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USE OF RADAR INFORMATION IN DETERMINING FLASH FLOOD POTENTIAL

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INTRODUCTION

An improved method has been designed for the use of radar information by operational people in the flash flood program. Radar estimates of maximum precipitation are compared objectively with the minimum, three-hour precipitation amounts required for flash flooding. Through this comparison, areas that have a potential for flash flooding are determined. The minimum rainfall required for flash flooding, called Flash Flood Guidance, is prepared and disseminated daily by River Forecast Centers.

Manually digitized radar (MDR) observations for a grid box about 40 n mi (74 km) square are transmitted hourly on teletype (Moore, Cummings and Smith, 1974). Using the three latest MDR observations, a three-step procedure is presented here for monitoring flash flood potential. This is followed by the description of a fourth step which requires detailed radar information, such as remote radar facsimile data (Hamilton, 1973). Each step does the following:

<u>Step 1</u> - Determines where the radar estimated rate of precipitation is of concern. It provides an early alert.

<u>Step 2</u> - Monitors precipitation rate and duration. This is an intermediate step that tells us when we should proceed with Step 3.

<u>Step 3</u> - Provides a first estimate of maximum rainfall for three hours within an MDR grid box. A range of precipitation is determined assuming stationary echoes and only hour-to-hour change in intensity of the strongest echoes within an MDR box.

<u>Step 4</u> - Accounts for observed echo movement which provides an improved estimate of maximum, three-hour rainfall.

STEPWISE PROCEDURE FOR ESTIMATING FLASH FLOOD POTENTIAL

<u>Step 1 - Early Alert - Critical Hourly MDR Number or Echo Intensity</u>

An MDR code number indicates the intensity of the strongest radar echo in a grid box. A theoretical range of rainfall rate is given for each MDR number (Table 1). If we use the highest rate, then the third column of Table 2 is the hourly MDR value which must be equalled or exceeded before the three-hour precipitation amount could exceed the indicated minimum required for flash flooding.* Conversely, when required MDR code values are not reached, this implies a precipitation rate insufficient for flash flooding. A caution in using Tables 1 and 2 is presented on page 9 (LIMITATIONS).

*In the future, the radar code may be changed such that a Video Integrator and Processor (VIP) level of maximum intensity will be reported directly for grid boxes 1/4 the area of the current MDR box. This will improve the use of the procedures outlined here. Flash flood alert criteria based on reported VIP levels are shown in Table 2 for use when the coding change is made (Column 4).

Table 1. Manually Digitized Radar (MDR) Code

Code No.	Coverage in Box	Intensity Category	Rainfall Rate In/Hr	Rainfall Rate mm/Hr
0	None			
1	Any VIP 1*	Weak	<.1	<3
2	≤1/2 of VIP 2	Moderate	.1-.5	3-13
3	>1/2 of VIP 2			
4	≤1/2 of VIP 3	Strong	.5-1	13-25
5	>1/2 of VIP 3			
6	≤1/2 of VIP 3 and 4	Very Strong	1-2	25-51
7	>1/2 of VIP 3 and 4			
8	≤1/2 of VIP 3 4, 5 and 6	Intense or Extreme	>2	>51
9	>1/2 of VIP 3 4, 5 and 6	Intense or Extreme	>2	>51

*VIP (Video Integrator Processor)

Table 2. MDR or VIP values which indicate precipitation may exceed minimum three-hour amount required for flash flooding.

Required Minimum Three-Hour Pcpn for Flash Flooding		Hourly Values That Must Be Equalled or Exceeded		Sum of Latest Three Values That Must Be Equalled or Exceeded*	
Col.1 Milli-meters	Col.2 Inches	Col.3 MDR	Col.4 VIP	Col.5 MDR	Col.6 VIP
25	1.0	2	2	6	4
38	1.5	4	3	6	4
51	2.0	4	3	8	6
64	2.5	4	3	10	7
76	3.0	6	4	12	8
89	3.5	6	4	12	8
102	4.0	6	4	14	10
114	4.5	6	4	16	11
127	5.0	6	4	18	12
140	5.5	6	4	18	12
152	6.0	8	5	20	13

*Hourly MDR values of 8 or 9 (VIP levels 5 and 6) were not considered because when these values occur they meet the criteria regardless of the sum of MDR numbers. Also, if VIP level 5 or 6 occurs between hourly observations, that too meets alerting criteria.

After an MDR value indicates a critical precipitation rate, we need to examine prior and subsequent hourly MDR values for the area of concern. We want to account for precipitation duration and hour-to-hour variation in intensity to arrive at the theoretical, maximum precipitation. This leads us to the second step - finding the sum of up to three consecutive hourly MDR values that indicate flash flooding is possible.

