SUMMER CONVECTIVE CELL RADAR PATTERNS OVER NORTHERN AND CENTRAL CALIFORNIA

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[Manuscript received March 13, 1962; revised June 22, 1962]

ABSTRACT

Previous studies of convective activity over northern and central California were based on data from scattered weather reporting stations. Radar, however, by maintaining a large area under constant surveillance, displays a more complete picture of convective cell formation and patterns. With the installation of the WSR-57 radar in Sacramento, Calif. in early 1960, the opportunity to study the formation and patterns of convective cells over northern and central California was made available. This article summarizes the findings of such a study for the summer months of 1960 and 1961.

1. INTRODUCTION

Until the advent of radar, climatological studies involving the collection of data over thinly populated areas and inaccessible terrain were limited to extrapolation from records of scattered reporting points. Such a method of extrapolation or interpolation has been accepted for such weather elements as temperature, moisture, wind, etc., but is difficult for studies which involve the occurrence or non-occurrence of convective cells. As pointed out by Court [1], "Thunderstorm days cannot be extrapolated very far in space, even in a topographically homogeneous region."

In an area such as northern and central California where reporting points are sparse and where a highly variable topography exists, some other means must be used to contribute toward a more significant climatological relationship. With the installation of the WSR-57 radar at Sacramento, having a range capability that encompasses most of northern and central California, the opportunity presented itself to examine the occurrence of convective cells in considerable detail.

The objective of this study was to observe and summarize in a climatological sense the areal and time distribution of convective cells, as observed by radar, over that portion of northern and central California within radar range. As by-products of the study, relationships between various parameters and the formation of new cells, along with establishment of patterns which might be expected from different synoptic situations were sought. Such data would be of some value to those concerned with forecasting thunderstorms, severe storms, fire weather, fire control, etc.

This study has been in progress for only two summers; therefore, any conclusions which may be drawn from this paper should be viewed with this in mind. The data offered here are not presented as conclusive, but are the findings of the authors at this early stage of development. This is a continuing study and is subject to periodic revision as more data are obtained.

2. THE RADAR

In order to understand better the data presented in this report, it is important that the detection capabilities of the radar are clearly understood.

The WSR-57 [2] is a 10-cm. radar with a maximum range of 250 n. mi. The radar operates at a peak transmitted power of 500 kw. and has a minimum detectable signal of approximately 10^{-14} watts. The 10-cm. wavelength is such that negligible attenuation results from precipitation or other hydrometeors.

The system was designed to detect only water droplets of precipitable size, thereby eliminating unwanted cloud formations which would obscure the rain patterns. The very high sensitivity of the receiver does result in the detection of some "wet" cloud formations at very close range, but these are readily distinguishable from precipitation.

Since electromagnetic energy propagation is essentially line of sight, the range at which a cell can be detected is a function of the cell's vertical development and the scanning elevation angle of the radar antenna, the latter being dictated by the location of the antenna with respect to the surrounding terrain. Reference will be made to this distance as the optimum range of detection, with the implication that all cells which occur within this range will be seen by the radar.

In Sacramento the optimum range of detection of summer convective cells is 150 n. mi.; this paper will deal only with cell formation within this range. Of course, many cells have been detected beyond this range, even to 250 n. mi., but it must be assumed that many of the smaller cells, with vertical development under 20,000 ft., for example, elude detection because the radar beam passes above the target or is blocked by surrounding terrain. As the energy propagation is approximately line of sight, and the surface of the earth curves away from the beam with increasing range, the result is an apparent increase in height with distance. For example, at a range of 100 n. mi. from the antenna at 0° tilt, the center of the beam is at approximately 6700 ft. and at 150 n. mi. the midpoint of the beam is at 14,900 ft., disregarding atmospheric refraction, which, of course, would alter these figures. This phenomenon is called "overshooting."

Although data have been compiled for ranges exceeding 150 n. mi. only the data for the area encompassed by the 150-n. mi. range circle can be considered accurate.

