Use of Radar Summary Maps for Weather Analysis and Forecasting

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ABSTRACT

A study of radar summary maps collected from July to December 1961 shows that the echo areas reported are closely associated with precipitation and that the reported echo intensities and heights of tops are valuable for assessing the occurrence of thunderstorms and other precipitation types. Use of past-hour motion arrows shown on the maps for prediction by translation gives better 3-, 6-, and 9-hr forecasts of echo areas over St. Louis, Mo., than does persistence. The symbols given to indicate the fractional echo coverage within echo areas are usefully related in summer to the probability that precipitation occurs at any point within the echo area. Such relationships can be combined with the probabilities associated with echo-area forecasts to obtain a probability for the future occurrence of echo at any particular point. Some means for extending such probability designations to route forecasts are briefly indicated.

A principal weakness of the present radar data observing and reporting methods is the coding scheme. The encoded echo observations are very general and the location of echoes within the areas indicated on the radar summary maps is not shown except for particularly noteworthy cases. However, the present data demonstrate both that radar is a valuable aid for terminal and enroute forecasting and that forecasts of useful accuracy and greater precision should be possible when more precise radar data become available.

1. Introduction

The installation of WSR-57 radars throughout most of the eastern half of the United States has been spurred by aviation's steadily increasing requirements for weather data, by the need for improved management of hydrologic resources, and by the need of many interests for improved warnings of severe storm occurrences. However, the manual techniques presently in use for reporting, encoding and plotting radar data do not take full advantage of present radar capabilities, or of modern methods for data processing and communicating.

This paper is an attempt to document the operational applications of the present radar observing and reporting system and to present practical methods that can be used immediately for improving the usefulness of the radar network.

2. The present weather-radar installations and data-handling system

On 1 February 1962, the Weather Bureau's operating network consisted of twenty-nine WSR-57, three SP or SP-1M, one Decca 41, and sixty-three WSR-1, -1A, -3, or -4 radars (Bigler, Hexter and Wells, 1962; see Fig. 1). Radar observations, made regularly at intervals of 1 hr at each station by Weather Bureau personnel, are encoded in a style that may be characterized as "abbreviated plain-language" and transmitted to Kansas City over one of three RAWARC[1] circuits.

The present observing procedure, described in detail in the *Weather Radar Surveillance Manual* (1962), requires that each observer make decisions that depend on his personal interpretation. The encoded information pertains to the location, movement, intensity, intensity change, and vertical development of isolated cells or especially strong echoes; in addition, the echo coverage is included for echoes in the form of bands, lines, or areas.[2] The message is a description of the radarscope display, and its quality varies with the complexity of the patterns, the scale of elements in the patterns, the time available to make and encode the observations, and the judgment of the observer. During a study of

[1] *RA*rep and *WAR*ning *C*oordination system. Circuits 7061, 7062, and 7063 serve the northeast, southeast, and central United States, respectively.

[2] Because of a delay in fitting the WSR-57's with accurate and reliable gain-control circuits and calibration equipment, intensity measurements with these radars have been semiquantitative at best. Comparative measurements of the intensities of echoes on the older WSR-1, -3, and -4, and SP radars have been even less satisfactory. However, it was planned to have all WSR-57's fitted with accurate gain-control circuits by the summer of 1962, making more valuable intensity measurements with these radars possible.

