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THE NATIONAL WEATHER SERVICE MANUALLY DIGITIZED RADAR PROGRAM AND SOME APPLICATIONS

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THE NATIONAL WEATHER SERVICE MANUALLY DIGITIZED RADAR PROGRAM AND SOME APPLICATIONS

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1. INTRODUCTION

Since its establishment some fifteen years ago, the radar network of the National Weather Service (NWS) has provided vital information for forecast and warning programs. Virtually all of the area east of the Rockies, including coastal waters, is now under surveillance of long-range WSR-57 radars. Coverage of the mountainous region of the West is obtained by having NWS personnel extract weather information from air traffic control radars of the Federal Aviation Administration. This information is transmitted to the NWS Radar Analysis and Development Unit (RADU) at Kansas City which composites it with plots of encoded radar information from the NWS network and disseminates over a facsimile network annotated charts of weather echoes for the 48 states (Fig. 1).

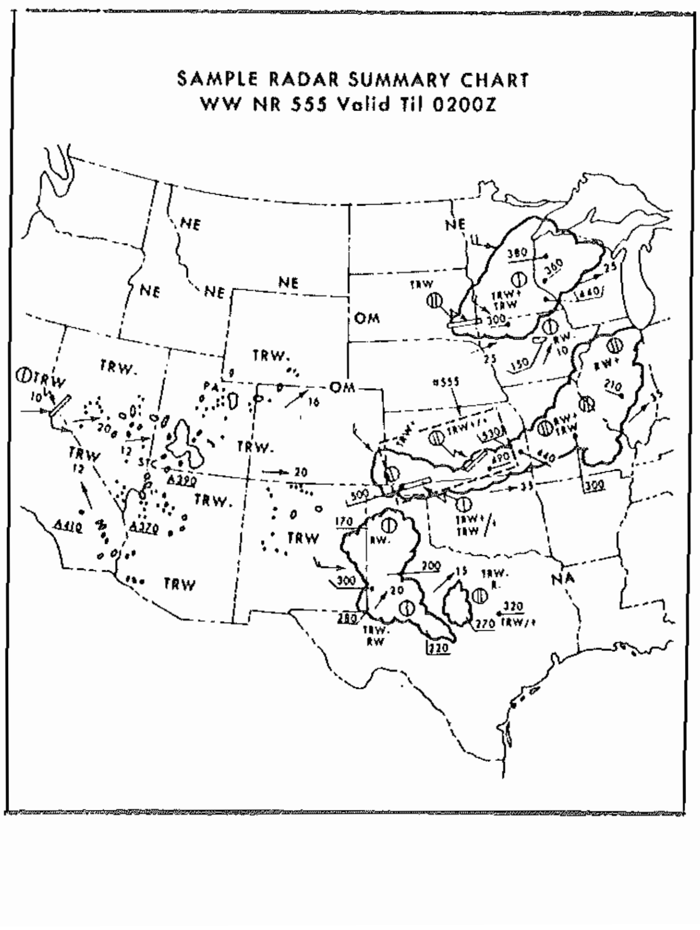


Fig. 1. Sample radar summary chart prepared at Kansas City and transmitted on facsimile network.

The facsimile charts plus teletypewriter circuit RAREPS (encoded hourly and special radar observations) from the NWS WSR-57's serve to keep users well informed on radar activity. It has long been recognized, however, that it would be desirable (1) to encode the data in digital form for ease of transmission and processing by computers, and (2) to automate the observations. Russo (1961) evaluated various types of radar codes and showed further that a digital code was most useful for describing synoptic scale weather patterns. Many others including Kessler (1961), Kessler and Wilson (1971), and Wilk and Gray (1970) have demonstrated the potential of computer compatible (digital) radar information. Unfortunately such data have not been available in real-time for routine forecast application. Neither have they been obtained on any large scale. The NWS Systems Development Office has a project underway which is aimed at automating the acquisition of digital data from network radars (McGrew, 1972). Pending completion of this project, called D/RADEX, the NWS on July 1, 1973, began adding new manually digitized data to the RAREP teletypewriter messages (which are now combined digital and plain language).

The manually digitized radar (MDR) program grew out of work in the NWS Southern Region aimed at improving probability of precipitation (PoP) forecasts. The principal PoP forecast guidance from the National Meteorological Center (NMC) is termed PEATMOS PoPs, from *P*rimitive *E*quation and *T*rajectory *M*odel *O*utput *S*tatistics (Glahn and Lowry, 1972). As a result of model running time and communications, the forecaster may have data as much as nine hours later than that input to the models which produce his guidance (Fig. 2). Moore and Smith (1972) developed a procedure which takes advantage of radar data to update the PEATMOS PoP guidance. They laid out the grid now used and devised a code, essentially the same as the present one, for digitizing data used in the procedure.

The MDR data have proved useful in a wide variety of other applications. These include weather-watch and diagnostic procedures, aviation briefing, quality control of radar data, forecast verification,and hydrologic uses. The data are now being archived on magnetic tape and will encourage further applications such as improved initial-moisture analysis of numerical models and forecast techniques based on a synoptic climatology of radar echoes. It is necessary to keep in mind, of course, that certain precautions should be observed; putting the data into a convenient digital form does not eliminate any of the problems, such as range attenuation, which are inherent in radar information.

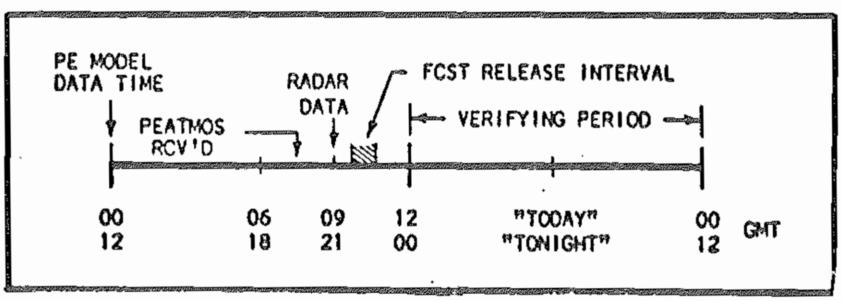


Fig. 2. Temporal relationship of radar update information and PEATMOS data. PEATMOS is the primary objective guidance for PoP forecasts but is based on data observed 10 hours prior to forecast.

2. DESCRIPTION OF THE MDR PROGRAM

The MDR data are manually encoded for each block of the grid shown in Fig. 3, which is a subset of the NMC coarse-mesh primitive equation model grid, shifted so that the NMC grid points fall in the center of every fourth radar box, the latter being about 40 nm square. The 40 nm grid was a necessary compromise between the desire for encoding detail and the constraints imposed by available observer and teletypewriter circuit time.

