NOAA Technical Memorandum ERL ARL-58

U.S. DEPARTMENT OF COMMERCE
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Environmental Research Laboratories

SUMMERTIME RADAR ECHO DISTRIBUTIONS OF MOIST CONVECTION OVER SOUTHERN NEVADA AND ADJACENT AREAS FOR 1971 AND 1972

Darryl Randerson

Air Resources Laboratory
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Two warm seasons of hourly radar echo activity are used to develop a preliminary climatological picture of the spatial and temporal distributions of moist convection over southern Nevada and adjacent areas. The echo distributions are adjusted for the probability of radar detection of surface precipitation. Results of the analysis quantitatively portray the enhancement of echo activity by mountainous terrain. During daylight hours, the high mountainous areas are shown to receive approximately 2 to 3 times more echo activity than the desert valleys and roughly 5 times more activity between midnight and 0700 LST. Spatial variations in echo activity are compared with different categories of K-index and precipitable water. The results suggest that by relating the spatial distribution of echoes to these stability parameters, measured from a single station, quantitative estimates can be made of the spatial variability of echo activity over a rather large area. In addition, local variations in radar echo activity are related to the 500-mb wind directions measured from a rawinsonde station located in the center of the area of analysis. Results show a strong dependency of echo activity for flow with an easterly component.

1. Introduction

With the population of the desert regions of the southwestern United States continuing to expand, the impact of summertime thunderstorms on people, property, and recreational facilities is quite likely to increase. Evidence of this trend is provided by information tabulated in Table 1. To compound the evolving problem, there has been little documentation of the behavior and of the spatial and temporal distributions of these thunderstorms. Only recent studies, such as those by Hales, (1972a, 1974, 1975), by Idso, *et. al.* (1972), and by Brenner (1973), have provided some information concerning the kinematics of the southwestern desert thunderstorms.

Through the analysis of weather data, Sakamoto (1972) was able to determine the frequency of occurrence of thunderstorms and hail days for five Nevada communities.

Although radar-echo data are available, there has been limited analysis of these data to provide information on the distributions of thunderstorms; especially over the heavily populated areas of southern Nevada and over the sparsely inhabited adjacent regions shown in Fig. 1. Knowledge of thunderstorm behavior over these sparsely populated areas is important because they contain many national parks, such as, the Lake Mead National Recreational Area, Death Valley National Monument, the Pahranagat Lake Wildlife Refuge, several national forests, numerous state parks, the Energy Research and Development Administration's (ERDA) Nevada Test Site (NTS), and several Air Force test and gunnery ranges. All these facilities are vulnerable to the inclement weather that can accompany thunderstorms. Total population within the region shown in Fig. 1 is approximately 500,000 inhabitants, not including the millions of tourists that visit the area each year. For example, about 9 million tourists visited Las Vegas, Nevada (LAS), in 1975.

Analysis of hourly, composite radar-echo charts available on the Western Region radar facsimile (RAFAX) network has provided some quantitative information on the spatial and temporal distribution of convective storms over the area defined in Fig. 1. Similar investigations have been completed by others. For example, one of the earliest radar climatological studies was compiled by Benner *et al.* (1962). The authors tabulated echo activity in 43-km squares enclosed within the 280-km range of a WSR-57 radar located in Sacramento, California. All echo data consisted of only initial echo cells developing during the period June through August 1960 and 1961. No attempt was made to follow the development of any individual cells beyond their initial appearance. Results of the echo

TABLE 1. Historical tabulation of some warm season storm damage in the Las Vegas valley and surrounding recreational areas.

Date	Accompanying Weather	Damage Estimate (Dollars)	Comments (Approx. Population)
July 23, 1923	hail, strong winds, flooding, heavy rain, 1.98".	20,000	Most damage to railroad tracks. (5000)
July 10, 1932	flooding	thousands	damage to homes and business houses southeast of Las Vegas. Two deaths in flash flood. (9000)
Aug. 9, 1942	1.75" rain, hail, flooding	thousands	(10,000)
June 13, 1955	hail, flooding	2 million	Water 4-ft deep in some areas. Federal aid granted. (50,000)
July 24,1955	flooding," tornadic winds" *	0.2 million	some individual losses great. (50,000)
Aug. 20, 1957	2.57" rain, flooding	0.5 million	record 24-hr rainfall. (70,000)
Sept.16, 1961	hail, winds est. 80-90 mph	1-2 million	great damage to some hotels and motels. (125,000)
Sept. 4, 1963	1.07" rain, flooding	1 million	$500,000 in damage to a shopping center. (150,000)
June 19, 1967	flooding	minor	1 drowning. (225,000)

Date	Accompanying Weather	Damage Estimate (Dollars)	Comments (Approx. Population)
Sept. 12, 1969	flooding	0.25 million	(250,000)
July 14, 1971	75 mph winds	minor	(275,000)
Aug. 21, 1973	"hurricane-like winds on Lake Mead, 10-ft waves"*	1.5 million	damage to boats great. (300,000)
Sept. 14, 1974	Nelson's Landing disaster** 40 mi south LAS Est. 3.5" rain (Glancy and Harmsen, 1975)	0.5 million	9 lives lost, total destruction to recreational facilities. Numerous boat, trucks and autos lost. Great financial loss confined to a small number of individuals. (325,000)
July 3, 1975	flooding, only .07" rain at McCarran Weather Station. Est. 3.0" west of city (Randerson, 1976)	4.5 million	2 lives lost, approx. 300 autos lost, flood damage to streets, homes and businesses. (350,000)

*quotations are from newspaper accounts

**Report on the flash flood of September 14, 1974, in El Dorado Canyon, NV. Prepared by Western Region Headquarters, National Weather Service, Salt Lake City, Utah, Nov. 74, 20 pp.

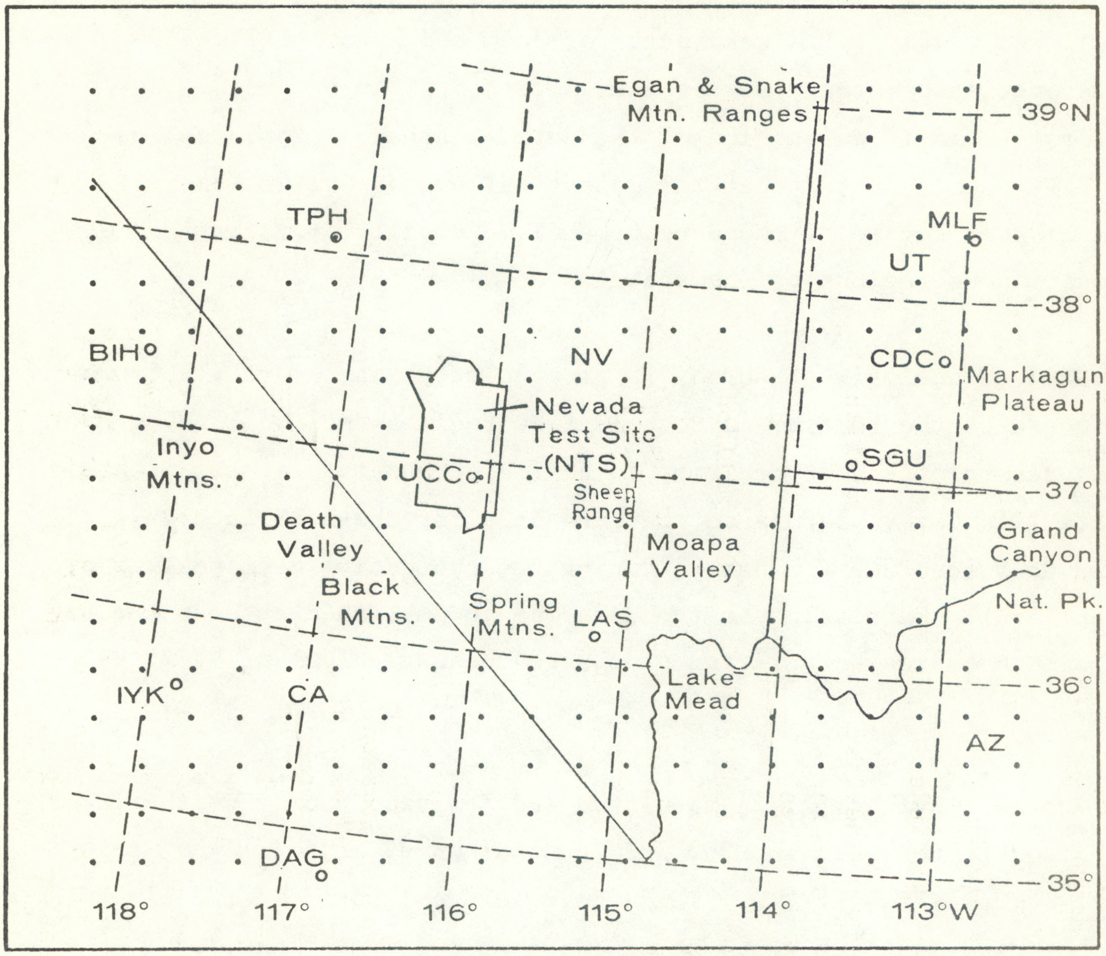

Fig. 1. Area considered in the echo summary for southern Nevada. Each grid point represents the center of a 28 by 28 km box.

summary showed that terrain played an important role in influencing the development of echoes. In addition, the authors observed a pronounced diurnal modulation in the echo activity with maximum echo development occurring during the afternoon between 1200 and 1500 LST.

In a study of thunderstorms in Arizona, Hales (1972b) compiled and analyzed hourly RAFAX echo data for July and August 1971. A gridded overlay of square meshes equivalent to 43 km on a side was used for systematic extraction of the data. Through this investigation, Hales demonstrated that the desert valleys of Arizona tend to have a diurnal regime of thunderstorms diametrically opposite that of the mountainous regions of the state.

Through analysis of hourly radar echo patterns, Myers (1964) was able to assess the role of macroscale flow regimes and local topography on the pattern of shower activity in central Pennsylvania. To create his data file, Myers tabulated the echo data for one-hour intervals, between 0845 and 2245 EDT daily, during the convective warm seasons of 1960 and 1961. Tabulation of the data was accomplished through the use of a gridded overlay consisting of square meshes equivalent to 10 km on a side.