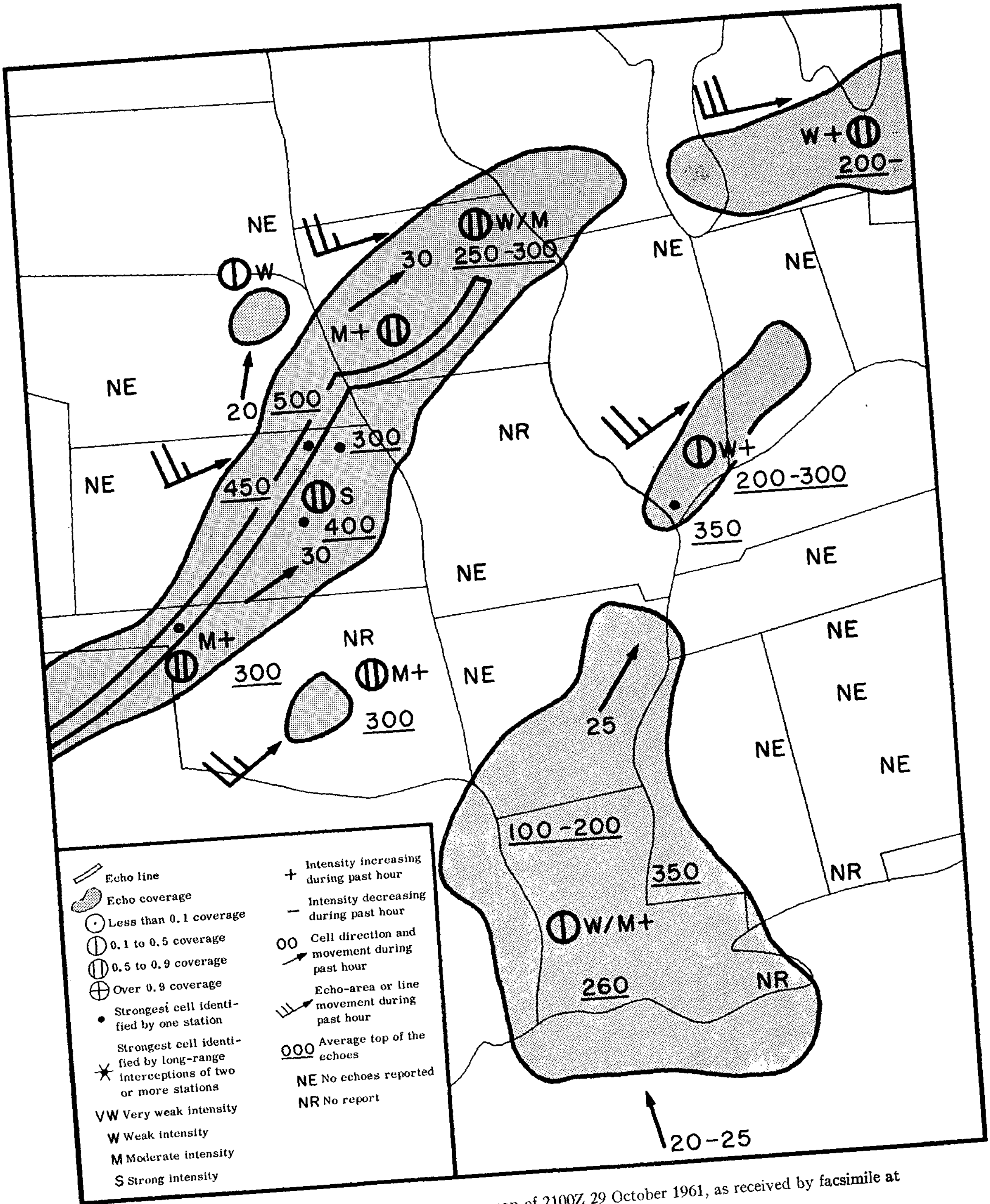

FIG. 1. Traced section of the radar summary map of 2100Z 29 October 1961, as received by facsimile at The Travelers Weather Service.

radar codes, Russo[3] found that different observers code the same weather situation is considerably different ways, and Weather Bureau observers who were interviewed agree that considerable variability accompanies use of this code.

Any data transmitted to Kansas City on one of the RAWARC circuits are also available to all others receiving on that circuit. Thus, some of the unedited information is used by Air Traffic Control Centers, flood forecasters, and others who need timely information, especially when the weather is stormy.

At Kansas City, the hourly data carried by the three RAWARC circuits are combined by two or more meteorologists of the Radar Analysis and Development Unit (RADU), who prepare an abbreviated plain-language summary of the weather in each of the three sections of the country served by a RAWARC circuit. Like the data originating at the radar sites, these summaries are transmitted hourly over their corresponding circuits. In addition to the hourly summaries, a map showing the radar weather observations over the entire nation is prepared each hour and one is transmitted over the national facsimile circuit at 3-hr intervals. The transmitted map shows the echo distributions by means of a self-evident code. The elements reported on the map include echo coverage, movement, intensity, intensity change, type, and vertical development. Some of this information is often omitted; however, the echo coverage, intensity, height, and area movements are reliably reported. Fig. 1 is a section of an actual radar map, with an explanation of the symbols used.

Since the analysis of the radar summary map is subjectively drawn, it is desirable to recognize the guides used by the analyst who prepares it. This information was obtained from Mr. H. E. Foster, Chief of RADU.[4] According to Mr. Foster, the analyst's most stringent requirement is to remain abreast of the meteorological situation, and to use this knowledge in the interpretation of the reported echoes. Basically, the echo locations and motions, as well as tops and intensities occurring on the summary, are directly as reported (except for an "averaging" of those overlapping reports which disagree). The shapes of areas or the exact way in which the various reports are consolidated depends to a certain extent upon the synoptic situation. According to Mr. Foster, the analyst tries to consolidate the various echoes in an area to fit the known synoptic situation. Quite frequently, the lines or area movements are calculated at RADU by comparison with the previous hour's position.

In short, the Kansas City meteorologists combine overlapping reports, reduce errors, and produce a summary which, as shown below in this report, is a fair description of the distribution of precipitation.

[3] Russo, Jr., J. A., 1961: A comparison of radar codes for multi-station synoptic observations. Tech. Memo No. 3, The Travelers Research Center, Inc., 51 pp.

[4] Foster, H. E., 1961: Personal communication, December.

3. Interpretation of the radar summary

Correspondence of echo areas with surface precipitation. To assess the usefulness of the radar summary for describing the weather, several studies were made to relate the occurrence of echoes, and categories of echo intensity and echo tops, to the weather.

The first study involved the correspondence between echoes reported on the radar summary and surface precipitation. One hundred radar summaries were chosen at random from those received at The Travelers Weather Service office late in the summer and during the fall of 1961. The occurrence or absence of an echo area over 16 selected stations was noted on each of the 100 radar summaries and recorded with the surface precipitation reported by the concurrent surface map. The stations used in this test are shown in Fig. 2. All are within 115 mi of a WSR-57 radar.