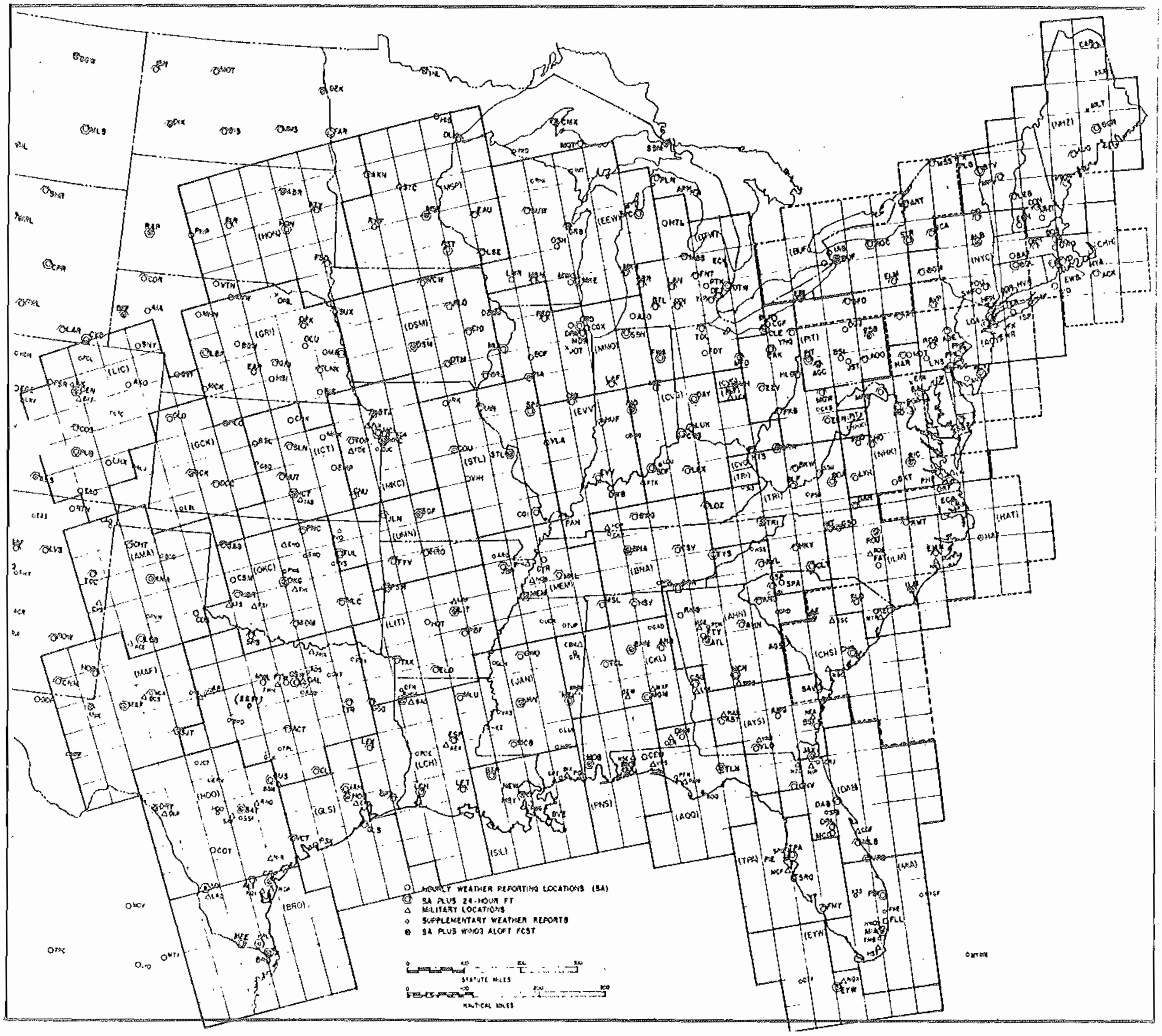


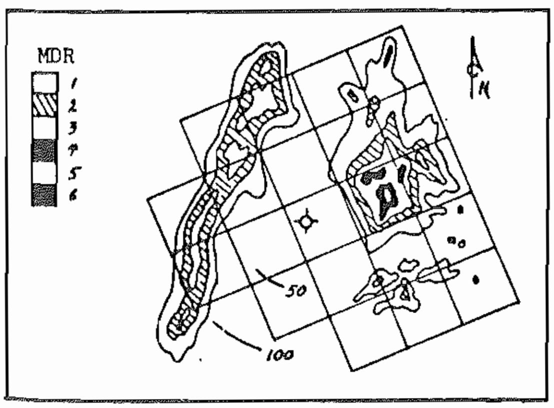
Fig. 3. MDR data grid. Area of responsibility for each radar is shown by heavy lines (radar site in parentheses).

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

*VIP (Video Integrator Processor)

The MDR code now used (Table 1) provides for information on echo intensity and coverage within each square and for an indication of line configuration or severe weather, both current and during the past hour. Each radar station transmits a series of digits applicable to each grid row of its area of responsibility, the shape of the area being variable from station to station as indicated by the slightly heavier grid lines in Fig. 3. MDR data, appended to the RAREP, are delimited by arrows at the beginning (↑) and end (←), as shown in Fig. 4.

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LN10TRW+/+ 355/122 298/77 234/150 35W 2718 CELLS
2422 MT 390 AT 345/102 TØP 370 AT 294/76
AREA9TRWX/NC 026/156 052/137 087/120 117/48 030/40
014/113 2310 MT 510 AT 076/64 TØP 480 AT 064/100
AREA4RW/- 98/120 117/130 165/80 135/45 2114 MT 320
AT 134/90
↑4422 44144 40096 0221 121 /11/12/21/22/31+34-35←
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Fig. 4. Sample radar observation. The PPI display with VIP contours (left) has been encoded for transmission (above) with MDR data delimited by arrows (↑, ←).

The data giving intensity and coverage in this particular report are in groups one through five and are the code numbers applicable to each square in row one, row two, etc. Data beginning with the solidus refer to line configurations and severe weather. The NWS has established criteria for the issuance of special radar reports and severe weather warnings based on radar information. A plus mark in the MDR data indicates that these criteria were met at the time of the observation;a minus indicates they were met during the past hour, and a solidus is used to denote a line-form echo at the present time. In each case the symbol is followed by the row and column coordinates of the square to which it applies.

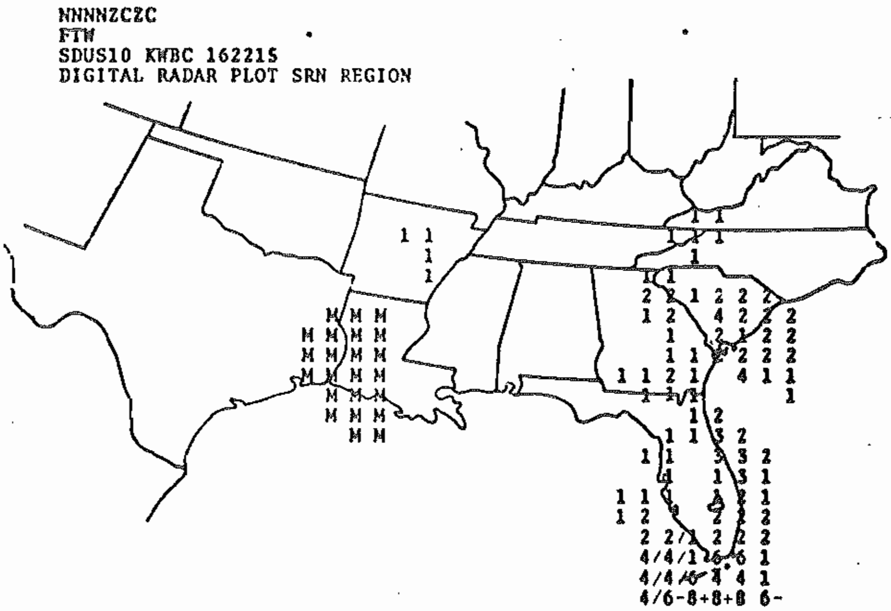

Fig. 5 Southern Region MDR data composite as received on teletypewriter. Symbols (+,- and /) appear to the right of the digit to which they apply.

While the data can be plotted by hand, a major advantage lies in the capability of making them available in mapped form in the teletypewriter request/reply system. Print-outs are available which show the current hour's digits composited in three regional displays, used in conjunction with transparent geographic overlays. Alternatively, rubber stamps have been used to apply the map reference. Fig. 5 shows the Southern Region map. Additional composites are planned which will show more detail in larger scale sectional displays such as depicted in Fig. 6. Such displays will contain 4-hour totals to be used in accounting procedures which have proved very effective in diagnosing flash flood situations, (see Section 4).