Kuo and Orville (1973) tabulated and analyzed hourly weather radar-echo data detected between 0900 and 2000 LST on 99 days in June, July, and August of 1967 through 1970. These data were collected in the Black Hills region on days in which cloud seeding operations were conducted. A gridded overlay with a 19-km square mesh was used to extract the data. These data were used to determine the spatial and temporal variations in convective activity in the vicinity of the Black Hills. In addition, they related echo occurrences to the direction of the air flow. A primary maximum in echo activity was discovered to occur downwind of topographical ridge lines.

Based on the success of the above studies, the objectives of this investigation are as follow:

1. determine the spatial distribution of radar echoes produced by moist convection over southern Nevada and adjacent areas,
2. document the diurnal variability of the echo activity over the region defined in Fig. 1 and,
3. determine the spatial variation in the frequency of occurrence of echoes as a function of K-index, precipitable water, and wind direction.

2. Area of Analysis

Figure 1 describes the 266,560 km^2 area over which the survey of radar echoes of moist convection was conducted. Notice, the gird is centered at approximately 37°N, 115.5°W and contains variations in terrain (Fig. 2) extending from below sea level (Death Valley) to a few mountain ridges towering to over 10,000 ft above mean sea level (MSL). A small portion of the Sierra Nevada range appears just southwest of Bishop, California (BIH), and the high Markagunt Plateau is evident to the east of Cedar City, Utah (CDC). In general, terrain of low elevation is found in the southwestern quarter of the grid while higher elevations tend to exist in the northern half of the grid. Within the grid, the largest city is Las Vegas, with an increasing metropolitan population of approximately 350,000 inhabitants in 1975. Other communities are identified in Figs. 1 and 2 by a three-letter format.

3. Radar Facilities

Two Air Route Traffic Control Center (ARTCC) radars detect weather-related echoes occurring within the area. Each radar antenna is located on a mountain top. The antenna of the Angel Peak radar (ANG) is situated 8874 ft MSL in the Spring Mountains to the northwest

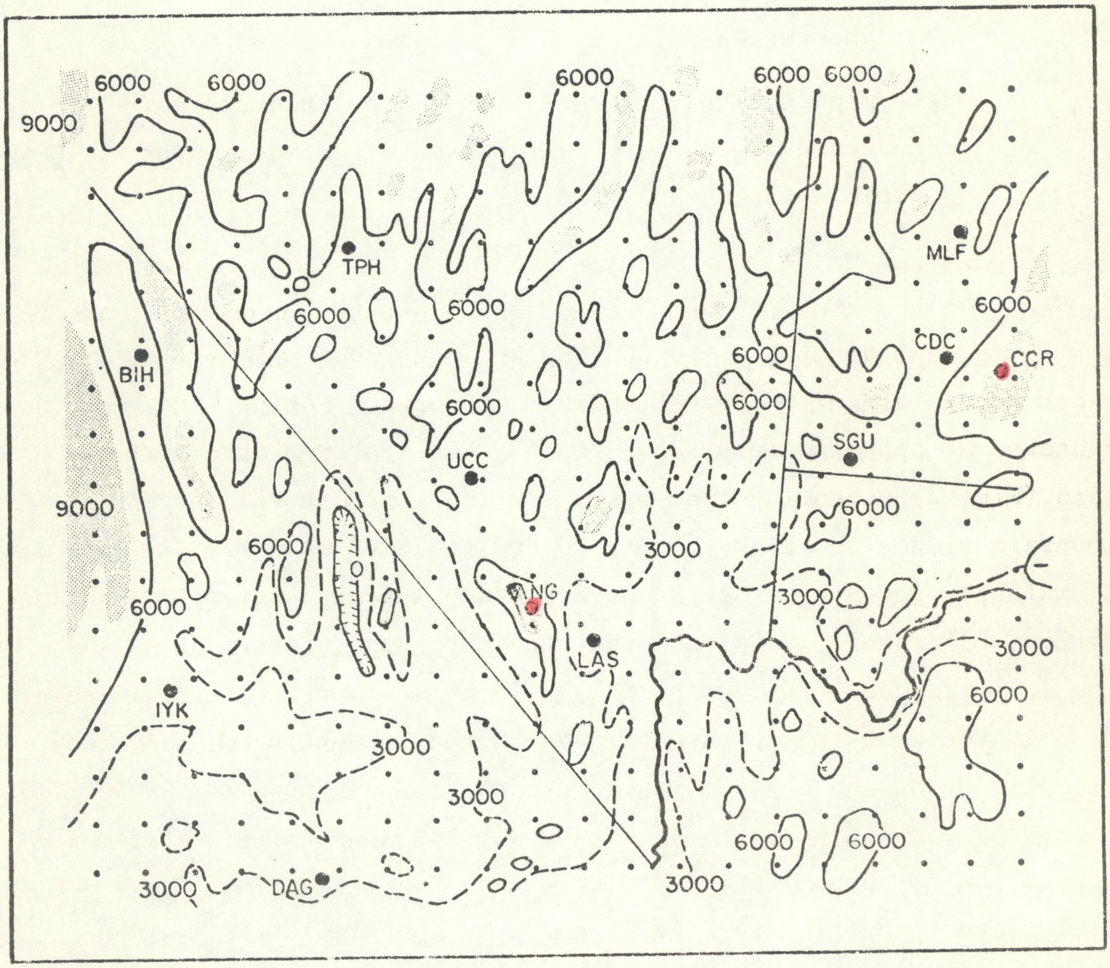

Fig. 2. Generalized topography over the area. The dashed line is the 3000-ft contour, the solid line the 6000-ft contour, and the shaded areas represent elevations above 9000 ft above MSL.

of Las Vegas. The Cedar City radar (CCR) antenna is located at an elevation of 10,754 ft MSL on the high plateau east of Cedar City. With allowance for the curvature of the earth and for normal atmospheric refraction of microwaves, the maximum range of these two radars is about 370 km. Design parameters of both radars are tabulated in Table 2. Weather related echo data are collected every hour on approximately the half hour and transmitted over a RAFAX system 15 min later.

It is essential to emphasize that ARTCC radars were designed and sited to provide the best possible detection of aircraft. Furthermore, these radars are equipped with special circuitry, such as, sensitivity time control and circular polarization to specifically remove most weather related targets. Such design qualities do not provide for optimum detection of precipitation. Despite these limitations, the ARTCC radars are capable of providing much useful weather data.[1] Moreover, Ronne (1971) concluded that some ARTCC radars probably display only moderate or greater precipitation intensities.

High mountainous terrain can restrict the detection of moist convection. Some of the effects of attenuation of the radar signal by terrain are illustrated by Fig. 3 which portrays the percentage probability of radar detection of moist convection associated with surface precipitation during summertime. The figure shows that the probability of detection is quite small along the western edge of the California-Nevada border while it is great over most of southern Nevada and southwestern Utah. These probability data were used to adjust the observed echo distribution to provide a more realistic estimate of echo frequency.

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[1] Benner, H. P., 1965: Evaluation of the operational feasibility of utilizing ARTC radar at Salt Lake City for weather surveillance, Weather Bureau Western Region publication, 31 pp.

Table 2. Design parameters of the Angel Peak (ANG) and Cedar City (CCR) ARTCC radars.

	CCR	ANG
wavelength (cm)	23	23
peak power (mw)	5	3
pulse length μsec)	2	6
min. detectable signal (dbm)	-114	-112
range (km)	370	370

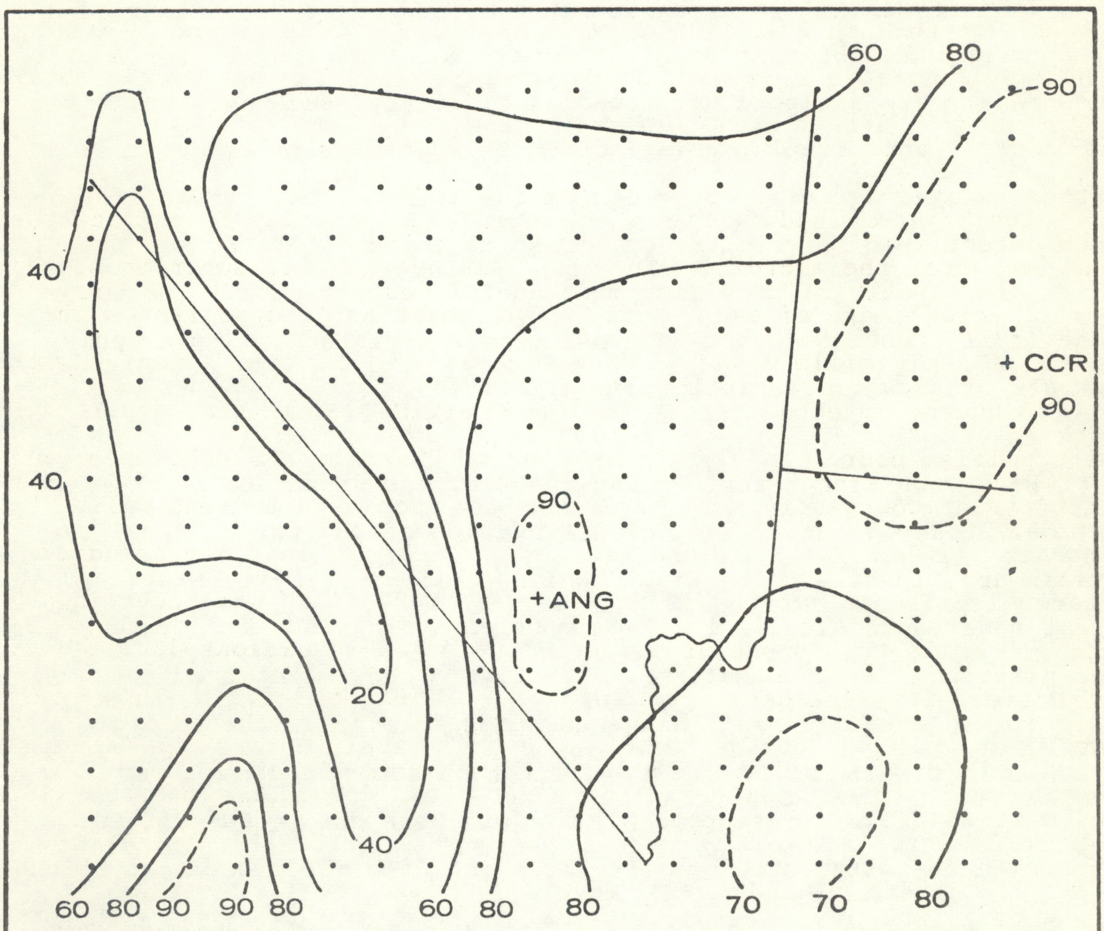


Fig. 3. Percentage probability of radar detection of surface precipitation during summertime (from Western Region Technical Attachment 73-11, dated 3-20-73).

