3320

DIGITAL RADAR DATA AS A PREDICTOR OF FLASH FLOOD POTENTIAL

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1. INTRODUCTION

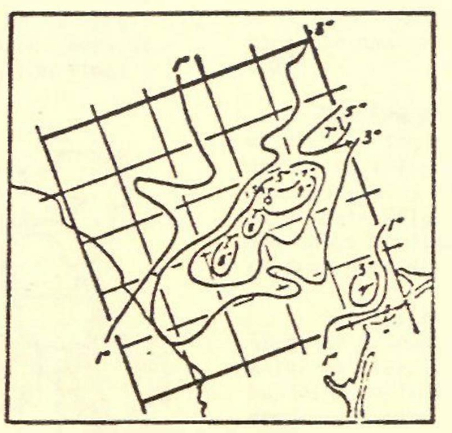
Interpretation of manually digitized radar (MDR) data on a grid as coarse as that presently in operational use by the National Weather Service (see paper by Moore, et al. in this preprintavolume) is a hazardous task. Such data are ambiguous and can be misleading to the unwary forecaster. However, with a prudent approach and a probabilistic point of view, it is possible to draw useful conclusions regarding the likelihood of flood-producing rainfall amounts from this type of radar intelligence. For this purpose an accounting procedure is needed in order that data taken over a period of several h urs may be assimilated into some meaningful, ititative index. Operational considerations ate that the procedure must be uncomplicated,a d, and must produce an index that is straight- ard. A scheme that satisfies these criteriaa a simple summing of the MDR values for a givena ock over a specified number of hours. This provides a starting point for the design of a code, any number of which might be devised. The one presently in use (Table 1) attempts to assign an order to echo descriptions that ascends numerically with increasing potential for flash flooding and other active weather, thus yielding totals which bear some general positive correlation to rainfall amounts. Inferences as to what this correlation should be are premature, but two long-duration heavy rain events which have occurred since the advent of the program show patterns of digit totals and measured rainfall which are in general agreement. Fig. 1 shows a Texas situation from September, 1973, while Fig. 2 shows a similar comparison for the central Gulf states from March, 1973.

TABLE 1. MANUALLY DIGITIZED RADAR (MDR) CODE.

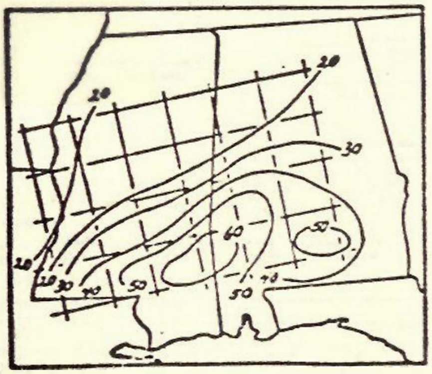
Code No.	Coverage in BOX	Intensity Category	Rainfall Rate in/hr
0			
1	any VIP1	Weak	<.1
2	≤1/2 of VIP2	Moderate	.1-.5
3	>1/2 of VIP2		
4	≤1/2 of VIP3	Strong	.5-1
5	>1/2 of VIP3		
6	≤1/2 of VIP3 and 4	Very Strong	1-2
7	>1/2 of VIP3 and 4		
8	≤1/2 of VIP3 4,5 and 6	Intense or Extreme	>2
9	>1/2 of VIP3 4,5 and 6	Intense or Extreme	>2

2. LIMITATIONS OF MDR DATA

For use as assistance in flash flood prediction, totals over much shorter periods, say 2-6 hours in most cases, must be employed. In the NWS Southern Region, 4-hour totals have received most of the attention, with lesser emphasis on 2 and 3 hours and little experimentation thus far with longer periods. Empirical guidelines for threshold values of digital totals indicating flood threats are developing as experience with the program is gained. It is not to be expected that a "magic number" will emerge as a universal precursor of flood events since factors such as local terrain, antecedent conditions and the inherent limitations of radar must always be considered. For instance, the map in Fig. 3 indicates - by means of hatching - those grid squares comprising the NWS Southern Region portion of the grid that lie at least partly beyond the 125-mile range of the radar designated to survey them in the MDR program. These areas are thus beyond what may be considered effective hydrologic range and digits ascribed to them must be regarded as suspect for hydrologic purposes. Due mainly to effects of range attenuation and partial beam-filling, digital values for these grid squares will tend to be somewhat low and users should bear this



ig. 1. torm-to al (24 hr) of MDR values (left) and rainfall(right) for south Texas area, September 26-27, 1973.