3. USE OF RADAR DATA TO UPDATE NUMERICAL PRECIPITATION GUIDANCE

The work by Moore and Smith (1972) using radar data for updating forecasts antedated the operational MDR program but the same grid was used and slight differences in the code do not affect the application of their technique to the new data. Their objective was to improve upon the PEATMOS PoP guidance forecasts for Atlanta GA, Birmingham AL, and Jackson MS. In developing the technique, a preliminary correlation

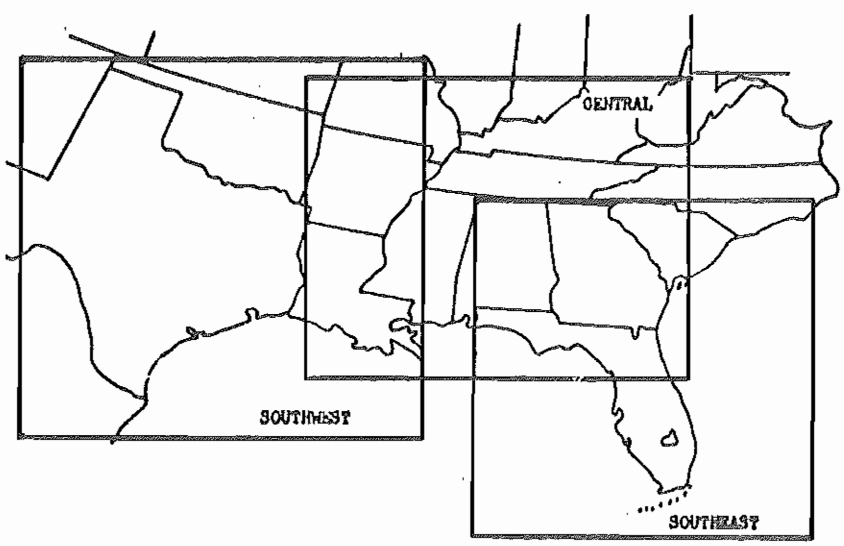

Fig. 6. MDR data sectional displays for Southern Region.

analysis was made to select areas which, when echoes were present, offered the greatest potential as predictors of rain at the predictand stations. It was found that areas of the same shape, as shown in Fig. 7, could be used for all three stations. Presence or absence of echoes (E) and percentage coverage (PCT) in Areas I, II or III were treated as binary or continuous predictors in a screening regression analysis which produced the equation:

$$PoPup = -0.014 + 0.332(PCT_{II}) + 0.510(PEATMOS) + 0.160(E_{I}) + 0.169(E_{III})$$

The equation applies to both the 0000-1200 GMT and 1200-2400 GMT forecast periods, each being the first 12-hour period of public forecasts issued about 2200 GMT and 1000 GMT, respectively. Radar predictor data were for 0840 GMT and 2040 GMT (see Fig. 2).

The updated probability (PoPup) is expressed as a function of the PEATMOS PoP guidance and the occurrence of echoes nearby. Use of the equation developed with data from December 1971 and January 1972 and tested for all three stations for February 1972 resulted in significant improvement over both the guidance and official forecasts. Subsequently, Peters and Barnes (1973) tested the technique in an operational environment at the NWS Forecast Office in Atlanta from December 1972 through February 1973 with similar excellent results. The conclusion in both of the tests was that, while forecasters no doubt consider the latest radar information when preparing their forecasts, improvement is possible through more systematic use of radar data. The availability of the data in digital form simplifies such a procedure.

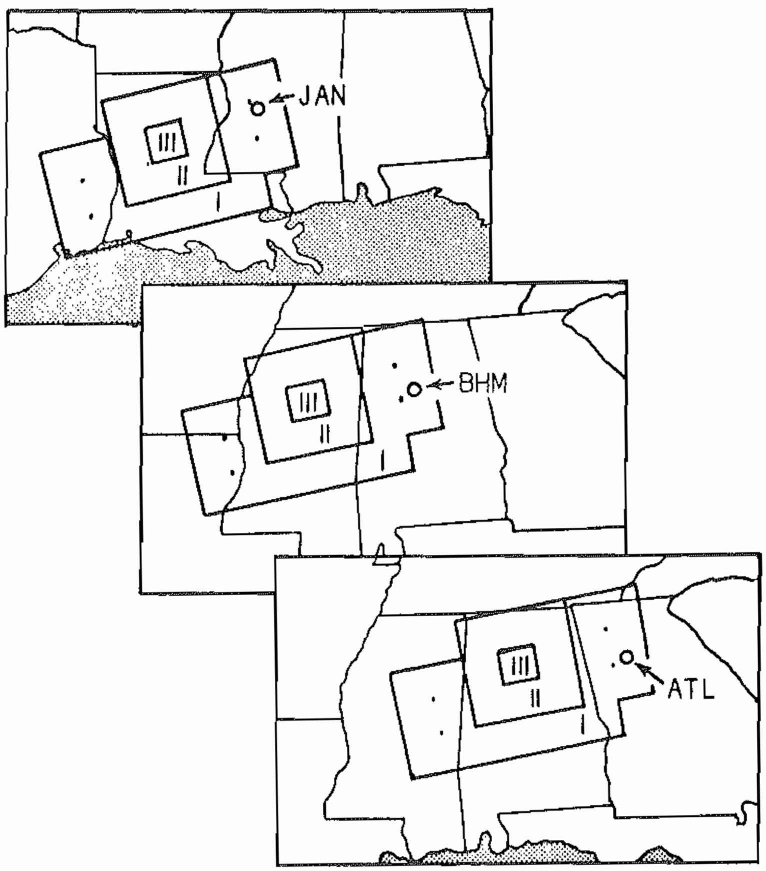

Fig. 7 Location of echo-predictor areas. Note in each case that the predictand city is in the same location, relative to the areas.

No additional improvement in forecast skill was found when attempts were made to utilize the coded information on intensity or fractional coverage in the above approach. The implication of this result and of the order of selection of the predictors (as they appear in the equation) may be that for updating 12-hour winter forecasts for the areas concerned, greater resolution in the radar data is not needed. This statement probably is not true for shorter-range forecasts and also may not be true for other areas and seasons.

In developing the present technique it was found that there was sufficient similarity in the rain-producing systems from one station to another and from one case to another that a standard configuration and placement of the area for predictor data was satisfactory. This was established in preliminary investigations in which information about prevailing wind was included. When the study was extended to include stations in Texas and Arkansas it was found that a simple "climatological" selection of the area for predictor data did not produce satisfactory results. The period used for the dependent data sample was very dry but it also was apparent that there was greater variability in the motion of the precipitation-producing systems, compared to those in the southeast, and that more selective placement of the "upstream" area in each case would have been desirable. After experimentation with various means of accomplishing this, including use of single-level observed or forecast winds, mean layer winds, and trajectories from guidance forecasts (Reap, 1972), it was concluded that it would be preferable to rely instead on actual movement of precipitation areas for the decision.

3.1 Application of pattern recognition techniques

To some extent movement of individual cells or areas of echoes is indicated in the RAREP. In practice movement is often deduced by plotting successive RAREPS and subjectively determining the motion. Now that data are available in digital form application of an objective pattern recognition technique seems both possible and desirable. The task is somewhat simplified by the nature of the MDR data and their application. A persistent problem with automated techniques (which seem usually to have been concerned with echo tracking for severe weather situations) is the "noise" introduced by motions of thunderstorm-sized echoes. We are concerned with motions of larger scale echo patterns and the ≈40nm mesh-length of the MDR grid smoothes out these small scale features.

Much remains to be learned of the nature and behavior of echo patterns when resolved and digitized on the scale of the MDR program. Experiments are still underway to determine the optimum size of the area over which to apply a pattern recognition technique and the optimum time interval over which echoes might be tracked. The results of the echo tracking and extrapolation procedure will have many different applications and for some of these it may prove useful to first "de-focus" the MDR data by application of some type of smoother. For other uses the MDR data are probably already sufficiently de-focussed.

The latest version of the MDR echo tracking/extrapolation program utilizes the raw data from a 16x16 window of the grid shown in Fig. 3. The echo isolation or grouping procedure is a fairly simple one, designed especially for a small computer, which attempts to simulate what a human analyst might do in interpreting the PPI display. First, all MDR values less than 3 are suppressed temporarily. Next, all echo-containing squares which touch along one face are grouped together. The groups are then expanded by inclusion of squares with MDR 2 which touch along at least one face. At this stage as many as four groups may share a MDR 2 square; shared squares are cataloged and attempts are then made to combine such groups. A restriction in group size comes into play at this point: groups will not be merged if their combined x- or y-dimension would exceed six MDR squares (∿ 250 nm). We rely on the meteorology to suppress groups of this size in the first grouping analysis; the MDR data seem to indicate that "hard-core" echoes (high MDR values) seldom exceed these dimensions without interspersed MDR 1's and 2's.

In the final grouping analysis all echo-squares assigned to groups are suppressed and an attempt is made to form additional groups of squares with MDR 2. The restriction is that as a minimum such groups must consist of four squares with MDR 2 arranged in a square array. In this way significant concentrations of moderate echoes, even though they cover half or less of a square, are recognized as a group.

