AFCRL-62-145

FINAL REPORT

PROJECT NO. A-491

AN ANALYSIS OF RADIO METEOR DATA OBTAINED BY SMYTH RESEARCH ASSOCIATES

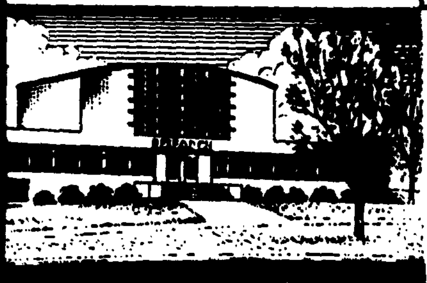
By

M. L. MEEKS

CONTRACT NO. AF 19(604)-6625

SEPTEMBER 1961

Prepared For
ELECTRONICS RESEARCH DIRECTORATE
AIR FORCE CAMBRIDGE RESEARCH LABORATORIES
OFFICE OF AEROSPACE RESEARCH
UNITED STATES AIR FORCE
BEDFORD, MASSACHUSETTS



Engineering Experiment Station
Georgia Institute of Technology
Atlanta, Georgia

AFCRL-62-145

ENGINEERING EXPERIMENT STATION
of the Georgia Institute of Technology
Atlanta, Georgia

FINAL REPORT

PROJECT NO. A-491

AN ANALYSIS OF RADIO METEOR DATA OBTAINED BY SMYTH RESEARCH ASSOCIATES

By

M. L. MEEKS

CONTRACT NO. AF 19(604)-6625

SEPTEMBER 1961

Prepared For
ELECTRONICS RESEARCH DIRECTORATE
AIR FORCE CAMBRIDGE RESEARCH LABORATORIES
OFFICE OF AEROSPACE RESEARCH
UNITED STATES AIR FORCE
BEDFORD, MASSACHUSETTS

NOTICES

"Requests for additional copies by Agencies of the Department of Defense, their contractors, and other Government agencies should be directed to the:

ARMED SERVICES TECHNICAL INFORMATION AGENCY
ARLINGTON HALL STATION
ARLINGTON 12, VIRGINIA

Department of Defense contractors must be established for ASTIA services or have their 'need to know' certified by the cognizant military agency of their project or contract."

"All other persons and organizations should apply to the:

U. S. DEPARTMENT OF COMMERCE
OFFICE OF TECHNICAL SERVICES
WASHINGTON 25, D. C."

ACKNOWLEDGEMENTS

The author wishes to thank Mrs. Joyce Nickelson for her contributions to this research. Her attention to the details of the machine computation and her work in the preparation of this report were essential.

ABSTRACT

Published data obtained by Smyth Research Associates on high-power high-gain meteor propagation at 200 Mc/s for 3 days in November 1957 have been compared with predictions. Three different forms were assumed for the radiant distribution. The assumed distributions consisted of three sources on the ecliptic, at the apex and at 65° from the apex toward and away from the sun. The first distribution consisted of three points on the celestial sphere, and the second and third distributions covered successively larger areas centered on these points at the apex and near the sun and anti-sun. The third distribution, consisting of a relatively small contribution from the apex and broad contributions from the sun and anti-sun concentrations, gave the best agreement with the data. The apex contribution appeared weak and varied from day to day. The sun and anti-sun contributions were nearly equal, showed little change from day to day, and seemed to extend beyond a 30° radius. The contributions of the anti-sun concentration occurred 1 or 2 hours earlier than predicted.

TABLE OF CONTENTS

This report contains 24 pages.

Page

LIST OF FIGURES

LIST OF TABLES

I. INTRODUCTION

The observation of meteors by radio has made it possible to determine the characteristics of meteors which are too faint to be seen with the naked eye and much too faint to be photographed. Radio observations can be more sensitive because they involve the reflection of electromagnetic waves from the ionized meteor trails rather than direct emission of energy from the meteor itself. Thus it follows that the faintest meteor which can be detected by a system will depend on the transmitter power and the gains of the antennas which are used to transmit and receive the radio waves. Radio systems with high power and high-gain antennas extend the threshold down to very faint meteors and permit very high rates of meteor detection.

Experimental studies conducted by Smyth Research Associates (SRA) (Heritage, Weisbrod, and Fay 1960) made use of high power and high gain. The meteor echo rates observed in these studies were as high as 30 bursts per minute in some cases. These experimental studies also made use of two independent receiving systems which operated simultaneously. Hence these data contain valuable information on the influx of meteors. Chapter II gives a brief description of the equipment, techniques, and geometry of these experimental studies.

One of the fundamental questions to be answered about meteors concerns the distribution of meteor radiants, that is, the distribution of directions of meteors in the upper atmosphere. Investigations of meteor radiant distributions should ideally determine the form of the radiant distribution as a function of time and as a function of meteor magnitude. Very large numbers of meteors must be analyzed to move in the direction of such a complete analysis, and the data obtained by Smyth Research Associates provides material for a step in this direction. Analytical methods developed by Meeks and James (1957) have made such an analysis possible. Chapter III describes the way in which various assumed radiant distributions were used to obtain meteor echo-rate-distributions for comparison with the observed distributions. The results of this analysis are summarized in Chapter IV.

It should be pointed out that the analysis described here could also be used to predict the distribution of echo rates for an arbitrary meteor propagation path.