The WSR-57 radar was designed to scan vertically as well as horizontally, thus permitting observation of the vertical profile of the convective cells. However, technical limitations restrict the Range Height Indicator to a range of 100 n. mi.; therefore, all data pertaining to convective cell heights are confined to cells which were observed within 100 n. mi. of Sacramento.

3. METHOD OF DATA COLLECTION

The use of time lapse film would, ordinarily, prove to be an invaluable aid in the collection of data for this type of study. Unfortunately, the time lapse film fails to show most of the cells through the ground clutter resulting from the rugged terrain of the Sierra Nevada and therefore could not be used.

The data gathered for this study were extracted from the radar presentations at the time of occurrence. Needless to say, this required an almost continuous watch of the radar scopes in order to detect the new cells as they appeared. What appeared to be a monumental task was greatly facilitated, however, by the reflection plotter, which allows the outlining of cells on the face of the PPI scope, and the use of plastic overlays on the PPI scope. Frequent observations were required to avoid counting any one cell more than once. During unusually heavy outbreaks the observations were only a few minutes apart. Obviously a system of this kind is going to result in some cells being missed or counted more than once; however, extreme care was taken and it is the opinion of the authors that the resulting error from this system is a very small percentage of the total.

A log was kept of the formation of new cells as they appeared on the radar scope for the period June 1 through August 31. In addition to the location by azimuth and range, the intensity, movement, top elevation (if within 100 n. mi.), and the time were logged.

Because of limited time, no attempt was made to follow the development of any individual cells beyond their initial appearance. All data presented apply to individual cells of convective origin at the time they became active showers or contained precipitable-sized water droplets. Certainly, any active convective shower is a potential thunderstorm, but how many of these convective showers

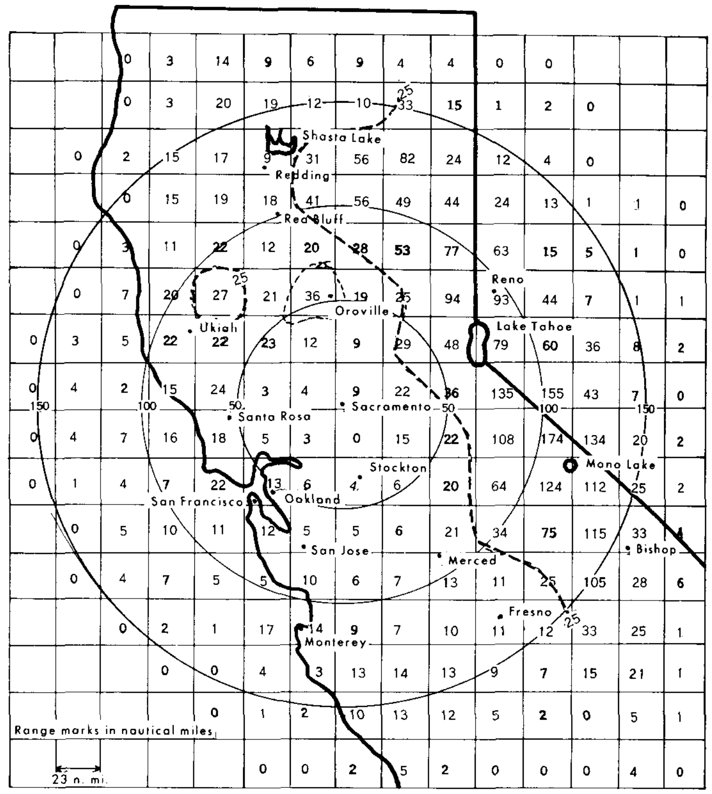

Figure 1.—Analysis of total number of occurrences of convective cell radar echoes in June, July, and August 1960 and 1961, within 150 n. mi. of Sacramento. Dashed line shows 25 occurrences.

actually developed into mature thunderstorms is not known. Coordination with the State of California Division of Forestry Fire Control Officer resulted in verification of many of the cells as mature thunderstorms. It is believed that convective showers may be an index to thunderstorm activity, particularly over mountainous terrain. Data collected thus far are inconclusive. However, efforts are continuing along these lines to obtain more data for study.

