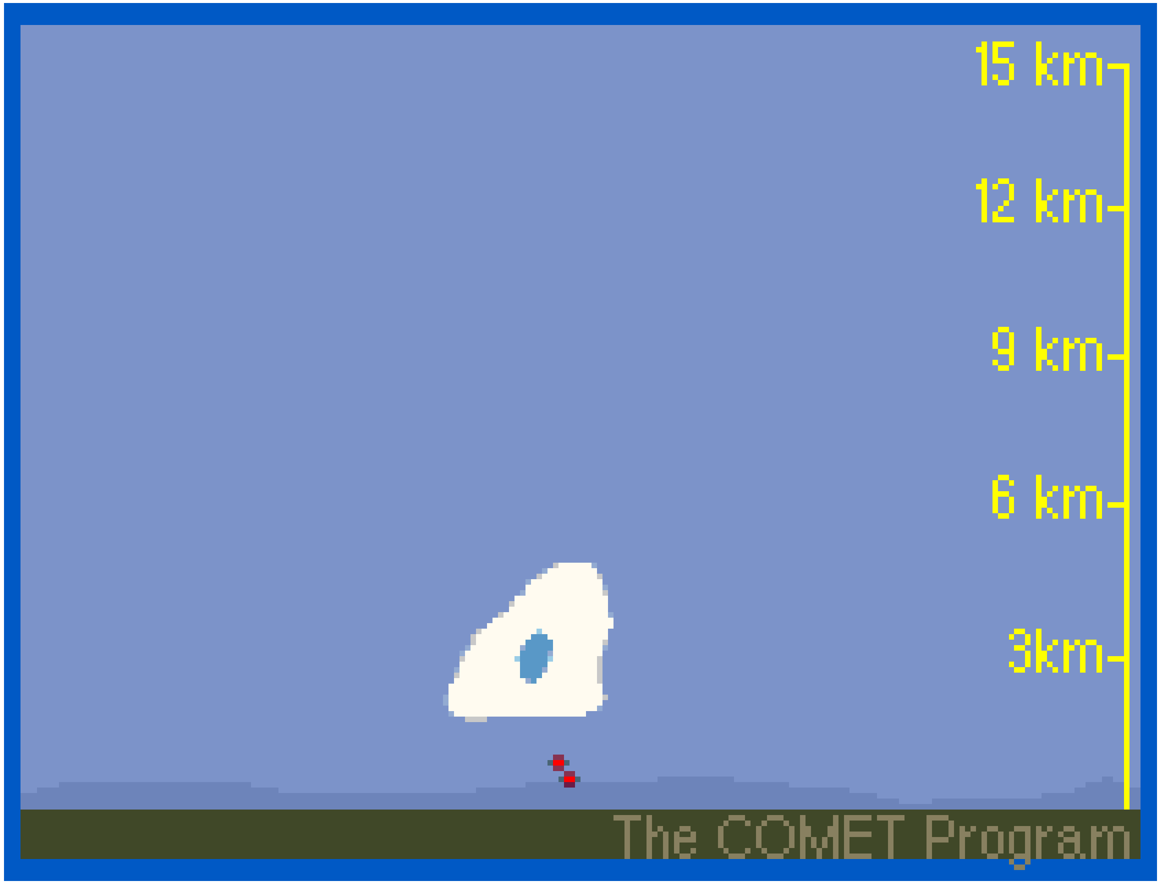


Squall Line Vertical Cross Section



[From Houze et al. (1989)]

