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Subject: Technical Letter 28 May 1982
Operational Detection of Severe Storms with Radar.

Detection of various types of severe weather (thunderstroms, hail, tornadoes, and heavy rains) have been studied using our weather radars. We have collected data intermittently for 30 years in southern, central, and northern Illinois. Key findings are summarized in this letter.

Echo Heights

The probabilities of severe weather were determined as a function of the maximum cloud type height observed by our weather radars. The probabilities are based on data collected during March through August 1971-1973, and in a 25,000 mi^2 (66,000 km^2) area in central Illinois.

The probability of a particular type of severe weather with an echo can be ascertained from the attached figure in the following manner[1]. First, determine the maximum echo height observed. Use this number on the abscissa, and move upward on the graph until the line of interest is intersected. The probability can then be found on the ordinate scale on the left. For example, if the maximum echo top is 40,000 ft, the probability of having hail is 40%; whereas the probability of a tornado is only 6% at this height.

One important level in echo top heights for 'very severe' weather events is 50,000 ft (15.2 km). Above 50,000 ft, the probability of occurrence of the most severe weather types increases rapidly. This has great importance in forecasting and detection of the presence of severe storms. The table below is based on the tallest echo in the central Illinois study area on days when rain occurred.

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(1) Note the following definitions:

a) 'Severe hail' was defined as a day on which 10% or more of the weather observers of the National Weather Service reported hail in central Illinois and when crop losses exceeded $100,000. About 15% of the total days with hail met this criterion. These severe hail days included most of the annual hail damage in central Illinois.

b) 'Severe thunder' was defined 1) when 70% or more of the weather observers reported thunderstorms, and 2) when damaging lightning occurred. These were 5% of the total thunder days.

PERCENT OF RAIN DAYS IN CENTRAL ILLINOIS WITH TALL ECHOES

	Maximum echo top height, feet, somewhere over area				
	≥60,000	*≥55,000*	*≥50,000*	*≥45,000*	*≥40,000*
Spring(1)	0	1	3	8	12
Summer(2)	3	10	30	47	62

(1) Spring = March, April, and May
(2) Summer = June, July, and August

One application of this information has been to planned weather modification operations. The percent of cloud seeding opportunities (days with rain) which would be missed by not seeding on days with echo tops observed (or correctly forecasted) to be equal to or greater than a given height can be determined in the above table. For example, a decision to not seed clouds on days with a maximum echo ≥50,000 ft would exclude 16% of all spring and summer rain days.

Shapes of Echoes

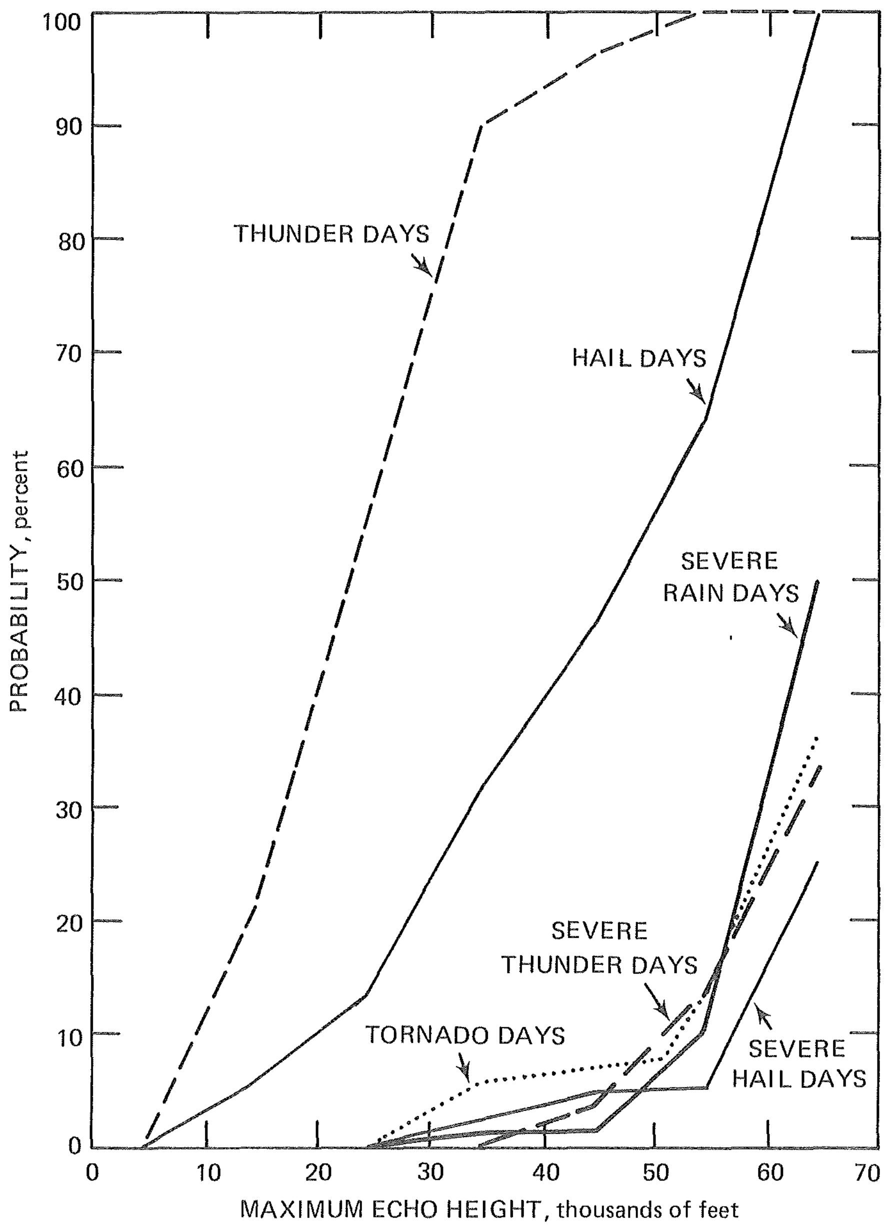
Water Survey scientists were the first (1953) to discover that a tornado attached to a thunderstorm north of our radar was associated with a hook-shaped echo. Further studies showed that sometimes the hook appeared, or was detectable by radar, with tornadoes. However, often (78% of the time) tornadoes occurred without appearance of the hook; hence it is not a very useful indicator.