4. AREAL DISTRIBUTION OF CONVECTIVE CELLS

The total number of convective cells observed during the study period, June through August, 1960 and 1961, was 4,020 (1,391 during the 1960 season and 2,629 during the 1961 season). Figure 1 shows the areal distribution of cells. The grids are 23 n. mi. on a side and the number within each square denotes the number of convective cells detected within the grid area for the combined years, 1960–61. Because there are only two years of data, totals rather than averages have been tabulated.

The distribution pattern is not particularly unusual, in fact it is quite as one might expect, with the greatest number of cells occurring over the higher ranges of the Sierra Nevada. Secondary maxima occurred just to the north of Lake Tahoe and in the Mt. Lassen area.

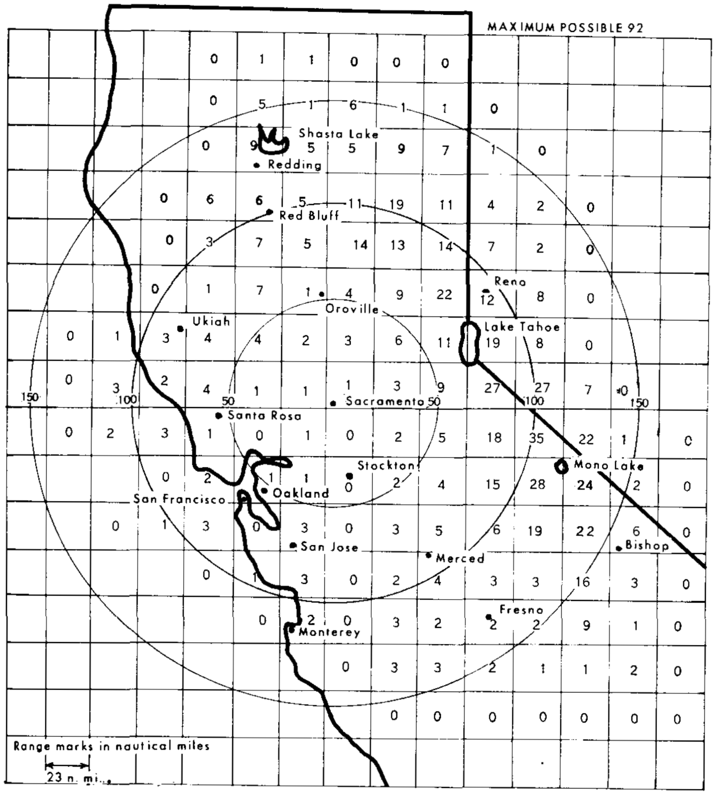

Figure 2.—Number of days convective cell echoes were observed in each grid block, June, July, August 1960. Total number of days in 1960 season was 89.

Relative minimum areas in the Sierra Nevada occurred in the American and Feather River basins, located east of Sacramento and Oroville, respectively. In the latter areas, the ridge lines on the west slope of the Sierra are oriented on a northeast-southwest line, which parallels the southwest flow aloft that is usually conducive to convective cell outbreaks.

In the areas of maximum activity the ridge lines are found to be more on a north-south line, normal to the southwest flow. The minor maximum located in the coastal range to the northeast of Ukiah is, again, situated over one of the highest regions of that range. It is suspected that the Sutter Buttes, a 2,000-ft. knoll, in the otherwise flat lower Sacramento Valley, plays a vital role in the occurrence of the other minor maximum located in the valley near Oroville.

Of note is the fact that the 25 isoline (dashed line on fig. 1) follows the 7,000-ft. contour of the west slope of the Sierra quite closely. A tabulation showed that 86 percent of all cells which formed east of the center line of the Sacramento and San Joaquin Valleys occurred east of the 7,000-ft. contour. Note a marked reduction in numbers beyond the 150-mi. circle. This is due to ranging, blocking, or overshooting as discussed earlier.

