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RESEARCH REPORT NO. 350

USE OF RADAR FOR QUANTITATIVE DETERMINATION OF PRECIPITATION FROM THUNDERSTORMS IN THE SOUTHWEST

by

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Practically all runoff from the semiarid rangelands of the Southwest results from intense convective rains. Records from the Walnut Gulch Watershed (80 recording raingages on a 58-square-mile watershed), Arizona show that 80% of the runoff producing storm cells cover an area of five square miles or less.2/ Since the U. S. Weather Bureau precipitation recording stations are much more widely scattered, the hydrologist finds it very difficult to obtain adequate precipitation records with which to correlate precipitation and runoff.

Radar has proved to be a very useful tool to the hydrologist and meteorologist in studying thunderstorms in the Southwest. Radar sets with 3-cm. wave lengths have been, and are being, extensively used to study the development and movement of convective cells and the relative precipitation intensities and characteristics within the cells. Various investigators have suggested methods to make quantitative determinations of precipitation. Some of these methods show promise, especially for studying frontal storms in the midwest, but none have so far proved satisfactory for measuring precipitation from convective thunderstorms in the Southwest. The pressing need for more complete precipitation information for hydrologic design in this part of the country, however, demands further investigation of these methods and continued efforts to improve and combine them as well as to develop new techniques.

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2/ "Some Properties of Precipitation Associated with Runoff from Walnut Gulch Watershed, Arizona," by Joel E. Fletcher, presented at the AGU Meeting, April 1961, Washington, D. C.

Byers and collaborators 3/ were among the first to develop a method for correlating radar signals with precipitation falling on a watershed. They manually averaged radar echoes from precipitation falling on a dense network of raingages. Empirical relationships were developed between echo area and echo volume and storm duration and total volume of rain. The method was tedious and subject to many errors, but it illustrated the fact that rainfall over a small area could be determined more accurately by radar than by raingages in the usual spacing.

Since this early work, investigators have concentrated on improving methods of recording and relating varying intensities of radar echoes with precipitation intensities and volumes. Some investigators have used photographic methods; others electronic devices. Both photographic and electronic methods have been combined with "gain-stepping" techniques to develop methods that appear to hold some promise for the hydrologist in the Southwest.

Hiser et. al. 4/ used continuous photographic integration to record return signals from precipitation. Films were exposed for relatively long periods of time (an hour or longer), and a densitometer was used to develop echo-contour maps for separate storm events. These maps were compared with isohyetal maps drawn from point precipitation at raingages. Fair correlation between the echo-contours and isohyetal maps was obtained, although uncertainties in range were a major problem. A variation of this method is used by the U. S. Weather Bureau 5/ with some success on frontal storms in the midwest. Twenty-four-hour

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3/ "The Use of Radar in Determining the Amount of Rain Falling Over a Small Area," by H. R. Byers and Collaborators. Trans. Amer. Geophys. Union, XXIX(1948):187-96.

4/ H. W. Hiser, H. V. Senn, and L. F. Conover, "Rainfall Measurement by Radar Using Photographic Integration Techniques," Trans. Amer. Geophys. Union, XXXIX(1958):1043-47.

5/ Richard D. Tarble, "The Use of Multiple Exposure Radar Photographs in the Weather Bureau Hydrologic Program," Proceedings Eighth Weather Radar Conference, April 1960.

isohyetal maps are developed using transparency photographs made with hourly repeated exposures using an automatic photo timer and Poloroid Land Camera. Unfortunately, this method does not appear to be suitable for use in the Southwest. Many times as many films would be necessary to follow the rapid changes in convective cells. This method would be both tedious and costly.

Austin and Richardson 6/ adapted a pulse integrator to measure the radar signal over a large area. The average signal was recorded electronically, thus avoiding the lengthy and costly photographic processes. They developed an empirical relationship between the return signal and precipitation using drop size as an added parameter. The use of empirical curves and parameters such as drop size is not attractive to the hydrologist in the Southwest. This method does, however, indicate the possible advantages of electronic over photographic methods.

The U. S. Weather Bureau 7/ has recently developed theoretical curves of rainfall rate versus echo intensity with attenuation as a parameter. Such curves would be of great benefit to the hydrologist. Unfortunately, little information is available on the accuracy of these theoretical curves, and their adaptability to varying radar and weather conditions is uncertain.

To the hydrologist, one of the most useful techniques in radar development is "gain-stepping." In "gain-stepping" the minimum detectable signal at the receiver is changed a predetermined amount in a series of steps. Originally, these steps were made manually, but now automatic devices are used. At each step a stronger return signal is needed to activate the receiver. The storm area "shrinks" as the minimum detectable radar echo is increased, and an echo-contour map can be developed from the photographs taken at each energy level.