Table 1 shows the relationship between precipitation reports on the surface chart and echo areas. The table shows that 87 per cent of precipitation heavier than drizzle is labeled by an echo area, and that drizzle is not usually associated with echoes reported on the radar summary charts. On the other hand, selected stations within radar echo areas reported precipitation only 54

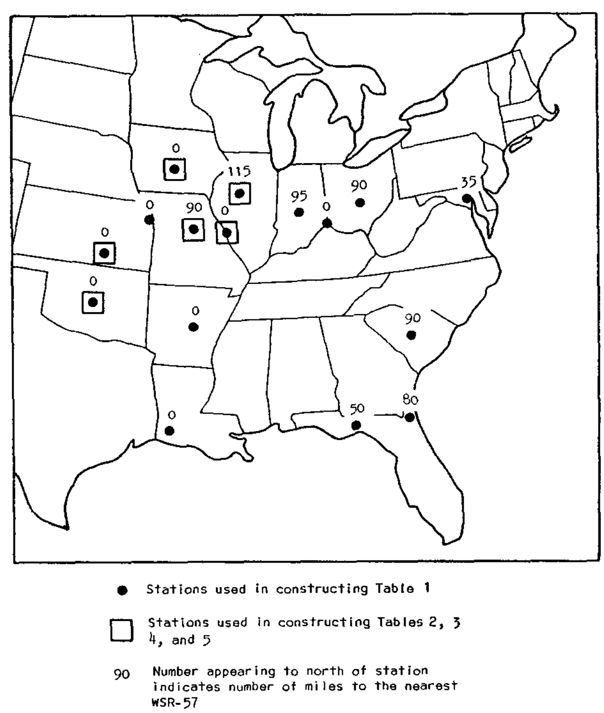

FIG. 2. Distribution of stations reporting surface weather conditions used for comparisons of radar and surface weather reports.

TABLE 1. Correspondence of precipitation to echo areas.*

Echo area?	Number of cases: No precipitation	Drizzle	Precipitation other than drizzle	Total
Yes	73	3	82	158
No	1278	11	12	1301
Total	1351	14	94	1459†

* Based on the reports of 16 selected stations on 100 pairs of surface weather and radar echo maps.
† The total number of cases is only 1,459 instead of the expected 1,600. The difference is the number of unreadable surface reports.

per cent of the time. This percentage is not higher because the boundaries indicated on the radar summary refer to the echo *areas* and not to the individual echoes. The density of echoes within the indicated boundaries are reported in four categories: widely scattered, scattered, broken and solid [⊙ (<1/10), ⦶ (1/10) to 5/10), ⦷ (6/10 to 9/10), and ⊕ (>9/10), respectively]. Therefore, the indication of an area boundary surrounding a station implies only a certain probability that echo exists over the station.

The relationships shown in Table 1 lead to the expectation that the proportion of precipitation-reporting stations within an echo area increases with the reported density of echoes within the area. To test this premise, the echo density and surface precipitation were recorded for all the available data from the end of July until December 1961 for the following six Midwestern cities shown in Fig. 2: Peoria, Des Moines, St. Louis, Columbia, Wichita, and Oklahoma City. The results appear in Table 2 which does indeed show that the probability of precipitation at the surface increases with reported echo coverage. However, the probability of precipitation corresponding to the ⦶ and ⦷ classifications shows seasonal variation, as indicated by Table 3.

TABLE 2. Echo coverage vs precipitation occurrence.*

Echo coverage†	Number of cases	Percentage with precipitation
⊕	10	100
⦷	276	59
⦶	84	40
⊙	8	0

* Based on six Midwestern stations reporting surface weather, and all available pairs of surface weather and radar summary maps from July to December 1961.
† For definition of symbols, see paragraph above.

TABLE 3. Breakdown by seasons of data given in Table 2.

Echo coverage	Jul–Sep 1961: Number of cases	Jul–Sep 1961: Percentage with precipitation	Oct–Dec 1961: Number of cases	Oct–Dec 1961: Percentage with precipitation
⊕	8*	100	2	100
⦷	150	50	128	69
⦶	64	16	20	70
⊙	7	0	3	0

* Seven of the overcast cases were associated with one large persistent echo area associated with the remnants of Hurricane Carla after it passed inland.

It is instructive to consider why the frequency of precipitation associated with reports of broken and scattered echoes is greater in autumn than in summer. This seasonal variation is probably best related to the tendency of precipitation to be more stratiform during the cold season, when its intensity is less. Therefore, much of the cold-season precipitation, being very light, remains undetected by radar. The greater percentage of stations reporting precipitation in scattered (than in broken) echo areas during autumn is perhaps best explained in terms of the statistical properties of small samples.

The percentage of stations reporting precipitation when echoes are broken shows an even greater seasonal variation with the months of September and October 1961 omitted than is shown by Table 3. In July and August, 32 per cent of stations inside broken areas reported precipitation, compared with 80 per cent in November and December.[5] This seasonal variation seems real and should be considered in making operational interpretations.

Relationship between precipitation type and height and intensity of echoes. Donaldson (1958) and others have reported that the intensity of convective storms increases with the height and intensity of associated radar echoes. Since the intensity and height of the echo areas are reported regularly on the radar summary, a study was made relating them to the type and intensity of precipitation occurring at the surface. For the same six stations and time periods discussed above, the relationship between reported hydrometeor types and the radar echoes is given by Table 4. This table relates precipitation reports at these stations when they are within echo areas, with the nearest notations of echo top and intensity given on corresponding radar summary maps. This table is suitable for use by the practicing forecaster, who must proceed from a knowledge of the echoes to the probability that a given type of weather will occur. For example, the probability that an echo of greater

[5] The "broken coverage" designation is applied when observed echoes cover more than half an area. The occurrence of precipitation with only 32 per cent of surface reports within such areas is probably due to more extensive echoes aloft, where the radar beam is, than at the ground.