Figure 2, with the same grid system as figure 1, shows the number of days out of the possible 92 on which cells were detected in each grid area during the 1960 season. The distribution pattern is strikingly similar to the pattern shown in figure 1. Because of the very large number of cells in 1961, time did not permit the inclusion of those data on figure 2, although it is suspected there would be no significant change to the pattern.

The short-period areal distribution was strictly a function of the synoptic conditions which produced the cells. Two distinct patterns of cell distribution were noted. The first occurred under synoptic conditions characterized by weak gradients aloft, conditional instability, and no marked large-scale convergence. Under these conditions, cells invariably formed first on the eastern slopes of the Sierra and then over the ridges, the greatest activity being located over the ridges lying normal to the flow aloft. Marked lack of convective activity was noted over the regions where the ridge lines paralleled the flow and no activity at all was noted over the valley and ocean areas. Some of these cells did move out of their source region into valley sections, but this report deals just with the formation areas.

The second distribution pattern was that associated with broad-scale convergence over the entire area. This usually resulted from the passage of a short-wave trough or the presence of a cold Low over northern California or just offshore. The air masses associated with these were by far the more prolific cell producers. Under these conditions, the terrain no longer played the major role in triggering convection. Cells formed over valleys, ocean areas, and mountains alike. Small groups of cells often formed in areas and lines and moved through the larger echo area. There was an inclination for echo propagation on the back edge and dissipation on the forward edge of these areas.

5. TIME DISTRIBUTION OF CONVECTIVE CELLS

During the 1960 season echoes were observed on 52 of the possible 89 days and in 1961 cells were observed on 54 of 92 days. It seems significant that even though there were nearly twice as many cells detected in 1961, the number of days on which cells were observed compares very closely. Figures 3 and 4 show the daily fluctuations of cells for 1960 and 1961. The graph for 1960 shows that there was generally a gradual buildup to a maximum with a more abrupt decrease as compared to a more random fluctuation for 1961. In light of the data from both years, it seems as though there are no outstanding features in the daily fluctuation of the number of cells.

The greatest number of cells on any one day in 1960 was 92, and these occurred as a result of a rather strong, sustained flow of moist air from the south. This circulation produced 16 consecutive days with cells, the maximum occurring on the 13th day and then a rapid falling off to no echoes three days later. The most observed on any one day during the 1961 season was 216 on August 21. Again the flow was southerly and moist, as a result of a deepening trough just off the coast of northern California. This

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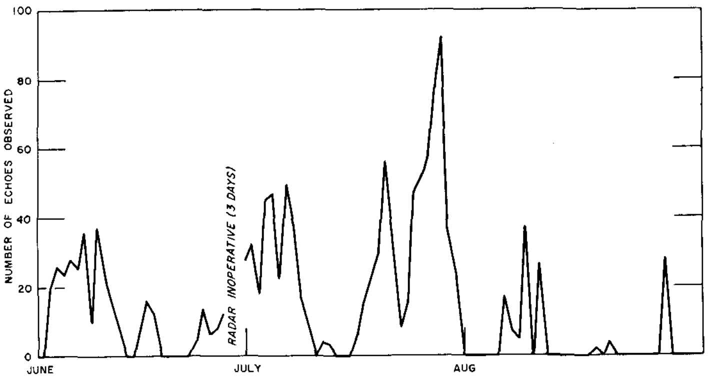

FIGURE 3.—Daily fluctuation in number of convective cell echoes in 1960 season.

