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The Weather Radar Set An/CPS-9 at McCulloch Peak, Oregon, provided data of changes in radar precipitation echo patterns in the vicinity of Marys Peak. Echo heights studied from data collected on 14 March 1963 averaged nearly the same upwind, directly over Marys Peak, and downwind. For the data of 28 March 1963, echo heights upwind and those directly over the peak averaged nearly the same while the heights downwind averaged 600 feet lower. In the first case shearing of the echo tops as detected over the peak might cause the similarity of the reported heights of the echoes. Study of the movement of the echoes near Marys Peak showed spreading of echoes in the second case, while no evidence of similar spreading was noted in the first case. The observations of these echo changes showed that Marys Peak has a definite effect upon the precipitation echo patterns.

A STUDY OF RADAR PRECIPITATION ECHO AS INFLUENCED BY MARYS PEAK

by

JAMES WALTER SEARS

A THESIS

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Typed by Barbara Johnson

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A STUDY OF RADAR PRECIPITATION ECHO AS INFLUENCED BY MARYS PEAK

INTRODUCTION

The study of radar echo patterns has continued from the beginning of the pictorial presentation of radar return. The varied information displayed upon the cathode ray tube, the most common presentation method, makes interpretation of the return, at times, uncertain and at all times somewhat subjective. Many of the cases of special interest are well understood. Anomalous propagation, multiple-trip return echoes and range attenuation present examples of this type of information. Noise and intensities give examples of two types of subjective information which need interpretation. Precipitation intensities found directly from radar scope intensities shown in Battan (5, p. 56) vary greatly with the type of precipitation and with the investigator observing the echoes. They also vary from time to time with the same radar due to electronic tube deterioration.

Echoes over mountains have intrigued many workers, including some from Oregon State University: Pike (15, p. 70), Washington (16, p. 38), Fosberg (9, p. 68), Decker (7), and Mendenhall (14, p. 36). Each of these persons have in their work wished for a more complete study of the echo patterns associated with a mountain peak. Pike and Washington studied the influence of the mountain on downwind precipitation and radar echo patterns. Fosberg's work with precipitation patterns was greatly affected by interference from Marys Peak. (9)

This paper explores the changes of the echo patterns in the near field of Marys Peak in the coast range of Oregon. The paper intends to show in which way a mountain affects a precipitation echo and to list some of the physical reasons for those changes to take place. No attempt is made to relate quantitatively all of the various parameters involved in radar return and observed precipitation; the sole attempt is to define what effect a mountain has on the observed precipitation echo.

OROGRAPHIC LIFTING

Meteorologists define orographic lifting as the lifting of air due to obstructions in the path of the air (11, p. 406). A parcel of air at sea level, approaching the Oregon coast and coming inland to the top of Marys Peak might experience a lift of 4100 feet.
The lifting of the air could cause several reactions in the surrounding air. Lifting of the entire surrounding airmass might result in transporting the parcel in the same position relative to all its environment. However, the air parcel shape may change, and the two changes possible are (1) that the parcel would undergo compression vertically and (2) the parcel would undergo compression horizontally. Of course, with compression of the parcel in one direction, it must grow in some other direction.
If the parcel contains precipitation sized droplets from the time it moves inland from the coast, then throughout its travel, the radar will follow it. The radar scope will then display any change in shape, movement or growth. This change in echo appearance constitutes the principal observational data for this study.

ADIABATIC LIFTING

By definition, an adiabatic process is a thermodynamic change of state of a system in which there is no transfer of heat or mass across the boundaries of the system (11, p. 10). In an adiabatic process, such as adiabatic lifting, compression always results in warming, expansion in cooling. In the dry-abiabatic lifting process, the warming or cooling equals 5.4°F per thousand feet. Dry-adiabatic means a process where no water vapor is present or not enough to cause condensation during part of the process.

Wet-adiabatic processes then produce condensation of water, which in turn warms the air. The total cooling for wet-adiabatic lifting equals 3.2°F per thousand feet. An air parcel at sea level and saturated with water vapor which moves inland and over the top of Marys Peak would cool about thirteen degrees Fahrenheit.

This process must produce enough condensed moisture so that precipitation-size particles may form. The radar will detect only water particles of greater than small rain-drop size (10). The radar scope displays the result of the wet-adiabatic lifting process and other processes which release water from air which starts at the coast, or at least upwind from Marys Peak, and continues past the peak.

Detection of water droplets in a cloud by radar is the important result of the discussion above. These processes form part of the explanation of this study because of their importance to the formation of the precipitation studied.

DESCRIPTION OF TOPOGRAPHY AND RELATIVE POSITIONS OF EQUIPMENT

The author chose Marys Peak for this study because of its height and its nearness to all available radar equipment. Marys Peak is the highest peak in the Coast Range of Oregon. For this particular study, because of the previously mentioned saturated adiabatic lifting processes, the height of the mountain in relation to surrounding terrain makes the detection of changes easy. The nearness of Marys Peak to the radar allows the operators of the radar to use shorter range indication on the scope and eliminates extraneous material.

Marys Peak is a rather isolated high peak (4097 feet above mean sea level) in the Coast Range of mountains in Oregon. From a contour map one can see one distinct range along the coast of Oregon with several breaks, and several mountains over three thousand feet high, but none as unique as Marys Peak which is not masked from McCulloch Peak.

The McCulloch Peak Research Facility, which houses the radar equipment used in this study, is 13.5 miles at 49^{o} azimuth from Marys Peak. McCulloch Peak (2204 feet above mean sea level) lies 35 miles East from the Oregon coast and about 5 miles Northwest of Corvallis, Oregon. Although none of the immediately surrounding mountains are over two thousand feet high, many exceed (Figure 1) one thousand feet.

DESCRIPTION OF EQUIPMENT

An AN/CPS-9 radar provided the radar data for this experiment. Sixteen millimeter pictures of each single sweep taken during the observational periods provide a record of all data used. Projection of the film at a later date gives a greatly increased image to analyze.

The plan position indicator (PPI) of the radar presents a picture in the horizontal plane of the precipitation echo encountered by the beam, at a zero degree elevation angle. See the Appendix, Figure 3, for the graph of radar beam height versus range. The range height indicator (RHI) depicts a vertical slice of the atmosphere with precipitation echoes plotted by range against height at the given horizontal azimuth. See Appendix, Table 5, for a tabulation of the characteristics of the AN/CPS-9 radar.

RESOLUTION AND DISTORTION

In any study of the top, bottom, or extent of precipitation echo, one must consider two properties of radar beams, resolution due to pulse length and distortion due to beam width.

> Resolution is the property of the radar which enables it to distinguish between two separate targets. In azimuth, the distance separating two precipitation areas of good reflecting qualities must be at least equal to the beam width at the given range. If this distance is less than equal to the beam width, then they will appear as one area on the scope. ......By their nature, the errors in resolution are in the direction of indicating more precipitation than is actually present (6, p. 1-10).

With the assumption that a one degree beam completely contains all of the power, then the resolution of the radar equals the width of the beam at a particular range (3, p. 8). However, a beam width measurement of the AN/CPS-9 at McCulloch Peak shows that one degree does not contain all the power. The distortion is then a function of the strength of the echoing material and strength of the power outside of the one degree beam (6, p. 10).

A group of echoes on one azimuth from the radar at one time must appear at least one half of the pulse length apart to be shown on a scope as separate echoes. For the AN/CPS-9 radar with a pulse length of either 0.5 or 5.0

microseconds, the resolution between one echo and another further out is 245 and 2455 feet respectively.