II. THE SMYTH RESEARCH ASSOCIATES MEASUREMENTS

The experimental studies of meteor echoes conducted by Smyth Research Associates made use of a high power radar system with a highly directive antenna located in southern Texas. The beam was directed toward the northwest with an elevation angle of $2\frac{1}{2}°$. Meteor echoes were received by two identical mobile units which were positioned at various points along an arc at a distance of 1300 km from the transmitter. The receiving units included high gain antennas which were directed at the area of the meteor zone (height ~100 km) that was illuminated by the transmitter. The parameters were such that the system was capable of detecting electron columns with electron densities of about 10^{11} per meter.

The locations of the transmitted beam, the illuminated area in the meteor zone, and the receiving sites are shown in Figure 1. The receiving positions are labeled N_1, N_2, N_3 and S_1, S_2, S_3. Two mobile receiving units operated simultaneously at pairs of positions N_1 - S_1, N_2 - S_2, and N_3 - S_3. At a given time the two receiving units observed meteors from different portions of the sky, and hence the observations were independent.

Various types of meteor echoes were observed during these measurements; however the echo-rate data are based on signals exceeding 125 dbm and lasting less than 10 seconds. The transmitter frequency was 200 Mc/s, which is high compared to the usual meteor-scatter frequencies. Echoes could be received only from sharply defined regions of electron density. Since diffusion in the upper atmosphere rapidly smears out the column of electrons produced by the meteoroid, it is to be expected that the effect of high frequency will be to shorten the duration of a meteor echo. Detailed studies by Loewenthal (1956) confirm this qualitative picture and show that the effect of high

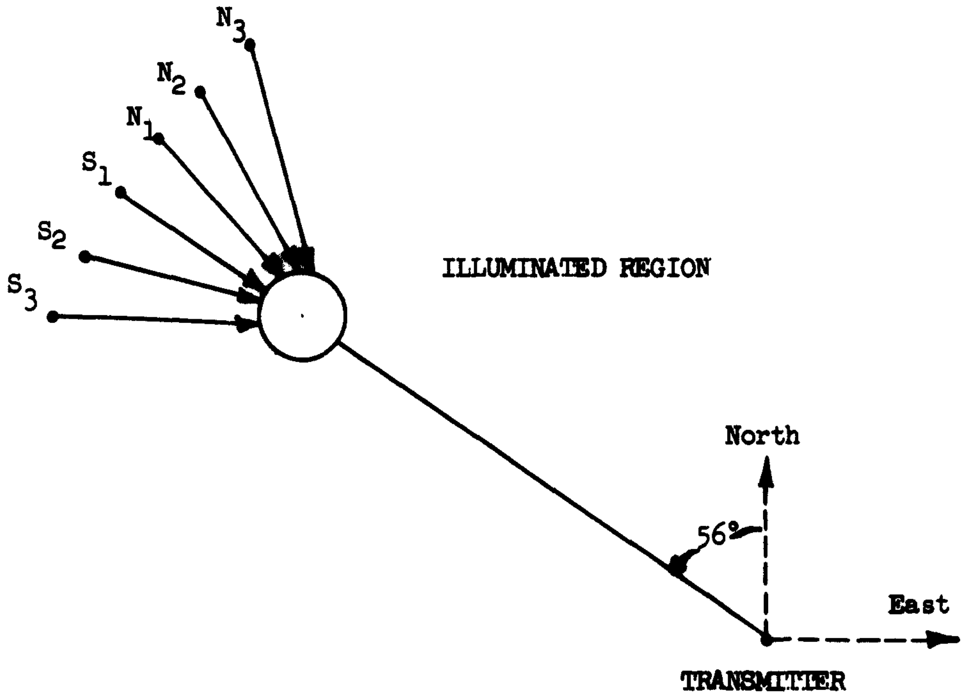


Figure 1. The six receiving sites are located 1300 km from the transmitter at 5° intervals on and about the extension of direct path from the transmitter to the illuminated region.

frequency is to reduce both the amplitude and duration of meteor echoes. The very high power and gain employed in the SRA measurements, however, tends to offset the relative decrease in echo amplitude at high frequencies.

The measurements made by SRA showed many echoes which exhibited a doppler frequency-shift and therefore were not specular echoes of the type assumed by Meeks and James (1957) for their analysis of the influence of radiant distributions on meteor echo rate. These nonspecular echoes are associated with overdense meteor trails. However, overdense meteor trails occur much less frequently than the underdense trails which give specular echoes.

We have chosen to analyze only that part of the SRA data in which the highest echo rates were observed. The occurrence of very high echo rates requires a high proportion of echoes from underdense trails because the flux of overdense trails is too small to account for these high rates. Thus the assumption of specular reflection can be made for the SRA data collected at a range of 1300 km. However, it should be remembered that measured echo rates do include nonspecular echoes; the exact proportion is unknown but sufficiently small to make meaningful an analysis on the assumption of specular echoes.

III. ANALYSIS OF SMYTH RESEARCH ASSOCIATES DATA

The analysis developed by Meeks and James (1957) has been used to compare a highly simplified model of the radiant distribution with observations (Meeks and James, 1959). The results of this analysis confirm the presence of three concentrations of radiants located at (1) the apex of the earth's way, (2) a point on the ecliptic 65° from the apex toward the sun, (3) a symmetrical point 65° from the apex toward the anti-sun. These points represent concentrations of radiants which are referred to respectively as the apex, sun, and anti-sun concentrations. These concentrations have previously been found by Hawkins (1956a,b).