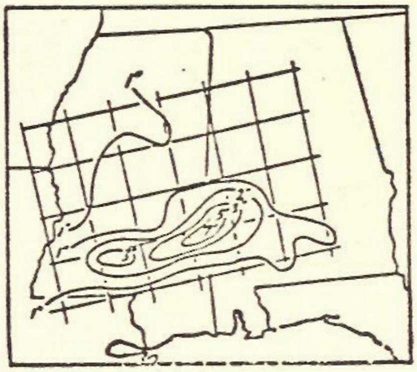


Fig. 2. Same as Fig. 1, but for 24-hr period on March 6-7, 1973.

in mind. This is of course also true to a lesser degree for grid squares beyond about 60 nm from the radar but the problem can be acute for the hatched squares.

An example of this effect occurred on April 15-16 in Upshur County, Texas, which lies roughly centered on the borderline between the southwestern-most square under surveillance by Little Rock (LIT) and the square adjacent on the west surveyed by Fort Worth (GSW) (subsequently moved to Stephenville, TX) - see arrow, Fig. 3. Heavy rains of up to 7 inches fell in the county the night of April 15, causing flooding near the border of the two grid ares. No warnings were in effect. The GSW r digits indicated moderate rains almost lusively (codes 3 and 5) with code 6 reported only one observation. This seems at best ao ginal range of digital values for rainfall ino amounts observed and strongly suggests theo ige problem since the locality of heavy rainso and flooding is 120-125 nm from the radar. But the radar at LIT saw only weak echoes (code 1) and these only a part of the time in a grid square where flooding occurred and substantial rains certainly fell. The locality of the flooding was about 175 nm from LIT.

It is essential to recognize the inherent ambiguity of MDR data and to exercise caution in its application even at closer range. Suppose, for example, that for four successive hours the code digit 6 were to be reported for a given grid-square (see code, Table 1). Since for each hour this is a snapshot datum there can be no certain knowledge of what implications the series of 6's might bear. Scattered, mostly weak and moderate-to-strong echoes with only isolated cells marginally reaching very strong intensity for brief periodso which coincidentally fell on observation times would produce such a series, but the flood potential of this situation is virtually non-existent. On the other hand a quasi-stationary concentration of heavy thunderstorm activity covering a full half of a grid-square with intensity ranging from mostly very strong to intense but with no intense echoes present at observation time might yield the same series of 6's but produce disastrous flooding. The probable meaning of four successive 6ós - or any digits - must be discovered empirically, perhaps on a seasonal as well as geographical basis.

This simple illustration is meant only to emphasize some limitations of MDR data which arise from the coarseness of the grid and the simplicity of the coding scheme. These limitations do not detract from the value of data in this form as a "flag" to signal the necessity for a closer appraisal of the situation over expressly localized areas. As useful thresholds are more definitely established through experience, the value of the program will be enhanced. Continuing investigation is being conducted toward this end.

3. HYDROLOGIC APPLICATIONS OF MDR DATAo

The MDR code presently in use has been ino effect since July 1, 1973. From March through June,1973, a somewhat different form was used which did not have the "additive" data feature, but attempted to incorporate this type of information into the basic message. Data acquired using the earlier form cannot be uniquely expressed in tho present code. Some of the cases presented took place under the earlier system and no attempt has been made to adjust the MDR totals. In general it is considered that totals under the former system would bear hydrologic implications comparable to those of the present one if increased by about 10% - 15%.

The French Broad River at Rosman, NC flooded on the evening of March 16th after rains of 5-6 inches fell in the general area. MDR numbers in the box containing the affected watershed had been generally small (Fig. 4) but for the five hours preceding the onset of flooding echoes of moderate intensity covered more than half the box (MDR 5 in early code).

Shortly before the automatic flash flood alarm gauge at Rosman sounded at 6 pm (EST) to indicate water was nearing danger levels, the 4-hour total had climbed to 16. The maximum 4-hour total of 20 occurred during the following hour. Experience elsewhere had suggested that 4-hour totals usually exceed 20 before flooding occurs, although values approaching this figure should prompt careful examination of the situation. It is obvious that

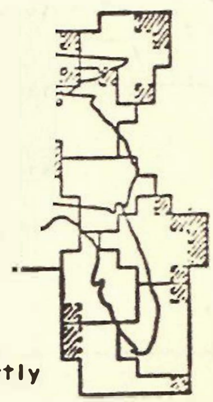


Fig. 3. MDR squares at least partly beyond 125 nm range (hatched).

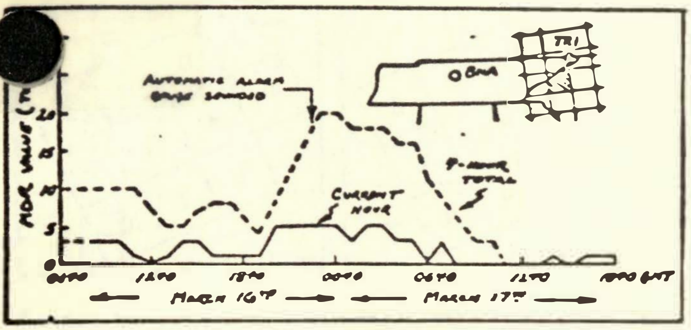


Fig. 4. Hourly MDR values and 4-hour totals for flash flood situation, March, 1973. Inset shows grid-square to which MDR values apply.

the many variables involved will preclude an arbitrary threshold to fit all cases. Similar flooding occurred the previous night at Spring City, TN, where the total also barely reached 20 offering further evidence that relatively low thresholds may apply for hilly, rocky terrain. Although the examples presented are based on 4-hour totals, it must be kept in mind that severe flooding can result in less than 4 hours. Indicated heavy rainfall of shorter duration in a flood-vulnerable area should always prompt consideration of a watch or warning and efforts to obtain rainfall reports.