Step 2 - Intermediate Alert - Critical Sum of MDR Numbers

We assume the rate of precipitation for an entire hour (starting thirty minutes before the observation time) within the MDR box is at the top of the range for a reported MDR number (Table 1). With this assumption we can determine the lowest sum (of up to three MDR values) that indicates precipitation could exceed the minimum required for flash flooding. This MDR sum is a necessary threshold condition (Table 2, Col.5). In deriving threshold values for sums of MDR numbers, hourly MDR code values of 8 or 9 were not included, but are given special consideration. They indicate extremely intense echoes with a precipitation rate greater than 2.0 inches (51 mm) per hour. When an MDR code 8 or 9 is reported, Steps 1 and 2 are skipped, and we start with Step 3.

Step 3 - Computation of Range of Maximum Three-Hour Precipitation

The highly non-linear relationship between MDR numbers and theoretical rainfall rate makes it advantageous to compute three-hour precipitation amounts from individual hourly MDR values rather than from the sum of multiple MDR values. Different combinations of MDR numbers can have the same sum, but imply markedly different precipitation. We assign one-hour precipitation amounts to each of the MDR numbers, allowing first for the lowest and then for the highest rainfall rate (Table 1). For MDR numbers 8 and 9, we can only assign a lower end of the range of precipitation. The upper end is undefined.

Moore, Cummings and Smith (1974) did provide a nomograph for using the sum of up to four MDR values in estimating the probability of any specific rainfall amount at an unspecified point within an MDR grid box. Their nomograph tries to consider all of the uncertainties involved. The authors state, however, that the nomograph was a "first cut" attempt based on a limited number of events. They also state that indications derived from their nomograph must be treated with caution. The approach presented here differs considerably because we are not as concerned with the probability of precipitation amount as we are with the theoretical maximum of precipitation. We have made assumptions toward that end. Examples of the computations will follow. In the first example, the importance of considering precipitation inferred from individual hourly MDR values will be shown by comparing the result with that obtained from the Moore, Cummings and Smith nomograph.

As stated earlier, Steps 1, 2, and 3 can be carried out by anyone receiving the MDR numbers. Furthermore, with a little programming effort, these steps could be computerized, with Step 1 providing an initial alert based on one observation and Step 3 providing a higher alert based on up to three observations. Step 2 is a procedure that facilitates manual handling of the data, but is not required in computer processing.

Examples Using MDR Information in Recognizing Flash Flood Potential

To illustrate Steps 1 through 3 and the use of Tables 1 and 2, let's consider cases in which 3.0 inches (76 mm) of precipitation in three hours or less must be exceeded before flash flooding is a threat.

Step 1 - Dividing 3.0 inches by 3 hours, we determine the critical precipitation rate to be 1.0 inch per hour. From Table 1 or Table 2 (third column) we see that code number 6 is the lowest MDR value indicating that this rate may be exceeded.

Step 2 - From Table 2 we also see that the sum up to three hourly MDR values must equal or exceed 12, or an MDR value of 8 or 9 must be reported, before the estimated three-hour maximum precipitation can exceed 3.0 inches.

Step 3 - To illustrate this step, the range of radar estimated three-hour precipitation will now be computed for several cases in which Steps 1 and 2 are satisfied by a reported MDR number of 6 or greater, and a sum of MDR numbers equal to 12 or greater.

Example 1 - Hourly MDR numbers reported consecutively are 0-0-0-6-3-3. From Table 1 we determine the maximum precipitation occurring somewhere in the MDR box each hour. We then add the lowest and highest hourly amounts separately. The sums thus arrived at represent the range of the estimated three-hour precipitation maximum.

	MDR Number	Lowest Precipitation	Highest Precipitation
	6	1.0"	2.0"
	3	0.1"	0.5"
	3	0.1"	0.5"
Total	12	1.2"	3.0"

The maximum precipitation in this example is estimated between 1.2 and 3.0 inches. Since 3.0 inches was the amount to be exceeded for a flash flood potential, radar indicates no probability of flooding due to precipitation that has fallen thus far, even though Steps 1 and 2 were satisfied. This conclusion differs from the conclusion that can be reached using the nomograph presented by Moore, Cummings and Smith. In their nomograph we find that the probability of three inches of rain is not near zero, but rather, for the three-hour MDR sum of 12, is about 23%. The 23% probability may be true if we did not know the individual MDR numbers, but we do! For example, if the sum of 12 resulted from hourly MDR numbers of 2, 2, and 8, we would have a higher probability of three inches of rain than we have in this example. The precipitation rate implied by MDR number 8 is much greater than MDR number 6, while the rates implied by MDR numbers 2 and 3 are the same.