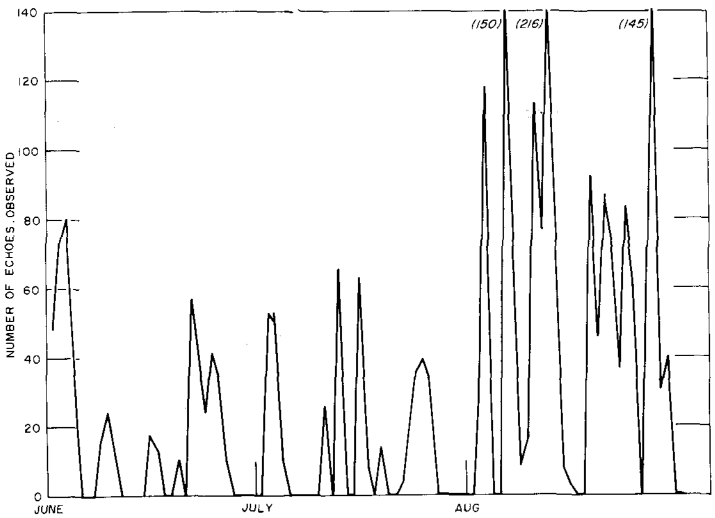

FIGURE 4.—Daily fluctuation in number of convective cell echoes in 1961 season.

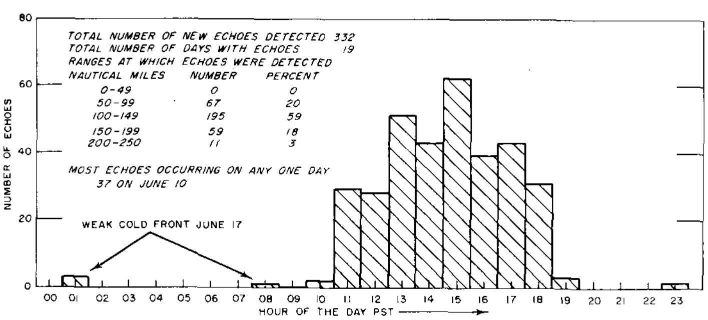

FIGURE 5.—Diurnal echo distribution, June 1960

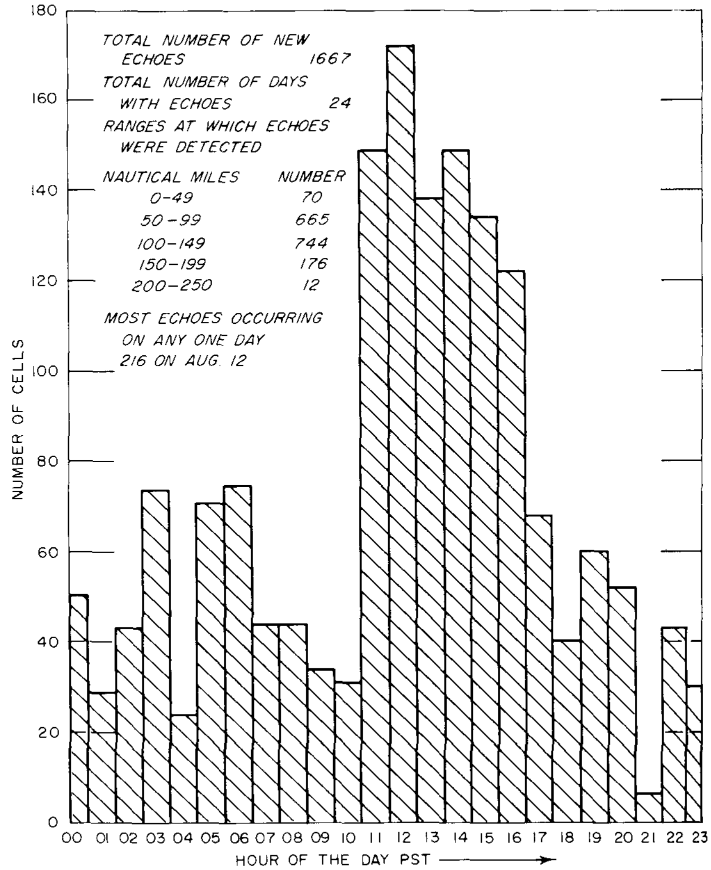

FIGURE 6.—Diurnal echo distribution, August 1961.

maximum also occurred near the end of a rather long period of cell activity which lasted 14 days. A short-wave trough moved across northern California on August 7, producing 150 new cells in the radar area, and then was followed by the deepening of another trough just offshore. This trough continued to deepen and became a closed Low at 500 mb. by August 12, when the maximum convective activity was observed. The trough then began to move north-northeastward and fill, with the convective cell activity dropping to zero three days later.