Another flood situation occurred late on the ning of March 6th as a line of severe thunderms moved into the southeastern portion of issippi and into southwestern Alabama causing nsive flooding in the Shubuta-Waynesboro area lississippi and heavy flood damage in southern Choctaw county, AL. Rains of 3-7 inches fell in these areas within a few hours around midnight. Excellent warnings preceded the severe thunderstorms in the affected counties although there was apparently little mention of the flood potential. Fig. 5 suggests that careful scrutiny of the numbers, particularly 4-hour totals, would have revealed no later than midnight the possibility of flash flooding in Wayne (MS), southern Choctaw (AL) and northern Washington (AL) counties. The resolution of the MDR grid will not permit a narrowing of this area but such is possible in offices which have access to the actual radar picture. This is in fact the way to get the most

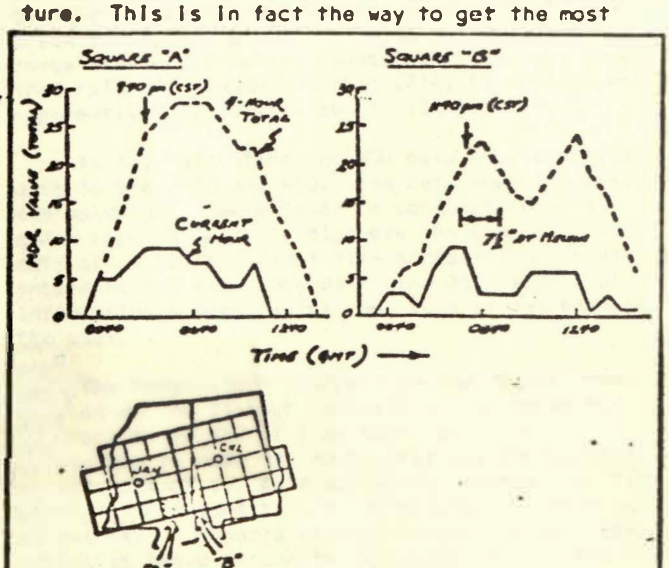


Fig. 5. Same as Fig. 4 but for March 23, 1973.

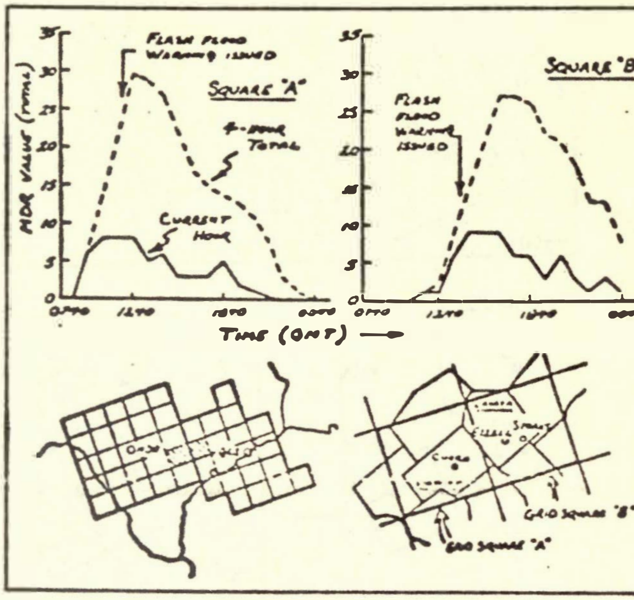


Fig. 6. Same as Fig. 4 but for March 23, 1973.

out of MDR data - the numbers can be used to "flag" boxes and focus attention quickly on a relatively small area, then other information (actual radar image or phoned-in rainfall reports) can be used to pinpoint affected areas or verify indications of what is happening.

Heavy rains also caused extensive flooding in southern Texas on the 23rd of March. In fact, the same weather system brought floods to parts of Louisiana, Arkansas, Mississippi and Alabama as well. Fig. 6 shows the very large MDR totals which preceded flash flooding in DeWitt and Lavaca counties of Texas. When the MDR total in grid square "A" exceeded 20 (at 5:40 am CST) the forecaster at Victoria used this information along with a detailed look at his own APS-20 radar and conventional data to issue a flash flood warning for DeWitt county.