A similar analysis has been used here except that many more points have been used to represent the form of the radiant distribution. These points have been weighted to represent the relative flux of meteors in various regions of the celestial sphere. The computation consists of a numerical evaluation of an integral as follows. Let us designate the receiver positions by the index P = 1, 2, 3...6 corresponding to the following paths, respectively N_1, N_2, N_3, S_1, S_2, S_3. We define the function S_p $(\delta, t - \alpha)$ according to the definition below.

$S_p(\delta, t - \alpha)$ = [The relative contribution at sidereal time t of meteors (with radiants at declination δ and right ascension α) to the meteor echo rate at station P.]

Also the function $R(\delta,\alpha)$ is defined as

$R(\delta,\alpha)$ = [Flux density of meteors per steradian from a point (δ,α) on the celestial sphere.]

The meteor echo rate $M_p(t)$ as a function of sidereal time t at receiver P will be given by

$$M_p(t) = \iint_{sky} R(\delta,\alpha)\ S_p(\delta,\ t - \alpha)d\Omega. \tag{1}$$

The numerical evaluation of this integral requires determination of $S_p(\delta,\ t - \alpha)$ at a number of points. This was done by choosing the right ascension $\alpha = 0$ and evaluating $S_p(\delta,t)$ for the range of values $\delta = (-30°,\ 5°,\ +30°)$ and $t = (0.5\ \text{hr},\ 0.5\ \text{hr},\ 24\ \text{hr})$. The values of $S_p(\delta,t)$ at these points were obtained with the digital computer program described by Meeks and James (1957). These values are shown in Tables I through VI.

The value of $R(\delta,\alpha)$ must be given for the same intervals; the matrix $R_{j,k}$ is given in Table VII. The letters A_i, B_i, C_i, and D represent weighting factors to be assigned, and the pattern of these letters shows the location in right ascension and declination of the concentrations near the apex, sun, and anti-sun for 14 November 1957, the mean date of the measurements.

The integral in Equation (1) can be evaluated approximately from

$$M_p(t) = \sum_{j=1}^{13} \sum_{k=1}^{48} R_{j,k}\ S^p_{j,t-k} \operatorname{Cos} \delta_j. \tag{2}$$

A digital computer program was written to evaluate Equation (2). The restriction to the declination interval -30° to +30° means that the computation covers only 54.5 per cent of the sky which is observable. This is not a serious restriction, however, because this declination region contains the ecliptic.

TABLE I

VALUES OF S_1 (δ, t) FOR RECEIVER LOCATION N_1

Declination	Time (Hours MST) 15.5	16	16.5	17
30°	2	5	6	7
25°		4	6	7
20°		4	7	6
15°		2	6	6
10°		2	6	6
5°		2	5	5
0°		2	6	5
-5°			5	4
-10°			3	4
-15°			1	4
-20°				4
-25°				3
-30°				2

Note: Values not specified are zero.

TABLE II

VALUES OF S_2 (δ, t) FOR RECEIVER LOCATION N_2

	Time (Hours MST)	
Declination	17.5	18
30°	4	13
25°	7	12
20°	10	12
15°	9	10
10°	7	8
5°	6	7
0°	5	6
-5°	5	5
-10°	5	5
-15°	2	2
-20°	4	2
-25°	3	2
-30°	2	1

TABLE III

VALUES OF S_3 (δ, t) FOR RECEIVER LOCATION N_3

	Time (Hours MST)	
Declination	18	18.5
30°		16
25°		15
20°		13
15°	12	
10°	9	
5°	8	
0°	4	
-5°	7	
-10°	6	
-15°	6	
-20°	6	
-25°	5	
-30°	5	

Note: Values not specified are zero.

TABLE IV

VALUES OF S_4 (δ, t) FOR RECEIVER LOCATION S_1

	Time (Hours MST)								
Declination	13.5	14	14.5	15	15.5	16	16.5	17	17.5
30°	1	2	2	1					
25°		1	2	1					
20°		1	2	2					
15°			2	1					
10°			1	2					
5°			1	4					
0°				1	4				
-5°					4				
-10°					4				
-15°						3	1		
-20°						3	2	1	
-25°						3	3	2	
-30°						3	3	2	1

Note: Values not specified are zero.

TABLE V

VALUES OF S_5 (δ, t) FOR RECEIVER LOCATION S_2

Declination	Time (Hours MST)																						
	15	15.5	16	16.5	17	17.5	18	18.5	19	19.5	20	20.5	21	21.5	22	22.5	23	23.5	0	0.5	1	1.5	2
0°																	4	3	5	4	3	2	1
5°												3	4	8	8	8	8	8	6	4	2	2	
-10°	1									3	8	8	9	8	9	7	7	6	4	3	2	1	
-15°		2	3	3	4	5	5	6	6	6	8	8	8	8	8	7	5	4	3	1			
-20°					3	3	4	5	6	6	7	7	7	5	5	4	4	1	1				
-25°						1	3	3	4	4	5	5	5	4	4	1	1						
-30°							1	1	2	2	3	3	2	1	1								

Note: Values not specified are zero.

TABLE VI

VALUES OF S_6 (δ, t) FOR RECEIVER LOCATION S_3

Declination	Time (Hours MST)																						
	15	15.5	16	16.5	17	17.5	18	18.5	19	19.5	20	20.5	21	21.5	22	22.5	23	23.5	0	0.5	1	1.5	2	2.5
5°										5	12	12	14	14	15	14	13	11	10	7	6	4	3	3
0°				1	5	7	8	10	11	12	13	12	10	10	10	4	4	3	5					
-5°	1	2	3	4	5	6	7	7	8	8	4	4	4											
-10°	1																							

Note: Values not specified are zero.