Observers took data for this study on days of instability showers. The radar operator tracked each cell detected on the PPI scope to determine if it would cross over Marys Peak. If so, RHI slices were taken through it. With this type of activity, the likelihood of having two cells close together is small.

METHOD OF ACQUIRING DATA

The desirability of studying the change of precipitation echo as it moves from low elevations to higher ones and then again over low elevations leads to the following problems: (1) How do you study a single echo throughout this span of travel? (2) How does one ascertain that the echo he studies is the same one at all times? This research effort tries to eliminate these uncertainties in the following manner.

First, if the precipitation echoes move in a direct line toward the radar site and pass over Marys Peak, both problems are solved. One may study the echoes from the first time they appear on the scope until they disappear by passing the radar. However, as in some of the cases cited in the paper, the echoes did not move directly toward the radar. Therefore, the author devised a different method of examining the echoes. The method used in this study depended upon the ability of the radar operator to calculate the speed of the echo movement and its direction of movement.

A radar operator can find the speed of echo movement by outlining a cell on the scope with a grease pencil and noting the time. After the echo travels away from the outline, he again outlines the echo and notes the time.

The operator then moves a cursor in line with both echo outlines to find the direction of movement. He then determines the distance traveled from the range marks on the scope. The distance traveled divided by the time interval equals the speed of the echo movement. These quantities determine the angle between RHI scans which will show the same echo in different positions. All of the data acquired contain three scans, one upwind of Marys Peak, one over the Peak and one downwind.

Determination of angle between RHI scans for data observation followed subsequent solutions:

ASSUME: One scan over Marys Peak at 229^{o} azimuth.

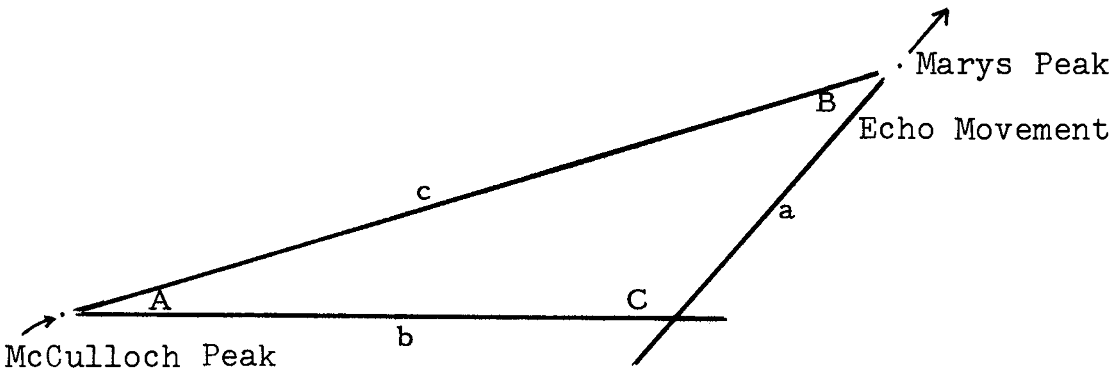
v = echo speed

t = time required for one data cycle

c = 13.5 miles

B = angle between echo movement and scan over Marys Peak

a = v x t.



GIVEN: Law of Tangents.

$$\frac{c + a}{c - a} = \frac{\tan \frac{(C + A)}{2}}{\tan \frac{(C - A)}{2}}$$

SOLVE: For A

The sample solution of this problem shown in Figure 2 assumes a given velocity of 30 mph and direction from 319^{o} azimuth.

Assuming, that any change in the echo appearance is continuous then interpretation of the change may be drawn for the travel of the echo over the peak (Figure 3). From drawings of this type the heights of the tops of echoes, the size, and shape were studied.

Radar operators took stepped gain pictures of the echoes to determine the stronger portions of the echo. The three decibel steps chosen for this study show the areas of echo which were half as strong as the preceding display. The size, shape, height and position of the stronger echo within the main echo were studied at all scans.

The AN/CPS-9 radar, using stepped gain, displays echo return at fixed echo strength levels. The levels chosen for this study were 0, -3, -6, -9, -12, -18, and -24 decibels. The zero decibel step presents the echo return of the weakest echo that can be detected by the radar at full receiver gain, the most sensitive position. For each of the three decibel steps below full receiver gain, the outline of the echo on the scope is twice as strong as the preceding echo outline. The last two steps are at six decibel intervals and they present precipitation echo with four times the strength of the preceding echo. Radar precipitation echo return from the 24 decibel step outlines echo 256 times stronger than the echo outline shown at zero decibel.

Iso-decibel echo contour lines describe the limit of the echo strength at any given level. Each picture taken of the radar scope outlines one of the levels of echo return (Figures 6, 7, and 8). The outline of the precipitation echo equals exactly the indicated decibel level and all of the echo within the outline is as strong or stronger than the indicated level.

Analysis proceeded by drawing iso-decibel echo contours of each echo at all scans from the projection of the film. The analyzer took the contour drawings to a light table, registered the base lines, and noted and tabulated the echo differences (Table 1). These procedures completed the mechanical analysis of the data.

RADAR OBSERVATIONS

Radar observations on the 14 and 28 of March 1963 show changes in the echo patterns as the echoes pass over Marys Peak. The data collection began at 9927 PST on the fourteenth and continued through 0216 PST, which gave 350 individual cases. On 28 March, the data collection began at 0403 PST and continued until 0800 PST, which gave 300 individual cases of observed echo.

Instability shower activity characterized the weather pattern for the case of 14 March. A cold front passed through the area just before midnight on 13 March. Behind the front came instability showers which left an accumulation of about 0.30 inch of rain on the coast of Oregon and about 0.10 inch of rain in the Willamette Valley.

Most echo tops reached thirteen thousand feet at full radar receiver gain. Echoes appeared widely separated in both time and distance. The echoes moved from an azimuth of 319° at a speed of 30 knots. The scans of two degrees separation result in scan separation of 0.473 miles or 2497 feet at a distance from the radar equal to the range between McCulloch Peak and Marys Peak. The tabulation in Table 1 shows the average heights of the echoes at the various decibel levels.

The echo top heights average nearly the same. The echoes directly over Marys Peak show shearing of the tops in sixty-eight percent of the cases.

With less than full radar receiver gain, the echoes average nearly the same height at all three positions. The author detected very few cases of echo shearing at these lower decibel levels. No noticeable change of the relative position of the strong portion of the echo with the weaker portions occurred.

Instability shower activity also dominated the weather pattern of 28 March 1963 but with significant differences from the case of 14 March. The echo appeared more frequently and the echo tops stopped at about ten thousand feet. Determinations of the echo movement reveal a fourteen mile per hour speed and from an azimuth of 219°. For the total three hundred cases studied between 0400 and 0800 PST, results were somewhat different from those cases of 14 March.

On the windward side of Marys Peak, echoes averaged about six hundred feet lower than over the peak. On the lee side of the peak, the echo heights average two hundred feet higher than over the peak, when analyzed as in the previous case. However, the echo movement from azimuth 219° does make this a different situation. The echoes moved nearly upwind from the radar site in such a manner as to pass over Marys Peak. The analyzer chose a five mile range in each direction from Marys Peak and noted the echo heights at these locations (Table 2).

The heights upwind average three hundred feet higher than over Marys Peak. The echo heights downwind average 3700 feet lower than echo heights over the peak.

On 28 March echo strengths varied from the case of 14 March. The radar detected only echo of less than twelve decibel strength.

Echo heights upwind from Marys Peak show closer spacing than either over the peak or downwind from the peak. Echo movement appeared erratic at times during this case, sometimes moving slowly and then speeding up. The average movement towards Marys Peak was fourteen miles per hour. However, movement in the vicinity of Marys Peak varies.

