Heavy Convective Rainfall Forecasting:
Parameters, Processes, Patterns, and Rules of Thumb

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The heaviest convective rainfall usually occurs in regions of high moisture, maximum ambient or elevated instability, best lift, and slow system movement.

Brilliant!! Eh?

Discussion Topics

- Forecast skills needed
- Parameters useful in assessing heavy rain potential
- Processes associated with heavy rain production
  - Low-level/upper-level jet dynamics; frontogenesis; boundaries
- Elevated convection
- Thunderstorm propagation
- Precipitation efficiency
- Climatology of heavy rain events across Ohio Valley
- Rules of thumb/summary

Basic Forecast Skills Needed

- Must possess good pattern recognition skills
- Must possess knowledge of local heavy precipitation climatology
- Must determine where, when, and how much rainfall will occur
- Must understand atmospheric processes and interactions, which determine the size, scale, and intensity of an area of precipitation
- Must understand and assess numerical models, especially model biases and why they occur
- Must possess good mesoscale/storm-scale analysis skills, both before and during an event, and effect on precipitation distribution and amounts
- Must understand system movement/propagation, which affects rainfall amounts in any one location
- These skills are gained through experience and research

Pattern Recognition

- Pattern recognition is very important. A good assessment and forecast of quantitative precipitation starts with recognizing those patterns and parameters that historically have produced heavy rainfall over particular areas.
- Forecasters must not only recognize patterns conducive to heavy rainfall, but they must especially understand atmospheric processes that may lead to heavy rainfall, given the recognized pattern.
- Caution: Important processes can occur on the synoptic-scale, mesoscale, and storm-scale that can alter precipitation amounts and distributions from those expected within a recognized pattern.
- Patterns can vary by season, geographic region, and scale.

How Much Precipitation Will Fall?

Precipitation amount in any given location is dependent on:

- Available moisture (both relative and absolute):
  - Look for high values of RH, PW, and low-level dewpoints.
- Degree and breadth of low-to-middle level moisture transport:
  - Horizontal and vertical extent of moisture field and transport.
- Rainfall rate/intensity:
  - Is precipitation convective or stratiform?
- Areal coverage of precipitation:
  - Is rain widespread (strong isentropic lift) or localized (scattered convection)?
- Motion and speed of precipitation area:
  - What is movement and speed of precipitation due to mean cloud-layer wind?
- Precipitation propagation:
  - Due to new cell development, is propagation forward, backward, or regenerative (cell training)?
- Precipitation efficiency:
  - How efficient is convection in converting ingested water vapor into rainfall that reaches the ground?

Will Flash Flooding Occur?

Flash flood potential is dependent on:

- Rainfall amount at a given location:
  - Dependent on the factors stated on previous slide.
- Topography:
  - Flash flooding is more likely in hilly and mountainous terrain than in flat areas.
- Antecedent conditions:
  - Flash flooding is more likely from future rain if the soil is nearly saturated and/or streams are running high from recent rain.

Assessing Heavy Rain Potential: Scale Analysis

First, assess the synoptic scale (the big picture):

- **Use observed and model data. There is a clear association between large scale forcing mechanisms (e.g., shortwave troughs, jet streaks, etc.) and convection. While these mechanisms may not initiate convective heavy rainfall, they do help to**
  - **Steepen lapse rates**
  - **Promote moisture transport**
  - **Affect vertical moisture, temperature, and wind shear profiles**

Next, assess the mesoscale (the smaller picture):

- **Perform a meso-analysis of surface, upper air, LAPS/MSAS, satellite, and radar (reflectivity and precipitation estimate) data.**
- **Identify surface boundaries, fronts aloft, convergence zones, enhanced inflow channels, etc. and their relationship to changing fields of moisture, instability, and lift.**

Finally, assess the storm-scale (the smallest picture):

- **If convection is ongoing, analyze temporal changes in storm structure, including the existence and effect of outflow boundaries, colliding boundaries, cell mergers, the convective cold pool, and preferred locations for new cell development (i.e., propagation characteristics.**

Integrated scale analysis will help the forecaster assess what will cause or is causing convective precipitation, and enhance the ability to produce short-term forecasts of future precipitation amounts, locations, and movements.

Parameters Useful in Assessing Heavy Rain Potential

Moisture:

High values of ambient or upstream surface to 850 mb dewpoints (above seasonal normal)

Surface to 500 mb relative humidity:

- High RH better for precipitation efficiency due to less dry air entrainment & evaporation

Precipitable water and percent of normal:

- Warm season ambient or upstream values about 1.5 inches or more; lower values possible in cool season (but still near relative max); values well over 100 % of normal

Instability:

CAPE:

- Surface-based storms: CAPE values can vary significantly and still result in heavy rain
- Elevated storms: May be little or no low-level CAPE, but elevated CAPE present
- Shape of CAPE: long, narrow positive area conducive to better precipitation efficiency; "fat" positive area promotes intense updraft, severe weather, but less efficiency

Lifted index:

- Warm sector convection: ambient LI < 0
- Elevated convection: ambient LI may be > 0 (stable boundary layer below frontal inversion) but unstable values exist upstream along the low-level jet

K index:

- Ambient or upstream values above 30 in the warm season; lower values possible in cool season (but still near relative max)

Parameters Useful in Assessing Heavy Rain Potential

Low-level features:

Low-level jet:

- Along or west of jet axis, or within jet exit region

Equivalent potential temperature (theta-e) and theta-e advection:

- Warm sector convection: along or just to north or west side (gradient) of 850 mb ridge axis, but often just downstream from max values
- Elevated convection: in downstream gradient zone (perhaps near 700 mb theta-e max)
- Theta-e advection: positive advection zones, especially useful for elevated convection in warm advection/isentropic lift regimes

Moisture transport vectors and moisture convergence:

- Often just downstream from maximum moisture transport vectors and near maximum area of moisture convergence

Strong warm advection/isentropic lift:

- Promotes broad forcing conducive to elevated MCSs; less important for surface-based storms

Warm cloud depth (temp of cloud > 0 C):

- Greater depth promotes higher moisture content of air and enhances collision-coalescence process

Parameters Useful in Assessing Heavy Rain Potential

Mid-level features:

500 mb flow:

- Broad south to west flow in mid-levels, perhaps near a broad ridge axis, with only weak shortwaves present promotes higher potential for regenerative MCS; strong mid-level systems favor faster movement and shorter duration rainfall

Upper-level features:

300/200 mb jet streak/divergence:

- Jet streak exit and entrance regions, especially those which exhibit substantial along-stream wind variation
- Area of upper-level divergence (convection can occur within or south and/or east of maximum divergence area)

Thickness gradient considerations:

Tight gradient:

- Baroclinic regime favors forward propagation along/right of 850-300 mb thickness grad

Moderate gradient:

- Tendency for forward cell movement, but with possible cell regeneration upstream assuming favorable low-level inflow; often present for elevated convection

Weak gradient:

- Weak winds and weak thermal gradient typical of warm sector, warm season convection; storms may develop or propagate backwards within a thickness diffluent area

Important Processes Related to Heavy Rain Production

Upper-Level Jet

Boundaries

Frontogenesis

Low-Level Jet

The Low-Level Jet: Formation Mechanisms

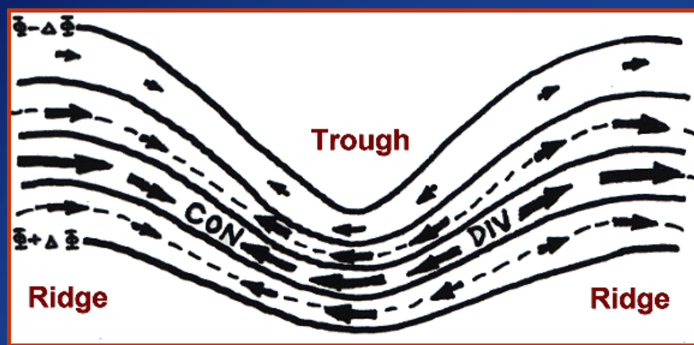
The low-level jet (LLJ) can form in 3 primary ways:

- Beneath exit region of upper-level jet streak (ULJ), where LLJ slopes toward divergence maximum on north (left) side of ULJ; isallobarically forced (responds to height/pressure falls); LLJ increases as exit region of ULJ approaches
  - **Cool season heavy stable precipitation**
  - **Northwest flow convective events**
  - **Tendency for forward MCS propagation and shorter duration of heavy rainfall**
- Beneath entrance region of ULJ, where LLJ slopes towards divergence maximum on south (right) side of ULJ; isallobarically forced; LLJ increases as entrance region isotach gradient (along stream variation) increases
  - **Very important to heavy rainfall (and snowfall) production in the Ohio Valley**
  - **Forcing is more closely located to warm, moist inflow and maximum instability**
  - **Better chance for slow-moving, backward propagating, and/or regenerative convection**
- Forms as an "inversion wind maximum" in late spring and summer in Plains at night at top of nocturnal inversion during benign synoptic conditions
  - **Important component of nocturnal MCS and heavy rainfall production in Plains states**

The Low-Level Jet: A Key Component of a Heavy Rainfall Event

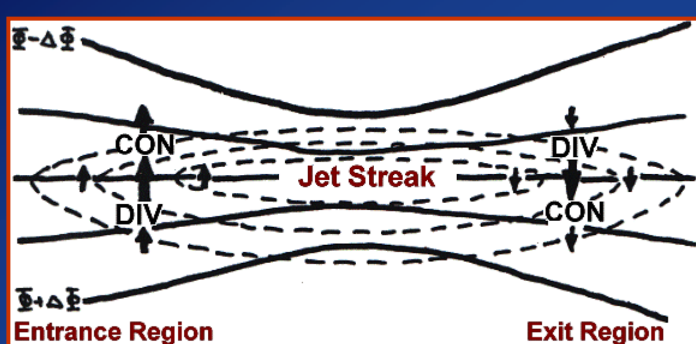
- **The LLJ is crucial to the initiation and sustenance of MCSs and heavy rain**
- **Heavy rainfall often occurs near the nose (exit region) and/or left (west) side of the LLJ axis where speed convergence, confluent flow, and lift are maximized**
- **Horizontal and vertical flux (transport) of moisture is related to strength of LLJ**
- **Differential advection of moisture, temperature, and high theta-e air can lead to air mass destabilization**
- **A strong LLJ in a baroclinic regime can lead to significant isentropic lift and production of elevated convection and heavy rainfall north of a surface boundary**
- **A quasi-stationary LLJ supports the regeneration of convective cells and/or cell training, which accentuates heavy rainfall amounts**
- **LLJ usually is positioned on southwest or west flank of a backward propagating MCS and along or ahead of a forward propagating system**

Upper-Level Jet Dynamics: Ageo Winds



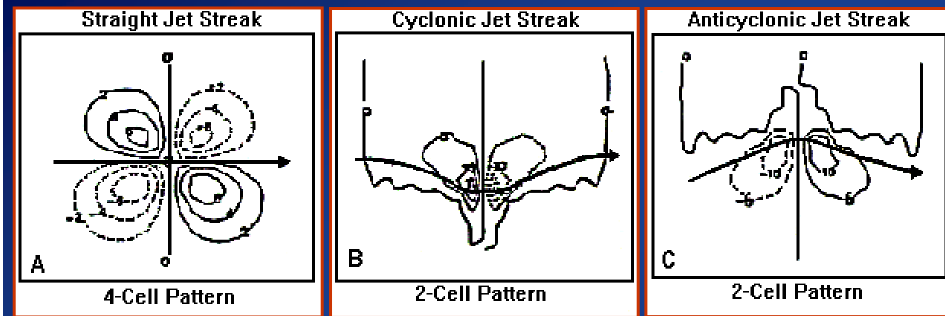
The along-stream component of the ageostrophic wind produces patterns of divergence and convergence due to curvature in the flow. Thus, a short wavelength between an amplified trough and downstream ridge usually results in strong upper-level divergence and vertical motion.

Upper-Level Jet Dynamics: Ageo Winds



The cross-stream component of the ageostrophic wind produces patterns of divergence and convergence due to accelerations (jet entrance regions) and decelerations (jet exit regions) in the flow. The stronger the along-stream wind variation, the greater the upper-level divergence due to this component. Superimposing jet streaks and curvature enhances upper-level divergence in right entrance and left exit regions.

Upper-Level Jet Dynamics: Effect of Curvature



4-cell DIV (dashed), CON (solid) pattern associated with a straight jet due to cross-stream ageostrophic wind component

Result: DIV/UVM in right entrance and left exit regions

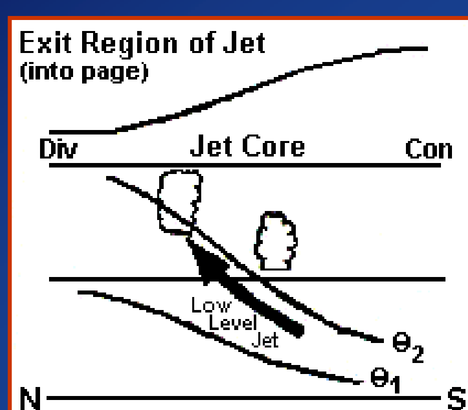
2-cell DIV, CON pattern associated with a cyclonically-curved jet due to cross- and along-stream ageo wind components

Result: DIV/UVM much stronger along and left of jet exit region axis

2-cell DIV, CON pattern associated with an anti-cyclonically-curved jet due to cross- and along-stream ageo wind components

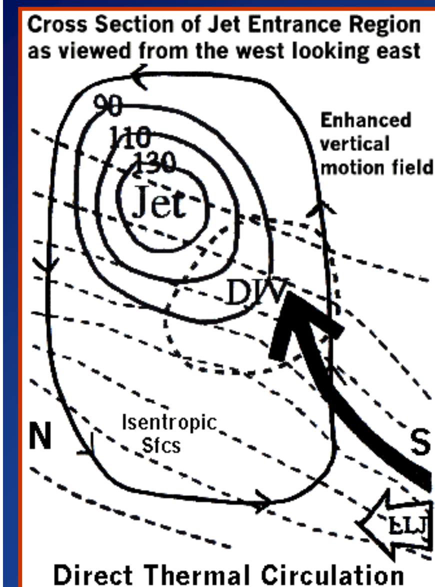
Result: DIV/UVM stronger along and right of jet entrance region axis

Upper-Level Jet Dynamics: Sloped Response of LLJ



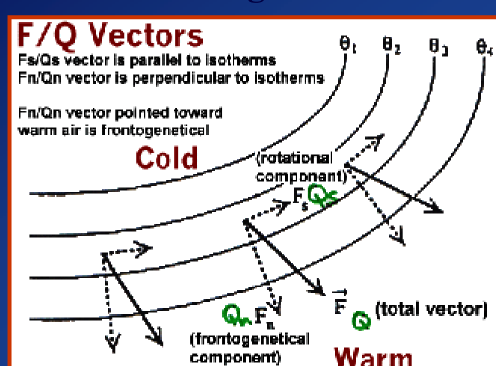
The LLJ often exhibits a sloped response along isentropic surfaces to upper-level divergence in jet exit and entrance regions. Thus, convection can develop south or east of the maximum upper divergence region in the left exit and right entrance regions, depending on the moisture and instability profile of the rising low-level air.

Upper-Level Jet Dynamics: Sloped Response of LLJ



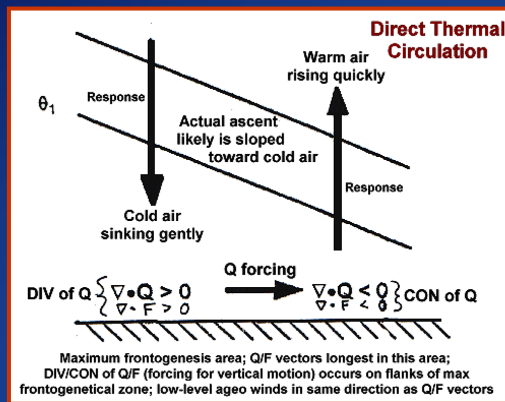
Jet streak entrance region cross-section (looking west to east) reveals its secondary ageostrophic direct thermal circulation (outer circle/box with arrows).   Isentropes slope upward from south to north toward jet streak. An enhanced LLJ rises isentropically toward divergence region in right entrance region. Lower branch of ageostrophic circulation "flows" from colder to warmer air counteracting the ambient southerly low-level flow. This creates convergence and frontogenesis in the low-to-middle levels beneath the entrance region. The resultant smaller-scale frontogenetical circulation complements the jet streak dynamics. This can lead to banded heavy precipitation, including snow in winter and a heavy rainfall producing MCS in the warm season.