Squall Line Evolution



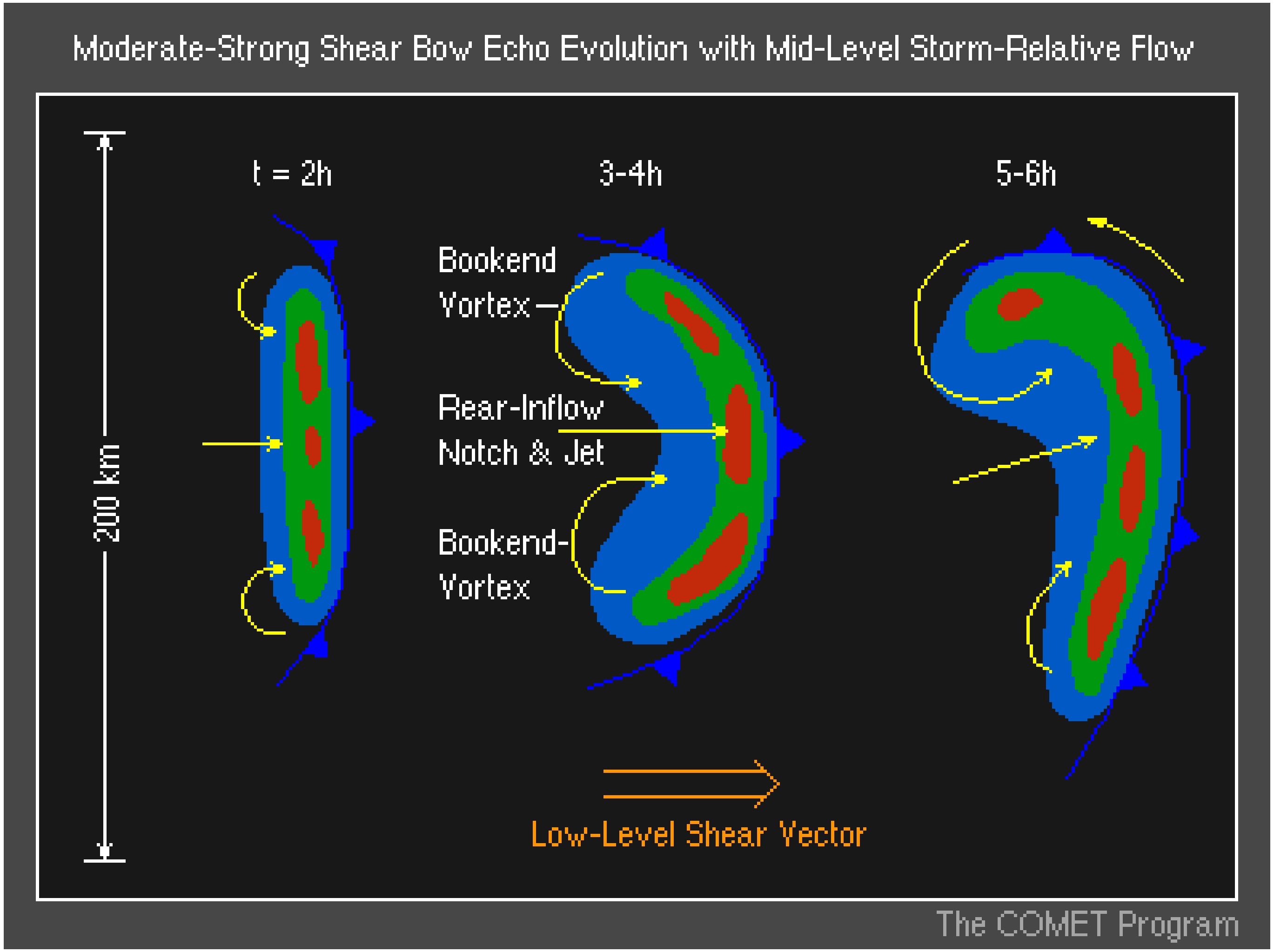
Weak – Moderate Shear

What would the vertical structure look like for strong shear?

