Heavy Convective Rainfall Patterns in the Midwest and Ohio Valley

NWS Louisville, KY

Will Heavy Rainfall Amounts Occur at a Location?

Precipitation amount at any given location is dependent on:

- *Available moisture*: Are high values of moisture available to convection?
- *Degree and breadth of moisture transport*: Horizontal and vertical extent of low-to-mid level transport/advection; rate of moisture replenishment to system
- *Rainfall rate/intensity*: Is precipitation convective or stratiform?
- *Areal coverage of rain*: Is rain widespread (MCS) or localized (scattered cells)? Affects duration
- *Motion and speed of rain*: Due to mean (steering) wind. Affects duration
- *Storm propagation*: Effective movement of area of convection due to new cell development on preferred flanks of systems
- *Precipitation efficiency*: How effective is convection in converting ingested water vapor into rainfall that reaches ground?

Parameters Useful in Assessing Heavy Rain Potential

Moisture:

- High ambient/upstream surface-to-850 mb dewpoints: Above seasonal normal
- High surface-to-500 mb RH: Little or no dry air in sounding; enhances precipitation efficiency
- Precipitable water: Amount of water in column if all moisture condensed out. Ambient/upstream PW values roughly ≥ 1.4” (warm season) or > 100% of normal (any time of year)

Instability:

- CAPE: Moderate values; intense updraft (high CAPE) throws particles out top of storm (decreased efficiency). Shape of CAPE in a sounding is important
- Lifted Index: Warm sector storms: ambient LI < 0. Elevated storms: ambient LI > 0 but < 0 upstream
- K Index: Ambient/upstream roughly > 33 in warm season. Lower values/ridge axis in cool season

Low levels:

- Low-level jet: Along/west of jet axis (warm sector storms) or within jet exit region (elevated storms)
- Equivalent potential temperature (θe) and θe advection: Higher θe = higher temp and/or moisture at a level. Warm sector storms: heavy rain along/near 850 mb θe ridge axis just downstream from max values. Elevated storms: heavy rain in downstream gradient of 850 mb θe (perhaps near 700 mb θe max). θe advection: positive advection zones (becoming warmer/moister), esp. for elevated storms
- Moisture transport/convergence: Just downstream from max moisture transport and near area of max moisture convergence

Parameters Useful in Assessing Heavy Rain Potential

Mid/upper levels:

- 500 mb flow: Broad south to west flow. Often near a broad ridge axis. Weak or no shortwave trough present which allows moist, unstable inflow to continue in low levels. Strong mid-level shortwave favors fast movement, short duration rainfall, and possible severe weather
- Jet streak/divergence: Exit and entrance regions. Anticyclonically-curved entrance, cyclonically-curved exit regions. Upper-level divergence

Thermal/thickness gradient (steering flow):

- Tight gradient: Fast mean flow. Forward propagation along/right of 850-300 mb thickness gradient
- Moderate gradient: Forward movement. Cell regeneration upstream if favorable low-level inflow
- Weak gradient: Weak winds/thermal gradient typical of warm sector convection. Storms may redevelop or propagate backwards/upstream

Other features:

- Strong warm advection/isentropic lift: Broad forcing/lift conducive to elevated MCSs
- Deep warm cloud depth ($T_{cloud} > 0$ °C): Promotes higher moisture content of air. Enhances collision-coalescence and precipitation efficiency

Low Level Jet: Key Component of a Heavy Rainfall Event

- Crucial to initiation, propagation, and sustenance of MCSs
- Low-level jet (LLJ) under right entrance region of upper-level jet (ULJ) usually is best pattern for heavy rainfall. Close to moist, unstable inflow. Conducive to slower-moving or regenerative convection
- Exit region and left (west) of LLJ axis where convergence, frontogenesis, and lift are maximized
- Horizontal and vertical transport (advection) of moisture related to strength of LLJ
- Strong LLJ in a baroclinic regime can lead to significant isentropic lift and elevated convection north of surface boundary
- Location and movement of LLJ (i.e., moist, unstable inflow) relative to a boundary and existing area of convection dictate whether storms will propagate forward, backward, or regenerate, and thus ultimately whether brief heavy rain or prolonged heavy rain and potential flooding will occur