Frontogenesis



Frontogenesis refers to a strengthening thermal gradient, and can be evaluated using Q or F vectors. Qn/Fn and Qs/Fs = components directed perpendicular and parallel to isotherms, respectively. Q/F vectors describe changes in the magnitude and orientation of a thermal gradient. Q/F pointing from cold to warm air implies frontogenesis. Qs/Fs describes temperature advection patterns, and forces ascent on synoptic scale. Qn/Fn describes how magnitude of thermal gradient is changing, i.e., either strengthening (frontogenesis) via confluence or weakening (frontolysis) via diffluence. Qn/Fn vectors are longest where gradient is changing most. Convergence of Qn/Fn represents forcing for mesoscale ascent possibly leading to banded precipitation or convection given sufficient moisture.

Frontogenesis

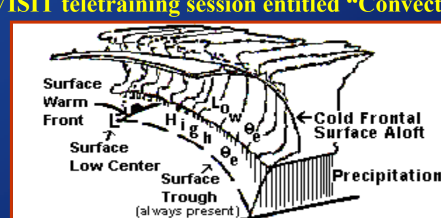


Frontogenesis produces a mesoscale direct thermal circulation that is sloped with height toward cold air. Q/F vector convergence (forcing for lift) occurs on southern/ eastern periphery of maximum frontogenesis area. A steeply sloped frontogenetical zone in low-to-middle levels can produce a definitive band of heavy precipitation superimposed on broader, lighter precipitation in cool season. Low-level frontogenesis also can force the lift needed to initiate deep convection and subsequent heavy rainfall.

Importance of Boundaries

- Boundaries have a profound effect on convective initiation and maintenance.
- Boundaries can be synoptic scale (fronts/troughs), mesoscale (rain-no rain boundaries; frontogenetical zones; horiz convective rolls), and storm-scale (outflow boundaries).
- Boundaries can be surface-based (important in warm season convection) or elevated (fronts/frontogenetical zones aloft, which are important in cool and warm season where precipitation field bares little resemblance to surface frontal positions).
- Models have difficulty in resolving mesoscale and especially storm-scale boundaries. Thus, model precipitation locations and amounts likely will be wrong.
- Diligent analysis critical to resolve boundaries in METAR, satellite, and radar data and their effect on heavy precipitation. Some boundaries and convergence zones are not resolvable in METAR or even mesonet data due to spatial scales of only a few kms.
- For much more detail, participate in VISIT teletraining session entitled "Convective Initiation by Low-Level Boundaries."

Example of a front or frontogenetical zone aloft initiating deep convection ahead of the relatively inactive surface boundary.

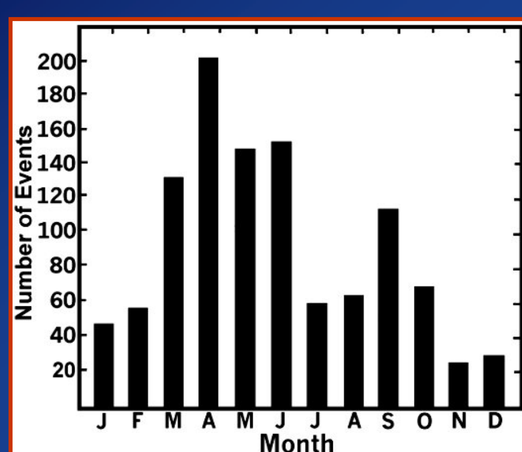


Elevated Convection

- Definition of elevated convection: thunderstorms that form above (north or east of) a frontal zone inversion and are associated with 1) elevated convective instability released by isentropic lift or 2) near neutral stability and frontogenetical forcing.

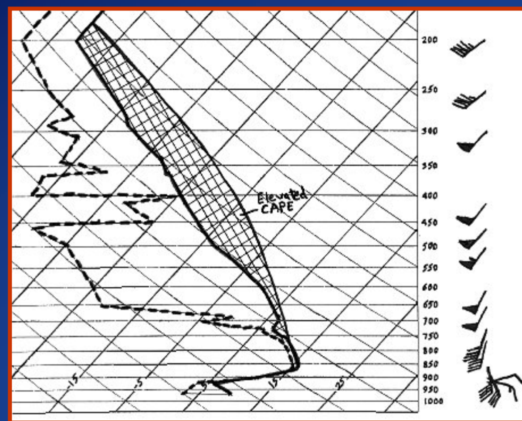
- Conceptual model for elevated storms with convective instability includes:
  - No positive CAPE (when lifting parcel from boundary layer) and ambient LI values > 0
  - Elevated instability present above frontal inversion; elevated CAPE (parcels lifted from level of maximum theta-e) more representative with values > 0; SI values may be < 0
  - High values of boundary layer-based CAPE and LI values < 0 typically located upstream in inflow air originating south of boundary
  - Surface winds often from northeast or east with south or southwest flow above inversion
  - Moderate-to-strong warm air advection and isentropic lift present aloft (baroclinic atmosphere)
  - Storms form in or near maximum zone of 850 mb positive theta-e advection (downstream from maximum theta-e values); storms may be closer to maximum 700 mb theta-e values
  - Storms located near maximum 850 moisture convergence zone associated with exit or left exit region of low-level jet
  - Storms may occur within right entrance region of upper-level jet streak near or south of upper-level divergence maximum

Elevated Convection: Histogram



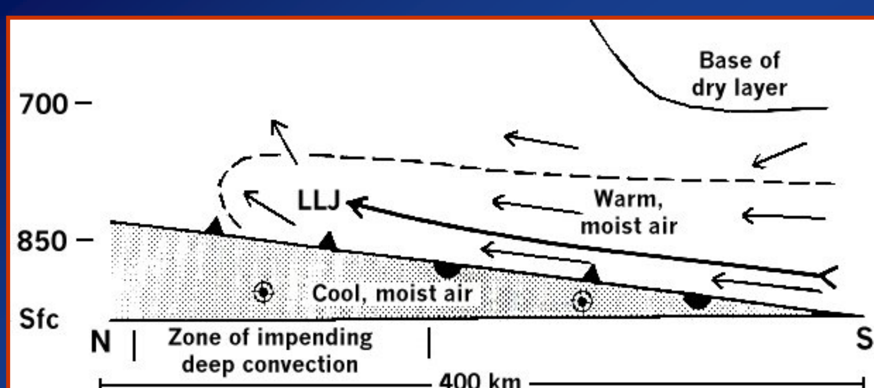
Histogram, by month, of elevated thunderstorms from 1978-1982. The distribution shows a primary maximum in the spring with a secondary maximum in early fall.

Elevated Convection: Sounding



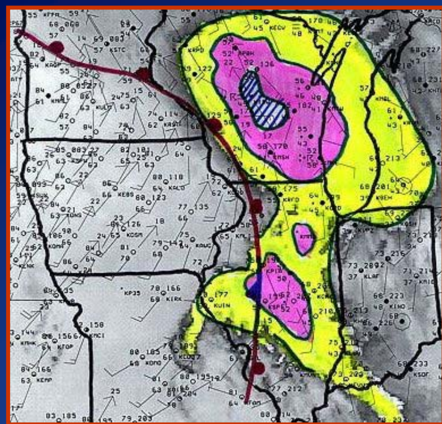
Example sounding in a pronounced elevated convective environment. The boundary layer is very stable and cool (LI = +7) due to a significant frontal inversion (note easterly winds below and southwesterly winds above). However, air mass is unstable above the inversion as SI = -6, TT = 56, and KI = 33. Also note that conventional CAPE = 0, but CAPE calculated from level of maximum theta-e (i.e., elevated CAPE) is nearly 2500 J/kg.