The winds taken from the Salem, Oregon rawinsonde sounding show light winds up to five hundred millibars, all about fourteen miles per hour and all from the same direction. No echo shear is evident on this day as in the previous case.

CONCLUSIONS

The orographic effects on radar precipitation echo exhibited by Marys Peak fall into two categories as shown in this study. However, the author knows that the cases used in this study also fall into two categories, but the results of the two cases differ markedly.

First, for cases of high winds, in the 30 knot vicinity, echoes show a tendency to move directly toward Marys Peak. At the peak itself they seem to lift somewhat and then their tops shear off at about the same height as the surrounding echoes. In other words, the wind shear (a 30° change in direction and a 15 knot increase in the vicinity of the tops of all echoes) seems to hold all of the tops of echoes at about the same height. Because of the ground clutter in the vicinity of the peak, no study of the change of the bottoms of the echoes could be made.

Analysis of the change of shape revealed the shear near the tops of the echoes as they pass over the peak. This shear may reduce any evidence of lifting due to the orographic effects present. The fact that the echoes reveal shear over the peak and in no other place tends to substantiate the theory that the mountains should cause a definite increase in the height of the precipitation echo.

The study of the intensities of the precipitation echo in the near field of Marys Peak did not reveal any major change in the intensity from the upwind, over the peak, or downwind positions. The shear of the echoes over the peak is present only in the weakest level of the echoes.

Second, for cases of light winds of about fifteen knots, echoes show a tendency to gain height near the mountain. The echoes observed gained about six hundred feet in their travel toward the peak and retained their increased height after passing the peak when analyzed within 2497 feet of the top of the peak. In the analysis at five miles upwind from the peak, the echoes exhibit an equal height with that over Marys Peak, but lose 3700 feet at five miles further downwind. The equal height upwind is probably due to another mountain in that vicinity which rises to 3612 feet.

For cases with light winds and slow echo movement, there seems to be a "bunching" of the echo behind the peak, that is, a compaction of the echo before it moves on, over, or around the peak. The iso-echo contours are closer together on the upwind side of the mountain than over the mountain or downwind. Echoes in this type of situation move around the peak to a greater extent than in the previous case, causing the precipitation echo to spread over a large area.

In conclusion, the orographic effects of the mountain clearly show in the radar precipitation echo patterns. The height changes of the echoes present pictures of the lifting due to the mountain. The shearing of the echo tops is directly a feature of the lifting of the echo into a layer of wind shear where there is no other echo. The congestion of the echo behind the mountain on 28 March shows the blocking effect of the mountain upon slowly moving echoes.

Those making judgments in cases of echo movement over or around a mountain peak might need to use caution when applying the conclusions of this study to all echo movement near mountains because of the limitation of this study to two synoptic cases. However, the general observations of height changes, shearing, and congestion of radar precipitation echo noted in this study should apply in other similar synoptic situations.

A RECOMMENDATION FOR FURTHER RESEARCH

A case study that would show in a different aspect the effect of the Coast Range mountains on the radar precipitation echo patterns should progress from this study. With a radar operating on the east side of the Willamette Valley taking RHI slices over Marys Peak observers could see the echo patterns above the Coast Range and across the valley. The travel of echoes across the valley from the mountains might show in greater detail the orographic effects on these echoes after they cross the mountains. At the same time this study could show the lee waves that both Pike (15) and Washington (16) demonstrated in their studies. This study could show in finer detail the lee waves and banded structure of precipitation echoes studied by previous workers. The additional study of different synoptic cases would undoubtedly show some different orographic effects from those demonstrated in this paper.

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APPENDIX

Table 1

Average height of echoes at the selected azimuths at 13.5 miles from radar. Height in thousands of feet.

Case of 14 March 1963

Decibel Level	Azimuth 231		Azimuth 229		Azimuth 227	
	No. of Cases	Height	No. of Cases	Height	No. of Cases	Height
24	4	5	6	5.3	4	5.8
18	16	6.6	11	6.5	12	6.8
12	18	7.7	15	8.6	12	9.0
9	16	9.2	15	8.8	12	9.1
6	16	10.9	14	10.6	15	10.9
3	19	12.4	16	12.5	15	12.4
0	19	13.3	15	13.1	15	13.4

Case of 28 March 1963

9	21	6.2	18	5.8	15	6.3
6	25	6.8	25	6.9	24	6.4
3	26	7.6	25	7.4	24	6.7
0	25	8.3	24	8.1	23	7.5

Table 2

The following table contains the variance values for the frequency table, Table 1.

Where: $$s^2 = \frac{\sum y^2 - \frac{(\Sigma y)^2}{n}}{n-1}$$

Case of 14 March 1963

Decibel Level	Azimuth 231	Azimuth 229	Azimuth 227
24	0.666	1.066	7.583
18	1.860	3.273	2.568
12	3.073	3.564	8.166
9	5.663	4.136	7.522
6	2.141	5.281	7.293
3	3.952	6.348	8.952
0	3.978	5.761	5.117

Case of 28 March 1963

9	2.083	0.896	3.351
6	3.179	5.965	3.214
3	3.403	4.168	3.681
0	4.613	4.623	4.493

Table 3

Height of echoes when echo movement was directly over Marys Peak and toward radar. Heights in thousands of feet.

Case of 28 March 1963

Height Upwind Five Miles	Height Directly Over	Height Downwind Five Miles
10	6.5	0
7	9	0
11.5	11.5	13
8	11	7
12.5	10	7
11.5	12.5	4
12	7	8.5
11	9.5	4
11	8.5	0
8	9	4
10	10.5	5.5
5.5	9	7
Sum 118.0	114	70
Average 9.8	9.5	5.8

Table 4

Synoptic Data

Ten minute rainfall observations taken by author.

14 March 1963

Time	Amount in Inches
0100-0110	0.02
0110-0120	0.02
0120-0130	0.02
0130-0140	0.01
0140-0150	0.01
0150-0200	0.01

Pressure at McCulloch Peak, nearly constant at 994.0 millibars.

Humidity at McCulloch Peak, constant at 100 percent.

Temperature at McCulloch Peak fell during the data observation time from 35 degrees F. to 33 degrees F.

Temperature at the campus fell from 40 degrees F. to 36 degrees during the time of observation.

SALEM RAWINSONDE 14 March 1963

694 11085 02005 01810 85381 54568 02413 70880 65671 02818
50533 84924 03327 40687 87973 03482
55555 00003 02017 11970 00532 22728 62649 33573 78823
44440 88997 55369 89007

SALEM RAWINSONDE 28 March 1963

694 11094 06054 01702 85434 00519 01918 70959 57747 02323
50550 73761 02357 40710 84884 02275
55555 00004 06051 11984 09032 22815 51549 33730 56722
44684 58754 55607 65682 66538 69726 77364 90941

Table 5

Characteristics of the AN/CPS-9 Radar Set

P_t (watts)	= 2.5×10^5	= power transmitted
λ (cm)	= 3.2	= wave length
h (μ sec)	= 0.5 or 5.0	= pulse length
PRF (sec^{-1})	= 931 or 186	= pulse repetion frequency
ϕ (deg)	= 1.0	= beam width in vertical
θ (deg)	= 1.0	= beam width in horizontal
MDS (watts)	= 1.6×10^{-13} or 1.6×10^{-14}	= minimum detectable signal

Antenna diameter (m) = 2.36

Antenna shape = Circular (solid)