Diurnal variations of convective cells must be divided into two categories: (1) the variations associated with large-scale convergence, and (2) those associated with conditional instability. The time distribution for the month of June 1960 (fig. 5) best typifies conditional instability situations. Cells began forming at about 10 a. m., usually on the eastern slopes of the Sierra, where solar heating has its greatest effect earliest in the day. There was a general increase in new cells as other areas began heating, reaching a maximum at 1500 PST, then dropping off gradually to no new cells by 2000 PST. Figure 6, although it summarizes both types of synoptic situations, does show the effects of the broad-scale convergence pattern. Over 50 percent of the cells observed during this month resulted from the convergence pattern. Notice the high incidence of new cell formation during the night and early morning hours. Figure 7 is a summary of the diurnal variations for the entire 6 months of data, showing the maximum occurring at 1500 PST.

6. TOP MEASUREMENTS OF PRECIPITATING CONVECTIVE CELLS

The histogram in figure 8 shows the height of tops of convective echoes, corrected for earth curvature and beam

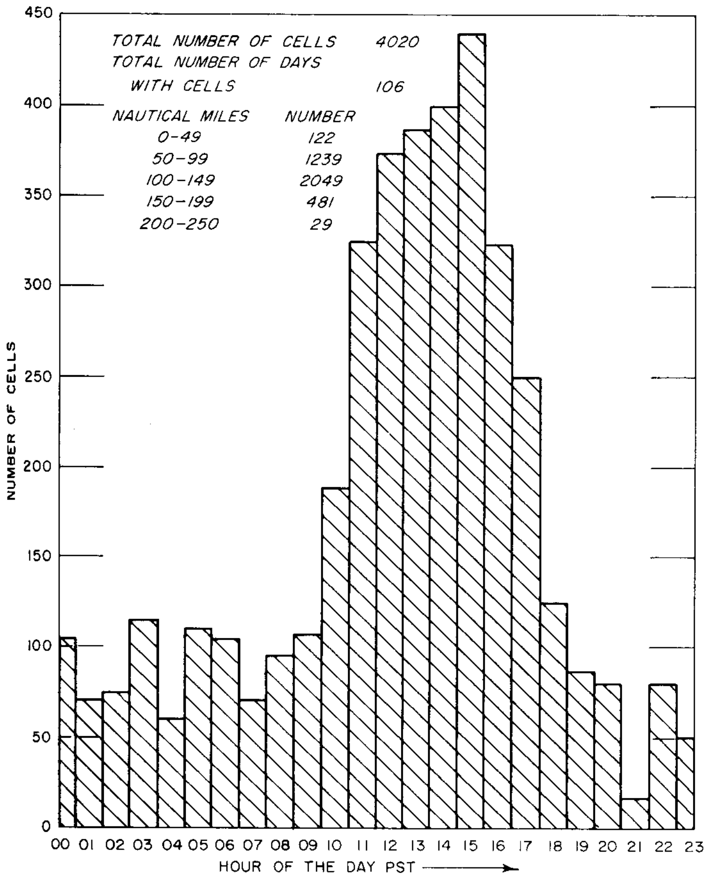

Figure 7.—Diurnal echo distribution June, July, August 1960–61.