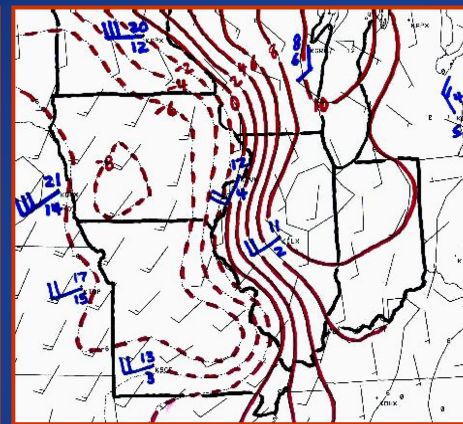
Elevated Convection: Schematic Drawing



Idealized north-south cross-section showing the structure just prior to the development of deep elevated convection above a wedge-shaped cool air mass. The arrows and dashed line represent a wedge of warm, moist air flow rising isentropically from south to north above the frontal surface. The long arrow is the low-level jet. The dots inside the circles in the cool air mass represent easterly flow (out of the page).

Elevated Convection: Example on May 14, 2001





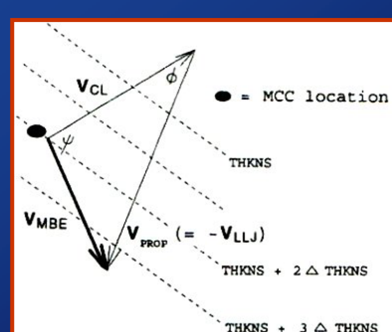
Left: Cold cloud tops (colored shading/hatching) on IR satellite imagery showing an MCS over WI and weakening storms over IL; surface plot and warm front at 1700 UTC. *Right:* MSAS LIs (dashed red: LI < 0; solid red: LI > 0) and surface winds; 850 mb plot at 1200 UTC (blue). Note that elevated MCS is occurring east of warm front in area of stable LIs. However, a tight LI gradient exists to the west with advection of warm, moist, unstable air by the LLJ into the MCS area. Air mass is capped west of front, despite ambient unstable air mass.

MCS Movement and Propagation

- Forecasting the amount and location of heavy rainfall depends highly on MCS movement.
- Motion of MCSs can be considered to be the sum of two components:
  - Advective component, given by the mean motion of existing cells comprising the system
  - Propagation component, given by the rate and location of new cell formation relative to existing cells.
- The advective component is well correlated to the mean flow in the cloud layer (V_{CL})
- The propagation component is proportional (but opposite in sign) and well correlated to the speed and direction of the low-level jet (V_{LLJ}); in other words, low-level jet represents a source of moist, unstable inflow to MCS and new cells form (propagate) toward this inflowing air.

V_{MBE} = movement of mesoscale beta elements (area of strongest cells/heaviest rain) within MCS. In this example, mean cloud flow causes system movement to northeast. However, new cells form on southeast side of parent MCS due to propagation to south-southwest, as new cells develop toward unstable inflow air within LLJ.

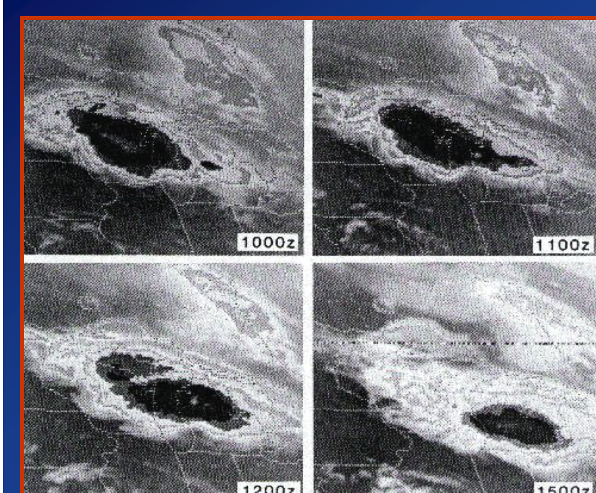
Ref: Corfidi, S., J. Merritt, and J. Fritsch: Predicting the Movement of Mesoscale Convective Complexes. *Wea. Fcstg., 11*, 41-46.



MCS Propagation

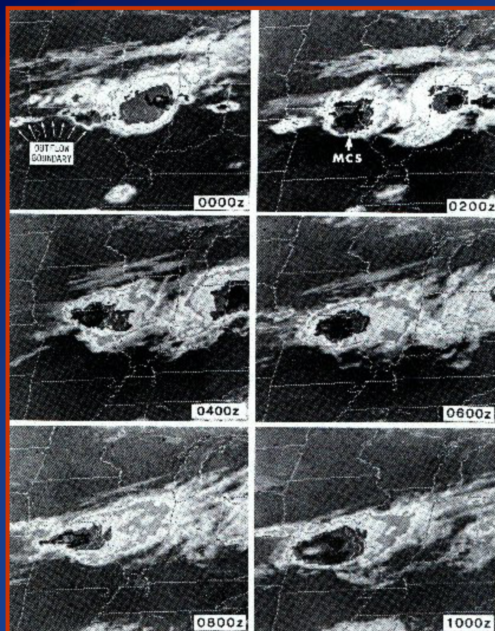
- Propagation refers to the apparent movement of a convective system due to new cell development on one flank where moist, unstable inflow air is present within the LLJ
- The main types of propagation include
  - Forward (fast forward and slow forward movement)
  - Quasi-Stationary (little overall movement)
  - Backward (MCS appears to move backward due to new cell development on upwind flank)
  - Regenerative (MCS and cells within MCS move forward, but new cells and/or other MCSs develop and move forward over same location)
- Prolonged heavy rainfall and flash flood threat due mainly to quasi-stationary, backward, and/or regenerative convection
- Short duration heavy rainfall (but may be a severe threat) due to fast forward movement (e.g., a bow echo)

MCS Propagation: Forward in Satellite



Example of a forward propagating MCS in IR satellite imagery (Mb enhancement curve). In 5 hours, the MCS progresses from Wisconsin to the southern Lower Peninsula of Michigan. Note that the preferred flank for new cell development is on the leading (downwind) edge of the parent MCS. New cells then merge with the MCS keeping it moving forward toward the low-level unstable inflow zone. Meanwhile, older cells in the upwind portion of the system weaken.

MCS Propagation: Backward in Satellite



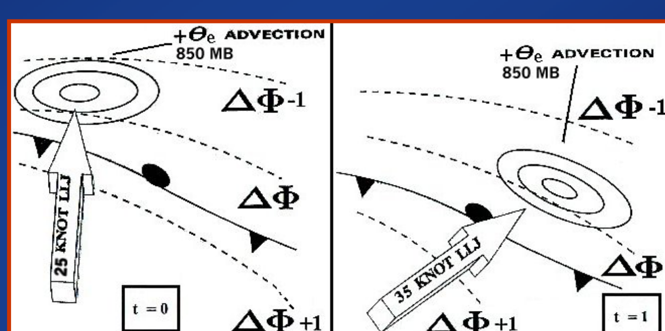
An MCS over central IL at 0000 UTC moved east while new cells developed and propagated backward within the preferred low-level moist, unstable inflow zone along an outflow boundary west of the MCS. Thus, by 1000 UTC, strongest cells in the new MCS were located over west-central MO.

Meanwhile, the initial MCS over IL propagated forward while new cells downstream were stationary near the east-central IN/west-central OH border. These cells then merged with the forward propagating MCS from IL which swept the system east.

Both MCS areas (MO and IN/OH border) represent potential flash flood locations.