4. Data

In previous developments of radar echo climatologies in the western United States, the echo data have been limited, in general, to daylight hours or to only three summer months. Since digitized radar data were not available, hourly ARTCC radar detections of moist convection were obtained from microfilm records of the Western Region RAFAX transmissions. Only the 1971 and 1972 warm-season hourly RAFAX charts were surveyed. Specifically, hourly radar-echo data were extracted from the microfilm record for two warm periods - 0030 LST, 6 June 1971 through 2330 LST, 29 September 1971 (2784 h) and 0330 LST, 1 June 1972 through 2330 LST, 30 September 1972 (2928 h) - for a total of 238 days or 5712 h of echo data.

The grid defined in Fig. 1 was used as an overlay to extract the echo data from the microfilm record. This overlay was superimposed on the projected image of each hourly RAFAX chart as it appeared on the screen of a microfilm reader. If *any portion* of an echo appeared within a grid square, an echo was counted as occurring within that square during the specified hour. No effort was made to classify the echo according to intensity or to specify what percentage of each grid box was filled by an echo at a given time. Thereby, the echo inventory only consisted of determining if any portion of an echo occurred or did not occur in a grid square. While this procedure reduces subjective decisions during data extraction, it introduces a smoothing error into the data. This error can displace the occurrence of an echo that barely enters the corner of a grid square to the center of the square - an error of almost 20 km in extreme cases.

Several other sources of error occur in specifying the location of the radar echoes. Small position errors probably are introduced at the ARTCC as the echoes are manually transferred to transparent overlays (placed over the radar scopes) and then transferred to composite charts for transmission on the facsimile line. Minor terrain alignment errors were introduced as the topography was transferred from a detailed topographical chart to Fig. 2. Finally, small position errors probably occurred in transferring the echoes from the microfilm reader to the grid array.

In some cases, echoes were described as mostly aloft or partly aloft on the RAFAX charts. These type echoes were retained in a separate array to determine if they contributed significantly to the observed radar echoes. Analysis of these data showed that they contributed less than one percent to the total number of hours of echo activity in each grid square. Consequently, these data were removed from the basic data set.

A computer program was written to read the echo data and to compute the following parameters for the entire period of record:

1. total number of hours of echo appearing in each grid square,
2. average number of hours of echoes per day appearing in each grid square,
3. total number of days of echo appearing in each grid box for each hour of the day, and,
4. a tabulation of the hourly operational status of both the CCR and ANG radars.

Some of these outputs and related calculations are described in this paper.

Information tabulated in Table 3 shows that only 45 observational hours were missing from the entire data set of 5712 h. A survey of the missing data revealed they occurred intermittently on days when no echo activity was detected one hour before or after the missing hour. Consequently, the missing hours were assumed to be echo free. Table 3 also shows that a total of 3550 h were echoless so that for approximately

Operational Status	1971 (hours)	1972 (hours)	Total Hours
ANG not available (NA)	38	259	297
CCR NA	8	42	50
Simultaneously NA	1	1	2
ANG out for maintenance (OM)	0	0	0
CCR OM	0	0	0
ANG Circular polarization (CP)	0	0	0
ANG Sensitivity-time-control (STC)	1	16	17
CCR STC	44	57	101
Simultaneous STC	0	0	0
ANG (MAG)	0	0	0
CCR MAG	1	8	9
Simultaneous MAG	0	0	0
Missing Data	21	24	45
No echoes entire grid	1774	1776	3550

Table 3. Summary of the operational status of the two ARTCC radars that detected the echoes of moist convection within the region shown in Fig. 1.

62 percent of the hours, no weather echoes were detected within the grid area. Moreover, Table 3 indicates that both the ANG and CCR radars seldom operated in modes that would compromise the data.

5. Echo Spatial Distribution

An analysis of the total number of hours of echo activity per 28-km square for both the 1971 and 1972 warm seasons is displayed in Fig. 4. The echo field has been adjusted for detectability by multiplying the total number of hours of detected activity by 100 and then dividing by the corresponding values at each grid point in Fig. 3. Figure 4 shows several distinct areas of maximum activity situated near high terrain. The most active echo area is found in the upper right-hand margin of the figure where 740 h of echo occurred over the high elevations of the Markagunt Plateau. Another maximum (507 h) is visible in the vicinity of Grand Canyon National Park in northern Arizona. Several other maxima appear in the vicinity of some of the larger mountain ranges in Nevada and California. By contrast, an axis of minimum activity extends from over the Colorado River Valley northward over low terrain (Fig. 2) in extreme southern Nevada. Another area of minimum activity appears in the eastern Mojave desert.

By comparing Figs. 2 and 4 it becomes apparent that the regions of maximum echo activity do not correspond precisely with the high terrain. In particular, the echo activity developing over the Spring Mountains appears to occur just to the northwest of the highest terrain while the maxima associated with the Sheep Range materializes on the ridge line, north of the highest terrain. This displacement may be real and may result from the developing convective activity not becoming intense enough for detection until it has moved away from the energy source - - the heated high terrain. Another explanation may be found in the artificially induced errors or in errors in the detectability field (Fig. 3).

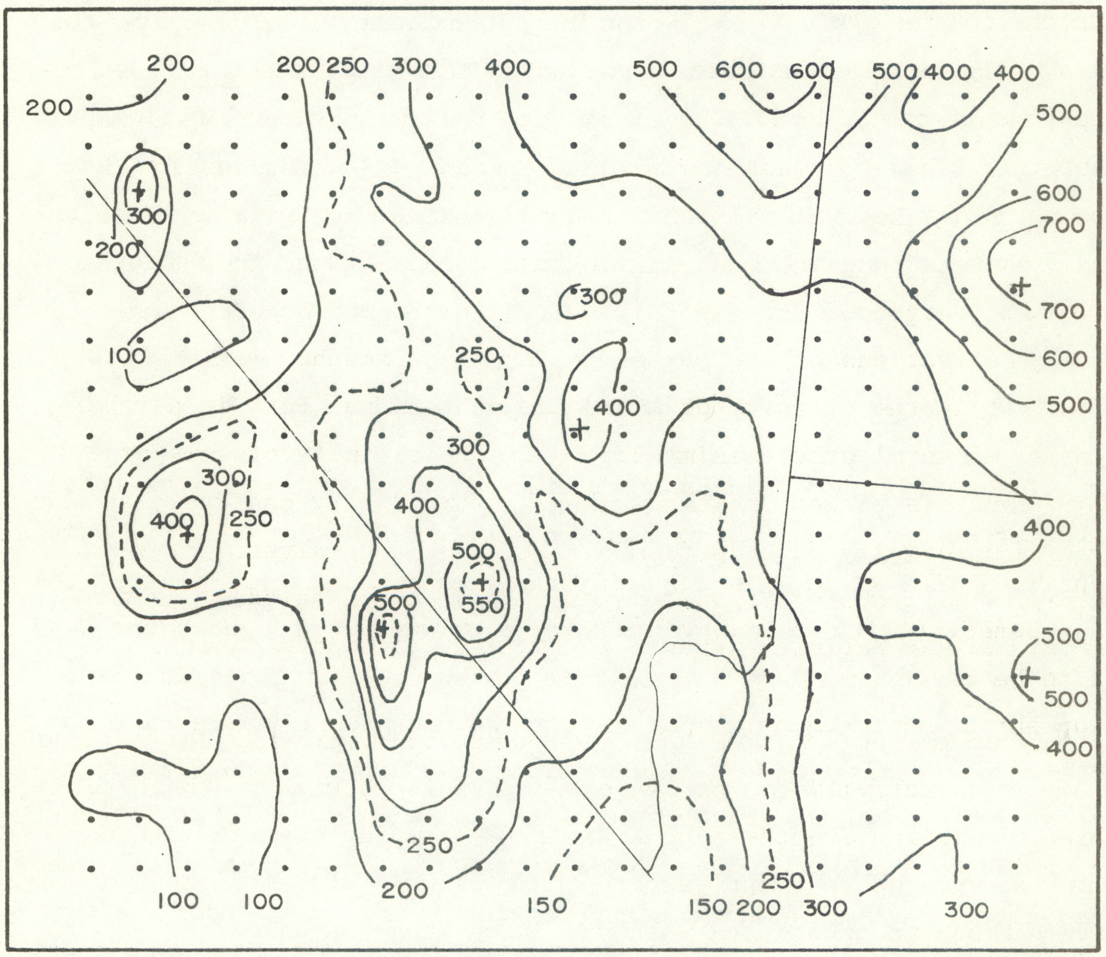


Fig. 4. Total number of hours of echo activity per 28 by 28 km square for June through September 1971 and 1972 after having been adjusted for detectability.

If desired, the contours in Fig. 4 can be converted to percentage frequency of occurrence of radar echo activity at any point within the grid (100 h of echo equals 1.75 percent). For example, during the warm season, radar echoes occur near the Spring Mountains during approximately 9 percent of the hours and 12 percent of the hours over the Markagunt Plateau. By contrast, echoes develop over the Colorado River valley during approximately 3 percent of the hours. Figure 4 demonstrates that LAS can be expected to receive roughly half the echo activity occurring in the vicinity of the Spring Mountains. Likewise, CDC will experience almost 70 percent of the echo activity occurring over the very high terrain to the east of the city. More pronounced differences occur in the vicinity of Death Valley.