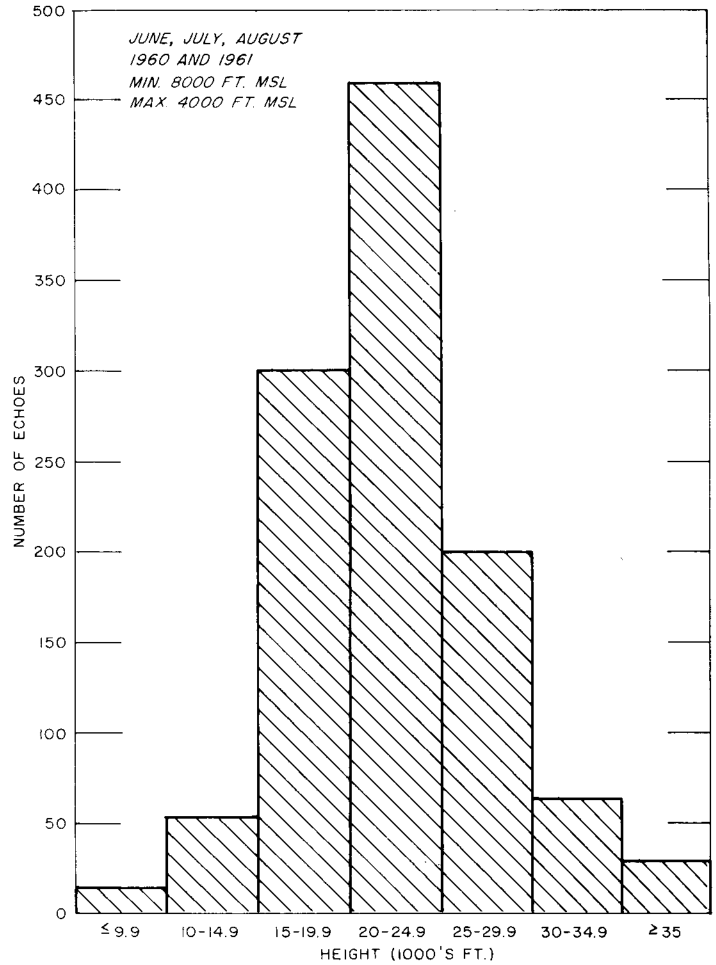

Figure 8.—Distribution and height of tops of echoes at initial detection, 1960–61. The minimum observed was 8,000 ft.; the maximum 40,000 ft.

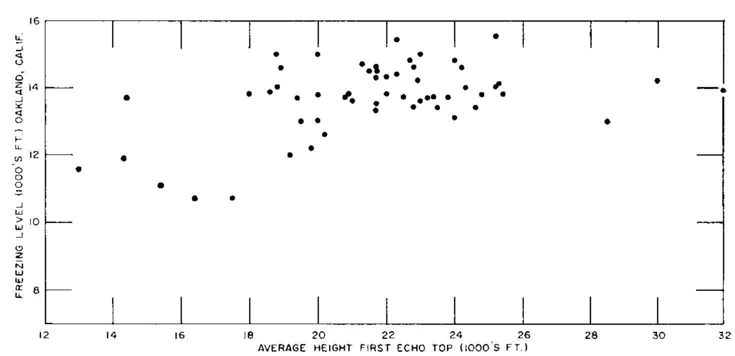

Figure 9.—Freezing level vs. average height of echoes at initial detection.

width, at the time they were first observed by the radar. As stated earlier, the WSR-57 radar theoretically does not detect clouds until they contain precipitable-sized water droplets. It is assumed, therefore, that the height measurements obtained are an index to the vertical development of the cell at the time it began to precipitate, or at least had the potential. A total of 1118 cells were observed within 100 n. mi. of the radar site and permitted top measurement. During the three months of data collected in 1960, 91 percent of the cells had reached the height of 20,000 ft. or more before containing droplets of precipitable size. In 1961, only 55 percent of cells reached 20,000 ft. or higher before containing droplets of the size found in precipitation. The 45 percent of the cells at heights lower than 20,000 ft. in 1961, is about proportional to the number which occurred in connection with broad-scale convergence associated with cold troughs and Lows, as is the 9 percent which occurred in 1960.