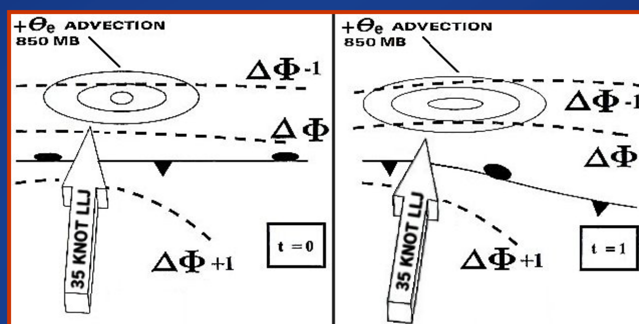
Characteristics of Forward Propagating MCS's

- Forward Propagating MCSs:
  - Maximum CAPE downstream or coincident with MCS
  - 850 mb theta-e ridge axis downstream or coincident with MCS
  - LLJ and strongest low-level moisture transport and convergence coincident with or downstream from MCS
  - Moderate-to-strong 850-300 mb mean winds and thickness gradient
  - MCS usually moves along or just right of 850-300 mb thickness contours
  - Progressive shortwave present which keeps MCS moving forward

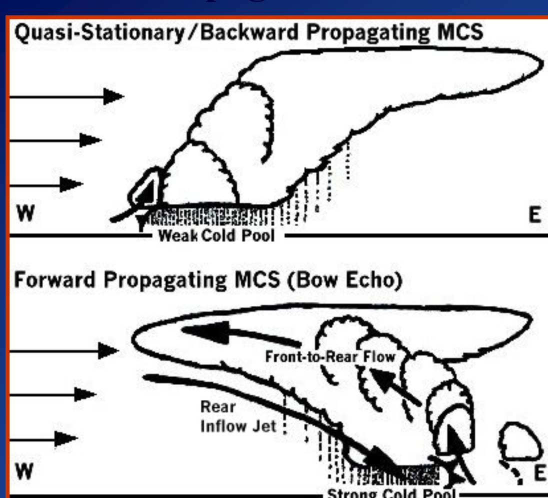


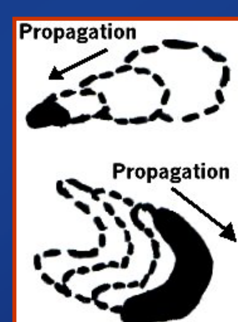
Characteristics of Backward Propagating MCS's

- **Backward Propagating/Quasi-Stationary MCSs:**
  - Maximum CAPE along and upstream from MCS (typically to W or SW)
  - Quasi-stationary east-west surface boundary (front or outflow boundary) present
  - 850 mb theta-e ridge axis along and upstream from MCS (typically to W or SW)
  - LLJ & strongest low-level moisture transport & convergence upstream from MCS
  - Relatively weak 850-300 mb mean winds and thickness gradient (although regenerating cells can occur when winds and gradient are stronger)
  - Possible diffluent thickness pattern aloft
  - May be near mean upper-level ridge aloft; weak shortwave present if any
  - Veering winds with height, but limited speed shear



MCS Propagation: Different Storm Structure

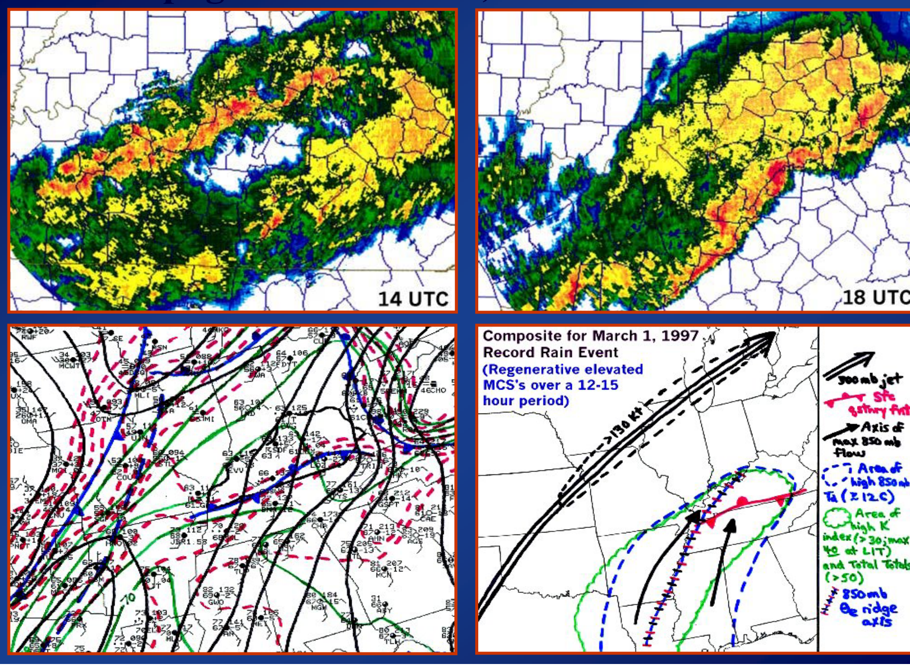




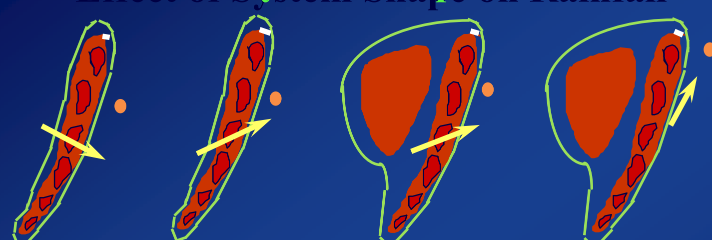
Top: Quasi-stationary/backward propagating MCS due to preferred inflow and new cell development on upwind end of MCS; flash flood threat.

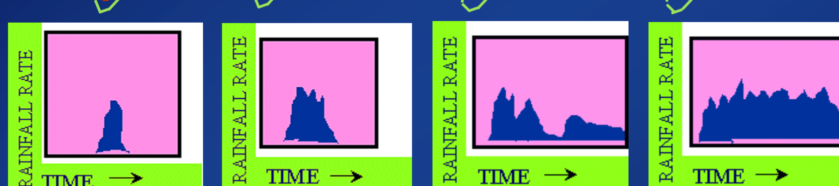
Bottom: Fast forward propagating MCS (bow echo); new cells develop on leading edge where rear inflow jet converges with storm-relative inflow; wind damage threat.

MCS Propagation: March 1, 1997 Record Rain Event



Effect of System Shape on Rainfall





- The graphs show rainfall rate and duration that would occur at the orange dots above depending on MCS shape (outlined by green lines) and movement (yellow arrows).
- A narrow squall line moving perpendicular to its major axis produces only a brief period of heavy rain at any one location, but is more likely to produce wind damage.
- A squall line with significant trailing rainfall moving nearly parallel to its major axis produces prolonged heavy rainfall, and an increased flash flood threat.

Precipitation Efficiency

Precipitation Efficiency is defined as the ratio of the precipitation that occurs at the surface over the lifetime of an MCS to the water vapor (moisture) ingested into the MCS updraft during the same period.

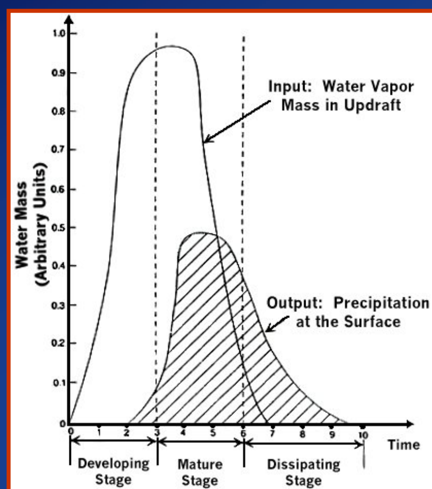


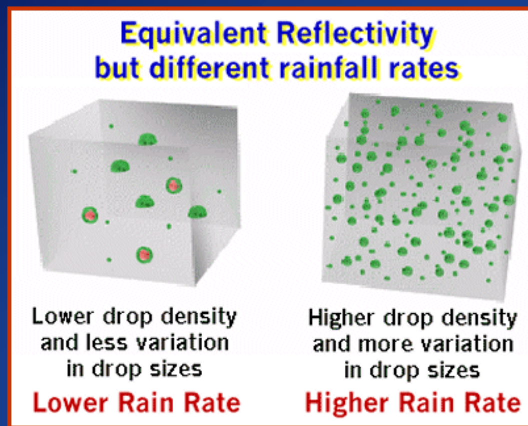
Diagram illustrating the input of water vapor to a thunderstorm versus output of rainfall at the surface. During the developing stage, input is very high with little or no surface precipitation. In the mature stage, water vapor is still being supplied within the updraft while heavy rain reaches the surface. The storm rains itself out in the dissipation stage (no input, only output). The "taller" the output curve versus input curve, the greater the precipitation efficiency.