6. Echo Diurnal Variability

To identify any diurnal variations in echo activity, the total number of echo occurrences by hour were calculated for the grid points identified in Fig. 5. In preparing the hourly data for analysis, the radar detectability was considered to be constant throughout the day and to be represented by the analysis in Fig. 3. Included in the development are two desert areas - - the Colorado River valley and the eastern Mojave Desert - - two mountainous regions - - the Markagunt Plateau and the Spring Mountains - - and, two areas of local interest - - the Las Vegas valley and the Nevada Test Site. In general, the desert areas contain rough, hilly country ranging in elevation from 2000 to 4000 ft above MSL while the mountainous regions consist of north-south mountain ranges with peaks extending above 10000 ft MSL.

The diurnal variability of echoes is portrayed graphically by plotting the total number of days of echo within each area versus time of day. In addition, the relative frequency of occurrence of echoes for each hour of the day was computed for selected areas. These values are

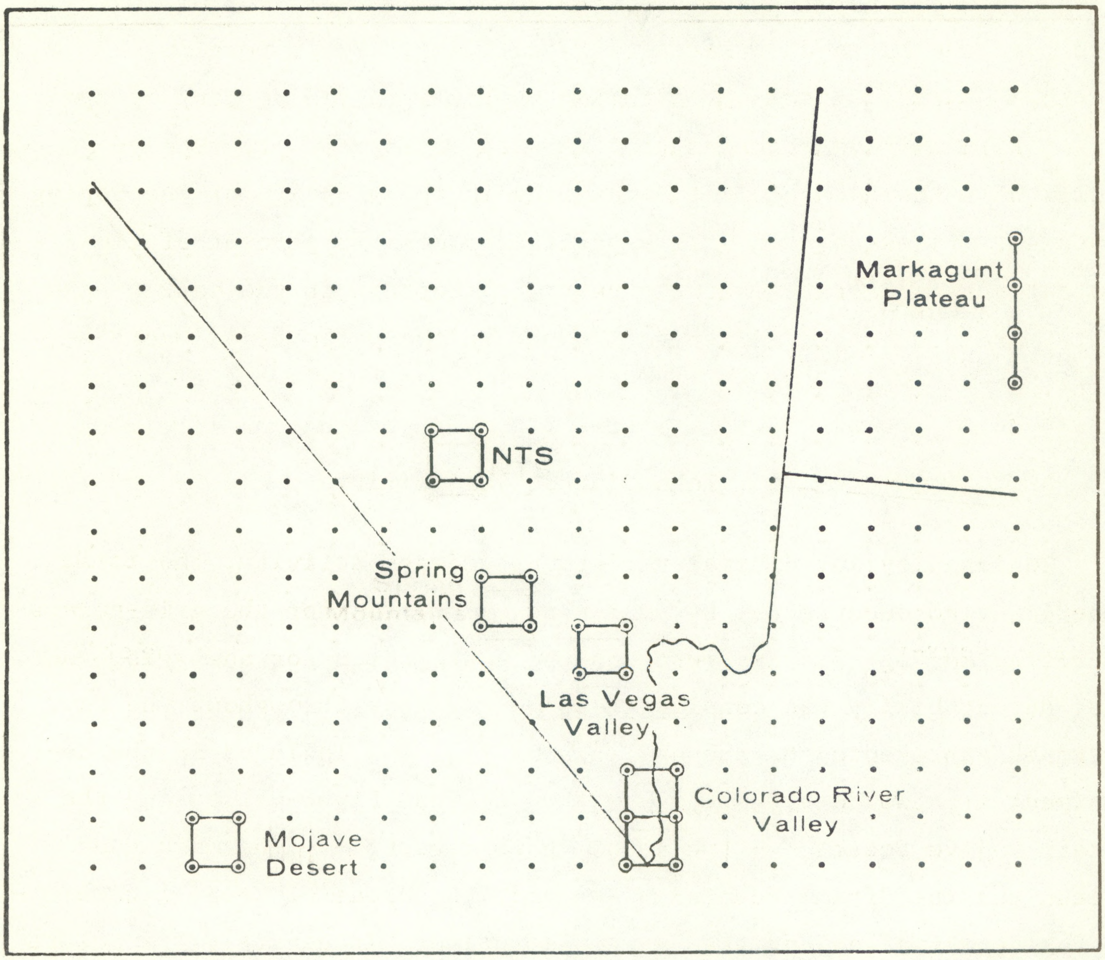


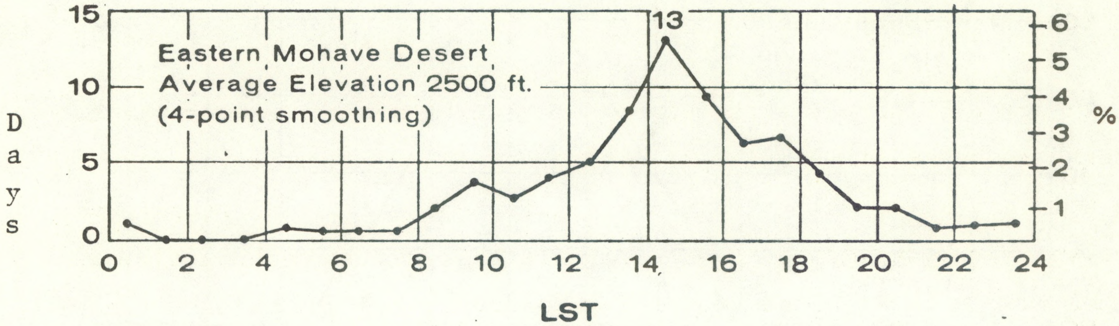
Fig. 5. Grid points used to spatially smooth echo data for each hour of the day.

labelled on the right-hand side of Figs. 6, 7, and 8, as percentage while the total number of days of echo are labelled on the left-hand side of the diagram.

Fig. 6 illustrates the diurnal variation of echoes over the two desert areas. A six-point spatial average (Fig. 5) was taken to form the Colorado River valley values and a four-point spatial average was used on the Mojave data. Fig. 6 reveals that maximum echo activity occurs over both areas at 1430 LST. Moreover, the graphs show that in these two regions, at 1430 LST, echoes occur on about 6 to 8 percent of the days. After 1430 LST, the echo activity decays to low values after midnight. Between midnight and 0600 LST, echo activity stabilizes at approximately 1 to 2 occurrences which could be thought of as the background to the echo activity in the absence of thermal forcing by the flux of sensible heat from the ground.

The temporal variability of the echo activity for the two mountainous regions is summarized by Fig. 7. In developing these charts, a four-point spatial average was used. In general, the charts in Fig. 7 show that the echo activity increases rapidly over the high terrain after 0700 LST, reaching a peak at approximately 1400 LST. Karr and Wooten (1976) observed a similar temporal variation over the Rocky Mountains in Colorado.

Figure 7 shows that the Markagunt Plateau region is the most active in the afternoon with a total of 64 days of activity at 1430 LST. In terms of percentage, echo activity can be expected to occur on 27 percent of the days at 1430 LST between June and September. Furthermore, a comparison of Figs. 6 and 7 illustrates how much more echo activity can develop over the high mountainous terrain than over the lower desert areas. As an example, consider the difference in activity between the Colorado River valley and the Spring Mountains. The two areas are about 148 km apart. At 1330 LST, echo activity can



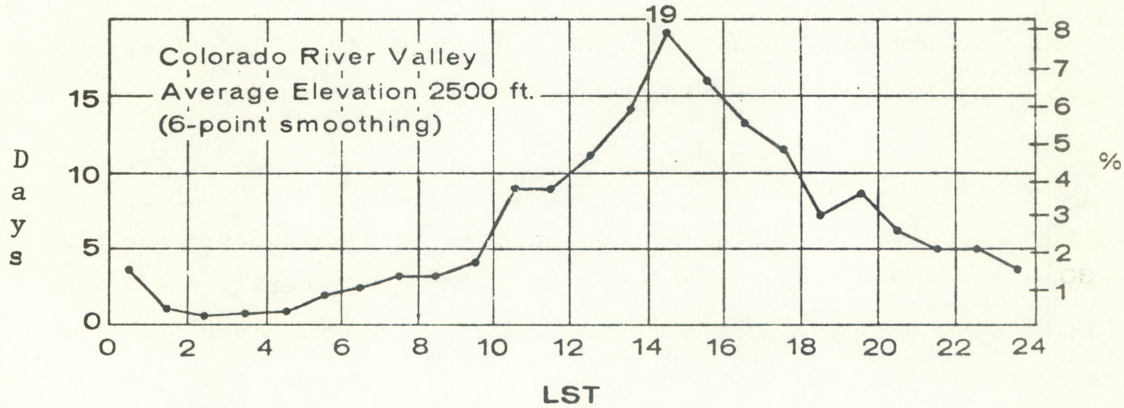


Fig. 6. Temporal variability of echoes of moist convection for two desert areas. The right-hand ordinate is labelled as percentage frequency of occurrence and the left-hand ordinate as total number of days of echo activity for the two warm seasons. Spatial smoothing is for the grid points indicated in Fig. 5. Adjusted for detectability.