Rains of 4-7 inches resulted in extensive local flooding in Cuero (in the center of DeWitt county) about 6 am. Thereafter (as seen in Fig. 6) the storm moved eastward into Lavaca county (grid square "B") where flooding occurred at about 9-10 am (CDT) in Ezzell and Speaks. Based largely on radar information the flash flood warning had been shifted eastward to include this county at 8 am. Shortly before and during the flooding the MDR totals exceeded 25 in the grid square containing Lavaca county.

Analysis of after-the-fact data from a flash flood occurrence in 1972 at Snyder, TX, was important in prompting an investigation into the usefulness of MDR data for hydrologic purposes. Snyder was again hit by flash flooding on June 15, 1973, but this time the digital data were available in real-time. Personnel on duty at WSFO Lubbock (LBB) and WSO Abilene (ABI), which has warning responsibility for Snyder, used the new data effectively in issuing warnings for the affected areas. The key to their procedure was reliance on conventional information and MDR data.

Fig. 7 shows successive 4-hour totals of MDR numbers for a part of the Midland radar grid. The analyses show a persistence of very strong or

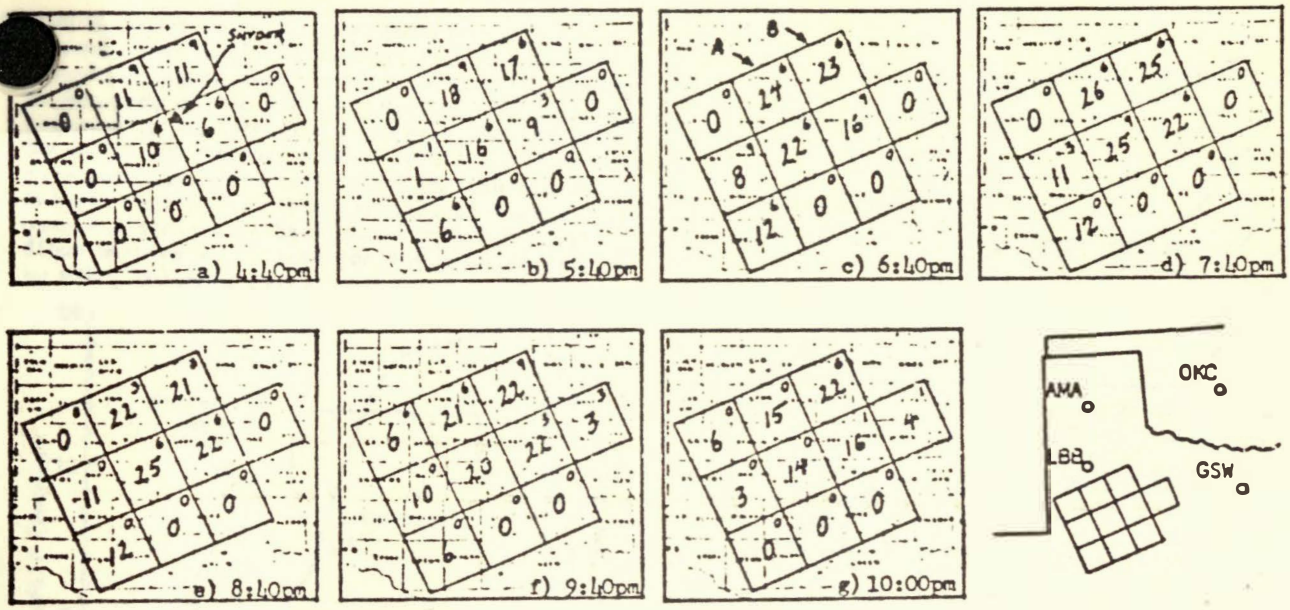


Fig. 7. 4-hour totals of MDR values, ending at time shown, for a portion of the Midland radar grid. Current hour's digit is shown in the upper right-hand corner of each box (9's summed as 7's). All times are CDT.

Intense echoes covering half or less of the grid boxes containing parts of Scurry county - particu- ly the two boxes just to the north. The digits mamight suggest flash flood warnings fora les in boxes A and B (Fig. 7c) at abouta pm (CDT) (LBB county warning areas), but thea through use of their local radar and contacta Midland, determined that the strongest echoes were over the southernmost parts of the boxes. It was also apparent that there was some "inflation" of the MDR numbers for these boxes because of hail.

This information was passed along to ABI which was also in contact with the Midland WSR-57 and wary of the growing MDR totals over the flood-prone area of Snyder. ABI made numerous calls to spotters in the Snyder area to check on actual rainfall and when the 4-hour total in the box containing Snyder exceeded 20 at 7:40 pm (CDT) a flash flood warning was issued for Scurry and Mitchell counties. Reports accumulated quickly that Deep Creek in Snyder was rising rapidly and several roads were under water. Subsequent analysis showed that rainfall exceeded 7 inches (Fig. 8) most of which apparently fell between about 7:30-8:30 pm.