Meteorological Pattern Recognition

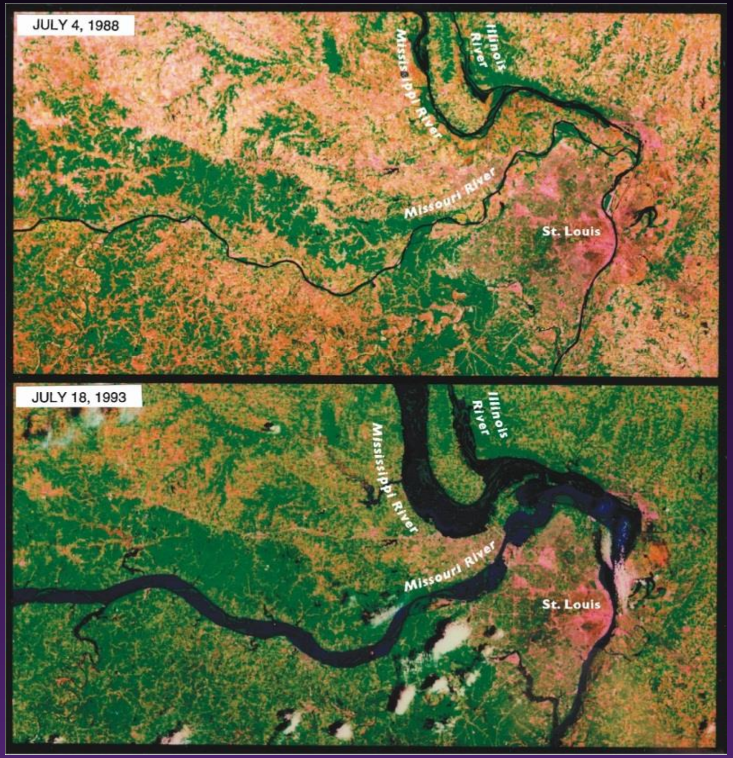
- A good precipitation forecast starts with recognizing those patterns and parameters which historically have produced heavy rainfall over particular areas
- Must understand atmospheric processes that may lead to and affect evolution of heavy rainfall within a recognized pattern. This includes jet streak dynamics, isentropic lift, frontogenesis, synoptic and mesoscale boundaries, moisture inflow/convergence, etc.
- Important processes on synoptic-scale, mesoscale, and storm-scale can alter precipitation amounts and distributions from those expected within a recognized pattern
- Patterns can vary by season, geographic region, and scale

Great Midwest Floods of Summer 1993

Caused by a large number of mesoscale convective systems (MCSs) that occurred over same general area within a synoptic pattern that did not change much. Economic losses estimated at $15-20 billion.

MS River during Great Midwest Flood of 1993

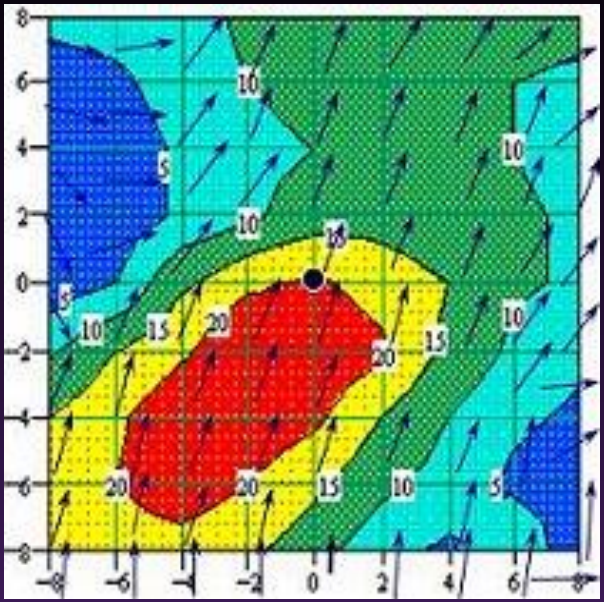
Junction of MS, MO, and IL rivers during drought of 1988 and Great Flood of 1993