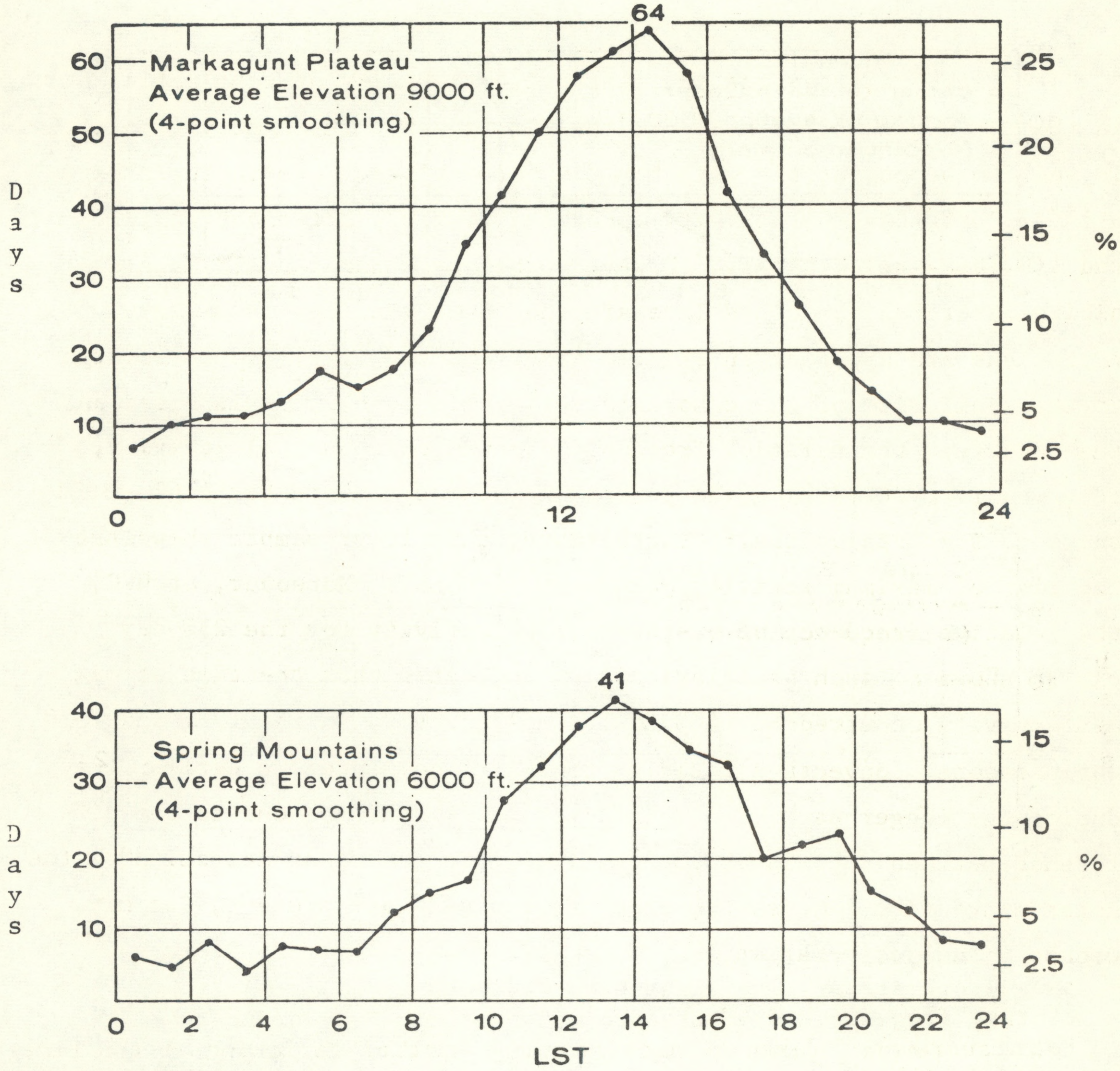


Fig. 7. Temporal variability of echoes of moist convection for mountainous regions. For remainder of legend see Fig. 6.

be expected to occur twice as often over the Spring Mountains as over the river valley and it averages about five times more frequently over the mountains for the hours between midnight and 0630 LST.

Figure 8 illustrates the temporal variability of echo activity in the Las Vegas valley and over the NTS region. The echo variability is seen to be compatible with the diurnal variation displayed in Figs. 6 and 7, with maximum activity appearing in early afternoon at 1230 and 1330 LST, respectively. However, the chart for the NTS data exhibits other maxima in the late afternoon and evening. Similar variations are apparent in Figs. 6 and 7 and are likely to be related to the small size of the echo data set. This conclusion is based on the fact that the relative frequency of cumulonimbus (Cb) activity, observed from UCC during the period June through September 1962 - 1971, shows no such variations.[2] Furthermore, this 10-yr sample shows that the time of maximum activity occurs at 1600 LST. Moreover, at UCC, the relative frequency of on-the-hour Cb activity for the 238-day sample shows no such oscillations and indicates that the time of maximum activity occurred at 1400 LST. Consequently, in the 1971 and 1972 warm seasons, convective activity tended to commence 2 h earlier than during the longer sample. This discrepancy could be due to the difference between the visual observation of Cb and radar detection of the moist convection. Moreover, when other clouds are present, Cbs may escape visual observation.

A survey was taken to determine the spatial variation of the time of maximum frequency of occurrence of hourly echo activity within each of the 340 grid squares. The results of this survey are presented in Fig. 9. This figure illustrates that the maximum frequency of occurrence

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2 Quiring, R. F., 1972: Frequency of occurrence and duration of thunderstorms and associated phenomena at Yucca Flat, Nevada. ARL in-house manuscript.

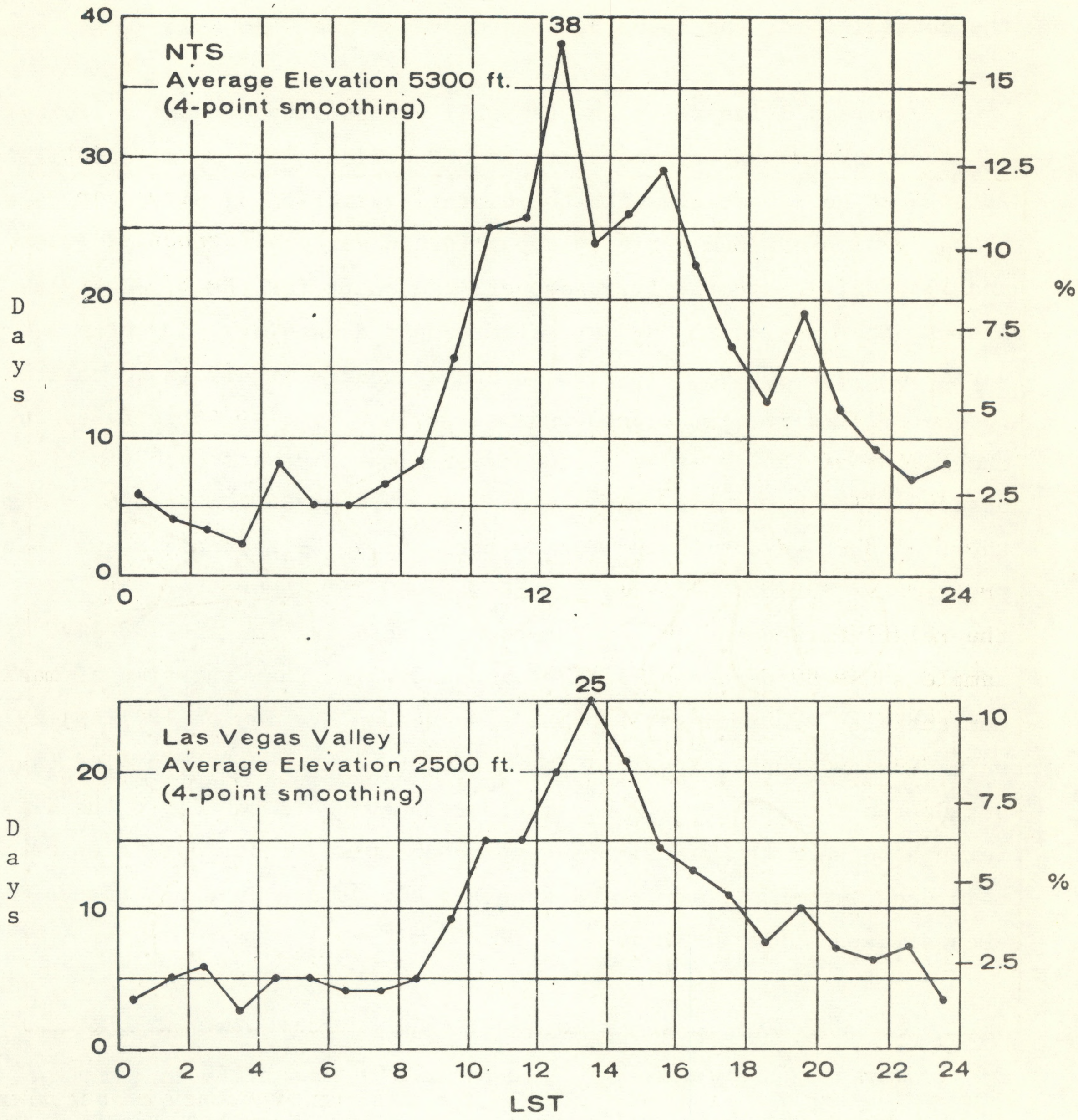

Fig. 8. Temporal variability of echoes of moist convection for regions of local interest. For remainder of legend refer to Fig. 6.

