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HEAVY RAINFALL FORECASTING TECHNIQUES

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1. Introduction

Subjective analysis and interpretation of observed and numerical model data are critical components of effective forecasting by a meteorologist. Subjective interpretation of objective model data is particularly crucial since the short range models contain inherent differences in their analysis and forecast components (Gerrity, 1977; Hoke et al., 1989). As a result, the models each exhibit certain strengths, weaknesses, and biases that affect their ability to predict precipitation, especially heavy convective rainfall (Junker et al., 1989). In addition, Junker and Hoke (1990) found that model forecasts of convective rainfall amounts and locations often are inadequate. Moreover, the quantitative precipitation forecast (QPF) performance of the Nested-Grid Model (NGM) varies according to season, geographic location, precipitation amount, and synoptic regime, with the worst performance during the convective season (Junker et al., 1992). For these reasons, numerical model output cannot be utilized directly in forecasting heavy to excessive rainfall. Instead, forecaster intervention is critical for more accurate prediction.

Various parameters and techniques are available to the meteorologist in forecasting heavy rainfall and flash flood episodes. These techniques, described in detail by Funk (1991), include:

A. Pattern recognition
B. Moisture availability
C. Low-level inflow and convergence
D. Jet stream structure
E. Warm air advection
F. Low-level equivalent potential temperature
G. Thickness diffluence
H. Thickness saturation
I. Preferred thickness
J. Rules of thumb.

These methods are employed by forecasters within the Forecast Branch of the National Meteorological Center (NMC) to produce operational QPFs and excessive rainfall outlooks (Funk, 1991).

The following material is a summary of heavy rainfall forecasting techniques presented by Funk (1991), in which information for each method has been consolidated into concise statements. In this form, the material can be utilized as a quick and easy reference guide by meteorologists at all National Weather Service Forecast Offices during subjective assessment and forecasting of heavy rainfall and flash flood situations.

In applying these techniques, however, caution must be exercised. No one method can be utilized by itself without consideration of all other parameters. In addition, some of the schemes on occasion may not work well, or may work well in one situation but not in the next, despite the apparent similarity in the synoptic or mesoscale environment. Thus, it is essential to know how and when to apply such techniques. Considerable experience and knowledge of the atmosphere, model data, and heavy precipitation systems are crucial.

2. Parameters/Techniques

A. Pattern Recognition

1. Recognizing synoptic and mesoscale patterns associated with heavy rainfall within observed and numerical model forecast data is critical.

2. Based on a thorough knowledge of heavy rainfall climatology, including spatial and temporal frequency distributions of the various types of heavy rainfall producing convective systems over the United States.

3. Based on conscious recall of previous heavy rainfall events within specific synoptic and mesoscale environments.

4. Examples: Maddox et al. (1979) "Synoptic", "Frontal", and "Mesohigh" systems; Spayd and Scofield (1983) "Cyclonic Circulation" (with embedded slow-moving convection) and "SHARS" (Subtle Heavy Rainfall Signatures) systems.

B. Moisture Availability

1. High ambient and/or inflow moisture must be present and maintained for organized heavy or excessive rainfall to occur.

2. Precipitable water (PW) values (ambient or inflow) greater than one inch and at or above normal (warm season).

3. K index values (ambient or inflow) 30 to 40 or more.

4. 850 mb and surface dew points (ambient or inflow) near or especially above 12°C and 17°C (60°F), respectively (warm season).

C. Low-Level Inflow and Convergence

1. Moderate-to-strong moist surface-to-850 mb inflow (10 kts or more at the surface; 25 kts or more at 850 mb) and convergence should be maintained to produce organized heavy or excessive rainfall. Such persistent southerly inflow converging toward a quasi-stationary low-level frontal or outflow boundary (especially those that are east-west oriented) can signify the potential for rainfall amounts approaching or exceeding 5 inches in a 24-hour period.

2. Once thunderstorms have formed, low-level convergence can maintain the convection, whether or not any other forcing mechanism, such as a 500 mb shortwave, is present.

D. Jet Stream Structure

1. Extremely important for developing and maintaining organized severe and/or heavy rainfall producing convection.

2. Favored locations for organized convective development and maintenance: 1) Right entrance and 2) left exit region of a jet streak, 3) exit region of a jet streak approaching the top of a ridge axis, 4) area of upper-level divergence, and 5) anticyclonic shear axis to the right of a jet core.

