TIME-LAPSE RADAR AS A MESOSCALE FORECAST TOOL

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1. INTRODUCTION

In recent years, there has been a realization among meteorologists that more attention must be paid to the accurate forecasting of significant, short term, small scale meteorological events (Pielke, 1977). Flash floods now claim more lives than any other meteorological phenomena (American Meteorological Society, 1978); downbursts have been identified as the cause of several serious aviation accidents (Fujita, 1978); and there is a general feeling that, when it comes to tornadoes and hailstorms, "we're doing things the same ways we were in the late 1950's" (personal communication with several operational meterologists).

There have been several advances in technology in the past five years that have been developed to try to change this situation: The National Weather Service's Digital Radar Experiment (D/RADEX), soon to evolve into Radar Data Processor (RADAP); Doppler Radar; and GOES high resolution satellite photographs. Each of these systems has had its share of promises, successes, and a few failures dealing with severe local storms. For background into D/RADEX and GOES and how they have performed in flash flood situations, see Weigel (1972), National Weather Service (1977a) and National Weather Service (1977b).

The purpose of this paper is to describe a time-lapse radar system that, when its cost is compared to D/RADEX or Doppler radar is quite inexpensive, reliable, and simple to use, and assists the meteorologist in making superior mesoscale forecasts.

2. THE SYSTEM

In April of 1975, the Kansas State Network installed an Enterprise Electronics WSR-74C radar. At that time KSN used a black and white WR-100 radar repeater scope to put the radar on the air for our viewers. The limitations of black and white radar for television display are well known. In August of 1976, KSN added a Technology Service Corporation/Development Laboratories WRT-75 colorizer/scan converter. The WRT-75 converts the radar images into a television picture that does not fade. It displays storm intensities in four colors: blue for the weakest echo; green for VIP 2; yellow for VIP 3 to 5.1; and red for VIP 5.2+. Because the converted radar images are constantly bright, time lapsing became feasible. In June, 1978, an Arvin/Echo videodiscassette frame storer was installed. A frame storer records one frame of a television picture at a time, similar to a single photograph taken by a still camera. The frame storer can then play back the frames at any speed, forward or reverse. This produces a time-lapse effect, similar to running the frames of a movie film through a projector. The medium for recording is a magnetic disc, somewhat similar to a phonograph record. There is no chemical development as with film and the images are ready to be replayed as soon as they are recorded. The recordings can be made on the 25, 50, 125, or 250 nm ranges, whichever is appropriate and the interval for recording frames is on the order of one to three minutes. An electronic clock automatically imprints the time on each frame.

3. APPLICATIONS

a. Storm Movement

The conventional way of determining precipitation movement is to make radar scope tracings at one-hour or 30-minute intervals and comparing the movement between observations. In some situations, this is perfectly adequate. But there are many cases when storms develop near strong vorticity maxima, in areas of strong upper level wind diffluence, or immediately ahead of or behind short wave troughs. In these cases, "differential movements" - invdividual storms moving in radically different ways within the same storm field - can occur. These movements tend to be smoothed severely when observed at intervals of 30 minutes or more. The time lapse radar can constantly chart the positions of echoes, making precise movement determinations possible. By extrapolation, excellent short term forecasts of the beginning and ending of precipitation at a given point can be made. Another advantage is that ground clutter is minimized as the colored echoes can be seen moving through the ground clutter area.

b. Flash Floods

The rainfall patterns associated with flash floods are fairly well known. They are: 1) Stationary or very slow moving cell or cluster of cells causing excessive rain in a small geographical area (example - the Russell County, Kansas flash flood of 1977 - see Smith (1977)); 2) Cells in a line of thunderstorms moving parallel to the line's orientation (Enid, Oklahoma, 1973 (Merritt, et. al., 1974) or Kansas City, 1977 (NWS, 1977b)); 3) Excessive rain primarily induced by orographic effects (Hurricane Agnes, 1969 (State Climatologists, 1972)). Certain flash floods will be a combination of the three types listed above (Big Thompson Canyon was a combination of types #2 and #3 (Maddox, et. al., 1977). While these patterns are well known, recognizing them during the frantic pace of an operational weather office during severe weather can be quite difficult (NWS, 1977a).

