

MCS CHARACTERISTICS, STRUCTURE, AND PROPAGATION

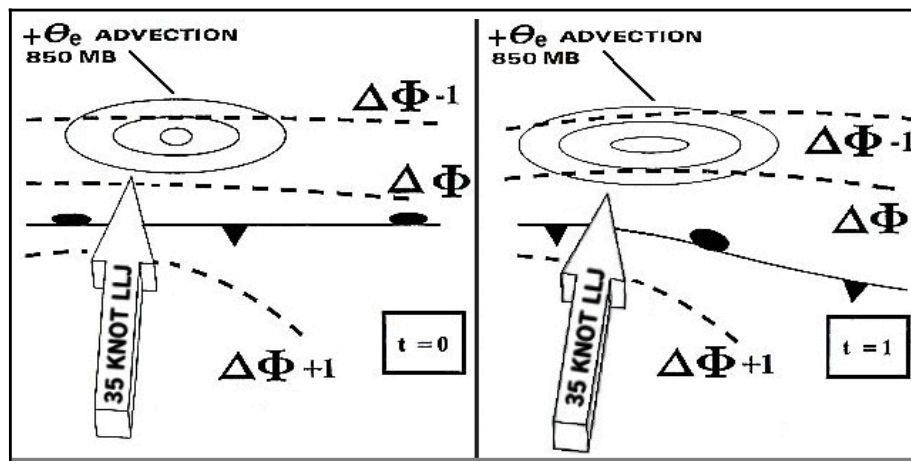
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From June to September 1993, numerous **mesoscale convective systems** (MCSs) affected the Mississippi and Missouri River Valleys which resulted in major flooding and flash flooding over a broad area. A study (Junker, *Weather and Forecasting*) considered all MCSs that caused 2 inches or more of rain in 24 hrs (85 total events). Events were categorized from smallest in areal extent of heavy rain and lightest amounts to greatest extent and heaviest amounts. The combination of these MCSs produced flash flooding and widespread serious river flooding from Missouri and Kansas north to the Dakotas, Minnesota, and Wisconsin. Below is a summary of environmental weather conditions associated with these events.

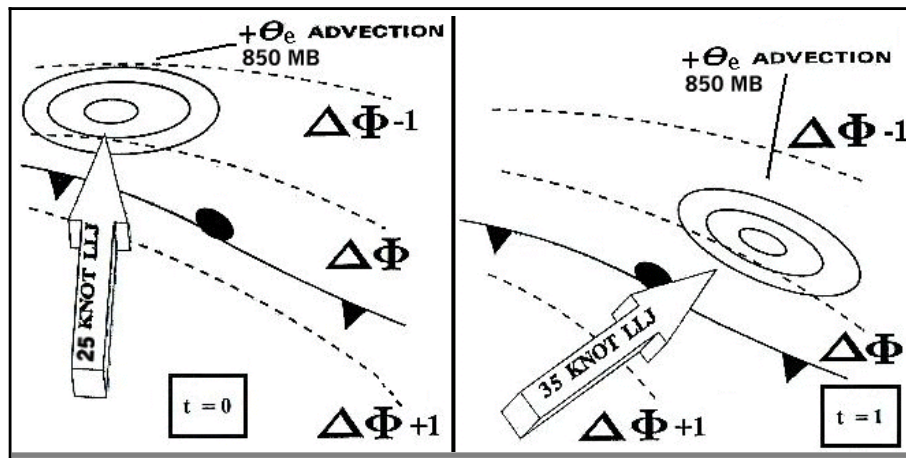
- The majority of cases were nocturnal, occurring between 0000 and 1200 UTC. Heavy rainfall from some MCSs lasted past 1200 UTC.
- High precipitable water (PW), K index, and mean relative humidity (RH) values were associated with events.
- For the most extreme cases (largest areal extent of 2, 3, 4, and 5 inch rain amounts), PW averaged 1.65 inches; K averaged 35. For smaller events, PW and K averaged about 1.4 inches and 30, respectively. Highest values were positioned just upstream from the location of the heaviest rainfall, i.e., MCSs usually occurred on the northern periphery of high moisture values. The exception was mean RH which was more co-located with heavy rain. High RH values equate to less environmental dry air entraining into an MCS to cause evaporation. Thus, high mean RH increases the precipitation efficiency of the MCS, as does a large warm (>0 °C) cloud depth.
- The majority of cases were associated with a low-level boundary as evident in either the low-level wind or moisture/temperature (i.e., equivalent potential temperature [θ_e]) gradient fields.
- Most events were associated with only weak-to-moderate vertical speed shear but with winds that veered with height. This is the case along or north of a low-level boundary where boundary layer winds with an easterly component veer to south or west aloft.
- Many cases occurred in an area of significant warm air advection/isentropic lift. The stronger the warm advection, the higher the potential for heavier rainfall over a larger area (assuming all other factors are equal), i.e., stronger synoptic- scale/mesoscale forcing is present.
- Heaviest rain usually fell just north of the strongest south or southwest 850 mb winds.
- Heaviest rain usually fell north of maximum 850 mb θ_e in a θ_e gradient zone but still in/near a θ_e ridge axis.
- The heaviest rain often occurred within an area of significant 850 mb positive θ_e advection, but frequently just south of the maximum θ_e advection values.
- Majority (about 60%) of events were centered near 500 mb ridge axis (where warm advection can be strong).
- A much higher percentage of cases were associated with low-level/850 mb warm advection than with 500 or 300 mb positive vorticity advection (PVA).
- Major events occurred with 700 mb temperatures < 12 °C (mostly 7-11 °C). An air mass usually is too capped for organized convection at temperatures > 12 °C. Some smaller events, however, did occur at higher temperatures.
- Most MCSs were associated with an area of 250 mb divergence in the gradient south of the maximum divergence due to sloped ascent of low-level unstable air parcels toward the upper-level divergence maximum. About 60% of all events occurred within the right entrance region of an upper-level jet streak, although some cases were not associated with a jet streak or did not fit the typical jet streak divergence patterns.