Radar Equation (5, p. 30)

$$\bar{P}r = \frac{\pi^5}{72} \quad \frac{P_t \, \theta \, \phi \, h \, A_p{}^2}{\lambda^6} \quad |K|^2 \quad \frac{Z}{R^2}$$

where: $\bar{P}r$ = average power returned

θ = ϕ, in radian

$A_p{}^2$ = apertural opening of antenna

λ is in millimeters

K^2 = 0.9300 for AN/CPS-9 at 0° C

Z = $\sum D^6$ = sum of drop diameters to the sixth power

R = range

$$C = \frac{\pi^5}{72} \left(\frac{Pt\ \theta\phi\ hAp^2}{\lambda^6} \right) |K|^2 \quad \text{for AN/CPS-9 at } 0^{o}C$$

$$C = 12.18 \qquad \frac{m^5\ watts}{mm^6}$$

$$\bar{P}r = C \ \frac{Z}{R^2}$$

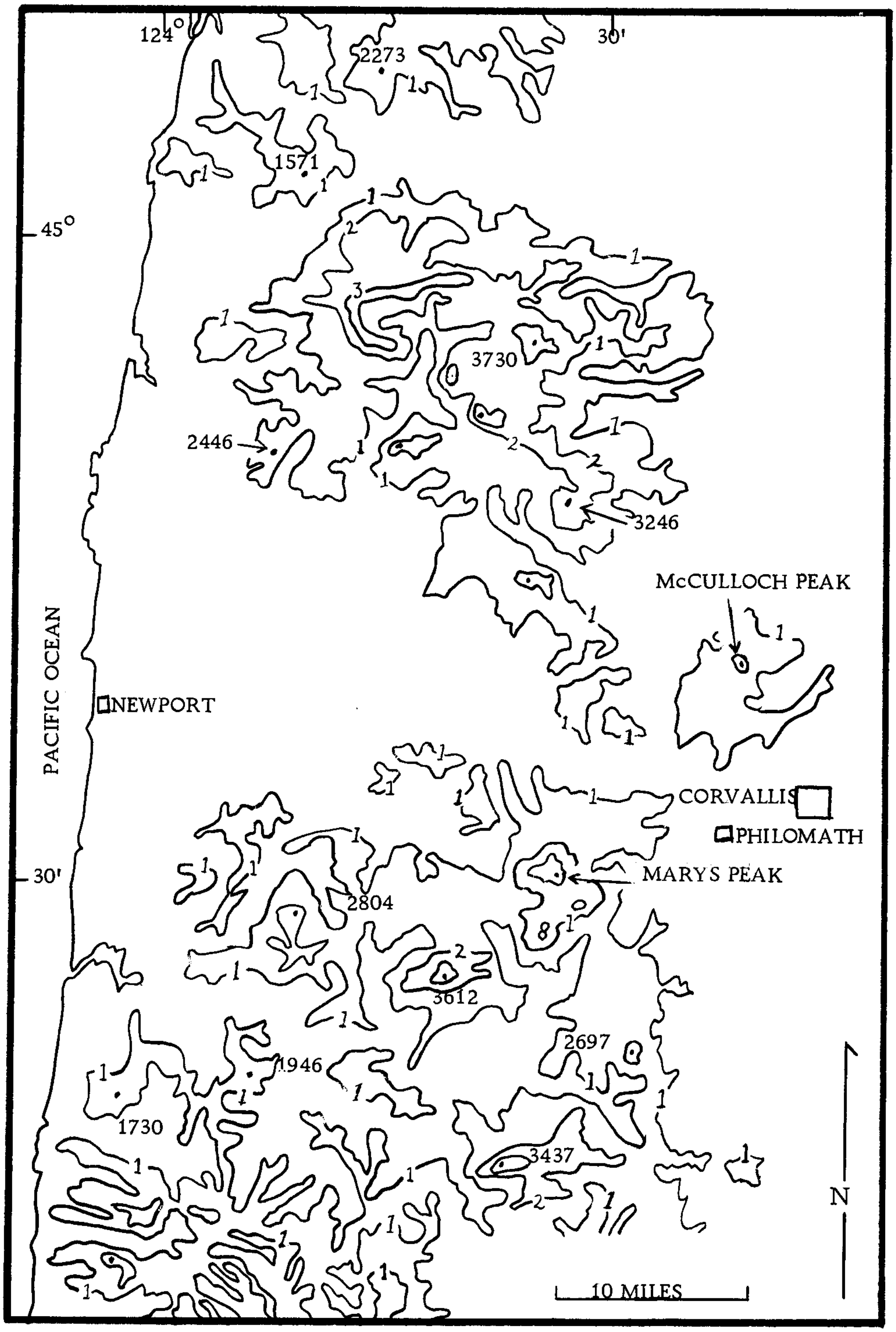
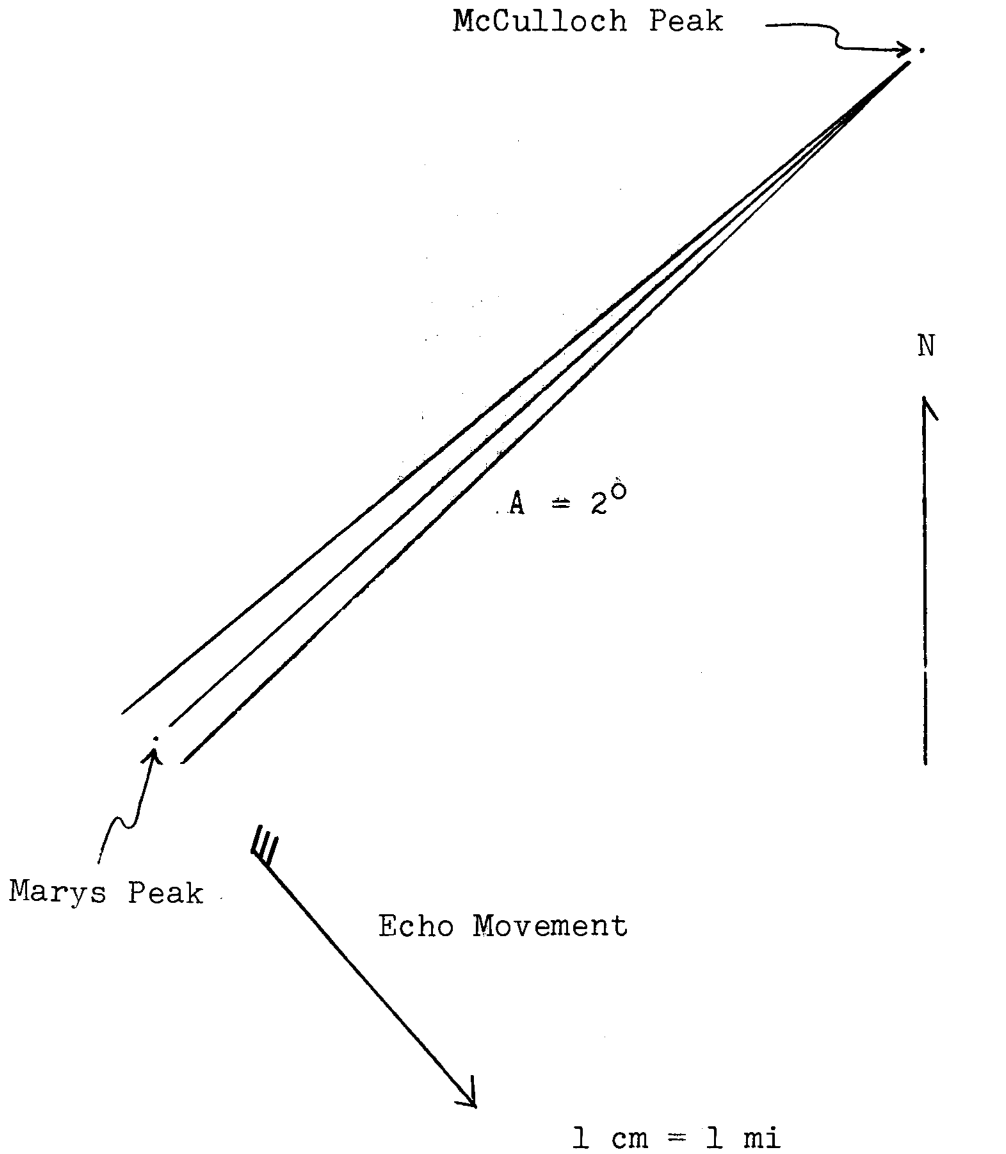


Figure 1. Prominent mountain peaks in Western Oregon. Contours are at 1000 feet intervals.