The above procedure accomplishes the grouping at time t_1. The procedure is repeated at the later time, t_2. In practice t_2 would be the latest available observation and t_1 would be an earlier observation. (Current experiments use a time interval, $t_2 - t_1$, of two hours). It can be seen that the grouping analysis ignores all MDR 1's and some MDR 2's. This seems justifiable in attempting to isolate significant echoes for tracking purposes even though earlier studies (Moore and Smith, 1972) have shown that even weak echoes (MDR 1) are significant indicators of subsequent precipitation downstream.

Once significant echo groups have been isolated it remains to match the groups at the two times and determine motion vectors. The matching program is similar to that discussed by Blackmer, et al. (1973) with significant differences introduced because of the nature and resolution of the MDR data. We assume that in the time interval $t_2 - t_1$ (two hours) echo patterns will seldom be displaced by more than one grid square in any direction. This is not to say that individual echoes or the centers of mass of echo groups are constrained by this limitation on motion, but rather that the average motion of the group elements will seldom exceed this. Such an assumption allows us to skip what appears to be often an integral step in pattern recognition techniques, namely the determination of an overall mean motion for all groups (what Blackmer, et al., call a "global match"). This is important since the scale of MDR data obliges us to consider a geographically large area over which many groups may exist and show significant and widely divergent motions.

The first step in the matching procedure is the superimposition of the t_1 groups onto the t_2 group analysis with no displacement in the x- or y-directions. The measure of fit (S) follows Blackmer, et al., and is defined as:

$$S_1 = \Sigma_{G_i} \left| MDR_2(x,y) - MDR_1(x,y) \right|$$

where i indicates the t_1 group number and Σ_{G_i} indicates a summation over all squares contained in group i at time t_1. Each t_1 group is then displaced sequentially, unchanged, by one Δx and one Δy and new values of S are derived. Hence, for each t_1 group there will be generated nine values of S.

For each group the optimum displacement is that which results in the minimum value of S. When shifted the optimum displacement, the area of each t_1 group will usually overlap squares of one or more t_2 groups. The t_2 group with which it has the greatest overlap is the match with the t_1 group and represents the old group in the new location. If two displacements give the same S-score, the optimum displacement for the group is the one which yields the greatest overlap with a group at t_2. If two or more t_2 groups have the same overlap with the optimally displaced t_1 group, the match is between the t_1 group and that t_2 group which represents the smallest motion vector (see below).

If the optimum displacement yields no overlap, then the t_1 group has been lost. Note that for average sized groups (6-10 squares) even a large displacement in two hours should still result in <u>some</u> overlap when the t_1 group is displaced only one square, hence this minimal displacement scan is not per se likely to result in many lost groups. Motion vectors are derived for matched groups by computing the displacement of the weighted mean centers of the groups. (Thus, even if the optimum displacement was zero, there may still be some motion of the group). If two or more t_1 groups are matched with the same t_2 group then merging is assumed to have occurred and the t_1 centers, weighted according to the number of echo-squares in each group, are combined before the motion vector is derived. If two or more t_2 groups are matched with the same t_1 group then splitting is assumed to have occurred. An analyst might accurately produce a motion vector in a splitting case by noting the most likely source, within the t_1 echo, of the t_2 echo, but this is difficult to accomplish objectively. As an approximation, the motion vector previously determined for the t_1 parent group is assigned to all t_2 daughter groups.

There may remain some t_2 groups not matched with t_1 groups. These may be either new groups (the seedlings of which may or may not have been present at time t_1 as MDR 1's and 2's) or t_1 groups displaced so far as to have been "lost". In either case these are simply called new groups and no motion vectors are determined for them.

The size of precipitation systems depicted by the MDR program and the coarseness of the MDR code contribute to the fact that echo groups, as isolated by the foregoing procedure, are not often well behaved with time. That is, the shape, orientation and number of squares constituting the group change from one time to the next. This does not necessarily complicate the matching program but it does tend to result in motion vectors which are not precise. This in turn, of course, complicates any attempt to accurately extrapolate group positions to a later time. However, for many uses even an approximate motion vector is sufficient - for example, in an objective probability of precipitation scheme it would be valuable to know whether or not an echo group is moving in the <u>general direction</u> of a station and at roughly what speed it is moving. Vectors derived as above are probably more useful in this regard than are the "snapshot" observations of echo motion as presently encoded in the RAREPs.

To produce a useful extrapolation and at the same time account for the variability of individual group configurations we are experimenting with extrapolating not the echo groups themselves but rather rectangular areas based on the weighted root mean square (RMS) deviations of echo-squares which constitute a group.

Fig. 8 illustrates an actual application of the program. For clarity, no attempt is made to show the extrapolated RMS boxes. The large scale echo pattern at 1535 (all times GMT) was more-or-less linear and consisted of four groups. A fifth group was isolated at the top of the array. (Note: the program operates on a 16x16 input array but in the process of grouping echoes the outer rows and columns are lost, hence the display in Fig. 8 shows only a 14x14 array.) The pattern at 1735 reflected a generally eastward motion with development of a new group (F) in the southeastern part of the array. Groups D and E (1535) merged into a single group D at 1735. Note the effect of the dominant group (D) on the motion vector. Group A was lost at 1735, probably because it moved north or into a missing-data area (shaded).

The northeastern end of group D split off to form group G at 1935. This being the case, the motion derived for D (at 1735) was assigned to both group D and group G at 1935. Observe that the extrapolated center position of group D (Δ), valid at 1935 (there being no way to anticipate splitting), is a very good approximation of the combined center positions of D and G at the later time. Apparent continued development in the southeastern part of the MDR array, as evidenced by the motion of group F, affects the apparent motion of group C by giving the group a much larger component of motion to the south than was observed (and extrapolated) at 1735. The apparent motion of group B should be ignored because of boundary problems. Group H has no history.