- Heaviest rain amounts often occurred north of an area of relatively strong 850 mb moisture transport.
- The length, location, and orientation of the low-level moisture flux convergence, low-level jet, and instability determined propagation characteristics which ultimately affected rainfall amounts in any one area. For very heavy rain totals, these factors should be long in length, directed along/nearly parallel to the mean (850-300 mb) wind, and be located upstream (i.e., on the west or southwest side) of the initial MCS. This favors new cell growth on the upstream side (rear flank) of an MCS resulting in a slow moving or quasi-stationary MCS as forward cell movement is negated by a backward propagation vector.
- Extreme rainfall events were associated with the strongest 850 mb winds and moisture flux that moved east/downwind slower than in lighter/less widespread events. Slower movement favors upstream cell development versus new cell formation on the forward flank of an MCS for a faster moving area of strongest winds and moisture flux, even if rainfall rates are nearly the same for both type systems.
- One difference in larger/heavier rainfall events from smaller scale, lighter cases (but ones that can still produce local flash flooding) was the width of moisture flux convergence. The larger the width (area) of convergence into a boundary, the greater the potential for merging and training convective cells and, therefore, higher rainfall amounts. There was less correlation between the magnitude of moisture flux convergence and the size/scope of events than there was with the width of high moisture flux convergence. The depth of moisture flux convergence also was important in producing heavy rainfall as deeper convergence favors heavier and more widespread rainfall totals.