TABLE 4. Distribution of precipitation types with echo intensity.*

Echo intensity	Percentage of precipitation type: Snow (39 cases)	Drizzle, freezing drizzle (8 cases)	Continuous rain, freezing rain, and sleet (81 cases)	Rain shower (31 cases)	Thunderstorm (41 cases)	All types (200 cases)
Greater than moderate (13 cases)	0	0	0	23	77	100
Moderate (26 cases)	0	4	27	23	46	100
Weak to moderate (32 cases)	0	10	34	31	25	100
Weak (120 cases)	27	3	52	10	8	100
Very weak (9 cases)	78	0	11	0	11	100

* Based on six Midwestern stations reporting surface weather and all available pairs of surface weather and radar summary maps from July to December 1961.

TABLE 5. Distribution of precipitation types with height of echo top.*

Height h of echo top, 10^2 ft	Percentage of precipitation type: Snow (39 cases)	Drizzle, freezing drizzle (7 cases)	Continuous rain, freezing rain, and sleet (72 cases)	Rain shower (29 cases)	Thunderstorm (42 cases)	All types (189 cases)
$400<h$ (13 cases)	0	0	0	15	85	100
$300<h\leq 400$ (24 cases)	0	5	8	29	58	100
$250<h\leq 300$ (38 cases)	0	0	37	26	37	100
$200<h\leq 250$ (44 cases)	0	9	75	11	5	100
$150<h\leq 200$ (49 cases)	41	4	43	10	2	100
$h\leq 150$ (21 cases)	90	0	10	0	0	100

* Based on six Midwestern stations reporting surface weather and all available pairs of surface weather and radar summary maps from July to December 1961.

than moderate intensity over a particular point is associated with a thunderstorm at that point is given by 0.77 times the entry from Table 3 corresponding to the given coverage symbol and season.

Since light or moderate rates are common to all precipitation types, it is not surprising that Table 4 fails to show a notable discrimination of precipitation type by echoes of weak and moderate intensity. Thus, the presence of weak echoes is not a sufficient criterion for estimating snow, since light rain and drizzle also give weak echoes. Common meteorological sense dictates the use of the bright-band height[6] at the radar station and the known or deduced distribution of surface temperature as the most important aids in the proper association of echoes and snow.

Table 5, showing the distribution of weather type in six categories of echo height, indicates better discrimination of weather type than is shown in Table 4; this may be due in part to more accurate determination of heights than of intensities, but associated physical mechanisms cannot be ruled out.

Tables 4 and 5 are combined in Fig. 3 where more explicit indication of echo and precipitation intensities is given than in the tables. It is evident that the echo heights and intensities, combined with surface temperatures and bright-band data should be useful for determining precipitation type.

Although echo intensities seem to be sufficiently well reported to aid significantly in the identification of precipitation type, the rate of precipitation of a given type is not well related to the intensity reports. The association of 25 per cent of the heavy-rain and thunderstorm cases with weak and very weak echoes may be indicative of inaccurate measurement of echo signal strengths. Proper assessment of this aspect of radar utilization would require the study of recording-rain-gauge records and point-echo intensity measurements.

4. Forecasting from the radar summary maps

Persistence of echo areas. The lifetime of a meteorological feature increases with its scale. Noel and Fleisher[7]

[6] The bright band, discussed extensively by Wexler (1955), for example, is a layer of enhanced radar signal, which marks the elevation at which descending snow melts to form rain.

[7] Noel, T. M., and A. Fleisher, 1960: The linear predictability of weather radar signals. Res. Report No. 34, Mass. Institute of Technology, Cambridge, Mass., 46 pp.