In this situation the MDR data provided guidance to the WSFO and WSO. The data were not used exclusively but were taken in conjunction with other reports to fully diagnose the event. MDR data allow for the first time a real-time accounting procedure for radar echoes making this source of information a more useful tool than it has been in the past.

The total-storm isohyets in Fig. 8 are super- sed on the 24-hour rainfall map prepared by Fort Worth RFC at 7 am (CDT) June 16. The comparison is made not to suggest any shortcoming on the part of our data collection system - particularly with regard to a discontinuous variable such as rainfall. Reports with asterisks are objective estimates based on surrounding observations and the zero reports may indicate no rain observed, no observation reported, or zero rainfall estimated. Note in this case that a 7 inch rainfall center went undetected by the regular reporting system while the MDR data clearly revealed significant precipitation in the area. (24-hour MDR totals are shown in parentheses in each box. The greatest part of the total occurred between 4:40 pm and 8:40 pm).

Enid, Oklahoma, suffered severe flash flooding on the night of October 10-11, 1973, with several fatalities and substantial property damage. The flooding resulted from torrential rains which ranged up to 20 inches over a period of several hours as revealed by a subsequent "bucket" survey. Rainfall amounts and concurrent MDR data are graphed in Fig. 9. Reference to Table 1 will show that the maximum rainfall rate associated with

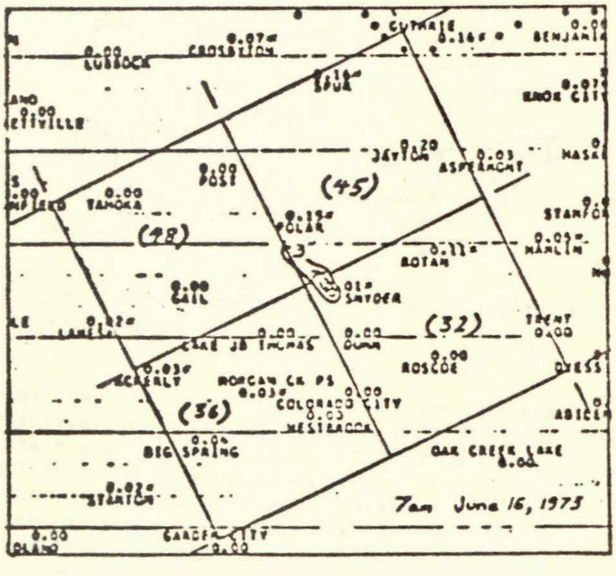
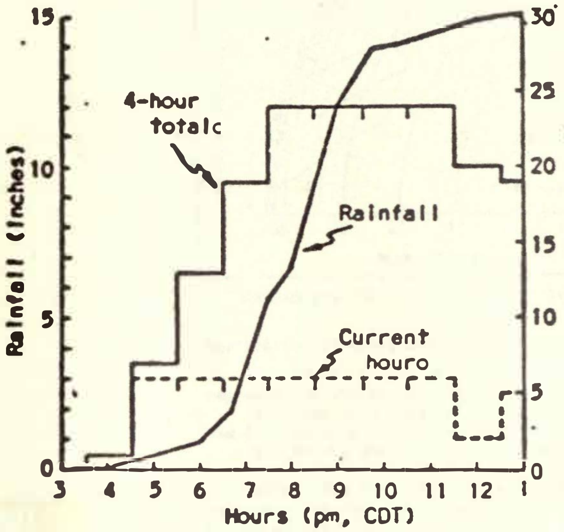


Fig. 8. Portion of Fort Worth RFC 24-hour rainfall map with superimposed MDR grid and 24-hour MDR totals (parentheses).a

...de 6, which persisted for several hours, is ... inches per hour. In general this code digit ...pears to adequately explain, within the limits of accuracy of the VIP calibration, the amounts observed at the official Enid station. The heavy accumulations between 6:40 pm (CDT) and 9 pm could have been associated with more intense echoes between regular hourly observations exactly in the manner discussed in Section 2 above. A flash flood warning was issued for the area at 7:30 pm by WSFO, Oklahoma City.



9.o Observed rainfall, hourly MDR values ando ·hour MDR totals for Enid flood, October 10-11, 173.o MDR data resembles a step functiono because values apply over one hour.

4. FORECASTING FLASH FLOOD POTENTIAL FROM MDR DATA

On September 26-27, 1973, heavy rains moved across portions of southern Texas. This is the same situation represented in Fig. 1, which shows storm totals of MDR data and measured rainfall for the event. An important aspect of the case, which has also been noted for other systems in different locations, is the organization and orderly progression of the patterns of MDR totals. Fig. 10 illustrates the movement of these patterns across the Hondo, TX (HDO) radar grid, a 5x5 sub-section of the overall grid (see Moore, et al. in this volume). Numerous flood events accompanied the system, coinciding generally with the maxima in the patterns. The city of San Antonio, where considerable flooding occurred, is indicated near the right-center of the grid - MDR 4-hour totals reached as high as 34 for the grid square containing the city.