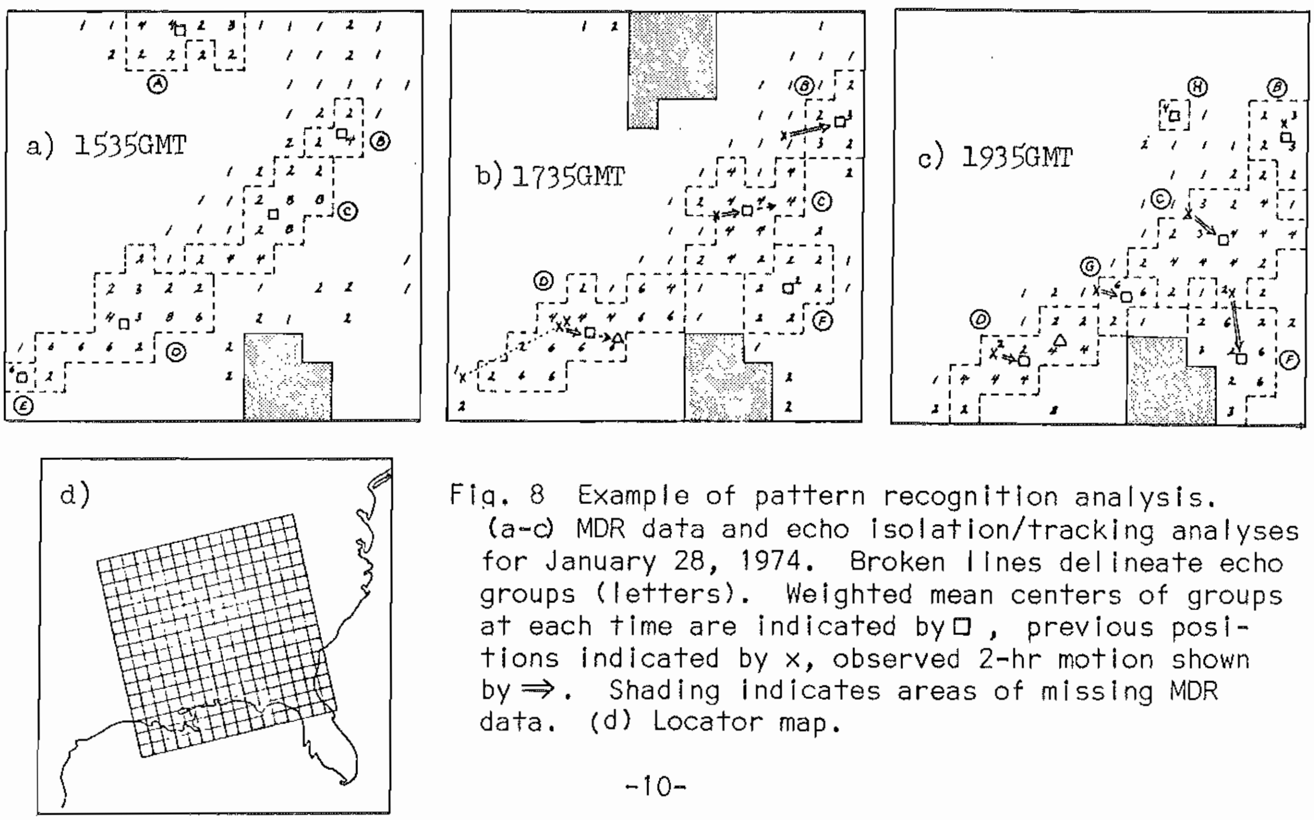

Fig. 8 Example of pattern recognition analysis. (a-c) MDR data and echo isolation/tracking analyses for January 28, 1974. Broken lines delineate echo groups (letters). Weighted mean centers of groups at each time are indicated by □ , previous positions indicated by x, observed 2-hr motion shown by ⇒. Shading indicates areas of missing MDR data. (d) Locator map.

4. DIGITAL RADAR DATA AS A PREDICTOR OF FLASH FLOOD POTENTIAL

Interpretation of MDR data on a grid as coarse as that presently in operational use 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 hours may be assimilated into some meaningful, quantitative index. Operational considerations dictate that the procedure must be uncomplicated, rapid, and must produce an index that is straightforward. A scheme that satisfies these criteria is a simple summing of the MDR values for a given block 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 some 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. 9a shows a Texas situation from September, 1973, while Fig. 9b shows a similar comparison for the central Gulf states from March, 1973.

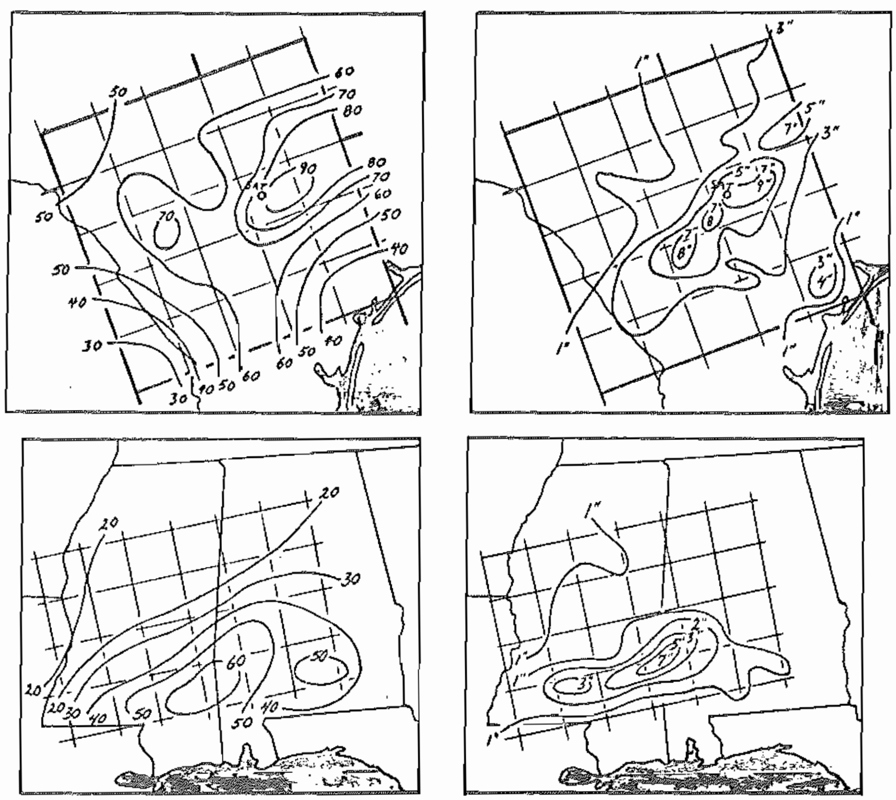

Fig. 9. Storm-totals (≃24 hrs) of MDR values (left) and rainfall (right). (Top) South Texas area, September 26-27, 1973. (Bottom) Southern Mississippi-Alabama area, March 6-7, 1973.

4.1 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. 10 indicates - by means of hatching - those grid squares comprising the 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 in mind. This is,of course, also true to a lesser degree for grid squares at all ranges from the radar.

It is essential to recognize the inherent ambiguity of MDR data and to exercise caution in its application even at close 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 periods 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 6's - or any digits - must be discovered empirically, perhaps on a seasonal as well as geographical basis.

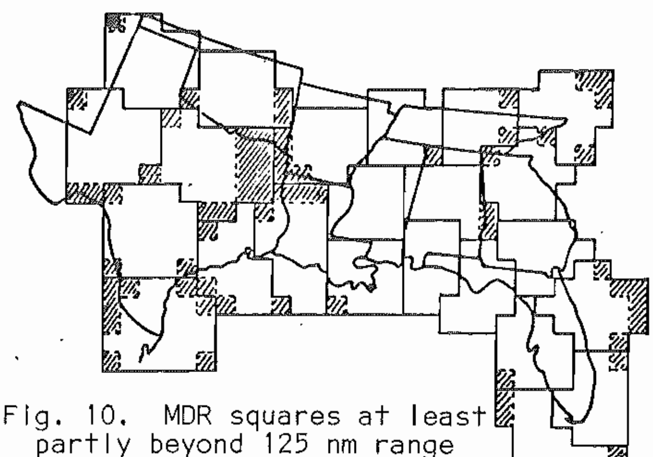

Fig. 10. MDR squares at least partly beyond 125 nm range (hatched).

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.

4.2 Hydrologic applications of MDR data

The MDR code presently in use has been in 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 the 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. 11) 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 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.

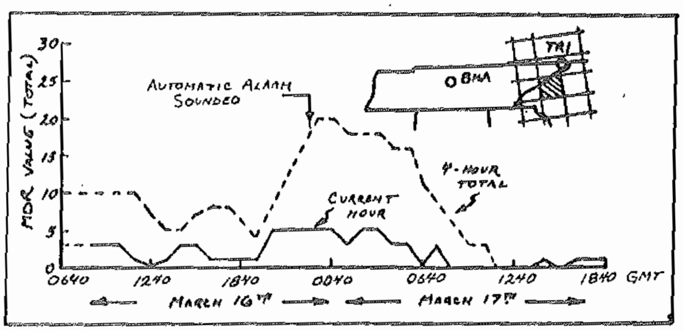

Fig. 11. Hourly MDR values and 4-hour totals for flash flood situation March, 1973. Inset shows grid-square to which MDR values apply.

Heavy rains 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.12 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. Ideally MDR numbers should be used in this way - to "flag" squares 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.

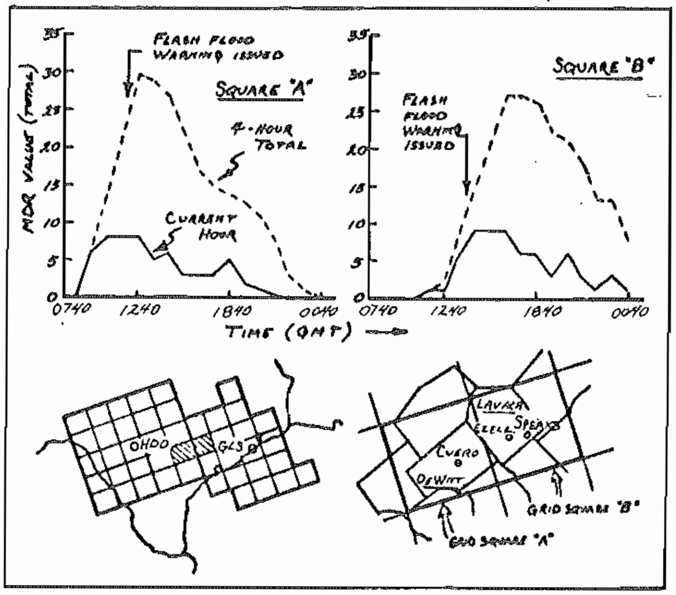

Fig. 12. Same as Fig.11 but for 3/23/73.