Figure 8 shows the combined data for both years. If one assumes that the majority of cells with heights less than 20,000 ft. occurred in association with cold Lows and troughs and the majority of those over 20,000 ft. were the result of orographic and thermal conditions, then the histogram shows the approximate proportionality of occurrence of the two synoptic conditions which produce the majority of convective cells in northern and central California during these months.

Assuming the height of the freezing level would have some influence on cell height at the time the cells became active, a plot was made (fig. 9) using the freezing level at Oakland, Calif., and the average cell height at time of first appearance for each day as ordinates. The resulting scatter is too broad and does not show a good correlation.

This, however, does not belie the fact that the average echo height was lower during broad-scale convergence patterns than with orographic conditions, but rather delegates the proof to a more concerted effort and the subject of still another study.

As stated earlier, convergence conditions were the most prolific producers of cells. However, convergence conditions occurred far less frequently than orographic influence conditions with the result that, for the seasonal picture the orographic influence supplied most of the cells, while convergence patterns supplied the heaviest concentrations at any one given time. Considerable variation was noted in the initial cell top measurements, with a minimum of 8,000 ft. and a maximum of 40,000 ft. Range apparently had little effect on this as both the maximum and minimum values were observed between 95 and 100 mi.

In the Midwest, the difference between echo top and the actual visual cloud top is on the order of 2,000 to 4,000 ft. at first sign of activity. Other studies [3] indicate a difference of as much as 5,000 ft. at time of first echo appearance. Therefore, after adjusting the height measurements obtained to allow for this difference, it was found that the vertical development of the cell before it contained precipitable-sized water droplets was generally above 20,000 ft. in both 1960 and 1961.

7. CONVECTIVE CELL MOVEMENT

Terrain played an important role in the speed and direction of movement of convective cells. Over the higher terrain, cells were observed which showed little or no movement, while elsewhere they showed an erratic or steady movement. Perhaps those which showed little movement resulted from orographic lifting and upstream propagation while others formed and were caught in a general wind flow, thus showing a more steady movement. The movement of cells conformed for the most part to the upper-level wind flow with some erratic motion noted. At times some remained stationary, which may be presumed to have been brought about by orographic processes of building on the upstream side and dissipation on the downstream side.

Passing now to the cyclonic or convergence patterns, we find a marked departure from the patterns due to orographic conditions. As mentioned earlier, lines and areas often formed in association with this type of synoptic condition. The orientation of the lines or areas with a southerly flow was in a north-south direction, usually at the forward edge of the impulse itself. This was evident from the appearance of the lines or areas on the radar scope prior to the actual movement of the trough as shown on the synoptic charts. In fact, there was one instance of an area appearing offshore and moving inland prior to the major perturbation which was well marked by more widespread line and area phenomena. The movement of the areas and lines was generally in the same direction as the broad-scale features which was much slower than the low-level flow. The cells themselves, which made up the lines or areas, followed the low-level wind flow more closely, at times moving four or five times faster than the area with which they were associated. By plotting the successive positions of the lines and areas, a definite pivoting action was noted in some cases. The northern portion would move in a west or northwesterly direction while the southern portion would move eastward or toward the northeast. There was a definite cyclonic movement when the area or line is considered as a whole. Considering the 250 n. mi. radius scanning of the radar, one can see the meso-scale phenomena with which radar is associated, especially with respect to picking up such small-scale convergence zones.

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2. V. D. Rockney, "The WSR-57 Radar," *Proceedings, Seventh Weather Radar Conference, Miami Beach, Fla., Nov. 1958*, American Meteorological Society, 1958, Sec. F, pp. 14–20.
3. R. Wexler, "Radar Echoes from a Growing Thunderstorm," *Journal of Meteorology*, vol. 10, No. 4, Aug. 1953, pp. 285–290.