3. Coupled upper-level jet streaks (convection within the right entrance of the polar jet and left exit of the subtropical jet simultaneously) greatly enhances severe and heavy rainfall potential from thunderstorms.

4. Favored areas of upper-level jet streaks can cause increased convergence within low-level wind maxima, thereby also increasing convective potential (i.e., upper-level/lower-level jet coupling through direct and indirect circulations) (Uccellini and Johnson, 1979).

E. Warm Air Advection

1. Associated heavy precipitation occurs most often at night and in the early morning (for example, nocturnal MCS's) and usually along or north of a frontal or outflow boundary.

2. Associated with the exit region of the low-level wind maximum, where moisture convergence and lift are maximized through isentropic ascent.

3. Heavy precipitation potential exists if model-forecasted thicknesses or 850 mb temperatures hold steady or sink southward in the face of southerly warm air advection, since the warm air is being lifted instead of actually warming the air at a particular level.

F. Low-Level Equivalent Potential Temperature (THETA-E)

1. Theta-e (θ_e) is a function of moisture and temperature, where high values (high θ_e air) are conducive for thunderstorm development.

2. Low-level (especially 850 mb) ridge axis coincident with upward motion and unstable air is a prime location for convective development (Juying and Scofield, 1989; Shi and Scofield, 1987). Downward motion within a ridge axis will suppress development.

3. In warm air advection/overrunning situations, a region of positive advection of θ_e by the low-level wind is where overrunning convection will be found. This area will be just north (not within) of the 850 mb θ_e ridge axis but may be in or close to the 700 mb ridge axis.

4. Tight gradients of θ_e (baroclinic situations) are favored for heavy precipitation.

G. Thickness Diffluence

1. Warm sector convection often develops within or near a region where 1000-500 mb thickness isopleths are diffluent (Fig. 1). It usually is observed along or near the southern edge of the mid-tropospheric westerlies.

2. Implies low-level convergence or upper-level divergence, but most likely a combination of the two, and, therefore, is an area conducive for convective development (Fig. 2).

3. Can also imply an along stream variation in the geostrophic wind, or where ageostrophic flow and upper-level divergence likely would exist in exit region of a jet streak (Uccellini and Johnson, 1979).

4. Model data readily indicate thickness diffluent regions, although no consistent relative maximum in model QPF has been noted in these areas.

H. Thickness Saturation

1. Organized heavy rainfall producing convection occurs most often when the ambient or inflow PW's represent at least 70 percent saturation of the ambient 1000-500 mb thickness. Less applicable for severe convection, where 70 percent saturation may not be achieved.

2. Basic idea is the ascent of potentially unstable air parcels and determining where lifting parcels will saturate and produce rainfall.

3. Diffluent and saturation thickness are not independent. Sufficient moisture must be present to cause saturation in a diffluent thickness region, or else convection likely will form farther north (downwind) within tighter thickness packing, as in overrunning situations (Fig. 3).

4. Useful technique, since convection can develop south of both frontal boundaries and model QPF in very moist environments.

I. Preferred Thickness

1. Heavy rainfall (one inch or more in 12 hours) tends to fall within a narrow range of 1000-500 mb thickness which varies according to season, geography (east of the Rockies), and moisture availability (Bohl and Junker, 1987) (Fig. 4). Rainfall typically occurs in the higher portion of a range when deep moisture is present.

2. Useful tool for determining the location of initial convective development when forcing mechanisms are weak. Less applicable during significant synoptic forcing.

J. Rules of Thumb

1. Large volume convective rainfall tends to occur farther south or southeast with time over the central United States if outflow boundaries from current or previous convection can intercept moist southerly inflow (Olson, 1985). Model data usually do not resolve this. However, convection occasionally can be maintained along or north of the boundary if deep-layered southerly inflow counteracts the boundary's southward push.

2. Heavy rainfall producing convection often develops within or along the upstream edge of a vorticity minimum ridge axis at 500 mb ("N" on model data).

3. Watch for convection BEHIND a weak shortwave if moist unstable inflow persists into a low-level boundary. The convection then is maintained by low-level forcing, despite lack of middle-level support. In other words, PVA is NOT always necessary to produce and maintain convection.

4. If a well-defined middle- and high-level tropical moisture connection exists in water vapor imagery, rain potential is typically higher than normally would be expected given the synoptic situation (Scofield and Robinson, 1992).

5. Inverted isobars signal the possibility of heavy rainfall.

6. MOS POPS may be low in potential excessive rainfall areas but may show a relative maximum in the right place. Thus, study MOS graphics, not just individual station output.