TABLE VII

FORM OF THE ASSUMED RADIANT DISTRIBUTION

	Right Ascension (Hours)																												
DEC	2	2.5	3	3.5	4	4.5	5	5.5	6	6.5	7	7.5	8	8.5	9	9.5	10	10.5	11	11.5	12	12.5	13	13.5	14	14.5	15	15.5	16
30°	D	D	C_1	C_1	B_1	B_1	B_1	C_1	D	D				C_2	C_2	C_2	C_2												
25°	D	D	C_1	C_1	B_1	B_1	B_1	B_1	C_1	D	D			C_2	C_2	B_2	C_2	C_2	C_2						SUN				
20°	D	D	C_1	C_1	B_1	A_1	B_1	C_1	C_1	D	D			C_2	B_2	B_2	B_2	C_2	C_2										
15°		D	C_1	C_1	B_1	B_1	B_1	C_1	C_1	D	D			C_2	B_2	A_2	B_2	C_2	C_2				D	D	D	D	D		
10°		D	D	C_1	C_1	B_1	C_1	C_1	D	D				C_2	B_2	B_2	B_2	C_2	C_2			D	D	C_3	C_3	D	D		
5°			D	C_1	C_1	C_1	C_1	C_1	D	D				C_2	C_2	B_2	C_2	C_2				D	C_3	C_3	C_3	C_3	D	D	D
0°			D	D	D	C_1	D	D	D					C_2	C_2	C_2	C_2	C_2			D	D	C_3	C_3	B_3	C_3	C_3	D	D
-5°					D	D	D	D	D						C_2	C_2	C_2				D	C_3	C_3	B_3	B_3	B_3	C_3	D	D
-10°						D	D														D	C_3	B_3	B_3	A_3	B_3	C_3	D	D
-15°						ANTI-SUN										APEX					D	C_3	C_3	B_3	B_3	B_3	C_3	D	D
-20°																					D	C_3	C_3	B_3	B_3	C_3	C_3	D	D
-25°																						D	C_3	C_3	C_3	C_3	C_3	D	D
-30°																						D	C_3	C_3	C_3	C_3	D	D	D

Note: Subscripts 1, 2, and 3 correspond respectively to the anti-sun, apex, and sun concentrations.

The echo-rate distribution was calculated for all six paths corresponding to the six receiver locations with each of three different radiant distributions. The assumed radiant distributions are listed below.

Distribution I. $A_1 = A_2 = A_3 = 1$ others zero.

Distribution II. $A_1 = A_2 = A_3 = 6$

$B_1 = B_2 = B_3 = 5$

$C_1 = C_2 = C_3 = 3$

$D = 0$

Distribution III. $A_1 = A_3 = 6, \quad A_2 = 2$

$B_1 = B_3 = 5, \quad B_2 = 1$

$C_1 = C_3 = 3, \quad C_2 = 0$

$D = 2$

Distribution I is the three point approximation used in Meeks and James (1959). Distribution II is a simple extension of Distribution I consisting of three regions of equal strength having an angular radius of 20° about the sun, apex, and anti-sun points of Distribution I. Distribution III was chosen after a comparison of the predictions based on Distribution II with the SRA data. Distribution III has a reduced apex concentration and broader sun and anti-sun concentrations, which have angular radii of 30°.

Figures 2 through 4 show the results of computations based on Distributions I and II compared to the SRA observations of echo rate. The predictions based on I are of course very crude because the high gain antennas used in this experiment do not produce the smoothing effect which is evident in previous computations (Meeks and James, 1959). Distribution II gives