Figure 2

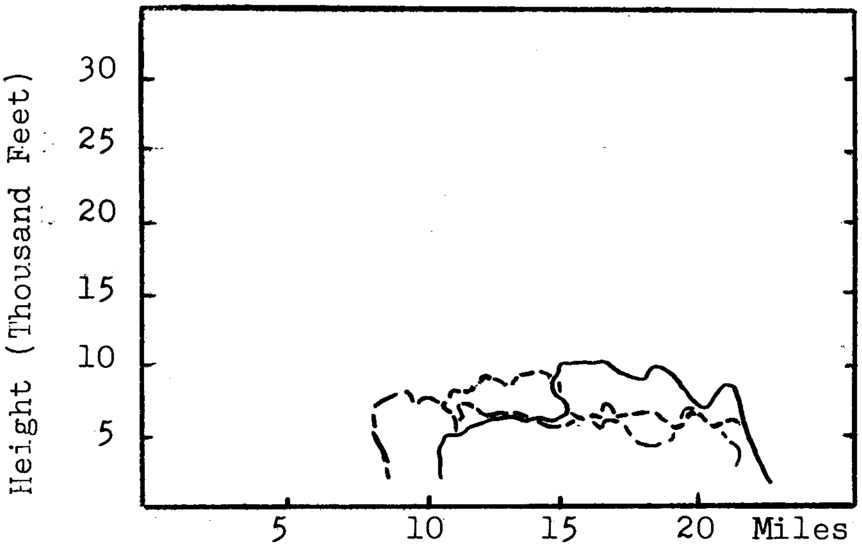


Sample Drawing of Scanning Lines for Echo Movement of 30 MPH, 319° Az.

Explanation of Figure 3

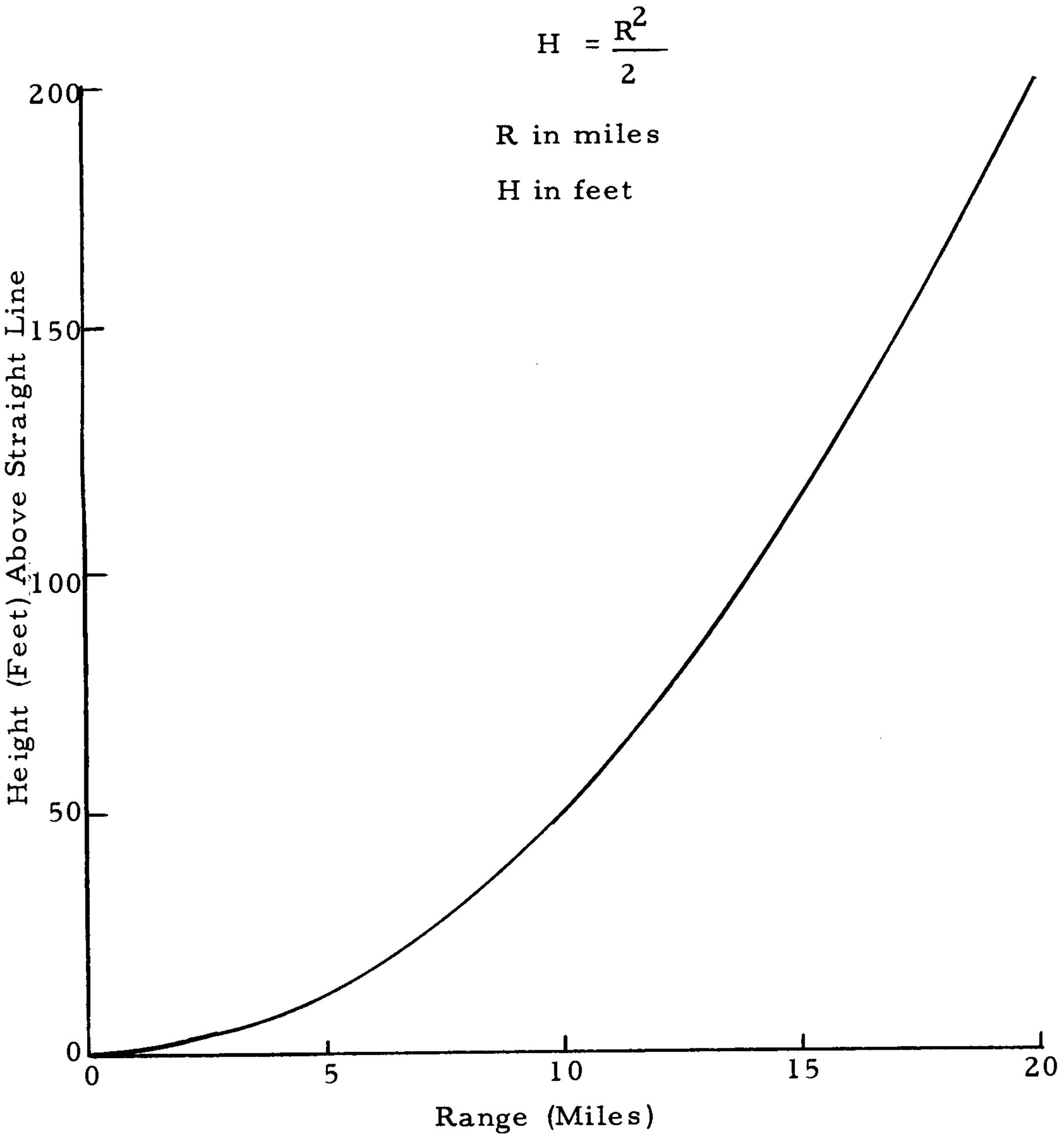
The solid line drawing in the figure shows the radar precipitation echo return at 0741 PST, 28 March 1963. The short-dashed line represented the echo return at 0746 PST on the same day. The long-dash and short-dash line represents the echo return at 0750 PST on the same day. All of the scans were taken on 229° azimuth and at full receiver gain.