Factors Affecting Precipitation Efficiency

- Moderate to high environmental relative humidity (> 65%); moisture/high RH throughout sounding (no dry air aloft); results in less dry air entrainment into storm
- Low cloud base height which decreases evaporation in sub-cloud layer
- Vertically deep warm cloud layer (Tcloud > 0 C) greater than 3 km; higher cloud liquid water content which enhances collision-coalescence process
- Strong storm-relative inflow and mixing ratios in low levels (0-2 km) to enhance moisture convergence
- Weak-to-moderate vertical wind shear in mid and upper levels; yields slower system movement and decreased entrainment
- Moderate values of CAPE (roughly 2000 J/kg or less); long, relatively "skinny" positive area on sounding to promote slow vertical acceleration; this increases residence time of droplets in cloud to increase growth with less particles existing top of storm; a "fatter" area of positive energy promotes intense updraft which increases severe threat but generally decreases precipitation efficiency
- A broad spectrum of cloud droplet sizes to enhance collision-coalescence (occurs when air mass has long trajectory over water)

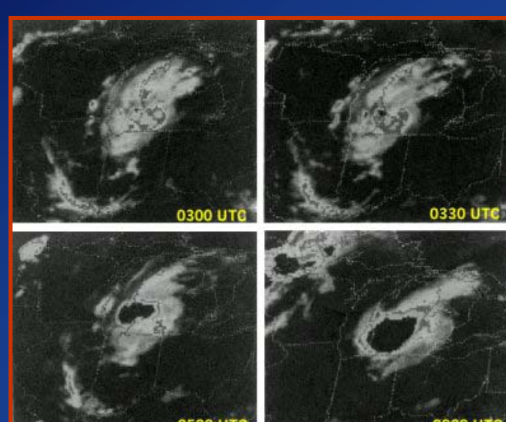
Factors Affecting Precipitation Efficiency

Not all reflectivity is created equally.



Equivalent radar reflectivity values can be generated from 1) a few large drops (or hail) but with a low droplet density and size distribution, and 2) many small drops with a high density and size distribution. However, the second scenario (typical in a maritime tropical air mass) would result in higher rainfall amounts. Thus, when evaluating reflectivity for precipitation estimates, know the environment the storm is within to help determine the efficiency of the storm.

Mesoscale Convective Vortices (MCV)



Due to large amounts of latent heat released within a large MCS/MCC, a mid-level low (mesoscale convective vortex) and increased winds on northern edge of MCS can develop. When MCS dissipates, these features can move downstream into an unstable air mass and produce convection where model data showed little or no QPF.

During afternoon, convection typically develops on periphery of MCV due to differential heating. At night, peripheral convection may dissipate, but deep convection may develop near center of MCV within area of maximum moisture convergence (similar to remnants of tropical systems).

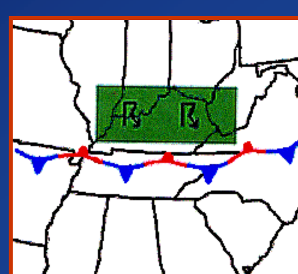
Heavy Rainfall Climatology: Patterns Across Kentucky and Southern Indiana

- In a recent study of heavy rainfall events (> 2 inches in 24 hours) from 1982-1996 across Kentucky and southern Indiana (155 events total), several patterns were documented to enhance the forecast process and ability to determine rainfall potential.
- Patterns included:
  - **Frontal Stable**
  - **Frontal Unstable**
  - **Frontal Warm**
  - **Synoptic Maddox**
  - **Synoptic Warm**
  - **Synoptic Cold**
  - **Mesohigh**
  - **SHARS (subtle heavy rainfall signature)**
- The most predominant patterns were Frontal Stable/Unstable and Synoptic Maddox, which can result in heavy rainfall anytime in the year.

Heavy Rainfall Surface Patterns (most common types)

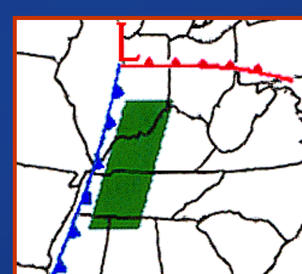
Frontal Stable:

E-W stationary or warm front present with heavy rain north of front; no elevated convection evident



Frontal Unstable:

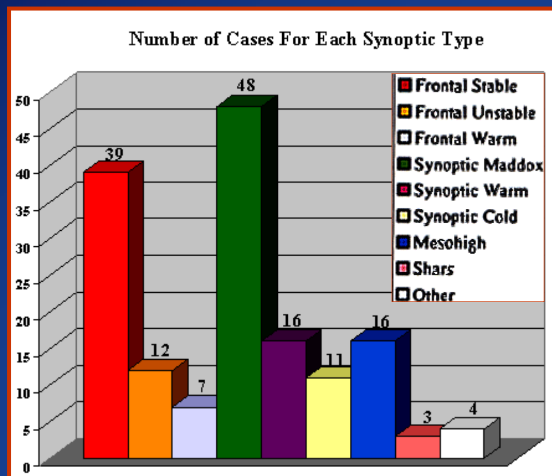
Similar to Frontal Stable except elevated convection is present north of front due to influx of higher instability from the south



Synoptic Maddox:

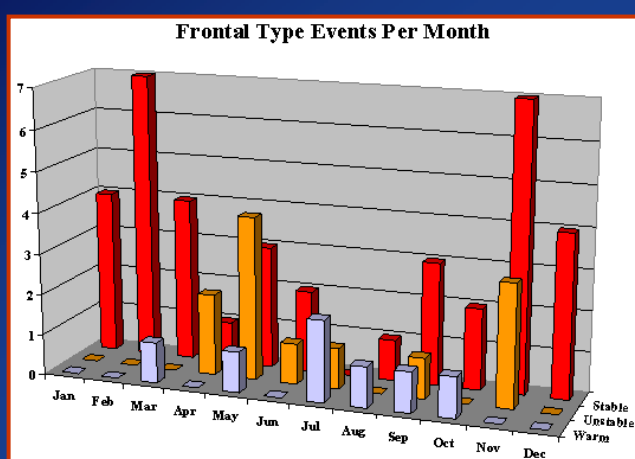
Heavy rain occurs along and just ahead of a slow moving cold front; convection may or may not be present

Number of Events per Pattern



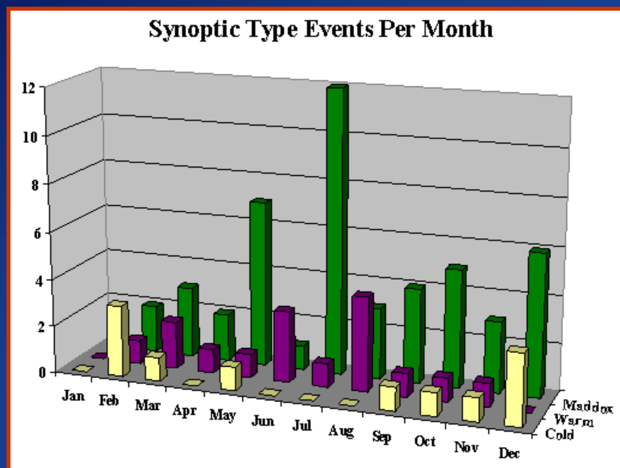
The Frontal Stable (red) and Unstable (orange) and Synoptic Maddox (green) types make up about two-thirds of the total number of heavy rainfall events across Kentucky and the southern third of Indiana.