Example 2 - Hourly MDR numbers reported consecutively are 0-0-0-6-6.

MDR Number	Lowest Precipitation	Highest Precipitation
6	1.0"	2.0"
6	1.0"	2.0"
Total 12	2.0"	4.0"

We have the same MDR sum as in Example 1, but the maximum precipitation in this case is estimated between 2.0 and 4.0 inches. Since 3.0 inches was the amount to be exceeded for a flash flood potential, the two MDR observations indicate a threat. There is no need to wait for a third observation. There should be an immediate consultation between appropriate WSOs, WSFOs and radar observers, because the radar observer can provide more detailed radar information (see Step 4). Also, attempts should be made to obtain current precipitation gage measurements to verify the radar estimates.

Example 3 - Hourly MDR numbers reported consecutively are 0-0-0-6-6-6. At the time the second 6 was reported, this example is identical to the previous example. We now proceed as though the third 6 was just reported, remembering that we always work with the latest three MDR numbers.

MDR Number	Lowest Precipitation	Highest Precipitation
6	1.0"	2.0"
6	1.0"	2.0"
6	1.0"	2.0"
Total 18	3.0"	6.0"

The three-hour estimated precipitation is now between 3.0 and 6.0 inches. The flash flood threat has increased. The Moore, Cummings and Smith nomogram gives a probability of about 45% for exceeding three inches.

Example 4 - The next hour an MDR number 2 is reported, then we have 0-0-0-6-6-6-2.

MDR Number	Lowest Precipitation	Highest Precipitation
6	1.0"	2.0"
6	1.0"	2.0"
2	0.1"	0.5"
Total 14	2.1"	4.5"

The minimum amount of precipitation required for flash flooding, three inches, is still within the range of the estimated precipitation amount for the latest three hours. Thus, the threat continues, even if flash flooding hasn't begun due to estimated earlier precipitation.

Example 5 - The next hour an MDR number two is reported, now we have 0-0-0-6-6-6-2-2. Since the MDR sum for the latest three hours is less than 12, the criteria in Step 2 is no longer satisfied.

MDR Number	Lowest Precipitation	Highest Precipitation
6	1.0"	2.0"
2	0.1"	0.5"
2	0.1"	0.5"
Total 10	1.2"	3.0"

Even though the latest three-hour precipitation is less than that required for flash flooding, we could have flash floods due to earlier precipitation. However, if action was required, it should have been taken earlier. Also, the earlier precipitation would have lowered the minimum three-hour amount now required for flash flooding. This is significant if the precipitation continues and intensifies.

Example 6 - This final example illustrates a case in which 3.0 inches is the minimum required for flash flooding and an MDR number 8 has just been reported. The consecutive MDR reports are 0-0-0-3-8. At the time the 8 is reported, the MDR sum, 11, is less than the Step 2 MDR sum criteria of 12. Remember, though, when 8 or 9 is reported, this immediately satisfies the Step 2 criteria, regardless of the MDR sum.

MDR Number	Lowest Precipitation	Highest Precipitation
3	0.1"	0.5"
8	2.0"	>2.0"
Total 11	2.1"	>2.5"

The estimated maximum precipitation amount in this case is between 2.1 inches and some unknown higher value which is greater than 2.5 inches. Since the upper end of the range is unbounded we have a threat. The WSFO forecaster should consult with the radar observer and also attempt to get precipitation gage measurements near the threatened area.

Step 4 - Detailed Computation of Precipitation Amount

Weather systems, which produce radar echoes and precipitation, usually are moving and not quasi-stationary as assumed in the previous examples. Very heavy but localized precipitation may fall initially over one part of an MDR box and later over another part of the same box, with no one river basin receiving enough precipitation to cause flash flooding. If we know this, then no action need be taken which would falsely alarm the public of a flash flood. This uncertainty illustrates a point. Although the MDR program has improved the communications and handling of radar observations, there are still inadequacies in this information. At times it is advantageous to work with the greater detail that appears on the radar overlays of echo intensity traced from the radar PPI scope. The radar data received via the Weather Bureau Radar Remote (WBRR) system can also be used if it contains the VIP levels of intensity.

How should the radar observer with his radar overlays, or a forecaster who receives data at frequent intervals via WBRR, maintain an accounting of how much precipitation may have fallen in the last three hours over any one location? They have a choice. They can use MDR values as suggested in the three preceding steps and then, if warranted, proceed to a fourth step described here, or they can use the MDR information as suggested in Step 1, and then, when threshold values are reached, proceed immediately to Step 4. Finally, they can disregard the MDR observations altogether and work only with radar overlays or WBRR pictures to complete Step 1 and Step 4.