There have been four cases of excessive rainfall in our area of interest since the radar time lapse system was installed (see Table 1). In three of the four cases, analysis of the time lapse radar allowed very accurate determinations of the area of heaviest rains to be made. The July 6th case, which occurred in Sumner County, Kansas, was a situation where severe thunderstorms were occurring in the City of Wichita (over and just east of the radar site); at the same time much of the rain was falling 30 to 40 miles to the south. When a viewer in Sumner County called the KSN weather department with a four inch rain report, we immediately realized that attenuation was a problem.[1] We then reviewed the time lapse in light of the attenuation problem and saw that the report of heavy rains in Sumner County was probably valid. We alerted the National Weather Service office in Wichita. Rain totals of up to 6.5" actually occurred, a flash flood warning was issued, but no significant flooding was reported. There is no doubt that attenuation by heavy precipitation is the most significant problem that this system has.

c. Severe Thunderstorms

The radar time lapse system can be of great value in short term forecasting of severe thunderstorms <u>when used with conventional techniques</u> (Mogil and Groper, 1977). The time lapse system makes right and left moving thunderstorms very easy to detect. Fujita (1978) has shown that strong thunderstorm generated winds (downbursts) can occur with "bowed echoes" that move quickly and go through a recognizable life cycle. The bowed echo cycle as well as the evolution of "spearhead" echoes can be observed on the system. The author has observed that rapidly collapsing thunderstorms (especially on very warm days) are candidates to produce strong winds. The dissipation process has been observed several times with strong winds (June 17 - eastern Sedgwick County; July 6 - eastern Sedgwick County; and September 5 - southeast Sedgwick County). However, it should be noted that the winds begin to occur very shortly after the dissipation process begins. Since there is a lag between the beginning of the dissipation process and the recognition of it in the time lapse display, it is likely that the winds have already begun by the time a warning could be issued. There would still be some warning value for areas "downwind."

d. Tornadoes

This is possibly the most exciting aspect of the radar time lapse system. The problems associated with radar tornado warnings are well known - the "hook" echo does not form in time for a warning to be issued in some cases, and in others, a false hook can form which will cause a false tornado warning. The author used a black and white time lapse radar system when employed by WKY (now KTVY) TV in Oklahoma City from 1971 to 1975. The black and white system proved to be quite effective at locating cyclonically swirling hook-shaped echoes - a sign that the hook was indeed associated with a mesoscale circulation and was genuine. Unfortunately, since colorized radar displays were unavailable at that time, the WKY time lapse system allowed little information to be gathered on the storm's internal-reflectivity structure.

The color time-lapse system allows the detection and recognition of cyclonically rotating hooks, but it also reveals much about the parent storm's reflectivity structure. From the tornadoes that have occurred since the system was installed, it is possible to infer the following characteristics about tornado producing thunderstorms:

1. Rotation can occur in three ways:
   a. Cyclonically rotating hook
   b. Right rear thunderstorm quadrant rotating as a whole
   c. Entire thunderstorm rotating
2. In the case of a. or b. above, at least part of the hook or rotating quadrant will be of at least VIP 3 intensity. On the radar's PPI, the

[1] 5-cm wavelength "C" band radar is subject to significant signal attenuation when moderate to heavy rains are occurring at or near the radar site. This is not a problem with 10 cm, "S" band radars like the WSR-57.

TABLE 1. EXCESSIVE RAIN OBSERVATIONS

Date	Location and Amount	Remarks
7/06	Sumner County, up to 6.5"	Attenuation, not recognized.
7/21	North Central Kansas, up to 4.4"	Recognized, estimated maximum amount of "4 to 6 inches"
8/27	Sumner and Harper Counties	Recognized, estimated position of maximum amount was SW Sumner County and actual location was SE Harper County. Estimated "3+ inches actual 3.25 inches" at Bluff City.
9/21	Great Bend	Recognized that heavy would occur in City. Up to 3.5" which caused street flooding.

hook should be "substantial" and survive some attenuation.

3. The reflectivity contours will have a cyclonic curvature as suggested by Fujita (1973), except in type c.

Because of the integration process used by the colorizer/scan converter, there may be times when a hook is visible on the radar's PPI, but is not readily apparent on the colorized display. This is due to two effects: smoothing in the integration, and the colors not exactly corresponding to the gray shades of the PPI. The latter problem is one strictly of interpretation and with experience can be easily overcome.

4. EFFECTIVENESS

How effective has the system been at detecting tornadoes? Table 2 is a list of significant occurrences since the system was installed. Our area of interest is Kansas sections of our viewing area (we have not gathered data in any other area) within roughly 80 nm (there is one case that was detected beyond this range).