Bow Echoes

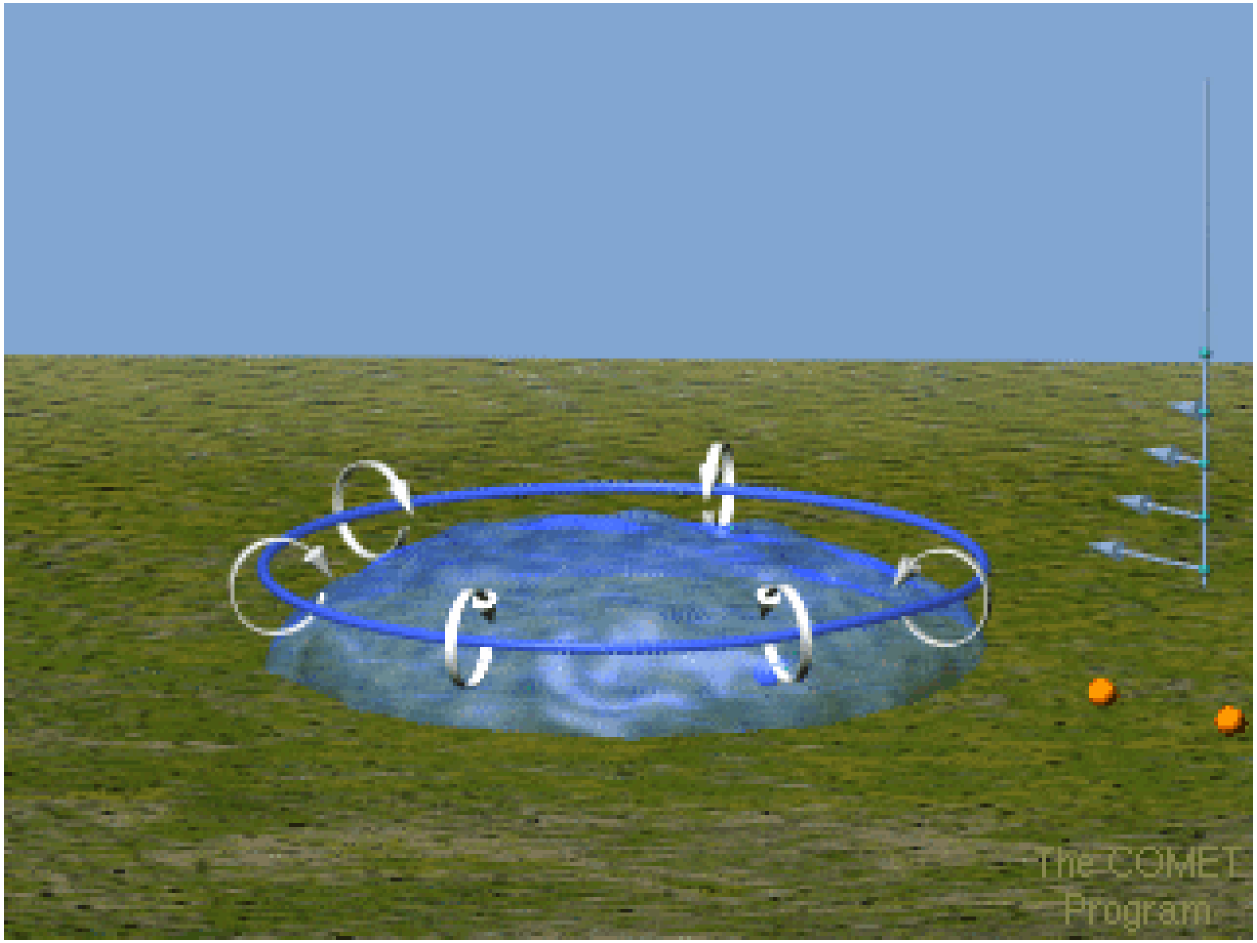
- Bow echo – special case when a squall line becomes bowed
- This occurs when the rear inflow jet is very strong, which can be identified on radar as rear inflow notch – weak echo region behind core of the bowed convective line
- Line-end vortices, or bookend vortices, often develop on the ends of the 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