Figure 3



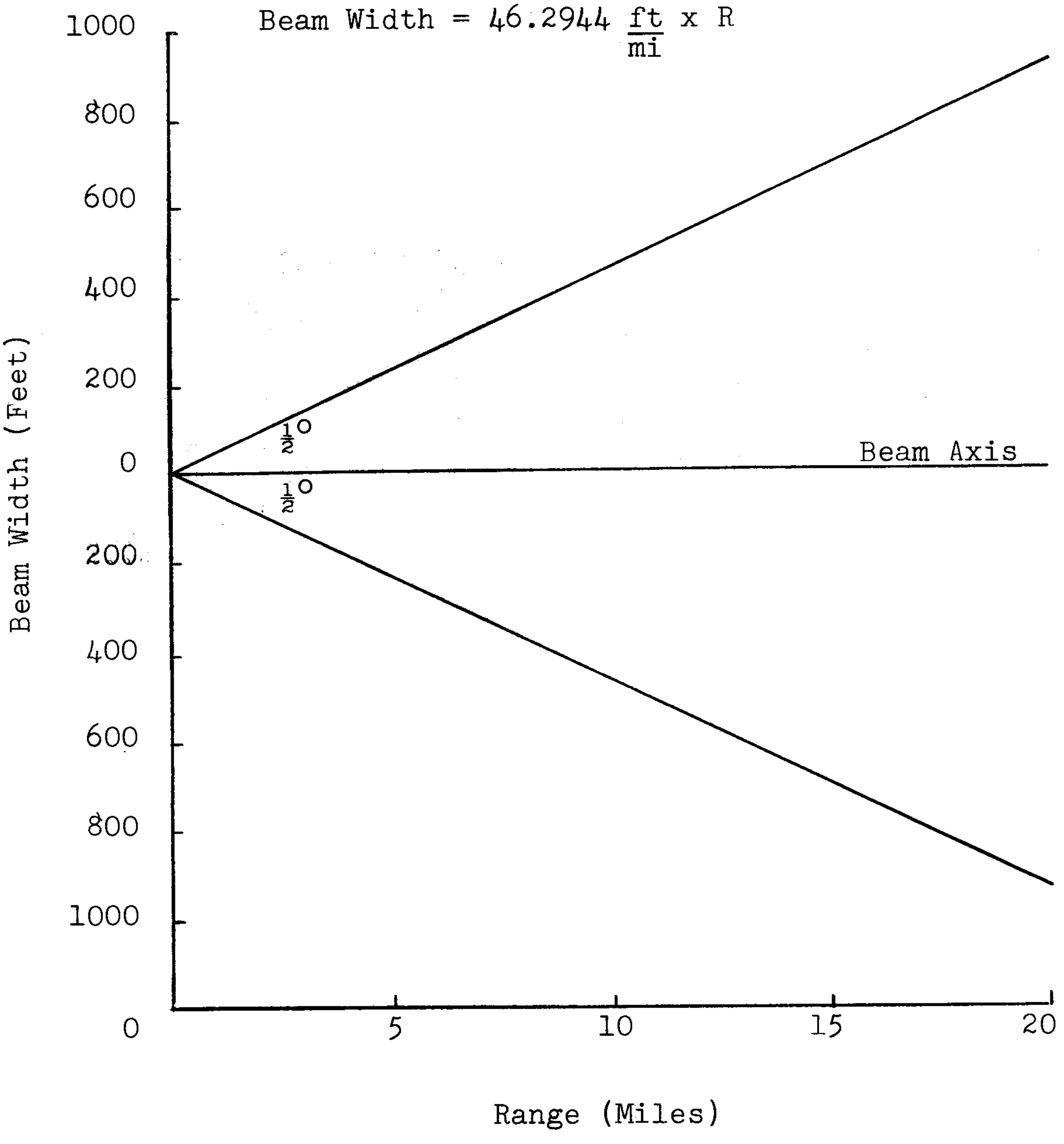
An Example of Echo Shape During Passage Over Marys Peak

Figure 4



AN/CPS-9 Radiation Beam Height
at 0^o Elevation

Figure 5



Beam Width Versus Range
For A 1° Beam

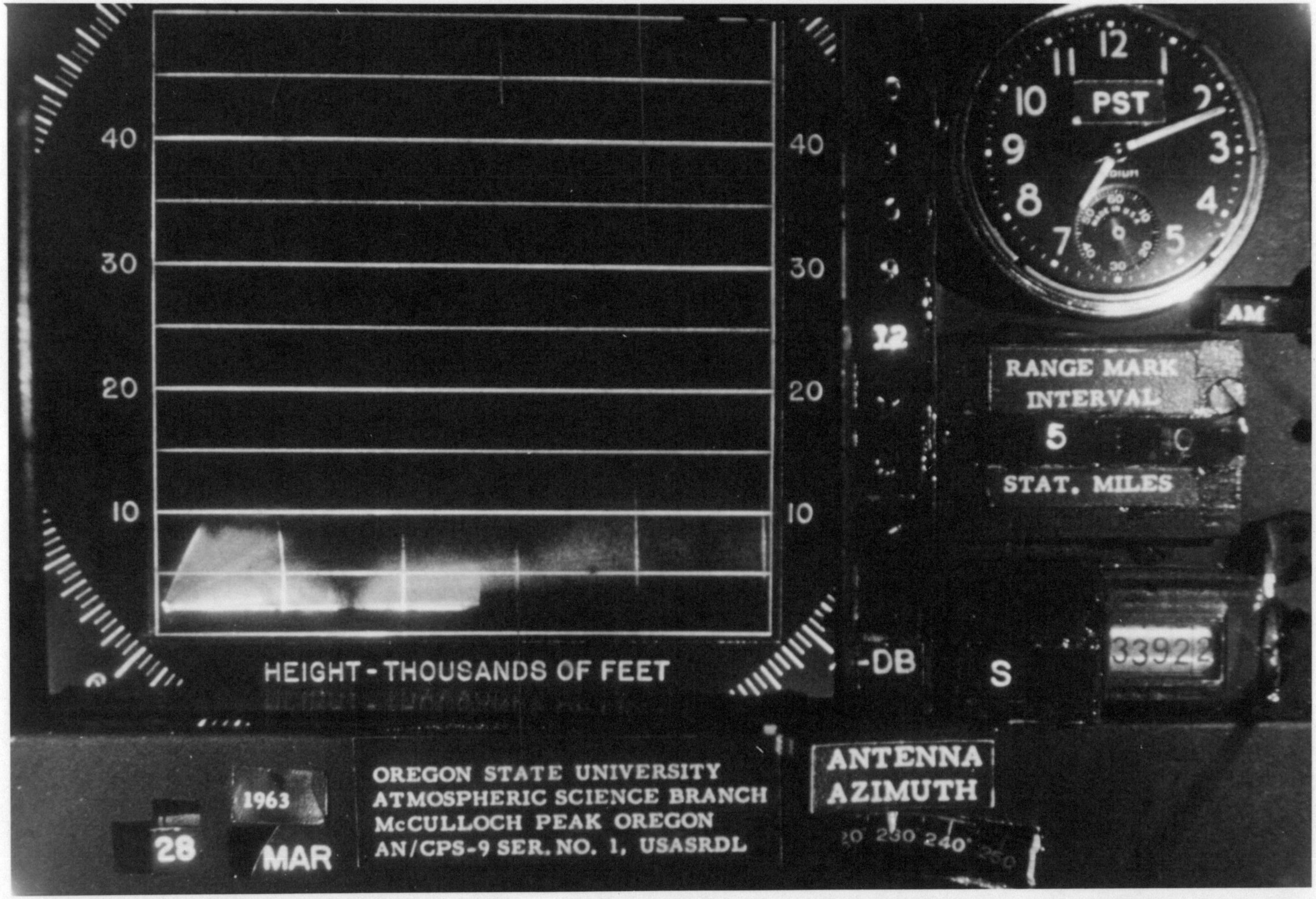


Figure 6. RHI scope depiction showing an example of data taken at -12 decibel receiver gain on 28 March 1963.