Great Midwest Floods of Summer 1993

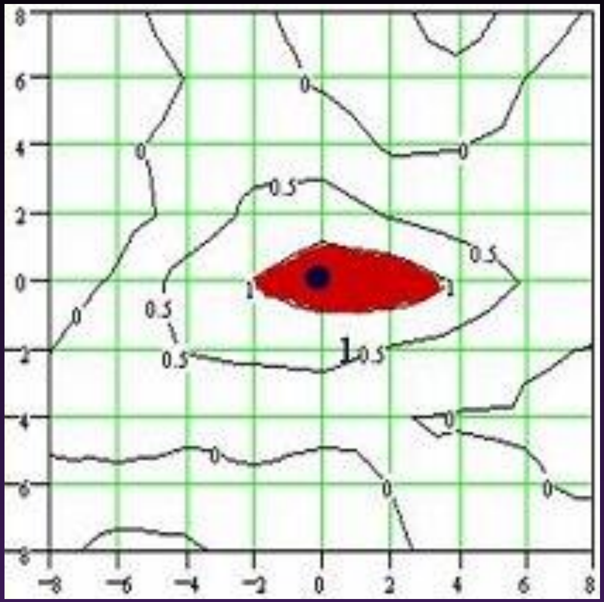
Composites of 12 largest MCS events. Dot = center of heaviest rain; 2x2° latitude grid

850 mb Winds/Isotachs (m/s)



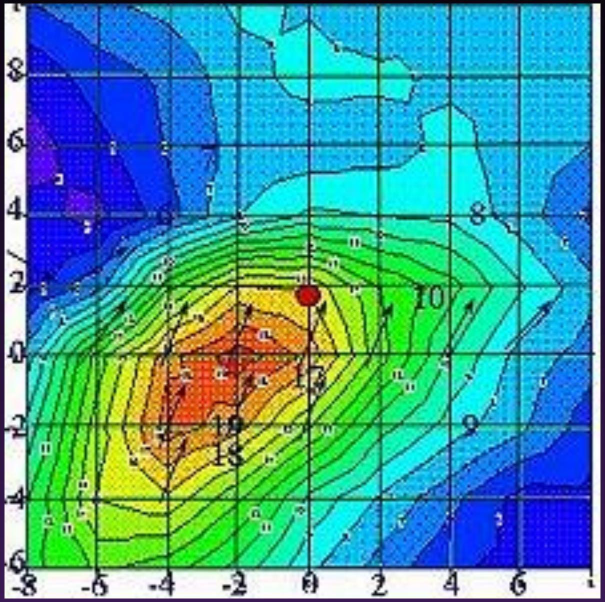
Heaviest rain near nose (exit region) of LLJ (common in elevated MCSs)

850 mb Temperature Advection



Heaviest rain within or near strongest warm advection zone (isentropic lift)

850 mb Moisture Transport



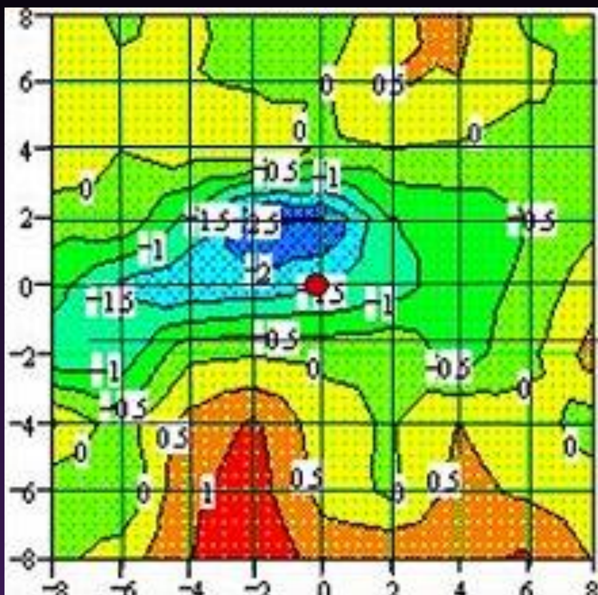
Heaviest rain just NE of strongest moisture transport; amount of transport dependent on characteristics of LLJ

Junker et al., 1999: A Study of Heavy Rainfall Events during the Great Midwest Flood of 1993. *Wea. Forecasting*, **14**, 701-712.