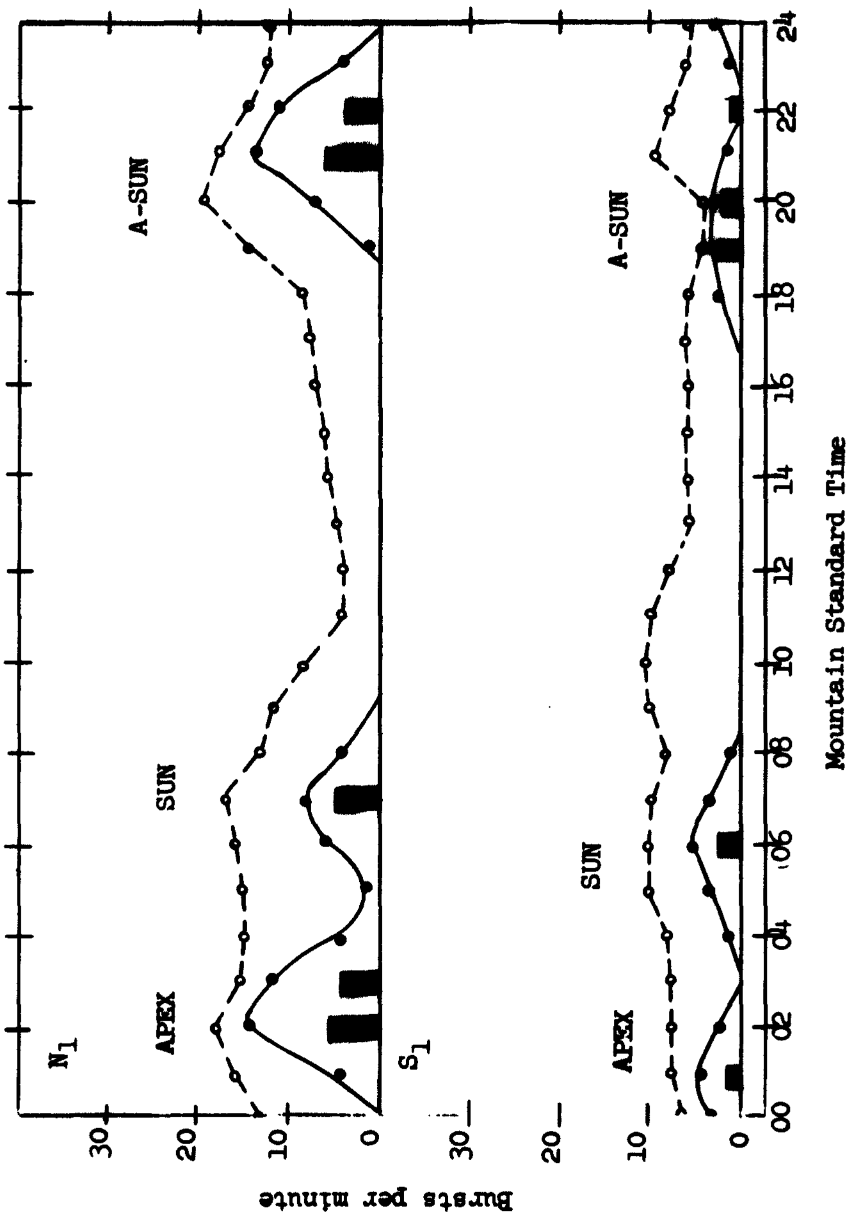


Figure 2. Observed Echo Rates (o- -o- -o) and Computations for Distributions I (▲) and II (●—●—●) for 11 November 1957.

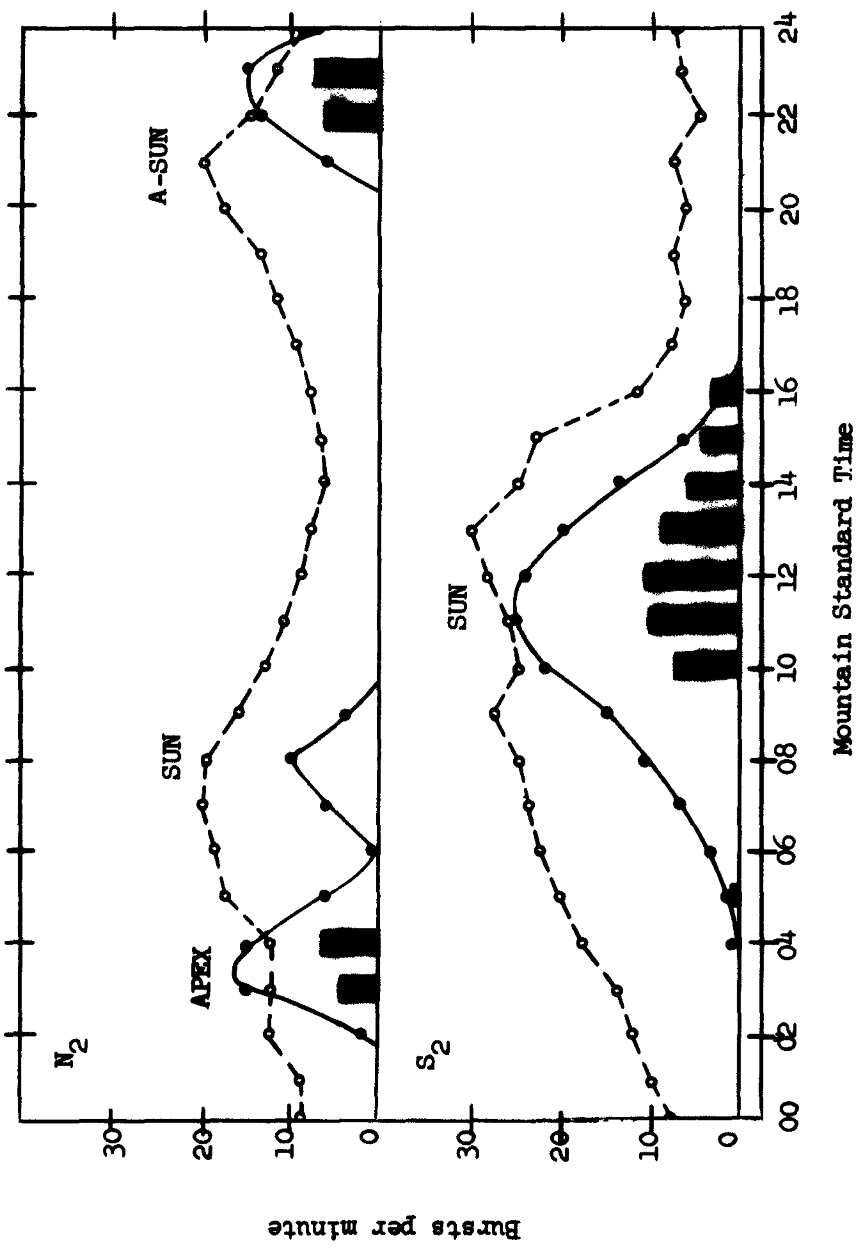


Figure 3. Observed Echo Rates (o- -o- -o) and Computations for Distributions I (▮) and II (●—●—●) for 14 November 1957.