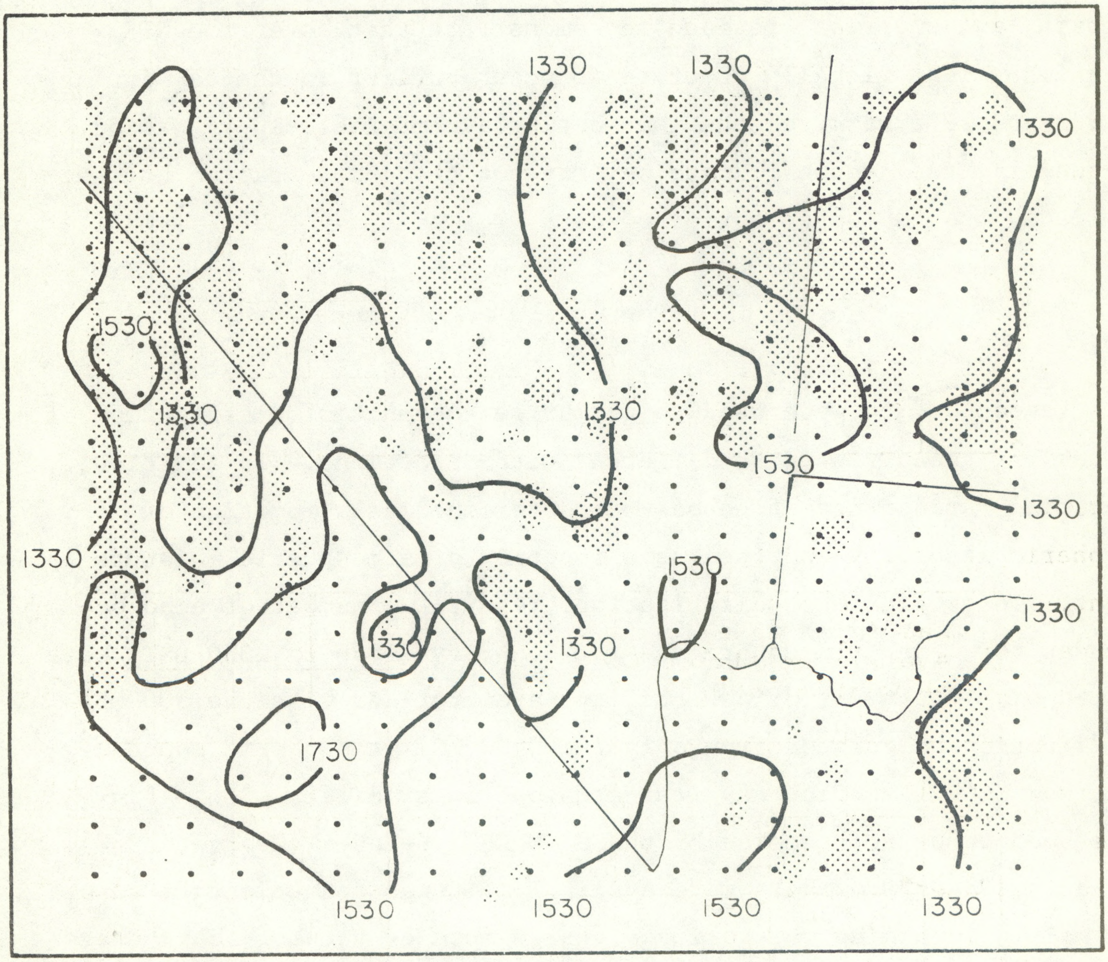

Figure 9. Isochrones of the time of the maximum frequency of occurrence of echo activity for the 238-day sample. Times are in LST. Shaded area represents terrain above 6000 ft MSL.

of echo activity is in the early afternoon over the high mountainous terrain and in the late afternoon over the lower desert areas. A similar variation in echo activity has been observed by Karr and Wooten (1976) in eastern Colorado. Some caution should be used in placing too much emphasis on these results because, in a preceding paragraph, evidence was provided to demonstrate that, over the NTS, cumulonimbus were visually observed to occur earlier in the day during the 1971 and 1972 warm seasons than during a comparable 10-yr period. Consequently, the sample climatology may not be representative of that established from a longer series of data.

7. Echo Distributions vs. Other Parameters

The echo data were used to summarize the spatial distribution of echo activity occurring with different wind directions. In addition, the spatial variability of echoes was determined as a function of atmospheric stability and then as a function of atmospheric moisture content. To obtain these distributions, the total number of echo occurrences for each grid square and for each day (0030 to 2330 LST) were compared with the value of a stability parameter and with the 500-mb wind direction calculated from only the 0400 LST atmospheric sounding taken from UCC. For each day, the atmospheric stability within Fig. 1 was assumed to be represented by the 0400 LST, K-index (George, 1960). Since only 238 days of data were available, it was convenient to stratify the K values into nine categories of three integer values each. These categories were bounded on the stable end by a category with $K < 6$ and on the unstable end by $K > 32$. The echo data were adjusted for detectability (Fig. 3).

Results of the analysis of echo distribution as a function of K-index show that for the 37 days with $K < 6$, echoes did not occur over most of the area enclosed in Fig. 1; however, over the Markagunt Plateau echoes were found to occur during 1.5 percent of the hours. In general, echoes did not occur during more than 10 percent of the hours until $K > 23$

and then these active areas were confined to the high mountain ranges. For example, in the category $24 \leq K \leq 26$, echoes occurred during 12 to 13 percent of the hours over the northern Markagunt Plateau and approximately 13 to 14 percent of the hours over the Spring Mountains. As K increased, the percentage frequency of occurrence of echoes was found to increase, with maximum values found for the 16 days when $K > 32$. Figure 10 shows the spatial distribution of the percentage frequency of occurrence of echoes for those days when $K > 32$. In this figure notice that the Colorado River valley and the eastern Mojave Desert experienced echo activity during approximately 10 percent of the hours while the large mountainous areas experienced echo activity during approximately 35 percent of the hours. In other words, when $K > 32$ these mountainous areas experience roughly 3.5 times more echo activity than the desert areas.

To compare the occurrence of echoes for the NTS area (Fig. 5) with the 0400 LST, UCC, 500-mb wind directions, the directions were categorized into 20-deg increments. The echo data were then surveyed and the occurrence (or non-occurrence) of a day with one or more echoes was recorded by wind category. Results of this tabulation are displayed in Fig. 11. In the top half of the figure the values on top of each bar are the total number of days of occurrence for each wind category. The bottom half of the figure shows the percentage relative frequency of occurrence of echo days within each 20-degree increment after normalization for wind frequency in each category. Of the 238 days in the sample, there were six days of missing wind data. These six days were removed from the data set since measured wind directions were unavailable.

To provide background information on the representativeness of the radar echo data, 10 yr of 0400 LST, 500-mb, summertime wind data from UCC were surveyed for Cb days as a function of wind direction. Observations of Cb clouds are routinely recorded on meteorological forms MF2-10A and MF2-10B (formerly WBAN forms 10A and 10B). Observations are made on an hourly schedule and are usually completed by 5 min to the hour.

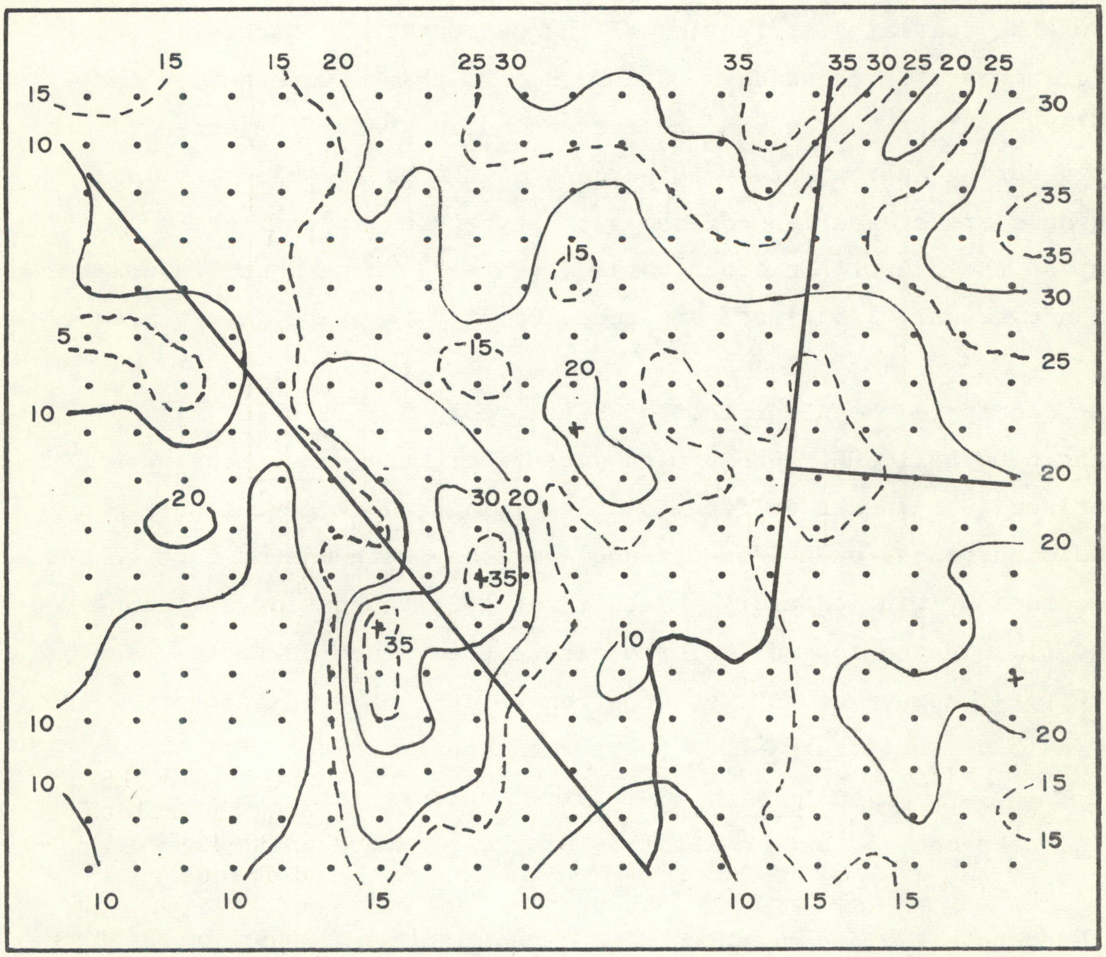

Fig. 10. Spatial distribution of the percentage frequency of occurrence of echo activity for 16 days when K>32. Adjusted for detectability.