Great Midwest Floods of Summer 1993

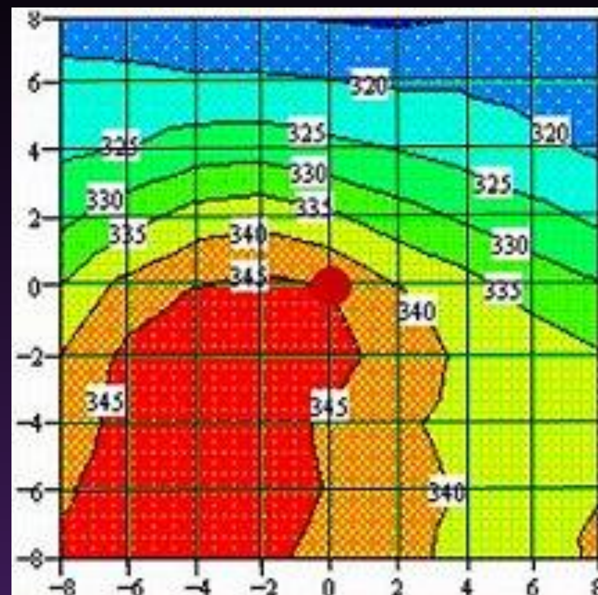
Composites of 12 largest MCS events. Dot = center of heaviest rain; 2x2° latitude grid

850 mb Moisture Convergence



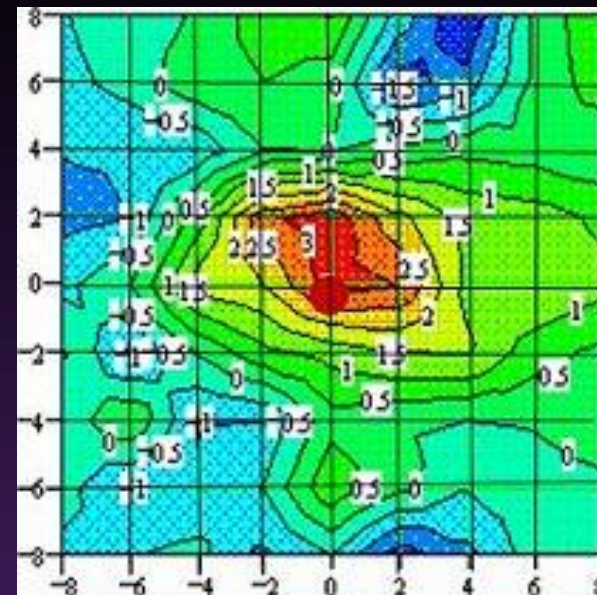
Heaviest rain near area of strong low-level moisture convergence (negative values/blue color above)

850 mb Equivalent Potential Temperature (θe)



Heaviest rain along θe ridge axis just downwind from max values (elevated MCSs more in gradient; warm sector cases closer to max)

850 mb θe Advection

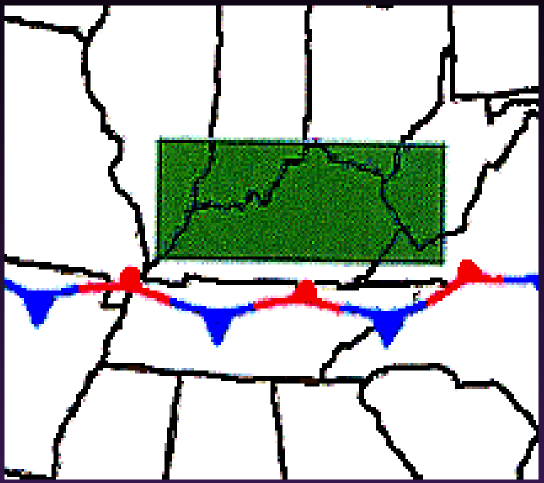


Heaviest rain in area of max positive θe advection (moisture and/or temperature increasing with time)