7. Models are subject to "convective feedback" shortwaves, which models induce through deep convection, strong vertical velocities, and latent heat release (Koch, 1985). Models then generate subsequent precipitation (often bullseyes) in response. These rainfall maxima typically are incorrect, overdone, and/or too far downstream from the actual event (Junker et al. 1989).

8. Models often miss, are too light, and/or are too far north (downstream) with convective QPF when the atmosphere is very moist.

9. Heavy to excessive rainfall and flash flood events can occur within very subtle (non-dynamic) systems as readily as with strong, well-defined systems.

3. References

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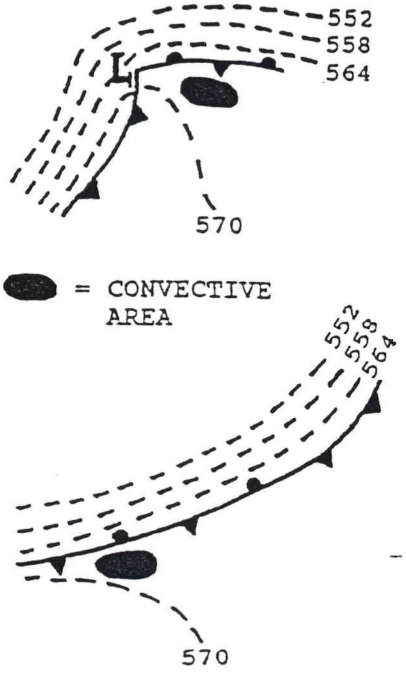


Fig. 1. Schematics of surface fronts and 1000-500 mb thickness configurations (in decameters) versus possible regions of convective development. Convection is depicted within a region of thickness diffluence.

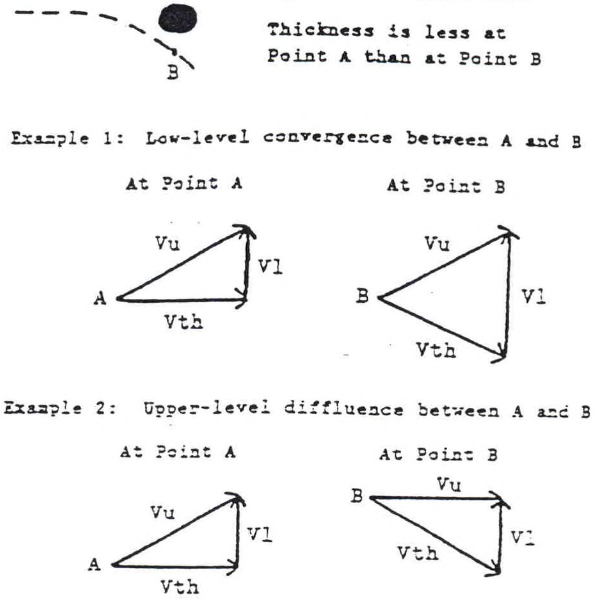
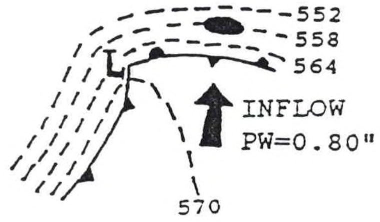


Fig. 2. Vector diagrams indicating two possible ways thickness diffluence can occur. Vu and Vl are the upper-level and lower-level geostrophic wind, respectively. Vth is the thermal wind, which "parallels" thickness contours and is defined as the vector difference between Vu and Vl. The length of the wind vectors is proportional to wind speed.

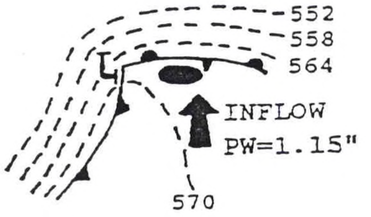
a



Especially Cool Season

● = CONVECTIVE AREA

b



Especially Warm Season

SATURATION THICKNESS

C 70 PCT SATURATION THICKNESS

ΔZ	PW	ΔZ	PW
528	.27	564	1.05
534	.35	567	1.15
540	.43	570	1.25
546	.55	573	1.40
552	.70	576	1.55
558	.80	579	1.70
561	.90	580	1.90

Fig. 3. Areas of potential convective development where 70 percent thickness saturation is achieved given the indicated inflow precipitable water (PW) values (a and b). Saturation may occur farther north within thickness packing for lower PW amounts (a), and farther south within thickness diffluence for higher PW amounts (b). Also, PW values (in inches) needed to produce 70 percent saturation at the indicated 1000-500 mb thickness values (in decameters) (c).