An obvious implication of the definition and continuity of these patterns is that they can be extrapolated in time. The pattern-recognition ...nique described in the paper by Moore, et al. ... promise of application to MDR totals as well ...single-hour values. Attempts to determine ...ect correspondence between the totals and ...ured rainfall will probably not meet with much success due to the coarseness of the data as presently acquired. However it may indeed be possible to assess the probability of flash flood-producing rainfall somewhere in a specific grid square based on MDR totals. This must be done

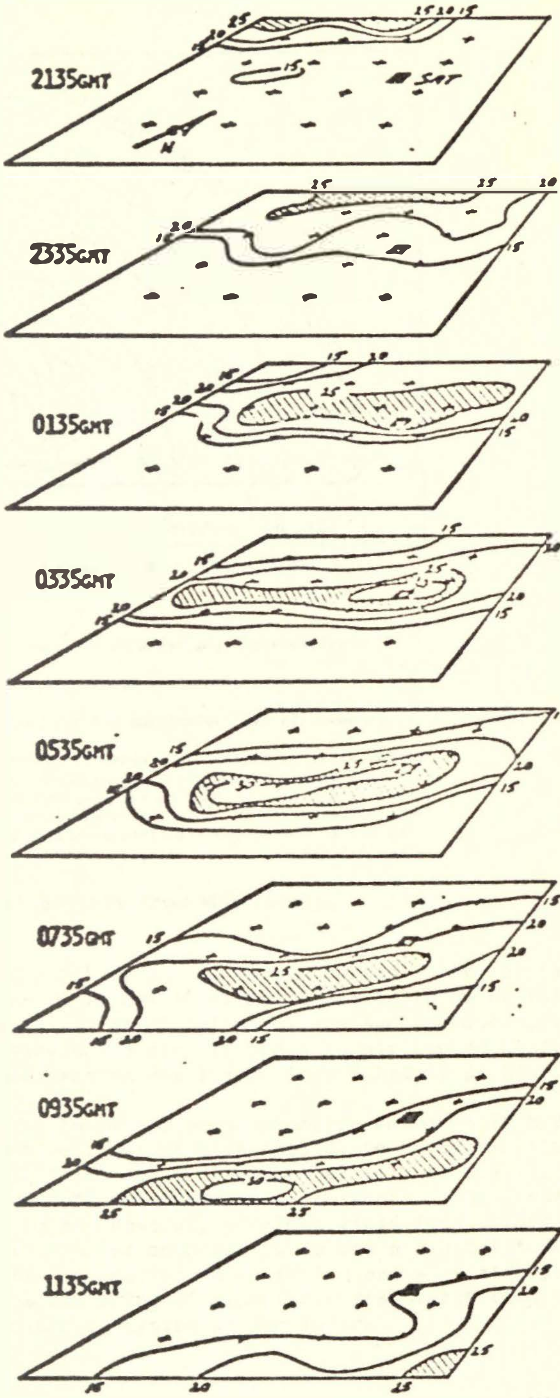
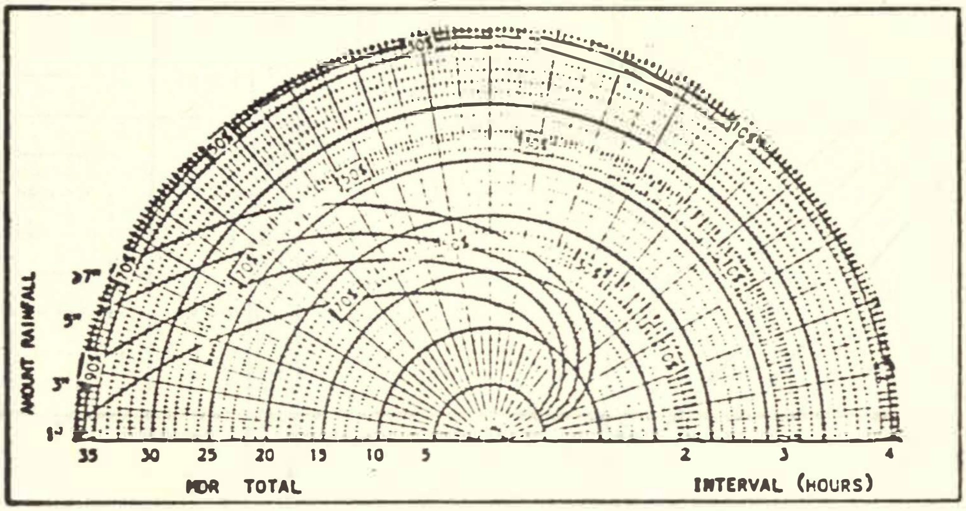