Rains of 4-7 inches resluted in extensive local flooding in Cuero (in the center of DeWitt county) about 6 am. Thereafter (as seen in Fig. 12) 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 <u>and</u> MDR data.

Fig. 13 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 intense echoes covering half or less of the grid boxes containing parts of Scurry county - particularly the two boxes just to the north. The digits alone might suggest flash flood warnings for counties in boxes A and B (Fig. 13c) at about 6:40 pm (CDT) (LBB county warning areas), but the WSFO, through use of their local radar and contact with 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 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. 14) — most of which apparently fell between about 7:30 - 8:30 pm.

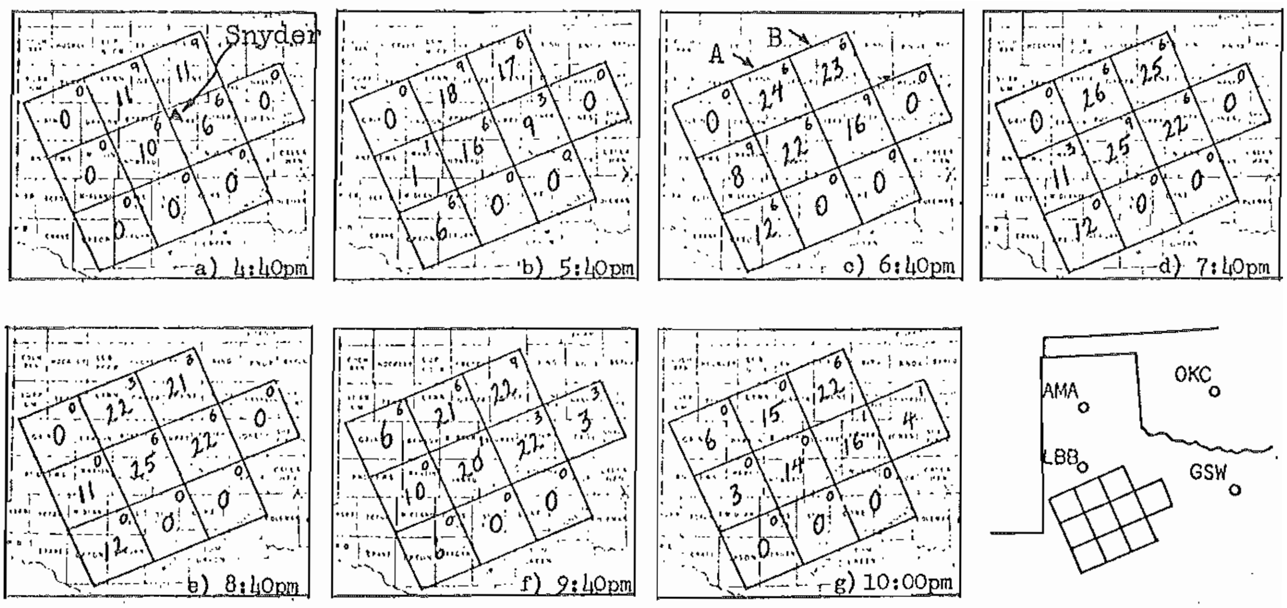

Fig. 13. 4-hour totals of MDR values, ending at time shown, for a portion of the Midland radar grid. Current hour's digit is shown in the upper right-hand corner of each box (9's summed as 7's). All times are CDT.

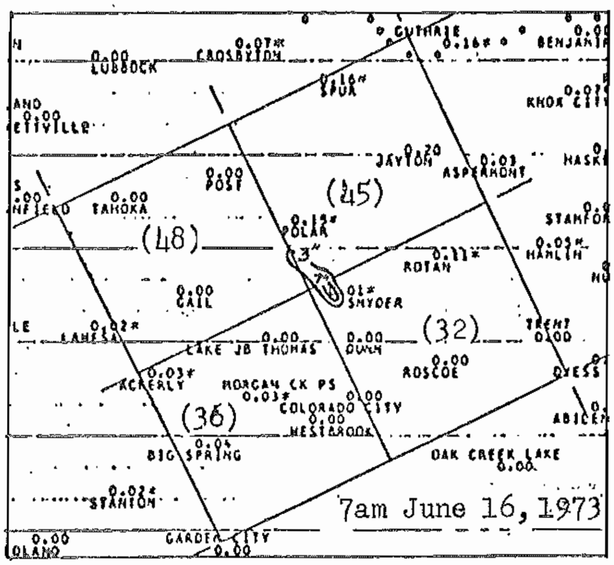

Fig. 14. Portion of Fort Worth RFC 24-hr rainfall map with superimposed MDR grid and 24-hr MDR totals.

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. 14 are superimposed on the 24-hour rainfall map prepared by the Fort Worth River Forecast Center at 7 am (CDT) June 16. 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.) Work is underway to produce a useful technique for incoporating such MDR totals into the rainfall analysis scheme for river forecasting.

4.3. 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. 9a, 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. 15 illustrates the movement of these patterns across the Hondo,TX radar grid, a 5x5 sub-section of the overall grid*. 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.

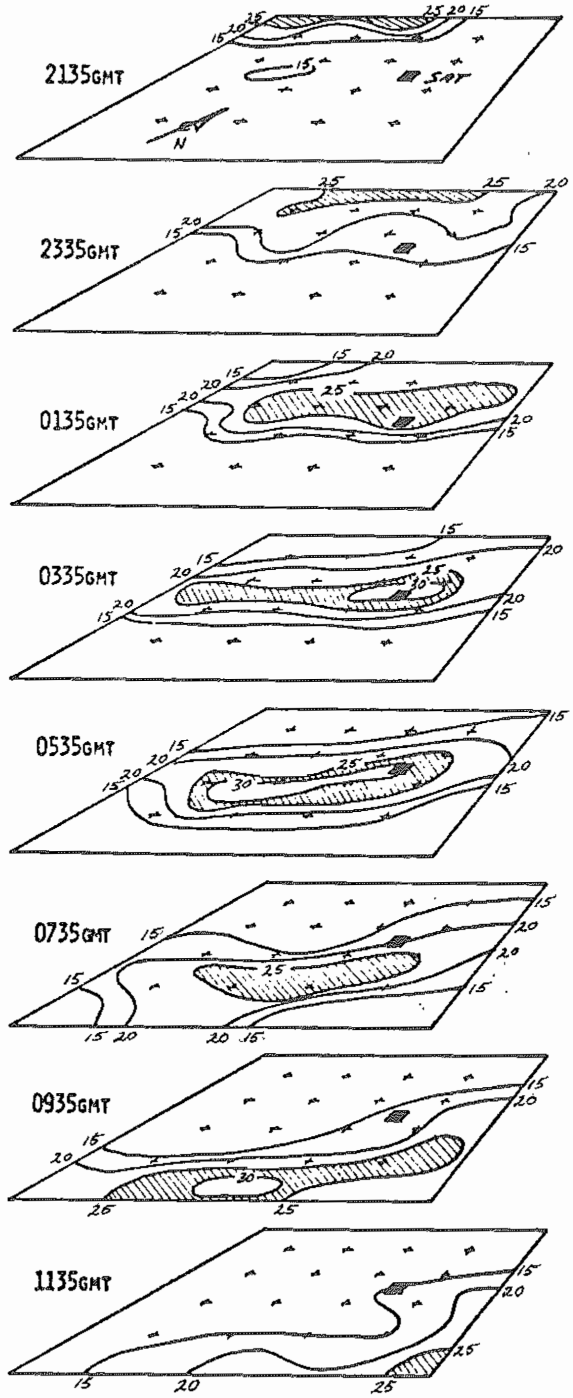

Fig. 15. 4-hour MDR totals for Hondo, Texas grid, September 26-27, 1973.

An obvious implication of the definition and continuity of these patterns is that they can be extrapolated in time. The pattern-recognition technique described in Section 3.1 holds promise of application to MDR totals as well as to single-hour values. Attempts to determine a direct correspondence between the totals and measured 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 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,

*Hondo lost the upper right-hand square when the Fort Worth radar was relocated to Stephenville (Fig. 3).

such estimates can be had through use of a nomogram relating MDR totals to flash flood potential (expressed in terms of probability) 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. 16 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.