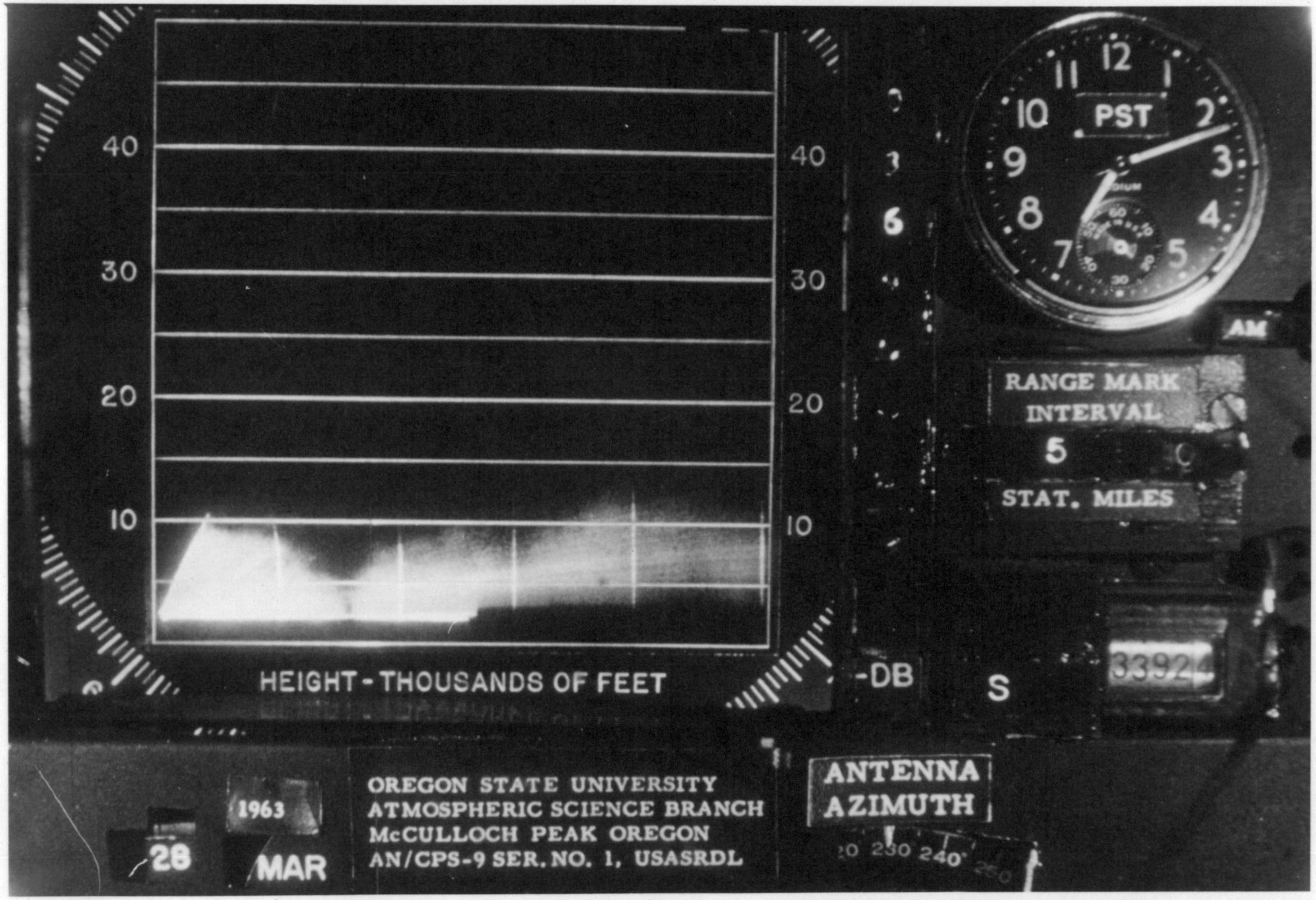


Figure 7. RHI scope depiction showing an example of the data taken at - 6 decibel receiver gain on 28 March 1963.

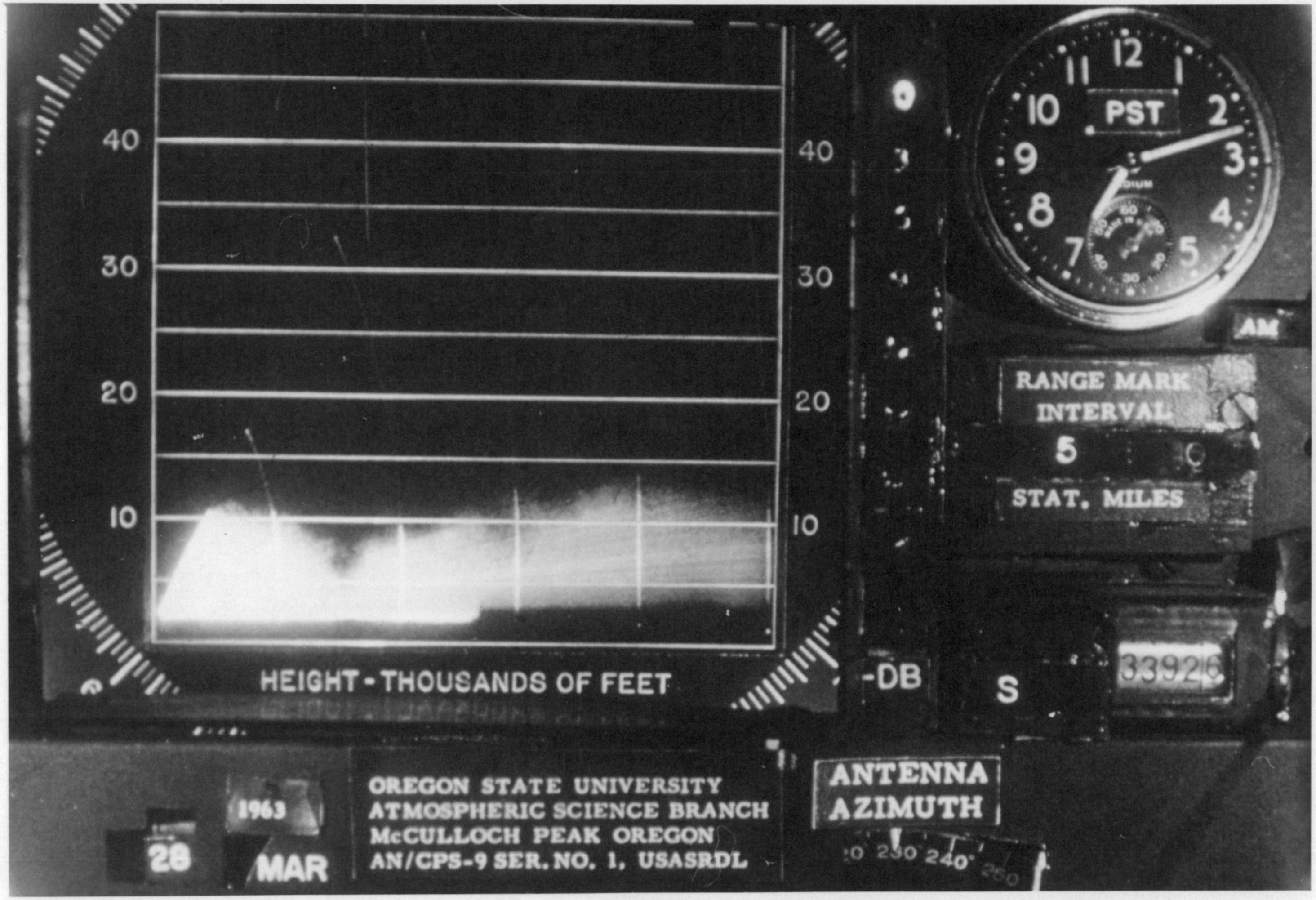


Figure 8. RHI scope depiction showing an example of data taken at full receiver gain (Zero decibel) on 28 March 1963.