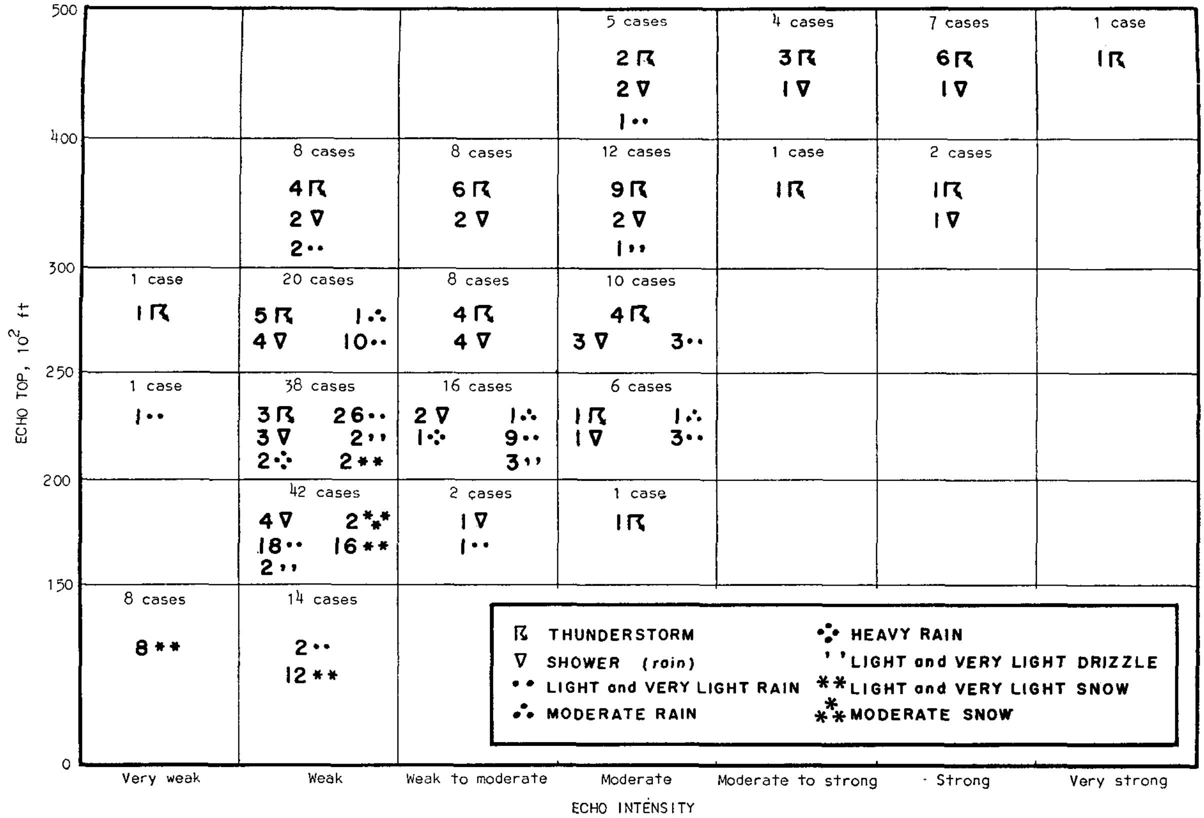

FIG. 3. Weather type as a function of echo intensity and echo top.

in a preliminary study found that linear prediction of details of a general radar echo pattern digitized in 5-mi squares shows little skill beyond 10 min. Boucher and Wexler (1961), however, have discussed the predictability of elements on the scale of a whole radar display, over periods of several hours, and show that translation gives useful several-hour forecasts of the location of a squall line or large area. However, the internal configuration of such lines or areas, being of a small scale, cannot be predicted in detail, but only in terms of suitably conservative statistical properties.

The radar summary maps provide a basis for studying some of the statistical properties of radar echo areas. Our first study concerns the relationship between persistence and size of echo areas. A random sample of 120 radar summary maps was chosen for the study. The size of each echo area on each map was measured and the map following the first by 3 hr was examined for evidence of persistence. Table 6 shows, in six area categories, the percentage of the echo area population that was identifiable on both maps. The reader may refer to Fig. 1 and note that the smaller echo areas shown in Nebraska and Oklahoma have areas of about 3,000 sq mi.[8]

[8] The unit mile throughout this report is the nautical mile.

TABLE 6. Persistence of echo areas.*

Area A of echo on the first chart, mi²	Number of cases on first chart	Percentage of cases identifiable on chart 3 hr later
$10{,}000 < A$	100	100
$5{,}000 < A < 10{,}000$	59	85
$3{,}000 < A \leq 5{,}000$	59	76
$2{,}000 < A \leq 3{,}000$	55	67
$1{,}000 < A \leq 2{,}000$	60	57
$A \leq 1{,}000$	34	24

* All but first row based on analysis of 240 charts, Aug–Dec 1961.

It appears that echoes whose areas are less than 1,000 mi² seldom persist for 3 hr, whereas those whose areas are greater than about 7,500 mi² almost always do. Since the majority of echo areas plotted on the radar summary are large, Table 6 indicates that the maps do give meaningful information concerning the echo distribution 3 hr subsequent. The smallest echoes (little larger than the station circles on the usual surface maps) should be considered principally in connection with forecasts of less than 3 hr.

Predictability of echo area locations. Since the larger-scale features persist for at least 3 hr, it is of interest to examine the predictability of their locations. Of course, this problem can be viewed as one form of the classical question of precipitation prediction. Its ultimate solution must depend on the appropriate definition of initial conditions by the use of radar, radiosondes, surface observations and other means. This report is concerned only with the extrapolative value of the information given on the radar summary maps.

The first data considered are the indicated echo-area motions, which are just the displacements observed during the preceding 1 hr. A test of the forecasting value of these data was made by applying them to the translation of echoes in the vicinity of St. Louis, Mo., for periods of 3, 6, and 9 hr. For each of these periods, over 800 translation forecasts calling for the occurrence or absence of echo area over St. Louis were made and compared with 800 forecasts based on the persistence at St. Louis of the echo observed there at the earlier time. All the available radar summary maps from August through December 1961 were used for the test.

Table 7. Results of all 3-hr translation forecasts of echo area over St. Louis.

Forecast	Number of subsequently observed conditions		
	Yes	No	Edge
Yes (99 cases)	75	17	7
No (704 cases)	16	671	17
Edge (19 cases)	8	8	3

Table 8. Results of all 3-hr persistence forecasts of echo area over St. Louis.

Forecast	Number of subsequently observed conditions		
	Yes	No	Edge
Yes (93 cases)	62	24	7
No (703 cases)	27	658	18
Edge (26 cases)	10	14	2

The most important results pertain to 3-hr forecasts and are illustrated by Tables 7 and 8. First, it is clear that the translation of echoes with their past movement produces point forecasts that are markedly better than forecasts calling for persistence at a point of the condition previously observed at that point. Excluding the forecasts and observations of an echo edge over St. Louis, 81.5 per cent of translation forecasts calling for echo occurrence were correct, while only 72.1 per cent of the persistence forecasts were correct. In other words, persistence forecasts of echo occurrence involved over 50 per cent more errors than translation forecasts.[9] A similar relationship exists between forecasts of the absence of echo made by translation and persistence. Of the "no echo" persistence forecasts, 96.1 per cent were correct; of the "no echo" translation forecasts, 97.7 per cent were correct.[10]

Of the subsequent echo occurrences, 82.5 per cent were correctly forecast by translation, compared to only 69.5 per cent by persistence.[11]

All the interesting results obtained are presented in graphical form in Figs. 4 though 9. These figures illustrate the results of the 6- and 9-hr forecasts as well as those tabulated and discussed above. In all figures, forecasts and observations of echo edges are excluded. Although the figures show that the accuracy of the forecasts drops considerably as the time period is extended to 6 and 9 hr, there is still reason for optimism concerning the value of radar as a forecast tool for these periods. Refined forecasting techniques and data-collection processes should produce improved forecasts. The discussion above and examination of the figures lead to the following general conclusions.