Frontal Events per Month



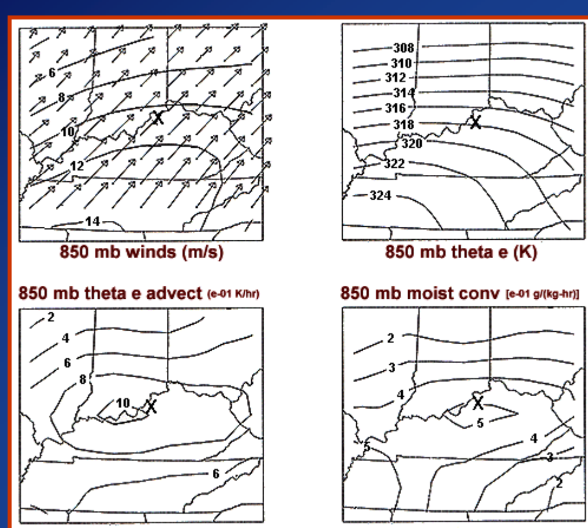
Frontal Stable events (red) are common in fall, winter, and early spring when the atmosphere typically is more stable. Frontal Unstable events (orange) are most common in spring and fall, when the presence of elevated instability results in elevated convection. Frontal Warm events (lavender) (heavy rain falls in the warm sector south of a warm front) can occur in summer.

Synoptic Events per Month



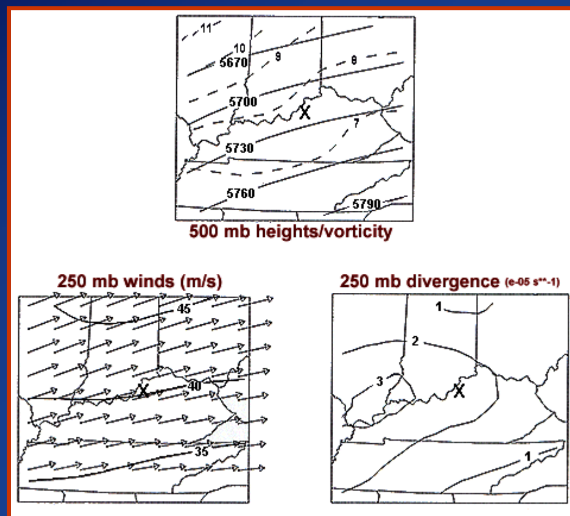
Synoptic Maddox events (green) can occur anytime during the year, including the winter. Synoptic Cold events (yellow) (post cold frontal heavy rain) is most common in winter, while Synoptic Warm (purple) (heavy rain within warm sector ahead of the cold front) is most prevalent in spring and summer.

Frontal Stable: 850 mb Pattern



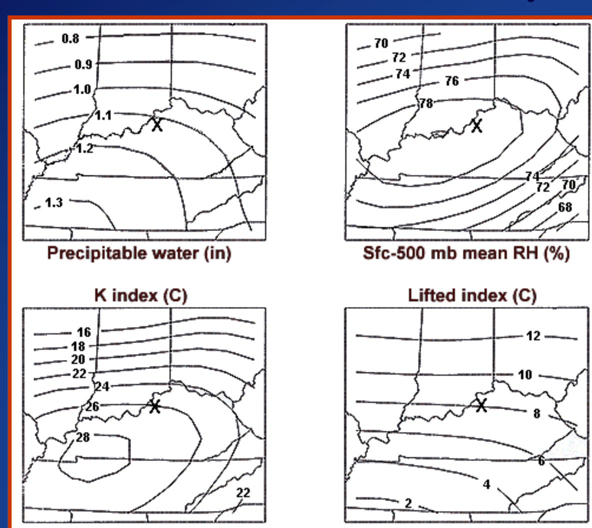
"X" = location of heavy rainfall versus various parameters. Heavy rain typically falls just downwind of the low-level maximum wind flow (within exit region) in an area of 850 mb moisture convergence and positive theta-e advection, downwind from highest theta-e values.

Frontal Stable: Middle/Upper Level Pattern



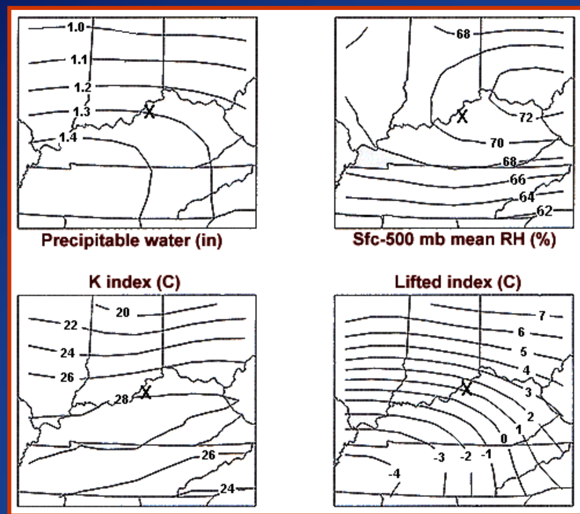
"X" = location of heavy rainfall. Frontal stable events occur within broad southwest flow at 500 mb and absence of a strong shortwave. Heavy rain occurs south of strongest 250 mb winds within or near right entrance region of jet, where upper-level divergence is present.

Frontal Stable: Moisture/Instability Pattern



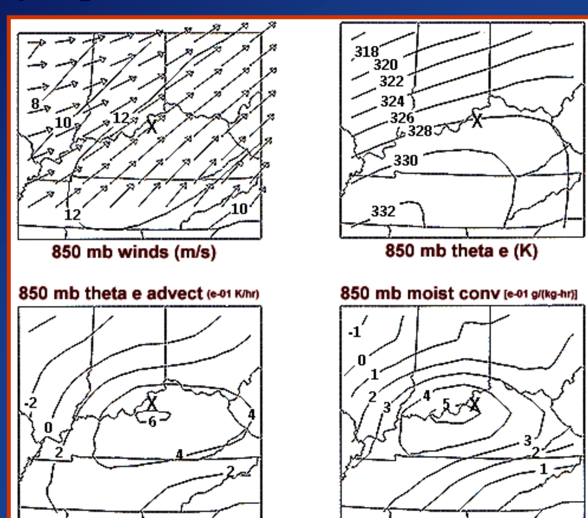
"X" = location of heavy rainfall. Heavy rain occurs just downwind of maximum values of precipitable water and K index, but within highest mean RH. Frontal stable events are associated with stable ambient LI values, with lower, but still stable values upstream.

Frontal Unstable: Moisture/Instability Pattern



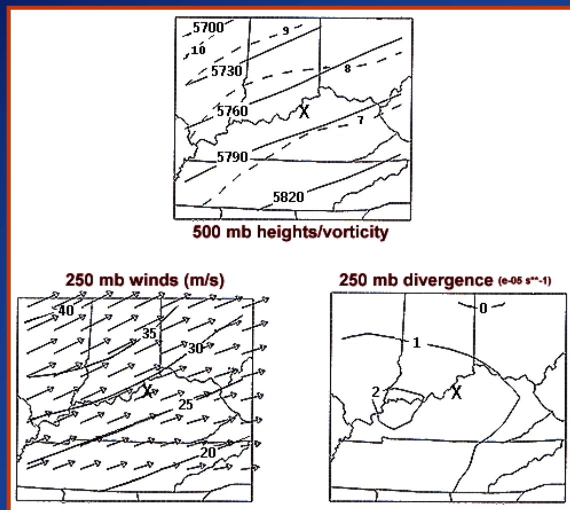
"X" = location of heavy rainfall. Frontal Unstable events differ from Frontal Stable in that ambient and upstream instability is higher, resulting in elevated storms as unstable air lifts isentropically. Also, moisture values often are higher in Frontal Unstable events, which seem to be displaced slightly from maximum mean RH area.