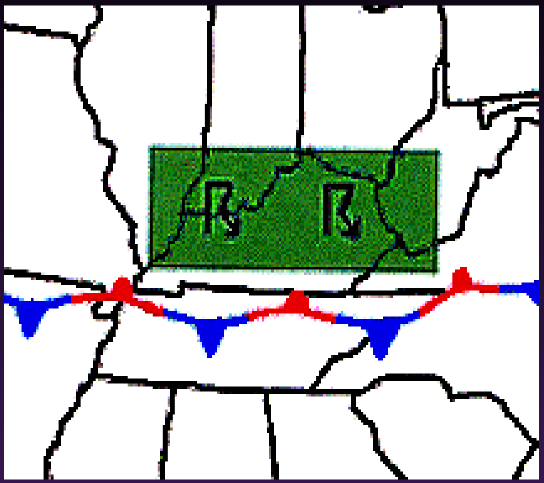
Junker et al., 1999: A Study of Heavy Rainfall Events during the Great Midwest Flood of 1993. *Wea. Forecasting*, **14**, 701-712.

Heavy Rainfall Patterns Across Ohio Valley

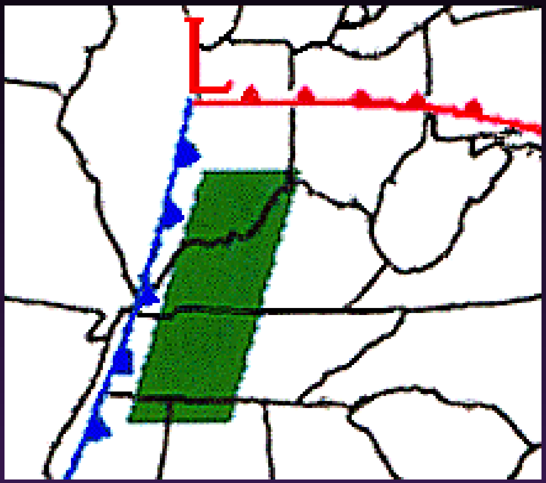
A study of heavy rainfall events (>2” in 24 hrs) from 1982-1996 across KY and southern IN (155 events) showed that most predominant patterns were called Frontal Stable/Unstable and Synoptic, which can result in heavy rain anytime in the year.



Frontal Stable:
E-W stationary or warm front with heavy rain north of it; no elevated convection; lower pressure to west; mainly cool season



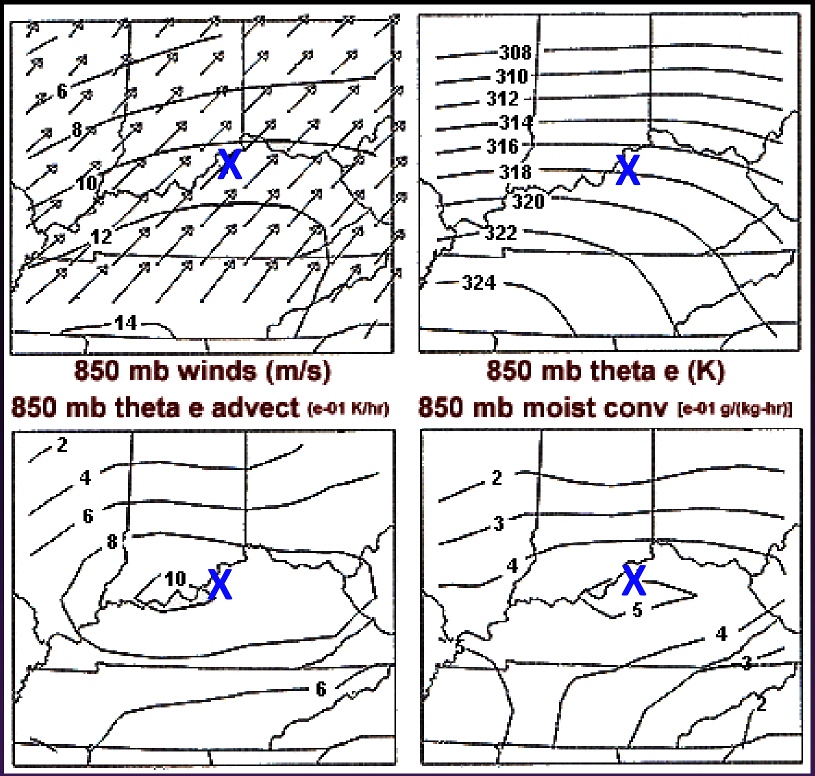
Frontal Unstable:
Similar to Frontal Stable except elevated convection is present north of front due to influx of higher instability from south