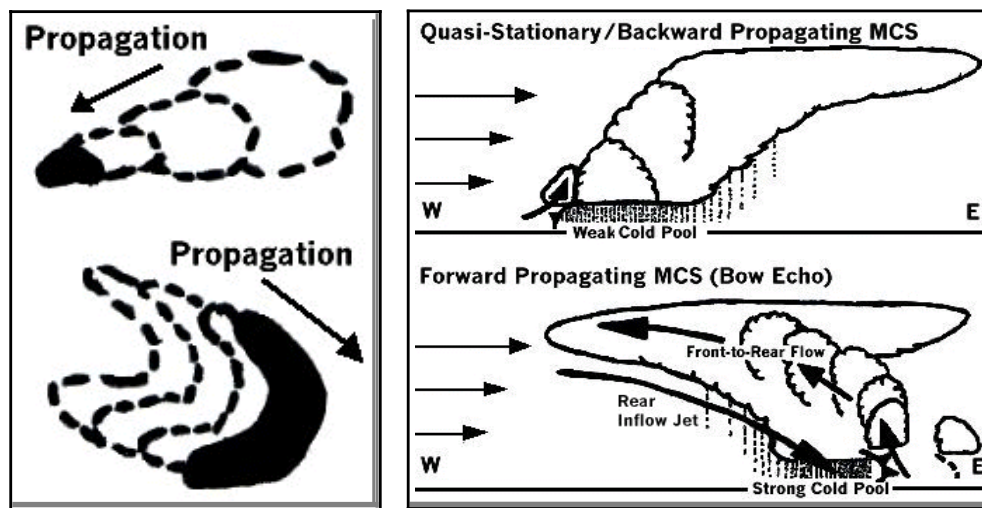
Below, moisture convergence, maximum low-level winds, and instability are located on the upstream (west or southwest) quadrant of the MCS. Thus, this is the preferred area for new updrafts and cell development. After cells develop, they move downwind with the mean (850-300 mb) environmental flow but weaken as they encounter less favorable conditions downstream. Renewed development can continue upstream with cell training over the same area. Thus, individual cells may move forward, but propagation is backward, resulting in a system movement that is slow-forward, quasi-stationary, or backward. Hail and some wind damage may occur with this type of MCS, especially in initial stages when some dry air aloft may be present. However, upon maturity, this type of system can be a prolific rainfall producer and a major flash flood threat.



Below, moisture convergence, low-level inflow, instability, and strong updrafts are maintained on the leading edge of the MCS. This favored environment moves downwind with time, as does the MCS as new cell growth occurs along the leading/forward quadrant of the system. Fast environmental flow with moderate-to-strong wind shear and a progressive shortwave aloft favor a fast-forward propagating MCS. This can result in quasi-linear convective systems (QLCSs) and bow echoes that produce significant wind damage along their leading edge, along with possible transient mesovortex tornadoes. A system-relative front- to-rear flow can cause trailing precipitation behind the leading intense line. Depending on the speed and movement of the QLCS and amount of trailing precipitation, heavy rainfall amounts and flooding can occur. However, high rainfall rates usually are short-lived with less flash flood potential than with quasi-stationary/backward propagating MCSs.



Below, schematics of stationary/backward and forward MCS propagation are shown. Moist, unstable inflow provided by the low-level jet is maintained on the west or southwest side of the stationary/backward MCS, while the inflow is maintained along the leading edge for forward propagating MCSs (including bow echoes).



Overall, MCS propagation is the sum of 2 components:

- **Advective:** Mean motion of cells in MCS. Cells move about 90% of speed and slightly right of mean 850-300 mb steering flow.
- **Propagation:** Rate/location of new cells relative to existing cells in MCS. Produces apparent movement due to new development on one flank. Proportional (but opposite in sign) to the speed/direction of the low-level jet (i.e., new cells form toward the low-level jet/inflow).

For an MCS to be stationary or propagate backwards, the propagation component must be equal or stronger than the advective component. If the advective component is greater, the MCS as a whole will move forward, whether or not new cells are developing on a preferred flank.

In essence, environments of backward and forward propagating MCSs can look similar. Propagation is in the direction of the maximum storm-relative convergence. Characteristics of the **convective cold pool** (cooler, denser air associated with the heavy rain within an MCS) often distinguishes a fast from slow moving system.

Strong Cold Pool:

- Large positive pressure anomaly compared to ambient pressure. Strong isallobaric flow
- Fast-moving gust front/MCS
- MCS motion faster than 850-300 mb mean wind
- Maximum convergence on MCS leading edge
- Severe weather with brief heavy rain
- More common during day in warm sector

Weak Cold Pool:

- Small positive pressure anomaly compared to ambient pressure. Weak isallobaric flow
- Slower gust front/MCS movement
- Balance between cold pool and inflow so cells redevelop and train over same area
- Prolonged heavy rain. little/no severe weather
- More common at night and for elevated storms