Fig. 10. 4-hour MDR totals for Hondo TX radar grid, September 26-27, 1973.

empirically and because these occurrences are relatively rare, such relations will likely always retain a subjective flavor. But it is not difficult to foresee an automated procedure for providing to the forecaster direct guidance in terms of probability which he can treat as an objective estimate of flash flood potential. As an interim measure, before plans for automation reach fruition, such estimates can be had through use of a nomogram relating MDR totals to flash flood potential (expressed in terms of ~~percent~~ probability)



PROBABILITY OF VARIOUS RAINFALL AMOUNTS (Somewhere in grid square) AS FUNCTION OF MDR TOTALS

Application of nomogram:

1. Locate the intersection of the "Rainfall Amount" curve of interest and the semicircle representing the accumulated MDR total for the period.
2. From this intersection proceed radially outward to the shaded semicircle representing the time interval to which the MDR total applies.
3. On the shaded semicircle read the probability value for the particular rainfall amount.

NOTE: The indicated probabilities are based on empirical findings and rainfall radar intensity relationships and are subject to revision as more data are accumulated. They should not be used as the probability of a given amount of rain at a specific raingage but as a first estimate of the given precipitation amount occurring somewhere in the 40 nm square MDR grid box. It is expected that the probabilities obtained in this manner will be refined by such additional information as can be obtained in the form of more detailed radar surveillance, rainfall reports, and forecaster judgment.

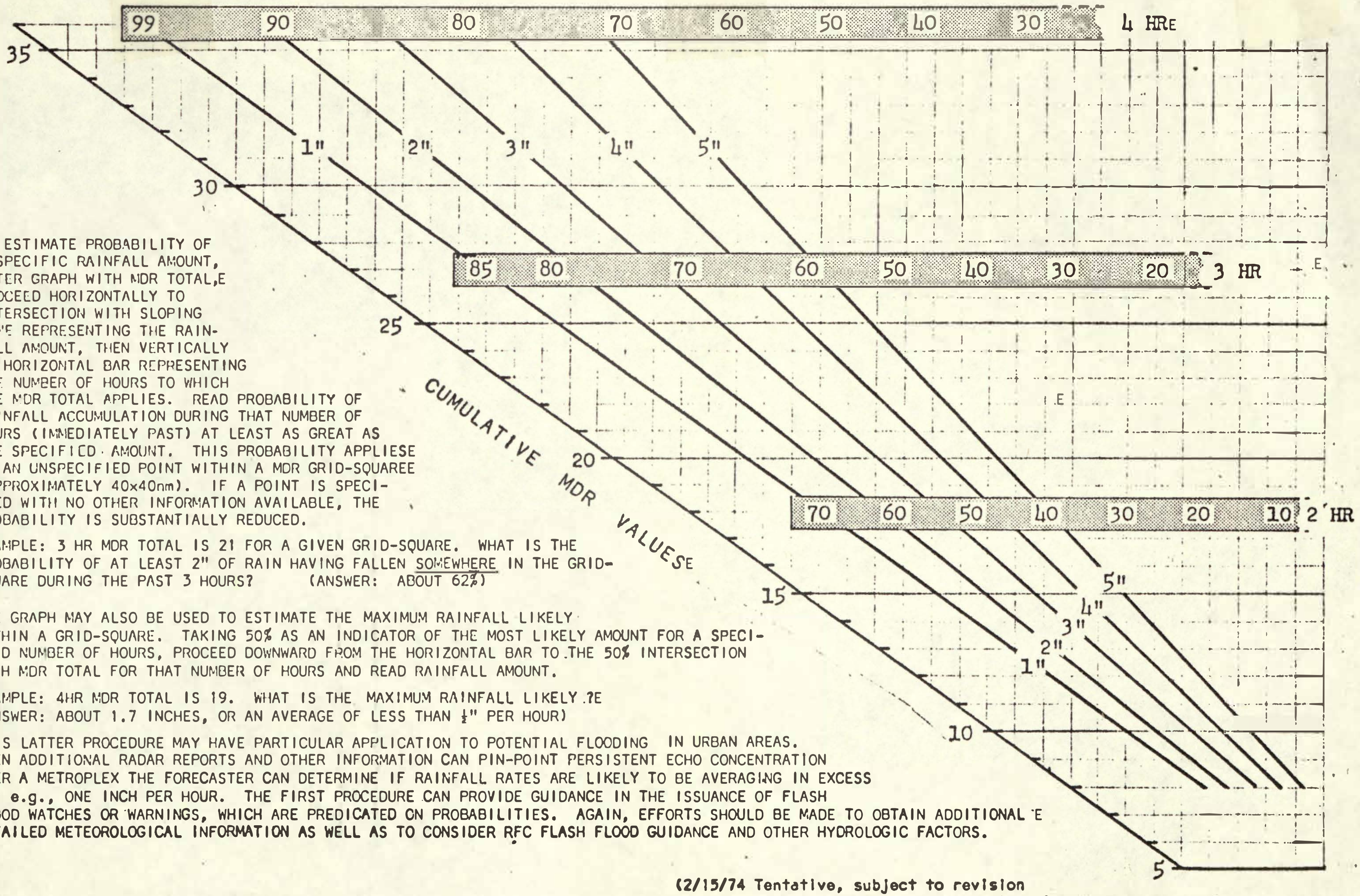
Fig. 1 Nomogram for estimating rainfall amounts from MDR totals.