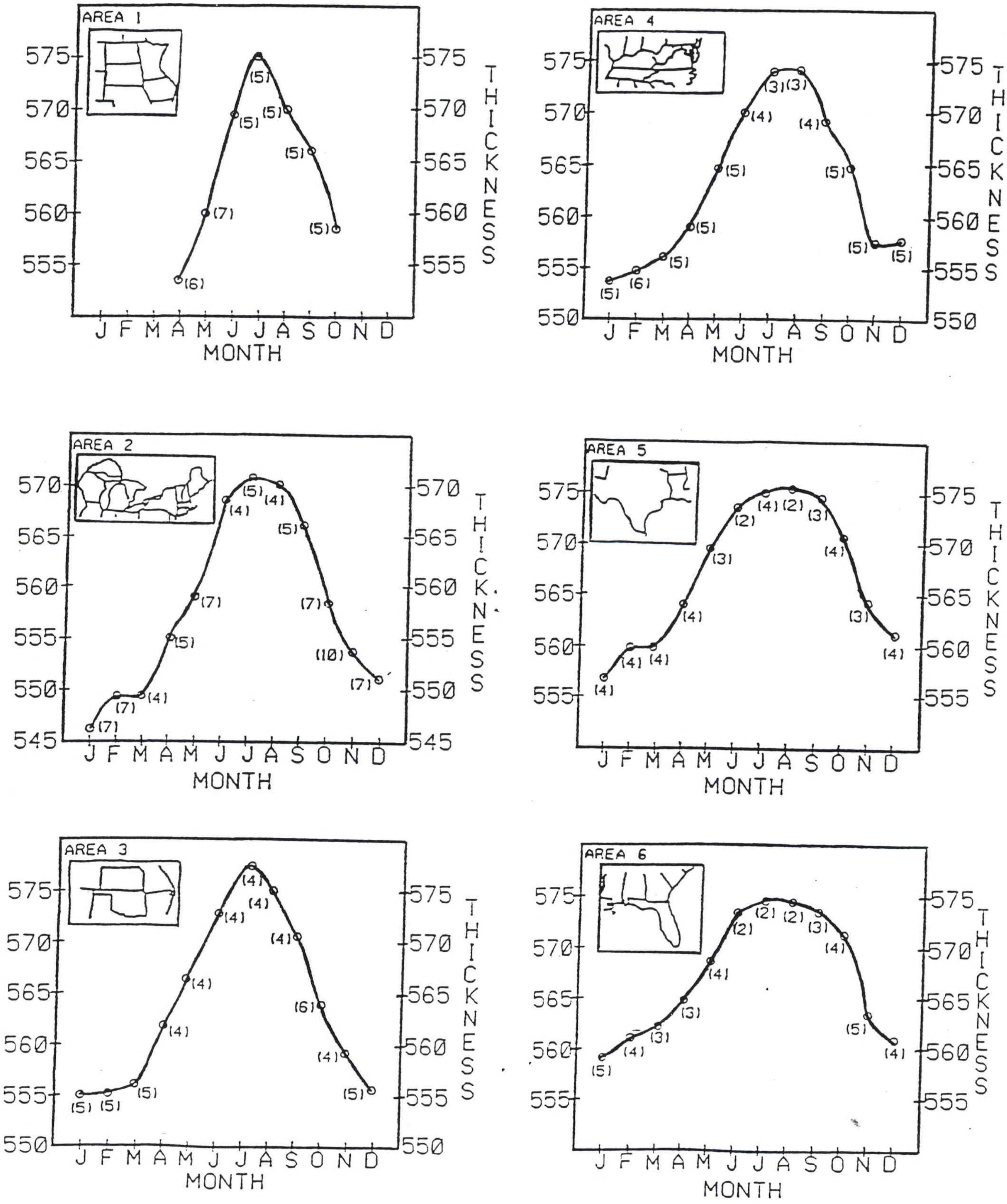


Fig. 4. Monthly preferred 1000-500 mb thickness values (in decameters) for heavy rainfall over the areas shown in the upper left corner of each diagram. In parentheses are standard deviation values (in tens of meters), which indicate that a narrow range of favored thickness exists for each month. Figure from Bohl and Junker, 1987.