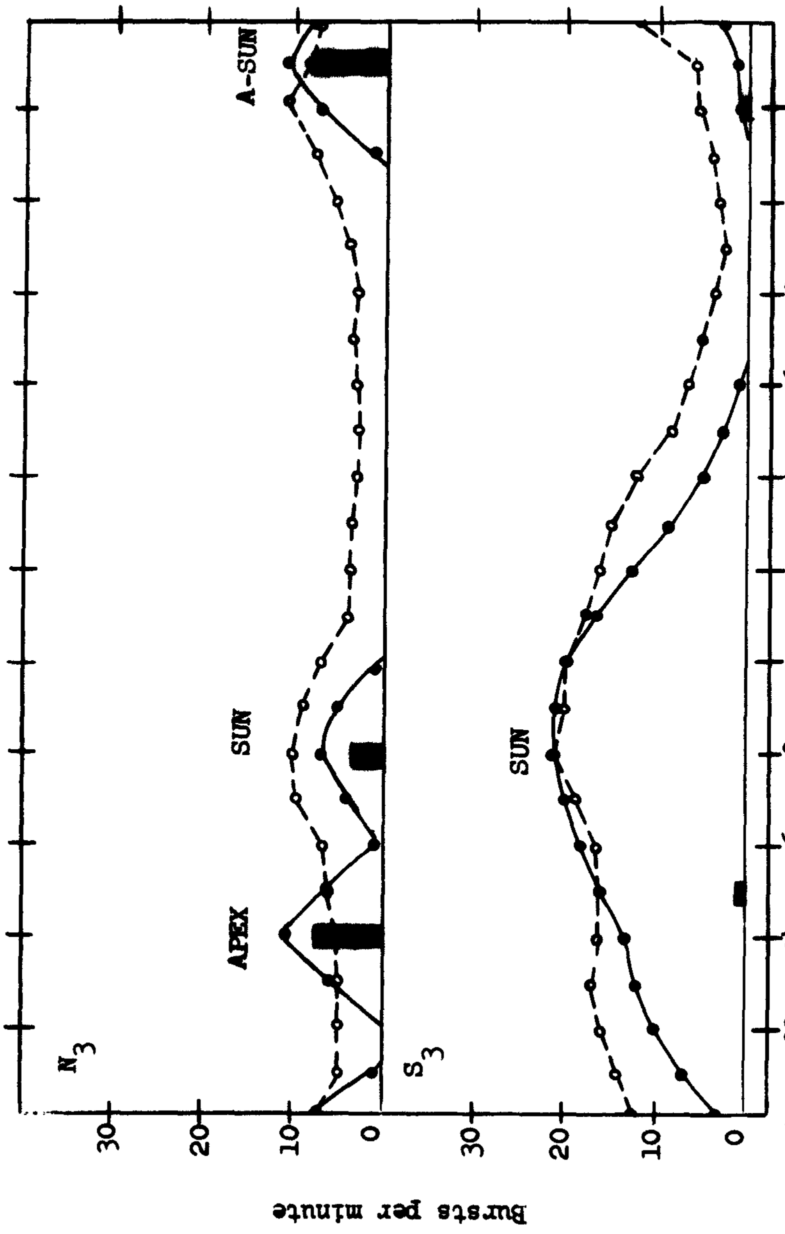


Figure 4. Observed Echo Rates (o- -o- -o) and Computations for Distributions I (▇) and II (●—●—●) for 19 November 1957.

much better agreement, but the apex concentration appears to be variable in the measured data and much weaker than assumed in Distribution II.

Figures 5 through 7 show results of computations based on Distribution III compared to SRA data. Here the agreement is improved. A background echo rate of about 5 bursts per minute should be added to the computed rates to improve the agreement further. This background echo rate is probably due to nonspecular echoes and echoes with radiants outside the declination interval (-30°, +30°).

The Leonid meteor shower occurred during these measurements with its radiant ($\alpha = 152°$, $\delta = +22°$) near the apex. This shower is at its maximum on November 17, and extends from about November 14 to November 20. The observed echo-rates show no evidence of this shower. However, the high meteor velocity of the Leonids (72 km/sec) would cause their trails to be produced at comparatively great heights where diffusion is rapid. Thus it might be expected that this stream would not contribute to the echo rate at high frequencies.