as a function of the amount of rainfall necessary to produce flash flooding. NWS River Forecast Centers provide estimates of these amounts which serve as guidance for the forecaster. He may choose to modify them either in general or for particular localities in his area of responsibility.

Fig. 11 shows the form a nomogram for this purpose might take. This represents a "first cut" attempt at generation of an operational tool for use in making watch or warning decisions in possible flood situations. It is based on a limited number of events and indications derived from it must be treated with caution - continual revision is to be expected. Also, it is likely that the probability values should be positioned differently for different locations. But in spite of the manifest shortcomings of any such nomogram, it does represent a step toward a sorely needed systematic approach to the flash flood forecast problem.

There has been extensive research in hydrologic applications of high-resolution automatically digitized radar data such as will be available from NWS network radars in a few years. The present program, however, provides field forecasters with their first opportunity to use a digital form of the information in real-time and will also permit the acquiring of experience transferable to the automated system of the future.

MDR TOTALS VS PROBABILITY OF [illegible]IOUS RAINFALL AMOUNTS



TO ESTIMATE PROBABILITY OF A SPECIFIC RAINFALL AMOUNT, ENTER GRAPH WITH MDR TOTAL, PROCEED HORIZONTALLY TO INTERSECTION WITH SLOPING LINE REPRESENTING THE RAINFALL AMOUNT, THEN VERTICALLY TO HORIZONTAL BAR REPRESENTING THE NUMBER OF HOURS TO WHICH THE MDR TOTAL APPLIES. READ PROBABILITY OF RAINFALL ACCUMULATION DURING THAT NUMBER OF HOURS (IMMEDIATELY PAST) AT LEAST AS GREAT AS THE SPECIFIED AMOUNT. THIS PROBABILITY APPLIES TO AN UNSPECIFIED POINT WITHIN A MDR GRID-SQUARE (APPROXIMATELY 40x40nm). IF A POINT IS SPECIFIED WITH NO OTHER INFORMATION AVAILABLE, THE PROBABILITY IS SUBSTANTIALLY REDUCED.

EXAMPLE: 3 HR MDR TOTAL IS 21 FOR A GIVEN GRID-SQUARE. WHAT IS THE PROBABILITY OF AT LEAST 2" OF RAIN HAVING FALLEN SOMEWHERE IN THE GRID-SQUARE DURING THE PAST 3 HOURS? (ANSWER: ABOUT 62%)

THE GRAPH MAY ALSO BE USED TO ESTIMATE THE MAXIMUM RAINFALL LIKELY WITHIN A GRID-SQUARE. TAKING 50% AS AN INDICATOR OF THE MOST LIKELY AMOUNT FOR A SPECIFIED NUMBER OF HOURS, PROCEED DOWNWARD FROM THE HORIZONTAL BAR TO THE 50% INTERSECTION WITH MDR TOTAL FOR THAT NUMBER OF HOURS AND READ RAINFALL AMOUNT.

EXAMPLE: 4HR MDR TOTAL IS 19. WHAT IS THE MAXIMUM RAINFALL LIKELY? (ANSWER: ABOUT 1.7 INCHES, OR AN AVERAGE OF LESS THAN ½" PER HOUR)

THIS LATTER PROCEDURE MAY HAVE PARTICULAR APPLICATION TO POTENTIAL FLOODING IN URBAN AREAS. WHEN ADDITIONAL RADAR REPORTS AND OTHER INFORMATION CAN PIN-POINT PERSISTENT ECHO CONCENTRATION OVER A METROPLEX THE FORECASTER CAN DETERMINE IF RAINFALL RATES ARE LIKELY TO BE AVERAGING IN EXCESS OF, e.g., ONE INCH PER HOUR. THE FIRST PROCEDURE CAN PROVIDE GUIDANCE IN THE ISSUANCE OF FLASH FLOOD WATCHES OR WARNINGS, WHICH ARE PREDICATED ON PROBABILITIES. AGAIN, EFFORTS SHOULD BE MADE TO OBTAIN ADDITIONAL DETAILED METEOROLOGICAL INFORMATION AS WELL AS TO CONSIDER RFC FLASH FLOOD GUIDANCE AND OTHER HYDROLOGIC FACTORS.

(2/15/74 Tentative, subject to revision as more MDR data are accumulated)