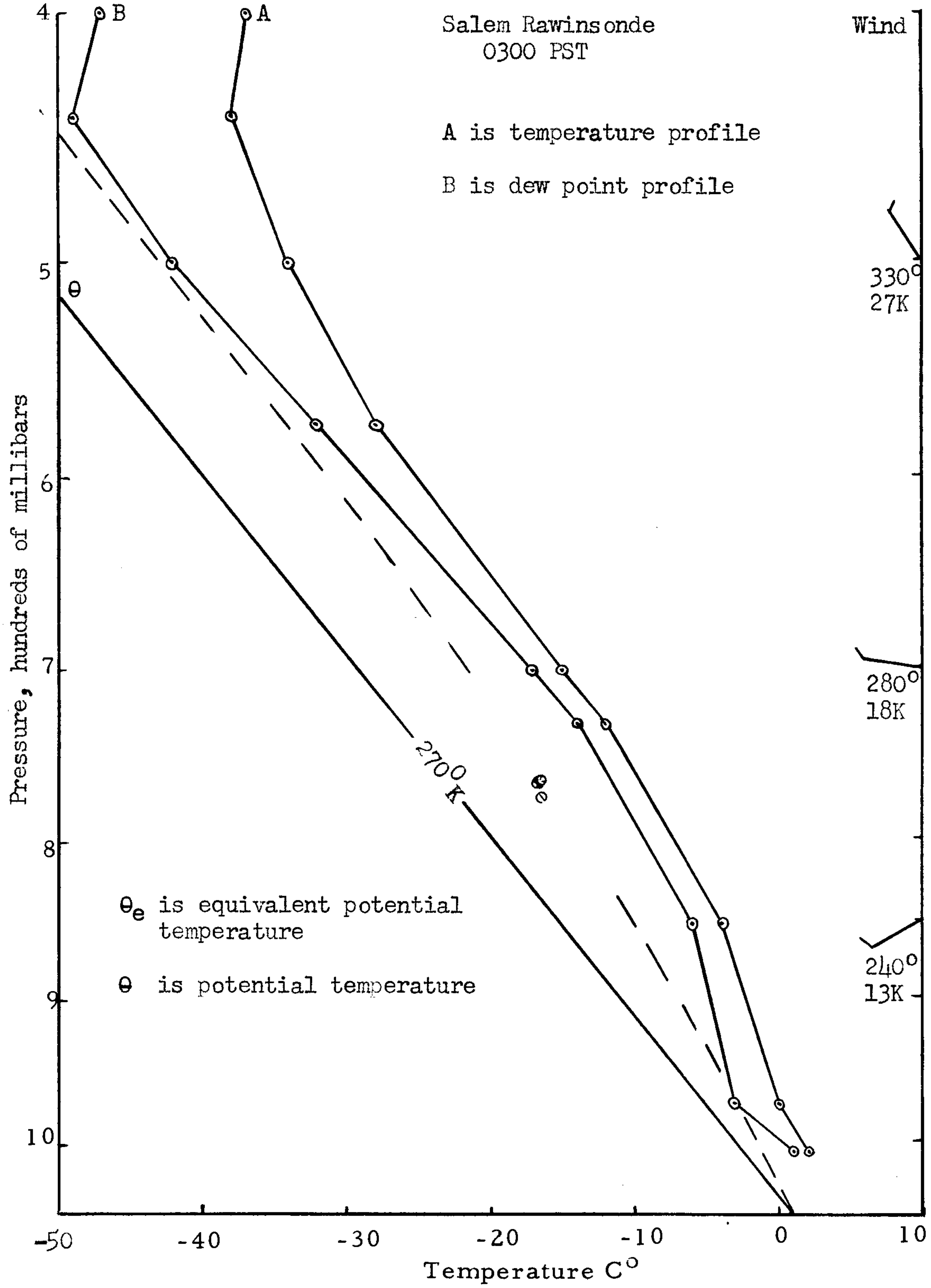


Figure 9. Salem, Oregon, Rawinsonde, 14 March 1963.

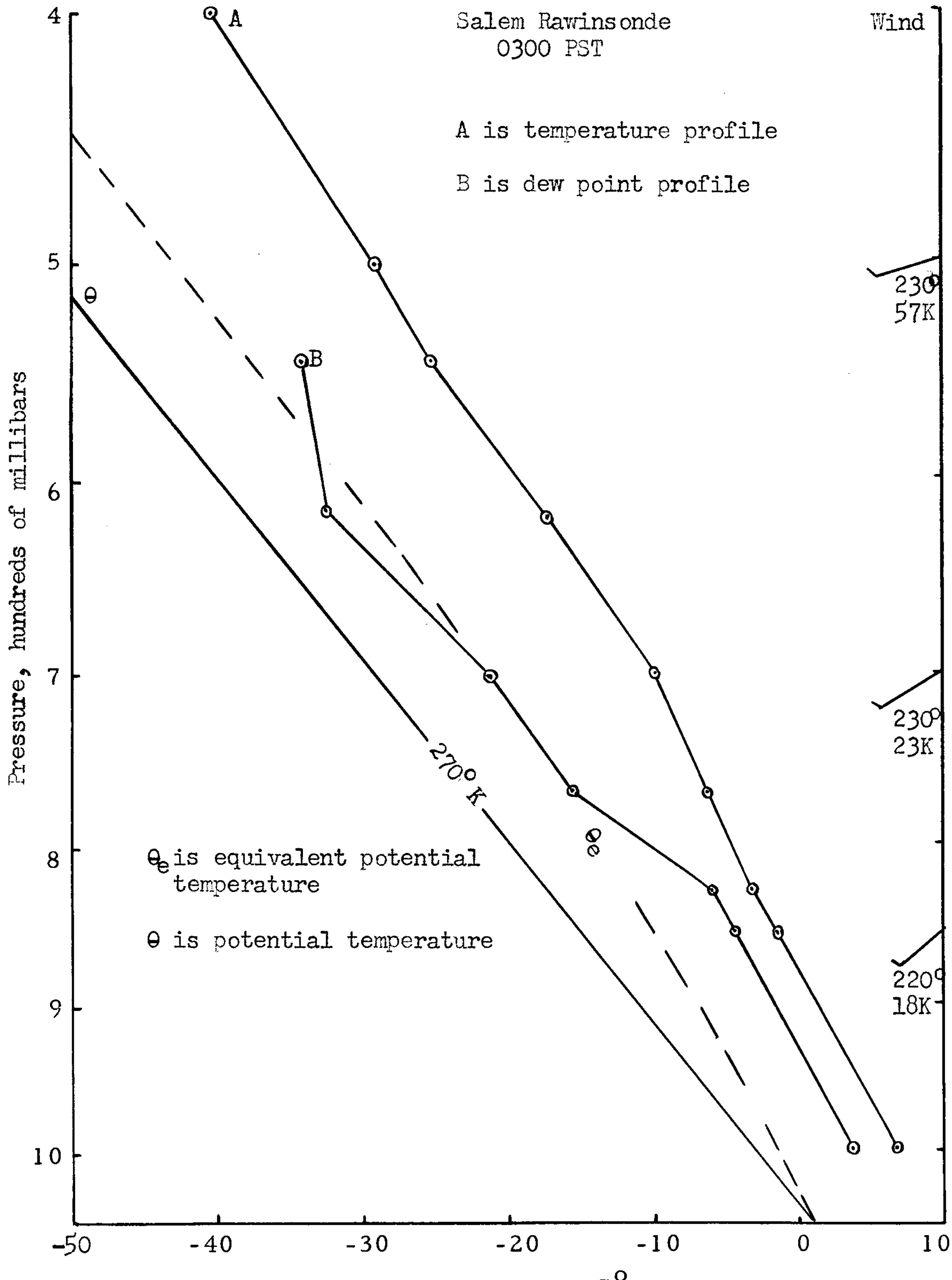


Figure 10. Salem, Oregon, Rawinsonde, 28 March 1963.