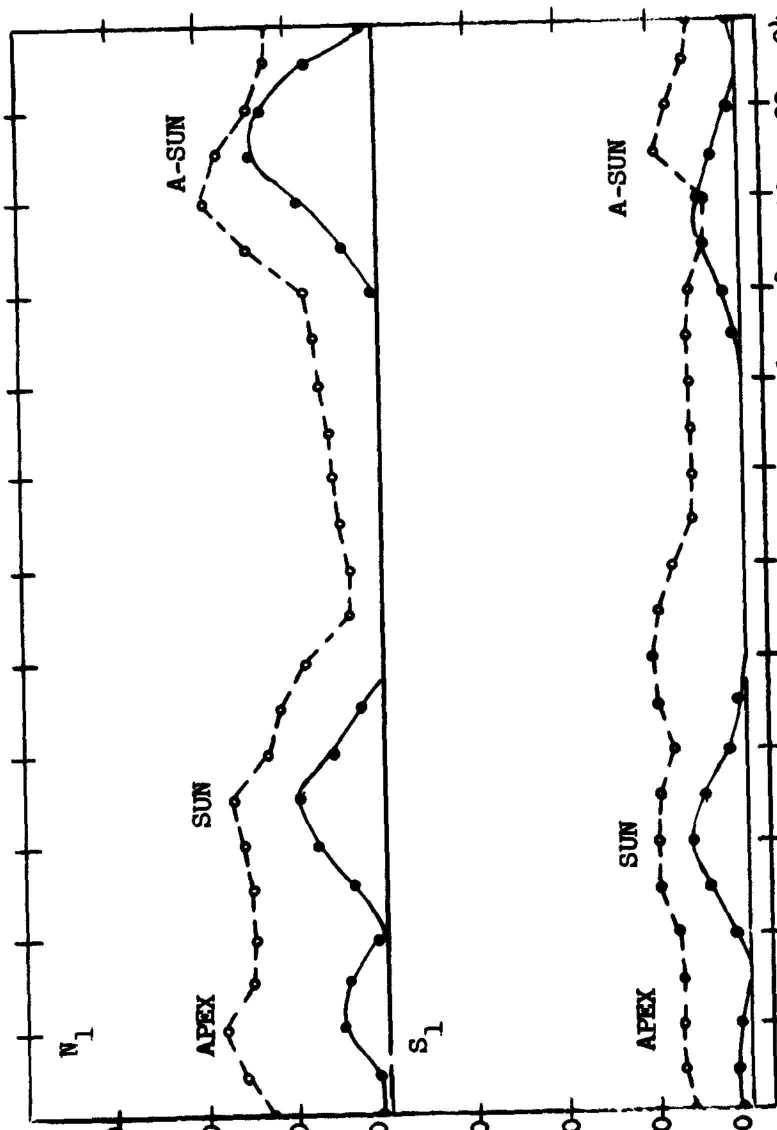


Figure 5. Observed Echo Rates (o- -o- -o) and Computations for Distribution III (●—●—●) for 11 November 1957.

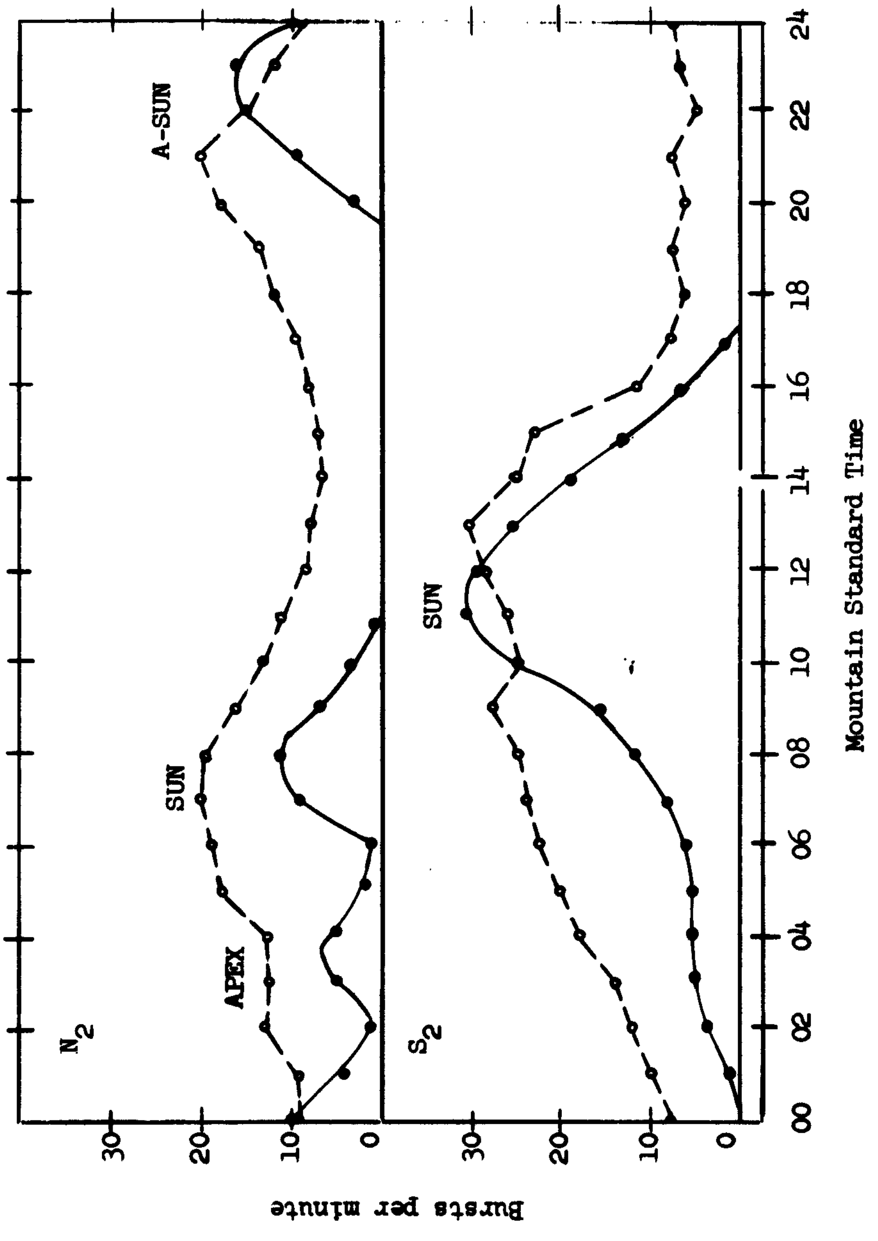


Figure 6. Observed Echo Rates (o- -o- -o) and Computations for Distribution III (●—●) for 14 November 1957.