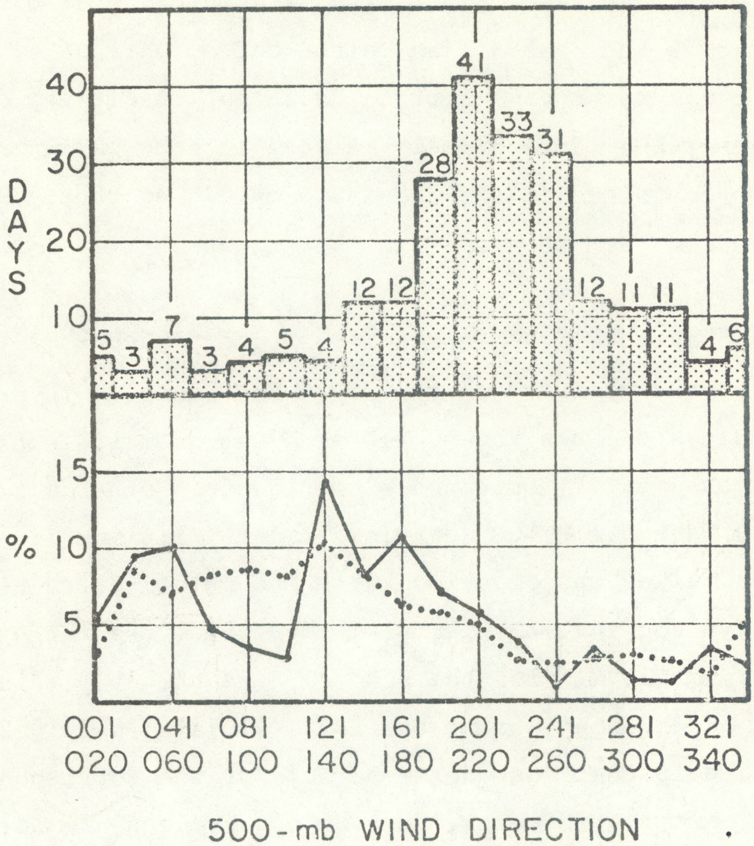

Figure 11. Distribution of the 1971, 1972 warm season, 0400 LST, 500-mb wind directions at Yucca Flat, Nevada, and the relative frequency of occurrence of echo days within the 30-degree, 500-mb wind increments after normalization for wind frequency in each category (solid line). Adjusted for detectability. The dashed line is the relative frequency of occurrence of Cb days (for 10 yr of summertime data) after normalization for wind frequency in each category.

A total of 1067 observational days were available from the period June through September (1962 - 1971), including 324 Cb days. The relative frequency of occurrence of Cb days as a function of wind category is plotted as the dashed line in the bottom half of Fig. 11. Observations of Cb clouds provide a broad basis for specifying days with moist convection that should be closely related to echo days. A total of 83 Cb days were contained in the 238-day sample. Of these 83 days, 75% were echo days for the NTS area (Fig. 5).

For the echo data, Fig. 11 shows a marked dependence of echo days on wind direction in the vicinity of the NTS. For example, 70 percent of the echo activity occurred when the 500-mb wind was from the eastern hemisphere while less activity appeared with flow from other directions. The peak (10.2%) for the 041 - 060 deg winds and the minimum for 101 - 120 deg are both anomalies in comparison with the relative frequency of occurrence of Cb days for the 10-yr sample. Moreover, the large amplitude of the primary maximum (14.4%) for the echo data is probably related to the large number of Cb occurrences during the 1971 (41 days) and 1972 (42 days) warm seasons relative to that considered normal for the correspondingly longer sample (33 Cb days). However, when Cb occurrences are not normalized for wind category, 70 percent of the 20 possible occurrences in the 121-140 deg category were Cb days in the 10-yr sample. In general, Fig. 11 demonstrates that most (68%) of the Cb days and 70 percent of the echo days occurred with winds having an easterly component at the 500-mb level.

Echo spatial distributions as a function of the 0400 LST atmospheric precipitable water (PW) content over Yucca Flat were surveyed. Precipitable water was categorized into 1/4-in groups ranging from less than 0.25 in to greater than 1.0 in. Analysis of the summarized data revealed that for the 81 days when $PW \leq 0.5$ in, little (< 1/2%) or no activity occurred over the whole area with the exception of the eastern half of the northeastern quadrant, where echoes occurred for 1 to 3 percent of the hours. Even for $0.51 \leq PW \leq 0.75$ echoes occurred on less than 5 percent of the hours over the whole area except for the extreme eastern part where echoes occurred on 5 to 10 percent of the hours with the 10-percent value isolated over the Markagunt Plateau. For the 46 days with PW>1.0 (Fig. 12), the high mountainous areas experienced echoes during 25 percent of the hours while, over the Colorado River valley, echoes occurred during approximately 5 percent of the hours.

A comparison of Figs. 10 and 12 with the sample climatology reveals that these figures may have practical value. The sample climatology can be specified from Fig. 4 by dividing the contour values by the total number of possible echo hours and multiplying by 100. Figure 4 then contains contours of the percentage frequency of occurrence of echoes. Such a conversion shows that echoes occur 12 to 13 percent of the time over the Markagunt Plateau and nearly 10 percent of the time over the Spring Mountains. If the percentage frequency of occurrence distribution in both Figs. 10 and 12 are compared with the corresponding distribution derived from Fig. 4, it becomes obvious that the spatial distribution of the echoes is very similar; however, the frequency of occurrence is greater for larger values of K and PW. This result indicates that the stability parameters from one upper-air station can be used as a guide in assessing the spatial variability of the relative frequency of occurrence of thunderstorm activity over a rather large mountainous area.

8. Probability of Echo Occurrence

As a possible aid in predicting the likelihood of thunderstorms over the area described in Fig. 1, the probability of occurrence or, more correctly, the relative frequency of occurrence (RFO) of a day with one or more hours of echo was computed for each grid square for various K and PW categories. *An echo occurrence was counted only when one or more echoes was detected within the 12-h period from 0600 to 1800 LST.* This period is essentially the one over which the 0400 LST sounding data (for UCC) would be used for local operational forecasts of daytime

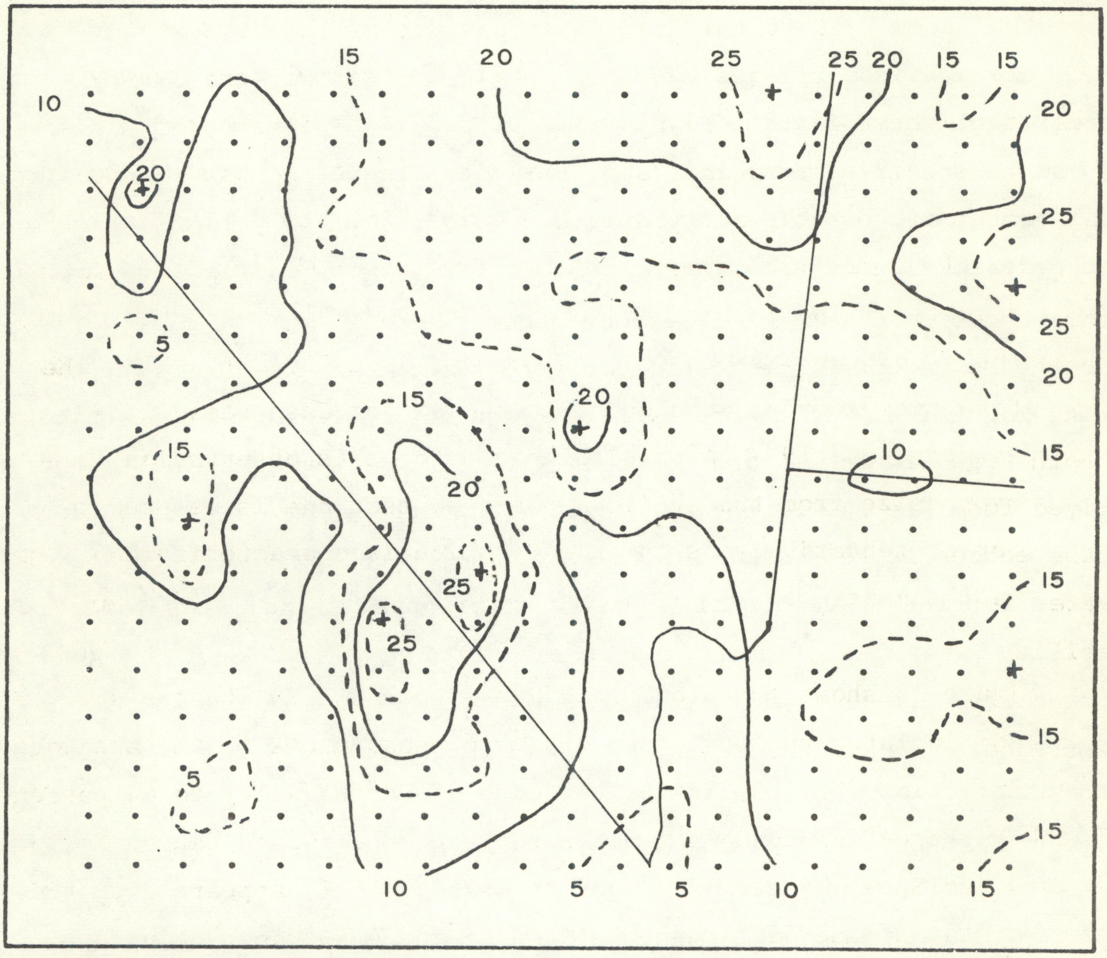

Fig. 12. Spatial distribution of the percentage frequency of occurrence of echo activity for the 46 days when the 0400 LST precipitable water content over Yucca Flat, Nevada (NTS), was greater than 1.0 in.

thunderstorms. *In this analysis, the data have not been adjusted for detectability* because non-occurrences cannot be adjusted and time tends to compensate for lack of detectability.

For the 37 days when $K < 6$, the RFO ranges from zero over most of the southeastern half of the area to 11 percent of the days having detectable echo occurrences over the Markagunt Plateau; the Spring Mountains generating a secondary maximum of only 3 percent, or one echo day out of 37. As atmospheric stability decreased, the RFO over the area increased except for the categories $12 \leq K \leq 14$ (20 days), $15 \leq K \leq 17$ (14 days), and $21 \leq K \leq 23$ (22 days), in which the general increase in activity was not detected. The lack of a steady increase in activity has been noted in 10 yr of warm season thunderstorm activity over the NTS where the relative frequency of cumulonimbus did not increase steadily for K values between 8 and 19[3]. A physical basis for this observation is not easy to synthesize from the available data so that one is tempted to account for it tentatively as an anomaly which is characteristic of this rather small sample.

Figure 13 shows that for the 27 days with $24 \leq K \leq 26$, the RFO ranged from isolated pockets of no observed occurrences in the area of limited detection (Fig. 3) in the vicinity of Death Valley to 44 percent over the Markagunt Plateau, the northern section of Grand Canyon National Park, and the Sheep Range. A secondary maximum (41%) appears over the Spring Mountains, the difference between 44 and 41 percent being one echo day out of 27. By contrast, an area of minimum RFO, in a region of high detectability, is clearly visible over the Colorado River valley. Notice that the axis of this region of minimum occurrence extends northward to a position northeast of the Sheep Range.