(1) Forecasts based on the persistence of echo areas are improved by taking their motion into account.

(2) The autumn translation forecasts show a greater improvement over point persistence than is the case in summer, and forecasting accuracies are generally higher in autumn than in summer. This probably results from the summer echoes' relatively small scale and short life, which reduces the value of both point persistence and translation forecasts.

(3) Accuracy of forecasts for all time periods, up to and including 9 hr, is improved by application of translation. However, forecasting accuracy decreases markedly with time.

Predictability of area intensities. Neither the form of the hourly airways surface reports nor that of contemporary radar summary maps is well suited to the study of the relationships between echo intensity and precipitation rate. However, recent studies[12] (Marshall, 1960; Kodaira, 1961) have shown that measurements of precipitation rate and echo intensity are closely related and that intensity measurements could be a valuable aid in operational hydrology and severe-storm diagnosis. Therefore, we have studied the predictability of intensity through use of extrapolation of previous intensity changes.

The map transmitted each 3 hr from Kansas City frequently bears notations concerning the observed change of echo intensity during the preceding 1 hr. These notations have been used with the echo intensisities reported on the maps 3 hr later to determine if

[9] If there were no average difference between forecasts made by persistence and translation in the universal population of such forecasts, this result would be obtained by chance only 6.5 per cent of the time.

[10] This difference is significant at the 4.5 per cent level.

[11] This difference is significant at the 2 per cent level.

[12] Hiser, H. W., and P. R. Ray, 1959: Investigation of rainfall measurement by radar. Final report to USWB by Univ. of Miami (Florida) on Contract Cwb-9540, 46 pp.

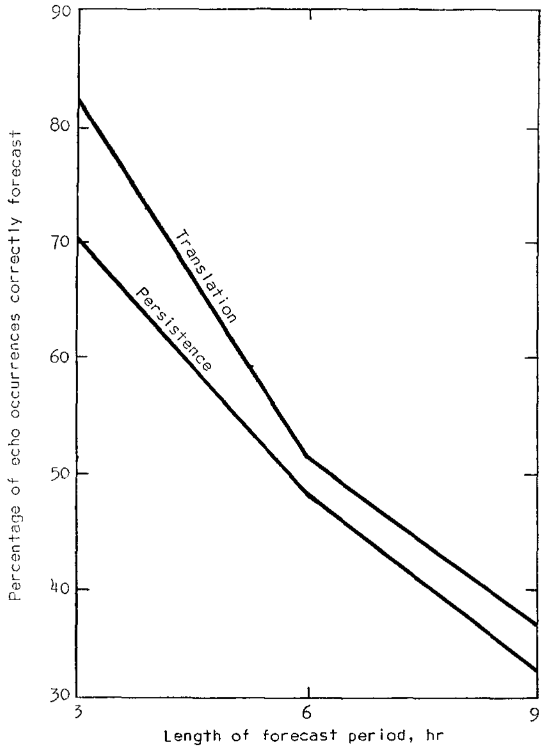

FIG. 4. Percentage of echo occurrences correctly forecast at St. Louis as a function of length of forecast period.

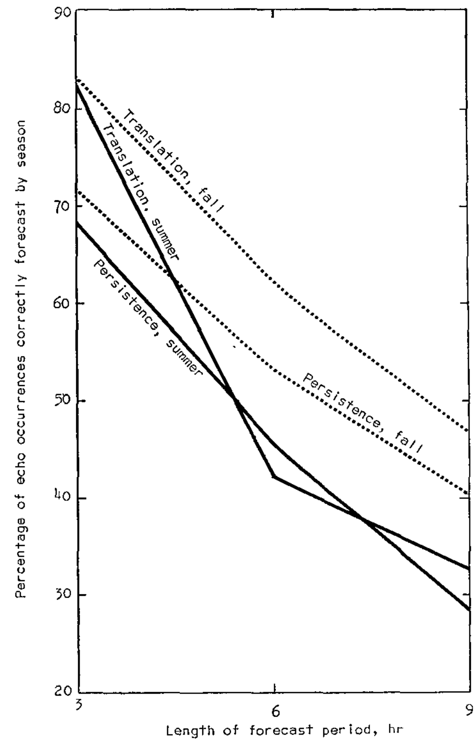

FIG. 5. Breakdown by season of results given in Fig. 4.

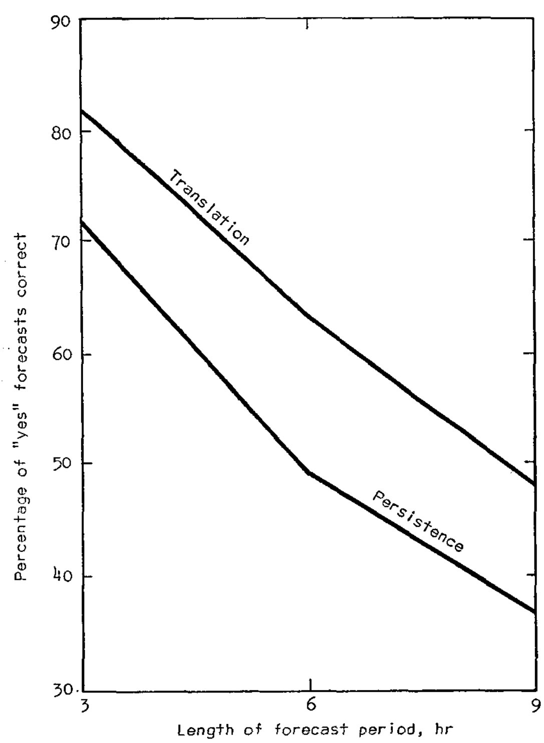

FIG. 6. Percentage of "yes" forecasts correct as a function of length of forecast period.