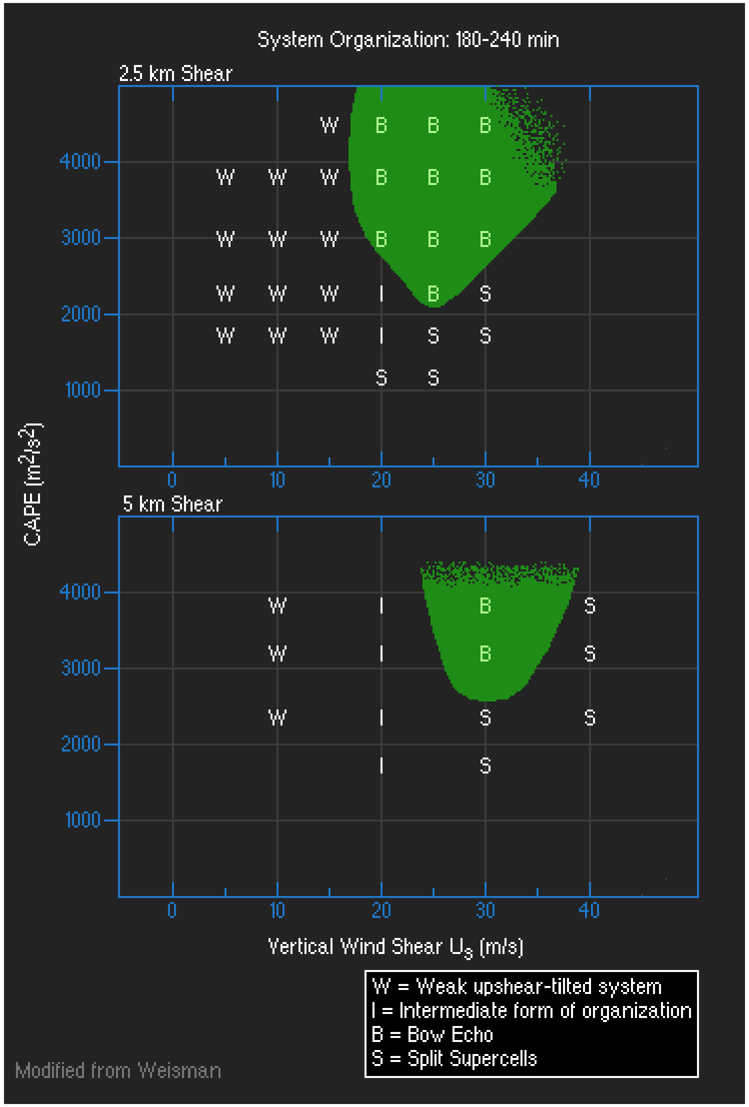
Moderate-Strong Shear Bow Echo Evolution with Mid-Level Storm-Relative Flow
t = 2h
3-4h
5-6h
200 km
Bookend Vortex
Rear-Inflow Notch & Jet
Bookend-Vortex
Low-Level Shear Vector
The COMET Program

Formation of Line-end Vortices



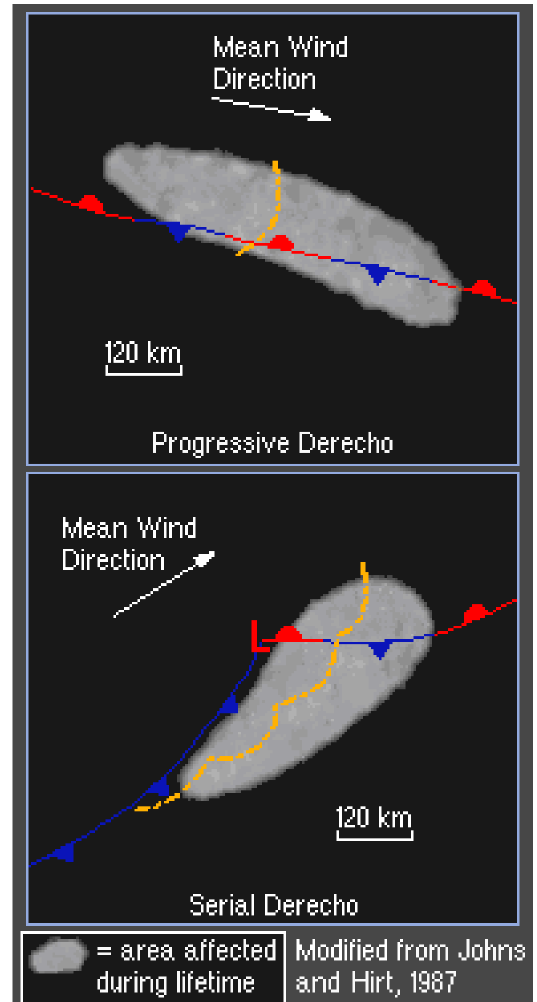
Cyclonic vortex to north; anticyclonic vortex to south

Bow Echo Environments



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.