The task involved in Step 4 is straightforward. Superimpose the hourly overlays or WBRR pictures applicable to the time period of concern. Concentrating on the area where earlier Steps show a problem may exist, visually determine the location that has had the greatest exposure to the combined effects of echo duration and intensity. Now, for this location, repeat Step 3 and determine the theoretical range of precipitation based on observed VIP levels. The result could be the same as previously determined in Step 3, but most often the computed precipitation will be considerably less due to moving echoes. This reduces the area and number of times a flash flood potential is indicated by radar.

At times it will also be necessary to account for precipitation when VIP levels significantly change between hourly observations. This accounting can be accomplished by taking intermediate observations and prorating for the different intensity durations. Fifteen-minute precipitation amounts, for example, can be determined by multiplying the hourly rate by 1/4 hour. For small time periods we can use a precipitation rate equal to the mid-point of the rates allowed for each of the VIP levels, except for VIP levels 5 and 6 where even for fifteen minutes there can be a large spread between the lowest and highest precipitation amount (Table 3).

Table 3. Precipitation Amounts Estimated From Observed VIP Levels

VIP Level	Theoretical Precipitation Rate (inches/hour)	Fifteen-Minute Precipitation Amount (inches)
0	0	0
1	<0.1	0
2	0.1 to 0.5	0.1
3	0.5 to 1.0	0.2
4	1.0 to 2.0	0.3 to 0.5
5	2.0 to 5.0	0.5 to 1.2
6	>5.0	≥1.3

It was mentioned above that the MDR values may be disregarded altogether where hourly radar overlays or WBRR pictures are available. VIP levels can be monitored for implied precipitation rates that could cause flash flooding (Step 1, Table 1). After recognizing the presence of a critical VIP level, we can convert the isolines of VIP levels to isolines of theoretical hourly precipitation amounts (highest and lowest amount). Then each hour, for the area of concern, we can mentally determine or graphically add the precipitation (highest and lowest amounts separately) for the latest two and three hours. Ultimately, we can end up with a range of one, two and three-hourly precipitation amounts for any area of interest. The results of this procedure would be superior to any effort that involves smoothing by assigning one VIP level (the maximum) to an area as large as an MDR grid box. Unfortunately, the time needed, especially if more than one observation is required each hour, may exceed the time available at a normally staffed station.

As stated earlier, there are plans to change to an all-digital radar code with boxes 1/4 the area of MDR grid boxes. As shown by Belville (1975), this would result in greater detail being available in the radar observations. The task of recording and communicating high resolution digitized radar data could be done by computer. Its feasibility is being demonstrated in the digitized radar experiments (D/RADEX) now being conducted at Pittsburgh and elsewhere. In D/RADEX automated radar observations are being taken every twelve minutes and collected in a 2-degree azimuth by 1 n mi (1.9 km) range format (Greene, 1975). The computer stores the information from 12-minute observations in 3 n mi (5.6 km) by 5 n mi (9.3 km) grid boxes and maintains a running total of theoretical three-hour precipitation amounts.

LIMITATIONS

It must be strongly cautioned that if for a particular case the radar observations of echo intensity, the theoretical relationship between echo intensity and rate of rainfall, or the estimated minimum amount of precipitation required for flash flooding are unrepresentative, then the procedures presented here can result in a misleading estimate of the potential for flash flooding. For this reason, it is important that all other available information, such as rain gage observations, be used in determining flash flood potential.

CONCLUSION

A procedure has been presented for using radar information to alert the Meteorologist, Radar Observer, Weather Service Specialist, and Hydrologist to the potential for flash flooding. By following this procedure, Forecasters, Hydrologists, and Radar Observers will be aware of areas in which MDR values imply a rate of precipitation and duration that could cause flash flooding. Two methods were shown for estimating the maximum rainfall amount from radar data. One method, using MDR values only, provides a first estimate of precipitation amounts. The other method requires more detailed radar information, but provides a better estimate of precipitation amount by accounting for changes in echo position and intensity. For both methods, there are serious limitations which could affect the determination of the flash flood potential. Therefore, other available information must also be used in appraising the situation.

The systematic approach proposed here is being tested at WSFO New York, N.Y. which is collocated with the radar. We hope to set up tests elsewhere.

ACKNOWLEDGMENT

The need for this development effort was suggested by Robert Fisher, WSFO Buffalo, N.Y., and Edward Yandrich, WSFO New York, N.Y. in an unpublished report, "Utilization of Digitized Radar Data In Potential Flood Situations." They expressed a need for better objectivity in using radar information to determine the possible occurrence and severity of flash floods, and offered a possible solution. Their suggested solution, although not adopted here, became the "seed" from which this paper grew.

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