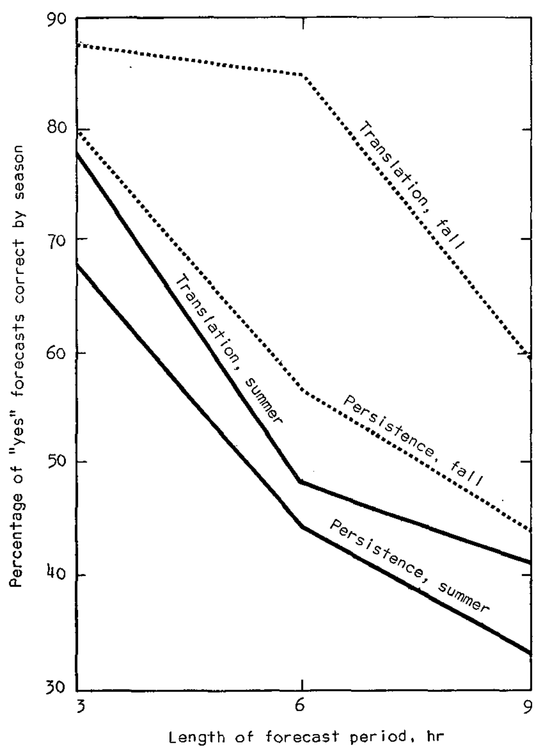

FIG. 7. Breakdown by season of results given in Fig. 6.

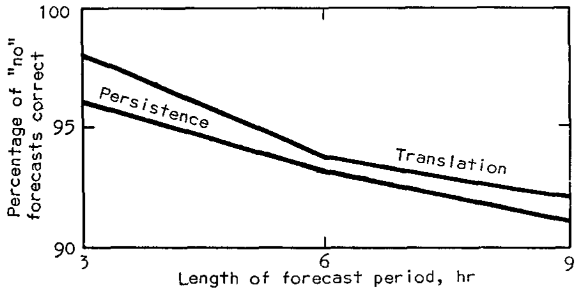

FIG. 8. Percentage of "no" forecasts correct as a function of length of forecast period.

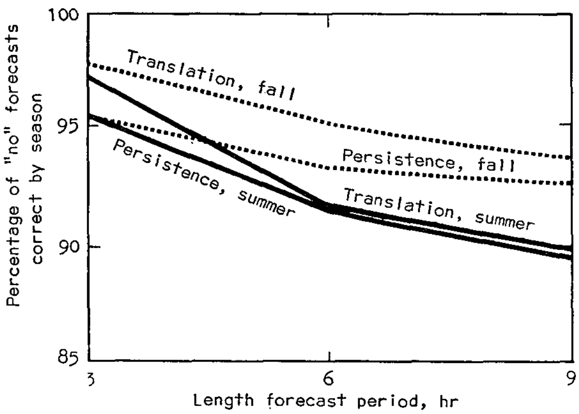

FIG. 9. Breakdown by season of results given in Fig. 8.

the intensity-change notations have value for 3-hr predictions.

One hundred reports of 1-hr intensity increase, 100 reports of intensity decrease, and 100 reports of no change during 1 hr were used in conjunction with the associated later maps to prepare Table 9. This table shows that, regardless of intensity change in the past hour, it is most probable that the intensity will not change in the next 3 hr. Only about 30 per cent of the intensity changes are predicted correctly, and it is apparent that on the basis of the reported intensities and intensity changes alone, the forecaster should always call for "no change."

The table also indicates, however, that the average change of intensity during the subsequent 3 hr tends

TABLE 9. Relationship of reported echo-intensity change during past hour to observed echo-intensity change over subsequent 3 hr.

Past hour's intensity tendency	Intensity change 3 hr later Increase	No change	Decrease
Increase (100 cases)	30	52	18
No change (100 cases)	12	68	20
Decrease (100 cases)	19	47	34

to be in the direction of that reported during the previous hour. The χ^2 test shows that this indication is significant at the 1 per cent level; it is what would be expected if there were important long-period trends in the intensity variations. Since climatology and synoptic meteorology also give evidence that long-period intensity variations exist, it seems important to continue this study, using carefully measured radar signal intensities at 1-hr intervals when such data become available.

Probability forecasting for enroute and terminal conditions. Reed[13] has given a detailed plan for the combination of radar and routine data in objective analyses. The general nature of the data given on the radar summary maps is not well suited to point precipitation forecasts because echo locations are not given on a point basis. However, by multiplying the fractional coverage implied by the coverage symbol by the probability that a given forecast of area location is correct, an estimate of the probability that echo occurs over any particular point is obtained. And the probability that a given precipitation type, such as a thunderstorm, exists at a point could be obtained by consulting Fig. 3 and extrapolating the previously reported echo intensity and height.

Once the probability of the local occurrence of a given precipitation type is obtained, it can be related to the probability of occurrence along a flight path if it is assumed that the local probabilities refer to an "area of influence." In thunderstorms, this area might be that within which thunder can be heard at a surface station.