	Physical characteristics
Size:	A-Cloud shield with continuously low IR temperature $\leq$-32ºC must have an area $\geq$100,000 km^2 B-Interior cold cloud region with temperature $\leq$-52ºC must have an area $\geq$50,000 km^2
Initiate:	Size definitions A and B are first satisfied
Duration:	Size definitions A and B must be met for a period of $\geq$6 h
Maximum extent:	Contiguous cold cloud shield (IR temperature $\leq$-32ºC) reaches a maximum size
Shape:	Eccentricity (minor axis/major axis) $\geq$0.7 at time of maximum extent
Terminate:	Size definitions A and B no longer satisfied

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, λ_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

MCV

Example of a Mesoscale Convective Vortex

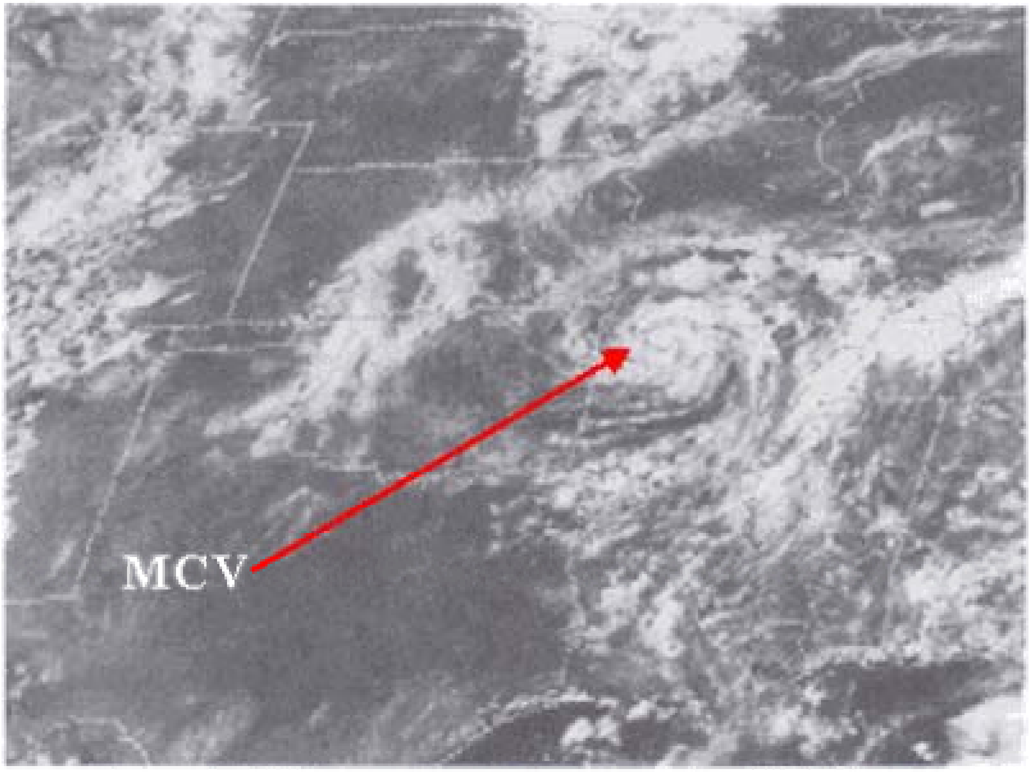


FIG. 9.30. Visible satellite image of an MCC-generated mesovortex on 1830 UTC 8 July 1982. From Menard and Fritsch (1989).

Menard and Fritsch (1989, MWR)