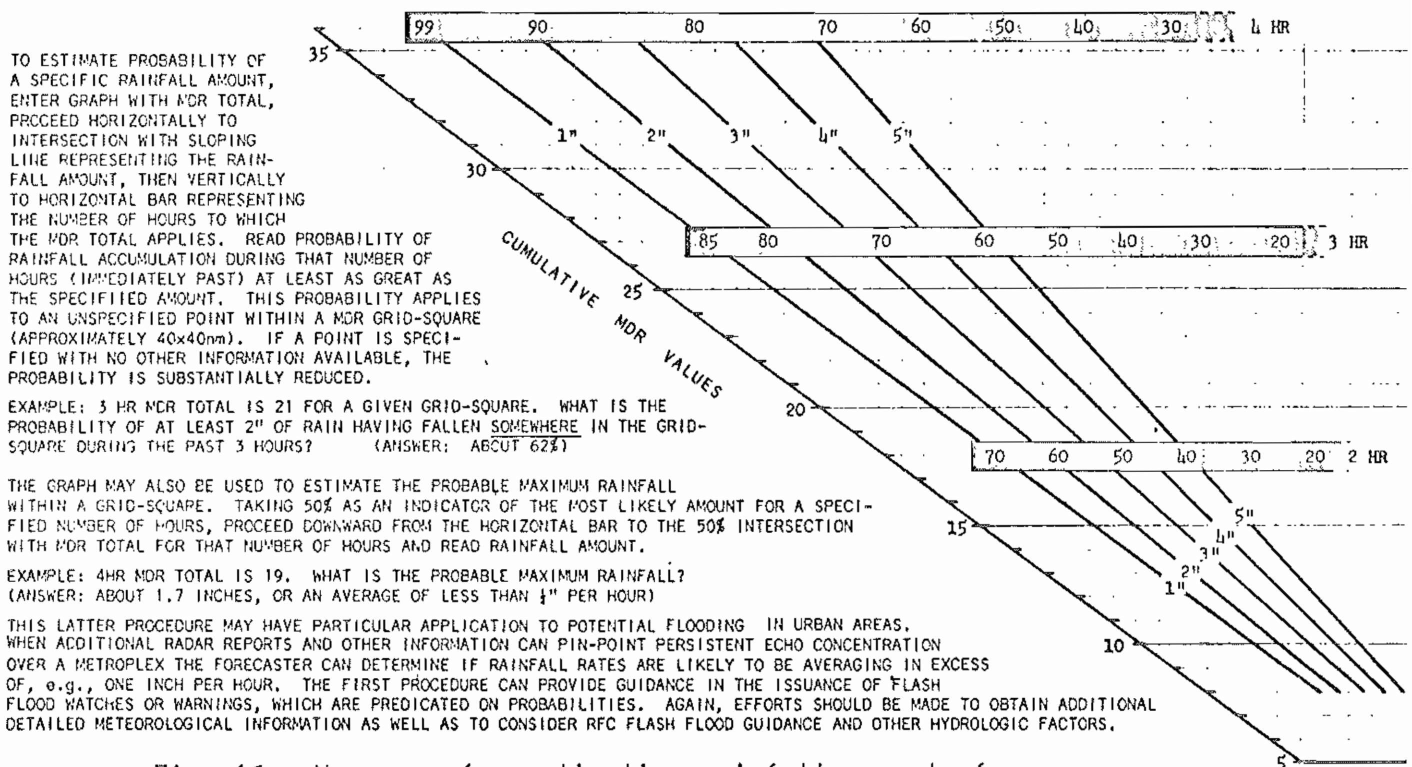

Fig. 16. Nomogram for estimating rainfall amounts from MDR totals.

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. Studies have generally shown the potential of such radar data as a hydrologic tool but it now appears that MDR data have demonstrated that high resolution is not always essential, even for small scale phenomena such as flash floods. Moreover, the present program 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.

5. ADDITIONAL APPLICATIONS OF MDR DATA

Various other applications of MDR data to short-range forecasts have been developed or planned, some utilizing objective extrapolation. MDR data might contribute to improved longer-range forecasts by making possible better initial moisture analyses for dynamic prediction models and through relationships based on synoptic climatology. The initial success of the MDR program has led to a proposal to encode the entire RAREP in a similar digital form. Observation and transmission time saved by eliminating redundancy in the present combined RAREP-digital reports should allow improvement of the resolution of the data to 20 nm or less and allow the addition of information, such as movement and echo tops, which is not now in the MDR data. Automation and more rapid dissemination of the RADU facsimile chart would then be possible. When this is accomplished it should be a simple matter to transmit simultaneously an extrapolated (forecast) radar chart.

The MDR data have been found useful for aviation briefings and no doubt will prove helpful in development of objective aviation forecasts. Although echo top information is not presently coded, inferences may be drawn concerning the potential for tops of various heights in a general area. Fig. 17 shows a relationship between echo intensity and tops, based on data for spring and summer afternoons in the central and eastern U.S. (Bonner and Kemper, 1971). A chart showing tops, inferred from echo intensities in probabilistic terms, could perhaps prove more useful than one providing more explicit, but less conservative, details on echo tops. Fig. 18 is a comparison of two such displays. Of incidental interest in this comparison is the apparent greater resolution of the MDR display (note the echo-free region in the southwestern Mississippi area).

Mogil (1974) has considered the application of MDR data to verification of severe storm forecasts. He finds MDR values ≥4 a good indicator of thunderstorm occurrence. While there are many uncertainties in the radar data due to attenuation and other problems, they do avoid the bias which previous severe storm records have shown to result from population distribution.

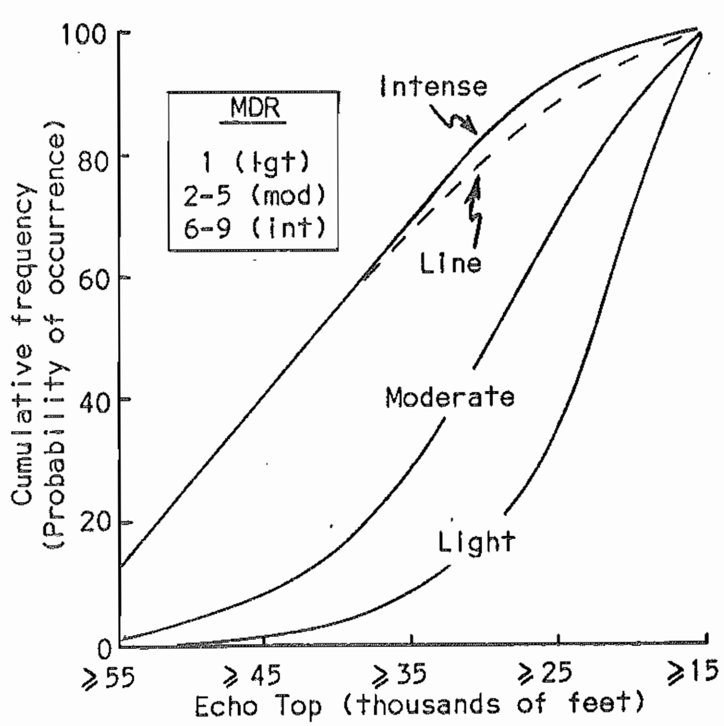

Fig. 17. Cumulative frequency distribution for classes of echo height and intensity (adapted from Bonner and Kemper, 1971).