Synoptic Maddox: 850 mb Pattern



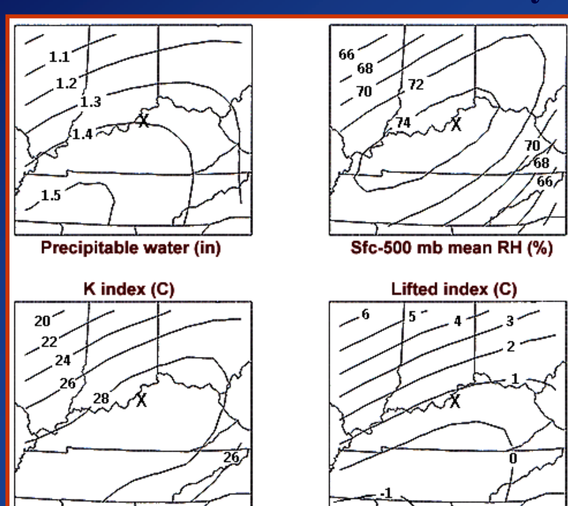
"X" = location of heavy rainfall. In this type, heaviest rain occurs within axis of 850 mb jet and along pronounced ridge axis in theta-e. Theta e values generally are higher than in frontal events. Moisture convergence and positive theta-e advection also are common.

Synoptic Maddox: Middle/Upper Level Pattern



"X" = location of heavy rainfall. Flow aloft generally is southwesterly and oriented nearly parallel to low-level front, which allows for slow system movement and a prolonged period of heavy rain. Rainfall is positioned to south/east of upper-level jet, sometimes within right entrance region where divergence is prevalent.

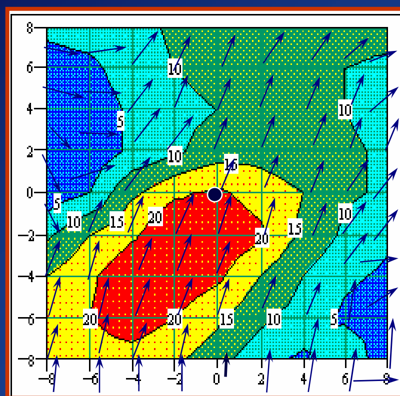
Synoptic Maddox: Moisture/Instability Pattern

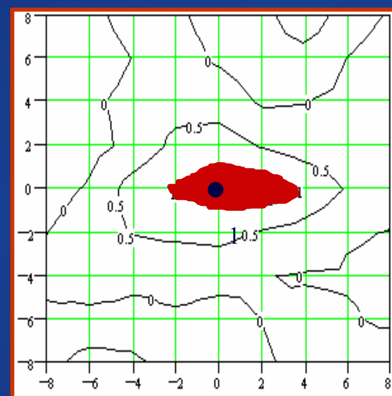


"X" = location of heavy rainfall. Heaviest rain occurs along a pronounced ridge axis in moisture (PW), K index, and mean RH. Ridge axis is oriented nearly parallel to low-level front and mid and upper-level flow. Varying degrees of instability are present in individual events, depending on time of year.

A Study of Heavy Rainfall Events during the Great Midwest Floods of 1993

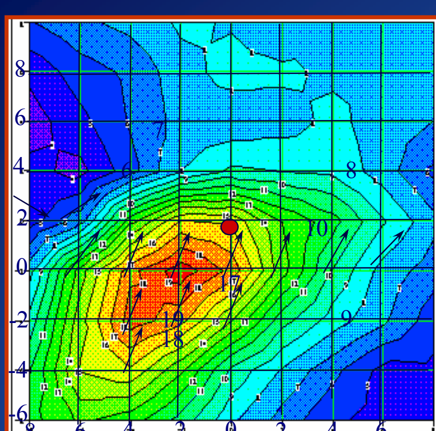
(from Wes Junker et al., W&F, October 1999)

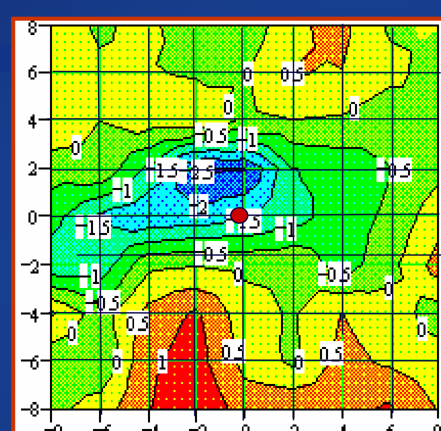




- **850 mb winds (arrows) and isotachs (in m/s; left) and temperature advection (right); the dot = center of heaviest rain; 2 x 2 degree latitude grid**
- **850 mb composites of the 12 largest events showed that the heaviest rain occurred near the nose (exit region) of the low-level jet in/near the strongest warm advection zone**

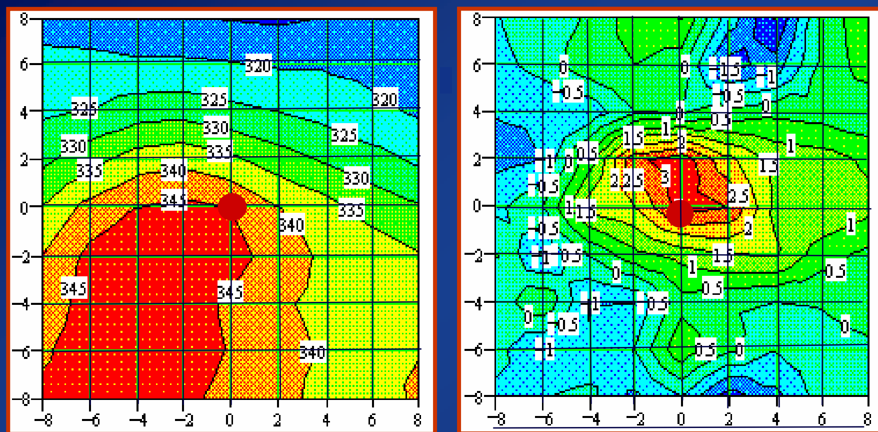
Great Midwest Floods of 1993





- **850 mb moisture transport/flux (left) and moisture flux divergence (right). Note that the heaviest rain occurred just northeast of the strongest moisture transport (left) and just southeast of the strongest moisture convergence (right). Red dot = center of heaviest rainfall.**
- **The degree and breadth of moisture transport (flux) and moisture convergence are dependent on characteristics of the low-level jet.**

Great Midwest Floods of 1993



- 850 mb theta-e (left) and theta-e advection (right).
- Heaviest rain (red dot) usually occurred along a theta-e ridge axis, but northeast (downwind) of maximum values, near or just south of the maximum in positive theta-e advection (where moisture and/or temperature values were increasing with time)

Rules of Thumb for Predicting Heavy Rainfall

- Rainfall maximum often occurs along low-level theta-e ridge axis just north or northeast of maximum theta-e values.
- Inverted isobars along a front (inverted trough) can signal heavy rainfall potential.
- Heavy rain can fall within a thickness diffluence area for convection along or ahead of a cold front, but within a thickness gradient for elevated convection north of a west-east boundary (warm/stationary front).
- Beware of thickness lines or temperatures that hold steady or sink southward in the face of southerly low-level inflow; this indicates strong adiabatic cooling from strong ascent that could result in heavy warm/cool season precipitation.
- K indices are a good measure of deep moisture; values above 35 show good potential for heavy rainfall; even in winter, a ridge axis of relatively higher values may signal heavy precipitation potential.

Rules of Thumb for Predicting Heavy Rainfall

- Beware of tropical connections as observed in water vapor imagery as moist middle and upper levels can result in higher precipitation efficiency.
- Beware of slow moving synoptic circulation elevated convective events, often within or on the southern edge of a comma type satellite signature associated with a strong low and middle-level system.
- Strong height falls and/or fast moving systems usually preclude prolonged heavy rainfall; instead, a large area of moderate rainfall amounts is more likely.
- Numerical models often forecast the synoptic pattern, low-level jet, and moisture distribution reasonably well, but normally cannot handle mesoscale details and outflows that dictate convective locations, rainfall amounts, and propagation.
- In summer, heaviest rainfall often occurs along outflow boundaries.

Summary

So how do I predict quantitative precipitation? There is no one magic method.

- Analyze each situation closely, as no two situations are the same despite what may be similar patterns. Scrutinize the synoptic, mesoscale, and convective environments; integrate current data and model output.
- Understand the processes (on various scales) that produce heavy rainfall and how these processes may evolve given the recognized environment.
- Does the environment favor high rainfall rates, fast or slow moving convection, cell regeneration, isolated or widespread convection, etc.?
- Use model guidance as a first guess but understand model limitations and biases and modify your forecast accordingly.