In other studies we sometimes have noted odd shaped echoes (wing shaped, or U shaped) associated with storms producing severe weather. These odd shaped echoes often resulted from the merger (joining together) of two echoes. This merging often resulted in heavy rain rates within minutes and occasionally the release of hail and damaging winds.

Echo Growth and Behavior

Water Survey studies of hail-producing storms and non-hail thunderstorms have provided other useful indications of the unique behavior of severe storms, as reflected in hail and strong wind production. Most severe rainstorms in Illinois and tornadic storms are also hailstorms; hence information about characteristics of hail-producing echoes is useful in the radar detection of "severe storms" in an area.

All possible echo characteristics were studied from the inception of the storm, called the "first echo," until its termination. The data came from radar operations during 1967-1974 in central and southern Illinois.



Daily severe weather probabilities as a function of maximum radar echo top heights.

On any given day, the relatively larger (taller) first echoes, including those with a greater depth from the top to their base, and with higher internal reflectivities, have a much greater likelihood of becoming hail-producing thunderstorms. First echoes should be monitored. On days when hail occurs in central Illinois, at least 20% of the taller half of the first echoes become hailstorms, and on 60% of the bad hail days, 70% of the taller first echoes become hailstorms. This is a powerful predictive tool.

Second, all hail-producing storms grow more than 5,000 feet (in their top heights) within 10 minutes after the first echo forms. They all had growth rates in excess of 1,000 feet per minute for at least 5 minutes. This growth rate is a useful predictor of future severe storm echoes (85% of all echoes with this rate became hailstorms).

The magnitude of the reflectivity in the storm aloft <u>alone</u> is not a good indicator of the occurrence of hail or its size. Although high reflectivities are always found in hailstorms, many non-producing thunderstorms also have high reflectivity. All Illinois hailstorms have reflectivities of $\geq 10^5$, but only 20% of all echoes with reflectivities of 10^5 produce hail; hence this is not a unique indicator of hail or severe weather.

We studied the likelihood of hail and severe weather to occur in a given 2000 square mile area. We found that the heights of approaching echoes which existed beyond (usually west) the area an hour before the hail provided important forecast information. If one or more of these echoes had tops of 40,000 feet or higher, and motion indicated arrival in the area about one hour later, there would be hail in the area in 80% of the cases. Echo top height of approaching echoes is a good predictor of the future occurrence of hail in a specific region.

Another useful finding is that 92% of all echoes with more than 2/3 of their volume (as defined by reflectivity of $10^{4.5}$ located above -5°C level) are hail producers. Another finding is that hail and heavy rain rates at the surface typically (75%) occur 10 minutes after a major increase in the volume of echo above the -5°C level. This rapid volumetric growth is 15 cubic miles for the reflectivity volume of 10^4.

Where hail actually occurs within a thunderstorm is not easily detected with standard weather radars. However, our studies indicated that most hail fell in the steep reflectivity gradients of thunderstorms, with 70% of the hail in the front edge of this storm core. All studies of tornadic echoes indicated the funnel was somewhere on the right side (usually south) of the echo.

The average difference in echo top heights between hail-producing thunderstorms and non-hail storms was 7,000 feet in the spring months of March-May, with 11,000 foot difference in summer months. Typically, echoes of thunderstorms on a given day show two classes of heights. Once noted, it serves as a generally useful predictor with the taller echoes likely hail producers.

Summary

The above results about how standard radar echo characteristics are related to severe storms indicate that there are several useful ways to use standard radar well before and during storm episodes in an area to help detect the approach of storms to the area, and then to minotor to determine which storms in the area of concern are producing severe weather. Although we have a doppler radar, we have not made similar extensive studies of its ability to uniquely detect tornadic storms or those with high winds.

The use of any type of radar for severe storm detection requires extensive area monitoring and rapid scanning in three dimensions. Considerable attention should be given to first echo dimensions, growth of echoes after formation, shifts in the volumes of the echoes particularly at higher altitudes, zones of higher reflectivities, and the constant monitoring of the echo top. These tasks require a dedicated radar system with signal processing and a computer. They also require radar meteorologists skilled to interpret the complex and rapidly changing echo characteristics.

Publications with Additional Information

1. Illinois Radar Research for Hail Suppression Applications, Report of Investigation 71, Ill. State Water Survey, Champaign.

2. Design of an Experiment to Suppress Hail in Illinois, Bulletin 61, Ill. State Water Survey, Champaign.

3. *Relationships between Severe Weather and Echo Tops in Central Illinois*, Preprint Volume, Tenth Conference on Severe Local Storms, AMS, Boston, 1977.