6/ P. M. Austin and C. Richardson, "A Method of Measuring Rainfall Over an Area by Radar," Proceedings Third Weather Radar Conference (Montreal, McGill University, 1952).

7/ Ablen F. Flanders, "The Weather Bureau's Radar-Hydrology Program," Proceedings Ninth Weather Radar Conference, October 1961.

In the "stepped-grey scale" method developed at McGill University, different intensities appear on the photo as varying shades of grey. These variations can be related to varying rainfall intensities.

Farnsworth and Mueller 8/ combined electronic integration with gainstepping. They designed an area integrator to reduce relative radar signals to digital output at the receiver. This combination, although it was based on very limited observations, appears to hold the most promise for future study. In this system, no photographs are needed. Kodaira 9/ suggested taking photographs at each level in a gain-stepping series and using these photos to develop iso-echo contour maps. Legg 10/ suggested a system involving a shape amplifier to present the stepped-grey scale in five distinct shades of grey rather than a continuous variation between white and black. This system seems desirable in that it avoids the complex photographic system suggested by Kodaira. Katz 11/ suggested using a calibration system at the antenna imput and recording the signal at that point. He maintained that the system could be calibrated in this way for nonlinearities during each measurement. Finally, in a paper presented last October at the Ninth Weather Radar Conference, 12/ Kodaira suggested a system that encompasses much of the information presented earlier by himself and others on radar areal-rainfall measurements. This system incorporates an echo contour device, a video signal recorder, and a computing device.

8/ G. W. Farnsworth and E. A. Mueller, "Radar Rainfall Area Integrator," Proceedings Conference Radar Meteorology. (Austin, University of Texas, 195?

9/ N. Kodaira, "An Iso-Echo Contouring Device," Proceedings Sixth Weather Radar Conference, March 1957.

10/ T. H. Legg, "Radar Weather Patterns in Stepped-Grey Scale," Seventh Weather Radar Conference, November 1958.

11/ Isador Katz, "Contour Separation: A Method for Obtaining Quantitative Measurements from Radar Photographs," Proceedings Eighth Weather Radar Conference, April 1960.

12/ N. Kodaira, "Radar Areal-Rainfall Measurements," Proceedings Ninth Weather Radar Conference, October 1961.

This last paper is typical of the more recent efforts to use radar to determine intensity and volume of rainfall. Primarily, these efforts have been to suggest improvements in existing techniques without proving these suggestions operational. While these systems are technically correct, none of them have been developed to a degree where they can be completely analyzed. Very little information is available on the accuracy of the relationships developed between the radar echoes and the actual rainfall intensities and volumes.

Truppi 13/ and Collis, 14/ among others, reported recently on digital processing of weather radar data. It appears that analog to digital to computer programs are readily available to the hydrologist for use with radar information. The problems which still exist in correlating radar echoes with rainfall intensities far outweigh the problems of data reduction.

Conclusions

(1) Radar is an excellent tool for qualitative studies of convective rain cells.

(2) Early developments indicated that radar might be very useful for quantitative studies of convective storms. Except for the U. S. Weather Bureau programs relating to frontal storms, more recent studies have tended to discourage this belief.

(3) The need for better precipitation records in the arid and semiarid regions of the Southwest demands further study in this field.

(4) One of the present methods, or a combination extracting the more desirable features of several methods, should be developed to the point where definite analysis is possible.

13/ Lawrence E. Truppi, "Reduction of Radarscope Data to Digital Form," Proceedings Ninth Weather Radar Conference.

14/ Donald T. Collis, "Digital Processing of Weather Radar Data," Proceedings Ninth Weather Radar Conference, October 1961.

Recommendations

Some of the more important radar and field requirements for study of rainfall intensities and volumes are listed repeatedly in papers on this subject. A few of these requirements are listed below:

(1) While X band radar sets are acceptable, and often desirable, for qualitative studies of precipitation, S band radar sets are strongly recommended for quantitative studies.

(2) Receivers should have ranges of 60 to 80 decibels to portray an adequate range of rainfall intensities.

(3) Logarithmic output is desirable to avoid effects of close saturation.

(4) Best results are obtained when the closest precipitation is at least 10 miles from the set. The minimum distance for effective study is approximately five miles.

Additional References

1. Battan, Louis J., Radar Meteorology, The University of Chicago Press, 19

2. Hiser, H. W.; Conover, L. F.; Gunn, H. V.; and Ray, P. R. Investigation of Rainfall Measurement by Radar. University of Miami.
   Final Report: September 1956
   Final Report: June 1957
   Final Report: June 1958
   Final Report: December 1959

3. Proceedings of the Sixth, Seventh, Eighth, and Ninth Weather Radar Conferences.