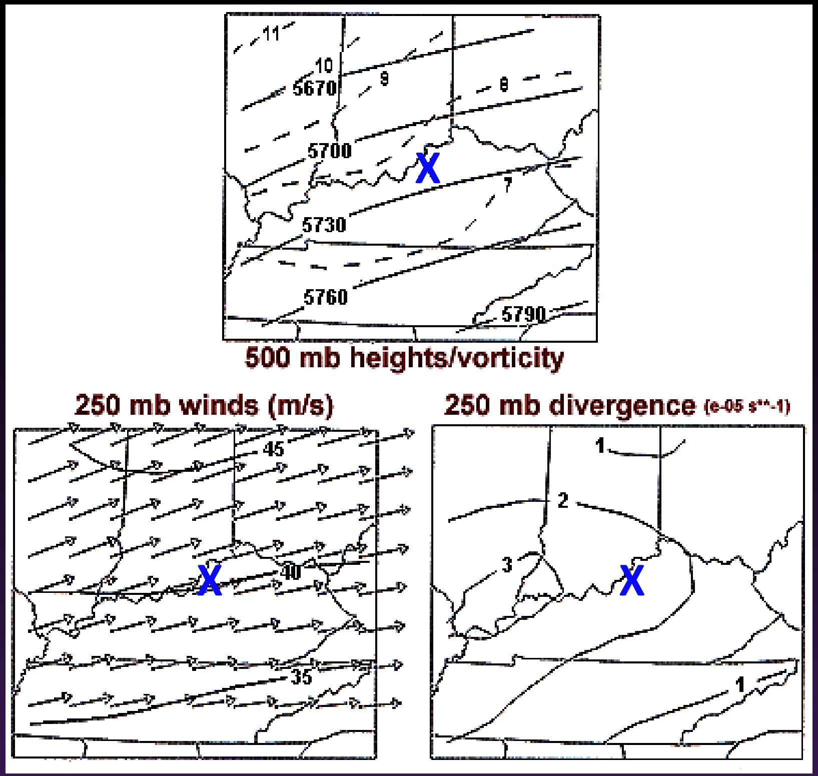


Synoptic:
Heavy rain along/ahead of slow moving cold front; trough aloft nearly parallel to front; convection may or may not be present

Heavy Rainfall Patterns Across Ohio Valley

Frontal: 850 mb & Mid/Upper Level Pattern





"X" = composite location of centroid of heavy rainfall

850 mb:

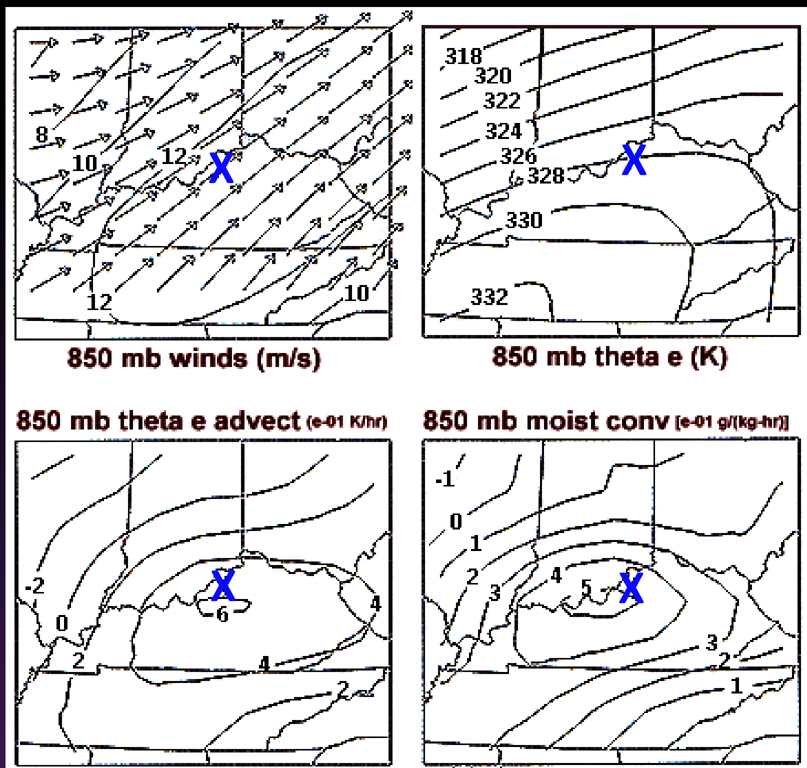
- Downwind from LLJ core within exit region
- Downwind from highest θe with tight gradient (baroclinic environment)
- Moisture convergence; positive θe advection