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[3]Quiring, R. F., 1974: The relative frequency of cumulonimbus clouds at the NTS as a function of K-value. In-house report no. 351-44, Air Resources Lab., Las Vegas, 6 pp.

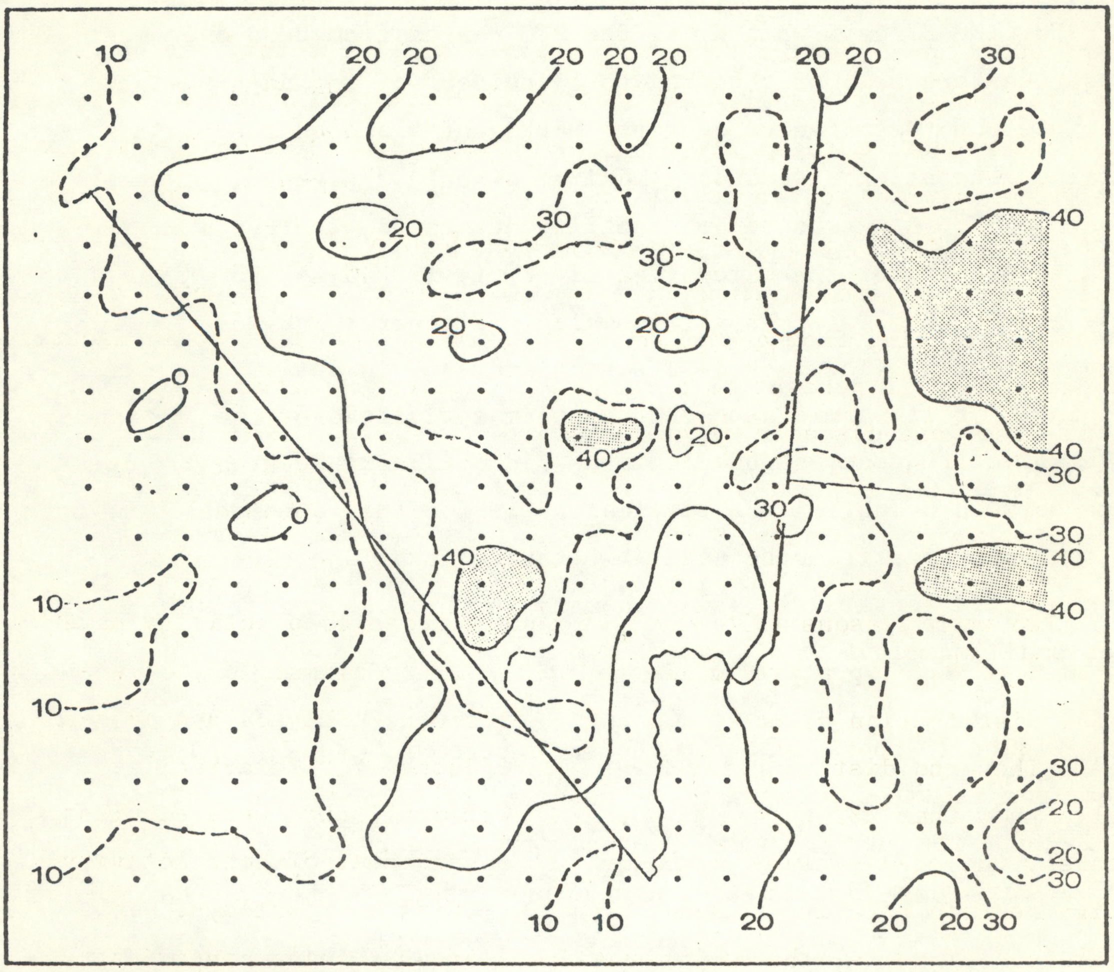

Fig. 13. Spatial distribution of the relative frequency of occurrence of a day with echo during the 27 days when $24 \leq K \leq 26$ at 0400 LST, Yucca Flat, Nevada (NTS). Not adjusted for detectability.

For the 16 days when K>32, Fig 14 shows that the RFO becomes quite large (88%) over the Markagunt Plateau and the Sheep Range. The Spring Mountains exhibit a secondary maximum of 81 percent, one occurrence less than over the Sheep Range and the Markagunt Plateau. The pronounced area of minimum RFO is again clearly visible over the Colorado River valley northward, as in Fig. 12. A minimum RFO of 31 percent occurs inside the 40 percent contour positioned to the east of LAS. Normal to this axis of minimum RFO, the gradient of RFO is quite large with values ranging from a maximum of 81 percent over the Spring Mountains to a minimum of 31 percent to a value of 75 percent southeast of SGU; a total east-west distance of only 250 km.

9. Summary

Two warm seasons (238 days) of hourly radar echo activity have been used to develop a preliminary picture of the climatology of the spatial distribution of echo activity over southern Nevada and adjacent areas. The echo distributions have been adjusted for detectability. Results show that 62 percent of the observational hours were echoless. Moreover, the echo summary confirmed the enhancement of echo activity by high terrain relative to the limited activity over valleys. In a climatological sense, the high mountainous areas receive approximately 2 to 3 times more echo activity than valleys during the daylight hours and 5 times more activity between midnight and 0700 LST.

A survey of the temporal variation in echo activity revealed that the maximum frequency of occurrence of echoes can be expected between 1230 and 1730 LST with the echo activity tending to occur in the early afternoon over the high terrain and in mid to late afternoon over valleys.

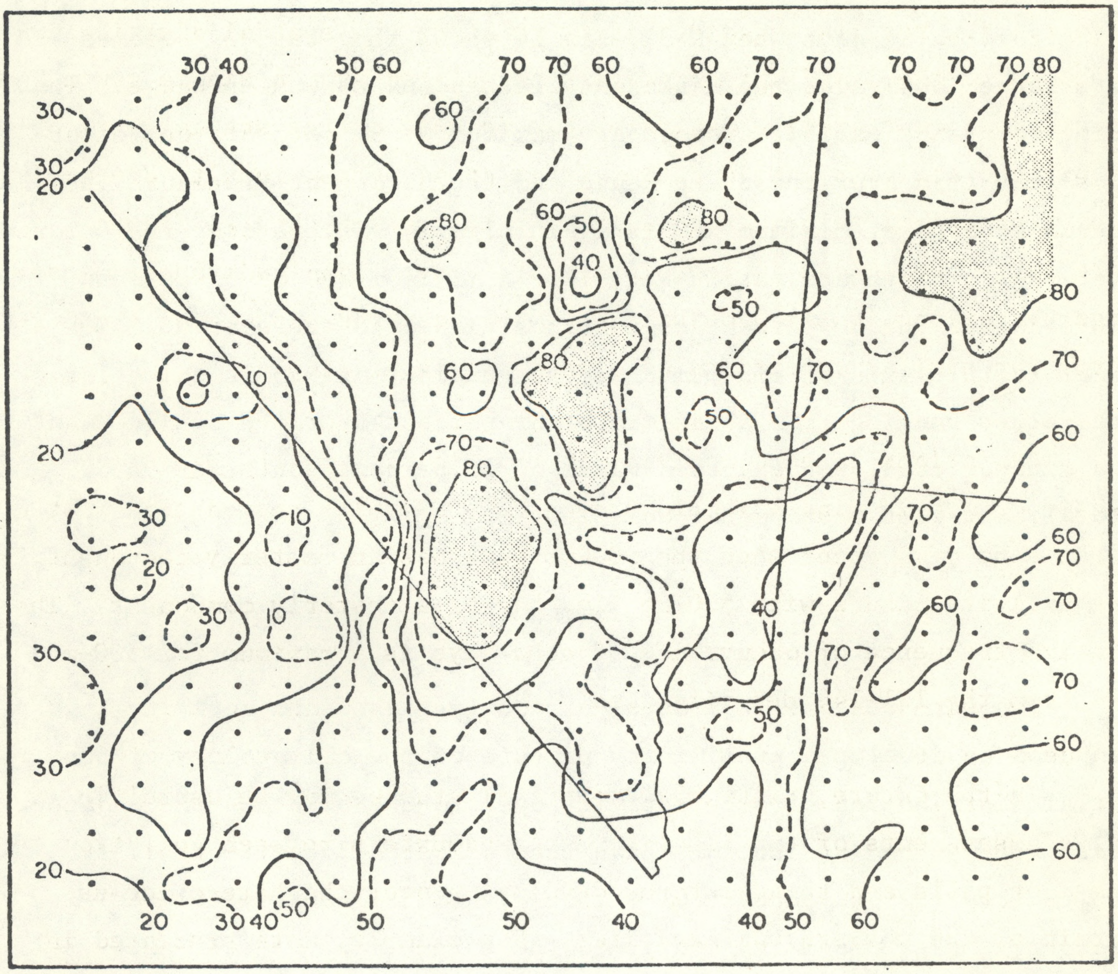

Fig. 14. Spatial distribution of the relative frequency of occurrence of **a day** with echo being observed during the 16 days when K>32 at 0400 LST, Yucca Flat, Nevada (NTS). Not adjusted for detectability.

Spatial variations in echo activity have been compared with different categories of K-index and the atmospheric precipitable water content. The results suggest that by relating the spatial distribution of echoes to the stability parameters calculated from a single rawinsonde observation, quantitative estimates can be made of the spatial variability of echo activity over a rather large area. These results are believed to have practical value, especially over the western United States where large variations in terrain elevation over small distances cause large variations in the probability of the occurrence of local thunderstorms for similar conditions of atmospheric stability.

Variations in echo activity in the vicinity of the NTS were related to 500-mb wind directions over UCC. Results showed that most of the echo days occur when the 500-mb flow has an easterly component. Less activity occurs with 500-mb flow having a westerly component. The relative frequence of occurrence of echo days is a maximum for 500-mb flow from the 121-140 deg direction.

In the future, radar climatological studies may be useful in making assessments of the likelihood of encounters between pollution plumes or palls and thunderstorms developing over the heterogeneous terrain of the western United States. For example, data presented in this paper could be used to infer that precipitation scavenging of pollutants is more likely to occur over mountainous areas than over valleys. In addition, radar climatologies of sparcely populated areas may provide knowledge of untapped sources of surface water in an area where the demands for water are increasing.

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