The summary of results is:

5 tornadoes; 3 detected, 1 detected after fact, 1 questionable

5 funnel clouds; 2 detected, 1 questionable, 2 not detected

3 visual reports questioned upon receipt due to lack of rotation. No tornado actually occurred in these cases.

1 possible false alarm. No reports of a tornado or funnel, but there was a delayed report of a power line break.

It could certainly be argued that there have not been enough cases to show conclusively that this system is superior to conventional radar. But in the cases that have occurred, the tornadoes have been detected 80% of the time (including the Augusta storm), three false alarms of tornadoes were correctly anticipated, and there would have been only one false alarm (assuming that the powerline break was not associated with a tornado) initiated by the use of the system out of literally hundreds of non-tornadic thunderstorms observed. There seems to be considerable potential for this system to increase the accuracy of tornado warnings significantly.

5. CONCLUSIONS

It should be emphasized that the interpretation of the time lapse presentation is subjective and there seems to be no practical way to automate the detection of rotation. The radar operator must be trained to interpret the display and have time to do so. In both cases where rotation was detected after the fact, other severe storms were occurring simultaneously which required the operator's attention. We are now aware of the need to examine every storm with great care. Objective determination of rotation is one significant advantage expected of Doppler radar.

It is very difficult to determine a cost/benefit ratio for this system. The colorizer/scan converter and the frame storer can be purchased for $35,000 to $40,000 and adapted to most any radar (of course, the better the quality of the radar, the better the quality of the time lapse images). D/RADEX cost roughly $37,000 per unit (personal communication with Carlos Garza, National Weather Service) and provides estimation of rainfall amounts. It has no tornado warning capability and specific storm movement capability. The cost of RADAP is expectd to be "slightly more" than D/RADEX, but cost is still very much an unknown with RADAP as the bids have not been received. The cost of Doppler radar is also unknown, but estimated to be on the order of $500,000 for the complete Doppler radar unit (personal communication with Don Burgess, National Severe Storms Laboratory). Doppler will provide tornado warning and wind shear warning capability and there is some indication (communication with Burgess) that it will have some utility in estimating rainfall. RADAP and Doppler will be available 3 to 7 years in the future operationally; time-lapse is available now.

While a detailed cost benefit analysis is not practical at this time, it seems clear that colorized, time-lapse radar can contribute significantly to mesoscale forecasting of all types and the cost is quite reasonable in view of the benefits.

TABLE 2. TORNADO OCCURRENCES

Date	Occurrence	Remarks
6/17	Tornado near Matfield Green	Detected
6/17	Tornado, north Augusta	Detected after fact
6/21	Tornado 2 N Greensburg	Detected
6/27	Funnel clouds and Leigh and McPherson (same parent storm)	Questionable detection
7/06	Tornado reported near Wellington, no tornado actually occurred	Questioned, no rotation
7/14	Tornado reported NW of Wichita, no tornado actually occurred	Questioned, no rotation
8/01	Two funnels (same storm) NE of McPherson	Detected
8/02	Brief funnel Sedgwick-Butler County line with dissipating t-storm	Not detected
8/14	Collar cloud and funnel cloud, eastern Ness County	Detected
9/12	Small funnel, 12 S. Rush Center	Not detected
9/13	1 tornado, 3 funnel clouds, Cowley County (same storm)	Detected
9/13	Tornado at Leon	Questionable detection after fact
9/17	2 reports of tornadoes in Butler County, no tornadoes occurred	Questioned at time, no rotation observed

"Questionable detection" indicates that there was brief evidence of rotation, but the evidence was inconclusive and a warning probably would not have been issued on this alone, but it would have reinforced a visual report.

"Detected after fact" means rotation was seen in post storm review, but was not detected at the time.

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correction

Dear Editor:

In my paper in Vol. 2, No. 1 of the National Weather Digest, a correction was made in the manuscript before it went to print to reduce the coefficients in the last two equations by one order of magnitude. Equation (9) was changed correctly. However, in the last equation, the coefficient originally read $1.7\text{x}10^3$. This was changed to $170\text{x}10^3$. In other words, the expression $\text{x}10^3$ was inadvertently left in. The correct equation on page 9, Vol. 2, No. 1, February 1977, should read:

$$I = -170\,\nabla\cdot\mathbf{V}_S\,\rho_O(x_0 - x_1)$$

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