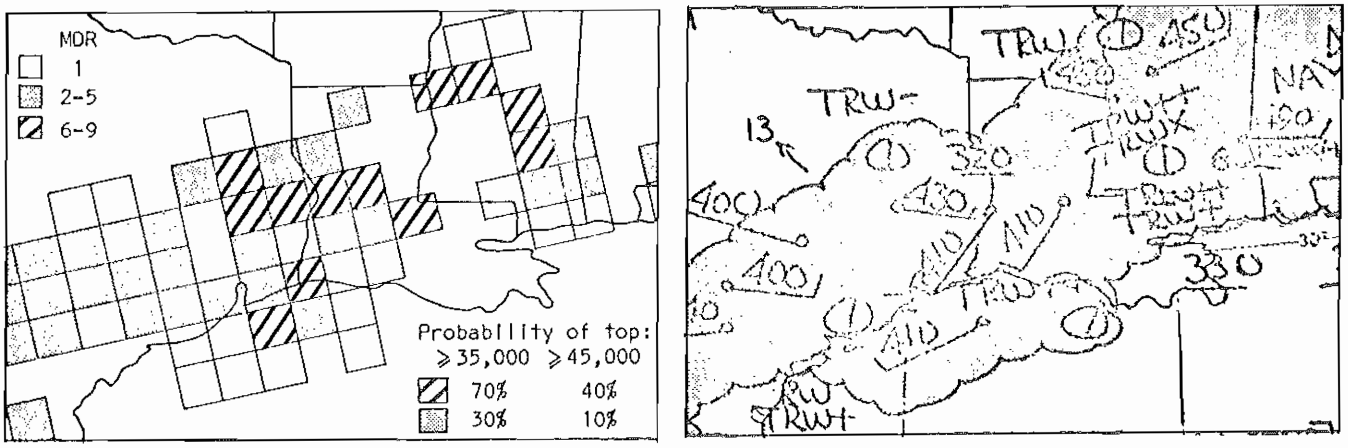

Fig. 18. Comparison of RADU chart (right) and height probability analysis from MDR data and Fig. 8 (left). Analyses are for 2340GMT, July 2, 1973.

Finally, it appears that MDR data can enhance the usefulness of satellite imagery. Work is under way to develop an automated procedure for compositing radar and satellite data but until such a product is available the MDR data provide a way of doing this. Fig. 19 shows the digital data superimposed on a satellite photo which approximates the type of imagery which will be routinely available at many NWS offices when the operational geostationary satellite system (GOES) is established.

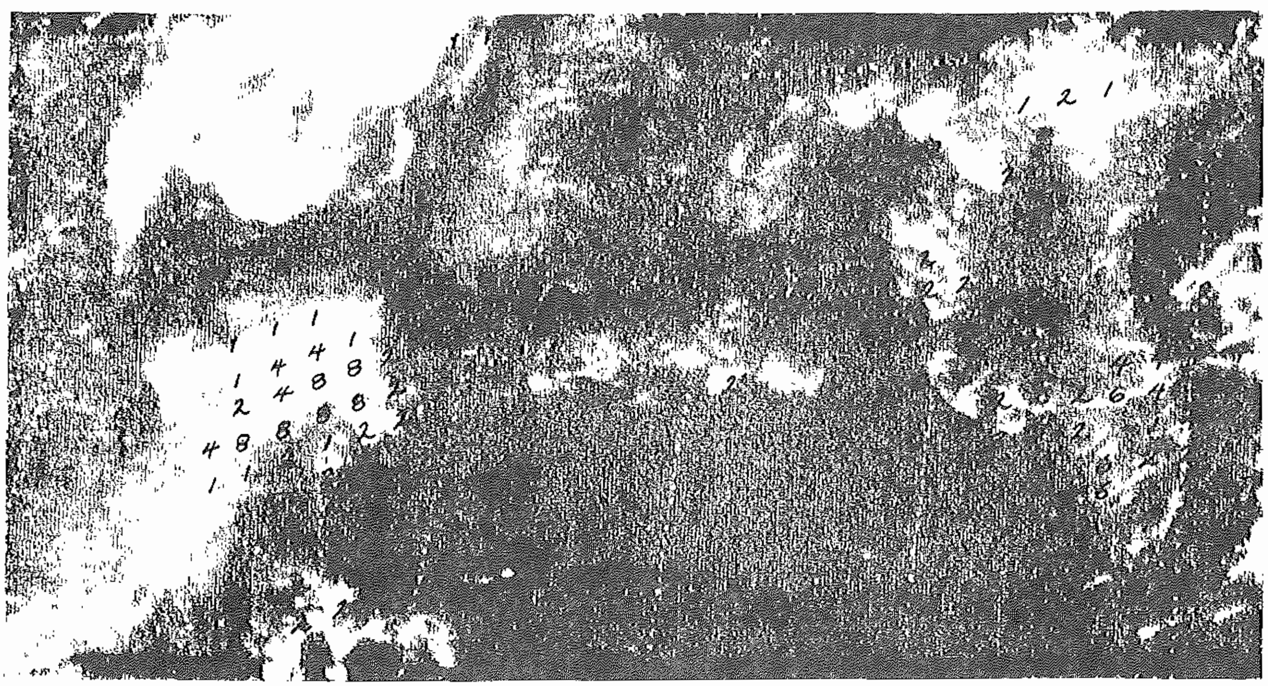

Fig. 19. Composite of ATS-3 satellite image and MDR data (≈ 1640GMT, September 16, 1973).

The composite illustrates the complementary nature of the two types of information. In the Florida area the satellite picture indicates scattered convective activity but gives little indication of intensity. The radar data provide an additional dimension. Note that mostly even digits prevail (indicating no more than half coverage) and that intensity ranges from 1 to 8 on the MDR scale. Over Texas the cloud cover looks about the same in the panhandle and around the San Antonio area, but the Amarillo radar reported no echoes while the MDR values indicate scattered intense to extreme echoes in south central Texas. In fact, flash flood warnings were in effect and over 3 inches of rain had fallen at San Antonio at the time of the picture.

6. CONCLUSIONS

Availability of manually digitized radar data has improved the utilization of this important source of information. As a result of ease of communication, computer compatibility, and its more quantitative character (compared to plain-language reports), the information in this form has a variety of present and potential uses. New applications are expected to result from the fact that the data are being archived in readily accessible form and many of the procedures or techniques developed with present data will be applicable in future years when a fully automated digitized radar program (along the framework of the NWS's experimental D/RADEX project) becomes operational.

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REFERENCES

Blackmer, R.H., Jr., R.O. Duda and R. Reboh, 1973: Application of pattern recognition techniques to digitized weather radar data. Final report, Contract 1-36072, SRI Project 1287, Stanford Research Institute, Menlo Park, California.

Bonner, William D. and James E. Kemper, 1971: Broad scale relations between radar and severe weather reports. Proc. Seventh Severe Local Storms Conf. Boston, American Meteorological Society.

Endlich, R.M., D.E. Wolf, D.J. Hall and A.E. Brain, 1971: Use of a pattern recognition technique for determining cloud motions from sequences of satellite photographs. J. Appl. Meteor., 10, 105-117.

Glahn, Harry R. and Dale R. Lowry, 1972: The use of model output statistics (MOS) in objective weather forecasting. J. Appl. Meteor., 11, 1203-1211.

Kessler, Edwin, 1961: Appraisal of the use of radar in observation and forecasting. Proc. Ninth Weather Radar Conf., Boston, American Meteorological Society.

REFERENCES (continued)

Kessler, Edwin and James W. Wilson, 1971: Radar in an automated National Weather System. Bull. Amer. Meteor. Soc., 52, 1062-1069.

McGrew, Russell G., 1972: Project D/RADEX (Digitized Radar Experiments). Proc. Fifteenth Radar Meteorology Conf., Boston, American Meteorological Society.

Mogil, H. Michael, 1974: Evaluation of severe weather and thunderstorm forecasts using manually digitized radar data and the SELS severe weather log. Proc. Fifth Conf. on Weather Forecasting and Analysis, Boston, American Meteorological Society.

Moore, Paul L. and Daniel L. Smith, 1972: Updating of numerical precipitation guidance. J. Appl. Meteor., 11, 1293-1298.

Peters, Brian E. and David P. Barnes, 1973: Evaluation of an objective radar technique for updating numerical precipitation guidance. NOAA Technical Memorandum NWS SR-73, 6pp.

Reap, Ronald M., 1972: An operational three-dimensional trajectory model. J. Appl. Meteor. 11, 1193-1202.

Russo, John A., Jr. 1961: A comparison of radar codes for multi-station synoptic observations. Technical Memorandum No. 3, Travelers Research Center, Inc.

Wilk, K.E. and K. Gray, 1970: Processing and analysis techniques used with the NSSL Weather Radar System. Proc. Fourteenth Conf. on Radar Meteorology, Boston, American Meteorological Society.