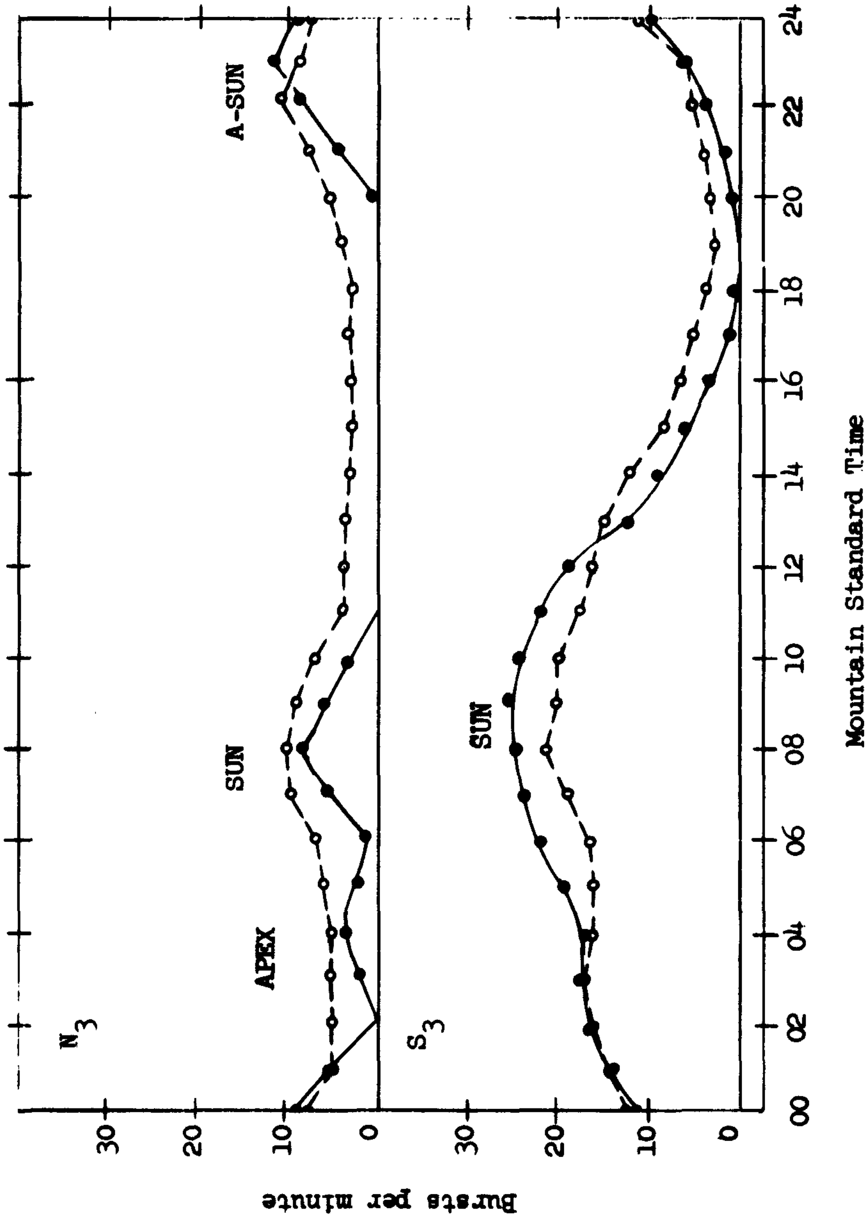


Figure 7. Observed Echo Rates (o- -o- -o) and Computations for Distribution III (●—●—●) for 19 November 1957.

IV. CONCLUSIONS

The comparison of computed and measured echo-rate distributions for the SRA observations leads to the following conclusions.

1. The apex concentration is weak and varies from day to day, producing negligible contribution to the counting rate on November 19, a very small contribution on November 14, and a larger contribution on November 11.

2. The sun and anti-sun concentrations seem to make nearly equal contributions to the echo rate, and these contributions appeared on all three days.

3. The relative echo rate on the six paths indicates good agreement with the computations. Significant day-to-day variations are seen only for the apex concentration.

4. The background echo rate of about 5 bursts per minute recorded on all paths is not accounted for by the assumed radiant distribution. This background is a result of nonspecular echoes and radiants outside the declination interval from -30° to +30°.

5. The sun and anti-sun concentrations seem to be broad and to extend beyond 30° from the central point of these concentrations.

6. The contributions of the anti-sun concentration occur 1 to 2 hours earlier than predicted.

7. The possibilities for meaningful predictions of echo rates by means of similar computations appear to be established.

Approved for release to sponsor:

Arthur L. Bennett

Arthur L. Bennett, Chief
Physical Sciences Division

Robert E. Stiemke

Robert E. Stiemke, Director
Engineering Experiment Station

Respectfully submitted:

ALB for

M. L. Meeks
Project Director

V. REFERENCES

Hawkins, G. S., 1956a, Mon. Not. R. Astr. Soc. 116, 92.

Hawkins, G. S., 1956b, Astr. J. 61, 386.

Heritage, J. L., Weisbrod S., and Fay, W. J., 1960, IRE Trans. on Antennas and Propagation AP-8, 57.

Loewenthal, M., 1956, "On meteor echoes from underdense trails at very high frequencies," M.I.T. Lincoln Lab., Lexington, Mass., Tech. Rpt. No. 132.

Meeks, M. L. and James, J. C., 1957, Proc. Inst. Radio Engrs. 45, 1724.

Meeks, M. L. and James, J. C., 1959, J. Atmos. Terr. Phys. 16, 228.