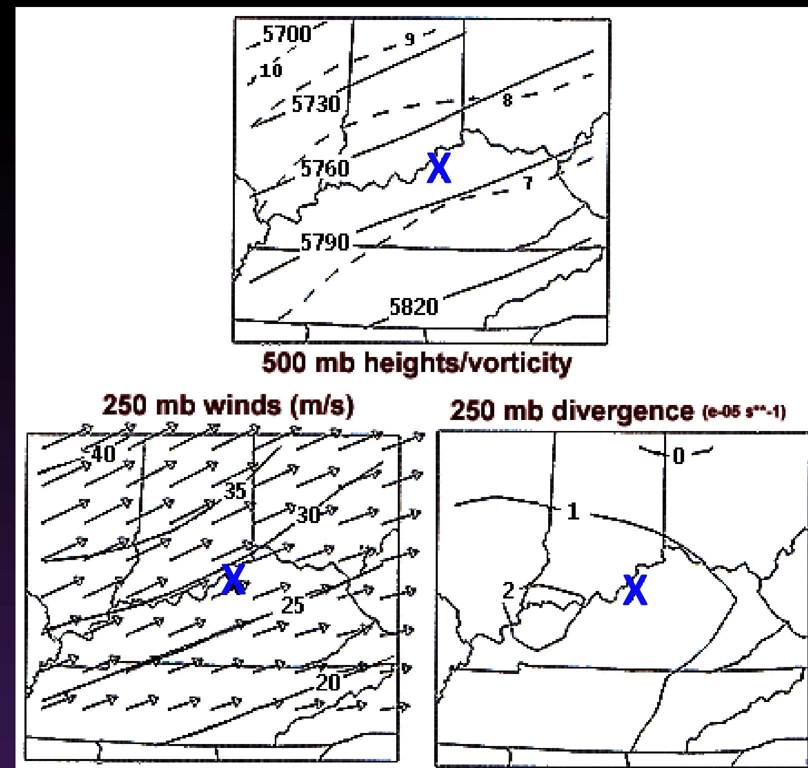
Mid/upper-levels:

- Broad southwest flow at 500 mb and absence of strong shortwave (flat ridge axis)
- Within/near right entrance region of jet and in area of divergence

Heavy Rainfall Patterns Across Ohio Valley

Synoptic: 850 mb & Mid/Upper Level Pattern





"X" = composite location of centroid of heavy rainfall

850 mb:

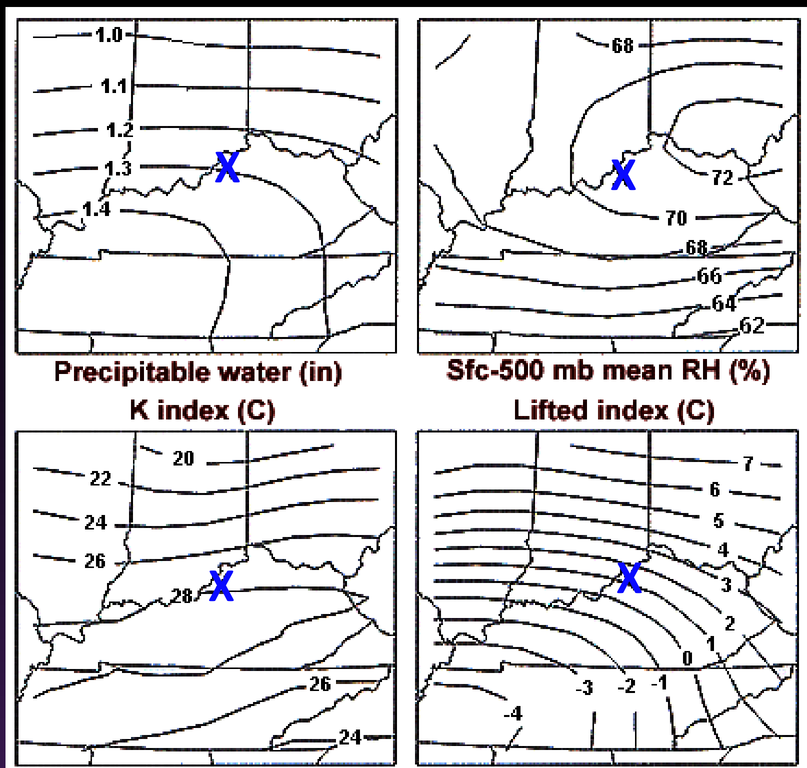
- Typically within axis/core of LLJ (highest values)
- Along/just left of pronounced θe ridge axis downstream from highest values
- Moisture convergence; positive θe advection

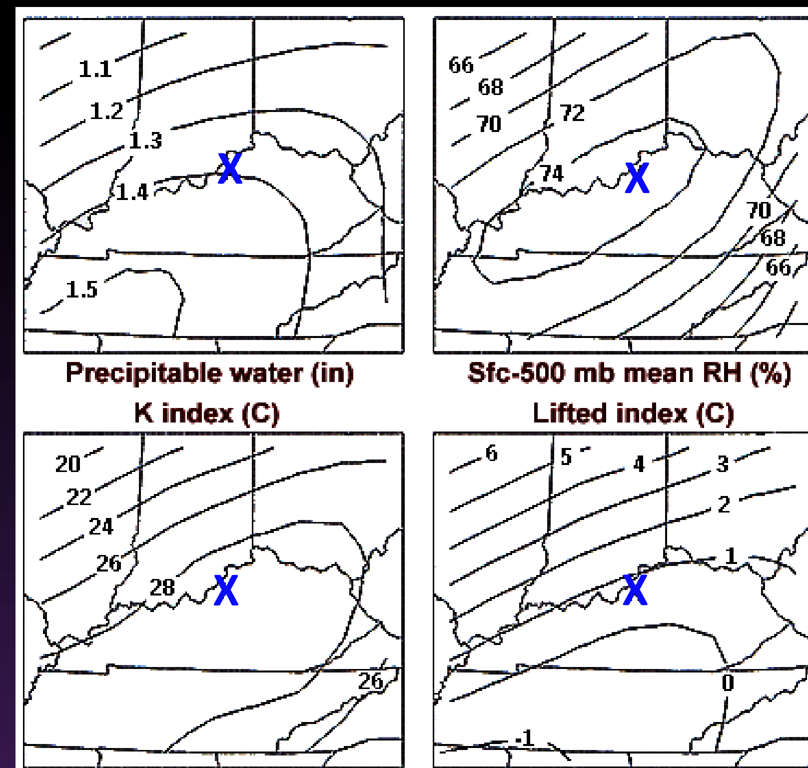
Mid/upper levels:

- Southwest flow nearly parallel to surface front causing slow system movement and/or cell regeneration
- Within/near right entrance region of jet and in area of divergence

Heavy Rainfall Patterns Across Ohio Valley

Frontal Unstable and Synoptic: Moisture/Instability Pattern





"X" = composite location of centroid of heavy rainfall

Frontal Unstable:

- Gradient of PW with values > seasonal normals
- Heaviest rain within/just SW of max mean RH
- Elevated convection so LI > 0, but unstable air (LI < 0) upstream south of front; within/near area of max K Index

Synoptic:

- Within or just left (west) of pronounced ridge axis in PW (> seasonal normals), K Index, and mean RH. Ridge axis parallel to front/flow aloft
- Varying degrees of instability are present in individual events, depending on time of year