It might be assumed that the area of influence can be represented by a square whose side is of length s. The number of squares along a route of length r is then r/s. If we denote the probability of a thunderstorm in any one square by p, the probability of a thunderstorm-free flight is then $(1-p)^{r/s}$, and the probability of encountering at least one thunderstorm square along the route is $1-(1-p)^{r/s}$. The probability of thunderstorms in all squares is $p^{r/s}$.

Even this simple analysis depends on the additional assumption that the probability of thunderstorm in the several squares is independent. This cannot be determined from present-day radar summaries, and it is evident that a proper study depends on standardized data, as Reed has already indicated.

5. Summary of forecasting and interpretation studies

The studies discussed above show that the echo areas on the radar summary maps generally locate the areas of precipitation and that the intensity and echo tops

[13] Reed, R. J., 1961: A plan for the integration of radar and routine data in the objective analysis of cloud, precipitation, and convective activity. Tech. Memo No. 11, The Travelers Research Center, Inc., 17 pp.

in an area are valuable for estimating the weather type. The echo-area movement arrows on the charts, based on the observed movement during the preceding hour, are valuable for predicting the location of the areas 3, 6, and 9 hr later. The coverage indicators given on the summer maps correspond nearly as expected to the frequency of surface-precipitation reports within echo areas. During the cold season, the "scattered" and "broken" symbols are associated with more frequent surface precipitation, probably because much of the widespread precipitation characteristic of that time is not detected by the radars.

Neither the radar data nor the surface reports of precipitation are in a form suitable for defining a useful correlation between precipitation rate and echo intensity. The reported 1-hr intensity changes do show a significant positive correlation with the intensity change over the next 3 hr, although the best intensity forecast one can make with present data is "no change." However, the existence of the correlation indicates both a measure of skill in radar-intensity observations and a long-period component of intensity variation which is probably a diurnal influence or associated with large-scale meteorological developments.

Weaknesses of the present system can be associated with several aspects of the present radar observing and reporting procedures.[14] First is the very general terminology of the echo reports; locations and intensities of particular echoes are rarely given except for the occasional cases of especially intense cells. It is usually impossible to tell from the maps when echo exists over a particular place, and only the probability that an echo exists at a particular place can be specified.

Second, the present system of encoding and reporting does not lend itself to modern computer techniques of data processing. In particular, the RAWARC code must be manually processed, and the maps must be visually interpreted.

Third, the subjective treatment of the data at practically every stage of collection and processing is associated with a multitude of effects that are practically impossible to evaluate and that introduce erratic elements into the time series of observations.

That positive results have been obtained in this study despite the deficiencies in the data discussed above argues for a vigorous attempt to improve the present observing and reporting system. In view of the results, we have little doubt that weather analyses and forecasts of increased precision will be possible as the initial specification of echo locations and intensities improves. The application of revised encoding and reporting techniques to improve the usefulness of the radar data is discussed in Section 6.

[14] The lack of weather radar data over mountainous areas of the United States is also an important weakness of the present system.

6. Recommendations

There is little question that the radar summary maps can contribute substantially to the accuracy of in-flight and terminal weather analysis and prediction. However, the present format does not lend itself to analyses and forecasts of highest precision, nor does it provide the data needed for evaluation of the accuracy of precise forecasts. The increasing speed and density of air traffic require that weather conditions be defined in areas much smaller than the 10,000-mi^2 or larger regions most often depicted on present charts.

Therefore, it is suggested that a study be made to investigate the operational feasibility of having the radar operators at each station prepare a standard-format digitized code indicating the distribution of the important echo characteristics in squares about 25 mi on a side. There are about 5000 such squares within the United States.[15] Since there are about 120 such squares within 150 mi of a radar, the length of a message containing one character for each square with echo and some additional identifying characters would be about the same as that of a typical hourly report of an airways station.

Our tests have indicated that a representative code embodying information in 50 squares could be prepared by the radar operator in about 10 min, which is comparable to the time presently required. Upon receipt, the coded message could be entered on a base map imprinted with the grids appropriate to each radar station in less than 2 min. Alternatively, the teletype data might be collated by a computer, and a map of the whole country prepared automatically within a few minutes of receipt. In fact, it is reasonable to suppose that a computer could process the incoming data to separate the information of interest to particular users, prepare teletype tapes for RAWARC or facsimile transmission, and prepare current weather analyses and extrapolative forecast charts clearly illustrating the conditions of special interest to each class of user.

We believe that a plan of this sort could be implemented at an early date with the aim of increasing the quantity and quality of radar-echo information with no increase of manpower. Such a system would be suited to mixing of the manual and computer processing techniques that characterize the current state of meteorological development and would provide data valuable for the further definition of weather-radar relationships. It could be modified or replaced at negligible additional cost relative to the present system

[15] A suitable national grid for radar data is formed by a cartesian-coordinate system laid over a Lambert conformal projection with standard latitudes within the United States. The angle formed between a parallel to the cartesian ordinate and a longitudinal meridian is $\theta = \sin\phi_0(\lambda_c - \lambda)$, where λ_c is the reference longitude and ϕ_0 is the standard latitude or the mean of two standard latitudes if there are two. With the reference longitude in the central U. S., the maximum angle (on the coasts) between the northward-tending lines of the cartesian grid and the local meridian would be about 15°.

when the national aviation weather system concept being considered for the later 1960's is implemented.

Further discussion is contained in the parent report[16] and in Kessler (1961).

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[16] Wilson, J. W., and Edwin Kessler, 1962: Use of radar summary maps for weather analysis and forecasting. Tech. Memo No. 14, The Travelers Research Center, Inc., 51 pp.

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